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U.S.COAST GUARD'S NEW POLAR ICEBREAKER DESIGN

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Abstract

The United States Polar Icebreaker fleet operated by the U.S. Coast Guard will be reduced to two ships, the Polar Star and the Polar Sea, in November 1988 upon the decommissioning of the Northwind, the last of the WIND Class icebreakers. The Coast Guard has recently completed a Contract Design for a Polar Icebreaker Replacement(PIR) to take the place of the decommissioned WIND Class icebreakers which were built in the 1940's. This design represents a multi-mission icebreaker which incorporates capabilities defined by the needs of DOD, NSF, NOAA, UNOLS, MARAD and the USCG. The design incorporates proven technology to provide a reliable platform to perform escort, resupply and scientific missions in both polar regions. The extensive science support incorporated in this vessel represents a major step forward in providing science capabilities for polar regions research. Other interesting aspects of this vessel include a bow thruster, AC cycloconverter propulsion system and helo securing and traversing systems. The characteristics and capabilities of the vessel as well as a brief synopsis of the design process completed at the time of the preparation of this paper will be discussed.

1. Introduction

The Coast Guard has completed a Contract Design for a new class of polar icebreaker intended to replace the last of the aging WIND Class icebreakers which are scheduled to be decommissioned during 1988. This design represents a multi-mission icebreaker capable of operating in both polar regions providing escort, logistics support and scientific research support as well as traditional Coast Guard missions such as search and rescue and enforcement of laws and treaties.

The evolution of this design began in 1984 with the Polar Icebreaker Requirements Study[1] which was a joint effort of the Coast Guard, Navy, National Science Foundation, NOAA and Maritime Administration. This study recommended that the Coast Guard immediately begin work on the design of a new polar icebreaker and that consultations be held with the Polar Icebreaker User's Council in considering all aspects of the design. The study also recommended that the new design contain "enhanced research support" capability as well as "essential escort and logistics support capabilities" and an "icebreaking capability between a WIND Class and a POLAR Class" icebreaker.

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Work on the design began in the fall of 1984 with the completion of the Sponsor's Requirements Document(SRD), which detailed the essential capabilities and characteristics of the PIR as a set of design requiements representing the needs and desires of all U.S. icebreaker users. A Feasibility Study, completed in December 1984, was then conducted by the Coast Guard to determine if the requirements of the PIR could be satisfied by utilizing the existing POLAR Class icebreaker hull. The Feasibility Study concluded that the use of the POLAR Class hull would, by limiting the size of the ship, greatly restrict the ability to provide all of the capabilities desired in the PIR and a new design was recommended. A parallel study, conducted under contract to the Coast Guard, to determine the suitability of existing foreign polar icebreakers concluded that while many design features of modern foreign icebreakers should be considered in developing the PIR design, no foreign icebreaker design had the capability to satisfy the requirements for the PIR. Based on the results of these studies, a Conceptual Design for the PIR was initiated with completion in September 1985. The Conceptual Design Report concluded that the required capabilities of the PIR including endurance, icebreaking and science facilities could be incorporated in a single design and a basic hull form was developed. This was followed by a Preliminary Design[2], completed in September 1986, during which the majority of the engineering problems were solved, the final hull form was developed and general arrangements plans were prepared. Extensive model tests and analytical studies were conducted during Preliminary Design to determine the optimum hull form, power requirements, superstructure and antenna arrangements and icebreaking capability. The PIR design process was concluded in January 1988 with the completion of the Contract Design phase which included resolution of the remaining engineering problems and developement of the contract specifications and drawings. Throughout the design process, comments and recommendations were solicited from the User's Council on a regular basis. Many of these became requirements were incorporated in the design where feasible.

2. Characteristics

The PIR has an endurance of 37,000 miles at 9.25 knots open ocean steaming. It will have the capability of breaking 4.5 feet of level polar ice at 3 knots continuous speed or 8 feet of polar ice by backing-and-ramming. To achieve these goals, the PIR design includes a hull form similar to the Polar Class icebreaker hulls (CGC POLAR SEA and POLAR STAR), twin screws, twin rudders, LOA of 460 feet, LWL of 401 feet, full load displacement of approximately 17,700 tons, maximum beam of 94.5 feet, and 30,000 SHP. The liquid load capacity includes 1,410,000 gallons of marine diesel fuel and 46,000 gallons of JP-5 fuel which will provide an endurance of 80 days underway. Accommodations are provided for 17 officers, 120 enlisted, 30 scientists and 1 visitor.

The PIR is designed to operate in the extreme environmental conditions which will be

encountered during equatorial passages and in polar regions. Air temperatures ranging from 95 deg F (summer) to -50 deg F (winter) and sea water temperatures ranging from 85 deg F (summer) to 28 deg F (winter) are the operating extremes designed into the PIR. The vessel is designed to survive 100 knot beam winds, severe topside icing and meet a two compartment floodable length standard for damaged stability. Table 1. contains a comprehensive list of the PIR characteristics.

3. Machinery Plant

The main machinery plant consists of a diesel-electric power generation plant that utilizes four medium speed diesel AC generator sets with two AC main motors which drive two fixed pitch propellers through AC/AC cycloconverters. The main generators provide power to the main motors through the AC/AC cycloconverters and a common bus allowing any combination of main generators to power either or both of the main motors. Power at 4160 volts is also provided through a distribution board to handle large auxiliary loads such as bow thrusters, hydraulic systems, deck machinery and cranes. 4160 volt power is transformed to 450/230 volts and provided through a ship service power distribution system for auxiliary machinery and lighting. This arrangement eliminates the need for a separate diesel generators to provide ship service power. A port generator is provided to supply electrical power for emergency use or when in port with no main generator operating. The port generator is located in the superstructure and will be mounted to isolate any vibration. A quiet ship condition can be achieved for science operations by securing the main generating plant and supplying power with the port generator.

With twin screws, twin rudders and a bow thruster, maneuverability and steerage for the PIR is greatly enhanced. This improves the operations of the ship for docking evolutions in port, for operating in restricted waters and for icebreaking evolutions. The ability to maneuver near navigational hazards and to cast ship within a polynia(open water area in the ice pack) will increase the number of scientific activities that the vessel may be tasked with during her deployments.

4. Structure

The superstructure consists of six levels and includes a helicopter hanger and flight deck on the 02 level. The hull structure includes six decks consisting of tank top, 1st platform, 3rd deck, 2nd deck, main deck, and 01 level.

5. Aircraft

The design includes a flight deck and hangar as well as securing, traversing and fueling systems for helicopter operations. These features allow the PIR to launch, recover and hangar two HH-65 Short Range Recovery(SRR) helicopters. The flight deck has also been designed to permit the launch, recovery and fueling of an SH-60 heavy lift helicopter which can provide excellent cargo and personnel transfer capabilities. The TALON securing system, which

is the Coast Guard version of the Navy HARPOON helicopter securing system, will allow the safe operation of the HH-65 helicopters with reduced flight deck personnel and in a wider range of ship motions. A cable and winch traversing system will provide a much safer, quicker and more efficient means of moving the helicopters between the flight deck and the hangar with reduced personnel. The flight deck arrangement allows scientific operations to take place during flight operations, interrupted only by the actual passage of the helicopter over the stern during launch and recovery.

6. Electronics

The communications suite on the PIR will be similar to that on the Coast Guard 378 Foot high endurance cutters and will provide all military and commercial communications capabilities, including satellite communications. External voice communications are provided from all scientific spaces. Navigation systems include a Global Positioning System(GPS), LORAN, OMEGA and inertial navigation. These systems provide the PIR with exceptional navigational and positioning data. Science electronic systems will be discussed in a later section.

7. Science Facilities

The PIR science facilities and capabilities are a significant improvement over past U. S. icebreaker designs. Deployments to the Arctic and to Antarctic regions very often have scientific missions combined with the Coast Guard primary mission to open and maintain clear ice channels and to escort vessels through these ice channels or through the ice pack. These scientific missions span the range from counting birds, seals and krill to taking bottom samples and measuring the geo-magnetic spectrum. To accomplish the variety of scientific research that may be scheduled for these vessels, the PIR design has been greatly influenced by the scientific community through several design meetings during the development of the contract design.

The dedicated science facilities aboard the PIR include an aft science conning station, two wet labs, one dry lab, an electronics lab, a computer/ navigation lab, a high-overhead vestibule, refrigeration facilities, communications center, a combination library/conference room, recompression and dive gear locker, five portable van laboratories, a bow boom, an instrument room, winch room, an accommodation ladder with handling gear, improved scientist berthing, two oceanographic winches, two trawl/core winches and a cable maintenance system. The science equipment and spaces incorporated into the PIR are far superior to the older icebreakers which the scientific community have utilized in the past. These features are described in more detail below.

Aft Science Conning Station: During science operations over the stern, control of the ship can be transferred to the aft science conning station to allow precise maneuvering of the vessel during science ops. This station is located on the 01 level aft of the deckhouse and extends the

full width of the vessel. This space has a conning station, three winch/crane control stations, a winch/wire data processing station, a chart table and a computer work station. The conning station provides propulsion and steering control while providing the operator with maximum visibility of the work area astern. Minor ship positioning adjustments to account for wire lead, sea conditions or personnel safety can be readily made from this improved aft vantage point.

Bow Boom: A portable bow boom holds 200 lbs of atmospheric and acoustic equipment 10 feet forward of the bow rail at a 0 to 15 degree angle above horizontal. The boom provides the advantage of positioning instrumentation ahead of the vessel to be able to record icebreaking reactions forward of the vessel and to measure sea conditions forward of the vessel prior to vessel interactions with seaway. A catwalk capable of supporting two 180 lb persons at the tip of the boom in sea state 4 conditions or less will be integral with the boom for access to equipment without removal of the bow boom.

Accommodation Ladder: In the past, access and egress from the ice was via a Jacob's ladder or scramble net or a cumbersome accommodation ladder. The accommodation ladder for the PIR will be integrated with a handling system and two portable ice platforms which will enhance the utility of the accommodation ladder in port and for science ops on the ice. The platforms attached to the ladder are dished shape on the bottom to minimize ice resistance when in use. When the vessel is hove to in ice for science ops, relative motion between the ship and the ice floe will not create excessive stress on the accommodation platform because its shape allows the platform to slide easily across the ice. Safe and easy access to and from the ice will be possible. In an emergency, the system is capable of lifting the accommodation ladder with a 180 lb person standing on the lower platform.

Science Labs: More than 2800 sq ft of deck area is dedicated to science labs, staging vestibule and walk in freezer. The two wet and one dry science labs have a combined deck area of 1600 sq ft and are located on the main deck aft. To improve the adaptability of the spaces for differing science projects, the laboratories can be subdivided to adapt to different requirements on each deployment. The wet labs include one 20 cu ft upright freezer and one 20 cu ft upright refrigerator along with other miscellaneous furniture and science equipment. The accessibility of the labs for retrieved samples is greatly improved via a vestibule staging area. A walk-in freezer of approximately 200 sq ft will provide storage for core samples. A computer/navigation lab and an electronics lab are also provided and will be discussed in the science electronics section.

To complement these lab spaces, area has been set aside to accommodate 5 portable science vans, three on the stern under the flight deck and two in the forward cargo hold on the second deck. These vans can become a temporary laboratory or storage space for the scientist and will

receive ship service power, water and heat. A standard size van(20 ft ISO) can be pre-outfitted by a scientific group prior to arrival at the ship and then simply loaded into position, secured and hooked up to facilities. The vans could be loaded at home port or at a foreign port depending on the designated logistics for the vans.

Approximately 7700 sq ft of weather deck space is available as working space for conducting science. Both the main deck working area aft and the interior science labs will a grid tiedown system for securing various equipment not normally carried onboard.

Vestibule: Often, the in past, bottom sample grabs or rossettes with sea water samples had to be removed from the samplers on the open deck in a harsh environment before moving to the laboratories for storage or analysis. This is not necessary in the PIR design because of the vestibule which is accessed by a roller curtain door so that scientific equipment can be moved from the weather to the science labs via the vestibule (or staging area). The high-overhead of 16 ft in the vestibule with overhead trolley then provides an enclosed work area with a workbench and a sink protected from the elements. Preparation of scientific experiments for use over the side or for storage and testing in the laboratory can be handled safely and comfortably within the vestibule.

Science Electronics: An extensive suite of elctronics has been provided for scientific purposes. While selection of a computer system will not be made until construction is almost complete, a dedicated science computer, anticipated to be at least as capable as a VAX 11/750 mini-computer, will be provided together with terminals, printers and plotters throughout the science spaces. A Precision Bathymetric Survey System(PBSS) will provide detailed contours of the sea floor. Current speed and direction to approximately 600m will be available from a Doppler Current Profiler. Voice and data(56 kilobyte) communication will be provided via INMARSAT. A Ships Data Video Monitoring System(SDVMS), with video displays throughout the ship, will display information on time, position, course, speed, distance, weather and general informational messages. A computer/navigation lab of approximately 250 sq ft, located as close as posible to the center of ships motions to minimize problems with the computer equipment, and an electronics lab of approximately 300 sq ft are provided for science uses.

Library/Conference Room: This area is a dedicated space for science oriented discussions or meetings. This space is located on the 01 deck aft, in close proximity to the science labs, and is equipped with a conference table, file cabinets, TV and chalkboard. This space is far superior to that provided for use as a science office on past icebreakers. Scientific teams aboard the icebreaker will be able to meet undisturbed to organize their experiments without interferring with the ship's operations or daily routine.

Scientist Berthing: The chief scientist's stateroom will be located on the same deck and in the vicinity of the CO's cabin.

It will provide over 400 sq ft of living and office space. The remainder of the scientists will live aft where there is one one-person stateroom and 14 two-person staterooms located in the vicinity of the library/ conference room. Each of these staterooms provides approximately 160 sq ft of living space.

Cranes: The PIR will be equiped with cranes capable of servicing approximately 95 percent of the weather deck area. In addition to the normal ship operations such as lowering small boats and handling cargo, the cranes will be utilized in place of A-frames for handling the oceanographic wires. The cranes will also be able to handle loads up to 15 tons at approximately 70 ft from the side of the ship.

Winches: To accommodate the myriad of oceanographic programs that may be scheduled, some of which are performed simultaneously, the PIR will have four science winches: two oceanographic winches and two trawl/coring winches each having 10,000 meters of wire rope or electromechanical (EM) cable. The ocean winches are all identical and have eight interchangable drums. The rated pull is 10,000 lbs. The trawl/core winches have a rated pull of 40,000 lbs. Each winch is controllable from either the winch room or remotely from the science conning station or from their respective cranes. The winch station includes: (1) CCTV, (2) VDT display and (3) crane controls. Each winch has a variable speed motor to allow adjustments for different equipment loads, line speeds and depth of water. An example of the varying speeds available is:

For the oceanographic winches:
High speed, low pull:
250-800 ft/min
Low speed, high pull:
155-500 ft/min

For the trawl/core winches:
High speed, low pull:
150-500 ft/min
Low speed, high pull:
95-300 ft/min

The winch consoles include a processor, color monitor and joystick control. The wire instrumentation monitoring system and a Data Acquisition and Control System (DACS) with system control and data recording functions reside at the console. The monitoring system operates in real time with a data update 10 times per second via a data multiplexing system. There are seven remote displays in the science conning station, pilothouse, vestibule, wet labs 1 & 2, dry lab and the computer/navigation lab.

Cable System Maintenance: This system consists of a wire brush cable cleaner, pressurized water wash, air dry unit, and pressure lubricator which can be used at cable speeds of 60-100 ft/min. The wire brush removes dirts, salt, scale, marine growth; the fresh water and air washes and dries the cable; the lubricator applies a liquid lubricant of varying viscosities at 100 psig. This system will reduce the total wear experience by the gear and should greatly extend its useful life. This system also includes a wire rope and cable emergency severence system to cut the wire in an emergency using a guillotine device.

Diver Support System: A dive gear locker with a minimum deck area of 450 sq ft will be located on the main deck. This area will provide enough space for the installation of a portable decompression chamber while deployed. A washroom, watercloset and shower will be integral with this space. Clear deck area is provided near the dive locker and into the decompression area to accommodate a recompression chamber. This area will serve as an excellent staging area for any dive operations required during science operations. The ability to carry a decompression chamber will add a degree of safety never before available on a U.S. polar icebreaker.

8. Summary

The Coast Guard is currently modifying the PIR Contract Design Specification into a performance oriented document which is being called a Design-Based Performance Specification. This will allow industry more latitude in their ability to provide alternative design solutions and an opportunity to incorporate innovative ideas in their construction proposals. It is anticipated that a draft request for proposal will be issued in the spring of 1989 for industry comment, followed by a request for proposal to build in the summer of 1989. This should result in a contract award in July of 1990 and an operational icebreaker in late 1994.

This paper has attempted to provide a broad overview of the Coast Guard Polar Icebreaker Replacement design characteristics and capabilities as well as the design process. The PIR design represents a vessel with polar icebreaking ability and marine research facilities which have not been available in any previous U.S. polar icebreaker. The design of the PIR is a compromise which responds to a diverse group of specific and in many cases conflicting desires. It satisfies all sponsor requirements which represent the needs of the U.S. icebreaker users.

With only two polar icebreakers remaining in the U.S. fleet as we are entering the 1990s, the addition of the PIR is of great importance to U.S. interests in the Polar regions, especially the polar research community. The extensive science capabilities of this ship will give it the ability to make major contributions toward our knowledge of the polar regions well into the next century.

References:

[1] "United States Polar Icebreaker Requirements Study", Interagency Report, July 1984, U.S. Coast Guard, U.S. Department of Transportation.

[2] "Polar Icebreaker Replacement Preliminary Design Report", September 1986, Naval Engineering Division, Office of Engineering, U.S. Coast Guard Headquarters.

TABLE 1.

POLAR ICEBREAKER REPLACEMENT
CHARACTERISTICS

LOA	459.5 FT
LWL	401.0 FT
BEAM(MAX)	94.5 FT
BEAM(WL)	88.1 FT
DRAFT	31.6 FT
DISPLACEMENT(FULL LOAD)	17,700 LONG TONS
SHAFT HORSEPOWER(SHP)	30,000 SHP
LIQUID LOADS	
DIESEL	1,410,000 GAL
FRESHWATER	24,000 GAL
JP5	46,000 GAL
BALLAST/TRIM(SW)	335,000 GAL
L/O	24,000 GAL
ICEBREAKING PERFORMANCE	4.5 FT CONTINUOUS AT 3 KTS 8.0 RAMMING
TRANSIT SPEED (OPEN WATER)	12.5 KTS
SERVICE ENVIRONMENT	
AIR TEMP	-50F TO 95F
SEA WATER TEMP	28F TO 85F
BEAM WIND	100 KTS
ENDURANCE	80 DAYS (28 FULL POWER) 180 DAYS PROVISIONS

MEETS TWO COMPARMENT FLOODABLE LENGTH STANDARD
FLOODING ALARMS ON BRIDGE

POSITIONING	
HEADING +/-5 DEGREES	WINDS 35 KTS STEADY UP 45° OFF THE BOW
SURFACE CURRENT 3.0 KTS	SEA STATE 5

HABITABILITY	
ACCOMODATION PROVIDED FOR	17 OFFICERS (INCLUDES CO) 12 CPO 109 CREW* 30 SCIENTIST 1 GUEST

*INCLUDES BERTHING MARGIN OF 13

PROVIDED--BARBER SHOP, LAUNDRY, SEABAG LOCKER, FOUL WEATHER GEAR STOWAGE, CONFERENCE ROOM, LIBRARY, GYM, SELF SERVICE LAUNDRY, CLASS 2A MEDICAL FACILITIES

TABLE 1. (CONT)

FLIGHT OPERATIONS
PROVIDED--HANGER FOR 2HH-65A HELOS, HELO SECURING AND TRAVERSING, 450 HOURS OF FUEL, HELO CONTROL STATION, AUTOMATIC FIREFIGHTING, AND NON-INTERFERENCE WITH OPERATIONS ON FANTAIL

MAIN PROPULSION
AC-CYCLOCONVERTER-AC DIESEL ELECTRIC PLANT
(SHIP SERVICE ELECTRICAL POWER PROVIDED BY MAIN GENERATORS)
2 FIXED PITCH PROPELLERS
2 RUDDERS

AUXILIARY SYSTEMS
TRIM TANKS
ANTI-ROLL TANK (PASSIVE)
HEELING SYSTEM
INPORT GENERATOR
LOW FRICTION HULL COATING
BOW THRUSTER
TOWING WINCH
1 ARCTIC SURVEY BOAT
1 LCVP
2 RHIB'S
LIFERAFTS FOR 219
DIVING LOCKER W/AIR COMPRESSOR
PORTABLE HYPERBARIC CHAMBER

NAVIGATION
CONNING STATIONS PORT, STBD, MIDSHIPS ON BRIDGE, OCEANOGRAPHIC DECK, ALOFT

MAX STERN, FLIGHT DECK AND ENGAGED SIDE VISIBILITY

LORAN, OMEGA, GPS AND INERTIAL NAVIGATION
EXTENSIVE COMMS SUITE WHICH INCLUDES INMARSAT

SCIENTIFIC SUPPORT
1 DRY LAB-512 SQ FT
2 WET LABS AND VESTIBULE-1568 SQ FT
1 INSTRUMENTATION LAB-354 SQ FT
1 COMPUTER/NAV LAB-412 SQ FT
BOW INSTRUMENT BOOM
4 WINCHES (HYDROGRAPHIC, CORING TRAWLING)
OPEN DECK SPACE-1770 SQ SIDE
-5950 SQ FANTAIL
TRANSDUCER SPACE
SCIENCE OFFICE/LIBRARY
'SEA BEAM' BATHYMETRIC SONAR
ICE ACCESS VIA SPECIAL ACCOMMODATION LADDER
CRANES -CAPACITY 15 TONS
-COVERAGE 95% OF DECK SPACE, OVERSIDE 15 TONS AT 64 FT
REFRIGERATED SPACE-FREEZER 320 SQ FT
DARKROOM

TABLE 1. (CONT)

SCIENTIFIC SUPPORT (CONT)

COMPUTER SYSTEM
CARGO CAPACITY -1300 CU FT APT
-34,700 CU FT FWD HOLD W/O VANS
-30,000 CU FT WITH VANS
ACOUSTIC DOPPLER CURRENT PROFILER
SHIPS DATA VIDEO MONITORING SYSTEM
CLOSED CIRCUIT TELEVISION

WARTIME CAPABILITIES
6 MACHINE GUN MOUNTS
ARMORY
DEGAUSSING
CBR WASHDOWN

ELECTROSLAG SURFACING FOR CONSTRUCTION, RESTORATION, AND REPAIR OF SHIP STRUCTURES

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ABSTRACT

With construction of new commercial ships in U.S. shipyards at an all-time low and Congressional appropriations insufficient to maintain a U.S. fleet of 600 ships, the priorities of the surviving U.S. shipyards are changing from that of shipbuilding to ship rebuilding, restoration and repair.

This paper presents a review of the international literature on the most recent developments in thick section surfacing by electroslag surfacing (ESS) using strip or wire electrodes. The advantages of this newly-developed technique from Japan are explained in comparison with the conventional surfacing processes, such as submerged arc surfacing (SAS). A number of innovations and applications in this area are introduced to emphasize the substantial economical advantage of strip ESS for ship repair and manufacturing.

ESS with strip electrodes is capable of overlaying a wide variety of corrosion and/or wear-resistant deposits on structural ship components with half the dilution level and twice the deposition rate of its closest competitor, SAS. Because of its significant economical merits, strip ESS has already become the dominant thick-section surfacing process in many industrialized countries, particularly in Japan, the Soviet Union and parts of Europe.

1. NOMENCLATURE

ESS -- Electroslag Surfacing
ESW -- Electroslag Welding
ESR -- Electroslag Remelting
SAS -- Submerged Arc Surfacing
SMAW -- Shielded Metal Arc Welding
GMAW -- Gas Metal Arc Welding

2. INTRODUCTION

The future requirement for new ships forecast by the Association of West European Shipbuilders (1) implies over a third of the world's shipyard capacity active in 1985 will have to close if it is to be brought into line with demand. Unfortunately, international competition and foreign labor rates have put virtually all commercial shipbuilding contracts out of reach for U.S. shipbuilders (2,3). This has created a fiercely competitive environment for the dwindling U.S. Naval contracts. With construction of new commercial ships in U.S. shipyards at an all-time low and Congressional appropriations insufficient to maintain a U.S. fleet of 600 ships (4), the priorities of the surviving U.S. shipyards are changing from that of shipbuilding to that of ship rebuilding, restoration and repair.

Various surfacing processes have been utilized to repair and rebuild corroded or worn ship components. For many years, SAS with strip electrodes was considered the most cost-effective method to overlay large components, such as ship propeller shafts, and now still prevails in the United States. The Japanese and Soviet shipbuilders, in particular, have developed highly cost-effective methodologies to rebuild large ship components using an innovative concept known as "Electroslag Surfacing".

In 1980, Kawasaki Steel (5) of Japan first developed a reliable strip ESS process, which rapidly spread throughout Japanese industries (6). Several Western European countries also adopted this process and are commercially manufacturing standard ESS equipment (7).

Strip ESS exhibits substantial advantages over strip SAS in the areas of process control, surfacing quality and economic productivity. It has completely replaced the less economical surfacing methods in Japan and the Soviet Union, but has yet to be "discovered" in U.S. shipyards and manufacturing industries.

The purpose of this study is to critically review the international literature on ESS and strip ESS. Of particular emphasis will be the flux chemistries and surfacing parameters that are associated with this processing innovation. The advantages of surfacing with the strip ESS method are reported.

3. CHARACTERISTICS OF ELECTROSLAG SURFACING

Although the strip ESS process is new, the fundamental principle of ESS is similar to that of the Electroslag Welding (ESW) and Electroslag Remelting (ESR) processes. Heat is generated by ohmic heating of a resistive slag by the passage of an electric current through a strip electrode, which

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is continuously fed into the molten slag pool. Figure 1 shows a schematic diagram of the ESS process.

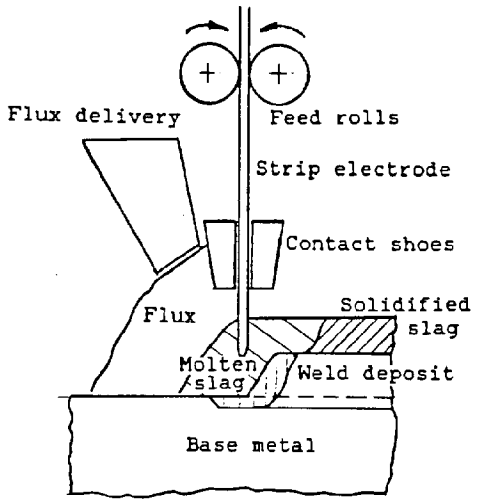

Figure 1. Diagram of the electroslag surfacing process.

The process appearance of strip ESS is nearly identical to that of strip SAS, except SAS is primarily arc-functioning while ESS is arcless and produces heat by I^2R (ohmic) heating of the molten slag. However, strip ESS exhibits a series of advantages over strip SAS in providing low dilution deposits, high deposition rates and better productivity.

The first important feature of strip ESS is low dilution in the deposits. In any surfacing process, a critical factor requiring precise control is the dilution ratio, expressed as:

$$\% \text{ Dilution} = B/(A + B) \times 100$$

where A is the cross sectional area of reinforcement of deposits above the base metal surface, and B is the cross sectional area of the melted base metal below the workpiece surface. In terms of surfacing, it is necessary to keep low dilution levels because the surfaced layer has to maintain its desired inherent properties, like wear or corrosion resistance. In SAS, the arc tends to penetrate more deeply and melt more base metal in comparison to ESS. For example, the strip SAS process typically produces a dilution ratio of 18% at a current density of 25 A/mm² (16.1 kA/in²), compared to approximately a 9% dilution ratio for the strip ESS process at 41 A/mm² (26.5 kA/in²) (8). Thus, the chemical composition of the overlay deposited by ESS will more closely resemble that of the filler metal.

The second important feature of ESS is its high deposition rate, which is a function of the current density. The use of a high current density in the SAS process will effectively make the arc hotter and stiffer, thus causing it to penetrate more deeply into the workpiece to increase the dilution ratio. On the other hand, the strip ESS process allows the use of almost double the current density to produce a much higher deposition rate while still maintaining a lower dilution level. This desirable combination of a high deposition rate and a low base metal dilution was the main incentive for Japanese industries to eliminate SAS in favor of ESS.

The third important feature of ESS is the feasibility of single layer deposition. By virtue of its low dilution and high deposition rate, surfacing can be most economically attained for the desired thickness of a corrosion or wear resistant layer with a designed chemical composition. Since the dilution level for strip ESS is almost half that of strip SAS, the strip ESS process can more likely eliminate the necessity for multiple layer deposits and result in greater cost effectiveness. Furthermore, thin overlays (about 3 mm or 1/8 in. thick) are far more advantageous by ESS because dilution decreases with overlay thickness for ESS but increases by SAS.

Further economical advantage is gained by the use of wide strip which deposits a greater surface area per unit time. Large strip widths (> 60 mm [2.4 in.]) are particularly more difficult to apply by SAS than ESS. In the SAS process, the arc is struck at one corner of the strip and then starts traversing the entire width of the strip (5,9). The strip is consumed by the oscillatory movement of the arc across the strip. However, in ESS the strip is consumed uniformly across its entire width. The movement of the arc in SAS is not necessarily uniform and leads to inconsistent penetration and lack of fusion. For this reason, SAS has been limited to a strip width of 75 mm, whereas using strips as wide as 300 mm (11.8 in.) is not uncommon in ESS. A comparison between the strip ESS and SAS process is presented in Table I.

4. FURTHER INNOVATIONS IN ESS FROM JAPAN

a. External Magnetic Field for ESS

In 1980, Nakano and his colleagues in Japan (5) first developed an electromagnetic controlled strip ESS method called the MAGLAY process. During surfacing with wide strips (> 60 mm [2.4 in.]), the formation of undercutting and lack of fusion defects were found to be related to the flow pattern of molten slag and metal, which is driven by the electromagnetic force induced by the high values of the surfacing current. Electric current, flowing parallel from the strip to the bottom of the molten pool, makes both slag and metal move from the edges of the pool toward the center. To counteract this force in the MAGLAY process, two direct current coils are mounted adjacent to the edges of the strip electrode resulting in counterbalancing magnetic forces. The use of an external magnetic field effectively (a) avoids undercut at the bead tie-ins, (b) eliminates slag entrapment, and (c) produces a more uniform thickness of overlay.

Table I. Comparison between submerged arc surfacing and electroslag surfacing with stainless steel strip electrodes (8).

	SAS	ESS
Strip:		
dimension (mm)	60 x 0.5	60 x 0.5
carbon content (%)	0.015	0.015
Parameters:		
I (A)	750	1250
V (V)	26	24
v (cm/min)	10	16
Current density (A/mm²)	25	41.7
Heat input (KJ/cm)	117	112.5
(KJ/cm²)	19.5	18.7
Bead thickness (mm)	4.5	4.5
Dilution (%)	18	9
Deposition rate (Kg/h)	14	22
Flux consumption	0.65	0.5
Carbon content of single deposit layer (base metal: 0.18% C)	0.045	0.030

b. "PZ" Arc-Facilitating Process

Strip surfacing at the Japan Steel Works also utilizes the electroslag mode of deposition but without the aid of magnetic devices (6). Their process is called "PZ". The important feature of this process is that an arc is always maintained at the strip extremities while most of the strip tip is still in the electroslag mode. The auxiliary arc facilitates bead tie-in and penetration, but avoids excessive dilution at the center of the bead caused by the Lorentz force. The 150 mm (6 in.) wide strips used in the "PZ" process provide a uniform overlay surface and a low dilution level in each bead.

c. "HS Process"

Kobe Steel Ltd. developed the high speed overlay welding technique called the HS Process (High Speed Strip Overlay Welding Process) which utilizes a strip that can be applied to an actual vessel even as a single layer process [10]. In terms of efficiency, the HS technique is claimed to utilize only a 75 mm (3 in.) wide electrode but competes attractively with the ordinary ESS process using a 150 mm (6 in.) wide electrode.

The key points of this technique are a high travel speed and a forward electrode inclination angle. Usually when the electrode travel speed exceeds 200 mm/min (7.8 in/min), the electrical transfer through the slag pool shifts from electroslag to submerged arc due to an increase in slag resistivity with decreasing slag superheating. The inclination angle of the electrode permits molten metal to enter the gap between the base metal and electrode and produces a buffer by preventing deep penetration into the base metal, and reduces the dilution of the surfacing layers.

5. INNOVATIONS IN THE SOVIET UNION

The ESS process is also widely used in the Soviet Union and Eastern Europe. A great amount of innovations were frequently reported in their technical journals. Although most articles are often lacking technical details, their basic designs and functions could still be reviewed.

a. Multi-Strip Feeding

The Paton Welding Institute started studies on ESS with two electrode strips in the late 1970's (11-13). The advantage of this dual strip feeding process is a substantial increase in deposition rate. When two strips are fed in parallel, the molten slag may rise between the two strip electrodes and directly contact with air, causing considerable convectional agitation. Thus, the distance between two strips has become another important parameter to be taken into account.

ESS with more than two wire electrodes has also been reported by V. Melikov (14). As many as 15 stainless steel electrodes (all 3 mm [1/8 in.] diameter wires) were simultaneously deposited over the entire 340 mm (13.4 in.) width of the workpiece in the downhand position with artificial cooling.

Shvartser (15) claimed two hardfacing processes with a group of plate electrodes. In one case, the high Mn steel electrodes were deposited on worn dredger buckets. In another case, the high Cr casting iron electrodes were deposited on worn steel blades, as shown in Figure 2. The absence of cracks and formation defects made it possible to greatly increase the service durability of hardfaced components and reduce the production cost in comparison with brazing expensive alloy.

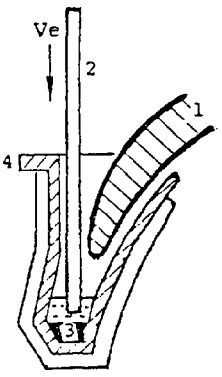

Figure 2. The hardfacing of buckets: the diagram of the process 1) component, 2) electrode, 3) deposited metal, and 4) solidification mold (15).

b. Plasma-Electroslag Deposition

A plasma-ESS method was reported by Batakshev et al. (16) to deposit high purity copper on low alloy carbon steels. The requirement of an auxiliary plasma is to counteract the high conductivity of the copper overlay.

In this process, the pilot arc is initially ignited in the plasma torch, followed by ignition of the plasma arc between the workpiece and the electrode of the plasma torch. A special flux is fed into the acting zone of the plasma jet. This flux contains elements with low ionization potentials (Ca, Na, Ba, etc.), which increase the stability of the plasma jet due to a decrease in electrical resistance. The flux soon melts and forms a slag pool. When the base plate is heated to a sufficiently high temperature, the copper filler metal is fed into the slag pool, and the plasma torch and the mold are moved at the same time, resulting in the surface overlay.

The plasma ESS process provides a means to control the time dependence of heating the parent metal without the use of consumable electrodes. It also prevents contamination of the deposited copper. In a steady-state operation with the optimum parameters of 450-500A/55-60V and a 30-40 mm (1.4-1.6 in.) deep molten slag pool, the process could produce a 2-3 mm (0.1 in.) thick and 15-20 mm (0.6-0.8 in.) wide deposit in a single pass.

c. Surfacing of Shaped Parts

A variety of examples could be found in the Soviet technical journals, reporting the use of ESS for the restoration of worn components having complex shapes. The surfacing of those shaped parts is performed by a modified electroslag welding process. A specially designed water-cooled mold is used to confine the molten slag and metal pool into the desired shape. Figure 3 illustrates the use of a shaped mold for surfacing the teeth of excavator buckets.

As Valits indicated (17), to restore a complicated shape, the energy of the melt must be sufficient to ensure both the transfer of the melt to the remote part of the mold and the complete fusion at that location. His experimental results verified that an increase in the voltage or the current density improved the quality of the deposited metal. However, when the current density was excessive, the slag pool could be "thermally saturated". The thickness of the deposited layer no longer increased, and the risk of short-circuiting was eminent.

For large-scale parts, the ESS operations were reported lasting more than 30 hours. To ensure a high quality of the deposited layer, the process must be stable and maintained without interruption. Stepanov (18) pointed out that the nonuniform adhesion of molten metal and the presence of a slag skull in long term ESS could cause rapid abrasive wear and local superheating in the tail part of the shaped mold. Thus, the inner surface of the mold has to be made of materials with high

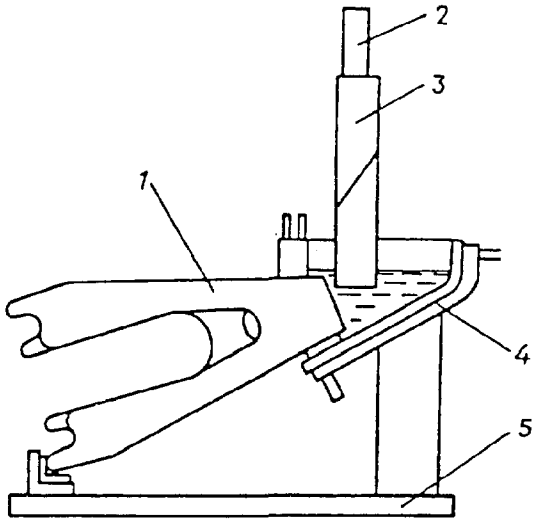

Figure 3. Diagram illustrating the ESS of an excavator shovel tooth with varying chemical composition metal: 1) tooth blank, 2) standard head, 3) consumable electrode, 4) mold base, and 5) frame.

thermal conductivity and also high resistance to the action of molten slag and metal pools. In this case, copper and its alloys do not ensure the required thermal efficiency. He reported an application using a damping heat conducting layer in the solidification molds. The inner contact surface of the mold was made of a less thermally conductive alloy steel, followed by a damping heat conducting layer made of pure copper, and finally by the water-cooled structural steel base. This method provides proper control of the cooling rate of the deposited metal, and ensures a uniform temperature distribution in the molds.

d. Surfacing of Thin-Walled Components

Multi-electrode surfacing usually makes it possible to deposit, in a single pass, a layer of metal having the required thickness and width nearly equal to that of the components. Although its use for thin-walled components risks the possibility of burning through, a report from the Tashkent Institute of Railway Transport Engineers claimed the development of a successful example for the ESS of the friction wedge of the damper of wagons whose maximum wall thickness was only 5 to 6 mm (≈ 0.2 in.) (19).

In this process, nine electrode wires (each 3 mm [1/8 in.] in diameter) are deposited simultaneously, and an AC (not specified in that paper, but believed) power source with a hard external characteristic is used. The main parameters of this process include: 32 volts, an electrode feed rate of 0.51 m/hr (20 in/hr), and a surfacing speed of 1.8 m/hr (70 in/hr). A few factors are critical to prevent burn-through defects, including the slag pool depth, the electrode extension, and the stationary (without longitudinal

displacement) feeding time of electrodes in the initial stage of surfacing for inducing the slag pool and the final stage of surfacing for filling the crater. By increasing the initial stationary feed time, the molten filler metal spread ahead of the electrode tip thermally protecting the base metal. A wear-resistant layer of 6-12 mm (0.24-0.47 in.) thick and 135 x 180 mm (5.3 x 7 in.) in size is reported being deposited in a single pass on the surface of mild steel.

e. Surfacing Layers With Compositional Gradients

In many cases of service, the different portions of an individual hardfaced work piece experience different degrees of wear. The geometrical loss due to the uneven wear reduces its life prematurely. The rational solution to this problem is to make the working surface from composite metal, whose wear resistance changes gradually to accommodate the differences in the severity of wear at different locations on the workpiece. By producing a part that wears uniformly, the functional life of the part is lengthened.

Shvartser (20,21) developed a special surfacing process to provide a wear gradient for an excavator shovel, which is illustrated in Figure 3. In service, the abrasive wear on its rear face increased substantially from the tail end of a tooth to its apex. In order to extend its life, a prescribed variation in chemical composition of the deposited metal was obtained by depositing a special composite electrode which consisted of two dissimilar metals (a high Mn steel and a high chromium iron) meeting along an inclined plane (Figure 4). The surfacing deposits adjacent to the front face of the teeth were a wear-resistant Cr iron, changing (towards the rear face) into a high Mn steel. In service, those hardfaced teeth maintained a consistent geometry (21,23).

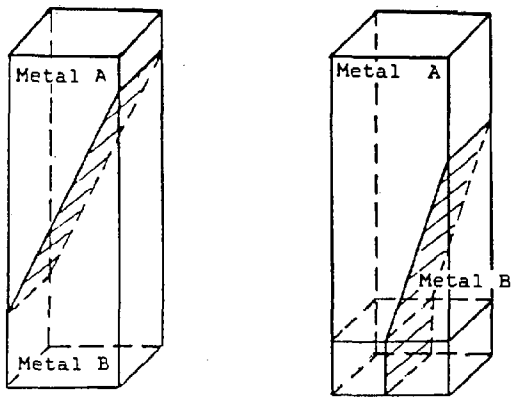

Figure 4. Two composite electrodes designed to provide surfacing layer with compositional gradient (20,21).

Recently, Gulakov et al. (22) analyzed both the buffer effect of the weld pool and the element transfer from the base metal (or the previous deposited layer) on the final gradient of the chemical composition. They constructed a model of the molten surfacing pool and proposed ways of reducing the difference between the required and actual compositional variation. A programming device was also designed to facilitate the gradient method of surfacing (23).

6. PROCESS DETAILS

a. Power Source

ESS is always carried out with direct current, constant voltage (DC-CV) power sources using reversed polarity (the strip electrode is connected to the positive terminal of the power source) in order to ensure adequate fusion to the base metal. Since the optimal current density for ESS is around 40 A/mm^2, the output rate of power sources at a 100% duty cycle should meet the following minimum load handling requirements: 1250A for 60 x 0.5 mm (2.4 x 0.02 in.) strips; 1800A for 90 x 0.5 mm (3.5 x 0.02 in.) strips; and 2400A for 120 x 0.5 mm (4.7 x 0.02 in.) strips (8). In practice, such high current levels are usually obtained by connecting two power sources in parallel.

b. Flux Chemistry

In strip ESS, it is very critical to establish stable ohmic (arcless) conduction of electricity through a shallow slag pool of only about 20 mm (0.79 in.) depth. To maintain a stable electroslag mode through a shallow slag, a special flux composition had to be developed. Such fluxes must provide greater electrical conductivity than would be needed for normal electroslag welding of the same plate material. Adding large quantities of fluorides, mainly CaF_2 and NaF and/or semiconductors, such as TiO_2 and FeO, can greatly raise the electrical conductivity of molten slag without risk of generating arcs. However, large quantities of TiO_2 in slag cause a deterioration in the detachability of the slag. Therefore, additions of fluorides are more preferable (5,8).

The level of electrical conductivity of slag is closely related to the fluoride content in the flux, as illustrated in Figure 5. The IIW (International Institute of Welding) Document XII-A-4-81 (24) indicated that in the $3CaO-3SiO_2-Al_2O_3$ ternary system, when the fluorides were less than 40% (balance ternary), the submerged-arc mode prevailed; and when more than 50% fluorides, the electroslag mode prevailed. In terms of the electrical conductivity of the slag, this corresponded to a transition range of 2 to 3 Ω^{-1} cm^{-1}. Above 3 Ω^{-1} cm^{-1}, a stable electroslag mode is easily achieved. However, to restrict the generation of fluoride type gases (due to a reaction: $2CaF_2 + SiO_2 \rightarrow 2CaO + SiF_4$), additions of CaF_2 were usually held at slightly less than 50%.

In Japan, fluxes for stainless steel overlays are principally supplied by Kawasaki Steel and Kobe Steel (6). The Kawasaki KFS-150 is a fused flux with an electrical conductivity of about 3 Ω^{-1} cm^{-1} at 1700°C. The composition of Kawasaki's patented flux (25) contains 50-60% CaF_2, 10-20%

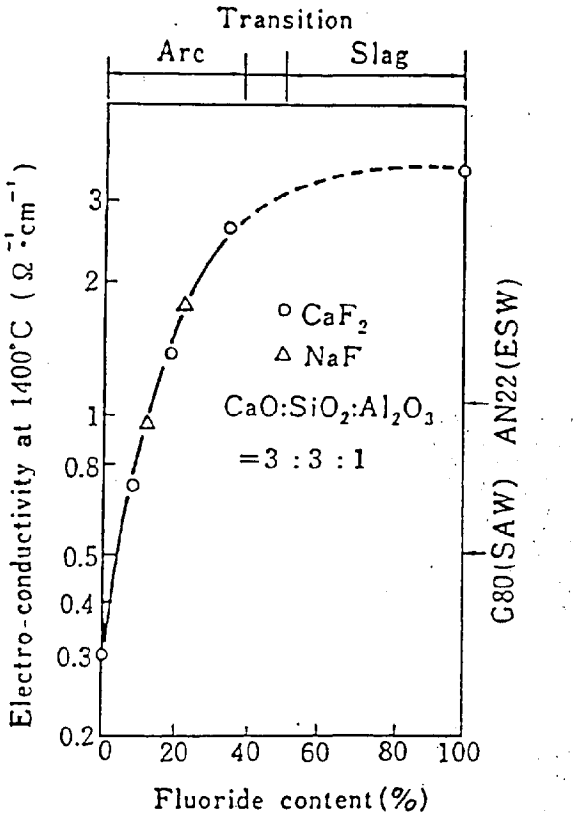

Figure 5. Effect of fluoride content in flux on electrical conductivity and current conduction type during Strip ESS (24).

SiO_2, 5-25% CaO and 10-30% Al_2O_3 in a ratio of SiO_2/CaF_2 of at least 0.20 and a ratio of CaO/SiO_2 of at least 0.50.

In the Soviet Union, a series of fluxes were developed for ESS. The ANF series fluxes are of high fluoride contents (> 50%) and high electrical conductivities (26). The AN-series fluxes, which were originally used in ESW, are also used for the thick layer build-up. Their fluoride contents are below 25% and electrical conductivities are comparatively low (26). Some new fluxes were occasionally reported being developed for certain special ESS processes (27). However, no concrete compositional information was presented.

In Western Europe, fluxes EST 122 and 201 are commonly used [8]. Some characteristic data of these two agglomerated fluxes are given in Table II. The flux EST 122 is specifically designed to be used for the depositions of all types of 300 and 400 series stainless steel strips. The flux EST 201 is designed for the deposition of the Ni-base alloys, such as 825, 600, 625 and 400 (7).

In a recent study (28) of ESS with stainless steel wire electrodes, fluxes of the CaF_2-CaO-Al_2O_3 system were studied. It was noticed that at higher CaF_2 percentages, (i.e. beyond 70%), the process

Table II. Fluxes Available From European Sources (7,8)

Content	EST 122	EST 201	Sandvik 37S
(%) Alkaline & alkaline earth oxides (CaO, MgO, K_2O, Na_2O)	50	50	50
(5) Amhoteric & alkaline earth oxides (Al_2O_3, TiO_2, ZrO_2)	25	25	25
(%) Silicon dioxide (SiO_2)	10 max	5 max	10
(%) Fluorides (expressed in F^-)	30	25	30
Flux density (kg/dm³)	0.85	0.85	0.85
Flux consumption rate (kg flux/kg strip)	0.5	0.5	

was once again that of arc conduction. As the percentage of the CaF_2 in the flux increased, there was a corresponding increase in the conductivity level. This, in effect, raised the current at the same wire feed speed, and gave rise to burn back problems. Hence, at higher CaF_2 percentages, arcing could be visible on the surface of the molten slag. On the other hand, below 40% CaF_2, the observed arcing noticed was the submerged-arc type as illustrated in Figure 6.

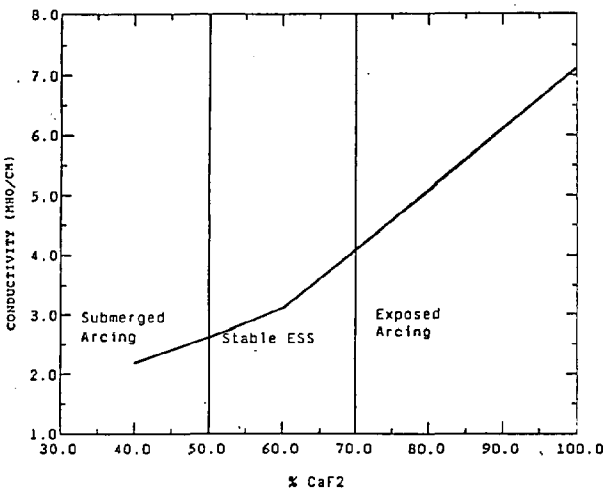

Figure 6. Effect of CaF_2 content in flux on electrical conductivity and current conduction mode during wire ESS (28).

Usually, CaO, SiO_2 and Al_2O_3 are common additions for optimizing the conductivity level of a CaF_2-based flux. The practice at the Oregon Graduate Center (28) indicated that optimizing the viscosity level of molten flux is of the same importance. Since conductivity and viscosity have an inverse relationship, adjusting the flux composition becomes a complex problem. SiO_2 is one compound which has a major influence on slag viscosity and slag flow (25). To maintain the desired viscosity, it is necessary to control a SiO_2/CaF_2 ratio of at least 0.2 and to avoid evolution of toxic gases like SiF_4 by the reaction:

$$2CaF_2 + SiO_2 = 2CaO + SiF_4$$

In addition, as specified by the Kawasaki patent (25), the minimum requirement for CaO/SiO_2 ratio should be about 0.5 for stable ESS.

c. Strip Electrode Sizes

The thickness of the strip electrode is always expected to be thin enough to facilitate coiling into rolls, in order to conveniently feed cladding during ESS. The Japanese appear to have standardized the 0.4 mm (0.016 in.) thickness for all strip widths. This differs from the European practice where a 0.5 mm (0.02 in.) thickness is most common.

The ESS process favors the use of wide strip as long as the capacity of the power supply is adequate to provide 1000-2000 amps, typically. That is because, at a given layer thickness, the most marked effect of increasing the strip width is a decrease in dilution and penetration. Usually, the penetration of overlay deposits is always more accentuated at the sides of the bead. However, the relative importance of this localized higher penetration is lessened when (a) the strip width is increased, and (b) bead overlapping is considered (8).

d. Voltage

Voltage is perhaps the most critical controlling parameter in the ESS process. In most ESS practice, the working range of voltage values is quite narrow, because of the shallow depth of the molten slag pool (5-10 mm [0.2-0.4 in]). Forsburg (7) reported that, for a fluoride-based flux, the stable range is usually 26-28 volts. When the voltage is below 24 volts, it is difficult to initiate the process, and the strip tends to stick to the base metal resulting in short circuiting. On the other hand, above 28 volts, the process starts arcing on the surface of the flux, and slag spatter becomes violent. Therefore, an accurate control in voltage is extremely important. Yu, et al. (28) found that the optimum voltage was closely related to the actual depth of the molten slag pool, and a stable ESS process could be performed at 22-24 volts. In addition, it was also shown (28) that an intentionally increased open-circuit voltage is beneficial to the initiation of ESS.

Even within the stable voltage range, fluctuations in voltage also affect the dilution, penetration and geometry of the surfacing layer as shown in Figure 7. By increasing voltage, the rising heat input increases the volume of base metal melted, thereby increasing the level of penetration and altering the geometry (width/ thickness) of overlays. Nevertheless, the dilution level still remains essentially constant or only slightly decreases with increasing voltage.

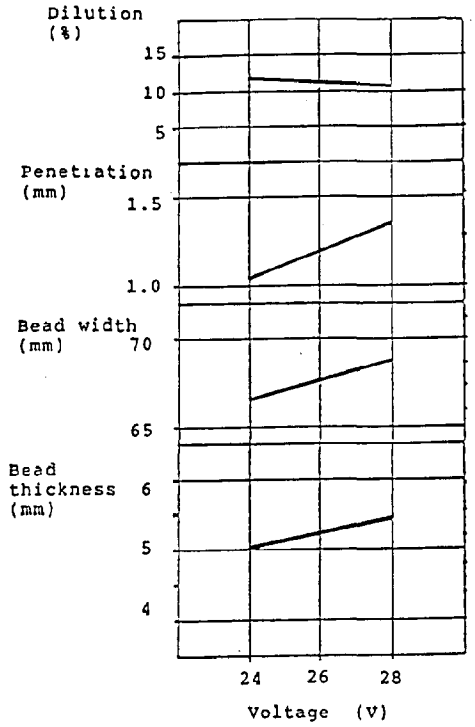

Figure 7. Influence of voltage for strip electrode, size 60 x 0.5 mm at 1250A surfacing current and 150 mm/min travel speed (7).

e. Current

ESS has been reportedly used (7) only with DC reverse polarity (electrode positive). At a given voltage and surfacing speed, increasing the ESS current directly increases penetration, bead width and thickness, but has little effect on dilution.

Stable and quiet welding conditions can be achieved within a given range of ESS current. The optimum current density for strip ESS is around 40-45 A/mm² (26-29 kA/in²). At the higher values of current density, the amount of slag spatter increases and the depth of the slag pool has to be raised to stablize the operation.

f. Travel Speed

At a given welding current and voltage, increasing the travel speed tends to increase dilution and penetration, while decreasing bead width and thickness (7). Increasing the travel speed in effect reduces the heat input and, thereby, decreases the electrical conductivity of slag. The

ESS process can only be stable when sufficient contact area between the molten slag pool and the melting strip is maintained. An excessively fast surfacing speed may cause the strip to be in contact with cold flux or insufficiently heated slag, thus resulting in sporadic arcing and process instability.

In general, the travel speed should be optimized for both economy (fast speed) and an adequate thickness of surfacing layer (about 4-6 mm [≅ 0.2 in.]) (8). Excessive travel speed results in not only a bead thickness less than 4 mm, but also in the risk of the formation of undercutting. On the other hand, too slow a travel speed results in a bead thickness above 6 mm. Then, the wetting angles of beads become too steep and slag entrapment may occur at the overlaps. In general, the optimum travel speed range is about 160-200 mm/min (6-8 in/min), which results in about a 10% dilution level, and consumes about 0.15 kJ/mm² (96 kJ/in²) heat input (28).

g. Other ESS Parameters

The strip extension, i.e. the conventionally called "stick-out" (the free length of the strip extending from the contact jaws to the slag pool), is not critical in this process. Usually it may vary from 25-40 mm (1-1.5 mm) (7).

The limitation of parent metal thickness depends on the heat input during ESS and the width of strips used. Forsburg (7) reported that in order to ensure sound ESS with a 60 x 0.5 mm (2.4 x 0.02 in) strip, the minimum parent metal thickness is 40 mm (1.6 in.). The minimum diameter of curved surface for ESS with the 60 x 0.5 mm strip electrodes is 250 mm (10 in.) for external surfacing, and 450 mm (18 in.) for internal surfacing. This is ideally suited for the rebuilding of ship propeller shafts. Practices at the Oregon Graduate Center (28) have found the above limitation was relatively conservative. For example, with a 60 x 0.5 mm strip, ESS could be performed on 25 mm (1 in.) thick plates.

7. APPLICATIONS OF STRIP ESS

Presently, strip ESS is entirely foreign technology, which has further widened the construction cost gap between the Asian shipyards and U.S. shipbuilders. However, utilization of this foreign technology and the substantial improvements in strip ESS anticipated at the Oregon Graduate Center will enhance the economic position of U.S. shipyards to rebuild worn, eroded or redesigned structural ship components, such as large propeller shafts, rudder horns, strut shafts, deeply corroded portions of the hull, hawse pipes and leading edges of rudder castings.

This process, though fully automatic, is also portable in the shipyard when a conventional (and inexpensive) carriage system is used to mobilize the strip ESS system in remote locations. A typical carriage system can handle 1500 amps and can pull power cables 30 m (100 ft.) long while being either track or manually guided. These carriage systems have been commercially manufactured in the United States for many years for submerged arc welding applications, particularly in shipyards.

8. CONCLUSIONS

Based on a computerized search of the international technical journals on the subject of electroslag surfacing, a critical review was performed and the following can be concluded:

1. ESS with strip electrodes is the most economical and productive method to overlay a wide variety of corrosion and/or wear resistant deposits on structural ship components, such as propeller shafts.

2. The highest deposition rates combined with the lowest base metal dilution are characteristic of ESS with strip electrodes compared to conventional surfacing methods, such as strip SAS, GMAW and SMAW.

3. The dominant thick-section surfacing process in Japan, the Soviet Union and several European countries is ESS.

4. Neither U.S. shipyards nor U.S. manufacturing industries have adopted the ESS process. Conventional surfacing methods are still utilized in the U.S.

5. Technically, the key difference between the newly-developed ESS process and other similar processes, such as SAS and ESW, is the flux chemistry.

9. ACKNOWLEDGMENT

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10. REFERENCES

1. P. A. Milne, "High Technology in Shipbuilding", Proc. Inst. of Mech. Engrs., Vol. 201, No. B2, 1987, pp 59-72.
2. L. M. Thorell and T. Watanabe, "Technical Collaboration Between Mitsubishi Heavy Industries and Todd Shipyards", in the Proceedings of the National Shipbuilding Research Program, 1986 Ship Production Symposium, Paper No. 5, Sponsored by SNAME Ship Production Committee, 1986.
3. T. S. Upham and W. M. Crawford, "Decentralization--The Management Key to Effective Accuracy Control", in the Proceedings of the National Shipbuilding Research Program 1986 Ship Production Symposium, Paper No. 4, Sponsored by SNAME Ship Production Committee, 1986.
4. "600 Ship Navy Won't be Sustained", Marine Log, January, 1988, pp 49-51.

5. S. Nakano, N. Nishiyama, T. Hiro and J. Tsuboi, "Maglay Process-Electro-Magnetic Controlled Overlay Welding Process with ESW", Kawasaki Steel Technical Report, No.2, March (1981), p 31.
6. "Welding Technology in Japan", Welding Research Council, N.Y., (1982), p 16-22.
7. S. Forsburg, "Resistance Electroslag (RES) Surfacing", Welding Journal, August 1985, p 41.
8. "Electroslag Strip Cladding"--A draft, Oerlikon Industries, (1985).
9. V. Pilous and R. Kovarik, "Experimental Determination of The Metallurgical and Technological Parameters in Surfacing with Austenitic Strip Electrodes", Welding International, No.1, (1987), p 84.
10. O. Tanaka, K. Takeba and Y. Matsushita, "High Speed Overlay Welding With Strip Electrodes", Stainless Steel, Nov., (1985), p 58.
11. V. Mastenko, E. Starchenko and V. Khodakov, " Stability of The Electroslag Process in Two Electrode Strip Surfacing", Welding Production, March, (1982), p 23.
12. V. Mastenko and E. Starchenko, "Effects of Variation in Welding Parameters on Weld Surfacing With Two Strip Electrodes", Automatic Welding, July 1984, p 50.
13. P. Blaskovic, S. Lesnak and J. Zajac, "Electroslag Surfacing in the Horizontal Position Using Two Strip Electrodes", Surfacing J. Int. 1, (2), (1986), pp 75-78.
14. V. Melikov, E. Sheinman and M. Brodyanski, "Special Features of the Multielectrode Wide-Layer Deposition of Austenitic Layers on Low-carbon Steel", Welding Production, Feb. 1982, p 7.
15. A. Shvartser, "The ESS of Components With a Group of Electrodes", Welding Production, Jan. 1981, p 27.
16. A. Batakshev, S. Berezhnitskii, A. Lamzin and O. Steklov, "Plasma-electroslag Deposition of Copper on Steel", Welding Production, July 1984, p 17.
17. K. Valits, A. Shvartser, V. Dorokhov and B. Matveev, "The Effect of the Conditions of ESS of the Quality of the Deposited Layer", Welding Production, May 1981, p 26.
18. B. Stepanov, V. Yakovlev, G. Surovtsev and I. Izyur'ev, "Using a Damping Heat Conducting Layer in Solidification Moulds for Electroslag Surfacing", Welding Production, May 1984, p 39.
19. E. Ashkinazi and E. Sheinmass, "Factors Affecting the Quality of Bonding in Wide-Layer Surfacing of Thin-Walled Components", Welding Production, Feb. 1986, p 24.
20. A. Shavartser, V. Shvarts and Nikitenko, "Calculating the Amounts of Components in a Varying Chemical Composition Alloy During Electroslag Surfacing", Automatic Welding, Feb. 1980, p 17.
21. A. Shvartser, V. Stoiko, Z. Nikitenko and I. Morgachev, "Excavator Shovel Teeth Reconditioned by Surfacing with Varying Composition Metal", Automatic Welding, March 1985, p 43.
22. S. Gulakov and B. Nosovskii, "Special Features of Production of Welded Joints with Regulated Distribution of Chemical Elements Along The Length", Welding Production, July 1982, p 8.
23. S. Gulakov and B. Nosovskii, "A Programing Device for Depositing a Layer of Metal with a Varying Chemical Composition", Welding Production, July 1985, p 52.
24. S. Nakano, T. Hiro, N. Nishiyama and J. Tsuboi, "The New Strip Electroslag Overlay Technique with Electro-Magnetic Control--The Maglay", IIW Document, XII-A-4-81, (1981).
25. J.Tatershi, T. Ishikawa, S. Nakano and N. Nishiyama, United States Patent 4,437,406, (1984).
26. B. Paton, (ed.), "Electroslag Welding & Surfacing", Vol.1, MIR Publishers, Moscow, (1983), p 172.
27. K. Valits, A. Shvartser and V. Stoiko, "A Flux For Electroslag Hardfacing of High-Manganese Steel", Adv. Spec. Electrometall., Vol. 1, No. 4, (1985), pp 162-165.
28. D. Yu, Y. K. Oh and J. Devletian, Unpublished research, Oregon Graduate Center, (1987).

CONVERSION OF SURPLUS OILFIELD SUPPLY VESSELS TO RESEARCH VESSELS

James A. Chance

Survey Boats, Inc.

There are still a great number of oilfield service vessels held by financial institutes and the Maritime Administration. These vessels can be bought at reasonable prices, but the great difference in mission requirements between an oilfield service vessel and a research vessel can make the conversion difficult. Design goals and constraints of OSV's are discussed in their relationship to the conversion of these vessels to research use. The conversion of a 150' supply vessel to a research vessel is discussed in detail.

The United States oilfield support vessel fleet is made up of four classes of vessels built to perform various jobs. Despite being built to very different criteria than typical research vessels, their low acquisition cost can make them interesting candidates for conversion.

The largest class of vessels and the most available for conversion are the supply boats. They are of steel construction and range from 150' to 180' in length. The overriding emphasis in their design is deck cargo capacity. They are very full in shape with a typical block coefficient being in the range of .65 to .70. Because they do not have to meet damage criteria, they have very limited freeboard. The initial stability is very high to give adequate stability with limited freeboard. The rear cargo deck is large and flat and typically runs two-thirds (2/3) the length of the boat. The forward one-third (1/3) consists of a focsle cabin with a deck house and pilot house above. The volume of the ship below decks is usually either deepframed or in ballast to reduce tonnage, except, of course, for the machinery space. Some vessels are equipped to carry bulk mud or liquid mud below the main deck. In any case, a supply boat with no deck load needs to carry substantial ballast to maintain submergence of the wheels and rudders while operating in a seaway. This limits the use of below deck spaces. Typical accomodations are for 16 men, including the ship's complement.

Two common variations of the common supply boat are the tug/supply and the four-point boat. A tug/supply is very similar to a normal supply vessel, but is equipped with much more power and a large towing winch. In addition to operating as a supply boat, they can be used as oceangoing tugs. Four-point boats have four mooring winches with 2,000 to 7,000 feet of cable. They are used for diver support and coring on a four-point anchor spread.

Utility boats are smaller steel vessels in the 90' to 120' range. They are used for field production support, diver and ROV support, surveying, maintenance, sandblasting and painting. They are designed to carry much smaller amounts of cargo, 12 to 20 passengers, and to function as work platforms in addition to transportation, block coefficients tend to be near .60. Because they must meet damage requirements, they have more freeboard than supply boats. The extra freeboard is usually taken advantage of by reducing the initial stability, which gives a gentler roll. The rear cargo deck is usually in the 50' to 60' range. Some utility boats have focsle cabins giving very good space utilization. Others have a deck house and a low bow giving a more practical deck height forward for diving work and increase visibility. Because the boats are smaller, tonnage is less of a problem, and the below deck areas are often used for accomodations. Staterooms are not as spacious as on supply boats, but are of reasonable size. A typical boat would have accomodations for 16 to 22 including the four-man boat crew.

Crewboats are used principally for the transportation of personnel and have very limited cargo capacity. They range in size from 65' to 150' with the vast majority at or near the 100' mark. Unlike supply boats and utility boats, the hulls are made of aluminum and are designed for planing, rather than displacement. The cargo decks are similar in size to that of a utility boat, but load capacity is much reduced, often to less than 35 tons. Passenger capacity is much higher with 50 to 60 passengers being typical. Accomodations for these passengers, however, usually consists of a seat and access to a head. No attempt is made to berth or feed the passengers. Modest accomodations for a four-man boat crew are usually provided. Crewboats have considerable freeboard, but because of their low polar moment of inertia, low mass and shallow draft, they tend to have a stiff, harsh ride. Their higher speed (20 knots) is achieved partially by lower weight and partially by horsepower 50% to 100% higher than a comparable displacement hull. Because the power is squeezed

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out of smaller engines, maintenance and repairs to the propulsion units are considerably higher.

Geophysical vessels range from 160' to 300' and are used to collect low frequency seismic reflections from the seafloor. The primary design characteristic of a geophysical vessel is a huge interior volume to house computer rooms, compressor spaces, workshops, accomodations for 30 to 50 people, and a vast amount of storage for equipment, stores, and supplies. A focsle cabin comes well aft of midship leaving a small back deck covered overhead by a continuation of the focsle deck. The focsle deck holds a deck house forward with a pilot house above.

Many geophysical boats are conversions of basic supply boats.

Geophysical boats are much more diverse than other classes of boats and it is difficult to refer to them as a class. Because they are designed for geophysical research, they are obviously suited for that type of research. Because of their relative scarcity and diversity, they will only be dealt with peripherally.

The first step in acquiring and converting a vessel is determining your needs. Not only must you define what your needs are, you must determine what they aren't. The biggest threat to a conversion is that it is inflicted with the Swiss army knife syndrome (SAKS). The symptoms are a crippling addition of paraphernalia that makes the maintenance and operation of the vessel much like trying to drive screws with a Swiss army knife.

Another point to remember is that flexibility is what gives a boat the ability to adapt to the future and weather the onslaught of SAKS. In practical terms, flexibility means extra deck space, cabin space, machinery space, electrical power, electrical circuits, winch and A-frame capacity, and bouyancy.

In our preliminary plans to purchase and convert a vessel for research use, much thought was given to a vessel capable of coring operations, supporting the larger sidescan systems, such as the EDO Deep Tow and the various SeaMarc systems, and 48 trace high resolution geophysical surveys. The mooring and/or dynamic positioning system required for coring, along with the large deck space needed were determined to be incompatable with the economical pursuit of our sidescan and geophysical survey requirements. Coring capability was deleted in order to optimize these other capabilities.

When a firm concept of needs is developed, the search for a vessel begins. In addition to the practical problems of making the modifications fit the tonnage of the vessel should be noted.

A research vessel under 300 gross tons is not subject to Coast Guard inspection. A research vessel over 300 gross tons is inspected, and by a set of rules different than those for cargo boats or passenger boats. A research vessel over 300 tons must meet subdivision and damage stability requirements much greater than a 300 ton cargo vessel. There is no practical way to do this. If the subdivision and stability problems could be met, there are a host of other rules (listed in 46 CFR Subchapter U), that make the conversion impractical. If for some reason a vessel over 500 gross tons is invisioned, then S.O.L.A.S. regulations would come into play.

Because the rules for uninspected vessels are considerably less stringent, virtually any inspected cargo or passenger vessel will meed the requirement for an uninspected research vessel.

Some research vessels under 300 tons are still subject to manning requirements. Those over 100 tons are required to have a three watch system for licensed crew members and deckhands. Two-thirds of the deckhands must have an A.B. ticket. Unlicensed crew members are not allowed to work both in the engine room and on deck. Those vessels over 200 tons must, in addition to the above, have a licensed master, first mate, and second mate, and engineer. Government vessels and vessels in the service of a public authority are exempt from these licensing requirements.

Blocking the tonnage openings, removing or modifying framing, or a reduction of ballast capacity can all increase tonnage. Most boats are built within one ton of a step in the rules, so a change of even a hundredth of a ton may cause you to fall in a higher tonnage class.

Other things that should be considered before purchasing a vessel are the freeboard, the position of blowers and exhaust trunks, tank vents (tank scantlings are determined by the height of the vent), access to engines after modifications, galley size, generator capacity, availability of below deck space (usually mud tanks) and ability to trim vessel after modification.

For our conversion project, we chose a 150' x 36' x 12.5' supply vessel which admeasured at 195.5 gross tons. There were two mud tanks below that could be converted to quarters and an additional mud tank aft that could be brought into ballast for tonnage reduction. The additional ballast could also counteract the forward trim due to modifications.

A typical conversion of a supply boat to a research vessel entails an increase in accomodations and stores, the addition of laboratories and workshops, the installation of deck gear and scientific instruments, and the modification of the propulsion and steering system to meet special low speed control requirements.

Our conversion followed these lines. Accomodations were increased from 16 persons to 24. 613 $ft.^2$ of lab space were added along with 298 $ft.^2$ of storage, and 130 $ft.^2$ of workshop. An A-frame and several winches were added along with a well for an ultrashort baseline acoustic positioning system,

a retractable subbottom profiler, and mounting points for various navigation antennas. A bow thruster was installed and the rudders were enlarged to aid in slow speed maneuvering. Generator capacity was increased and isolated circuits were provided.

A careful analysis of the requirements to operate the sidescan and geophysical equipment gave us our design goals. In addition to the above, it was necessary for us to leave adequate deck space for our intended mission, comply with ABS loadline requirements, and Coast Guard Subchapter C requirement.

During the search for a suitable conversion candidate, preliminary design concepts had been developed. Although we need 88' of clear deck, we only needed the full width near the stern. This gave us room to build storage rooms, lab space, and a workshop on the perimeter of the deck. It also gave us a foundation for a 21' x 23' electronics lab on the upper deck.

When we began the conversion, the boat admeasured 199.5 tons. The addition of a walk-in cooler and freezer, transducer wells, deck lockers, and additional waste holding tanks increased the tonnage to well above 200. The conversion of the aft mud tanks to ballast, in theory, brought us just below our 200 ton goal. Unfortunately, the Coast Guard officer measuring the boat decided that two companionways were excessive by about 25 cubic feet each. This brought us above the 200 ton goal. The officer didn't believe me when I told him that the freezer and cooler were portable and not a part of the structure. A study was made of all tonnage in the vessel to try to find a way to exempt a small amount. It was found that a linen locker had a wall surface large enough for a tonnage opening. A tonnage opening was installed, the vessel was readmeasured at 199.95 tons, and the vessel was exempt from licensing requirements.

Because the additional cabin on the main deck formed three sides of a well, insufficient bulwark area was left for ABS-required freeing ports. To alleviate this problem, a raised watertight floor was used in each cabin aft of the main cabin with freeing port area below.

A further problem developed with ABS loadline requirements. ABS requires a Coast Guard-supervised stability test. The Coast Guard is only authorized to supervise stability tests on inspected vessels or vessels in the process of being inspected. When the local Coast Guard office discovered the bottle neck, they managed to bend the rules enough to accomodate us.

When the vessel was delivered and put into service, several problems arose. The most noticeable was a sharp, snappy roll. The seakindliness could be improved by pumping the vessel down, but then the decks would stay too wet for comfortable work. The violent movement was caused by the extreme stiffness of the vessel. In our normal operating state, we had a $\overline{GM}$ of over 10 ft. Our roll period was under four seconds. After a brief period, we determined that there was not an economical way to reduce $\overline{GM}$ and still maintain dry decks. Stabilizers are not effective at such low speeds and flume tanks designed for such a short roll period were of an impractical shape and would have little, if any, effect on roll period. It was decided to add bilge keels not only to increase dampening through eddy making, but to increase the entrained mass and the effective polar moment of inertia about the longitudinal axis. Bilge keels on supply boat hulls do not usually meet with much success. Because the boats are hard chined, the bilge keels tended to reduce eddy loss at the chine, almost as much as they increase it around their own periphery. In addition, the fullness of the hull usually hampers effective placement of the bilge keels. Rather than place the bilge keels below the chine in a near vertical position, we put them about two ft. above the keel and in a horizontal plane. This gave us a better angle of attack for eddy loss and also appeared to give a better bite to increase entrained mass. These modifications exceeded our expectations. The roll period was increased to above five seconds and complaints dropped to zero. We were able to increase the freeboard to about two and one-half (2½) ft. to give reasonable deck dryness. Check flaps on the freeing ports further reduced deck wetness.

A second problem encountered was an inability to easily maintain slow speeds. In clutch, the boat ran about four knots. Our desired low speed was two and one-half (2½) knots. Trolling valves were installed on the marine gears to remedy this problem. The valves work by modulating the oil pressure to the clutch engagement cylinder. This allows the clutches to slip in inverse proportion to the oil pressure giveing control of shaft RPM below idle speed. This allowed us to meet our low speed requirement.

The vessel is currently being used to operate Shell Offshore's EDO deeptow sidescan system in the Gulf of Mexico. We are in our second year of operation without any downtime due to vessel operations. In addition to the two EDO sidescans, the vessel is equipped with an EDO narrow beam fathometer, an O.R.E. 30 KHz subbottom profiler with E.P.C. recorder, an EDO Nav Track V acoustic positioning system, and a Sonardyne Compatt long baseline acoustic positioning system. Topside positioning is obtained through a John E. Chance & Associates Starfix system with cubic argo, GPS, and loran supplying backup data.

The real question is not whether a conversion is possible, but whether it is economically practical. The SEIS SURVEYOR cost us $1.9 million, included the cost of bringing existing machinery and structure to like-new condition. Our preliminary cost estimate for a new vessel was $2.7 million. Job performance is identical to a new boat, but maintenance costs are slightly higher. Altogether, we appear to be doing better by about $9,000 per month.

The way we chose to modify our vessel is only one of many approaches. Standard utility boats can be made quite sufficient for light research by adding a "doghouse" to the back deck. Their general nature is much more akin to research needs than a supply boat. Since they are under 100 tons, they can be operated in an economical manner.

Supply boats cry out for containerization. There large flat decks can easily hold six forty-footers with deckspace leftover.

Crewboats are fast and have surprising room for use on protected waters where their limited endurance and poor seakindliness is not a problem.

Any conversion, however, takes careful planning. The problems are more plentiful and the solutions are fewer. Only through careful planning, innovative thinking, and a willingness to compromise can success be achieved.

RESEARCH VESSELS: A SYSTEMS ENGINEERING APPROACH

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ABSTRACT

This paper presents the case for the application of systems engineering methodology to coordinating existing research vessel operations and planning for future construction and operation of the research fleet. An essential part of such systems engineering is modeling research vessels.

A preliminary research vessel model is described. For a unique set of inputs, output is given which includes the physical characteristics of the vessel, its operating patterns, and its construction and operating costs. A sketch design is included which illustrates and verifies these outputs. It demonstrates what can be done with a minute or two of computer time.

BACKGROUND

At some time in the future, perhaps five hundred to a thousand years from now, the world must become a no-waste system. All organic and industrial processes must eventually return their products and byproducts into the global resource bank. The independence enjoyed to a large degree by manned satellites, resulting from recycling, will expand to global proportions. Considering the inevitable increase in population and the vast resources contained in sea water, there should be little doubt that the oceans will, perforce, play a major role in that self-sufficient future condition.

The seas will then be teeming with activity. The extraction of protein, minerals, energy, various metals and chemicals, the location of habitats on and in the ocean, and the puruit of life's pleasures will serve to populate the oceans with cities, pleasure places, and industrial facilities. (We must assume that mankind will have by then given up fighting each other and instead will join in a common effort at keeping the world a good place to live.)

While we need not perhaps plan now for the year 3000, we should and can start along that path by planning for 25 or 50 years hence, well within the lifetime of many of us. A vast anount of data will be required for colonizing the oceans, and much if not most of those data will be gathered by ships.

Ships are long-term projects; they take several years from conception to commissioning and have a useful life of 20 to 30 years. They are expensive to build, and unlike land structures are very difficult and costly to alter when once built. Finally, the rigors of the environment in which they operate, and their mechanical complexity, make vessel operating costs a large proportion of the expenses of any enterprise which depends upon them.

So the effort now being made, through UNOLS (University-National Oceanographic Laboratory System), to coordinate the construction and operation of the U.S. fleet of research craft must be greatly expanded to meet the financial, personnel, and organizational restraints of the future.

ATTACKING THE PROBLEM

Systems engineering has long proven its worth as a tool in planning and decision-making for complex systems. Few land-based systems can match marine research operations for complexity and indeterminateness. The variables are almost limitless in number, and in size range from the swirling global weather patterns causing El Nino, down to the degree of seasickness among a team of scientists rolling about at sea. These variables all combine to complicate the design of the fleet of ships which for the foreseeable future must be the primary data-gathering oceanographic instrument.

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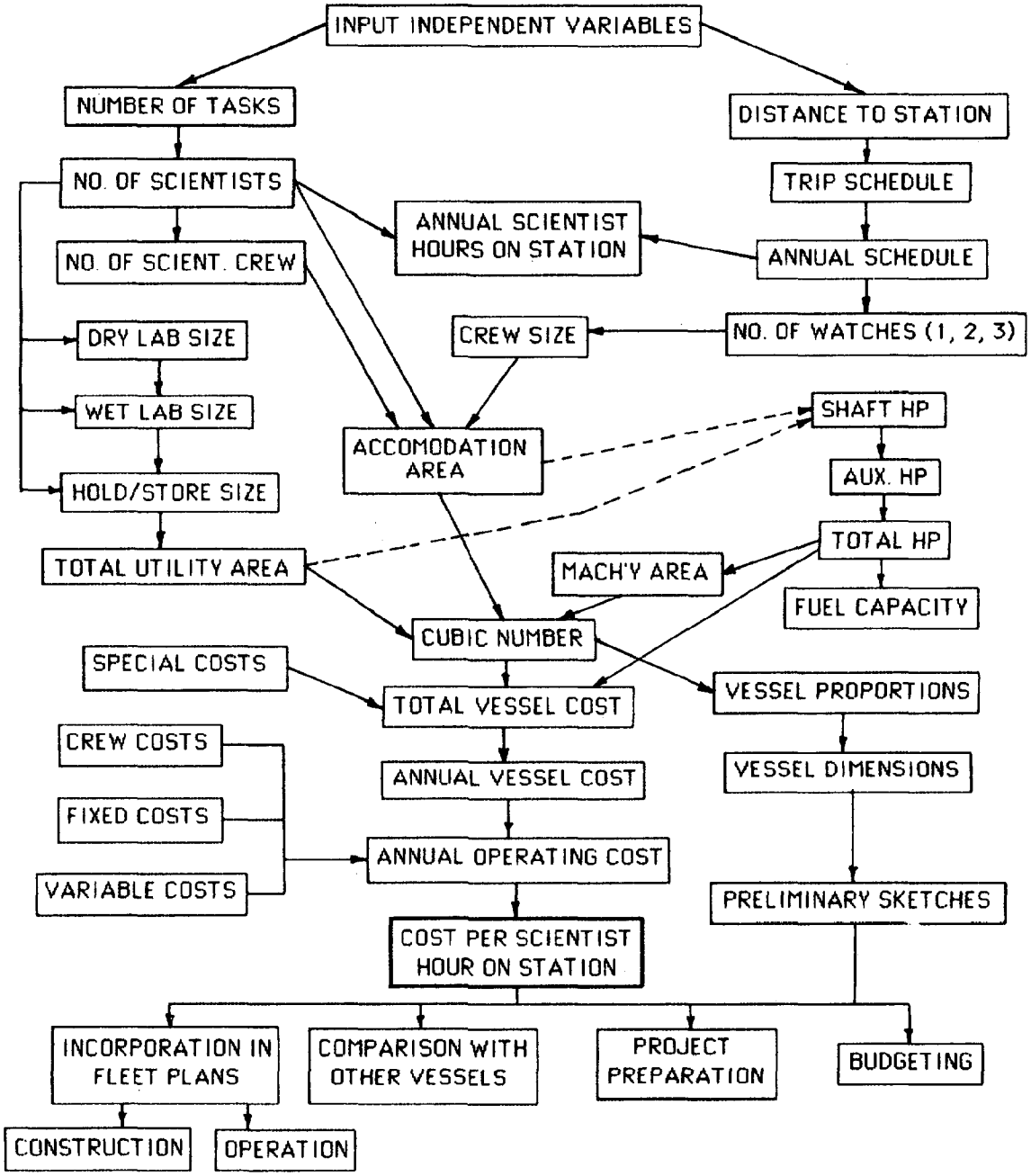
This paper describes a simple working model for use as a tool in planning the research fleet of the future, or any vessel in it. With easily ascertained inputs, it can in a matter of minutes delineate a vessel in terms of its physical characteristics, functional capabilities, and construction and operating costs, thus providing all the major bits of information for planning marine research operations.

BUILDING THE RESEARCH VESSEL MODEL

In constructing a model, the important parts are the beginning and the end. Of these it is vital to select the correct end product because that is the part which is fed into the decision-making and planning processes. The "bottom-line" of this present model is:

Fig. 1. Block Diagram for Research Vessel Model



"Cost per Scientist-Hour on Station"

This output probably best expresses the cost-effectiveness of a research vessel, which, after all, exists for the purpose of putting scientists out where they can do their work. However, all the other outputs derived from operating the model can be useful in the planning process. These peripheral outputs can include: a full description of the vessel; the size of staff required to man it; vessel construction cost; vessel operating costs. While the values of the ooutputs must be considered estimates only, they can provide a very precise basis for comparing different vessels, and a reasonably accurate first-pass estimate of the major physical and financial elements of the vessel system.

As a starting point for the model, I have selected two primary parameters. The first is the number of different tasks the vessel is to be engaged in, on which will depend the number of scientists on board. The second primary parameter is the average distance to the vessel's research station from the base port, which will largely determine the size of the vessel.

Fig. 1 is a block diagram illustrating the major elements of the model and their interrelationships which connect the start and end described above. The general design of the model is based on considerable experience the author has had in modeling fishing vessels [1], [2]. A number of assumptions are employed in order to make the model as simple and easily operated as possible. These assumptions are realistic, but if changes are desired, they are easily made in the program.

A RUN-THROUGH OF THE MODEL

Looking at the left side of Fig. 1, on the number of tasks depends the number of scientists, from which is derived the size of the scientific crew (that portion of the ship's company which actually handles and maintains the scientific gear), the size of the dry and wet laboratories, and the space for storage of specimens and gear.

On the right side, having to do with the vessel, the distance to the station (an average) sets the trip schedule and hence the annual schedule. The trip length dictates the number of watches stood per day which determines the crew size.

The annual scientist-hours on station are calculated from the number of scientists carried and the hours on station taken from the annual schedule. Total accomodation area is summed from the living areas assigned to the scientists, the scientific crew, and the ship's crew. (The area derived in the program is nominal, to match other areas used in vessel size determination, and represents about half the actual habitation area.)

The shaft horespower (SHP) to give the required speed is approximated from the total utility area and the accomodation area (this will be checked later on and adjusted upwards or downwards as necessary); auxiliary horsepower for generators, refrigeration, etc., is taken as a function of SHP. From the total horsepower is derived the fuel capacity needed and the size of the machinery space.

From the three areas - utility, accomodation, and machinery - can be determined the cubic number, hence size, of the research vessel. Using preset but variable vessel proportions (length to beam, beam to depth, etc.) the vessels dimensions are easily calculated. Finally, to check the vessel delineation portion of the, program and to help visualize the vessel, a scale preliminary sketch can be made.

From the cubic number, total horsepower, and any special costs such as unusually extensive electronics, complex rigging, etc., the total vessel cost of construction can be reasonably accurately derived. The annual vessel cost, i.e. debt retirement, is dependent on the particular financial arrangements made for paying for it.

The annual operating cost is composed of the crew costs (wages, insurance, etc.), fuel cost, fixed costs such as insurance, variable costs like port fees, etc., and the annual vessel cost. The annual operating cost divided by the annual scientist-hours on station gives the final criterion - cost per scientist hour on station.

If the model is operated with a range of values assigned to one of the variables, such as 4, 6, 8 scientific tasks, the outputs describe a number of vessels with differing characteristics and performance. The criteria for the specifc application can be applied to this series of vessels to identify the one with that mix of values which is most advantageous.

DISCUSSION OF SOME OF THE PARAMETERS

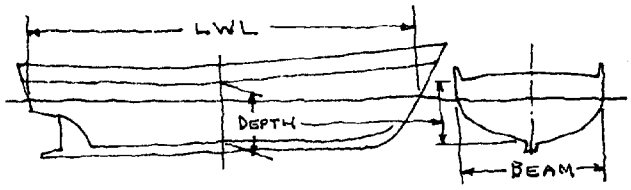
Non-naval architects often have trouble with some of the factors with which naval architects deal on a daily basis. Following are discussions of two of these:

Vessel Size

How big is a vessel? To the layman, length is usually considered an adequate description of size. But is a destroyer, with a length of 400 ft, beam 40 ft, and depth 25 ft. the same size as a 400 ft tanker with beam and depth of 75 ft and 50 ft? Obviously not.

For the naval architect size is most accurately stated as "displacement", which is the actual weight of the vessel and its contents, equaling the weight of the water it displaces. But this is an arcane quantity, difficult to come by, and constantly changing as cargo and fuel are taken aboard or discharged.

Fig. 2. Cubic Number Definitions



CUBE = LWL × BEAM × DEPTH

Fortunately, for general use in and out of the profession, there is a simple number, known as the "Cubic Number", or CUBE, which equals LWL x Beam x Depth. LWL is the waterline length, Beam is the maximum width, and Depth is the vertical distance from main deck to the juncture of the plating with the keel (see Figure 2). These dimensions are usually listed in descriptions of vessls (but don't confuse Depth with Draft!).

CUBE is a most useful number. For vessels in similar service, the displacement and cost of building and operating will be very nearly proportional to CUBE. It is independent of the proportions of the vessel and of its condition of loading. Unless the vessel is rebuilt, it will accurately define the real size of the vessel throughout its life.

Vessel Speed Limitations

Virtually all research vessels are of the displacement type which seem to travel along in a hole they dig in the water, as opposed to planing craft, which appear to be skipping along the very surface of the water. Whereas the top speed of planing craft is limited only by the size of engines which can be installed, or by the foolhardiness of the driver, the top speed of displacement craft has a well-defined limit. This limit can be expressed as:

Table 1.
Computer-generated Research Vessel

Number of tasks assigned	5
Avg. distance to research area	200 n. mi.
Average round trip steaming	2 days
Average time on station	10 days
Average time between trips	3 days
Days at sea per year	250
Number of trips per year	17
Number of scientists	10
Number in scientific crew	5
Number in ship's crew	8
Area of dry laboratory	160 sq ft
Area of wet laboratory	160 sq ft
Storage for gear and specimens	320 cu ft
Length over all	131.1 ft
Length waterline	120.6 ft
Beam	30.44 ft
Draft, max.	12.43 ft
Depth of hull	17.76 ft
Loaded displacement	600 Tons
Cubic number	65,210
Shaft Horsepower	575
Auxiliary horsepower	345
Fuel capacity, U.S. gallons	16,000
Steaming speed	11 knots
Total vessel cost	$2,860,000
Annual operating costs	$1,640,000
Annual scientist-hours on station	13,333
Cost per scientist-hour on station	$123

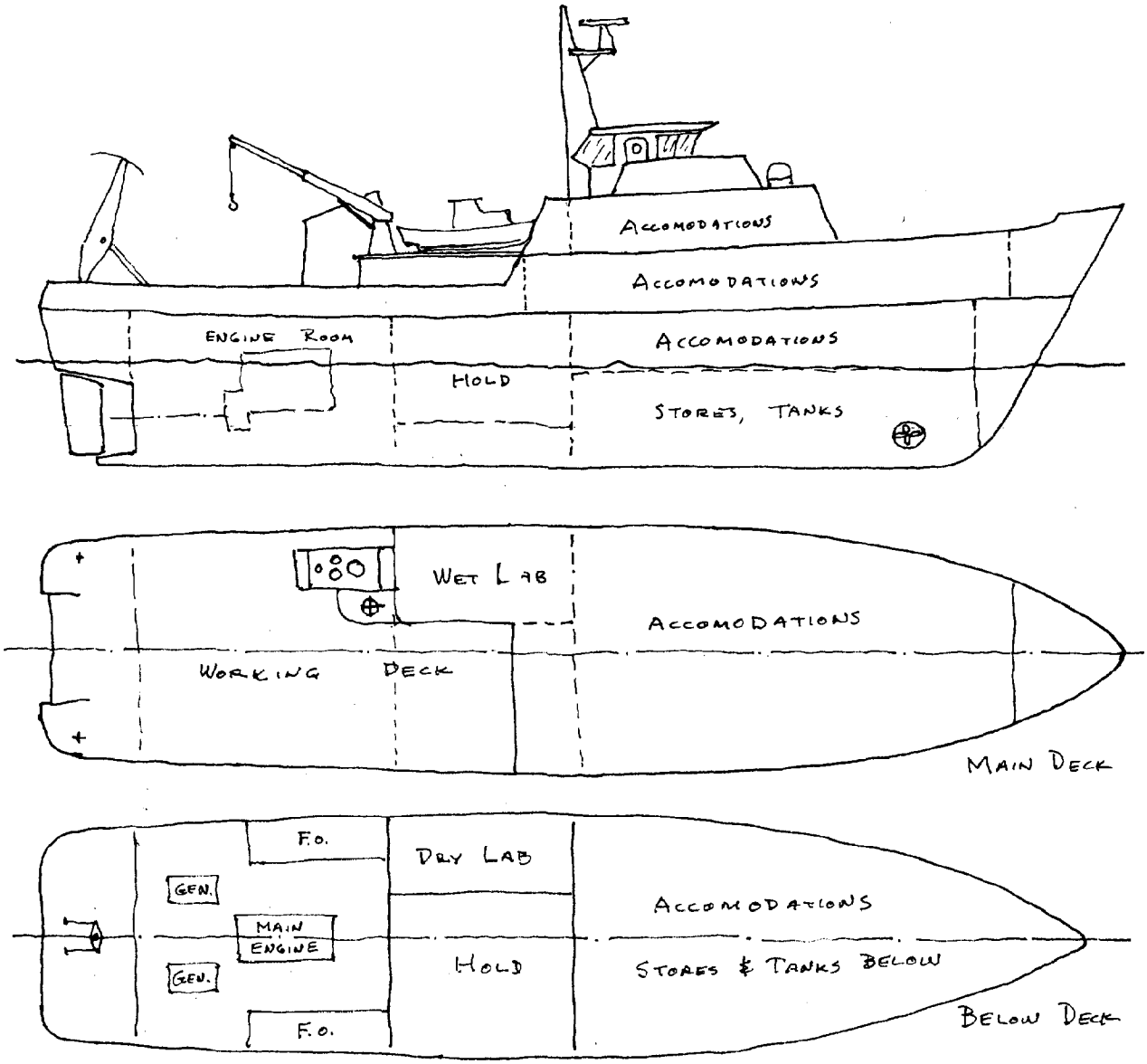
Upper Speed Limit, knots = 1.2 to 1.3 x LWL

For example, by this rule a 100 ft vessel will have a top speed of 12 to 13 knots. Above this speed, the average displacement hull will require a disproportionate amount of additional horsepower to realize a very small gain in speed. (Oceanographers will recognize the above equation as similar to the formula for the speed of a deepwater wave.)

A SAMPLE COMPUTER RUN

A preliminary program was written incorporating the elements shown in Fig. 1. The resulting data are given in Table 1. The primary inputs are: the number of tests the ship must support, and the average distance from the ship's base to the research area. The primary output is the cost per scientist hour on station. To get from the input to the output, the program has a good

Fig. 3. Sketch Design Based on Computer Output



many constants and semipermanent variables relating the various blocks as indicated in Fig. 1. and the elements within the blocks; the values of these are taken from past experience of the author.

A sketch is included (Fig. 3) to illustrate how the computer output can be verified by a simple scale drawing.

When the program is run with six tasks instead of five, hence more scientists, etc., the vessel becomes larger, costing more to build and to operate. Nevertheless, the cost per scientist-hour drops from $123 to $119. This gain in economy must, however, be balanced against the difficulty of efficiently scheduling six instead of five projects from one vessel.

SUMMARY

The quantifications used in this program , even though reasonable, are subject to further verification. Nevertheless, the ability of the program to be quickly revised, and to translate a new set of inputs into a new hypothetical vessel in a minute or two, should make this type of software a useful tool to the marine research planner and administrator, and to the designer of research vessels.

Using the power of the computer, this very simple program can be expanded to incorporate the finest level of detail which could be desired.

REFERENCES

1. C. Hamlin and J Ordway. Design Study: An Optimum Fishing Vessel for the Georges Bank Groundfish Fishery. Springfield, VA.: National Technical Information Service, 1972.

2. C. Hamlin and J. Ordway. Design Study: An Optimum Vessel for the Northern Shrimp Fishery. Unpublished.

MONOHULL RESEARCH VESSEL SEAKEEPING AND CRITERIA

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ABSTRACT

Seakeeping performance of several classes of existing and proposed monohull research vessels is compared. Performance was estimated using the U.S. Navy's Standard Ship Motion Program (SMP). Other vessels considered include the AGOR 9/10 and the proposed UNOLS medium-endurance monohull research vessel. All of these vessels are compared to the U.S. Navy's COR seakeeping criteria for the new AGOR 23. The Navy's COR seakeeping criteria for the AGOR 23 are discussed and suggestions for increasing the clarity and usefulness of such criteria are provided.

INTRODUCTION

Modern ocean research missions increasingly demand high standards of ship motion performance from oceanographic research vessels. Most of the current U.S. fleet of research vessels were commissioned before the advent of seakeeping criteria and modern analysis capabilities for ship motions.

The synthesis of hull forms exhibiting improved seakeeping performance is still an activity guided by judgement and intuition. However, once a design has been postulated modern analysis methods permit efficient performance assessment during the design development process.

These new analytical capabilities have created the opportunity for the oceanographic community to express their desires for seakeeping performance in the form of seakeeping criteria which in turn become objective goals for the designers. As the custom of promulgating such criteria is a relatively recent development, this paper seeks to contribute to the evolution of such criteria by reporting on the performance of existing and proposed research vessels as compared to criteria currently in use.

BRIEF HISTORY

Modern ship motion analysis had to await the development of modern models for the ocean wave environment. The seminal event was the landmark paper by Dr. W.J. Pierson, Jr. in 1952 [1]. This was followed in 1953 by a paper marking the collaboration of Drs. Pierson and Manley St. Denis [2] which presented a ship motion theory describing the ship as a tensor operator acting on the seaway. Ship motions therefore became subject to the same statistical descriptions of second-order stationary random processes which have been successfully applied to the seaway.

The thirty-five years since the Pierson/St. Denis paper has seen remarkable growth and success in the application of analysis to ship motions. A practical analysis of coupled pitch and heave was developed as early as 1967 [3]. A complete analysis of the six-degree-of-freedom rigid body motions was available by 1971 [4] and the U.S. Navy's Standard Ship Motion Program SMP was available by 1981 [5] offering improved treatment of forward speed dependent terms such as roll damping.

Probabilistic treatments of the analysis of vessel risk and operability in temporally and spatially varying climatologies were described in 1981 [6].

All of these accomplishments could be regarded, in the parlance of modern risk analysis, as progress in the definition of the **demand** functions. Progress in defining the corresponding **capability** functions has lagged. Dr. St. Denis compiled one of the early volumes addressing the limits of operability for various activities [7]. Included in [7] are discussions of the threshold of malaise, safe footing, slamming and shipping of green water on deck.

Spouge [8] published criteria for deck wetness, slamming and roll which he applied to a British fisheries protection vessel and Kennel, et. al. [9] have published criteria for these functions, pitch and vertical acceleration. These criteria are summarized in Table 1.

TABLE 1

Seakeeping Criteria

	British Fisheries Protection Vessel	U.S.N. Combatant Mobility
	Ref. [8]	Ref. [9]
Vert. Accel. on Bridge (g's)	--	0.4
Deck Wetness	36/hr	30/hr
Slamming	20/hr	20/hr
Roll, Signif. Amplitude	10°	8°
Pitch, Signif. Amplitude	--	3°

The most comprehensive and recent seakeeping criteria applied to research vessels are those specified for the acquisition of the AGOR 23. These criteria are presented in Table 2. These criteria may be seen to be much more sophisticated than those of Table 1. Many more seakeeping processes are considered and the criteria are parameterized by vessel operation, speed and sea state.

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TABLE 2
AGOR 23 COR - Seakeeping Criteria

Condition	Sea State (Feet)	Ship Speed (Knots)	Heading (Deg.)	Roll (Deg.)	Pitch (Deg.)	Wetness (Num/Hr)	Slam (Num/Hr)	Lat'l Accel Bridge	Vertical Accel (g's) Bridge	Stern	Midship
TRANSIT	8.2'	12.0	All	8.0°	3.0°	30	20	.2	.4	.---	.---
OPERATING	12.2'	6.0	Best	8.0°	3.0°	30	20	.2	.4	.4	.---
ON STATION	11.0'	0.0	Best	5.0°	3.0°	5	5	.2	.4	.4	.4

Notes: 1) Roll, pitch and accelerations are specified as the maximum (with respect to sea state modal period) significant single amplitude values.
2) Best heading is not defined in the AGOR 23 COR.

These criteria represent, from the designers point of view, a significant advance towards a design for seakeeping process. There is however, in our opinion, room for further improvement. In this paper we offer what we hope is constructive criticism along with some suggestions regarding fruitful directions for improved seakeeping criteria development.

CRITIQUE OF AGOR 23 SEAKEEPING CRITERIA

The seakeeping criteria of Table 2 are prescriptive rather than functional criteria. It is not known to the authors whether these prescriptive criteria are in fact based on an underlying consideration of functional limits but any such consideration has not been carried through to the final criteria in such a way that the designers can benefit from the underlying functional background. The limits are not related to any activity which might assist the designer in developing a solution to the real problems faced by the scientists aboard the research vessel. It would be an improvement to state activity related functional criteria such as the limiting acceleration environment in which a circuit board can be soldered, the conditions under which a biological sample can be dissected, the limits for handling chemical glassware and the limits on launching and retrieving packages of different sizes and types. An example of how such functional activity based information could benefit the design process would be the selection of a space with minimal accelerations for a critical activity sensitive to acceleration.

Similarly the prescriptive criteria do not provide any insight into the relative importance of various seakeeping processes. Stated another way, what is the relative value of increased performance margins (margin is the positive excess of criteria limit over seakeeping performance) in roll compared to a similar margin in pitch (or some other mode)?

A closely related criticism concerns the fact that the criteria are all posed as deterministic limits acting as step-function capability. Presumably many of the the science activities affected by the seakeeping performance undergo gradual degradation of performance. Even concerns such as structural failure can be regarded equally well from a probabilistic perspective subject to a distributed capability function. Certainly those activities which rely on human performance are subject to capability functions reflecting human variability.

Another criticism regarding unstated relative importance can be lodged with respect to speed and sea state parameters. For instance, what is the relative value of increased performance margins at (for example) 12 knots in sea state 4 versus 8 knots in sea state 5? If the designer has the opportunity to increase the performance margin in one case at the expense of the other, which is to be preferred?

VESSEL PERFORMANCE

The performance of four monohull research vessels was predicted using the Standard Ship Motion Program SMP [5]. Two classes of existing research vessels, the AGOR 9/10 and AGOR 14/15, were examined. Also examined were the AGOR 14/15 class following a planned lengthening and a proposed new medium endurance research vessel (MERV) under the UNOLS fleet replacement program [10]. The conceptual design for the proposed new vessel was developed with particular attention towards improved seakeeping performance. Table 3 presents the particulars of each of these vessels.

TABLE 3

Monohull Research Vessel Particulars

	AGOR 9/10	Existing AGOR 14/15	Modified AGOR 14/15	Proposed New Vessel [10]
Length	196'-0"	220'-0"	254'-6"	212'-0"
Beam	39'-0"	46'-0"	46'-0"	64'-0"
Draft	15'-3"	15'-0"	15'-6"	15'-2"
Displacement	1490	1948	2685	2469
Year(s) Built	1965	1968/69	1989/90	--

Table 4 presents the seakeeping performance for each of these four research vessels and compares their performance to the AGOR 23 seakeeping criteria.

Condition (C) in Table 4 is not an AGOR 23 COR criteria condition. Condition (B) is an AGOR 23 COR criteria condition but it can be seen that none of the vessels examined can satisfy the criterion for pitch in condition (B). Condition (C) has been added to indicate a reduced sea state where all of the vessels excepting the AGOR 9/10 can satisfy the pitch criterion.

This situation illustrates one of the most troublesome problems with the AGOR 23 COR seakeeping criteria, that being the lack of definition regarding "best heading". All of the vessels examined could satisfy the pitch criterion in condition (B) at headings in the neighborhood of 90° (beam seas) but they would concurrently violate the criterion for roll. The AGOR 23 COR is not definitive regarding the extent to which the criteria are joint. Table 4 was constructed under a particular interpretation regarding "best heading" which will be described in the following paragraph.

TABLE 4
Comparison of Seakeeping Response

AGOR 23 COR, Existing AGOR 14/15, Modified AGOR 14/15, AGOR 9/10 and 212' MERV

Vessel	Sea State (Feet)	Ship Speed (Knots)	Heading (Deg.)	Roll (Deg.)	Pitch (Deg.)	Wetness (Num/Hr)	Slam (Num/Hr)	Lat'l Accel Bridge	Vertical Accel (g's) Bridge	Stern	Midship
(A) TRANSIT CONDITION											
AGOR 23 COR	8.2'	12.0	All	8.0°	3.0°	30	20	.2	.4	.---	.---
EXISTING AGOR 14/15				4.78°	2.98°	0	0	.079	.152	.241	.152
MODIFIED AGOR 14/15				4.54°	2.63°	0	0	.064	.143	.216	.131
AGOR 9/10				**10.15°**	**4.09°**	2	0	.111	.338	.366	.21
MERV				5.91°	2.70°	0	0	.158	.169	.185	.20
(B) OPERATING CONDITION											
AGOR 23 COR	12.2'	6.0	Best	8.0°	3.0°	30	20	.2	.4	.4	.---
EXISTING AGOR 14/15			60°	5.69°	**3.63°**	0	0	.106	.151	.233	.156
MODIFIED AGOR 14/15			60°	4.28°	**3.23°**	0	0	.085	.150	.225	.142
AGOR 9/10			60°	**11.4°**	**4.57°**	0	0	.145	.283	.293	.206
MERV			150°	5.72°	**3.27°**	0	0	.090	.072	.096	.11
(C) OPERATING CONDITION [Note: not an AGOR 23 COR Condition]											
AGOR 23 COR	8.2'	6.0	Best	8.0°	3.0°	30	20	.2	.4	.4	.---
EXISTING AGOR 14/15			60°	4.04°	2.44°	0	0	.073	.117	.185	.119
MODIFIED AGOR 14/15			60°	3.08°	2.17°	0	0	.057	.114	.175	.108
AGOR 9/10			60°	**8.16°**	**3.35°**	0	0	.104	.238	.246	.16
MERV			150°	4.52°	2.20°	0	0	.084	.053	.07	.096
(D) ON STATION CONDITION											
AGOR 23 COR	11.0'	0.0	Best	5.0°	3.0°	5	5	.2	.4	.4	.4
EXISTING AGOR 14/15			135°	**6.10°**	**3.33°**	0	0	.081	.086	.178	.107
MODIFIED AGOR 14/15			135°	4.32°	2.88°	0	0	.061	.085	.168	.092
AGOR 9/10			135°	**11.0°**	**4.05°**	0	0	.107	.150	.221	.142
MERV			135°	**7.11°**	**3.01°**	0	0	.125	.096	.147	.16

Best heading is chosen as the heading which minimizes both normalized roll and normalized pitch response.
Bold lettering indicates an exceedence of the AGOR 23 Circular of Requirements.

TABLE 5
Comparison of Seakeeping Response With Alternate "Best Heading"

AGOR 23 COR, Existing AGOR 14/15, Modified AGOR 14/15, AGOR 9/10 and 212' MERV

Vessel	Sea State (Feet)	Ship Speed (Knots)	Heading (Deg.)	Roll (Deg.)	Pitch (Deg.)	Wetness (Num/Hr)	Slam (Num/Hr)	Lat'l Accel Bridge	Vertical Accel (g's) Bridge	Stern	Midship
(B) OPERATING CONDITION											
AGOR 23 COR	12.2'	6.0	Best	8.0°	3.0°	30	20	.2	.4	.4	.---
EXISTING AGOR 14/15			105°	6.81°	2.99°	0	0	.108	.123	.172	.141
MODIFIED AGOR 14/15			105°	5.18°	2.68°	0	0	.086	.123	.171	.124
MERV			180°	4.05°	**3.45°**	0	0	.052	.057	.085	.064

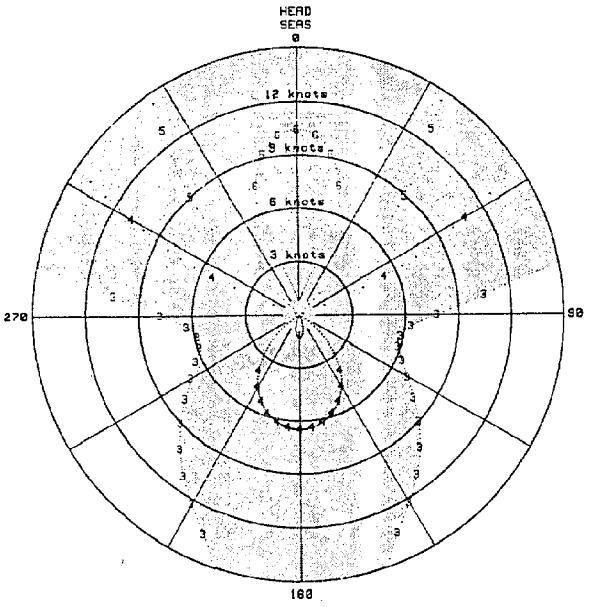
Best heading is chosen as the heading which maximizes the **sum of the normalized margins** for roll and pitch response.
Bold lettering indicates an exceedence of the AGOR 23 Circular of Requirements.

Pitch and roll as functions of heading angle were normalized by their respective greatest values, thus producing functions with ordinal magnitudes ranging from zero to one. The "best heading" was determined to be that heading corresponding to an intersection between the normalized pitch and roll functions which possessed the least ordinal value among all intersections between these normalized functions.

Consider, for example, an alternate "best heading" based on the margin between the actual response and the criterion, normalized by the criterion value. Table 5 shows the "best heading obtained as the heading corresponding to the maximum of the sum of the normalized margins in roll and pitch responses. The headings so obtained are clearly different from those in Table 4. With the "sum of margins" approach it is seen that the existing and modified AGOR 14/15 now meet both roll and pitch criteria whereas they had violated the pitch criterion in Table 4. However the proposed medium-endurance research vessel still violates the pitch criterion under this definition of best heading. Even the "sum of margins" approach is not satisfactory since it can be shown that the proposed medium-endurance research vessel satisfies both the roll and pitch criteria

FIGURE 1
Speed-Polar Diagram

AGOR 14/15 Existing Ship Zero Trim
Short-crested
Significant Wave Height = 12.20 Feet
Pitch Angle
(Degrees)
Statistic : Maximum Significant Single Amplitude



.... 1 ....Pitch Angle = 2.00 DEG
.... 2 ....Pitch Angle = 2.50 DEG
.... 3 ....Pitch Angle = 3.00 DEG
.... 4 ....Pitch Angle = 3.50 DEG
.... 5 ....Pitch Angle = 4.00 DEG
.... 6 ....Pitch Angle = 4.50 DEG
.... 7 ....Pitch Angle = 5.00 DEG

(and the remaining criteria as well) at a best heading around 120° where roll is 7.88° and pitch is 2.88° .

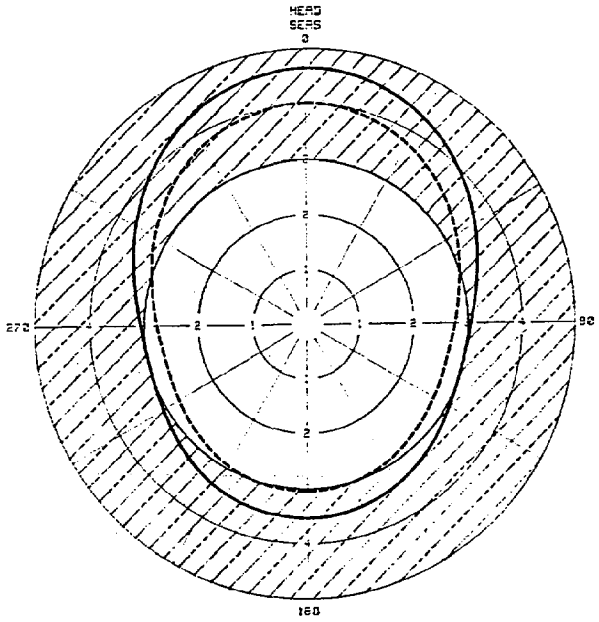
It is obvious that these definitions of best heading are arbitrary and may not reflect the intent of the authors of the AGOR 23 COR seakeeping criteria. Clearly other definitions are possible and an alternative definition may be in some way "better" than those discussed above. Alternative approaches to the formulation of seakeeping criteria which resolve this issue will be discussed in a later section of this paper.

POLAR DIAGRAMS

Another perspective on vessel performance is achieved by producing speed-polar and response-polar plots. Figure 1 is an example speed-polar plot of pitch for the existing AGOR 14/15. Speed-polar plot grids directly present the operational parameters of speed and heading which are under the control of the ship's officers. The polar angle corresponds to the heading angle, the radii correspond to speed. The contours are iso-response lines. The shaded regions represent combinations of speed and heading where the 3° pitch limit of the AGOR 23 COR is exceeded in a short-crested sea state characterized by a 12.2 foot significant wave height.

FIGURE 2
Response-Polar Diagram

Comparison of Seakeeping
for Existing and Modified AGOR 14/15
Short-crested
Significant Wave Height = 12.20 Feet
Pitch Angle
(Degrees)
Statistic : Maximum Significant Single Amplitude



6 Knots : Existing AGOR 14/15
6 Knots : Modified AGOR 14/15
3 DEG AGOR 23 COR Criterion

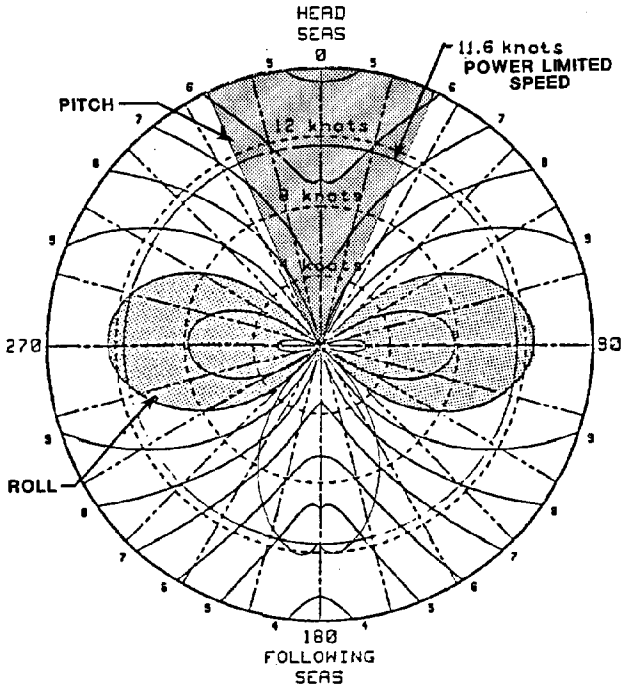
An example of a new kind of polar plot for response is introduced in Figure 2. We denote this type of presentation as a *response-polar* plot. Figure 2 shows the response-polar plot for pitch corresponding to the speed-polar plot of Figure 1. Again the polar angles correspond to heading but the radii now correspond to significant pitch amplitude. The contours are now iso-speed lines. The region outside the three degree radii is shaded to indicate that operating conditions in that region exceed the AGOR 23 COR pitch criterion.

Figures 1 and 2 are mappings of the same response process in the polar plane. The speed-polar plot is a particularly useful presentation for the ship operators while the response-polar plot is perhaps more useful for analysis during the design process. One of the attractive features of the response-polar plot is the simple way in which the region violating a stated criterion can be indicated. Another practical advantage is the topologically simpler regions defined by the iso-contours in the response-polar plot. These simpler regions make both plotting and interpretation easier.

One measure of operability which can be derived from the speed-polar diagram is the ratio of the "operable" domain to the total domain. For the diagram shown in Figure 1 this measure of operability is 0.281. Assuming that every speed and heading combination is equally desirable in a sea state with significant wave height of 12.2 feet, then the operability fraction subject to a step function pitch criterion of 3° is 0.281.

FIGURE 3
Speed-Polar DIAGRAM

Superposition of Significant Pitch
on Significant Roll (Degrees)
in Short-crested Sea State 6



A similar measure can be constructed from the response-polar plot in Figure 2. Taking as our example the modified AGOR 14/15, the polar arc through which the 6 knot iso-speed contour lies within the operable domain represents 0.491 of the potential arc (360°). Assuming that every heading is equally desirable when operating at 6 knots in a sea state with significant wave height of 12.2 feet, then the operability fraction subject to a step function pitch criterion of 3° is 0.491.

Through superposition of speed-polar or response-polar diagrams operability subject to joint criteria can be evaluated. Figure 3 is a superposed speed-polar diagram showing the operability of the proposed new medium-endurance research vessel [10] subject to joint roll and pitch criteria of 10° and 5° respectively in sea state 6. Installed power limits the vessel speed in this sea state to 11.6 knots so operability is measured over the zero to 11.6 knot speed domain. The operability, measured as described above, is 0.672 for roll alone, 0.859 for pitch alone, and 0.531 subject to the joint criteria. This approach to evaluating operability could be extended in the obvious manner to any number of joint criteria.

TOWARDS A GENERAL CRITERIA STRUCTURE

Prior to the development of modern analysis methods for seakeeping performance designers relied solely on judgement and experience to achieve seakindly forms, with occasional objective feedback from model tests. Owners and operators of research vessels communicated their desires for seakeeping performance to the designer, primarily through subjective and qualitative descriptions.

The advent of modern ship motion analysis has created the opportunity to objectify this communication process between owner/operator and designer. However, modern computer analyses can generate more data than either the designer or the owner/operator can effectively evaluate in the absence of adequate criteria. The current state of criteria development could be characterized as a series of performance gates. At this level of development the role of analysis is limited primarily to confirming the success of a proposed design, but cannot play an effective role in guiding the designer towards new and more efficient designs. The proposal for future criteria development contained in this section would result in the codification of both subjective and objective owner/operator requirements in such a way that designers could make use of modern analysis tools to seek improved designs.

In the course of discussing the AGOR 23 COR seakeeping criteria and the evaluation of vessel performance with respect to those criteria a number of criticisms have been set forth. These criticisms are summarized as follows:

* There is no metric for the relative importance of each criteria.
* There is no metric for the relative importance of each operating condition (i.e. speed, heading and sea state).
* There is no clear definition of "best heading".
* The criteria are prescriptive rather than functional.
* The criteria are provided as step-function deterministic limits where in many instances the true capability function is distributed.

An underlying problem is that the criteria exist in a vector space where each individual criterion may be regarded as a component of a vector. The design problem is satisfied if each criterion is satisfied. Any individual criterion is either satisfied or it is not, there is no provision for partially satisfying a criterion. Stated another way, there is no basis for stating a preference between one satisfactory solution and another.

The conventional mathematical solution to a problem of this character is to compose a vector dot product between a design solution vector and a static weighting vector. Such a dot product produces a scalar valued objective function which can then be the subject of optimization procedures.

It is not possible to compare vector A with vector B directly. No statement such as "vector A is *better* than vector B" is possible. However, if a weighting vector, W, is stipulated it is possible to state that scalar a = **W•A** is greater than, equal to, or less than scalar b = **W•B**. This is the property which recommends the dot product as the means to formulate objective functions for vector processes.

Application of this approach to generate scalar seakeeping rank functions is associated with the late Nathan Bales [11] who applied the concept to the optimization of destroyer seakeeping. More recently van Wijngaarden [12] has applied this technique to small ships operating in the North Sea which more closely resemble a typical research vessel. The Glosten Associates have recently applied this technique to an investigation of surge, heave and pitch stable spar buoy hull forms under consideration for an *R/V FLIP* replacement [13].

Seakeeping operability of a research vessel must be evaluated in an environment subject to the following environmental parameters and operational factors under the control of the bridge:

Environmental and Operating Factors

H_S	Significant Wave Height
T_O	Modal Wave Period
V	Ship Speed
χ	Heading Angle

Each process or activity critical to the success of a particular scientific mission takes place at some location in ship coordinates. As there may be many critical activities there will, in general, be many locations of interest. To make a criteria most general and useful, these locations should be defined functionally (e.g. chemical lab sink; biological dissection table; electronics repair workbench; etc.). This will permit the designer to vary

the selection of space for these activities in order to obtain the highest overall operability.

Location in Ship

$\xi = (\eta_1, \eta_2, \eta_3)$ Location in Ship

There are many seakeeping responses potentially of interest. In general the local accelerations and relative orientation of the virtual gravity vector will be most representative of the environment experienced by shipboard personnel, instruments and apparatus. The local relative motions (between the ship and sea surface) and shipping of green water are expressive of the environment for launching and retrieving gear over the side. Local accelerations (for instance at a boom tip) are associated with fluctuating forces which may limit operations, while local velocities would relate to the required performance of motion compensating mechanisms. Emergence and slamming relate, among other things, to sonar performance, emitted noise and forward speed maintenance.

Response Factors

$x_n(\xi)$,	n=1,2,3,4,5,6	Displacements
$x_n(\xi)$,	n=7,8,9,10,11,12	Velocities
$x_n(\xi)$,	n=13,14,15,16,17,18	Accelerations
$x_n(\xi)$,	n=19	Relative Displacement
$x_n(\xi)$,	n=20	Relative Velocity
$x_n(\xi)$,	n=21	Relative Acceleration
$x_n(\xi)$,	n=22	Slamming
$x_n(\xi)$,	n=23	Shipping of Green Water
$x_n(\xi)$,	n=24	Relative Orientation of Virtual Gravity Vector

Mission Profile

A mission profile consists of N discrete missions, $\mathcal{M}_1, \mathcal{M}_2, \ldots, \mathcal{M}_N$. For each mission the number $\mathcal{M}_i$ is a weight expressing the relative importance of that particular mission with respect to all the other missions considered. Each mission is characterized by a climatology and operating profile which may be described using discrete probability as follows:

$P(H_s,T_o)$ Joint Probability of Significant Wave Height and Modal Period

$P(V,\chi|H_s,T_o)$ Conditional Probability for Speed and Heading Given Significant Wave Height and Modal Period

$P(V,\chi,H_s,T_o) = P(H_s,T_o)\, P(V,\chi|H_s,T_o)$ Joint Probability of Wave Height, Period, Speed and Heading

The joint probability for significant wave height and modal period can be obtained from climatologies such as [14]. The conditional probability for speed and heading can be developed from mission requirements and vessel speed and power relationships in a seaway.

For the global set of N missions there are K locations, ξ_j (j=1,2,....,K), within the ship where mission critical activities must take place. For any given mission only a subset of these K locations may be of importance.

There are twenty-four response processes listed in the example global response list above. For any given mission, $\mathcal{M}_i$, and each location of interest, ξ_j, a subset of the global response list will be of mission importance. For each such response a weight, $w(\mathcal{M}_i, x_k(\xi_j))$, should be assigned and a criterion value, $c(\mathcal{M}_i, x_k(\xi_j))$.

The weight, w(•), should be composed in such a way as to reflect both the relative frequency with which the given activity at the given location must be preformed and the relative importance of the activity to mission success.

The final value of the scalar objective function, Ω, is obtained from a probability weighted summation over all missions, sea states, operating conditions, locations and responses; of the products of the weighting function with a function developed from the response and the associated criterion value. An example equation showing one form which such an objective function could assume is shown in the box at the bottom of this page.

There are many possible forms for the function $f(x_k(\xi_j), c(\mathcal{M}_i, x_k(\xi_j)))$. Three possible forms will be discussed.

First form:

$$f(\cdot) = \frac{c(\cdot) - x(\cdot)}{c(\cdot)}$$

Second form:

$$f(\cdot) = \int_{x(\xi)}^{\infty} p_c(\eta)\, d\eta$$

where: $p_c(\eta)$ is the probability density for the capability function

Third form:

$$f(\cdot) = 1.0 \quad \text{if} \quad x(\cdot) < c(\cdot)$$
$$= 0.0 \quad \text{if} \quad x(\cdot) \geq c(\cdot)$$

The first of these functional forms is a linear function with the property that $-\infty < f(\bullet) < 1.0$. A response of zero will produce a function value of one, a response equal to the criterion value, c(•), will produce a value of zero, and responses greater than the criterion value will produce negative function values (a penalty).

Example Equation for Objective Function

$$\Omega = \sum_i \mathcal{M}_i \sum_V \sum_\chi \sum_{H_s} \sum_{T_o} P_i(V,\chi,H_s,T_o) \sum_j \sum_k w(\mathcal{M}_i, x_k(\xi_j))\, f(x_k(\xi_j), c(\mathcal{M}_i, x_k(\xi_j)))$$

The second functional form may be nonlinear and reflects a modern perspective on risk and operability where capability is a distributed probability function. In this instance the function f(•) can take on values between zero and one where zero means that x(•) entirely exceeds the capability and one means that x(•) is entirely below the capability.

The third and final functional form shown may be regarded as a special case of the second form, where capability is a step function occurring at the criterion value, c.

All of these functional forms share the property that the best criterion score is one. Since the criterion score contributes to the final value of the objective function, Ω, as a product with the weight, all of the relative importance is embodied in the weight function, $\mathcal{M}w(\bullet)$. The authors preference is for the first functional form as it is simple, linear, and offers a penalty for criterion exceedence.

All of these functional forms are appropriate for non-exceedence type criteria. In the case of exceedence type criteria there are fairly obvious modifications which could be made to each of these functional forms so that they would properly participate in the scalar objective function.

SUMMARY

Seakeeping criteria as currently applied to the development of new research vessel designs represent a significant improvement over the situation of only a few years ago. Such criteria serve as both goals and guides for design development. However, the current criteria lack clarity regarding the concept of "best heading". They also do not provide any guidance regarding the relative importance of various criterion or operating conditions. Likewise there is no guidance embodied in the criteria which would assist the designer in determining the proper location on board ship for critical activities.

It is the authors' opinion that most oceanographic research activities are sensitive to either local accelerations or relative motions, or both. Rational seakeeping criteria of the future should emphasize these processes.

For many oceanographic research activities lateral and longitudinal accelerations are better expressed in vessel rather than earth coordinates. Accelerations in vessel coordinates should include the first-order contributions of gravity which arise from roll and pitch. SMP does not compute vessel coordinate accelerations but the addition of this feature should be considered for future program enhancements. An alternative approach achieving this objective would be the use of post-processors such as those discussed in reference [15].

Proposals have been set forward for a general criteria structure which would address the identified concerns. Implementation of such a general criteria would require effort on the part of the scientific and naval architectural communities. Such effort would however be rewarded by better designs and greater research productivity.

REFERENCES

1. Pierson, Dr. W. J. Jr., "A Unified Mathematical Theory for the Analysis, Propagation and Refraction of Storm Generated Ocean Surface Waves," Parts I and II, N.Y.U. College of Engineering, Prepared for the Beach Erosion Board, (1952).

2. Pierson, Dr. W. J. Jr. and St. Denis, Dr. Manley, "On the Motions of Ships in Confused Seas," SNAME *Transactions*, Volume 61 (1953).

3. Korvin-Kroukovsky, B. V. and Jacobs, W. R., "Pitching and Heaving Motions of a Ship in Regular Waves," SNAME *Transactions*, Volume 65 (1957).

4. Salveson, N., Tuck, E. O., and Faltinsen, O., "Ship Motions and Sea Loads," SNAME *Transactions*, Volume 78 (1970).

5. Meyers, W. G., Applebee, T. R. and Baitis, A. E., "User's Manual for the Standard Ship Motion Program, SMP," DTNSRDC (Sept. 1981).

6. Hutchison, B. L., "Risk and Operability Analysis in the Marine Environment", SNAME *Transactions*, Volume 89 (1981).

7. St. Denis, M., "On the Environmental Operability of Seagoing Systems," SNAME T&R 1-32 (1973).

8. Spouge, J. R., "The Prediction of Realistic Long-Term Ship Seakeeping Performance," North East Coast Institution of Engineers and Shipbuilders *Transactions* (1985).

9. Kennel, C., White, B., and Comstock, E. N., "Innovative Naval Designs for North Atlantic Operation," SNAME *Transactions*, Volume 93 (1985).

10. Hutchison, B. L. and Laible, D. H., "Conceptual Design of a Medium-Endurance Research Vessel Optimized for Mission Flexibility and Seakeeping," SNAME *Marine Technology*, Volume 24, No. 2, (April 1987).

11. Bales, N. K., "Optimizating the Seakeeping Performance of Destroyer-type Hulls," *Proceedings*, 13th Symposium on Naval Hydrodynamics, Japan, (1980).

12. van Wijngaarden, A. M., "The Optimum Form of a Small Hull for the North Sea Area," *International Shipbuilding Progress*, Vol. 31, No. 359, (July 1984).

13. "Study of Large Spar Buoy Hull Forms for Motion Minimization - Phase 1 - Linear Motion Analysis of Cylindrical Stepped Buoys," The Glosten Associates, (June 1988).

14. Lee, W. T., Bales, S. L., and Sowby, S. E., "Standardized Wind and Wave Environments for North Pacific Ocean Areas," DTNSRDC Report No. SPD-0919-02, (July 1985).

15. Hutchison, B.L. and Bringloe, J.T., "Application of Seakeeping Analysis," SNAME *Marine Technology*, Vol. 15, No. 4, (October 1978).

REMOVAL OF THE WRECK OF THE EX-USS TORTUGA

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In December 1987, the ex-USS TORTUGA (LSD-26) was set adrift off the coast of Southern California as a target for a missile exercise. Instead of being sunk as planned, the ship went aground on the southeast coast of San Miguel Island during a storm. The stern section broke off before wreck removal operations could begin, leaving the fore section approximately 355 feet long, weighing about 4400 tons, grounded on a hard bottom and impaled on a very large boulder. Salvage operations commenced with the piece-by-piece removal of the superstructure. This lowered the center of gravity and, most importantly, reduced the ground reaction to a reasonable level. Most spaces below the well deck were holed and open to the sea. Bulkheads and piping were repaired and welded over where possible and low pressure air was piped to each space for dewatering purposes. On-site computerized salvage computations were utilized to predict ground reaction, stability and remaining hull girder strength. Work was accomplished with consideration for environmental concerns. Finally, on 20 August 1988 the wreck was pulled from its strand, towed to sea and scuttled in a designated deep water site.

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THE REALITIES OF BAREBOAT CHARTERING

Terry MacRae

Hornblower Dining Yachts
NAPVO
(National Association of Passenger Vessel Owners)

There is a growing problem in the commercial passenger vessel industry associated with the use of private yachts and uninspected vessels being chartered for the purpose of carrying passengers for hire. Owners and agents of these vessels are inducing businesses and private parties to sign "bareboat charter agreements" which in theory transfer the ownership and control of the vessel to the charterer. Many of these private parties and corporations then utilize these vessels for business purposes. They risk violations of federal regulations as well as other local regulations if more than six passengers are on board on the vessel. The National Association of Passenger Vessel Owners, a group whose members operate U.S. Coast Guard inspected passenger vessels - which allow them to carry passengers for hire in accordance with regulations - are concerned for the well-being of charterers and passengers who may unknowingly or unintentionally use a vessel not licensed for the intended purpose of the charter. NAPVO supports a position of public awareness, self-regulation, and increased enforcement activity of the regulatory agencies responsible for vessel charter activities.

The concept of a bareboat charter was originally developed to handle business relationship issues associated with commercial cargo carriers. For example, when "Texaco" has a surplus of oceangoing tankers which they wish to utilize, they may "bareboat charter" them to "Exxon", generally for a five or ten year period. Both companies are experienced in the management of vessels; including the crewing, fueling, provisioning, insuring, berthing and navigation of this type of vessel. Once a true bareboat charter agreement or demise charter is consummated, the charterer becomes the effective owner of the vessel for all but title or legal ownership purposes. He is responsible for the use, care, control and loss of the vessel during the charter period. "Bareboat" literally means the charterer has leased a bare vessel.

If you own a private yacht or other vessel which does not meet the appropriate standards set by the U.S. Coast Guard or other regulatory agencies to enable it to carry passengers for hire, you might perceive that there is a lucrative market in turning that vessel into a part-time business enterprise. As a result of this perception, there are many owners who charter their vessels on a part or fulltime basis to defray maintenance, berthing and ownership costs. There are also a large number of agents operating privately-owned vessels under contract for the same purpose.

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Some of these vessels could be inspected and licensed in accordance with the regulations if the owners would make the decision to spend the additional money required to make the vessels comply with safer standards. However, many of them are foreign built or owned vessels or vessels which are not constructed according to the safety or engineering standards required by U.S. Law. A great number of owners and agents utilize the concept of "bareboat charter" to circumvent the requirement to use vessels which are in compliance with all the appropriate regulations. In effect, they're passing some of the risks associated with safety, liability and propriety along to the charterer. This strategy results in the creation of additional risks for both the owner and charter. *Table 1* shows some of these risks.

There is certainly no intent to infer that there are not legitimate bareboat charters - they obviously have a place within the marine industry. Extended duration trips, small (6 passengers) groups on small vessels and charters to industry professionals fully aware of the risks and responsibilities are certainly legal and appropriate examples of legitimate bareboat charters. There are many reputable companies offering services which include legal bareboat charters. Charterers, however, should be careful to avoid situations where an otherwise legitimate bareboat charter may be structured so that the charterer violates passengers-for-hire regulations. The definition of a passenger used by the U.S. Coast Guard in this context is shown in *Table 2*.

Unlike the example cited previously with the oil companies, most individuals or companies chartering a vessel are interested in a 3 to 4 hour cruise activity with a group of friends, business associates or family. They generally have no experience in operating vessels, have no knowledge of captains and crews which they must directly hire, nor are they skilled or knowledgeable in the provisioning, fueling and insuring of vessels, and generally have limited, if any, experience in the direction or supervision of passenger-carrying vessels. In many cases these are multi-million dollar vessels over 100 feet long with complex machinery and navigation equipment.

Under the concept of "bareboat chartering", to be a true bareboat charter the charterer must take control and possession of the vessel for the duration of the charter. Over the years, the regulatory agencies and courts have established guidelines as to what constitutes transfer of control and possession. Some of these guidelines are shown in *Table 3*. In order to constitute a true bareboat charter, most or all of these elements of control must be the charterers direct responsibility. It is worth noting here that the execution of a legal document alone will not create a valid bareboat charter. If the parties do not conduct the business relationship in a way that transfers the possession and control of the vessel to the charterer for the duration of the charter, and take all the risks associated therewith, it most likely will not be construed as a valid bareboat charter.

Is it reasonable to believe that the owner of a large passenger vessel or multi-million dollar private yacht is willing to totally transfer the control and possession of a vessel to an inexperienced charterer for a short period of time for a small charter fee or percentage of an agents charter revenues? The vessel owner is unlikely to be able, in a short period of time, to evaluate the charterer's capability to accept control of the vessel. The charterer of the vessel is certainly not in a position, without the proper experience, to evaluate the risks and provide the services necessary to truly take control of the vessel during the charter period.

Any reasonable evaluation of the bareboat charter concept will tell you that typical charter users such as a company introducing a new brand of perfume, a convention group out for a night on the town or a bride and groom wishing to be married at sea, are not likely to be qualified - nor interested - in accepting the risks associated with taking control and possession of a complex vessel for an evening with business associates or friends.

In many cases the charterers of the vessel are not told of their risks and responsibilities until time of departure, at which time often a charter agreement is presented to them as "only a formality". An agent may have arranged for the crew, provided the food and beverage, assured them that the vessel will be filled with fuel, and otherwise attended to all details which an owner would normally have to manage. The agent cannot legitimately maintain control of the vessel and is not responsible for the crew or the liabilities associated with the vessel. Even a small problem such as an overactive bilge pump in an engine room could provide a small oil slick (water pollution) and expose the charterer to a $5,000 fine.

In many cases, agents give the appearance that their vessels are inspected and suitable for the appropriate purposes. For instance, some West Coast companies ask the U.S. Coast Guard Auxiliary to provide a safety inspection of their vessels so they can advertise that they are "U.S. Coast Guard inspected". Obviously these vessels do not meet the USCG standards, as the U.S. Coast Guard Auxiliary can only provide a complimentary safety inspection which they would provide to any non-commercial or recreational boater.

There are many other regulatory influences associated with the chartering of vessels and the carrying of passengers. Some of these are listed in *Table 4* This is by no means a comprehensive listing, as each area has its own specific regulations pertaining to commercial charter activities. Many of these regulations apply only to vessels that are licensed to carry passengers-for-hire. If an owner is using the bareboat charter to circumvent these regulations, he will generally be unaware or unconcerned about the need to comply with many other regulatory requirements.

One of the greatest concerns of NAPVO members pertains to the risks associated with operating unsafe vessels. Any vessel carrying a large number of passengers which has a problem will be viewed negatively by the public at large. Other transportation related industries, such as trains or airlines are more heavily regulated and thus have very few private carriers attempting to circumvent regulations. The boating industry does not fit into the same category. Can you imagine the potential problems with airline safety if airplanes could be chartered to carry passengers without compliance with Federal Aviation Authority Standards! The National Transportation Safety Board has recently become aware of the potential for problems associated with illegal and unsafe bareboat charters and may become more active with bareboat charter issues.

Owners and bareboat charterers are subject to a number of fines and penalties should they be cited and proven guilty of operating outside of the regulations. The fines for carrying passengers-for-hire go up to $2,000 per passenger, and further, have resulted in seizure of vessels. In addition, operators and crew which have U.S. Coast Guard licenses or certificates may have these suspended or revoked. *Table 5* shows the civil

penalties which can be assessed for violation of the passengers-for-hire regulations. This does not include any of the local county or state regulations, which could also result in fines, penalties, and/or suspensions.

While the enforcement of these regulations is not the U.S. Coast Guard's highest priority, they have recently increased their efforts to make vessel owners, operators, and the boating public more aware of the risks and penalties associated with violation of federal regulations. Clearly their greatest mission is marine safety, and as a result, the huge amount of activity throughout many U.S. ports associated with the chartering of unsafe vessels is of great concern to them. In many areas where the Coast Guard marine safety office has adequate staff and appropriate priorities they have dramatically reduced the number of unlicensed charter vessels and unscrupulous agents attempting to deceive the unknowing public with sham bareboat charter agreements. However, on the West Coast alone there are still over 75 vessels representing a capacity of over 3,000 passengers offered for charter. A list of some recent USCG enforcement activities and their probable results is included in *Table 6.*

While the U.S. Coast Guard has not been completely successful in halting illegal charters, they are continuing to aggressively enforce regulations pertaining to passengers-for-hire on unsafe vessels. They recognize that the risk of a disaster associated with continuation of such unsafe practices increases daily. This is especially true when you consider special events such as the Statue of Liberty celebration and the Americas Cup race viewing. The U.S. Coast Guard certainly understands that a company or individual without appropriate experience does not fully intend to take possession and control of a large vessel in such a high risk environment.

In addition to the U.S. Coast Guard's efforts to more aggressively enforce charter regulations, insurance companies have begun to reevaluate their charterer's liability coverage. They too recognize the risks and costs associated with operating vessels that are not suitable for their intended purpose. In many cases they are not told that the owner is transferring control and possession of the vessel to novices. In addition, marina operators and owners have begun to question whether bareboat charter activities within their marinas are safe. Claims associated with the operation of a charter vessel will certainly go beyond the charterer of the vessel if there is a major problem. In most cases, the charterer of the vessel has not been properly insured, and is sailing from docks owned by others. Most berthage and dock use leases prohibit operation in violation of local, state and federal regulations. In other words, marina operators and owners have the ability and the obligation to stop bareboat charterers illegally carrying passengers-for-hire without the help of other regulatory agencies.

If you are associated with these types of activities, and at risk, or you are interested in keeping the commercial passenger vessel industry safe, we would encourage you too to take action to stop illegal charter activities and violation of passenger vessel regulations. The U.S. Coast Guard encourages calls from the concerned public regarding these issues. A listing of the appropriate Marine Safety Office phone numbers is included in *Table 7.* Like any regulatory agency, the U.S. Coast Guard's resources are limited, and their efficiency will be much greater with more accurate information. *Table 8* provides some guidance to assist the public in providing the required information about bareboat charter violations.

The National Association of Passenger Vessel Owners (NAPVO) also encourages the public's support of NAPVO member sponsored chartering and commercial vessel activities. Ultimately, when agents and owners who are attempting to operate in violation of the regulations face the realities of bareboat chartering, they will have to reevaluate their business practices. Recent changes in the tax law have already made it less practical for owners to continue to operate vessels as marginal businesses, with large depreciation losses providing tax benefits.

NAPVO membership supports increased enforcement by regulatory bodies which will keep passenger vessel industry safety records intact. NAPVO further continues to support the U.S. Coast Guard, and commends them on their continued efforts to keep the passenger vessel industry safe.

Table 1 - Risks for Owners and Charterers in Illegal Bareboat Charters

- Fines and Vessel Seizure
- Lack of experience of user in:
  - Procuring insurance, fuel and provisions
  - Hiring and supervising crew
- Liability
  - Personal injury
  - Vessel damage (hull insurance)
  - Protection & Indemnity insurance
- Jones Act compliance
- Vessel safety issues

Table 2 - Definition of a Passenger

On an uninspected passenger vessel, means an individual carried on the vessel except–

i) the owner or representative of the owner;

ii) the managing operator;

iii) a crewmember engaged in the business of the vessel who has not contributed consideration for carriage on board and who is paid for services on board; or

iv) a guest on board a vessel that is being operated only for pleasure who has not contributed consideration for carriage on board.

Title 46 CFR §2101.21D

Table 3 - What Constitutes a Valid Bareboat Charter?

The vessel's owner must relinquish total control and possesion of the vessel, including :

- Hiring and supervision of Captain and Crew
- Fueling
- Provisioning (catering)
- Docking and port fees
- Navigation and route
  (charter must be free to take vessel on any route)
- Survey on delivery and return

Table 4 - Regulatory Bodies Concerned with Illegal Bareboat Charters

- United States Coast Guard
- United States Customs Service
- Alcholic Beverage Control
- Internal Revenue Service
- Public Utilities Commission
- Local law enforcement agencies
- County health & sanitation departments

Table 5 - Penalties for Illegal Passengers-for Hire Operations

Violations found proven carry a maximum civil penalty of $5,000 per incident (per passenger) and could potentially lead to forfeiture of the vessel. It should also be realized that should an injury occur on a vessel operating in violation, insurance policies carried by the vessel's owner would probably be void and the parties involved (including the agent) would carry much more liability in civil litigation.

Table 8 - Information You Should Have To Report an Illegal Bareboat Charter

- Vessel name
- Location of departure
- Planned departure and return time.

Also helpful are the names of the Captain(s), crew, passengers, owner and/or agent.

Time is of the essence. Advise the Coast Guard immediately.

Table 6 - Selected Charter Violation Case Histories

Vessel Name	Date	Location	Alleged Infraction	Proposed Penalty
DULCINEA	May 1986	San Francisco, CA	Illegally carrying 136 passengers Violation of Jones Act	$27,000 $34,000
KIALOA	October 1987	Richmond, CA	Improper Bareboat Charter	$52,000
PARADISE II	July 1988	Erie, PA	Carrying passengers-for-hire without a proper license.	Vessel Seized
CAROL ANN	July 1988	Erie, PA	Illegal Charter Operation	$43,000

Table 7 - Investigative Division or Marine Safety Offices

USCG District	City	Phone
First	Boston, MA	617-835-9040
	Portland, ME	207-833-3251
	Providence, RI	401-528-5335
Second	St. Louis, MO	314-425-4657
	Peoria, IL	309-360-7195
	St. Paul, MN	612-725-7452
	Davenport, IA	319-322-6297
	Huntington, WV	304-529-5524
	Marietta, OH	614-373-5476
	Louisville, KY	502-582-5194
	Evansville, IN	812-335-6275
	Cincinnati, OH	513-684-3295
	Memphis, TN	901-222-3941
	Greenville, MS	601-497-2400
	Nashville, TN	615-852-7362
	Decatur, AL	205-355-7158
	Paducah, KY	502-442-1621
	Pittsburgh, PA	412-644-5808
Third	New York, NY	212-664-7859
	New London, CT	203-645-6003
	Philadelphia, PA	215-597-4337
	Gloucester City, NJ	609-488-5199
Fifth	Norfolk, VA	804-827-3276
	Baltimore, MD	301-922-5145
	Wilmington, NC	919-671-4881
	Morehead City, NC	919-670-2438
Seventh	Miami, FL	305-350-4524
	Key West, FL	305-296-6825
	Jacksonville, FL	904-791-2648
	Tampa, FL	813-826-2190
	Savannah, GA	912-944-4347
	Charleston, SC	803-677-4392
	San Juan, PR	809-725-2697
	Ponce, PR	809-766-3497
	St. Croix, VI	809-842-2368
Eighth	New Orleans, LA	504-682-6251
	Morgan City, LA	504-687-0515
	Baton Rouge, LA	504-687-0271
	Houma, LA	504-868-5595
	New Iberia, LA	318-369-6221
	Corpus Christi, TX	512-529-3162
	Brownville, TX	512-529-2583
	Galveston, TX	409-527-6638
	Houston, TX	713-526-7558
	Mobile, AL	205-537-2998
	Port Arthur, TX	713-527-8333
	Lake Charles, LA	318-687-7226
Ninth	Cleveland, OH	216-522-4405
	Buffalo, NY	716-846-4168
	Alexandria Bay, NY	315-953-8482
	Chicago, IL	312-353-5080
	Detroit, MI	313-226-7777
	Milwaukee, WI	414-291-3788
	Sturgeon Bay, WI	414-743-9448
	Duluth, MN	218-720-5285
	Toledo, OH	419-979-6372
	St. Igance, MI	906-643-8086
	Muskegan, MI	616-759-7508
Eleventh	Long Beach, CA	213-499-5500
	Santa Barbara, CA	805-965-0407
	San Diego, CA	619-895-5848
Twelfth	San Francisco, CA	415-536-3149
Thirteenth	Seattle, WA	206-399-7510
	Portland, OR	503-422-0312
Fourteenth	Honolulu, HI	808-551-2070
Seventeenth	Juneau, AL	907-586-7307
	Anchorage, AL	907-271-5137

RELATIONSHIP BETWEEN SEAKEEPING REQUIREMENTS AND SWATH SHIP GEOMETRY

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ABSTRACT

Even though in 1987 there were only a dozen SWATH craft and ships afloat around the world, word of their markedly superior seakeeping performance is spreading rapidly. This paper reviews the characteristics of existing SWATH craft and ships from the standpoint of the stated seakeeping objective. Hullform differences between four SWATH craft and ships, including the Navy's SSP KAIMALINO, are analyzed and interpreted. Important considerations for the early stage design of a SWATH ship are discussed. Differences in the range of feasible hullform geometries for coastal areas and unrestricted ocean operations, and for low speed vs. moderately high speed applications, are pointed out.

Introduction

Naval architects know they can increase the seaworthiness of a surface ship design and reduce its pitch motions in moderate seas by making the ship bigger and, in particular, longer. Increased waterline length is advantageous because long steep waves occur relatively infrequently in the world's oceans.

Another factor that contributes to the reduced motions of large monohull surface ships is that the wave exciting forces acting on them are smaller, relative to the ships' mass. The first-order determinant of wave exciting forces is the ships' waterplane area (area of the horizontal cross-section through the hull at the design waterline). Waves also act on the submerged portions of the hull, but the wave forces decrease exponentionally with depth of submergence.

SWATH (Small-Waterplane-Area Twin-Hull) ship configurations make it possible for the naval architect to raise the periods of maximum pitch and roll response significantly higher than for a large monohull ship, while simultaneously bringing about a very marked decrease in wave exciting forces. The underlying reason is that, typically, a SWATH ship will have no more than one-third of the waterplane area of a monohull of equal displacement.

It should be acknowledged that there is a price to pay for these benefits. Comparative design studies have shown that adopting the SWATH configuration results in a larger full load displacement to carry the same payload weight as a monohull. Consequently, SWATH hullforms should be considered only for applications requiring excellent seakeeping performance for the size of ship in question.

Existing SWATH Craft and Ships

In 1987, to the author's knowledge, there were 12 SWATH craft and ships operating in the world, spanning the size range from 22 LT to about 3500 LT. Thus far, 5 SWATH craft have been built in the U.S. and 7 have been built in Japan. Japan has both the largest SWATH, the KAIYO [1], and the smallest, the MARINE ACE [2]. The U.S. Navy has the distinction of having the oldest SWATH, the 220 LT SSP KAIMALINO [3]. The TWIN DRILL [4] (formerly the DUPLUS) was not included in these totals because, while it started out life in the mid-1960s in Holland as a SWATH, since then blisters have been added which increased the waterplane area substantially. The TWIN DRILL, which displaces 1400 LT, is the only known example of an MWATH (Medium-Waterplane-Area Twin-Hull) ship.

The 3500 LT diving support ship KAIYO was delivered to the Japan Marine Science and Technology Center in June 1985. It was designed and built by Mitsui Engineering and Shipbuilding Co. In the U.S. commercial development of the SWATH concept has been limited to craft of less than 150 LT. However, in November 1986 the Navy awarded a contract for the construction of the lead ship of a class of 3360 LT SWATH ocean surveillance ships (T-AGOS 19 class) to McDermott Shipyard in Morgan City, LA. The T-AGOS 19 was designed in-house by the Navy [5]. Looking ahead, the Navy has plans for other classes of SWATH auxiliary ships. There is also growing activity in the U.S. in commercial applications of SWATH ships. Two new U.S. SWATH craft are currently under construction.

SWATH SEAKEEPING OBJECTIVE

This paper summarizes what the author has learned, while working at the David Taylor Research Center (DTRC), about hullform selection for SWATH ships for good seakeeping performance. The approach and judgments contained herein are simplified by considering heave, pitch and roll motions to be uncoupled. Nevertheless, it is believed that the information presented provides a basis for early stage design by naval architects with little previous familiarity with the SWATH concept.

Designing a SWATH ship is different than designing a semi-submersible drilling rig or work platform because SWATH ships are so much smaller. Drilling rigs are sized and designed to provide very little deck motion even in severe storm seas. As a consequence, semi-submersibles have 50 or 60 ft. of clearance from their operating waterline to the

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underside of the working platform. Moreover, they displace 20,000 to 40,000 LT.

The objective of SWATH ship design usually is not near-zero deck motion. Instead, the objective is to reduce ship motion to an acceptable level. For Navy designs acceptability is usually defined as the following motion limits [6] for onset of degraded human performance:

significant single amplitude pitch	3 degrees
significant single amplitude roll	8 degrees
significant single amplitude vert. accel.	0.4 g's

Automotive engineers have developed electrically controlled suspension systems that can be changed from a "highway" setting to a "sport" setting at the flick of a switch. The designer of a SWATH ship must select a combination of strut and lower hull geometry, and appendages, which has an inherent capability for smooth, steady "highway" performance in the design operational sea conditions and "sport" performance in severe sea conditions. In naval architectural terms, the former is called "platforming" while the latter is "contouring" behavior.

Table 1. Summary of design operating conditions for existing SWATH craft and ships.

Craft Name	Displ. (LT)	Design Max. Operational Sea State	Design Operating Speed (kts)	Clearance to Wet Deck (ft)	Design Operating Draft (ft)
MARINE WAVE	25	3	16	2.7 (Est.)	5.2
HALCYON	57	4	18	4.5	7.0
SSP KAIMALINO	217	4	0-5	6.0	15.3
KOTOZAKI	232	4	0-5	4.0	10.5
SEAGULL	338	5	23	7.7 (Est.)	10.3
KAIYO	~3500	4	0	11.0 (Est.)	20.7

IMPORTANCE OF DESIGN OPERATING SPEED AND SEAWAY CONDITIONS

Table 1 summarizes published information on the design operating conditions for a number of existing SWATH craft and ships. It is interesting to note that the KAIYO was designed for operations through Sea State 4 [1] while SEAGULL was designed for operations in Sea State 5 [7]. Given that the displacement of SEAGULL is smaller by a factor of 10, how is this possible? Two key factors are the difference in their design operating speeds and the difference in seaway conditions where the two ships operate. How those differences affected these two SWATH designs will be discussed later in this paper.

Comparison of the SSP KAIMALINO and the KOTOZAKI

The SSP KAIMALINO and the KOTOZAKI are similar in size and both were designed for good seakeeping at 0 to 5 knots in Sea State 4. In addition, they are both capable of transit speeds of about 20 knots. Yet Figure 1 shows these two craft are very different in appearance. Why is this so?

The SSP KAIMALINO was designed by the Naval Ocean Systems Center (NOSC) as a work platform for their Hawaii Laboratory [8]. The seas in the vicinity of the NOSC Lab on the island of Oahu are often rough. Sea State 5 and Sea State 6 conditions characterized by long modal periods are experienced frequently. The necessity of coping with rough seas influenced the configuration of the craft, even though the

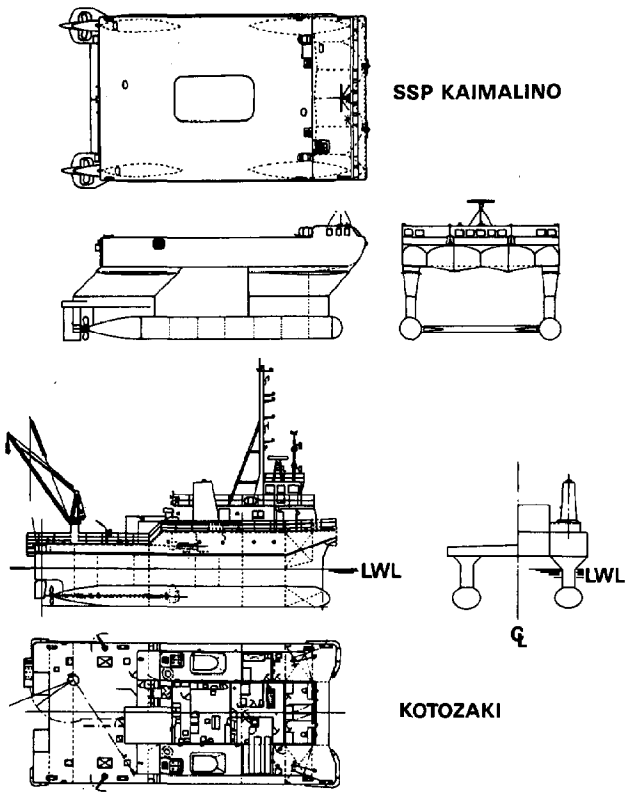

Fig. 1. Comparison of the hullforms of the SSP KAIMALINO and the KOTOZAKI.

design operating condition is Sea State 4. In contrast, the KOTOZAKI was designed to carry out water and bottom surveys in the Seto Inland Sea of Japan [9]. The KOTOZAKI went into service in March, 1981 and as of January, 1985 had accumulated more than 700 operating days [9]. The largest observed wave height during these operations was only 8 ft. Thus, the prevailing sea conditions for the two craft are markedly different. Since both craft are reported to be very successful in providing small ship motion response, it is instructive to compare their dynamic and hydrostatic characteristics.

Figure 2 is a plot of available data on the measured pitch natural periods for the SSP KAIMALINO [10] and KOTOZAKI [7], as well as three other SWATH craft designed by Mitsui [7, 11]. The pitch period of the SSP KAIMALINO is 9.7 sec., while the KOTOZAKI's pitch period is 8.9 sec. Also shown on Figure 2 is the pitch period trend line for hypothetical geosims of the KOTOZAKI. (A geosim is a hullform that has exactly the same proportions as the base ship because all dimensions have been multiplied by the same scale factor.) The pitch periods of two of the three other Mitsui SWATH craft fall on this trend line. The MARINE ACE has a substantially shorter pitch period, but is an early experimental prototype. Figure 3 is a similar plot for the roll natural periods. The roll period of 15.8 sec. for the SSP KAIMALINO is substantially longer than the KOTOZAKI's roll period of 10.7 sec. Two of the three other Mitsui craft have roll periods that are close to the trend line for geosims of the KOTOZAKI. One reason why the roll

period of the SEAGULL is somewhat shorter than the trend line is that the buyer specified that the transverse metacentric height had to be large enough to resist the heeling moment that would result from all 450 passengers crowding along the rail on one side of the ship.

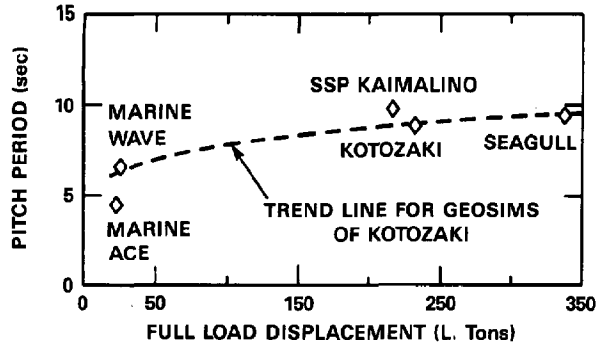

Fig. 2. Pitch period trend line for existing SWATH craft.

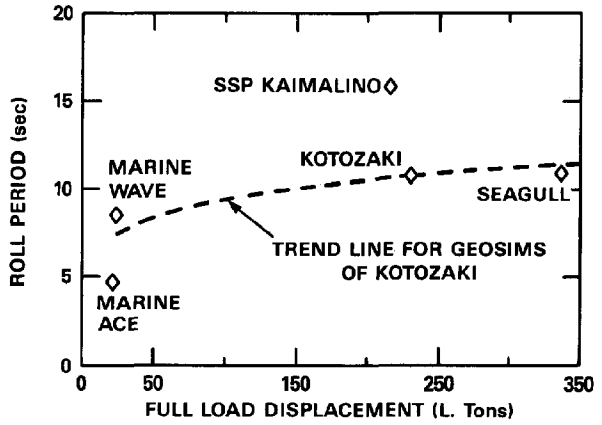

Fig. 3. Roll period trend line for existing SWATH craft.

Figure 4 is a plot of available data on the heave natural periods for existing SWATH craft. The SSP KAIMALINO's heave period of 8.5 sec. is considerably longer than the KOTOZAKI's period of 5.8 sec. The heave periods of the Mitsui-designed craft appear to follow a trend line for geosims. In this case, the trend line was based on the MARINE ACE because there is data available on the total strut waterplane area of this craft [2]. The trend line for the waterplane area of geosims of the MARINE ACE is shown in Figure 5. It was a surprise to see that the estimated waterplane area of the RMI-designed HALCYON [12, 13] falls on this trend line. This is also the case for the CHUBASCO's waterplane area, which was furnished courtesy of SWATH Ocean Systems, Inc. Since all of the Mitsui SWATH craft have similar oval hull cross-sections, and since their heave periods fall on the trend line for geosims, it is reasonable to infer that the waterplane areas of the KOTOZAKI and SEAGULL would fall on the trend line shown in Figure 5. This inference leads to an estimated total waterplane area of 536 sq. ft. for the KOTOZAKI, while the SSP KAIMALINO has only 247 sq. ft. of waterplane area. Even after making an adjustment for the small difference in the displacements of these two craft, their waterplane areas differ by a factor of 2.

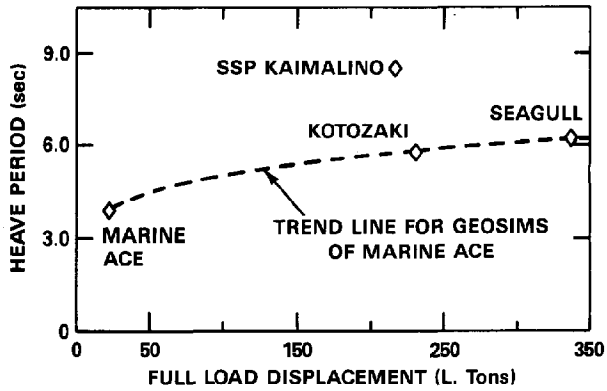

Fig. 4. Heave period trend line for existing SWATH craft.

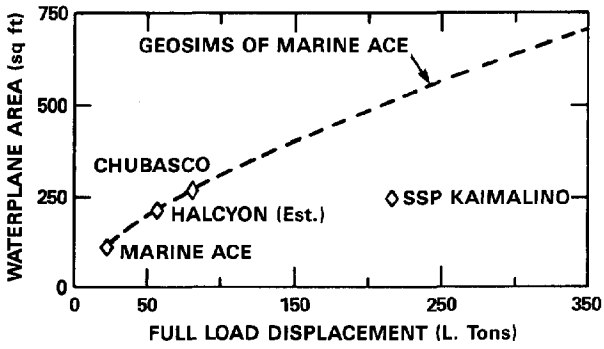

Fig. 5. Waterplane area trend line for geosims of the MARINE ACE.

The greatly reduced waterplane area of the SSP KAIMALINO further reduces wave exciting forces in a given seaway relative to the forces that would be acting on the KOTOZAKI. Because of its very small waterplane area, the SSP design needs a 10-ft. wider hull spacing to satisfy intact roll stability requirements. In addition to increasing deck area and enclosed volume, the wider hull spacing results in greater roll inertia. This is one of the reasons that the roll period of the SSP is substantially longer than the KOTOZAKI's roll period.

The exceptional seakeeping performance of the SSP at low speeds is shown in Figures 6-8. These full-scale trial measurements [14] were taken near Oahu at a nominal ship speed of 5 knots. The measured sea spectra during these trials had significant wave heights between 11 ft. and 13.5 ft. The measured spectral wave energy peaked at a wave period of about 12 sec. This is termed the modal period of the wave spectrum. The Navy criteria for onset of degraded personnel performance are also plotted on Figures 7 and 8. Only in following seas is the limit of 3 deg. single amplitude pitch exceeded. At this heading, assuming linearity of motion responses, the pitch limit would be reached in seas with a sig. wave height of about 8 ft., i.e., high Sea State 4. This was the original design objective. On the other hand, Figure 8 shows that the measured roll motions are far below the limit of 8 deg. single amplitude even though the trial conditions correspond to high Sea State 5. Similarly, the vertical accelerations are only one-fourth of the criterion of 0.40 g's sig. single amplitude. These very low acceleration values are the result of the SSP's long heave and pitch periods. The measured vertical acceleration values are also well below the

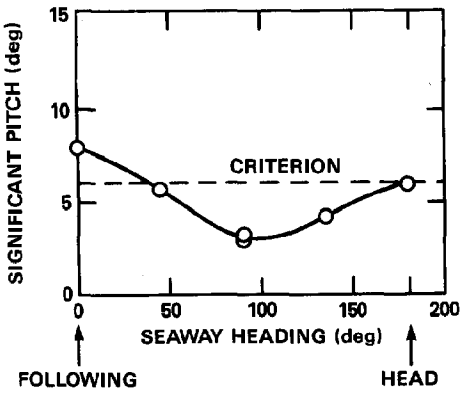

Fig. 7. Variation of significant pitch double amplitudes with seaway heading for the SSP KAIMALINO at a nominal speed of 5 knots [14].

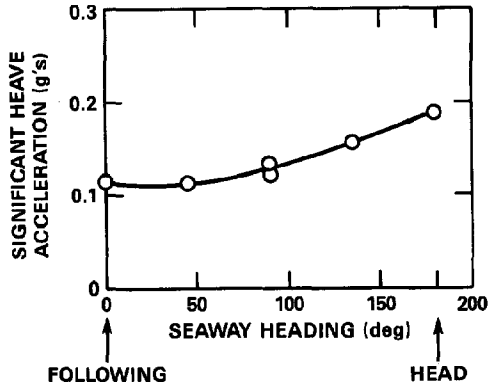

Fig. 6. Variation of significant heave acceleration double amplitudes with seaway heading for the SSP KAIMALINO at a nominal speed of 5 knots [14].

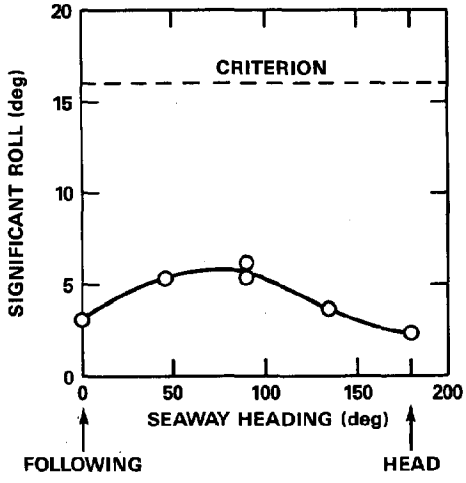

Fig. 8. Variation of significant roll double amplitudes with seaway heading for the SSP KAIMALINO at a nominal speed of 5 knots [14].

more stringent criterion of 0.20 g's which is often used for applications requiring the handling of equipment on deck.

In the author's judgment, it would have been possible to satisfy the Sea State 4 seakeeping objective with a SWATH design that had substantially more waterplane area than the SSP if low speed performance was the only requirement. However, NOSC also desired the ability to transit along the coast at a speed of 20 knots or more. Given the common occurrence of Sea State 5 and 6 conditions, it is advantageous for the SSP to have a long heave period for best transiting performance.

Figure 9 shows the effect of a ship speed of 20 knots on the ship/wave encounter period for a ship heading into waves of various periods. It can be seen that the encounter period with the waves of maximum energy in a seaway having a 12-sec. modal period is 7.7 sec. The ratio of the SSP's heave period (8.5 sec.) to the wave encounter period is called the heave tuning factor. In this case the heave tuning factor is 1.10. Figure 10 shows schematically the variation in nondimensional heave response for a SWATH operating at low speeds as a function of the tuning factor value. The least heave response occurs when the tuning factor is greater than 1.20. This region is termed the supercritical region and it is characterized by platforming motion behavior. The subcritical region covers values of up to 0.75 for the tuning factor. In the subcritical region the ship moves up and down in phase with the wave, and with a heave amplitude about the same as the wave amplitude. The greatest heave motion response occurs when the value of the tuning factor is nearly unity, i.e., heave resonance. When the encounter period is equal to the heave period, a SWATH ship operating in regular waves can experience heave motions as large as twice the wave amplitude. Moreover, at resonance the ship's heave motion will be out of phase with the wave, thereby increasing the incidence of wave impacts on the wet deck. In a more realistic irregular seaway the amplification of heave responses in resonant wave lengths will be smaller, but will still be very evident.

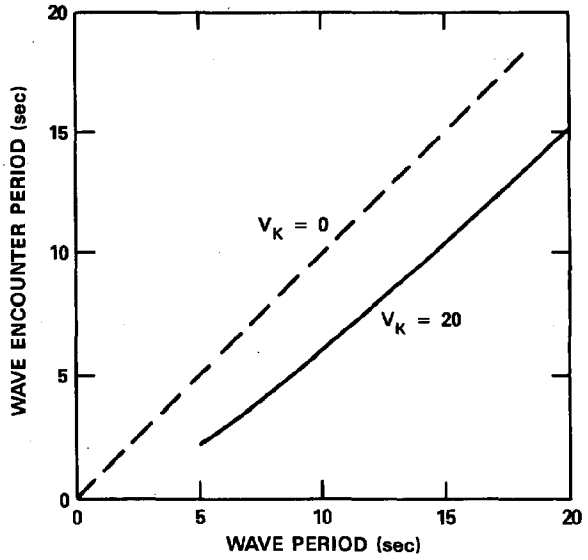

Fig. 9. Effect of ship speed on wave encounter period in head seas.

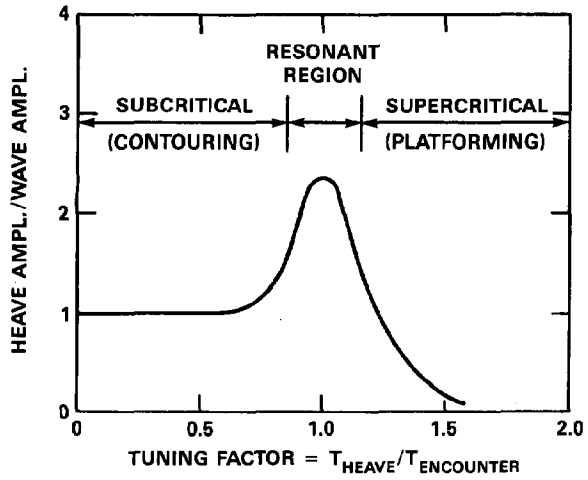

Fig. 10. Typical variation in SWATH ship heave response at low speeds as a function of tuning factor.

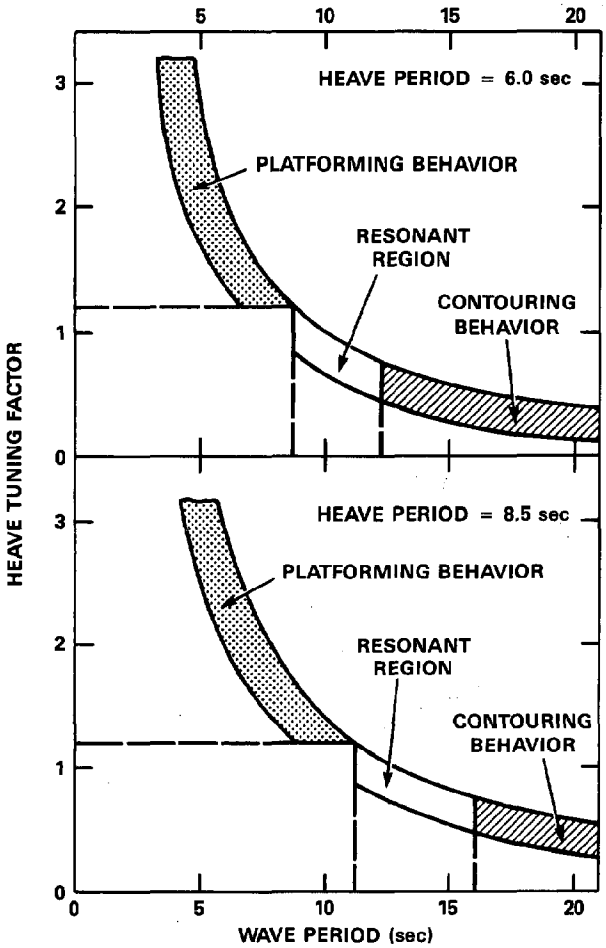

Fig. 11. Comparison of the regions of platforming and contouring response at 20 knots in head seas for ship heave periods of 6.0 and 8.5 seconds.

Figure 11 compares the regions of platforming and resonant response at a ship speed of 20 knots for two different heave periods: 6.0 sec. and 8.5 sec. The former is approximately the same as the heave period of the KOTOZAKI. For a ship moving at 20 knots in head seas, a 8.5 sec. heave period extends the region for platforming behavior through wave periods of 11 sec., while a 6 sec. period limits platforming behavior to wave periods of less than 9 sec. A SWATH craft having head sea platforming capabilities limited to wave periods of less than 9 sec. would have been unacceptable for operations off of Oahu.

Passenger Ferry SEAGULL

Figure 11 is also helpful for explaining why the passenger ferry SEAGULL, which displaces only 338 LT, is able to sustain operations in Sea State 5. The SEAGULL has a heave period of 6.2 sec. and a pitch period of 9.5 sec. [7]. In head seas, at its normal transit speed of 23 knots, the SEAGULL will exhibit platforming heave response in waves having periods shorter than 9 sec., and will exhibit platforming pitch response in wave periods shorter than 12 sec. According to Narita [7], the most probable wave period on the SEAGULL's route is 6 sec. Thus, the SEAGULL has natural heave and pitch periods that provide minimal heave and pitch responses on its design operating route. With platforming behavior it is essential that there is an adequate amount of clearance to the underside of the wet deck. At its design waterline the SEAGULL has about 7.7 ft. of wet deck clearance amidships and about 9.4 ft. of clearance at the bow and stern. Usually, the SEAGULL operates at a draft about 6 inches deeper than the design value, so the wet deck clearance is about 7 ft. amidship and about 9 ft. at the bow and stern. The ferry company which operates the SEAGULL has a policy of cancelling operations only when seas with wave heights in excess of 3.5 m (11.5 ft.) are forecast [9]. Typically, if a given seaway has a significant wave height of 11.5 ft., the average height of the one-tenth highest waves will be about 14.7 ft. The corresponding wave amplitude is 7.35 ft. Since there is little ship heave motion at its design operating speed, the SEAGULL has about the minimum acceptable amount of wet deck clearance amidships for its operating requirements.

Diving Support Ship KAIYO

In contrast to the SEAGULL, the seakeeping requirements of the KAIYO apply to operations which are carried out with the ship at rest. It is judged that the most demanding of the KAIYO's operations is lowering one of the submersible diver decompression chambers into the water. This is carried out through the ship's center well using four vertical guide rails. During this operation only a minimal amount of pitch and roll motion can be tolerated. In addition, the relative vertical motion between the ship and waves must also be small. The latter requirement can be met by ensuring a platforming-type heave response in the design sea conditions.

It is estimated that the KAIYO has a heave period of about 10.5 sec. Figure 12 shows the wave period regions for platforming and contouring response for zero ship speed. The limiting wave period for platforming is about 8.8 sec. Referring to Figure 13, it can be seen that modal periods as short as 8 sec. have a high probability of occurrence in 2.5 m

seas (high Sea State 4). It is for this reason that high Sea State 4 is considered to be the limiting condition for the diving support portion of the KAIYO's mission. This example also illustrates why zero speed, open ocean operations are among the most demanding seakeeping requirements that a SWATH designer must satisfy.

SELECTION OF WATERPLANE AREA FOR LOW SPEED OPERATIONS

Figure 14 compares the estimated heave period of the KAIYO with the trend line developed in Figure 4 based on existing small SWATH craft. The heave period of the KAIYO

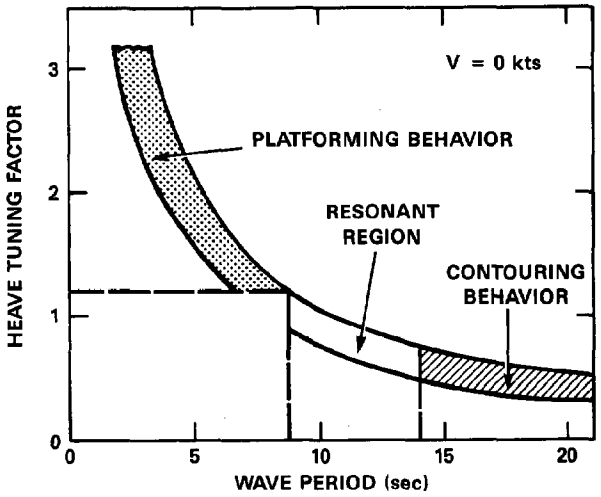

Fig. 12. Regions of platforming and contouring response in head seas for a ship heave period of 10.5 seconds.

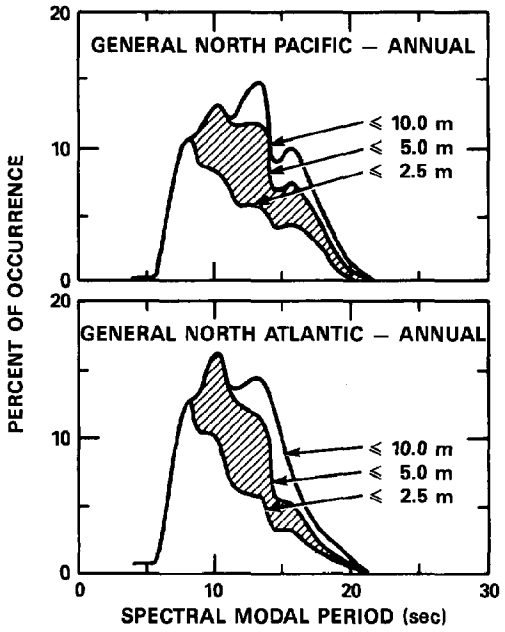

Fig. 13. **Variation in probability of occurrence of different spectral modal periods for several significant wave height bands [6].**

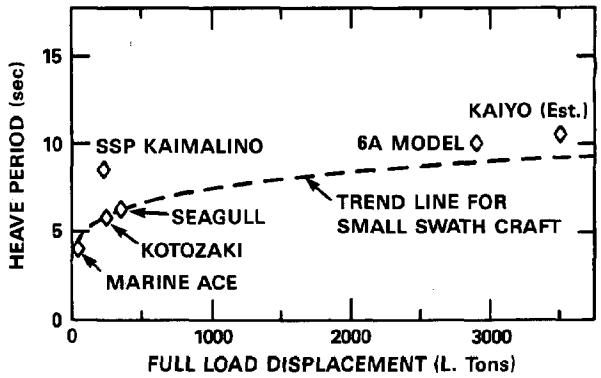

Fig. 14. Comparison of the estimated heave period for the KAIYO with the trend line for small SWATH craft.

is 15 percent above the trend line. It appears that a conscious decision was made to raise the heave period. Also shown in Figure 14 is the data point for the DTRC 6A model, which was designed as a candidate configuration for a 2900 LT oceanographic research ship. The measured heave period for the 6A model is 10.1 sec. [15]. This data point is also about 15 percent above the trend line. Results of the seakeeping experiments with the 6A model were documented by Kallio [15].

The heave natural period of a surface ship can be estimated using the equation shown below:

$$T_{HEAVE} = 2\pi\sqrt{\frac{V\,(1 + A'_{33})}{g\,A_{WP}}} \qquad (1)$$

where

V = the displaced volume of the ship
A'_{33} = the hydrodynamic heave added mass divided by the ship mass
g = gravitational acceleration
A_{WP} = total waterplane area

For a simple SWATH ship with lower hulls having a circular cross-section, such as the 6A model, the A_{33} term has a value of about 0.70. This means that the hydrodynamic heave added mass is 70 percent of the ship's mass. For a monohull, the heave added mass is typically equal to the ship's mass.

The SWATH designer has only two ways of increasing the ship's heave period. Either the value of A_{33} must be increased or the total amount of waterplane area must be reduced. It has been determined from model experiments that the heave added mass of a SWATH ship with elliptical lower hulls having a horizontal axis 1.8 times the vertical axis amounts to 120 percent of the ship's mass. For a given design displacement and waterplane area, selection of 1.8:1 elliptical lower hulls would result in a heave period that is 14 percent longer than the equivalent configuration with circular lower hulls. However, in most cases practical design considerations will preclude the use of such highly elliptical hulls. Recent Navy designs have had oval cross-section hulls with a horizontal axis 1.4 times the vertical dimension. The added mass of a SWATH with this type of lower hull is almost 90 percent of the ship's mass.

In addition to the structural considerations, the designer's ability to reduce waterplane area is constrained by the need to maintain adequate static roll stability. For a SWATH ship,

the amount of transverse waterplane inertia, I_T, is approximately equal to the following:

$$I_T = (\text{waterplane area}) \times \left(\frac{\text{hull spacing}}{2}\right)^2 \qquad (2)$$

Equation (2) shows that, if the amount of waterplane area is decreased by 50 percent, the hull spacing must be increased by the square root of 2, i.e., 41.4 percent. So large an increase in hull spacing usually is undesirable from an overall design standpoint because it will result in a large increase in structural weight and enclosed volume.

Effect of Panama Canal Beam Limit

For Naval designs there is a reluctance to accept the concept of a relatively small displacement ship that cannot pass through the Panama canal. Consequently, the overall beam is not allowed to exceed 105 ft. The 2900 LT SWATH 6A configuration has a hull spacing of 75 ft. and an overall beam of 90 ft. [15]. A feasible alternative geometry is a SWATH with 20 percent wider hull spacing, resulting in an overall beam of 105 ft. With 20 percent wider spacing, it is possible to reduce the amount of waterplane area to 70 percent of the 6A value without reducing transverse stability. This approach would increase the heave natural period to about 12.1 sec., as compared with 10.1 sec. for the 6A geometry. However, referring back to Figure 13, there is essentially the same probability of encountering Sea State 6 spectra with a 12 sec. modal period as with a 10 sec. period. The amount of waterplane area would have to be decreased to a very small value to raise the heave period sufficiently to ensure platforming heave behavior at zero speed in the open ocean. Faced with the impracticality of ensuring platforming heave responses, what the SWATH designer must do is to provide an adequate amount of heave damping.

Low Speed Heave Damping

Figure 15 shows the plan view of a 1981 DTRC model of a notional 3000 LT SWATH designed for low speed operations. This model has elliptical lower hulls with the horizontal axis 1.8 times the vertical axis, thereby increasing the heave added mass and damping. Even so, it was determined from free oscillation tests that the bare hull heave damping factor for this model at zero speed was only one percent of the critical damping value. Addition of the bow and stern fins shown in Figure 15 increased the measured heave damping factor to 3.6 percent of the critical value. The measured heave damping factor values at other speeds are shown in Table 2.

Table 2. Effect of stabilizing fins on the measured heave damping factors for the model of a 1981 notional 3000 LT SWATH ship.

Full-Scale Speed, Kts	0	3	11
Bare Hull Damping Factor	0.010	0.012	—
Appended Damping Factor	0.036	0.057	0.263

It is apparent from the experimental data that the four fixed fins on this model had a dominant effect on total ship heave damping at zero speed. Moreover, with the fins in place there is a 50 percent increase in the measured heave damping factor as ship speed is increased from zero to 3 knots. At 11 knots, the measured damping factor is seven times greater than with the ship at rest. Analyses have determined [16] that the amount of heave damping is largest when the total fin area is distributed between forward and aft pairs of fins, similar to the distribution shown in Figure 15. Making the aft fins larger than the forward fins also serves to counteract the destabilizing Munk moment [16].

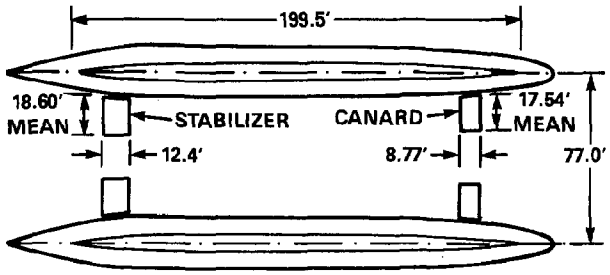

Fig. 15. Plan view of 1981 model of notional 3000 LT SWATH ship.

While the amount of heave damping at 3 knots is small even for the fully appended model, the resulting reduction in maximum heave response is significant. Figure 16 shows the measured nondimensional heave response at a full-scale speed of 3 knots in regular head waves. The peak heave response was only 1.6 times the wave amplitude, and it occurred in waves with a period of about 13 sec. Contouring behavior is evident in wave periods of 15 sec. or greater, since the measured heave responses are equal to the wave amplitude. Below a wave period of 12 sec. there is little heave motion. In these shorter period waves the model shows platforming behavior.

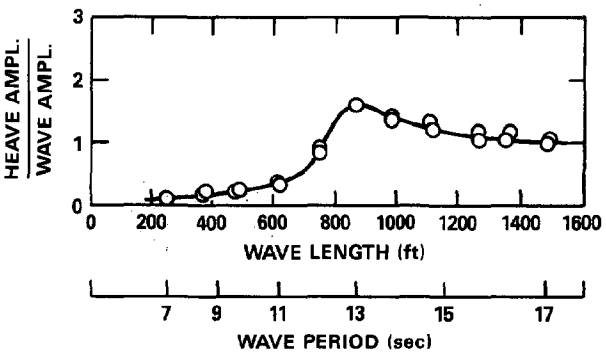

Fig. 16. Measured nondimensional heave response at 3 knots in regular head waves for the 1981 model of a 3000 LT notional SWATH ship.

Implications for Ship Heave Accelerations

Due to the lightly damped, tuned nature of a SWATH ship's heave response curve at low speeds, the peak heave acceleration occurs at the heave natural frequency. Consequently, the ballpark value of the ship's peak heave accelerations in the design operating Sea State can be computed using a simplified method. For any single-degree-of-freedom oscillation, the acceleration amplitude is equal to:

(frequency of oscillation in radians)^2 × oscillation amplitude. Assuming that the ship's heave motions increase linearly with increasing wave height, the peak heave response for the notional 1981 design for a 3000 LT SWATH ship would be 1.6 times the design wave height. As an example, it will be assumed that the design maximum operating condition is high Sea State 6, defined by a significant wave height of 19.7 ft. The measured heave frequency of the appended model at 3 knots is 0.546 rad/sec. The significant double-amplitude heave acceleration for this ship in its design limiting sea condition is estimated as shown below:

$$\begin{aligned}\text{Sig. double-ampl. accel.} &= (0.546)^2 \times 19.7 \text{ ft.} \times 1.6 \\ &= 9.41 \text{ ft/sec.}^2 \\ &= 0.29 \text{ g's}\end{aligned}$$

The corresponding significant single-amplitude acceleration value of 0.145 g's is well below the standard Navy criterion of 0.4 g's. While the estimate assumes heave motion only, and so applies only to the acceleration value at the ship's center of gravity, worst case assumptions were used for heave response period and amplitude. Confidence in this estimating methodology is gained from published full-scale trials data for the KAIYO [1]. The highest reported significant single-amplitude acceleration value for the KAIYO in high Sea State 6 is 0.16 g's. The estimated heave period of the KAIYO is 10.5 sec., while the heave period of the 1981 DTRC 3000 LT Model is 11.5 sec. Thus, the two ships are roughly comparable.

The amount of waterplane area for the 3000 LT model is essentially the same as for the 6A model. However, the highly elliptical lower hull of the former results in a measured heave period that is 1.4 sec. longer. In the light of the very low heave acceleration values, it is judged that the 6A model's heave period of 10 sec. is sufficiently long. Using the same assumptions and methodology as in the previous example, the estimated significant single-amplitude heave acceleration for a SWATH with a 10 sec. heave period is 0.19 g's in high Sea State 6. A personnel limit of 0.20 g's is frequently assumed for the handling of gear on deck. A shorter heave period is advantageous for ensuring contouring behavior in the long period waves which have the greatest energy in State 7 and higher seas.

Figure 17 compares the previously developed waterplane area trend line for small SWATH craft with the trend line for geosims of the 6A model. It can be seen that the 6A model, at 2900 LT, has only 73 percent as much waterplane area as a scaled-up SWATH craft would. The reason is that the planned SWATH oceanographic ships have especially stringent seakeeping requirements. However, there may be other applications where an amount of waterplane area close to the small craft trend line would be acceptable. For informational purposes, the estimated waterplane area of the TWIN DRILL is plotted on Figure 17. The TWIN DRILL has almost 60 percent more waterplane area than a 6A model geosim.

SELECTION OF PITCH PERIOD FOR LOW SPEED OPERATIONS

The previously discussed full-scale trials data for the SSP KAIMALINO, Figures 6-8, consists of measured motion and acceleration levels far below all but one of the standard Navy motion limit criteria. The sole exception is the pitch limit of 3 degrees significant single amplitude. An underlying reason is that its pitch period of 9.7 seconds is shorter than the measured wave spectra modal period of 12 seconds. While it can be seen in Figure 2 that the SSP's pitch period is longer than the typical value for a SWATH craft of its size, the seas around Oahu often have substantial wave energy in the range of periods near 10 seconds.

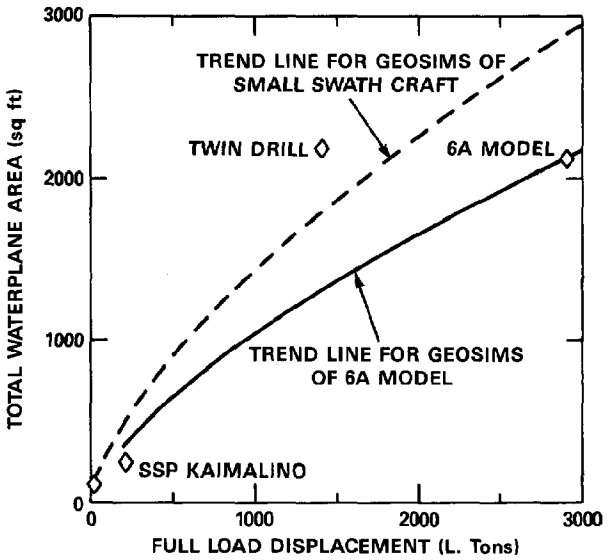

Fig. 17. Comparison of the waterplane area trend lines for SWATH craft and geosims of the 6A model.

Two factors that affect the zero speed pitch period of a surface ship are the ship's length and the value of the longitudinal metacentric height (GM_L). The GM_L is a measure of the ship's longitudinal waterplane inertia. The equation for estimating a ship's pitch period is shown below.

$$T_{PITCH} = 2\pi\sqrt{\frac{L^2 (k_p^2 + A'_{55})}{g\, GM_L}} \qquad (3)$$

where

- L = length of the ship
- k_p = the pitch gyradius divided by the ship length
- A'_{55} = the hydrodynamic pitch added inertia divided by the ship mass times the ship length squared
- g = acceleration of gravity
- GM_L = longitudinal metacentric height

In the case of the SSP, equation (3) gives an estimated pitch period of 9.3 sec., as shown below.

$$T_{PITCH} = 2\pi\sqrt{\frac{(80.0)^2 \times [(0.28)^2 + 0.060]}{32.174 \text{ ft/sec.}^2 \times 12.6 \text{ ft.}}}$$

$$T_{PITCH} = 9.3 \text{ sec.}$$

The SSP's GM_L of 12.6 ft., which is large for a SWATH craft of its size, resulted in a shorter pitch period than is optimum for Hawaiian waters. The relatively high GM_L is due to the tandem-strut configuration of the SSP, combined with the desire for access to the lower hulls. Due to its fins, the pitch period increases to 14 sec. at 15 knots [10].

Figure 18 compares the author's estimate of the KAIYO's pitch period with the extrapolated trend line for small SWATH craft. Surprisingly, the estimated pitch period of 14 seconds for the KAIYO falls right on the trend line. The measured pitch periods for two DTRC models designed for low speed operations are considerably longer. Referring to Figure 13, it is apparent that there is considerable likelihood of encountering Sea State 6 spectra with modal periods as long as 16 seconds. In order to minimize pitch motions in such a seaway, the pitch period of a SWATH designed for low speed operations should be at least 20 percent longer, or 19.2 seconds. Since this long a pitch period is achievable with a suitably designed SWATH ship of 3500 LT, a trend line is shown in Figure 18 for geosims of the assumed design.

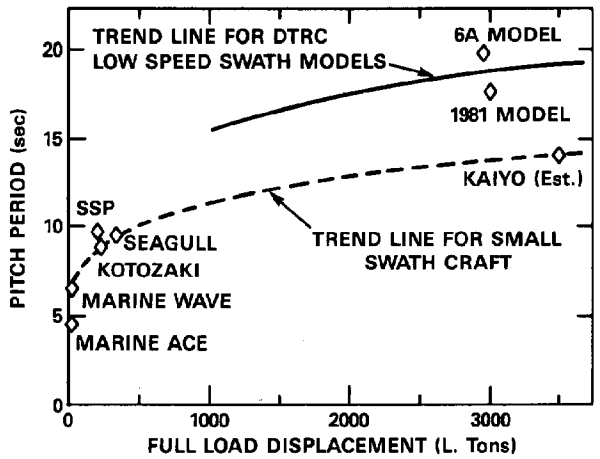

Fig. 18. Comparison of the estimated pitch period for the KAIYO with the trend lines for small SWATH craft and DTRC models.

It is judged that there are two reasons why the KAIYO's pitch period is shorter than the author's SWATH ship trend line. The first reason is that, in order to minimize the strut length and avoid shifting the longitudinal center of buoyancy too far forward, the lower hulls of overhanging strut SWATH configurations are relatively short. Typically, the lower hull of a SWATH with an overhanging strut at the stern is 15 percent shorter than the lower hull of an equivalent 6A type configuration [15]. This decrease in lower hull length results in a decrease of roughly one-third in the hydrodynamic added pitch inertia, compared with a 6A configuration. Since for a 6A configuration the hydrodynamic added pitch inertia is approximately equal to the pitch mass moment of inertia, the reduction in total pitch inertia for the overhanging strut hullform is about 17 percent. The resulting decrease in the pitch period would be 9 percent. In reality, the shorter lower hulls also reduce the pitch mass moment of inertia, with the result that the reduction in pitch period is closer to 11 or 12 percent. A second factor that comes into play is that both ends of the struts of overhanging strut configurations tend to be fuller than with 6A configurations. Consequently, for equal strut lengths the GM_L of a SWATH with overhanging struts will be greater than for a 6A type design. A larger GM_L value further decreases the ship's pitch period. One solution to this problem is to adopt a shorter strut for KAIYO type designs. Obviously, there are practical limits on how far the naval architect can go in this direction for a given design.

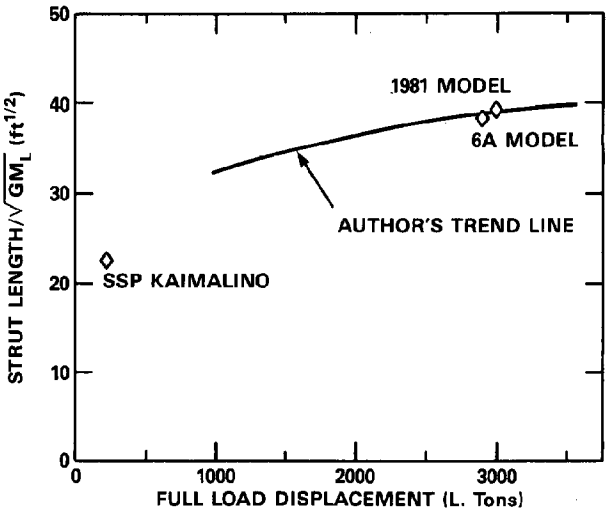

Fig. 19. Trend line for the ratio of strut length to the square root of GM_L for low speed SWATH ships.

Longitudinal Metacentric Height

SWATH ship designers are often concerned about the effect of their GM_L selection on pitch performance, but a more meaningful parameter is the ratio of strut waterline length to the square root of GM_L. Figure 19 shows a trend line developed by the author for the value of this ratio as a function of ship displacement. This trend line is intended to apply only to 6A type SWATH configurations being designed for low speed applications. For informational purposes, the data point for the SSP is also shown. Strut length is used, rather than lower hull length, because most of the ship's mass is concentrated within the strut length. Strut length is thus the best measure of the ship's pitch gyradius.

Within the small community of SWATH ship designers there has been much discussion of the relative merits of configurations with a single strut per side and those with a pair of struts, in tandem, on each hull. In 1976 DTRC carried out seakeeping experiments on a series of SWATH models called the SWATH 6 series. In the initial series of experiments [15], motions and accelerations were measured with three different strut configurations on the same lower hull. The first two, struts A and B, were single-strut configurations. The third configuration, strut C, was a tandem-strut configuration having the same waterplane area as struts A and B. The design displacement of the SWATH 6 models was 2900 LT. The previously mentioned 6A configuration had the shortest struts and the lowest GM_L at 20 ft. The 6B struts were longer, resulting in a GM_L of 38 ft. The 6C configuration, with tandem struts, had a GM_L of 45 ft. Experimental data for the 6B and 6C models showed similar heave and pitch motion responses at all headings and speeds in both regular and random waves. Figure 20 compares the heave and pitch responses of all three strut configurations at zero speed in random head waves. Based on these results, it was concluded that the strut hydrostatic characteristics, namely GM_L, have a greater effect on SWATH seakeeping than whether each hull has one or two struts.

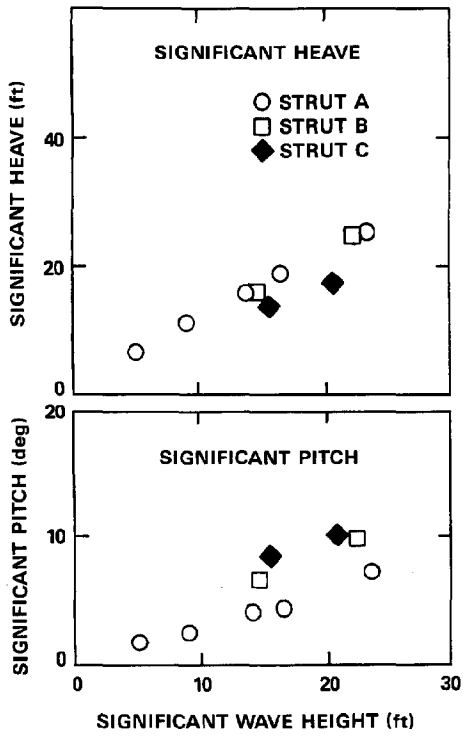

Fig. 20. Significant double amplitudes of motions in random head seas for SWATH 6 series models at 0 knots [15].

Importance of the Separation Between LCB and LCF

The maximum buoyant force exerted on a SWATH by the crest of a long wave tends to be centered about the centroid of the waterplane area, which is termed the longitudinal center of flotation (LCF). Ship weight, on the other hand, is centered near the longitudinal center of buoyancy (LCB). Consequently, if there is substantial separation between the LCF and the ship's LCB, the wave buoyant forces will result in a pitch moment. Since the small GM_L of a low speed SWATH results in a small hydrostatic pitch restoring moment, substantial pitch motion can be caused by the LCB/LCF separation. This problem can be avoided if the naval architect selects strut and lower hull geometries which result in minimal LCB/LCF separation.

SELECTION OF ROLL PERIOD FOR LOW SPEED OPERATIONS

It was explained earlier in this paper that the wide hull spacing of a SWATH ship results from the need to satisfy static stability requirements. The wide beam makes it possible for the designer to largely detune the roll motion characteristics of the ship from the wave periods of concern in the design Sea State. Figure 21 compares the author's estimate of the roll period for the KAIYO with the extrapolated trend line for small SWATH craft. Also shown in Figure 21 are the measured roll periods for the 6A model and the 1981 model of a notional 3000 LT design. Based on the average roll period for these two models, a trend line was developed for low speed SWATH ship designs. Figure 21 shows that the KAIYO's estimated roll period of 18 seconds lies midway between the trend line for small craft and the trend line for DTNSRDC models. While the KAIYO's roll period is very long by monohull standards, if the ship had been designed for Sea State 6 operations a roll period of at least 20 seconds would have been chosen.

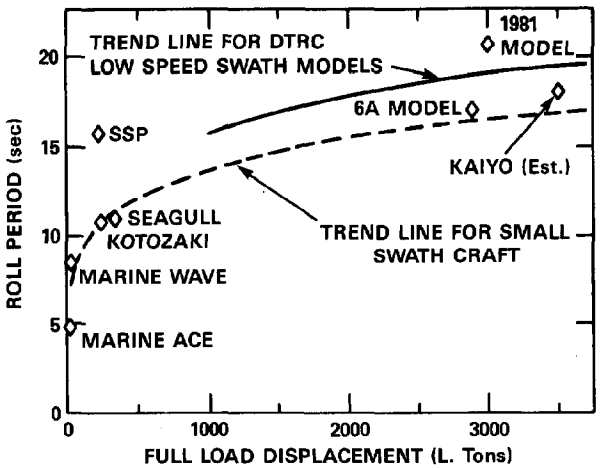

Fig. 21. Comparison of the estimated roll period for the KAIYO with the trend lines for small SWATH craft and DTRC models.

The two dominant factors that affect the roll period of a surface ship are the waterline beam and the transverse metacentric height (GM_T). The equation for estimating a ship's roll period is shown below.

$$T_{ROLL} = 2\pi\sqrt{\frac{B^2\,(k_r^2 + A'_{44})}{g\,GM_T}} \qquad (4)$$

where

- B = waterline beam
- k_r = the roll gyradius divided by the waterline beam
- A'_{44} = the hydrodynamic roll added inertia divided by the ship's mass times the waterline beam squared
- g = acceleration of gravity
- GM_T = the transverse metacentric height

Using the 6A model as an example, the above equation gives an estimated roll period of 17.9 seconds, as shown below.

$$T_{ROLL} = 2\pi\sqrt{\frac{(81.25)^2 \times [(0.487)^2 + 0.20]}{32.174\ \text{ft/sec.}^2 \times 11.06\ \text{ft.}}}$$

$$T_{ROLL} = 17.9\ \text{sec.}$$

In this sample calculation the value used for the ship's roll gyradius is the value assumed for the 6A model experiments. Subsequent studies have determined that a more typical value for the roll gyradius of a SWATH is an amount equal to 46 percent of the waterline beam.

Transverse Metacentric Height

For monohulls, a rule of thumb value for the GM_T is 10 percent of the ship's waterline beam. This percentage is also

reasonable for a SWATH ship and has the virtue of making the SWATH sensitivity to heeling moments about the same as a monohull. On the other hand, from the viewpoint of designing a SWATH for seakeeping, the most meaningful parameter is the ratio of waterline beam to the square root of GM_T. Figure 22 shows a trend line developed by the author for the value of this ratio as a function of ship displacement. The basis for the trend line is the average value of the $B/\sqrt{GM_T}$ ratio for the 6A and 1981 models. For comparison purposes the data point for the SSP is also shown. Usually, the minimum acceptable value for GM_T for a Navy design is established by the requirement to resist the heeling moment due to a wind speed of 100 knots [17]. Because SWATH ships typically have relatively high GM_T values, the intact stability requirements are easily satisfied. However, damaged stability considerations may dictate a higher GM_T.

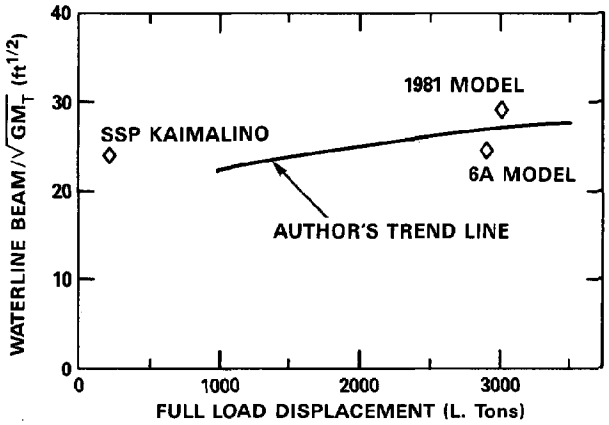

Fig. 22. Trend line for the ratio of waterline beam to the square root of GM_T for low speed SWATH ships.

Generally, the naval architect has more latitude in selecting the GM_T value than for other hydrostatic parameters. Care should be taken to ensure that the resulting roll period differs from the pitch period so that coupled pitch and roll motions are minimized. Similarly, the roll period should not be exactly twice the heave period, to minimize coupled heave-roll motions. The easiest solution is to select a roll period that is more than twice the heave period.

EFFECT OF FORWARD SPEED IN HEAD SEAS

For a monohull the effect of forward speed in head seas is to shift the peak pitch response to somewhat longer waves. For a SWATH the trend is similar but the shift is more pronounced. Figure 23 gives the measured heave response of the 6A model at various speeds in regular head waves. At 20 knots the peak heave response occurs at a wave period of 15.5 seconds, whereas at zero speed the peak occurred at the ship's heave period of 10.1 seconds. It follows that the ship/wave encounter period at 20 knots with the 15.5 sec. wave must be about 10 seconds. Figure 9 confirms this. Since wave periods as long as 16 seconds have a reasonably high likelihood of occurrence in Sea State 6, a speed of 20 knots is not high enough to ensure platforming behavior for the 6A model in all Sea State 6 conditions.

Perfect platforming behavior implies there is zero heave motion. In such a situation the relative bow motion response is 1.0 because it is equal to the wave amplitude. A reasonable minimum acceptable clearance to the wet deck would be an amount equal to the average amplitude of the one-tenth highest waves in Sea State 6, i.e., 12.5 feet. Figure 24 shows the measured relative bow motion response of the 6A model at several speeds in regular head waves. At 20 knots the relative bow motion is about 1.7 times the wave amplitude for wave periods between 14 and 15 seconds. This type of response leads to a required wet deck clearance of 21 feet, using the same criterion of the average of the one-tenth highest waves. Little benefit can be gained from active control in this situation because the ship/wave encounter period at 20 knots is less than the ship's heave period of 10 seconds. It is very difficult to force a SWATH ship to move faster than its heave natural period. Since the 6A model was designed for transiting at 20 knots in Sea State 6, it had 20 feet of clearance.

The situation with regard to pitch responses is considerably different. Because forward speed decreases the period of encounter with waves of a given length in head seas, platforming pitch responses can be maintained in longer period waves. Alternatively, the previous goal of platforming in wave periods up to 16 seconds can be achieved with a shorter pitch period. It follows that a higher GM_L is acceptable for SWATH ships that normally operate at 10 to 15 knots than for a SWATH designed for very low speed operation. Figure 25 compares the author's trend line for the ratio of strut length to $\sqrt{GM_L}$ for medium-speed SWATH ships to the trend line shown in Figure 19 for low speed ships.

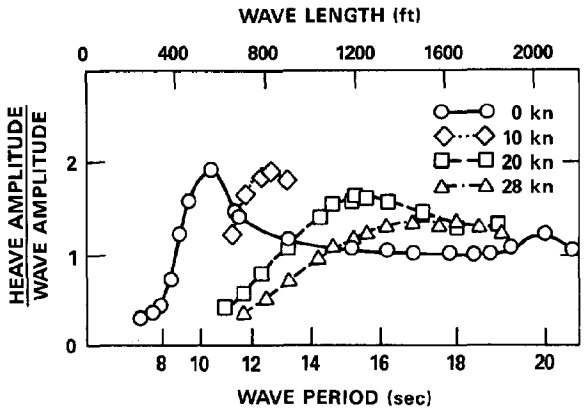

Fig. 23. Effect of forward speed on the heave response of the 6A model in regular head waves [15].

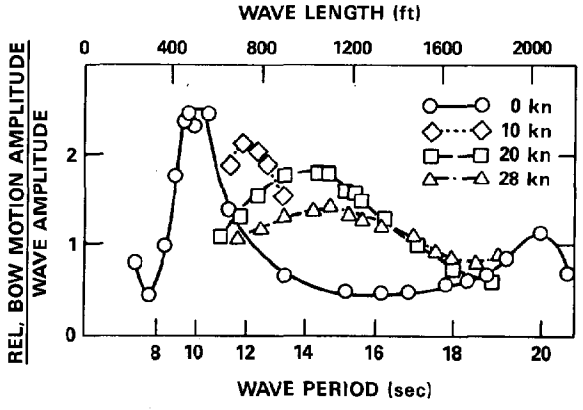

Fig. 24. Effect of forward speed on the relative bow motion response of the 6A model in regular head waves [15].

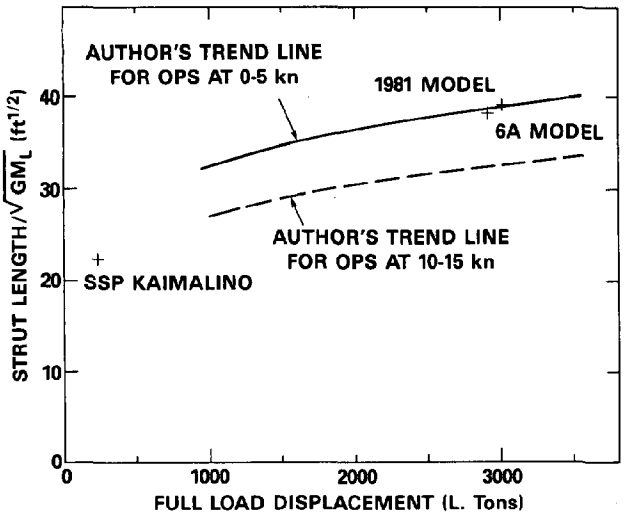

Fig. 25. Effect of forward speed on the recommended ratio of strut length to the square root of GM_L for SWATH ships.

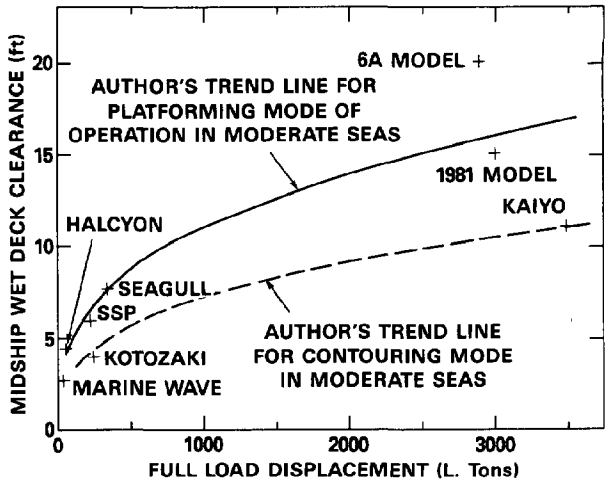

Fig. 26. Comparison of trend lines for midship wet deck clearance for contouring and platforming modes of operation in moderate sea conditions.

The preceding discussion assumes that it would be deemed acceptable for a 3000 LT SWATH to slow down in Sea State 7 and higher seas, thereby reducing wave impacts by contouring the waves of greatest energy. If the SWATH design of interest is exclusively for low speed operations, then a reduced amount of wet deck clearance is acceptable because the ship will contour all but the shortest period waves in Sea State 6. The 1981 low speed 3000 LT design had a wet deck clearance of 15 feet. The T-AGOS 19 also has 15 feet of clearance at the forward end of the cross-structure, but only 11 feet of clearance amidship. According to the author's estimate, the KAIYO has 11 feet of wet deck clearance. Presumably, the operators of the KAIYO will slow down in very severe seas. The instinctive response to slow down, learned from operating monohulls in severe seas, is also the best response for a SWATH ship. However, this is not always the case with SWATH craft.

Figure 11 shows the regions of platforming and contouring response for a typical SWATH craft with a heave period of 6 seconds, at a speed of 20 knots. It can be seen that contouring behavior will occur in waves of 13 seconds or longer. In these long waves it will be possible to gain substantial benefit from active motion control, since the wave encounter periods are longer than the craft's heave period. Even though these same conditions are likely to be close to the pitch resonance conditions, this would not pose a problem because the pitch motions of such a craft are well damped at 20 knots.

Figure 26 compares trend lines developed by the author for the minimum recommended amount of midship wet deck clearance for SWATH ships designed to platform or contour moderately severe seas for the ship's size. Small SWATH craft will usually be designed with a platforming philosophy for such conditions, while larger SWATH ships will usually be designed with a contouring philosophy. In either case, it is recommended that somewhat more clearance be provided at the forward end of the cross-structure than in the midship region. It probably bears repeating that all SWATH ships should be designed to contour extreme seas at a low speed, similar to a monohull.

EFFECT OF FORWARD SPEED IN FOLLOWING SEAS

Up to this point there has been relatively little discussion of pitch motions, which everyone knows are a serious problem with monohulls. The reason is that the author has assumed that a sufficiently long pitch period has been chosen to detune the ship from the wave periods of concern at low or moderate speeds in head and beam seas. In following seas the pitch response of a SWATH can be detuned only for very low speed operation. Figure 27 shows that at moderately high speeds in following seas, wave encounter periods of 20 to 40 seconds are very likely. Moreover, these very long encounter periods occur over a wide range of wave lengths. For this reason, wave encounter conditions corresponding to pitch resonance cannot be avoided. There are similarly long wave encounter periods at moderately high speeds in stern quartering seas. The likelihood of experiencing wave encounter periods corresponding to either pitch or roll resonance is high.

Fortunately, these very long encounter periods also make it possible to derive considerable benefit from active control. Figure 28 shows the results of a recent analysis of the effect of active control on the limiting significant wave height for a notional 1600 LT SWATH transiting at 12 knots [18]. As has been explained in more detail by McCreight and Stahl [6], the limiting wave height is the lowest wave height at which one of the motion limit criteria is exceeded. Figure 28 shows that active control raised the limiting wave height considerably in stern, quartering and beam seas, but was of no benefit in bow or head seas. In this analysis active control was used to reduce both pitch and roll motions. Interestingly, the improvement with just the aft fins active was found to be the same as with both pairs of fins active.

SUMMARY

In this paper the author has described the principles and key considerations in SWATH hullform selection for excellent seakeeping. The importance of strut hydrostatic characteristics and damping provided by the stabilizing fins was explained in considerable detail. The necessary differences in approach for

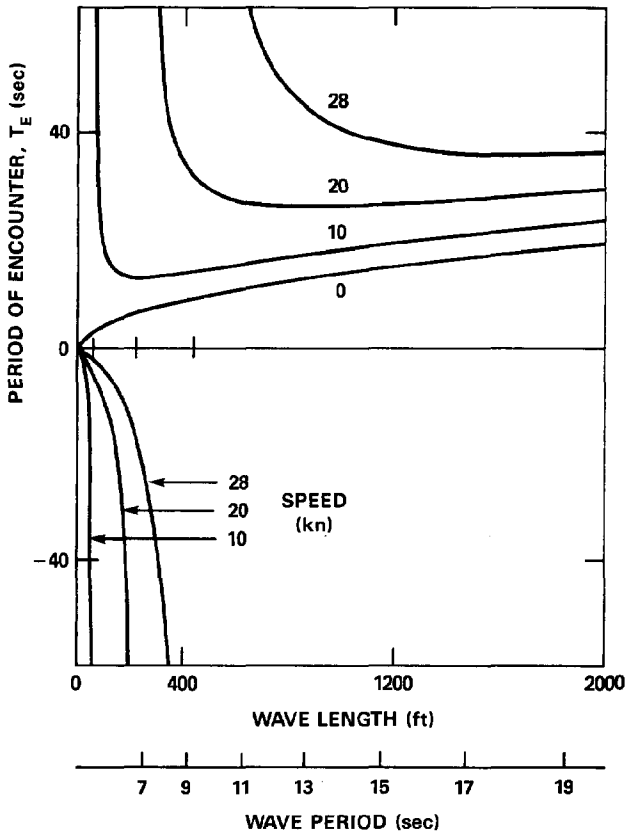

Fig. 27. Effect of ship speed on wave encounter period in regular following seas [15].

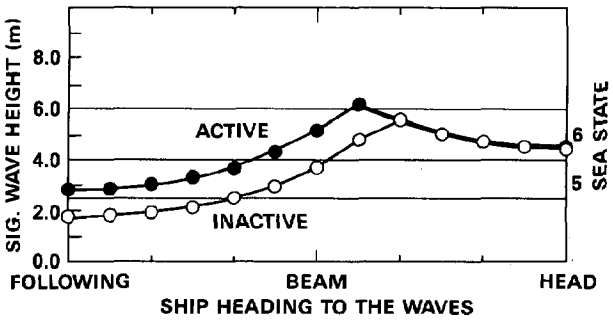

Fig. 28. Predicted effect of active control on the limiting significant wave height at various headings for a notional 1600 LT SWATH transiting at 12 knots [18].

the design of small SWATH craft and larger oceangoing ships were discussed. Rather than being somehow intrinsic in the SWATH concept, excellent seakeeping performance was shown to be the result of a careful, engineering-based approach to SWATH hullform design.

REFERENCES

1. Saeki, M. and Nakamura, H., "Motion Characteristics of the KAIYO," OCEANS '86, Washington, D.C., Sep. 1986.
2. Oshima, M., Narita, H. and Kunitake, Y., "Development of the Semi-Submerged Catamaran (SSC)," NAVAL ARCHITECTURE & OCEAN ENGINEERING, Society of Naval Architects of Japan, Vol. 18, 1980.
3. Hightower, J.D. and Seiple, R.L., "Operational Experiences with the SWATH Ship SSP KAIMALINO," Paper No. 78-741, AIAA/SNAME Advanced Marine Vehicles Conference, San Diego, CA, Apr. 1978.
4. "IUC's New Multipurpose Vessel 'Twin Drill' Combines Geophysical, Geotechnical, ROV Technologies," SEA TECHNOLOGY, Feb. 1985.
5. Covich, P.M., "SWATH T-AGOS: A Producible Design," Paper No. 86-2384, AIAA 8th Advanced Marine Systems Conference, San Diego, CA, Sep. 1986.
7. McCreight, K.K. and Stahl, R.G., "Recent Advances in the Seakeeping Assessment of Ships," NAVAL ENGINEERS JOURNAL, Vol. 97, No. 4, May 1985.
7. Narita, H., et al., "Design and Full Scale Test Results of Semi-Submerged Catamaran (SSC) Vessels," Proceedings, First International Marine Systems Design Conference on Theory and Practice of Marine Design, London, Apr. 1982.
8. Lang, T.G., "SSP KAIMALINO; Conception, Developmental History, Hurdles and Success," Paper No. 86-WA/HH-4, ASME Winter Annual Mtg., Anaheim, CA, Dec. 1986.
9. Mabuchi, T., Kunitake, Y. and Nakamura, H., "A Status Report on Design and Operational Experiences with the Semi-Submerged Catamaran (SSC) Vessels," Proceedings, RINA International Conference on SWATH Ships and Advanced Multi-Hulled Vessels, London, Apr. 1985.
10. Fein, J.A., Ochi, M.D. and McCreight, K.K., "The Seakeeping Characteristics of a Small Waterplane Area, Twin-Hull (SWATH) Ship," 13th ONR Symposium on Naval Hydrodynamics, Tokyo, Oct. 1980.
11. Komoto, M., Nishimura, K. and Nakamura, H., "Mitsui Sea Saloon 15 'Marine Wave'," Paper No. AIAA-86-2368, AIAA 8th Advanced Marine Systems Conference, San Diego, CA, Sep. 1986.
12. Luedeke, G., et al., "The RMI SD-60 SWATH Demonstration Project," Paper No. 10, RINA International Conference on SWATH Ships and Advanced Multi-Hulled Vessels, London, Apr. 1985.
13. Lewis, Q.M., Jr., "Trials and Tribulations—Operational Experiences with the HALCYON," Joint SNAME/ASNE Mtg., Philadelphia, PA, Dec. 1985.
14. Fein, J.A., "Low Speed Seakeeping Trials of the SSP KAIMALINO," David W. Taylor Naval Ship Research and Development Center Report No. SPD-0650-04, Mar. 1978.
15. Kallio, J.A., "Seaworthiness Characteristics of a 2900 Ton Small Waterplane Area Twin-Hull (SWATH)," David W. Taylor Naval Ship Research and Development Center Report No. SPD-620-03, Sep. 1976.
16. Lee, C.M. and Curphey, R.M., "Prediction of Motion, Stability, and Wave Load of Small-Waterplane-Area, Twin-Hull Ships," Trans. SNAME, Vol. 85, 1977.
17. "Design Data Sheet—Stability and Buoyancy of U.S. Naval Surface Ships," DDS 079-1, Naval Ship Engineering Center, Aug. 1975.
18. McCreight, K.K., Hering, J.A., and Waters, R.T., "Seakeeping and Maneuvering Assessment of Swath AGOR 23 Configurations," David W. Taylor Naval Ship Research and Development Center Report No. SPD-1198-01, July 1986.

CONCEPTUAL DESIGN OF AN INTERMEDIATE SIZE OCEANOGRAPHIC RESEARCH SHIP FOR THE UNIVERSITY-NATIONAL OCEANOGRAPHIC LABORATORY SYSTEM

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ABSTRACT

In response to requirements set by the UNOLS Ship Improvement Committee, SEACO and Maritime Applied Physics Corporation completed the conceptual design of an intermediate-size Small Waterplane Area Twin Hull (SWATH) general purpose oceanographic research ship. After consideration of alternatives, a 150 foot, 1070 ton, tandem strut, diesel-electric SWATH was conceived. This paper reviews the requirements and describes the resultant design.

SHIP REQUIREMENTS

The general ship requirement, as provided by the UNOLS Ship Improvement Committee is quoted below:

> "The ship is to serve as an intermediate size general research ship. The overriding required characteristic is that the ship provide the most stable environment possible in order to allow both over-the-side and laboratory work to proceed in greater capacity and in higher sea states than is now possible. Other general requirements are for large scientific parties and greater flexibility in use of laboratory/deck spaces than is now available aboard intermediate size ships."

A portion of the detailed performance requirements are listed in Table 1.

TABLE 1 - UNOLS PERFORMANCE REQUIREMENTS

Draft:	18 feet maximum
Speed:	14 knots for 2 hours 12 knot in sea state 4 10 knots in sea state 5 6 knots in sea state 6
Endurance:	6,000 Nautical Miles, or 15 days @ cruise plus 15 days towing, or 15 days @ cruise plus 15 days stationkeeping
Stationkeeping:	150 foot watch circle at +/- 45 degrees from specified heading under the influence of: - 35 knot wind - 2 knot current - 12 foot seas
Payload:	Specified Mission Equipment Plus 50 Ton Itinerant Load
Accomodations:	30 persons in 2 person staterooms 2 persons in 1 person staterooms
Deck Live Load:	1200 psf
Centerwell:	15' x 30'
Seakeeping:	Sea State 4 / Sea State 5
Heave:	2.2 ft. heave / 4 ft heave
Pitch:	3 deg. pitch / 4 deg. pitch
Roll:	3.5 deg. roll / 4.5 deg. roll
Mission Equipment:	Cranes - 20,000 lb offload (side and/or stern) - 10,000 lb working close in to stbd side - 5,000 lb at 30 ft from stbd side A-Frames - Stbd side, 30,000 lb lift - Stern, 30,000 lb lift, 15' x 25' throat Portable Laboratories - 2 ea., 8'x 8'x 20' vans, 12,000 lb ea. Winches - 1 ea oceanographic w/40,000 ft 1/2 inch wire - 1 ea hydrographic w/30,000 ft 3/8 inch wire SEABEAM, navigation & stationkeeping systems
Laboratory Space:	2,000 sq. ft. minimum
Damaged Stability:	1 compartment flooding
Deck Tiedowns:	1 inch threaded sockets on 2 foot centers
Towing Loads:	12,000 lbs @ 6 knots 25,000 lbs @ 2.5 knots
Noise:	Continuous acoustic doppler profiling at 12 knots SEABEAM continuous operation at 8-10 knots

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DESIGN FEATURES

General characteristics of the resulting design are provided in Table 2. A profile drawing is found at Figure 1. The present work represents one trip around the classic "design spiral" in a funding constrained effort. The design configuration presented in this paper will change as refinements are made in subsequent design iterations. Principal features of the design and the rationale which led to their selection are discussed below.

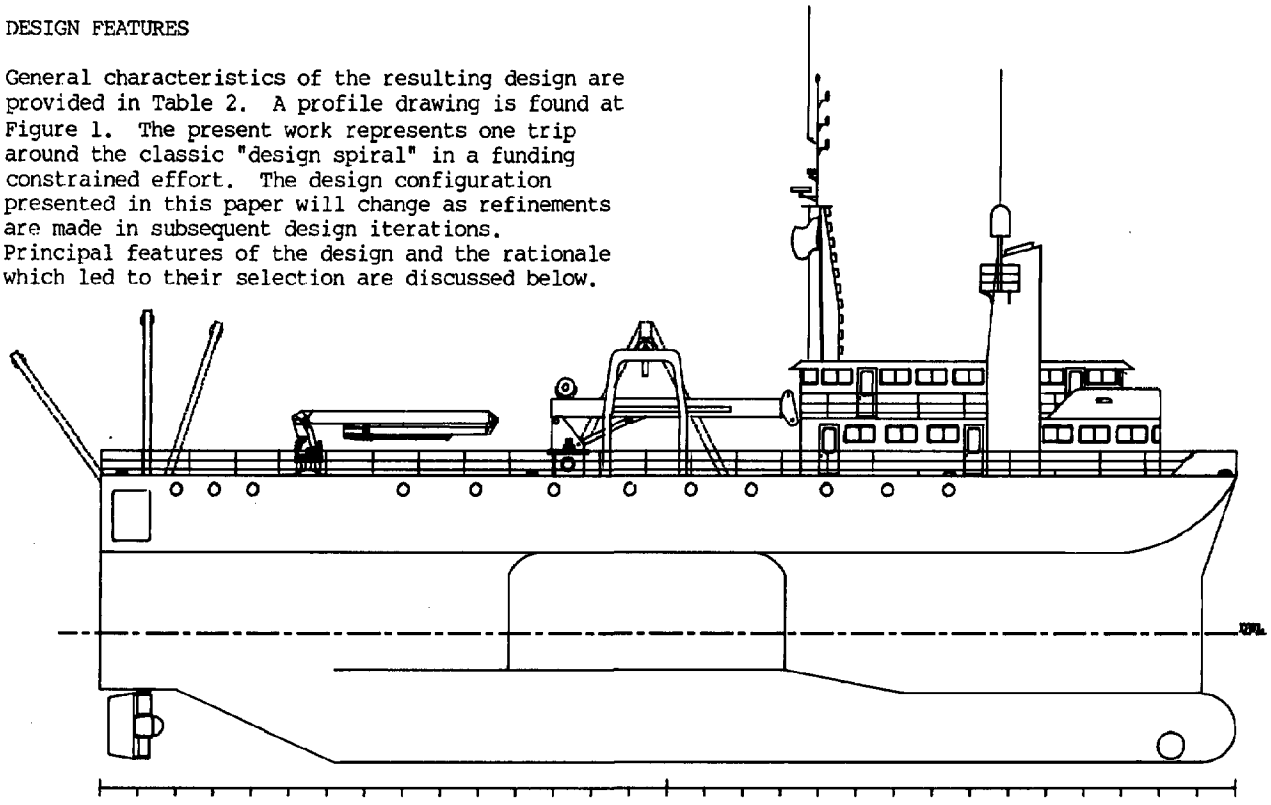

FIGURE 1 - UNOLS 150 PROFILE

TABLE 2 - GENERAL CHARACTERISTICS OF UNOLS SWATH-150

Basic Dimensions
- Length Overall: 150'
- Beam on Main Deck: 75'
- Beam at Lower Hulls: 74'-1.7"
- Draft at Full Load: 17'
- Construction Material: HSLA-80 Steel
- Forward Strut Length: 55'
- Aft Strut Length: 54'
- Center Well Diminsions: 15' x 30'

Basic Hydrostatics
- Full Load Displacement: 1070 Long Tons
- Vertical Center of Buoyancy: 8'-3.62" ABL
- Waterplane Area: 961 ft^2
- Transverse Waterplane Inertia: 820,000 ft^4
- Tons Per Inch at DWL: 1.64
- Vertical Center of Gravity: 24.65'
- GMT: 5.6 feet
- KML: 47 feet "
- Longitudinal Center of Buoyancy: 75.5' from FP
- Longitudinal Center of Flotation: 81' from FP

Vessel Performance
- Endurance: 5,600 nautical miles @ 17' departure draft
- 7,000 nautical miles @ 18'-4" departure draft
- Cruise Speed: 12 knots
- Maximum Speed: 14.5 knots
- Stationkeeping: 150 foot watch circle under UNOLS conditions.

Mission Features:
- Accommodations: 32 persons
- Laboratory Area: 3,650 sq. ft.
- Open Deck Working Area: 5,000+ sq. ft.
- Winches:
  - Markey-8 (30,000 lbs/30,000 ft/100 ft/min)
  - Pinehill Aluminum Waterfall Type (2x30,000 ft)
- Vans: 2 ea. 12,000 lb (8x8x20')

Main Machinery:
- Main Engines: 2 ea., 900 kw @ 1200 rpm
- Auxilary Engines: 2 ea. 250 kw
- Main Propulsion: 2 ea. Azimuthing Thrusters, 94" at 1,000 shp
- Bow Thrusters: 2 ea. 34" Tunnel Thrusters
- Driveline: AC/DC Electric
- Propulsion Motors: DC Motor @ 1,000 shp/1150 rpm
- Total Electrical Capacity: 2190 kw

Fuel Consumption at Cruise: 750 lbs/hr (125 gph)
Full Fuel Load: 188 long tons @ 18'4" draft

Stern Configuration

UNOLS committee members expressed a preference for designs in which the upper hull structure is the aft-most extension of the hull. In such designs, oceanographic personnel are able to work over the stern without concern about directly fouling the propellers or steering gear. Although superior seakeeping, resistance and mission load capacity could result from an extension of the lower hull beyond the transom, such a hull form was not considered to be operationally acceptable. The present concept design employs tandem struts with the trailing edge of the aft struts in the same vertical plane as the transom.

Waterplane

UNOLS specified stringent motion requirements including the desire for heave motions of 4 feet or less, a significant roll limit of 4.5 degrees and a significant pitch limit of 4.0 degrees all in sea state 5 . The significant wave height for sea state five was defined as 12 feet with a modal period of 9.2 seconds. Early in the conceptual design it was concluded that a tandem strut design would provide a vessel with minimum waterplane area while affording the required stability and lower hull access. The present design has a waterplane area of 961 square feet, a transverse metacentric height of 5.6 feet, a longitudinal metacentric height of 47 feet. With these characteristics, a 20,000 pound load handled 10 feet over the side induces a heel of 3.7 degrees while a 50,000 pound load handled 5 feet over the stern causes a trim of 2.1 degrees.

Resistance

The design requirements included a 12 knot cruising speed in sea state 4 and a maximum speed of 14 knots. The selection of a tandem strut arrangement made it necessary to vary lower hull geometry as a function of longitudinal station to obtain desirable wavemaking drag characteristics. Resistance predictions for a number of hull forms were compared before the hull form shown in Figure 2 was selected. The forward section of the hull consists of a cylinder with diameter of 9 feet. Between the forward section and the expanded midbody lies a semi-conical transition. In this transition, the 4.5 foot radius of the forward section is maintained and triangular flat plate is used to fill the space left as the four quadrants are expanded. The resulting semi-conical expansion

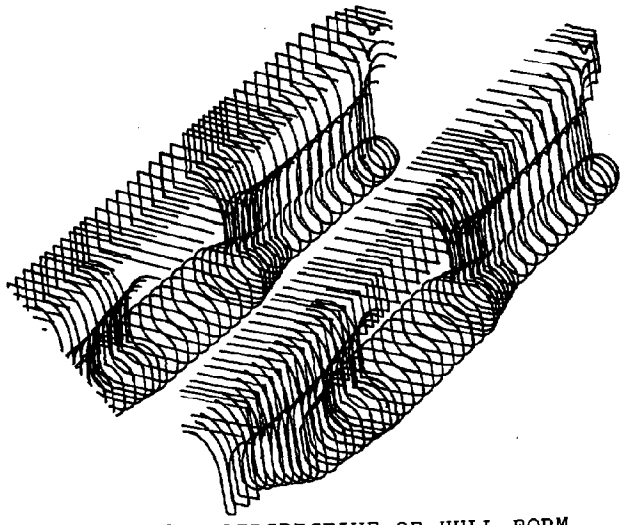

FIGURE 2 - PERSPECTIVE OF HULL FORM

can be fabricated by rolling only one radius. The midbody has principal dimensions of 17 feet (width) by 12 feet (height) while the 4.5 foot radius is maintained at the four corners. The resistance is given as a function of speed in Figure 3.

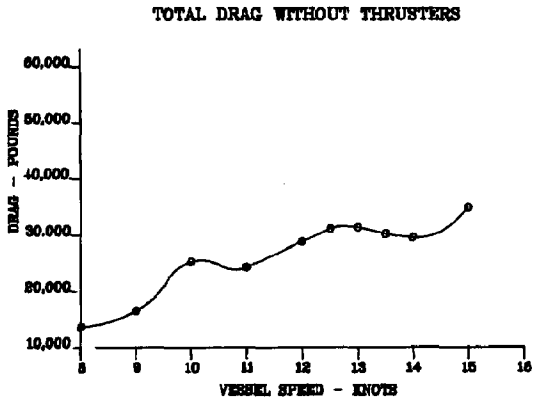

FIGURE 3-PREDICTED RESISTANCE VERSUS SPEED

Propulsor

Requirements for stationkeeping included a 150 foot watch circle under the combined influence of a 35 knot wind, 2 knot current and 12 foot seas. Under the these forces, the ship must be capable of maintaining heading within +/- 45 degrees of any specified heading. This requirement was analyzed to determine the maximum transverse thrust and pivoting moment required. Following analysis of various combinations of loads at various headings, stationkeeping performance was collapsed to a single requirement for 50,000 pounds of athwartship thrust. Under all conditions investigated, the wide spacing of the propulsors provided adequate pivoting moment; however, the athwartship thrust requires special propulsion machinery. Two approaches were considered. The first used transverse tunnel thrusters fore and aft with conventional propellers behind the lower hull while

the second employed azimuthing thrusters suspended below the aft struts. The size of the four tunnel thrusters needed to produce 50,000 pounds of transverse thrust led to a substantial increase in machinery weight. For this reason, the use of azimuthing thrusters was assumed in the baseline design. An open 94 inch propeller was selected for the zee drive input from a 1,000 horsepower D.C. electric motor. When used in conjunction with modestly sized bow thrusters, this arrangement is capable of producing the required transverse.

Structure

HSLA steel was selected as the hull material while superstructure above the weather deck was designed in 5456 aluminum. Athwartship wave-induced bending forces of 963 tons were assumed to act at 8.5 feet above baseline to compute the primary load in the hull structure. Secondary loads (normal loads), including slam loads on the underside of the upper hull, were based upon accepted Navy structural criteria. Primary and secondary loads were combined, again using Navy criteria, to determine the design stresses. Parametric summaries of plate- stiffener combinations were used to select the combination which produced minimum panel weight. Overall structural weight estimates were made by performing detailed structural design at more than 30 locations and expressing results as a panel weight per unit area. These results were then used to extrapolate all panel weights to yield the overall structural weight estimate. The resulting structural design employs transverse frames on 18 inch centers and exhibits a structural weight to full-load displacement ratio of 0.57.

Weight

A modified Ship Work Breakdown Structure (SWBS) was used to account for ship weight. The feasibility of the design is closely tied to accurate prediction weight and center of gravity location. For this reason, disproportionate attention to weight accounting was given in this conceptual design phase. The resulting three digit breakdown yields a fully loaded displacement of 1070 long tons as summarized in one-digit form in Table 3.

TABLE 3 - ONE DIGIT WEIGHT BREAKDOWN

WEIGHT CATEGORY	VCG	WEIGHT (lbs)	LCG
Hull Structure	27.4	1366134	77.6
Propulsion Plant	18.4	125794	75.7
Electric Plant	29.7	30490	45.0
Command & Surveillance	33.1	11319	47.1
Auxiliary Systems	32.8	181824	75.6
Outfit & Furnishings	30.1	48950	76.4
TOTAL LIGHTSHIP	27.4	1764511	76.5
Fuel & Lube Oil	5.0	340480	70.0
Water	30.0	21000	12.5
Foodstuffs	33.3	15000	56.3
Personnel & Effects	45.0	15000	70.0
Itinerant Equipment	40.0	112000	110.0
Margin (7.3% of lightship)	21.0	128811	60.0
FULL LOAD DISPLACEMENT	24.6	2396802	75.5

Endurance

The endurance requirement was established not by the overall range specification but by the requirement for 15 days of transit followed by 15 days of oceanographic towing. The fuel required for this mission is 188 long tons with a 6 percent tankage margin. A decision was made to allow draft to increase beyond 17 feet to temporarily accommodate the situation in which this fuel is required in conjunction with the specified itinerant mission payload of 50 tons. Since the clearance between the upper hull and the water line is large at the 17 foot draft (10.5 feet), the additional draft does not result in a severe degradation of seakeeping capabilities. To accommodate the 188 ton fuel load and the full itinerant load, the vessel must sail at a draft of 18'-4". The vessel will return to its design draft gradually during the subsequent 112 hours of transit. Fuel tanks were located in the lower hulls amidships to minimize trimming moment as fuel is used.

Arrangement

Factors which determined arrangement included specification of a large center well, the need for quiet laboratory space, a desire for excellent habitability, a specified capability for load handling over the starboard side, the stern and through the center well, and the general hydrostatic requirement to move the longitudinal center of gravity as far forward as practical. The resulting arrangement has machinery spaces forward, laboratory spaces aft on the centerline and berthing space outboard along the aft two-thirds of the upper hull. The arrangement works well with the bulkheads required for damaged stability (one-compartment criteria). The arrangement of bulkheads allows an open transverse dimension of 41 feet along the centerline thereby providing for relatively large laboratories which have large-hatch access to the center well and stern porch. A compromise in this design is the placement of messing facilities above the auxiliary machinery space; however, it was felt that sufficient

acoustic treatment could be provided to minimize the noise level in the messing area.

Seakeeping

Results of seakeeping predictions indicated a capability to meet UNOLS requirements at most headings. However, the heave requirement in head and following seas proved troublesome. The longitudinal GM was increased to make room for propulsion machinery in the aft strut. This increase led to excess vertical accelerations at the extreme ends of the vessel. It is anticipated that geometric changes in the aft strut thickness and GML in conjunction with fixed bilge keels for lower hull damping will correct the vertical acceleration.

SUMMARY

As a first-pass conceptual design, the current effort demonstrates the feasibility of meeting UNOLS requirements for an intermediate-size oceanographic ship with SWATH technology. The present design offers realistic estimates of weight, modest powering requirements, excellent mission capabilities and good seakeeping. Future efforts will be centered on the improvement of at-rest seakeeping performance in head and following seas.

DESIGN OF A SEMISUBMERGED SWATH RESEARCH AND SURVEY SHIP

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ABSTRACT

Variable draft is shown to be an essential feature for a research and survey SWATH ship large enough for unrestricted service worldwide. An ongoing semisubmerged (variable draft) SWATH can be designed for access to shallow harbors. Speed at transit (shallow) draft can be comparable to monohulls of the same power while assuring equal or better seakeeping characteristics. Seakeeping with the ship at deeper drafts can be superior to an equivalent SWATH that is designed for all operations at a single draft. The lower hulls of the semisubmerged SWATH ship can be devoid of fins. A practical target for interior clear spacing between the lower hulls is about 50 feet. Access to the sea surface for equipment can be provided astern, over the side, or from within a centerwell amidships. One of the lower hulls can be optimized to carry acoustic sounding equipment. A design is presented in this paper for a semisubmerged ship with a trial speed in excess of 15 knots, a scientific mission payload of 300 tons, and accommodations for 50 personnel.

1. SEMISUBMERGED SWATH TECHNOLOGY

A single draft for the full range of operating conditions is a common feature of typical SWATH ship designs. This constant draft characteristic is found in the SWATH ships built by Mitsui[1,2], most notably the KAIYO[3], and the SWATH T-AGOS[4] which is now under construction for the U.S. Navy. The constant draft design for ships of this size (about 3,500 tons displacement) poses two significant drawbacks. One is that the draft must be at least 25 feet to satisfy seakeeping requirements. This draft is restrictive for access to many harbors that would be useful for research and survey functions. The second is that hull and column (strut) hydrodynamics generally result in the SWATH being a larger ship and having greater power requirements than for an equivalent monohull. The ship size and hull configuration, together with the necessity for stabilizing fins, usually leads to a higher capital cost than for a rougher riding, but otherwise equivalent, monohull.

The distinguishing feature of the semisubmerged SWATH ship is variable draft. Sufficient allowance for ballast transfer is made to enable the ship to vary its draft under all load conditions. The shallowest draft is well within usual harbor limits and gives the lower hulls a slight freeboard. It also permits transit in low to moderate sea conditions using less propulsion power than is needed by a constant draft SWATH. The semisubmerged SWATH gives more design flexibility to provide for deep draft conditions that strike a balance between operating requirements and seakeeping characteristics. Intermediate "storm" drafts can be selected that are a compromise between seakeeping, speed, and upper hull clearance to avoid slamming. A discussion of these and other tradeoffs in semisubmerged SWATH ship design for oceanographic applications is given in a paper by Gaul and McClure[5]. A more general discussion of design tradeoffs is given in a later paper[6].

The semisubmerged SWATH technology gives rise to some notable contrasts with constant draft SWATH ships. For any propulsion power applied, the semisubmerged SWATH has a range of speed that depends on draft. Highest speeds are obtained at minimum (transit) draft. Because the lower hull freeboard is small at transit draft, seakeeping at service speed can be made equal to or better than an equivalent monohull. The ship is designed for maximum speed at transit draft so the lower hull form is more akin to a surface craft than a submarine. This allows use of a nearly rectangular cross section for the lower hulls which provides damping of vertical motion. For moderate speeds at deeper drafts with the highly damped lower hull form, the ship need not be equipped with stabilizing fins. Since maximum speed is achieved with the columns (struts) out of the water, it is practical to use two

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columns, rather than one, on each lower hull. The four column configuration at deep drafts minimizes the variation of ship motion response with change in course relative to surface wave direction. The width of the ship and lack of appendages on the lower hulls increases the utility of a large underside deck opening (moonpool) amidship.

The basic Semisubmerged SWATH Research and Survey Ship design has evolved from requirements first stated by the Institute for Geophysics of the University of Texas (UTIG) in 1984. Blue Sea McClure provided the only SWATH configuration in a set of five conceptual designs procured competitively by the University. Woods Hole Oceanographic Institution, on behalf of the University-National Oceanographic Laboratory System, subsequently contracted for a revision of the UTIG design to meet requirements for an oceanographic research ship. The design was further refined to meet requirements posed by the U.S. Navy for an oceanographic research ship. The intent of this paper is to use this generic design to illustrate the main features of semisubmerged SWATH ships.

2. DESIGN APPROACH

The design discussed in this paper is for a general purpose oceanographic research and hydrographic survey ship to be used in both coastal and deep ocean environments. The design is readily adaptable to other applications such as geophysical research and exploration. The overriding design goal is good seakeeping, both dead-in-the-water and underway. Typical missions which were assessed in developing the design are:

1) Physical, chemical and biological oceanography.
2) Multidiscipline environmental investigations.
3) Ocean engineering and marine acoustics.
4) Hydrographic surveys.
5) Gravimetric and magnetometric surveys.
6) Geophysical surveys.

The basic design approach is to provide a variable draft (semisubmerged) SWATH ship to suit the complete range of anticipated operating conditions. The ship is designed to float on the lower hulls fully loaded. This is required to obtain a suitable draft for entry into shallow water harbors and to reduce propulsion requirements while transiting in mild to moderate weather conditions. The ship can be operated at deeper drafts for transiting in heavy weather and while conducting mission related activities at low speeds. The design is optimized to have minimum response to wave motions in this mode of operation.

Unique features of the semisubmerged SWATH ship configuration have been used advantageously in positioning research equipment and improving operations. For example, a single bow thruster is in the port side lower hull to avoid interference with sonar transducers that are positioned exclusively in the starboard side lower hull. The diesel generators are in the upper hull to minimize acoustic noise radiation underwater. At normal operating draft, the greater depth of the propellers compared to a monohull suppresses cavitation and associated acoustic radiation. The underside moonpool in the centerwell gives favorable access for launch and retrieval of equipment at a position close to the center of ship motion. The three deck upper hull and crane arrangement gives good access to winches and other equipment. The broad expanse of flat main (weather) deck gives ample space for installation of vans, retention of off-line equipment, landing of helicopters, and installation of antennas and above water instrumentation.

3. CONFIGURATION AND ARRANGEMENTS

The Semisubmerged SWATH Research and Survey Ship consists of a rectangular upper hull supported by two slender columns on each of two lower hulls. Table 1 is a list of principal particulars. General arrangement drawings for the bow elevation, outboard profile and working (third) deck are given in Figures 1, 2 and 3, respectively.

Four columns (struts), two port and two starboard, extend upward from the lower hulls to provide support for the upper hull. Each column is 60 feet in length, 9 feet 6 inches in width, and 23 feet 6 inches high. The columns are offset outboard on the lower hulls.

The ship has a maximum beam of 104 feet 11 inches which encompasses the lower hulls and allows passage through the Panama Canal. Each of the lower hulls have a width of 27 feet 11 inches and a depth at midship of 17 feet 6 inches. The clear space between the inboard sides of the lower hulls is 49 feet 1 inch. There is no cross bracing between the hulls.

The ship is designed to have a transit draft of 16 feet 8 inches (approximately 10 inch freeboard amidship) when fully loaded and with the ballast tanks empty. Under all load conditions, the ship can be ballasted down to a normal operating draft of 27 feet. It may be operated at intermediate drafts as dictated by sea conditions. This feature is especially useful during transit to permit higher speeds and to save fuel by operating at the shallowest draft that is consistent with seakindliness requirements. To allow for ease of deploying and retrieving equipment, the ship can be ballasted to a special operating draft of 34 feet. At this draft, the clearance from the water to the third deck work area is 9 feet 6 inches.

The upper hull has three continuous decks: main (weather), second, and third, reckoning from the top down. In the middle of the upper hull is an open centerwell bounded vertically by the main

Table 1. Principal Particulars

Ship		
Length, Overall on Lower Hulls	225	ft
Beam, Overall	104.9	ft
Height, Keel to Main Deck at side	61.5	ft
Draft, Transit, Full Load	16.7	ft
Draft, Storm	23	ft
Draft, Normal Operations	27	ft
Draft, Special Operations	34	ft
Lower Hulls (2)		
Length	225	ft
Beam	27.9	ft
Depth, Midship	17.5	ft
Spacing, Transverse Centerline	77	ft
Columns (4)		
Length, Overall	60	ft
Beam, Overall	9.5	ft
Height	23.5	ft
Spacing, Transverse Centerline	90	ft
Spacing, Longitudinal Centerline	110	ft
Upper Hull		
Length, Centerline at Third Deck	162	ft
Beam, Midship	90	ft
Beam, Maximum	99.5	ft
Depth to Main Deck	20.5	ft
Displacement		
Light Ship	2522	LT
Transit Draft (16.7 ft)	3530	LT
Storm Draft (23 ft)	3989	LT
Normal Operations Draft (27 ft)	4179	LT
Special Operations Draft (34 ft)	4511	LT
Power		
Main Diesel Generators (5)	6030	KW
In-Port/Emergency Generator	300	KW
Propulsion Motors (4)	6400	HP
Bow Thruster (1)	500	HP
Speed		
Clean Hull Trial at 16.7 ft Draft	15.6	kt
In-Service Transit at 16.7 ft Draft	14.6	kt
Clean Hull Trial at 27 ft Draft	11.8	kt
Range		
Transit Draft at 12 knots	10,100	nm
Endurance		
Stores and Supplies (Minimum)	60-120	dy
Accommodations		
Marine Crew	20	
Technical Crew	30	

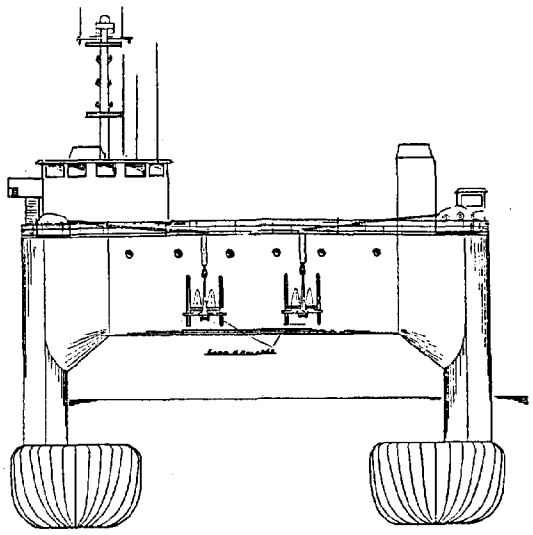

Figure 1. Bow elevation.

and third decks. The centerwell at the third deck level is comprised of a moonpool (opening in the third deck) which is surrounded by work and staging areas. There is adjacent access to all laboratories, stern and starboard side work areas, change room, storage rooms, and other mission spaces. The centerwell is serviced by a 10-ton capacity overhead traveling gantry crane for handling miscellaneous loads. The centerwell overhead is formed by the main deck with a flush hatch access and affords an interior clear height of 17 feet.

The third deck also contains a work platform with an area in excess of 2,000 square feet located across the stern of the ship and continuing around the starboard side. Direct access is provided from this deck to the main and biochemistry laboratories. The stern platform is serviced by an A-Frame on centerline and a 20-ton telescopic boom crane on the starboard quarter. The work area on the starboard side is serviced by one winch and a 12 ton J-frame in addition to 20-ton and 10-ton deck cranes. The work area has access to the various laboratories. Scientific storage areas are arranged adjacent to the laboratories and work areas. The remaining part of the third deck forward contains the main and auxiliary machinery for the ship.

The second deck contains quarters, ship storage spaces, and lounge and recreational facilities, as well as the galley and mess room. The aft open deck platforms at this level can carry winches or other mission equipment. Two vans can be connected to the second deck accommodation space on the port side.

The main deck and second decks incorporate two hydraulically powered, 20-ton telescopic boom cranes with a 6,000 pound lift capacity at a

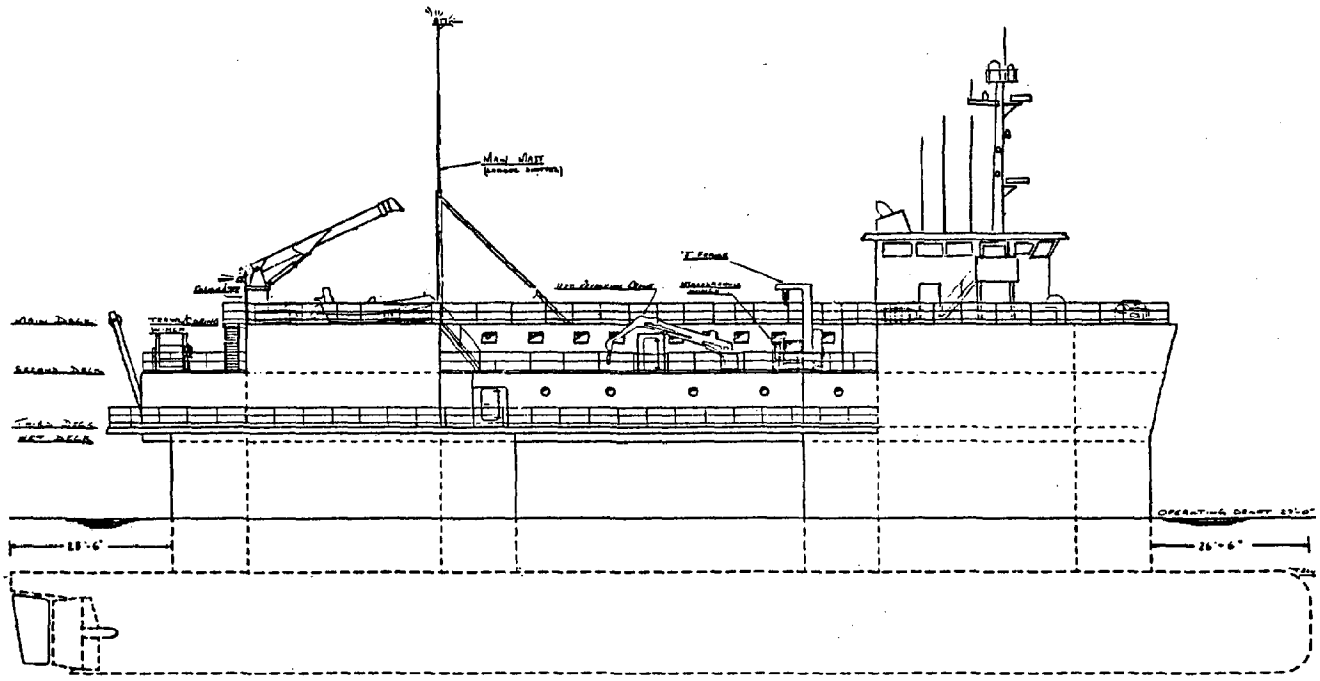

Figure 2. Outboard profile.

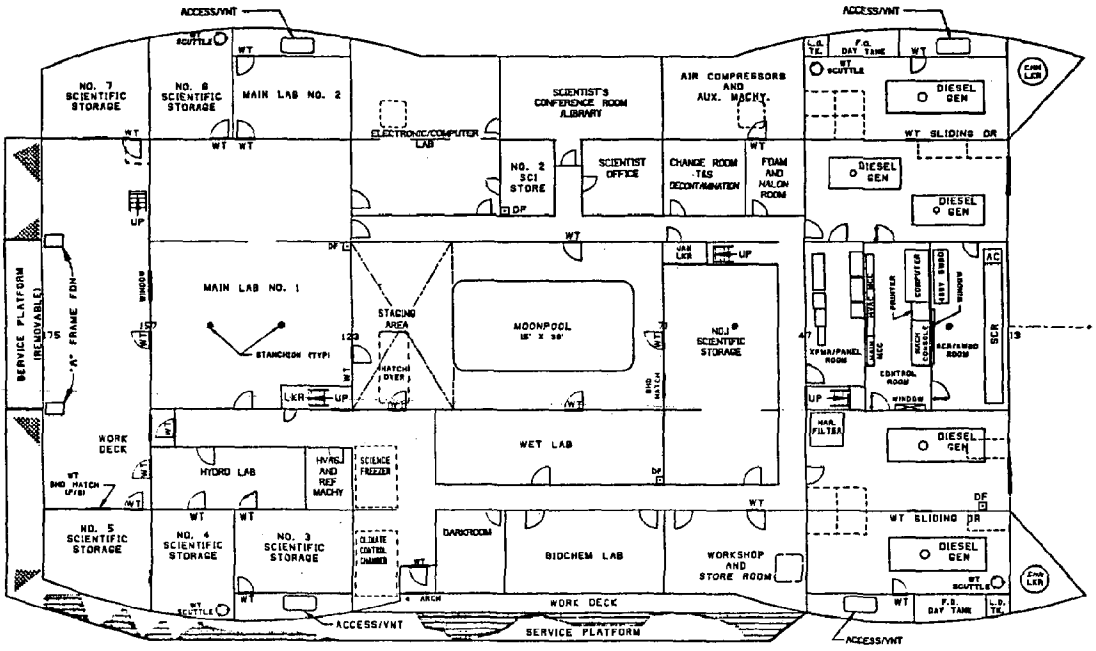

Figure 3. Third deck general arrangement.

radius of 50 feet. There is one hydraulically powered 10-ton articulated boom crane with a 4,500 pound lift capacity at a radius of 28 feet. The wheelhouse is located above the 01 level on the starboard side. A remote docking station is provided on the port side. The helicopter hovering area is located on the port side. Ship masts are forward and aft on the main deck. They are configured to accommodate antennas and instrumentation for research and survey applications.

The five main diesel engine generator sets, power conversion system, main electrical switchboard, various auxiliary machinery, and transformers are located on the third deck. The DC propulsion motors and gears are located in the lower hulls. One fixed pitch propeller per hull, fitted in a fixed propulsion nozzle, is driven through a reduction gearbox. A 300 KW inport/emergency generator is located in the deckhouse at the main deck level. Ballast water tanks are in the lower hulls and columns. Fuel storage tanks are located in the lower hulls only.

4. STABILITY

The stability of the semisubmerged SWATH is much higher than that of a comparable monohull. At the light ship and transit operating draft conditions, the lower hulls are at the surface and have some nominal freeboard. Initial intact stability is very high because of the large waterplane area. At a transverse inclination angle of a few degrees, one hull goes awash, reducing the waterplane area and the slope of the righting arm curve. Stability in this condition is, however, very high compared to a monohull. As the heeling moment is increased, the ship tends to rotate about the lower hull that remains on the surface. At an angle of about 15 degrees, the upper hull begins to enter the water and stability of the ship increases dramatically.

As ballast is added to the loaded transit draft condition, the lower hulls are submerged and the waterplane area is reduced to only the cross section of the columns. Minimum initial stability occurs when both hulls are just awash. However, at this point the application of a heeling moment will cause one hull to broach the surface, rendering the stability characteristics similar to those described above for the shallow draft condition.

At still deeper drafts, the ship floats with only the columns piercing the water in both the upright and inclined conditions. This is the desired operating draft range which gives minimum motion response to the seaway. The transverse stability (GM) in the fully loaded condition at the normal operations draft is about five (5) feet. This allows for a 0.5 foot margin for vertical center of gravity. The vessel has been designed with greater stability in the longitudinal direction than transversely to improve motion characteristics while underway.

Intact stability is adequate for safety and to permit moderate load transfers on board. Loads up to about 20 long tons can be moved transversely from the center of the moonpool to the deck edge or from the deck edge to 16 feet outboard without the need of simultaneous ballast compensation. Transfer of ballast or fuel oil can be used to counterbalance larger load shifts. The upper hull is designed to be watertight to the main deck, except for the centerwell, while maintaining strength with light weight. The buoyant upper hull thus provides a large margin of safety in the event of partial flooding of compartments in the lower hulls and columns. Furthermore, the lower hulls and columns are subdivided into watertight compartments to control the volume that is likely to be flooded in any single incident. The design complies with USCG regulations for certification for single compartment flooding and damaged stability. Some special interpretations have been approved by USCG to adapt the conventional ship rules to the realities of the semisubmerged SWATH ship.

5. SHIP MOTION RESPONSE

The dominant advantage that the semisubmerged SWATH ship offers is drastic reduction in ship motions. The improved seakeeping is provided in both the transit mode and, more importantly, during on-station research operations. This motion response reduction allows the semisubmerged SWATH ship to operate in much higher seas than can be tolerated with an equivalent monohull. At transit draft, the freeboard of the lower hulls is only about one foot. Wave crests wash over the lower hulls and increase resistance to heave. The radical decrease in waterplane area above the lower hull reduces buoyant forces caused by wave action and ameliorates motion response. It should be noted that this is a key difference between a semisubmerged SWATH ship and a conventional catamaran vessel.

Model tests of several designs have confirmed that the semisubmerged SWATH ship, even at transit draft, will have lower motion response than a comparable monohull. Figure 4 illustrates relative motion responses for a conventional monohull and a semisubmerged SWATH ship (at normal operations draft). In beam seas, roll of the monohull can be more than five times higher than that of the semisubmerged SWATH. In pitch, the monohull response typically is two to three times higher. This feature alone prompts the consideration of semisubmerged SWATH ships in place of monohulls for research and survey applications.

The response of the ship to a seaway is highly dependent on wave period or, more precisely, on encounter period which is a function of wave period, ship speed, and relative heading. At zero speed, encounter period equals wave period. The semisubmerged SWATH ship characteristics are such that ship heading at zero speed

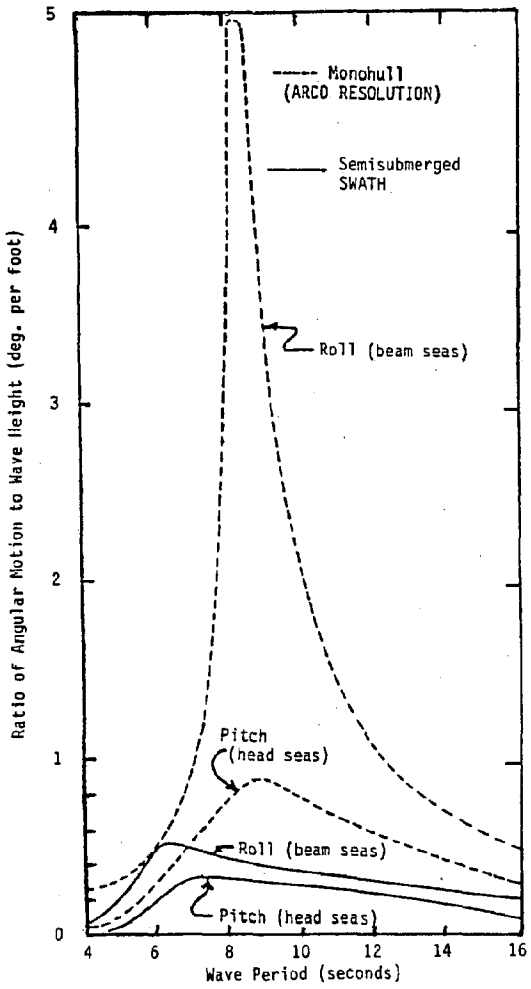

Figure 4. Typical ship motion response.

relative to wave direction causes little change in motion response. If the operation requires that the ship lie in the trough of the waves, this can be done as comfortably as lying head to the wind. When underway in head seas, the apparent period of encounter is shorter than the wave period, so ship motions are very small. In following seas, the encounter period is longer than the wave period, so motion amplitudes tend to be greater than at zero speed. However, at these long periods the accelerations are very small. Deck motions rarely will exceed the acceleration threshold for seasickness discomfort (about 0.2 g).

6. SHIP PERFORMANCE

For purposes of calculation, stated in-service SHP has been converted to installed BHP by allowing for total mechanical and electrical systems losses of 15.7%. Total fuel consumption has been calculated based on operationally required BHP with appropriate fuel conversion rates specified by the engine supplier and with ample design margins. Propeller-nozzle efficiencies were calculated for the design based on input hull related data developed from previous self-propulsion model test results of similar designs. Model tests previously done indicate that these estimates will be well within five percent of actual values. The range in calm water at a ship speed of 14.6 knots is 5,700 nautical miles with ten percent fuel reserve. The range at a speed of 12 knots is 10,100 nautical miles.

The estimate of shaft horsepower versus speed for the semisubmerged SWATH at transit draft is shown in Figure 5. The curve is based on clean hull and calm seas. Installed horsepower and machinery ratings reflect the SHP needed to propel the ship at a clean hull trial speed of 15.6 knots. Model test data also were acquired at transit draft in head and following seas to allow accurate calculation of performance in Sea State 4. The design gives in-service ship speed of more than 15 knots for the average of all headings in SS-4. The worst condition for propulsion is in head seas (Figure 6).

7. SUMMARY

The semisubmerged SWATH hull form has been adapted to the requirements for an oceanographic research and hydrographic survey ship. The design provides for unrestricted operations in ice-free areas worldwide. The ship can be brought to a full load draft that allows access to harbors that serve major oceanographic and survey organizations. Performance of the ship will match or exceed comparable monohulls. Seakeeping will allow operations in one or two sea states higher than can be done with equivalent monohull ships.

The design of the Semisubmerged SWATH Research and Survey Ship incorporates some noteworthy features that either are not found in equivalent monohulls or are significant improvements in mission capabilities. The objective throughout the design has been to adapt inherent attributes of the semisubmerged SWATH configuration to the particular requirements for research and survey applications. Notable special features are summarized below.

(1) The ship is designed to operate over a variable (selectable) range of drafts (and corresponding clearance between the upper hull and sea surface). The shallow draft of less than 17 feet fully loaded allows access to most harbors with facilities appropriate to this class of oceanographic research ship. Ship motions in the seaway are minimum at the normal operations draft of 27 feet which typically would be used in exposed deep water locations for conducting technical activities. At the special operations draft of 34 feet, the level trim elevation of the stern and centerwell work decks is less than ten feet above still water. A slight adjustment of trim (by shifting ballast) can change or even close the air gap to the aft work deck.

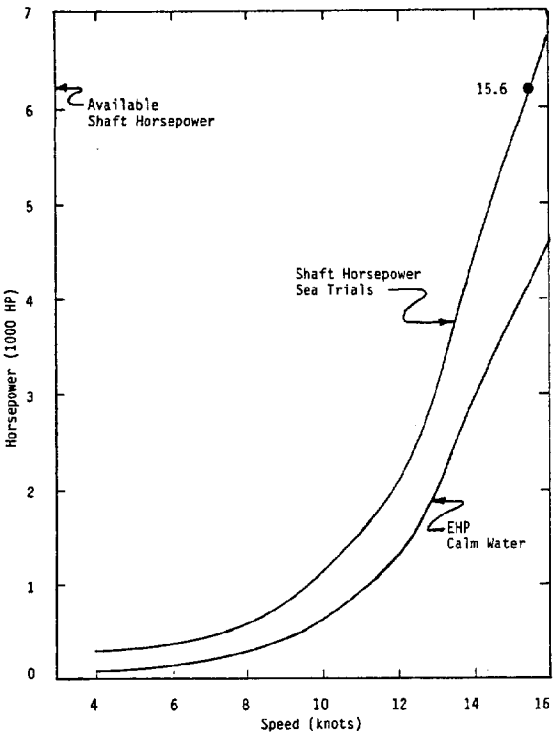

Figure 5. Transit speed in calm water.

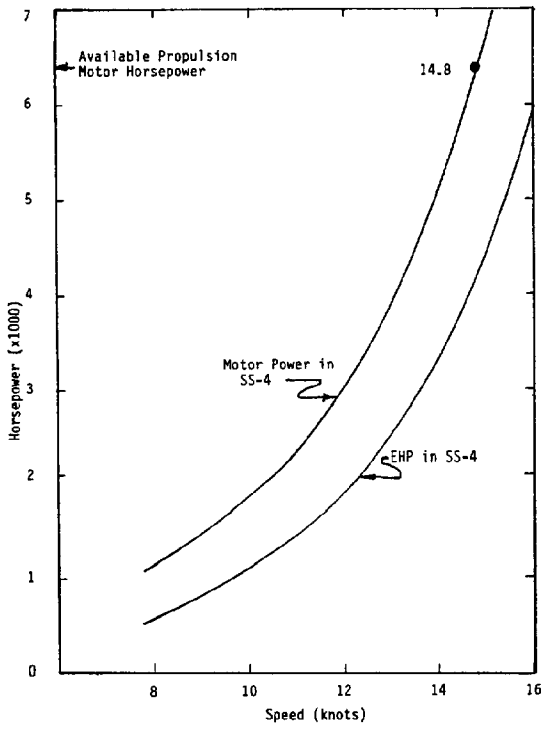

Figure 6. Transit speed in SS-4 head seas.

(2) The four-column design, coupled with lower hull geometry and overall weight distribution, gives ship motion response at deep drafts and zero speed that essentially is independent of heading relative to surface wave direction.

(3) The design has been developed and model tested to achieve superior propulsion and motion performance at the transit draft in light to moderate sea states, including Sea State 4. The predicted speed in Sea State 4 in the head seas condition (worst case) is 14.8 knots. In following seas, the speed is 15.9 knots. A major advantage of the variable draft SWATH configuration is the ability to transit at higher speeds in moderate sea states with less power than for monohulls. This is achievable because the incremental increase in resistance due to waves is significantly less than for a monohull.

(4) A key issue for evaluation of performance at transit draft is seakeeping of the semisubmerged SWATH compared to an equivalent monohull. At this shallow draft, the semisubmerged ship does not behave like a conventional catamaran because the lower hulls are ballasted to a freeboard of only about one foot. Figure 7 shows pitch response based on comparative model tests of a semisubmerged SWATH and a comparable monohull. Ship speeds nominally were 10 knots in head seas of Sea State 4. The full scale displacement of the SWATH at transit draft is 2025 LT and of the monohull is 2285 LT. The SWATH pitch response is less than for the monohull across the entire range of wave periods from 5 to 16 seconds.

(5) The deck service cranes are arranged such that a load in excess of 5,000 pounds can be transferred between the centerwell and over either side or the stern. This gives flexibility for loading supplies and equipment as well as for supporting oceanographic operations.

(6) A capability for load transfer up to ten tons is provided within the entire centerwell by a horizontal gantry crane mounted on the underside of the main deck.

(7) With its 77 foot transverse propeller separation, the semisubmerged SWATH has enormous turning capability for precise heading control in adverse conditions. The long lower hulls and slender struts have high directional stability for good tracking. The conventional rudder arrangement is designed to give maximum heading control at slow speed. Course keeping in a seaway is much better than for a monohull.

(8) The starboard lower hull is designed as a "quiet" hull with sonar transducers located forward and away from ship service equipment. A single bow thruster is provided and is located in the port side lower hull.

(9) The centerwell containing the moonpool is enclosed with clear headroom of more than 17 feet. A removable hatch in the main deck allows entry into the centerwell of objects up to 25 feet long. The hatch is positioned over the moonpool to allow free-fall access from the

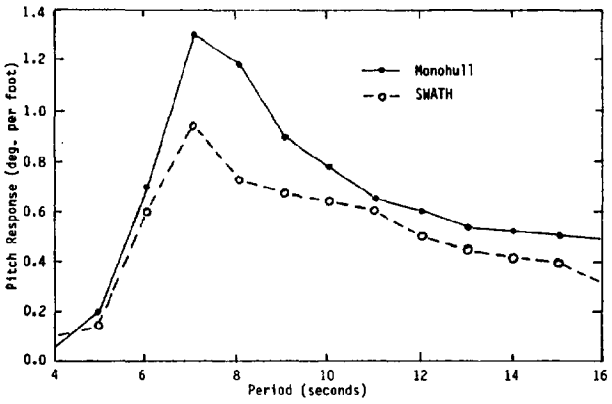

Figure 7. Underway comparison of pitch response for monohull and semisubmerged SWATH.

main deck to the water between the columns and lower hulls.

(10) A large open main deck area is provided which could be upgraded to work deck, storage area or helicopter landing area.

(11) Laboratory space of 4250 square feet is provided. All laboratories are located in the aft portion of the third deck and are contiguous to the centerwell, the aft work area, and the starboard side work area.

8. REFERENCES

1. Narita, H., T. Mabuchi, Y. Kunitake, H. Nakamura, and M. Matsushima, "Design and Full Scale Test Results of Semisubmerged Catamaran (SSC) Vessels," Paper presented at First Int'l. Marine Systems Design Conf., London, England, April 1982.

2. Oshima, M., H. Narita, Y. Kunitake and H. Nakamura, "Semi-submerged Catamaran (SSC) Application in Marine Transport and Ocean Development," Proceedings PACON 84, Marine Technology Society, Symposium at Honolulu, Hawaii, April 24-27, 1984.

3. Saeki, Muneharu, and Hiroshi Nakamura, "Motion Characteristics of the KAIYO," Proceedings of Oceans, Symposium at Washington, D.C., September 23-25, 1986.

4. Covich, P. M., "SWATH T-AGOS, a Producible Design," Paper AIAA-86-2384, AIAA 8th Advanced Marine Systems Conference, San Diego, California, September 22-24, 1986.

5. Gaul, R. D., and A. C. McClure, "Development of the SWATH Ship Concept for Research Ship Design," Proceedings of Oceans, Symposium at Washington, D. C., September 10-12, 1984.

6. McClure, A. C., and R. D. Gaul, "Let SWATH be SWATH," Proceedings, U. S. Naval Institute, April 1987.

TANKAGE ARRANGEMENT FOR SWATH SHIPS

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Naval Sea Systems Command

ABSTRACT

SWATH ships are being developed for a variety of applications requiring superior seakeeping in rough seas. Certain aspects of the design and operation of SWATH ships combine with the inherent hydrostatic characteristics of this type of hull to magnify the importance of tankage arrangement to the successful design and operation of these ships. This paper describes the hull form basis of the problem in comparison to conventional monohulls. The major parameters affecting tankage arrangement are discussed including uncertainty during design, topside ice accumulation, and the role of mission equipment and loads. An approach to the solution of the problem is described that is compatible with the design process. Application of the proposed approach to the arrangement of tankage on a large oceanographic ship is described.

1. INTRODUCTION

The U. S. Navy has actively developed SWATH ship technology since 1970. The Navy's first SWATH ship designed for open ocean operations, the 3,400 ton T-AGOS 19 (Figure 1), is currently under construction. A 5,400 ton oceanographic research ship, the T-AGS(OCEAN), is under design in NAVSEA. Studies completed as part of these efforts indicate that certain aspects of ship design and operation combine with the inherent hydrostatic characteristics of the SWATH form to magnify the importance of tankage arrangement in the design of SWATH ships. This paper describes some aspects of the SWATH ship tankage problem and a proposed solution that is compatible with the NAVSEA design process.

2. BACKGROUND

SWATH ships are designed for superior seakeeping in high sea states. This improved hydrodynamic performance is derived from the characteristics of the hull form, particularly the small waterplane area. The small waterplane area of SWATH ships also results in hydrostatic characteristics that are significantly different than those normally encountered in ship design.

SWATH ship hydrostatic characteristics are compared with monohull hydrostatics in reference 1. Figure 2 (reproduced from reference 1) indicates than the moment to change trim one inch (MT1") is much lower for SWATH designs than for the monohulls normally encountered with values typically less than 20 percent of the monohull MT1". Consequently, SWATH ships will be much more sensitive to the variations in longitudinal center of gravity (LCG) encountered during design and while operating.

Designs for SWATH ships are produced by NAVSEA using the same design approach used for monohulls. This process includes inaccuracies and uncertainties that are routinely absorbed by the margins used as well as the checks and balances inherent in the process and the monohull form. SWATH designs produced with this process are expected to contain the same inaccuracies and uncertainties and the process is expected to provide the same checks and balances. However, the checks and balances inherent in the SWATH form differ from those of monohulls in terms such as the MT1", a measure of the trim sensitivity of the hull form. As a result, the design process must be modified to reflect this less forgiving hull form.

For example, the design process corrects misalignment of a monohulls LCG and longitudinal center of buoyancy (LCB) through changes in arrangement and hull form. These changes are usually small. Past experience with many similar designs allows selection of a hull form and arrangement likely to succeed. This generally assures a good starting point. Convergence of the design spiral is also enhanced by the high moment to trim of the monohull form which makes the design relatively insensitive to small changes in longitudinal moment.

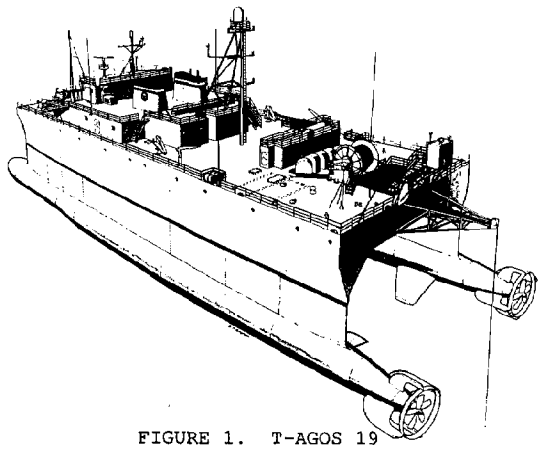

FIGURE 1. T-AGOS 19

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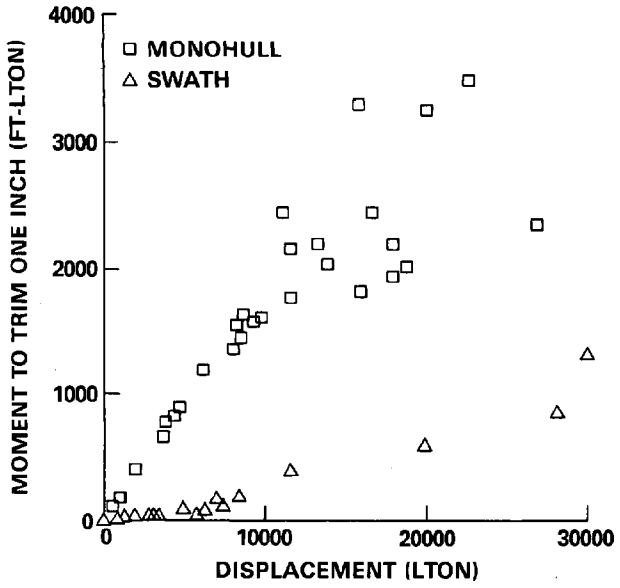

FIGURE 2. MOMENT TO TRIM ONE INCH

The SWATH design data base is sparse by comparison and the design is much more sensitive to fluctuations of the LCG. As a result, the risk associated with converging to a balanced design solution is much greater.

SWATH hull forms are likely to be selected for those missions requiring sustained operational performance in rough seas, typically sea state 5 and above. Such sea conditions are often encountered in the northern parts of the Atlantic and Pacific Oceans that are strategically important. Ships operating in these areas must contend with environmental factors other than rough seas. The occurrence of winter storms is common in these areas. These storms often result in a significant accumulation of ice on the upper parts of ships.

This added topside weight can be a hazard to monohulls due to the associated reduction in stability. The effect on the stability of a SWATH ship is less dramatic due to the much greater reserve buoyancy of the SWATH form. T-AGOS 19 calculations showed that the design could withstand 100 knot beam winds with a uniform layer of ice 12 inches thick on the main deck. This result indicates that the design has an adequate intact stability margin of safety. However, realistic ice storms do not produce uniform layers of ice on ships. Ice build-up tends to be most severe on those parts of the ship to windward. The bow of a ship is particularly likely to receive heavy ice build-up since ships often head into the relative wind. Ship generated spray also adds to the rate of ice accumulation near the bow.

The weight and bow-down moment due to this asymmetric accumulation of ice on a SWATH ship can result in significant operational limitations if uncompensated. The reductions in cross-structure clearance due to the added weight of the ice and the trim due to its asymmetry will increase the rate of cross-structure slamming in waves. The resulting hull pounding is expected to limit operations and may damage the ship.

Operation of SWATH ships is also expected to be affected more than comparable monohulls by the changes in LCG due to consumption of fuel, stores, and mission expendables. Mission expendables are particularly important since large weights may be deployed from the ship in a short time. Fuel and stores are expected to be less of a problem because of the slower rate of consumption.

The factors discussed above suggest that better control over longitudinal weight distribution is required during the design and operation of SWATH ships than commonly used in monohulls. Several methods are known for achieving the desired level of control including:

- use a trim control system
- lengthen the design period to obtain convergence
- provide excess tankage and balance the ship by shifting fuel and ballast water
- use solid ballast

Some of these methods may provide only part of the required control over trim. For instance, solid ballast can be used to counteract trim encountered during design and construction but provides no relief from trim encountered at sea due to expenditure of loads or ice accretion.

The excess tankage approach has been used in the T-AGOS 19 and T-AGS(OCEAN) designs because it is compatible with design periods of different length, does not require introduction of additional systems into the design, and provides solutions to both the design problem and the operational problem. The major design limitation of the approach is the amount of excess volume required. An operational consequence of the excess tankage approach is the presence of fuel tanks in a ship that should be only partially filled or empty. Pressing up all available fuel tanks prior to getting underway greatly reduces trim control and may violate other naval architectural constraints. The discussion that follows reflects this method for controlling trim.

3. TANKAGE ARRANGEMENT PHILOSOPHY

The approach taken is to estimate the forward-most and aft-most locations of the ship's LCG likely to be experienced. All components of the ship's full load weight are included as well as the weight of topside ice, if applicable. The required range of fuel weight LCG is then derived to provide the desired degree of trim control. This degree of control is nominally assumed to be that necessary to achieve zero trim. Finally, the range of LCG locations required for the compensating sea water ballast is assumed to equal or exceed that of the fuel.

The approach is strongly dependent on the estimates of the expected variation of lightship LCG and the weights and moments of topside ice. Relevant data exists for only the T-AGOS 19 design at this time. Use of this limited data base implies a degree of risk in the approach. However, the approach compensates for this risk by attempting to estimate the worst case situations likely to be encountered. For instance, the aft-most LCG limit results from the lightship LCG being the maximum expected amount aft of the estimated location, forward loads being expended, all of the ship's fuel onboard, and the aft-most topside icing condition expected. This

"worst-of-the-worst" approach was adopted to address this problem throughout the design spiral. As a design proceeds, increased confidence in the lightship LCG location or topside icing studies for the configuration being designed should allow reduction of these allowances.

4. LIGHTSHIP LCG VARIATION DURING DESIGN

The lightship LCG of a SWATH design should be accurately estimated as soon as a stable ship size and arrangement are available. The lightship LCG will change as the design progresses through the design process due to inaccuracies within the process and design changes. The variation of the lightship LCG during the T-AGOS 19 design is shown in Figure 3. The left-most data point is the Feasibility Study estimate and the right-most point is the Contract Design point. The lightship LCG estimates generally fell within a band about two feet wide. This band represents 1.05 percent of the length between perpendiculars (LBP) for this design. The lone data point that is outside this band is the first Contract Design estimate. A major piece of the mission equipment was located near the bow for this iteration and subsequently moved to the stern. This configuration related LCG shift combined with start-up problems associated with the complex weight accounting procedures used account for this anomalous data point.

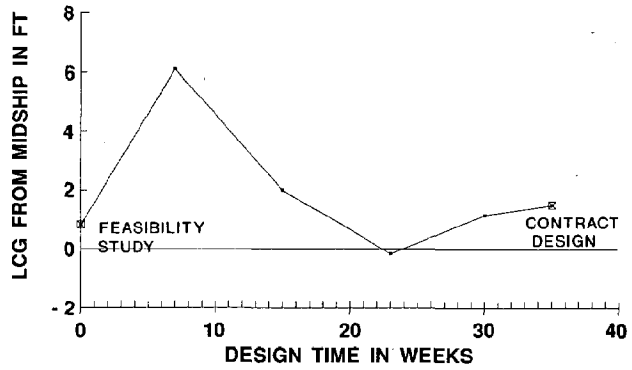

FIGURE 3. T - AGOS 19
LCG VARIATION DURING DESIGN

Figure 3 represents data for one ship that is not yet built. Data for other Navy SWATH ships designed for open ocean operations does not exist. Consequently, the method described below will assume that lightship LCG may vary by as much as 1.05 percent of the LBP of the design in question. This variation may be on either side of the estimated LCG.

Some reduction in the expected amount of lightship LCG variation should be possible during the later design stages after the design process has stabilized. Figure 3 shows that progressively smaller adjustments were made to the lightship LCG with each successive estimate. The additional design iterations eliminate errors and produce design information such as system drawings that improve the accuracy of the estimated LCG. Use of a Preliminary Design between Feasibility Studies and Contract Design should also reduce the expected lightship LCG variation. While use of a Preliminary Design is standard practice at NAVSEA, schedule constraints precluded following this approach on the T-AGOS 19 program.

5. EFFECT OF VARIABLE LOAD

The variable load (excluding fuel and sea water ballast) is divided into two groups to reflect the variable payload nature of some ship missions. The first group contains those weights that remain on the ship throughout a given voyage but may vary from one voyage to another. Laboratory equipment and accommodation vans are examples of such weights. The second group contains those weights that may be expended during a single voyage such as disposable anchors and seismic explosive charges. The range of LCG values expected for these two groups of loads should be estimated for all loadout conditions expected throughout the life of the ship.

6. EFFECT OF TOPSIDE ICING

Little data exists on the effects of ice storms or frozen spray on SWATH ships. The effects of topside ice accumulation were studied during the T-AGOS 19 design (reference 2). Expected ice accumulation was estimated for operating areas of interest in the North Atlantic, North Pacific, and the South Bering Sea where heavy icing conditions are known to occur. Head and beam ship headings relative to the storm were considered.

Ice accretion data was produced by a method that incorporates analytic and empirical techniques. This approach was selected because of the need to model the different, complex shape of a SWATH ship which is outside the conventional ship data base. The T-AGOS 19 geometry was modeled including topside details such as rails, masts, and deck equipment. Air and water temperatures, wind conditions, and the properties of wind and ship generated spray were defined. The icing model includes the relevant dynamic and thermodynamic aspects of the ice formation and accretion processes. Size and liquid content of the expected spray droplets, the dynamics of the flow of droplets around the ship, and the thermodynamics of the icing process were modeled. These factors were then used to estimate the volume and density of ice for each of the ship components modeled. Finally, the weight and centers of gravity of the accumulated ice were calculated. The results are tabulated in Table 1.

TABLE 1
SUMMARY OF ICING ACCUMULATIONS FOR T-AGOS 19

LOCATION	SHIP HEADING	ICE LOAD LB/1000	ICE LCG AFT DECK EDGE FT	AVG ICE LOAD/BEAM LB/FT	AVG ICE LOAD/MN DK LEN LB/FT
W N ATL	BEAM	414	90.8	-	2,179
	HEAD	426	88.0	5,325	-
C N ATL	BEAM	324	90.1	-	1,705
	HEAD	371	92.9	4.638	-
E N ATL	BEAM	235	91.3	-	1,237
	HEAD	252	89.3	3,150	-
W N PAC	BEAM	925	91.7	-	4,868
	HEAD	881	80.7	11,013	-
W/C N PAC	BEAM	85	91.9	-	447
	HEAD	82	85.0	1,025	-
S BER SEA	BEAM	29	95.8	-	153
	HEAD	31	61.0	388	-

This data must be scaled to reflect configurations that differ from the T-AGOS 19. A simplistic scaling method has been used in the absence of more rigorous analysis. A fundamental assumption in this approach is that the geometry of the ship is similar to the T-AGOS 19 including such key variables as cross-structure clearance, arrangement of topside equipment, and deckhouse configuration. The flow of air and spray around the ship is expected to be similar for such similar ships. Ice accretion properties are also expected to be similar since ice formation is strongly influence by the dynamics of spray when it first encounters a ship.

The scaling method assumes that the average weight of ice per foot of main deck beam is constant when the ship is pointed into the wind for the different icing cases. Similarly, the same average weight of ice per foot of length is assumed when the wind is off the beam. The distance from the forward deck edge to the LCG of the ice is assumed to be the same as on the T-AGOS 19. Table 1 shows the average weight per foot of ice accumulated for the different locations and headings from the T-AGOS 19 study. The table shows that the average ice load may be as much as 11,000 pounds per foot of main deck beam when running into the storm and as much as 4,900 pounds per foot of main deck length with the storm on the beam. The weight and LCG of ice expected for a similar SWATH configuration can then be estimated using the main deck beam and length for the design. These results can then be combined with the ship's LCG to estimate the largest bow and stern trim moments due to topside icing expected for the design.

This simplistic ice scaling method is not expected to be valid for configurations that are significantly different from T-AGOS 19. Major variables to be considered are main deck height, deckhouse size and location, and type and location of topside equipment since these parameters are known to influence ice accumulation.

7. SAMPLE PROBLEM - T-AGS(OCEAN)

Application of the approach described above is illustrated by an example. The hull form used is the T-AGS(OCEAN) as it existed midway through Preliminary Design. Weights were taken from the third Preliminary Design weight report. Characteristics of the design are:

Length Overall	279 ft
Between Perpendiculars	230 "
Main Deck	220 "
Beam at Main Deck	84 "
Weight - Full Load	5,361 tons
- Lightship	3,766 "
- Fuel	1,256 "
- Other Loads	339 "
Longitudinal Center of Buoyancy (at full load displacement)	111 ft aft of FP

Loads were broken down into the following groups for the purpose of assessing the limits of LCG variation:

		Weight (tons)	LCG (ft aft FP)
ME	-Mission Expendables	100	194.74
MNE	-Mission Non-Expendables	150	159.87
FW	-Fresh Water	27	115.00
FDT	-Fuel in Day Tank	34	85.00
ML1	-Miscellaneous Loads 1	35	93.33
ML2	-Miscellaneous Loads 2	20	56.85

The ML1 group includes those load items that would remain with the ship throughout a voyage (crew & effects, lube oil, hydraulic fluid, and residual ballast water). The ML2 group might be expended during a voyage (ship ammunition, personnel stores, general stores).

This data can be used to estimate the forward-most and aft-most locations of the LCG of the ship without fuel or ballast water. The calculations for the aft case are summarized in Table 2 and the forward case in Table 3. The results for both cases are illustrated in Figure 4.

TABLE 2
STERN TRIMMING MOMENTS

ITEM	WEIGHT	LCB-LCG	MOMENT	NEW LCB-LCG
LS+LSM	3765.93	- 3.51	- 13218	
MNE	+ 150.00	- 48.85	- 7328	
SUB	3915.93		- 20546	- 5.25
ML1	+ 35.39	17.69	626	
SUB	3951.32		- 19920	- 5.04
ME	+ 100.00	- 83.72	- 8372	
SUB	4051.32		- 28292	- 6.98
FW	+ 26.88	- 3.98	- 107	
TOT	4078.20		- 28399	- 6.96

TABLE 3
BOW TRIMMING MOMENTS

ITEM	WEIGHT	LCB-LCG	MOMENT	NEW LCB-LCG
LS+LSM	3765.93	0.90	3389	
MNE	+ 150.00	- 48.85	- 7328	
SUB	3915.93		- 3939	- 1.01
ML1	+ 35.39	-17.69	- 626	
SUB	3951.32		- 4565	- 1.16
ML2	+ 20.28	54.17	+ 1098	
SUB	3971.60		- 3467	- 0.87
FDT	+ 34.00	26.02	+ 885	
SUB	4005.60	30.32	- 2581	- 0.64
TSI1	+ 412.97		+ 12521	
TOT	4418.57		9939	2.25

ME - Mission expendibles
MNE - Mission Non-Expendibles
FW - Fresh Water
FDT - Fuel in Day Tank
ML1 - Miscellaneous Loads 1
ML2 - Miscellaneous Loads 2
TSI-1 - Topside Ice 1
LS - Light Ship
LSM - Light Ship Margin

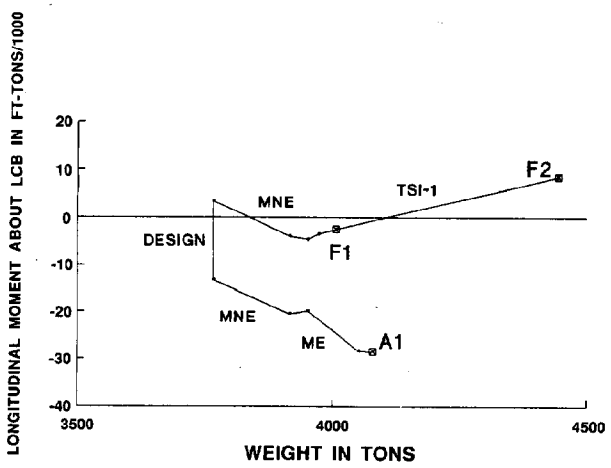

FIGURE 4. T-AGOS (OCEAN)
LONGITUDINAL MOMENT SUMMARY

The departure point is the estimated lightship weight and LCG. T-AGOS 19 experience indicates that this LCG estimate may vary as much as 1.05 percent of the LBP(+/- 2.4 ft for the example). Consequently, the lightship LCG is expected to be between 109.7-114.5 ft aft of the FP. The weights and moments of the loads expected to be in place throughout a voyage (MNE & ML1) are then added. Next, weights and moments of the loads that may be expended during a voyage are added (ME & FW for the aft case, ML2 & FDT for the forward case). Since the weights and moments excluded from the two tables (and the two branches of Figure 4) are on the opposite side of the LCB in each case, the two points (marked A1 and F1 in Figure 4) represent the maximum bow and stern trimming moments of the ship without fuel, ballast water, or ice. These moments must be offset by the moments of the fuel and ballast water to maintain an even keel in the absence of ice.

The centroid of the topside ice is well forward of the LCB for all of the locations and headings covered in the T-AGOS 19 study. As a result, the addition of ice can only reduce the stern trimming moment. Only bow down trim moments are expected. The maximum bow down trimming moment results from heading into a storm in the western North Pacific. These conditions result in an accumulation of 413 tons of ice with an associated bow down trimming moment of 12,500 foot-tons. The effect of this weight and moment can be seen in Figure 4 (marked F2). The tankage arrangement must provide adequate moments to compensate for the forward and aft moments at points A1 and F2 in Figure 4 to maintain an even keel with topside ice.

The limiting moments required are shown in Tables 2 and 3. These moments and the fuel LCGs required to assure zero trim using the 1229 tons of fuel in the design are:

	MOMENT (FOOT-TONS)	FUEL LCG (FT from FP)
LCG for (ice)	9940	119.1
LCG for (no ice)	- 2581	108.9
LCG aft (no ice)	-28399	87.9

The tankage arrangement must allow the fuel LCG to be placed anywhere from 88 ft to 119 ft aft of the FP to assure zero trim with the specified amount of fuel on board.

This approach was used as guidance during the T-AGS(OCEAN) design. The locations of fuel and ballast tanks selected at the end of the Preliminary Design are shown on the inboard profile (Figure 5) of the T-AGS(OCEAN). Most of the forward half of the hulls and lower parts of the struts have been used for fuel and ballast tankage. Other smaller tanks have been located in the aft half of the hulls and struts. Additional tankage in the aft half of the ship was not practical because of main propulsion machinery and steering gear volume requirements combined with an operator preference for horizonal access between the machinery spaces.

This configuration is a compromise that reflects machinery requirements and operator preferences as well as trim control requirements. The consequences of this compromise are illustrated by the fuel/ballast polygon for the design shown in Figure 6. This plot defines the range of trim moments that can be generated by the fuel and ballast systems on the ship. Any trim moment inside the polygon can be generated through a suitable distribution of the fuel

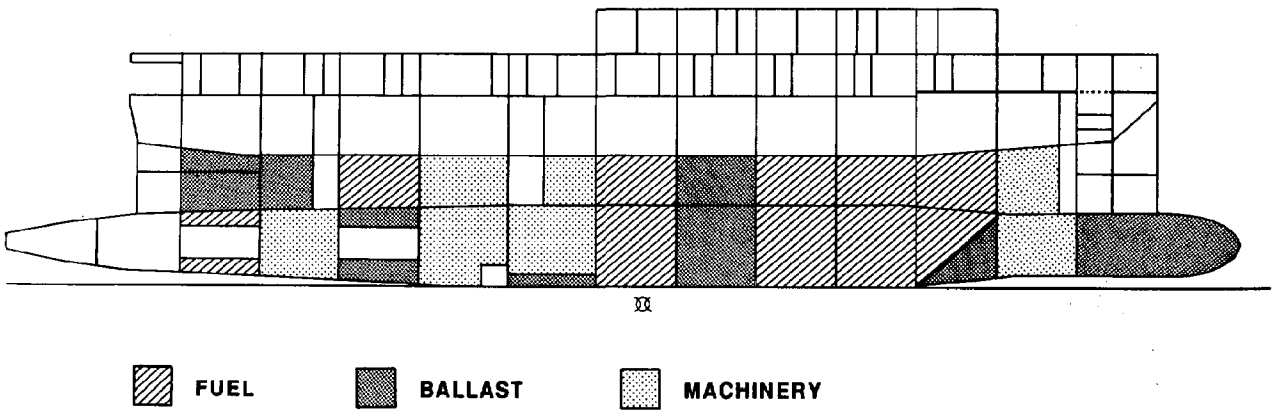

FIGURE 5. T-AGS (OCEAN) TANKAGE ARRANGEMENT

and seawater ballast onboard. Although trim moment is plotted against fuel weight, the sum of fuel and ballast weight is held constant for all cases. For example, the 80,000 foot-tons of bow trimming moment is generated by 400 tons of fuel and about 800 tons of ballast water in the forward tanks.

The LCB of the ship at the design draft is shown on the plot for reference. The guidelines produced by this method (tabulated above) are also indicated. The plot shows that the tankage arrangement chosen by the end of Preliminary Design can generate larger bow trimming moments than recommended by this method at the beginning of Preliminary Design. In general, the design can also generate adequate moments to trim the ship by the stern. Slightly less than the recommended trimming capacity is provided when the full fuel load is onboard and when the fuel tanks are almost empty. These conditions are not considered significant due to the maturity of the design and the nature of the intended operations.

The trim polygon represents the design at the end of Preliminary Design while the guidelines were formulated to compensate for inaccuracies that are encountered throughout the design process. In particular, the variation in the lightship LCG of the design following Preliminary Design is expected to be much less than anticipated early in a design. Consequently, the 8,300 foot-ton allowance for variation in the lightship LCG could be reduced. Furthermore, evolution of the design has shown that the lightship LCG has moved aft slightly during Preliminary Design. As a result, the need for the tankage system to provide the recommended capacity for trimming the ship by the stern is reduced.

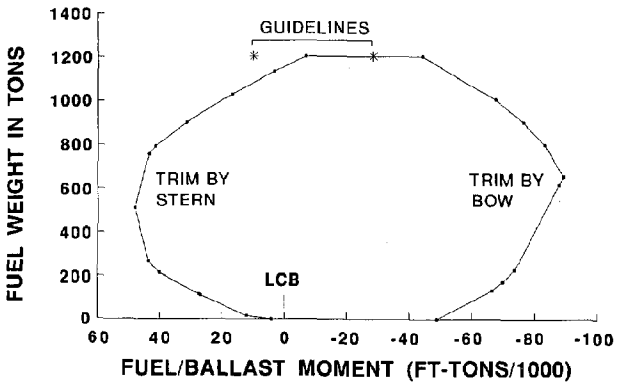

FIGURE 6. T-AGS (OCEAN) FUEL/BALLAST POLYGON

Operational factors also reduce the probability of needing the stern trimming moments recommended by the guidelines. Heavy icing conditions and the expenditure of mission equipment are unlikely when the full fuel load is being carried. Figure 6 shows that the maximum recommended stern trimming moments can be provided by the tankage system after 100 tons of fuel have been burned. Should mission equipment be expended and heavy ice be encountered upon leaving port, unwanted trim can be eliminated by taking on additional ballast water at the expense of a slight increase in draft. Forty tons of ballast in the aft most tanks will provide 8,400 foot-tons of stern trimming moment with a resultant four inch increase in draft.

8. CONCLUDING REMARKS

The approach to SWATH ship tankage arrangement outlined above is intended to assist the designer in producing a balanced design. It is a first-step approach that has not been thoroughly validated by design application. However, it is based on sound principles and parallels the approach used in the T-AGOS 19 design. The T-AGOS tankage arrangement seems to be adequate although this design is not yet build.

The dominant factors in the approach are:

- variation of lightship LCG during design
- large variable mission loads
- location of LCB relative to lightship LCG and ice LCG
- topside icing

Accurate estimates of these factors should be vigorously sought as part of the design.

ACKNOWLEDGMENT

The contributions of Christos Kasselas of NAVSEA in performing the above analysis is greatly appreciated.

REFERENCES

1. Kennell, C.,"SWATH Ship Design Trends", presented at the RINA International Conference on SWATH Ships and Advanced Multi-Hulled Vessels, London, 17-19 April 1985.

2. Zahn, P. B., et al,"Considerations for Northern Latitude Operations of the SWATH T-AGOS", ARCTEC Report 1259C, March 1986.

SWATH SHIP DESIGNS FOR OCEANOGRAPHIC RESEARCH

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ABSTRACT

This paper describes several different SWATH vessel designs with relation to their value for oceanographic research operations. All of these vessels follow the same SWATH design rules, but are of different size and provide different capabilities to cover a wide range of research requirements. The vessel lengths vary from 64 ft to 247 ft. A common feature is low motion, both at rest and underway, which permits research work to be conducted in 1 to 2 sea states beyond that of a similar-sized monohull.

The ability of SWATH vessels to maintain transit speed and provide a steady working platform in rough sea conditions gives them high potential for increasing the efficiency, reliability, and safety of seagoing research operations.

1. INTRODUCTION

Herein we describe several different SWATH vessels in relation to their value for oceanographic research operations. Oceanography consists of the search for knowledge of the physical and chemical properties of the oceans and their boundaries, the nature and extent of their living organisms, the nature of the seafloor and its substructure, and the interactions of all of these aspects of the world's oceans with each other and with human intervention into the environment. The value of a research ship relates to how much of this search it can support effectively and economically. The UNOLS Fleet Replacement Committee report [1] of June 1986 states that the overriding requirement for new vessels is improved seakeeping to allow both overside and laboratory work to proceed in higher sea states than is now possible.

The instruments used by oceanographers are many and diverse, reflecting not only the different scientific disciplines but also the different objectives of particular research cruises. Geology and geophysics require contact with the seafloor, either with mechanical devices or by remote sensing systems. Piston- and box-corers are lowered and recovered on site, while seismographs are deployed and later recovered. Acoustic mapping of seafloor topography, on the other hand, is done both in concentrated areas and while conducting long transits. Physical oceanographers study the dynamics of the ocean circulation in many scales, ranging from local studies using collections of current meters to long range topography observations using networks of acoustic sources and receivers. Chemical oceanographers collect samples to study the diffusion of chemical constituents throughout the ocean volume, and in concentrated areas such as newly located hot vents on the ocean floor. Biologists collect samples from the surface down to the seafloor sediments using devices ranging from nets and traps to manned undersea vehicles. Ocean engineers participate in all of these endeavors in order to develop more capable instruments and vehicles to support the needs of scientific research.

While not all research ships can support all of the different scientific tasks, their value is enhanced by their ability to support several tasks, particularly during the same cruise. There are other factors which affect the value of a research ship. Can it handle the winches and wires needed for deep ocean investigations? Does it have the endurance and comfort for long voyages, both in fuel and consumables and in personnel efficiency? Does it need payload capacity for large and heavy deckloads or for computer equipment and tape storage? Is it capable of supporting long time-series measurements or just short term data collection? Can it handle several overside instruments? How about safe small boat operations? Is it a good platform for communications with other ships, shore and satellites?

The basic requirements for research ships are to be able to go to the desired locations, and to conduct the desired research operations, in a safe and economical manner. Existing ships come in different sizes to meet the needs of different research operations, but they all suffer from restrictions on transit speed and on research effectiveness caused by rough sea conditions. For example, 12 knots is commonly given as the cruising speed of larger research ships, although not often attained. A speed of 9-10 knots in many transits is normal, which is about a 20% reduction. Since transit is often 30-50% of the total voyage, this means a decrease of 6-10% in time available for research work. Heavier seas will cause a greater reduction, and on station they can cause delays in preparing, deploying and recovering equipment; they have also been the cause of loss or damage to equipment, and injury or death of personnel. Even in "normal"

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conditions at sea, ship motions have a degrading effect on human performance, ranging from total wipe-out by sea sickness to the less noticeable but more prevalent increase in fatigue. Since scientific organizations pay for each day at sea, whether they are getting data or not, the ratio of working time to total time is a measure of the value of the ship to their research. Reduced ship motions at sea provide a multiple payoff.

2. FOUR STRUT SWATH SHIPS

The oceanographic research vessel designs discussed herein are all four-strut SWATH (Small Waterplane Area Twin Hull) vessels, shown schematically in Figure 1. Each design has twin

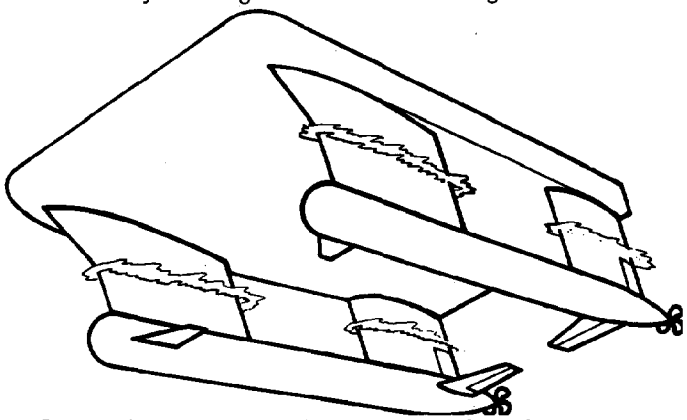

Figure 1. Schematic illustration of a four-strut SWATH.

submerged hulls that support a cross structure above water by means of four streamlined struts. Canard fins are placed near the forward ends of the submerged hulls, and larger stabilizing fins are placed near the aft ends. The fins dynamically stabilize and trim the vessel at moderate to high speeds. Optionally, the fins can be automatically controllable when underway to further reduce the already small motions in waves.

Several sources provide basic information on SWATH vessels [2,3,4]. Both two-strut and four-strut SWATH vessels have greatly reduced motion in waves relative to monohulls. Motion is reduced because: (1) the small waterplane area minimizes the buoyancy changes when waves pass, (2) the submerged hulls and fins damp motion, (3) SWATH vessels have long natural periods of resonance in heave, pitch, and roll due to their small water plane area, and (4) at higher speeds, their fins can be controlled to reduce motion. The motion of a SWATH vessel in waves is typically around one fourth of a similar-sized monohull, or conversely, a SWATH ship will have the motion characteristics of a monohull about four times its length [5,6]. Another feature of SWATH vessels is their ability to reduce their freeboard height through ballasting with sea water. Also, well-designed SWATH ships will not exceed the heel of equal-sized monohulls when handling loads over the side.

Still another feature of SWATH vessels is their low wavemaking drag relative to monohulls due to the deep submergence of their lower hulls. This wavemaking drag can be even further reduced by shaping the hulls and struts so that their wavemaking is partially canceled. In the case of four-strut SWATHs, their lower hulls are typically bulged out in the region between struts to reduce drag. In moderate to high sea states, SWATH ships exhibit much lower drag over a wide range of speeds than monohulls because rough seas have very little effect on SWATH ship drag[7].

The characteristics of significantly different SWATH designs will be significantly different. This is true of any design field: large differences in design form will produce large differences in design characteristics. One of the greatest differences between SWATH designs is whether they have four or two struts.

A primary advantage of four-strut SWATHs is that they typically have less motion at rest or when moving slowly than two-strut SWATHs[8]. This is mostly due to the gap between struts on each side that permits waves to pass through, thereby reducing the side pressures and side loads that cause roll and sway in beam seas. It is also due to their waterplane areas being concentrated near the four corners. A third contributor to reduced motion is the longer natural periods in roll and heave which are characteristic of the four-strut SWATHs relative to two-strut SWATHs. A fourth contributor is increased hull damping in the vertical direction due to the absence of struts in the midsection, especially when this midsection is bulged out to reduce drag. Reduced motion at rest or at low speeds is especially important for vessels whose primary missions are carried out at rest or at low speeds.

Another advantage of the four-strut SWATHs is that they do not require the automatic fin control at moderate to high speeds in order to reduce motion, broaching, or diving in large waves, as do some two-strut SWATHs. (The four-strut SSP KAIMALINO operated for its first year in the rough Hawaiian waters without automatic control, and still operates between islands much of the time without automatic control. In the higher sea states operators of the SSP prefer to turn off the automatic system and to control the hydraulically-driven fins manually because they have more precise control over motion).

Other advantages of four-strut SWATHs are less strut weight and cost due to their reduced strut surface area, better lower hull form for enclosing engines because of the drag-reducing mid-section bulges, and a better structural arrangement for inclusion of center wells. On the other hand, potential advantages of two-strut SWATHs are slightly less beam, and possibly a simpler strut-to-cross-structure structural arrangement.

3. 64-FOOT SWATH

This smallest SWATH, as designed by the Semi-Submerged Ship Corporation (SSSCO)*, would serve the needs of researchers interested in coastal observations which require less than 7 days at sea. Figure 2 shows one of many possible cabin arrangements and sizes, since the main deck is designed to carry all structural loads. A SWATH vessel's ability to operate with more speed and

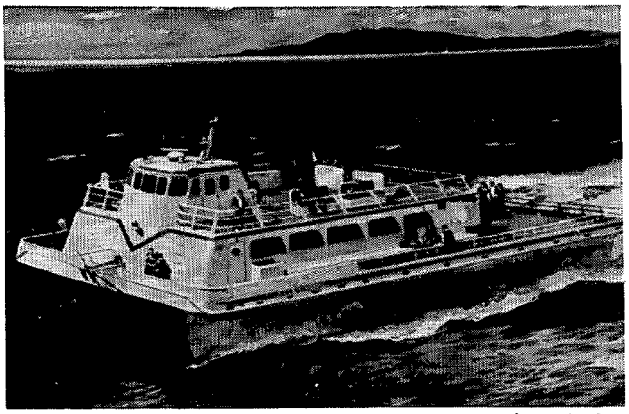

Figure 2. Artist's rendering of SSSCO's 64-ft multi-purpose SWATH design, shown outfitted for one of many possible applications.

steadiness than an equivalent monohull should reduce the at-sea time needed to obtain data, collect samples or recover instruments. Its ample deck space for its size should make it possible to carry more instruments, and to conduct training sessions for students in instrument preparation, deployment and recovery. Such a craft would be particularly useful for the physical, chemical and biological measurements associated with coastal environmental monitoring. Inflatable workboat operations and scientific diving explorations would benefit from its stability and maneuverability, since its motions when lying-to are strongly damped, and its width between propellers provides an effective turning moment. Hydrographic surveys of the bottom could be easily conducted using standard sonar equipment. This small SWATH would even be capable of conducting seismic surveys, using air guns and towed acoustic streamers, with accurate course control in rough seas. It would be equipped with a stern-mounted A-frame, siderail davit posts, maindeck tiedown fittings, maindeck electrical power boxes, and a suitable crane. Its physical and performance characteristics are shown in Table I, together with those of the other SWATH designs. Three vessels in this size range have already been built in the United States under a patent license from the lead author. These are SUAVE LINO (renamed BETSY, the tender for the 12-meter America's Cup winner STARS AND STRIPES), HALCYON, and CHUBASCO.

* SSSCO Design team: T.G. Lang, P.V.H. Serrell, W.J. Sturgeon, and U.W. Hird.

TABLE I. SWATH RESEARCH VESSEL (RV) CHARACTERISTICS

	RV1✱	RV2✱	RV3	RV4
BASIC CHARACTERISTICS				
LENGTH (FT)	64	88	150	247
BEAM (FT)	35	46	75	95
DRAFT (FT)⁄	5-7	13-15	10-16	19-24
FREEBOARD (LO/HI-FT)+	2-7	8-13	4-14	4-20
DISPLACEMENT (LT)	59	228	688	2489
HULL MATERIAL	ALUM	ALUM/ST	ALUM/ST	STEEL
FUEL CAPACITY (GAL)	1260	6000	34100	151000
FULL SPEED (KTS)	16	19	14	18
CRUISE SPEED (KTS)	14	13-15	13	15
CRUISING RANGE (N M)	638	300	7000	11400
ENDURANCE (DAYS)	7	14	30	40
PRPLSN POWER (HP)	2X300	2X2200	2X625	4X1500
ENGINE LOCATION	L.HULLS	U.HULL	L.HULLS	U.HULL
GENERATORS (KW)	30	250	466	4X1090
AUX GENERATORS (KW)	30	30	2X150	250
THRUSTORS (HP)	0	0	2X300	2X470
OFFICERS AND CREW	2-6△	10	12	25
SCIENTISTS	10	6	20-24	35-40
ITINERANT LOAD (LT)	11	16	50	100
DECK AREA (SQ FT)	1230	3120	6000	13782
CENTER WELL (FT*FT)	0	12X23	15X30	15X30
HOLD DOWNS @ 2 FT	—	—	YES	YES
LOADING CRANE	1	1	2	2
TOWING CRANE	0	0	1	1
OVERSIDE CRANE	1	1	2	2
OVERSIDE A FRAME	0	1	2	2
STERN RAMP	0	0	1	1
STERN A FRAME	1	1	1	1
HYDRO WINCH	2	3	2	2
HEAVY WINCH	0	0	1	1
VANS—8*8*20 FT	1	2	3	4
WORK BOATS	1	1	2	3
GANTRY CRANE	0	1	1	1
LAB AREA (SQ FT)	337	300	2500	4787
UNISTRUTS	YES	NO	YES	YES
CLEAN POWER (KW)	0	30	75	75
FUME HOODS	NO	NO	YES	YES
HVAC	OPT	OPT	YES	YES
COMP AIR (CLEAN)	OPT	YES	YES	YES
SEA WATER (CLEAN)	YES	YES	YES	YES
REFR STORAGE (CU FT)	30	60	100	100
SCIENCE STOR (CU FT)	VAN	VAN	6000	15000
DATA STORAGE (CU FT)	VAN	VAN	1500	3000

✱ WEIGHT OF OCEANOGRAPHIC EQUIPMENT FOR RV1 AND RV2 IS CONSIDERED PART OF ITINERANT PAYLOAD. RV2 IS THE SSP KAIMALINO, AS CURRENTLY CONFIGURED.

⁄ THE LEFT AND RIGHT VALUES REFER TO FULL PAYLOAD, BUT WITH HALF AND FULL FUEL LOADS, RESPECTIVELY.

\+ THE LEFT AND RIGHT VALUES REFER TO BALLASTED-DOWN AND NON-BALLASTED FULL LOAD CONDITIONS, RESPECTIVELY.

△ THE SMALLER VALUE REFERS TO DAYTIME OPERATIONS.

4. 88-FOOT SWATH

This vessel is the SSP KAIMALINO [9,10,11], a 227-ton SWATH built in 1973 by the U.S.C.G Shipyard, Curtis Bay, Maryland for the Naval Ocean Systems Center (Figure 3). The KAIMALINO has operated in the rough seas off Hawaii since 1975 as a range support craft, and is capable of coastal operations for periods of up to two weeks duration. This relatively old SWATH design has performed exceptionally well, and has required only minor hydrodynamic and structural changes. However, changes made by a new design would greatly improve the SSP characteristics in Table I.

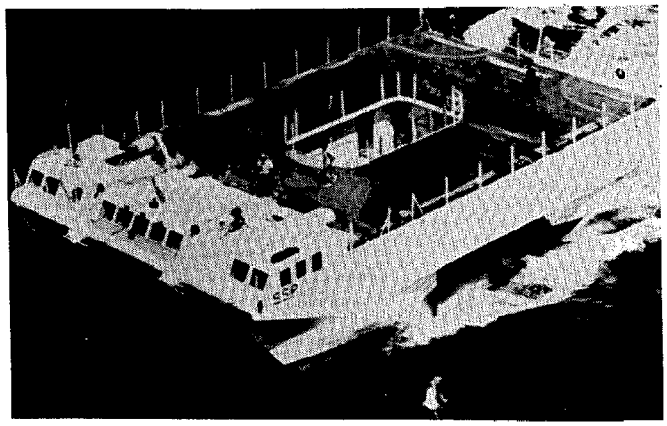

Figure 3. Navy photograph of the 227-ton SSP KAIMALINO operating in the waters off Hawaii.

In addition to the capabilities of the 64-footer, the KAIMALINO has demonstrated the ability to support large ROV operations through its center well, and to deploy and recover sizable hardware over the sides and stern. This size of craft should be capable of handling ROVs and AUVs, and scientific diving groups. Its open-ocean speed should make it valuable for rapid deployment and recovery of instrument packages from the surface, floating in mid-water, and from the seafloor.

To learn first-hand about performing scientific research aboard a SWATH, the National Science Foundation and the Office of Naval Research sponsored four short test cruises aboard the KAIMALINO, and nine scientific projects were conducted in February 1985 [12]. The following are excerpts from Ref. 12. "During one storm, winds gusted between 45 and 60 kts and seas were 6-8 ft. Even in these fairly heavy seas, ship motions were never great enough to shift gear on the main deck or equipment on the countertops in a van on the main deck." "The stability and steadiness that were experienced was called simply extraordinary." "During the storm, participants who usually get seasick (in less severe weather, they said) did not." "KAIMALINO's most critical trials, which it passed with consistently high marks, were instrument deployments and recoveries." "Operating from the center well was especially attractive. There was no need to steady instruments when they were suspended near the surface. Participants repeatedly expressed their surprise at this." "The usual rolling of conventional ships can make it at least difficult, and sometimes impossible, to prevent instrumentation deployed over the side of a vessel from swinging against the hull. This was not a concern on the KAIMALINO because of the ship's extremely slight roll." "Without exception, participants of the KAIMALINO evaluation cruises were enthusiastic about the SWATH. All felt that the SWATH design is well worth pursuing for an oceanographic vessel."

5. 150-FOOT SWATH

The SSSCO 150-foot SWATH design (Figure 4) would serve as an intermediate size general research ship and permit open ocean operations of up to 30 days duration. Its range is 6000 miles, and it can handle the standard suites of oceanographic instruments with overside cranes, davits, and A-frames, and with a hydraulic A-frame at the stern. The stern has a ramp or vertical lift deck section to expedite launch and recovery of scientific

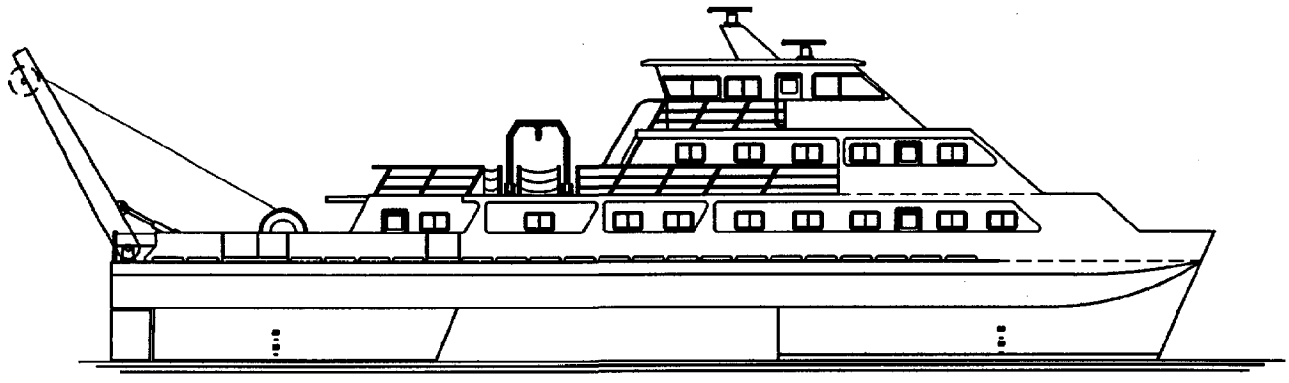

Figure 4. Profile drawing of SSSCO's 150-ft SWATH oceanographic research ship design.

equipment. The 15 x 30 ft center well provides for launch and recovery of ROVs, AUVs and DSVs of ALVIN size. This SWATH is capable of towing sensor packages such as DEEP TOW, GLORIA, SEAMARK, and seismic streamers, and can deploy seafloor work vehicles such as RUM. Its 2500 sq ft of laboratory area and 6000 sq ft of usable deck area can support several scientific groups. The lab space consists of a subdividable main lab, hydro lab, wet lab, electronics/computer lab, climate controlled reefer, and freezer. In addition, 1200 sq ft of science storage space is available. Two standardized 8' x 8' x 20' portable deck vans can be carried to provide additional laboratory, berthing, storage or specialized use space. This vessel can maintain station and work in sea states through 5 having significant wave heights to 12 ft. Its pitch and roll will not exceed 5 degrees, and vertical accelerations will not exceed 0.10g.

6. 247-FOOT SWATH

This large SWATH [13] (Figure 5), was designed by SSSCO under contract from the Woods Hole Oceanographic Institution. It matches the university ships MELVILLE and KNORR in length, exceeds them in laboratory space and usable deck space, speed, low motions in rough seas, and in cruising range, but falls short in payload weight and endurance. This SWATH's range is 11,400 nm at 15 kts, or 16,880 nm at 12 kts, each with a 15% fuel reserve. It carries 336 LT of oceanographic equipment, including a 100 LT itinerant payload, and has an endurance of 40 days. The large center well of this SWATH permits safe handling of large packages in sea conditions that would cancel operations of the MELVILLE and KNORR. In addition to the standard suite of winches, A-frames, davits and cranes, this SWATH has a large gantry crane mounted at the center well. This SWATH carries 35 scientists and 25 crew. Its large usable deck space of 13,800 sq ft provides space for all deck equipment and for the location of four vans for additional berthing, labs and storage.

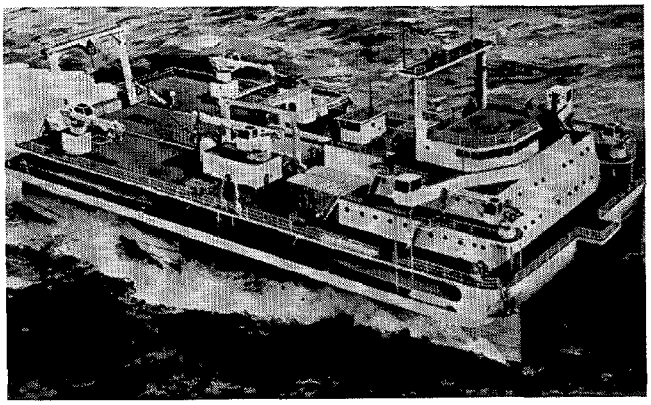

Figure 5. Artist's rendering of SSSCO's 247-ft oceanographic research vessel SWATH design.

This design has a diesel-electric propulsion system with four Caterpillar 3516 diesel generators located in the cross structure. Electric motors drive two Kort nozzles mounted at the ends of the lower hulls and two thrustors mounted near their bows. Thus, underwater noise should be very low, both underway, when station keeping, and when traveling at low speed.

Normal research work should be possible through S.S. 6, and limited work through S.S. 7. The estimated natural periods in pitch, roll, and heave are 11.6 sec, 21.0 sec, and 11.0 sec. Predicted motions in S.S. 6, having a significant wave height of 18 ft, are +/- 2.8 deg pitch, 3.4 deg roll, +/- 4.1 ft heave, and +/- 0.12 g of vertical acceleration. Human factors data indicate that roll angles should be limited to +/- 7 deg to maintain 80% effectiveness, and that the tolerance threshold for vertical acceleration varies from +/- 0.08g for 4-sec periods to about +/- 0.18g for periods above 10 sec or below 1 sec. Since SWATH ships typically exhibit about 1/4 the motions of similar-length monohulls, this SWATH's seakindliness greatly exceeds those of a monohull.

7. SUMMARY

The cost of research operations at sea emphasizes the need for efficiency, reliability and safety. Risks to personnel and instruments on research ships are greatest when equipment is being handled on deck in rough sea conditions. Research groups are made up of some experienced people and sometimes novices, including new graduate students and volunteers. Even the older hands have few opportunities to keep their seagoing skills sharp. The potential for injury or accident is always present. A SWATH's inherent advantage in stability and low motions, both underway and when stopped, certainly will contribute to greater safety. In addition, the large deck area reduces the need for crowding of equipment and the difficulty in fairleading wires and cables, all of which increase the hazards of operations on deck.

Reliability of research operations is degraded when the ship cannot meet its scheduled transit schedules, and when it must curtail operations on station because of rough seas. The ability of a SWATH to maintain speed in higher sea states than can a comparably-sized monohull ship, and to continue research operations while stopped in rough seas should contribute to greater reliability. The large deck area, well above the waterline, improves the capability to continue working in unfavorable conditions.

Efficiency and productivity is affected by a variety of factors. Cost of operations is significant to sponsors of research programs. Expeditions which are aborted, or which return with less results than planned because of ship limitations have a depressing effect on sponsors, particularly at times of new budget preparation. Loss of equipment because of difficulties in recovery in rough seas is not uncommon. Even when the seas do not present hazardous conditions for deck

operations, their motions affect personnel with varying degrees of discomfort, ranging from increased fatigue to debilitating sea sickness. There is an associated cost in time, related to mistakes and slowness in accomplishing tasks that are normally easily done in calm conditions.

The outstanding characteristics of these SWATH designs are their low motions in rough seas and their large areas available for research use. Both of these factors contribute to the increase in efficiency, reliability and safety of research operations.

ACKNOWLEDGMENTS

We thank P.V.H. Serrell, a member of the SSSCO design team, for reviewing this paper.

REFERENCES

1. A Plan for Improved Capability of the University Oceanographic Research Fleet, UNOLS Fleet Replacement Committee Report, June 1986.

2. Lang, T. G., "The SWATH Ship Concept and its Potential", AIAA/SNAME Advanced Marine Vehicles Conference, San Diego, April 1978, Paper 78-736.

3. Lang, T. G., Sturgeon, W. J., and Bishop, C. B., "The Use of Semi-Submerged Ships to Support New Technology at Sea", MTS/IEEE, Oceans 79 Conference, San Diego, Sept. 1979.

4. Lang, T. G. and Sloggett, J. E., "SWATH Developments and Comparisons with Other Craft", RINA-International Conference on SWATH Ships and Advanced Multi-Hulled Vessels, Paper # 1, London, April 1985.

5. Woolaver, D. A. and Peters, J. B., "Comparative Ship Performance Sea Trials for the U.S. Coast Guard Cutters Mellon and Cape Corwin and the U.S. Navy Small Waterplane Area Twin Hull Ship Kaimalino", DTNSRDC-80/037, March 1980.

6. Narita, H., et al., "Design and Full Scale Test Results of Semi-Submerged Catamaran (SSC) Vessels", IMSDC 82, London, 1982, Paper 11.

7. Sloggett, J. E. and Lang, T. G., "SWATH: The Past, the Present, and the Future", The Institute of Marine Engineers, Bicentennial Maritime Symposium,Sydney,Australia, Jan 1988.

8. Sturgeon, W.J., "Analysis of Motion Picture Data on Motions in Beam Waves for Single and Tandem Strut SWATH Ship Models Scaled to 1800 Long Tons", Memo, Code 631, Naval Ocean Systems Center, September 1977.

9. Lang, T. G., "SSP KAIMALINO; Conception, Developmental History, Hurdles and Success", ASME Winter Annual Meeting, Anaheim, California, December 1986, Paper 86-WA/HH-4.

10. Lang, T. G., Hightower, J. D., and Strickland, A. T., "Design and Development of the 190-Ton Stable Semisubmerged Platform (SSP), J. Eng. Ind., 1974, Pages 1105-1111.

11. Hightower, J. D. and Seiple, R. L., "Operational Experience with SWATH Ship SSP Kaimalino",AIAA/SNAME Advanced Marine Vehicles Conference, San Diego,Apr. 1978, Paper 78-741.

12. Kaharl, V., "SWATH: Calm Seas for Oceanography", The Oceanography Report, EOS, Vol.66,No.36, American Geophysical Union 0096-3941/6636-0625,September 1985, Pages 626- 627.

13. Dinsmore, R.P., and Lang, T. G., "Replacement of the University Research Fleet and a 2,500 Ton SWATH Ship Candidate", AIAA 8th Advanced Marine Systems Conference, San Diego, CA, September 1986, Paper 86-2378.

SWATH CHARWIN - RANGE SUPPORT SHIP

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ABSTRACT

The small waterplane area twin hull (SWATH) CHARWIN was built in 1984 for commercial fishing. This 80 foot steel SWATH successfully harvested scallops off the East Coast of Florida. In 1985 the fishing gear was removed and the CHARWIN was marketed to the offshore oil industry. Because of the depressed state of offshore oil no orders were confirmed and the ship was laid up. In 1987, the Naval Coastal Systems Center investigated using the CHARWIN as a range support ship for instrumentation development. CHARWIN was modified for this mission in May of 1988, and has been successful in that role operating out of Fort Lauderdale and Panama City, Florida. This paper describes the CHARWIN and its conversion and use as a range support vessel.

CHARWIN - History and Background

The SWATH CHARWIN has the following characteristics:

Length	80 feet
Beam	40 feet
Draft	9 feet
Displacement (Full Load)	193 Lt
Speed (Max)	10 Kts

CHARWIN is a unique vessel in several ways. At the time of its inception and building during 1983/84, it was the first all steel SWATH to be built in the United States. It is unique in that its design and construction was a private commercial venture which utilized standard shipbuilding practices and modular construction techniques. Further, she was built as a work boat for the commercial fishing industry. In these ways it differed from other

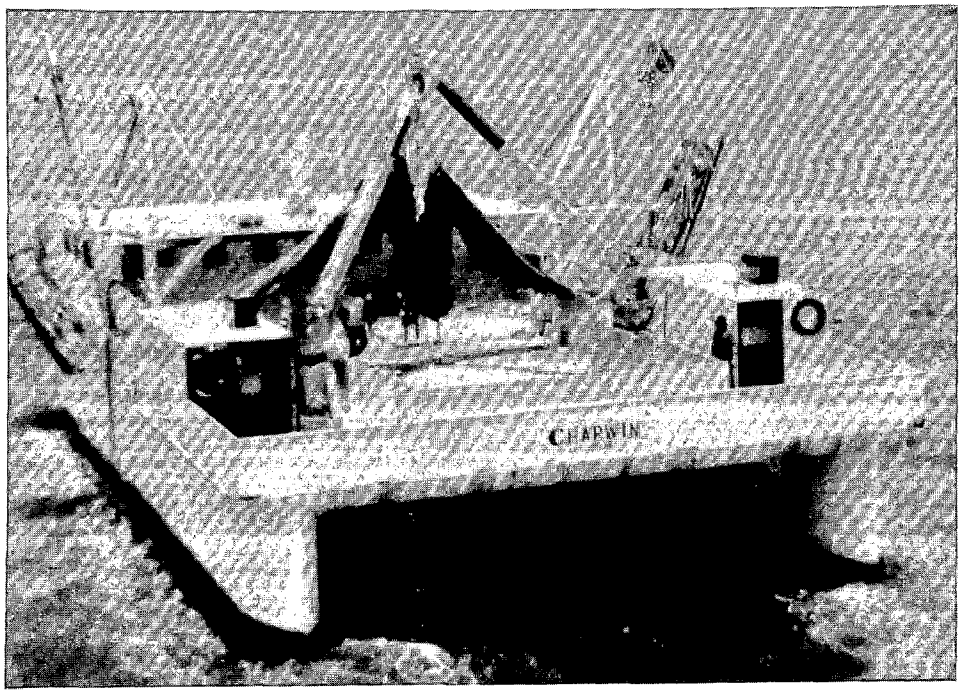

FIGURE 1 SWATH CHARWIN

CH2585-8/88/0000-1169 $1 ©1988 IEEE

U.S. SWATHS, such as the Navy's Kaimalino which is a steel/aluminum research vessel built by the Government; or the Suave Lino a smaller all aluminum boat built as a privately owned yacht.

CHARWIN is a rugged work boat which was outfitted as a scalloper as shown in Figure 1. Construction was started in January 1984 and sea trials were completed in May 1984. The modular construction techniques used were important factors in this short delivery schedule.

As a scalloper her large deck area allowed her catch to be spread out over the deck. This was in contrast to the conventional method of "piling" used by monohull trawlers. Spreading the catch in this manner prevented heat build up in the lower layers which resulted in less product spoilage and higher yields.

The SWATH design allowed CHARWIN to run against strong tides which would force other conventional monohull trawlers to resort to tacking along the trawl run. This forced tacking results in allowing a higher sand and debris content to enter the nets to another factor in quality and profitability.

A major factor in the design of CHARWIN was her cargo capacity. At 104 long tons CHARWIN could handle about three times as large a catch as a standard monohull. Additionally, by distributing this load over the large deck both fore and aft, the vessel avoided heavy deck loading on the stern which has caused the loss of many conventional trawlers.

The efficiency of the SWATH design resulted in a lower fuel and oil consumption than originally anticipated. Of course the seakindliness of the design made life much easier on the crew during heavy weather.

The lower hulls and struts of CHARWIN were designed to meet both the fishing mission load requirements and ease in construction. The lower hulls are 6' 4" in diameter. The struts are four feet wide and 75 feet long. Although this is a large waterplane area for a SWATH of this size, and it did compromise some of the seakeeping performance people have come to expect from such craft, it was outstanding in meeting the fishing mission requirements. Even with this large waterplane area, the vessel when rated by its two most experienced Captains proved to be far more seakindly than monohull trawlers of similar size. These observations cited operations in which sea conditions included waves up to twenty-five feet.

When the scallop catches declined in 1985 new business was sought from the oil industry which unfortunately was also suffering a sever decline at the same time. Although interest was expressed in CHARWIN from several sources the coincidence of these two unhappy events forced the owner to lay up CHARWIN.

Activation and Modification

The Naval Coastal Systems Center, Panama City, Florida is charged with the development of advanced ocean systems. Up until mid 1987 NCSC utilized the USS FIDELITY MSO 443, one of three active vessels of this class, as a test platform for systems under development. FIDELITY was part of a class which resulted from the Navy's mine warfare experience gained during the Korean War. She was commissioned in 1953 and subsequently modernized in the mid 1960's. This class vessel carries a crew of 70 enlisted and 6 officers.

Due to limited availability of the FIDELITY, NCSC obtained CHARWIN as a uniquely qualified replacement. She was selected because as a SWATH, she could provide good seakeeping, had the large open deck area required, had the capability to handle the heavy deck load, and could accommodate the center well required for installation of support equipment. However, significant modifications were required.

Having been laid up for almost three years made it necessary that CHARWIN be hauled out of the water and given a thorough inspection and overhaul.

Once the decision was made to utilize CHARWIN NCSC personnel worked closely with the owner Charles Rains, President of WINCHAR, Inc., his naval architect De Jong & Lebet, Inc., and the shipyard where the work was to be accomplished, St. Augustine Trawler Inc. In order to save as much time as possible, since the system development schedule was of paramount importance, this close cooperation was vital. Many decisions were taken on a day-to-day basis and design changes were implemented as the work progressed.

In addition to re-installing new engines, decisions had to be made regarding their type and location. Original plans to install direct drive diesels in the lower hull were called into question because of the possibility of acoustic interference. The use of a hydraulic drive was investigated and subsequently rejected in favor of a deck mounted belt drive system. In its final configuration the vessel is powered by two 485HP GM 8U9TI main engines located on the after deck in small engine compartments on either side. The belt drive required several modifications owing to the limited availability of proper component parts.

The existing deckhouse with the spartan accommodations found on most fishing vessels was inadequate for the new mission. The scientific party to be embarked had to be housed and facilities provided for the instrumentation that would be brought aboard. One half of the existing deckhouse was converted from a ships control center to a housing compartment with six berths, two small heads, and a galley/messing area. The other half of the deckhouse was converted into the scientific operations center for use by the systems operators.

These spaces were air conditioned and supplied with the appropriate power required to support the testing operations.

The modifications to these spaces were kept as simple as possible since the requirement for the vessel is limited primarily to day work with only occasional overnight operations anticipated.

A pilot house with modest berthing facilities for the crew was added on top of the existing deckhouse. A crew of three, supplemented by a fourth member for prolonged operations, was provided for. The after portion of the deck was given over to housing the necessary power generation equipment and the large winch and reel required to handle the scientific package. Space was also available to handle three instrument vans which carried the associated systems electronics.

The most significant modification was the addition of a center well and seachest to accommodate the instrumentation. The well was cut in the main deck and a shelter to provide protection for the instrumentation package, and to accommodate a special support structure for raising and lowering the instruments was built over the well. Because of the weights and strains anticipated these structures were of significant size.

The seachest design ran through several iterations from a simple swingdown system originally thought to be adequate to a much more complicated structure. The seachest, extending from the main deck to keel depth, a distance of approximately sixteen feet, is protected by a seven by twenty-eight foot fairing. This fairing was the object of considerable discussion not only because of the size but because of concerns over the effect on the sensor electronics. It was finally mandated that the structure be constructed of stainless steel to minimize any interference with the system.

This large structure was permanently secured between the lower hulls with large horizontal foil bracings. Inactive fins were added forward on the lower hulls to provide additional motion dampening while underway. Figure 2 shows the seachest as finally constructed.

Activation and modifications began February 25, 1988 and sea trials for both CHARWIN and the installed system were completed May 20, 1988 when the CHARWIN sailed. Needless to say this time period was extremely short. Labor and weather problems had their part to play in complicating the work of the overhaul.

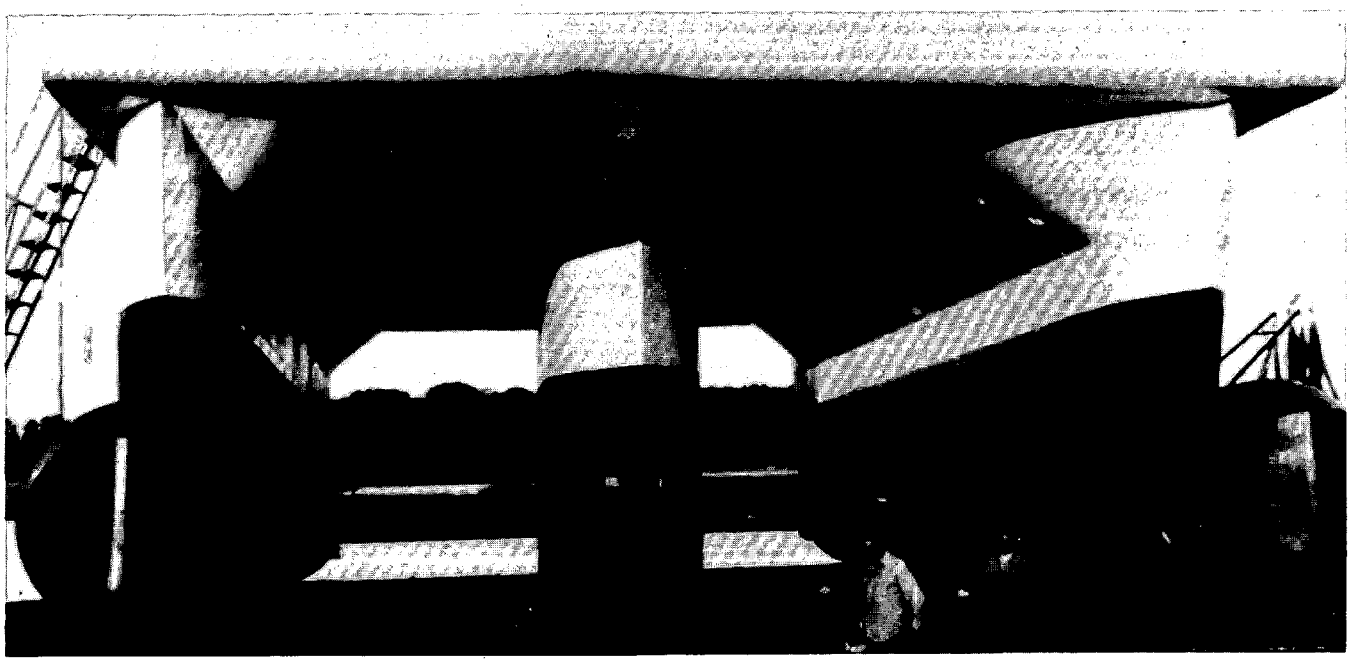

FIGURE 2 SEACHEST MODIFICATION

Material and equipment problems required ad hoc decisions on the spur of the moment but finally all was completed. Figure 3 shows CHARWIN just after sea trials with all equipment on board.

OPERATIONS

After sea trials of both vessel and scientific equipment were completed in the St. Augustine area where the modifications took place, CHARWIN began operations out of Fort Lauderdale. After completing operations in the Fort Lauderdale area, the vessel transited to Panama City in 3 1/2 days. She subsequently has returned to Fort Lauderdale for additional operations in that area.

The vessel has proved to be completely successful in that she provides a stable platform equally capable of transiting at ten knots or towing equipment through the seachest at two to five knots.

In operating in both the Atlantic Ocean and the Gulf of Mexico under various sea conditions, it is clear from comments from the onboard operators that CHARWIN compares favorably with the FIDELITY, more than twice her length, in regards to both vessel and equipment operation.

In addition to these attributes CHARWIN is a comparatively low cost platform. Her crew of three or four slashes the major operating cost (manpower) incurred by a military manned vessel engaged in similar activities. Use of the FIDELITY with her 76 man complement will be necessary for final operational evaluation, but CHARWIN with her small crew has provided the Navy with an inexpensive platform during this part of the systems development cycle.

Lessons Learned

SEACO, the vessel's operator, has had extensive prior SWATH experience, as operators of the Navy's SWATH Kaimalino and having participated in the early operations of Suave Lino. Our current work with CHARWIN confirms the outstanding utility of yet another SWATH variant.

The installation of the large seachest housing presented the possibility of a significant change in the seakeeping characteristics of the original vessel. Since this was an item of such concern during the early stages of planning, the owner, WINCHAR, constructed a six foot model for empirical testing in the St. Johns river. NCSC subsequently requested that the model be tested at the Stevens Institute of Technology tow tank facility. The result of this test showed satisfactory performance.

Finally, the transition of the CHARWIN from fishing vessel to test platform can be considered highly successful, and demonstrates the versitility of the SWATH design.

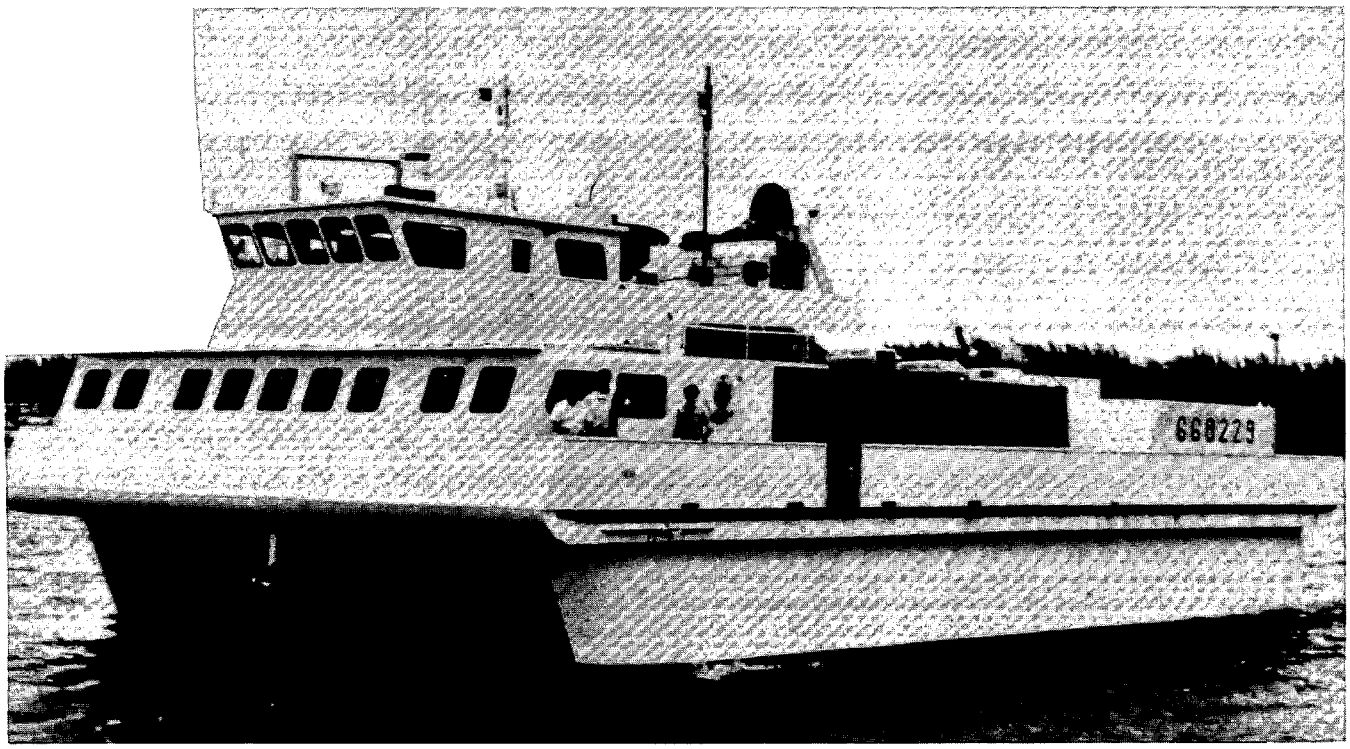

FIGURE 3 CHARWIN UNDERWAY

AUTOMATED ANALYSES OF NUTRIENTS IN SEAWATER WITH THE TECHNICON TRAACS-800 AUTOANALYZER SYSTEM

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ABSTRACT

During 1987-88, we adapted methods for automated analyses of nutrients by Technicon's newest generation industrial autoanalyzer so that the TrAAcs-800 could be used to analyze low levels of nutrients in open-ocean water. The TrAAcs-800 system runs three to five times more samples with longer steady states and better separation between peaks than can older generation autoanalyzer systems like our Technicon AA-II or our Alpkem IWA-6. On completion of a run the TrAAcs operating program automatically calculates sample concentrations from the linear regression slope obtained from the standards which are run and corrects for baseline drift, changes in absorbance, and carry-over.

INTRODUCTION

From June 1987 to May 1988 the Technical Support Services Group of the Department of Oceanography at Texas A & M University adopted oceanographic nutrient methods to allow the determination of low concentrations of phosphorus, nitrogen and silican species in seawater using a "new generation" TrAAcs-800 auto analyzer developed by Technicon Corporation. We evaluated its performance in meeting our needs for accuracy and precision of the four nutrients PO4, NO2, NO3 and SI(OH)4 both in the laboratory and at sea aboard our research vessel.

The purpose of this note is two-fold: first, to summarize the results of our Technical Report 88-02-T published in April 1988, and second, to update our findings subsequent to that report.

AUTOANALYZER AND METHODS

The TrAAcs-800 System is a computer controlled, segmented flow analysis, wet chemistry analytical system. The small-bore components allow samples to be run three to five times faster with longer steady-states for each peak and with a better separation between peaks than did the "older generation" Technicon II and Alpkem IWA-6 Analyzers.

The Traacs System soft-ware prints real time data next to the peaks during the run and upon completion of the run automatically corrects for baseline drift, any changes in the standard absorbances, and carryover. It then recalculates the concentrations from the corrected peak heights and prints this corrected data under the original run (Fig. 1). The raw data and calculated concentrations are stored on a floppy disk from which one can make x-y plots of the standards, take a closer look at each of the results, correct for errors and/or anomalous peaks, and recalculate the run.

The flow rate for the TrAAcs System must be within certain limits, depending upon the length of the flowcell, so that the de-bubbling software will cause the bubbles to be ignored. The optimum flow rate is about one-half what it is for earlier systems, so we have adapted our nutrient methodologies to fit the slower flow rate.

The nutrient methodologies we are using at TAMU are modified from those pioneered by Dr. Lou Gordon's autoanalyzer group at Oregon State University (E.L. Atlas, et al. 1971). The recipes, manifold diagrams and other pertinent information concerning the methods modification for the TrAAcs-800 can be found in our Technical Report 88-02-T (M.A. Spears et al. 1988).

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PRELIMINARY LAB RESULTS

Preliminary results from the TrAAcs-800 gave limits of detection as follows: 0.15 ug-at/l for phosphate; 0.05 ug-at/l for nitrite; 0.5 ug-at/l for nitrate; and 0.5 ug-at/l for silicate. Laboratory accuracy and precision data (derived from a run consisting of 45 shots of 13 different standards) are givin in Table 1. The first column gives the number of the standard (roman numerals designate the working standards used to form the calibration curve, and ordinary numbers designate other known concentrations used as samples). The second column gives the number of times each was analyzed. The succeeding four sets of three columns give the known concentration, the mean TrAAcs calculated concentration, and the standard deviation for each respective nutrient.
(SEE TABLE 1)

LATEST LAB RESULTS

Our latest TrAAcs data were compiled in May of 1988 from fourteen runs consisting of 350 samples. With some modifications to our analytical methods (detailed in the discussion which follows), we have been able to improve the limits of detection to 0.04 ug-at/l for phosphate, 0.02 ug-at/l for nitrite, 0.1 ug-at/l for nitrate, and 0.2 ug-at/l for silicate.

The mean standard deviations and coefficients of variation are as follows:

NUTRIENT	S(UG-AT/L)	CV
P04	±0.03	0.013
N02	±0.01	0.011
N03	±0.09	0.003
SI(OH)4	±0.18	0.006

FIELD RESULTS

Field data were obtained from two 24-bottle CTD casts taken in the Gulf of Mexico on 31 January and 1 February 1988 during cruise 88-G-02 aboard R/V GYRE. Samples from each depth were drawn into three nutrient bottles and replicate samples then drawn from each of those bottles. This provided three distinct analyses with replicates for each CTD cast.

At sea, subsampling precision within each distinct run averaged ± 0.02 ug-at/l for phosphate, ± 0.2 ug-at/l for nitrate and ± 0.1 ug-at/l for silicate (Spears et al., 1988).

Property-property plots of the average nutrient concentrations versus temperature and versus sigma-t density were quite similar to results obtained with a Technicon AA II used on cruises 87-G-11 and 87-G-12 (Spears et al., 1988). Both the 1987 and 1988 data agree with historical data for the Western Gulf of Mexico (Morrison et al., 1983).

DISCUSSION

Linear standard curves and flat symmetrical peaks with good separation indicated that the TrAAcs-800 can support accurate nutrient analyses of open ocean seawater. However, noisy baselines and poor sensitivity at low level concentrations still have to be improved.

The improvement in our latest TrAAcs data is the result of several factors. All lines, joints, and butt joints were replaced. Large pump tubes for the samples were replaced with smaller matched pairs. This enabled the orange-yellow debubbler pump tubes to better remove air which enters when the sampler moves from position to position. The flow-rates were altered slightly to better fit the optimum flow-rate for each length flow cell. The sampling rate was reduced from 75 samples per hour to 60 samples per hour, and the sample to wash ratio was changed from 5:1 to 3:1.

The following is our evaluation of TrAAcs-800 System strengths and weaknesses.

STRENGTHS

1. Has the capability to run samples three to five times faster than older autoanalyzers.

2. Peak height measurements and calibration factors produce concentration data that is almost identical to that computed by hand.

3. Prints real-time data next to the peaks.

4. Automatically recalculates samples with a linear regression slope from all the standards and corrects for baseline drift, any change in standard absorbance and carryover.

5. Stores raw data and calculated results on a floppy disc.

6. Prints relative absorbances.

7. Numerous options available for recalculating and plotting data.

8. Compact and easily transported.

WEAKNESSES

1. The system is fragile.

2. The flowcells in particular are extremely fragile yet must be flushed on a regular basis for best results.

3. Technicon provides minimal information about software and instructions for field servicing a defective module.

4. Reliable initial baselines are often difficult to obtain or keep.

5. Sample cups are too small and easily contaminated.

6. The system is not as sensitive as the older generation AA-II.

REFERENCES

1. E.L. Atlas, L.I. Gordon, S.W. Hager & P.K. Park. A Practical Manual For Use of the Technicon Autoanalyzer in Seawater Nutrient Analyses (Revised). Tech Report 215, Department of Oceanography, Oregon State University, Corvallis, OR 97331, 1971, 49 pages.

2. Technicon Instruments Corporation, AA-II Industrial Methods 155-71W (Orth-phosphate in water and seawater); 186-72W (Silicates in water and seawater); 161-71W/B (Nitrite in water and seawater); 158-71W (Nitrate and Nitrite in water and seawater). 1972-1976

3. Alpkem Corporation, Manual for the IWA-6 Industrial Water Analyzer. 1981

4. Glibert, P.L. & T.C. Loder. Automated Analysis of Nutrients in Seawater; A Manual of Techniques. Tech Report WHOI-77-47. Woods Hole Oceanographic Institution, Woods Hole, MA 02543, 1977, 46 pages.

5. Whitledge, T.E., S.C. Malloy, C.J. Patton & C.D. Wirick, Automated Nutrient Analyses in Seawater. Tech Report BNL 51398, Brookhaven National Laboratory, Upton, NY 11793, 1981, 216 pages.

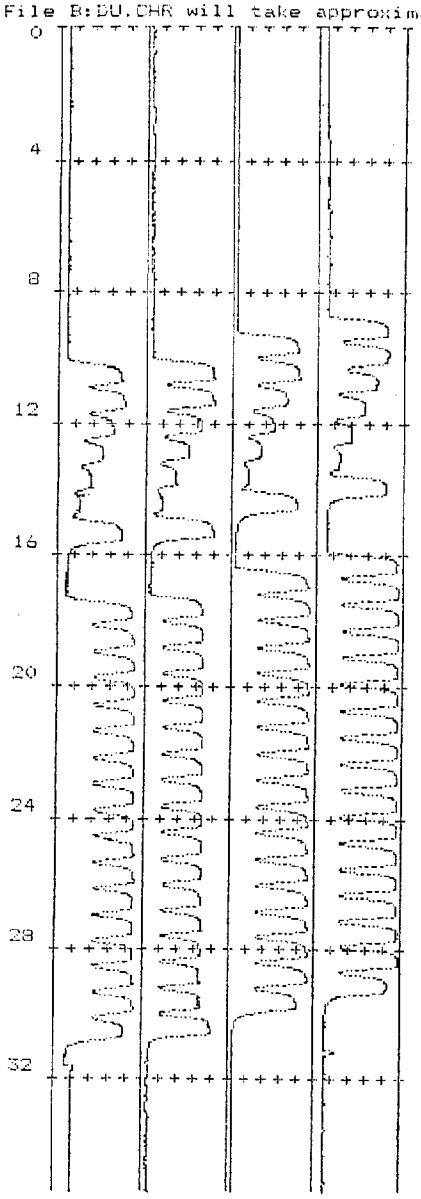
6. Technicon Instruments Corporation. TrAAcs-800 Industrial Methods 811-86T (Silicates in water and seawater); 817-87T (Nitrite in water and seawater); 812-86T (Orthopphosphate in water and seawater); 818-87T (Nitate in water and seawater). 1986-1987.

7. Whitehouse, M.J. & V.R. Woodley. Automated Seawater Nutrient Analysis, British Antarctic Survey-National Environment Research Council, High Cross, Madingley Road, Cambridge CB30ET, U.K., 1987, 41 pages.

8. Morrison, J.M., W.J. Merrell Jr., R.M. Key and T.C. Key, Property Distributions and Deep Chemical Measurements Within the Western Gulf of Mexico. J.Geophys. Res., 88(C4); 1983, 2601-2608

9. Spears, M.A., J.D. Guffy and D.C. Biggs. Automated Analyses of Nutrients in Seawater with the Technicon TrAAcs-800 Autoanalyzer System. Technical report 88-02-T, Department of Oceanography, Texas A & M University, College Station, TX 77843, 1988, 68 pages.

FIGURE 1:
a) Chart of a TrAAcs-800 analytical run with five calibration standards and one sample which was analyzed sixteen times to evaluate analytical accuracy and precision. b) Gives the corrected results for the run. The known concentrations of the four nutrients in the mixed standard analyzed sixteen times were 1.32 ug-at/l for phosptrate, 0.72 ug-at/l for nitrite, 20.5 ug-at/l for nitrate and nitrite, and 19.5 ug-at/l for silicate. The high cv for phosphate (71.0%) is the artifact of a baseline shift after the run.



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Channels					1		2		3		4		
Base:					24		31		36		25		
Gain:					75		75		27		75		
					PO4 uM		NO2 uM		NO3 uM		Si(OH)4 uM		
Base drift correction made													
Carryover correction made													
Gain drift correction made													
Init base					428		284		214		490		
Conc.					1.806e-01		1.709e-01		3.222e+00		2.737e+00		
PK	1	CP	1	typ P	1.125	N	0.8323	N	17.66	N	16.61		
Rel Abs					0.1037		0.1233		0.3457		0.1167		
PK	2	CP	2	typ C	1.162		0.8399	N	17.86	N	16.93	N	
PK	3	CP	3	typ C	0.9746	N	0.7024		14.99		14.38		
PK	4	CP	4	typ C	0.7860		0.5646	N	12.07		11.47		
PK	5	CP	5	typ C	0.5742	N	0.4366	N	9.079		8.569		
PK	6	CP	6	typ C	0.3708	N	0.2866		6.164		5.685		
PK	7	CP	7	typ C	1.127	N	0.8390	N	17.74	N	16.67		
PK	8	CP	8	typ H	0.1725	M	0.1779	M	3.386	M	2.768	M	
PK	9	CP	9	typ L	0.1471	M	0.1662	M	3.227	M	2.610	M	
PK	10	CP	10	typ L	1.295	N	0.7204	N	20.28	N	19.28		
PK	11	CP	11	typ S	1.320	N	0.7235		20.51	N	19.61		
PK	12	CP	12	typ S	1.322	N	0.7296		20.51	N	19.63		
PK	13	CP	13	typ S	1.318		0.7233		20.55	N	19.66		
PK	14	CP	14	typ S	1.325	N	0.7236		20.47		19.68		
PK	15	CP	15	typ S	1.316	N	0.7262	N	20.49	N	19.55		
PK	16	CP	16	typ S	1.317		0.7254		20.40		19.50		
PK	17	CP	17	typ S	1.308		0.7309	N	20.29		19.55		
PK	18	CP	18	typ S	1.311		0.7250		20.48	N	19.50		
PK	19	CP	19	typ S	1.307	N	0.7233		20.51	N	19.62		
PK	20	CP	20	typ S	1.304	N	0.7292		20.46	N	19.57		
PK	21	CP	21	typ S	1.296		0.7258	N	20.52	N	19.61		
PK	22	CP	22	typ S	1.293	N	0.7271	N	20.41		19.62		
PK	23	CP	23	typ S	1.284	N	0.7207	N	20.48	N	19.61		
PK	24	CP	24	typ S	1.286		0.7155	N	20.40		19.67		
PK	25	CP	25	typ S	1.282	N	0.7194	N	20.52	N	19.88		
PK	26	CP	26	typ G	1.100	N	0.8398	N	17.98		17.22		
Last base					796		268		207		540		
Conc.					1.806e-01		1.709e-01		3.222e+00		2.737e+00		

Sample statistics

Anal	level	cups	avg	std dev	cv
1	all	15	1.3052	0.0154	0.0118
2	all	15	0.7245	0.0040	0.0055
3	all	15	20.4666	0.0667	0.0033
4	all	15	19.6174	0.0904	0.0046

Anal 1: linear fit 1.535e-02 1.810e-02.
Carryover factor: 0.00%.
Anal 2: linear fit 9.153e-03 1.074e-01.
Carryover factor: 0.00%.
Anal 3: linear fit 1.980e-01 2.187e+00.
Carryover factor: 0.00%.
Anal 4: linear fit 2.030e-01 3.074e-01.
Carryover factor: 0.00%.

TABLE 1:
Summary of laboratory precision for our 4-channal TrAAcs-800 System from Summer 1987 methods development work. Accuracy can be evaluated by comparing known concentrations of each nutrient (first column in each set), with the calculated means (X) and standard deviations (S) in columns two and three of each set.

#	n	[PO4]	X	S	[NO2]	X	S	[NO3]	X	S	[SI(OH)4]	X	S
I	7	1.88	1.88	.02	1.02	.98	.03	31.1	31.1	.1	30.3	30.2	.2
II	3	1.25	1.22	.02	.68	.68	.02	20.8	20.8	.3	20.2	20.4	.1
III	3	.63	.63	.01	.34	.38	.03	10.4	9.9	.1	10.1	10.7	.2
IV	5	0	.08	.01	0	.06	.02	0	.2	0	0	.5	.3
5	3	.20	.22	.03	.07	.07	.03	2.7	2.7	.1	2.6	3.2	.3
6	3	.30	.30	.01	.13	.13	.01	5.4	5.2	.2	5.3	5.7	.1
7	3	.65	.64	.01	.25	.24	.01	10.7	10.2	.1	10.5	11.0	.1
8	3	1.30	1.30	.02	.50	.49	.01	21.4	21.0	.2	21.1	21.4	.2
9	3	1.96	2.10	.05	.75	.73	.01	32.1	32.1	.1	31.6	31.7	.2
10	3	.13	.14	0	.07	.14	.01	2.1	2.2	.1	2.0	3.1	0
11	3	.31	.32	.01	.17	.28	.09	5.2	5.2	0	5.1	6.2	.1
12	3	.80	.81	.02	.90	.89	.01	10.4	10.4	.1	10.4	10.5	.2
13	3	.68	.67	.01	.22	.22	.02	10.4	10.5	.1	10.4	10.7	.1
		.78	.79	.02	.39	.41	.02	12.5	12.4	.1	12.3	12.7	.2

AN APPLICATION OF A LOW FLOW CURRENT METER TO BROAD TEMPERATURE RANGE ESTUARINE CURRENT MEASUREMENTS

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ABSTRACT

Instruments utilizing heated thermistors as sensors can measure currents over the range of 5 to 50 cm/s. Owing to their small size and great sensitivity, such devices are ideal for the estimation of benthic boundary layer thicknesses, stirring rates in *in-situ* incubation experiments and currents in and around sessile creatures. Such an apparatus is presented and a means of removing ambient temperature effects from data discussed.

INTRODUCTION

A small device for measuring fluid flow rates in the range of 5 to 50 cm/s has application in a variety of ocean science endeavors. This sensor can measure benthic boundary layer thicknesses, flow rates in and around sessile creatures, such as sponges or anemones, or stirring rates in *in-situ* incubation experiments. Heated thermistors, of the type described in this paper, provide a good means for measuring low flow rates. Their small size allows placement in confined areas and they exhibit highest sensitivity in the range of 0 to 20 cm/s.

Thermistor properties that facilitate measurement of fluid flow, unfortunately, make the instrument highly sensitive to changes in ambient temperature. Strategies to overcome this problem include a self compensating bridge (Reidl, 1972; LaBarbera and Vogel, 1976; and MacIntyre, 1986) and mathematical treatments to generate a temperature-independent power dissipation coefficient (Rasmussen, 1962; Katz, 1987; and Lents, 1986).

A self compensating bridge consists of a low resistance value heated thermistor on one leg of the bridge and a high resistance unheated thermistor on the other leg of the bridge. The unheated thermistor is kept out of the fluid flow and will change in resistance proportionally to the change in ambient temperature. The voltage across the bridge determines the voltage supplied to the bridge by a difference amplifier and a power supply transistor. This circuit provides approximately 10% precision over a 5° temperature range (MacIntyre, 1986).

Ambient temperature effects may also be corrected for mathematically. A simple bridge with a heated thermistor and a constant supply voltage is used to determine the power dissipated across the thermistor for a given flow speed and ambient temperature.

This paper is an extension of the mathematical treatment of flow measurements, described above, applied over a temperature range of 15 to 35° as would be found in southern estuarine environments.

METHODS

A bridge is constructed with one leg consisting of a 100 K resistor and a 1 M potentiometer and the other a 1 K thermistor and resistor selected to match the resistance that the thermistor will have at a temperature approximately 10° above the highest expected ambient temperature. Thermistors of nominal resistance higher than 1 K were tried and found to require too high a power supply voltage while thermistors of lower nominal resistance were unstable at higher temperatures.

Power to the bridge is provided by an adjustable voltage regulator. The proper supply voltage is determined as follows. With the thermistor in water of the highest temperature in the desired range of operation, the voltage is slowly increased until the voltage drop across the resistor

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R_1 (Figure 1) and the thermistor are equal. For a 1 K thermistor and a desired operating temperature of 45° the supply voltage was approximately 16.3 V. The thermistor is then placed in water of the highest expected temperature and the 1 M potentiometer is adjusted to give a bridge voltage of approximately 0.5 V. The bridge output voltage is buffered with a unity gain differential amplifier and converted to a 0 to 10 KHz frequency for the sensor output.

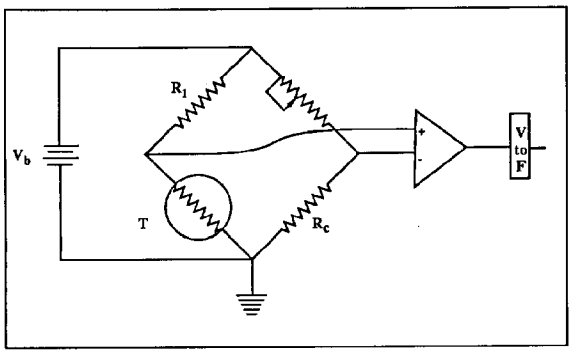

Figure 1. Simplified Flowmeter Circuit Diagram.

As a fluid moves over the sensor, heat is removed from the bead and the power dissipation coefficient increases. The power dissipation coefficient may be defined as:

$$K = \frac{P_b}{(T_b - T_a)} \qquad 1)$$

Where K is the power dissipation coefficient, P_b is the power supplied to the sensor bead, T_b is bead temperature and T_a is ambient temperature. Equation (1) is applicable in situations of small ambient temperature range or small range in flow rate. In the case of large ambient temperature range and/or flow rate, equation (2) gave more useful results.

$$K' = \frac{P_b}{T_b} \qquad 2)$$

Power supplied to the thermistor bead is defined as:

$$P_b = \frac{V_t^2}{R_t} \qquad 3)$$

Where V_t is the voltage drop across the thermistor and R_t is the thermistor resistance. The voltage drop across the thermistor and the resistance of the thermistor are, in turn, defined as:

$$V_t = V_o + V_c \quad \text{and} \quad R_t = \frac{V_t R_1}{V_b - V_t} \qquad 4)$$

Where V_o is the output voltage of the bridge, V_c is the voltage across the compensating resistor, V_b is the bridge supply voltage and R_1 is the resistor in series with the thermistor.

Finally, bead temperature can be derived from thermistor resistance data supplied by the manufacturer. A simplex optimization algorithm fitted the inverse of bead temperature to resistance as:

$$\frac{1}{T_b} = C_1 + C_2 \operatorname{Ln}(R_t) + C_3 \operatorname{Ln}(R_t)^3 \qquad 5)$$

Where C_1, C_2 and C_3 are coefficients determined by the minimization of the sum of the squared residuals in the optimization routine.

The above equations and knowledge of the ambient temperature permit the calculation of a power dissipation coefficient for the thermistor sensor.

The sensors are calibrated in a 1 m^3 temperature-controlled tank. A turntable, fitted with the sensor is placed in the tank and the drive motor and slip rings positioned over a cutout in the tank lid. When a desired temperature is reached, the stirring motors are shut off, and the tank temperature monitored at the level of the sensor. The turntable is rotated once while speed and power dissipation data are collected. Calibrations are then made in 5° intervals over the range of 15 to 35°.

RESULTS AND DISCUSSION

Five calibration data sets were generated over the 15 to 35° range. Each temperature curve was fitted, with the previously mentioned optimization algorithm, to the equation:

$$K = A + B \operatorname{Ln} U \qquad 7)$$

Where A and B are coefficients arrived at by the same method as the thermistor bead temperature coefficients, and U is the flow speed. This equation is inverted in order to calculate flow speed, U , from power dissipation, K, as:

$$U = \exp\left[\frac{K - A}{B}\right] \qquad 8)$$

Figure 2 is a plot of the power dissipation coefficient, derived from equation (1), for each temperature.

For speeds less than 15 cm/s or an ambient temperature range of 15° or less, the effects of ambient temperature changes are corrected for by equation (1). One aspect of this calibration method is a slightly higher power dissipation coefficient at 30° than at 25°. When a bridge was constructed to operate 20° above the highest temperature in the desired range, its calibration produced similar results. The thermistor manufacturer warns of long term instability for operation at temperatures above 50°, prompting the selection of the lower operating temperature.

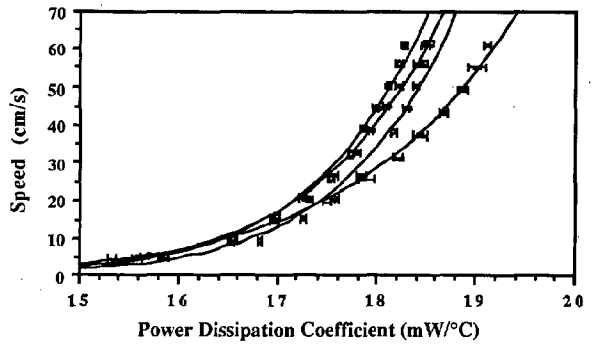

Figure 2. Speed versus power dissipation coefficient as derived with equation (1).

Figure 3 shows speed versus power dissipation coefficient, derived from equation (2), for the same data. Equation (2) provides a family of calibration curves that increase regularly in power dissipation as ambient temperature decreases and have very little scatter in data. Although equation (2) provides curves of very steep slope, the uncertainty in the measurement is small enough to permit a flow speed resolution of ± 10%.

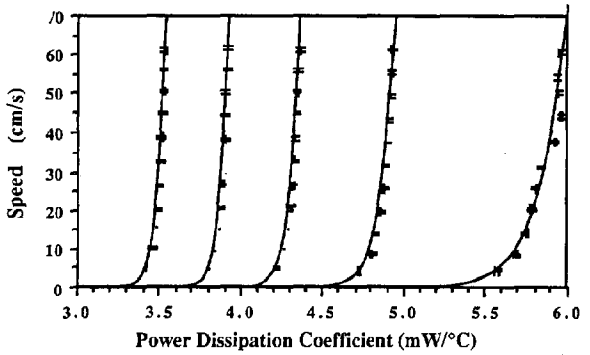

Figure 3. Speed versus power dissipation coefficient, K', as derived with equation (2).

Over wide ambient temperature and speed ranges, the calibration curves shown in Figure 3 are more desirable owing to their uniform slope and spacing. Values for A and B at temperatures other than those calibrated may be estimated by a piece-wise linear approximation or fitted to a polynomial equation. The curve coefficients from Figure 2 do not have a linear relationship to ambient temperature and thus do not lend themselves to simple approximation for temperature other than those calibrated. Table 1 lists optimized values of A and B for each calibration curves in Figure 3

Ambient temperature	A	B
35	3.352	0.0443
30	3.741	0.0429
25	4.137	0.0535
20	4.628	0.0746
15	5.355	0.1474

REFERENCES

Katz,I., and E.J. Shaughnessy, 1987. Digital temperature compensation of a thermistor flowmeter. *J. Phys. E. Sci Instrum.* 20: 561-564.

LaBarbera, M. and S. Vogel, 1976. An inexpensive thermistor flowmeter for aquatic biology. *Limnology and Oceanography*, 21: 750-756.

Lents, C., F. Incropera and R. Viskanta, 1986. Application of heated thermistors to speed measurements in thermohaline solutions, *Solar Energy*, 36(2): 179-186.

MacIntyre, S., 1986. A flow-measuring system for use in small lakes. *Limnology and Oceanography*, 31(4): 900-906.

Rasmussen, R., 1962. Application of thermistors to measurements in moving fluids, *Review of Scientific Instruments*. 33(1): 38-42.

Reidl, R. and R. Machan, 1972. Hydrodynamic patterns in lotic intertidal sands and their bioclimatological implications., *Marine Biology*, 13: 179-209.

DESCRIPTION OF CONVERSION OF AN EG&G VMCM INTO A MVMS (Multi–Variable Moored Sensor)

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ABSTRACT

A standard EG&G VMCM has been modified to acquire data from external sensors. The external sensors are mounted on a compact backpack which attaches to the VMCM's cage. Some simple changes to the VMCM's A/D board opened up eight analog voltage channels. Changes to the VMCM's firmware were made to allow control over the period of time between toggling external power on and the A/D sampling cycle. Some sensors with low power consumption were powered continuously and their signals passed through a low pass filter (TC 8 min) in order to match time constants and minimize aliasing. Sixteen VMCM's were modified and three deployments of the MVMS's were made in 1987 with durations of 3 to 4 months as part Biowatt II, funded by the Office of Naval Research. Data return was better than 80%. Reasons for loss of data include tape breakage, underwater connector failure, pressure case flooding, and fouling.

1. INTRODUCTION

Ocean processes are highly variable in space and time. Improved understanding of these processes requires higher resolution sampling than is possible from shipboard. For any given project there are a suite of variables that are of interest, and the ability to monitor many of these variables concurrently is highly desirable. Our interest in the development of a multi–variable moored sensor was fueled by the requirments of the program Biowatt (Bioluminescence and Optical Variability in the Sea). Briefly, the major goal of Biowatt is to predict patterns of oceanic bioluminescence and relate these to variability in optical properties over appropriate spatial and temporal scales (see Marra and Hartwig,1984). The best hope for meeting these objectives is to supplement the classic shipboard sampling with a mooring that would obtain data on bio–optical and physical variability over an annual cycle, and resolve time scales as short as a few minutes (see Dickey, Hartwig and Marra, 1986). For the Biowatt II mooring, the variables selected for measurement were: currents, temperature, photosynthetically available irradiance (PAR), beam transmission, chlorophyll fluorescence, conductivity and dissolved oxygen (DO). Two of the sensors, the SeaTech fluorometer and the ENDECO type 1133 oceanographic DO sensor, were developed in cooperation with the respective companies specifically for the Biowatt mooring. The SeaTech fluorometer was designed to have lower power consumption and better noise characteristics than other available fluorometers. The ENDECO DO sensor was designed to employ a pulsing technique (Langdon, 1984) which improves long term accuracy. Also, because the output is independent of the membrane, anti–foulant wax can be directly applied to the membrane surface.

A field proven unit, the VMCM (Weller and Davis, 1980), was chosen to serve as the primary data–gathering and recording instrument in the system. The other sensors for irradiance, fluorescence, beam transmission, conductivity and dissolved oxygen were mounted on a backpack which was in turn mounted on the pressure case of the VMCM (Figure 1). The following sections describe the physical, electrical and programming modifications to the VMCM necessary for converting the the VMCM into a Multi–Variable Moored Sensor (MVMS) capable of logging nine 0–5v analog channels with power toggling of sensors and anti–alias filtering.

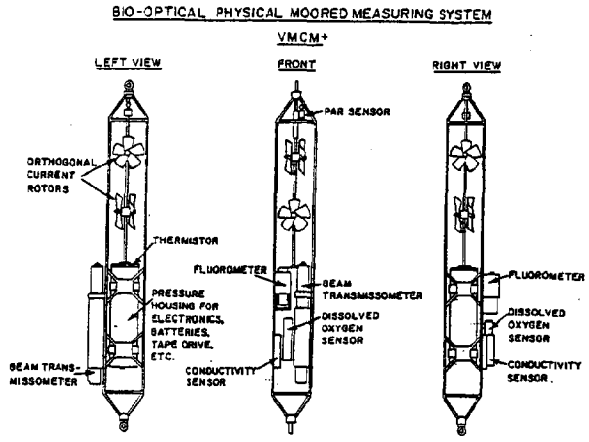

Fig. 1 Physical layout of sensors on MVMS.

CH2585-8/88/0000- 1181 $1 ©1988 IEEE

2. DESIGN CONSIDERATIONS

The VMCM had to be modified to accept at least five external analog signals. Given the desired deployment times of 3–4 months data storage limitations set the maximum sampling frequency at once every 4 min. The 4 min sampling rate in turn created the necessity of low–pass filtering key signals, such as irradiance, beam transmission, and conductivity in order to avoid aliasing. The fluorometer and DO sensor are pulsed output devices and therefore are not conveniently filtered. Therefore these sensors were power toggled to come on just before the A/D sampling cycle. Details of all the modifications necessary to meet the design objectives are given in the following subsections.

2.1 Data input

The standard EG&G VMCM uses a time–multiplexed scheme to gather temperature data, auxiliary voltage and current consumption of each circuit board. Using this idea it is possible to substantially increase the instrument capabilities by simply replacing the front end of the A/D board and doing minor modifications to the instrument firmware. This instrument already logs all data that is converted by the A/D board into the cassette storage system. Therefore, with very simple changes the instrument is open to acquire signals from external sensors. For our application some signal processing is necessary to interface these sensors to the A/D board, as is explained in the next paragraphs.

2.2 Signal processing

2.2.1 Anti–aliassing filters

The spectrum of the signals sampled by the A/D do not have significant energy levels above half the sampling rate. However,the vertical movement of the MVMS through the water column due to mooring oscillation, combined with the signal change along that path, make neccessary the use of anti–aliasing filters. Just as a quick example, consider the signal from the PAR sensor. Mooring motion will cause the water column above the sensor to oscillate approximately one meter with a period varying from 5–12 s. The output of this sensor will vary from 7–14% m^{-1} depending on the clarity of the water. Therefore, the signal that is being sampled will contain a significant high frequency component that will cause aliassing noise.

Since the sampling rate is 4 min a first order low–pass filter with a cutoff frequency of 10 min. and a 20 dB/dec attenuation slope after the cutoff will sufficiently attenuate the movement–induced high frequencies to a level smaller than the quantization step. In other words, the noise due to aliassing will be smaller that one bit.

2.2.2 Matching the time constants

One of the parameters measured was the salinity. This parameter is calculated from the temperature and conductivity of the water. The conductivity sensor used was the Sea Bird Model SBE–4 whose response time is very small compared to the temperature signal from the EG&G VMCM which has a response time of approximately 240 s. In order accurately to compute salinity it is desirable to match the time constants of the conductivity and temperature sensors. Therefore the conductivity signal was passed through a low–pass filter with a time constant of 240 s.

2.3 Data storage

There is no need of any modification to the data storage capability of the EG&G VMCM. The instrument is already prepared to write all the data sampled by the A/D to the tape.

Each data record consists of the following:

Description		# of bits
Preamble		8
Record count		16
North vector		16
East vector		16
Rotor 1 count		16
Rotor 2 count		16
Compass		8
Temperature		16
Pressure		16
Auxiliary	PAR	16
CM1	Battery Voltage	16
CM2	Not used	16
CM3	Dissolved O_2	16
CM4	Conductivity	16
CM5	Transmissometer	16
CM6	Dissolved O_2 Temp.	16
CM7	Not used	16
CM8	Fluorometer	16
Parity		4
TOTAL Data bits		276
Inter record gap		76
Total # of bits per record		352

450 ft tape= 17.25 10^6 bits
Therefore, the data capacity is about 49,000 records.

Each record contains: the record number, east and north components of the current, upper and bottom rotor counts, compass, and the extra channels used to measure the signals from the external sensors. The deployment periods were slighty shorter than four months and since the tape capacity is 49K records,the fastest sampling rate possible is 4 minutes.

2.4 Power consumption

Special consideration was given to this area of the design. The relatively large amount of sensors and small volume available for the batteries made it necessary to switch off some of the power–hungry sensors while the system was not sampling. The power–toggling was used only with those sensors that do not need anti–aliassing filters. The power–toggling effectively decreases energy requirements. As an example, the DO sensor consumes 11 mA–h if operated continuosly. Switching power on only during the sampling period, which is about 14 s every 240 s reduces the power requirements of this sensor to 0.64 mA–h. The standard EG&G VMCM turns the A/D board on and off using a control line. We used that line to gate the solid state power switches that feed the above mentioned sensors. A simple modification to the firmware was performed in order to have this control line turn on and off at the appropiate times giving the sensors enough time to settle their outputs.

Using the above scheme for the DO sensor, the fluorometer, and the analog output buffers, the power budget of the instrument is the following:

INSTRUMENT	DUTY CYCLE	VOLTAGE	STD BY CURRENT	ACTIVE CURRENT	ENERGY (4 MONTHS)
	%	V	mA	mA	A–h
VMCM electronics	100	6	4.5	3	9.1
Signal Processing Bd.	5	6	6	12	19.3
Tape Recorder	5	14	–	350	4.2
Conductivity	100	14	13	–	37.4
PAR	100	14	1	–	2.8
Dissolved Oxygen	5	14	–	11	1.9
Transmissometer	100	14	10	–	28.8
Fluorometer	0.4	14(*)	–	2.5 A	23.7

* Separate 14 V supply for the fluorometer.

The battery pack was composed of lithium cells (Electrochem DD size Model BCX72–3B76), since the alkaline types available did not have enough capacity to supply the external sensors during a four month deployment.

The cells were distributed as follows:

6 Volts 60 A–h for the VMCM and S.P. board, 14 Volts 30 A–h for the fluorormeter, 14 Volts 90 A–h for the rest of sensors and tape recorder.

2.5 Special interfacing requirements

2.5.1 Conductivity F/V conversion

A Sea–Bird SBE–4 instrument was used as a conductivity sensor. Its output is a frequency signal. The MVMS is prepared to measure analog voltages, therefore a frequency to voltage conversion is necessary and is performed as part of the signal processing board functions. The F/V uses a constant charge pump capacitor technique, which has a very linear response, very low drift with temperature, and requires only 1.0 mA. After the F/V conversion the signal is low–pass filtered (240 s time constant) to equate its response time to the temperature sensor's.

2.5.2 Isolation requirements of the DO sensor

Proper operation of the ENDECO DO sensor requires that the instrument be electrically floating with respect to the seawater. In contrast, the VMCM and PAR sensor ground to the seawater via their pressure cases. To isolate the DO sensor from the VMCM during the 2 s every 4 min that the DO sensor was actively sampling, there is a circuit consisting of two relays which switch the DO sensor to internal power and isolate electrical grounds for 2 s whenever external power is sensed to come on. After 2 s, electrical connection with external power and common ground is re–established so that the analog DO and DO temperature voltages could be sampled by the VMCM. This circuit proved to be unreliable and was the primary cause of low data return by this sensor. A better approach for the future would be to float the VMCM and PAR pressure cases or find some other means of isolating the DO sensor.

2.5.3 Adjustable input range for PAR sensor

The mean value of the output signal from tha PAR sensor is highly related with the depth. In order to have a good dynamic range not using logarithmic amplifiers (rejected for their problems with temperature), the anti–aliassing filter used for the PAR signal is designed to have three different switch–selectable gains. This permits us to field set the gains according to the instrument depth or the signal range for that deployment site.

3. DESCRIPTION OF THE MVMS

3.1 Signal processing board

The signal processing board contains three very–low–cutoff frequency, first–order, low–pass

filters, a low-power frequency-to-voltage converter, and several solid state switches. The solid state switches are used to turn on and off the fluorometer (which requires switching 14 volts at 2.5 A) and the power line that feeds the DO sensor (14 volts at 12 mA). Both swicthes are gated by the same control line that turns on and off the A/D board of the EG&G VMCM. The frequency signal from the conductivity sensor is transformed into a voltage signal using the frequency-to-voltage converter. After the conversion, the signal is passed through a low-pass filter with a time constant of 240 s to equate the sensor response to the temperature sensor. The transmissometer and PAR sensor signals are passed through filters with a 600 seconds time constant to reduce aliasing caused by the vertical movement of the instrument through the water column due to the mooring oscillation. Power consumption requirements make neccessary the use of very low power operational amplifiers.

3.1.1 Voltage-to-frequency converter

The converter is based in a switched capacitor technique described in the Linear Technology switched capacitor technical literature. It based on charging a capacitor to a precise reference voltage level, then tranferring that charge to the input of a low-pass filter. The frequency signal drives the charge transfer from the capacitor to the filter, the higher the frequency the larger the charge transferred. Since the filter output is proportional to the average current provided by the capacitor this voltage will also be proportional to the frequency that switches the charge. This technique yields a very linear transfer function and has low power consumption. The circuit shown in Fig. 2 consumes 1.2 mA and the frequency range is from 0 to 13 Khz.

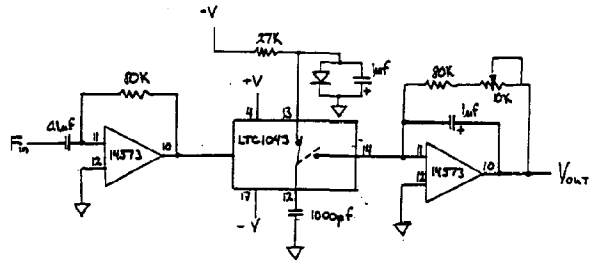

Fig. 2 Schematic diagram of low-power V/F circuit for conductivity sensor.

3.1.2 Low-pass filters

The fact that the three filters plus the voltage converter and switches should fit in a 3 by 4 in. circuit board made impossible the use of conventional low-pass filter designs which need large capacitors to achieve large time constants. In standard first-order low-pass filter designs, the value of the time constant is given by the product RC, where R is the resistance and C the capacitance of two critical components of the circuit. It would be very simple to increase indefinitely those values to obtain any large value of time constant. However, there are practical limitations. For the capacitor, there will be a maximum size, and also the leakage currents which are proportional to their capacitance and produce undesirable unstabilities in the output. For the resistor, large values are undesired because the bias currents needed for the operational amplifier will produce a very large (and temperature dependent) voltage offset at the output. The solution suggested to obtain very large time constants consists of using Miller's Theorem to increase the effective capacitance of a capacitor. The technique is implemented using a simple inverter amplifier circuit as shown in Fig. 3, where a capacitor

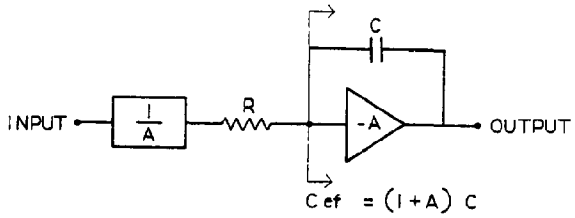

Fig. 3 Block diagram of low-pass filter implementing Miller effect.

has been put in parallel with the output and the input of the amplifier.

The effective capacitance (with respect to ground) seen at the input of the amplifier is the ratio between the differential increment in current and the differential increment in voltage with respect to ground when a given differential voltage increment is applied to that input. Since the amplifier will pull the voltage up and down at the other end of the capacitor, the current through the capacitor is proportional to the voltage difference across it. This current is proportional to the gain of the inverter and thus the effective capacitance is proportional to the gain. Therefore, the effective capacitance can be increased, increasing the gain and without increasing the real value of the capacitor.

The formulation that shows quantitatively the capacitance change is as follows.

For a given dVi:

$$Ceff = dI/dVi$$

and $dI = (dVi - dVo) * C$ where C is the real capacitance

also $dVo = -A * dVi$ where A is the Gain of the inverter

replacing it in the second equation results in:

$$dI = (dVi - (-A*dVo)) * C$$

$$dI = (1+A) * dVi$$

that is Ceff = (1+A) * C

The main limitation of this scheme is that the dynamic input range is decreased proportionally to the increase in effective capacitance. To solve this inconvenience, an attenuator prior to filtering is neccessary and an amplificqation after the filtering restores the dynamic range of the signal. The final circuit for the low-pass filter is similar to a simple "RC" configuration except that a very large capacitance is artificially achieved through the use of Miller's effect. It is interesting to note, that the amplification stage used for increasing the effective capacitance, also serves to amplify the filtered signal, restoring the dynamic range previous to the attenuation section. Figure 4 shows the final circuit diagram for the frequency to voltage converter and the three low-pass filters. The first stage of the filter is an inverting amplifier with a gain of 0.45 for the conductivity channel and 0.1 for the PAR and beam transmission channnels. The second stage is a high input impedance non-inverting amplifier with a gain of 1. This stage serves as a buffer to avoid deteriorating the "RC" of the final stage. The 4.75 MOhms resistor and the 10 uF metallized polyester capacitor in the final stage of the filter form the RC(1+A) time constant. With the above values, and using above equations the resultant time constant of the circuit is about 550 s.

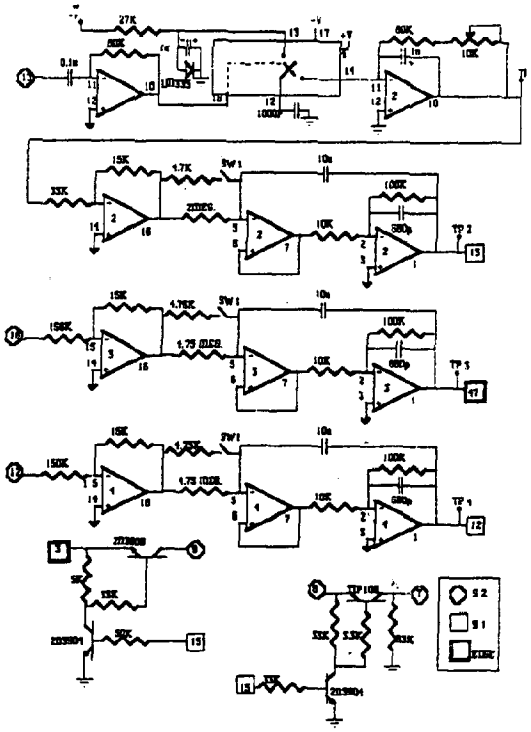

Fig. 4 Schematic diagram of signal processing board circuit including: V/F, three low-pass filters and power toggling transistors.

3.3 Modifications to the A/D board

The standard EG&G VMCM has an A/D board used to convert the temperature sensor signal, an auxiliary voltage input and the current consumption of eight interface boards. The eight current consumption channels are grouped in one of two eight-channel multiplexers. The current measurement is accomplished using a resistor network pulling down the power supply and feeding the corresponding interfaces. To make these eight channels available for external measurements, this resistor network is replaced by a half socket connector which is used as the signal input for the signals from the Signal Processing board. In order to have appropiate gain values, some resistor values need to be changed.

3.4 Modifications to the firmware

The original firmware of the EG&G VMCM had to be changed to allow extra time for some of the sensors to stabilize their output before being sampled. Changing the contents of 456EH (EPROM U3) on the memory board from 06H to FFH analog power control signal "VSW" on time was stretched to 12.7 seconds. The following list shows the current meter (CM) channels in the order in which they were sampled, the time relative to power-on that they were sampled and the sensor assigned to that channel.

CM	Sampling Time (sec)	Sensor
1	0.7	Battery Voltage
7	2.1	(unused)
5	3.5	Transmissometer
4	4.9	Conductivity
2	6.4	(unused)
8	7.8	Fluorometer
6	9.2	DO temperature
3	10.6	DO

Note that the fluorometer and DO sensors, which both have stabilization times of 7 seconds, were sampled last.

4. EVALUATION OF PERFORMANCE

4.1 Sample data set

Fig. 5 shows a representative data set from the second deployment for the instrument located at 10 m. This deployment spanned the period from mid May to mid August 1987. The data indicates that fouling was not a problem with the PAR, fluorescence or DO sensors. The anti-foulant treatment on the transmissometers was not as successful. In one case a barnacle was observed growing in the light path. The data show a steady decline in transmission with time puncuated by occasional abrupt increases which are

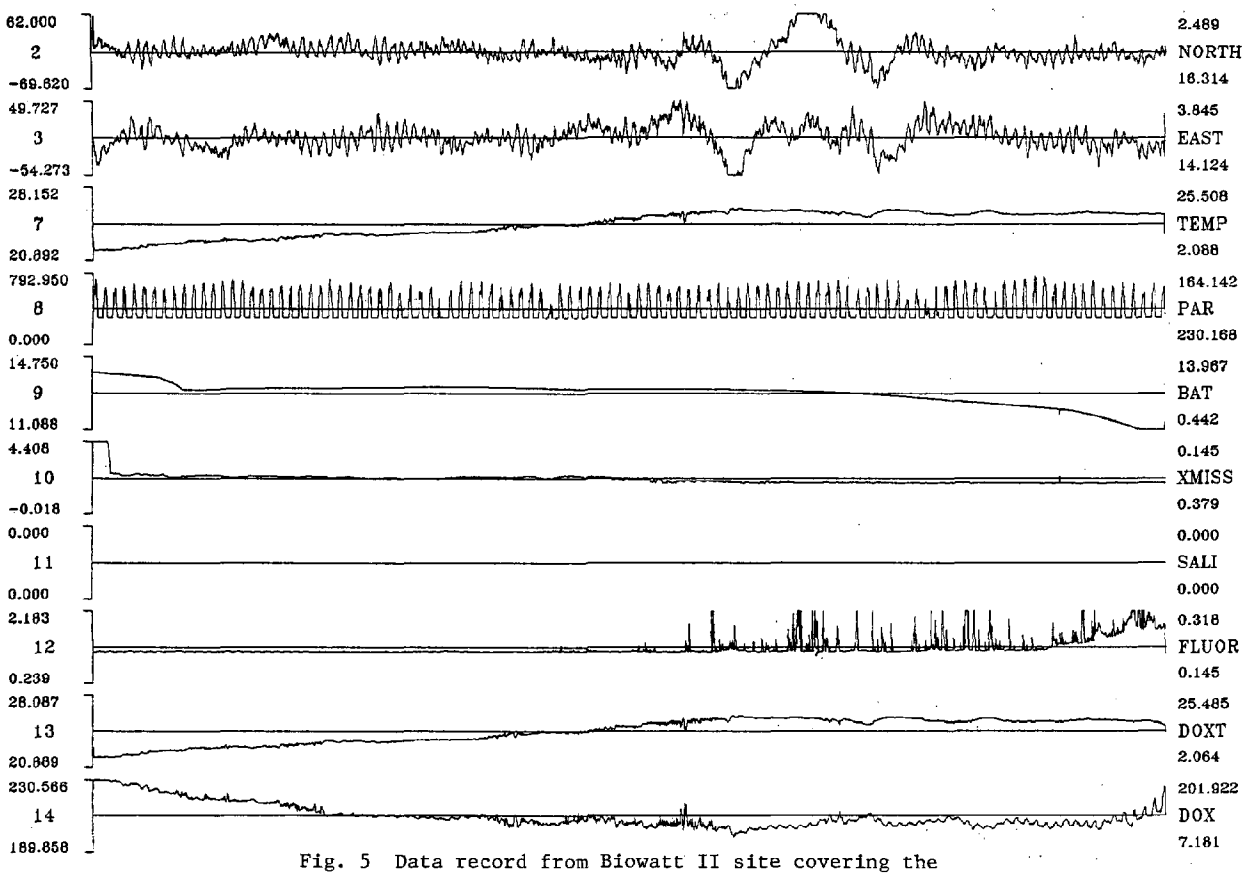

Fig. 5 Data record from Biowatt II site covering the period May 13- Aug 30, 1987 for 10 m. Figures to the left of each panel are the min and max for the y axis. Figures to the right are the mean and Std. Dev.

probably the result of accumulated material being washed off during periods of strong currents. Note that the DO sensor is sensitive enough to detect a tiny diurnal signal which is in the expected phase relationship with the PAR signal.

4.2 Table of data return.

DEPLOYMENT	1([1])	2	3	
DAYS	72	109	84	
	%	%	%	AVG/SENSOR
Current	88	97	100	95
Temperature	88	97	100	95
Irradiance	63	97	100	87
Transmission	68	97([2])	100	87
Fluoresecence	75	72	100	82
DO temperature	75	71	86	77
Dissolved Oxygen	50	64	46	53
Conductivity	100	100	100	100
AVG/DEPLOYMENT	76	87	92	

[1] Tape broke resulting in loss of all data from 120 m.
[2] Data suspect evidence of fouling.

5.0 CONCLUSIONS

A standard EG&G VMCM curent meter was adapted and used to be the host of several bio–optical and physical sensors: irradiance, transmissometer, conductivity, fluorescence and dissolved oxygen. The modifications included adapting the VMCM frame to hold the sensors externally, some hardware and software changes to sample the additional sensors and adding a signal processing board to anti–alias the signals and do some control on the sensors.

The maximum deployment time of this instrument is mainly related to the biofouling. Secondarily, relationship between power consumption of the sensors and power available due to space limitations defines the maximum deployment time. Finally, the data storage system used puts also a limit to the deployment time. In our case, the three limiting factors described above indicated a four months deployment time as a safe limit.

In the future, it is the intention of the group that developed this system to make full use of the availability of solid state memory and digital signal

processing techniques in conjuction with widespread power switching to realize longer deployment times. Attention will also have to be paid to longer acting anti–foulants for the optical instruments.

6. ACKNOWLEDGEMENTS

The conversion of the EG&G VMCM into a MVMS instrument was funded by the Office of Naval Research contract no. N00014–84–C–0132 under the Biowatt II program. The Biowatt Mooring Group consisted of principal investigators and technical support staff at Lamont–Doherty Geological Observatory (LDGO) and the University of Southern California (USC). At LDGO the members were: I. Bitte, C. Langdon, J. Luther, M. Maccio, J. Marra, and L. Sullivan. At USC: A. Bratcovich, T. Dickey, D. Manov and J. Scott.

7. REFERENCES

Dickey, T., E. Hartwig and J. Marra. (1986). The Biowatt bio–optical and physical moored measurement program. EOS Trans. AGU. 67:650–651.

Langdon, C. (1984). Dissolved oxygen monitoring system using a pulsed electrode: design, performance and evaluation. Deep–Sea Res. 31:1357–1367.

Maccio, M., C. Langdon and J. Basna. (1986). Signal Processing Board for VMCM's. Manual. Lamont–Doherty Geological Observatory Technical Report

Marra, J. and E.O. Hartwig. (1984). Biowatt: A study of bioluminescence and optical variability in the sea. EOS Trans. AGU. 65:732–733.

Weller, R.A., and R.E. Davis. (1980). A vector measuring current meter. Deep–Sea Res. 27: 565–581.

TRIBUTYLTIN AND MUSSEL GROWTH IN SAN DIEGO BAY

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ABSTRACT

During three San Diego Bay field tests (1987-1988), juvenile mussels (Mytilus edulis) were exposed to mean ambient tributyltin (TBT) concentrations from 7 to 500 ng/l for 12 weeks. Mussel lengths and weights, seawater [TBT] and various physical/chemical parameters were measured weekly. TBT bioaccumulation was measured at the end of each test. At mean seawater [TBT] $\geq$200 ng/l significant reductions in mussel growth rates were observed. Other environmental factors appear to modify the effects of TBT on juvenile mussel growth below 100 ng/l TBT. No clear relationship between growth rate and [TBT] in mussel tissues at concentrations below 1.5 ug TBT/g tissue was found. Although there appears to be a linear relationship between TBT bioaccumulation and seawater [TBT], the relationship between bioconcentration factor and seawater [TBT] appears to be inverse and exponential. No dose-related mortality was observed.

INTRODUCTION

Mussel growth can be an effective and dynamic indicator of environmental stress because it represents an integrated response of biological processes to the environment (1). The effects of tributyltin (TBT) on mussel growth have been studied in the laboratory (2, 3, 4, 5, 6), the field (7) and in a Portable Environmental Test System (PETS) for a site-specific, flow-through bioassay (1). In laboratory tests with juvenile mussels, significant reductions in growth have been reported at 240 and 400 ng/l TBT (2, 3, 4, 6) for tests lasting 49 and 7 days, respectively. In another test with adults, significant reductions were reported at 310 ng/l TBT after a 66-day exposure period (5).

These tests have limited environmental significance for several reasons. First, high TBT concentrations ([TBT]) are only characteristic of enclosed basins with poor tidal exchange and many organotin-painted vessels (8, 9, 10). Most harbor environments have much lower [TBT] and environmental impact is more difficult to assess. Second, mussel growth under laboratory conditions is significantly different than field growth and therefore not environmentally realistic (11). Third, growth rate may be affected by [TBT] in tissues. Previous field studies have shown that from 60 to 112 days may be necessary for TBT to reach equilibrium in tissues of mussels and oysters, respectively (12, 13).

Stephenson et al. (7) avoided some of these problems by conducting a 3-month field study of juvenile mussel growth in San Diego Bay and reported significant growth reductions for transplanted mussels in the Shelter Island yacht basin at 230 ng/l TBT. However, TBT measurements were extremely limited, and as in most field studies, the control site selection and subsequent comparisons were misleading. Reductions in mussel growth rates attributed to TBT exposure may have resulted from unmeasured stress factors (11, 14). Most field assessments of TBT effects on bivalve growth (7, 15, 16, 17, 18) have not adequately defined natural TBT variability or measured other stress-inducing physical/chemical factors that could affect growth.

Site-specific, flow-through bioassays potentially provide more meaningful results because they combine the advantages of controlled laboratory dosing with realistic field test conditions. In our previous PETS experiments in San Diego Bay, juvenile mussel growth was identified as the most sensitive TBT bioindicator tested, but the results were conflicting (1, 12). In one test, no effects occurred after 56 days at 160 ng/l TBT. In another, significant reductions in mussel growth were found after 63 days at 70 ng/l TBT. TBT effects were overestimated due to system-induced stress and the inability to provide realistic conditions for juvenile mussel growth (12).

Important issues in predicting environmental impact remain unresolved due to inconclusive results from laboratory, field and site-specific studies. Part of this deficiency can be attributed to the paucity of bivalve growth measurements at TBT exposures <100 ng/l that are characteristic of most harbor environments. We conducted extensive field studies to monitor weekly changes in seawater [TBT] and juvenile mussel growth rates to clarify some of these issues. Since our previous work has suggested other environmental factors can

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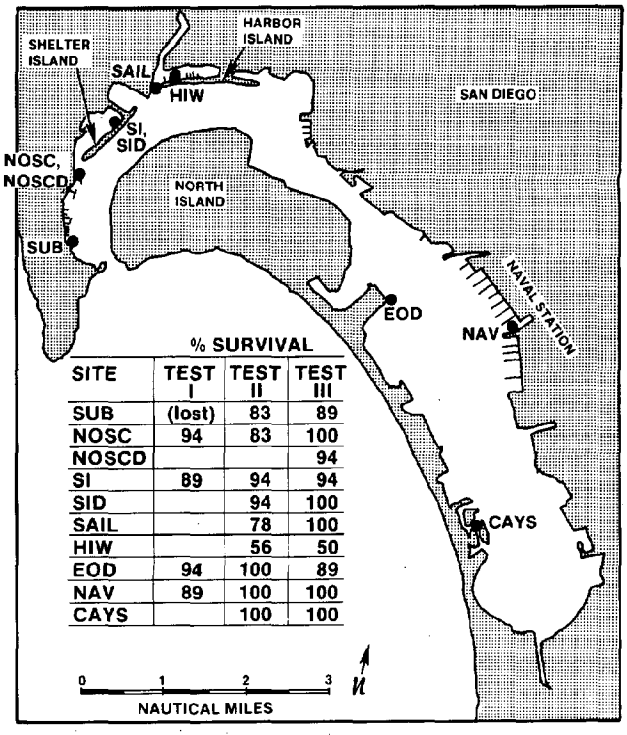
modify TBT effects in juvenile mussel growth, various physical/chemical factors were monitored at each site to assess their separate and combined effects on growth. This report summarizes the results of these studies and discusses their significance in relation to previous work.

METHODS AND MATERIALS

Three separate tests were conducted over a 12-month period at 10 different sites in San Diego Bay (Figure 1). Test I lasted 18 weeks (August to December 1987). Tests II and III lasted 12 weeks; January to April 1988, and April to July 1988, respectively. All mussels (Mytilus edulis) were collected from a large population at a relatively clean site near the mouth of San Diego Bay (Figure 1) where [TBT] in seawater and mussel tissues were low (~30 ng/l TBT, ~0.12 ug TBT/g tissue, respectively). Animals were initially selected by length. Each test began with 18 animals (10-12 mm in length, $\bar{X} \cong 11.0$ mm) per tray. All test mussels were suspended from floating piers and continuously submerged 1 m below the surface or 3 m below the surface at "deep" sites. Whole animal wet weights and lengths, seawater [TBT], chlorophyll-a, temperature, salinity, dissolved oxygen and pH were measured weekly. During Tests II and III, temperature measurements were made continuously at 30-minute intervals with a field-deployed, battery-operated Tempmentor (Ryan Instruments). TBT accumulated in mussel tissues was measured at the end of each test. Copper was only measured in mussel tissues from selected sites in Test III. Each test was limited to 12 weeks to minimize the effects of gametogenesis on growth rate.

Ten different sites were monitored (Figure 1): six Navy sites and four marina sites. The six Navy sites were selected for low [TBT] (8) and varying levels of boating activity. Subase San Diego (SUB) and Naval Station San Diego (NAV) had many large vessels. The Explosive Ordnance Disposal Pier (EOD) had the fewest boats and was the test site in previous PETS experiments (1, 12). Navy Sailing Club Recreational Marina (SAIL) and Naval Ocean Systems Center (NOSC) were selected for proximity to yacht basins with high TBT levels. NOSCD was approximately 3 m below the surface at NOSC. The four marina sites in three yacht basins were selected for high seawater [TBT] (8). The yacht basins studied were Shelter Island (SI), Harbor Island (HIW), and Coronado Cays (CAYS). SID was approximately 3 m below the surface at SI. Deep sites were included because previous measurements had shown that [TBT] was lower near the bottom (19).

TBT concentrations in seawater and mussel tissues were measured according to Stallard et al. (20). For seawater, purge and trap hydride derivatization was followed by atomic absorption spectrophotometry. For tissues, acid/solvent extraction was followed by grignard derivatization and gas chromatography with flame photometric detection. All TBT measurements are reported to two significant digits. Copper in mussel tissues was measured by AA after acid digestion. Chlorophyll-a was measured by fluorometry after cold extraction (21).



% SURVIVAL

SITE	TEST I	TEST II	TEST III
SUB	(lost)	83	89
NOSC	94	83	100
NOSCD			94
SI	89	94	94
SID		94	100
SAIL		78	100
HIW		56	50
EOD	94	100	89
NAV	89	100	100
CAYS		100	100

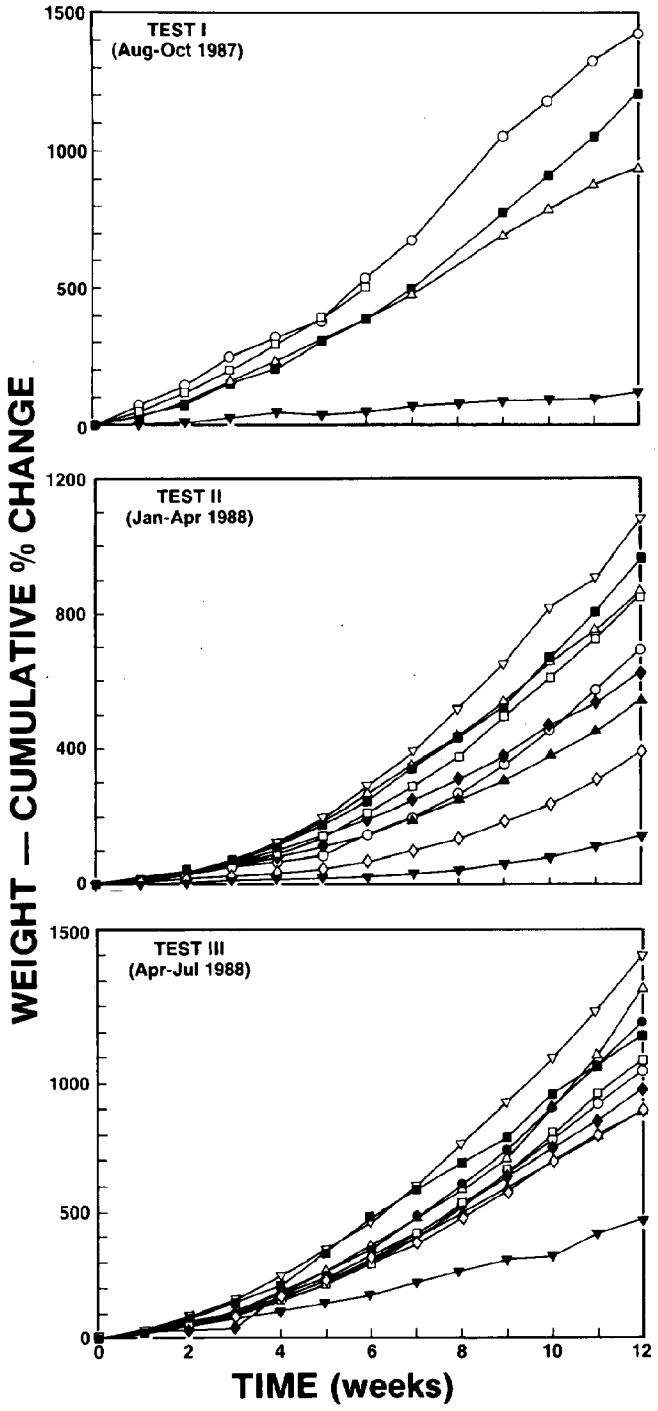
Figure 1. Percent mussel survival (n=18) at San Diego Bay test sites for Test I, II and III.

For each site, cumulative percent increases in lengths and weights were calculated to normalize size effects and estimate relative growth rates for graphic presentation. Statistical analyses were conducted only on survivor data. Serial ANOVAs ($p < 0.05$) were performed on weight and length data at each sampling interval to test for differences among sites. If differences were detected, Duncan's new multiple-range test was used to determine which sites were similar. A series of linear regression analyses were performed to compare slopes of calculated growth rates. Slopes differing by more than two standard errors ($p < 0.05$), were considered significantly different.

Although changes in mussel weights and lengths were used to assess TBT effects on growth, weight measurements appeared to be more accurate and sensitive indicators. The relationship between weight changes and [TBT] in seawater and tissues will be emphasized here. Length data are included for comparisons with other work.

RESULTS

Percent survival by site and test are shown in Figure 1. Survival was generally high at all sites except HIW, where it was very low (50-56%). Figure 2 includes relative growth estimates from changes in mussel weights, calculated mean growth rates



Site		Growth Rate (mg/wk)	Growth Rate (mm/wk)	Seawater $\bar{X}$[TBT] (ng/ℓ)	Tissue $\bar{X}$[TBT] (µg/g)	BCF
NOSC	(○)	253	1.42	80	1.4	17,500
EOD	(■)	246	1.43	10	0.32	32,000
NAV	(△)	175	1.22	8.4	0.37	44,000
SUB	(□)	—	—	19	—	—
SI	(▼)	17	0.21	530	4.5	8,500
SAIL	(▽)	158	1.20	56	0.33	5,900
EOD	(■)	141	1.22	11	0.08	7,300
NAV	(△)	134	1.19	9.0	0.10	11,100
SUB	(□)	132	1.10	18	0.23	12,800
NOSC	(○)	91	0.94	59	0.54	9,200
HIW	(◆)	95	0.92	130	0.69	5,300
CAYS	(▲)	78	0.83	80	0.75	9,400
SID	(◇)	55	0.66	200	1.0	5,000
SI	(▼)	17	0.31	360	1.7	4,700
SAIL	(▽)	246	1.62	28	0.53	18,900
NAV	(△)	205	1.54	6.5	0.12	18,500
NOSCD	(●)	204	1.44	15	0.45	30,000
EOD	(■)	197	1.39	7.0	0.12	17,100
SUB	(□)	180	1.32	10	0.34	34,000
NOSC	(○)	178	1.29	27	0.79	29,300
HIW	(◆)	157	1.25	72	0.56	7,800
CAYS	(▲)	153	1.17	42	0.78	18,600
SID	(◇)	147	1.15	64	1.1	17,200
SI	(▼)	70	0.69	200	2.3	11,500

Figure 2. Mussel growth expressed as cumulative % change in weight for Test I, II, III. Mean mussel growth rates (mg/wk, mm/wk) paired with mean TBT seawater concentrations (ng/l), final TBT concentrations in tissues (ug/g) and calculated bioconcentration factors (BCF).

(mg/wk and mm/wk), mean [TBT] in seawater (ng/l) and tissues (ug TBT/g tissue wet weight), and bioconcentration factors (BCF) (calculated as the ratio of TBT in tissue to TBT in seawater) for Tests I, II and III. Test I values only include data for the first 12 weeks for comparisons with Tests II and III. Since tissue [TBT] was measured at the end of the test, the values are 18-week means. Growth rates (± 95% CL) are shown in Figure 3. Figures 2 and 3 show that there were distinct differences among sites in each test and that some growth rates in each test were significantly different.

Copper concentrations in the tissues of mussels from SAIL, EOD, NOSC, SID and SI were 3.3, 3.4, 3.4, 9.9 and 21.4 ug Cu/g tissue wet weight, respectively. There was little variability among sites in salinity, dissolved oxygen and pH, so these factors will not be presented or discussed. Means, minima and maxima for [TBT] in seawater, temperature and chlorophyll-a are given in Table 1. The highest [TBT] with the most extreme natural variability was measured in the vicinity of marinas and is presented in Figure 4. Most test sites had lower and less variable [TBT]. [TBT] decreased at most sites, particularly SI, from Test I to Test III.

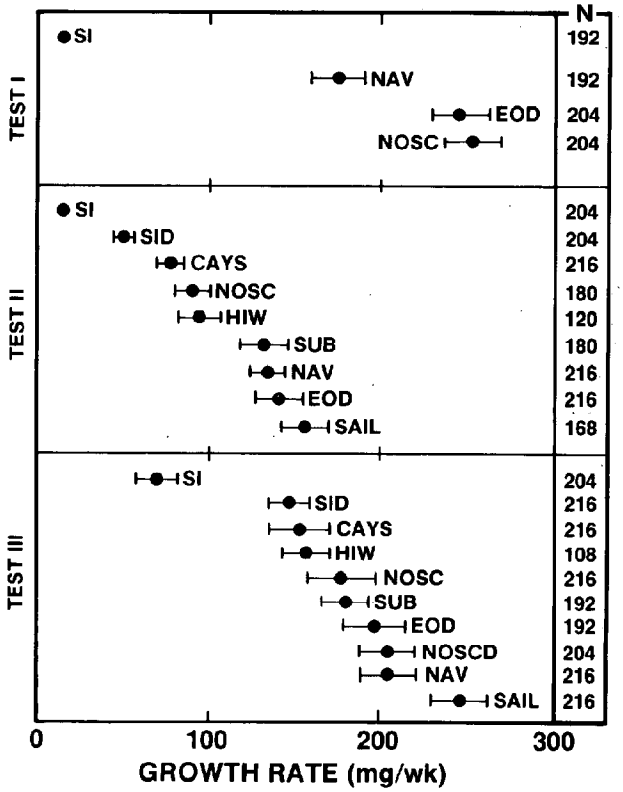


Figure 3. Mean mussel growth rates (mg/wk) by site for Test I, II, III. Error bars indicate 95% confidence limits (±2 standard errors). N = number of measurements.

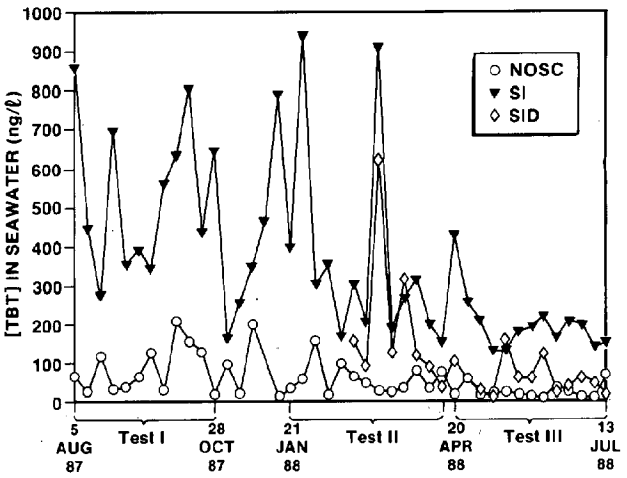


Figure 4. Natural weekly variability in seawater [TBT] for Tests I, II, III.

The graphs in Figure 5 were generated to clarify some of the relationships suggested by the data in Figure 2. A comparison of mussel growth rate and seawater [TBT] (Figure 5A) suggests no clear relationship below 100 ng/l TBT. At 80 ng/l TBT growth rates ranged from 78 to 253 mg/wk. At 200 ng/l TBT and above growth rates were much lower. A comparison of growth rate and [TBT] in mussel tissues (Figure 5B) shows that there is no clear relationship below 1.5 ug TBT/g tissue. Between 1 and 1.5 ug TBT/g tissue, mussel growth rates varied from 64 to 253 mg/wk. Growth rates were much lower above 1.5 ug TBT/g tissue.

There appears to be a linear relationship between [TBT] in mussel tissues and mean [TBT] in seawater (Figure 5C). However, the relationship between mussel BCF and [TBT] in seawater (Figure 5D) appears to be inverse and exponential. The relationship between BCF and mussel growth rate is also exponential (Figure 5E). The highest BCF's are all associated with growth rates above 170 mg/wk. Nearly all sites with the slowest growing mussels were associated with BCF's below 15,000, while the majority of fastest growers were associated with BCF's above 15,000.

DISCUSSION

The results of three 12-week field studies indicate that TBT and other highly variable natural factors affect juvenile mussel growth. Although the lowest growth rates were at the highest [TBT] (≥200 ng/l), all other growth rates were not well correlated with [TBT]. Growth rates were highest in the summer when both temperature and chlorophyll-a were high. There was no correlation between [TBT] and survival, even at high [TBT]. Two important questions to be answered are 1) at what concentration does TBT become the dominant factor affecting growth and bioaccumulation, and 2) what other factors modify mussel growth rates in San Diego Bay? The literature indicates that temperature and nutrition are the most important

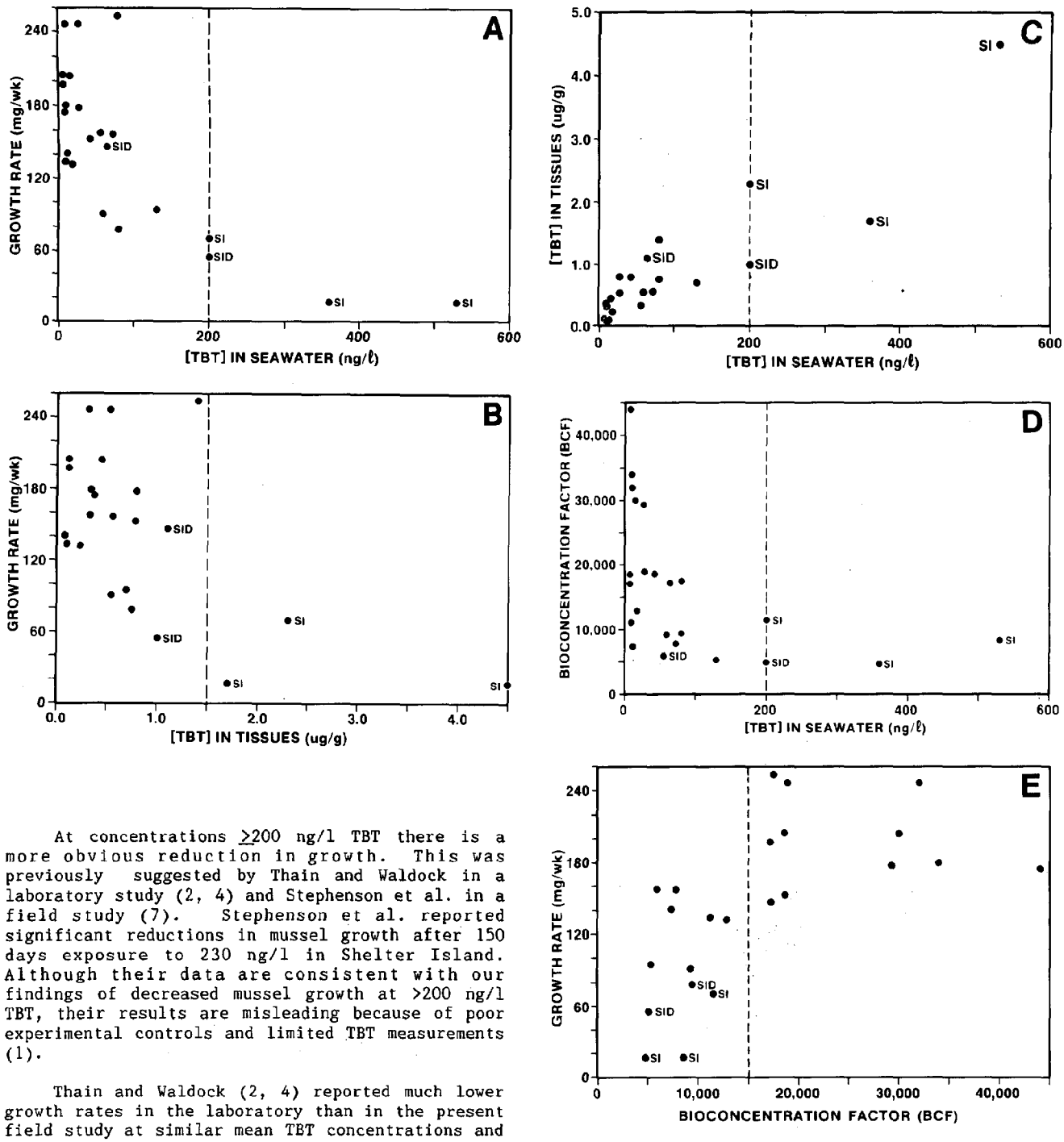
Table 1. Means, minima, maxima for [TBT] in seawater, temperature and chlorophyll-a.

	SUB	NOSC	NOSCD	SI	SID	EOD	SAIL	NAV	HIW	CAYS
[TBT] (ng/L)										
Test I										
Mean	19	80		530		10		8.4		
Min	9.0	15		270		1.0		2.8		
Max	48	210		860		18		12		
Test II										
Mean	18	59		360	200	11	56	9.0	130	80
Min	6.0	18		150	36	4.9	27	3.8	20	22
Max	47	160		940	620	36	100	16	320	210
Test III										
Mean	10	27	15	200	64	7.0	28	6.5	72	42
Min	4.4	8.0	3.4	130	17	3.8	9.7	2.3	36	18
Max	19	70	42	430	160	10	75	12	140	140
TEMPERATURE (°C)										
Test I										
Mean	19.6	19.8		21.1		22.7		23.5		
Min	18.1	18.4		19.0		20.9		21.4		
Max	21.5	20.7		22.9		25.1		25.0		
Test II										
Mean	15.5	16.0		16.5	17.3	17.0	16.2	17.1	16.4	17.9
Min	12.8	13.0		13.4	16.2	14.1	13.1	13.4	13.2	12.8
Max	19.6	19.8		20.2	19.1	21.8	19.9	21.4	20.3	23.5
Test III										
Mean	17.0	17.7	17.3	18.9	17.4	20.4	18.7	20.8	19.2	22.5
Min	13.0	13.9	13.4	16.0	14.6	16.8	15.3	18.3	16.7	18.8
Max	21.1	21.5	21.8	22.7	18.8	23.9	22.2	24.0	22.6	25.8
CHLOROPHYLL-A (ug/L)										
Test I										
Mean	2.10	2.75		2.95		1.78		2.05		
Min	0.76	1.53		2.04		1.23		1.29		
Max	3.44	3.45		4.24		2.45		3.08		
Test II										
Mean	2.33	2.37		1.61	3.01	2.01	1.90	1.92	2.31	2.28
Min	1.22	1.49		1.10	1.82	1.07	1.04	1.11	1.32	1.12
Max	6.39	5.41		2.31	4.89	3.29	3.35	2.90	5.41	4.87
Test III										
Mean	3.89	3.27	3.68	2.36	5.43	1.52	2.54	1.40	2.48	1.74
Min	1.50	1.46	1.12	1.60	1.89	0.79	1.53	0.60	1.57	0.95
Max	9.92	5.86	6.72	3.50	13.16	2.08	4.41	2.49	3.56	3.17

factors controlling mussel growth and that temperature, nutrition and mussel growth have a high degree of temporal and spatial variability (22, 23). Site and seasonal differences in these factors seem to be important in the present study.

Effects on Growth Rates

The lowest growth rates were measured at the highest [TBT] in all three tests (Figure 5A). The four lowest growth rates were from the Shelter Island yacht basin, characterized by very poor tidal flushing and many other factors that affect mussel growth (1). However, the highest growth rates were not at the lowest [TBT]. Mussels at NOSC, exposed to a mean of 80 ng/l TBT, grew faster than all others. Growth rates of mussels exposed to 80 ng/l TBT at NOSC and other sites ranged from 78 to 253 mg/wk. Below 100 ng/l TBT the potential TBT effects on juvenile mussel growth may be reduced by environmental factors that enhance growth or amplified by factors that retard growth. This may explain the wide range of mussel growth rates measured in this study.



At concentrations ≥200 ng/l TBT there is a more obvious reduction in growth. This was previously suggested by Thain and Waldock in a laboratory study (2, 4) and Stephenson et al. in a field study (7). Stephenson et al. reported significant reductions in mussel growth after 150 days exposure to 230 ng/l in Shelter Island. Although their data are consistent with our findings of decreased mussel growth at >200 ng/l TBT, their results are misleading because of poor experimental controls and limited TBT measurements (1).

Thain and Waldock (2, 4) reported much lower growth rates in the laboratory than in the present field study at similar mean TBT concentrations and exposure periods. At SI in Test III, mussels increased in weight approximately one order of magnitude more than their laboratory control animals (220 vs 20%). SI mussels in Test I were exposed to TBT concentrations an order of magnitude higher than laboratory animals (530 vs 50 ng/l) and increased in weight by about the same amount (70 vs 65%).

Figure 5.
A) Mussel growth rate and seawater [TBT].
B) Mussel growth rate and bioaccumulation.
C) Mussel bioaccumulation and seawater [TBT].
D) Bioconcentration factor and seawater [TBT].
E) Mussel growth rate and bioconcentration factor.

Only Shelter Island sites are indicated (SI, SID). The vertical dashed lines are for emphasis only.

In previous PETS bioassays at the EOD site (12), we found significant reductions in mussel growth rate at 70 - 80 ng/l TBT, concentrations much lower than reported in other laboratory or field studies (2, 3, 4, 5, 6, 7), but the bioassay results were conflicting. This inconsistency suggested that TBT effects on juvenile mussel growth were artificially enhanced and overestimated due to stress on the test animals (1). The present study clearly shows that 80 ng/l TBT does not affect mussel growth unless the animals are stressed by other factors.

TBT Bioaccumulation

The early laboratory work suggests bivalve growth rates are directly affected by accumulated TBT (3, 17, 24). Figure 5B shows that the lowest growth rates are associated with the highest [TBT] in mussel tissues and that below 1.5 ug TBT/g tissue there is no clear correlation between TBT in mussel tissues and mussel growth rates. Test I mussels at NOSC accumulated 1.4 ug TBT/g tissue. Excluding the Shelter Island yacht basin, this is the highest tissue level measured in San Diego Bay mussels (Seligman, 1988, pers. comm.). Yet, the growth rate for these mussels (253 mg/wk) was the highest measured in all tests. It appears that high tissue levels of TBT (1.4 ug TBT/g tissue) do not reduce mussel growth rate unless the animals are stressed by other factors.

Davies et al. (13) have shown that TBT accumulation by oysters in the field is generally higher than in the laboratory and it takes longer to reach equilibrium. Laughlin et al. (25) suggest similar differences in accumulation of TBT by mussels based on a laboratory study. They also report a significant difference between measured BCF's (~5,000) and the BCF predicted (260) by TBT partitioning coefficients. Recently, it has been suggested that oysters may have BCF's near 500,000 (Huggett, 1988, pers. comm.). In the present study, most mussels with growth rates above 170 mg/wk had BCF's above 15,000. This suggests a relationship between mussel growth rate and bioaccumulation. The present study clearly shows that mussel BCF's below 10,000 can result from field exposures as low as 11 ng/l TBT or as high as 530 ng/l TBT. These differences are attributable to stressed animals. In the laboratory, stress can be caused by maintenance under unnatural conditions (26, 27, 28). In the field this stress could be attributed to TBT, other contaminants or physical/chemical factors (1).

Kiorboe et al. (29) suggested growth rates in optimum laboratory studies do not approach growth rates in the field primarily because M. edulis derives additional nutrition from suspended particulates. They may also accumulate additional TBT from these suspended particulates. Laboratory studies have shown that TBT rapidly binds to suspended sediment particles, algal cells and bacterial cells (25, 30, 31, 32), and that suspended particulates enhance TBT bioaccumulation in mussels (11, 25) and oysters (11, 24).

Previous flow-through bioassays (12), Hawaii microcosm studies (Seligman, 1988, pers. comm.), San Diego Bay monitoring studies (Dooley, 1988, pers. comm.) and the present three field studies have shown a similar relationship between bivalve BCF's and seawater [TBT]. Results from the present study suggest the BCF is not a very precise predictor of [TBT] in mussel tissue since other factors can affect growth rates and TBT bioaccumulation. It also casts doubt on the utility of extrapolating environmental impact from tissue levels (4, 9, 16), extrapolating seawater TBT concentrations from tissue levels (13, 33, 34,) or using field data to verify laboratory data (16, 17).

Natural Variability

There is a wide range of mussel growth rates in San Diego Bay and a wide range of factors affecting growth. Daily maximum temperature changes of up to 5°C and overall temperature ranges of over 8°C were measured. There were order-of-magnitude shifts in seawater [TBT] and chlorophyll-a concentrations at some sites (Table 1). Previous measurements have shown that [TBT] near the bottom are significantly lower than near the surface (19), and tidal fluctuations in [TBT] vary by a factor of 20 near Shelter Island (35, 36). Water bodies cannot be adequately characterized without accounting for this kind of spatial and temporal variability (37).

The site with significantly lower growth rates in all three tests was Shelter Island. Growth rates at SID were significantly higher in each test. Juvenile mussels near the bottom in Shelter Island grew significantly faster than those near the surface. They also had less TBT and copper in their tissues. Mussel growth rates and TBT in mussel tissues generally decreased between Tests I and II and increased between Tests II and III, while [TBT] in seawater generally decreased between Test I and III. Higher growth rates are generally attributed to higher temperatures and more phytoplankton (22, 23). If phytoplankton increase TBT bioavailability to mussels (25), and higher temperatures increase filtration rates (22) mussels will accumulate more TBT at higher phytoplankton concentrations and higher temperatures.

In Test I summer temperatures at some sites reached 25°C, which may reduce growth because they approach levels that adversely affect mussel physiology (38). However, Page and Hubbard (39) suggested that water temperature is not a significant factor in regulating mussel growth in California waters. San Diego Bay is very near the southern limit of the range for M. edulis (40) and high temperatures may be a limiting factor at some sites. The highest growth rates were not found at the warmest sites. This implies that San Diego Bay mussels may have adapted to higher temperatures or potentially higher growth rates were reduced by temperature stress. We did not find significant temperature or chlorophyll-a effects even though we believe they are important factors, as suggested from other work (22, 23).

Copper

Field studies provide realism but generally lack the control necessary for establishing cause-and-effect relationships, particularly with TBT (11). There are many variables other than TBT which may affect mussel growth. For example, copper concentrations between 3 and 10 ppb have been shown to reduce mussel growth rates in laboratory studies (41, 42). Copper concentrations in Shelter Island between 8 ppb and 12 ppb have been reported (43, 44). Copper alone could reduce growth in mussels. Shell deformities have also been reported at these copper concentrations (45). TBT effects can be overestimated if contaminants like copper are ignored. None of the field studies attributing growth anomalies or depressed growth in bivalves to TBT (7, 9, 18) have included measurements of other factors that could affect growth rates.

Copper concentrations were more than an order of magnitude higher than measured [TBT] (44). Measurements from Test III show mussels also accumulated copper in their tissues to levels an order of magnitude above TBT tissue levels. Mussels near the surface not only accumulated more TBT, but more copper as well. Observed differences in growth at SI and SID could be attributed to a variety of factors, including TBT, copper, temperature or chlorophyll-a. This type of variability is seldom included in laboratory bioassays or measured in field tests.

Summary

Environmental impact of TBT cannot be predicted until TBT levels in seawater and tissues have been correlated with sublethal responses in nature to clearly demonstrate a cause-and-effect relationship. An extensive field study was conducted here but the relationship remains unclear. The results of three 12-week field studies suggest that mean seawater [TBT] $\geq$ 200 ng/l caused significant reductions in mussel growth rates. Other environmental factors appear to modify the effects of TBT on juvenile mussel growth below 100 ng/l TBT. As in most field studies, absolute conclusions about TBT impacts cannot be made from these results. However, it has been demonstrated that the apparent effects of TBT on juvenile mussel growth and bioaccumulation are significantly different than suggested by previous laboratory and field studies due to other environmental factors that can reduce or amplify TBT effects.

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REFERENCES

1. Salazar, M. H. and S. M. Salazar. 1987. TBT effects on juvenile mussel growth. In: Proceedings, Oceans 1987 Conference, Halifax, Nova Scotia, Canada, 28 Sept - 1 Oct 1987, Organotin Symposium. Vol. 4 pp. 1504-1510.

2. Thain, J. E. and M. J. Waldock. 1985. The growth of bivalve spat exposed to organotin leachates from antifouling paints. ICES Paper CM 1985/E:28, International Council for the Exploration of the Sea, Copenhagen.

3. Thain, J. E. 1986. Toxicity of TBT to bivalves: Effects on reproduction, growth and survival. In: Proceedings, Oceans 1986 Conference, Washington, D. C., 23-25 Sept 1986, Organotin Symposium, Vol. 4, pp. 1306-1313.

4. Thain, J. E. and M. J. Waldock. 1986. The impact of tributyl tin (TBT) antifouling paints on molluscan fisheries. Wat. Sci. Tech. 18:193-202.

5. Valkirs, A. O., B. M. Davidson, and P. F. Seligman. 1987. Sublethal growth effects and mortality to marine bivalves from long-term exposure to tributyltin. Chemosphere 16(1):201-220.

6. Stromgren, T. and T. Bongard. 1987. The effect of tributyltin oxide on growth of Mytilus edulis. Mar. Poll. Bull. 18(1):30-31.

7. Stephenson, M. D., D. R. Smith, J. Goetzl, G. Ichikawa and M. Martin. 1986. Growth abnormalities in mussels and oysters from areas with high levels of tributyltin in San Diego Bay. In: Proceedings, Oceans 1986 Conference, Washington D. C., 23-25 Sept 1986, Organotin Symposium, Vol. 4, pp. 1246-1251.

8. Grovhoug, J. G., P. F. Seligman, G. Vafa and R. L. Fransham. 1986. Baseline measurements of butyltin in U. S. harbors and estuaries. In: Proceedings, Oceans 1986 Conference, Washington D. C., 23-25 Sept 1986, Organotin Symposium, Vol. 4, pp. 1283-1288.

9. Waldock, M. J., J. E. Thain and M. E. Waite. 1987. The distribution and potential toxic effects of TBT in UK estuaries during 1986. Appl. Organomet. Chem. 1:287-301.

10. Maguire, R. J. 1987. Environmental aspects of tributyltin. Appl. Organomet. Chem. 1:475-498.

11. Salazar, M. H. 1986. Environmental significance and interpretation of organotin bioassays. In: Proceedings, Oceans 1986 Conference, Washington D. C., 23-25 Sept 1986, Organotin Symposium, Vol. 4, pp. 1240-1245.

12. Salazar, S. M., B. M. Davidson, M. H. Salazar, P. M. Stang and K. Meyers-Schulte. 1987. Field assessment of a new site-specific bioassay system. In: Proceedings, Oceans 1987 Conference, Halifax, Nova Scotia, Canada, 28 Sept - 1 Oct 1987, Organotin symposium, Vol. 4 pp. 1461-1470.

13. Davies, I. M., J. C. McKie and J. D. Paul. 1986. Accumulation of tin and tributyltin from anti-fouling paint by cultivated scallops (Pecten maximus) and Pacific oysters (Crassostrea gigas). Aquaculture 55(2):103-114.

14. White, H. H. and M. A. Champ. 1983. The great bioassay hoax, and alternatives. In: R. A. Conway and W. P. Gulledge (Eds.), Hazardous and Industrial Solid Waste Testing: Second Symposium. ASTM STP 805. American Society for Testing and Materials. pp. 299-312.

15. Alzieu, C. 1986. TBT detrimental effects on oyster culture in France - Evolution since antifouling paint regulation. In: Proceedings, Oceans 1986 Conference, Washington, D. C., 23-25 Sept 1986, Organotin Symposium, Vol. 4, pp. 1130-1134.

16. Waldock, M. J. 1986. TBT in UK estuaries, 1982-86. Evaluation of the environmental problem. In: Proceedings, Oceans 1986 Conference, Washington, D. C., 23-25 Sept 1986, Organotin Symposium, Vol. 4, pp. 1324-1330.

17. Thain, J. E., M. J. Waldock and M. E. Waite. 1987. Toxicity and degradation studies of tributyltin (TBT) and dibutyltin (DBT) in the aquatic environment. In: Proceedings, Oceans 1987 Conference, Halifax, Nova Scotia, Canada, 28 Sept - 1 Oct 1987, Organotin Symposium, Vol. 4, pp. 1398-1402.

18. Wolniakowski, K. U., M. D. Stephenson and G. S. Ichikawa. 1987. Tributyltin concentrations and Pacific oyster deformations in Coos Bay, Oregon. In: Proceedings, Oceans 1987, Halifax, Nova Scotia, Canada, September 28 - October 1, 1987, Organotin Symposium, Vol. 4:1438-1442.

19. Seligman, P. F., J. G. Grovhoug and K. E. Richter. 1986. Measurement of butyltins in San Diego Bay, Ca. In: Proceedings, Oceans 1986 Conference, Washington D. C., 23-25 Sept 1986, Organotin Symposium, Vol. 4, pp. 1289-1296.

20. Stallard, M. O., S. Y. Cola and C. A. Dooley. 1988. Optimization of butyltin measurements for seawater, tissue and marine sediment samples. In press: Appl. Organomet. Chem.

21. Venrick, E. L. and T. L. Hayward. 1984. Determining chlorophyll on the 1984 CALCOFI Surveys. CalCOFI Rep., Vol. 25:74-79.

22. Seed, R. 1976. Ecology. Marine mussels: Their ecology and physiology, pp 13-65. Edited by B. L. Bayne. Cambridge: Cambridge University Press.

23. Newell, R. C. 1979. Biology of intertidal animals. 3rd ed., Marine Ecological Surveys Ltd., Faversham, Kent, 781 pp.

24. Waldock, M. J. and J. E. Thain. 1983. Shell thickening in Crassostrea gigas: organotin antifouling or sediment induced? Mar. Poll. Bull. 14(11):411-415.

25. Laughlin, R. B., Jr., W. French and H. E. Guard. 1986. Accumulation of bis(tributyltin) oxide by the marine mussel Mytilus edulis. Environ. Sci. Tech. 20:884-890.

26. Bayne, B. L. and R. J. Thompson. 1970. Some physiological consequences of keeping Mytilus edulis in the laboratory. Helgo. Meeres. 20:526-552.

27. Bayne, B. L., P. A. Gabbott and J. Widdows. 1975. Some effects of stress in the adult on the eggs and larvae of Mytilus edulis L. J. Mar. Biol. Assoc. U. K. 55:675-689.

28. Bayne, B. L., D. L. Holland, M. N. Moore, D. M. Love and J. Widdows. 1978. Further studies on the effects of stress in the adult on the eggs of Mytilus edulis. J. Mar. Biol. Assoc. U. K. 58:825-841.

29. Kiorboe, T. F. Mohlenberg and O. Nohr. 1981. Effect of suspended bottom material on growth and energetics in Mytilus edulis. Mar. Biol. 61:283-288.

30. Yamada, J., K. Tatsuguchi and T. Watanabe. 1978. Uptake of triproplytin chloride by Escherichia coli. Agric. Biol. Chem. 42:1867-1870.

31. Blair, W. R., G. J. Olson, F. E. Brinckman and W. P. Iverson. 1982. Accumulation and fate of tri-n-butyltin cation in estuarine bacteria. Microb. Ecol. 8:241-251.

32. Dooley, C. A. and V. Homer. 1983. Organotin compounds in the marine environment: Uptake and sorption behavior. Naval Ocean Systems Center Technical Report #917.

33. Thain, J. E., M. J. Waldock and M. Helm. 1986. The effect of tri-butyl-tin on the reproduction of the oyster Ostrea edulis. ICES Paper CM 1986/E:14, International Council for the Exploration of the Sea, Copenhagen.

34. Bryan, G. W., P. E. Gibbs, G. R. Burt and L. G. Hummerstone. 1987. The effects of tributyltin (TBT) accumulation on adult dog-whelks, Nucella lapillus: long-term field and laboratory experiments. J. Mar. Biol. Assoc. U. K. 67(3):525-544.

35. Clavell, C., P. F. Seligman, P. M. Stang. 1986. Automated analysis of organotin compounds: a method for monitoring butyltins in the marine environment. In: Proceedings, Oceans 1986 Conference, Washington D. C., 23-25 Sept 1986, Organotin Symposium, Vol. 4, pp. 1152-1154.

36. Stang, P. M., D. R. Bower and P. F. Seligman. 1988. Vertical and temporal variability of tributyltin in San Diego Bay. (In prep.)

37. Carpenter, J. H. and R. J. Huggett. 1984. Meaningful chemical measurements in the marine environment - transition metals. In: H. H. White (Ed.), Concepts in Marine Pollution Measurements. Maryland Sea Grant Publication, University of Maryland, College Park, pp. 379-403.

38. Bayne, B. L., D. A. Brown, K. Burns, D. R. Dixon, A. Ivanovici, D. R. Livingstone, D. M. Lowe, N. M. Moore, A. R. D. Stebbing, and J. Widdows. 1985. The effects of stress and pollution on marine animals. Praeger Special Studies, Praeger Scientific, New York.

39. Page, H. M. and D. M. Hubbard. 1987. Temporal and spatial patterns of growth in mussels Mytilus edulis on an offshore platform: relationships to water temperature and food availability. J. Exp. Mar. Biol. Ecol. 111:159-179.

40. Soot-Ryen, T. 1955. A report on the Family Mytilidae (Pelecypoda). Allan Hancock Pacific Expeditions, Vol. 20(1):261 pp. The University of Southern California Press, Los Angeles.

41. Manley, A. R., L. D. Gruffydd and P. C. Almada-Villela. 1984. The effect of copper and zinc on the shell growth of Mytilus edulis measured by a laser diffraction technique. J. Mar. Biol. Assoc. U K. 64:417-427.

42. Stromgren, T. 1982. Effect of heavy metal (Zn, Hg, Cu, Cd, Pb, Ni) on the length growth of Mytilus edulis. Mar. Biol. 72:69-72.

43. Krett Lane, S. M. 1980. Productivity and diversity of phytoplankton in relation to copper levels in San Diego Bay. Naval Ocean Systems Center Technical Report #533.

44. Johnston, R. K. 1988. The response of marine fouling communities to a pollution gradient in San Diego Bay, CA. Master's Thesis, San Diego State University (in prep.).

45. Sunila, I. and R. Lindstrom. 1985. Survival, growth and shell deformities of copper- and cadmium-exposed mussels (Mytilus edulis L.) in brackish water. Estuar. Coastal. Shelf Sci. 21:555-565.

TRIBUTYLTIN ANALYSES IN ASSOCIATION WITH NOAA'S NATIONAL STATUS AND TRENDS MUSSEL WATCH PROGRAM

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ABSTRACT

The concentration of butyltins including tributyltin (TBT), dibutyltin (DBT) and monobutyltin (MBT) were determined in bivalves and sediments from 36 U.S. coastal sites. Bivalves (oysters and mussels) from 97% and sediment from 75% of these sites were contaminated with butyltins. The average bivalve total butyltin concentration (640 ng/g as Sn) was 18 times higher than the average sediment concentration (36 ng/g as Sn). The most toxic butyltin, TBT, accounts on average for 74% in bivalves and 80% in sediments of the total butyltins present. Sediments may be a long-term chronic source of butyltins to estuarine ecosystems even after TBT inputs cease. Temporal concentration changes were found for Gulf of Mexico oysters, but no seasonal trends were apparent. Continued temporal monitoring will be required in order to determine what effects bans or limitation of TBT uses have on environmental levels of these contaminants. Bivalves are excellent indicator organisms for this purpose.

1. INTRODUCTION

The National Status and Trends Program for Marine Environmental Quality was established to define the geographic distribution of contaminant concentrations of organisms and sediments, determine temporal changes in those concentrations, and document biological responses to contamination. The Mussel Watch component of the NOAA Status and Trends (S&T) Program employs bivalves (oysters and mussels) as sentinel organisms of contaminant loading. Sediments are also monitored as a longer term integrator of contamination to the ecosystem.

Bivalves have proven to be valuable sentinel organisms for various pollutants[1,2,3] and reflect the current contamination burden of an ecosystem, while sediments reflect long-term contaminant loading of an ecosystem[4,5,6]. The increased concern about butyltins, especially tributyltin (TBT) from antifouling paints[7,8,9,10], led to the decision to include the analyses of butyltins, including TBT, as part of the ongoing NOAA Status and Trends Mussel Watch Program. Oysters are reported to bioconcentrate TBT from water by factors of 2,300 to 11,400 times the water concentration, rapidly reaching an equilibrium plateau and slowly depurating[11].

In order to evaluate the current status of U.S. coastal ecosystems with regard to TBT contamination, bivalves and sediments were analyzed for butyltin content. Additional oyster samples from all Gulf of Mexico sites from 1988 and selected Gulf of Mexico sites for 1986 were also analyzed to provide information on temporal variations of butyltin concentrations.

2. METHODS

Mussels and oysters were collected from 3 stations at 36 coastal sites distributed on the Atlantic, Gulf of Mexico, and Pacific coasts, including one site from Hawaii. Individual stations at each site were generally from 50 to 1000 m apart. An attempt was made to avoid known point-sources of contamination in site selection. Sample locations have been previously reported[12].

Mussels (*Mytilus edulis*) or oysters (*Crassostrea virginica* or *Ostrea sandwichensis*) were either collected by hand, tonging, or dredging. Sediments were collected with a box corer or by hand. The top 1 cm was sampled with a Teflon coated scoop. Rigorous protocols were followed to avoid sampling contamination[13]. The tongs and dredges were steel. The oyster shells were cleaned by scrubbing with seawater before opening. The animal tissue was removed from the shell and a combined sample consisting of 15 to 21 individuals was stored frozen in combusted glass jars until analysis. In the laboratory, the sample was homogenized with a Tekmar tissumizer. The animals from each station at a site were either analyzed individually (Galveston Bay) or a composit sample for each site was analyzed. Dry weight was determined on a 1-g aliquot.

The analytical method described here is a modification of previously reported methods[14,15,16]. Analytical sample sets consist of eight samples, a blank, and a spiked blank. The blank consists of all the glassware, reagent, and the internal standard (I.S.) but no sample. The spiked blank is the same except for the addition of tributyltin chloride (2.28 μg as Sn), dibutyltin dichloride (DBT, 2.38 μg as Sn), and monobutyltin

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trichloride (MBT, 2.50 μg as Sn) as reference standards. Samples spiked with these reference standards were also analyzed.

Bivalve extraction consists of weighing a 15-g sample into a 250-ml centrifuge tube, adding tripropyltin chloride (2.26 mg as Sn) as the I.S. followed by sodium sulfate (40 g) and 0.2% tropolone in CH_2Cl_2 (100 ml). The sample was extracted for 3 min with a Tekmar tissumizer. The sample was then centrifuged and the supernatant was decanted into a 500-ml flat bottom flask. The extraction was repeated two more times using 0.2% tropolone in CH_2Cl_2 (100 ml) each time and the extracts combined in the 500 ml flat bottom flask.

Sediment extraction consisted of weighing 20 g of freeze-dried sediment, adding tripropyltin chloride as internal standard, and 100 ml of 0.2% tropolone in methylene chloride in a 250 ml amber bottle with a Teflon-lined screw cap. The bottle was capped and rolled for 3 hrs. The sample was centrifuged, and the organic phase was decanted into a 500-ml flat bottom flask. The sample was extracted two more times using 100 ml of 0.2% tropolone solution and rolling for 16 and 3 hrs, respectively. The organic phase was collected in the 500-ml flask.

Hexylation

After the tissue or sediment samples were extracted, they were concentrated to 10-15 ml by means of a water bath at 60°C in a 500-ml flat bottom flask connected to a three-ball-Snyder column. The samples were transferred to 50-ml centrifuge tubes, the flat bottom flasks were rinsed twice with about 10 ml of hexane and the rinses were added to the centrifuge tubes. A clean Teflon boiling chip was added and the samples were heated in a water bath at 60°C until vigorous boiling stopped (at this point, no methylene chloride remains). The samples already in hexane were purged with nitrogen and 4 ml of 2M hexylmagnesium bromide (Grignard reagent) was added. The hexylation reaction was carried out overnight at room temperature. Five ml of 6M hydrochloric acid was added in order to neutralize excess Grignard reagent. The organic fraction was decanted, and the aqueous fraction was extracted twice more with 15 ml of pentane. The combined organic phases were concentrated on a rotary evaporator to about 5-10 ml and were further concentrated to 2 ml in a concentrator tube. The hexylated organotin compounds were separated from other polar organics using a column containing 15 g of combusted alumina and 10 g of combusted silica. The column was eluted with 50 ml of pentane. The pentane fraction was further concentrated to 500 μl in a concentrator tube in a water bath at 60°C.

Gas chromatography analysis

Samples were spiked with tetrabutyltin as recovery standard and then analyzed by gas chromatography on a HP 5790 gas chromatograph (GC) equipped with a capillary column (DB-5, 25 m x 0.25 mm ID x 0.25 mm coating. thickness) and a flame photometric detector (FPD). The GC temperature was programmed from 60°C, at a rate of 12°C/min, to a final temperature of 300°C with a hold time of 10 min. The injector temperature was 300°C and the detector temperature was 250°C. The FPD had a hydrogen-rich flame consisting of hydrogen (80 ml/min) and air (100 ml/min). The carrier gas, helium, had a flow rate of 1 ml/min. A 610 nm filter was used in the FPD in order to be specific for tin-containing compounds. The presence of the butyltins was confirmed by gas chromatograph/mass spectrometry analysis[12].

3. RESULTS AND DISCUSSION

The total butyltin bivalve concentration in ng Sn/g dry weight of tissue are reported in Table 1. The concentrations range from less than 5 (the limit of quantitation) to 3760 ng Sn/g. The bivalve concentration of total butyltin is highest in Hawaii and the West Coast, with the Gulf and East coasts having lower and similar mean concentrations (Table 1). The ranges of concentrations, however, show considerable overlap. The mean total butyltin concentrations for mussels and the two species of oysters collected are also given in Table 1. Mussels collected for this study had higher mean concentrations than oysters, *C. virginica*, although the ranges have a large overlap. All of the West Coast samples analyzed were mussel and all the Gulf of Mexico samples were oysters (*C. virginica*). The butyltin comcentrations determined for the five mussel and four oyster samples from the East Coast generally fall within the range of the West and Gulf Coast concentration ranges. Therefore, the higher West Coast concentrations may be due to sampling only mussels which may have higher bioconcentration factors or the West coastal sampling sites may contain higher water concentrations of butyltins. The composition of the butyltins is important because TBT is more toxic than the other butyltins[11]. The mean percent of TBT and ranges of TBT percent are also reported in Table 1. The concentration of TBT accounts for 25 to 100% of all the butyltins present with a mean of 74%. The mean percent TBT is highest for the East and Gulf coasts and lower for the West Coast and Hawaii samples. Oysters (*C. Virginica*) have a higher mean percent TBT than mussels (*M. edulis*) or the one sample of *O. sandwichensis*. Again it

TABLE 1. BIVALVE TOTAL BUTYLTIN CONCENTRATION AND % TBT

SITES (#)	MEAN(ppb)	RANGE	% TBT	RANGE
ALL(36)	640	<5-3760	74	25-100
EAST(9)	340	50-770	78	64-100
GULF(17)	310	<5-1180	84	50-100
WEST(9)	1210	200-2820	55	25-70
HAWAII(1)	3760		41	
ORGANISIMS				
M. EDULIS(14)	890	170-2820	60	25-100
C. VIRGINICA(22)	328	<5-1180	85	50-100
O. SANDWICHENSIS(1)	3760		41	

should be noted that the ranges of the means overlap. This may reflect differences in the ability of these bivalves to take up or metabolize TBT or difference in the butyltin composition of their respective growing waters.

The sediment total butyltin concentration ranged from less than 5 (the limit of quantitative) to 282 ng Sn/g with a mean of all sites of 36 ng Sn/g (Table 2). The Gulf of Mexico sediments had the lowest mean total butyltin concentration, while the East and West Coast and Hawaii sites had similar concentrations. Eight of the 17 or 46% of Gulf of Mexico sites contained no detectable butyltins. The mean total butyltin concentration for the remaining 9 sites (22 ng Sn/g) is still lower than the concentrations for the other areas.

TABLE 2. SEDIMENT TOTAL BUTYLTIN CONCENTRATIONS AND % TBT

SITES(#)	MEAN(ppb)	RANGE	% TBT	RANGE
ALL(33)	36	<5-282	77	42-100
EAST(8)	64	5-117	64	48-100
GULF(17)	12	<5-89	93	54-100
WEST(7)	58	6-282	77	50-100
HAWAII(1)	66		42	

The percentage of TBT in the sediment samples ranged from 42 to 100% with a mean of 77%. The lowest percent of TBT was found in sediments from Hawaii, while Gulf coastal sediments had the highest mean percent TBT. Of the 25 sites where percent TBT could be calculated, 11 were 100% TBT (7 of 9 for the Gulf Coast). Most of the butyltins found in sediments are in the form of undegraded TBT, which is also the most toxic of the butyltins. This is consistent with a mean partition coefficients determined for TBT and DBT of 4.0×10^4 and 4.5×10^2, respectively[17]. Therefore, only 4.1% and 0.044%, respectively, of TBT and DBT total water column concentration are associated with particles. This indicates that only a small percent of the butyultins found in the water column will reach the sediments. It also indicates that if TBT and DBT concentrations in the water column were equal and equilibrium were reached, that the sediments would initially contain 99% TBT and only 1% DBT. This is consistent with the findings of this study that 44% of the sediment samples analyzed contained 100% TBT. Even though the sediment butyltin concentrations are low, they may be a long-term chronic source of TBT to the ecosystem.

The Gulf of Mexico bivalve total butyltin concentrations reported in Table 1 were for samples collected in 1987. Bivalve samples collected in 1988 at all of the Gulf sites and in 1986 at 6 of the sites were also analyzed. The total butyltin concentrations for 1986, 1987, and 1988 for each site are plotted as a bar graph in Figure 1. Generally the concentrations remain approximately the same over this time period. The exception is site CCNB (Corpus Christi, Neuces Bay) where the concentration was considerably higher in 1987 and nearly the same in 1986 and 1988. Concentration at some sites decreased, while others increase between 1987 and 1988. The mean butyltin concentration for all the Gulf sites was 310 and 290 ng Sn/g for 1987 and 1988, respectively. From this Gulf of Mexico data there is no apparent change in the mean butyltin concentration between 1987 and 1988 and large changes would not be expected until the input of TBT is limited. These temporal data will allow future investigations to determine recovery time from TBT contamination when limits are placed on the use of TBT-containing anti-fouling paints.

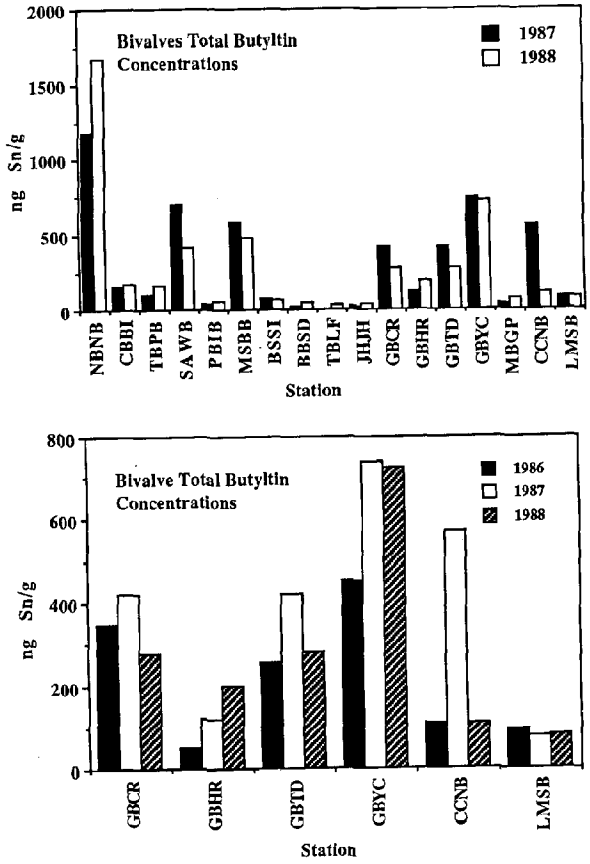

Figure 1. Gulf of Mexico Bivalve (oysters) Total Butyltin Concentration in 1986, 1987 and 1988.

4. CONCLUSIONS

Butyltins, predominantly TBT, were found in 97% of bivalve and 75% of sediment samples analyzed. Considering that TBT has been found to have a half-life of a few days in the water column[17,18], the detection of an average of 640 ng/g as Sn of butyltin in bivalve samples was unexpected. These results indicate that bivalves must be very efficient at bioaccumulating TBT from the water column. Based on reported bioconcentration

factors of 2,300 to 11,400[11], TBT must be a consistent contaminant of these bivalve gowing regions at mean concentrations in the range of 50 to 200 ng Sn/l. Sediments may be a long-term chronic source of TBT to growing waters even after limits on TBT uses are instituted. The temporal data indicates no large increase or decrease in TBT concentrations between 1986 and 1988. Determination of TBT concentration in oysters at these sites after limits are placed on TBT uses will provide valuable information on recovery time of these ecosystems.

5. ACKNOWLEDGMENTS

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6. REFERENCES

1. Farrington, J.W., Risebrough, R.W., Parker, P.L., Davis, A.C. deLappe, B., Winters, J.K., Boatwright, D. and Frew, N.M. Hydrocarbons, polychlorinated biphenyls, and DDE in mussels and oysters from the U.S. Coast, 1976-1978, The Mussel Watch. WHOI Tech. Report, WHOI-82-42, 1982, 106 p.

2. Farrington, J.W., Goldberg, E.D., Risebrough, R.W., Martin, J.H. and Bowen, V.T. U.S. "Mussel Watch" 1976-1978: An overview of the trace metal, DDE, PCB, hydrocarbon and artificial ratio-nuclide data. *Environ. Sci. Technol.*, *17*, 1983, pp. 490-496.

3. Farrington, J.W., Albaiges, J., Burns, K.A., Dunn, B.P., Eaton, P., Laseter, J.L., Parker, P.L. and Wise, S. Fossil Fuels. In: The International Mussel Watch: Report of a Workshop Sponsored by the Environmental Studies Board Commission on Natural Resources. National Research Council, 1980, pp. 7-77.

4. Wakeham, S.G. and Carpenter, R. Aliphatic hydrocarbons in sediments of Lake Washington: 1976. *Limn. Oceanogr.*, *21*, 1976, pp. 711-723.

5. Van Vleet, E.S. and Quinn, J.G. The contribution of chronic petroleum inputs to Narragansett Bay and Rhode Island Sound sediments. *J. Fisheries Res. Board. Can.*, *35*, 1978, pp. 536-543.

6. Wade, T.L. and Quinn, J.G. Geochemical distribution of hydrocarbons in sediments from Mid-Narragansett Bay, Rhode Island. *Org. Geochem.*, *1*, 1979, pp. 157-167.

7. Oceans '86 Conference Record, Organotin Symposium 4, Marine Technology Society, Washington, D.C., 1986, pp. 1101-1330.

8. Oceans '87 Proceedings, International Organotin Symposium, 4, Marine Technology Society, Washington, D.C., 1987, pp. 1295-1524.

9. Thompson, J.A.J., Sheffer, M.G., Pierce, R.C., Chau, Y.K., Cooney, J.J., Cullen, W.R. and Maguire, R.J. Organotin Compounds in the Aquatic Environment: Scientific Criteria for Assessing their Effects on Environmental Quality, National Research Council of Canada, Ottawa, Canada, 1985, pp. 1-284.

10. Interagency Workshop on Aquatic Monitoring and Analyses for Organotin Compounds, Eds. Landy, R.B., Holm, S.E. and Conner, W.G. 1986 NOAA/National Ocean Services National Marine Pollution Program Office, 1986, pp. 1-53.

11. Hall, L.W., Jr. and Pinkney, A.E. Acute and sublethal effects of organotin compounds on aquatic biota: An interpretative literature evaluation. *CRC Critical Reviews in Toxicology*, 14, 1985 pp. 159-209.

12. Wade, T.L., Garcia-Romero, B. and Brooks, J.M. Tributyltin contamination in bivalves from U.S. coastal estuaries. *Environ. Sci. Technol.*, 1988 (in press).

13. Brooks, J.M., Wade, T.L., Atlas, E.L., Kennicutt, M.C. II, Presley, B.J., Fay, R.R., Powell, E.N. and Wolff, G. Analyses of Bivalves and Sediments for Organic Chemicals and Trace Elements from Gulf of Mexico Estuaries, 1987, 355 pp.

14. Maguire, R.J. Butyltin compounds and inorganic tin in sediments in Ontario. *Environ. Sci. Technol.*, *18*, 1984, pp. 291-294.

15. Unger, M.A., MacIntyre, W.G., Greaves, J. and Huggett, R.J. GC determination of butyltins in natural waters by flame photometric detection of hexyl derivatives with mass spectrometric confirmation. *Chemosphere*, *15*, 1986, pp. 461-470.

16. Rice, C.D., Espourteille, F.A. and Huggett, R.J. Analysis of tributyltin in estuarine sediments and oyster tissue, *Crassostrea virginica*. *Appl. Organometallic Chem.*, *1*, 1987, pp. 541-544.

17. Hinga, K.R., Adelman, D. and Pilson, M.E.Q. Radiolabled butyltin studies in MERL enclosed ecosystems. Proceedings Oceans '87, Vol. 4, International Organotin Symposium, IEEE, New York, 1987, pp. 416-419.

18. Lee, R.F., Valkirs, A.O. and Seligman, P.F. Fate of tributyltin in estuarine waters. Proceedings Oceans '87, Vol. 4, International Organotin Symposium, IEEE, New York, pp. 1411-1415.

LAKE SUPERIOR WINTER WEATHER STATION

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ABSTRACT

The National Data Buoy Center, under the auspices of the National Weather Service, has maintained a network of eight environmental data collection buoys on the Great Lakes since 1979. A critical consideration is the severe winter weather on the Lakes, requiring retrieval of the buoys every autumn and their redeployment in the spring after the end of the "ice" season. Deployment and retrieval of all eight buoys every year are major operational and logistical undertakings for both NDBC and the Coast Guard, which provides the ship support for the NDBC moored buoy program. To preclude working under unsafe weather conditions, the buoys are normally deployed after the start of the shipping season and retrieved prior to its end. Consequently, several weeks of the shipping season each spring and fall are without the benefit of the reports from these weather buoys.

Faced with limited Coast Guard resources and uncontrollable weather during the winter months, NDBC decided to establish a buoy station in Lake Superior as an experimental "ice buoy" to report meteorological and oceanographic data year-round. The station was established on November 7, 1985, for long-term evaluation, which is still ongoing (Figure 1). A second ice buoy station was planned for a September 1988 deployment in northern Lake Michigan in order to broaden the scope of the experiment. All our experience to date looks promising; however, final conclusions cannot be drawn until additional winter experience with these buoys has been obtained.

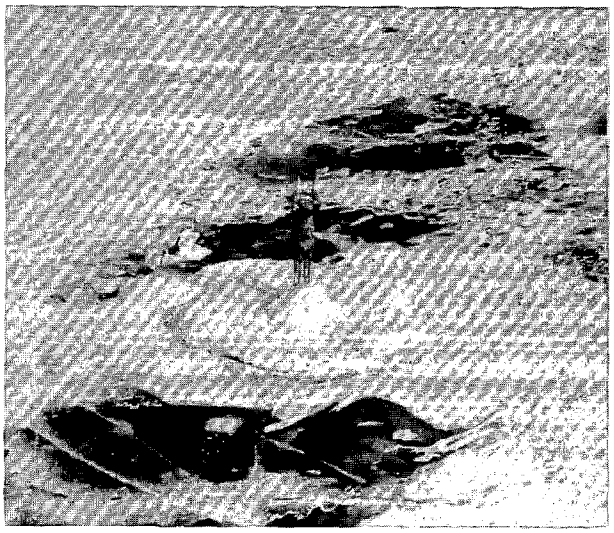

Figure 1. NDBC Ice Buoy 12D07 at Station 45001, February 1986

1. INTRODUCTION

Since 1979, the National Data Buoy Center (NDBC), under the auspices of the National Weather Service (NWS), has maintained a network of eight environmental data collection buoys on the Great Lakes (Figure 2). The network employs three buoys on Lake Superior, two buoys on Lake Huron, two buoys on Lake Michigan, and one buoy on Lake Erie. The standard method for operating this network is to deploy the buoys after the start of the shipping season and to retrieve them before the end of the season. This typically results in a period of several weeks during the shipping season when no buoy data are available. Each year, it is not uncommon for the Lake Carriers' Association and NWS Forecast Offices in the Great Lakes Region to request NDBC to extend the buoy time on the Lakes.

The fundamental aspect of the problem of accomplishing earlier deployments and later retrievals is that these operations require major operational and logistical efforts by NDBC and the Coast Guard, which provides excellent ship support. However, available ship services are necessarily confined to function within the framework of existing Coast Guard resources and operational requirements in the Lakes. Consequently, means to increase buoy station endurance time on the Great Lakes were investigated, and the challenge quickly evolved into the concept of a survivable "ice buoy."

2. ICE BUOY SYSTEM SELECTION

In early 1985, NDBC undertook a series of engineering design analyses to investigate alternate "ice buoy" concepts and to select the most likely candidate for further field testing. These analyses evaluated various types of buoys, which had been ruggedized to withstand ice, and the possible methods of instrumenting these buoys to provide basic meteorological parameters (i.e., wind speed and direction, barometric pressure, and air and water temperatures). One initially attractive concept involved a new type of "ice buoy," developed by the Coast Guard, 2.2 meters in diameter and 6.1 meters in length. This buoy is designed to "ride up" on light ice and to submerge under the ice during a "freeze-over." NDBC took a serious look at "throw-away" sensors to instrument this type of buoy, with the understanding that the sensors would be lost each winter. An additional consideration if this type of "ice buoy" were to be used would be the loss of data collection in the spring after the buoy reappeared but

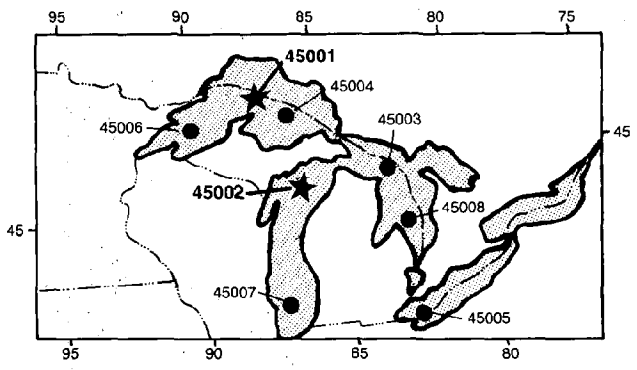

Figure 2. Buoy Station Locations in the Great Lakes

prior to a service visit by NDBC/USCG technicians to restore operation of the meteorological sensors.

Another candidate for possible use as an "ice buoy" was a 12-meter, 100-ton discus buoy — a venerable hull built in the early 1970's that has survived many years of operation in the North Pacific and North Atlantic Oceans. NDBC engineers performed several computer simulations of "worst-case conditions," which indicated the buoy should survive the harsh Great Lakes winter under all except the rarest of extended, severe, arctic-type conditions. Various parameters, such as topside icing, ice floes, fast ice, reserve buoyancy, ballasting techniques, and freezing precipitation, were considered in selection of the 12-meter hull as a test platform. An additional consideration for using the 12-meter hull was that this class of buoy was scheduled for removal from the "fleet" due to high annual maintenance costs when used in a saltwater environment.

Next, NDBC personnel conducted interviews with several Great Lakes ice "experts." They all agreed the 12-meter buoy should have a good to excellent chance for survival if all precautions were followed and the buoy were located in an open lake. That is, the buoy should not be deployed in a bay or harbor that could make it susceptible to being driven ashore during the spring ice breakup.

3. INITIAL ICE BUOY DEPLOYMENT, 1985-1986

In early 1985, buoy hull 12D07 was available for immediate use as an experimental "ice buoy." It was readied for deployment during that summer, was towed from NDBC in mid-September, and arrived in Chicago in early October. The Coast Guard Cutters KATMIA BAY and MOBILE BAY shared in towing the buoy up the Mississippi River to Sault Ste. Marie, the site of final outfitting.

After all sensors, power supplies, and electronics equipment were installed, the buoy was deployed in mid-Lake Superior at station 45001 in early November 1985. The existing NOMAD buoy on that station was retrieved. On February 7, 1986, the Coast Guard provided on overflight of the buoy and took pictures of its condition (Figure 3). The buoy had considerable ice accumulation, but there was no lake ice in the immediate area. On February 12, position data received from the buoy indicated it was moving slowly off station. An overflight conducted by the Coast Guard on February 15 confirmed the buoy was moving, and was amid considerable "brash ice" (Figure 4). However, all systems continued to work. It was difficult to determine whether the mooring was still attached and being dragged about the lake bottom, or if it had been severed. Figure 5 gives one an idea of the considerable movement (a total of 300 miles) experienced by the buoy for the months of February, March, and April 1986. Because the buoy moved into shallow water during early April, the mooring was assumed to have parted. On April 10, the buoy came to rest in a small bay on the east side of Manitou Island.

Buoy 12D07 was recovered by the Coast Guard Cutter SUNDEW in late April 1986, and towed to Houghton, Michigan. A complete inspection

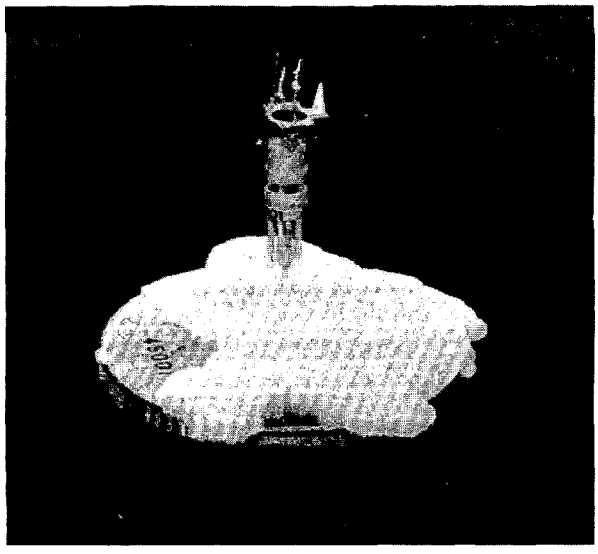

Figure 3. Overflight Photo of 12D07, February 7, 1986

of the buoy revealed only minor damage to the rubber fender that extends around the perimeter of the buoy deck. The fender is required to prevent metal-to-metal contact between the buoy and a ship during servicing operations. Upon completion of the physical inspection, a new suite of electronics equipment, sensors, and power supply batteries was installed.

Early in May 1986, the SUNDEW towed buoy 12D07 back to station 45001 and moored it using an all-chain mooring. The all-chain mooring was expected to provide an improved holding capability in the event a moving ice field interfered with buoy stationkeeping. Our previous experience with a nylon line, inverse-catenary mooring at station 45001 indicated that abrasion from either dragging on the lake bottom or rubbing against large sections of ice caused mooring failure.

4. 1986-1987 AND 1987-1988 WINTERS

In order to gain further general operational experience over several winters and to test the all-chain mooring, the "ice buoy" 12D07 experiment continued through the winters of 1986-1987 and 1987-1988. During the relatively mild 1986-1987 season, the all-chain mooring performed satisfactorily and the buoy maintained its original position. There was very little ice on Lake Superior that winter. The performance of the buoy payload and sensors was also satisfactory throughout the winter.

The next winter turned out to be more harsh than the 1986-1987 season. In early February 1988, both barometers on the buoy began reporting erratic data, apparently as a consequence of ice accretion on the pressure ports. On February 10 the buoy began to drift, dragging over 1,000 feet of chain and a 20,000 pound concrete sinker-type anchor. The drift stopped on February 18, but began again at the start of March. The buoy finally came to rest at 47°35'N, 87°04'W, some 37 miles from its initial position at 48°01'N, 87°43'W. The final location was in water over 200 feet deeper than the original position. Since the all-chain mooring was designed with a scope (length-to-depth ratio) of approximately 1.4, sufficient chain was present in the mooring to accommodate the additional depth at the new location.

Figure 4. 12D07 Amid Brash Ice, February 15, 1986

On May 15, 1988, a Coast Guard cutter attempted to free and retrieve the mooring, but the effort was not successful. Since the mooring would not budge, it was assumed that it was fouled on an underwater obstruction of some sort. Consequently, the buoy was left where it was rather than risk breaking the mooring to return it to the original station 45001 position.

Figure 6 shows 12D07 while it was drifting in February 1988. Curiously, the ice coverage on the lake does not appear to be severe, yet substantial drift is occurring as is evident from the buoy wake. Note that the buoy freeboard is only about six inches. This means the buoy is carrying about 120 long tons of extra weight. If the entire mooring and concrete sinker (combined weight of 38,000 pounds) were suspended, as was likely when Figure 6 was taken, the buoy still was holding almost 230,000 pounds of ice on deck (corresponding to an average thickness of about 3 feet).

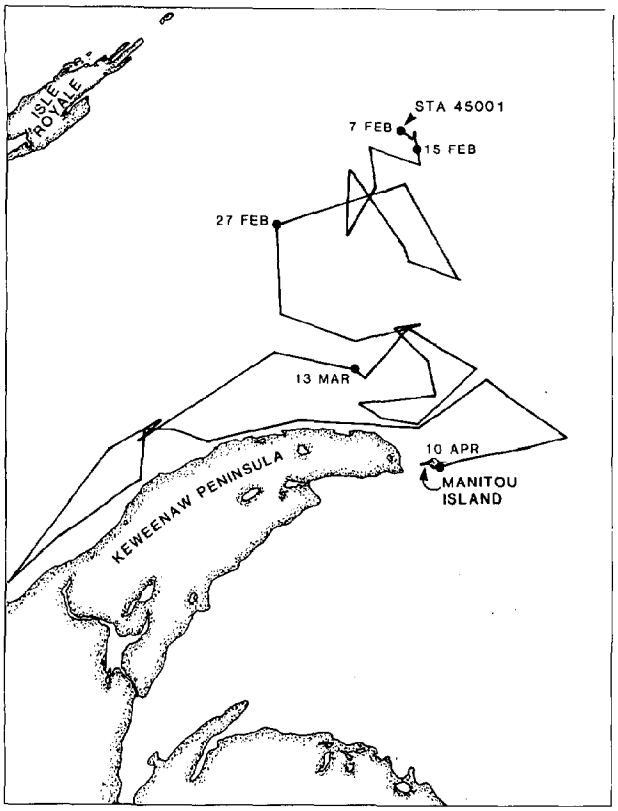

Figure 5. Track of the Movement of 12D07, February 1986

5. CONCLUSIONS

NDBC will continue the "ice buoy" experiment during the 1988-1989 winter with buoy 12D07 at station 45001 in Lake Superior. In addition, NDBC has replaced the 3-meter buoy at station 45002 in upper Lake Michigan with a second "ice buoy," hull 12D08. This will enable additional winter experience to be obtained in somewhat different lake conditions.

In general, the technical considerations involved in year-round operation of large discus buoys on the Great Lakes are well understood as a result of the "ice buoy" deployments to date. The issue of long-term cost-effectiveness is not as clear. Operational factors affecting cost-effectiveness include the frequency of mooring loss and the rate of damage to buoy hulls. It is hoped that the 1988-1989 deployments at stations 45001 and 45002 will further help in the determination of these factors. Nevertheless, the technical feasibility of long-term, year-round operation of "ice buoys" on the Great Lakes has been clearly demonstrated.

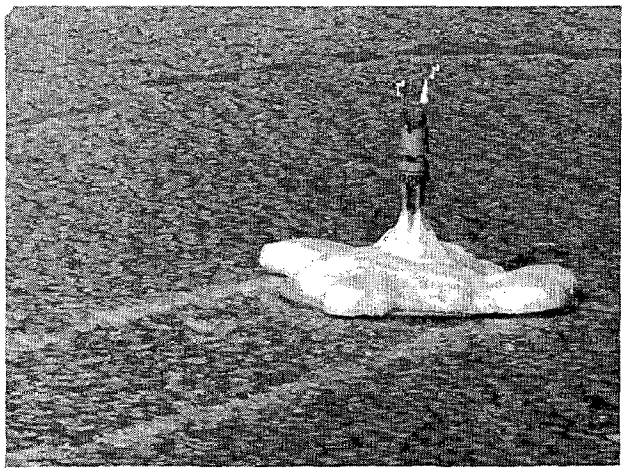

Figure 6. 12D07 Adrift in Feburary 1988

INFRARED LASER WAVE HEIGHT SENSOR

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ABSTRACT

The National Data Buoy Center (NDBC) has a requirement for an accurate, reliable, economical method of measuring ocean wave activity at its Coastal-Marine Automated Network (C-MAN) meteorological stations. This paper describes a diode-laser-based ocean wave height sensor developed to fill this need. The device, called the Infrared Laser Wave Height Sensor (IR LWHS), was designed for use in a remote, unmanned, marine environment.

1. INTRODUCTION

The National Data Buoy Center (NDBC) operates a network of remote, unmanned meteorological data acquisition/transmission stations, the Coastal-Marine Automated Network (C-MAN). The C-MAN stations are located in various coastal areas, primarily at USCG light stations and on fixed, offshore platforms. The C-MAN stations monitor various environmental parameters, including wave height and wave period. The outputs of the various sensors are processed by the C-MAN data acquisition system and are transmitted to the National Weather Service via the GOES satellite system and landlines.

As part of its waves development program, NDBC has investigated various sensing methods, including accelerometers, wavestaffs, and reflective devices (i.e., radar, acoustic, laser). The IR laser distance-measuring method has proven to be the most adaptable to NDBC requirements for installation, operation, and long-term maintainability; therefore, it is the preferred method for those coastal locales for which a favorable look angle is achievable (i.e., within approximately 15 degrees of vertical).

2. INTENDED USE

The IR LWHS was designed to operate in a continuous mode (24 hours/day) in a marine environment, including marine growth, oil films, sunglint, ocean spray, rain, snow, and fog. The unit had to be small and light enough that it could be installed and removed by a single technician working in awkward positions, such as the underside of offshore platforms. Because the only power available at some C-MAN locations was battery/solar charger units, consumption had to be held to a minimum.

Schwartz Electro-Optics, Inc., of Orlando, Florida, was selected to design and build the IR LWHS from NDBC specifications derived in part from the above requirements.

3. DESIGN

The IR LWHS employs a pulsed GaAs/GaAlAs diode laser and an avalanche photodiode detector along with the appropriate transmitter/receiver optics in a side-by-side (as opposed to a coaxial or concentric) configuration. Range is determined by measuring the round-trip propagation time of a 10 nanosecond, 850 nanometer laser pulse to the water surface and back, generating a continuous voltage proportional to the distance from the sensor to the surface of the water. The change in voltage level is proportional to wave height. The device is housed in a cylindrical, stainless steel housing approximately 9 inches (22.86 centimeters) in diameter and 1 foot (30.48 centimeters) in length. Total weight is 15 pounds (6.8 kilograms). A flange on the rear of the unit is used for mounting. The external electrical connection consists of one waterproof electrical connector, with six conductors for electronic circuit power, heater power, and signal output. A thermostat-controlled heater, made up of a quartz window with a high-transparency conductive heater coating on the inner surface, covers the optics and prevents the buildup of ice or moisture.

The pulse repetition frequency is 1500 pulses/second. When the signal is passed through a low-pass (10-Hz bandwidth) filter, the analog output signal is effectively the result of averaging 150 range measurements. This averaging technique greatly improves the measurement accuracy.

An RC differentiator circuit is used to prevent false returns from aerosols (i.e., fog, mist, ocean spray). The backscatter from aerosol has a slow rise time relative to the transmitted light pulse due to the extended volume of the aerosol (backscatter signal energy from an aerosol is a function of the aerosol volume). Therefore, the RC differentiator is an effective signal processing technique for discrimination against aerosols. Also, since near backscatter from aerosols give the largest returns, the receiver is time-gated such that signals from less than 6 meters (the required minimum range) are ignored.

Table 1 lists the NDBC specifications for the IR LWHS. The Schwartz Electro-Optics, Inc., sensor meets or exceeds all requirements.

Table 1. NDBC Specifications for the IR LWHS

PARAMETER	RANGE
OPERATING VOLTAGE	10.5-15.0 VDC, 12-15 VDC NOMINAL
SENSOR CURRENT	≤ 1.0 A AT 12 VDC
HEATER CURRENT	≤ 1.0 A AT 12 VDC
FREQUENCY RESPONSE	FLAT FROM 0 TO 1 HZ
ACCURACY, STATIC	±1% FULL RANGE
ACCURACY, DYNAMIC	±3% OF TROUGH-TO-PEAK WAVE HEIGHT, OR ±10 CM, WHICHEVER IS GREATER
RESOLUTION	≤ 0.1% OF FULL RANGE
SENSOR RANGE	MINIMUM ≤ 6.0 M, MAXIMUM ≥ 50 M
OUTPUT SIGNAL	0-5.0 VDC
SCALE FACTOR	LINEAR, TYPICALLY 0.1 VDC/METER
LOAD IMPEDENCE	≥ 10 KOHMS
BEAM SIZE	≤ 1° FULL ANGLE
AIR TEMPERATURE	−15°C TO +50°C
WIND	0-60 M/S
HUMIDITY	TO 100%, CONDENSING OUTSIDE SENSOR HOUSING
RAIN	MODERATE TO HEAVY, TO 13.0 CM/HOUR, FREEZING IN WINTER
SNOW	NONE TO FREQUENT AND HEAVY, TO 60 CM IN 24-HOUR PERIOD
MEAN TIME BETWEEN FAILURES	≥ 2 YEARS

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4. SENSOR EVALUATION

During the past six months the IR LWHS has undergone evaluation at the Chesapeake Light Platform. A wavestaff is being used as a reference. Data are taken synoptically for 20-minute periods once each hour. Data from both the IR LWHS and the wavestaff are sampled and processed by separate Data Acquisition, Control, and Telemetry (DACT) payloads. The data are sampled and converted to digital at the rate of 256 samples per 100-second segment. The segments overlap, with the last 50 seconds of one segment comprising the first 50 seconds of the subsequent segment. Data from all segments comprising the 20-minute acquisition period are processed into one data set. The data from each segment are processed using an FFT to produce a 129-element data set representing the 0.00- to 1.28-Hz energy spectrum. Although data are acquired and processed for the entire 0- to 1.28-Hz spectrum, only the 0- to 0.40-Hz data are used. Following some further processing, the data are used to calculate three sea state parameters: significant wave height, probable maximum wave height, and spectral peak period.

Wave data to date have shown good agreement between the wavestaff and the IR LWHS. The difference between the two sensors is usually less than 0.1 meter. This difference may be due to the fact that the two sensors are located in different positions on the platform, with the IR LWHS being on the outboard corner, and the wavestaff being inboard, where the support structure of the platform could affect wave action. Figure 1 shows a time-series plot of the significant wave height from 0600 UTC June 9, 1988, to 0600 UTC June 11, 1988. Figure 2 shows the average wave period for the same time frame.

Two different problems have been observed during the evaluation period. On two occasions during the winter months, when local temperatures dropped to approximately $-10°C$, data dropouts of about 12 hours occurred. When the temperature increased, data transmission resumed. Heat generated by the quartz window heater, along with heat from the electronics, should have been sufficient to keep the optics free of ice or moisture and the unit operating. Subsequent temperature chamber tests at $-15°C$ failed to duplicate the malfunction, and it has not yet been determined if the problem is related to the IR LWHS or to some other part of the system.

Another problem encountered has been a "spike" in the significant wave height reported by the IR LWHS, relative to the wavestaff, of about 0.5 meter. This problem has appeared for short periods of time, almost always around 1800 UTC, on about one-half of the days during the evaluation period. Figure 3 shows a time series plot of the significant wave height from 0000 UTC June 4, 1988, to 0000 UTC June 6, 1988. As in Figure 1, there is good agreement between the wavestaff and the IR LWHS, with the notable exceptions of "spikes" in the IR LWHS data around 1800 UTC on each of the three days. This anomaly, as yet, has not been resolved. It is not believed to be originating with the IR LWHS. Testing will continue until the observed anomalies are resolved.

5. CONCLUSIONS

Tests conducted at NDBC and at Schwartz Electro-Optics, Inc., have shown no basic problems with the IR LWHS sensor. The Infrared Laser Wave Height Sensor will provide a reliable, accurate, and economic method for measuring wave activity in areas where the sensor can be properly mounted. The sensor must be mounted in a stationary position above and perpendicular to the surface of the water. Experimentation has shown that data can be obtained from a laser pulse for angles up to 15° from the perpendicular. However, for greater angles, the return signal diminishes, and the wave geometry makes accurate data acquisition difficult.

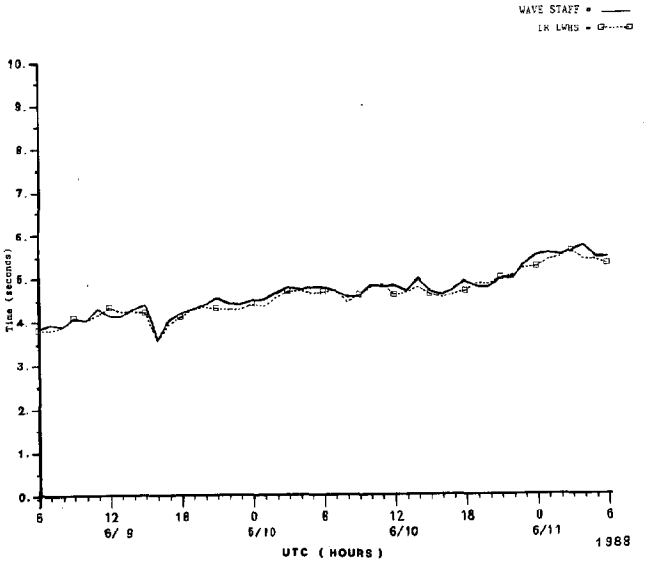

Figure 2. Time-Series Plot of Average Wave Period for 0600 UTC June 9, 1988, to 0600 UTC June 11, 1988.

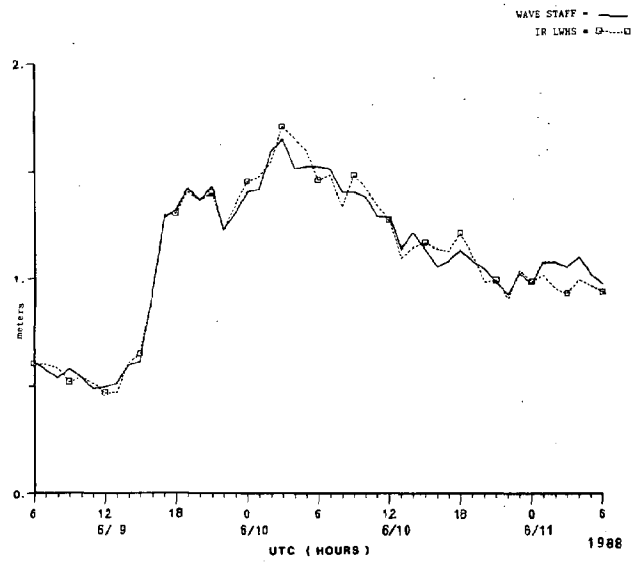

Figure 1. Time-Series Plot of Significant Wave Height from 0600 UTC June 9, 1988, to 0600 UTC June 11, 1988.

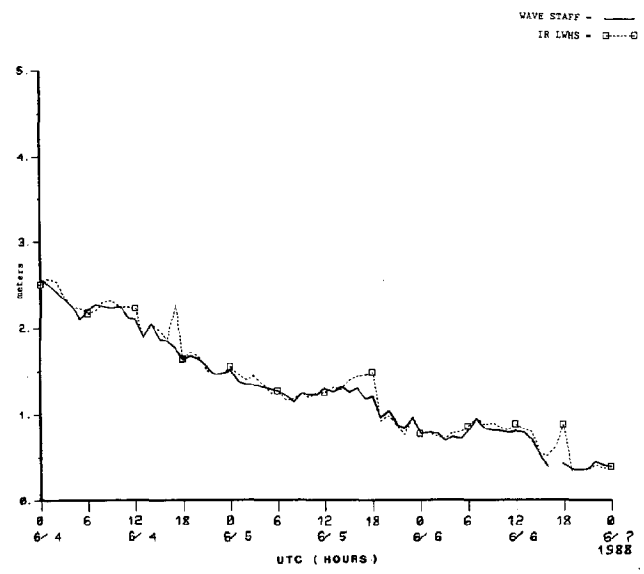

Figure 3. Time-Series Plot of Significant Wave Height from 0000 UTC June 4, 1988, to 0000 UTC June 6, 1988.

WavePro: AN AUTONOMOUS WAVE PROCESSOR WITH LONG-RANGE TELEMETRY

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ABSTRACT

A real-time wave processing system with long-range telemetry capabilities has been developed. The system is housed in an accelerometer wave-measuring bouy and consists of a wave data acquisition module, a versatile processor/ controller module, and a satellite navigation and telemetry module. Real-time information including the wave height power spectrum, the longitude and latitude of the bouy is computed in situ and transmitted via the telemetry link. Selected data products and raw data are archived on magnetic tape at regular intervals or when the significant wave height exceeds a predetermined threshold.

The WavePro is useful in applications where wave data must be taken in remote locations, which are lacking line-of-sight telemetry paths required by existing RF systems. Extended deployment periods are made possible by transmitting only statistically significant frequency domain data products.

This paper focuses on the system architecture and implementation details.

INTRODUCTION

Sea Data has developed a self contained wave processing system called the WavePro. The system is based on the Datawell Waverider bouy with an integral accelerometer. It processes wave information in real time, and transmits the complete wave spectrum via the GOES system. A polar orbiting satellite navigation system (SATNAV) is used to determine the coordinates of the bouy which are appended in the GOES record. The WavePro also includes a recording device to archive all data products along with important storm events in the form of raw data. The system is controlled by two low-power microcomputers, one of which controls the data acquisition and system timing, and the other which performs the necessary wave signal processing computations. The latter is built around a Vector Processing Language (VPL) which assures software robustness and field programmability. All system submodules are powered by internal alkaline batteries supplying power for 9-12 months depending on the sampling and transmission schemes.

In the following, some background work is mentioned and references to related/similar systems are given.

Real time transmission of wave information has been the focus of scientists and engineers for at least two decades. Datawell has set a de facto industry standard with their bouys (Waveriders) featuring RF transmission of analog real-time wave measurements. Successful deployment results and world wide experience have been reported and published [3].

The National Data Buoy Center (NDBC) deployed the first weather/wave processing bouy in 1971 and since then, at least seven generations of bouys have been developed taking advantage of technological improvements. Each new generation improves the performance, reliability, and deployment time, and reduces the overall experiment cost [9].

IFREMER has developed an electronic module, compatible with Waveriders, which computes the omnidirectional spectrum of sea-state on board and transmits the results using the ARGOS positioning and transmitting system. Deployment results have been reported in [4].

Although it is impossible to cover here all related works in the area (and we apologize for unintentional omissions), it would be a mistake not to give a reference to the remarkable engineering work of the WAVESPEC [10] in 1984 Despite the fact that the WavePro was developed independently of the WAVESPEC, the similarities of the two systems are noticable. The improvements/advances of the WavePro are:

* A 60 MB recording option with data play back capability.
* Field programmability to parameter and algorithm level without opening the hatch cover.
* Usage of the SATNAV navigation system.
* Safer and less expensive battery system using alkaline batteries instead of lithium.
* Minimal modifications to the Waverider bouy electronics.
* Reduced module assembly time. It typically takes under one hour to remove and put back together a WavePro from a Waverider bouy.

Evaluation of initial WavePro field data are encouraging so far. It is expected to improve the performance/cost ratio and make WavePro a valuable research tool to the scientific community.

SYSTEM ARCHITECTURE

Figure 1 shows a block diagram of the WavePro. The major subsystems are:

a. The Waverider bouy and the Accelerometer
b. The Data Acquisition and Timing module
c. The Wave Processor and System Controller
d. The GOES transmitter
e. The SATNAV module
f. The T/R switch and the Antenna.
g. The Archival Recorder.
c. The Power Supply Subsystem

Wave height is sensed by measuring the vertical acceleration of the bouy. This signal along with temperature measurements are fed to the Data Acquisition and Timing

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Module (DAS-18a) which conditions, digitizes and qualifies the sensing parameters. The DAS-18a includes a very stable clock which is used to synchronize the operation of the entire WavePro (except the GOES transmitter). At given intervals, DAS-18a turns on the Wave Processor and System Controller (WPC-18) to process the "raw" data. The WPC-18 keeps its own timing and controls the operation of the GOES transmitter, SATNAV receiver, and the Archival Recorder. Depending on the time and the past sea conditions, the WPC-18 can perform wave processing, control of data archival, comparison of current sea state with previous ones, error recovery, positioning correction, timing correction or a combination of the above. These WPC-18 functions are programmed in VPL, which allows the end user to alter them to best suit the needs of the experiment. A robust power distribution system involving a "battery booster" is used to provide for a wide range of current demands, from a few milliamperes to several amperes.

The first two WavePros were built in 1987. Since then, the design has been refined and substantially improved. The technology used in all submodules has been in use for several years and 95% of the WavePro firmware is identical to previously well-tested wave processing systems which have been used offshore.

SYSTEM DESCRIPTION

a. Waverider bouy and the Accelerometer

The Datawell Waverider bouy contains an integral heave sensor to measure vertical acceleration. The associated electronics convert the acceleration signal to vertical displacement by integrating it twice. The accelerometer is protected from temperature gradients by foam insulation and electronic compensation is used to reduce the effect of temperature variations. The bouy dynamics have been modeled precisely and a second order transfer function is available [2]. The output of the Waverider electronics is a square wave frequency signal (1v pp) proportional to vertical displacement at a rate of 0.98 Hz per meter.

Modifications of the Waverider bouy (and the integral electronics) by Sea Data are kept to a minimum with the exception of the battery system. The original Leclanche cells were replaced by potted alkaline battery packs which provided three times more energy for the same volume. Alkaline batteries also reduce the risk of hydrogen generation and gas leaking which is inherent to Leclanche cells. The Datawell's modulation circuit and RF transmitter are disabled. A new antenna mounting plate has been fabricated to accept the 400MHz antenna used for GOES transmissions and SATNAV receptions.

b. The Data Acquisition and Timing module

The Data Acqusition and Timing module (DAS-18a) is manufactured by Sea Data and performs three major functions: data collection, preprocessing and precise overall system timing. It consists of a waveform shaper and frequency multiplier to improve the resolution of the wave height (frequency) output from the Waverider, a 12 bit integrating A/D to measure air temperature and water temperature (options), a 1 ppm time base circuit over the operating temperature range, and a microcontroller. The microcontroller handles all data conversions and formulates "records" of data to be sent for futher processing to the Wave Processor and System Controller (WPC-18).

The DAS-18a is built exclusively from CMOS components and the microcontroller has the capability to be placed in a virtually zero power consumption state during periods of inactivity. A regular interrupt given by the system time base "wakes up" the microcontroller every 30 sec to check what function has to be performed. Note that WPC-18 is held in standby mode by the DAS-18a until a record of data is ready to be processed. This reduces the power consumption of the electronics to less than 1mA in standby (75% of the deployment time) and 90mA in Data Processing mode (under 5% of the deployment time).

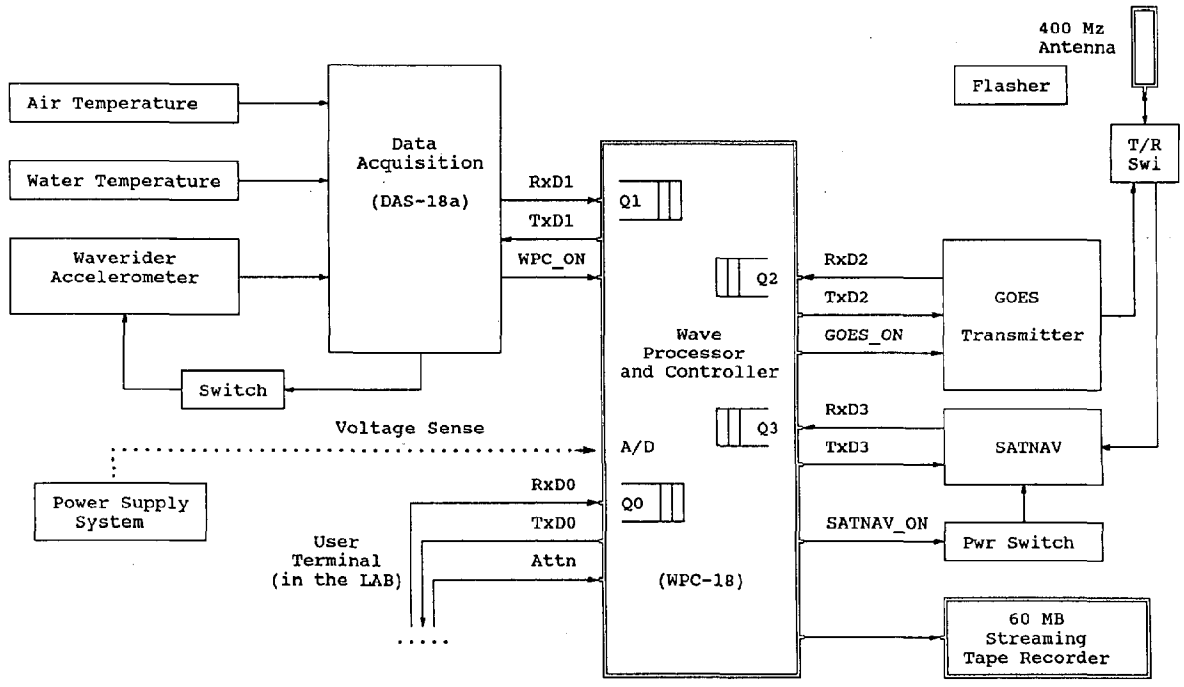


Figure 1: The WavePro Block Diagram

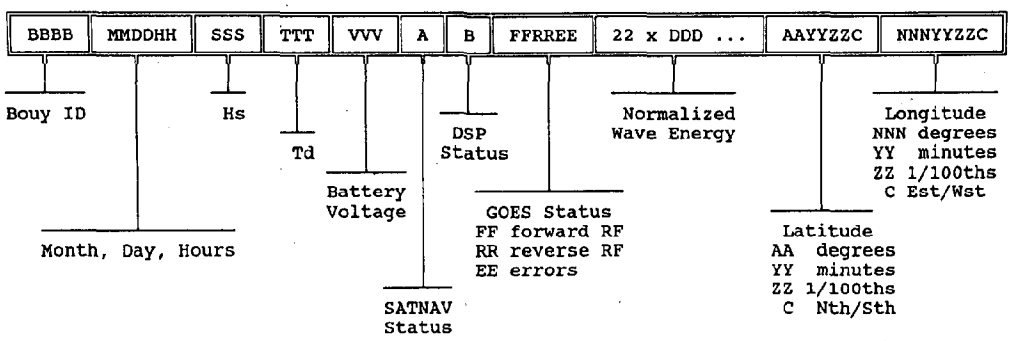


Figure 2: The GOES Message Data Record

c. The Wave Processor and System Controller

The Wave Processor and System Controller (WPC-18) is a low power modular microcomputer (based on the C-44 bus) manufactured by Sea Data. The hardware consists of a CPU, 256KB of EPROM, 32kB of EEPROM, 256KB of RAM, four UARTS, calendar timer, watchdog circuitry and numerous external I/O interface components.

The real power of this system is in the operating software called the Vector Processing Language (VPL). VPL is a combination of a real-time environment with an embedded compiler/interpreter executing pre-compiled FORTRAN and "C" modules. The language syntax is modelled after "C", where all pre-built FORTRAN and "C" routines are callable and executable at full CPU speed. The design philosophy of VPL is similar to the "modular decomposition" approach recommended in [8] which is well recognized by professional software writers for oceanographic applications [7].

The most significant feature of VPL is that it can be customized to meet the most demanding system requirements by the end user. The end user has access not only to "operating parameters" of the WavePro (such as the sampling rates, the conditions for recording on tape, the windowing parameters etc) but also to the operating algorithms. For example, a standard RS-232 terminal (or a portable computer) can be attached to the WavePro and without opening the hatch cover, one can instruct the WPC-18 to change the spectrum processing methodology by including the effects of the bouy dynamics.

In the lab, short data collection cycles can be initiated and executed in several minutes instead of waiting for hours or days. VPL also allows simulation and testing of the behavior of the system in fault conditions, such as GOES malfunctions, SATNAV errors, low battery voltages etc. In fact, the VPL code can change the functionality of the system in case of a severe error. For example, if the battery voltage level decreases a below certain point, VPL can decide to "shut down" the SATNAV and make GOES transmissions less often.

d. The GOES Subsystem

The GOES transmitter used in the WavePro is manufactured by Synergetics [11] and consists of the Master Control Module (3401B) and the GOES Transmitter Module (3426A). The transmitter synthesizes a 400Mz signal at a 40W power level. It also includes a very stable TXCO time base with 1ppm long term stability over a -40 C to 55 C temperature range. The Master Control Module is a microprocessor based controller with 4-8KB of RAM. Data transmitted asynchonously to this module are stored temporarily in the RAM buffer and become available for transmission. GOES transmissions take place at specific times, which are programmed into the Master Control Module. The Master Control Module includes the GOES-SOFT, which is a high level real-time firmware package. This package provides time keeping facilities and the necessary H/W and S/W handshake with the data source (the Wave Processor and System Controller). The format of the transmitted record is shown in Figure 2.

e. The SATNAV module

The SATNAV module is manufactured by Mars Electronics [6] (VIGIL RX). It receives position information on a UHF channel (400MHz) from the "Transit" Navigation System of satellites which has been well-proven with over 90,000 military and commercial users worldwide. At present, the five operational satellites in various polar orbits provide at least one "pass" every 70 minutes for users located at 50 degrees latitude. This time is improved at higher latitudes. The SATNAV module not only computes the latitude and longitude but it also computes when the next satellite pass is expected. This information is (optionally) used by the WPC-18 to control power switching of the SATNAV to conserve battery energy. The SATNAV is accurate to 200m approximately; an error indicator is provided to qualify the validity of the reported coordinates.

f. The T/R switch and the Antenna

The GOES transmitter and the SATNAV receiver share the same antenna. Since GOES transmits 40W signals and the SATNAV can receive no more than a few microwatts, a UHF Transmit/Receive switch has to be inserted. This switch is fabricated by Sea Data and the GOES transmitter is adapted to control the position of the switch. Futhermore, the WPC-18 can (optionally) keep track of GOES transmissions and enable the SATNAV at non-overlapping time intervals.

The Synergetics Model 14A half-wave quadrafilar helix antenna was used, tuned at 401MHz and capable of transmitting 50 watts. It was found that this antenna was suitable not only for GOES transmissions but also appropriate for SATNAV receptions.

g. The Archival Recorder

A small capacity (2MB) or a high capacity (60MB) recorder can be installed in the WavePro. In both cases, the recorder is used to record data products, raw data and system information. The data products consist of the band averaged wave spectrum and its moments, and the position (coordinates) of the WavePro. The raw wave data are recorded either

conditionally or at fixed time intervals. The system information records include timing, battery voltages, operating temperature, SATNAV positioning error indicators, GOES forward/reverse RF power, software error codes etc.

The Wave Processor and System Controller computes the significant wave height and decides when and for how long to record raw data. More complicated recording conditions can be easily programmed (in the field). As an example, the user might program the Wave Processor to record data according to the following scheme:

> If the wave energy in the frequency band 0.3Hz to 0.5Hz is more than 20% of the total wave energy, record data until the significant wave height is less than 5 meters. Independently of the above conditions, store 1 hour of raw data every 2 days starting at 10:00 at night.

The High Capacity Recorder (HCR-660) is a low power streaming recorder, recording data in the industry standard QIC-24 format on 600' tape. It contains its own tape drive, formatter (manufactured by Tandberg and adapted for low power operation by Sea Data), a microprocessor based controller and a 128-256K solid state data buffer. The recorder module includes its own switching power supply and can store 60MB of data, consuming only 6AH of battery energy (at 15V). The recorder includes both write and read electronics incorporating an automatic read-after-write correction mechanism. More details about the HCR-660 can be found in [5].

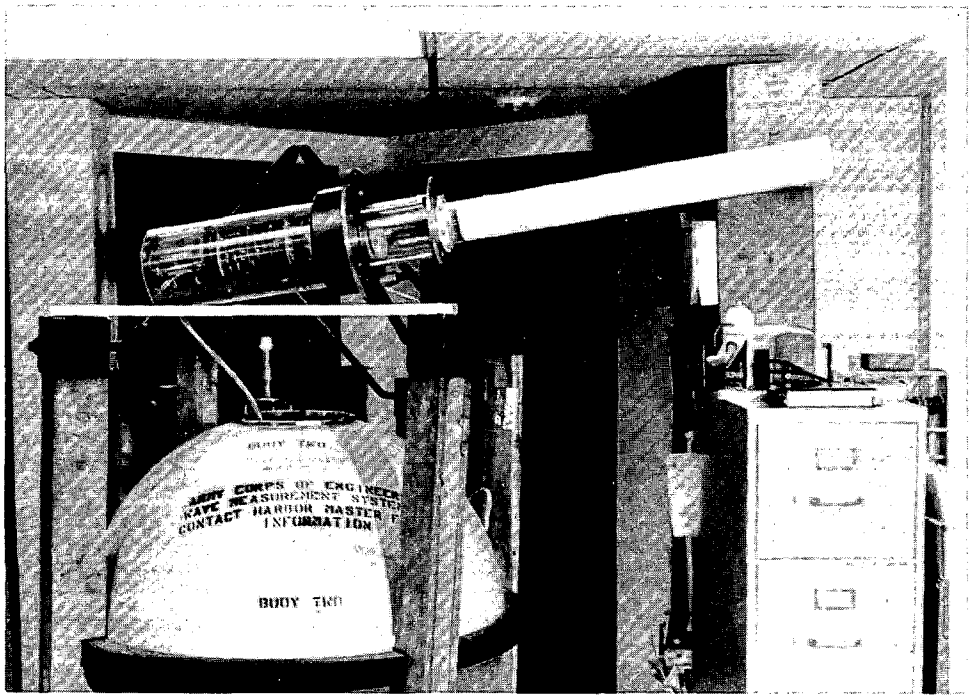
h. The Power Supply Subsystem

The power supply system of the WavePro was a very challenging electronic design. The various system components require a wide range of supply currents ranging from 0.8mA for the heave sensor, to 200mA for the main processing CPU, and up to 8500mA for the GOES transmitter. At the same time, the average current drain of the system cannot be more than a few milliamperes for deployments of 9-12 months. To achieve these requirements, a rechargable battery was used to provide the "peak" currents of the system. A WPC-18 controlled charger was used to charge this battery from the primary batteries, calculating the amount of energy taken out and (optionally) compensating for temperature. A high efficiency micropower switching regulator is used to charge the 12v battery accepting input voltages from 8v to 24v. A "watch dog" timer and additional direct voltage sensing circuit was used to monitor the state of the battery. It was found experimentally that under these operating (charging/discharging) conditions, the efficiency of the battery (charge in/charge out) is better than 95% for a temperature range of -15 to 40 degrees C.

The GOES module requires 12v at 5mA in standby mode, 250mA when data are transmitted to its buffer, and 8A during UHF transmissions. It is powered directly from the rechargable battery since it turns itself ON/OFF asynchonously with respect to the rest of the system.

The SATNAV module contains its own switching regulator requiring 9-30v input with a current drain of 600 mA (at 12V). The SATNAV is powered from the primary or the secondary (rechargable) batteries via an electronic switch which is controlled by the WPC-18.

The Waverider heave sensor electronics are powered from the primary cells by an electronic switch under DAS-18a control.



Figute 3: The DAS-18a ready to be inserted in the Waverider

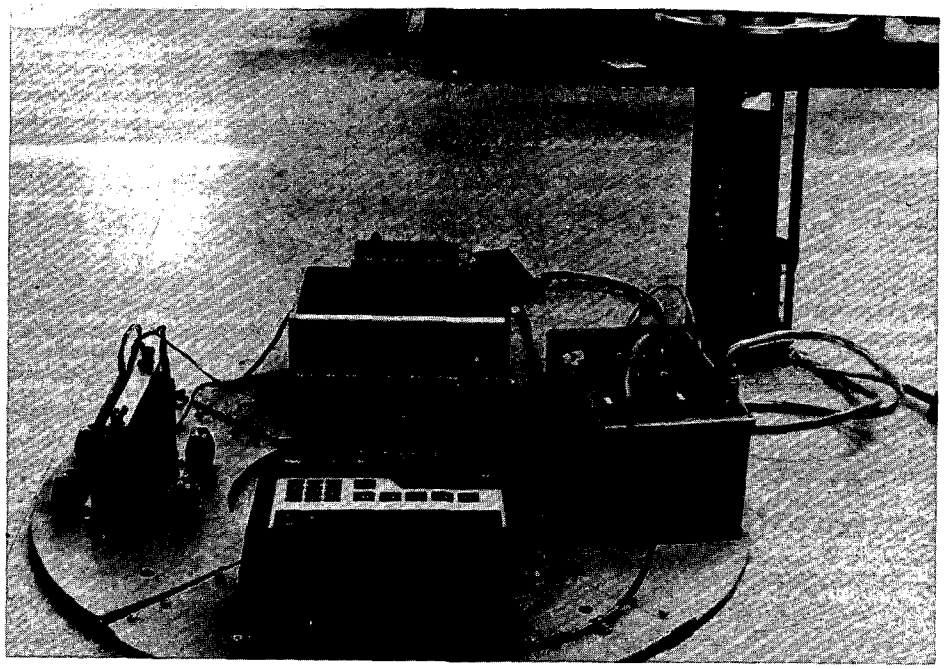


Figure 4: WavePro Electronics (GOES, T/R Switch, SATNAV and WPC-18)

CONCLUSION

The concluding remark of this paper is similar to the last sentence of reference [10]: The only way to appreciate the difficulties in putting together the prototype WavePro system is to ask the technicians and engineers who had to work over the hull with one hand through a single 8" hole for several hours.

The WavePro is a stand alone, in-situ wave processing system with long range telemetry and positioning capabilities. It is intended to be used to monitor real time wave conditions in remote areas for deployment periods of 9-12 months. The WavePro is engineered to be modular and adaptable to a broad class of experiments involving customized processing.

REFERENCES

[1] Bowers G., Kontopidis G., "A Novel Approach to Real-Time Wave Processing," in Proc. IEEE Oceans'87, Halifax, Canada, Sept. 1987, vol. 3, pp. 1142-1148.

[2] Datawell BV. Operation and Service Manual for the Waverider. Haarlem, Netherlands, 1980.

[3] Draper L. (editor) "The Waverider Discussion," Proceedings, Institute of Oceanographic Sciences, May 1975.

[4] Ezraty R., Racape J.F., "Directional and Omnidirectional Sea State Information Obtained from Instrumented Bouys," in Proc. MDS'86, New Orleans, April 1986, pp. 315-321.

[5] Kontopidis G., "Design and Implementation of Streaming Tape Data Loggers," in IEEE Proc. 4th Symposium Oceanographic Data Systems, San Diego, Feb 1986, pp. 156-165.

[6] Mars Electronics. VIGIL RX SATNAV Manual. Berks, England 1986.

[7] McClintock J.D., Davidson L.W., "Advanced Ocean Wave Synthesis, Analysis, and Generation Software," in Proc. IEEE Oceans'87, Halifax, Canada, Sept. 1987, pp. 554-557.

[8] Parnas D.L, "On the Criteria to be Used in Decompositing Systems into Modules." Comm. ACM, vol. 15, no. 12, pp. 1053-1058.

[9] Prine G.D., Timko R.E., "Acquisition of a Value Engineered Environmental Payload," in Proc. MDS'86, New Orleans, April 1986, pp. 602-604.

[10] Smith R.D., Lawson J.L., Campbell E.C., "WAVESPEC -- A New Wave-Measuring and Processing Bouy," in Proc. MDS'86, New Orleans, April 1986, pp. 402-408.

[11] Synergetics International. Model 3401B Master Control Module (03401-94102) and Model 3426A GOES Transmitter Module (03426-94101). Colorado, 1986.

MEASURED TRANSFER FUNCTIONS FOR SHIPMOTIONS IN NATURAL SEAWAYS

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ABSTRACT

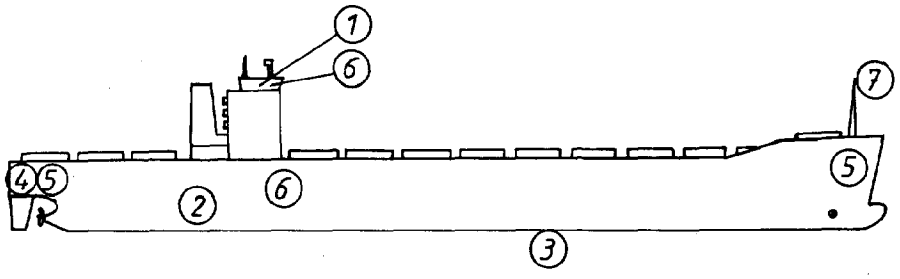
In cooperation between the Institute for Shipbuilding of the University of Hamburg, the German Hydrographic Institute, the Max Planck-Institute for Meteorology, the German Weather service and the GKSS-Research Center a numeric model was developed to determine the optimum route for a ship, which means minimum costs.
To verify different moduls of the model, measurements of the ship's motions, the ship's operational data and the actual wave field were taken. The wave measurements, using a method developed from GKSS, were carried out by means of the marine radar on board the ship.
The measurements of the ship's behaviour in the seaway are compared with simulation runs of the routing model under assuming the measured wind and wave conditions.

1. INTRODUCTION

To find the route of most favourable costs it is evident to know about the future winds and seastates and about the behaviour of the ship under these conditions.
The routing model [1] proceeds from the ship's motion in the regular seaway. With the pitching and heaving motions the increase of the resistance is determined and then transferred to natural seaway, assuming linear behaviour. Now the required power and the fuel consumption can be determined. The optimization has to find the route of minimum total costs. It is an optimization in space and time and delivers not only the coordinates of the optimum track, but also the recommended speed. This implies good cooperation between the ship's management and the routing institution.
The new method of wave measurements from board a fast going ship [2] provides the possibility to test the programs which have been developed for the routing. Full scale measurements of the ship's seakeeping were carried out from January until March 1988 on board the container vessel 'Stuttgart Express' of the HAPAG LLOYD AG. The particulars of this ship are given in table 1.

Table 1. Main particulars of the 'Stuttgart Express'

length over all	240.5 m
length between perpendiculars	233.0 m
breadth	32.2 m
draught	9.0 m
service speed	21.0 kn



1 Date, time, position, course, draft, trim, loading conditions
2 Torque, number of revolutions
3 Doppler-log, echo-sounder
4 Average rudder angle
5 Vertical accelerations
6 Horizontal accelerations
7 Relative wind velocity and direction

Fig. 1. Ships profile with measuring locations

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2. THE EXPERIMENT

The 'Stuttgart Express' was sailing it's regular track across the North Atlantic Ocean between North Europe and the east cost of North America.
The ship was equipped with the 'Marine Voyage Recorder' [3]. This is a 'Black Box' which provides most of the relevant data (such as ship's speed and course, torque and number of revolutions, wind speed and direction) for the experiment.

Measurements were taken in routine every three hours during the local day.

The ship's motions were recorded by four rigidly installed accelerometers. Two of them are sensitive in vertical direction and two in horizontal direction [4]. Figure 1. shows all measuring locations. The accelerations were sampled during a period of 10 minutes with 10 cps and stored digitally.
For each measurement the operational data were stored additionally.

The used method of wave measurements by means of a marine radar is described in [2], [5] and [6].
Each wave measurement is composed by a series of 32 consecutive photographs. They are done by taking photos from the pattern of the radarbackscatter field as it is displayed on the PPI, when no "sea clutter" suppression is switched on.

Fig. 2. Camera mounted on radar tubus

For this purpose a picture camera was installed on top of the radar screen (fig. 2.) to photograph the pattern of each rotation of the antenna (fig. 3.). Thus the samples were taken in a space - time box.

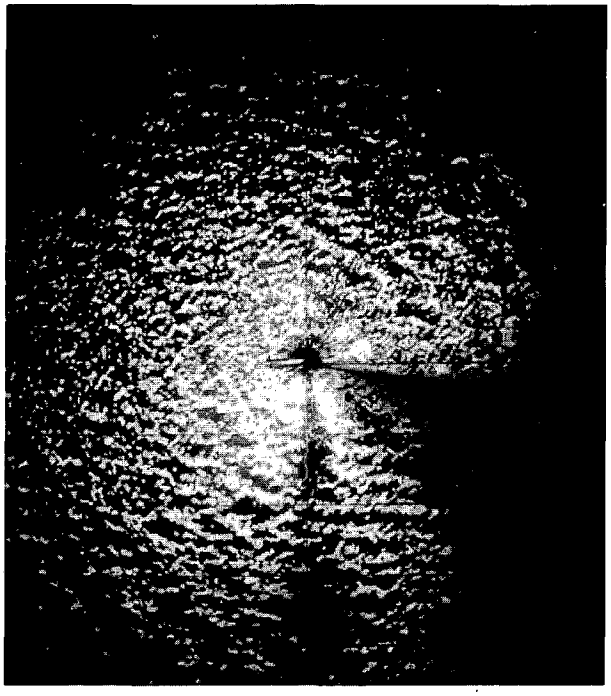

Fig. 3. Photo of radar screen during one rotation of the antenna

Table 2. The ship's and environmental data at time of measurement.

Date:	3/11/1988	Time:	13:29 UTC
Position:	51°N, 27°W	Course:	270°
Speed:	16.5 kn		
Draught:	9.5 m	Trim:	0.5m
Volume of displacement:		45750 m³	

Wind and wave conditions from bridge observation.

Wind:	Bft 6-7	Direction:	160°
Waves	Hs=4m	Direction:	160°
Swell	T=9sec	Direction:	180°

3. DATA ANALYSIS

The purpose of the analysis of the experiment is to obtain the motion spectra and the wave spectrum in order to get a 'measured' transfer function. The results are compared with computer simulations. In the further analysis the propulsive data will be analysed and compared with computer calculations (especially the increase of resistance).

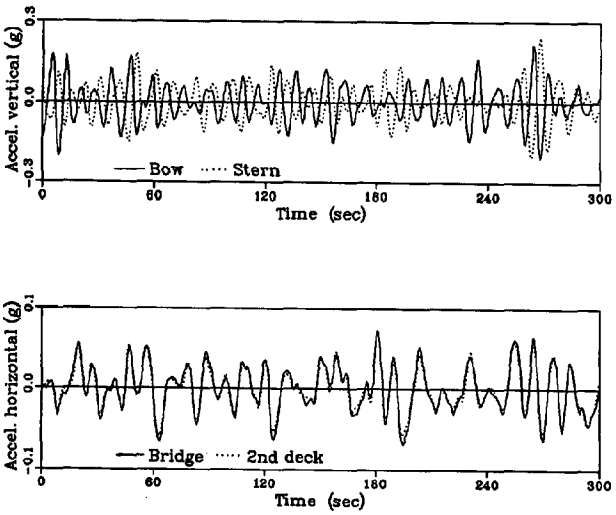

Fig. 4. Measured horizontal and vertical accelerations

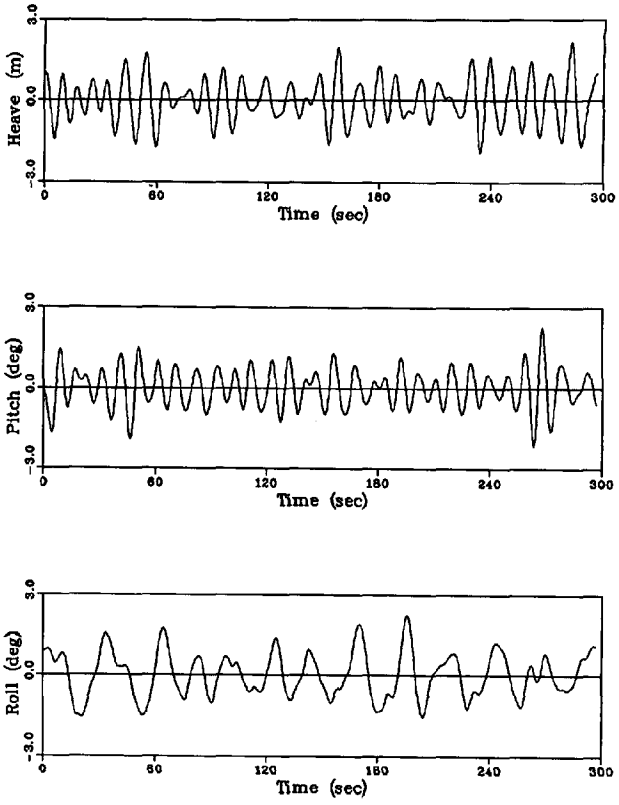

Fig. 5. Computed time-series of the rolling, pitching and heaving motion

In this paper one first example is given. The choosen measurement was taken on march 12, 1988 at 13:29 UTC. The observed wind and wave conditions are given in table 2.
The time series of the four accelerations are shown in figure 4. From the difference of the two vertical accelerations the pitch angle and from the difference of the horizontal accelerations the roll angle con be calculated. These calculations are described in [4]. For the calculation of the heaving motion the measured accelerations are used together with the before calculated pitching and rolling angle. Figure 5. shows the computed series of rolling, pitch and heave in the time domain.
The spectra of motion are computed by a Fast Fourier Transformation over the hole sample period. The power spectra shown in figure 6. are averaged over 9 frequency bins.

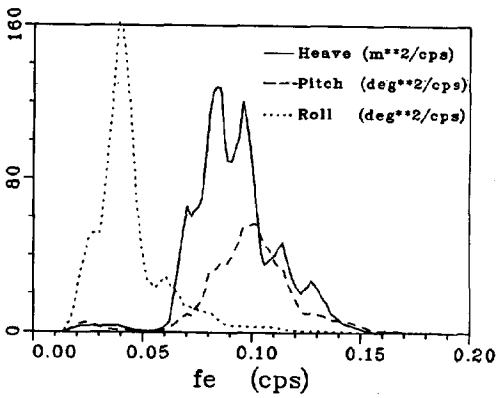

Fig. 6. Power spectra of the rolling, pitching and heaving motion

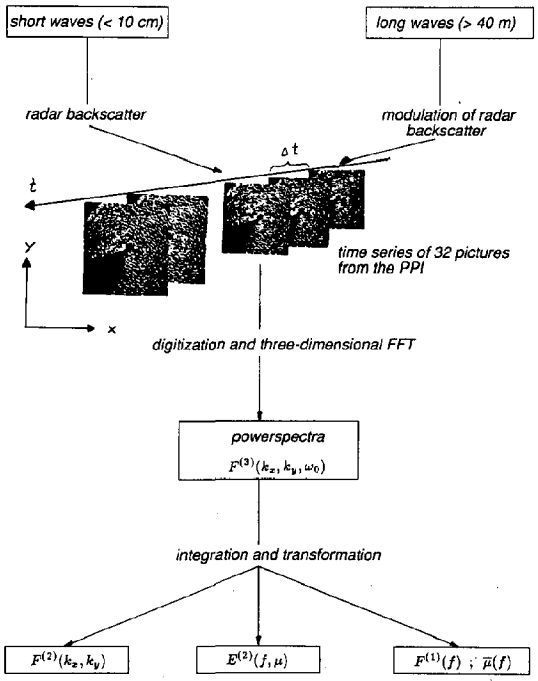

Fig. 7. Flow diagram showing the data recoding and analysis procedure

The flow diagram (fig. 7.) shows the steps of the used wave measurement and analysis. The sea wave measurement is composed by a series of photos. For analysis the pictures were digitised and sent to a computer.
The most important step in the analysis is the three dimensional FFT. This results in wave spectra defined over the two wavenumber components and the frequency:

(1) $F^{(3)}(k_x, k_y, \omega_0)$

The index $^{(3)}$ in (1) gives the dimension of the Fourier domain that is used. Two of the three dimensions are given by the wavenumber components k_x, k_y and the third dimension is given by the frequency ω_0.
The three dimensional spectral presentation is the most complete presentation of a wave measurement. Therefore other kinds of presentations may be calculated from (1) by integrations and transformations (see [5] and [6]).
To get the two dimensional image spectra the energy (1) has to be integrated along the frequencies. Here one big advantage of the image time series becomes evident. If the integration is done only for positive frequencies, the energy is separated from it's mirror part. Therefore the resulting wavenumber spectra are unambiguous.

Time series taken from board a sailing ship are Doppler shifted caused by the velocity $\vec{u}$ of the ship.

If:

(2) $\omega_0 = \sqrt{g|\vec{k}|tanh(|\vec{k}|h)}$

is the frequency of the wave with the wavenumber $\vec{k}$, this wave will be seen under the shifted frequency:

(3) $\omega_e = \omega_0 + (\vec{k} \cdot \vec{u})$

from board the sailing ship. Therefore the frequency in (1) has to be replaced by the frequency of encounter:

(4) $F^{(3)}(k_x, k_y, \omega_e)$.

Here the next advantage becomes evident. The speed of the ship displaces the wave energy parallel to the frequency axes. Thus by integrating along the frequencies the Doppler shifted energies are projected to the wavenumber plane k_x, k_y unaffected by the Doppler shift:

(5) $F^{(2)}(k_x, k_y) = \int_0^\infty F^{(3)}(k_x, k_y, \omega_e) d\omega_e$.

All the other spectral presentations of the wave spectra, that are calculated out of (5) are unaffected by the Doppler shift as well.

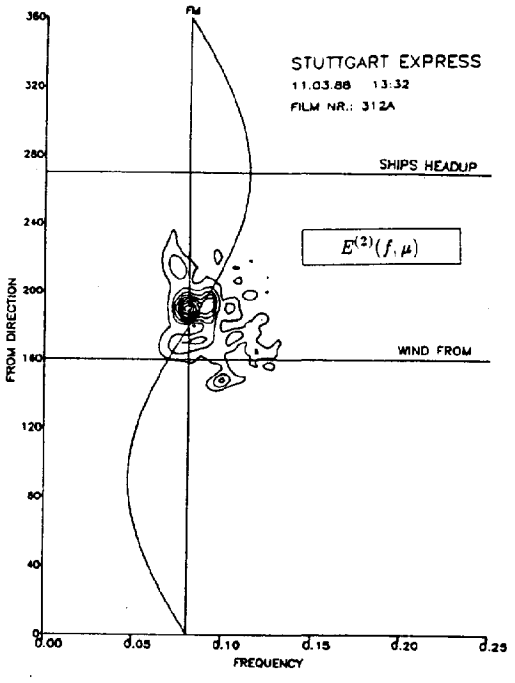

Fig. 8. Two-dimensional wave spectrum

Figure 8. shows the two dimensional, normalized wave energy spectrum as a function of frequency and direction. The distance of the isolines is 1/10 of the maximum. The auxiliary line is to find the Doppler frequency for energy with the frequency 'FM'.
The one dimensional spectrum is shown in figure 9. As this is the integration of energy given in fig.8. over all directions for each frequency bin, there is no Doppler shift in this spectrum. The absolute scaling for one dimensional spectrum was estimated by aid of spectral parameters (i.e.: the peak frequency and the Phillips constant).

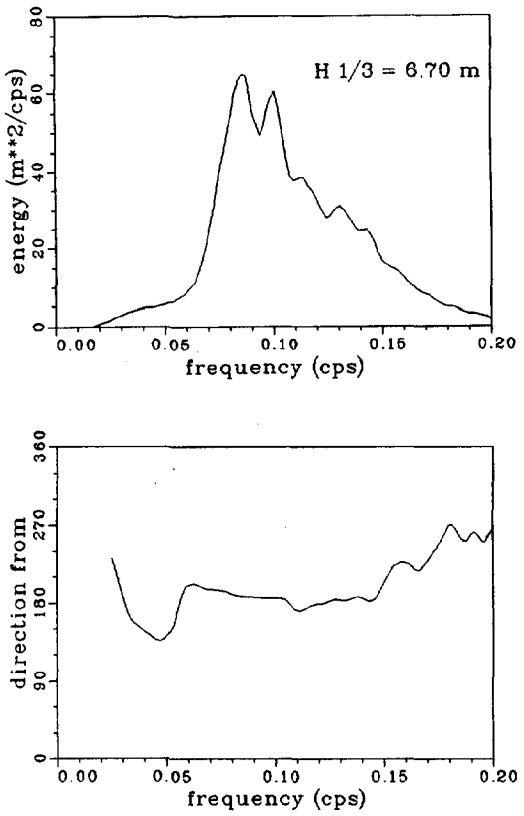

Fig. 9. One-dimensional energy spectrum and mean direction of the seaway

4. RESULTS

For a first comparison between the measurements and the computer simulation, a 'measured' transfer function for the pitch and heave motion was calculated. Pitch and heave are the motions which are mainly responsible for the increase of resistance and thus for the loss of speed in the seaway. Therefore the rolling motion is neglected here.

The transfer function is defined as the square root of the spectrum of motion devided by the inciting wave spectrum. For the determination of the frequency of encounter (fe) in this case a mean direction for the wave propagation of 190° (up to north) was taken. The ship's course was 270°. This results in an angle of encounter of 100°.
The dotted line in figure 10 is the result of the measured transfer function from the choosen example. The solid line gives the transfer function for pitch and heave calculated with the modul of the program used in the routing model. For these computations the actual trim and loading condition of the ship on it's regular seaway were fitted to the program.
For the reason of better comparison the calculations were not only made with the angle of encounter 100° but also with it's 15° neighbours 85° and 115°.

Figure 10 shows the comparisons between the predicted and 'measured' transfer functions. For this one example the

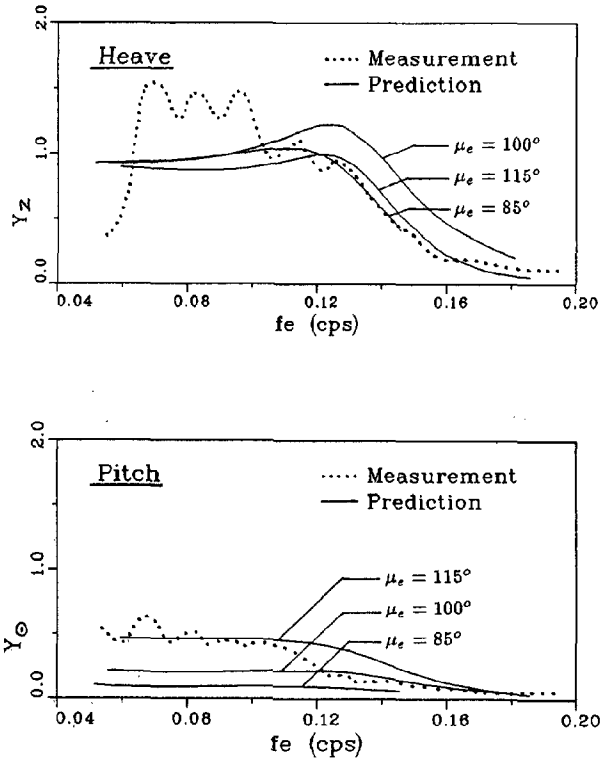

Fig. 10. Measured and predicted transfer function for the pitching and heaving motion

comparison is good for frequencies higher than 0.1cps. In the low frequency range (up to 0.07cps), where only a low wave energy was detected, the measured transfer function overshoots. But this phenomenon continues up to 0.09cps.

This result may be a hint that the used parameterisation is too rough. The different solutions for the prediction show how sensitive the transfer function is on the angle of encounter. In this example the direction of the wave field was characterised by only one mean value. Figure 8. showing the two dimensional wave spectrum demonstrates how rough this simplification is. If the parameters of encounter would be calculated out off the two dimensional presentation, results should be more coincidentally.

6. REFERENCES

[1] STOCKDREHER, E. (1986), Vergleich gemessener und berechneter Fahrtverluste eines Schiffes im Seegang. Diplomarbeit, Institut für Schiffbau der Universität Hamburg, September 1986

[2] ZIEMER,F. and W. ROSENTHAL (1987), On the Transfer Function of a Shipborne Radar for Imaging Ocean waves. Proceedings of IGARSS'87 Symposium, Ann Arbor, May 1987 pp. 1559-1564.

[3] WITT, J. (1987), Bergungsfähiger Schiffsdatenschreiber (Marine Voyage Recorder). Hansa 1987, Nr. 17, pp 1029-1030.

[4] STOCKDREHER,E. and F.ZIEMER (1988), Übertragungsfunktionen für Schiffsbewegungen im Seegang. Berichtsheft zum 9. Duisburger Kolloquium Schiffstechnik/Meerestechnik.

[5] YOUNG, I.R., W. ROSENTHAL and F. ZIEMER (1985), A three dimensional analysis of marine radar images for the determination of ocean wave directionality and surface currents. J. Geophys.Res., Vol. 90, pp. 1049-1059.

[6] ZIEMER, F. (1986), Untersuchung zur quantitativen Bestimmung zweidimensionaler Seegangsspektren aus Messungen mit nautischem Radar. GKSS-Externer Bericht 87/E/10,151 pp.

INFLUENCE OF FREQUENCY AND DIRECTIONAL SPREADING ON WAVE TRANSFORMATION IN THE NEARSHORE REGION

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ABSTRACT

A three-dimensional, physical model study of a harbor entrance jetty in Yaquina Bay, Oregon using spectral and directional spectral waves was completed. The 1:45 scale model consists of an entrance channel protected by two rubble mound jettys with actual bathymetry offshore of the entrance. Site-specific wave spectra, representative of the most severe hindcast storms in a 20 year period, were selected for study. A range of spectral parameters, including frequency and directional spreading, were modeled. Peak prototype periods were 12.5, 14.3 and 16.7 sec. Prototype zero-moment wave heights ranged from 14.4 to 23.0 ft. Surface water elevations were measured offshore and near the jetty head for two water depths. The effects of depth and frequency and directional spreading on transformation of wave period and height in the nearshore region are presented and compared.

1. INTRODUCTION

Irregular waves are routinely used in physical model tests of port facilities and breakwaters. Real ocean waves are short-crested, however, and have directional spreading which spreads energy over many directions. Sand et. al. (1983) measured diffracted wave energy in the lee of an entrance breakwater for unidirectional and directional spectral waves. They found larger waves for the directional cases. In model tests of wave transformation over a submerged elliptical mound, Vincent and Briggs (1988) found significant differences between monochromatic, spectral, and directional spectral waves. Kirkegaard et. al. (1980) measured motions of a moored vessel near an open jetty. They also found differences in response between spectral and directional spectral waves. Thus, it appears that the inclusion of directional spreading can have a significant effect on the design of port facilities and breakwaters.

The north jetty of the Yaquina Bay, Oregon entrance channel has a history of repeated deterioration and rehabilitation. A "placed-stone" construction technique with larger armor units has been proposed to restore the jetty to its original length. Thus, three-dimensional stability tests of this entrance jetty were conducted in the directional spectral wave basin of the USAE Waterways Experiment Station's Coastal Engineering Research Center (CERC) to verify this design. Site-specific extreme storm events were hindcast for a nearby deep-water site and numerically transformed to a shallow water depth corresponding to the location of the wave generator in the model. Six unidirectional and six equivalent direc-tional spectra were selected from the 20 year hindcast period as representative extremal events. Three gages were set up in the basin to measure incident and jetty head wave conditions for the stability study for two water depths. Thus, the effect of depth and frequency and directional spreading on wave transformation at the jetty head can be quantified.

This paper includes a brief description of the physical model and test setup. Next, a description of the six unidirectional and directional spectra test conditions is given. The model wave generation procedure is then discussed. Finally, results are presented showing the effects of transformation on peak wave period and zero-moment wave height.

2. MODEL DESCRIPTION AND TEST SETUP

Yaquina Bay is an estuary located on the Oregon coast, approximately 110 miles south of the mouth of the Columbia River (Figure 1). Two rubblemound jetties protect the 40-ft deep, 400-ft wide entrance channel, which passes through a narrow opening in an offshore reef. This basaltic reef lies 3500 ft seaward of the channel entrance and extends northward for 17 miles.

A three-dimensional physical model (Figure 2) of the Yaquina Bay entrance channel jettys was constructed in CERC's 96-ft long by 121-ft wide directional spectral wave generator (DSWG) basin. The electromechanical DSWG is 90 ft long and consists of 60 paddles in four portable modules of 15 paddles per module (Outlaw and Briggs 1986). The origin of the local coordinate system is at the edge of paddle 1. The y-axis and the north axis are aligned with the DSWG. Three capacitance wave gages (Figure 2) were used to measure surface water elevations in the basin.

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One was used to measure incident wave conditions near the DSWG and the other two flanked the head of the north jetty near the reef. Table 1 lists the gage coordinates.

Table 1
Gage Coordinates

Gage No.	X-axis ft	Y-Axis ft
1	5.0	45.0
2	46.0	42.0
3	46.0	45.0

An undistorted model scale of 1:45 was selected based on several factors including a) DSWG size and capabilities, b) required nearshore bathymetric area, c) available stone sizes, and d) preclusion of stability scale effects. Thus, it was not possible to model the entire entrance channel, nearshore bathymetry, and inner harbor. Since the main focus of the study was on the jetty head area, only 32 ft of the north jetty and 21 ft of the south jetty were modeled. The nearshore bathymetric features and offshore reef were duplicated to the extent that further wave transformation prior to interacting with the channel entrance was properly modelled. Thus, the DSWG was located at a depth corresponding to 58 ft in the prototype (1.29 ft model). To quantify the effects of depth changes, tests were also conducted at a water depth of +10.0 ft mllw, representative of a storm tide and set-up. The corresponding water depths were 68 ft prototype and 1.51 ft model. Incoming wave energy was damped with passive absorbers at the back end of the entrance channel. The interested reader is referred to reports by Grace and Dubose (1988) for detailed descriptions.

3. PROTOTYPE WAVE SPECTRA

The Wave Information Study (Corson, et. al.1987) data base was used to hindcast the initial deep-water spectra. They were multi-modal in frequency and direction with locally-generated wind-sea and distant swell components. The numerical model, SHALWV, (Hughes and Jensen 1986) was used to transform six "worst case" directional spectra to the shallow water depth of the DSWG. This model included source/sink and finite depth mechanisms such as refraction, shoaling, wave bottom interactions, and depth-related breaking. Six unidirectional and six directional spectra were selected from these numerically transformed SHALWV results.

Table 2 summarizes peak period T_p, zero-moment wave height H_{m0}, and overall mean wave direction $\bar{\theta}$ for each case. The angle $\bar{\theta}$ corresponds to the swell direction and is measured counterclockwise from east. All waves approach from the southwest quadrant. Figures 3 & 4 illustrate the range of frequency spreading for the six unidirectional and six directional spectra, respectively. The directional spreading for the directional cases ranged between 10 to 30 deg (Briggs, Grace, and Jensen 1988). The differences between the unidirectional and directional spectra are due to variations in input and boundary conditions used in SHALWV.

Table 2
Prototype Wave Spectra

Storm ID	T_p sec	H_{m0} in	$\bar{\theta}$ deg
	Unidirectional Series		
1969	16.7	22.3	15
1970	14.3	19.0	9
1972	12.5	14.4	19
1973	14.3	16.7	15
1974	16.7	19.0	21
1983	16.7	18.7	14
	Directional Series		
1969	16.7	23.0	10
1970	14.3	19.0	2
1972	14.3	15.4	11
1973	14.3	17.1	4
1974	16.7	20.3	21
1983	16.7	20.3	9

4. MODEL WAVE GENERATION

The twelve SHALWV storms were converted for use in the DSWG using the 1:45 scale. Table 3 summarizes the target model wave parameters.

Table 3
Target Model Wave Parameters

Storm ID	T_p sec	H_{m0} in	$\bar{\theta}$ deg
	Unidirectional Series		
1969	2.49	5.95	15
1970	2.13	5.07	9
1972	1.86	3.85	19
1973	2.13	4.46	15
1974	2.49	5.16	21
1983	2.49	4.99	14
	Directional Series		
1969	2.49	6.12	10
1970	2.13	5.07	2
1972	2.13	4.11	11
1973	2.13	4.55	4
1974	2.49	5.42	21
1983	2.49	5.42	9

The spectra were converted into control signals at each of the 61 DSWG paddle drives using a double summation, deterministic amplitude, random phase, frequency domain method (Briggs, Borgman & Outlaw 1987). Since the D/A rate for

the DSWG is 20 Hz, time series of 12,000 points or 600 sec were generated. An initial calibration phase was conducted to measure and correct the control signals. A response amplitude operator (RAO) was calculated for each of the twelve control signals to compensate for observed variations in peak period, wave height, and spectral shape (Briggs and Jensen 1988).

5. DATA COLLECTION & ANALYSIS

Wave elevation data was sampled at 10 Hz. A minimum of 200 waves at the peak period was collected for each case (Goda 1985). The data records were zero-meaned and tapered by a 10% cosine bell window. For the frequency spectral analysis, the data was band averaged with a bandwidth of 0.0671 Hz within lower and upper cutoff frequencies of 0.2013 and 1.476 Hz, respectively. A typical value for degrees of freedom is 68. A Gaussian smoothing technique (Borgman 1984) was used in the directional spectral analysis within the same frequency limits to calculate directional spreading.

6. WAVE TRANSFORMATION RESULTS

Only the effect of wave transformation on peak period and zero-moment wave height are presented in this paper. The interested reader is referred to a report by Briggs, Green, and Grace (1988) for complete results from all tests.

Table 4 lists the measured peak periods for the unidirectional and directional cases at the two depths for the incident gage 1 and the average of gages 2 and 3 at the jetty head. The normalized value is the ratio of the average period to the incident period.

Figure 5 shows the influence of depth and directional spreading on peak period transformation. Normalized directional peak period is plotted against normalized unidirectional peak period for five of the storms. The 1972 storm is not plotted because it lies off the edge of the plot. The left-most symbol represents the lower water depth. The 45 deg line is shown to indicate equivalence between unidirectional and directional periods. A value above the line implies that the directional period is larger than the corresponding unidirectional period for the same depth. Conversely, a value below the line indicates the opposite relationship. A horizontal line between points on the graph (i.e. 1973, 1974) indicates a constant directional period which is uneffected by changes in water depth. Likewise, a vertical line between points (i.e. 1969, 1970) indicates a constant unidirectional period. The increase in depth for the 1972 storm caused the unidirectional period to decrease while the directional period remained constant. This storm was the only one to experience a significant increase in period due to transformation in shallow water. The 1983 storm is interesting because the increase in depth caused a shift from a higher directional period to a higher unidirectional period. In general, the periods increased more for the unidirectional than the directional cases. The average increase for the unidirectional cases was 1.08 and 1.05 for the two depths, respectively. The directional cases were invariant to depth change, maintaining a constant 1.01 increase for both depths.

Table 4
Measured Peak Periods

Storm	Gage 1 sec	Ave 2 & 3 sec	Normal.
	a) Depth = 1.29 ft		
	Unidirectional Series		
1969	2.46	2.50	1.02
1970	2.19	2.18	0.99
1972	1.79	2.69	1.50
1973	2.53	2.68	1.06
1974	2.56	2.51	0.98
1983	2.68	2.73	1.02
	Directional Series		
1969	2.49	2.57	1.03
1970	2.01	2.08	1.03
1972	2.54	2.47	0.97
1973	2.53	2.50	0.99
1974	2.56	2.52	0.98
1983	2.47	2.57	1.04
	b) Depth = 1.51 ft		
	Unidirectional Series		
1969	2.46	2.50	1.02
1970	2.19	2.18	0.99
1972	2.15	2.73	1.27
1973	2.53	2.65	1.05
1974	2.56	2.47	0.97
1983	2.53	2.67	1.06
	Directional Series		
1969	2.49	2.58	1.04
1970	2.01	2.11	1.05
1972	2.54	2.47	0.97
1973	2.51	2.50	0.99
1974	2.56	2.52	0.98
1983	2.47	2.56	1.03

Table 5 lists the measured and normalized zero-moment wave height for the twelve storms for the two depths. Figure 6 shows the influence of depth and directional spreading on wave height transformation for the two depths. The same relationships described for the wave periods in Figure 5 apply for the heights in this figure. Also, a line parallel to the 45 deg line indicates no change in the relationship between unidirectional and directional storms due to depth (i.e. 1969). A decrease in the slope of the line connecting two depths indicates an increase in the unidirectional height relative to the directional height due to an increase in depth (i.e. 1970, 1972). Similarly, an increase in the slope of the line shows an increase in directional height relative to the unidirectional value (i.e. 1973, 1974, 1983). The trans-

formed wave heights at the jetty head were smaller than the incident conditions at gage 1. As expected, the heights increased for all cases due to depth increase. The unidirectional cases were higher than their corresponding directional cases except for the 1970 storm at low depth. The average normalized height for the unidirectional cases was 0.83 and 0.94 for the two depths, respectively. For the directional cases, this average increased from 0.75 to 0.87 due to the increase in water depth.

Table 5
Measured Wave Heights

Storm	Gage 1 in.	Ave 1 & 2 in.	Normal.
	a) Depth = 1.29 ft		
	Unidirectional Series		
1969	5.87	4.13	0.71
1970	5.15	4.08	0.79
1972	3.89	3.96	1.02
1973	4.35	4.20	0.97
1974	5.09	4.10	0.81
1983	5.12	4.07	0.80
	Directional Series		
1969	5.46	3.84	0.70
1970	4.83	4.04	0.83
1972	4.19	3.93	0.94
1973	5.23	3.93	0.76
1974	5.65	3.87	0.68
1983	5.93	3.98	0.67
	b) Depth = 1.51 ft		
	Unidirectional Series		
1969	6.79	5.65	0.83
1970	5.89	5.59	0.95
1972	4.53	5.16	1.14
1973	5.23	5.43	1.04
1974	5.89	5.00	0.85
1983	5.99	5.42	0.90
	Directional Series		
1969	6.07	4.93	0.81
1970	5.55	5.04	0.90
1972	4.89	5.06	1.03
1973	6.11	5.43	0.89
1974	6.32	5.01	0.79
1983	6.74	5.58	0.83

7. CONCLUSIONS

The effects of depth and frequency and directional spreading on wave transformation in the nearshore region were investigated using a 3D physical model of Yaquina Bay, Oregon. The 1:45 scale model consisted of an entrance channel protected by two rubble mound jetties with an irregular bathymetry and submerged reef offshore of the entrance. Six unidirectional and six equivalent directional spectra, representative of the most severe hindcast storms in the past 20 years, were numerically transformed to a shallow water depth of 58 ft (all units prototype). These storms had peak periods of 12.5, 14.3, and 16.7 sec and zero-moment wave heights ranging from 14.4 to 23.0 ft. The twelve storms were calibrated and tested at two water depths: 0 and +10.0 mllw.

Results from this limited series of tests with one incident gage and two gages near the jetty head confirm previous investigators findings that directional spreading can have a significant effect on the modeling of wave environments in the nearshore region. In general, the periods shifted more for the unidirectional than the directional cases due to wave transformation. The period was not affected by depth changes for the directional cases. Wave heights for all cases were reduced at the jetty. Increases in depth produced increases in the transformed wave heights. Except for the 1970 storm at 0ft mllw, the transformed unidirectional heights were always larger than their corresponding directional values.

8. ACKNOWLEDGEMENTS

The writers wish to acknowledge the Office, Chief of Engineers, USAE, for authorizing publication of this paper. It was prepared as part of the Laboratory Simulation of Spectral and Directional Spectral Waves work unit, Coastal Flooding and Storm Protection program of the Civil Works R & D program. We would also like to thank R. E. Jensen, D. L. Green, D. A. Daily, W. G. Dubose, and W. D. Corson for their help.

9. REFERENCES

Borgman, L.E. 1984. "Directional Spectrum Estimation for the S_{xy} Gages," USAE Waterways Experiment Station, LE Borgman, Inc., November.

Briggs, M.J., Borgman, L.E. and Outlaw, D.G. 1987. "Generation and Analysis of Directional Spectral Waves in a Laboratory Basin," OTC 5416, Offshore Technology Conference, Houston.

Briggs, M.J., Grace, P.J., and Jensen, R.E. 1988. "Directional Spectral Wave Transformation in the Nearshore Region, Volume I: Directional Spectral Performance Characteristics," USAE Waterways Experiment Station, Technical Report (in pub.), Vicksburg, MS.

Briggs, M.J., Green, D.R., and Grace, P.J. 1988. "Directional Spectral Wave Transformation in the Nearshore Region, Volume II: Jetty Head Comparisons," USAE Waterways Experiment Station, Tech. Report (in prep.), Vicksburg, MS.

Briggs, M.J. and Jensen, R.E. 1988. "Simulation of Extreme Storm Events in Coastal Structural Models," OSDS 88, Corvallis, OR, September.

Corson, W.D., et. al. 1987. "Pacific Coast Hindcast Phase II Wave Information," WIS Report 16, USAE Waterways Experiment Station, Vicksburg.

Goda, Yoshimi. 1985. **RANDOM SEAS AND DESIGN OF MARITIME STRUCTURES**, University of Tokyo Press, Japan, pp. 1-323.

Grace, P.J. and Dubose, W.G. 1988. "Jetty Rehabilitation Stability Study, Yaquina Bay, Oregon," Tech. Report (in pub.), USAE Waterways Experiment Station, Vicksburg, MS, pp 1-57.

Hughes, S.A. and Jensen, R.E. 1986. "A User's Guide to SHALWV: Numerical Model for Simulation of Shallow Water Wave Growth, Propagation, and Decay," IR CERC-86-2, USAE Waterways Experiment Station, Vicksburg, MS.

Kirkegaard, J., Sand, S.E., Ottesen-Hansen, N.E. and Hvidberg-Knudsen, M. 1980. "Effects of Directional Sea in Model Testing," Ports '80, Norfolk, VA.

Outlaw, D.G. and Briggs, M.J. 1986. "Directional Irregular Wave Generator Design for Shallow Wave Basins," 21st ATTC, Washington, DC, Aug.

Sand, S.E., Kirkegaard, J., Larsen, J. and Rodenhuis, G.S. 1983. "Numerical and Physical Modeling of Directional Diffraction of Waves," **Coastal and Port Engineering in Developing Countries**, Colombo, March.

Vincent, C.L. and Briggs, M.J. 1988. "Refraction Diffraction of Irregular Waves Over a Mound," ASCE WPCOE Journal (In press), New York.

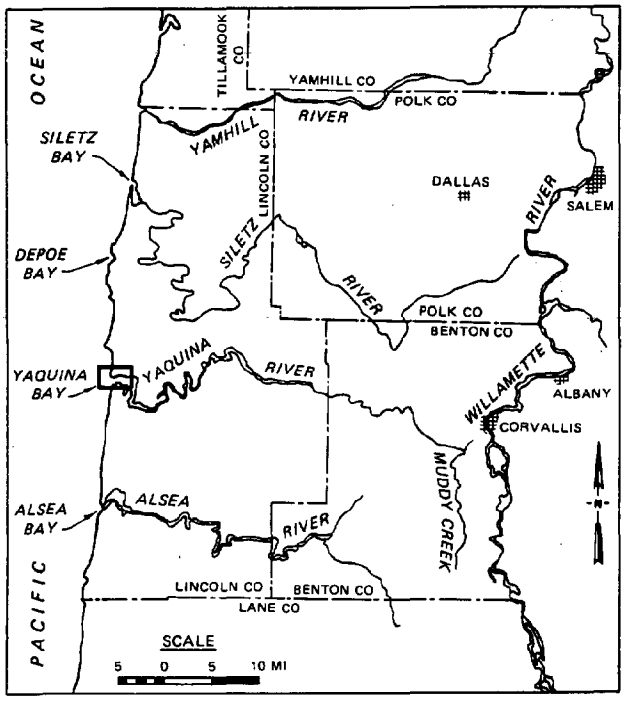

Fig. 1. Yaquina Bay, Oregon

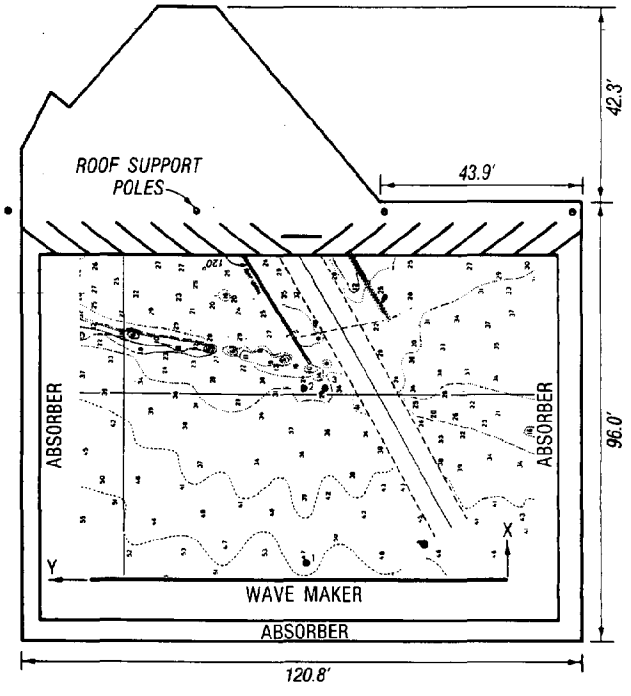

Fig. 2. Physical Model Setup

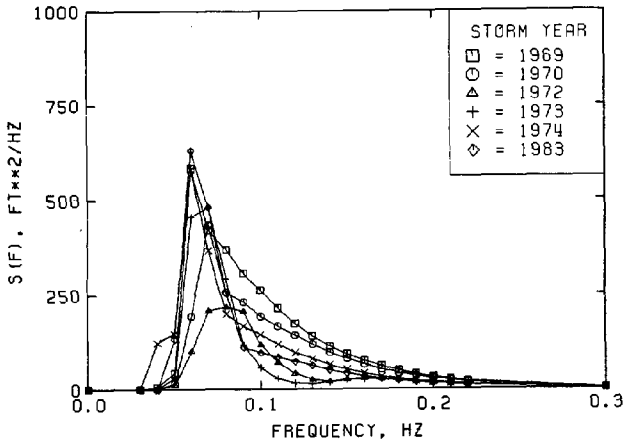

Fig. 3. Six Prototype Unidirectional Storms

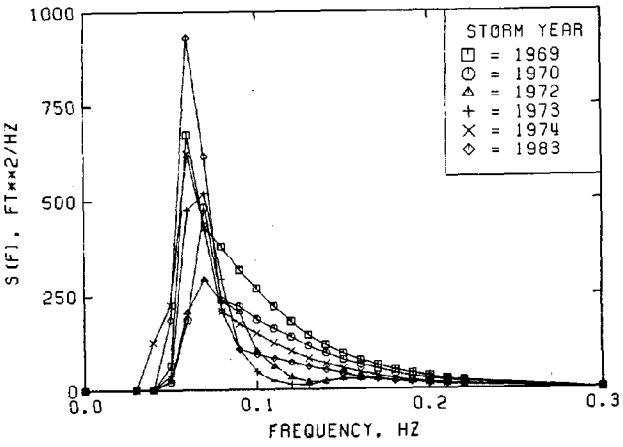

Fig. 4. Six Prototype Directional Storms

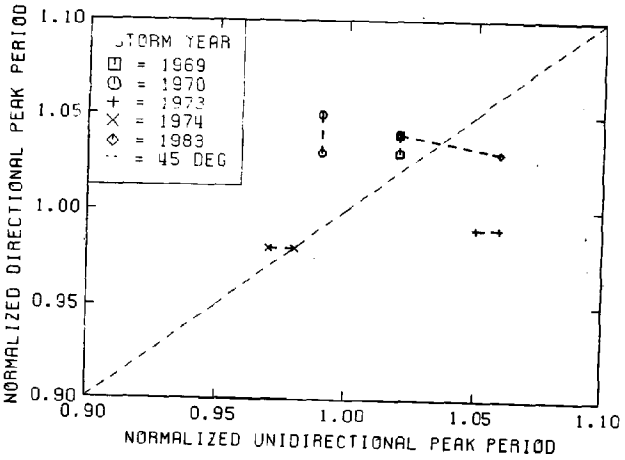

Fig. 5. Peak Period Transformation

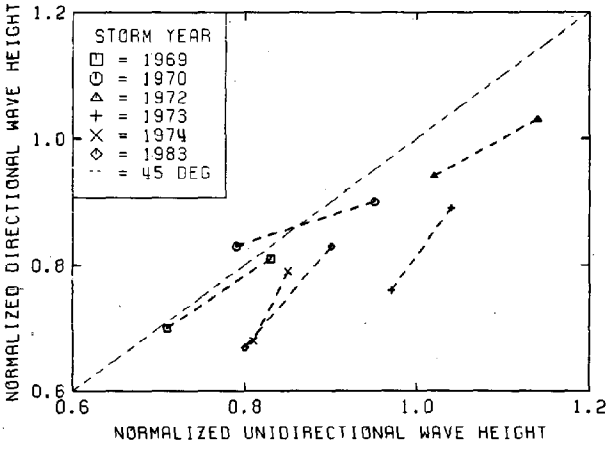

Fig. 6. Wave Height Transformation

TIDAL CIRCULATION DATA FROM THE LOS ANGELES/LONG BEACH HARBORS

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ABSTRACT

A synoptic data collection effort was undertaken between June and October 1987 at the Ports of Los Angeles and Long Beach, CA. Three months of tidal data from offshore and within the harbor, 1 month of current data and half tidal cycles of current profiles throughout the harbor were obtained. The data are to be used for model verification and calibration.

Tidal elevations were referenced to MLLW by analysis of average water surface elevations at each site and adjustments for variance in monthly mean sea surface elevations from MSL. Excellent agreement is obtained between this method and traditional surveying from a benchmark.

The method of collecting and analyzing the data is described. Samples of plotted data are presented, and hydraulic gradients are compared with resultant water velocities.

I: INTRODUCTION

The Ports of Los Angeles and Long Beach, California are conducting planning studies for harbor development in coordination with the Los Angeles District of the US Army Corps of Engineers (COE). The COE is charged with responsibility for providing deeper navigation channels and determining effects of the harbor expansion on the environment. To upgrade the Corp's capability to determine these effects based on state of the art modeling technology, the US Army Engineer Waterways Experimient Station (WES), is executing the Los Angeles/Long Beach Harbors Model Enhancement Program.

The program is separated into two major studies. The first will address the question of long period wave energy in the Harbors and its effect on moored vessels. The second will provide improved tidal circulation modeling with a more efficient numerical model system which will couple hydraulics and water quality variables. The prototype data for model calibration and verification has been collected by the Prototype Measurement and Analysis Branch (PMAB) of the Coastal Engineer Research Center (CERC) of WES. This report describes the methodology and results of the data collection effort.

II: DATA COLLECTION

The general requirements and schedule for each task in the program was prescribed in the Management Plan for the Model Enhancement Program. Data collection was divided into three subtasks: tidal data, in situ current data, and current profile data. Data were collected for varying intervals between 10 June 87 and 14 October 87. Measurement intervals for each subtask varied, but deployment times were nested to provide a period of simultaneous data from all three elements from 6 to 14 August 1987. Requirements of the final data sets and the instrumentation and techniques used to obtain them are discussed in this section. Figure 1 is a site map showing deployment locations of all instruments.

Tidal Data

The requirement of this subtask was to obtain time series of water surface elevations of two outside and two inside locations for a minimum of 90 days. Each data set was to be a continuous record of elevations relative to a Mean Lower Low Water (MLLW) datum at six minute intervals with a total error of no more than ±0.05 ft. Eight tide gages, consisting of a bottom mounted pressure transducers with self contained power and internal data storage capacity (Sea Data 635-11) were deployed. Each gage was attached with stainless steel bolts to a vertical mount which was welded to a 600 lb. railroad wheel. A subsurface buoy was attached to the wheel with a length of retreival line coiled in a cannister. The cannister, in turn, was attached to the wheel with a transponding accoustic release. The release served the dual purposes of a transponding beacon, for locating the instrument package, and as a means of releasing the buoy and recovery line at the end of the deployment.

In addition to the 8 tide gages specifically deployed for this study, data were available from a National Ocean Service (NOS) primary control tide station (#33) located inside Los Angeles Harbor, and from four pressure sensors located around the harbor perimiter. These four pressure

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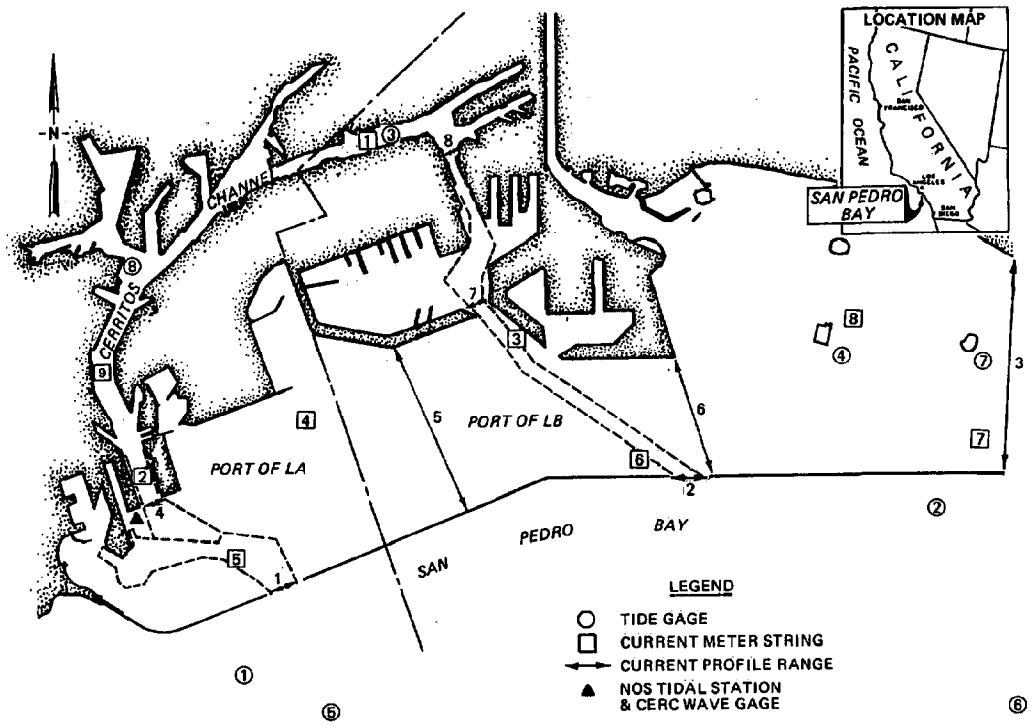

Figure 1. Site map with instrument locations.

sensors were installed by CERC to obtain long term measurements of harbor surge events under a separate subtask of the Model Enhancement Program entitled Wave Data Acquisition. They were originally configured as low frequency wave gages, but post processing of the time series produced continuous tidal data.

These data were processed to provide additional boundary conditions for the model and in quality control checking of the primary tide data sets.

Currents

The requirement for this subtask was a 30 day record of the vertical velocity profile at the major tidal exchange openings inside the harbor and at the harbor complex perimeter. Desired accuracy in speed and direction was ±0.1 knot and 2 degrees, respectively. Samples were needed at a similiar frequency as the tidal data, that is, continuous time series at average intervals of three minutes (Fig. 1).

The vertical profiles were obtained by deploying a total of 19 meters, with up to three current meters on a string supported by a surface buoy on a taut mooring. To reduce the risk of collision, the gage sites were moved to the sides of major entrances and channels. Spatial coverage was obtained at 9 sites by reducing the number of meters to two or one at those sites where strong vertical gradients were not expected.

The current meters were ducted impeller type with an internal compass for direction (Endeco 174). Velocity is measured by counting impeller revolutions over the selected averaging interval, and an instantaneous direction taken at the end of that interval. Both values, along with temperature and conductivity are recorded on a magnetic tape. The averaging interval selected was two minutes, allowing a total tape capacity of 34 days.

Each meter was calibrated prior to deployment at the National Space Technology Laboratory, NSTL, MS, calibration facility by tank tow at known velocities through still water. The calibration coefficients for each impeller/bearing combination were used in post-processing the data. Compasses were bench checked and accepted if within manufacturers tolerances without individual corrections.

In a typical current meter string (CM), a spherical 36 in. diameter steel buoy is attached to a 900 lb. railroad wheel with a 1/4 in. diameter mooring cable. A taut moor is maintained in spite of the tidal variation by including a length of 1 in. diameter rubber cord below the buoy. The cable was attached at either end with 3/8 in. screw-pin shackles. Each buoy supported an 8 ft. mast with a radar reflector and amber marker light. For additional visibility, two or three "guardian" buoys of similiar design (but without instruments) were placed around the instrued buoy approximately 200 ft. away.

To allow the meter to rotate around the mooring as current directions changed without fouling on the mooring, a split teflon bearing sleeve was

attached to the 1/4 in. cable at the appropriate depth for each string. A hinged stainless steel clamp went around the bearing and locked with a captive hinge pin. The meter was attached to a ring on the clamp with 3/8 in. screw-pin shackle, safety wired after closure. This arrangement permitted rotational freedom and a means for diver changeout of the gage during inspection without recovering the entire mount.

Profiling meters were of a similiar type to the in situ meters (Endeco 174 SSM), but equipped with a cable for telemetry of the data to the surface. Profiles were taken from a 26 ft. vessel between 6-14 August 87. A vertical profile consisted of 3 measurements, taken near bottom (B), at mid depth (M), and near surface (S) at one location, called a station. A range is a transect across an entrance or interface between major harbor sections with three to five stations. Profiles were scheduled to be taken at hourly intervals for 13 continuous hours for each range.

Data Recovery

Positions were obtained for all measurement sites with LORAN, supplemented when possible by visual and radar bearings to identifiable shore features. The LORAN was calibrated for local variance by occupying known locations with the boat and recording both time differences (TD) in microseconds and the LORAN's automatic conversion to latitude and longitude. The offset from true position was entered into the microprocessor controlled LORAN for automatic adjustment of calculated position. After this calibration, known positions were again occupied on each day of operation. Thus, a correction factor for each region of the harbor, valid for each day's atmospheric conditions, was obtained that allowed an improvement from LORAN's typical accuracy of ±100 meters to ±10 meters.

Of the 8 tide gages deployed, 7 were recovered. Of these, 2 experienced electronic failures and 1 experienced a tape drive failure. Since four of the gages were redundant, tidal data recovery was 100%, in regard to the requirement for two outside and two inside gages operating during the period when the in situ meters and the profiling meters were operating.

Of the 18 in situ current meters deployed at 9 sites, 13 were recovered between 9 & 12 Sept. The surface buoy at site #9 was found adrift on 21 Aug. A dive team failed to locate the meter or its mooring. Due to the proximity of ship and tug traffic in the area, this buoy and mooring were likely pulled off station by a vessel. The remaining unrecovered gages were the upper meter of CM site #4, both meters at CM site #5, and the single meter at CM site #8. The buoys at these sites were intact, the moorings undamaged, but the meters were removed at the shackle connecting the meter to the swivel. Since the shackles and their safety wires had been individually inspected a week after deployment, the most likely conclusion is that the meters were stolen by persons using dive gear.

The buoy from CM site #2 was located on board a commercial derrick barge moored adjacent to the meter site. The elastic section of the mooring had parted when the contractor attempted to move the buoy to accomodate repair work on a nearby wharf. Divers were able to recover the three meters, which were still attached to the mooring cable and the weight at the deployed location.

For the current profiles, each range was profiled on the scheduled stage of tide to include a peak flood or ebb and a tidal reversal. When a range contained only three stations, each station was profiled at approximately one hour intervals, as planned. The one hour return interval proved less attainable when a range contained five stations, and return intervals varied from 1-1/2 to 2 hours. Increased travel time between stations, increased anchoring time in deeper water, and the occasional instrument malfunction all contributed to the overall increase in return intervals. Overall data recovery from the current meters was ~75% of the measurement plan goal.

III: Data Analysis

Tidal Data

Raw data from the recovered tide gages were processed using SEA11.FOR, a program which converts raw ASCII data into tide, time, and wave record files. The tide file at this stage is a time series of absolute pressure values. Atmospheric pressure taken at Long Beach Airport at hourly intervals, was used to recover sea level pressure and the resultant time series converted to a depth time series through multiplication by a constant of 2.246 ft/psi.

The required datum for all tidal time series was MLLW. Since it was impractical to level each gage from shore using traditional surveying techniques, an assumption was made that the average free surface elevation over the deployment interval was constant throughout the harbor region. This is valid over a limited area with insignificant fresh water inflow and where no net transport can occur within the area over the time interval.

Mean Sea Level (MSL) is defined as the arithmetic mean elevation of the sea surface over a specific 19 year metonic cycle.[1] Means calculated over shorter intervals will vary, and are calculated by the National Ocean Service (NOS) for monthly and annual departures from MSL at each primary control tide station.[2] Thus an average free surface elevation for the deployment interval is not necessarily MSL.

Each tidal depth time series had the average depth of that time series subtracted (demeaned), converting it to a time series relative to the average free surface at that site over the deployment interval. If the exact elevation of

the free surface at any time and place (relative to MLLW or to any arbitrary datum) was of primary importance, then the average surface from each gage over a selected interval (for example, monthly) could be compared with the average departure of the nearest NOS primary control tide station during the same interval. In fact, a primary control tide station, #33, is located inside Los Angeles Harbor (see Fig. 1).

In the numerical model, the elevation of the free surface of each tide gage relative to other tide gages is the forcing function that drives the circulation of the model. Since the monthly average varies, its use as a datum would produce discontinuities in the records each month. A constant datum, such as MLLW, for all gages over the entire interval is appropriate and produces a continuous record.

To convert the datum to MLLW, the monthly mean sea levels relative the MLLW for tide station #33 were obtained from the Tides Analysis Branch of NOS for June through October.[3] These monthly levels were again averaged to obtain a single offset representative of the deployment interval, 3.09 ft. This was added to the demeaned depth time series to obtain the tidal elevation above MLLW at each site.

To validate the supposition of constant average sea level throughout the harbor, monthly means relative to MLLW were also calculated for each tide gage. Means, the average mean and the difference in means between months (Δ) are listed in Table 1 for the NOS tidal station #33 and the CERC tide gages. Direct comparison is only valid for those months when the gage was operational for nearly the entire month.

The cumulative average water levels at each station are within 0.03 ft. The individual monthly averages show more variation, though the differences, between months indicate the same trends are occurring at each site.

To verify clock accuracy (nominally ±1ppm), deployment, recovery and shut-off times, as recorded in the field, were checked against the data sets indicated times. Deployment and recovery are apparent from pressure records and shut off time from the last time word in the series. Agreement within the 3.75 minute sampling interval was considered adequate verification.

Tidal accuracy is addressed in more detail under Part IV Discussion. Figure 2 is an example of a tidal elevation time series from gage #1, located outside of the harbor breakwater for the period 4 August to 9 September.

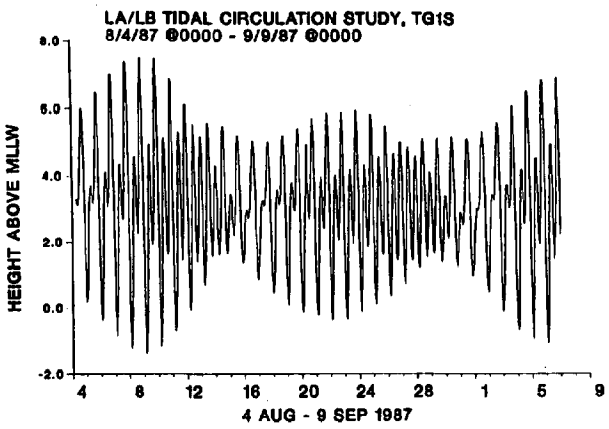

Figure 2. Tidal elevations, site gage 1.

Current Data

For the in-situ meters, raw data in ASCII format is converted to separate velocity (feet per second), direction (degrees from magnetic north), temperature (degrees C), and conductivity files. Direction data words were converted to true north by adding the magnetic variation specific to the LA/LB area, -13.55 decimal degrees. Clock accuracy was verified and adjusted as required by comparison with recovery and shut-off times. One meter had a significant clock error and was not processed, leaving a total of 12 useable data sets.

The current profile data required no analysis since it was read directly in engineering units

Table 1. Monthly Mean Sea Surface Levels

June-Oct 87, Sea Level Variations and Differences (Δ)
Elevations in ft. rel to MLLW

Month	TS-33	Δ	TG-1	Δ	TG-3	Δ	TG-6	Δ	TG-7	Δ
June	2.88		2.95		2.90		--		--	
July	3.09	0.21	3.10	0.15	3.12	0.22	--		--	
Aug	3.14	0.05	3.15	0.05	3.15	0.03	2.99	0.15	2.99	0.16
Sept	3.23	0.09	--		--		3.14		3.15	
Cum. Aver.	3.09		3.07		3.06		3.07		3.07	

velocity were visually averaged during observation of the output.

IV. DISCUSSION

Before examining implications of the data collected, certain investigations should be conducted regarding its confidence level. Due to time constraints, a rigorus statistical analysis will be postponed until subsequent reports, but direct observations of trends and selected samples will provide some criteria for evaluation of the validity of the measurements. General characteristics of the observed harbor circulation patterns will be discussed.

Tidal Data

Perhaps the most basic concern is the overall shape of the tide curves over the deployment. Classic semi-diurnal behavior is evident in Fig. 2. Another obvious test is to compare the measured tidal data with the predicted tide for the same period. Exact agreement is never obtained, but given the proximity of the tide station, and by selecting periods with low atmospheric anomolies, a close agreement can be expected between observed and predicted tidal elevations.

Figure 3 shows the predicted tide for 7-8 August[4] (average atm. press. 29.8 in Hg, average wind speed < 7.5 kt) overlaid with measurements from wave gage LA4, located several hundred ft. away. A shift upward of the measured data, on the order of 0.3 ft., is evident while the overall range of

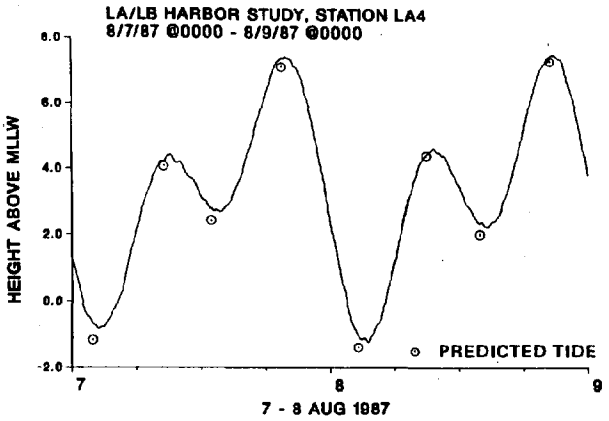

Figure 3. Predicted tide versus measured tide, gage LA4 for August 7 and 8.

8.3 ft is matched exactly. The average August departure from the annual sea level for NOS tide station #33 between 1963 and 1981 is + 0.20 ft. It would be impossible to accurately distribute the remaining 0.1 ft of difference between gage error and predicted tide error.

A better indication of the final accuracy is obtained by comparing two tide gages at the same location. A residual is calculated between any two gages by subtracting one time series from another and is a plot of the instantaneous hydraulic head existing between them. Since each data set was de-meaned independently, the departure from zero of the residual from two gages at the same location is an indication of the overall accuracy of the instruments. The best approximation to this condition occurs with sites 1 and 6, located outside the harbor breakwater at approximately the same depth.

The residuals between sites 1 and 6 are plotted in Fig. 4. The mean of the residual is included, which would theoretically be equal to zero over a sufficiently long time interval if the assumptions made in selecting the datum are valid.

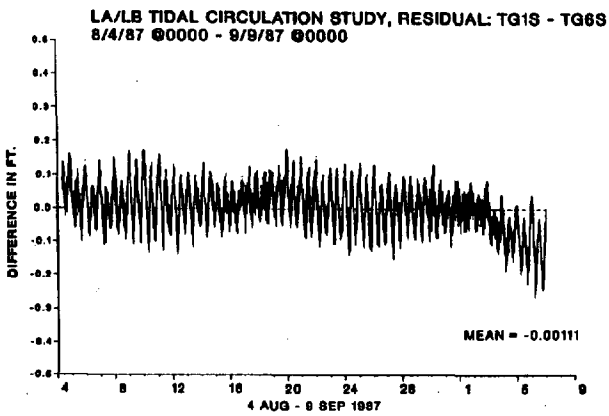

Figure 4. Residual time series; tide gages 1 to 6.

The means of all residual pairs, which range from 0.0001 ft to 0.0038 ft, are the result of cancellation of variance somewhat larger at any one time, but indicates an overall accuracy commensurate with the stated specifications of the sensor and well within the experimental requirements.

Unlike the primary and back-up tide gages, the wave gages were installed nearshore on harbor structures, and were accessible (via diving rodmen) to standard leveling.[5] Wave gage LB4 was surveyed in on two occasions to a nearby benchmark. The average of the two surveys is 17.60 ft. below MLLW.

Two data sets, A and B, cover the period of consideration. A simple average of their two mean water depths gives

$$[-20.65 + (-20.77)] / 2 = -20.71$$

Adjusting to MLLW by the average difference used in the previous analysis:

$$-20.71 + 3.09 = -17.62$$

The agreement within 0.02 ft is less than the variance of the two surveys.

Current Data

Rose plots, which display current velocity and direction as polar vectors, with shading representing percent of occurance, provide the most condensed display of the current data for statistical purposes. The plots for meters #3B and 2M (Fig. 5) indicate predominant flow in line with the orientation of the nearby retaining walls. Additionally, a net mass transport, or circulation, in a counter clockwise direction through the Cerritos Channel is apparant.

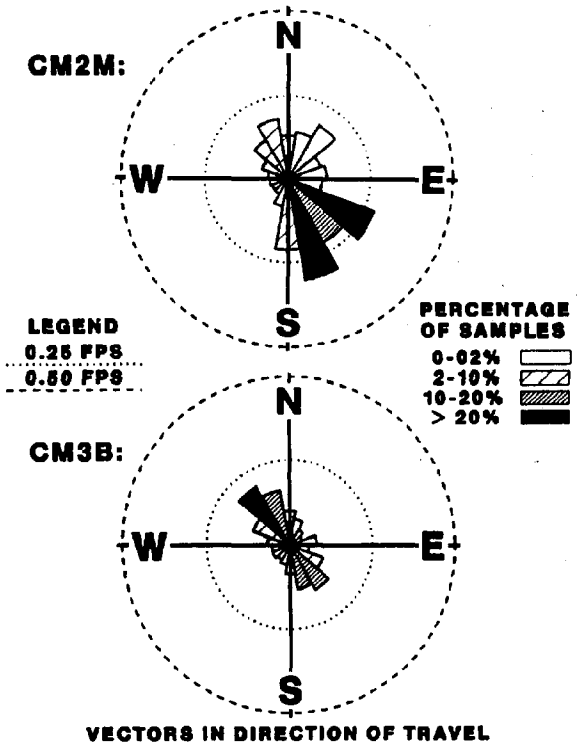

Figure 5. Current vector rose plots meters 2M and 3B.

The skewness observed in the rose plots are the result of statistical representation of cumulative events, and do not imply a flow occuring at any one time. To see the instantaneous currents, time series representations are required, as shown in the next section.

To observe details of the harbor flow patterns and to illustrate the correlations between sites at simultaneous times, currents must be observed at a smaller scale. Two nested windows were selected for detailed observation: the 7th and 8th of August, and 0000 hours to 0400 hours on 8 August. At these times scales, it is also convenient to combine the velocity and direction information into a single vector time series plot. Figure 6 shows the 2 day residual between tide gage 1 and 3, with the simultaneous vector plot of current meter 2S. At 1800, 7 August the residual abruptly goes from positive (flood) to negative (ebb). The current reverses at the same hour, increasing to maximum ebb 8 hours later, when the residual reaches an extreme of -0.4 ft.

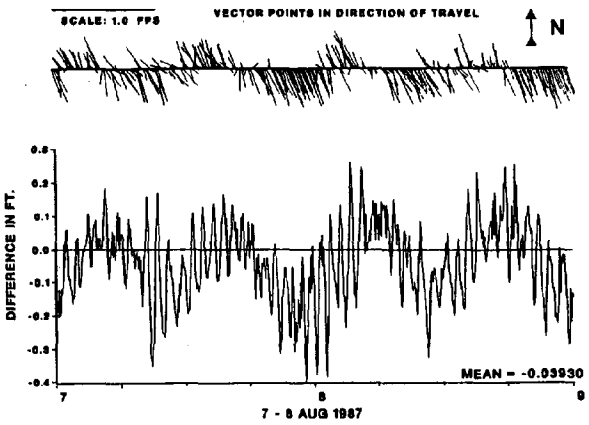

Figure 6. Residual time series tide gages 1 to 3 and resultant current vectors, meter 2S on August 7 and 8.

Further evidence of the net clockwise flow in the Cerritos Channel is evident, since the flows outward at the Western opening clearly surpass the flow inward.

Conclusions

A synoptic data collection effort at Los Angeles/ Long Beach Harbors was completed that provides adquate data to calibrate and verify a three dimensional numerical model of tidal circulation. Three months of tidal data, 1 month of current data and half tidal cycle current profiles were obtained throughout the harbor. Project requirements and schedules as directed in the Management Plan were fully met.

Conclusions resulting from the study are:

Use of a common mean water surface as a datum for synoptic tidal measurements over limited space and duration provided reasonable results in this situation and is a cost effective alternative to independent leveling of offshore gages.

Tidal circulation in LA/LB Harbor during the collection period was characterized by small scale spatial and temporal variations, including strong vertical stratification. Currents are shown to be in correct orientation and phase with the measured surface elevation slopes.

Flow in the Cerritos Channel was basically divergent/convergent from the two openings, but sufficient amplitude and phase differences existed to result in a net circulation counterclockwise. A migrating node existed at the back of the channel.

V: ACKNOWLEDGEMENTS

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VI: REFERENCES

1. Harris, D. L. "Tides and Tidal Datum in the United States," Special Report No. 7, Feb. 1981, US Army Engineer, Waterways Experiment Station, Coastal Engineering Research Center.

2. Harris, D. L. "Tides and Tidal Datum in the United States," Supplement to Special Report No. 7., Feb. 1981, US Army Engineer, Waterways Experiment Station, Coastal Engineering Research Center.

3. Scherer, Wolfgang. Personal Conversation, Feb. 1988, US Department of Commerce, NOAA, Natioal Ocean Service, Sea and Lake Levels Branch.

4. "Tide Tables 1987," 1986, US Department of Commerce, NOAA, National Ocean Service.

5. Hicks, Steacy D.; Morris, Phillip C.; Lippincott, Harry A.; and O'Hargen, Michael C. "User's Guide for the Installation of Bench Marks and Leveling Requirements for Water Leveling Stations," Oct. 1987, US Department of Commerce, NOAA, National Ocean Service.

WAVE IMPACT FORCES ON THE JONES ISLAND EAST DOCK, MILWAUKEE, WISCONSIN

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ABSTRACT

On December 15, 1987, a moderate storm on Lake Michigan generated waves characteristic of a 2- to 4-year return period. These waves propagated through the breakwater entrance at Milwaukee, Wisconsin, and moved partially constructed concrete slabs at the Jones Island East Dock. The wave characteristics of the December 15, storm were hindcast and compared to calculated design waves for the structure. The uplift forces due to the storm waves were also hindcast and compared to computed wave force envelopes. The comparison suggested that the slowly varying uplift forces for which the dock was designed would not have produced the motion. It was concluded that the rapidly varying vertical impact forces, amplified by the generation of standing waves, caused the observed motion. The results show that further research is required regarding impact forces encountered by cantilevered horizontal platforms. The need to consider these forces for future designs of horizontal platforms is indicated.

INTRODUCTION

The engineer involved with coastal structures and shoreline facilities is almost always faced with the problem of predicting and designing for the impact forces of incident waves. There exists a large amount of information on wave forces on vertical structures subjected to breaking, broken, and nonbroken waves. This information is readily available to the design engineer in standard sources such as the Army Corps of Engineers Shore Protection Manual [1] and the Naval Facilities Engineering Command Coastal Protection Design Manual DM-26.2 [9]. Many reference texts and a large amount of published literature also address such forces. However, little information is available regarding wave forces in the vertical direction on overwater horizontal structures.

The lack of information about vertical or uplift forces on horizontal structures makes it difficult for the engineer to consider the widest possible range of options when attempting to select the best design for a particular application. The case considered in this paper is that of a cantilevered horizontal platform extending seaward of a vertical curvilinear wall; the platform is above stillwater level but subjected to impact of large storm waves. A brief and inadequate discussion of uplift forces is given in Design Manual DM-26.2 [9]. Only ten papers (in English) were found in the research literature (since 1960) applicable to the problem. None of them address the specific configuration of interest--a cantilevered platform backed by a vertical curvilinear wall.

Recent experience with an extended dock platform has suggested a method to approach such a design problem and has also illustrated the requirements for further research needed. Much of the, admittedly scarce, literature considers only the slowly varying forces to be important for design purposes. However, it has become apparent that the short duration, rapidly varying, forces resulting from the impact of the wave on the underside of the platform can be an important design criteria.

The nature of these forces may be similar to the more familiar horizontal breaking wave forces on vertical planar structures, but some significant differences appear to exist. The wave need not be breaking in order to generate rapidly varying, vertical impact forces. The effect is more related to the slamming forces on a ships hull. Furthermore, if the horizontal platform is backed by a vertical wall, standing waves are formed. This will significantly increase the uplift forces (both slowly and rapidly varying). The efficiency of the vertical wall in reflecting wave energy and the manner in which it is reflected is an important design consideration.

Available Literature

As previously mentioned there appears to be little or no useful information in the design manuals or handbooks available to the designer of coastal structures concerning rapidly varying uplift forces. There also appears to be little cross-over from the field of naval architecture to coastal engineering. Information from studies on hull slamming forces is the most likely avenue to further research targeted for the coastal engineer.

The type of information available, in English, is presented in Table 1. This list is not meant to be exhaustive but it does appear to be representative. Table 1 shows that most of the available information is from model scale experiments and only two

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Table 1
REPRESENTATIVE RESEARCH ON WAVE UPLIFT FORCES

Date	Author	Title	Platform Structure		Problem Treatment			Forces Studied		Depth		SWL-Platform Distance	
			Open	Vertical Wall	Scale Model	Prototype Scale	Analytical	Slowly Varying	Rapidly Varying	Constant	Variable	Constant	Variable
1963	Elghamry [3]	Wave Forces on a Dock	X		X								
1966	Furudoi and Murota [7]	Wave-Induced Up-Lift Forces Acting on Quay-Aprons		X	X	X		X	X	X			X
1967	Wang [13]	Wave Pressures on Horizontal Pier	X										
1967	Verhagen [12]	Impact of Flat Plate on Water (Cross-over from Naval Architecture)	X						X				X
1969	French [5]	Wave Uplift Forces on Horizontal Platforms	X		X			X					
1970	Wang [14]	Water Wave Pressures on Horizontal Plates	X										
1971	Elghamry [4]	Uplift Forces on Platform Decks	X		X			X	X		X		X
1978	Tanimoto and Takahashi [11]	Wave Forces on a Horizontal Platform	X		X			X	X		X		X
1979	French [6]	Wave Uplift Pressures on Horizontal Platforms	X		X			X			X		X
1986	Lee and Lai [8]	Wave Uplift on Platforms or Docks	X	X			X		X		X		X

papers consider a cantilevered horizontal platform backed by a vertical wall. An examination of these papers clearly illustrates that much more research and experience, utilizing cross-overs to related fields, is required. It is expected that the information presented in this paper, regarding prototype scale experience, will provide some guidance to the design engineer as well as indicate the need for future investigations.

Description Of Dock

New docking space for the Port of Milwaukee is being constructed at the eastern edge of a lakefill on Jones Island, Milwaukee, Wisconsin (Figure 1). The dock is called the Jones Island East Dock (JIED). The facility is located on Lake Michigan but is protected to some degree by a breakwater, as shown in Figure 1. The dock is subjected to waves transmitted through the harbor entrance.

The JIED consists of a north-south wall of alternating cell and arc coffer dams, as shown in Figure 2. The coffer dams are made of vertical sheet piles arranged into 13 circular cells and 12 intervening arcs. The cells are approximately 54 feet in diameter and the centerline distance from cell to arc is about 32 feet. The sheet piles penetrate the mudline at an elevation of 547 feet, referenced to the International Great Lakes Datum (IGLD) and extend into mud to an elevation of about 534 feet (IGLD). The lakeward half of the cells and arcs

are capped by cantilevered concrete slabs as shown in Figure 2. The bottom of the slabs are at elevation 583.3 feet (IGLD), which is nominally about 4 feet above still water level.

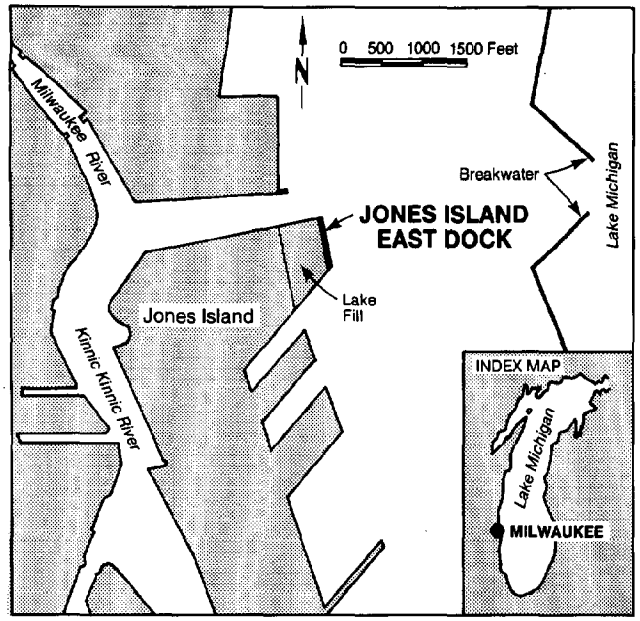


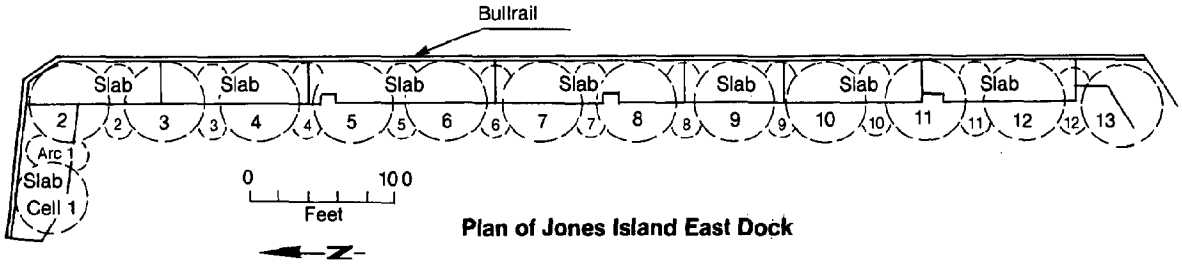
Figure 1. Jones Island East Dock at Milwaukee, Wisconsin.

ANALYSIS OF PLATFORM MOVEMENT

On December 15, 1987, the partially completed slabs of the JIED were observed to move vertically during a moderate winter storm (Figures 3 and 4). According to an eye witness, the slabs tended to rotate with the seaward edge of the slabs rocking upward 6 to 8 inches. The slabs moved up and down in response to the movement of the storm wave crests from north to south along the JIED wall (Figure 4). The purpose of the investigation presented here was to report the design wave characteristics, determine the severity of the December 15 storm waves, hindcast the resultant wave characteristics, calculate the applied uplift forces using the most recent research literature, compare these recently computed uplift forces with those used in the initial design, compare the calculated movement of the dock platform due to these forces to the observed movement, and determine if and where further research is required.

Incident Wave Characteristics

Significant wave characteristics for engineering design in the Great Lakes have been hindcast by Resio and Vincent [10]. They hindcast wave height and period for locations approximately 12 miles offshore for recurrence intervals of 5 to 100 years, on a seasonal basis, and for three different shoreward approach directions. Waves affecting the JIED must approach Milwaukee from the east north-east direction, pass through the en-



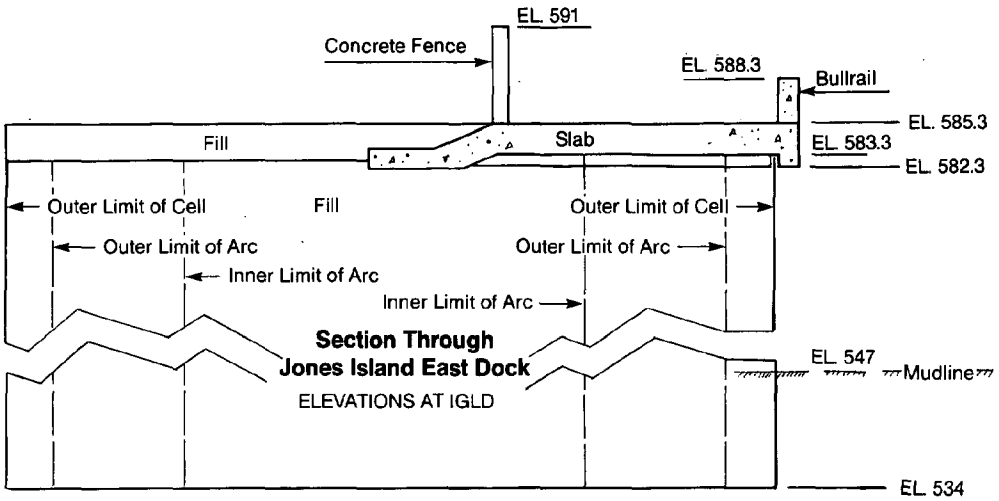


Figure 2. Plan and Section of the Jones Island East Dock.

trance to the Milwaukee breakwater and impinge on the JIED.

To obtain design wave characteristics at the JIED, these deep water wave characteristics off Milwaukee (Table 2) have been propagated shoreward, shoaled, refracted, diffracted through the breakwater entrance, and shoaled to the face of the JIED. The analysis was made using the methods outlined in the Shore Protection Manual [1]. Winter conditions are the most extreme and will result in the highest waves. Although ice conditions may modify the effects of waves on the shoreline, open water winter conditions were used as the example conditions throughout for the following discussions. The results of the analysis are shown in Table 3.

December 15, 1987, Storm

On December 14, 1987, winds were 4 to 8 knots from the northwest sector throughout the morning. During the early afternoon the wind began to shift to the north and increase in speed. The lake level was 579.0 feet (IGLD). By late evening the speed had increased to 15 to 18 knots out of the east northeast. By about 3:00 a.m. on December 15 the wind speed had increased to over 20 knots and blew from the northeast; the speed increased to about

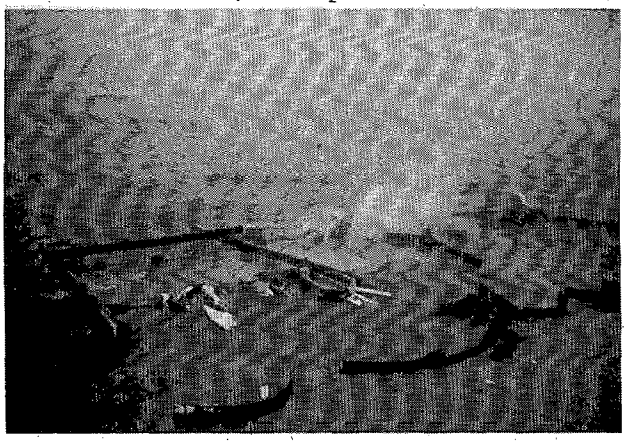


Figure 3. Jones Island East Dock on December 15, 1987. Photograph shows the partially completed slabs at cells 12 and 13.

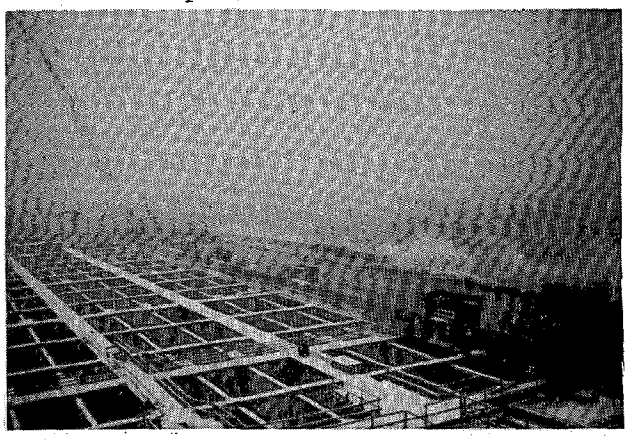


Figure 4. Jones Island East Dock on December 15, 1987. Photograph shows the partially completed slabs at cells 2 through 7.

Table 2
DEEP WATER DESIGN WAVE INFORMATION FOR LAKE MICHIGAN AT MILWAUKEE, WISCONSIN

Return Period (years)	Significant Wave Height[a] (feet)	Highest 1% Wave Height (feet)	Significant Wave Period (seconds)	Deep Water Wave Length (feet)
1[b]	6.6	11.0	6.8	237
2[b]	9.4	15.7	7.6	296
5	13.0	21.7	8.6	379
10	15.6	26.1	9.4	452
20	18.4	30.7	10.2	533
50	22.0	36.7	11.2	642
100	24.6	41.1	12.0	737

[a] Data is interpolated between Resio and Vincent (1976) shoreline grid points 38 and 39, for winter season, and for waves approaching normal to the shoreline.

[b] Extrapolated values.

Table 3
DESIGN WAVE INFORMATION
AT THE JONES ISLAND EAST DOCK

High Lake Level at 582 Feet (IGLD)

Return Period (years)	Significant Wave Height (feet)	Highest 1% Wave Height (feet)	Significant Wave Period (seconds)	Deep Water Wave Length (feet)
1	2.2	3.5	7.2	187
2	3.1	5.1	8.1	216
5	4.4	7.1	9.1	253
10	5.0	8.4	10.0	280
20	5.9	8.9	10.7	312
50	6.7	9.1	11.8	350
100	7.1	9.3	12.6	373

High Lake Level at 582 Feet (IGLD)

Return Period (years)	Significant Wave Height (feet)	Highest 1% Wave Height (feet)	Significant Wave Period (seconds)	Deep Water Wave Length (feet)
1	2.2	3.5	7.2	171
2	3.0	5.1	8.1	195
5	4.4	7.1	9.1	227
10	5.0	7.4	10.0	251
20	5.9	7.5	10.7	280
50	6.7	7.5	11.8	315
100	7.4	7.5	12.6	339

30 to 35 knots from the northeast until approximately 8:00 a.m. At this time the wind speed began to drop and the wind shifted quite rapidly to the north and then to the northwest. Maximum gusts were observed at 6:00 a.m. and were 51 knots out of the northeast. Heavy snowfall was associated with the storm; thunderstorms were observed. The lake level had risen to 580.6 feet (IGLD). Barometric pressure drop and rise was relatively rapid (small, "tight" storm).

Hindcast Waves from Storm Condition

Depending on a variety of factors, a best estimate of deep water waves generated by the storm indicates significant wave heights (H_s) of 10 to 12 feet, with periods (T) of 8 seconds, and wave lengths (L) of 328 feet. These deep water waves were attenuated by shoaling and refraction as they moved toward the breakwater channel. Lake levels at the time of the storm resulted in a water depth of approximately 40 feet at the breakwater gap. At this depth for wave periods in the range of 8 seconds, the shoaling coefficient is less than one (about 0.92). The refraction coefficient is between 0.92 and 1.00 depending on the direction of wave approach in deep water; 0.98 provides a reasonable estimate. Thus, the wave at the breakwater gap is estimated at H_s = 9 to 11 feet; T = 8 seconds; L = 250 feet.

Accepting the calculation technique used [2], the major uncertainties in this estimate involve definition of the meteorological conditions. The most significant condition is the size of the storm and the resulting fetch of the wind. The assumption of a duration limited wave generating event would yield the highest deep water wave heights, 12 to 14 feet, for sustained 30 knot winds for 12 hours. Atmospheric stability and the uncertainties involved with wind data collection and the conversion of airport wind to over-water wind are other factors. Estimates of all of these factors based on an examination of their effect were made. The evidence indicates a rather "tight storm" that would decrease the fetch. The calculations assumed a wind speed toward the high end of the observations. There is a reasonable confidence level of characterizing this storm as generating 10- to 12-feet deep water waves.

The waves at the breakwater were then diffracted through the gap and propagated to the JIED. The resulting incident progressive wave height at the dock face is estimated to be 3 to 4 feet (H_s-significant wave height) and 6 to 7 feet (H_1-one percentile wave height). This corresponds to a return period of between 2 and 4 years (see Table 3).

Wave Forces

Because of the geometry of the cell-arc wall at the JIED, some portion of the impinging progressive waves will be transformed into standing waves at and near the wall. The theoretical limit of wave heights and associated vertical velocities of the standing wave are twice those of the incident progressive wave reflecting from a planar wall. This fundamental change in the wave characteristics from progressive to standing wave must be considered in the force calculations.

After the movement was reported, the stability of the completed dock was studied using the methods outlined in readily available references [6][9]. This analysis indicates uplift forces up to 1,000 psf as shown in Figure 5. Forces of this magnitude will not cause movement of the dock, which will resist uplift forces of over 1,500 psf. Thus, we concluded that the standard references were insufficient to explain the observed movement.

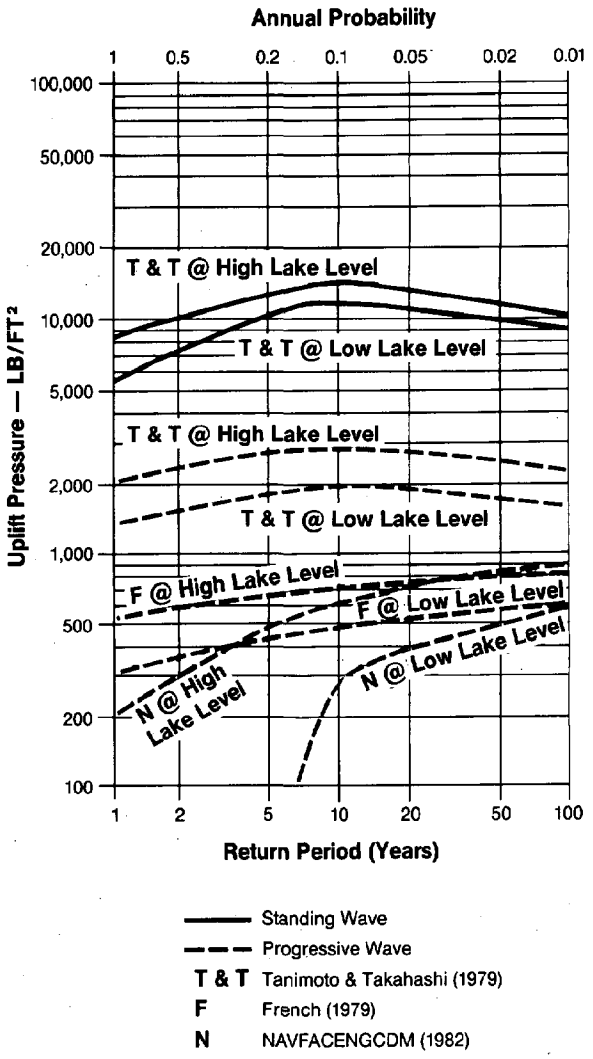


Figure 5. Wave uplift pressure envelopes for the Jones Island East Dock.

Based on the observations of the December 15 storm we suspected that the very short-term impact force may have been important. This force is frequently ignored in conventional design and techniques to evaluate it are not published in recognized design manuals. A computer search of the technical literature was made to determine if research information was available that would explain the movement (Table 1).

There are experimental methods for estimating the uplift pressures due to sudden impact based on these references. Envelopes can be developed for both the slowly varying (SV) sustained pressures, called "BOURRAGE" and the rapidly varying (RV) shock or impact pressures, called "GIFLE." Using the information reporting experimental data by Tanimoto and Takahashi [11], the pressure curves for both purely progressive and purely standing waves at high (582 feet) and low (575 feet) lake levels were computed and are shown in Figure 5. Impact pressures (RV) are one to two orders of magnitude higher than quasi-static (SV) pressures.

The actual impact pressures will be between the limits represented by purely progressive and standing waves. We cannot estimate how much of the impact can be attributed to standing waves and how much attributed to progressive waves. The efficiency of wave reflection from the complex shape of the vertical structure is difficult to assess. For simplicity we consider the uplift force per slab is a combination of progressive-standing pressure times the slab area exposed.

Calculation Of Platform Deflection

Estimates of the motion of the dock platform in response to the wave-induced forces were based on a number of assumptions to facilitate simple calculations. It is assumed that the platform is a rigid body, and is simply connected (pinned) at the landward bottom corner. It is also assumed that the platform motion is two-dimensional and in the vertical plane.

In addition to the above assumptions and data, it was necessary to know or assume the distribution of the wave-induced forces along the dock and the time history of the moments. The wave forces that tend to uplift the dock are of two kinds: (1) Slowly varying (described as sustained, bourrage, etc.,) dynamic forces that are associated with the velocities (nonsteady) of the wave, and the hydrostatic forces, and (2) rapidly varying (described by various terms including impact, slapping, slamming, shock, gifle, etc.) forces that have high but very short duration peaks.

The method outlined in the standard literature appears to address the slowly varying dynamic form [6],[9]. The estimation of the rapidly varying forces is still in an experimental or research stage. A schematic representation of the time history of the uplift pressure on the dock platform is shown in Figure 6.

Simplifying assumptions were necessary to proceed with computations based on rapidly varying forces. Given the uncertainty inherent in estimating the magnitude of this force, and its duration, a triangular shape of the force curve variation in time is probably reasonable. Since the platform overhang is much shorter than a wavelength, a uniform spacial distribution (average pressure) is reasonable. Note, however, that there may be time-of-peak variations from cell-to-cell section along the dock.

The assumption of a simply connected rigid body allows straightforward application of conservation of angular momentum to estimate the movement of the platform slab. On initial contact with the wave the platform remains motionless until the wave pressure moment exceeds the weight moment. At this point angular motion (rotation about the backedge) begins and is described by:

$$M = I\,\theta_{tt}$$

where M = net moment, I = moment of inertia, θ_{tt} = angular acceleration

Angular velocity and angular deflection can then be found from:

$$\theta_t = \int \theta_{tt}\,dt \quad \text{and} \quad \theta = \int \theta_t\,dt$$

The maximum deflection (θmax) occurs when the angular velocity becomes zero ($\theta_t = 0$). An expression for θ_t was derived by evaluating the integral of θ_{tt} which can be expressed in terms of the maximum moment due to wave impact (P_{max}), the magnitudes of the slowly varying component (SV) and weight moments (W), the moment of inertia (I), and the rise time of the rapidly varying component (t_r). These terms are illustrated in Figure 6. The rise time is estimated as one half of the impact duration of the rapidly varying impact force given by French [6]:

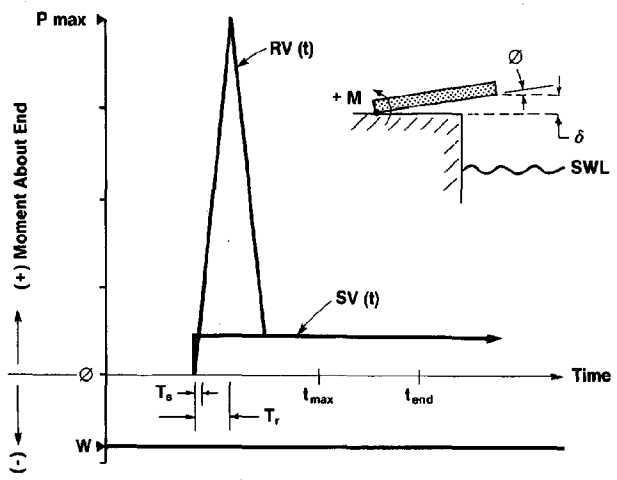
$$t_i = 0.1\,(H/g)^{-1/2}$$

where

H = incident wave height, and
g = acceleration of gravity

The expression of the slowly varying force and resultant moment as a constant is justified since the times of movement of the slab to maximum displacement was much less than the waver period.

Using the expressions derived for θ_t, the time of maximum deflection of the platform was found. Using this time and the expression of displacement (the integral of θ_t) the angular deflection of the platform was calculated. Small angle approximations were invoked throughout the analysis. The vertical displacement of the free end of the dock platform was calculated from the angular displacement. The derived expressions for θ_{tt}, θ_t, and θ were incorporated in a BASIC program which was used



EXPLANATION

P_{max}	= Maximum Moment Due to Wave Forces	T_s	= Time Between Initial Impact and Start of Movement
W	= Weight Moment	T_r	= Rise Time to P max
RV	= Rapidly Varying Moment	t_{max}	= Time of Maximum Deflection
SV	= Slowly Varying Moment	t_{end}	= Time of Return to Ground

Figure 6. Time variation of moments for the Jones Island East Dock slabs.

to find the time and value of the platform displacement. The program was written to account for the discontinuity in the RV(t) function.

The estimated uplift based on these calculations is shown in Figure 7 for both the progressive and standing wave cases. The results shown in this figure are for the dock platform as completed with all backfill and road surface material in place. The observed movement and wave height estimated for December 15, 1987, storm are plotted on Figure 8. This figure represents movement calculated for only the bare slab, without fence, bullrail, or backfill portion of the structure as it existed during the storm.

The length of dock platform involved in the impact of the wave is also taken as a parameter, shown as N = 1 to 4 in Figures 7 and 8. The value of N represented the number of cell-to-arc (centerline to centerline; see Figure 2) segments of dock platform "hit" by the wave. The restoring force is, in every case, taken as due to the weight of the entire section of platform (N = 4).

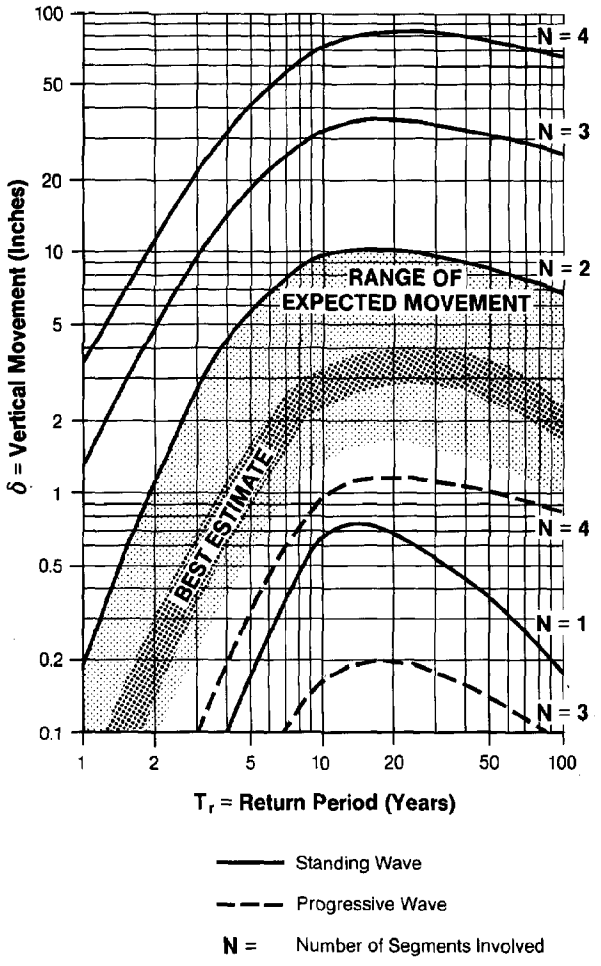


Figure 7. Expected movement of completed dock based on observed movement of the Jones Island East Dock slabs.

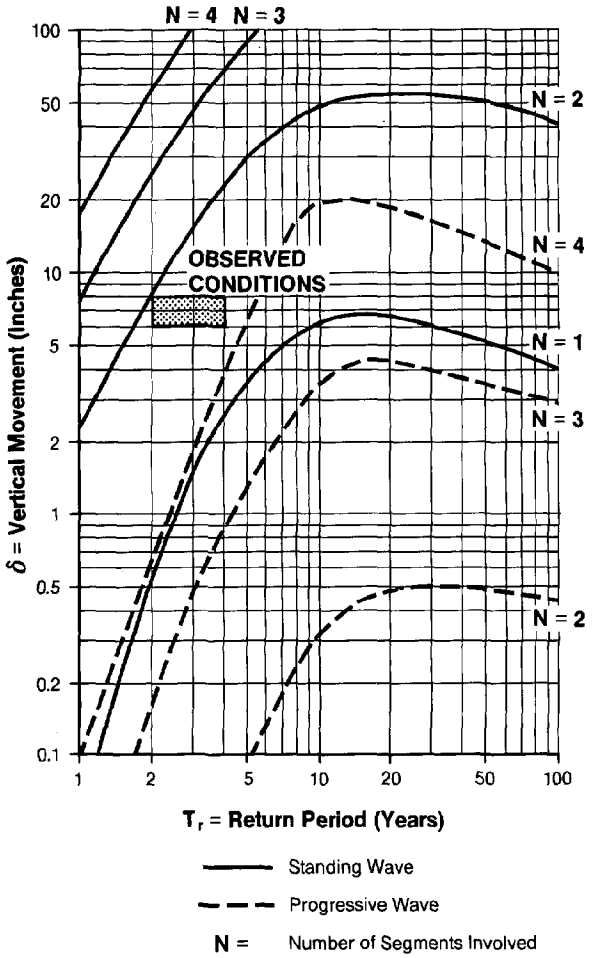


Figure 8. Observed movement for slab only compared to calculated moment for a range of assumptions.

The results of the analysis of the bare slab (Figure 8) show that the rapidly varying impact forces as formulated here can account for the observed movement. The effect of standing waves is also evident and must be present to some extent. It is not possible to quantify the effect of wave reflection in increasing the force since the area of the slab involved at any one time is not known. In this case, the expected effect of impact forces on the dock as completed (Figure 7) is estimated by assuming the same position on the "maps" of deflection, number of segments, and wave climate (return period). A preliminary examination of the expected lengthwise distribution of forces indicates that approximately half (N = 2) of the slab will be involved based on the assumed angle of wave approach. This is consistent with visual observations.

If these dynamic wave forces are of importance, as the research data tend to indicate, by Figure 5, the dock slab can be expected to experience upward movement of 3 to 6 inches every few years (see Figure 7). The effect of the movement of the dock under various storms is difficult to estimate. Civil engineering works of this kind and size are

seldom, if ever, designed for this magnitude of motion. The downward motion may be dampened by the water under the slab and between the underside of the slab and the cellular cofferdam and the upward motion of adjacent slabs. If this dampening is sufficient, then there may be no structural effect from the movement. On the other hand, a sharp drop of the slab onto the cell could possibly cause settlement of the crushed rock fill in the cells, structural damage to the slabs and structural damage to the sheet piles of the cells and arcs. The potential for lateral movement also exists.

CONCLUSIONS

The December 15, 1987, storm at Milwaukee, Wisconsin, generated waves with a 2 to 4 year return period. The wind-generated waves associated with the storm, while not especially large at the Jones Island East Dock, were partially transformed into standing waves. These standing waves imparted to the partially completed dock slabs a rapidly varying force greater than current design manuals predict. These rapidly varying forces caused the slabs to move.

Further research is needed to define the uplift forces (pressures) on horizontal platforms backed by vertical walls. The vertical walls should consist of both planar and curvilinear form. When the results of the research is complete, it should be made available to the design engineers. This will allow the analysis of a wider range of potential designs for particular applications and permit a better evaluation of overwater horizontal platforms.

ACKNOWLEDGEMENTS

The authors wish to acknowledge the assistance of Mr. Dick Horning for the preliminary derivations of the angular deflection equations used in the deflection analysis; the help of Ms. Mary Landsteiner for assistance in coding the computer routine used for the parametric studies leading to Figures 7 and 8; and comments from Mr. Jonathan French on the approaches taken in the analysis and the theoretical basis behind these techniques.

REFERENCES

1. Coastal Engineering Research Center. Shore Protection Manual. U.S. Army Waterways Experiment Station. Vicksburg, Mississippi. 2 Volumes. 1984.

2. ————————. Computer Program: JONSWAP (MACE-12) Deep Water Wave Forecasting. U.S. Army Waterways Experiment Station, CETN-I-34, 1985.

3. Elghamry, Osman A. Wave Forces On A Dock. University of California, Institutional Engineering Research, Technical Report HEL-9-1, Berkeley, California. October 1963.

4. ————————. Uplift Forces on Platform Decks. Offshore Technical Conference, Pap. No. OTC1381. May 1971. Pp. 1-538 through 1-548.

5. French, Jonathan A. Wave Uplift Pressures on Horizontal Platforms. W. M. Keck Laboratory, Report No. KH-R-19, Hyr. and Water Resources, Division of Engineering and Applied Sciences, California Institute of Technology, Pasadena, California. July 1969.

6. ————————. Wave Uplift Pressures on Horizontal Platforms. ASCE Civil Engineering in Oceans III. September 1979. Pp. 187-202.

7. Furudoi, Teruaki and Akira Murota. Wave-Induced Up-Lift Forces Acting on Quay-Aprons. Technology Reports of the Osaka University. Vol. 16. No. 734. 1966. Pps. 605-616.

8. Lee, Jiin-Jen and C. P. Lai. Wave Uplift on Platforms or Docks in Variable Depths. Proc. 12th Coast Engineering Conference. Taipei, Taiwan. November 1986.

9. NAVFACENGCOM. Coastal Protection, Design Manual 26.2. Department of the Navy. Naval Facilities Engineering Command. 200 Stovall Street. Alexandria, VA 22332. 1982. 356 pages.

10. Resio, D. T., and C. L. Vincent. Design Wave Information for the Great Lakes, Report No. 3, Lake Michigan. United States Army--Corps of Engineers, WES, Technical Report H-76-1. 1976.

11. Tanimoto, Katsutoshi and Shigeo Takahashi. Wave Forces on a Horizontal Platform. Proced. 5th Intern Ocean Dev. Conf. Tokyo, Japan. September 1979. Pp. D1-29 to D1-38.

12. Verhagen, J. H. G. The Impact of a Flat Plate on a Water Surface. Journal Ship Res. December 1967. Pp. 211-223.

13. Wang, Hsiang. Estimating Wave Pressures On a Horizontal Pier, Technical Report No. R546. Naval Civil Engineering Laboratory, Port Hueneme, California. October 1967.

14. ————————. Water Wave Pressure on Horizontal Plates. Proc. ASCE, V. 96, No. HY10. October 1970.

A HIERARCHICAL MULTIPROCESSOR DATA ACQUISITION SYSTEM FOR FIELD MEASURMENT OF STRUCTURAL RESPONSE IN BREAKWATER CONCRETE ARMOR UNITS

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Abstract

A custom, high performance, field data acquisition system for measurement of wave loads, motions, and dynamic stresses on large (42 ton) concrete armor units is described. Twenty 42 ton dolos armor units were instrumented and installed as part of the rehabilitation of the breakwater at Crescent City Harbor, California. A data acquisition computer system was designed using a hierarchical, parallel architecture involving 47 cooperating computers including microcomputers permanently cast within the concrete dolosse. The data acquisition system has sufficient processing capability to make decisions about the type of incoming data and perform appropriate action. Successful operation of the system during the period 1987-1988 resulted in data being successfully acquired from full scale concrete armor units for the first time.

1 Introduction

The lack of adequate full scale field data has slowed progress in applying physical and numerical models to the problem of assessing the loads on concrete armor units. Progress in solving this problem requires the modeling of complex interactions of physical processes and because of the severe environment of breakwaters, very little prototype scale data are available. Hydraulic models of breakwaters using concrete armor units are routinely used for most designs. However, contemporary hydraulic scale models consider only stability and assume that all armor units have sufficient structural strength if stability conditions are maintained. Experiences with breakage of concrete armor units have shown that armor unit structural strength must be considered in the structural design process. No method is presently available to predict the loads, forces and stress required to establish structural strength requirements. As part of an effort to develop a structural design procedure, the US Army Corps of Engineers, Waterways Experiment Station (WES) has concluded a program to acquire data on the structural response of dolos armor units in the prototype. The site for the study was Crescent City, California where a previously constructed breakwater was rehabilitated with new layers of 42 ton dolosse. Because of the severe wave conditions at Crescent City and the desire to acquire dynamic structural response data, new measurement technology had to be developed. To meet the technical objectives the system had to have the capability of continuously recording data resulting from measurements with an aggregate sampling rate greater than 66,000 samples per second. This paper describes the dolos data acquisition system developed for Crescent City and its performance during a two year measurement period which included numerous major storms.

2 Dolos Configuration

Selection of the test section of instrumented dolosse was made after a careful evaluation of different proposed strategies. Participants at the Workshop on Measurement and Analysis of Structural Response in Concrete Armor units (Howell, 1985) discussed the tradeoffs among various options and arrived at a recommended consensus. Sixteen dolosse were placed in an approximate four by four matrix near the mean water line with six accelerometer equipped dolosse in the center. Four dolosse were placed in the bottom layer under the top layer. This test section was placed on the breakwater to permit all of the dolosse to receive substantially the same incident waves. By limiting spatial variability of the incident waves, statistical analysis of the prototype data will be comparable to physical modeling studies.

3 Measurement Plan

The measurement plan for this study was developed after consideration of many alternative plans and several approaches to the problems of instrument survivability and data acquisition. A key decision was to define the fundamental measured parameters as the two moments and the torque taken about the shank-fluke interface (Figure 1). This measurement could be taken by internally mounted strain gages, therefore providing protection for the instruments. Experiments with finite element method (FEM) nu-

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merical models indicated that given measurements of moments and torques the FEM models could give stress distributions throughout areas of interest in the dolos (Howell, 1986).

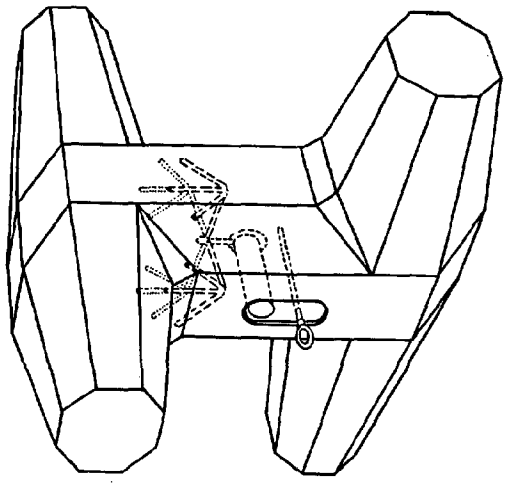

Figure 1: Dolos Instrumentation

4 Dolos Instrumentation

All dolos instrumentation was permanently sealed inside the concrete armor unit. The internal microcomputer system for each dolos digitizes the strain at a 500 Hz sample rate, and accelerometer data at a 50 Hz sample rate. This rate is sufficient to capture all high energy dynamic modes resolvable with the strain gages located at the shank-fluke interface. A rosette of steel reinforcing rods upon which strain gages were mounted is located at the four faces of the section through the shank-fluke interface. The rosettes are located 10 cm below the surface of the concrete. Only the vertical shank-fluke interface was instrumented as a cost saving measure. Algebraic combinations of strains allow estimates of the horizonal and vertical bending moments, the axial thrust, and the torque about the shank-fluke interface.

5 Dolos Processor

The first element in the data acquisition system is the Dolos Processor, a microcomputer system which is permanently sealed inside the trunk of the dolos (Figure 2). The dolos processor performs signal conditioning, analog to digital conversion of the strain gage data, and houses the accelerometer platform for the six dolosse which contain accelerometers. The accelerometers assembly is composed of three 1G linear servo accelerometers and three 100 rad per sec/sec angular servo accelerometers. The combination of six accelerometers allows the determination of motion of any point on the dolos, assuming rigid body dynamics. The ranging of the accelerometers was chosen to determine an accurate kinematic velocity vector just before impact, because impact energy can be calculated from the velocities. The dolos processor can be commanded to select the strain signals as well as amplifier gain. The data rate is reduced by having the Dolos Processor combine selected strain signals to compute resultant moments and torques, reducing six channels of strain to three channels of moment and torque data. The dolos processor was implemented

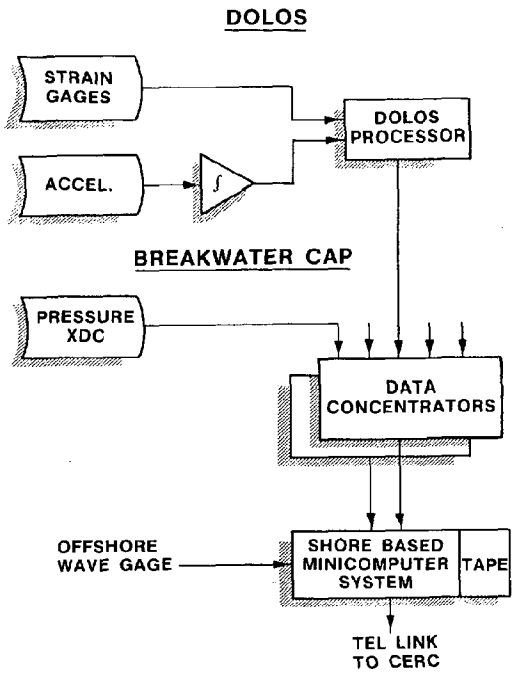

Figure 2: Major Data Acquisition System Components

with a CMOS STD bus microcomputer system using the Hitachi 64180 microproccessor operating at 6.1 MHz. Both the microcomputer board and the CMOS A-D board were manufactured by WINSystems, of Arlington, Texas.

Various methods of communicating data from the dolos were investigated. The high data rates eliminated from consideration most types of low bandwidth RF and acoustic telemetry systems. A high data rate telemetry system would have required batteries that were impractical due to cost and size limitations. Use of a cable allowed power to be supplied to the dolos instrumentation and data to be retrieved at high rates. The dolos data were formatted as a serial binary data stream allowing the number of conductors to be limited to eight. By minimizing the number of conductors, a highly reliable cable was constructed consisting of the core cable, an extra thick polyurethane jacket,

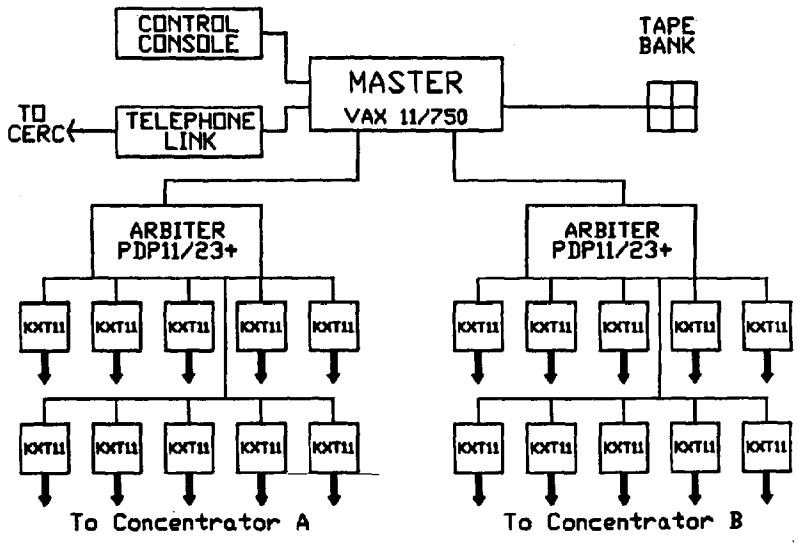

Figure 3: Shore Based Data Acquisition System

covered by a double layer of steel armor, with a final jacket of polyethylene, yielding a total outside diameter of 2.2 cm. If a cable were allowed to oscillate with the high velocity, oscillatory flows associated with the armor layer of a breakwater then it would fail due to fatigue. A system employing a modified 3-inch stud link anchor chain was developed that increased the density sufficiently to prevent flow induced motion.

The data from each dolos was sent to the shore based computer using a RS422, asynchronous binary, protocol at 38.4K Baud. Data were framed in one second packets which included a synchronization preamble and a unique I.D. for each dolos. The duty cycle over the link was 94%, and was managed by a CMOS version of the Z-80 SIO operating in DMA mode. The dolos processor was programmed in a combination of Pascal for high level routines and carefully coded, inline assembly language routines for the time critical functions. A real time multi-tasking executive was used to coordinate execution of six tasks which performed the required functions.

6 Concentrators

Each dolos cable terminated at one of two Data Concentrators which were located in holes cast on the harbor side of the breakwater (using the breakwater itself as a protective structure). Up to ten dolos cables were terminated at each Concentrator. The Concentrators distributed power to each dolos and combined the serial links from each dolos into one shore cable, maintaining a separate physical wire pair for each dolos. The shore cable provided one physical wire pair for the command serial link from the shore computer which was redistributed by the Concentrator to each individual dolos. All data connections were RS422 and were buffered and regenerated in the Concentrator. The cable distance form the Concentrator to the shore based computer was 5,500 feet.

Each Concentrator contained a single board computer named an SAU (Serial Analog Unit). The SAU is hosted on the same CMOS STD bus platform at the Dolos Processor. The SAU sampled 12-bit pressure data at 5 Hz and transmitted it asychronously directly to the shore computer on a dedicated physical pair of wires also at 38.4K Baud. Additionally each SAU contained functions which allowed remote control of power for each dolos, permitting the selective powering up of dolos, and preventing the failure of one dolos cable from draining power from the whole system.

The Concentrator was supplied power at 48 VDC and current ranging from 0.5 Amp to 3.5 Amps depending on the number of dolosse powered on. This corresponded to a shore end supply voltage which ranged from 56 VDC to over 150 VDC. A KEPCO model 10E150 power supply with analog voltage programming was used at the shore end with a special feed back circuit to automatically adjust the output voltage to compensate for the shore cable drop over varying current requirements.

7 Data Acquisition System

A semi-trailer van was modified to house the shore based data acquistion components. The trailer contained the data acquistion computers as well as a 25 kw diesel powered

generator and a power line conditioner. The trailer was outfitted with an air conditioner and heater unit, various graphics and text terminals, telephones, and office space.

Figure 3 shows the block diagram of the computer system used for the shore-based data reduction and storage system. Since all data were formatted in packets they could be processed independently for each dolos. Since many small computers are less expensive than a large computer of equivalent power, a hierarchical, parallel architecture was selected.

7.1 KXT-11

Each Dolos communicated with a Digital Equipment Corporation (DEC) KXT-11 single board computer that performed the lowest level processing tasks. The KXT-11 consists of a DEC T-11 microprocessor supported by several powerful IO modules and a DMA controller. Each KXT-11 was configured as a slave processor residing on the bus of an arbiter processor (a DEC PDP-11/23+). The KXT-11 has a section of memory which is dual ported (accessible by both the slave and the arbiter processor) which helped to synchronize DMA transfers between the arbiter and the KXT-11. Each KXT-11 ran a program created by the DEC MicroPower/Pascal realtime executive and received 3612 bytes per second (of serial data transmitted at 38.4K Baud) from each dolos. The KXT-11's were programmed to receive the serial data under the direction of the DMA controller. During system startup, the incoming data were sychronized so that each second of data started with the synchronization preamble embedded in the data stream. The KXT-11 program checked each second of data to look for an impact (an impact was defined to be two successive instances of the difference between the current and previous sample exceeding a programmed threshold). If the strain data did not contain an impact then they were decimated by a factor of ten. Otherwise the data were not decimated. A program option allowed the KXT-11 to send only undecimated data to the arbiter.

7.2 Arbiters

The next layer of processing was done by 3 DEC PDP-11/23+ computers. Five KXT-11's resided on the bus of each PDP-11/23+ computer. The number of KXT-11's per arbiter was determined by the bus and network bandwidth. The Q-bus used by the PDP-11's of the has a rated bandwidth of 3.3 MB/sec, however in practice only about 20% of that bandwidth was found to be useable due to system overhead and network controller throughput limitations. The arbiters were also controlled by a program written in MicroPower/Pascal. The arbiters were booted and downline loaded via an Ethernet physical link using the DECNet software protocol. Then they were sent the current system time and configuration, and then a copy of the KXT-11 program was copied into arbiter memory. Each KXT-11 was then loaded, booted, and configured by the arbiter. While one packet (representing one second's data) was being received, the previous second's data was timestamped and formatted in order to allow for interpretation by post processing data analysis routines and sent to the host computer via the Ethernet link.

7.3 Host Computer

The last layer of processing was performed by a DEC VAX 11/750 computer running the VMS operating system. The VAX had 4 high density 500 MB cartridge tape drives, manufactured by Megatape Corporation, and a 456 MB RA81 disk to record data. Data was initially recorded on disk and then backed up to tape offline in order to avoid exceeding the bus bandwidth of the VAX computer. The VAX was the development platform for all data acquisiton software and was also a server, responding to boot requests from the arbiters. Asynchronous serial interfaces were used to communicate to the Concentrators to configure dolos processors and control power to the instrumented dolosse. The VAX communicated to SAU's that sent data from breakwater pressure sensors and from the moored wave buoys.

8 Waveriders

Three wave measuring buoys were deployed offshore of the dolos test section of the breakwater. The buoy nearest the breakwater was .1 mile offshore, the next buoy was 0.6 miles offshore in a line perpendicular to the breakwater. The third buoy was located 6 miles offshore. During the fall of 1987, The buoys were moved so that 2 were about 0.3 miles offshore and the third 3 miles offshore. The buoys telemetered data to the data collection trailer where the data were digitized.

9 Development Problems

While developing a data acquisition system as complex as the one required for Crescent City some development problems were encountered. The orginial design data sampling rate was 400 Hz for strain and 40 Hz for accelerometers. After a more thorough analysis, it was determined that 500 Hz was required to accurately represent dynamic loads. The Baud rate had to remain the same since 38.4K Baud is the maximum asynchronous speed supported by the KXT-11. This limitation imposed a high duty cycle upon the communicating processes, and severely limited allowable system overhead time. The dolos processor used DMA character output while the KXT-11 used DMA character input. The KXT-11 could in fact not interpret the received data quickly enough to maintain synchronization with the incoming data flow when using the conventional interrupt per received character technique of acquiring the incoming

data. The Micropower/Pascal software used in the KXT-11 did not support DMA input although the hardware had the capability. So, the necessary support software had to be developed for DMA input from a serial port. The command links from the VAX to the Data Concentrators and the dolosse were required to operate at a Baud rate of 38.4K also. Although the asynchronous communication controller the VAX supported the 38.4K Baud rate, the VMS operating system did not. After consulting with DEC, a patch was developed for the appropriate VMS driver so that the 38.4K Baud rate was available.

10 System Performance

Although the data acquisition system was designed to collect data from 20 dolosse, it never had to perform under full load. While 20 dolosse were instrumented, only 17 were operational when data acquisition began. One instrumented dolos was broken during placement, and two others had their cables damaged during the early nesting phase of the breakwater. By the end of experiment, only eight dolosse were operating. The failures of the dolosse were primarly due to problems with their cables being overtensioned and crushed.

During one thunderstorm in April 1987, the Data Concentrators suffered damage to their RS422 receivers due to lightning. On December 2nd 1987, an intense storm produced lightning that not only damaged the Data Concentrator's but also every KXT-11's RS422 receivers. Due to overtopping storm waves, access to the breakwater to repair the Data Concentrators was not possible until the waves subsided 3 days later. Fortunately the Data Concentrators successfully protected the dolosse from the lightning induced voltage surge. Subsequently, additional lightning protection and isolation equipment was installed.

On two separate occasions, the waverider buoy closest to the breakwater broke loose and was rendered unusable after being battered upon the breakwater rocks. Although it is not common practice to place wave buoys in such a hazardous shallow water environment, it was essential to the project to try to measure the incident wave statistics as accurately as possible, and this buoy was considered sacrificial.

Two of four pore pressure transducers buried in the breakwater cap failed during the summer of 1987. Since they were grouted in place, it was impossible to determine their mode of failure.

During the data collection period of 1987-88 over 20 GigaBytes of raw data were collected. The collected data are free of noise and transmission errors, due the digitization of the data inside the dolosse. Preliminary analysis of the data has shown significant static loads which vary with tide and wave loads of the same order of magnitude as static loads. Very few impact events were observed and there was negligible dolos motion within the resolution of the of the accelerometers (Howell, 1988). Several storm events were recorded with breaking waves in excess of 10 meters.

11 Conclusions

Availability of low power, high performance microcomputers, and distributed IO processors allows the development of large, high performance data acquisition systems, previously uneconomical. Microcomputer technology is sufficiently reliable to permit a no maintenance design philosophy as long as sufficient redundancy is incorporated into the total design. Development of such systems requires sophisticated real time, multitasking software. Performance analysis of hardware/software data acquisition systems remains a difficult task and actual performance was not determined until the system was fully operational. Real time data reduction which is possible with the hierarchical, parallel architecture allows significant cost savings in the overall system. Special packaging of instrumentation and low power microcomputers permit data acquisition in extremely severe environments, previously considered too hostile. Through the development of these new measurement techniques, prototype data that had been previously unobtainable have been acquired.

12 Acknowledgement

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References

Howell, G. L.,ed. 1985. Proceedings of the Workshop on Measurement and Analysis of Structural Response in Concrete Armor Units., Jan 23-24; Waterways Experiment Station, Coastal Engineering Research Center, Vicksburg, Mississippi, 421 pp.

Howell, G. L. 1986. A System for the Measurement of the Structural Response of Dolos Armor Units in the Prototype.*The Dock and Harbor Authority*, vol. 67, number 779, May 1986.

Howell, G. L. 1988. Measurements of forces on dolos armor units at prototype scale., *Proceedings 21st International Conference on Coastal Engineering*, June 1988, Costa del Sol, Spain, American Society of Civil Engineers.

WAVE ENERGY DISSIPATION BY REEF BREAKWATERS

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ABSTRACT

Shoreline erosion has become a chronic problem around much of the U.S. coast. Fulford (1985) has shown using segmented reef breakwaters is one of the most effective strategies for providing shoreline protection. Reef breakwaters are essentially homogenous piles of stone without the multi-layer cross sections of traditional breakwaters. The effectiveness of a reef is partly due to its ability to dissipate wave energy and additionally due to the bulk of the salient which accumulates behind the structure. Extensive laboratory model tests have been used to define performance characteristics of reefs. Results from these tests have been used to develop equations that predict wave transmission and reflection characteristics which can then be used to determine the ability of the structure to dissipate wave energy (Ahrens 1987b). The equations fit the data well, approach logical limiting values, are easy to use, and are consistent with the physics of the interaction between waves and rubble structures as it is currently understood.

1. INTRODUCTION

Erosion is a chronic problem along U.S. coasts. Properly designed riprap revetments can prevent erosion, but can also interfere with the use of the shoreline. Block revetments have not proved to be reliable against wind wave attack. Using offshore breakwaters has been recognized as an effective way to cope with erosion, and at the same time, provide access to the shoreline for recreational purposes (Fulford 1985, Dally and Pope 1986). The concept of reef breakwaters is another step toward more effective methods to combat coastal erosion.

A reef breakwater is a low-crested rubble-mound breakwater without the traditional multi-layer cross section. This type of breakwater, in essence, is a homogeneous pile of stone with individual stone weights similar to those used in the armor and first underlayer of conventional breakwaters. Because of their high porosity, reef breakwaters are stable to wave attack and, at the same time, can dissipate wave energy effectively.

It is anticipated reef breakwaters would be used primarily for beach stabilization or to protect eroding shorelines in a shore parallel or near parallel manner. Generally these functions can allow, or possibly benefit from, larger transmitted wave heights than can be tolerated in a harbor. This suggests considerable cost savings could be achieved by using lower crested structures. In a discussion of a variety of typical coastal erosion problems, Fulford (1985) concludes reef breakwaters represent the most satisfactory general approach to shoreline stabilization.

This paper will not discuss the stability of reefs other than to mention their low profile and high porosity makes them surprisingly stable to severe wave conditions. Stability of reef breakwaters is discussed in Ahrens (1987a, 1987b). The purpose of this paper is to discuss the performance characteristics of wave transmission, wave reflection, and energy dissipation by reefs. Performance characteristics were determined by an extensive series of laboratory model tests.

2. LABORATORY SETUP, CONDITIONS, AND PROCEDURES

Reef breakwater model tests were conducted in a 61 cm wide channel within CERC's 1.2 m high by 4.6 m wide by 42.7 m long wave tank. Water depths at the reef were 25 cm for most tests and 30 cm for a few tests. Water depths at the wave generator were 25 cm greater than at the reef and waves shoaled over a 1 on 15 slope to reach the concrete platform the reef was built on. This setup insured very severe wave conditions could be produced at the structure. The testing channel was open to a wave absorber area on the landward side of the reef so there could be very little ponding effect behind the breakwater to complicate evaluation of stability.

All tests were conducted with irregular waves. Spectra were JONSWAP type in the deeper portion of the wave tank prior to wave breaking. Incident and reflected spectra were resolved with three parallel wire resistance wave gages in front of the reef by using the method of Goda and Suzuki (1976). Period of peak energy density of the spectra, T_p, ranged from about 1.45 to 3.60 seconds and the range of incident zero-moment wave heights, H_{mo}, was about 1.1 to 18.2 cm. Two gages were used behind the reef to measure transmitted wave heights. See Figure 1 for a profile view of test channel.

Two basic types of tests were conducted during the laboratory investigation. Most tests fell into a

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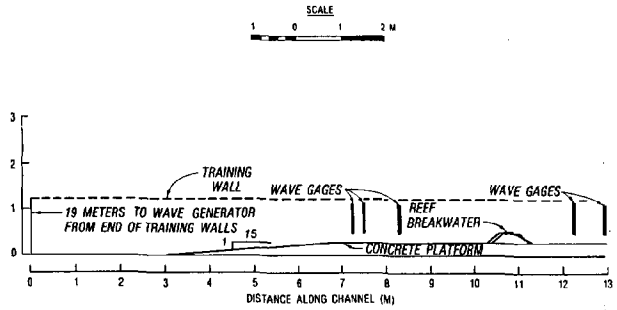

Figure 1. Profile view of test channel

category where the primary objective was to determine stability of the reef to a specific wave condition and wave transmission and reflection data were obtained as a by-product. These are referred to as stability tests. The other category was tests conducted at the completion of a stability test to determine transmission and reflection characteristics of a damaged structure to a variety of less severe wave conditions. These are called "previous damage" tests. Table 1 organizes the tests into subsets and gives important characteristics of each subset. In Table 1, stability tests have odd subset numbers and "previous damage" tests have even numbers. For stability

Table 1
Basic Data For Each Subset

Subset No.	No. of Tests	Water Depth, d_s (cm)	Crest Height as Built, h_c' (cm)	Median Stone Weight, W_{50} (gr.)	Area of Breakwater Cross Section A_t (cm^2)
1	27	25	25	17	1170
2	3	25	NA	17	1170
3	29	25	30	17	1560
4	12	25	NA	17	1560
5	41	25	35	17	2190
6	11	25	NA	17	2190
7	38	25	32	71	1900
8	26	25	NA	71	1900
9	13	30	32	71	1900
10	5	30	NA	71	1900

NA denotes not applicable to "previous damage" test series.

tests, the stone was dumped in the dry testing channel and pushed around primarily by foot to conform to a template outlining the desired profile of the structure. This procedure was used to prevent overly careful placement of the stone, but at the same time to insure the initial profile of all reefs within a subset would be reasonably consistent. Desired initial profile for a stability test is a trapazoid with a crest width of three stone diameters and having both seaward and shoreward slopes of 1 on 1-1/2. When the profiles were surveyed, initial crest elevation of reefs within a subset could vary as much as ± 1.5 cm from the desired height. Duration of wave action for stability tests was one and one-half hours for tests with T_p of 1.45 sec and up to three and one-half hours for tests of T_p of 3.60 sec. This duration gives a total of between 3500-4000 waves based on T_p and the reefs appeared to be at equilibrium with wave conditions well before the completion of a test. At the completion of a stability test, there was a final survey to document the equilibrium profile of the reef. Figure 2 shows initial and typical equilibrium

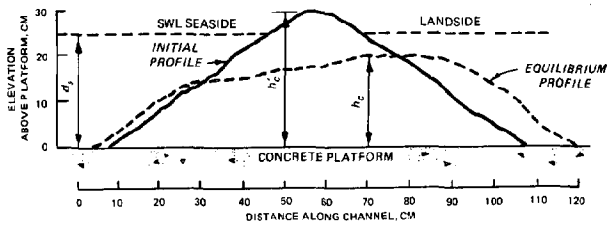

Figure 2. Initial and equilibrium reef profile caused by severe wave conditions.

profile caused by severe wave conditions. After some stability tests, previous damage tests would be conducted. Previous damage tests always used wave conditions less severe than the preceding stability test so there was almost no change in the profile during this type of tests.

Two sizes of stone were used in this study. The smaller stone was an angular quartzite with a median weight of 17 grams. The other stone was a blocky diorite with a median weight of 71 grams. Stone characteristics are given in Table 2. The stone used had shapes and surface texture typical of the type of stone which might be used for a reef. Further details on laboratory setup and stone characteristics are given in Ahrens (1987b).

Table 2
Stone and Gradation Characteristics

Characteristic	Quartzite	Diorite
2% weight (gr)	7.0	14.0
Median weight, W_{50} (gr)	17.0	71.0
98% weight (gr)	28.0	139.0
Density (gr/cm^3)	2.63	2.83
Porosity	44%	45%

3. PERFORMANCE OF REEFS

Performance, as used in this paper, refers to characteristics of wave transmission over and through a reef, wave reflection from a reef, and wave energy dissipated by a reef. Wave energy dissipation cannot be directly measured, but can be infered from measurements of wave transmission and reflection. It has only been relatively recently that reliable methods to measure the reflection of irregular waves have been available (Goda and Suzuki 1976). This means that reliable estimates of wave energy dissipation by coastal structures are rather unusual, see Seelig and Ahrens (1981) for a related study. The shortage of information about the nature and magnitude of energy dissipation is unfortunate since for many situations this ability of rubble-mounds could be regarded as their most important measure of performance. This paper will show how the wave dissipation process can be parameterized for reefs and will present quantitative values of dissipation for specific reef configurations. A method to predict wave dissipation will be discussed and compared to laboratory data.

Wave Transmission

To calculate wave energy dissipated by a reef it

is necessary to know the wave transmission and reflection characteristics of the structure. The wave transmission coefficient used in this study was defined

$$K_t = \frac{H_t}{H_c} \tag{1}$$

where H_t is the zero-moment transmitted wave height and H_c is the zero-moment wave height measured at the same location as H_t but with the reef not present in the testing channel, i.e., a calibration wave height. The transmission coefficient given by Equation 1 has the advantage of not including natural losses of energy due to wave breaking between the incident and transmitted gages; these losses can be significant for severe conditions. There is however, no shoaling between gages since the floor of the channel is horizontal in this section (see Figure 1). Using Equation 1 definition of K_t makes it easier to quantify the relative ability of various reef configurations to reduce wave transmission, but tends to give values somewhat higher than the traditional transmission coefficient. The definition actually compounds the tendency for high transmission coefficients which would be expected because of the high porosity of the reef and its lack of an impermeable core.

One of the most important variables necessary to define the performance of a reef is the relative freeboard, F/H_{mo}, where F, the freeboard is given by

$$F = h_c - d_s$$

Figure 3 is a conceptual sketch showing how different modes of wave transmission can be identified as a function of the relative freeboard.

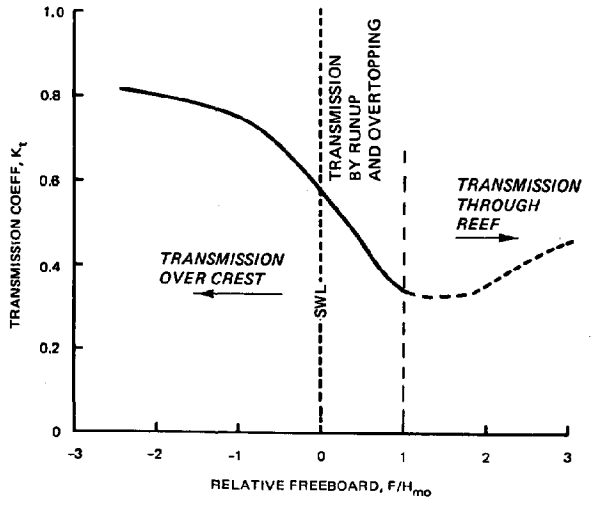

Figure 3. Conceptual sketch of dominant modes of wave transmission for a reef as a function of relative freeboard.

To develop formulas to predict wave transmission Ahrens (1987b) found it necessary to divide reefs into two catagories. High reefs had little or no wave transmission by overtopping and low reefs had substantial amounts of wave energy going over the crest, either because the crest was submerged or by overtopping.

high reefs, $F \geq H_{mo}$

K_t = f (void size, reef width, relative wave length

$$= f\left(\frac{d_{50}}{H_{mo}}, \frac{A_t}{d_s d_{50}}, \frac{L_p}{d_s}\right) \tag{2}$$

where "f" indicates a functional dependence and d_{50} is a typical stone dimension given by

$$d_{50} = \left(\frac{W_{50}}{W_r}\right)^{1/3}$$

and W_{50} is the median stone weight and W_r is the unit weight of the stone. Surprisingly the above parameterization can be consolidated rather well for reefs into one variable (Ahrens 1987b).

low reefs, $F < H_{mo}$

K_t = f (reef height, reef width, void size)

$$= f\left(\frac{F}{H_{mo}}, \frac{h_c}{d_s}, \frac{A_t}{d_s L_p}, \frac{A_t^{3/2}}{d_{50}^2 L_p}\right) \tag{3}$$

The functional relations given above for wave transmission and below for wave reflection were used with regression analysis to develop prediction equations for K_t and K_r as shown in Ahrens (1987b).

Wave Reflection

The method developed by Goda and Suzuki (1976) was used to resolve wave spectrum into incident and reflected components. Following Goda and Suzuki the reflection coefficient is defined

$$K_r = \sqrt{\frac{E_r}{E_i}} = \frac{H_r}{H_{mo}}$$

where E_r and E_i are the reflected and incident wave energy of the spectrum respectively, and H_r is the zero-moment reflected wave height. Compared to wave transmission, it was relatively easy to develop an effective parameterization for K_r.

K_r = (relative wave length, reef height, reef shape)

$$= f\left(\frac{L_p}{d_s}, \frac{h_c}{d_s}, \frac{F}{H_{mo}}, \frac{A_t}{h_c^2}\right) \tag{4}$$

Conservation of Wave Energy

Using the conservation of energy gives the following relation

incident wave energy = transmitted wave energy + reflected wave energy + dissipation by natural breaking + dissipation by reef

Based on the above relation, the following equation can be written to account for additional energy dissipation due to the presence of the reef

$$D_s \simeq \left(\frac{H_c}{H_{mo}}\right)^2 \left(1 - K_t^2\right) - K_r^2 \qquad (5)$$

where the ratio of H_c to H_{mo} was determined prior to normal testing of the structure during calibration of the wave channel. It was found the wave height calibration ratio, H_c/H_{mo} was largely a function of H_{mo}/d_s and the following equation could be used to estimate the ratio,

$$\frac{H_c}{H_{mo}} = \frac{1.0}{1.0 + \left(\frac{H_{mo}}{d_s}\right)^{C_1} \exp\left[C_o + C_2\left(\frac{H_{mo}}{d_s}\right)\right]} \qquad (6)$$

where C_0 , C_1 , and C_2 are dimensionless calibration coefficients with the following values:

$$C_o = -3.16$$
$$C_1 = 0.86$$
$$C_2 = 3.56$$

4. WAVE DISSIPATION BY REEFS

To discuss wave energy dissipation by reefs it is convenient to refer to the processes of wave transmission and reflection which can be measured directly. Since dissipation by reefs can be regarded as a function of all the variables shown in Equations 2, 3, and 4, it is obviously a very complex process. To simplify the discussion three heights of reef will be analyzed in detail but using the insight gained from analysis of all tests. The three reef heights to be considered have the following characteristics: one is submerged, one has its crest near the still water level, and one is non-submerged. The relative height, h_c/d_s , is used to define the heights of the reefs. Ranges of relative height of the reef tests to be used in the following analysis are:

$\frac{h_c}{d_s}$ = 1.20 +/-0.05, typical high reef

$\frac{h_c}{d_s}$ = 1.00 +/-0.05, water level reef,

$\frac{h_c}{d_s}$ = 0.80 +/-0.05, typical submerged reef.

Figure 4 shows the percent of incident wave energy dissipated by typical high reefs as a function of the relative reef width, A_t/d_sL_p . For these tests there is a reasonably strong trend for wave dissipation to increase with increasing reef width. The substantial data scatter shown in Figure 4 is characteristic of situations where the dependent variable is a function of other independent variables in addition to the one shown. It is clear from Figure 4 that the scatter is not random because predicted dissipation follows the observed values very well. Figure 5 helps

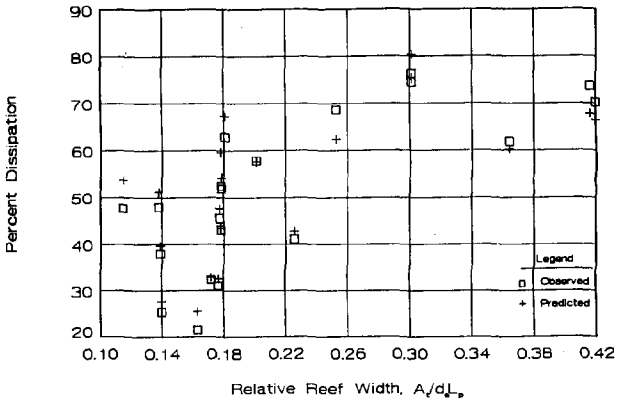

Figure 4. Percent of incident wave energy dissipation as a function of relative reef width for $h_c/d_s \simeq 1.2$.

illustrate influence of a second independent variable by using both the ordinate and abscissa for independent variables relative freeboard, F/H_{mo} , and relative reef width, A_t/d_sL_p , respectively and with values of the dependent variable, percent wave energy dissipated, denoted by single digit integers. The integer represents the percent dissipation divided by ten and rounded off to the

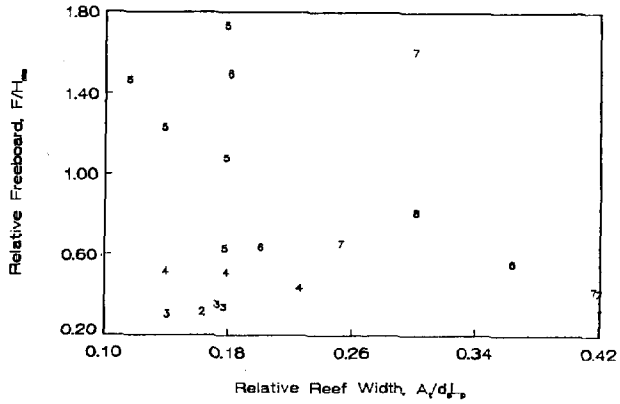

Figure 5. Percent dissipation divided by ten and rounded to nearest integer value shown as a function of relative reef width and relative freeboard for $h_c/d_s \simeq 1.2$.

nearest integer value, eg. "5" represents a test where the observed dissipation of wave energy by the reef is about 50 percent. Figure 5 shows that for condition where wave overtopping is strong, i.e., $F/H_{mo} < 0.50$, the influence of the relative width of the reef is quite important in dissipating wave energy. For conditions where there is little wave overtopping, i.e. $F/H_{mo} > 1.0$, the relative reef width, as formulated, is not very important and the relative wave length, L_p/d_s, and the reef transmission variable $(L_p d_{50}^2)/(H_{mo}A_t)$, are important to the dissipation process. This is because for high reefs wave reflection is strongly dependent on the relative wave length and wave transmission through the structure is strongly dependent on the reef transmission variable (Ahrens 1987b). From another perspective it can be noted that for high reefs that a substantial portion of

the dissipation occurs within the structure and that this mechanism is quite dependent on the stone size. In addition both wave reflection and transmission through the reef increase with increasing wave length. The above mechanisms indicate that wave energy dissipation should decrease as wave lengths and stone sizes increase with the influence of wave length rather pronounced on non-overtopped reefs. Figure 6 shows the relative wave length and relative freeboard as the independent variables and the dissipation denoted as an integer, using the same format as Figure 5. It can be seen in Figure 6 that the relative wave length has substantial influence on the dissipation process especially for infrequenly overtopped reefs, i.e., $F/H_{mo} > 1.0$.

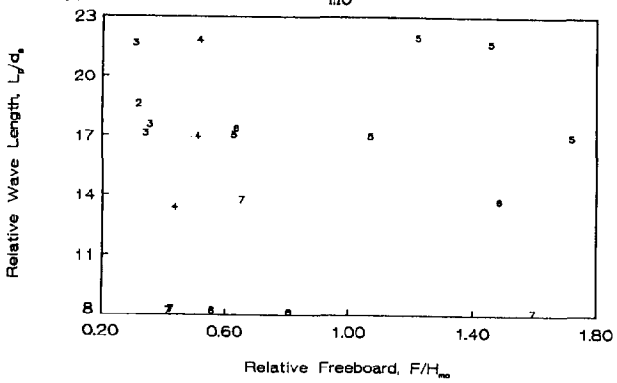

Figure 6. Percent dissipation divided by ten and rounded to nearest integer value shown as a function of relative freeboard and relative wave length for $h_c/d_s \simeq 1.2$.

Test data for reefs with their crest near still water level are shown in Figure 7. The trend of increasing dissipation with increasing reef width is similar to that for typical high reefs (Figure 4) except that levels of dissipation are slightly lower. For tests shown in Figure 7 the

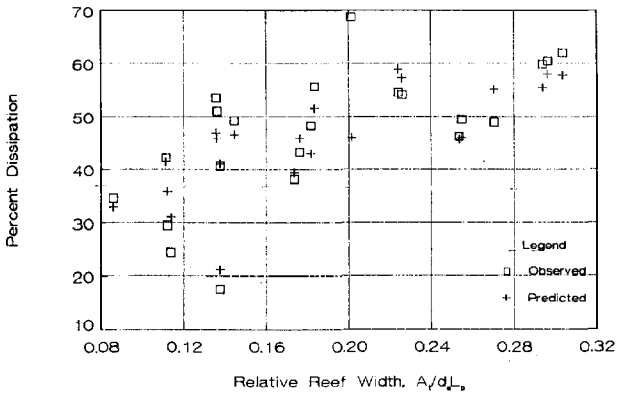

Figure 7. Percent of incident wave energy dissipated as a function of relative reef width for $h_c/d_s \simeq 1.0$.

range of the relative freeboard is too small for this variable to have much affect. About the only other variable which has substantial influence on this subset of data is another width parameter which includes the stone size. Analysis indicates that after accounting for reef width effects using, A_t/d_sL_p, there is a small tendency for dissipation to decrease as stone size increases. The influence of stone size tends to decrease as the height of the reef decreases since an increasing portion of the transmitted wave energy goes over the crest. Since this data subset spans transition between where the dominant mode of transmission is over the crest and where it is by runup and overtopping, there is a reversal in the trend of wave transmission with wave height in this interval. The reversal in the role of wave height causes difficulties in parameterizating dissipation for reefs near the still water level. It should be concluded then that for reefs with their crest near the still water level, that it is the width as measured by the relative reef width which has the most influence on dissipation.

Figure 8 shows wave energy dissipated by a submerged reef as a function of the relative reef width. As with higher reefs, there is a trend of increasing dissipation with increasing relative width. The submerged reef also continued the trend of decreasing dissipation with decreasing relative crest height.

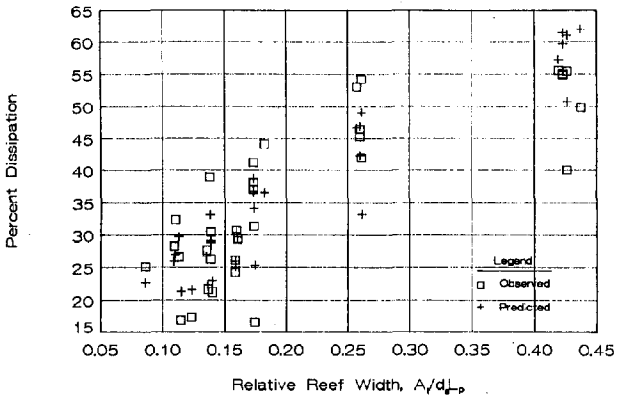

Figure 8. Percent of incident wave energy dissipated as a function of relative reef width for $h_c/d_s \simeq 0.8$.

Submerged reefs tend to cause waves to break prematurely; this process is referred to as wave tripping. For a fixed submerged freeboard, tripping is more effective the larger the wave. This characteristic can be seen in Figure 9 where the independent variables relative freeboard and relative reef width are shown on the ordinate and abscissa, respectively, and the percent dissipation divided by ten is shown as in an integer.

There is another aspect of energy dissipation which affects reefs of all heights although its effect is somewhat more noticeable in Figure 9. If wave conditions become too severe in relation to the size of the reef the tripping process can become rather ineffective. The ability of the reef to disrupt wave action can be parameterized using the variable, $A_t/H_{mo}L_p$. This variable seems to dominate the dissipation process for $A_t/H_{mo}L_p < 0.5$. Within its range of dominance a surprisingly simple formula relates percent dissipation to disruption effects, i.e.

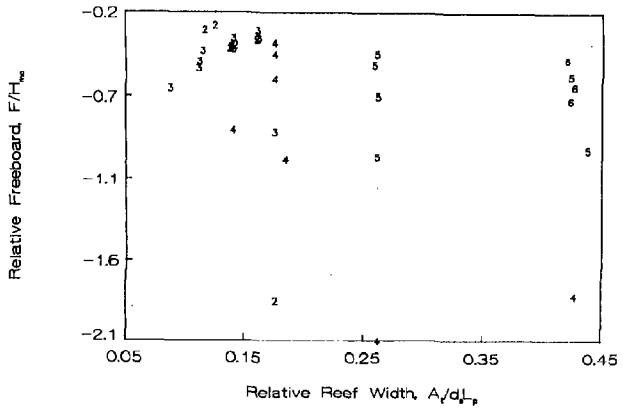

Figure 9. Percent dissipation divided by ten and rounded to nearest integer value shown as a function of relative reef width and relative freeboard for $h_c d_s \simeq 0.8$.

$$\text{percent dissipation} \quad 100 \frac{A_t}{H_{mo} L_p} \qquad (7)$$

$$\text{for} \quad \frac{A_t}{H_{mo} L_p} \lesssim 0.5$$

It is wave disruption effects which cause the somewhat confusing data scatter in the upper left hand corner of Figure 9 and lower left corner of Figure 5.

6. SUMMARY AND CONCLUSIONS

An approach to evaluating effectiveness of reef breakwaters based on their ability to dissipate wave energy is presented. While this approach is unusual, it provides a method to judge performance which is directly related to the reef's function. As a tentative criteria, the Baltimore District of the Corps of Engineers considers dissipating 50 percent of the incident wave energy during storm events with a 5 year return interval to be satisfactory performance for a reef breakwater.

To simplify and focus the discussion three different heights of reef are treated in this paper: (1) a non-submerged reef, (2) a reef with the crest near the still water level, (3) a submerged reef. Using the relative height, h_c/d_s, to define typical reef heights, dissipation by reefs was found to be in the range shown in Table 3.

Table 3. Percent of incident wave energy dissipated by reefs.

Characteristic Height	Range of Wave Energy Dissipated, Percent
$\frac{h_c}{d_s} \simeq 0.8$	17-56
$\frac{h_c}{d_s} \simeq 1.0$	17-68
$\frac{h_c}{d_s} \simeq 1.2$	22-76

The considerable range of dissipation for each characteristic height in Table 3 was shown in the paper to be partly due to the relative width of the reef, $A_t/d_s L_p$. However, the dissipation process is quite complex and it is impossible to show simple graphs of dissipation versus an independent variable that do not show considerable apparent data scatter. Much of the scatter can be explained by using the model for wave transmission and reflection given in Ahrens (1987b), in the conservation of energy relation, Equation 5, and correcting for natural losses of energy due to wave breaking not associated with the presence of the reef using Equation 6. Energy dissipation can be estimated very well by the above prediction method, as shown in Figures 4, 7, and 8. The range of conditions for which this method can be applied is wider than used in this paper; see Ahrens (1987b) for details relating to ranges of the various conditions tested. For severe wave conditions a small reef can become relatively ineffective in disrupting wave action. Equation 7 can be used to define and directly estimate percent energy dissipation for these conditions.

ACKNOWLEDGEMENTS

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REFERENCES

1. Ahrens, J. P. "Characteristics of Reef Breakwaters," U.S. Army Corps of Engineers Coastal Engineering Research Center, TR 87-17, Vicksburg, MS., Dec 1987b.

2. Fulford, E. T., "Reef Type Breakwaters for Shoreline Stabilization," Proceedings of Coastal Zone 85, Baltimore, MD, Sept, 1985.

3. Goda, Y. and Suzuki, Y., "Estimation of Incident and Reflected Waves in Random Wave Experiments," Proceedings of the 15th Coastal Engineering Conference, Honolulu, Hawaii, July 1976.

4. Dally, W. R. and Pope, J., "Detached Breakwaters for Shore Protection," U.S. Army Corps of Engineers Coastal Engineering Research Center, TR 86-1, Vicksburg, MS, Jan 1986.

5. Ahrens, J. P., "Reef Breakwater Response to Wave Attack," Proceedings ASCE Conference on Berm Breakwaters: Unconventional Rubble-Mound Breakwaters, Ottawa, Canada, Sep 1987a.

6. Seelig, W. N. and Ahrens, J. P., "Estimation of Wave Reflection and Energy Dissipation Coefficients for Beaches, Revetments, and Breakwaters," U.S. Army Corps of Engineers, Coastal Engineering Research Center, Fort Belvoir, VA, Feb 1981.

Why Breakwaters Break

E.H. Harlow

Soros Associates

I. The Forces of Nature
II. The Works of Man
III. Mechanisms & Dynmics
IV. Maintenance

A breakwater by definition is a work of man built in the water for the purpose of breaking down the waves of the sea, so as to shelter certain objects to the lee. In other words, it is a confrontation between a possibly irresistable force and what is hoped will prove to be an immovable object. It is hardly surprising that although man's efforts may succeed for a while, eventually natural forces will prevail. The question is, for how long can we succeed?

I. The Forces of Nature

There is an old saying that water will wear away a stone, and it is literally true. There is no material that can withstand indefinitely the abrasion and solvent action of unlimited amounts of moving water. And the ocean is almost always moving, in response to winds and currents on the spinning shpere of the earth. But breakwaters break long before the materials have been reduced to grains of sand. The forces they must resist are of four types: impacts, currents, abrasion and piping.

A. Impacts

The crest of a large breaking wave striking a stationary object might be likened to several dozen fire hoses being turned against it simultaneously. Or, worse, if the face of the crest is parallel to the surface of the object, its kenetic energy is stopped in near-zero time, causing instant shock pressures, as the water velocity is turned 90°. The part that turns upward causes a geyser. The part that is turned downward causes damage. The intensity of the pressure is limited mainly by the quantity of air (bubbles) in the water. For example, if the portion of breakwater being struck is impervious, and there is no air in the water, the virtual incompressibility of the water can produce near-infinite instantaneaus pressure. Whenever this happens, some portion or particle in the structure must move.

B. Current

When a breakwater is built, it will surely deflect natural current. In doing so, the natural flow is nearly always increased. The result is usually to increase wave energy, change its direction, increase undermining, and to carry away the eroded particles to a down-current location away from the breakwater.

C. Abrasion

As loose particles are detached from a breakwater or are carried against it by moving water, the result is akin to sandblasting. It becomes more intense with time, as the supply of sand increases. Rock pieces and concrete shapes become rounded. They are jostled into new positions under the effects of gravity and wave action. The large contact pressures at the three points where each piece is supported causes more sand particles to be worn off, and add to the supply of the sand-blasting material.

D. Piping

This is the term applied to the ejection of particles from a mass when water exiting at a free surface has sufficient velocity to carry sediment particles with it. It occurs frequently in embankments, along the top of a less pervious layer, causing a series of

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holes that undermining the slope above. It occurs in the seaward slope of breakwaters, as a wave recedes, and water in the voids rushes out into the trough. If there are particles free to escape, the velocity may carry them out, too.

II. The Works of Man

Perhaps the oldest type of breakwater is the rubble mound. It may be as long as needed to project a harbor, or an entrance to a harbor, in which case it may be called a jetty. There may be two, on either side, with an opening just large enough to exclude the worst storm waves. It may be as narrow and steep-sided as possible without slope failure, (to save costs.) "Possible" involves the art and science we are discussing, although with the selection of sizes, arrangement and kinds of pieces of stone and possible cast concrete shapes, of which there are a great many. The largest pieces are placed on the outside of the seaward slope in the hope that the biggest waves will not roll them down the slope.

Blocks are often cast, if of concrete, or cut, if of stone, and piled in ordered tiers, with an almost vertical face toward the sea. They are more often used as a revetment, with land backfill on the shoreward side. Each block must be heavy enough to withstand the worst waves without being dislodged. The slots between and around blocks become the water wedges during wave action, tending to pry them loose.

Caissons of concrete are often so large as to be the full height of the breakwater, and are placed close together to form a wall. The slots between the caissons, and the foundation materials upon which they rest become the water wedges. Various means of sealing these slots and protecting the foundation from undermining have been devised.

Sheetpiling is often driven in a single row with structural support or in double rows with backfill between, to form a breakwater. This latter is often done in cellular configuration, particularly to form temporary cofferdams for deep excavations. The sheetpiling, generally of steel but potentially of concrete, forms a highly impervious wall embedded in the sea bottom to prevent undermining.

Hybrids of various kinds have been built. One example is the use of large diameter concrete piles or caissons driven into the bottom like sheetpiling to form a continuous wall.

Caissons are often combined with rubble mounds, particularly in Japan, with the concrete caissons generally on the landward side, and large cast concrete units, known as "armor," on the seaward side.

Partial mounds are often used on the seaward side of sheetpiling, to help guard against undermining and to help reduce overtopping.

III. Mechanisms and Dynamics

When the forces of nature meet the works of man, we see how devious is the former in circumventing the ingenuity of the matter.

A. Macrophysics

A breakwater will break whenever the forces on a part of it are too large for the forces holding it together. This has happened many times, for example:

A stone or piece of armor in a rubble mound is lifted out of its position;

A caisson is shifted, bounced or broken;

A hole is eroded in the seabed in front of the structure, causing it to be undermined;

A block or caisson is toppled, forward or back;

A whole section of a rubble mound is virtually liquified and flattened;

A whole section is fractured and collapses.

Events like this can occur when nature produces waves much larger than expected, or waves with much longer period, such as tsunamis, where the volume of water and the mass of a single wave are much larger than for normal conditions. Intersecting wave crests from different directions can cause monsters.

During a storm the level of the sea may rise many feet higher than anticipated, owing to hurricane (typhoon) conditions, combining barometric rise and storm surge, along with big waves.

Catastrophic events can also occur when, owing to cost constraints, optimism or ignorance, man's works fail utterly

because we do not understand or allow for extreme natural forces. An example of this might be the building of a road and 24 lovely vacation houses on

Napatree Point, Rhode Island, all totally wiped out in one storm in 1938.

B. Microphysics

The detailed abrasive mechanics of water and stone, or concrete are not well documented. Little is known about the rate of attrition, the degree of rounding of particles, loss of fines from core materials, shifting of pieces as their edges wear and become sand. Neither do we know much about the pressure changes in a micro-seale within a rubble mound or between caissons or stones.

We know that changes in position and elevation of marked points on breakwaters are sometimes measured. Long-term records are scarce. Most significant changes occur during severe storms, as they do in the case of beaches and shoals. The effects of the minute particle reactions are concealed beneath these major events, but it is obvious that as each piece becomes smaller and more rounded, the water forces will more easily move it. The angle of internal friction of the mass, or of the base, will become smaller, chinks or breaks in block, caisson or sheetpile walls will become larger, and water will squirt through them faster and with greater force.

Rubble mounds tend to become flatter with time. It is argued that if the seaward slope is built with a berm, creating an ogee contour like that encountered in beaches or old structures, the stability will be improved. Yet, for each sea level there is a beat-shaped ogee slope. If all storms achieved the same level, the shape would be well adapted to it. But eventually a super-storm will reach a higher level. Then the berm will be too deep to trip the breakers, and they will strike against the upper portion, as if it were part of a uniform slope, with similar devasting effects. This phenomenon was demonstrated in model tests for a proposed massive breakwater to protect nuclear floating power plants. Designed for the "probable maximum hurricane," it withstood all wave action when water level was at predicted elevation. But when some observer insisted that a still higher elevation be tried. The model breakwater unraveled at the top.

Breakwaters break because we are unable to forecast and design for all the conditions they will meet during their lifetime. If we were able to do this, cost constraints would prevent it in most cases. Therefore, breakwaters must be carefully watched, particularly after each storm, and repaired.

IV. Maintenance

The first and most obvious repair is the replacement of components. For rubble mounds, a supply of spare outer armor and under layers should be kept on shore, ready for deployment. For blocks, depending on whether the damage is displacement or rupture, new blocks and means for patching, sealing, concreting. For sheetpiling, additional sheeting, piles and materials for sealing and concreting.

To avoid long delays in making repairs, planning must provide for early mobilization of floating or land equipment to place the materials.

B. Reinforcement

It may be prudent in some cases to reinforce the damaged structure in a major revision. For example, the breakwater at Sines, Portugal, a rubble mound with dolos outer layers and a heavy concrete capwall, was reinforced after its storm damage in the late '70's by adding an extensive seaward shelf of very heavy (90 t) concrete cubes.

Other caisson-type breakwaters have been reinforced with wide rubble-mound beams to break up wave energy over some distance, preventing the clapotis action, the impacts and the undermining that sometimes occurs with vertical-wall structures.

JAMSTEC/DEEP TOW SYSTEM

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ABSTRACT

The development of JAMSTEC/Deep Tow system began in the late of 1970s and presently two systems, which have depth capabilities of 6000 and 3000 meters, are operated. The characteristic features of the JAMSTEC/Deep Tow system are as follows:

(1)Real time visual observations are possible by black and white or color TV which is used with 7800 or 4500 meters of tow cable respectively.
(2)Selective bottom sampling could be carried out by visually observing the sea floor with the use of grab and dredge equipped on the deep tow.
(3)Quantitative monitoring of the tow cable is possible by a special deep tow sheave named "Gimbal Sheave".
(4)A delicate ship control in the deep towing and operation in the rough sea conditions are possible by a semi-submerged catamaran(SSC) "Kaiyo".

In present, the JAMSTEC/Deep Tow is indispensable for the site survey of manned submersible and the deep sea research in JAMSTEC.

1. INTRODUCTION

The first JAMSTEC/Deep Tow system has been developed and operated since 1977[1]. The second system was developed in 1982. The first one was developed for finding artificial objects such as low level radio active wast packages on the deep ocean floor. Its depth capability is 6200 meters. The second one was developed for the site survey in the dive areas of Japanese manned submersible "Shinkai 2000". Its depth capability is 3500 meters. For convenience, we will call these systems as 6000-meter system and 3000-meter system respectively. The 6000-meter system comprises of a 7800-meter long tow cable, a black and white TV system and a 100 kHz side scan sonar. The 3000-meter system comprises of a 4500-meter long tow cable, a color TV system and a 70 kHz side scan sonar. Each component of the both systems such as still camera and CTD is primarily exchangeable. The tow cable is a double armored coaxial cable (RG8/U) of which outer diameter is approximately 17 mm in both systems.

In these five years, the primary role of the JAMSTEC/Deep Tow system is the site survey for manned submersible. Many significant engineering and scientific results were obtained by the JAMSTEC/Deep Tow. In present, the deep tow is indispensable for the deep sea research in JAMSTEC. As Japanese 6500-meter manned submersible will be in operation from 1990, it is necessary to establish a new site survey system. We are planning to increase the capability of the 6000-meter deep tow system by expanding the visibility of the camera, by adding a small ROV which could be launched from the deep tow, and by exchanging a coaxial cable with a fiber-optic cable. In this paper, we would like to introduce the system configuration, operation, significant results and future developments of the JAMSTEC/Deep Tow system.

2. SYSTEM DESCRIPTIONS

The JAMSTEC/Deep Tow system comprises of (1) towed sled equipped with underwater instruments such as sonar and camera, (2) on board units of underwater instruments which are housed in a container van, (3) launch/ recovery and on board towing gears such as A-frame, Gimbal Sheave, winch and tow cable, (4) acoustic navigation system for precise underwater positioning, and (5) research ship which is equipped with basic scientific instruments such as precision depth recorder or Sea Beam. In the following sections basic features of the sub systems or system components will be described.

2.1 Sonar

There are two sonar systems, one of which comprises of a 100 kHz side scan sonar and a 3.5 kHz sub-bottom profiler[2], and the other comprises of a 70 kHz side scan sonar and a 4.8 kHz sub-bottom profiler. The 100 kHz sonar, which has 300-meter maximum range per side, is used primarily for searching artificial objects in the ocean floor, because its resolution is better than the 70 kHz sonar. On the other hand, the 70 kHz wide range sonar, which has 1000-meter maximum range per side, has great advantage in geomorphological and geological studies.

The 100 kHz sonar was purchased from ORE in 1978, and lost in 1983 during deep towing in the steep wall of submarine caldera. After the accident we purchased side scan transducers from Klein and modified on board sonar unit. The 70 kHz sonar was manufactured by Nippon Electric Company (NEC) in 1982(Fig.1). Sonar data in each system is displayed on a dry paper graphic recorder and stored in a 1/4-inch analog data recorder.

2.2 Still and TV Camera

Benthos model 372, 35 mm cameras and model 382, 100 Ws strobes are used in both systems. A real time black and white TV by NTSC system is used in the 6000-meter system because of great attenuation of the video signal through the RG8/U coaxial cable 7800 meters in

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length. The minimum lumious intensity is 0.35 lux. A real time color TV by NTSC system is used in the 3000-meter system. 4.5 MHz band width is required to transmit color video signal. As it is difficult to amplify homogeneously from D.C. to 4.5 MHz, the transmit center frequency is shifted to 6.2 MHz, thus the video signal is frequency modulated with plus minus 4.2 MHz shift frequency and transmitted via 4500-meter coaxial cable. The minimum luminous intensity for practical use is 150 lux using a three-tube image intensifier. Recently, we replaced the camera with the latest CCD camera of which minimum luminous intensity is 32 lux.

Lightings are two 250 W quarz iodide lamps for black and white TV, and four 250 W quarz iodide lamps for color TV. It is possible to select either black and white or color TV by a command signal from on board unit in the 3000-meter system. There are two more command signals for the actuation of still camera and strobe and also grab sampler. CTD data are transmitted with the video signal.

The original black and white TV was purchased from Hydro Products in 1973 and totally modified by JAMSTEC and Shonan High-Frequency Laboratory (SHL)[3]. The color TV was developed by JAMSTEC and SHL in 1982 (Fig.2)[4]. The video data are recorded in 1-inch cassette(U-matic) and 3/4-inch cassette(VHS). As the video data are replayed easily on board, it is not necessary to develop the photo film on board.

2.3 Sampling Devices

During the deep tow camera observation, it is possible to carry out sampling by use of grab sampler and box dredge. The grab sampler could be dropped at a sampling point by watching TV monitor. The box dredge, which is named the "Deep Tow Dredge", could be used any time by simply lowering camera frame close to the bottom. The sizes of the grab and dredge are 50 cm cube and 40W x 15H x 50L cm respectively. The grab sampler is suitable to collect sediments, on the other hand, the dredge is useful both for sediments and rocks.

2.4 Towed Frame

The JAMSTEC/Deep Tow adopts a direct towing method which suspends a towed frame(sled) directly to the cable stop(termination). The advantage of this method is that it is easy to keep the towed frame very close to the sea floor even in very rough topographies. On the other hand, a depressor towing method, which a neutral buoyant towed frame is towed behind a depressor or a heavy weight, has an advantage that the towed frame is very stable because it is free from the up and down motion caused by a surface ship. As the towing speeds of sonar and camera are approximately 2 kt and 1 kt respectively, an open frame is more stable than a faired topedo shape as for towed body. Also, open frame is stable by vertical motions, while the faired topedo shape is feasible to cause pitching which degrades sonar records and is harmful for camera observations.

2.5 Launch and Recovery System

A launch and recovery system is one of the most significant factors to influence the operating efficiency of the total system at sea. There are two typical cranes for launch and recovery. The first one is an articulated boom crane which is used by Scripps MPL/Deep Tow. The advantage of this crane is that it is possible to launch and recover the deep tow very close to the sea surface. Therefore, it is possible to operate the system in rough sea conditions. Also, as the crane rotates with a ship changing her course, this minimizes the possibility to injure the tow cable at the top sheave of the crane. The second one is an A-frame which we use in JAMSTEC and is commonly used by research ships. In this case, as the distance between the top sheave and the sea surface is greater than 4 or 5 meters, the towed sled is likely to swing by pendulum motion and is apt to collide with the ship hull which will damage the instruments.

In order to avoide the collision, we put four unti-swing ropes on the towed frame. These ropes are holded by four deck men to stop swinging during launch operation. The other end of each rope is attached to the tow cable with attatchment during towing. In recovery, the ropes are detached from the tow cable and are used as in the launching. In general, the recovery is more difficult than the launch, because it is more difficult to attach a rope on the towed frame than to detach it. As the above method is very simple but reliable, the JAMSTEC/Deep Tow can be launched and recovered at any sea state.

2.6 Winch and Tow Cable

There are two winches for the deep tow, i.e. a 8000-meter winch with 7800 meters long tow cable and a 4000-meter winch with 4500 meters long tow cable. The 8000-meter winch, which comprises of a 200 KVA electric-hydraulic unit, a traction winch and a storage winch, was built to be used on the ships of opportunity. The 4000-meter winch is aimed to be used both on the mother ship "Natsusuima" of manned submersible "Shinkai 2000" and semi-submerged catamaran (SSC) "Kaiyo". The tow cable is wound directly in the 4000-meter winch drum and its hydraulic power is supplied by both ships. The 8000-meter winch was modified from direct winding to the present system because there was a difficulty in level winding of the tow cable. As far as the level winding is maintained, we consider that the traction winch is not always necessary.

The tow cable is a double armored coaxial cable(RG8/U) of which outer diameter is approximately 17 mm, breaking strength is 19 tons and weight in water is 0.85 t/km. The maximum length which this cable breaks by its own weight in water is 22000 meters, while the deepest water is 11000 meters in reality. Here we will estimate the safety factor of the tow cable when it is used in the depth of 6000 meters. We will assume that the weight of towed frame in water is 1 ton and cable length which will be payed out is 6500 meters, then the static tension at the winch is 6.5 tons, thus the safety factor of the tow cable is 3. According to our measurements of cable tension during deep towing, the dynamic tension does not exceed plus minus 50 % of the static tension. Therefore, we consider that there is not serious problem on the strength of the tow cable in the deep towing at a depth of 6000 meters.

It seems that there is no quantitative standard on a cable life. As electrical deterioration of the coaxial cable is faster than mechanical deterioration of the armor strands, we measure periodically a high frequency characteristics of the cable for estimating cable life.

2.7 Gimbal Sheave and Deep Tow Display

Gimbal Sheave is an unique tool which was specifically designed for the deep towing(Fig.1)[5]. The characteristic features of the Gimbal Sheave is that it is possible to eliminate damages of the tow cable at the sheave and also to measure all towing data such as cable length, tension, towing angle and rotation of three gimbal axes(Fig.3). These data are processed by a micro computer and displayed on a color CRT named Deep Tow Display(Fig.4). This is useful not only to understand visually and quantitatively the status of deep towing but also to maneuver the ship. Approximate positions of the towed frame which is obtained by the deep tow display is used as a back up of acoustic positioning.

2.8 Precise Underwater Positioning

A precise underwater positioning is to the utmost important for the deep tow surveys. A long base line (LBL) acoustic navigation system was purchaced from ORE in 1977[6]. After several trials and errors the system was almost in practical use in 6000 meters of water depth by 1982. From 1983 to 1986, we improved software and updated the onboard units such as computer, displays, receiver etc.. We also modified a release mechanism of the ORE transponder to improve release reliability in the depth of 6000 meters[7]. This LBL system was intended to be used on the ships of opportunity.

Taking these experiences into account, new underwater positioning systems, which comprise of LBL and SSBL, by Oki Electric Company (OKI) were equipped on the mother ship "Natsushima" and SSC "Kaiyo" in 1982 and 1985 respectively. The most advatageous feature of the SSBL (Super Short Base Line) acoustic positioning system is that there is no need to put transponders on the botom if the ship positions could be obtained by LORAN C or GPS. As an accuracy of the SSBL system is 1.5 % of slant range, the accuracy degrades with increasing water depth. Although the SSBL is not so accurate as LBL in the deep water, it is useful in surveying wide area by the deep tow.

2.9 Ship Capability and Maneuverability

As the deep tow itself has no mobility, the capability to guide the deep tow sonar or camera to the desired point or on the intended line depends on a ship maneuverability and positioning accuracy. Both mother ship "Natsushima" and SSC "Kaiyo" have excellent maneuverabilities at low speeds, and equipped with precise surface and underwater positioning system. Especially, the SSC "Kaiyo" has a dinamic positioning system (DPS) and has a capability to steer any directions at low speeds by use of two main propulsions and eight side thrusters. It is usually very difficult to steer the ship in a side wind at low speeds. The hight of the work deck of "Kaiyo" is 7 meters above the sea level. Although this is three times higher than the mono-hull ships, there is no problem in launch and recovery of the deep tow, because "Kaiyo" is very stable and four anti-swing ropes attached on the towed frame prevent swinging. The maximum deep tow operating wind speed is approximately 20 m/s in "Kaiyo", while it is less than 15 m/s in "Natsushima".

2.10 Operation of the JAMSTEC/Deep Tow[8]

The JAMSTC/Deep Tow is operated by Deep Sea Reserch(DSR) group organized by four to six members on board and no supporting technitian is required. All on board check, maintainance and repair are carried out within the DSR group. Launch and recovery of the deep tow, deploymemt of transponders, operation of accoustic positioning system and winch control are carried out by ship's crew.

The deep tow sonar is towed at 60 to 120 meters above the sea floor and at speed of appoximately 2 kt. According to our experience in operating the deep tow system, it is very important to keep the cable inclination as vertical as possible in rough topographies. If the cable inclination is very large, the towed frame is apt to collide with the steep slope, because the depth of the towed frame will not change rapidly with cable hoisting. Usually, the towing speed of the sonar is faster than the camera, damage of the sonar by collision is greater than the camera.

In 1983,we lost the deep tow sonar in the steep wall of submarine caldera of which average gradient was 35 degrees. As the cable inclination at that time was 27 degrees relative to horizontal plane, the tow cable touched the slope. Without knowing the fact, the tow cable was hoisted at full speed to keep the sonar away from the slope. Shortly, the sonar touched the bottom while the tow cable continued hoisting. Finally, the cable stop came out and the sonar was lost. This accident was a valuable lesson not to hoist the tow cable by force but to watch the cable tension carefully and to keep the cable inclination as vertical as possible.

The maximum operating sea state for the deep tow is up to 5 by "Natsushima" and up to 6 by "Kaiyo". Although launch and recovery would be possible in more rough sea conditions, ship control and camera observation is difficult and sonar record degrades.

3.SIGNIFICANT RESULTS AND FINDINGS BY THE JAMSTEC/DEEP TOW

3.1 Experiments for Finding Artificial Objects in the Deep Ocean

Experiments to search for small artificial objects by use of deep tow sonar and camera were carried out in 1983 and 1986.

In 1983, 22 drum cans, 200 l in volume, 60 cm in diameter, 90 cm in length and 200 kg in water weight, were deployed over the side to a depth of 5700 meters in the North West Pacific Basin. These targets were deployed within a diameter of 50 meters at the surface. According to the sonar survey, they were scattered approximately within 300 meters on the

bottom. This means that the drum cans dropped almost vertically through 5700 meters of water colum. After the sonar survery, the deep tow camera was guided to the target area by precise LBL acoustic navigation. Finally, drum cans were observed and photographed for three times.

In 1986, almost the same experiment was carried out in the Hachijo Depression, 150 nautical miles south of Tokyo. Fifteen drum cans were deployed to a depth of 1400 meters and they were searched by sonar and camera as in 1983. The drum cans were detected by sonar and observed by camera for five times (Fig.5&6). The importance of this experiment is that the sonar echo was identified as the drum can, because the position of the sonar echo coincided with that of the camera where the drum can was sighted(Fig.7). Another important finding is that the same drum can was observed for three times and the distribution of each position was approximately within plus minus ten meters(Fig.7). This is a measured realtive accuracy of the LBL positioning system.

3.3 Significant Scientific Findings

Between 1977 to 1988, more than fifty five deep tow cruises for experiments and site surverys were carried out. Singnificant scientific findings so far are listed below.

(1)In 1982, remarkable ripple marks and sand dunes at a depth of 2000 meters, which indicate strong bottom current, were found in the Suruga Trough, 70 nautical miles south west of Tokyo.
(2)In 1983, a big submarine earthquake(M7.7) occured in the central sea of Japan of which water depth was around 3000 meters. Many cracks, small trenches, teared fishes and yellowish deposits were found on the sediments[9].
(3)In 1986, biological comunities by giant clam and tube worm originated by cold water spring were found in the Sagami Trough, 40 nautical miles south west of Tokyo.
(4)In 1987, hot springs and biological communities by giant clam, white crab etc. were found in the submarine volcano Kaikata Seamount in the Bonin Islands[10].
(5)In 1987, a hydro-thermal activity and associated biological communitites were found in the North Fiji Basin, south of triple junction.
(6)In 1988, hydro-thermal activities and associated biological communities were found in the Okinawa Trough.

4.FUTURE DEVELOPMENTS

As a Japanese 6500-meter manned submersible will be in operation from 1990, it is necessary to establish a new 6000-meter site survey system. The deep tow survey efficiency, i.e. coverage per day, decreases with increasing water depth because of great hydrodynamic resistance of the tow cable. At present, the observation swath width by the deep tow camera is 6 meters square at maximum. Also, it is very difficult to stop and observe at a point of interest. In above reasons, we are planning to increase the visibility of the camera and to add a small ROV which could be launched from the deep tow. For these purposes it is by all means necessary to use a fiber-optic cable instead of a coaxial cable (Fig.8). Already we finished factory and at sea tests of the fiber-optic tow cable.

5.SUMMARY

A real time color TV, which is installed on the 3000-meter deep tow camera, is one of the most characteristic survey equipment in the JAMSTEC/Deep Tow system. It is very useful both for geological and biological investigations.

A manned submersible is highly sophisticated man-machine system which requires many operating personnel and lots of money to operate the system. On the other hand, the deep tow requires less people and money than the manned submersible, and could be operated in rough sea conditions.

Sea Beam, JAMSTEC/Deep Tow and manned submersible "Shinkai 2000" are the basic tools for the deep sea research in JAMSTEC. A heavy duty ROV "Dolphin 3K", which has a depth capability of 3300 meters, joined the deep sea research from 1988.

6. ACKNOWLEDGEMENTS

We acknowledge the contributions of several colleagues in JAMSTEC, especially in the Deep Sea Research Department, who assisted in developing and improving the JAMSTEC/Deep Tow system. We are grateful to Dr. F.N. Spiess and Mr. D.E. Boegeman of Scripps Instituiton of Oceanography for cordial advice and encouragement. Part of this work was supported by Bureau of Atomic Energy of Science and Technology Agency.

7. REFERENCES

1 . Hotta,H. et al. "Preliminary Sea trial of Deep Sea Floor Survey System", JAMSTECTR (5), P.27-44 1980 (in Japanese)
2 . Ohtsuka,K., Nakanishi,T. and Hotta,H. "Deep Tow Sonar System", JAMSTECTR (8), P.1-28 1982 (in Japanese)
3 . Tsuchiya,T. and Ohtsuka,K. "Development of TV System for the Deep Tow", JAMSTECTR (11), P.13-29 1983 (in Japanese)
4 . Ohtsuka,K., Tsuchiya,T. and Hashimoto,J. "Development of Color TV System for the Deep Tow", JAMSTECTR(19), P.249-262 1988 (in Japanese)
5 . Momma,H. and Hotta,H. "Development of a Gimbal Type Sheave for Deep Towing " Proc. Oceans '83, vol.I, P.270-273 1983
6 . Nakanishi,T. et al. "Laboratory and at Sea Tests on Long Base Line Acoustic Navigation System", JAMSTECTR (3), P.39-49 1979 (in Japanese)
7 . Momma,H., Tsuchiya,T. and Hotta,H. "Improvement of Release Mechanism for Transponders", JAMSTECTR (9), P.67-74 1982 (in Japanese)
8 . Momma,H. and Hotta,H. "Operating Techniques of Deep Towing and Accurate Positioning", Proc. 8th Ocean Engineering Symposium, P.57-62, 1987 (in Japanese)
9 . Hotta,H. et al. "Visual Observations in the Central Area of the 1983 Central Sea of Japan Submarine Earthquake", JAMSTECTR (14), P.37-53 1985 (in Japanese)

10. Deep Sea Research Group "Preliminary Report of Deep Tow Survey in Kaikata Sea Mount (DN87-3-MCS) "JAMSTECTR (19), P.223-230 1988 (in Japanese)

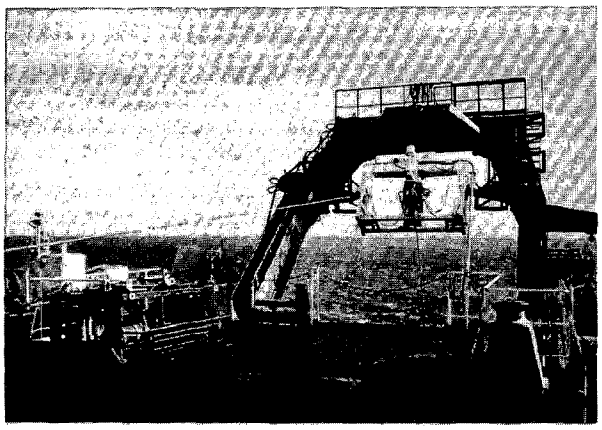

Fig.1. A-frame, Gimbal Sheave and deep tow sonar on board Semi-Submerged Catamaran "Kaiyo".

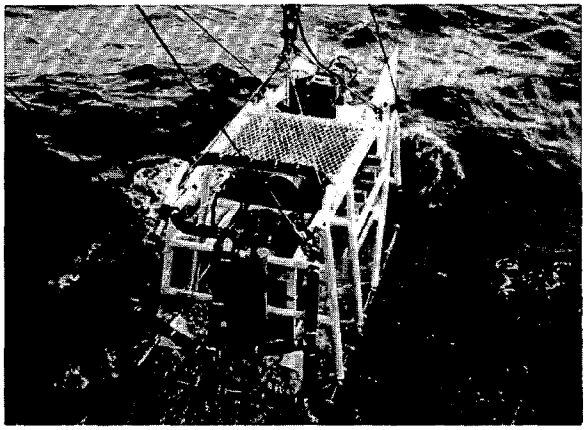

Fig.2. Deep tow camera in recovery. Four unti-swing Kevlar ropes are visible in the corners of the towed frame.

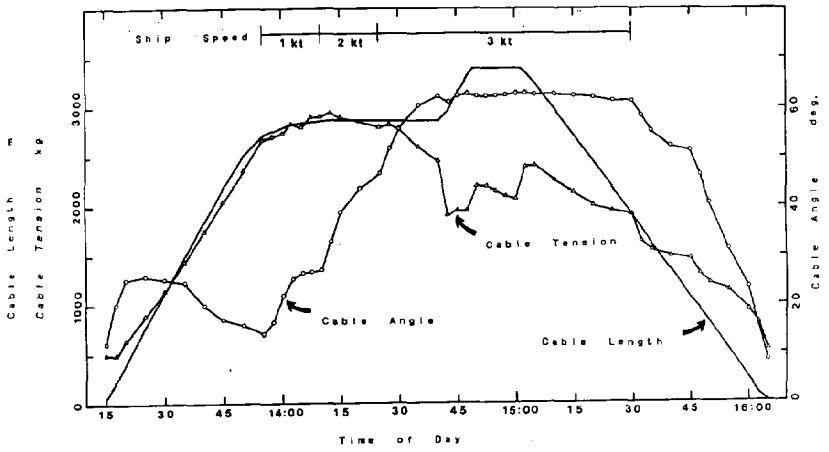

Fig.3. All the deep tow cable data are measured by Gimbal Sheave. This figure shows relation between ship speed and cable tension.

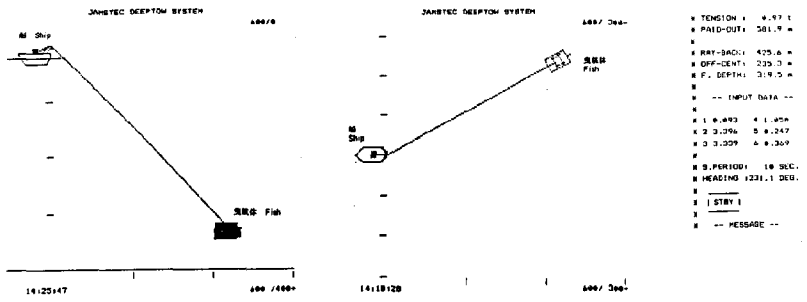

Fig.4. Deep Tow Display is useful for visually recognize the towing status and also for ship maneuvering.

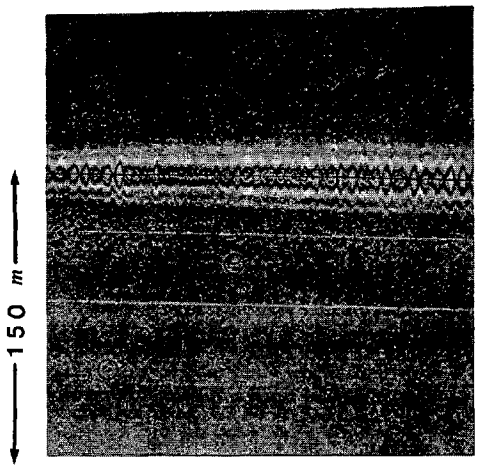

Fig.5. Sonar echoes (in circles) of 200*l* drum cans filled with concrete by a 100 kHz side scan sonar. The echoes are intentionally enhanced for visual convenience.

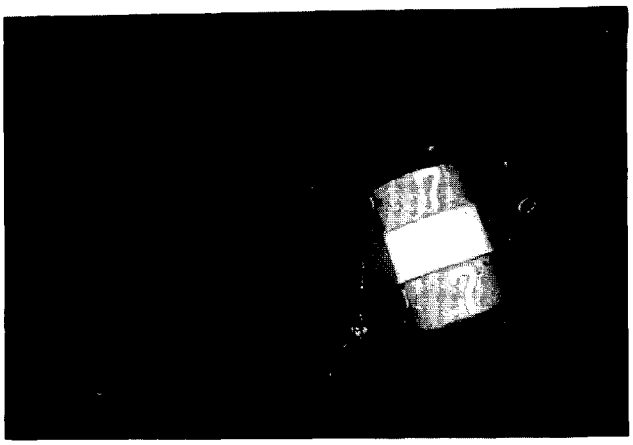

Fig.6. One of fifteen drum cans on the sea floor of 1400 meters of water depth. This No.7 drum can was sighted by camera for three times.

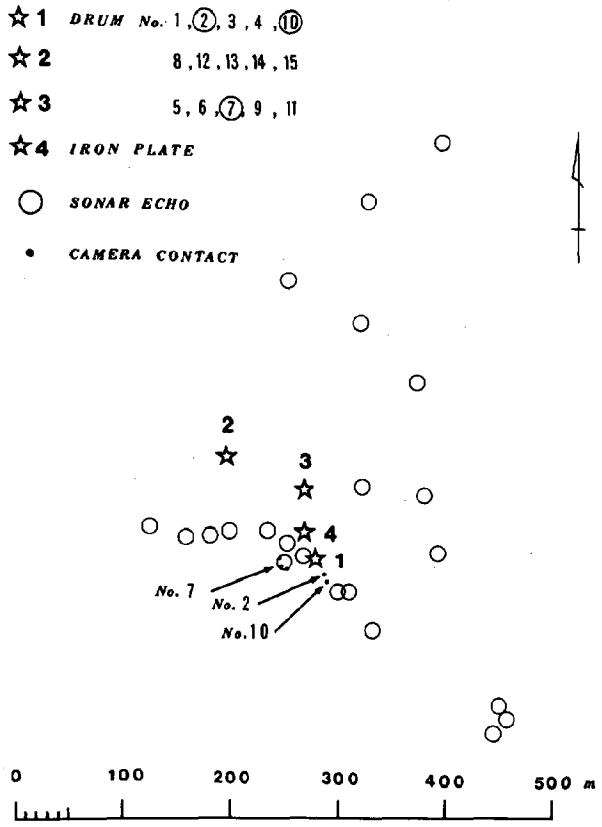

Fig.7. Positions of sonar echoes (circles) and camera contacts (dots) are illustrated. Numbered stars are positions where drum cans were deployed over the side. They drifted approximately 60 meters toward the south during descent.

Fig.8. Fiber-optic tow cable which was manufactured by Ocean Cable Company (OCC) for testing.

EAVE III
UNTETHERED AUV SUBMERSIBLE

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ABSTRACT

The Marine Systems Engineering Laboratory of the University of New Hampshire designed and constructed two new untethered AUV submersibles in 1987. These vehicles were designed as testbeds for the investigation and demonstration of several concepts including: multi-vehicle cooperation, inter-vehicle communication, and automated decision making. These vehicles are designed such that additional sensors and software can be included to augment the system and make it an adaptable autonomous testbed.

This paper describes the basic system hardware and software architecture as well as the existing sensor subsystems. It describes results of underwater tests conducted in the fall of 1987 with respect to preliminary sensor and vehicle performance. This paper also describes plans for future developments and important concept tests of these vehicles which are of significance to the long range application of autonomous submersible technology.

1. INTRODUCTION

The Marine Systems Engineering Laboratory of the University of New Hampshire has been involved in developing state-of-the-art technology for autonomous underwater vehicles (AUVs) since 1977. This laboratory has previously developed two generations of unmanned AUVs.

The third generation system, described in this paper, was developed as a generic testbed with an increase of several orders of magnitude in processing power and memory capability. It was developed for the purpose of testing knowledge-based guidance and control concepts (AI), inter-vehicle acoustic communication and cooperation, and bandwidth compression and transmission of imaging systems data. It will serve as a versatile testbed in the future for various advanced technology development concepts.

2. PROGRAM GOALS AND OBJECTIVES

The primary goal of the program described herein was to design and develop two AUVs with state-of-the-art processing and data storage capability, navigation, and sensor systems. The electronic hardware and software architectures are designed such that knowledge-based concepts could be developed and tested on the vehicles. This involves designing a system in which AI languages such as Lisp can be ported and run with a real time operating system on the vehicles' computer hardware. The system is also designed such that a high baud rate (4800) acoustic link can be used for inter-vehicle and vehicle to launch communication. This link is also used to transmit real-time compressed video imaging data between the vehicle and the launch site, and can provide tele-presence capability.

3. EAVE III SYSTEM DESCRIPTION

The EAVE III is an unmanned untethered submersible. It is designed as a highly maneuverable, sophisticated system which can be easily modified to perform various types of missions and experiments. A drawing of this vehicle is shown in Figure 1, and a vehicle specification is shown in Figure 2.

The vehicle consists of two buoyancy tubes which contain the system computers, two battery tubes which house the lead calcium batteries, and six DC brushless thrusters used to maneuver the vehicle vertically, horizontally (forward and backward), laterally as well as in heading (yaw).

The system sensors include an acoustic obstacle avoidance system operating at 300 kHz, an acoustic depth (uplooking) and altitude (downlooking) sonar both operating at 200 kHz, a pressure depth sensor, a water temperature sensor, a

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flux-gate compass and an acoustic long and short baseline navigation system which operates at either 30 kHz or 100 kHz.

A work package installed on the EAVE III vehicle was an underwater video system. The video camera used for the system was a Sub Sea Systems, Inc. SL99/WA silicon intensifier target (SIT) camera, capable of operating from full sunlight down to 0.0001 ft. candles. It offers a 110 degree angle of view, with auto iris and motorized focus. A Kodak MVS-500 8mm VCR handled video recording, which provided a light-weight, compact power solution to video documentation.

An RF telemetry system was installed on the vehicle for use in fresh water environments. The telemetry system was used to transmit data from the vehicle to the launch barge and to a shore station. The system consists of Joslyn Defense Systems RFM-2A RF modems operating at 27 MHz, and standard C.B. antennas.

The computer system architecture (Figure 3) is time ordered, modular, and hierarchical. The low level consists of three 68000 processors which handle all of the fast (<1 second) system requirements. This lower level effectively can run the vehicle in a preprogrammed scenario without the upper level. This is important in determining basic vehicle performance and diagnostics of subsystems. The low level processors perform the functions of controlling and reading sensors, preprocessing data, monitoring vehicle status parameters, and controlling vehicle motion by constantly modifying the six thruster speeds as a result of processing the sensor data through the software control algorithm.

The interface to the upper level is designed such that either the MSEL high level knowledge-based architecture, or any other architecture (such as the National Bureau of Standards (NBS) RCS controller) could be tested with this system.

The high level computers consist of 68020 processors housed in a VME bus system. The VME bus has been chosen for use in EAVE as the framework upon which to build a testbed for AUV knowledge based systems development. Each module in the high level model is allocated to a separate processor, in our case a Motorola 68020 CPU. These processors all share a global bus and have significant dual port memories to allow local use by the CPU, as well as remote communication by other CPUs sharing the bus.

4. SYSTEM STATUS AND SUBSYSTEM TEST RESULTS

The two vehicles were designed and fabricated during the course of 15 months, and underwent extensive laboratory and field tests. A total of approximately 200 untethered mission tests were conducted over the late summer and fall of 1987 at the Lake Winnipesaukee test facility in New Hampshire. A one mile square area of the lake was surveyed acoustically prior to testing to develop maps of the lake bottom for use in the software world model.

The field tests progressed from sub-system tests to vehicle performance tests to mission demonstration tests of various types. The demonstration tests included: (1) cooperative testing utilizing the National Bureau of Standards RCS controller as the high level processing system, (2) conducting a barrel search, detection, and video taping mission using the MSEL system, and (3) employing Lisp software in the MSEL high level software system on the VME computers to conduct a mission similar to (2) above.

Integrating all of the subsystems into a total vehicle system presented the predictable problems normally encountered in such an effort. These problems generally involved the categories of interface definition, interprocessor communications, acoustic signal filtering, etc. All of the problems of any significance were solved or are understood and are being corrected at this time.

The software in this system, for both the low level and high level architectures provides significant capabilities for an AUV. This software proved to be very reliable as evidenced by the number of test missions which were accomplished. The most dramatic and significant accomplishment in this area was the development of a means of running a symbolic language (Lisp) on a real time operating system (pSOS) on an untethered AUV submersible. This advance not only demonstrates feasibility, but also makes possible the actual implementation of symbolic processing concepts and provides a development environment for further research in automated decision making.

5. EAVE III PERFORMANCE

The EAVE III vehicle has two modes of vertical control. It is capable of either running in the depth or altitude (terrain following) control modes. The modes can be changed as the vehicle is underway by simply changing one parameter in the

command string. The data indicates that it controls equally well in either mode. Throughout the mission, the vehicle remains within ±.6 meters of its altitude or depth.

The EAVE vehicle is capable of motion in 3 dimensions (x, y, z) as well as yaw. In order to determine performance a series of tests were conducted to determine the vehicle's response in each axis. A tabulation of results is summarized in Table 1. The data indicates that for the control gain settings used the vehicle typically moves in the forward direction with an average velocity of .5 Mps and little, if any, overshoot. Backward motion velocity is .35 Mps with little overshoot. The backward velocity is slower than forward due to the decrease in prop efficiency in the reverse direction. Similarly the parameters for slide motion, vertical motion and rotation can be read directly from the tabulation. It is important to note that the vehicle possesses an oscillation in yaw, of about 10 degrees with a period of oscillation of about 20 seconds. This problem is currently being addressed in a new controller designed for this vehicle.

TABLE 1
EAVE III Performance Summary

MOTION TYPE	AVE. VEL. VEL. (MPS)	OVERSHOOT	OSCILLATION DEG. SEC.
Forward	.5	none	10 - 20
Backward	.35	none	same
Slide	.20	none	same
Climb	.35	none	same
Dive	.25 deg/sec	none	same
Rotate	6	12	same

NOTE: Average velocities can be increased by changing gain settings in software.

6. MSEL/NBS COOPERATIVE TESTS

A series of tests were conducted both in the laboratory as well as in the field in order to properly interface the NBS RCS high level controller software to the EAVE III low level system. Most of the problems were resolved, and NBS tested their software on the vehicle at the Lake Winnipesaukee test facility. The software system was able to control the vehicle through the NBS "EMOVE" level software.

NBS also designed an interface to the RF telemetry system, described earlier, in order to have a means of telemetering vehicle position data in real time to the barge and island terminals. An interference problem was avoided by transmitting data at 10 second intervals for a 1 second period to the barge. A UHF telemetry system on the barge then relayed the data to the shore facility for plotting of vehicle position.

The NBS team was able, over the testing period to demonstrate RCS control by running the following types of missions:

- Straight line motion
- Diamond pattern motion
- Pseudo circular motion
- Raster search motion

7. MSEL/NUSC DEMONSTRATION TESTS

The purposes of these field tests were to:

- Demonstrate EAVE III search capability.
- Demonstrate bottom object detection capability.
- Demonstrate modification of vehicle control as a result of detection, and control of a camera to videotape a bottom object.

Divers from the NUSC facility laid three objects in the test area. These objects consisted of 2 sets of 55 gallon drums welded together on end to form an object with dimensions of approximately 8 feet in length and a diameter of approximately 30 inches. The third object was an 8 foot aluminum drum of approximately 20 inches in diameter.

Barrel Detection and Video Taping

The vehicle was to detect the barrels, halt its forward progress, turn on a video camera and VCR, perform some maneuver over the barrel, turn the camera off, and then continue with the original mission. This sort of mission interruption is composed of two parts: the detection of the bottom object and the reaction to that detection.

Experiments with various barrel detection algorithms were tested in the Data Assessment and Situation Assessment modules of the laboratory emulation system. The detection of a bottom object is based on changes in the altitude readings. The Data Assessment algorithm deals with the computation of the slopes between the various readings, and the Situation Assessment algorithm looks at sequences of slopes. Certain sequences are taken to mean an object was just passed.

A raster search of the area was made to determine the location of the objects. This was successfully accomplished. The planned line spacing between tracks was 2 meters. The data suggests that the vehicle usually was within 1 meter of planned track even considering the yaw problem discussed earlier. At the ends of each track in the raster search the

vehicle performs a 180 degree turn and simultaneously slides 2 meters to the next track position.

The objects were detected using the downlooking acoustic altitude sonar system described earlier. This system has a 10 degree beam and operates at 200 kHz. It has a resolution of approximately 4 cm and proved adequate to the task.

The concept was to fly over the objects, and when an object was detected, turn on a downlooking video camera, (also discussed earlier). The vehicle would then back up to the object location, climb to some preselected altitude above the object, descend along the original track path and then resume its mission plan. In conjunction with this mission, NUSC provided divers to videotape the vehicle as it maneuvered over the objects. A videotape of these missions was attained and produced by NUSC.

Figure 4 is a plot of raw position data for one of the object (barrel) detection missions. The location of the objects are easily identified by the very dark areas which are created by the vehicle backing up over the barrel, and then climbing and descending to resume the planned path. Notice also that one track veers off for approximately 10 meters before returning to track. The vehicle missed the barrel on this track. It appears that a multipath was read by the navigation system and believed as true for approximately 10 meters of track. The lane spacing for this mission was planned at 1 meter for the three sides of the figure.

8. LISP PLANNER ON REAL-TIME OPERATING SYSTEM IMPLEMENTATION

Field tests were conducted with the reduced version of the hardware architecture described earlier. The purpose of these tests were to use the high level MSEL system in conjunction with the low level system to perform intelligent missions. Of particular interest was the testing of the Lisp Planner module which would demonstrate the feasibility of placing a Lisp or symbolic processing environment on a real time operating system on an AUV.

The mission begins with the low level vehicle executing a preplanned search mission which takes it over a submerged barrel. This preplanned mission continues with the upper level monitoring all data which is passed from the Sensor Manager and Effector Manager. Once a barrel is detected in the Sensor Manager it passes this information along with current vehicle position. Once the barrel data is received, the planner:

- Interrupts the default plan
- Formats a series of new vehicle path commands
- Outputs path series to the IV-1624.

A task on the I/O board then handles the sending of path segments to the Effector Manager computer. When the last default path segment has completed, the path which the vehicle was executing before the barrel was detected is continued. Further execution follows the preplanned path set in the Effector Manager.

The Planner and Lisp environment performed as expected when a message was sent from the Sensor Manager stating that a barrel had been detected. Upon detection of a barrel, the default plan was to:

- Hover at current location; turn on camera and light
- Vertical climb of 10 meters
- Vertical descent 10 meters; turn off camera and light.

A plot of the successful mission is shown in Figure 5. This figure shows a plot of x, y, z, altitude and bearing as a function of time. The vertical hash lines represent command changes of the preplanned mission contained in the Effector Manager. The time scale shown represents about 15 minutes. The data indicates that the Sensor Manager sent a barrel detect message to the upper level system shortly after command #6 started.

9. FUTURE PLANS

A current major effort of this laboratory is aimed at fully implementing the EAVE vehicle's high level knowledge-based architecture on the EAVE III vehicles now that feasibility has been proven. This will allow for further research and demonstration in the area of automated decision making which is a key development area for untethered AUV submersibles.

We are also currently evaluating and implementing an acoustic communications link for both image transmission and telepresence capability.

Current plans also include flying both vehicles simultaneously in the near future. This will provide a realistic environment in which to demonstrate developments in the area of communications to and between vehicles, as well as concepts of multi-vehicle cooperation.

Recent technology advances in power sources indicate that this vehicle can be fitted with a new power supply system to lengthen its mission time to 80 hours in the same physical package that currently exists on the vehicle. This is also planned for the near future.

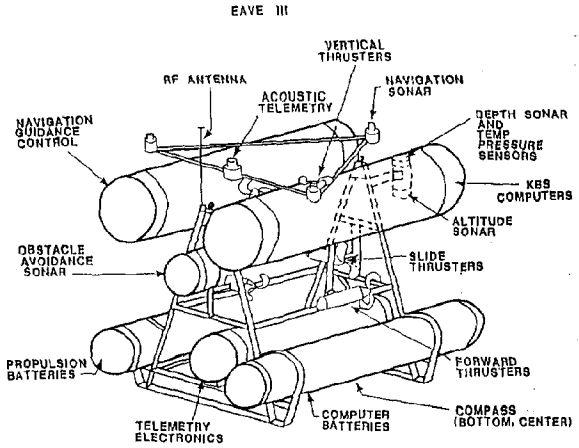
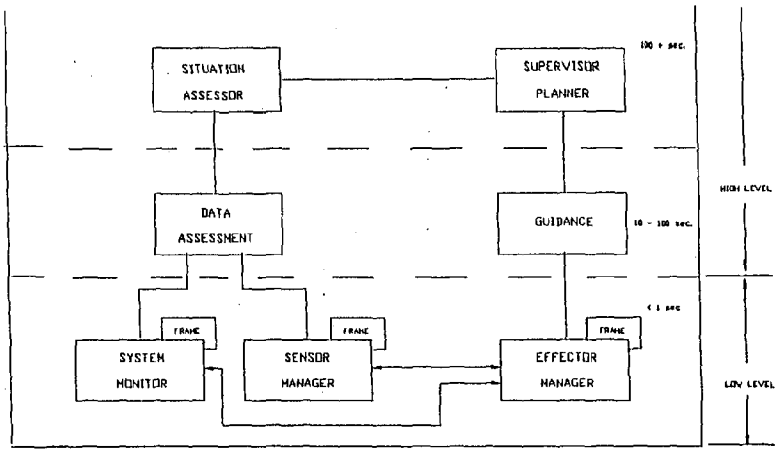


Figure 1.

EAVE III VEHICLE SPECIFICATIONS

Overall Dimensions	: Height – 51 inches Width – 41 inches Length – 51 inches
Weight	: 1000 lbs (air)
Speed/Endurance	:1 knot / 4 hours
Max Speed	: 1.5 knots
Power (battery)	: lead calcium – 2KW–HRS
Payload	: 50 lbs.
Thrusters	: DC Brushless (6)
Degrees of Freedom	: 5
Depth Rating	: 500 feet
Navigation System	: Acoustic – 30 KHz or 100 KHz Long Baseline / Short Baseline
Sensors	: Obstacle Avoidance Altitude Sonar Water Temperature Flux–Gate Compass Pressure Transducer System Monitors
Communications	: Acoustic Telemetry RF Telemetry
Computers	: 68020 based system on VME Buss 68000 based system (MSEL–CPU)
General Characteristics	: Highly Maneuverable Autonomous Unmanned Untethered Knowledge Based System

Figure 2.



KBS/EAVE SOFTWARE ARCHITECTURE

Figure 3.

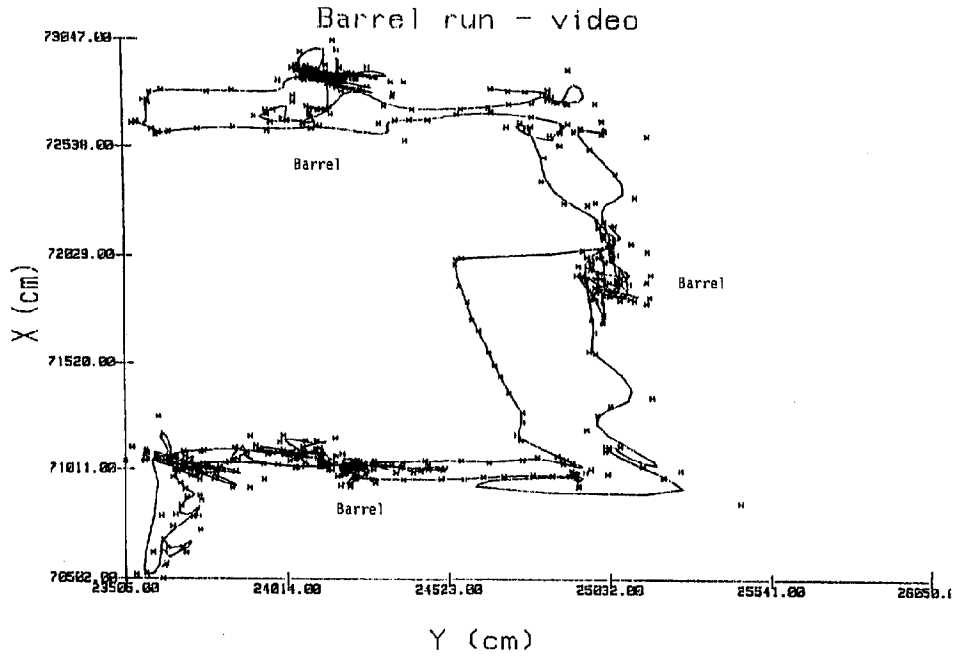


Figure 4.

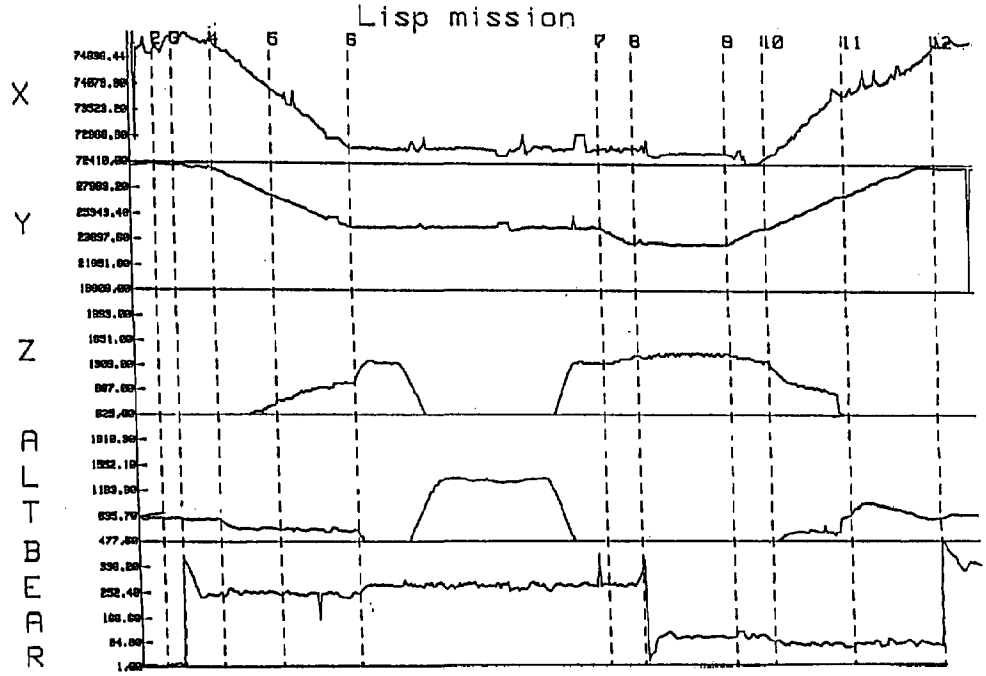


Figure 5.

An Autonomous Underwater Vehicle (AUV) Flight Control System Using Sliding Mode Control

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ABSTRACT

This paper discusses ongoing work at Martin Marietta in the design of an advanced AUV control system. This work focuses on the application of a nonlinear control technique known as sliding mode control (SMC) to an AUV testbed being developed at Martin Marietta. AUV's present new challenges in the area of dynamic closed loop control. AUV control systems must be able to robustly control movement at all angles of attack or sideslip, adapt to changing mission payloads and dynamics, and provide a tolerance to control element failures. SMC provides a theoretical framework for the design of controllers that can meet these requirements. The AUV control system has been designed using SMC and is being prepared for at sea testing onboard the Martin Marietta AUV testbed in early 1989.

1. BACKGROUND

In 1984, Martin Marietta Aero and Naval Systems began a program of independent research and development (IRAD) directed towards the development of critical AUV technologies. As part of this program an IRAD was begun which focused on the problem of dynamic control of an AUV. The primary goal is the development of an AUV flight control system (FCS) that can increase the mission capabilities of an AUV, and that is also robust to varying environments, dynamics, and control element failure.

To demonstrate critical AUV technologies, development was begun in 1985 of the Mobile Undersea Systems Test (MUST) Laboratory (1&2). The MUST vehicle (fig 1) is a modular underwater vehicle capable of serving as an open ocean test platform for a wide range of R&D projects. The baseline vehicle will be 30 feet long, 4.5 feet in diameter, capable of speeds from 0-8 knots, with an operating depth of 2000 feet. MUST will undergo sea trials in late 1988 and early 1989, and then will be available to support government and Martin Marietta R&D programs. The MUST lab will serve as the AUV FCS testbed.

2. INTRODUCTION

Proposed missions for AUV's require that they have a wide range of dynamic maneuvering capabilities. AUV missions will require the vehicle to be capable of tracking complex trajectories omnidirectionally. This includes the ability to operate in regions of high angles of attack (alpha), where the dynamics are highly nonlinear and as yet cannot be predicted with a high degree of accuracy. The application of nonlinear model based control techniques significantly increases AUV capabilities and mission effectiveness. This is because these techniques use all available information about the nonlinear dynamics directly. A single nonlinear controller can be designed that will allow uniform operation over the entire range of dynamics with robust performance and stability guarantees.

3. AUV FLIGHT CONTROL SYSTEM

Introduction

MUST is capable of high speed transit using its control surfaces and main propeller, and hovering near zero speed with its four thrusters and main propeller. In addition there is a third operating region which is not pure transit or hover. This hybrid region we have defined as transition. Transition requires the use of all available force effectors - control surfaces and thrusters. The significant achievement of this IRAD has been the design of a robust FCS for the hover and transition regimes. This FCS allows the AUV to use its full dynamic operating range, thereby increasing its mission capabilities and effectiveness.

In addition a SMC trajectory transit controller was developed in conjunction with the Woods Hole Oceanographic Institute's Deep Submergence Lab (2). The design of the the transit, hover, and transition controllers will be discussed in detail as well as the modelling required for these model based controllers. Two different models were developed and used for the controldesign and testing effort: a 6-DOF constant coefficient nonlinear model valid for alphas to +/- 20 ° for the transit,regime and a 6-DOF nonlinear model valid for all alpha, for the transition and hover regimes.

Sliding Mode Control and Trajectory Tracking

SMC has been proposed for both robotic and air/spacecraft applications (4-7). SMC has excellent robustness, stability, and disturbance rejection properties. SMC has been studied extensively in the Soviet Union over the past twenty years(8). The development of this FCS follows the SMC development of Slotine (9) for robotic applicaitons.

Trajectory Tracking Using SMC

A trajectory for an underwater vehicle defines its position and associated velocity at any instant in time. The use of trajectory tracking controllers allows the path of the vehicle to be explicitly defined and tracked. A sliding surface is a manifold in the phase plane. This surface is chosen to be time varying such that it always contains the commanded states (Fig. 2). The dynamics of the AUV can be represented by scalar equations of the form:

$$\ddot{x}_i(t) = f(X;t) + b(X;t)u(t) \qquad (1)$$

where: $X = (x_i, \dot{x}_i)$ for $(i=1,n)$ = actual state vector
$f(X;t)$ = nonlinear dynamics
$b(X;t)$ =control gain
$u(t)$ =control setting

For simplicity , the subscripts will be dropped.

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The sliding surface for this system can be defined as (9):

$$s = \dot{\tilde{x}} + \lambda \tilde{x} \quad (2)$$

where: $\tilde{x} = x - x_d$

$$\dot{\tilde{x}} = \dot{x} - \dot{x}_d$$

$X_d = (x_d, \dot{x}_d, \ddot{x}_d)$ = desired state vector

Lambda in the context of SMC will determine the bandwidth of the closed loop system (9).

The resulting sliding control law is:

$$u = (-f' - k\,\mathrm{sgn}(s) + \ddot{x}d - \lambda\dot{\tilde{x}}) / b' \quad (3)$$

where: sgn = sign function

k = Time varying feedback gain
b', f' = estimates of nonlinear dynamics

The time varying feedback gain is determined by the level of modelling uncertainty and neglected dynamics and is defined as:

$$|f(X;t) - f'(X;t)| < F(X;t) \quad (4a)$$

$$b = (b_{max} / b_{min})^{1/2} \quad (4b)$$

$$k = b(F + \eta) + (b - 1)\,|-f' + \ddot{x}d - \lambda\dot{\tilde{x}}| \quad (4c)$$

η = positive constant

where: F(X;t)= bound on the additive uncertainty
b= bound on control gain uncertainty
b_{max}, bmin = bounds on b'

The control law (eq. 2) is defined so that the following sliding condition is always satisfied:

$$1/2\, d/dt(s)^2 \leq -\eta |s| \quad (5)$$

The sliding condition ensures that all trajectories not on the sliding surface will tend towards the sliding surface. The objective of SMC is to design a control law such that the system will remain on the sliding surface (S=0) in which case the tracking errors decay exponentially. If the system is not on the sliding surface (Sπ0) then it will be driven back to the sliding surface because the control law has been designed to satisfy the sliding condition (eq 5). The control law has two components. First, there is a component that compensates for the known nonlinear coupled dynamics (f'). Second, there is a feedback component (k) that compensates for model uncertainties or simplifications, disturbances, etc., making the resulting control robust.

The switched control (eq. 3) will cause the system to chatter along the sliding surface at a high frequency as it approaches the desired state. To prevent chattering a thin boundary layer around the sliding surface is defined across which the feedback is interpolated. The uncertainties and disturbances which are used to define the boundary layer thickness are dynamic. Therefore the boundary layer should also be dynamic in order to always fully realize the best tracking performance within the control bandwidth (10). Since the system by definition will always remain inside the boundary layer then some level of tracking performance of the system can be guaranteed. The tracking errors will be bounded. There is a trade-off for SMC between bandwidth, tracking precision and modelling uncertainty (10):

$$\text{Tracking precision} \approx (\text{Bandwidth})^2 * \text{Uncertainty} \quad (6)$$

Hover Control

Hover has been defined as that operating region where the thrusters are used to control the dynamics of the AUV. MUST has five thrusters: two vertical, two lateral, and the main propeller along the long axis of the vehicle. Nominally the hover region is limited by forward speed as the two vertical and horizontal thrusters become ineffective at speeds greater then 1.5-2.0 knots. The thruster arrangement gives MUST the ability to control five degrees of freedom: yaw, pitch, sway, surge, and heave. Roll is the only degree of freedom that cannot be actively controlled. During hover the roll will be passively controlled by the gravity buoyancy separation along the Z-axis. The hover regime is characterized by nonlinear hydrodynamics which cannot be modeled with a great deal of accuracy. This requires the use of nonlinear model based control to meet proposed performance requirements.

Control System Structure

The SMC hover control system that has been designed is a single trajectory controller that is valid for all alpha and all speeds within the hovering region. The sliding surface for each loop has been chosen as in eq. 2 with an additional integral term to eliminate steady state errors.

Commands are issued to the controller in a three dimensional cartesian inertial reference frame. The commands consist of initial and end point positions (X,Y,Z), attitudes (pitch, heading), associated rates, and times at the beginning and end points. One of the major problems in the design of trajectory tracking systems is the generation of suitable trajectories to meet system and operational requirements. This problem is further compounded when required to do this on-line. To address this problem we have come up with a simple, and effective way to generate trajectories on-line. The trajectory generation portion of the controller will be discussed in more detail later. Once the trajectory has been generated in the inertial reference frame it is transformed into the body fixed coordinate system.

The body referenced trajectories are tracked using five single input, single output (SISO) SMC controllers. The dynamics of the system are second order as in eq.1 with the state vector (X) consisting of the vehicle attitude and translational rates, b(X;t) being the gain of the thruster along each DOF, u(t) is the percentage of available static thrust along each DOF. The nonlinear hydrodynamics and inertial effects are reflected in f(X;t) for the body and b(X;t) for the thrusters. The system inertia consisting of inertia and added inertia is a matrix which has been diagonalized for the controller and is included in f ' and b'. The inertial crosscouplings are generally small and are accounted for in the feedback portion of the controller. The thruster arrangement along with the diagonalized inertia matrix allows us to effectively decouple each control loop. Although the resulting SMC system is SISO all crosscouplings between the degrees of freedom are accounted for in the estimates of f ' and b'. The uncertainties and neglected dynamics in the model have been bounded and are included in the SMC feedback.

The controller as described requires full state feedback .The baseline MUST system has only sensors for angular position, and angular rates, and a simple water relative forward speed sensor. A

second hover controller was designed using SMC that only used this partial state information. This second hover controller does not have nearly the performance of the full state feedback hover controller. The second controller is only intended to be used in midwater where precise maneuvering is less of a requirement. When the vehicle is operating in proximity to the bottom in a precision hovering task the full state feedback hover controller must be used. In this mode it is logical for the vehicle to station itself relative to an object on the bottom. To do this MUST will be outfitted with a high frequency acoustic navigation system. This system consists of a set of acoustic transceivers on the vehicle and an acoustic transponder on the bottom. The system, known as SHARPS (Marine Telepresence, Inc.) was originally designed for use by underwater archioligists but has been modified for use in this application. The system operates at 300 KHZ ,thus avoiding the multipath problem, with accuracies of several centimeters.

Control Analysis

The control analysis for the hover region consisted of; determination of lambda(control bandwidth) in eq. (2); tradeoffs between model uncertainties or simplifications and tracking performance; determination of open and closed loop response; sensitivity to time delays ,etc.

In order to analyze the bandwidth of the vehicle as well as the closed loop characteristics, the full nonlinear simulation has been used. The analysis consisted of frequency response analysis of the full nonlinear dynamics. A sine wave of varying amplitude and frequency was input into the command input of one loop at a time. A fourier analysis was done on that particular output state. For a given amplitude several frequencies were run and the results for that amplitude were used to create frequency response diagrams. This frequency analysis can also be used during the at sea testing to evaluate the closed and open loop characteristics of the real vehicle, but more importantly to verify the model and simulation. This kind of real time frequency analysis has been done for flight testing aircraft (12).

Selection of lambda is based primarily on the following:

(1) nonlinear frequency response
(2) digital loop closure constraint
(3) neglected time delays
(4) actuator dynamic response
(5) sensor dynamics
(6) model fidelity (uncertainty)

The open loop frequency response of MUST was determined for the yaw, pitch, surge, and sway loops. The response was generated with one loop open at a time. The other degrees of freedom were run closed loop. These open loop bandwidths give a good estimate of where the closed loop bandwidths (lambda) should be set. The selection of lambda has a significant effect on the sensitivity to parameter uncertainty. The tracking error is inversely proportional to lambda. The sensitivity to parameter uncertainty can be reduced by using a bandwidth that is several times the open loop natural frequency. Extensive parameter sensitivity studies have been conducted with the 6 DOF model to determine the significant parameters.The determined values of lambda are conservative. They will limit the effects of parameter uncertainty yet are below the upper constraints. The vehicle will have the potential for improved tracking by increasing lambda, yet the stability margin will be large and the control activity should not be excessive.

Trajectory Generation

The trajectory generator creates five scalar position functions corresponding to each degree of freedom when a vehicle move is commanded. Each position function must satisfy certain specified end conditions and is subject to velocity, acceleration, and no-overshoot constraints. The no-overshoot constraint is imposed in order to prevent vehicle collisions with obstacles.

The end conditions for each degree of freedom are specified initial and final positions and velocities: pi , pf , vi , and vf. The trajectory generation problem is to determine a position function p(t) with $t \in [0,T]$ such that $p(0)=pi$, $p(T)=pf$, $d/dt(pi)=vi$, and $d/dt(pf)=vf$ and such that velocity, acceleration and no-overshoot constraints are satisfied. The type of scalar trajectory that is used for each degree of freedom is of the form constant acceleration-constant velocity-constant acceleration. A velocity profile corresponding to this type of trajectory is illustrated in fig 3. This profile, of course, reduces to the commonly used trapezoidal profile when the end velocities vi and vf are both zero. When the starting acceleration a and the ending acceleration b are of maximum magnitudes, then this is called a candidate velocity profile, and a trajectory corresponding to such a profile is called a candidate trajectory. Candidate trajectories are important in addressing the trajectory existence problem.

The velocity and acceleration constraints for a scalar trajectory are specified by the parameters vmax, amax, and bmax and can be graphically represented by a constraint polygon in the velocity vs. time plane as illustrated in fig 4 Trajectories are constrained such that:

$$|\dot{p}| \leq vmax,\ |\ddot{p}| \leq amax \text{ for } t \in [0, t') \qquad (7)$$

$$|\dot{p}| \leq bmax \text{ for } t \in (t', T]$$

where: t' = the time at which the constraint boundaries due to the acceleration bounds intersect

An important property for velocity profiles that satisfy the velocity and acceleration constraints is that they must lie within the polygon. In the figure, the maximum velocity for all permissible profiles is labelled vu (in this case vu=vmax) and the minimum velocity is labelled vl (in this case, vl is determined by the acceleration constraint boundaries).

For a candidate velocity profile, it is clear that |a|=amax and |b|=bmax. In addition, once the constant velocity v_c is specified, the candidate velocity profile is determined. A candidate velocity profile is represented by $v_{vc}(t)$ and a corresponding position function is given by:

$$p(t)=pi+\int_0^t v_{vc}(t)\,dt \qquad (8)$$

Now, for a given set of end conditions and velocity and acceleration constraints, it can be shown that there is a unique candidate trajectory, if it exists, that satisfies these end conditions. The candidate trajectory is very useful for the trajectory generation problem because of the following:

(i) If the candidate trajectory does not exist , then there is no other trajectory that satisfies these end conditions and constraints.

(ii) Suppose a candidate trajectory exists that satisfies the specified end conditions and velocity and acceleration constraints. Then, if this trajectory overshoots, then all trajectories that satisfy the end conditions and velocity and acceleration constraints overshoot. The proofs are omitted due to their length.

The trajectory generator first attempts to find scalar trajectories that are candidate trajectories when a move command is given, the corresponding position functions of which would be of the form (eq. 8). If some of the candidate scalar trajectories cannot be found,

then, by virtue of the above two statments, no trajectory exists for the given move command. If all candidate scalar trajectories exist, then these trajectories can be used for the move or other scalar trajectories of the form constant acceleration-constant velocity-constant acceleration may be used provided that the end conditions and constraints are satisfied.

Transition control

In this paper we have distinguished between the hover and transition controller although these will actually only be a single controller. Control of the vehicle in the transition region requires the use of both thrusters and control surfaces. The transition region is important because it will allow the vehicle to operate in the very low speed ranges as will be required to effectively accomplish some proposed missions. The limitations of the transition controller are that the vehicle must operate in a region where the fins can contribute to the total control. Nominally this will require that the fins to operate at alphas less than 45° in both forward and reverse motion. Above 45°, the fins generate little lift. A requirement for transition control is that there is sufficient overlap between the thrusters and fins. The MUST vehicle has little overlap, thus making transition control difficult. For purposes of transiton control development, larger thrusters were modeled.

Control System Structure

The desired control input is determined using a combined control gain, which accounts for the reduced thruster performance and the low lift developed by the fins at low forward speed. This combined gain is then used to apportion how much of the control force is to be developed by each of the thrusters and control surfaces. The input command structure and trajectory generation are the same as in hover mode.

During hover, MUST uses only its four thrusters to provide maneuvering control. As forward speed increases, the thrusters begin to lose effectiveness. When this happens, the controller determines whether the control surfaces can provide sufficient lift to augment the thrusters. If the local angle of attack on the rudder or sternplane is greater than 45 degrees in either forward or reverse motion, the fins are not used for control. If the angle is less than 45 degrees, the fins are commanded to move to a deflection angle that provides the required force, assuming it is achievable. Once the fins have been deflected, the controller will first check to see whether the fins can produce sufficient control force, and will reduce the thruster command if possible. This logic provides a smooth transition from using only the thrusters to using only the control surfaces for maneuvering control. The uncertainties and neglected dynamics in the model have been bounded and are included in the SMC feedback.

Transi controlt

The transit mode for the MUST vehicle consists of forward motion at speeds greater than 2 ft/sec. The vehicle is controlled in this region by four independently actuated tail fins each with a 60 degree range of motion. The thrusters are not used for control. Forces along the X-axis are supplied by the main motor. In the transit mode, the vehicle states that are controlled are depth, pitch, pitch rate, heading, heading rate, forward speed, and roll angle.

Control System Structure

Depth control is achieved with an outer depth guidance loop supplying a pitch command to an inner pitch angle control loop. The measured states are u, q, and theta. W is estimated from the depth rate and vehicle attitude. The commanded pitch angle and pitch rate are functions of the desired depth, depth rate, depth acceleration and forward speed. The sliding surface is first order in terms of pitch rate error and pitch attitude error. The sliding surface is defined the same as in eq 3 with an integral term added to eliminate steady state errors. The control law resulting from these assumptions takes the same form as eqs 2 & 3 where b(X;t) is the gain per degree of sternplane deflection, and u (t) is the sternplane deflection.

The estimation of the pitch forces and moments is based on a low alpha coefficient model of the vehicle dynamics (3). This is adequate because the vehicle will be operating in a low alpha region where constant coefficient models are valid.

Alternate control structures such as control from depth to sternplane were tried but have significant drawbacks such as requiring the measurement of acceleration(2). The depth to sternplane dynamics are nonminimum phase so blindly applying SMC will make the system unstable. This can be easily remedied by neglecting the nonminimum portion of the depth dynamics in the computation of f ′ in the control law.These dynamics would be bounded and included in the feedback gain.

Closed loop control of heading is accomplished in a similar manner to the inner pitch loop. Commanded yaw angle and yaw rate are functions of the desired track. The measured states are u , psi and r. The sliding surface is composed of yaw rate errors and heading angle errors. The control law takes the same form as the longitudinal equation with b(X;t) defined as the control gain of the rudder, and the other terms correspond to yaw control.

Control Analysis

Determination of transit control parameters is analagous to the hover analysis. The same characteristics must be examined about speeds of 2 to 8 knots. The primary complication is that the frequency response becomes a function of forward speed. The nonlinear simulation has been the final analysis tool for traditional checks such as parameter sensitivity, stability margin, frequency response and expected transient response.

Vehicle Dynamic Model

The nonlinear model based controller being developed for MUST required the inclusion of a hydrodynamic model in its algorithms. Accordingly, a model of the MUST vehicle dynamics was developed which is valid for all alpha(3), which can accurately model highly nonlinear maneuvers such as are seen during hover. A detailed model of the thruster dynamics is included in the model, as are representative models of the vehicle sensors and actuators. These models comprise the AUV simulation that is being used as part of the MUST lab development.

The hydrodynamic model is based upon body-buildup techniques and relies on semi-empirical methods for the prediction of forces and moments. The model computes the forces and moments of each component individually, and then sums them together with interference effects to form the total forces and moments. The advantage to this approach is that fluid phenomena such as stall or vortex shedding can be properly modeled. The thruster model splits the developed thruster forces into four components, two related to the open water characteristics of the thruster, and two representing the degradation of thrust due to vehicle motion. These motion interference effects can be substantial, especially for forward speed. The sensor models include the effects of threshold, limits, and random noise. The control surfaces are modeled as second order systems with deadband, voltage and slew rate limits, hysteresis, friction, and hydrodynamic loading.

Results

The design of the hover and transit FCS have been completed and are being integrated into the MUST vehicle. For purposes of control validation the controllers have been run in the full AUV nonlinear

simulation. This has allowed for various sensitivity studies to be conducted.

To show the capability of the FCS, typical hover and transit maneuvers have been selected. Figure 5 shows a hover maneuver where the vehicle is moving around an object while staying pointed at the object. This would be a maneuver required to do some close up inspection with a forward looking sensor. Figures 6&7 show the resulting tracking errors throughout this maneuver. These plots show the robustness of the SMC FCS because the model used in the control design has underestimated all forces, inertias, and control gains by 50%.

A sample transit which consists of a low speed turn of 90 degrees coupled with a 100 foot depth change. The resulting tracking error in heading is shown in fig 8 , and for depth in fig 9. The performance of the transit controller is comparable to a linear gain scheduled controller. The advantage is that the SMC transit system is a single controller with specific stability and robustness guarantees. In addition the performance should be more consistent with a single controller over the entire speed range.

4. CONCLUSION

The use of SMC for the development of AUV flight control systems provides increased system capabilities and mission effectiveness. A SMC FCS has been designed for an AUV testbed being built at Martin Marietta Aero & Naval Systems. The goal is to take this FCS to sea and fully explore and document its capabilities. To date the SMC FCS system has shown excellent performance in all operating regimes and at all angles of attack This performance has been verified through the use of a high fidelity 6-DOF simulation that accounts for dynamic and hardware nonlinearities.

References

1.Herr,W.J., Collins,K., "MUST, A Large Versatile AUV Technology Testbed System," Underseas Defense '87, San Diego Ca., Oct. 1987

2.Herr, W.J., " AUV Technology, Development and Demonstration Program," OCEANS '88, Baltimore , Md., Oct. 1988.

3.Dougherty, F., Sherman, T., Woolweaver,G., "Modeling and Simulation of an AUV," Modeling and Simulation Symposium at C.S. Draper Labs, Cambridge, Mass, June 1988.

4.Stalford, H., Garrett, F., "Robust Nonlinear Control for High Angle of Attack Flight," AIAA 25th Aerospace Sciences Meeting, Reno, NV, January 1987.

5.Vidyasagar, M., Sprong, M., "Robust Linear Compensator Design for Nonlinear Robotic Control," IEEE Transactions on Automatic Control, Vol RA-3, No. 4, pp. 345-351.

6.Yoerger, D., et al., "Robust Trajectory Control of Underwater Vehicles," Proceedings of the Fourth International Symposium on Unmanned, Untethered Vehicle Technology, Durham NH, June 1985.

7.Slotine, J-J., "Robust Control of Robot Manipulators," Journal of Robotics Research, Vol. 4, No. 2, 1985.

8.Utkin, V. , "Variable Structure Systems: Present & Future," Automation and Remote Control, February 1984.

9.Slotine, J-J., "Tracking Control of Nonlinear Systems Using Sliding Surfaces," PhD Thesis, MIT Dept. of Astronautics and Aeronautics, Cambridge, MA, May 1983.

10.Asada, H., Slotine, J-J., Robot Analysis and Control, New York, NY, John Wiley Sons, 1986.

11.J. Gera, J.T. Bosworth, "Dynamic Stability and Handling Qualities Tests on a Highly Augmented, Statically Unstable Airplane," Guidance and Navigation Conference, Monterey, CA, 1988.

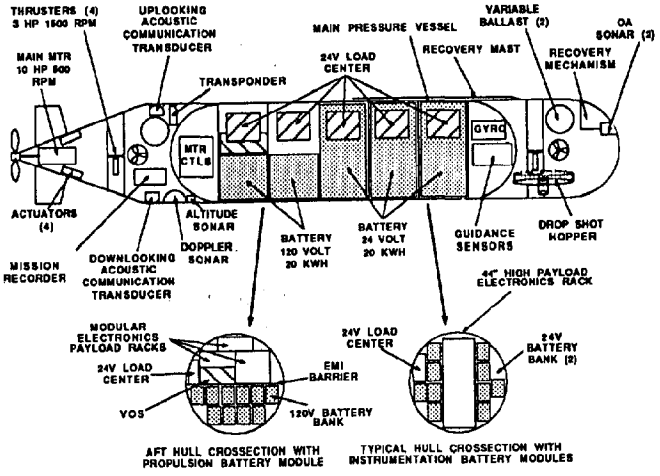

FIGURE 1. MUST VEHICLE

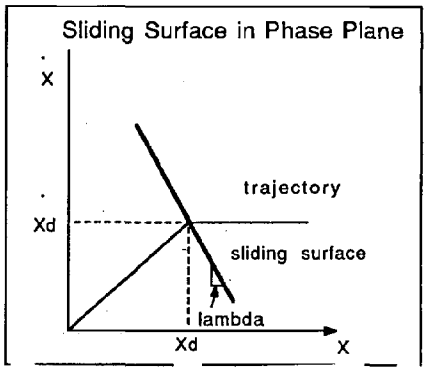

FIGURE 2. SLIDING SURFACE

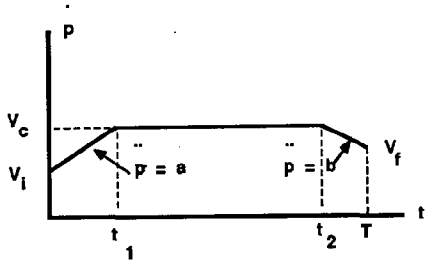

FIGURE 3. CONSTANT ACCELERATION - CONSTANT VELOCITY-CONSTANT ACCELERATION

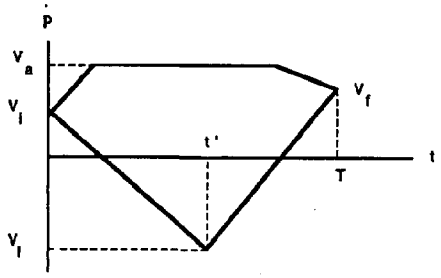

FIGURE 4. CONSTRAINT POLYGON

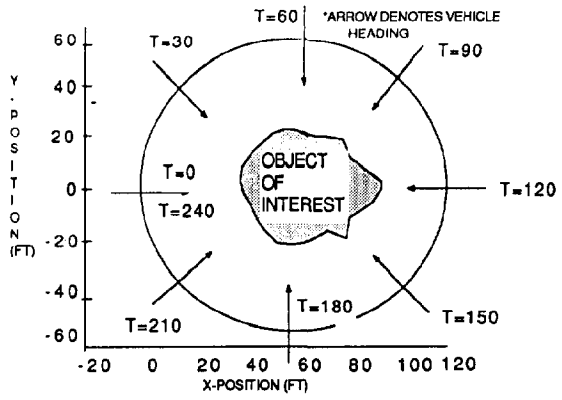

FIGURE 5. SAMPLE HOVER MANEUVER

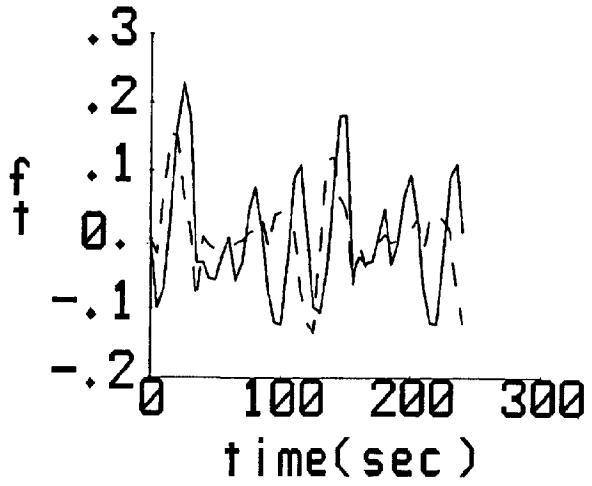

FIGURE 6. ERRORS IN TRANSLATION FOR HOVER MANEUVER

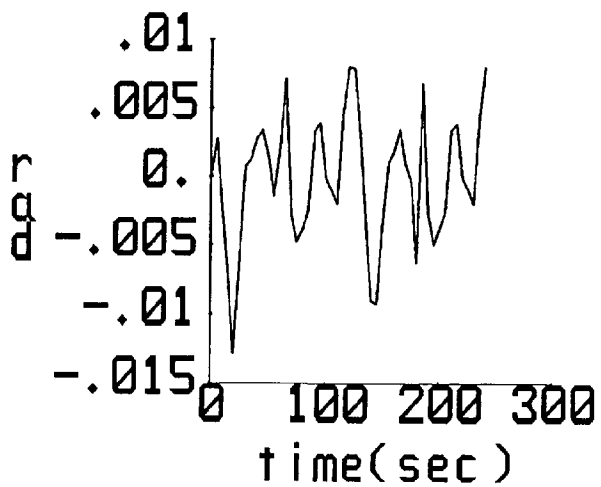

FIGURE 7. ERRORS IN HEADING FOR HOVER MANEUVER

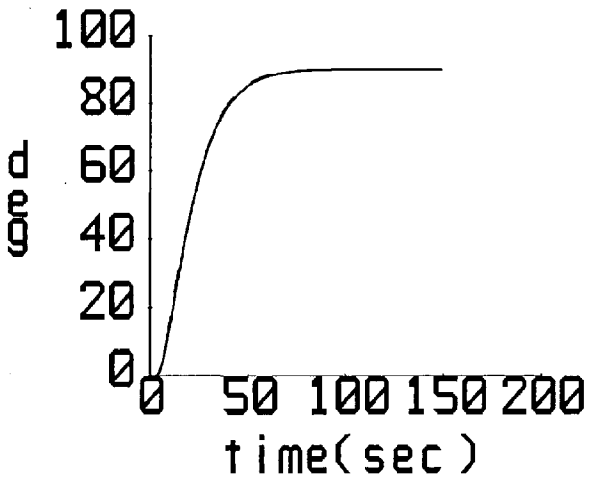

FIGURE 8. HEADING AND HEADING COMMAND VS. TIME FOR A TRANSIT COURSE CHANGE

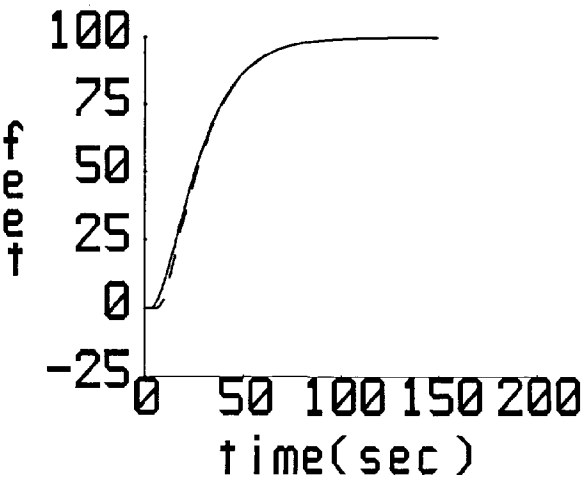

FIGURE 9. DEPTH AND DEPTH COMMAND VS. TIME FOR A TRANSIT DIVE

THERMAL MODELLING OF ELECTRO-MECHANICAL CABLES FOR ROV APPLICATIONS

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ABSTRACT

A method for predicting the steady-state and transient temperature distributions for electro-mechanical cable reels is shown. A generalized, finite difference analysis technique is introduced which generates two-dimensional steady-state solutions and one-dimensional transient solutions for cable temperatures. The method allows a variable number of layers, turns per layer, cooling methods, cable resistive heating levels, and ambient conditions. The paper includes an example application of the model to an ROV umbilical cable.

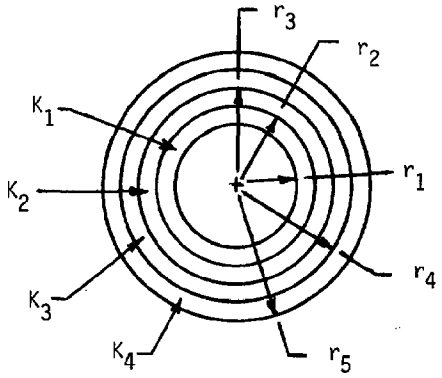
NOMENCLATURE

Cable Characteristics
- K_1: Thermal conductivity of conductor insulation
- K_2: Thermal conductivity of inner sheath material
- K_3: Thermal conductivity of strength member material
- K_4: Thermal conductivity of outer sheath material
- r_1: Electrical core radius
- r_2: Inside radius of inner sheath
- r_3: Outside radius of inner sheath
- r_4: Outside radius of strength member
- r_5: Outside radius of cable
- $\dot{E}g$: Resistive heating loss from cable

Interstitial Space Characteristics
- C : Fractional contact area between adjacent cables
- C_f: Fractional contact area at the drum flange surface
- K_{INT}: Thermal conductivity of interstitial medium
- X_{INT}: Mean thickness of interstitial gap

Reel Characteristics
- X_f: Thickness of reel flange
- X_R: Thickness of reel
- K_R: Thermal conductivity of drum reel material

Figure 1: Cross-section of an electro-mechanical cable with an inner and outer sheath, a strength member, and electrical conductor insulation.



Ambient Conditions
- t_∞ : Ambient temperature
- h_i : Convective heat transfer coefficient on inside of drum reel
- h_o : Convective heat transfer coefficient on outside of drum reel
- h_f : Convective heat transfer coefficient on drum flange surfaces

INTRODUCTION

Recent trends in the ROV industry have been toward deeper and more powerful vehicles. Because of the critical role of the umbilical cable in these systems, efforts have been made to optimize cable design and reduce cable diameter. Unfortunately, the design goals of more power and smaller cable diameter can lead to cables with a high resistive heat loss. If the vehicle is operated with a significant quantity of cable wrapped on the winch drum, overheating and cable damage may occur. Because of a large variety of cable types and operational conditions, rules-of-thumb should be used with caution. Experience with double-armored cables and low resistive heat loss may not be appropriate for KEVLAR-reinforced cables with high heat loss.

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This paper describes a computer model developed to evaluate overheating concerns and to assist in cable design. A generalized, finite difference analysis technique is used which provides two-dimensional solutions for cable reels having a variable number of layers, turns per layer, cooling methods, cable resistive heating levels, and ambient conditions. The analysis technique is particularly beneficial in conducting cable sensitivity analyses, which identify the critical design and environmental parameters related to cable core temperature. The approach provides greater accuracy and versatility than a simple closed-form solution, and helps the designer to specify acceptable cable designs.

EFFECTIVE THERMAL CONDUCTIVITY

For modelling purposes, the cable central core is assumed to be surrounded by a homogeneous material having an effective thermal resistance equal to the sum of the resistances of each layer. Based on the core surface area shown in Figure 1, this can be written in cylindrical coordinates

$$\sum \text{Resistance} = R_{IN} + R_{IS} + R_{SM} + R_{OS}$$

where

$$R_{IN} = \text{Insulation resistance} = \frac{r_1}{K_1} \ln \frac{r_2}{r_1}$$

$$R_{IS} = \text{Inner sheath resist} = \frac{r_1}{K_2} \ln \frac{r_3}{r_2}$$

$$R_{SM} = \text{Strength member resist} = \frac{r_1}{K_3} \ln \frac{r_4}{r_3}$$

$$R_{OS} = \text{Outer sheath resist} = \frac{r_1}{K_4} \ln \frac{r_5}{r_4}$$

The sum of the resistances can be equated to an overall resistance based on an effective thermal conductivity of the composite to give

$$K_{EFF} = \ln \frac{r_5}{r_1} \Bigg/ \left[\frac{1}{K_1} \ln \frac{r_2}{r_1} + \frac{1}{K_2} \ln \frac{r_3}{r_2} + \frac{1}{K_3} \ln \frac{r_4}{r_3} + \frac{1}{K_4} \ln \frac{r_5}{r_4} \right]$$

where

K_{EFF} is the effective thermal conductivity of the cable composite

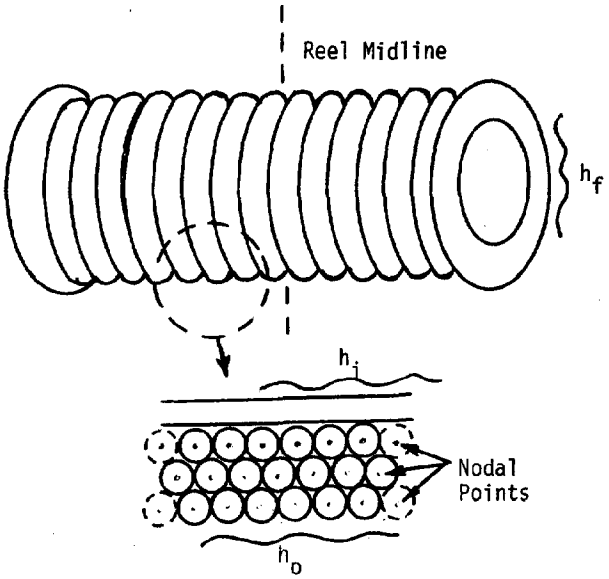


Figure 2: Sketch of cable reel showing cable stacking arrangement and cooling paths.

STEADY-STATE MODEL

When wound onto the drum reel as shown in Figure 2, heat is conducted between cable layers. Excess heat is ultimately dissipated through convective cooling on the inside of the drum reel, characterized by convective heat transfer coefficient h_i; at the outside cable layer surface, characterized by h_o; and at the exposed drum flange surfaces, characterized by h_f. All Convective heat transfer coefficients were calculated assuming natural convection (a worst case).

For modelling purposes, nodal point locations are defined at the core of each cable composite. Due to the presumed symmetry of the cable stack about the drum midline, only one-half of the drum is analyzed.

Following the conduction through the cable composite, heat travels to adjacent cables through direct contact with neighboring walls and by conduction through air in the interstitial spaces, as shown in Figure 3. Heat conduction through cable contact can be approximated (between nodes m,n and m,n+1) as

$$q_{n,n+1} = K_{EFF}\, C\, \Delta Z \frac{t_{m,n} - t_{m,n+1}}{\Delta X - 2 r_1}$$

where

C is the fractional contact area ratio between cables

$t_{m,n}$ is the core temperature at node m,n

$\Delta X, \Delta Z$ equal the outside cable diameter

For heat transfer through the interstitial spaces, we assumed an average space thickness exists for the region not in contact with the adjacent cables. The heat transfer through this interstitial space will be written

$$q'_{n,n+1} = K'_{EFF}(1-C)\,\Delta Z\,\frac{t_{m,n}-t_{m,n+1}}{\Delta X - 2\,r_1}$$

where

K'_{EFF} is an effective thermal cond of the flow path including the interstitial space

With these definitions, an energy balance was written for each node of an N x M system of nodes (N is the number of layers on the reel; M is the number of turns). Appendix A summarizes the nodal equations resulting from this energy balance at various positions on the cable reel. A sample application of this set of equations for a reel having 4 cable layers and 8 turns per layer, resulting in a 4 x 4 system of nodes (a symmetrical temperature distribution about the reel midline is assumed) is shown in Figure 4. A Fortran program was written to solve this set of nodal equations to obtain the steady-state temperature distribution on the winch drum during prescribed operational conditions.

FIGURE 4: MATRIX REPRESENTATION FOR 4 X 4 SYSTEM

$$\begin{bmatrix} 2+H/K & -1 & 0 & 0 & -1 & & & & & & & & & & & \\ -1 & 3 & -1 & 0 & 0 & -1 & & & & & & & & & & \\ 0 & -1 & 3 & -1 & 0 & 0 & -1 & & & & & & & & & \\ 0 & 0 & -1 & 2+\frac{hoeAZ}{K} & 0 & 0 & 0 & -1 & & & & & & & & \\ -1 & 0 & 0 & 0 & 3+H/K & -1 & 0 & 0 & -1 & & & & & & & \\ & -1 & 0 & 0 & -1 & 4 & -1 & 0 & 0 & -1 & & & & & & \\ & & -1 & 0 & 0 & -1 & 4 & -1 & 0 & 0 & -1 & & & & & \\ & & & -1 & 0 & 0 & -1 & 3+\frac{hoeAZ}{K} & 0 & 0 & 0 & -1 & & & & \\ & & & & -1 & 0 & 0 & 0 & 3+H/K & -1 & 0 & 0 & -1 & & & \\ & & & & & -1 & 0 & 0 & -1 & 4 & -1 & 0 & 0 & -1 & & \\ & & & & & & -1 & 0 & 0 & -1 & 4 & -1 & 0 & 0 & -1 & \\ & & & & & & & -1 & 0 & 0 & -1 & 3+\frac{hoeAZ}{K} & 0 & 0 & 0 & -1 \\ & & & & & & & & -1 & 0 & 0 & 0 & 2+\frac{Hf+Hf}{K} & -1 & 0 & 0 \\ & & & & & & & & & -1 & 0 & 0 & -1 & 3+Hf/K & -1 & 0 \\ & & & & & & & & & & -1 & 0 & 0 & -1 & 3+Hf/K & -1 \\ & & & & & & & & & & & -1 & 0 & 0 & -1 & 2+\frac{Hf+hoeAZ}{K} \end{bmatrix} \begin{bmatrix} t_{11} \\ t_{12} \\ t_{13} \\ t_{14} \\ t_{21} \\ t_{22} \\ t_{23} \\ t_{24} \\ t_{31} \\ t_{32} \\ t_{33} \\ t_{34} \\ t_{41} \\ t_{42} \\ t_{43} \\ t_{44} \end{bmatrix} = \begin{bmatrix} (\dot{E}g_{11}+Ht_\infty)/K \\ \dot{E}g_{12}/K \\ \dot{E}g_{13}/K \\ (\dot{E}g_{14}+hoeAZt_\infty)/K \\ (\dot{E}g_{21}+Ht_\infty)/K \\ \dot{E}g_{22}/K \\ \dot{E}g_{23}/K \\ (\dot{E}g_{24}+hoeAZt_\infty)/K \\ (\dot{E}g_{31}+Ht_\infty)/K \\ \dot{E}g_{32}/K \\ \dot{E}g_{33}/K \\ (\dot{E}g_{34}+hoeAZt_\infty)/K \\ (\dot{E}g_{41}+(H+Hf)t_\infty)/K \\ (\dot{E}g_{42}+Hft_\infty)/K \\ (\dot{E}g_{43}+Hft_\infty)/K \\ (\dot{E}g_{44}+(Hf+hoeAZ)t_\infty)/K \end{bmatrix}$$

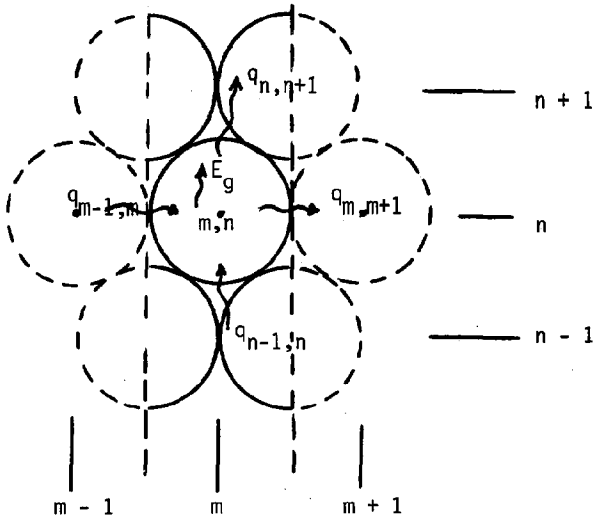


Figure 3: Heat transfer between adjacent cables via direct cable contact and through the interstitial air gaps.

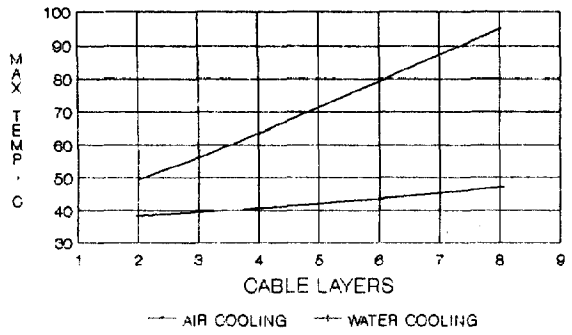
TRANSIENT ANALYSIS

A solution for the transient thermal behavior of an electro-mechanical cable reel was also developed. This solution was originally developed as a means to validate the steady-state analysis described above. An initial transient model used homogeneous boundary conditions (the temperature at the reel boundaries was assumed to be equal to the surrounding ambient temperature), which made an analytical solution manageable.

The utility of this simplified transient model highlighted the benefits of having a complementary transient analysis technique to be used with the steady-state model. In a later effort, an analytical solution was first attempted with convective boundary conditions. These conditions resulted in the solution of a nonhomogeneous differential equation with nonhomogeneous boundary conditions. Initial attempts at solving this problem analytically resulted in failure.

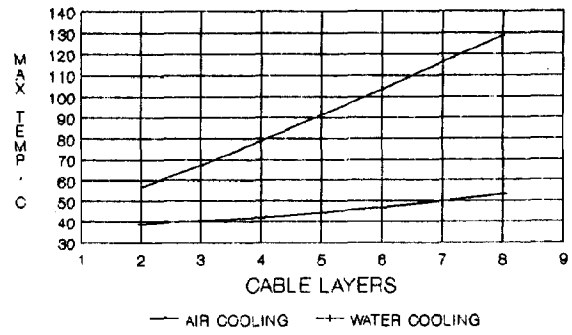
Although not described in detail in this paper, a successful numerical solution was developed using finite difference techniques. This solution uses the Crank-Nicolson algorithm for approximating the temperature derivative within the reel [1]. Good agreement is seen between the maximum temperatures predicted by the transient model and the temperatures predicted by the above steady-state model at the drum midline.

Figure 5:Max Cable Temperature
Resistive Heating Level: 1.15 W/M



KEFF=0.367 W/M-C, Ambient Temp=37.8 C

Figure 6:Max Cable Temperature
Resistive Heating Level: 1.84 W/M

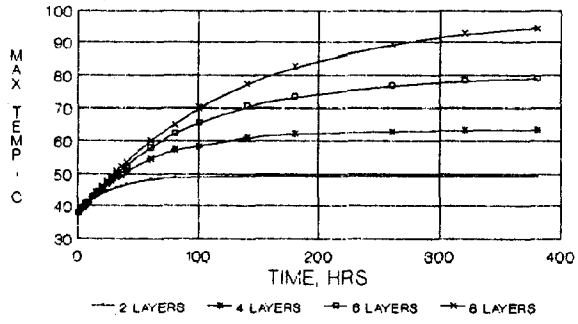


KEFF=0.367 W/M-C, Ambient Temp=37.8 C

SAMPLE ANALYSIS

Figures 5 and 6 demonstrate the application of this analysis technique to predict maximum steady-state cable temperatures on a sample winch drum with two resistive heating levels. Note that the maximum temperature occurs at an intermediate layer on the drum. In these examples the Gemini ROV cable was analyzed. As would be expected, cable temperatures will increase as more cable layers are wrapped on the winch drum. Cable temperatures exceeding recommended operational temperatures of 82 degrees Celsius are seen when more than 6 layers of cable are on the drum at the lower heating level, and when more than 4 layers of cable are on the drum at the higher heating level. Using water cooling methods, acceptable operational temperatures are predicted for more than eight layers at both power levels. Additionally, the transient behavior of cables can be simulated to identify worst-case time constraints for operating vehicles at high power levels. Figures 7 and 8 demonstrate that cable failure can be avoided even at high resistive heating levels for many jobs that do not require continuous around-the-clock operations. Figure 6 shows that maximum temperatures can approach 130 degrees Celsius when 8 layers of the Gemini cable are wrapped on the winch drum and operated at the higher resistive heating level. However, Figure 8 indicates that it will take in excess of 400 continuous hours of operation to reach this level. Additionally, Figure 8 shows that the Gemini cable should perform successfully for up to 75 hours under these severe conditions before the recommended design limit of 82 degrees Celsius is reached.

Figure 7: Transient Response
Resistive Heating Level: 1.15 W/M



K(On Reel)=0.567 W/M-C, Alpha=2.36SQCM/HR

The sample analysis described above is only one way in which the cable thermal model can be used. Existing cable designs can be evaluated with this model to determine the chances for mission success under specific vehicle requirements, or to help establish the acceptable operational envelopes for that vehicle. Alternative cooling methods for the drum reel can be investigated. But perhaps the most value from this model is seen in helping the cable designer to specify acceptable thermal properties for new cable composites. In so doing, new cable designs can be developed to power advanced ROV's during prolonged missions without overheating or cable damage.

REFERENCES

1. Myers, G.E., "Analytical Methods in Conduction Heat Transfer", McGraw-Hill, New York, 1971.

APPENDIX A

NODAL EQUATIONS FOR STEADY-STATE MODEL

General Equation

$$-t_{m-1,n} - t_{m,n-1} + 4\,t_{m,n} - t_{m,n+1} - t_{m+1,n} = \frac{\dot{E}g_{m,n}}{K}$$

Boundary Conditions

1) Outside (n = N)

$$-t_{m-1,N} - t_{m,N-1} + \left(3 + \frac{hoe\Delta Z}{K}\right) t_{m,N} - t_{m+1,N} = \frac{\dot{E}g_{m,N} + hoe\Delta Z\, t_{\infty}}{K}$$

2) Inside Boundary (n = 1)

$$-t_{m-1,1} + (3 + H/K)\, t_{m,1} - t_{m,2} - t_{m+1,1} = \frac{\dot{E}g_{m,1} + H\, t_{\infty}}{K}$$

3) Reel Flange (m=M)

$$-t_{M-1,n} - t_{M,n-1} + (3 + H_f/K)\, t_{M,n} - t_{M,n+1} = \frac{\dot{E}g_{M,n} + H_f t_{\infty}}{K}$$

4) Reel Midline (m=1)

$$-t_{1,n-1} + 3\,t_{1,n} - t_{1,n+1} - t_{2,n} = \frac{\dot{E}g_{1,n}}{K}$$

5) Node 1,1

$$-t_{1,2} + (2 + H/K)\, t_{1,1} - t_{2,1} = \frac{\dot{E}g_{1,1} + H\, t_{\infty}}{K}$$

6) Node M,1

$$-t_{M-1,1} + \left(2 + \frac{H+H_f}{K}\right) t_{M,1} - t_{M,2} = \frac{\dot{E}g_{M,1} + (H+H_f)\, t_{\infty}}{K}$$

7) Node M,N

$$-t_{M-1,N} + \left(2 + \frac{H_f + hoe\Delta Z}{K}\right) t_{M,N} - t_{M,N-1} = \frac{\dot{E}g_{M,N} + (H_f + hoe\Delta Z)\, t_{\infty}}{K}$$

8) Node 1,N

$$-t_{1,N-1} + \left(2 + \frac{hoe\Delta Z}{K}\right) t_{1,N} - t_{2,N} = \frac{\dot{E}g_{1,N} + hoe\Delta Z\, t_{\infty}}{K}$$

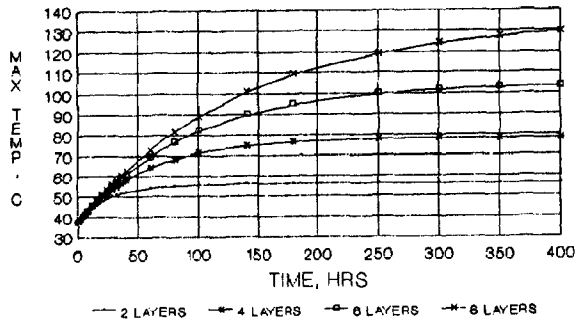
DEFINITIONS

$$K_{EFF} = \ln\frac{r_5}{r_1} \Big/ \left[\frac{1}{K_1}\ln\frac{r_2}{r_1} + \frac{1}{K_2}\ln\frac{r_3}{r_2} + \frac{1}{K_3}\ln\frac{r_4}{r_3} + \frac{1}{K_4}\ln\frac{r_5}{r_4}\right]$$

$$K'_{EFF} = 2(r_5 - r_1) \Big/ \left[\frac{X_{INT}}{K_{INT}} + \frac{2(r_5 - r_1) - X_{INT}}{K_{EFF}}\right]$$

$$K = [\, K_{EFF}\, C + K'_{EFF}\, (1-C)] \,/\, (1 - r_1/r_5)$$

Figure 8: Transient Response
Resistive Heating Level: 1.84 W/M



K(On Reel)=0.587 W/M-C,Alpha=2.36SQCM/HR

$$h_{oe} = \frac{1}{1/ho + (r_5 - r_1)/K_{EFF}}$$

$$h_{ie} = \frac{1}{1/hi + X_R/K_R + (r_5 - r_1)/K_{EFF}}$$

$$h'_{ie} = \frac{1}{1/hi + X_R/K_R + X_{INT}/2K_{INT} + [(r_5 - r_1) - X_{INT}/2]/K_{EFF}}$$

$$H = h_{ie}\, C\, \Delta Z + h'_{ie}\, (1-C)\Delta Z$$

$$h_{fe} = \frac{1}{1/h_f + X_f/K_R + (r_5 - r_1)/K_{EFF}}$$

$$h'_{fe} = \frac{1}{1/h_f + X_f/K_R + X_{INT}/2K_{INT} + [(r_5 - r_1) - X_{INT}/2]/K_{EFF}}$$

$$H_f = h_{fe}\, C_f \Delta X + h'_{fe}\, (1 - C_f)\Delta X$$

$\dot{E}g_{m,n}$ is the resistive heating loss from the cable core, watts/ft

A LISP ENVIRONMENT FOR REAL-TIME OCEAN SYSTEMS

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ABSTRACT

There is a constant demand for increased capabilities and intelligence in underwater autonomous vehicles and ocean instrumentation. One way to implement these new capabilities is through symbolic processing systems which use the LISP language and its extensions. A previous hindrance to placing LISP in real-time ocean systems was due to poor performance, large memory requirement, and virtual implementations of LISP.

This paper describes a unique system which integrates a high performance LISP environment and a real-time operating system, PSOS. High level tasks can be written in Common LISP and Flavors and controlled by the real-time operating system. This system executes on a single VME bus board with a 32 bit CPU and 4 megabytes of memory. Successful field tests were conducted on the EAVE autonomous vehicle which performed simple vehicle path planning.

1. INTRODUCTION

Over the past ten years the focus at MSEL has been to develop intelligent ocean systems which effectively deal with the environment, unexpected events, and time constraints. The continuing research program, EAVE (Experimental Autonomous VEhicle), has been the testing ground for autonomous underwater systems. Since the vehicle is completely autonomous, all intelligence must be placed on board. Current directions include a knowledge-based system for guidance, control and mission planning. As the need for more capable ocean systems grows, the importance of symbolic processing to emulate some intelligent behavior becomes vital [1,2].

The goal of AI research over the past 25 years has been to develop programming approaches and algorithms which more closely approximate intelligent behavior, i.e., have greater symbolic reasoning. Throughout this time LISP has been used extensively as the implementation language because of its symbolic processing capabilities [3]. Another reason why LISP is an appropriate choice for knowledge-based systems and expert systems is that it is interpreted and allows fast prototyping. A unique feature of the language is that both functions and data are represented in the same way, namely, "s-expressions". This similar representation enables functions and data to be handled by the same mechanisms: this enables functions to modify the knowledge base by creating new functions. The implementation of expert systems with LISP is made simpler by the availability of object-oriented programming.

In the past several incompatible dialects of LISP were used. The recent development of Common LISP is aimed at increased portability and consistency of applications. Presently, Common LISP is running on myriads of computers from PCs to mainframes, and expert systems build tools are available for all these environments. The advantage of Common LISP is further increased by the introduction of Common LOOPS, a compatible object-oriented programming package.

As expert systems and symbolic processing capabilities continue to enter the domain of real-time reasoning and control, new methodologies to deal with time constraints must be developed. Previous work in this area has produced some useful techniques, but there are no widely accepted procedures for the design of real-time expert systems. The testing and development tools available at MSEL include the two languages, Common LISP and Standard LISP, and the object-oriented programming package, Flavors, running on a conventional real-time operating system, PSOS [4]. PSOS is a product of Software Components Group.

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The techniques used in this work exploit the connection between a real-time operating system, PSOS, and a multitasking LISP environment. The event driven capability of PSOS is needed in a real-time knowledge-based system. This will allow knowledge sources to be triggered asynchronously and executed in a fixed time domain. This combination enables LISP tasks to use the same event mechanism, message passing and signaling as C tasks. In addition, the priority feature can be used to schedule tasks or knowledge sources for a given context or emergency condition.

The ability for applications written in C and LISP to communicate through PSOS interprocess communication primitives has two important functions. Most importantly, this provides a foundation on which to implement the symbolic to numeric interface. The second purpose enhances system performance. Since symbolic and numeric tasks can exchange information, device interfaces and numeric processing may be done more efficiently in C with results being passed to tasks in LISP.

2. SYSTEM DESCRIPTION

The system architecture of the MSEL EAVE vehicle is a hierarchical control system shown in Figure 1; this is used as a framework for knowledge-based systems development [5]. It is implemented with four 32 bit microprocessors (Motorola 68020) operating on the industry standard VME bus (Ironics IV-3201 and IV-3204). These processors communicate with 68000 based sensor and effector manager processing systems through an intelligent serial I/O controller. The four upper level modules communicate over the VME bus through dual port memory which uses mailbox interrupts to enhance message throughput.

The Supervisor module shown in Figure 1 is a rule-based planner which will accept real-time inputs to plan a new path. Since this is implemented as a rule-based system, symbolic processing capabilities are necessary at that level [6]. A comparison of the software architectures of the symbolic and numeric systems is shown in Figure 2. The Supervisor module which utilizes symbolic processing is shown on the right of Figure 2. It is important to note the similarity between the symbolic and numeric architectures in Figure 2; these similarities make the communication and control between C and LISP tasks possible. The only difference between the two architectures is:

LISP application -- planner
LISP environment
LISP to PSOS interface

The LISP environment is a result of a multi-year research program at the University of Utah on high performance portable LISP systems [7]. This package was purchased and ported to the Ironics Performer 32 VME development system running Unisoft Unix System V.2. Since the operating system in EAVE is PSOS, it was necessary to port the LISP environment to PSOS. This was accomplished by designing a PSOS to Unix interface for the LISP kernel; this allows the LISP system to make PSOS system calls for I/O and control. One portion of the interface is spawned by the root task on system initialization and remaps all Unix systems calls to PSOS. The other function of the interface provides parameter passing compatibility with PSOS for each system call. This environment, plus interface and PSOS, occupied about 600 Kbytes with additional memory required for LISP heap space.

3. RESULTS

In the fall of 1987 successful field tests were conducted on EAVE [8]. A mission was programmed to detect submerged barrels with acoustic sensors and plan a new path. The sensor processing functions of the low level vehicle detected a barrel and sent a message to the planner module through the I/O controller. The goal of the planner was to interrupt the currently executing path and generate a new path near the barrel; in addition, a video camera and lights were activated by the vehicle to photograph the barrel. Once the exception path was completed, the normal survey continued. In this test the planner used had a simple algorithmic design, yet written in LISP. The importance of this demonstration is the fact that a LISP environment was placed in an autonomous underwater vehicle for the first time.

4. CONCLUSION

As expert systems and symbolic processing capabilities continue to enter the domain of real-time reasoning and control, new methodologies to deal with time constraints must be developed. The unique symbolic development environment at MSEL is a tool for development and testing of concepts as well as a run time system for working underwater autonomous vehicle. This system will be used to implement a new symbolic processing operating system which will be the foundation for current and future development in intelligent time constrained systems. The system described in this brief paper utilizes the framework of a conventional real-time operating system to provide a novel solution to this important problem.

It is recognized that future efforts in the design of real-time symbolic systems requires work in the following areas:

- Intelligent Scheduling Algorithms
- Rule-Base Design Applicable to Real-Time Applications
- Understanding Impact of Garbage Collection on Performance
- Computer Architecture to Real-Time Applications
- Low Latency Communication Protocols

5. REFERENCES

1. Russel, G.M. and Lane, D.M., "A Knowledge-Based System Framework for Environment Perception in a Subsea Robotics Context", IEEE Journal of Oceanic Engineering, July 1986, pp. 401-412.

2. Kaisler, Stephen, "Expert Systems: An Overview", IEEE Journal of Oceanic Engineering, Vol. OE-11, No. 4, Oct. 1986, pp. 442-448.

3. Kaisler, Stephen, "LISP: An AI Programming Language", IEEE Journal of Oceanic Engineering", Vol. OE-11, No. 4, Oct. 1986, pp. 468-473.

4. Shevenell, Michael P., "Hardware and Software Architectures for Realizing a Knowledge-Based System on EAVE", Fifth International Symposium on Unmanned Untethered Submersible Technology, June 1987, University of New Hampshire, pp. 220-237.

5. Blidberg, D. Richard., "Time-Ordered Architecture for Knowledge-Based Guidance of an Unmanned Untethered Submersible", Oceans 84 Conference Record, Sponsored by MTS/IEEE, Sept. 1984, pp. 571-575.

6. Chappell, Steven G., "A Blackboard-Based System for Context Sensitive Mission Planning in an Autonomous Vehicle", Fifth International Symposium on Unmanned Untethered Submersible Technology, June 1987, University of New Hampshire, pp. 467-476.

7. Griss, Martin L., Benson, Eric and Maquire, Gerald O., "PSL: A Portable LISP System", 1982 ACM Symposium on LISP and Functional Programming, Pittsburg, PA.

8. "Intelligent Control for Multiple Autonomous Undersea Vehicles", Marine Systems Engineering Laboratory, MSEL Report #88-03, University of New Hampshire, Jan. 1988.

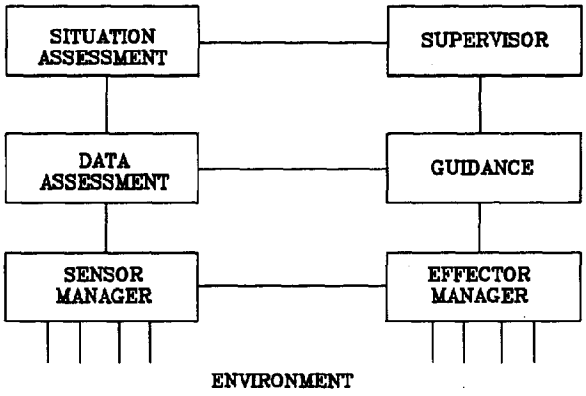

FIGURE 1. CONTROL ARCHITECTURE

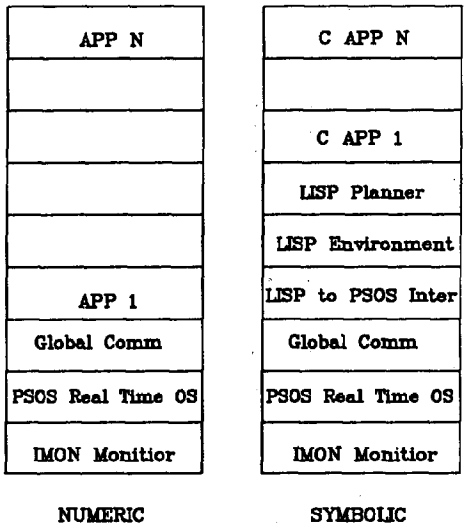

FIGURE 2. SOFTWARE ARCHITECTURE

A GUIDELINE SYSTEM FOR THE NAVY'S SUBMARINE RESCUE SHIP (ASR) CLASS

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ABSTRACT

This report documents the development and testing of a Guideline System (GLS) for the Navy's two Auxiliary Submarine Rescue (ASR) ships - the USS Pigeon (ASR-21) and the USS Ortolan (ASR-22). The ASR Guideline System was developed as a result of positioning related problems during operation of the ASR deep diving Personnel Transfer Capsule (PTC). The GLS provides guidance for the PTC during descent and ascent and provides the capability to maintain relative position of the capsule during saturation diving operations at or near the seafloor. Development of the ASR Guideline System was initiated in 1985 by the Naval Civil Engineering Laboratory (NCEL) under the sponsorship of the Naval Sea Systems Command (NAVSEA) and is scheduled for installation on ASR-21 and ASR-22 during their routine overhaul periods.

1.0 INTRODUCTION.

The USS Pigeon and the USS Ortolan provide saturation diving capabilities for the Navy with their onboard Mark II Deep Diving Systems (DDS). Both the USS Pigeon and its sister ship the USS Ortolan utilize DDS hardware of the same design.

The Personnel Transfer Capsule is the manned transport capsule used for saturation diving missions. The PTC is suspended from the surface ship by a Strength, Power and Communications Cable (SPCC) and is also connected via an Air Supply Hose Bundle (refer to Figure 1). The PTC is essentially a 7-ft diameter sphere capable of transporting divers to a depth of 850-feet. Once at depth, divers have an operating radius of approximately 100-feet from the PTC due to their umbilical link to the capsule.

2.0 SUMMARY OF PTC OPERATION.

Prior to deployment of the PTC, the ASR deploys a 4-point mooring and positions herself over a target on the seafloor. The PTC is deployed through the ship's centerwell to the operating depth. During the mission, surface conditions (wind and current) can move the ASR away from its original position and/or sub-surface current can cause the capsule to move away from the target. In many situations, this results in movement of the capsule (and divers) away from its original position. If the capsule is moved more than 90 to 100 feet, the target will no longer be within the working radius of the PTC. If this occurs, the PTC and divers must be returned to the ASR and the ship must be repositioned (warped) in its mooring before continuing diving operations.

In many cases, deployment of the GLS will allow uninterrupted operation of the PTC regardless of surface and sub-sea effects on the ship and/or the PTC.

3.0 GUIDELINE SYSTEM DESCRIPTION

Two GLS Guidewires restrain the PTC in the horizontal direction during deployment, operation and recovery as shown in Figure 1. A pair of deck mounted air winches are used to deploy and recover a Guideweight and provide motion compensation to de-couple vessel motion when the Guideweight is on the seafloor.

During motion compensation, GLS winches provide constant tension to the Guidewires to allow the system to respond to ship heave motion. There is essentially no limit to the amount of ship heave the winches can compensate. However, the system is limited to the same operating conditions as the PTC and associated ASR DDS hardware: Sea State 3 and 2 knot current.

The GLS interfaces with the ASR's existing complement of DDS hardware and provides an extended capability for the ship's saturation diving system. However, the GLS is an *optional* capability. i.e., The PTC may be deployed with or without employing the GLS.

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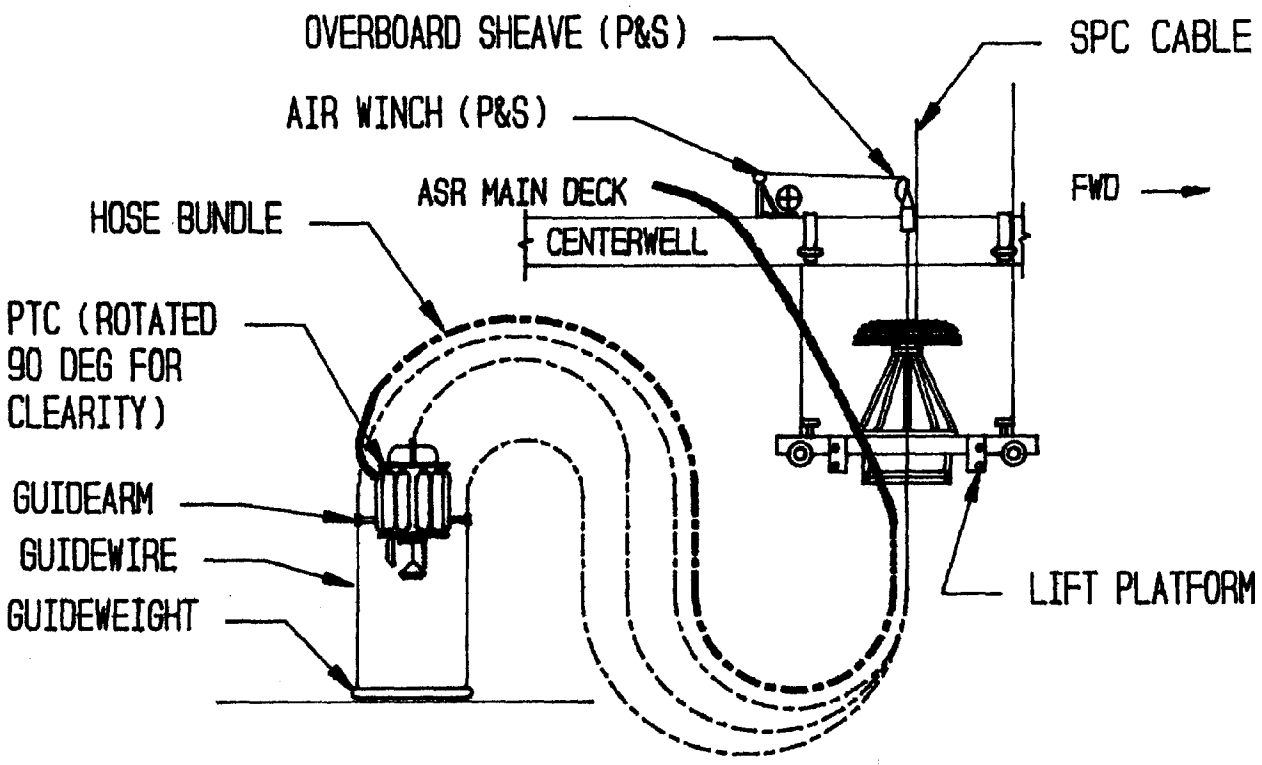


FIGURE 1 - PTC GUIDELINE SYSTEM GENERAL ARRANGEMENT

4.0 GUIDELINE SYSTEM COMPONENT DESCRIPTION AND SHIP INTERFACE

The major components of the ASR Guideline System are as follows: Winch Assembly; Guidewire; Control Panel Assembly; Fairlead Assembly; Guideweight; Guideweight Lock Assembly; and Guidearm Assembly.

WINCH ASSEMBLY. The GLS uses two Ingersol-Rand model K5UL air winches to raise and lower the Guideweight and provide motion compensation. Air winches were selected for GLS due to their inherent low maintenance, high reliability, and constant tension capability.

WINCH BOOSTER RELAY VALVE. A pilot operated high volume booster relay with back-flow capability is mounted on each winch inlet port. Pilot air pressure to the booster relay is controlled by the Constant Tension Pressure Regulator mounted on the GLS Control Panel.

GUIDEWIRE. Each winch has 1000-ft of 0.5-inch diameter torque balanced wire rope on its drum. A 3x46 wire rope construction was selected for the Guidewires because of its flexibility and excellent torque-free (non-rotating) performance under load.

CONTROL PANEL ASSEMBLY. Both GLS winches are operated from a single control station located at the starboard forward corner of the ASR centerwell. A series of gauges and pilot operated valves at the control panel are used to monitor and control air pressure to each winch.

GUIDEWEIGHT. The Guideweight "anchors" the two Guidewires at the seafloor to provide horizontal stability to the system. The weight is filled with approximately 6,000 pounds of lead ballast.

GUIDEARM ASSEMBLY. Two Guidearms are mounted on each PTC. During operation, the Guidearms are extended and locked in place by surface divers. A capturing device at the end of each arm is opened and closed around the Guidewire.

5.0 GUIDELINE SYSTEM OPERATION

GLS DEPLOYMENT. The first step to deploy GLS is to release/unlock the Guideweight from the Lift-Platform and lower it to the seafloor. The descent of the weight is accomplished in the CONSTANT TENSION mode. Constant tension insures a smooth and level (horizontal) deployment of the weight by

maintaining a constant and equal tension on each Guidewire. Guidewire tension is a function of angle "theta" and can be described as follows (refer to Figure 2):

The system is in equilibrium when,

$T_1 d_1 = T_2 d_2$ (1)

Where,

T = line tension

$d_1 = r*\cos(\text{theta}) + h*\sin(\text{theta})$ (2)

$d_2 = r*\cos(\text{theta}) - h*\sin(\text{theta})$ (3)

Substituting (2) and (3) into equation (1):

$T_1[r*\cos(\text{theta}) + h*\sin(\text{theta})] = T_2[r*\cos(\text{theta}) - h*\sin(\text{theta})]$.

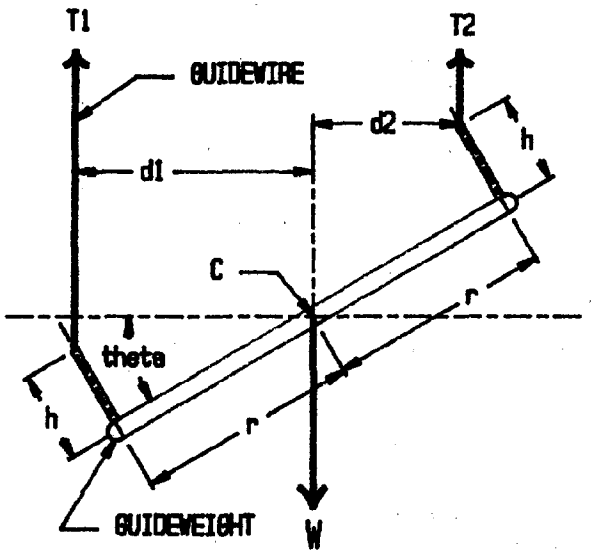


FIGURE 2 - GUIDEWEIGHT ANGLE -VS- TENSION

T is proportional to +/- h*sin(theta) or more simply sin(theta). As angle "theta" increases, the distance (d_1) decreases, and to maintain equilibrium, tension (T_1) increases. This increase in line tension causes winch #1 to pay-out Guidewire #1 until T_1 is equal to T_2 and the Guideweight is level. This relationship applies during ascent and descent of the Guideweight.

GLS CONSTANT TENSION/MOTION COMPENSATION OPERATION. The two GLS winches provide motion compensation to de-couple the motion of the ship from the stationary Guideweight on the seafloor. This is due to the constant line tension feature of the GLS winches.

Motion compensation or constant tension is a result of air pressure changes at the winch air cylinder/piston interface. During NORMAL operation, the GLS winch functions as a conventional air winch. Line tension and speed are proportional to air pressure and flow rate respectively. During CONSTANT TENSION operation, the same relationships between air pressure/line-tension and flow rate/line-speed described above apply. However, there are additional relationships that take affect when torque is *externally* applied to the winch drum. In this case, the external torque is due to heave motion of the ship via the Guidewire.

When torque is externally applied to the drum, the air winch is converted into an air compressor. In general terms, when the externally applied torque exceeds the torque imposed by the system-supplied air pressure, the winch operates in reverse (out-haul) and compresses the cylinder air to force the air back through the inlet port and out through the GLS winch booster relay exhaust port. The result is "constant" line tension. This of course is the ideal case. In actuality, line tension is never constant. It fluctuates between maximum and minimum values due to friction and inertial effects as the winch hauls-in and pays-out during operation. However, as long as the maximum and minimum values are within acceptable limits, motion compensation performance is considered adequate.

PTC DEPLOYMENT. Once the Guideweight is on the seafloor, the Lift-Platform and PTC are deployed. Surface divers extend the Guidearms and capture the Guidewires. The PTC is then lowered to its operating depth while being restrained between the two Guidewires.

GLS RECOVERY. The Guideweight is recovered after the PTC and Lift-Platform have been recovered and secured on deck. The GLS recovery procedure is accomplished with the Lift-Platform secured in the ASR centerwell. The weight is raised in the CONSTANT TENSION mode to insure a level ascent. As the weight makes contact with the bottom of the Lift-Platform, four locking devices on the Lift-Platform are forced open. The recovery operation is essentially a "hands-off" operation at the Lift-Platform/Guideweight interface.

6.0 GUIDELINE SYSTEM TEST PROGRAM

A series of tests were conducted on land and at sea to investigate the performance of an air winch as a constant tension device and to evaluate the feasibility of integrating a new system into the ASR's present inventory of deck hardware. In addition to those tests listed here,

several studies of a guideline concept were conducted at NCEL between 1968 and 1974. (References 1-3).

6.1 GLS LAND BASED TEST (Dec 85)

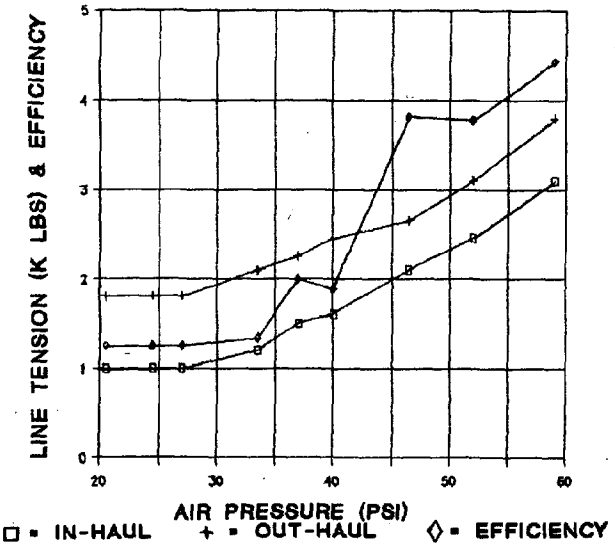
The Land Based Test was the first GLS hardware test. The purpose of this test was to investigate the performance of the Ingersol-Rand, model KSUL, air winch during constant tension operation. In order to evaluate the applicability of this winch for an ASR guideline system, it was important to determine a typical range for maximum and minimum line tension values at various air pressures during simulated ship heave motion conditions.

Minimum/maximum tension values at any given air pressure can be used to "measure" the efficiency of an air winch for motion compensation applications. For example: If the minimum/maximum tension values were 1000 and 1800 pounds at say 20 psi, the tension percent increase would be 80% and the tension range would be 800 pounds. The inverse of the tension percent increase will be used as a measure of winch efficiency. For this example, the efficiency would be 1/0.80 or 1.25.

TEST RESULTS.

The tension/pressure profile for this test is summarized in Figure 3. The OVER-HAUL and IN-HAUL tension values represent the respective maximum and minimum tensions values when the test support winch: 1) pulled the wire rope off-of (over-haul) the GLS winch; and 2) paid-out wire to allow the GLS winch to haul-in (in-haul) wire rope. The average efficiency of the winch was 2.3 over a load range of 1000-3000 pounds.

FIG 3. LAND TEST WINCH PERFORMANCE
TENSION -VS- PRESSURE, DEC 86



6.2 NCEL SHALLOW WATER TEST (May 86)

A shallow water test was conducted to investigate the following parameters: 1) Motion compensation performance of the GLS winch in a seaway; 2) Motion compensation performance of a small GLS-sized ram tensioner; and 3) Horizontal stability of the Guideweight during descent and ascent using constant-line-tension winch operation.

Guideweight pitch is an indication how well the two GLS winches are able to operate in parallel. A pitch angle greater or less than zero, is an indication that winches are not operating in parallel. The pitch angle is also an indication of the distance between the two Guidewires. The risk of entanglement increases as the pitch angle increases due to the possibility of twisting the wires (hourglass) when the two wires approach each other. On the other hand, roll angle has no effect on the distance between the Guidewires and therefore does not contribute to the risk of entanglement.

TEST RESULTS.

HORIZONTAL STABILITY OF GUIDEWEIGHT. The horizontal stability of the Guideweight during deployment and recovery was well within acceptable limits for this system. Pressure/tension control of each winch was accurate enough to maintain less than 5 degrees of horizontal pitch and roll during all phases of Guideweight deployment and recovery.

RAM TENSIONER PERFORMANCE. The average ram efficiency was 3.9 between a load range of 1150 and 1650 pounds. Although this represents a higher efficiency than that of the air winch, air winch motion compensation performance was considered adequate for GLS. Furthermore, in terms of system complexity, the higher efficiency from the ram tensioners was less important than the disadvantage of adding two ram tensioners to the ship's existing inventory of hardware.

6.3 PIERSIDE TEST (Dec 86)

The pierside tests were performed at San Diego Naval Station, Mole Pier in approximately 35-feet of water. There were three main objectives for the Pierside Test: 1) Validate critical hardware interfaces between GLS and the ASR; 2) Install and conduct static and dynamic tension tests for the GLS winches and fairlead assemblies; and 3) Develop preliminary operating procedures and train the ASR-21 crew in preparation for follow-on tests.

TEST RESULTS

GUIDEARM INTERFACE. The prototype Guidearm design was a "bolt-on" configuration. The bolt-on Guidearms did not require structural modifications to the PTC and for this reason did not effect certification of the PTC for unmanned use. There were no significant interface related problems encountered at the Guidearm/PTC area.

OPERATIONAL TESTS. A critical part of the success of deploying GLS is the Guidearm/Guidewire capturing procedure. Two surface divers were used to extend and retract the PTC Guidearms as planned. Diver feedback indicated that alignment (rotating) of the PTC a few degrees to capture the Guidewires was not difficult.

6.4 ASR-21 AT-SEA TEST (Sept 87)

The GLS At-Sea Test was required to fully validate the GLS/ship hardware interface and test the operational compatibility of the new system. The test location was approximately 7.5 miles northwest of Point Loma, San Diego, Ca. Water depth at this location was approximately 650-feet. The main objectives of the test were to demonstrate the capability of GLS during PTC operation and to verify that the existing ASR SS air system was adequate to support GLS operation.

After deployment of the GLS and PTC, the USS Pigeon was repositioned (warped) 250-feet from its original position in its mooring to simulate the effects of surface conditions on the ship with the GLS and PTC deployed.

TEST RESULTS

HORIZONTAL STABILITY OF GUIDEWEIGHT. The weight remained horizontally level within a few degrees during all phases of deployment and recovery. Guideweight stability performance was identical to performance during the NCEL Shallow Water Test of May 1986.

WINCH PERFORMANCE. The At-Sea Test was an opportunity to confirm the predicted air consumption/flow rate for the GLS winches during all phases of GLS operation. The predicted air flow rate and line speed for each winch was 200 SCFM and 50 ft/min. A line speed of 35 ft/min is considered the minimum acceptable speed for the GLS winch during weight recovery. The ASR has 2 air compressors rated at 150psi and 250SCFM each.

ONE SS COMPRESSOR ON-LINE. As was expected, GLS operation was limited at best. One compressor was not adequate to maintain a minimum of 35 FPM during GLS recovery. However, with a single compressor operating, deployment and motion compensation are unaffected and a de-rated or emergency recovery is possible at a reduced line speed.

TWO SS COMPRESSORS ON LINE. Air consumption during weight recovery was below the predicted rate and line speed was well above the minimum required speed of 35 ft/min. The air consumption rate was approximately 190 SCFM and a continuous recovery of the weight from 650-foot depth was possible at an average line speed of 80 ft/min.

OPERATIONAL LIMITATIONS. As a result of the At-Sea test the following GLS operational limitations were defined.

1) MAXIMUM HORIZONTAL MOVEMENT OF SURFACE VESSEL. If the ship moves horizontally on the surface to the extent that the guidewire makes contact with the ship's hull, wire chafe at the hull will occur (refer to Figure 4). The maximum allowable horizontal distance is a function of water depth and can be approximated as follows:

Maximum allowable angle of the Guidewire as it leaves the overboard sheave is a function of ship geometry and is approximately 19°.

Therefore, $\tan 19^{\circ} = W_{max}/D$
or, $W_{max} = 0.34 * D$

Where W_{max} = maximum allowable warp

and, D = water depth.

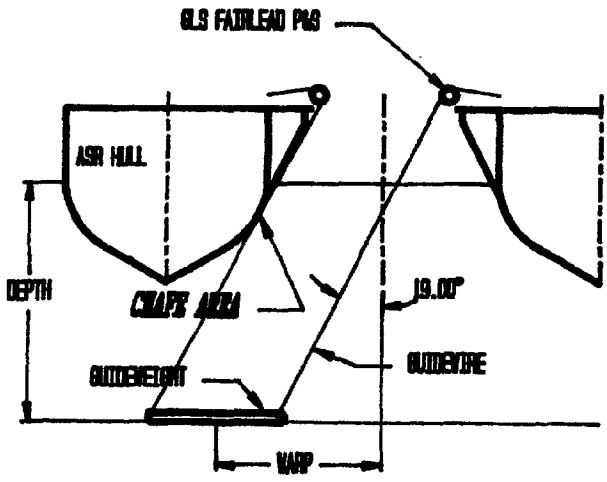


FIGURE 4 - WARP OF ASR WITH GLS DEPLOYED

2) During conditions where the surface vessel has moved horizontally in the mooring, the distance between the Guidewire and the Guidearm may be too great to allow the divers to connect (or disconnect) the tensioned Guidewire at the Guidearm. If this condition exists, the GLS winch operator must slack each Guidewire to allow the diver to connect (or disconnect) the Guidewire at the Guidearm.

7.0 SUMMARY

The development of the ASR Guideline System was in direct support of fleet operations and was a result of the ship's request for this added capability. The ASR GLS project started at the conceptual level at NCEL in mid-FY85. The following year and a-half was spent designing, fabricating and testing GLS components. The final developmental test (At-Sea Test) was successfully conducted in September 1987. The first article GLS is scheduled for installation on ASR-21 this year as part of the ship's routine overhaul program.

One of the most challenging aspects of this project was to integrate the new system into the ship's existing inventory of deck hardware with minimal impact and complexity. With this in mind, the GLS may have had a different configuration if it had been included in the initial design of the ASR class.

8.0 ACKNOWLEDGMENTS

The author would like to thank Captain Appleby, Lieutenant j.g. Harper, and the crew of the USS Pigeon for their cooperation and assistance with the design and testing of the prototype Guideline System. Their efforts made it possible to bridge the gap between the Navy's fleet and R&D assets and make the transition from product development to end product user in the most efficient manner possible.

A special word of thanks is extended to Master Diver GMCM Powell, the ASR-21 dive team, and the COMSUBDEVGRU-ONE Unmanned Vehicle Detachment (UMV) for their assistance and input during the development and testing of the ASR-21 system.

9.0 REFERENCES

1) Technical Report R-703, Naval Civil Engineering Laboratory, Technical DYNAMIC STRESS RESPONSE OF LIFTING LINES FOR OCEANIC OPERATIONS, by Dr. Francis Liu, November 1970.

2) Technical Note N-1099, Naval Civil Engineering Laboratory, TAUT GUIDELINE FOR OCEAN LOAD HANDLING SYSTEM, EXPERIMENTAL RESULTS, by, Dr. F. Liu and H. Kusano, June 1970.

3) Technical Note N-1365, Naval Civil Engineering Laboratory, GUIDELINE SYSTEMS FOR DEEP-SEA DEPLOYMENTS, Dr. Francis Liu, December 1974.

SCIENTIFIC IMAGING: PROBLEMS AND SOLUTIONS FOR ROVs

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ABSTRACT

Imaging systems utilized on ROVs are primarily for vehicle piloting and positioning (i.e. tool use and instrument emplacement). The use of ROVs for science missions requires records of images for future qualitative and quantitative evaluations. The scientific use of standard ROV imaging systems is often difficult due to: (1) the need to change the field-of-view of the video camera for piloting, and (2) the often standard configuration of the still (film) camera. Precise calibration for areal or volumetric coverage is a necessity and several variance minimizing procedures can be utilized. Considering the ROV as a mobile platform, imaging packages for specific science missions can be added which take advantage of the small-scale maneuverability and placement capabilities of the system.

INTRODUCTION

Low-cost remote operated vehicles (ROVs) are slowly becoming standard instrumentation for a variety of oceanographic disciplines. Off-the-shelf units provide the ability to perform reconnaissance of sampling sites and verify sampling procedures in-situ. These systems are, however, limited in their ability to perform more complex imaging tasks for sampling and observation. The use of ROVs for complex science missions requires records of images for future qualitative and quantitative evaluation. Imaging systems utilized on ROVs are primarily for vehicle piloting and positioning. These systems are difficult to use for scientific purposes due to: (1) the need to change the field-of-view of the video camera for piloting, and (2) the often standard horizontal configuration of the still (film) and video cameras. We consider the ROV as a mobile platform. Imaging systems and components for specific scientific needs are designed and added to the vehicle. High resolution data which was previously unavailable with standard sampling methods, due to their averaging nature, is now possible due to the fine-scale maneuverability and placement capabilities of the system. In this paper, we describe systems which have been designed (or are in the design stage), and procedures developed to accomplish specific scientific tasks.

VIDEO TRANSECTS

Video transects for enumerating biota are probably the most easily accomplished and standard procedure for ROV systems. Problems exist, however, for determining area of coverage (path width x distance).

Area of coverage for single frames (one field) or overlapping areas can be determined using standard still photography calibration techniques. The most direct method is to: (1) place a calibrated frame in the field of view of the camera, (2) set the camera to a pre-determined angle, and (3) delineate the useable area of coverage on the viewing screen. Once the area of coverge is known, overlapping areas can be cummulatively added along a transect by using reference points in the field of view to create a strip of adjacent fields (see Stewart et al. 1985 for an application of this technique).

Camera systems which are on pan-tilt heads can be calibrated for a continuous series of tilt angles. The area of coverage for a series of tilt angles is determined, then a regression model is constructed with tilt angle as the independent variable and area of coverage as the dependent variable.

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Another procedure for determining path width and linear distance covered utilizes a set of parallel lasers (Tusting 1986) mounted on the vehicle (Figure 1). The parallel beams (typically spaced at 10 cm) delineate path width. Linear distance covered is either determined with a navigation system or by flying the ROV out a known length of tether from a downweight.

Parallel lasers also allow estimation of vehicle stability during a transect (combined pitch and height off bottom). When the vehicle is flying in proper configuration over the bottom, the ratio of the distance between the laser spots to the screen width will be a set value. When pitch or vehicle height exceeds some predetermined limit, the ratio will exceed the standard and the subsequent images will be edited from the data set.

Ideally, a camera dedicated to transect imaging would be added to the vehicle. This configuration would allow unimpeded movement of the standard vehicle camera for piloting and a standard fixed mount for the survey camera.

USE OF CCD CAMERAS

Video images are often needed for single frame or frame-by-frame analysis. Utilizing CCD (or similar) imaging technology can solve a variety of problems inherent to specific applications.

A review of how CCD imaging compares to standard tube pick-up devices is appropriate. Tube cameras, regardless of type, scan at the NTSC standard of 60 fields per second. A single video frame is made up of two fields interlaced. Essentially, a video frame when viewed in real time is a 1/30 second representation of the real world. When viewed in single frame mode, however, the image is a single field ($1/60^{th}$ second), not a complete frame ($1/30^{th}$ second).

The imaging problem inherent to this technology is image blur or ghosting. Often, fast-moving phenomenon are recorded that move rapidly through the field of view. Because each frame is only $1/60^{th}$ second exposure, the object moves rapidly within and between fields, causing indistinct images. The undefined edges of subjects in each field make motion analysis or single frame analysis difficult.

CCD technology can alleviate these problems by "shuttering." The CCD is essentially a sophisticated microchip capable of electronically manipulating an image. The typical CCD chip contains an array of pixels which make-up the picture elements recorded. As light reaches a pixel, a charge is accumulated which is representative of the object color and intensity. The charge in each pixel is accumulated through the period since the last scan or "reading" of the chip. Typically, this is $1/30^{th}$ second.

CCD chips have a unique property, though, that will allow faster "shutter" speeds. If one wishes the frames recorded at $1/500^{th}$ second or $1/1000^{th}$ second, the charge in each pixel is dumped $1/500^{th}$ second or $1/000^{th}$ second respectively, before the chip is "read." The chip effectively yields these shutter speeds while the system continues at standard field and frame rates. Since charges are accumulated at rates equivalent to the amount of light present, the faster shutter speeds require more light to be effective. The advantage is well defined edges of objects requiring image analysis in frame grabing or motion analysis systems.

VOLUMETRIC IMAGING

Studies of particles, zooplankton, and larval fish in the mid-water require the ability to survey a known volume of water. While nets and trawls can survey large volumes, they miss small-scale patterns of patchiness and association between organisms. Photographic techniques have the inherent ability to discern small-scale patches and associations.

Hamner and Carlton (1979) first described a technique which enumerated zooplankton from calibrated volumes in focus in a photograph. Using a 1:1 extension tube and 80 mm UW Nikkor lens on a Nikonos camera, they photographed aggregations of reef zooplankton and computed densities of organisms. Working distances of 35 to 48 cm were possible with the system so as not to disturb the individuals under observation. This same system could be adapted to any 35 mm format system. Variation of lens focal length, focus distance, extension tube distance, and aperature will yield a wide series of volumes in-focus for enumerating various types of organism. This system has been used successfully from a manned submersible and is being adapted for ROV use.

The same system described for a still camera can also be adapted to a video

system. Alternatively, close-up diopter lenses could be added to the primary lens. Though not as easily calibrated or viewed, this system could be used for real-time verification of vehicle position within patches of small plankters and to position other sampling devices.

Honjo et al. (1984) described a towed system for enumerating particulates in the deep sea. The system consisted of a 35 mm deep-sea camera, electronic flash and stack of fresnel lenses beneath the flash which produced a collimated beam of light. Knowing the depth of the beam and the length and width photographed by the camera, a known volume of water is illuminated in each frame. The advantages of this system are that there is no need to determine what is in and out of focus, and particulates in the water between the camera and light column are not illuminated (reducing masking of objects in the zone of the beam). Youngbluth (1984) and Tusting (1986) describe how this system was adapted for use on manned submersibles. Although requiring more hardware, and hence weight, than the previous system described, this also could be adapted (for smaller volumes) for ROV use.

A continuous light source focused through a fresnel lens stack to produce a collimated beam can be used with video systems. Tusting et al. (1988) built a small system for use on NURC ROVs (Figure 2). Initially, this system will utilize the standard cameras in our ROV systems. We plan to have a dedicated CCD video system, framework, and independent tether for the entire system so it can be fitted to any ROV vehicle. The CCD or other chip type video system is critical to reduce ghosting of particles moving through the beam. Ghosting will be a problem when using motion-analysis systems or single frame image analysis systems for enumeration.

LOW-LIGHT IMAGING

The intensity and spectral composition of light can affect the behavior of organisms, especially in deeper water where light is of limited spectral composition or absent. Using available light, an ICCD or SIT camera can reduce the impact of the vehicle on organism behavior. Low-light imaging will increase the depth of the field-of-view due to the even light distribution in front of the camera. A strong light source near the camera lens causes the aperature to close so the foreground is exposed properly. Attenuation away from the light source reduces the reflectance back to the camera so little in the distance can be discerned.

When a light source is required, several options are available. Use of a Kodak 1A (red) filter over a white light source can reduce the impact on crustacean behavior (Lawton 1987). This is particularly important when using the collimated light source for plankton enumeration in low current environments where attraction is a factor. Due to the constraints of red light transmission in water, observations must be made relatively close to the camera and light source. Again, the vehicle here would be used as a mobile platform to deliver the low-light camera to a study site or the camera used primarily for search tasks.

CONCLUSIONS

The preceding discussion demonstrates how current imaging technology can be used to solve unique sampling problems. A number of custom imaging systems and variations of present systems are available for specific scientific tasks. These tasks range from relatively simple strip transects to locating and enumerating small patches of mid-water macro zooplankton. Matching specific scientific objectives to available technology and hardware requires close collaboration of the science party with ROV operations personnel to ensure successful missions.

REFERENCES

Hamner, W.M., and J.H. Carlton. 1979. Copepod swarms: Attributes and role in coral reef ecosystems. Limnol. Oceanogr. 24: 1-14.

Honjo, S., K.W. Doherty, Y.C. Agrawal, and V.L. Asper. 1984. Direct optical assessment of large amorphous aggregates (marine snow) in the deep ocean. Deep Sea Res. 31: 67-76.

Lawton, P. 1987. Diel activity and foraging behavior of juvenile American lobsters, Homarus americanus. Can J. Fish. Aquat. Sci. 44: 1195-1205.

Stewart, L., P. Auster, and A. Shepard. 1985. Remote operated vehicle (RECON - IV) survey of benthic conditions at dredged material disposal sites off New England. ROV'85 Conference proceedings. Marine Technology Society. Washington, D.C. p. 137-145.

Tusting, R.F. 1986. Non-conventional techniques for sampling and collecting marine organisms. PACON 1986. MPM 1/12-18.

Tusting, R.F., F.M. Caimi, and L.D. Taylor. 1988. Collimated illumination system user information manual. Harbor Branch Oceanographic Institution. Technical Note No. 25. 13 p.

Youngbluth, M.J. 1984. Water column ecology: In-situ observations of marine zooplankton from a manned submersible. Occ. Paper in Biology, Mem. Univ. Newfoundland. 9:45-57.

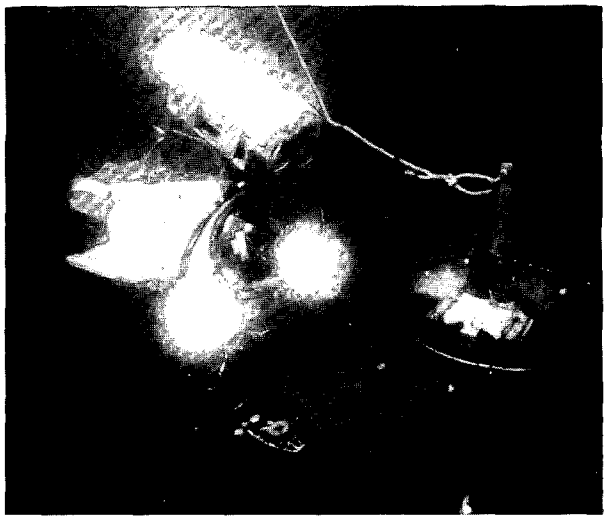

Figure 1. NURC's Minirover MK II with the parallel laser scaling unit attached over the camera dome. Also shown is the skid system/manipulator which elevates the vehicle off the bottom to reduce vertical thruster prop wash. The downweight serves as a sample and tool receptacle.

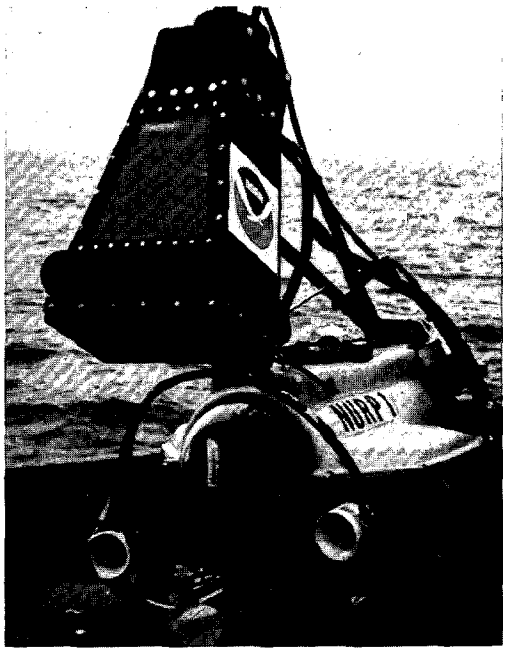

Figure 2. Mounted above the camera dome is a continuous collimated light source for zooplankton enumeration. The camera is tilted perpendicular to the axis of the light. A rotary current meter (center, below dome) is used to determine the volume of water passing through the field-of-view.

AUV TECHNOLOGY DEVELOPMENT AND DEMONSTRATION PROGRAM

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ABSTRACT

This paper presents an overview of Martin Marietta Aero & Naval Systems's Mobile Undersea Systems Test (MUST) Laboratory and the plan for AUV technology development and demonstration. The projects for technology development are focused on capabilities critical to attaining desired Autonomous Underwater Vehicle (AUV) performance. MUST is being developed to test and demonstrate these technologies in the infinitely variable ocean environment. The MUST Lab encompasses a general purpose, modular unmanned underwater vehicle including required support systems, and a land based Simulation and Integration Lab. The baseline vehicle is 30 feet long, 4.5 feet in diameter and capable of diving to 2000 feet. MUST will have completed sea trials and be operational by January 1989. MUST and the technology development projects are funded by Martin Marietta but the MUST system will be made available to support other industrial, academic and government test requirements.

1. INTRODUCTION

Since Martin Marietta entered naval systems development in the early 1980's at Aero & Naval Systems in Baltimore, a primary focus has been Anti-Submarine and Undersea Warfare. For this area, advanced teleoperated and autonomous underwater vehicle (AUV) systems can potentially meet many critical national defense requirements through the 1990's and into the 21st century. This conviction is based upon an understanding of Navy requirements, maturity of ocean engineering and foundation technologies, and readiness of new technologies to provide the advanced sensory and control performance required for AUVs.

In 1984, an internal program of research and development was implemented for critical AUV technology. That work is directed toward new and improved sensors and sensor processing (Ref. 1), robust vehicle dynamic control (Ref. 2 and 3), and automated high level vehicle control and planning that builds on the first two technologies to attain advanced teleoperated and autonomous performance as shown in figure 1. This plan was chosen because it focuses on the technology critical to attaining autonomous performance. Additional work is directed toward improved materials and energy systems.

To test and demonstrate these technologies, a requirement was identified for a testbed system to provide validation of the technology at sea under actual environmental conditions. An evaluation of available operational systems indicated that no suitable system exists. Therefore, development began in 1985, of the Mobile Undersea Systems Test (MUST) Laboratory. MUST, shown in figure 2, consists of a modular underwater vehicle capable of serving as a test platform for a wide range of systems in the open ocean, and the components required to operate and maintain the system from a ship at sea. To optimize the use of MUST, an Integration and Simulation Facility has been constructed in Baltimore.

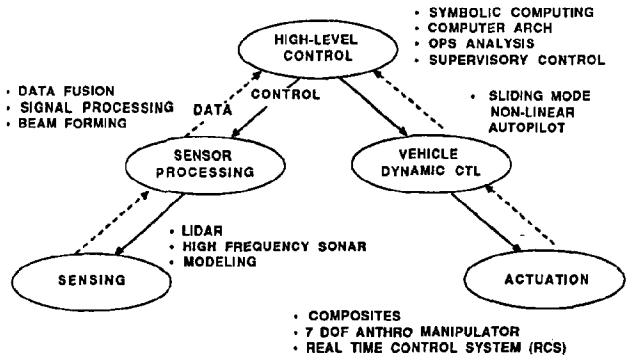

Figure 1. AUV Technology Focus at Martin Marietta

MUST is being tested in San Diego Bay and will undergo trials at sea in 2000 foot depths in December of 1988. Initial Operational Capability (IOC) is set for early 1989, when Martin Marietta research projects are scheduled for installation on MUST.

2. MUST SYSTEM OVERVIEW

2.1 REQUIREMENTS

The potential operational impact of AUVs was analyzed and results indicated that a wide range ofmissions, characterized by the generic list which follows, can be performed or augmented by AUVs.

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Advanced Submarine Target
Submarine Tactical Decoy
Submarine Strategic Decoy
Submarine Minefield Negotiation
Seabed Search and Survey
Reconnaissance
Surveillance
Mine Delivery

An extensive mission analysis was done by decomposing each mission into segments and establishing performance boundaries for parameters including speed, range, duration, payload, sensors, and processing. The requirements for a testbed to test and demonstrate the critical technologies for each segment requiring technology development were treated as operational requirements for the testbed. However, MUST is not required to perform the complete evolution of all phases of any one mission and thus become an operational system.

As general requirements for a successful testbed it was agreed that MUST shall be:

- a complete system that can be installed on a ship of opportunity in a short time and perform repeated dives at sea without returning to port
- reliable, easy to operate and maintain, and have minimum development risk
- modular and versatile, with payload capacity and performance required to be useful through the 1990's.

2.2 SYSTEM COMPONENTS

The centerpiece of the MUST System is a modular underwater vehicle. The baseline configuration is 30 feet long, 4.5 feet in diameter, and contains 53 cu ft and an electronics payload power capacity of 7 Kw. The vehicle is supervised during dives and between dives maintained from the Control/Maintenance Center that contains the Control Consoles and related electronics. As the requirement for additional space for research payload support electronics grows a separate control van will be added. The Deployment system consisting of vehicle launch and recovery system and Hangar provide for vehicle handling during all phases of operation at sea. An AUV Integration and Simulation Laboratory in Baltimore provides a wide range of services from payload checkout to training and dive data analysis.

2.3 SYSTEM OPERATION

During initial sea trials, the baseline vehicle will be operated in a supervised control mode. A block diagram of the control and communication architecture is shown in figure 3. Extensive vehicle software is permanently stored on an optical disc and loaded into random access memory over a SCSI port when the vehicle is powered-up. Before launching, initialization of the vehicle's onboard program for the planned dive is done at 9600 Baud, over a 1000 foot cable. The cable can be removed before or after launching by disconnecting a wet make/break connector. After the vehicle has completed an initial dive maneuver, the operator in the Control Center will use an ultra-short baseline acoustic tracking system with a transponder mounted on the vehicle to monitor the vehicle's position. The support ship will maneuver to follow the vehicle and stay within range of communication using a low bandwidth acoustic data link. The acoustic link will be used to supervise the vehicle by monitoring onboard parameters, sending new commands, modifing the program active on the vehicle and activating other stored programs.

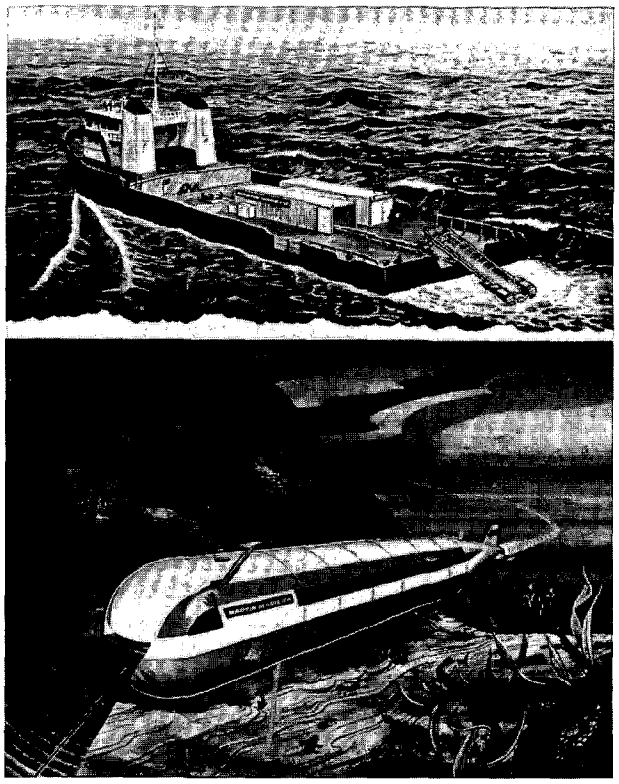

Figure 2. Mobile Undersea System Test (MUST) Laboratory at sea.

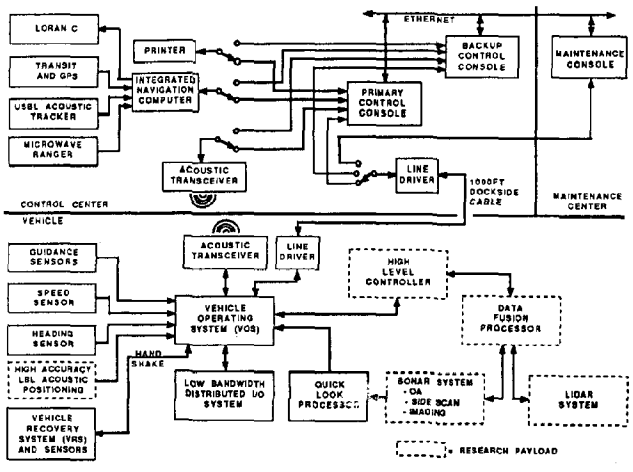

Figure 3. MUST System Control and Communication Block Diagram

As research payloads are installed, such as the non-linear sliding mode autopilot, LIDAR, etc. and eventually the high-level autonomous controller as shown in figure 3 with dashed lines, the operational architecture will evolve.

3. VEHICLE DESCRIPTION

3.1 CONFIGURATION

The general arrangement of the MUST vehicle is shown in figure 4. Typical transverse section views are shown for segments with battery modules configured for minimum and maximum separation of the centers of buoyancy and gravity in the verticle axis (ZBG). The main pressure vessel is the central structure of the vehicle and the fore and aft fairings,that support all external sensors, motors and actuators, are attached to each end of the pressure vessel. Power is derived from batteries in the main pressure vessel for the onboard control system, propulsion motors and research payloads. The extensive heat generated by the large volume of onboard electronics is dissipated to the sea by conductive heat sink mounting of the motor controllers and forced air circulation through the electronics racks and circumferentially along the inside wall of the aluminum hull.

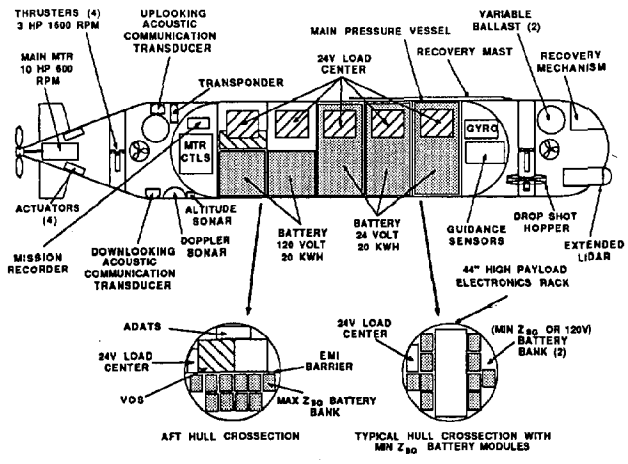

Figure 4. MUST Vehicle Configuration.

Testbed versatility and adaptability are realized with this modular design that permits:

- varying the vehicle length from 22.5 to 35 feet by changing the number of hull sections from 2 to 7
- changeout of components within the freeflooded fairing sections to add research payloads such as a towed array attachment interface, fiber optic tether payout system, or different sensor packages
- reconfiguration of the vehicle by swap out of hull sections that have been assembled with energy storage and research payload electronics
- changeout of motors and/or propellers for increased speed, thrust and efficiency.

3.2 CAPABILITIES

Operating depth of the vehicle is 2000 feet. It can be launched and recovered in a sea state 3. Redundant systems on the vehicle ensure that it returns to the surface for recovery. Forward speed of the baseline vehicle with the 10 HP main motor is 0 to 8 knots.

Typically, underwater vehicles are developed for a specific purpose or mission, and optimized to minimize the size and cost of the system. In contrast, MUST is designed to meet a wide range of requirements and thus it has an unprecedented payload capacity and flexibility. This has been accomplished with an innovative pressure vessel design. Payload space in the main pressure vessel is configured to permit the use of standard 19 inch wide rack mount equipment (per EIA-RS-310C) to avoid the cost and schedule impact, on each research project, of custom packaging. It was impossible to determine all potential payload requirements for MUST at the outset of the design process. However, a suite of payload subsystems was generated that represented the worst case requirements to serve as the strawman for sizing the vehicle. The strawman included extensive computing and signal processing equipment, and all relevant sensors and navigation equipment. The results of an analysis of the strawman payload power and duty cycle requirements for the generic missions resulted in a range of connected payload power from 3.5 to 7.5 Kw.

The total payload, weight and volume of the dry electronics rack space based on the lead acid battery system for the various potential configurations of the vehicle are listed in Table 1. Note that the 5 section, 30 foot baseline vehicle configuration which has been built has over a ton of payload capability and 53 cubic feet of payload volume available in the main pressure vessel.

Table 1. Vehicle total payload weight and volume of dry electronics (* Baseline vehicle configuration).

Vehicle Length (feet)	No. of Hull Sections	Payload Weight (pounds)	Payload Volume (cu. ft)
35.0	7	3100	77
32.5	6	2760	65
30.0*	**5**	**2350**	**53**
27.5	4	1940	41
25.0	3	1530	29
22.5	2	1120	17

The vehicle was designed to have endurance on the order of a normal working shift, with full propulsion and payload power requirements. The number of battery modules connected to the propulsion and payload power busses can be set in between dives to maximize endurance or range depending on planned speed and amount of payload electronics power and weight. If the payload electronics do not require the full volume, an optional 20 batteries can be installed in the center cylinder, enabling the vehicle to operate with 3.5

Kw of payload for 28 hours at slow speeds or for 8 hours at the maximum speed of 8 knots. The maximum achievable range with that configuration is 100 miles at 4.5 knots. When the pressure vessel is full of payload electronics, which uses 7.5 Kw, the maximum endurance is 12 hours with a maximum range of 50 miles. See figure 5, for vehicle endurance as a function of speed for these various battery and payload configurations.

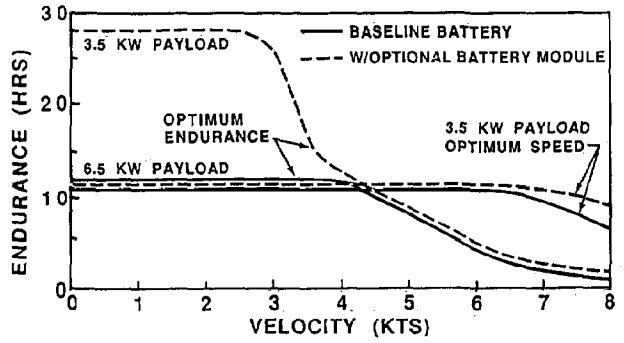

Figure 5. Vehicle Endurance as a Function of Speed for Various Battery and Payload Configurations.

3.3 SUBSYSTEMS

3.3.1 STRUCTURE

The central structural element of the vehicle is a cylindrical pressure vessel with hemispherical endbells. An exploded view is shown in figure 6. The pressure

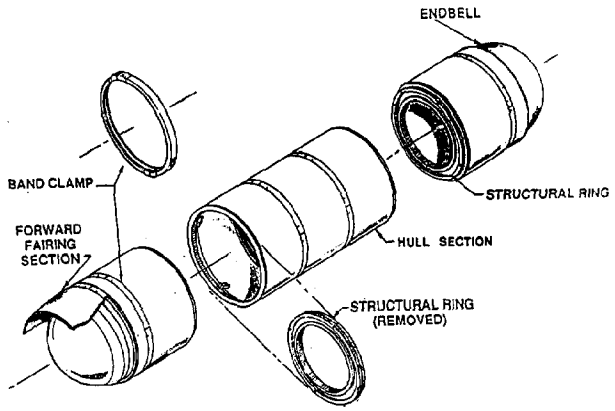

Figure 6. Vehicle Main Pressure Vessel Exploded View.

vessel is optimized to provide the maximum payload volume, minimum diameter and weight, and has a modular structure for ease of payload and battery access. The design is a bolstered shell multi-segment structure made of 6061-T6 aluminum. The removable support rings allow the payload to occupy the full inside shell diameter. Each cylindrical segment is 2.5 feet long, which accommodates 10 boxes with two batteries arranged end-to-end and standard electronic rack mount equipment. The baseline configuration is being constructed with 5 segments, however the system is capable of accommodating 2-7 segments, resulting in a vehicle length from 22.5 to 35 feet. The forward and aft sections are free flooding fiberglass fairings. The forward fairing is hemispherical in shape to provide the maximum volume for various payloads such as forward looking sensors with a minimum impact on the drag. The aft fairing has a smooth transition to a 17 degree taper for good hydrodynamic performance.

3.3.2 POWER

The power source on the baseline vehicle is 100 car-battery size, rechargeable, lead-acid suspended electrolyte batteries, that are low risk, low cost, and that satisfy the requirement for range and duration. An additional battery module can be added for optimized endurance. The system can be upgraded with silver-zinc or higher energy density batteries.

The 12 volt batteries can be connected to a 120 VDC buss for propulsion or a 24 VDC buss for instrumentation. The reconfigurability of the battery system allows the vehicle to be optimized for mission profiles ranging from high thrust-short duration to low thrust-long duration by allocating the batteries between the two power busses, as explained in Section 3.2. The power busses are floating so the power systems are tolerant of a single point ground fault.

The propulsion power bus is centralized in the 120 VDC load center located in the aft hemisphere of the main pressure vessel. The instrumentation power bus is made by interconnecting the 24 VDC load centers located in each hull section. All the load centers contain remotely operated breakers, and current and voltage sensors which give the vehicle control over the battery and load configuration during a dive.

3.3.3 PROPULSION AND ACTUATORS

The vehicle's propulsion system consists of a 10 HP motor that drives a 3 bladed propeller at 0-600 RPM for transiting and four 3 HP motors driving tunnel thrusters from 0-1600 RPM for hovering and low-speed vertical and lateral excursions. The tunnel thrusters are arranged in pairs forward and aft of the main pressure vessel, perpendicular to the long axis of the vehicle, one vertical and one lateral. The motors are 3 phase brushless AC motors electronically commutated by DC power supplies located in the main pressure vessel. Control of vehicle attitude during transit is accomplished with four control fins on the aft fairing, driven independently by four stepper motor and worm gear actuators.

3.3.4 VARIABLE BUOYANCY

The vehicle is designed to be launched and operated near neutral buoyancy. Final corrections of the vehicle weight and center of gravity are made using fixed ballast lead in calm shallow water. Independent variable buoyancy systems (VBS), one located in the bow fairing and one in the aft fairing, provide overall buoyancy and pitch trim adjustment.

The VBS systems are sized to accommodate variations in water density and hull compressibility. Each system is capable of 60 pounds change in buoyancy in sea water, for a total capacity of 120 pounds. The systems operate by pumping one cubic foot of oil from a hard tank to a soft bladder. This design offers high reliability and low maintenance without requiring plumbing penetrations into the main pressure vessel. The valves and motor pump are operated by the vehicle control system, controlled manually from the Control Center or by automatic vehicle control in response to the thruster force required to hover level at a constant depth.

3.3.5 CONTROL

The vehicle is controlled by two Motorola 68020 processors which are the heart of the Vehicle Operating System (VOS). These processors and all of the memory and I/O boards are off-the-shelf VME buss circuit boards, and are housed in a standard VME chassis in the aft pressure vessel section. The VOS runs a commercial multiprocessor real time operating system that provides the VOS with an extensive expansion capability. The VOS will respond to commands stored on the vehicle before launch, commands sent to the vehicle after launch via the acoustic communication system, and commands from onboard research payloads. Onboard research payloads will control the vehicle via an interface to the VOS, designed to allow access to all system data and input of any commands at the fastest rate of the system, 10 Hz. Supervisory control by the operator is always possible since the VOS prioritizes commands based on their source. Commands received over the acoustic data link are handled with the highest priority.

An efficient, modular, event-driven state table process system was created to allow for easy software maintenance, application software development, and simulation. This design has the fundamental architecture of and is compatible with the Real-time Control System (RCS) being used at the National Bureau of Standards and Martin Marietta.

The VOS interfaces to most of the sensors and actuators over a serial bus using a 4 conductor cable to run through the vehicle. This minimizes the cabling and inter-segment connector requirement. The control sensors include depth, magnetic heading (flux gate), forward speed (mechanical flow meter), pitch and pitch rate, roll and roll rate, yaw rate and altitude above sea bed. Provisions have been made for a gyrocompass and doppler sonar.

The vehicle dynamic control system design was accomplished using frequency domain design techniques with a 6 degree-of-freedom linear model of MUST and then verified and refined with time domain techniques by evaluating the vehicle dynamic performance for specific trajectories, using the model with a full non-linear hydrodynamically accurate representation of the vehicle. The autopilot, operating at 10 Hz, will provide stable vehicle transiting trajectories and automatic control of attitude during hover and transiting.

3.3.6 ACOUSTIC COMMUNICATION

Although the vehicle is capable of operating autonomously, it has an acoustic half duplex communication system that allows the operator in the Control Center onboard the support ship to obtain status information and send commands to the vehicle during the mission. This advanced system, which can operate in multipath environments, was developed in conjunction with the Naval Ocean Systems Center (Ref. 4). It is called the Adjustable Diversity Acoustic Telemetry System (ADATS).

Each end of the link implements multipath/doppler resistant transmission techniques with several custom circuit boards and an industrial IBM PC controller. The operator onboard the ship can adjust the amount of frequency and time diversity based on the performance of the link, local environmental conditions, and the relative positions of the vehicle and the support ship. As the amount of diversity increases, the data rate decreases. These features permit robust communication at 200 Baud in the presence of multipath and doppler shift or up to 2400 Baud when favorable conditions exist. Because of its small size and multipath performance of the underwater components, this system should adapt easily to a sonobuoy for aircraft-to-vehicle communication or be installed on other vehicles for vehicle-to-vehicle communication.

3.3.7 RECOVERY SUITE

Highly reliable vehicle surfacing is accomplished by a multiply redundant weight release system. During normal operations, the VOS operates an independent electrical release to drop the recovery weight. An electrically isolated low power processor with dedicated sensors and battery pack called the Vehicle Recovery System (VRS), ensures reliable return of the vehicle to the surface in the event of a hazardous condition. The faulty conditions it monitors include lack of VOS activity, water leaks, high temperatures and excess depth. If a fault is detected, the VRS causes the the release of the recovery weight with an independant actuator. Two other independent mechanical releases can drop the ballast to initiate a recovery: a corrosive link works after 36 hours in sea water and an over-pressure device actuates before the vehicle reaches crush depth. When the 250 pound drop weight is released the rudders are put to one side and the vehicle spirals to the surface at speeds approaching 8 knots due to positive buoyancy.

Once the vehicle is near the surface a 10 foot mast with RF beacon and strobe light, is mechanically raised. The recovery line is deployed with a high visibility, radar reflective buoy attached. Once floating on the surface in this fail-safe mode, the vehicle can be located by the support ship.

3.3.8 RECORDING AND PROGRAM STORAGE

A 400 Mbyte write-once-read-many (WORM) optical disc drive logs all control data at 10 Hz and communications as it occurs. At a nominal recording rate of 790 bytes/sec, 68 MBytes are used per 24 hour dive. The WORM drive can be commanded to play back

for any specified time interval. While the vehicle is underwater, playback can occur over the acoustic link or tether and when on deck over the tether, or the disc can be removed. This system will be used for dynamic performance evaluation and troubleshooting and functions as a traditional black box recorder. The vehicle program is also written onto the WORM disc at the control console before the disc is installed in the vehicle. A small program in PROM boots the VOS over a SCSI port. This reduces the time to install new versions of the program into the vehicle which is very helpful during a development project.

4. CONTROL/MAINTENANCE CENTER

The Control/Maintenance (C&M) Center, shown on figure 7, is a 40 foot long by 8 x 8 foot van outfitted to provide self-contained operations control when the vehicle is in the water and maintenance and refurbishment when the vehicle is onboard in the Hangar. The C&M center is connected to the Hangar by a 20 foot long by 4.6 foot wide companionway separated by heavy plastic curtains, providing a buffer for the operations area.

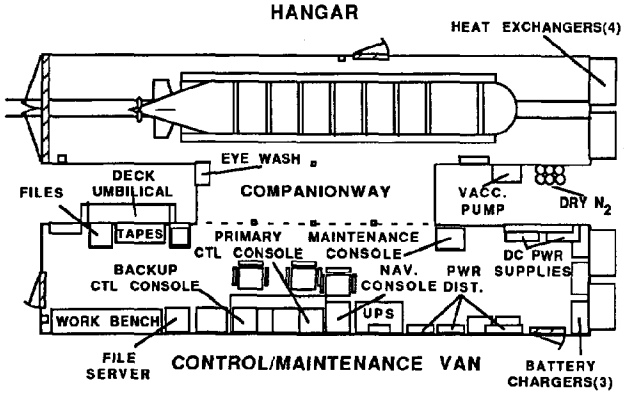

Figure 7. C&M Center and Hangar Plan View

4.1 CONTROL

The vehicle is controlled from the Primary Control Console, which is a Sun Microsystems Series 3 terminal server with a color graphic display, keyboard and mouse. A fully-redundant Sun Microsystems Series 3 workstation is located adjacent to the Primary Control Console and configured as a Backup Control Console. Another rack houses the integrated navigation system (INS) that computes ship and vehicle geodetic position using Loran C, Transit/GPS and Microwave receivers to measure ship's position and an ultrashort baseline (USBL) acoustic tracking system with depth telemetry transponder on the vehicle and ship's gyro repeater to measure the vehicle's position relative to the ship. The INS sends the vehicle geodetic position in latitude and longitude to the control console which then transmits this information to the vehicle for use in way point navigation. This system defers the requirement for an inertial navigator onboard until requirements for accurate, fully autonomous navigation are established for the testbed. An INS remote display on the ship's bridge enables the ship's captain to steer the ship to stay within communication and tracking range of the vehicle.

The Control Console was implemented with a Sun workstation in the C language under UNIX, with the Sunviews windowing system. The entire operator interface has been implemented in fixed windows on the color workstation display. The operator inputs commands using the mouse, and keyboard.

The primary window for vehicle operation, shown in figure 8, has a fixed area for status display, mode control switches, messages received from the vehicle, and messages transmitted to the vehicle. The large window in the lower left corner displays windows tailored to specific operator functions such as vehicle command generation, enhanced status monitoring, or dive log editing. Commands available include:

- Hover: hold or change heading and depth or altitude while compensating for ocean currents
- Waypoint: transit at a given speed and maximum pitch angle to a new position defined in latitude and longitude or in relative or absolute northings and eastings or polar coordinates in meters, feet, or yards. This command also has a glide distance parameter defined which lets the vehicle coast or not when it reaches the new position
- Stop and Shutdown: provides decelerated and "dead stick" stopping capabilities
- Navigation Update: for periodic updates of the vehicle's dead reckoning position algorithms (based on surface tracking system onboard the mother ship.)
- Status: requests transmission of parts or all of the onboard sensors and status buffers. This can be set up for automatic repeats
- Power: turns on or off any of the breakers for the payload electronics or battery banks
- Manual Thrust: operates any of the thrusters, actuators or variable buoyancy pumps for testing or emergency propulsion (if sensors for control loops are inoperational)
- Services: includes other functions such as acoustic communication data rates, clock synchronization, setting of default control gains and timer values, flight recorder data playback.

All of the commands can be stacked in the command queue, which allows command groups to be stored and acted on as a single complex command.

4.2 REFURBISHMENT AND MAINTENANCE

The C&M Center supports refurbishment of the vehicle between dives which involves battery recharging and drop shot, corrosive link, recovery float compressed gas, and VRS battery replacement. During refurbishment, the vehicle 24 VDC instrumentation can be powered by a set of power supplies and a Sun Series 3 color workstation located in the C&M Center near the opening to the Hangar used as a test console. This allows the operator to work close to the vehicle and technicians during pre-dive checkout, fault isolation, and installation of new subsystems. This work can be done at the same time post-dive data analysis and mission planning are being done on the primary and backup control consoles.

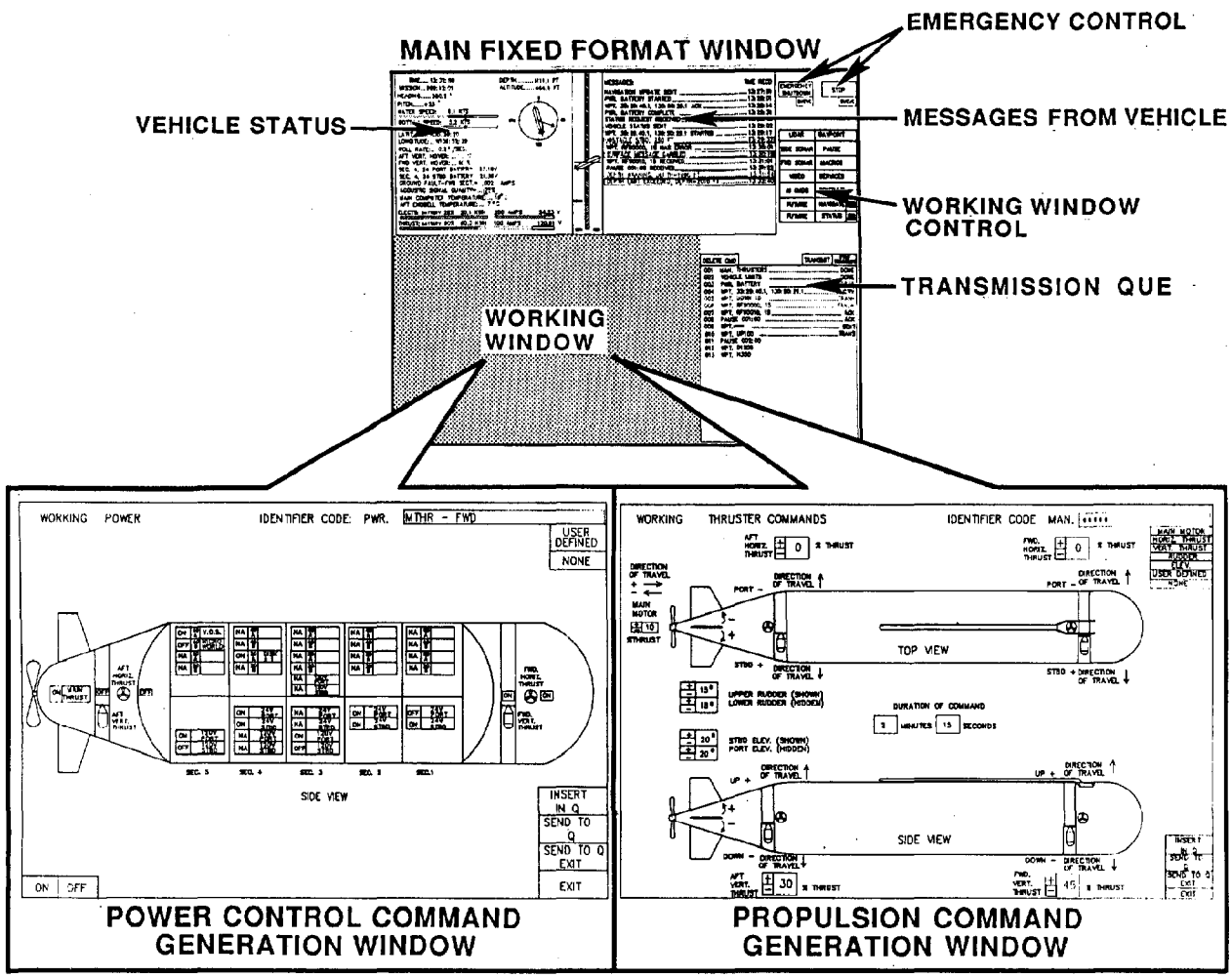

Figure 8. Control Console Window System, With the Main Fixed Format Window and Two Working Windows.

5. DEPLOYMENT SYSTEM

The Deployment system is designed to maintain positive control of the vehicle during all phases of launch, recovery, refurbishment, and maintenance, with minimum manpower and rigging requirement on deck, without using divers or men in small boats and with minimum impact on ship installation. The system consists of a launch and recovery ramp and trunnion, vehicle dolly train and tracks, powering system and hangar. The system is being installed on a 194 foot offshore oil mud boat which will fill it's tanks to attain 4 foot freeboard.

5.1 LAUNCH AND RECOVERY RAMP AND TRUNION

The central feature of the design is a ramp connected to a drive cart by a strong arm with universal joints at each end, that transports the vehicle over the stern of the ship where it pivots into the water over wheels mounted on a trunnion which permits the ramp to yaw. This three degree-of freedom- mechanism (translation, pitch and yaw) launches and recovers the vehicle without ever picking it out of the water and suspending it from an overhead structure. This approach eliminates any condition where the large mass of the vehicle (>18000 lbs with entrained water) is able to act as a pendulum on the rocking ship. The three degrees-of-freedom provides flexibility to decouple the motion at the transom of the ship from the surface of the ocean, even when the waves and the ship are not in phase. Our design builds on the concept and experience of the Advanced Undersea Search System (AUSS) Launch and Recovery system developed at the Naval Ocean Systems Center (NOSC) which was used successfully for over 80 dives.

The recovery sequence, illustrated in figure 9, commences when the vehicle surfaces and deploys the recovery buoy and line. The buoy is snagged from the ship and removed, and a line that has been fed down the ramp through the docking cart is attached to the vehicle recovery line. The ship gets underway at minimum forward speed, 1-3 knots, and then the vehicle, which is now in tow behind the ship, is pulled up to and mated with the docking cart. The vehicle and docking cart are pulled up the ramp by a drive cart linked to the main power drive system. A latch at the top of the ramp, on the forward fairing dolly, holds the vehicle in place on the dolly train, setting in the ramp. At this point the vehicle is out of the sea and safely held. The drive cart is next used to pull the ramp and vehicle onboard. This concept provides a safe, reliable method of recovering the vehicle in rough seas. Launching is accomplished by releasing the vehicle from the ramp and letting it slide into the water and clear the ramp.

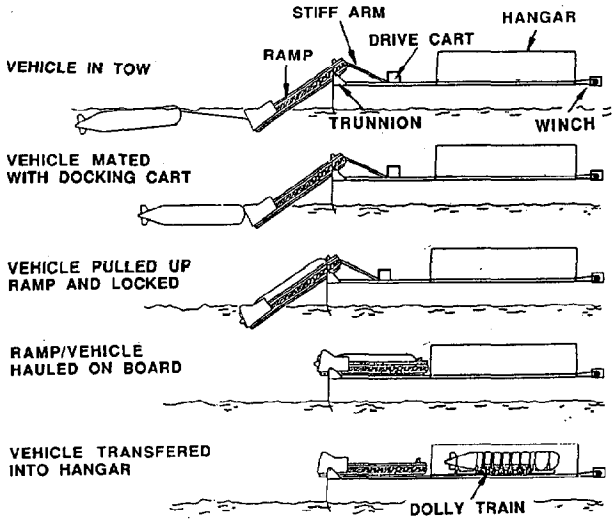

Figure 9. Vehicle Recovery Sequence

5.2 VEHICLE DOLLY TRAIN AND TRACKS

The vehicle rests on a train of dollies, one per vehicle faring and hull section, and slides into and off of the dolly train on Delrin pads. When the ramp is flat on the deck, the dolly train carrying the vehicle is pulled from the ramp into the hangar along a set of tracks which hold the dolly train captive and that are continuous from within the ramp to within the hangar. Once inside the hangar the vehicle is opened at one of the hull joints at a time and the dolly train is separated at that same point by anchoring one part while the other is translated to provide the desired separation for access into the vehicle for refurbishment and maintenance.

5.3 POWERING SYSTEM

The powering system for all phases of operation consists of a 75 HP hydrostatically driven winch located forward of the hangar. This winch has two steel cables running off in the aft direction but wrapped in opposite directions. The cables are 1-3/8 inch diameter extra improved plow steel selected for the systems peak load of 41,000 pounds. The onboarding cable runs straight to the drive cart which pulls the ramp onboard while the overboarding cable rounds a sheave located just forward of the trunnion and experiences maximum load of 10,000 pounds.

5.4 HANGAR

The Hangar is an extensively rebuilt 40 foot offshore container. The base was replaced with a rigid structure with 18 inch I-beams to support the dolly tracks. The rigidity of the structure and the non-compliant dollies provide a reliable stackup for the interface between vehicle hull sections to permit alignment during opening and closing of the pressure vessel. The hangar is mounted to the ship using proven deck fittings but with sufficient freedom of translation so that deck flexure is not transmitted into the hanger base.

6. AUV INTEGRATION AND SIMULATION LABORATORY

While MUST is designed to be readily mobilized onto a ship of opportunity, an AUV Simulation and Integration Laboratory (Dry Lab) has been built in Baltimore to facilitate making the most efficient use of MUST while it is operating a sea. The Dry Lab is intended to allow verification of interfaces and functional checkout of payloads without tying up MUST while it is in an operational configuration onboard a ship. This capability minimizes the operational time required to complete research tests and demonstrations. This approach, which is shown in figure 10, is being used to stage the integration and testing of research developments at Martin Marietta in an efficient serial manner.

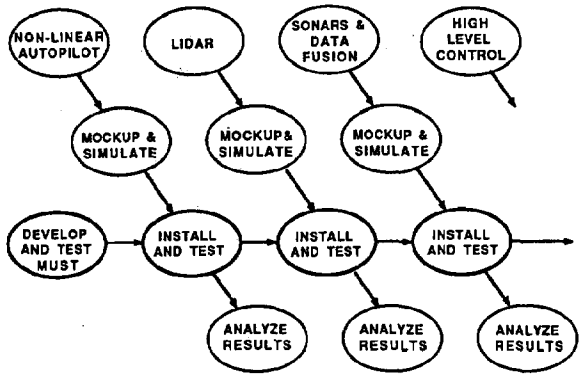

Figure 10. System Use Plan

The Dry Lab shown in the block diagram in figure 11 consists of a physical mockup of the vehicle which supports installation of rackmount electronics inside the pressure vessel and sensor/actuator packages in the fairings. Power to the payloads is provided by a variable DC supply which permits simulation of the voltage range as the vehicle batteries go from the fully charged to fully discharged state. The power distribution, VOS and

distributed input/output system are functional duplicates of the real system. The Dry Lab VOS is connected to a Sun System 3 terminal server configured exactly as the surface control console over a cable but at a Baud rate equivalent to that of ADATS.

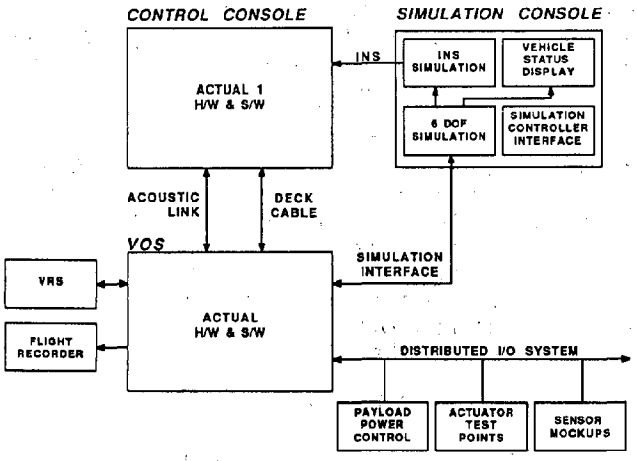

Figure 11. Dry Lab Block Diagram.

Simulation of the system's response is done in a second Sun System workstation by running the 6 degree of freedom non-linear hydrodynamic model of the vehicle (including sensor and actuator models) interfaced to the Dry Lab VOS by a dedicated RS-232 serial data link and ship Integrated Navigation System model connected to the Surface Control Console by an RS-232 link configured just as the actual INS interface. The VOS command outputs go to the model in the simulation workstation which provides sensor feedback to the VOS and the surface control console. Operating conditions such as bottom profile, water currents and acoustic transmission parameters are controlled at the simulation workstation. Additional important uses for the Dry Lab include independent verification and validation (IVV) of MUST software, operator training, mission planning and post dive data analysis and mission reconstruction.

7. MUST AND AUV TECHNOLOGY TEST PROGRAMS

7.1 MUST TEST PROGRAM

The MUST test program consists of parallel efforts on the Deployment System and Vehicle, followed by system integration and sea trials.

The Deployment System test sequence began with stress tests of critical load path components and function of critical mechanisms in the factory. Next the Deployment System is being installed on the support ship and functional validation of all phases of operation will be done except for vehicle refurbishment (opening and closing the Vehicle) by operating with a test vehicle which is a low cost replica with the same shape, mass properties and recovery mechanisms as the actual vehicle. Deployment tests will be performed in San Diego Bay and offshore in varying sea states before operation begins with the real vehicle.

The vehicle test program has included hardware subsystem tests such as hydrostatic pressure test of the main pressure vessel and software component and interface tests. Before hardware and software integration began the complete software system was tested using test software written to permit efficient repetitive execution of complex scenarios to exercise many of the elements of the system software. The fidelity of the tests were ensured by testing the system against the hydrodynamic model of the vehicle. This test configuration has been expanded upon in the implementation of the Dry Lab described in Section 6. A simple version of the simulation has been embedded in the VOS so that these complex system software tests can be repeated when vehicle hardware and software integration is complete and after IOC for pre and post dive checkout and recertification after system modifications.

Additional early validation of the system software architecture and function is being obtained in a cooperative effort with Applied Remote Technology (ART) by installing MUST software and control electronics and sensors into ART's 21 inch diameter vehicle, XP-21, which can be operated from a small ship in the bay and shallow waters offshore.

Following shallow water verification of the MUST vehicle mass properties and functional checkout, the vehicle will be recovered for the first time by the Deployment System in San Diego Bay and MUST sea trials will commence. After verification of system function in near shore depths of 75 to 200 feet, qualification dives in depths of 2000 feet will be made. After this checkout period, extensive sets of maneuvers will be performed to tune the autopilot, determine the dynamic capabilities of the vehicle and validate the hydrodynamic model. This work is scheduled for completion by the end of January and constitutes IOC of the MUST Laboratory.

7.2 AUV TECHNOLOGY TEST PROGRAM

As soon as the IOC milestone is reached, installation and test of AUV technology developments will commence. The first effort will add a non-linear model base (sliding mode) autopilot which will provide significant performance benefits over the standard linear autopilot with speed scheduled gains (Ref. 3).

Following tests of transit and mid-water hover performance, a high frequency short baseline positioning system (SHARPS) with fraction of an inch accuracy and a range of 100m will be used to measure position with reference to a bottom mounted transponder inorder to provide feedback for hovering control near the seabed. This autopilot should be able to hold position and attitude even with the vehicle at an angle to a current.

Next the LIDAR (Light Detection And Ranging) developed at Martin Marietta will be installed and tested. The LIDAR determines the range to an object by measuring the time for a laser pulse to reflect from the object. The laser is a Nd:Yag which emits 40mJ pulses 13 nsec in duration at 20 Hz. The infrared output is

frequency doubled to a green, 532 nm color which is in the water transmission window. The laser can be scanned over ±45 degrees in pitch and yaw, with 9 mrad resolution at 400 deg/sec. The return signal is detected by a photomultiplier with active grid control and digitized at 1.3 Gigahertz. The maximum range for target detection depends primarily on the optical properties of the water and the type of target. Based on experiments we performed in the Scripps Visibility Lab (Ref. 6) and predictions from our laser propagation model, detections at 70-100m in clear ocean water is expected. Building on the performance of the near-bottom high-accuracy hover capability of the sliding mode autopilot, the Vehicle will be maneuvered to scan targets of interest on the seabed to collect LIDAR performance data.

The LIDAR is a testbed for optical sensor systems technology in a similar way that MUST is a testbed for AUV technology. The LIDAR will accept improved lasers and support imaging and communications configurations of the same basic system.

Additional projects will add obstacle avoidance and imaging sonars, a sensor data fusion processor and a high-level controller which builds on the advance dynamic control and sensing package to demonstrate robust autonomous control.

8. PROGRAM ORGANIZATION

Martin Marietta is developing MUST as a capital facility, funding the entire project internally. However, the program organization is set up with all the discipline and formality associated with a major government project. We have established the system requirements and developed a plan combining inhouse engineering and review with a strong team of contractors.

A team lead by Ken Collins at Applied Remote Technology (ART) in San Diego was the lead designer of the vehicle and is building the vehicle and VOS and surface control console software. ART will perform shallow water testing in San Diego Bay. Aeronautical Research Associates of Princeton (ARAP) developed the 6 degree-of-freedom hydrodynamic coefficients to model the vehicle dynamics, evaluated the benefits of various fairing shapes and developed the linear autopilot control equations and actuator requirements. Perry Offshore Inc. (POI) did preliminary design of the vehicle power and propulsion and deployment studies. We designed and fabricated the Launch and Recovery System and Hangar at Martin Marietta in Baltimore. Martin Marietta will perform MUST at-sea trials offshore San Diego with support from ART and other subcontractors.

9. SUMMARY

When the Mobile Undersea System Test (MUST) facility reaches IOC in January 1989, Martin Marietta will have an unprecedented capability to test and demonstrate AUV technology at sea. The modular vehicle design has the versatility to support a wide range of test requirements. Beginning in 1989, Martin Marietta research equipment will be integrated according to established interface control specifications and operation of MUST as a testbed will begin. Additional requirements for the use of MUST can be accommodated because modules for the vehicle can be built, debugged, and interfaces checked in the AUV Dry Lab at Martin Marietta without using the operational system. The success of MUST will be measured by its operational reliability during at sea tests and the degree to which it meets the requirements for future research projects. The AUV technology development underway at Martin Marietta when combined with capabilities being developed by others such as fault tolerant computers, high density energy sources and improved inertial navigation will provide the foundation for operational AUVs in the 1990's.

10. REFERENCES

1. Chande, A. M., and K. M. Noon, "Obstacle Avoidance and Navigational Sensing for an Autonomous Underwater Vehicle", Proceedings of the 1986 SPIE Symposium on Optical and Optoelectronic Engineering, October 1986.

2. Dougherty, F., T. Sherman, and G. Woolweaver, "Modeling and Simulation of an AUV.", Proceeding of the Modeling and Simulation Symposium for Underwater Systems and Subsystems, C.S. Draper Laboratories, Cambridge, MA., June 1988.

3. Dougherty, F., T. Sherman, G. Woolweaver, and G. Lovell, "An AUV Flight Control System Using Sliding Mode Control.", Procceeding of the MTS/IEEE Oceans 88 Conference, November 1988.

4. Barbera, Anthony J. et. al., A Language Independant Superstructure for Implementing Real-Time Control Systems. Proceeding of the International Workshop on Highlevel Computer Architectures, 7.28-7.39, San Diego, CA., May 1984.

5. Mackelberg, J., L. Bodzin, H. McCracken, T. Diamond., Naval Ocean Systems Center Navy Case Number 71243 patent application.

6. Martin Marietta, Laser Pulse Propagation Test Summary, Report Number IRB21D0186-1, July 1986.

7. Herr, W.J. and K. Collins., "MUST - A Large Versatile AUV Technology Testbed System", Proceedings of Underseas Defense Conference., October 1987.

DIVING IN HAZARDOUS AND POLLUTED WATERS

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ABSTRACT

Diving units today are concerned with factors other than just blowing bubbles. Among potential diver hazards, the consequences of exposure to water-borne contaminants are of particular concern. Direct skin contact with certain pollutants is obviously serious business, yet more insidious dangers may result from exposure to pathogens during normal respiration, depending on the equipment worn. Standard SCUBA gear is NOT adequate protection. For several years, the NOAA Diving Program has coordinated research and development to confront diver exposure to waters containing hazardous substances. The magnitude of this problem is significant, and exposure pathways are varied. NOAA's evolution of protective diving equipment and operational guidelines provide a basis for further education and development.

INTRODUCTION

Diving units today, whether scientific, commercial, or municipal, have several safety factors under scrutiny when planning operations. The management of potential diving accidents and rescue evacuation protocols is a popular topic. The diving environment is a part of every basic diving class, where hypothermia, venomous organisms, and other hazards are required reading. But as man-made contaminants pervade our coastal waters, another significant concern should be on the diving supervisor's mind. Divers working in areas of potential biological or chemical pollution must be protected against the medical consequences of exposure to water-borne hazardous materials. The abundance of these pathogens may be surprising since detection techniques are often limited. There are also several pathways of exposure which require prophylaxis. Since the mid-1970's, the NOAA Diving Program has pursued efforts to define equipment modifications and operational procedures to confront this problem.

NOAA first became concerned with the protection of our divers in polluted waters when the Northeast Fisheries Center became active in environmental monitoring efforts in the New York Bight dump site areas. NOAA, the U.S. Naval Medical Research Institute (NMRI), and the University of Maryland, cooperated on a pilot study of the effectiveness of routine diving equipment in protecting the diver from pathogenic microorganisms found in estuarine waters[1]. The nature of the beast began to emerge.

It was soon apparent that the diversity of unsafe conditions to which NOAA divers had exposure potential was not limited to microbial hazards. Working divers today routinely dive with petroleum products, toxic chemicals, and radioactive materials as "buddies". An informal working group evolved among representatives of NOAA and the Environmental Protection Agency (EPA), U.S. Navy, U.S. Coast Guard, and commercial diving industry. A workshop under the auspices of the Undersea Medical Society brought this group together to exchange ideas and experiences[2] and an interagency agreement between NOAA and EPA secured funding for the development of procedures to ensure diver safety in contaminated waters[3].

Since every diver likes their toys, the logical first step in solving this problem involved the modification of diving equipment. The early methods employed the "shotgun" approach with commercially available apparatus. Several suits and breathing systems were evaluated for effectiveness in providing as complete an isolation from the environment as possible. Minor modifications were made to some items to increase protection, but a consensus swiftly evolved towards a system of a drysuit mated with a full-face mask or helmet.

This initial decision was the last simple one encountered. The significance of disinfection methods on materials, the system's swimmability/range of motion, and hyperthermia resulting from total encapsulation were immediately recognized.

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EXPOSURE PATHWAYS

As the diving apparatus increases in complexity, so does the surface support necessary to conduct a safe operation. Protection of tenders and topside personnel is essential and often logistically more complex. It is possible that the safest person during management of a toxic spill may be the diver!

As if that is not enough to contemplate, routine diving tasks were recognized to risk exposure to substances of at least equal consequence to well-publicized oil spills and other obvious situations. Underwater hull cleaning involves positioning a diver's head inches from toxic paints as they are introduced into the water column. Jetting of pipelines may re-suspend contaminants which have been buried in the sediment. Injuries to commercial divers working in polluted water environments, and the prevalence of associated equipment malfunctions are well known[4]. Newspaper accounts and personal communications have reported cases of police rescue divers in metropolitan areas who have experienced medical problems after working dives. Why did gastrointestinal problems cause an 80% absenteeism rate among divers one week after a training exercise in harbor waters? Possibly a case of bad taco dinners after the dive, but maybe a lot more. It is important to understand these more insidious pathways to exposure as the proper configuration of protective equipment is developed. Although pollutants in water are generally thought to be dispersed or diluted, prudent planning would have to include the chance encounter with a pocket of full strength or concentrated contaminant.

BREATHING APPARATUS

Requirements

Second only to direct innoculation, the most effective way to infiltrate the body with a contaminant is to breath an aerosol. Standard SCUBA is woefully inadequate protection against contaminants in the ambient water since the same mechanical conduit is used for both inhalation and exhalation. During a normal respiratory cycle using SCUBA, water droplets frequently congregate on the exhaust valve as it opens and closes. The next inspiration atomizes these droplets, which contain any ancillary substances as well. The importance of maintaining a dry breathing apparatus becomes paramount. The best choice is a full-face mask or helmet which minimize the number of penetrable seals and allows for separate inlet and exhaust channels.

Demand Systems

Band masks and some lightweight helmets, while giving the rugged appearance of increased protection, are really SCUBA regulator components mounted in a rubber or fiberglas hat. These systems must be modified to create a one-way gas flow and positive internal pressure to keep water out. The normal exhaust port can be blocked off and the secondary "chin" exhaust valve brought into primary use. It may also be possible to create a separate exhaust valve location using an alternate helmet penetration. Various off-the-shelf products were modified with prototypes to fully develop these ideas. Figure 1 illustrates an early design.

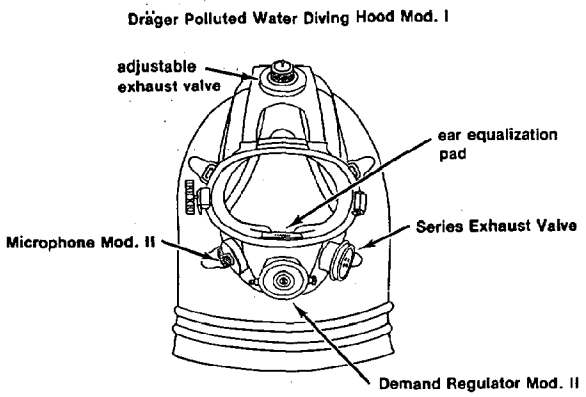

Figure 1. Initial modification of Drager Diving Mask

An exception is the AGA Divator full-face mask, which has an excellent gas flow configuration and a built-in positive internal pressure. Unfortunately, the AGA is a mask rather than a helmet, limiting its use to less than maximum levels of protection.

A useful modification to an existing exhaust port can be accomplished by placing an additional mushroom valve in line with the original (Figure 2). This series of exhaust valves (SEV) provides greater reliability and eliminates "splashback". The SEV concept has proven worthwhile, and is now available on several off-the-shelf helmets.

The diaphragm separating ambient water from the regulator demand lever is a thin, flexible membrane and a possible weak link

in the protection of the diver. Various methods have been attempted to completely cover the diaphragm and reference ambient pressure from inside the helmet, thus minimizing entry problems. Unfortunately, this disrupts the helmet design enough to cause breathing resistance.

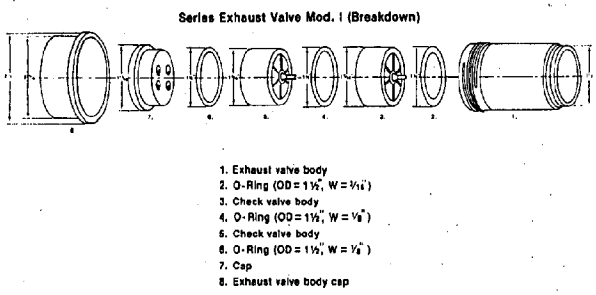

Figure 2. Series Exhaust Valve (SEV)

Free-flow Helmets

A functionally simpler configuration is inherent to free-flow helmets. Inlet and exhaust valves are separate, and the steady gas flow creates the positive internal pressure required to prevent water entry. Free-flow means a surface-supplied configuration, which has significant advantages for contaminated water diving:

Increased gas supply allows duration to be increased - of extreme significance if the diver must undergo surface decontamination while still suited up.

Diver-to-surface communications and a direct tether to the surface are essential to safety in hazardous areas.

Several commercially available free-flow hats are acceptable, provided they are capable of dry mating to an appropriate exposure suit. Some brands of drysuits may be ordered with modified neck yokes, comprising an integrated system which is "well-suited" for polluted water diving.

EXPOSURE SUITS

Certain criteria are vital for exposure suit selection. From the outset, only variable volume drysuits which permitted reasonable range of motion were evaluated. A minimum number of "breakable" seals and zippers is desirable, and boots should be attached. The exterior surface must be resistant to degradation when in contact with toxic substances and must also withstand the rigors of post-dive decontamination. Foam neoprene drysuits fail to meet these needs. Suits with smooth outer surfaces such as the Viking and Drager have demonstrated the best performance. The suit MUST mate dry to the helmet used for optimal protection.

Dry suits containing air are subject to significant pressure differentials when submerged, dependent on diver posture. If a tear occurs in the diving dress, this pressure imbalance contributes to entry of ambient water and any ancillary materials. Diver protection was considerably upgraded by an offbeat approach: design an inner, form-fitting suit for wear under the drysuit, seal the two suits together at the neck and wrists, and fill the space between with water, as shown in Figure 3.

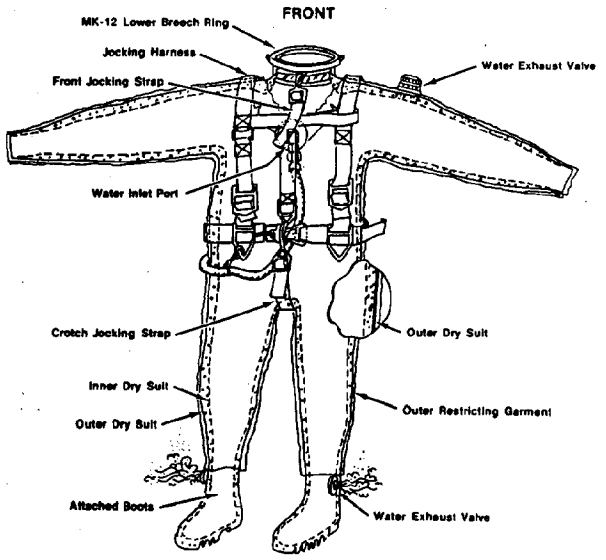

Figure 3. Dual layer, water-filled Suit-Under-Suit (SUS)

This "suit-under-suit" (SUS) design eliminates the tendency for suit infiltration, and can actually reverse the pressure differential in favor of the diver. Clean surface water is circulated via umbilical through a penetration in the drysuit and out exhaust valves installed near the ankles. This provides an outward gradient to minimize contact of toxicants with the diver's skin in case of a tear in the outer suit. The elimination of air spaces makes the entire dress neutrally buoyant and much easier to swim.

Thermoregulation is now possible, controlled from the surface and with a diver by-pass valve. This was a major step in solving the danger of overheating a totally encapsulated diver, especially working in a warm water environment. This hyperthermia can overcome a diver with minimal warning, and must be monitored closely by the diving supervisor.

The U.S. Navy MK-12 Surface Supplied Diving System, configured with a modified Viking SUS drysuit, has been selected as an optimal diver protection system for use by NOAA, EPA, and other agencies in contaminated waters (Figure 4).

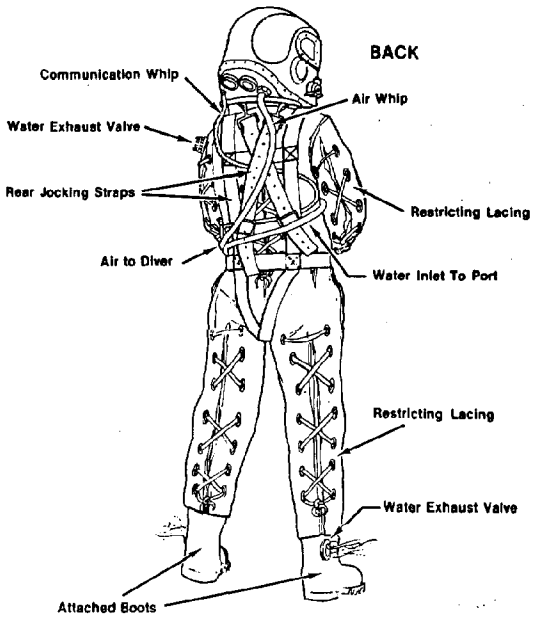

Figure 4. Detail of SUS Design for USN MK-12

TESTING

NOAA has sponsored a dynamic testing and evaluation program since this project was undertaken. Initial suit and breathing apparatus studies were conducted in clean waters, and actually began as a spin-off from other efforts. As design and implementation progressed, the testing environment was manipulated with trace chemicals[5] and dyes to evaluate system integrity[5]. Range of motion studies conducted with NMRI and UCLA showed no significant decrement[6] in range of motion for underwater work[6]. Thermal studies evaluated the efficiency of the SUS, resulting in a maximum safe operating limit of 50 degrees Centigrade (122 degrees Fahrenheit). Air-filled suits were comparatively evaluated, yielding a limit of 40 degrees Centigrade (104 degrees Fahrenheit)[7]. Additional tests at the NOAA Experimental Diving Unit in 1987 incorporated inner cooling suits. Field tests at the NOAA EDU and in Seattle, WA successfully integrated diving operations with the surface containment precautions necessary for a full-scale hazardous materials response effort[8]. The systems were ready for field operations.

OPERATIONAL EVALUATION

The opportunity for the first operational evaluation of NOAA polluted water diving systems occurred in the spring of 1987. Scientists at the Florida State University were planning phosphate mineral formation studies in an South Pacific island lake containing toxic levels of hydrogen sulfide. Diver assistance would be required to position a coring device in the lake bottom, where the H_2S concentrations approached 85 ppm. NOAA agreed to provide personnel and equipment to assist the scientific effort. A Superlight 17B demand breathing system was chosen since the transport of gas bottles was thought to be a major difficulty at the lake's remote location. A Viking SUS with a third outer jocking garment provided exposure protection. Since the diver's rising air bubbles might carry hazardous concentrations of H_2S up to the surface personnel confined on a raft above, considerable pre-planning in medical advice and evacuation protocols was prudent. Protective breathing apparatus and monitoring devices were on station for all those topside.

Unfortunate delays in the arrival of integral diving system components and several on-scene equipment failures frustrated the attempts to conduct a progression of exploratory dives on schedule. Lots of determined effort finally effected the culmination of pre-mission activities.

A six-inch, six-foot long sediment core was successfully extracted from the lake bottom during a climactic 110 FSW, 24-minute dive. Diver hyperthermia was a significant factor, primarily caused by the excessive time necessary for dress-in with this system. A simpler mating configuration of suit to helmet, such as that of the MK-12 breech-ring assembly, would have reduced this complication. In hindsight, chilling of the SUS water input would have been beneficial, although this was not indicated by previous test data.

CONCLUSIONS

NOAA's development of a safe protective system for diving in contaminated waters has been fortunate to yield many commendable results in both techniques and equipment modifications. The work is by no means complete, and remains a dynamic investigation. Here are a few salient points for any unit desiring to operate safely in hazardous or polluted waters.

Standard diving equipment (especially SCUBA) is NOT adequate diver protection in contaminated water.

Positive pressure, surface supplied breathing apparatus is optimal.

The level of protection needed requires increasingly complex equipment. Consequences like unanticipated hyperthermia may result.

Surface personnel may be exposed to at least equal levels of hazards as the diver. Coordination of topside operations is a significant undertaking, especially if these folks must wear protective clothing and breathing systems[9].

The diseases to which a diver is exposed may not be acute. Long term incubation periods may exist. Divers should maintain current immunizations, and should be monitored by supervisors for any unexplained illnesses.

Further information is available from:

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6001 Executive Blvd., Rm. 304
Rockville, MD 20852-3806

301-443-8007

REFERENCES

1. Craven, J.P. et al. 1981. Special Issue on Microbial Hazards of Diving in Polluted Waters. Marine Technology Society Journal. Volume 15 - No. 2.

2. Wells, J.M., and M. Heeb. 1983. Protection of Divers in Water Containing Hazardous Chemicals, Pathogenic Organisms and Radioactive Material. Undersea Medical Society, Report No. CR 60(CW) Z-1-83.

3. U.S. Environmental Protection Agency, and National Oceanic and Atmospheric Administration. Interagency Agreement. 1983. Diver Safety in Contaminated Waters. AD-13-F-1-826-0.

4. McLellan, S.A., and R.F. Busby. 1982. Evaluation of the Use of Divers and/or Remotely Operated Vehicles in Chemically Contaminated Waters. USEPA Contract No. 68-03-3113, Task 42-3.

5. Nash, J. 1983. Chemical Tank Testing of Modified Commercial Diving Helmets and Dress. USEPA Contract No. 68-3-3056.

6. Bachrach, A.J., G.H. Egstrom, and J.M. Wells. 1985. Biomechanical Assessment of MK-12 Dive System NOAA Modification for Anti-Contaminant Use in Contaminated Waters. Eighth Joint Meeting of the Panel on Diving Physiology and Technology. Washington, D.C. and Honolulu, HI.

7. Wells, J.M. 1985. Diving Operations in Heated/Contaminated Water. Eighth Joint Meeting of the Panel on Diving Physiology and Technology. Washington, D.C. and Honolulu, HI.

8. Stringer, J. 1985. Surviving Underwater Deathtraps. National Oceanic and Atmospheric Administration. NOAA Magazine, Vol.15 - No. 1, Winter 1985.

9. Traver, R.P., and J.M. Wells. 1984. "Summary of On-Scene-Coordinator Protocol for Contaminated Underwater Operations. International Diving Symposium '84. New Orleans, LA.

THE USE OF NITROGEN-OXYGEN MIXTURES AS DIVERS BREATHING GAS

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ABSTRACT

"The Use of Nitrogen-Oxygen Mixtures as Divers Breathing Gas" discusses the use of nitrogen-oxygen mixtures as a substitute for air by divers, detailing their advantages in terms of reduction of decompression obligation and extension of "bottom time".

The paper concentrates especially upon the use of such mixtures by the NOAA Diving Program and the experience gained thereby. The NOAA-developed mixture known as NOAA NITROX I, in use since 1978, has been gaining increased acceptance in the diving community. A new mixture, NOAA NITROX II, is still in the process of development. The NOAA-developed Continuous NITROX Mixer is also discussed.

INTRODUCTION

Air has been used as a breathing gas by divers since the beginning of diving. Its principal advantage is that it is readily available and inexpensive to compress into cylinders or use directly from compressors with surface-supplied equipment. It is not the "ideal" breathing mixture because of the decompression liability which it imposes. Since decompression obligation is dependent on inspired nitrogen partial pressure and time, not "depth and time", this obligation can be reduced by reducing the nitrogen content of divers breathing gas and substituting for the removed nitrogen a gas which is metabolized away by the body, i.e oxygen.

NITROGEN-OXYGEN MIXTURES

The toxic properties of oxygen at elevated pressure limit the depth and time to which it can be breathed pure or as a component of a nitrogen-oxygen (NITROX) mixture. If both the toxic properties of oxygen and its decompression-obligation-reducing properties are taken into account, an "ideal" gas mixture for any depth/time combination can be produced. Such a mixture would offer the maximum decompression advantage without the risk of oxygen toxicity. Advantages of such a mixture relative to air are:
1) extension of "no-decompression" time limits, 2) reduction of decompression time if no-decompression limits are exceeded, and 3) reduction of residual nitrogen in the body following a dive. The latter would either increase the time allowable on repetitive dives or reduce the surface interval required to make repetitive dives, or both.

The decompression procedure which must be followed when NITROX is used is based on the concept of "equivalent air depth" (EAD). This procedure equates the inspired nitrogen pressure of a NITROX mixture at one depth to that of air at another depth, the EAD. This procedure has been used for over 20 years with semi-closed and closed-circuit mixed-gas underwater breathing apparatus. Such equipment is both very expensive and complicated.

NOAA NITROX

In 1978, NOAA introduced diving procedures and decompression tables for a standard mixture of 68% nitrogen, 32% oxygen called NOAA NITROX I (NNI). It can be used with normal SCUBA or surface-supplied equipment, and is the best general-purpose NITROX mixture for use in the 30- to 130-foot depth range. The NNI tables (Appendix E of the NOAA Diving Manual) are identical in format and use to the U.S. Navy Standard Air

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Decompression Tables, thereby eliminating the necessity of learning to use a new set of tables and providing a means of mixing air and NNI dives. During the last few years, there has been an increase in the acceptance and use--and misuse of NITROX by the diving community. Figure 1 compares the no-decompression limits of air and NNI.

The use of NNI approximately doubles the no-decompression limits at most depths. One "not-so-obvious" advantage is the extension of useful "on-the-bottom" time. At 130 feet, the no-decompression time for air is 10 min. while the NNI no-decompression time is 20 min. If two minutes are required for descent, air gives the diver 8 minutes of useful time at depth while NNI will allow 18 minutes.

Figure 2 shows the repetitive groups for air and NNI for dives to the same depth and time. The repetitive groups, and thus the residual nitrogen times, are significantly lower for NNI. This is of great value in reducing the surface interval between dives and/or extending the time of repetitive dives. The net result of all of the above is more bottom time per day.

Figures 3 and 4 show the advantages of NITROX use in repetitive diving to several depths and with different surface intervals.

Economics and time savings are key factors with respect to diving operations. Breathing gas mixtures are normally prepared by mixing oil free, pure gases in appropriate proportions and checking the mixtures with oxygen analyzers. The expenses associated with the purchase of gas, equipment, and utilization of qualified personnel can be significant. So can the consequences of shortcuts and/or poor procedures. For example, traces of oil in a high pressure oxygen mixing or pumping system can lead to an explosion. Too much or too little oxygen in the mixture could lead to oxygen toxicity or decompression sickness. The extreme case of accidental use of pure gases (N_2 or O_2) has proven to be fatal.

Personnel time and ship time associated with diving operations can also be significant. The increase in useful "bottom time" which is provided by the use of NITROX mixtures often makes it very cost-effective. The reduced nitrogen pressure at depth slightly reduces nitrogen narcosis. During ascent and decompression stops, it also reduces the probability of decompression sickness. The subjective post-dive feeling of "well-being" (reduced fatigue) reported by some users suggests that sub-clinical DCS is reduced. Subtle effects of increased oxygen pressure on nitrogen uptake and elimination remain to be determined.

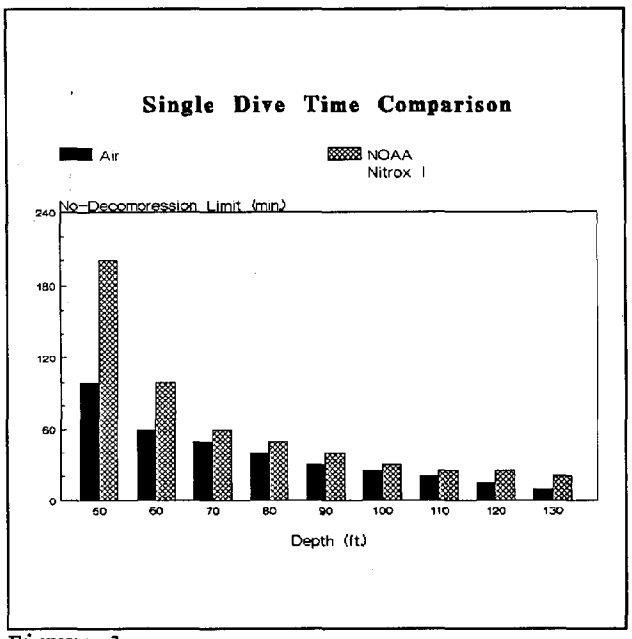

Figure 1

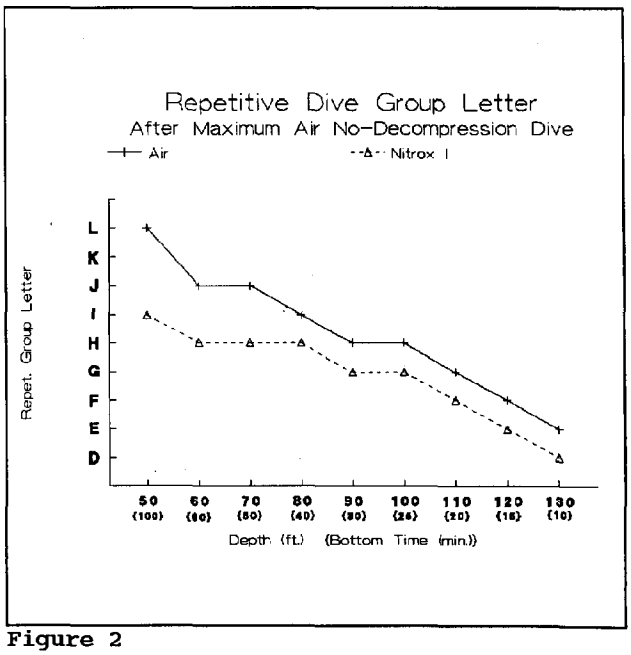

Figure 2

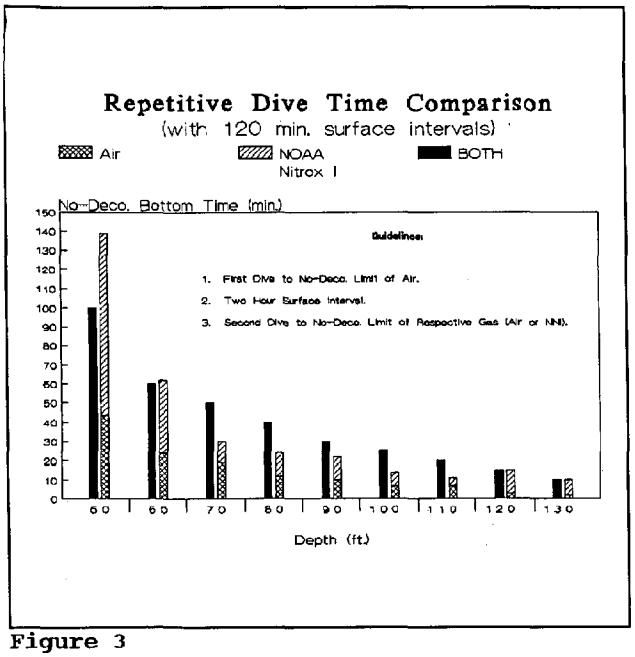

Figure 3

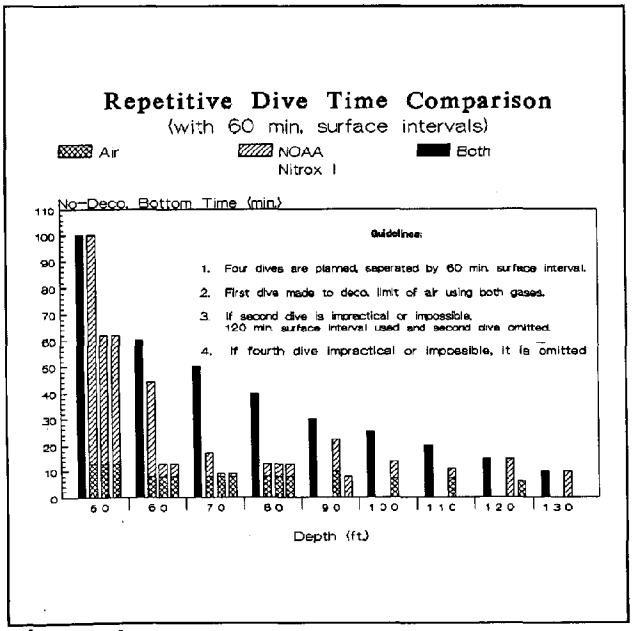

Figure 4

Another NITROX mixture, NOAA NITROX II (NNII) is currently being evaluated. It contains more oxygen than NNI, thereby reducing the decompression obligation even more, but its use will be limited to depths of 100 feet or less.

THE NOAA CONTINUOUS NITROX MIXER

The NOAA Diving Program recently developed a system for mixing air and oxygen at atmospheric pressure, and compressing it to pressures of over 3,000 psig. Oxygen concentrations from 21-40% can be easily and accurately mixed. The system utilizes a "non-oil-lubricated" compressor, and the design is such that both large storage cylinders and SCUBA cylinders can be filled and/or cascaded simultaneously. This feature eliminates the requirement for a gas booster pump, and significantly reduces the cost and time required to prepare NITROX.

Three NOAA Continuous NITROX Mixer units (Fig. 5) are currently in use at NOAA diving units, and Hyperbarics International recently installed a system on Key Largo. For the preparation of large quantities of NITROX (in oxygen-clean systems), mixing of pure oxygen and oil-free air is probably the most "time effective" method. The use of pure oxygen and nitrogen is an obsolete method of preparation. NOAA has established a color coding and labeling system for NITROX mixtures (Fig. 6), and uses dedicated cylinders for NITROX. Air is never put in NITROX cylinders and NITROX is never used in air cylinders.

A final analysis for oxygen is conducted by the diver prior to using NNI.

TRAINING

Training of NOAA working-level divers in the use of NITROX in open circuit SCUBA requires one day; a four-hour lecture period and a four-hour practical session. The lecture portion includes a heavy emphasis on oxygen toxicity. The potential consequences of misuse of NITROX, decompression and repetitive diving procedures, and mixing air and NITROX repetitive dives are covered. The practical sessions include safe handling of oxygen-rich gas mixtures, gas sampling, and oxygen analysis. Brief written and practical exams are given in the afternoon. These divers are "users" of NITROX. Training in the preparation of mixed gases is considerably more extensive, and generally limited to unit diving supervisors or those divers responsible for diving lockers and breathing gas preparation. Due to the extra cost, equipment, complexity, and training required for the use of NITROX, its use in NOAA is currently limited to those diving units to which it can make a

significant contribution to cost effectiveness. As its advantages become better known, we anticipate more requests to establish mixing systems at diving units.

OTHER CONSIDERATIONS

In addition to its relatively recent use in open-circuit SCUBA, NITROX has long been used in closed-circuit mixed-gas underwater breathing apparatus (UBA)[1]. These units maintain a constant partial pressure of oxygen rather than a fixed percentage of oxygen as do open circuit units.

When the oxygen pressure is set at a level where the percentage of oxygen at a particular depth is greater than that in air, the EAD is less than the actual depth, providing a decompression advantage over air.

Helium-oxygen (HELIOX) mixtures are normally used on deep dives to eliminate nitrogen narcosis. At shallow depths (less than 150 fsw) HELIOX offers a significant decompression advantage over NITROX. However, the cost of helium and the complexity of breathing gas preparation make HELIOX impractical for use in shallow diving with open-circuit UBA. In closed-circuit UBA, where exhaled gas is recirculated, HELIOX becomes very economical, and is actually the breathing gas of choice.

Currently, the cost and complexity of closed-circuit UBA limits its use to the military and highly specialized diving units. NOAA is currently working with private industry, scientific diving organizations, and other government agencies to maximize the utilization and availability of mixed gases and closed-circuit UBA at reasonable cost.

CONCLUSION

Mother Nature provided the planet Earth with a NITROX atmosphere known as air. She never said that air was the best breathing medium for divers. Here, as in many other fields of endeavor, human beings have used their knowledge of natural laws to go one step beyond what Nature has provided for them.

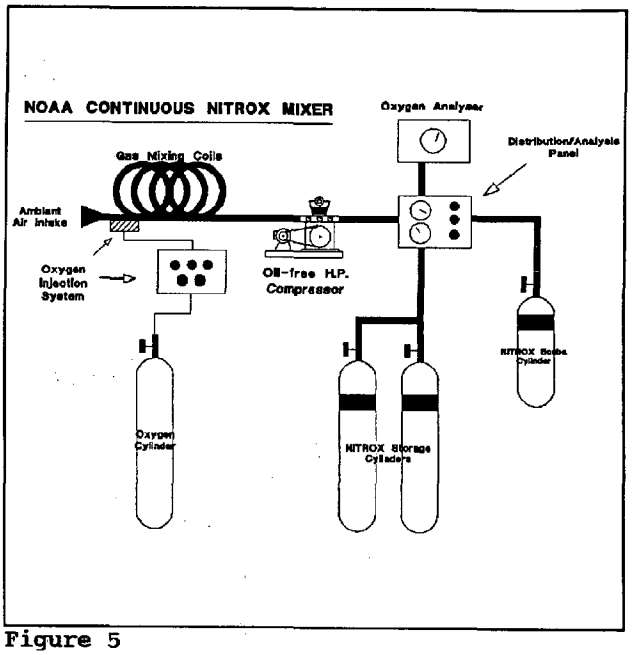

Figure 5

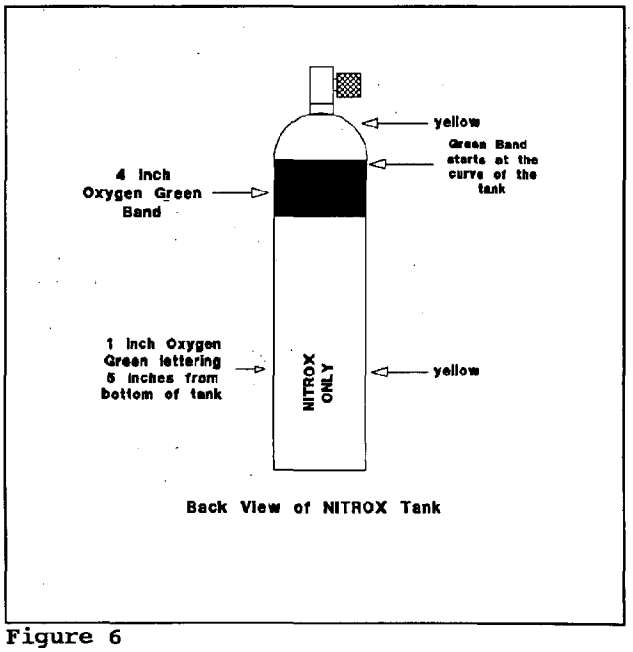

Figure 6

[1]. For example, the U.S. Navy Mk 15 and Mk 16 and the Biomarine CCR 155.

INTEGRATED REMOTE SENSING OF DIVE SITES

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ABSTRACT

A par avant survey of dive sites using remote sensing equipment increases the efficiency and success of any dive program performed for ecological, geological, archaeological or other specific search and survey purposes. The type of equipment deployed can include side scan sonar, sector scanning sonar, magnetometers, profilers, very high accuracy positioning systems or a combination of this equipment depending upon the focus of the dive program and general hydrography and geology of the area. Pre-dive survey and analysis whether through the use of a single piece of remote sensing equipment or a combination is further enhanced by integration of data on computer. The use of remote sensing, the integration of data and its use on dive surveys is demonstrated by four examples of at sea surveys. These examples relate to programs of specific search, fisheries research and nautical archaeology.

INTRODUCTION

Remote sensing underwater was in its infancy until the development of the acoustic bathymetric sounder in the 1930's. Since the first third of this century, every decade has produced great strides in the development of equipment and techniques to remotely sense and image both natural and man made structures underwater. In the late 1980's the use of this equipment and the development of integrated remote sensing techniques have greatly increased our ability to predict the environment and existing conditions before commencing diving operations whether by manned submersibles or by divers alone.

Without a full understanding of the conditions surrounding a dive site, dive operations become more time consuming and often have less predictable results than if the site is surveyed beforehand.

Acoustic imaging with both accurate high frequency bathymetric sounding equipment and side scan sonar is usually the first equipment chosen for remote sensing operations but both the magnetometer and ROV's can provide information that may not be detected by either of these imaging systems.

Planned survey methodology and proper employment of the tools selected is also necessary to maintain the quality of the remote sensing data recorded. Often, when the exact location of a dive target is not known, a search is required prior to dive operations. For recently lost targets, thorough research of wind, deep water currents, wind driven surface current, last known location of target as well as potential target location on the seabed is necessary to provide the highest probability of success in the shortest amount of time. For older targets research is necessary of historical loss records, bathymetric charts, and target construction details.

The tools used to pinpoint a dive site are often chosen as a result of such research. The environment in a specific dive area may preclude the use of any of the survey tools. Rugged geology, for instance, complicates the use of side scan sonar in both operations and interpretation of the sonar record. On the other hand, high current velocities, while having little effect on most sonar systems, make the use of many smaller, less powerful, ROV systems impractical. Searching for small targets using a proton precession magnetometer in areas of geological formations containing magnetite can be difficult at best. High noise environments often complicate the use of acoustic mapping systems. When the environment is not optimal for common remote sensing systems, a combination of systems will often provide the data needed to complete the dive operation with minimal time and cost.

METHODS

Often in cases of marine survey using towed systems, the water depth, type of operation, and bottom type will dictate the best methods to use. However, for the described examples, the methodologies included the following parameters:

For Side scan sonar operations, scanning ranges were between 25 m and 150 m per side. On the shorter ranges, in order to gain the best possible resolution, 500 kHz was the primary frequency used. At the longer ranges, 100kHz was used in order to minimize attenuation over the longer acoustic travel paths.[1] Tow speeds ranged

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from two knots for specific target mapping to six knots for large object search operations. During search operations, lane spacing was between 100 meters per side to 250 meters per side. For all sonar operations, primary support vessel positioning was achieved by using LORAN C.

During magnetometer searches, tow speeds ranged from 0.5 to 4.0 knots. Speeds were determined by target mass and the water depth at the dive site. Lane spacing was five meters for small targets and up to 30 meters for large targets. Three types of positioning were used to position the support vessel during magnetometer deployments. For operations using wide lane spacing, LORAN C was adequate enough to maintain vessel track. For operations to map or locate smaller targets, either a radio transponder net was set up on shore or visual surface markers were used to maintain vessel track. The latter technique is difficult unless the search area is small, the water depth shallow and current almost non-existent.

During ROV operations, the surface vessel was usually positioned into a multi-point moor over the dive site. Often at depths where an ROV is required and especially if there is any current, a downweight system is married to the ROV umbilical. A length of free umbilical off the downweight line allows for ROV maneuvering. The length of the free tether is dependent on the maneuvering required and the hydrographic conditions encountered at the site.

Detailed mapping of a specific shipwreck was done with a Sonic High Accuracy Ranging and Positioning System (SHARPS). Deployment of SHARPS was accomplished by placing the surface vessel in a 3 point moor over the dive site. In order to calibrate the acoustic grid on the site of the *HARRIET S JACKSON*, the team measured the speed of sound in the water using two of the receiving stations. Three transceivers were then set up on the 1st or 2nd futtock of the frames on the wreck. Extreme care is necessary when positioning the transceivers to insure that they are absolutely stable during the mapping process. These transceivers were set in a triangle forming a plane to which 3-D measurements are referenced. The sea's surface was the reference plane for locating the vertical position of the receivers and the distance measured from this datum and recorded. When this was accomplished, three divers, working in rotation, mapped the site using a trigger fired acoustic "gun".[2]

For planning search programs for recently lost targets, computerized drift studies were required to narrow the search areas. The northeastern coastal region is very tidally active and flotsam can often be tracked back to a point of loss.[3] This work was performed by Dr. Richard Limeburner of The Woods Hole Oceanographic Institution. To back track flotsam from a terminal location drift was broken into the three components of wind, tide and low frequency current. All three components were used to determine a path to the source. Limeburner modified conventional wreckage drift analysis by factoring the wind drift speeds by the amount of windage or keel the flotsam possessed.

MATERIALS

All the magnetometers used for the surveys were of a proton precession design. The equipment used included a Geometrics model 806, a Geometrics model 866 and a Barringer model M-123. All magnetometers were interfaced to a computer using custom interfaces designed and manufactured by Marine Systems Technology. These interfaces allowed magnetometer and positioning data to be logged to a single RS-232 computer port. Because of it's portability, the computer used was a Zenith model 182 laptop. The data was then transferred to a 386 based desktop computer and processed into contour and isometric projections.

SHARPS, manufactured by MTI Pocasset, MA consists of four small transducers each capable of transmitting or receiving high frequency acoustic signals. A 386 based desktop computer controls system operation including acquisition, processing display and output of position data. Each transceiver is connected to the system controller through a coaxial cable which provides power and a data path.

The side scan sonar used for the pre-dive surveys include an EG&G Image Correcting, dual frequency model 260 and a Klein model 401. These systems provided high resolution images at ranges of 100-200 meters from the tow path as well as being capable of short range close-up inspection of targets. Positioning was performed by either a Northstar model 800 LORAN C or a Motorola MR III positioning system.

RESULTS AND DISCUSSION

Search

In 1908 the steamship *YANKEE* sank off the coast of New Bedford, Massachusetts. Subsequent salvage efforts were unsuccessful and the ship was extensively dynamited to minimize it as a hazard to navigation.

In a pre-dive survey of the wreck the tools chosen were a side scan sonar and a magnetometer. Because of the large size (>100 m) of the target and its probable location in shallow water (10 m) on a moderately flat seabed, a side scan sonar was the first tool used to search for the site. Ranges used were 150 m per side and lane spacing was 250 m providing 33 per cent overlap during the search. Tow speeds of 6 knots were deemed appropriate for a target of this size at 150 meters range.[4] Once located the target was imaged at progressively lower speeds and shorter sonar ranges.

The outline of the shipwreck (A) and surrounding seabed is shown in Figure 1. In normal sonar

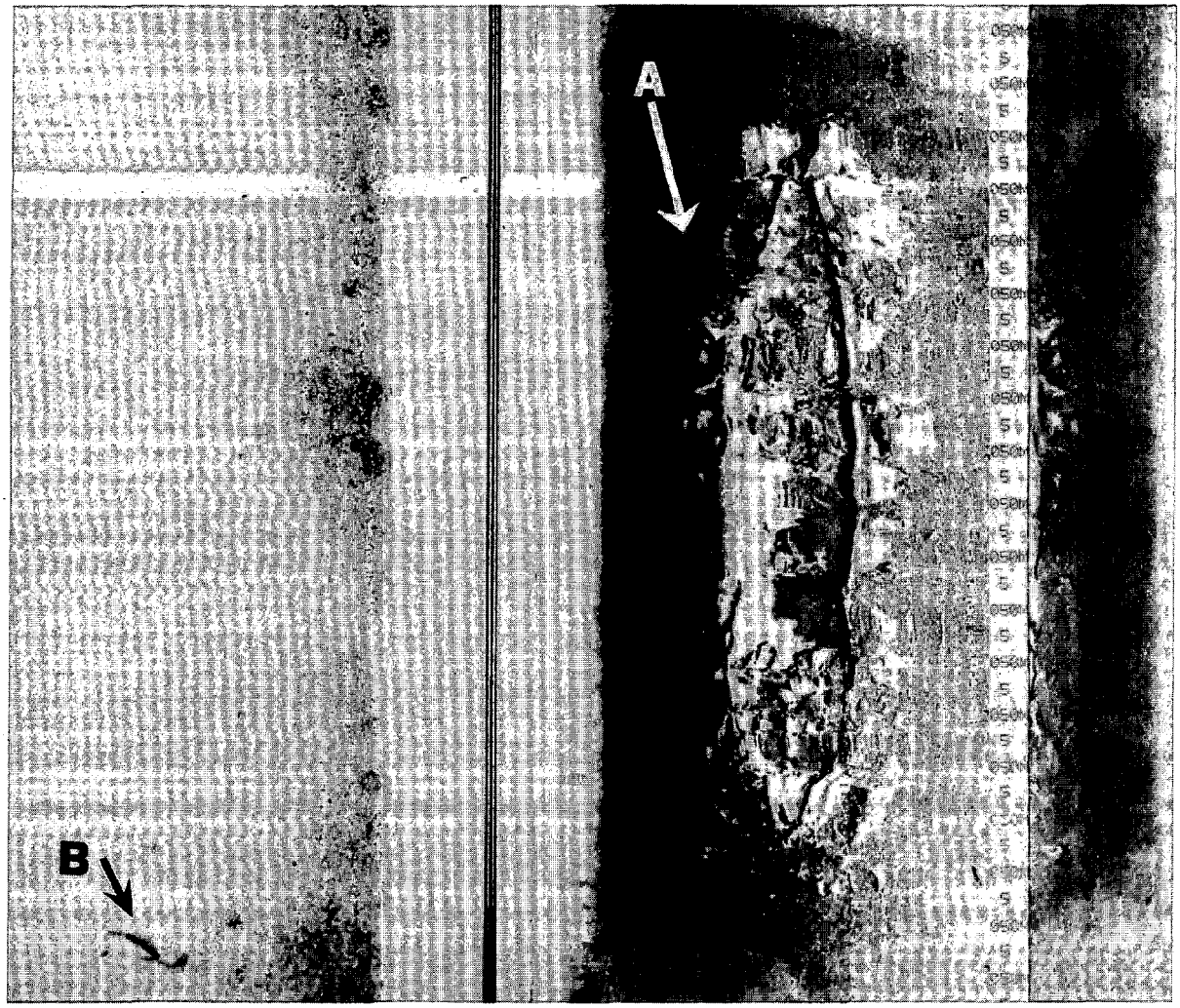

Figure 1: Side scan sonar image of the remains of the steamship *YANKEE* (A). Due to dramatic changes in seabed make-up and reflectivity, an isolated target (B) is barely recognizable in relation to the primary target.

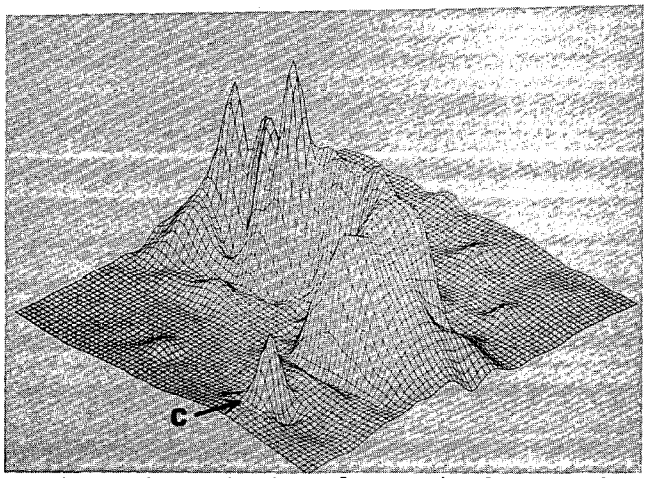

Figure 2: An isometric projection of magnetic data at the site of the steamship *YANKEE*. A magnetic anomaly (C) separate from the main wreckage has appreciable ferrous mass.

operations the small target (B) may easily go unnoticed considering the large size of the primary target and the difference in bottom reflectivity of the seabed surrounding the two objects.

A magnetometer survey was made at the site to determine the amount of buried debris around the prime target. The data was processed into an isometric projection for easier visual interpretation (Figure 2). The magnetic survey shows a large amount of scattered debris that probably occurred during the demolition. More importantly, the position of the magnetic anomaly (C) shown in Figure 2 was determined to be the same as target (B) in Figure 1. It was subsequently scanned with sonar at close range and high frequency. A 500 kHz sonar record of the target shows that it had considerable relief from the seabed (>1m) as evident by the size of the acoustic shadow. (Figure 3) Dive results on this target identified it as being a large section of hull plate from the main body of the shipwreck.

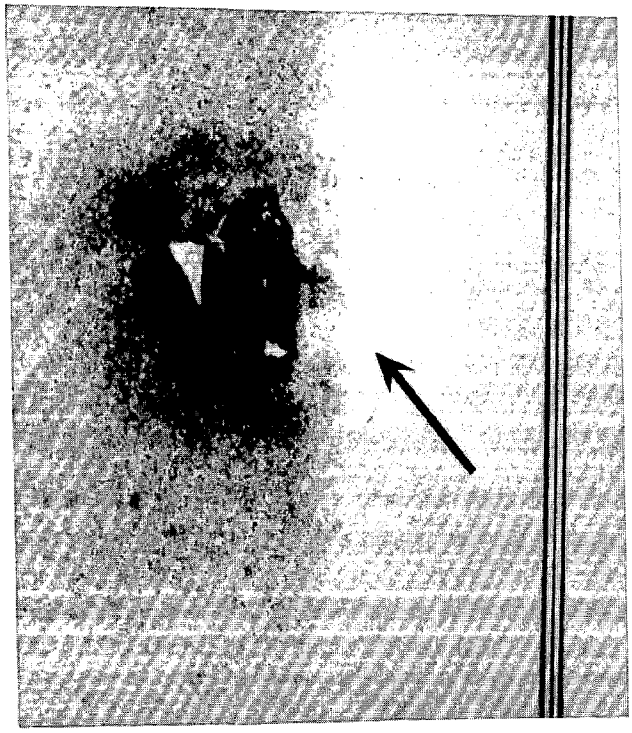

Figure 3: A short range sonar scan of targets B and C (Figures 1 and 2) shows a sizable section of debris with relief from the seabed of over 1 meter. Divers identified this debris as sections of hull plate, probably blown away from the main wreckage during demolition.

By combining both sonar and magnetometer data it was possible to determine the integrity of the main target and the distribution of any other anomalies around the main site. This made dive operations and identification of the debris field far easier and less time consuming.

In searches for downed aircraft, sonar is an essential tool. The possibility of search operation success, particularly in aircraft search, can be increased by integration of a variety of data from several sources. This can best be illustrated by the following two examples. The aircraft in each example was tracked by FAA radar and lost without warning. The search plan relied on the radar plot information and computer generated current and wind drift of aircraft debris. The radar plot would normally be the location to center the search. Debris from the aircraft can be used to generate a current and wind drift model that may further confirm the center of the search area. The degree of error is obviously a function of the duration between actual loss and the time the debris was recovered. Error is also a function of the quality of data available on current and tide. As the error enlarges, the most probable search area increases in size.

The first aircraft search, conducted off Block Island, RI, was based solely on what was believed to be accurate radar information. A sonar search of the probable impact area did not result in any likely targets. Twenty three days after the aircraft disappeared, small pieces of debris confirmed to be from the subject aircraft, was located 60 miles from the search area. At this point wind, tide and low frequency current data were assembled and processed into a drift plot and search area.

Because of the time between the aircraft loss and the finding of the debris, the new search area was large. The area was also well-removed from the area searched on the basis of the radar information. But based on this new data and the redirected search a likely target was located with sonar five days later. The target, once located at long sonar ranges and high tow speeds, was repeatedly scanned at close ranges. Since these high resolution sonar runs did not exclude this as the suspect aircraft, a small ROV was used to video the target. The ROV confirmed that this was indeed the badly broken remains of the lost aircraft.

In the second example, a search was conducted for a light aircraft lost off the island of Nantucket, Massachusetts during a landing approach. Other than a portion of landing gear found approximately 10 hours after the incident, no flotsam was ever located. For this search, wind drift computer analysis of flotsam in the Nantucket Shoals area was also provided by Dr. Richard Limeburner.[5] His results provided a drift of the debris over the previous 10 hours. Side scan sonar was used as the primary search tool with divers confirming sonar targets. The computer generated drift plots, coupled with the FAA radar tracking data, were used as a primary basis for the sonar search plan.

Although many sunken aircraft are found near-intact, our analysis of the FAA radar and control to aircraft communications suggested that this aircraft impacted the sea surface at high speed. We therefore analyzed all targets very carefully.

A pre-sonar search included a fly over at low altitudes by a fixed wing search aircraft. From the air, one target was located and subsequent sonar inspection and research proved it to be a steel shipwreck approximately 20 years old.

A number of other targets were found and positioned using the side scan sonar. The area surrounding Nantucket Shoals has moderate to high tidal currents and for this reason positioning the target accurately before the dive operation was important. One target in particular provided an acoustic reflection much like that of a fixed wing aircraft with proper dimensions and shadowing. The target position was carefully determined and the surface vessel moored in a one point moor. Divers were deployed to the site. The target proved to be a mooring block and chain assembly discarded or lost from a offshore navigational buoy. The divers inspected the site carefully to be sure that the lost aircraft was not in the region or being masked from the sonar by the old mooring. They found that the mooring block and portion of the chain made up part of the target while the remainder of mooring chain had fallen to the seafloor perpendicular to the block. This orientation gave the entire assembly the appearance on the sonar record of a light aircraft. This particular search was suspended during the winter of 1987-88 without locating the aircraft, but further work is planned in the region indicated by the drift plots.

Fisheries Research

In 1978, the town of Yarmouth, Massachusetts obtained approval to construct a tire reef in adjacent Nantucket Sound. The approval was conditioned on a monitoring program proposed and undertaken by the Massachusetts Division of Marine Fisheries.[6] The Division combined diving observations with sonar imaging to assess the potential of the site, the construction of the reef as to density and distribution of tire units, and stability of the tire units.

The typical tire unit placed on the reef consisted of four tires secured together by non-metallic bands, vented at the top, and ballasted with concrete. The tire units were placed at random within a 200 meter diameter circle.

The reef was located in shallow water, about 30 feet. The area was therefore subject to the energy of any major storm out of the south. After 515 tire units were deployed, a sonar record was made of the reef. The record allowed divers to more efficiently survey the tires because they could better plan their dive survey. Underwater visibility was ten feet maximum, so divers were unable to accurately log distribution.

A comparison of two sonar records of the tire reef, one taken in 1981 and the other in 1988, indicate that the reef is generally stable. Changes in the distribution of the tire units in some isolated areas of the reef, we believe to be caused by some commercial fish trawling activity that has been reported on the site (Morris Johnson, Yarmouth Department of Natural Resources - personal communication).

The reef still must face the forces of a severe hurricane. Several storms with southerly winds up to 50 knots have hit the area. One hurricane with winds between 60 - 80 knot winds also impacted the area in 1984. None of these winds have caused sea conditions that appear to have changed the tire reef distribution.

Nautical Archaeology

In another example, a shipwreck having sunk in 1893 began to emerge from the sands of the high energy eastern coastline of Cape Cod and was located by a local fisherman. Our historical records indicated that the wreck was the barkentine *HARRIET S JACKSON*. We made a reconnaissance dive on the site and found a remarkably well-preserved sailing vessel in this shallow marine shoreline. The keel and many of the frames and inner timbers were present. This suggested that the vessel may have quickly buried after it came ashore and may, as many shipwrecks in this vicinity do, become periodically exposed for short periods of time. That possibility could best be answered by a multidisciplined remote survey of the site. We further decided to determine how discreet the site was and to utilize SHARPS to record the construction detail of the exposed remains.

First, the site was acoustically imaged using an EG&G model 260 Side Scan Sonar and dual-frequency towfish. The sonar image supported the divers reconnaissance observations but also provided spatial relationships of the site components. The divers noted that the foremost frames of the vessel were gone and that the forward part of the keel and keelson were slowly separating from the body of the ship.

The side scan sonar record was the first large scale, two dimensional plan view of the wreck site which provided an important quantification of the vessel remains on the site.

A magnetometer was used to survey the site to determine if any anchors, chains or other iron fittings were present but buried around the site. Although the vessel's hull was primarily fastened with copper and bronze, she had iron sister ribs installed sometime after her construction. These sister ribs were not observed during the initial reconnaissance dive; they did present a significant read-out on the magnetometer and this construction detail and source for the unexpected magnetic anomaly was later confirmed by divers. The magnetometer survey indicated that the portions of the vessel that were missing for the wreck were not in the immediate area of the wreck. The absence of anchors and chains led the team to believe that the wreck had been quickly salvaged between the grounding and several weeks before the upper decks were destroyed and the remaining hull buried by a storm.

Since there was a considerable amount of relief to the site the team realized that that a three dimensional representation would be required to fully document the site. The SHARPS was deployed on the site to map the wreck in three dimensions. Aboard the support vessel the survey team was able to fully monitor the progress of the mapping. The computer screen displayed the position of the probe as the diver traced out the lines of the keel and frames where they protruded from the sediment. Approximately one third of the way forward from the stern some ceiling planks were intact and these were plotted by the diver swimming along the joining edges and triggering the transmitter at intervals of three centimeters.

Each of these data points were automatically recorded by the computer. The total time it took for the diver to map the site was just over three hours. In that time, the system recorded 10,000 data points directly to the computer.

Since the three axis data is accessed sequentially, the resulting line drawing is a three dimensional representation displayed on a CRT and printed on a plotter. A further advantage of the 3-D data is that it can be rotated on the CRT by the computer and printed or examined from a variety of perspectives.

The integration of remote sensing and detailed mapping of this site provides us with complete information about the wreck and its surrounding environment. Not only is the map of the site excellent documentation with which further deterioration of the site can be assessed but also later work on the site by divers can be greatly aided by the application of these instruments.

Work In Progress

A project still in progress is a fisheries investigation and survey of one ghost gillnet that was lost on Jeffries Ledge, in the Gulf of Maine. The net was first found during a three year study of derelict demersal nets using submersibles and subsequently re-surveyed every year since 1984.[7] Recent surveys have been with an ROV during months when a submersible was not available. Efforts to map the net with either a side scan sonar or sector scanning sonar have been frustrated by weather or operational problems. However, the investigation is documenting the impact of the net, especially during winter months, which is of particular importance because important groundfish, such as cod, are present.[8]

CONCLUSION

All of these examples integrate one or more combinations of instruments that give the researcher, program manager, or diver means to better document, search, or understand the subject of their work. The shipwreck site information was better described with the use of the combination of the magnetometer and sonar or through the use of these two instruments and SHARPS. The fisheries research which utilized divers and the sonar continues as the distribution of the tire units in successive sonar images are being compared with the use of a computer. The use of computer generated drift plots for debris from downed aircraft coupled with sonar and ROVs will assist dive operations to recover submerged aircraft.

Integration of instruments and onboard computers, especially on small craft and through relatively inexpensive means will allow the researcher or group with a modest financial capability to acquire data that will justify and satisfy their honest effort. Also the combination of data that can be gathered increases an overall understanding and interpretation of the conditions at the site. The operation may not always be successful, as in one of the one of the aircraft searches mentioned above, but the quality of the operation and the chance of success is greatly increased.

The ability and means to integrate remote sensing instruments and the computer will remain dynamic and relate to (even more) modest financial demands and increasing personal innovation.

REFERENCES

1. Fish, J. P. *State of the Art Sonar Images.* Skin Diver Magazine, January 1983

2. Fish, J. P., Carr, H. A. and Geisel, F. A. *SHARPS: High Accuracy Mapping Of Submerged Shipwrecks.* Sea Technology, March 1988

3. Butman, B., Beardsley, R.C., Magnell, B., Frye, D., Bermersch, J.A., Schlitz, R., Limeburner, R., Wright, W.R., Noble, M.A. *Recent Observations Of the Mean Circulation on Georges Bank.* Journal Of Physical Oceanography, 12 (6), p.569-591

4. Fish, J. and Carr, H. A., (unpublished manuscript) *Seabed Target Detectability Using Wide Area Search High Speed Sonar Tow Methods.* Technical Note No. 12, 1987,(available from: American Underwater Search and Survey)

5. Limeburner, R., Beardsley, R.C. *Seasonal Hydrography and Circulation Observations on Nantucket Shoals.* Journal Of Marine Research Supplement 2,40, 1982 P.371-406

6. Carr A. and Amaral E. H., *Review of the Potential for Artificial Reefs along Coastal Massachusetts.* Proceedings MTS OCEANS 81, 1981

7. Carr, H. A. and Cooper R. A. *Submersible and ROV Assessment of Ghost Gillnets in the Gulf of Maine.* Proceedings MTS OCEANS 87, 1987 (p. 622-624)

8. Carr, H. A. 1988 *Long Term Assessment of a Derelict Gillnet In The Gulf of Maine.* MTS OCEANS 88, 1988 (Manuscript in process)

HUMAN POWER GENERATION IN AN UNDERWATER ENVIRONMENT

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ABSTRACT

A pilot study of SCUBA divers pedaling an underwater bicycle/ergometer is described. The ergometer design and experimental procedure used for tests on 14 male and female subjects in the age group 22-46 is presented. The average useful power output for subjects who are regular bicyclists or who participate in a regular exercise program was 0.12 HP at the optimum cadence of 50 rpm. Non-bicyclists and less fit subjects tended towards a lower cadence for maximum performance. These results, and the test subjects' reactions to the tests, are discussed in relation to the design and safety of a human-powered submersible.

INTRODUCTION

The 1st Annual International Submarine Races will be held in West Palm Beach, Florida on June 23-25, 1989. The competition is for small subsea vehicles, propelled solely by human power, which will be judged on their speed, cost-effectiveness and innovation of design. Entries will be limited to free flooding submarines, having two crew members sustained by SCUBA equipment. Sponsored by the H. A. Perry Foundation and the Department of Ocean Engineering at Florida Atlantic University, the competition is intended to inspire innovative research and development in the areas of hydrodynamic efficiency, propulsion, and life support systems for subsea vehicles. With the restriction of human power, the designer's attention must focus on the optimization of these critical parameters.

In addition to its organizational involvement, Florida Atlantic University will also be entering a vehicle in the competition. Background research into previous human-powered vehicle projects showed that pedaling is the most efficient method of converting human power to mechanical power [1], so this type of transmission was chosen for the vehicle design.

There is generally a certain pedaling rate (cadence) which is most comfortable for an individual bicyclist on land and which is easiest to sustain for long periods of time. This phenomenon is well known to racing bicyclists and much work has been done to determine the optimum cadence [2]. Maximum power is achieved at approximately 90 rpm.

The optimum cadence for a SCUBA diver moving his limbs against water resistance should be lower than for the bicyclist in air and the 'useful' power transmitted to the pedals will also be lower. Some research in this area has been done by the Navy Experimental Diving Unit in Panama City, Florida, who conducted a series of tests on diver work performance between 1971 and 1978 [3, 4]. Their data was collected under conditions of high pressure and below normal temperatures, using a bicycle-type ergometer. Trained Navy divers were tested in a flooded hyperbaric chamber at simulated depths of up to 1600 feet of sea water (fsw).

The Navy studies were primarily concerned with the effects of extreme pressure and cold. Since the human-powered submarine races will be conducted in semi-tropical waters off the coast of Florida, at depths less than 20 fsw, this earlier research does not apply to the conditions that the race competitors will experience. Therefore the present project was undertaken, with the following objectives:

a) to measure the maximum sustained useful power output of a SCUBA diver when pedaling
b) to assess the optimum underwater pedaling cadence
c) to gain experience dealing with SCUBA divers exercising at high workrates and appraise the safety hazards.

This paper describes the ergometer design and experimental procedure used for a series of tests on fourteen SCUBA divers. The results are discussed in relation to the design and safety aspects of a human-powered submersible.

TEST EQUIPMENT

The experience of earlier research in the area of human-powered vehicles suggests that a recumbent bicycling position is the most efficient [5]. Therefore, a recumbent frame was salvaged from a previous man-powered land vehicle project and was

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converted into the underwater ergometer shown in Figs. 1 and 2.

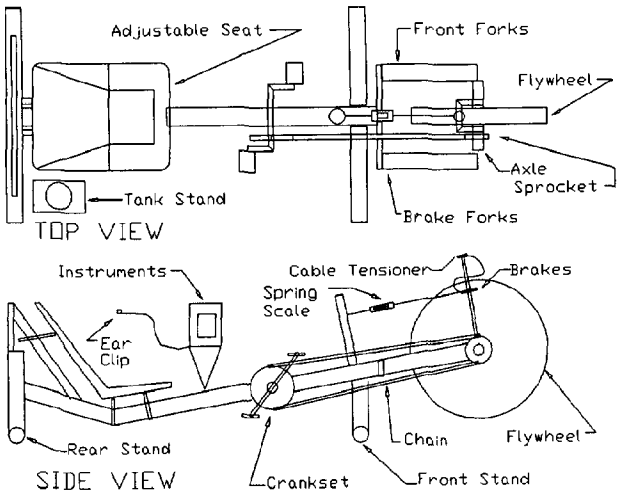

Fig. 1. Schematic Diagram of the Bicycle/Ergometer

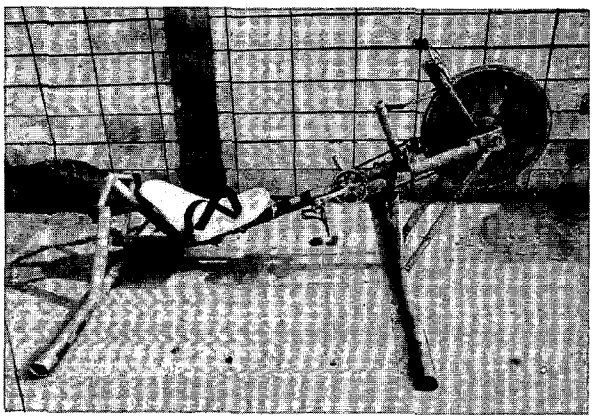

Fig. 2. Side View of the Bicycle/Ergometer

The ergometer utilizes an inertial flywheel which is connected via a chain drive to a standard bicycle crank set and pedals. Attached to the axle of the freewheel is a fork which is free to rotate independently about the flywheel axle (Fig. 3). Mounted on this fork are a set of bicycle caliper brakes, with a device for adjusting the amount of contact force of the brakes. The fork is restrained from rotation by a spring scale calibrated in lbf, which is attached between the fork and the frame of the test stand. Since the brake pads are positioned at a radius of exactly one foot from the axle of the flywheel, the force indicated on the spring scale is numerically equal to the resisting torque generated, measured in units of foot-pounds.

Pedal cadence and subject heart rate were monitored with a standard bicycle computer system which provides these functions. The cadence was measured by a magnetic pickup near the crank arms of the pedals.

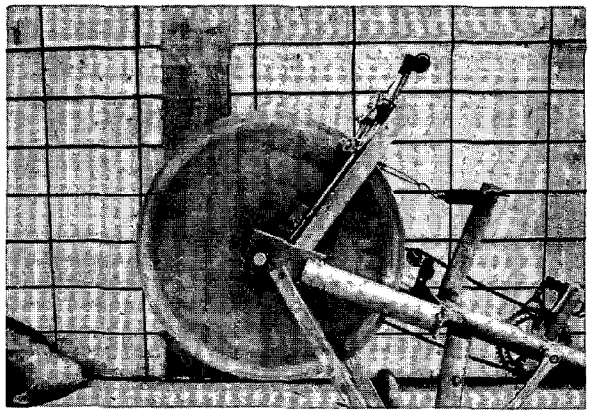

Fig. 3. Flywheel and Brake Mechanism

Heart rate was measured using an optical pickup, which is clipped to the subject's ear lobe and shines a light through the lobe to a photocell on the other side of the clip. Blood pulses obstruct some of the light and the photocell records a pulsing light source. The computer compares these pulses with its internal clock and displays the subject's heart rate in beats per minute.

The electronic pickups which were exposed to water were encased in epoxy and therefore perfectly water tight. The instrumentation was sealed inside a commercially available, clear vinyl, plastic bag (Fig. 4). The bag was sealed by means of a bolt-down metal closing rail. The pickup wires were sealed as they exited the bag by placing them between layers of an adhesive putty between the closing rails. The instrument bag was then tied to the ergometer and allowed to float at the eye level of the subject diver and the test operator (Fig. 5). This allowed the subject to monitor and control his cadence while the test operator monitored the subject's heart rate.

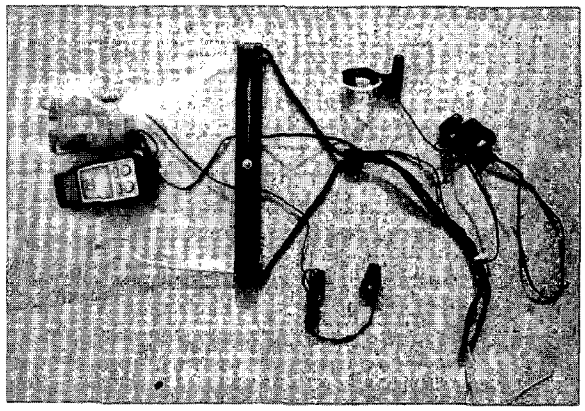

Fig. 4. Heartrate and Cadence Instrumentation

The seat on the ergometer was adjustable to accommodate variations in leg length. There was a simple seat-belt arrangement to secure the subject in the seat (Fig. 5) and toe-clips on the pedals. The ergometer was placed in a pool at the FAU Department of Ocean Engineering, which caused the

subject's chest to be at a depth of ten feet of fresh water (ffw).

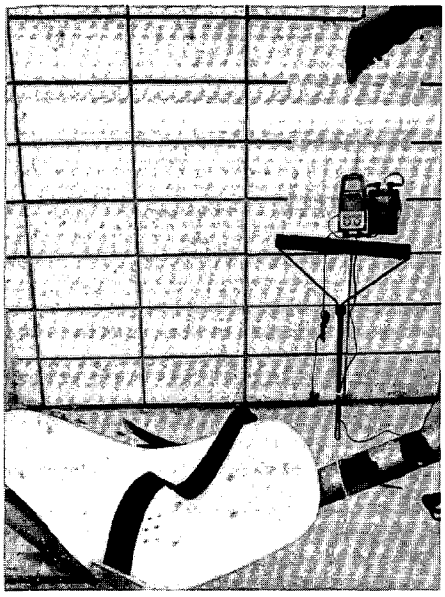

Fig. 5. Seating Arrangement and Instrument Location

A SCUBA regulator was selected based on its ability to supply large quantities of air to the subject [6] and the same regulator was used for all subjects. The regulator was attached to a standard SCUBA tank of 80 cubic foot capacity, which was installed next to the seat of the ergometer.

TEST PROCEDURE

Testing was performed in accordance with the widely accepted Monark bicycle fitness test [3]. This procedure is summarized in the flow chart of Fig. 6. The subject is required to pedal at a fixed cadence against an applied load, which is gradually increased until the heart rate reaches 70% of maximum. Each subject's maximum allowable heart rate (MHR) is computed by the formula:

$$MHR = 220 - (\text{subjects's age})$$

The optimum underwater cadence was thought to be in the range 40 - 60 rpm. This range was selected intuitively after several trials on the ergometer by one of the researchers, who is an experienced racing bicyclist. Three test cadences of 40, 50 and 60 rpm were then chosen. The order of the cadences was randomized, so that the results would not be biased by a "learning effect" and subjects rested for at least one hour between trials, to eliminate the fatigue factor.

The pressure in the SCUBA tank that supplied the air to the subject was noted at the beginning and end of the test and the difference was recorded. This data was used to give an approximate indication of the air consumption rates that can be expected in the operation of a human-powered submarine.

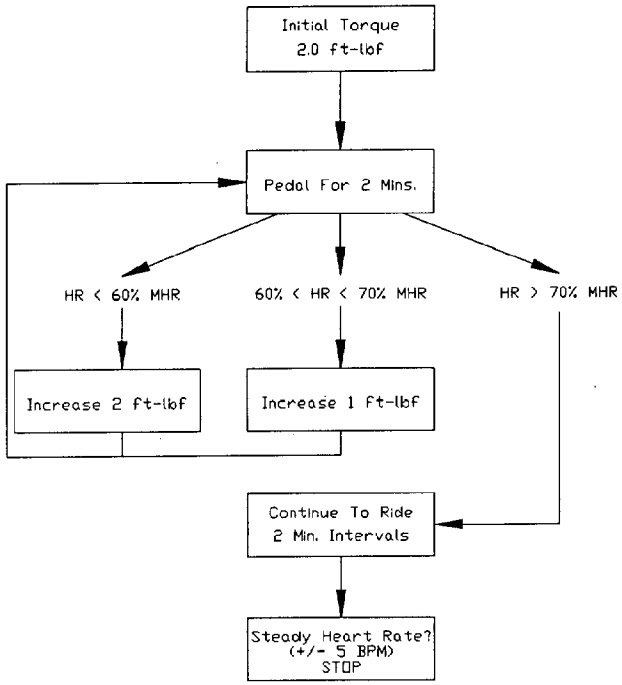

Fig. 6 Test Procedure Flow Chart

As an aid to data analysis, the subjects filled out a questionaire after the tests, giving details of their SCUBA and bicycling experience, and frequency of participation in other exercise or sport. They were also asked to comment on several aspects of the test equipment, such as the seating arrangement, belt constraint and air supply. Finally, they listed any forms of discomfort felt during testing, which ranged from nervousness and anxiety, through headaches and aching legs, to claustrophobia, lack of air and dizziness.

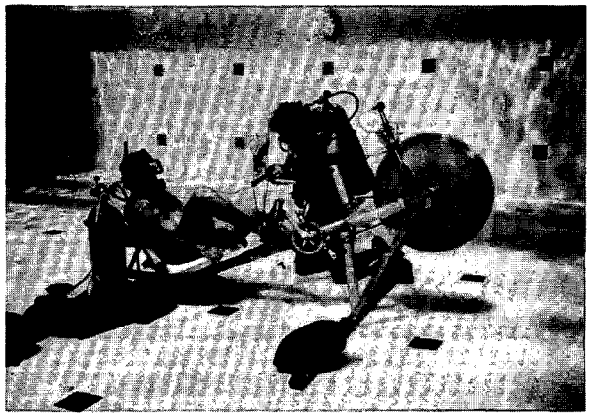

Fig. 7. Underwater Testing

Figure 7 illustrates underwater operation and testing on the ergometer.

TEST SUBJECTS

Test subjects were male and female volunteers from the Department of Ocean Engineering. They were all certified divers, but their ages ranged from 22 to 46 and there was a wide variation in level of fitness. As a safety precaution, all subjects were required to undergo an independent fitness evaluation, prior to the underwater tests. Details of the test subjects are presented in Table I.

TABLE I. Details of Test Subjects

Subject Number	Male/Female	Age	SCUBA Experience	Cycling Experience	Regular Exercise
1	M	29	E	R	Y
2	M	24	E	T	Y
3	M	24	E	T	Y
4	M	26	N	T	Y
5	M	34	E	N	N
6	F	38	E	N	Y
7	M	46	E	O	N
8	M	26	E	N	N
9	M	26	E	O	N
10	F	22	N	N	N
11	F	32	N	T	Y
12	M	37	N	O	Y
13	F	28	E	N	N
14	M	23	E	N	N

Key: SCUBA Experience: N - novice
E - experienced
Bicycling Experience: R - racing
T - regular
O - occasional
N - non-bicylist
Regular exercise program: Y - yes N - no

RESULTS

There was a wide scatter in absolute values of output power, due to the variation in fitness and bicycling technique between the subjects. However, a significant downward trend in power output was apparent in all cases at 60 rpm (Figs. 8 and 9).

Figure 8 presents the data for those subjects whose peak power occurred at 50 rpm. These people were all regular bicyclists and/or participated in a regular program of fitness training. Four of the five subjects were male (#6 was female) and it is interesting to note that, despite the wide spread in their maximum power (0.09 - 0.17 HP) at 50 rpm, the data for these males converges to 0.09 HP at 60 rpm.

The highest output of 0.17 HP was generated by subject #1, who is an experienced SCUBA instructor and a competitive racing bicyclist in training. This figure correlates well with information from the Navy Experimental Diving Unit which suggests that only 50% of a diver's sustained gross power output (approximately 0.33 HP for an extremely fit male) can be converted to useful mechanical energy. The remaining 50% is wasted through resistance to motion underwater [7].

Note that for subject #1, the 40 rpm data point is slightly low, since the limit of the applied load on the ergometer was reached when his heart rate was only 65% MHR (rather than 70%).

The second highest power output was from subject #4, who was a novice SCUBA diver. This suggests that the data is not a function of a subject's previous SCUBA experience, provided that he or she has sufficient confidence to complete the tests.

Power output from the female subject (#6) is predictably lower than for the males. Although relatively fit, she was a non-bicyclist, and lack of technique may also be a factor here.

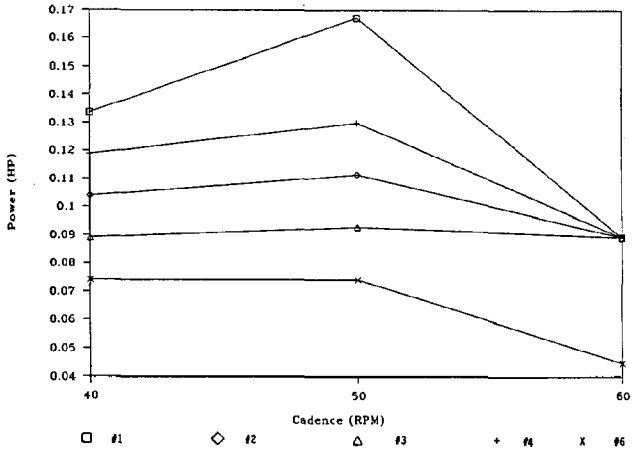

Fig. 8 Power Output for Subjects Peaking at 50 rpm.

The data for the subjects who peaked at 40 rpm is presented in Fig. 9. None of these male subjects were regular bicyclists, nor did they partake in a

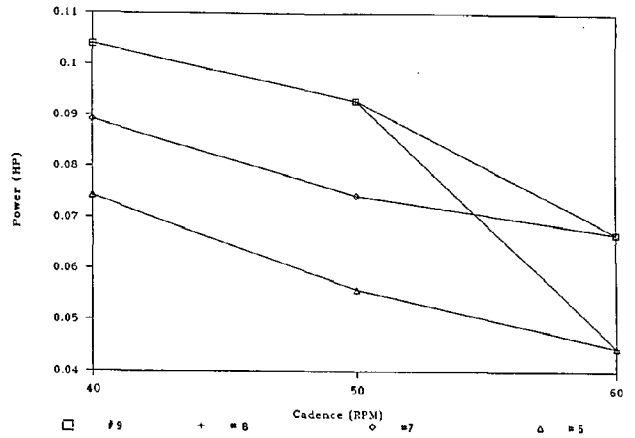

Fig. 9 Power Output for Subjects Peaking at 40 rpm.

regular exercise program. The maximum power ranges from 0.08 HP to 0.10 HP, with a similar spread of data at 50 rpm and some convergence at 60 rpm, although this is less marked than in Figure 8.

Mean values of the data are presented in Figure 10, where the upper line represents those subjects who partake in regular exercise (bicycling or otherwise) and the lower line represents the subjects who do not. The optimum pedaling cadence is about 50 rpm for the former group, whereas the less fit subjects prefer a lower cadence, of 40 rpm or less. Mean peak values of useful output power are 0.12 HP for the 'fit' group and 0.08 HP for the others.

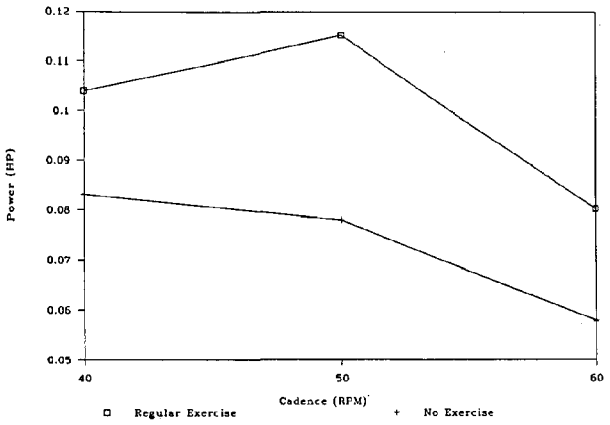

Fig. 10. Effect of Regular Exercise on Mean Power Output

INCOMPLETE TESTS

Subjects #10-13 failed to complete the tests, due to physical or mental discomfort. Of these, three were inexperienced SCUBA divers. The fourth subject was unable to attain the 70% MHR, because of tired leg muscles.

Subject #14 successfully completed the tests, but the data was suspect due to equipment malfunction and has been discarded.

DISCOMFORT DURING TESTING

Information provided by the test subjects on the questionnaire, regarding any discomfort they experienced during the tests, is summarized in Table II. This information has been used to identify specific safety hazards for the operator of a human-powered submarine and potential areas where equipment development or a special training regime would alleviate operator discomfort in the stressful environment of the submarine races.

The most common complaint from the test subjects was an inadequate air supply. Since the regulator was selected on the basis of its reported ability to deliver large quantities of air (see Test

TABLE II. Summary of Discomfort Symptoms Experienced During Testing

Symptom	Subject Number													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Headache during test	X													
Headache after test	X		X								X			
Leg ache					X	X	X			X			X	
Claustrophobia	X											X		
Tightness in chest	X		X									X		X
Lack of air	X		X			X				X	X	X		
Dizziness	X											X		
Tunnel vision												X		
Potential black-out												X		
Nervousness/ anxiety											X	X		
Dry mouth									X					
Neck strain														X

Equipment section), this suggests that development of a high flowrate SCUBA system would be advantageous for the human-powered submarine. One subject complained of a dry mouth, so a humidifier should also be incorporated.

Four subjects suffered from tightness in the chest. The majority of these were tall people and we believe that the problem may be overcome by extending the length of the bicycle frame and redesigning the seat to permit a wider range of adjustment. The neck strain problem for subject #14 would also be solved by this modification.

Five people, all non-bicyclists, complained of leg ache, which was simply caused by the unaccustomed exercise. Two subjects, who were inexperienced SCUBA divers, confessed to anxiety during the tests, but the majority were relaxed.

The reason for headaches during and/or after testing is not fully understood, but we hope to gather more data on this subject during future projects. Finally, claustrophobia is an individual problem, which would probably be exacerbated in the enclosed environment of a human-powered submarine.

The experience of subject #12, who suffered all the symptoms of a potential blackout, emphasizes the hazardous nature of these tests. This project would not have been attempted without:

a) the background of an established diving program for the training of scientific divers, within the Ocean Engineering Department.
b) the collaboration of the University's Department of Professional and Human Services, who certified all subjects as physically fit and advised on the test procedure.
c) an experienced SCUBA instructor to conduct the tests.

AIR CONSUMPTION

By the nature of the Monark bicycle test (see Fig. 6) the work rate is not constant, but gradually increases. Therefore, the air consumption rate (which is a function of work rate [8]) will also gradually increase. The subjects' air consumption was monitored by noting the reading of the contents gage at the beginning and end of each test and thus the most meaningful data was gathered from subjects whose maximum work load was equal to the initial applied load of 2 lbf. This occurred for subject #s 5, 6 and 8 at 60 rpm.

The respiratory minute volume for each of these subjects, averaged over a four minute period of pedaling against a constant resistance, was 75 liters ± 15%. The accuracy of this figure is limited by the precision of the contents gage and by the short pedaling time, but it validates the maximum respiratory minute volume at high work loads of 100 liters, quoted in Ref. [8].

Further research is required in this area, which will be the subject of a future project.

CONCLUSIONS

This project has demonstrated that the maximum power output and optimum cadence of a SCUBA diver pedaling underwater depends upon fitness and/or bicycling expertise, but not SCUBA experience. The latter affects only a subject's ability to complete the tests successfully.

The maximum measured power from a racing bicyclist was 0.17 HP at 50 rpm. Underwater bicycle training of the subject and improvements to the air delivery system may increase the power by perhaps 10 - 15%. This data will be used for optimization of the propulsion and transmission devices on the FAU human-powered submersible.

Subjects experienced discomfort such as tightness of the chest and neck strain after relatively short periods (i.e. ~ 10 minutes) of working on the ergometer. Since these symptoms were caused by a non-ideal pedaling posture, it is important that the interior of the submarine is customized for the intended operator.

The testing program demonstrated the potential for blackout when a SCUBA diver is working at maximum rate underwater. This justifies the safety guidelines for the human-powered submarine races, which stipulate that a deadman switch must be installed for both occupants, and that only one of the two may generate power (the other being responsible for vehicle control and safety).

Fruitful related areas for further research include:

(a) SCUBA diver air consumption under maximum sustained workload
(b) modifications to air delivery systems, to provide unrestricted flow on demand
(c) cause and prevention of the headaches experienced by test subjects.

ACKNOWLEDGEMENTS

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REFERENCES

1. Brooks, A. N., "Some Observations on the Energy Consumption of Human-Powered Vehicles", Proc. 1st H.P.V. Sci. Symp., Anaheim, CA, Nov. 1981, pp. 42-53.

2. Spinnetti, R., "Backward Versus Forward Pedaling: Comparison Tests", Human Power - The Technical Journal of the IHPVA, Vol. 6, No. 3, Fall, 1987, pp. 1 and 10-12.

3. James, T.W., "Modified Collins Pedal-Mode Ergometer: Development and Medical Tests", Navy Experimental Diving Unit Report No. 1-76, 15 June, 1976.

4. Middleton, J.R. and Miller, B.E., "Evaluation of Kinergetics Breathing Gas Heater", Navy Experimental Diving Unit Report No. 9-78, April 1978.

5. Wilson, D.G., Forrestall, R. and Henden, D., "Evolution of Recumbent Bicycles and the Design of the Avatar Bluebell", Proc. 2nd HPV Sci. Symp., CA., Oct. 1983, pp. 92-103.

6. Morson, P.D. "Evaluation of Commercially Available Open Circuit Scuba Regulators", Navy Experimental Diving Unit Report No. 8-87, August 1987.

7. Schwartz, H., Navy Experimental Diving Unit, Panama City, FL., Private communication, Dec. 1987.

8. British Sub-Aqua Club Diving Manual, p. 84, Stanley Paul & Co., London.

NOAA FLEET HAZARDOUS MATERIALS AND HAZARDOUS WASTE MANAGEMENT

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ABSTRACT

"NOAA Fleet Hazardous Materials and Hazardous Waste Management" details the objectives, development, and implementation of a hazardous materials and hazardous waste program for NOAA hydrographic, oceanographic, and fishery research ships.

The paper discusses key elements for development of the program, namely, conducting shipboard and ship base hazardous materials and hazardous waste surveys, reviewing EPA and OSHA regulations, developing a hazardous materials and hazardous waste manual for shipboard use, and conducting hazardous materials and hazardous waste awareness training.

The paper also discusses implementation of the resulting hazardous materials and hazardous waste policy, content of the manual, training information, shipboard and shoreside procedures, and maintenance of the program to reflect changing hazardous materials and hazardous waste regulations and shipboard needs.

INTRODUCTION

The Office of Marine Operations (OMO), a component of the National Ocean Service within the National Oceanic and Atmospheric Administration (NOAA), manages and operates a fleet of 23 hydrographic, oceanographic, and fishery research ships. The ships perform a variety of missions and serve as mobile platforms for visiting scientific parties conducting oceanographic and atmospheric related projects.

As trustee of the Nation's oceans and in response to shipboard concerns, legal requirements, and federal, state, and local environmental regulations, OMO has developed and implemented a successful NOAA fleet hazardous materials and hazardous waste program which is centered around a hazardous materials and hazardous waste manual prepared as a guidance document for fleet personnel.

The NOAA Fleet Hazardous Materials and Hazardous Waste Manual states, "Hazardous materials and hazardous wastes are encountered by NOAA Fleet personnel both aboard ship and at shore facilities. These materials/ wastes come in many forms with varying degrees of hazard. Some are highly flammable, some are toxic, while others are considered a minimal hazard if handled and stored properly. These materials are used for numerous purposes, including degreasing, as additives to fuels and lubricants, cleaning agents, solvents, and as paints or coatings. Some NOAA Fleet employees encounter one or more of these substances on a routine basis through the normal course of their work while others are infrequently, if ever, exposed to the same hazards." [1]

OBJECTIVES

The objectives of the NOAA program are twofold: 1) to protect the health and safety of personnel and the environment, and 2) to ensure compliance with applicable EPA and OSHA regulations. Through interpretation of applicable regulations with emphasis on protection of personnel and the environment, the NOAA program has satisfied the combined objectives.

To gain the support of those individuals who lacked an awareness of the problem, OMO cited medical concerns, legal concerns, regulations, directives, and the overall direction in which hazardous material and hazardous waste issues were heading. However, like any program where benefits, improved productivity, or reduced costs are difficult to measure, obtaining adequate funding and support was not without obstacles. We were fortunate to have been mandated to comply with EPA and OSHA regulations at about the same time that concern over hazardous material handling and hazardous waste disposal was being voiced by fleet and shoreside support personnel.

NOAA's early commitment to meeting the objectives has saved a great deal of time and effort. NOAA has managed to keep abreast of regulatory requirements and at times has taken the lead in developing standards for the marine industry. The organization is still benefiting from the approach that was taken as new developments and related tasks become evident.

APPROACH

OMO initially developed a statement of work emphasizing the objectives and detailing specific tasks that included: reviewing applicable health, safety, and environmental regulations; surveying NOAA ships and fleet facilities for hazardous materials and hazardous wastes; preparing a guidance document for fleet personnel; and conducting awareness training for employees who routinely work with hazardous materials/chemical products. NOAA was fortunate to

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have in-house expertise on the subject, and the Hazardous Materials Response Branch in Seattle, Washington worked out the plan.

Regulations

Due to the simultaneous development of the program and the lengthy regulatory process, the Resource Conservation and Recovery Act (RCRA) Amendments of 1984 and OSHA's Hazard Communication Standard were of great concern during the development of the program. We reviewed the regulations to determine which portions of RCRA and the OSHA standard were applicable to shipboard operations. We also considered how future developments would impact the program and tried to stay one step ahead of the regulatory process. OMO's interpretation of the legal language and complexity of the regulations has been in keeping with NOAA objectives to protect the health and safety of the personnel and the environment. Key provisions of the regulations are described below.

RCRA Amendments of 1984

Prior to the RCRA Amendments of 1984, generators of less than 1000 kg (2200 pounds) of hazardous waste per month were exempt from regulations governing the disposal of hazardous wastes. According to Attorney Michael A. Brown, former Enforcement Counsel for the EPA, "The specter of up to 2200 pounds per month of unregulated hazardous wastes being placed into the environment by each of the estimated 130,000 small generators caused Congress great concern."[2]

In short, as a result of Congressional enactment of the RCRA amendments, on March 17, 1986 EPA promulgated regulations governing small quantity generators. The rules, now similar to those imposed on large quantity generators, require that generators of more than 100 kg but less than 1000 kg of hazardous waste per month (small quantity generators):

- o Obtain a U.S. EPA Identification Number.
- o Use the full Uniform Hazardous Waste Manifest when shipping hazardous waste off site.
- o Submit wastes only to hazardous waste transporters with U.S. EPA Identification Numbers.
- o Accumulate waste on site for no more than 180 days, or 270 days if the waste is to be shipped more than 200 miles, unless generators obtain a hazardous waste permit.
- o Ensure that generators' hazardous waste is managed at a hazardous waste facility with interim status or a permit under RCRA.[3]

OSHA Hazard Communication Standard

Similarly, the Hazard Communication Standard has been viewed as a much needed but long debated rule that became bogged down by technical detail, political interference, and state and local regulations. As NOAA forged ahead, trying to determine to what degree the standard was applicable to the marine industry, NOAA recognized the benefits of incorporating the OSHA standard into the program.

The Hazard Communication Standard is a three-tiered program comprised of 1) chemical labeling, 2) material safety data sheets (MSDS), and 3) employee information and training. In short, all chemical containers must be labeled. Chemical labels are to be applied to containers by the chemical manufacturers or importers. The labels must identify the contents of the container and warn of any specific hazards of the contents. Secondly, OSHA requires that employers maintain an MSDS for each hazardous chemical product purchased or used in a facility. An MSDS is a form that describes the characteristics and properties of a chemical product. Specific physical and health hazard data is given. Employees may review MSDS's of chemicals in their work areas. Thirdly, every employer shall provide hazard communication information and training to all employees. Employees will be made aware of the chemicals in their work area, the hazards of those chemicals and the availability of information about hazardous chemicals at their workplace. The OSHA standard requires that training be conducted once for existing employees, once for new employees, and again should new hazards be introduced into the workplace.[4]

Surveys

Surveys were conducted aboard NOAA ships and at shoreside support facilities to determine the types and amounts of hazardous materials, chemicals, and wastes handled along with current stowage, disposal, and handling procedures. Materials or products that could be considered hazardous due to their toxic, irritating, reactive, flammable or polluting nature were identified and inventoried. From a report of the results of the surveys comes the following, "We identified and inventoried [over 300] substances which pose varying degrees of hazard ranging from chlorinated solvents (which have a known carcinogenic potential) to relatively innocuous products such as laundry detergents . . . . Ninety-five percent of these products were found to be commercially prepared and packaged compounds used as ships' stores (required to maintain or operate the ship). These products were used for a wide range of activities including; degreasing, washing, lubricating, fuel additives, antifreeze, ice melting, water conditioning, and for scientific purposes. The remaining five percent was comprised of reagent chemicals that had apparently been left on board by previous scientific parties. These products and chemicals were stored in a variety of locations, with most in the original product container supplied by the manufacturer."[5]

There was no information about the chemical products found aboard the ships other than what was labeled on the products' containers by the manufacturers. Material Safety Data Sheets of the majority of products inventoried were obtained. Certain products were no longer being made and some manufacturers were no longer in business, thus some MSDS's were unavailable.

In addition to the materials mentioned above, several 55 gallon drums were found at the marine centers (major OMO ship bases) containing used solvents, lubricating oils, antifreeze, and bilge slops.

DEVELOPMENT

The outcome of the surveys indicated that the type of hazardous materials used aboard NOAA ships was limited mostly to chemical products in relatively small amounts. However, NOAA realized the need for inventory control

of those products, improved procedures for chemicals brought aboard NOAA ship's by visiting scientific parties, proper procedures for the disposal of shipboard-generated hazardous waste, and hazardous materials awareness training.

Inventory Control

In order to reduce the numerous types and amounts of chemical products aboard NOAA ships and to provide some sort of control over inventory, NOAA investigated the existence of a list of products approved for shipboard use. We found out that the U.S. Coast Guard Commandant Instruction for listing products approved for use as ships' stores was not appropriate. The Coast Guard was in the process of limiting its approval program to list only those industrial type chemicals that would be encountered aboard ship in bulk. NOAA was informed that commercial chemical products would be regulated by the Consumer Products Safety Commission (CPSC) and that commercial chemical products readily available for home use would be acceptable for use as ships' stores.

We have found that the CPSC review process, the OSHA standards, and the liability concerns associated with the use of hazardous materials have had a self-regulating effect on chemical product manufacturers. "Non-hazardous" alternatives are being developed and marketed. By using less hazardous ingredients in smaller amounts, a chemical product manufacturer can produce an effective less hazardous alternative, for example a cleaning compound formerly containing hydrofluoric acid may now use citric acid as the effective ingredient.

Visiting Scientists

The majority of pure chemicals found during the surveys were left aboard ship by visiting scientific parties, and to a certain degree, they posed the greatest potential hazard. This caused somewhat of a dilemma since OMO needed to develop procedures for handling these materials without restricting the scientists from performing their projects.

In keeping with OSHA's Hazard Communication Standard, shipboard personnel are required to be apprised of the specific hazardous materials in the workplace, and since the chemicals brought aboard by the visiting scientists vary from project to project and ship to ship, responsibility for providing information about the chemicals lies with the scientists. In addition, based on RCRA requirements, responsibility for proper deposition of the chemicals at the completion of a project also rests with the scientists and the laboratories they are affiliated with.

Disposal Procedures

Laboratory chemicals notwithstanding, shipboard generated hazardous waste such as used solvents, degreasers, and antifreeze now must be accounted for and handled in accordance with RCRA requirements. Unlike that of a shoreside production facility, shipboard generated hazardous waste is varied and noncontinuous. It is the accumulation of this varied and often unidentified waste stream which will pose a hazard and be in violation of RCRA requirements.

A simple means of avoiding problems and providing for proper handling of a varied noncontinuous waste stream is to label all wastes, funnel the waste through a single point of contact at each shoreside facility, provide for temporary storage at the facility, and set up a purchase agreement for routine disposal with a licensed disposal contractor.

Training

The nature of NOAA shipboard employment caused the development of an atypical approach to meet the hazard communication standard's "one time" training requirement. Accessibility of personnel, ship/shore rotation of officers, winter in-port personnel turnover, and costs were all factors in determining how the OSHA training requirement would be met.

The logistics of training shipboard personnel is such that OMO holds one training session at each marine center per year for key shipboard personnel. Due to the above factors, OMO realized that annual training is required during the first several years to ensure coverage of those key employees going from shore to ship assignments, and that annual refresher training is required for previously trained key personnel to ensure the subsequent individual training of new employees as they report aboard ship. Specific policy concerning training and other issues is discussed in the section that follows.

IMPLEMENTATION

Based on the surveys and review of the regulations, OMO issued an instruction titled "Hazardous Materials and Hazardous Waste; policy, guidance, and training."[6] The purpose of the Instruction is to promulgate the NOAA Fleet Hazardous Materials and Hazardous Waste Manual and to establish policy and training requirements for procurement, storage, use, and disposal of hazardous materials and hazardous waste aboard all NOAA ships, marine centers, and ship bases. In summary, this instruction requires that:

o Vessel commands and Facility Directors make every effort to reduce quantities of hazardous materials, use alternative materials wherever possible, inventory hazardous materials quarterly, and obtain, maintain, and make accessible to all personnel MSDS's for all hazardous materials inventoried.

o Visiting scientific parties provide an inventory list and MSDS's of all hazardous materials brought on board NOAA ships to the vessel command. On departure from the ship, visiting scientific parties shall provide an inventory of hazardous materials showing that all hazardous materials brought aboard have been properly used up or removed in suitable waste containers.

o Each marine center and ship base obtain an EPA Hazardous Waste Generator Identification Number for disposal of hazardous wastes at its facility. Arrangements shall be made with a licensed hazardous waste disposal contractor for routine removal of hazardous waste from the facility and from NOAA ships that arrive in port. NOAA ships will dispose of their hazardous waste while in port.

o Hazardous waste from outside facilities is not to be accepted for storage or disposal at our facilities and spills of hazardous materials that threaten human health or environment, or exceed quantities listed in 40 CFR 117.3, shall be immediately reported to the marine centers and the National Response Center (800-424-8802).

o Training be taken by all Commanding Officers, Executive Officers, shipboard department heads, ship base port captains, and marine center safety officers. Personnel receiving this training will be responsible for the subsequent training, once a year, of all shipboard and shoreside personnel under their supervision who may be exposed to hazardous materials.

o Annual hazardous material training be scheduled and conducted by each marine center for all newly appointed personnel listed above and for those in need of refresher training. Records shall be kept of all shoreside and shipboard hazardous material training.

The "HAZMAT Manual"

The NOAA Fleet Hazardous Materials and Hazardous Waste Manual is the vehicle supporting the policy and objectives explained in the preceding sections of this paper. It is at the center of the NOAA program and has been used successfully as a guide for responding to past and present problems and changes associated with hazardous materials and hazardous waste management.

A description of each chapter and some of the highlights of the manual are discussed below.

General Questions - The manual defines a hazardous material as a product or material that is flammable, reactive, toxic, or stored in a hazardous form unless it can be readily purchased by the public through a commonly found commercial outlet and is stored and used in the same way a typical household consumer would use it. The manual goes on to define and give examples of hazardous waste, the dangers hazardous materials and hazardous wastes pose, and where in the manual more specific information on disposal guidance, emergency response, and reference material can be found. This section answers additional questions concerning which materials are considered "safe" for use aboard ship and their storage requirements.

Sources of Information - Provides information, telephone numbers, and guidance on when and whom to call in the case of medical or environmental emergencies due to personnel exposures or spills. The section mandates that spills exceeding the amounts listed in 40 CFR 117.3 or threatening human health or the environment be reported to the National Response Center.

Transportation - Discusses Department of Transportation (DOT) requirements for manifesting, labeling, and placarding of hazardous materials and hazardous waste during its transportation and provides a list with phone numbers of qualified shippers.

Human Health - This section is a comprehensive guide for shipboard personnel covering the risk of exposure, the effects, and the precautions associated with hazardous materials encountered aboard ship.

Fleet Inspection Checklist - Lists the criteria that will be used by the NOAA Fleet Inspection Team, which performs annual shipboard inspections for material condition and safety, to evaluate shipboard compliance with the program.

Emergency Response Procedures - Guidance on what to do in case of a spill.

Disposal Guidance - Provides guidelines for disposal of specific wastes from NOAA ships and ship bases. Lists alphabetically everything from aerosol cans to waste oil, the preferred disposal method, and the waste hazard. States several cardinal rules: avoid unknowns, segregate nonhazardous from hazardous, if you buy it use it up, if you think it might be hazardous it probably is, and avoid buying hazardous materials because their wastes are usually hazardous. Lists points of contact and telephone numbers for waste disposal agencies and disposal contractors at NOAA ship base locations.

Material Safety Data Sheets - Discusses information that can be found on material safety data sheets, how to obtain them, and provides a location to keep them on file.

Reportable Quantities - Lists the quantities of hazardous substances per 40 CFR 117.3 that if spilled need to be reported to the National Response Center.

Reference Library

In addition to the manual, the following reference books were distributed to the ships and ship bases.

NIOSH/OSHA Pocket Guide to Chemical Hazards - Presents condensed chemical and physical information on generic chemicals.

Clinical Toxicology of Commercial Products, Fifth Edition - Provides chemical, physical, toxicological, and proprietary information on commercial products. Useful in determining the constituents of a product and then determining its properties. Also provides a listing of manufacturers of commercial products.

Hazardous Materials Injuries. A Handbook for Pre-Hospital Care - Provides first aid and toxicological response information to help first responders treat victims of hazardous material exposure.

Handbook of Poisoning, Eleventh Edition - Provides first aid and toxicological information to help physicians or medical technicians treat victims of hazardous material exposure.

The Condensed Chemical Dictionary, Tenth Edition - Provides chemical and physical information on numerous chemicals.

1984 Emergency Response Guidebook, DOT P 5800.3 - Keyed to the Department of Transportation placarding system, this reference provides information to help the first responder mitigate a chemical spill.

Glossary for Hazardous Materials, Hazardous Chemicals, Hazardous Substances, Hazardous Waste - A comprehensive glossary of terms and definitions.

Training

Training sessions are conducted in accordance with Reference 6 and OSHA's Hazard Communication Standard to impart the policy, procedures, and information discussed throughout this paper. The training lasts approximately 2 hours per session and is intended to increase the hazardous material awareness of fleet personnel. Commanding Officers are instructed concerning requirements of the program, namely: limit quantity and use; inventory quarterly; maintain MSDS's; inform and instruct the crew; and dispose of wastes properly.

RECENT DEVELOPMENTS

Several additional requirements and improvements in the program are being investigated based on feedback from the fleet and ship bases. We are developing more specific guidance on the handling and disposal of radioactive materials by visiting scientific parties. We have obtained EPA Small Quantity Generator Numbers for NOAA ships to facilitate hazardous waste disposal at non-NOAA ports and are responding to recommendations that resulted from a recent OSHA inspection.

Radioactive materials are strictly regulated by the Nuclear Regulatory Commission (NRC) and are the responsibility of the designated laboratory radiation safety officer licensed by the NRC to procure controlled radioactive sources. OMO has reviewed the NRC regulations as published in 10 CFR 19, 20 and 34 to ensure compliance by visiting scientific parties. Interpretation of the regulations and a policy statement concerning use of radioactive materials will be provided as an update to the HAZMAT manual.

Several NOAA ships have attempted to dispose of hazardous materials while in port at non-NOAA facilities. Disposal contractors have refused to accept the shipboard generated waste without an EPA generator number. In accordance with EPA recommendations, OMO has obtained generator numbers for those ships requiring hazardous waste disposal at non-NOAA facilities.

OSHA recently inspected NOAA's Pacific Marine Center for compliance with the Hazard Communication Standard and found that the NOAA program has been implemented properly. Procedures are being written to inform employees of the hazards of non-routine tasks and to apprise contractors of potential chemical hazards.

CONCLUSION

The Office of Marine Operations, acting on behalf of the National Ocean Service within the National Oceanic and Atmospheric Administration, has developed and implemented a successful NOAA fleet hazardous materials and hazardous waste program. To briefly summarize, components of the program include:

- o the OMO Instruction based on applicable regulations,
- o the HAZMAT manual for use by fleet personnel,
- o the reference library containing additional technical information,
- o a current MSDS inventory, and
- o annual awareness training.

In keeping with NOAA's mission as trustee of the Nation's oceans, the program satisfies the objectives of protecting the health and safety of personnel and the environment from the risks associated with hazardous materials and hazardous waste.

REFERENCES

1. Kummerlowe, David and Harris, Lori, NOAA Fleet Hazardous Materials and Hazardous Waste Manual, December 1986, p. i.

2. Brown, Michael A., "1984 RCRA Amendments (Non-UST)," Environmental Laws & Regulations: 1986 Update, Government Institutes, Inc., April 24-25, 1986, pp. I-12 to I-13.

3. U.S. Environmental Protection Agency, "Small Quantity Hazardous Waste Generators: Questions and Answers on the Final Requirements for 100 to 1000 kilograms/month Generators," March 24, 1986.

4. Miller, Marshall Lee, "OSHA's Hazard Communication Regulation," Environmental Laws & Regulations: 1986 Update, Government Institutes, Inc., April 24-25, 1986, pp. XII-1 to XII-8.

5. Kummerlowe, David, "Update on Hazardous Materials/Waste Management Program," January 24, 1986 (internal memorandum).

6. Office of Marine Operations, "OMO Instruction 6280, Hazardous Materials and Hazardous Waste; policy, guidance, and training," May 13, 1987.

U.S. COAST GUARD OIL IDENTIFICATION SYSTEM

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ABSTRACT

The Coast Guard Oil Identification System has been supporting field investigators enforcing the requirements of the Federal Water Pollution Control Act for more than ten years. At the heart of the Oil Identification System is the Central Oil Identification Laboratory (COIL), the Coast Guard's and the United States' only forensic laboratory dedicated to the analysis of petroleum samples for oil spill source identification. This paper gives a synopsis of the development of the Oil Identification System, an overview of the current analytical techniques used to identify oil samples, and descriptions of several recent cases of special interest.

INTRODUCTION

The Coast Guard Oil Identification System (OIS), which is managed by COIL, serves as a powerful tool to aid field investigators in determining the source of "mystery" oil spills as mandated by federal law. COIL uses several complementary chemical tests that exploit the unique, intrinsic properties of petroleum oil and make it possible to match a spilled oil with its correct source. Thus, OIS provides the means to fix oil pollution responsibility, assess penalties and help recover federal pollution cleanup funds expended during an incident. OIS serves as a deterrent to deliberate oil pollution discharges and encourages the reporting of and acceptance of responsibility for accidental spills. Figure 1 is a flow diagram depicting the operation of the OIS.

OIS methodologies are continuously reviewed and updated to keep pace with changing technology. The information on analytical techniques and laboratory statistics presented in this paper is current through the end of 1987.

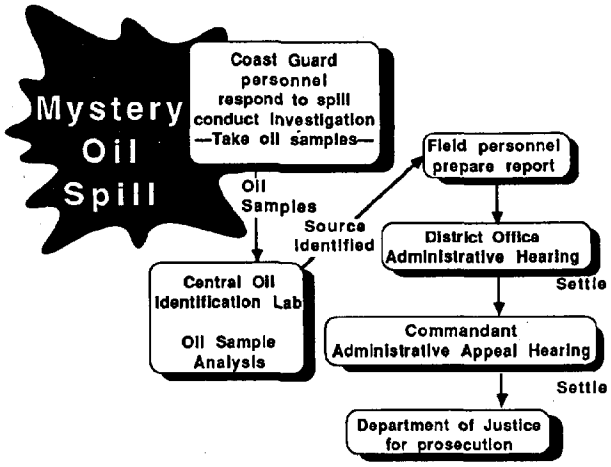

FIGURE 1
U.S Coast Guard Oil Identification System Flow Diagram

HISTORY

In 1972, the Federal Water Pollution Control Act (FWPCA) assigned general responsibilities to the U.S. Coast Guard for the protection of the marine environment including enforcement of the nation's anti-pollution discharge laws and regulations in U.S. waters. To carry out these responsibilities, the development of a system to identify pollutant sources was necessary. The Coast Guard Research and Development Center was tasked with this project in 1973. Over the next four years many analytical tests and procedures were evaluated for their ability to distinguish among all types of petroleum oil. In 1977, the R&D Center published its final report detailing the "Oil Spill Identification System".[1] COIL was established as the principal operating arm to implement the system at the R&D Center facilities in Groton, Connecticut. Formal operations began on November 17, 1977.

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One of the first steps for COIL and the new OIS was the setting of legal precedent for it's "oil fingerprinting" technique. This occurred in December 1978 at a federal criminal jury trial, under the Federal Water Pollution Control Act, involving spilled oil. In this case, U.S. vs DISTLER, Judge Charles M. Allen ruled that "chemical evidence" would be admissible thus establishing the necessary precedent.

On April 1, 1979, administrative control of COIL was transferred to the Coast Guard Oceanographic Unit in Washington, D.C. and plans were made to relocate the laboratory to that facility. A new laboratory was constructed at the Washington Navy Yard Annex from existing Oceanographic Unit space. A brief shut down period from June through October 1980 occurred to facilitate the move, set up equipment and train new personnel. COIL operations under the parent Oceanographic Unit were short lived. The Oceanographic Unit was closed for budgetary reasons in April of 1982. At that time COIL became the fifth branch of the Port and Environmental Safety Division, Office of Marine Environment and Systems, Coast Guard Headquarters.

In 1984, planning began again to relocate COIL to a less costly, more supportive location. The present location on the University of Connecticut's Avery Point Campus was selected and COIL moved into newly refurbished spaces during March of 1986.

On October 1, 1986, COIL was established as an independent Headquarters Unit operating under the direction of Chief, Office of Marine Safety, Security and Environmental Protection. COIL is manned by a Commanding Officer, one civilian chemist, one yeoman, and nine Marine Science Technicians.[2]

At the time of preparation of this paper, yet another administrative reorganization is in progress. COIL will be merged with the Marine Fire and Safety Research Staff resulting in a new Headquarters Unit named Marine Safety Laboratories.

WHAT IS OIL IDENTIFICATION?

Petroleum is a complex mixture of thousands of different organic compounds. It is formed from a variety of organic materials, chemically converted under differing geological conditions over long periods of time. The infinitely variable nature of these factors results in distinct chemical differences between oils formed under dissimilar conditions and/or environments. While oil from one crude oil field is readily distinguishable from another, differences in the makeup of oils from the same crude oil field can often be observed as well. Refined oils are fractions from crude oil stocks, usually derived by distillation processes. Two refined oils of the same type differ because of dissimilarities in the characteristics of their crude oil feed stocks as well as variations in refinery processes and any subsequent contact with other oils mixed in during transfer operations from residues in tanks, ships, pipes, hoses, etc. Thus, all petroleum oils, to some extent, have chemical compositions different from each other.

The Coast Guard OIS uses these unique, intrinsic properties of petroleum oil which make it possible to match a spilled oil with the correct source. The system is designed around five analytical methods: Thin-Layer Chromatography, Fluorescence Spectroscopy, Infrared Spectroscopy, Gas Chromatography, and High Performance Liquid Chromatography. Each of these analytical techniques measures different chemical properties of an oil sample and has been shown to produce results independent of the others. The results of analysis by any of these methods can be presented in graph form. Data produced for spill samples and suspected source samples analyzed on the same instrument, on the same day, and under identical conditions are visually compared. If two oil samples thus compared are chemically identical, they are said to be from a common source. In nearly every case, oils from other suspected sources will be simultaneously eliminated from consideration as the pollutant source because they are chemically different as determined by the test methods.

CURRENT ANALYTICAL METHODS

The following sections provide an overview of the current oil identification methods used at COIL. A more technical description of the OIS is contained in Report CG-D-52-77 "Oil Spill Identification System", Final Report, June 1977, U.S.C.G. R&D Center (reference 1). This document is available through the National Technical Information Service, Springfield, VA 22161.

Thin-Layer Chromatography (TLC). This method separates the different components of an oil on a silica gel plate and presents a colored spot pattern for comparison. Methanol is used to selectively extract components from an oil sample. Then extracts from the spill and suspected sources are spotted near one end of a pre-coated glass

plate. The plate is then placed in a development chamber where solvents are used to separate the components along the length of the plate. After the separation has been completed, the plate is viewed under ultraviolet light and the colored spot patterns are visually compared. Permanent records of these spot patterns are recorded with photographs.

The TLC method has been changed very little since its original concept described in reference 1. This procedure provides a rapid and easy to perform comparison of oil samples. However, because of problems encountered with evaporation of light oil samples and the method's sensitivity to impurities, its current use has been restricted to cases involving heavy, viscous oils.

Fluorescence Spectroscopy (FL). Spectroscopic methods rely on chemical absorption and emission of light. The fluorescence method is based on the emission of light in the ultraviolet wavelength region. Aromatic compounds, which may comprise only a small percentage of a petroleum oil, have the ability to absorb ultraviolet light energy and then re-emit this energy over a number of different wavelengths. The re-emitted light is detected and recorded as a fluorescence spectrum. This spectrum provides a pattern for comparing different oil samples.

The efficiency of the FL method has been improved by the addition of new, state-of-the-art instrumentation. The Perkin-Elmer MPF-66 Fluorescence Spectrophotometers, computer controlled instruments, currently in use at COIL are much less labor intensive and less susceptible to operator inconsistencies than previous instruments used.

Infrared Spectroscopy (IR). The infrared method looks at absorption of infrared light over a spectral region which corresponds to the bond vibrations of the molecules that form the oil. The sample is scanned with a beam of light over the infrared frequency range and the absorptions at each frequency are recorded on a chart which provides a permanent record of the analytical measurement. A number of absorptions are common to all petroleum oils. These absorptions allow the analyst to identify the sample as a petroleum product. Other absorptions are used for uniquely identifying individual oil samples.

The IR method has also benefited from improvements in analytical instrument technology. However, since the sample cells require careful cleaning after analyzing each sample, IR continues to be the most labor intensive technique used at COIL.

Gas Chromatography (GC). This method separates an oil's components primarily on the basis of boiling temperature. The separation of the components is carried out under controlled conditions so that the same component will be eluted from the gas chromatographic column at the same relative point in time for all samples. The separation is based on the partitioning of molecular species between an inert carrier gas and a stationary liquid phase by repeated absorption-desorption. The components of the injected sample are separated by passing the volatilized sample, in helium, through a fused silica capillary chromatographic column coated with a stationary liquid phase of methyl silicone. As the separated components are eluted from the column, they are sensed by a flame ionization detector (FID). Simultaneously, a quantitative measurement of the components is recorded on a strip chart, or chromatogram, which provides a record for comparison of different samples.

The GC method has probably benefited more from advances in technology than any of the other OIS methods. The introduction and widespread use of capillary chromatographic columns has occurred since the OIS was established. These have greatly enhanced the degree of resolution obtained in GC separations. New generation robotic auto samplers provide reliable overnight operation of the instruments. Chromatographic data reconstructions using a computer data station and digital plotter have reduced the need for time consuming reanalysis of samples when closer examination of particular regions of an original chromatogram is required. All of these advances have improved the effectiveness and efficiency of the method.

High Performance Liquid Chromatography (HPLC). This method is used to separate the components of a mixture on the basis of polarity of the individual components. It relies on the partitioning of molecular species between a carrier liquid and a stationary liquid phase by repeated adsorption-desorption. A dilute solution of petroleum oil in acetonitrile and dichloromethane is injected into a reverse phase liquid chromatographic column and developed using acetonitrile as the eluent. The effluent of the column containing the separated components is passed through both ultraviolet absorbance and

fluorescence detectors. The detector responses are simultaneously recorded on a strip chart which provides a permanent record for comparison with other samples.

The performance of the HPLC method has been improved over the years by various sample handling and filtration techniques and by the addition of a state-of-the-art solvent handling system.

Who Spilled the Oil? The chromatograms and spectrograms produced by the methods discussed above represent different aspects of an oil sample's inherent characteristics. This graphical data, or "fingerprint", for each spilled oil sample is qualitatively compared to the data for each suspected source sample in a particular case to determine if they are related.

From the moment oil enters the environment, evaporation, dissolution, photochemical oxidation, biodegradation and other forces begin to alter the oil's characteristics or "fingerprint". These combined processes are termed weathering and can significantly complicate the data interpretation. For these reasons data interpretation in oil spill source identification is not straight forward. It is fundamentally different from that of ordinary chemical analyses. The experienced oil spill analyst is familiar with the complexities of the weathering processes and their impact on the test methods. The analyst must be able to distinguish real differences between two oils from those apparent differences resulting from weathering alterations. Interference from contaminants can usually be recognized as such and discounted when weighing the test results. However, at times, severe weathering and/or contamination can mask most of the inherent differences between similar type oils. In such cases, comparison of the test results may be inconclusive. Only nine percent of the cases analyzed over the past four years have resulted in indeterminant conclusions, and many of these were due to the unavailability of a sufficient quantity of spilled oil sample for complete analysis.

Laboratory Operations. A rigorous quality assurance program monitors both instrument performance and sample preparation technique to ensure results are accurate and reproducible.[3] Personnel undergo extensive training programs at COIL and leading civilian institutions with expertise in the analytical methodologies used in the laboratory. Procedures are continually monitored and labwork reviewed at several levels. At the beginning of each week, a standard reference oil is analyzed on each of the instruments and the results compared to the prior week's data to detect any changes in performance. As an additional check on instrument reliability and oil sample preparation technique, a duplicate aliquot of one sample in each case is independently analyzed for consistency and reproducibility. These and other internal checks monitor all procedures used in the laboratory.

Oil sample preparation, testing, and storage are conducted in accordance with the controlling American Society for Testing and Materials (ASTM) concensus standards or U.S. Coast Guard Standards. The Coast Guard actively participates in the work of ASTM Committee D-19 on Water and Subcommittee D-19.31 on Identification of Waterborne Oils to establish new standards and update existing ones to reflect "state-of-the-art" practices in oil identification. Current applicable ASTM Standards include D3415 - Identification of Waterborne Oils, D3326 - Preparation of Samples for Identification of Waterborne Oils, D3650 - Comparison of Waterborne Petroleum Oils by Fluorescence Analysis, D3328 - Comparison of Waterborne Petroleum Oils by Gas Chromatography, D3414 - Comparison of Waterborne Petroleum Oils by Infrared Spectroscopy, and D3325 - Preservation of Waterborne Oil Samples.[4] Work is progressing on a new standard for Comparison of Waterborne Petroleum Oils by High Performance Liquid Chromatography and updates of standards D3328 and D3415 to address the latest improvements in technology. ASTM approval of the analytical techniques enhances their credibility and legal acceptance.

CASES OF SPECIAL INTEREST

Thousands of oil pollution investigations have been processed through the Coast Guard OIS over its eleven year history of operations. Although OIS results are designed primarily for use in legal proceedings stemming from pollution incidents, on occasion, oil spill source identification can be very useful during the response phase of an incident. Most analyses are complete in four days or less. In critical cases, a request for priority analysis usually results in a determination within 24 hours. In addition to performing analyses for Coast Guard pollution investigations, as workload permits, COIL makes its expertise available to other federal, state and local government agencies for a variety of problems involving oil identification. Several recent cases of special interest are described below.

Was that really my oil? One noteworthy case began with the grounding of an oil tanker in the Deleware River causing a major crude oil spill.[5] The vessel's owners initially accepted responsibility for the spill and began cleanup efforts. But, when large amounts of oil appeared more than a mile upstream from the spill site, they refused to accept responsibility for this "new" oil. In their view, the oil was not from their tank vessel. Time was critical and a decision to open the federal Pollution Fund to continue the cleanup operations was imminent. Oil samples from the river and the tank vessel were collected by CG Captain of the Port personnel and flown to COIL for testing. Overnight analysis linked all of the spill samples to the tanker. The ship's owners accepted the Coast Guard findings and completed the cleanup. As a result, an estimated three to four million dollar obligation from the Pollution Fund was avoided at a time when the fund was critically low.

Which tank? In another case, a mystery spill of heavy oil was discovered in the water adjacent to the loading dock of an oil terminal in Boston. Just prior to the discovery, a tank vessel had completed off-loading a cargo of fuel oil to the facility and departed. Coast Guard investigators took samples of the spill and samples from the shore facility storage tanks. They also obtained composite samples of the tank vessel's cargo which are routinely taken for customer quality assurance purposes. These samples were hand delivered to COIL for testing. Analysis of the samples revealed that the spilled oil, the cargo from the tank vessel, and product from one of the shore facility storage tanks were all the same oil. However, small but significant differences, probably introduced by residues in the shore facility tank, enabled COIL to distinguish between the facility samples and the spilled oil. The spill samples were identical to the tank vessel cargo samples. When the vessel arrived at its next port of call in Houston, Coast Guard investigators obtained additional samples from the vessel's tanks and forwarded them to COIL for comparison. This subsequent analysis confirmed the result that the mystery spill had originated from the tank vessel.

Homicide? Responding to a completely different situation, COIL assisted the District Attorney for Queens County, NY investigate a fatal automobile accident. The accident was caused by oil poured onto a roadway. COIL compared samples of oil collected from the roadway and the wheelwell of the wrecked car with samples from a nearby residence where the suspect in the case had recently changed the motor oil in his automobile. The analysis linked the residue samples from the oil change operation to the samples from the wrecked car and roadway while simultaneously eliminating samples collected from other possible sources in the area. The analysis results and testimony of the COIL analyst were presented to the Grand Jury for the case to help secure an indictment of the defendant on manslaughter charges. This was the fifth homicide investigation assisted by COIL.

Arson! In a different type of law enforcement action, COIL assisted the Connecticut State Fire Marshal in the investigation of a suspected arson case. A store owner was suspected of trying to torch his business establishment to collect insurance proceeds. An old fire extinguisher filled with kerosene was used to spread the accellerant throughout the attic space of the store, and a fire ignited. The fire was discovered very quickly and extinguished by the local fire department before the building was destroyed. The fire extinguisher was recovered with some of the kerosene still inside. COIL analysis matched this kerosene with samples seized from the suspect's residence.

Old Oil. Another interesting case analyzed by COIL involved a laid-up tank vessel in Portland, Oregon. In order to conduct some needed maintenance, the vessel was ballasted down by the bow. An oil slick appeared in the water near the vessel. Coast Guard investigators collected samples of the spill, from the bunker tanks of the vessel, and from oil trapped in a seachest which had been exposed by the ballasting operations. Analysis matched the spilled oil to the oil trapped in the vessel's seachest and indirectly linked it to the oil from the vessel's bunker tanks. When MSO Portland personnel received these results, they requested COIL to re-analyze samples in storage at COIL from a mystery spill that had occurred in the same area a year before. These old spill samples also matched the oil trapped in the vessel's seachest, enabling the Coast Guard to seek reimbursement of the federal pollution funds expended on cleanup of the previous spill.

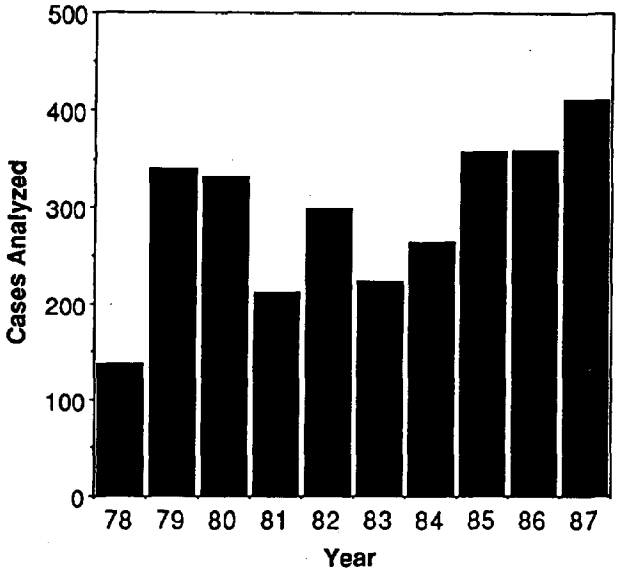

FIGURE 2 — COIL Caseload by Fiscal Year

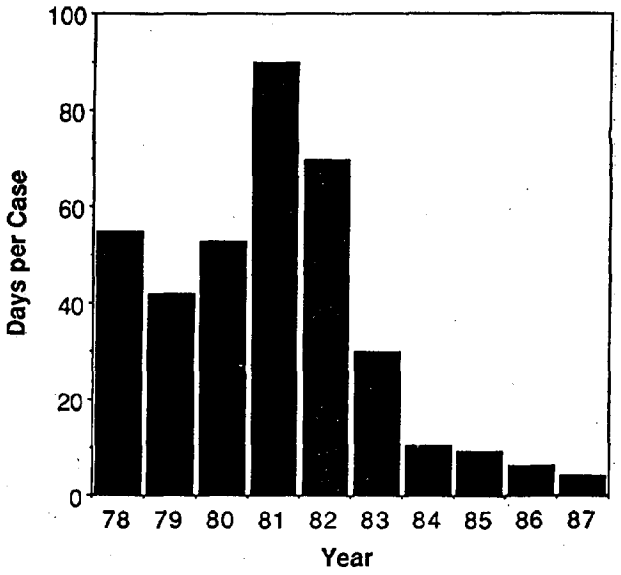

FIGURE 3 — COIL Average Case Analysis Time

CONCLUSIONS

As demonstrated by these examples, the OIS plays a very vital role in the Coast Guard's efforts to protect the marine environment as well as in many other applications. Figures 2 and 3 illustrate the increasing workload trend and improved efficiency of OIS operations over the past ten years. The efficiency of COIL, measured by average case analysis time, has vastly improved from early operations. During Fiscal Year 1987 more than 10,700 chemical analyses on 2,478 oil samples representing 411 pollution investigations were completed. This was accomplished while maintaining an average case turnaround time of 4.3 calendar days. Today the Coast Guard OIS continues to fulfill the purpose for which it was designed while COIL personnel strive for better and more efficient ways to accomplish their tasks.

REFERENCES

1. **Report CG-D-52-77 "Oil Spill Identification System"**, Final Report June 1977, U.S.C.G. R&D Center.
2. **COILINST M5400, March 2, 1988,** "Central Oil Identification Laboratory Organization Manual".
3. **"COIL Methods and Procedures Manual"**, August 18, 1987.
4. **"1986 Annual Book of ASTM Standards"**, Section II, Volume 11.02, American Society for Testing and Materials.
5. **Crane, R.D. and Kelley, M.,** "COIL", Commandant's Bulletin, Issue 14087, July 19, 1987, U.S. Coast Guard (G-BPA), Washington, D.C., pp 9-10.

A COURSE IN HAZARDOUS MATERIALS

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Todays industries use materials unknown as recent as a decade or two ago: synthetic plastics and fibers, explosives, corrosive acids, pyrophoric liquids, combustible metals, toxic and radioactive materials, highly flammable petroleum fuels and many more. Much of this material is transported in both large and small quantities over water. Since the Coast Guard is tasked with regulating the transportation of these materials in ships, an understanding of the inherent dangers and proper handling of hazardous materials is of paramount importance to individuals charged with the enforcement of these regulations. The need to provide training for future officers of the Coast Guard in the area of Hazardous Material Transportation is being met at the Coast Guard Academy.

The course, "Hazardous Materials in Marine Transportation," is designed to give cadets the theoretical base upon which their future decisions, as officers, can be made regarding various aspects of hazardous material transportation including containment and safety systems, research and development, environmental protection, and domestic and international regulations. Three major areas — Chemical Hazards, Marine Transportation and Environmental Response are discussed in detail. Lectures are presented addressing specific topics within these areas. Guest lectures, audiovisual materials, demonstrations and field trips are employed to enhance the understanding of course content. Additionally, during a drill based upon a realistic spill response scenario, the cadets must plan and execute the proper response procedures learned in class. This allows the cadets to apply the course material in a practical, real-world situation.

The chemistry of hazardous materials at first look seems to be as varied as the number of chemicals one may encounter in industry. Upon closer examination however, the hazards can be sorted into three basic categories: chemical reactivity, fire/explosion and health. These are commonly referred to in the course as the "HAZ MAT BUGS."

The introduction into chemical reactivity is given as a review of chemical terms and chemical families: acid/base, oxidizers, organic compounds such as solvents and other petroleum products, and radioactivity. Each of these topics is discussed in class using examples to illustrate the chemical principles. One area described in detail is water reactivity. Other types of chemical reactivity are also presented. These include self-reactivity (polymerization), air reactivity, reactivity with materials of construction and reactivity with other substances. These lectures prepare the students for exercises in cargo compatibility, which involves the proper stowage of hazardous materials for safe transportation. The students are provided general guidelines and a list of cargoes. Using this information they must complete a proper loading and stowage plan for these materials on board a hypothetical vessel.

The second major element for examination is fire/explosion hazards. An unwanted by-product, in some instances, of chemical reactivities and improper stowage of non-compatible chemicals, is fire and/or explosion. The theory behind both fire and explosion is presented. General characteristics and hazards of fires involving solids, liquids and gases are extensively covered. The burning characteristics and hazards of flammable metals are also briefly mentioned. Thermal transport by conduction, convection and radiation is introduced. The student is exposed to the concept of the fire tetrahedron and the interrelationship of the components that make up this model.

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These concepts are then used for applying extinguishing theory to the different classes of fires. Best methods of extinguishment and use of different extinguishing agents are discussed, as they apply to different situations involving the fires of liquids, gases and solids, both normal and metal. Movies and slides are utilized to supplement the course lecture.

The last of the "Haz Mats Bugs" to be discussed is health. A large amount of time is spend describing toxicity. Acute and chronic toxicities are defined and examples of each are given. The measurement of toxicities using parameters such as LD_{50} (Lethal dose that kills 50% of a test population) and Draize testing (skin irritancy/corrosion) are discussed. Transportation health guidelines such as the different classifications of poisons (Poison A, B, etc.) are also described. After a general introduction, the focus is turned to the toxicity of certain substances. As an example, solvents and pesticides are studied for their acute toxic action as well as the chronic effects that one may experience with an exposure over a long period of time in fairly low concentrations. Benzene and other substances are used to illustrate the differences in the toxicities.

The course then turns to the specific area of occupational health (industrial hygiene). Threshold limit values (TLVs) are related to both qualitative and quantitative fashions. Controls used to minimize health risks from exposure to chemical substances are also described. Engineering, administrative and personal protective measures are prioritized for the student.

Lectures dealing with the chemistry of hazardous materials utilize approximately one-half of the semester. Once a student is familiar with these concepts the course shifts to the problems associated with transportation of hazardous materials.

The Coast Guard is the primary government agency concerned with the transportation of hazardous material over water. This transportation occurs in two separate and distinct modes; bulk and packaged. Inevitably associated with hazardous materials, are the laws and regulations that govern their transportation. Although not a "regulations intensive" course, some knowledge of regulations is required to obtain a better overall understanding of the transportation of hazardous materials. Laws and Treaties empowering the Coast Guard with the regulation of hazardous material transportation are introduced. Time is devoted to defining the codification of these laws and general organization of the overall applicable regulations. The content of each part of the regulation is presented briefly in order to provide the student with some reference point in the event of future involvement. Three areas of particular interest to the Coast Guard, namely the packaged, bulk and pollution regulations, are covered in more detail.

Under the "packaged" hazardous material regulations, the problems involved in offering a hazardous material for shipment through classifying, packaging, marking, labeling/placarding and describing the material on shipping papers, are extensively covered. Use of the Hazardous Material Table in the regulations is introduced. A comparison of International and U. S. Regulations is made and an assignment is given requiring the students to properly prepare a hazardous commodity for shipment in compliance with the applicable regulations.

In covering the "bulk" transportation of hazardous materials, time is spent on the general design of bulk carriers — petroleum tankers,chemical tankers, and liquified gas tankers. Specific design areas covered include cargo containment, vessel arrangement, cargo transfer systems, safety equipment and any "special hazards" associated with the transportation of cargo on each type of vessel. In these areas, concepts from the first half of the semester are related to actual engineering practices applied in vessel construction to minimize the "Haz Mat Bugs." Reference to applicable regulations in the construction and operation of these vessels is made. Unique cargo hazards as specifically outlined in the regulations are also related. Comparisons between petroleum, chemical and liquified gas tankers pointing out the necessary "high technology" sophistication are made. Photographs and blueprints of vessels showing the various configurations are utilized in the classroom. Field trips to chemical, petroleum and gas tankships, as available, are scheduled to enforce classroom-learned concepts. Literature supplied by the chemical industry and movies are combined in the lectures to supplement and reinforce the material presented.

An overview of the Coast Guard's role in Commercial Vessel Safety, Marine Environmental Protection and Port Safety and Security is presented. Coast Guard Organization from the Headquarters level to field Marine Safety Offices is outlined. The Coast Guard responsibility and role in hazardous materials spills is covered. Applicable "responsible" laws are introduced.

As an available tool for assigning hazardous material mishaps the students are introduced to the Coast Guard CHRIS (Chemical Hazard Response Information System) system. The use of this system for hazard assessment, personnel protection and containment, treatment and recovery, is stressed. Briefly introduced is HACS (Hazardous Assessment Computer System) and its potential use in spill situations. Spill scenarios are then presented and students utilize the information discussed to determine appropriate organization and remedial action.

The topic of hazardous waste management is covered briefly. Different methods of waste disposal from landfills to "state of the art" plasma incineration are introduced. Coast Guard involvement in the approval of vessels for the incineration of waste at sea is also discussed.

In order to pull the varied course material together as the semester nears completion, a chemical spill drill is conducted by the students and members of the Coast Guard Strike Team. Each member of the class is assigned a position on the spill response team ranging from On-Scene Commander to decontamination team member. Department of Science faculty and the local media are invited to play various roles during the exercise to increase the realism. The students are required to begin organizing two weeks before the drill and develop a general contingency plan. On the day of the drill, Strike Team members brief the students concerning the material spilled, weather conditions, and available materials. The students then take over and make all safety, clean up, and public relations decisions reacting to information provided by the instructor and role players.
The entire event is videotaped for an in-class critique. This exercise provides the students with an opportunity to utilize their knowledge, don equipment, and think on their feet just as a response team would in the field.

The "Hazardous Materials in Marine Transportation" course is, in essence, a "capstone" course for those students majoring in Marine or Applied Sciencs and is also of great importance to naval and other engineering disciplines. Management majors find the course a useful and practical technical elective. It's a contemporary and practical course for the technically oriented individual. At the same time, however, certain management principles are strategically introduced to make the course complete. Cadet evaluation indicates that the course is well received. We believe it's a practical course involving research, planning, writing, knowledge/use of engineering/scientific/technical information that results in accomplishment of "real world" Coast Guard mission — something the cadets will be required to do many times in the future as Coast Guard officers.

AN ARGOS METEOROLOGICAL OCEANOGRAPHIC SPAR BUOY FOR ANTARCTIC DEPLOYMENTS

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ABSTRACT

A specially configured spar buoy with a 150 meter kevlar multielement sensor string has been designed for deployment in the Antarctic Ice Fields. The buoy collects a full suite of meteorological data combined with hourly samples from the oceanographic sensor tether. Water column sensors consist of ten medium resolution multiplexed temperature and pressure sensors along with six pairs of high resolution conductivity and temperature sensors to provide an estimate of the salinity structure below the buoy. Data relay is carried out using the ARGOS capability of the two orbiting NOAA Satellites. A pair of developmental buoys were deployed this past winter in the open waters of the Weddell Sea, Antarctica from the German Oceanographic Research Vessel POLARSTERN. Recent data shows the rate of mixed layer cooling prior to freeze-up.

INTRODUCTION

The Antarctic Meteorological Oceanographic Spar Buoy or the AMOS Buoy was developed by Polar Research Laboratory for Lamont-Doherty Geological Observatory as a means of collecting environmental data from the Antarctic Seas. The buoy design borrows design concepts previously used in PRL's SALARGOS[1] Arctic buoy and the open ocean ASID[2] buoy. The Meteorological measurements consist of Air Temperature, Barometric Pressure and Wind Speed. The Oceanographic measurements consist of Temperature and Conductivity along a 155 meter electromechanical cable which hangs below the 4.5 meter long spar buoy hull. The underwater sensors are spaced along the cable at 10 meter intervals with four of the six C/T pairs positioned in the first 35 meters of the water column and the ten low resolution temperature sensor modules positioned from 45 meters down. The three cable depth sensors are positioned to break the cable into thirds so that cable catenary shape can be determined thereby making it possible to make depth corrections to the individual sensors. While using an open ocean PRL drifting buoy with a 300 meter string Picket[3] demonstrated that pressure sensors on subsurface cables have the potential to provide information on the vertical current structure of the water column. He was able to detect the passage of an eddy based on data from a pair of depth sensors on the cable. Sensor data is sampled every hour and sent out over a telemetry link to the ARGOS data collection system on board the currently active US NOAA Polar Orbiting Satellites.

Buoy development for three drifters was started in the fall of 1985 with the first deployment during the Antarctic winter of 1986 followed shortly afterwards with loss of the buoy during a storm. Following the short-lived deployment of the first AMOS Buoy, the remaining two drifters were returned to PRL for extensive sensor recalibration and long term burn-in testing. During the spring of 1988 the two remaining AMOS Buoys were deployed into the open ocean approximately 480 nautical miles north of Dronning Maud Land Antarctica from the the ice strengthened German research vessel, POLARSTERN. The results of these recent deployments will be reviewed.

SCIENTIFIC OBJECTIVES

The Southern Ocean has long been recognized as a major component in the ocean/atmosphere system. Oceanographically, the region serves as the dominant area for deep and bottom water formation and deep ocean ventilation. Atmospherically, the region serves as an important climate modulator through the insulating effect of the extensive seasonal sea-ice cover. This sea-ice, in turn, is intimately coupled to the ocean/atmosphere system. Its temporal and spatial distribution is determined by the nature of the atmospheric forcing and the ocean's density structure. The atmospheric forcing though, is itself modified by the presence of sea-ice, while the ocean's density structure is modified by the growth and decay of the ice, which in turn, affects the magnitude of the deep ocean ventilation and deep water formation. The air/sea/ice system is thus highly interactive and understanding of this interaction is necessary to determine the nature of such important phenomena as deep water formation, oceanic heat ventilation, sea-ice distribution and climate modification.

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To obtain this requisite understanding requires extensive modeling efforts and the collection and analysis of the appropriate data. To date, however, the models are dependent upon numerous parameters and forcing functions of unknown character and the data necessary to refine these unknowns are virtually nonexistent. As a consequence the models are overly simplified, highly tuned and lack the observational framework against which to gauge their success. Even the basic data required to test simple conceptual ideas are lacking due to the inherent difficulties of collecting data in the Antarctic sea-ice field.

In the austral winter of 1986, POLARSTERN made an expedition to the Atlantic sector of the Southern Ocean. There, the vessel sailed through the sea-ice field along the eastern margin of the Weddell Sea to the Antarctic continent and back out over the winter season. The expedition, the first of its kind in the winter Antarctic, was multidisciplinary in nature while focused on obtaining those data necessary to advance our general understanding of the air/sea/ice system.

A specific component of that program was the deployment of three prototype meteorological/oceanographic salargos type drifters (AMOS Buoys) capable of operation over the full range of conditions from open water to fully formed sea ice. The drifters, described in detail below, were designed to provide time series data (as opposed to spatial series provided by ship measurements). These time series would reveal the nature of the seasonally varying atmospheric forcing and upper ocean (thermal/saline) response to this forcing as the system evolves through an annual cycle. These data would thus provide fundamental observational evidence pertaining to the interactive nature of the air/sea/ice system while providing a foundation against which to test, evaluate and improve the existing models.

TECHNICAL DETAILS

The AMOS Buoy uses a standard 8 inch diameter 1/8 inch wall Arctic aluminum type hull to house the electronics and batteries. This hull is encased with a 12 3/4 inch diameter 0.3 inch wall glass fiber sheath with the interspace filled with polyurethane flotation foam. The length of the hull is 15 feet. The sheath was used in an attempt to protect the thin walled aluminum cylinder from blocks of sea ice during freeze up and during ice breakup. The buoy electronics are housed within an internal rack which slides into the hull. Fourteen alkaline battery packs are located at the base of the rack. A 63 inch long ARGOS antenna housing is positioned at the top of the hull. A special barometric pressure port is situated inside the housing. The port includes a special water trap to prevent water from getting to the pressure sensor during periods of complete buoy submersion. The air temperature ventilator and the ruggedized wind speed sensor are located at the top of the antenna housing. A heavy tapered section of polyurethane rubber called a carrot is used to reduce bending stress on the 155 meter ocean sensor cable where it attaches to the base of the buoy. The cable conductors enter the buoy hull through a compression seal at the base. Sensors are positioned along the cable with conductor breakouts every 10 meters as illustrated in Figure 1. The sensor fairings act to protect the delicate sensor modules during handling and at deployment. Both the high resolution conductivity/temperature and low resolution multiplexed faired modules are shown in the photo of Figure 2 taken during an ice bath test. Underwater connectors are spliced to the cable triples at the breakout points.

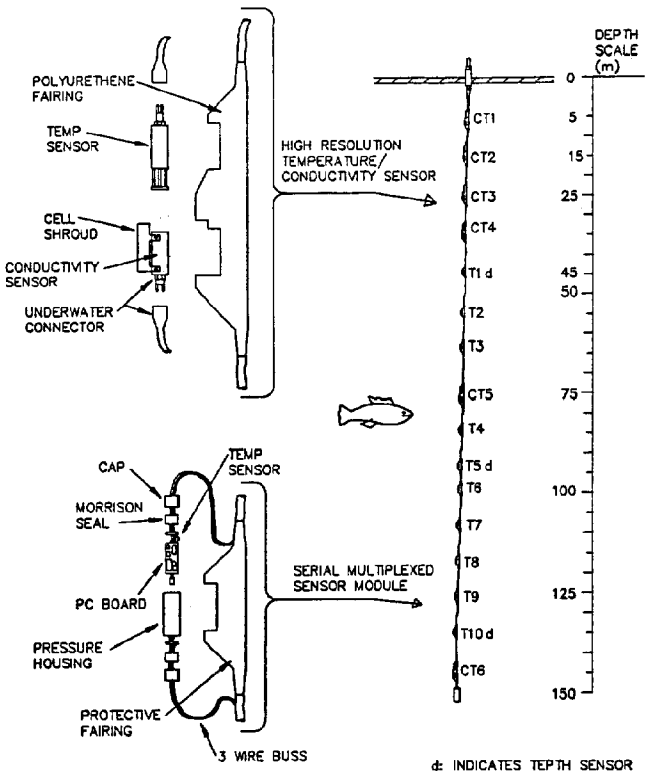

Figure 1. AMOS Buoy Sensor String Schematic.

The 155 meter sensor cable contains 13 twisted triads and 5 twisted pairs of number 24 stranded (19/36) wires with low density polyethylene insulation. A kevlar braid passes over a low density rod filler. The conductors are wrapped around the kevlar with a protective layer of mylar tape between. A 0.10 inch polyurethane jacket is added for protection of the conductors from rafting ice below the buoy, the cable is free flooding. The overall diameter is 0.82 inches.

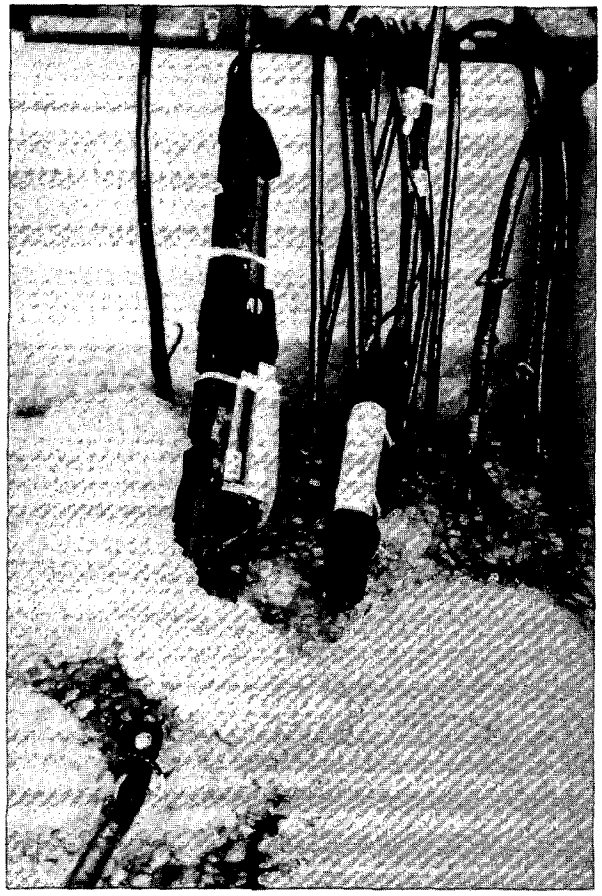

Figure 2. Sensor Fairing Clusters.

The measurements made by the AMOS Buoy are listed in the table below showing ranges covered, resolutions, averaging period and accuracy.

MEASUREMENT	RANGE	RESOLUTION	AVERAGING	ACCURACY
Barometric Pressure	950 - 1050 mB	0.1 mB	50 sec	1.0 mB
Air and Hull Temperature	-21 to +29°C	0.2°C	10 sec	1.0°C
Wind Speed	4 to 51 m/s	0.2 m/s	0.2 sec	1 m/s or 10%
Sea Subsurface Temperature				
Low Resolution	-2.0 to 3.12°C	0.02°C	20 sec	0.1°C
High Resolution	-2.0 to 25°C	0.001°C	10 sec	0.03°C
Cable Depth				
D1 :	35.25 to 48.0 m	0.05 m	0.1 sec	0.2 m
D5 :	74.5 to 100.0 m	0.1 m	0.1 sec	0.5 m
D10:	16.5 to 152 m	0.14 m	0.1 sec	0.7 m
Conductivity	14 to 59 mmho/cm	.0003mm/cm	0.1 sec	.0003mm/cm
Battery Voltage	12.8 to 19.1 vdc	0.1 vdc	0.1 sec	0.1 vdc

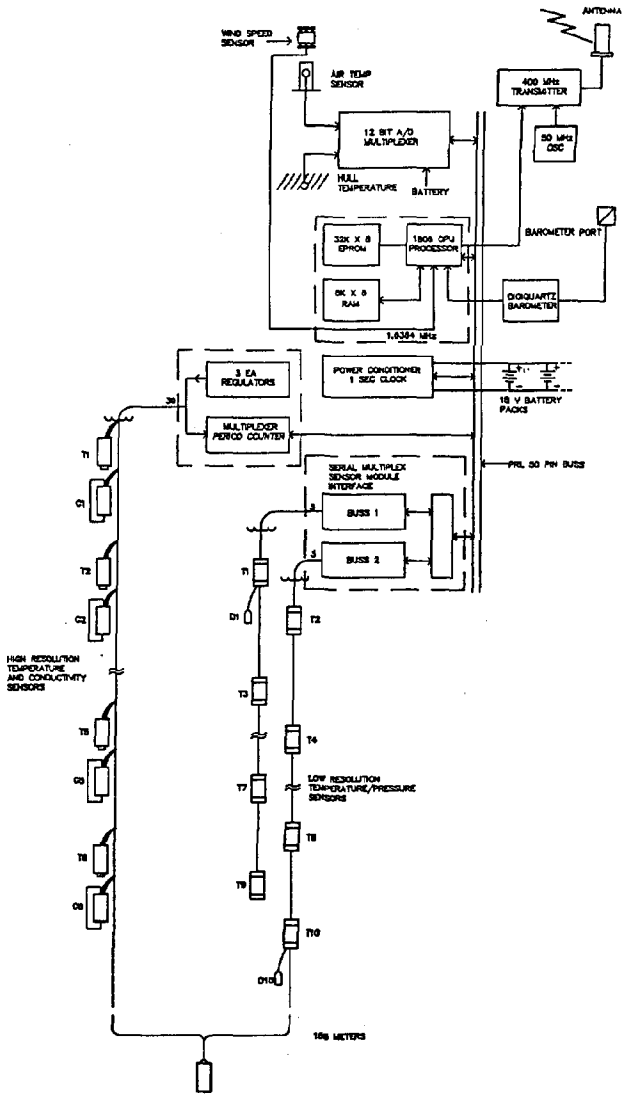

Figure 3. AMOS Buoy Functional Block Diagram.

The sensors are sampled once every hour starting at the buoy reset time. Two ARGOS transmission groups, each with a full complement of eight frames, are required to accommodate a one hour sample. Three hours of data are held in a buffer consisting of six separate ARGOS groups. These data are sent out over a six minute period and then repeated. The ARGOS data format is outlined below.

FRAME	WORD NUMBER			
	1	2	3	4
1	Barometer	Battery	Air Temp	Hull Temp
2	Blank	Wind Spd	Blank	Heading
3	C1H	C1L	C2H	C2L
4	C3H	C3L	C4H	C4L
5	C5H	C5L	C6H	C6L
6	T1H	T1L	T2H	T2L
7	T3H	T3L	T4H	T4L
8	T5H	T5L	T6H	T6L

1	Barometer	Battery	Air Temp	Hull Temp
2	Blank	Wind Spd	Blank	Heading
3	T1	T2	T3	T4
4	T5	T6	T7	T8
5	T9	T10	D1	D5
6	D10	BLANK	BLANK	SAMP
7	SAMP	SAMP	SAMP	SAMP
8	SAMP	SAMP	SAMP	SAMP

The barometer words are ten bits to the accommodate the 100 millibar range with the 0.1 millibar resolution. The battery word is six bits and the remaining words are all eight bits. The sixteen bit high resolution conductivity and temperature data are indicated as C1H and C1L where the high and low bytes are indicated by the letters H and L. The low resolution temperature data words are indicated as T1 through T10 and the depth data is indicated as D1, D5 and D10. SAMP indicates the hour that the sample was taken.

The system block diagram of Figure 3 defines the major functional blocks making up the AMOS buoy electronics. A card cage holds the five system printed circuit boards as shownin the photo of Figure 4. Each of the boards communicate over a common 50 conductor buss. The boards consist of an encoder/processor, an analog to digital converter, a power conditioner, a serial multiplex module interface and the 16 bit multichannel period counter. The sensor sampling is carried out under control by an RCA Cosmac 1806 8 bit microprocessor while executing a controller program written in assembly language.

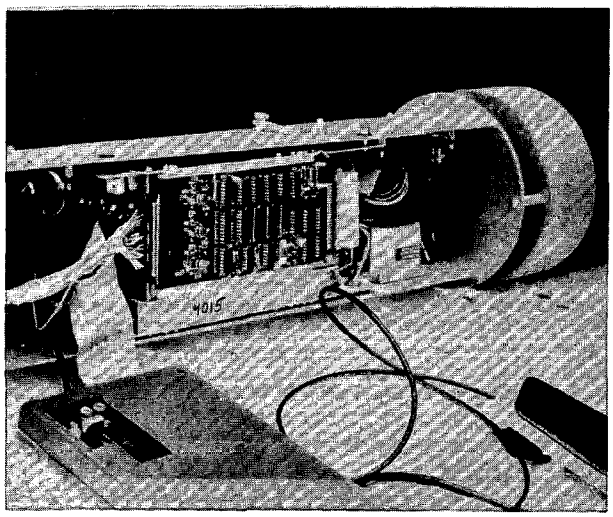

Figure 4. AMOS Buoy Electronics.

Barometric pressure is measured using a Paroscientific Digiquartz transducer which produces a frequency output which varies with atmospheric pressure as described by a series of third order equations. The frequency is measured using a 50 second gate period to open a 16 bit accumulator to the input pulse train from the sensor.

A sun shield and air ventilator is located at the top of the ARGOS antenna 2.5 meters from the buoy water line. A Yellow Springs Instruments thermistor network is located within this housing to make the air temperature measurement. The sensor and the associated electronic signal conditioning have a combined accuracy of better than ±0.2°C.However, errors associated with solar heating effects on the ventilator add to the total system error accounting for an overall accuracy of ±1.0°C. The same sensor and signal conditioning technique are used to make the ice/water temperature measurement except that the sensor is located on a spring loaded holder in contact with the inside surface of the hull one meter below the buoy water line. Data from this sensor is also used to correct the barometric pressure sensor for temperature effects.

The wind speed sensor is located above the air temperature ventilator. A three bladed savonius rotor turns on a sapphire jewel bearing under the influence of the wind. The rotation rate of the rotor is measured using a magnetic pickup to sense the passage of six small ferrous slugs at its base. The rotor is 2-1/4 inches in diameter and is housed in a 4 inch diameter housing. This sensor represents many years of development to provide a robust, yet relatively low threshold device. The approximate transfer function of the sensor is $WS = 0.7 + 0.05 * F$ where WS is the wind speed in meters per second and F is the frequency in hertz. Sensor calibrations are carried out using the wind tunnel at the University of Southern California at Los Angeles. The measurement is made by accumulating the electrical pulses from the sensor in an eight bit counter.

The eight bit low resolution temperature and depth sensors are individually multiplexed on one of two three wire data busses. The design is such that up to 64 modules can communicate on the same buss, in this case each buss holds five modules thus providing isolation so that a partial cable failure or a flooded unit will not affect the operations of the second. Each sensor module is interrogated with two, 11 bit serial data words. One of the data words contains the address, the other is a command word. When the address matches that of the programmed module address the module samples the sensor data and transmits it back up the line in two, 11 bit data words. Each 11 bit word consists of eight data bits , a parity bit, a start bit and a stop bit. The multiplexed signal output from the sensors is delivered to the buoy processor via the interface. A simplified block diagram of the module electronics is shown in Figure 5. The major components consist of an 8 bit analog to digital converter, a power regulator, analog signal conditioner, line isolation components, a pressure sensor and a temperature sensor. In its normal operating mode, each module's Asynchronous Receiver Transmitter (ART) processes all serial data appearing on the cable pair. When the identification code word matching a module's preprogrammed code word

appears on the cable pair, the module's ART accepts the next 8 bit word as a command word.

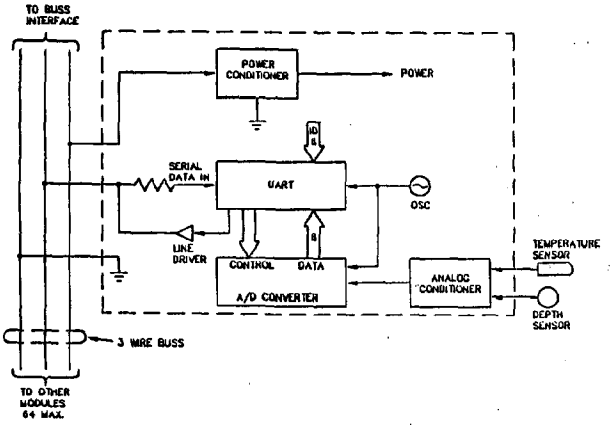

Figure 5. Three Wire Multiplexed Sensor Module Block Diagram.

After the command word reception, the ART signals the A/D to process the temperature or depth signal and return the resulting 8 bit data to the ART. Upon receipt of the end of conversion pulse from the A/D, the ART sends two 11 bit words back up the cable pair. The digital words appearing on the cable pair are formatted so that no responding module could cause another module to respond.

Primary power is supplied from a bank of fourteen each 18 volt alkaline battery packs each with a capacity of 18.4 amp-hours. The average current drain is 23.5 milliamps with 62% of the load due to the processor and 33% due to the ARGOS transmitter which uses 500 milliamps for 0.92 seconds every minute, the remaining 5% of the power consumption is attributed to sensor power and sampling. With this load the battery pack will provide power for the buoy for 456 days.

DEPLOYMENT

The first prototype drifter was deployed on July 28, 1986 at approximately 62 S and 1 W in newly consolidated pancake ice 40 cm thick as shown in the photo of Figure 6. Unfortunately, this first prototype proved defective and on board testing revealed the problems to be common with the remaining two drifters which were returned to PRL for repair and later deployment. The defective drifter was tracked for a total of 19 days before it stopped transmitting during a period of heavy weather. The 19 day drift is shown in the plot of Figure 7. Later testing of the remaining two drifters suggested that the failure was due to leakage through the pressure sensor housings via faulty connector seals. The sensors were returned to the manufacturer and refurbished. The calibrations on the 16 bit temperature sensor oscillators were suspect so they were sent to the Northwest Regional Calibration Center in Bellevue, Washington for recalibration. As a group the twelve sensors were placed in large temperature baths. At each calibration point, the bath

Figure 6. AMOS Buoy 6440 Deployed in 40 cm of Ice at 62°S 1°W on 28 July 1986.

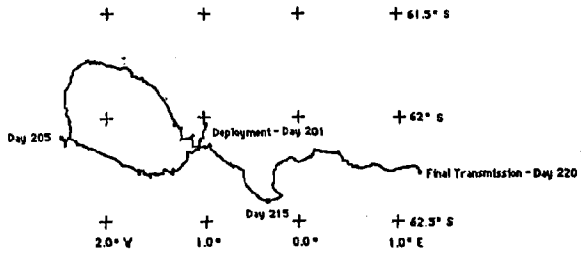

Figure 7. Drift Track of AMOS Buoy 6440.

temperature was stabilized to within one millidegree Centigrade and the temperature was measured using a Standard Platinum Resistance Thermometer. The output frequency from each sensor was read 12 times giving a mean which was used to arrive at that calibration point. A total of seven different points were taken in the process to make a least squares fit to calculate coefficients to a third order equation. The quality of the calibration was verified by calculating the temperature using the equation and taking the difference between the measured and calculated terperatures, the resulting average standard deviation was .003°C.

The refurbished drifters were deployed from the POLARSTERN on March 5, 1988 at about 62 S, 0 W within approximately two nautical miles of one another under open ocean conditions. The close proximity of the two drifters allows replication of data and provides a consistency check on sensor readings. Over the first month of transmitted data, the temperature data show excellent consistency. Later data has not yet been processed in one drifter due to recently resolved problems with Service Argos magnetic tape distribution. Conductivity/temperature/depth measurements made from the ship at the time of deployment were unreliable so inter-sensor comparisons were not possible. Temperature sensors all tested within specifications on the ship just before deployment.

Both drifters experienced significant sensor dropout shortly after a smooth deployment into calm waters for reasons not yet diagnosed. It is expected, however, that improved string design techniques developed by PRL over the past year, which make the in-water system much more rugged, will result in greatly improved reliability. This is currently being successfully verified in sea tests on other programs. In one drifter, all high resolution/conductivity sensors failed as did 5 of the 10 low resolution temperature sensors. In the other drifter, 4 of the 6 temperature conductivity pairs failed as did 1 low resolution temperature sensor. No additional failures were experienced subsequent to those occurring at deployment. In general, the meteorological data, low resolution temperature and depth sensor data return is excellent. The drifters are presently locked in the sea-ice field which developed in late June.

CONCLUSIONS

A substantial amount of information concerning the upper ocean evolution is obtained from the temperature data. Interesting observations collected thus far reveal the rate of mixed layer cooling and expansion prior to ice onset as shown in the temperature time history plot of Figure 8. Data indicate that there is a strong coherency of temperature fluctuations across the entire pycnocline, possibly indicating passage of a warm core eddy through the region as suggested in Figure 9. The data reveal the linearity of the thermocline as it increases from the freezing point in the mixed layer to approximately .4°C at the 155 meter depth near the temperature maximum. The temperature sensors show slight, but consistent, offsets from the absolute temperature (approximately .32°C; this amount has been added to the temperatures in Figures 8 and 9). This is corrected by comparison to the functioning high resolution sensors in the mixed layer. If possible, the sensors will be recalibrated upon recovery during the austral summer of 1989.

ACKNOWLEDGMENTS

This project benefited from: Rosemary Macedo who oversaw the 1988 drifter deployment; the chief scientist, Dr. D. Fuetterer who graciously accommodated the drifter program; and from the excellent assistance of the crew and Captain of the POLARSTERN. The extra effort given by Kevin Brooks and Noley Baker of Polar Research Laboratory and Miguel Maccio of Lamont-Doherty during development and testing of the drifters is gratefully acknowledged.

This research was supported by National Science Foundation Division of Polar Programs grant DPP 85-01976.

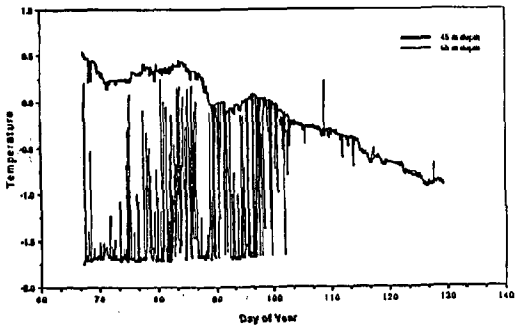

Figure 8. Temperature measurements from sensors at 45 and 65 meter depth. The shallower sensor is in the warm summer mixed layer and the deeper one in the temperature minimum layer. The water at the 65 meter depth is entrained into the mixed layer by day 104 during the fall cooling period. this is revealed by the convergence of temperatures and the decrease in magnitude and frequency of the 65 meter temperature fluctuations. This reflects the increased thermal inertia of the mixed layer as its volume increases.

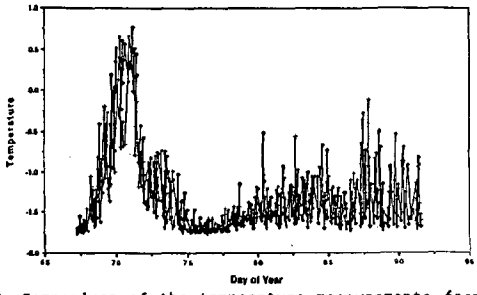

Figure 9. Comparison of the temperature measurements from the two drifters, located approximately 2 nautical miles apart, at the 105 meter depth level. Note that the sharp temperature increase is probably due to the passage of a warm core eddy through the region from days 68 to 78.

REFERENCES

1. Burke, Samuel P. and Morison, James, "An improved SALARGOS Buoy for deployments in Polar Seas" Oceans 87 Conference, September 1987, Halifax, Nova Scotia, Canada, pp 49 - 53

2. Kozak, R. and Anderson, J., "Overview of the NOAA Data Buoy Center Drifing Buoy Development Programs" NOAA NDBC Report WP219, ARGOS Users Conference May 21, 1984, Seattle, Washington

3. Picket, R. L. and Lee, J., "Estimating Vertical Current Structure From Satellite-Tracked Drifters" Marine Technology Society Journal Volume 18 Number 4, pg 4 - 8

METHODS OF OBTAINING WEATHER DATA IN REAL TIME

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ABSTRACT

Small craft owners who have access to a personal computer now have several methods of obtaining real-time meteorological data before venturing out to sea. These data include high quality NDBC buoy and coastal marine observations, cooperative ship observations, coastal marine forecasts, wind forecasts for coastal marine locations, and graphical weather maps. These observations and forecasts are typically not available on a timely and continuous basis via radio or television. They are available by dialing into a variety of on-line meteorological data bases or receiving the data directly from a commercial satellite. Strengths and weaknesses of these methods are discussed.

1. INTRODUCTION

Mariners who have personal computers can obtain a variety of weather observations and forecasts which will help them decide whether they should venture out to sea. Unfortunately, obtaining this data will usually cost them money. So, before describing these data access methods, we should first ask the question: "Why use a PC when you can get weather information via NOAA Weather Radio or the Weather Channel?"

There are several good answers. First, some data are not available via these traditional sources. For example, water temperatures from the National Data Buoy Center (NDBC) buoys and tide levels from coastal stations are typically not reported. These observations may be very important to fishermen. Second, because of manpower constraints, NOAA Weather Radio reports are updated about once an hour, except under emergency conditions. Because buoy observations arrive later than the regular airport observations, it is not uncommon to have observations 1 to 2 hours old being broadcast via the Weather Radio. Observations are available in a much more timely manner via a PC, typically arriving within 5 minutes of issuance. In bad weather, timeliness can be important.

Now that I've covered the "Why," I'll address the "What" and the "How." Namely I'll discuss what products are available that would interest the mariner and then how to access them.

2. THE WEATHER PRODUCTS

2.1 Observations

As you might guess from my affiliation, I'm "high" on observations produced by NDBC. These observations are transmitted hourly from about 55 moored buoys and 40 Coastal-Marine Automated Network (C-MAN) stations. The locations of these stations are shown in Figures 1 and 2. Many of the stations are located within 20 miles of the coast. All stations report winds, sea level pressure, and air temperature. All buoys and a few C-MAN stations report significant wave height, dominant wave period, and water temperature. A few C-MAN stations also report tide data. An overview of NDBC data is given by Hamilton[1]. The network of stations is slowly expanding and NDBC is expecting to be able to measure relative humidity at a number of stations in the near future.

The main strength of these data are their excellent quality[2]. Scientists and weather forecasters regard these reports as much superior to ship data. All data are monitored daily and removed from distribution if the data

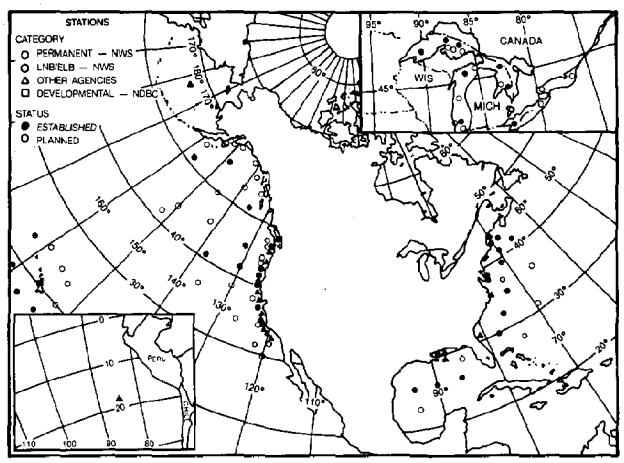

Figure 1. NDBC Buoy Locations

become invalid. Because they are available hourly, they provide a good indication of deteriorating weather conditions. They also give an indication of how well the marine forecasts are verifying. One disadvantage of the data is that they are usually available only in coded form. However, with a little effort, most people can mentally decode an observation quickly. Information on station identification and codes is available from NDBC's Data Systems Division at (601) 688-2836.

Another source of observations consists of reports from coastal airports and other hourly observing stations near the coast. These stations maintain a continuous weather watch and quickly transmit a report when thundershowers are in the area, or the ceiling and visibility measurements quickly change. The primary advantage of these data are their visibility and current weather information. A few stations report tide data. The biggest disadvantage is that the winds often don't represent the winds reported in the marine environment. They are frequently lighter than marine winds because of land-induced turbulence.

A third source of observations is cooperative ship data. These are reports from small craft operators or commercial fisherman who radio the information back to shore. Confidence in the quality of these observations is generally low, however they can provide a good indicator of weather tendency. For example, the absolute accuracy of a wave height report may not be that great due to human estimation, but the observation that seas are building rapidly is invaluable. A big disadvantage is that the observations are made infrequently, usually after everybody has reached the fishing grounds! Also, more observations are available during good weather.

2.2 Forecasts

In addition to observations, various forecast products are also available. Obviously, the most important is the coastal marine forecast for your local area issued by the National Weather Service (NWS). This provides the expected wind and wave conditions for waters extending out to 20 miles offshore from a stretch of coastline 100 to 200 miles in length. Similar forecasts are also available for tidal bays. If you obtain nothing else, obtain these forecasts before making your decision to venture out. One disadvantage of these forecasts are their "broad brush" approach,

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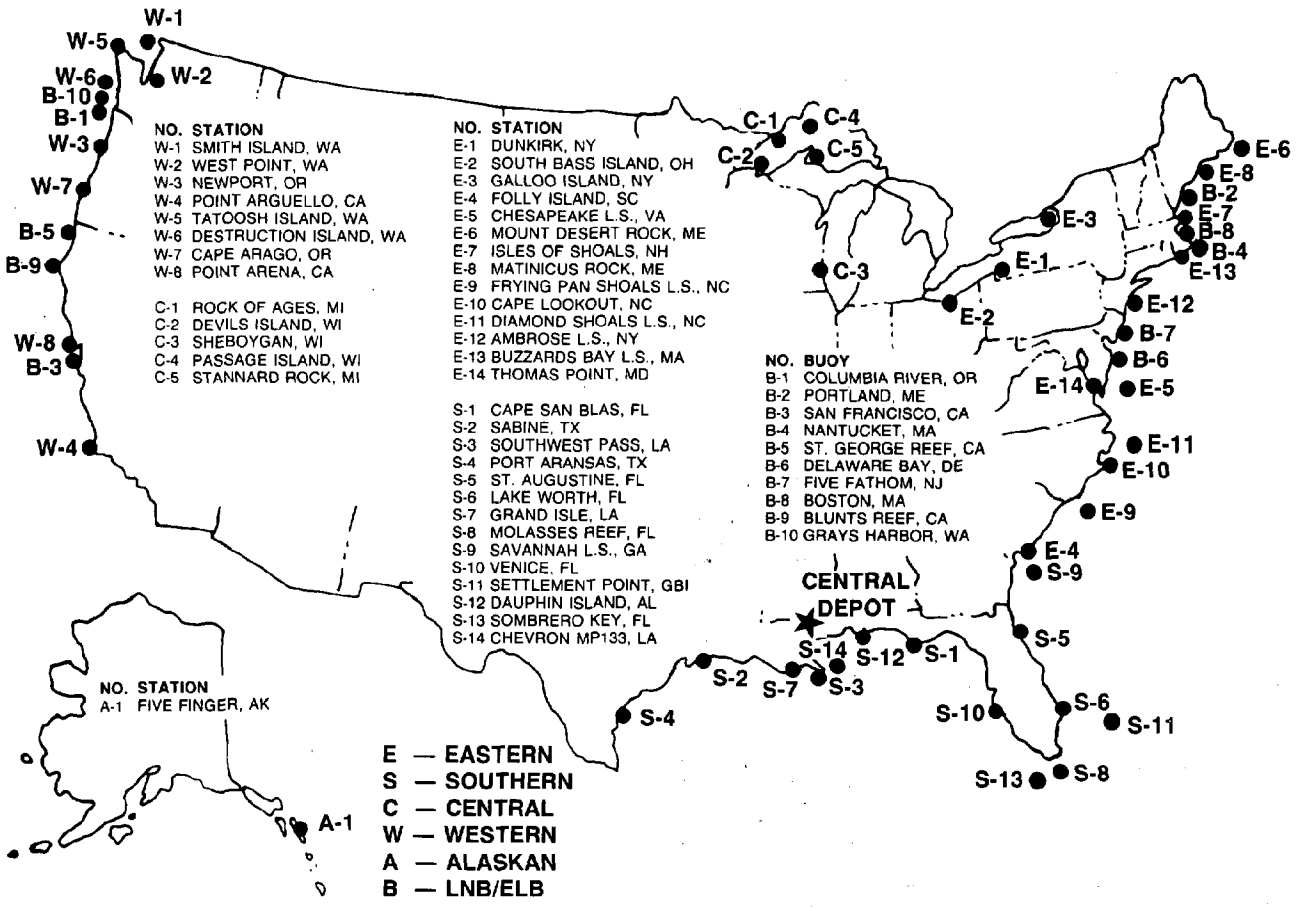

Figure 2. C-MAN Site Locations

sometimes specifying a large range of wind and wave conditions because they cover a large section of coastline for a 12-hour period.

A second product that can be very helpful is Model Output Statistics (MOS) Offshore Wind Forecasts. This little-known product provides forecasts of wind direction and speed for 3-hour intervals for the next day for specific offshore locations. The locations are sites where coastal observations are available, and are typically spaced about 50 miles apart. These wind forecasts are available twice a day and are produced directly by a computer using the MOS method[3]. An example forecast is given in Figure 3. Because the forecasts are point- and time-specific, they are better than the winds contained in the coastal marine forecasts in "average" weather conditions. During unusual weather, for example, when the coastal marine forecast calls for winds higher than 25 knots or thunderstorms, then the winds in the coastal marine forecasts should be relied on.

The MOS forecasts should be particularly helpful to sailboat operators. Sailboaters may not want to venture out if the winds are forecast to be mostly less than 5 knots. Six to twelve knots may be ideal, but beyond that it may be a rough ride for some of the small sailboats in unprotected waters. The MOS Wind Forecasts help provide this kind of resolution. Because of improvements in computer weather forecasting and the additional NDBC observations in the coastal zone, these forecasts are expected to improve considerably in the next few years. One disadvantage of these forecasts is that wind speeds for a few locations exhibit a high or low bias, because of the observational data set that these forecasts are based on. Some sites had very poor anemometer exposure, while others were located on offshore towers 100 or more feet above the water. With a little experience, you can spot these biases and adjust for them. These biases should be reduced when MOS forecasts use NDBC observations. The locations are given in NWS Technical Procedures Bulletins Nos. 332, 339, and 340, available by calling (301) 427-7462.

Finally, graphical weather maps and analyses are available. There appear to be only a few reasons why small craft operators might want this data. First, they could be able to more accurately locate and time frontal passages. Second, regional sea-surface temperature maps are transmitted twice each week. These maps could be of interest to fishermen if they know how to correlate the location of certain species with a certain range of water temperatures and/or gradients.

3. DATA DELIVERY METHODS

So much for the "what," how about the "how?" I will consider four possible data delivery methods. The first method is simply continuing to rely on NOAA Weather Radio. Then, I'll explore the possibility of dialing into an NWS computer, which is only available if you live in certain areas. Third, I'll discuss how you can dial into private meteorological firms' on-line data bases. Finally, I'll explore the Cadillac of data delivery methods: using a satellite dish and software to continually monitor the weather yourself. Table 1 lists which products are available for each data delivery method.

First, I'll briefly mention the old standby, NOAA Weather Radio. As mentioned previously, not all observations are reported and the information is updated hourly, causing late observations to be broadcast. In addition, MOS wind forecasts are not available. This is partially because of time constraints, and partially because of the perception that these forecasts serve as guidance for only trained meteorologists. Of course, NOAA Weather Radio is free and you can take it with you anywhere.

Next, if you live in either the Cleveland, Ohio; Washington, DC; Boston, Massachusetts; or Portland, Maine area, you will be able to dial into an NWS computer for free and retrieve certain products if you are willing to provide cooperative weather observations when you are at sea. Local marine forecasts are available, and this is the only source of cooperative marine weather observations. However, all the systems, except for the one in Cleveland, are updated infrequently. Therefore, they do not contain "perishable" products such as the buoy, airways, and radar observations. Because these NWS computer systems are PCs or small

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      1902 1903 2003 2101 0000 0000 0000

8R3   1305 1509 1708 1607 9999 9999 1708 1110
      1007 1414 1311 1312 9999 9999 1412
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Figure 3. MOS Wind Forecasts issued at 1200 UTC, July 28, 1988, for the Gulf Coast. Station NPA is Pensacola, Florida. The first forecast calls for winds blowing from 190 degrees (S) at 6 knots. The time for this forecast is found at the top of the column, the 28th at 1800 UTC. Forecasts are then given at three-hour intervals.

minicomputers, access is limited. Typically, only one phone line into these systems exist. If you are interested in providing cooperative observations and dialing into these systems, contact these local NWS forecast offices.

The third option consists of dialing into a data base maintained by a private meteorological company. Users can obtain the most recent version of all products except for the cooperative ship observations. Computer graphic displays are also available if you have an appropriate terminal. Some services will decode coastal airways and buoy observations, and place the data in a nice tabular format. Previous observations are also available if a user is interested in determining a trend. The cost is about $60 for each hour of connect time. Typically, the user will dial a local TYMNET phone number to access the remote computer, thereby eliminating long distance charges. One possible problem with this method is the occasional garbled messages you'll receive due to noisy phone lines. This is more of a problem in remote, rural areas. Another disadvantage is that in severe weather, you'll need to frequently redial in order to keep abreast with the latest information. A list of companies that I know of which currently offer this service is given in Table 2.

Finally, a user can receive and store his own weather data via a satellite dish and software running on his own PC. The two-foot-diameter dish will be pointed to a geostationary commercial satellite where a continuous stream of weather data is available. The data stream will be passed through a controller, which is leased from a private meteorological firm, and onto a PC. Software continually monitors the receipt of the data and stores whatever products you indicate. Products can also be automatically printed upon receipt. All products are available within a couple of minutes of their issuance, so this is a great way to maintain a continual weather watch. The disadvantage of this system is the price. The initial price for the dish, controller, and software runs between $3,000 and $5,000, and the monthly data service fee costs $95-$230 each month, depending on your exact data needs. Though this is out of the price range of all but the most "well heeled" individuals, it is not out of the question for groups like fishermen cooperatives and yacht clubs. These groups could even provide a phone line so that members can dial in from home.

I know of two companies that currently offer this type of service — Contel (703) 790-2094 and Zephyr Weather Information Services (617) 898-3511. The Zephyr system uses software written under MS-DOS and can run on any IBM PC/XT or compatible with a hard disk. The Contel software is written under the Xenix operating system and an IBM PC/AT or compatible is needed. The Zephyr software is less expensive and was designed for a single user. The Contel software permits multitasking. In other words, if you want to have mariners at a remote location dial into your computer, or run word processing and spreadsheets at the same time, you will be concerned about multitasking.

Table 1. A list of which products are available through several data delivery methods. Y means that the product is available; N means that it is not. P means that some of the product is available.

	DELIVERY METHODS			
WEATHER PRODUCTS	**NOAA WEATHER RADIO**	**DIAL INTO NWS COMPUTER**	**DIAL INTO PRIVATE DATA BASE**	**RECEIVE FROM SATELLITE**
NDBC OBSERVATIONS	P	N*	Y	Y
AIRWAYS OBSERVATIONS	Y	Y	Y	Y
COOPERATIVE SHIP OBSERVATIONS	N	Y	N	N
COASTAL MARINE FORECASTS	Y	Y	Y	Y
SPECIAL MARINE WARNING AND RADAR REPORTS	Y	N*	Y	Y
MOS WIND FORECASTS	N	N	Y	Y
GRAPHICAL MAPS	N	N	Y	Y

*THESE PRODUCTS ARE AVAILABLE THROUGH THE CLEVELAND, OHIO, NWS COMPUTER FOR THE GREAT LAKES.

Table 2. Private Meteorological Companies Offering Data Bases for Public Access

The Weather Network Oceanroutes, Inc. 3760 Morrow Lane, Suite F Chico, CA 95928-8865 (916) 893-0308	Weatherbase, Inc. 2185 South 3600 West Salt Lake City, UT 84119 (801) 973-3131
Acces-Weather, Inc. 619 W. College Ave. State College, PA 16801 (814 237-0309	WSI Corporation 41 North Road Bedford, MA 01730 (617) 275-5300

4. CONCLUSION

Mariners who own PCs have a wealth of real-time weather data available for them. Though the choice of data delivery methods and costs vary considerably, the mariner should be able to find a service to meet his needs and pocketbook. As the price of PCs continues to fall, more mariners should be turning to them for obtaining their weather data. The aviation community has already begun to use PCs to obtain more of their weather briefings, and I predict that the marine community will follow this established trend.

5. REFERENCES

1. Hamilton, G.D., "National Data Buoy Center Programs," *Bull. Amer. Meteor. Soc.*, 67, 411-415, 1986.

2. Gilhousen, D.B., "A Field Evaluation of NDBC Moored Buoy Winds," *J. Atmospheric and Oceanic Tech.*, 4, 94-104, 1987.

3. Carter, G.M. "Automated Prediction of Surface Wind from Numerical Model Output," *Mon. Wea. Rev.*, 103, 866-873, 1975.

INTERACTIVE MARINE ANALYSIS & FORECAST SYSTEM (IMAFS): THE OCEANOGRAPHIC WORKSTATION OF THE FUTURE

P.M. Friday, J.S. Lynch, and F.S. Long

Office of Ocean Services
National Ocean Service
National Oceanic & Atmospheric Administration
U.S. Department of Commerce

ABSTRACT

The National Oceanic & Atmospheric Administration (NOAA) and the U.S. Navy have begun development of the Interactive Marine Analysis & Forecast System (IMAFS). The system will provide forecasters, research scientists, and data managers with the means to access and integrate interdisciplinary data sets from several sources, from archived to real-time data. The system will support NOAA's programs, including: climate and global change, fisheries productivity, environmental quality, coastal hazards, and marine weather. The interactive analysis of oceanographic (biological, chemical, and physical) and atmospheric data sets is fundamental for understanding and predicting the environment.

1. INTRODUCTION

The Nation is facing a number of critical environmental issues, including marine pollution, fisheries depletion, and global climate change. NOAA has begun an aggressive program to address these and related issues by focusing existing resources and proposing new initiatives through the Climate and Global Change Program and the Coastal Ocean Program.

The Climate and Global Change Program is a systematic effort to understand the processes of oceanic and atmospheric change (seasonal to interdecadal) so that scientific predictions can be developed. The Coastal Ocean Program is an integrated approach to understanding biological, chemical, and physical processes and variability in the Nation's coastal ocean (the Exclusive Economic Zone).

Towards this end, NOAA is implementing a number of new activities aimed at providing timely and useful information to decision-makers. In order to provide these timely services, NOAA is developing an interactive workstation and communications capability to support the marine programs.

2. OBJECTIVE

The objective of this project is to develop and implement an Interactive Marine Analysis and Forecast System (IMAFS). The system is an interactive (man-machine mix) analysis and forecast tool, based on existing technology, with supporting communications capabilities. The system will be used for preparing analysis and forecast products, product quality assurance, and database management at NOAA's field sites. The program builds upon an ongoing multi-Line Office effort to establish a computer workstation which when combined with program-specific software can be applied in a number of disciplines, including global environmental monitoring, climate and global change analysis and prediction, marine weather forecasting, and coastal ocean analysis and prediction.

3. RATIONALE AND BACKGROUND

Ocean data sets and products are only of minimal value for climate research and ocean applications if they are not generated and integrated into a useful form and made available to those who are trying to understand ocean variability. Therefore, a significant need exists to implement an interactive analysis and applications system which will provide : the means to develop new and improve existing analysis and forecast products of the upper ocean; the interactive capability to display, manipulate, and disseminate the products; and the ability to manage the associated databases.

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Recognizing the success that the OAR Program for Regional Observing and Forecasting Services (PROFS) has had in applying this interactive system approach to weather forecasting, NOS has recently stimulated some NOAA inter-Line Office cooperative activity to beging applying this technology to ocean needs. Design specifications of IMAFS are being prepared by NOS. The hardware component of IMAFS, the prototype workstation, is being developed by PROFS with funding provided by NOS, National Marine Fisheries Service (NMFS), National Weather Service (NWS), and the Navy to meet specific programmatic requirements, including a "demonstration" capability to illustrate the type of support possible for global change, fisheries, and coastal ocean programs.

IMAFS is being designed to store, process, and display conventional observations, gridded fields, digital satellite data, and climatologies. The system will integrate the overlay of multiple data and product sets, and will include some interactive and computational applications capabilities, such as: annual mean and anomalous SSTs based on monthly SST analyses; interannual and interdecadal trends; upper ocean (0 - 400m) heat content and heat transport from BATHY/TESAC and current data; and estimates of upper ocean kinetic and potential energy from in situ and remotely sensed data.

A number of additional applications could also support the global change, fisheries, and coastal ocean programs. These applications include, but are not limited to:

Climate and global change applications
- ENSO (El Nino/Southern Oscillation)
- Global Change (WOCE, GOFS, TOGA,...)
  - water level anomalies/variability
  - sea ice anomalies/variability
  - ocean circulation anomalies
  - mass/energy transport
- Coupled air-ocean model verification
- Pattern separation
- Reanalysis

Fisheries applications
- Global fisheries monitoring
- Species migration/trends
- Species populations/trends
- Resource assessment

Coastal environmental applications
- Coastal zone & estuarine studies
- Pollution monitoring
- Coastal hazards mitigation
- Habitat monitoring

Other ocean-related applications
- Data archiving and retrieval
- Data quality control
- Applied research

The communications capabilities of the system are being designed to utilize a wide-area network to distribute data and generalized large-scale products from appropriate central databases to the IMAFS workstations (see Figure 1). Communications ports at the IMAFS sites will be used to establish local-area networks to support other federal and state offices using compatible PC systems. The resulting local-area networks will ensure that:

1) data and regionally produced products can be accessed at other federal and state offices; and

2) data collected and products produced by the federal and state offices will be accessible via the same local system to the IMAFS for distribution to other users.

The telecommunications network will: allow access to databases at a variety of places; disseminate data/products to regional IMAFS workstations; and provide two-way transfer of data and products from regional IMAFS sites to other federal/state offices. IMAFS is being designed to utilize existing databases [eg. the Comprehensive Ocean-Atmosphere Data Set (COADS) and NOS/OMA status and trends data] and communications systems.

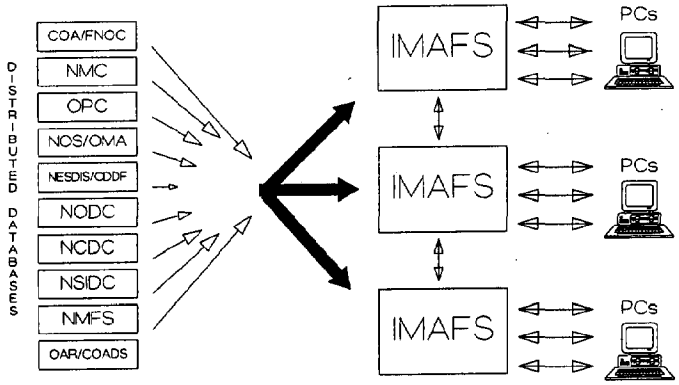

Figure 1. Distributed database network.

4. THE FUTURE

This project is linked to the NOAA Climate and Global Change Program, the NOAA Coastal Ocean Program, and the NWS modernization program. These activities will incorporate the IMAFS approach into their programs, building upon the workstation and generic software developed by OAR PROFS. The parallel development efforts can provide considerable cost savings, such that each Program can focus on specific applications pertinent to their activities.

The Climate and Global Change Program will provide for the development of specific applications software related to ocean climate processes, particularly as related to seasonal, interannual, and interdecadal variability of the global ocean.

The Coastal Ocean Program will provide for the development of specific applications software related to forecasting daily, weekly, monthly, and seasonal variability in the coastal ocean (the U.S. Exclusive Economic Zone) pertaining to fisheries productivity, environmental quality, and coastal hazards. Also, it is important to note that due to the broad spectrum of expected participants, the Coastal Ocean Program will need to establish a substantial communications network among NOAA's laboratories and regional centers.

The NWS Modernization Program intends to use IMAFS technology as a prototype marine weather forecasting system (similar to the prototype regional forecasting system at Denver, CO) to demonstrate the potential benefits of this capability in the 1990s. Specific applications software related to marine weather forecasts, nowcasts, and warnings will be developed through the NWS Modernization Program.

IMAFS is being designed for maximum compatibility with other NOAA workstations, including systems at OAR's marine laboratories, NMFS's regional centers and laboratories, NESDIS's archive facilities, NWS's Great Lakes Forecast Center, and NOS's status/trends and ocean services programs. IMAFS builds upon an open architecture approach, providing the capability to expand memory capacity and upgrade the hardware configuration. Software is being designed for modularity, such that: (1) the generic workstation can accept, display, and process virtually any data set, gridded field, or satellite image; and (2) separate applications module will be developed for climate and global change, coastal ocean, marine weather, and possibly other activities.

5. IMPLEMENTATION

FY89 ACTIVITIES: IMAFS workstations will be procured by NOS and installed at the NOAA Ocean Products Center (OPC, Camp Springs, MD) and the NOAA Center for Ocean Analysis and Prediction (COAP, Monterey, CA). These workstations and additional systems in place at OAR will be used to develop new and innovative techniques and applications software specifically related to seasonal, interannual, and interdecadal variability of the ocean-atmosphere system addressed by the Climate and Global Change Program.

FY90 ACTIVITIES: Additional IMAFS workstations will be installed at other NOAA facilities. Several systems will be installed at the NOAA archive centers [National Oceanographic Data Center (Washington, D.C.), National Climatic Data Center (Asheville, NC), and the National Snow & Ice Data Center (Boulder, CO)] so that:

- climate-related data and operational products generated with IMAFS during the 1990s can be archived and made available to the retrospective user community in a timely manner; and
- the data archive centers can begin on-line services to make archived data sets available to NOAA users on the IMAFS network.

Systems will be installed at the Regional Fisheries Centers (Woods Hole, MA; Miami, FL; Seattle, WA; and LaJolla, CA) for the development of region-specific fisheries applications based on national guidance products prepared and distributed by the Center for Ocean Analysis and Prediction, the Ocean Products Center, the Navy-NOAA Joint Ice Center, and the Climate Analysis Center during the 1990s.

Software development for climate, fisheries, and coastal ocean applications will continue at OPC, COAP, and PROFS, and new development efforts will be initiated by the Fisheries Centers.

COMMUNICATIONS: Two existing communications capabilities can be utilized in the early phase of this project: the communications system at COAP; and the NASA Space Physics Analysis Network (SPAN) with existing nodes at CAC and the NOAA archive centers. Real-time data sets will be disseminated via the COAP. Archival data sets will be communicated via NASA/SPAN, the COAP, or CD-ROM (Compact Disk - Read-Only Memory). Both COAP and SPAN systems utilize a Packet Assembler/Disassembler approach,

which sorts and schedules the wide variety of available NOAA products, and disseminate only those products requested by users.

As presently envisioned for the early phases of this project, COAP will serve as a centralized distribution site which will access real-time and some archival data and products from existing databases, merge and create new climate and fisheries products, provide unrestricted access to NOAA IMAFS users, and disseminate data/products to appropriate federal and state users.

6. BENEFITS

Benefits of this program include:

- Increased availability and enhanced utility of real-time and archived data, analyses, products, and model output by users (NOAA, federal, and state) for specific ocean applications;

- Ability to incorporate and combine a wide variety of data and product types, including the ability to merge the various data/products to generate new products to meet specific ocean applications; and

- Ability to provide two-way communications to exchange data/product sets generated at national processing centers, national archive centers, regional IMAFS facilities, ocean research laboratories, fisheries regions, and local PC workstations.

- Because multiple NOAA programs are using or expect to use the IMAFS technology, significant leverage can be applied within each participating program to access common system elements at minimal or no cost.

THE GLOBAL OCEAN PLATFORM INVENTORY

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National Oceanic and Atmospheric Administration
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ABSTRACT

By initiating a comprehensive inventory of in situ ocean platforms that routinely collect oceanographic and marine meteorological data, the National Oceanic and Atmospheric Administration's Office of Ocean Services (OOS) has taken the first step toward improving the coordination of the globally dispersed elements of the system of platforms. The resultant database should form a basis for improving the measurements per se, eliminating redundant sensors, and revealing geographic areas that are in need of increased coverage. OOS is exploring advanced data communications techniques for making this database available to the scientific community.

INTRODUCTION

Our present source of information for understanding and forecasting the ocean's structure, variability, and dynamic interaction with the atmosphere is a loosely organized network of global satellite and conventional observation platforms. This network is a composite of platforms used for both operational and research needs, operated by a varied group of agencies, each with different missions and objectives. Consequently, the network is a costly, poorly coordinated mixture of observing systems. Thus some ocean regions may have a significant amount of data being collected while other areas have no observational coverage at all. Furthermore, incompatibilities in platform type and location, measurement instrumentation, data format, quality control procedures, and communications links, combined with inadequate national or global data assimilation capability, preclude optimum exploitation of the valuable data that are being collected worldwide. This is a costly, inefficient, unacceptable situation for operational forecasting. The problem is exacerbated by the inability of existing systems to handle the increasing volume of data from both conventional and remote observation platforms.

The development of a comprehensive operational capability for ocean analysis and prediction requires that every available observation be used to the maximum extent. This is especially important because the spatial and temporal coverage of the existing network is sparse and expensive when compared with the coverage of equivalent measurements available over land masses. As the Nation's civilian agency engaged in environmental monitoring and prediction, NOAA is addressing both near- and long-term improvements aimed at providing major improvements in forecast accuracy and in the efficiency of both sensor systems and human effort in collecting data that will be fully utilized.

NOAA's Office of Ocean Services has taken a first step toward improving the coordination of a globally -based ocean observation system by initiating a survey of in situ platforms that routinely collect oceanographic and marine meteorological data. The resulting computerized database describes the number and types of federally owned and sponsored in situ observing platforms. Additionally, the Office is presently working with U.S. coastal and Great Lakes states to inventory the monitoring systems they support in nearshore regions. An inventory of international programs will soon be initiated. The federal inventory will be expanded to include the information derived from these state, local, and international inventories.

When fully completed, the database will provide a tool for rational decision making regarding quality control of data, possible joint procurement of observing systems within and among agencies to include operation and maintenance, and a coordinating service vital to making effective and efficient use of all data. Furthermore, the database will provide opportunities for those interested in deploying new ocean sensing platforms to review similar systems that already exist in a particular region of interest. OOS

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is now exploring ways to make this database readily available to federal and non-federal entities.

DESCRIPTION OF THE OCEAN PLATFORM DATABASE

The file structure of the ocean platform database is depicted in figure 1. It is organized into four interrelated files, each containing a different set of facts about the platforms. In the figure, ovals represent database files. The directed lines between the ovals denote key fields (i.d. numbers) in one file that identify related records in the other file. Labels identify the nature of the relationship and numbers in parentheses represent the number of fields available for each record in support of the relationship. For example, each platform record may identify as many as six programs related by common factors such as sponsorship, ownership, maintenance responsibility, and access to data.

Central to figure 1 and to the database is the platform class file . (The platform class file for VOLUNTEER OBSERVING SHIPS is shown as figure 2.) Fields of the platform class file are clustered in five groups: A heading

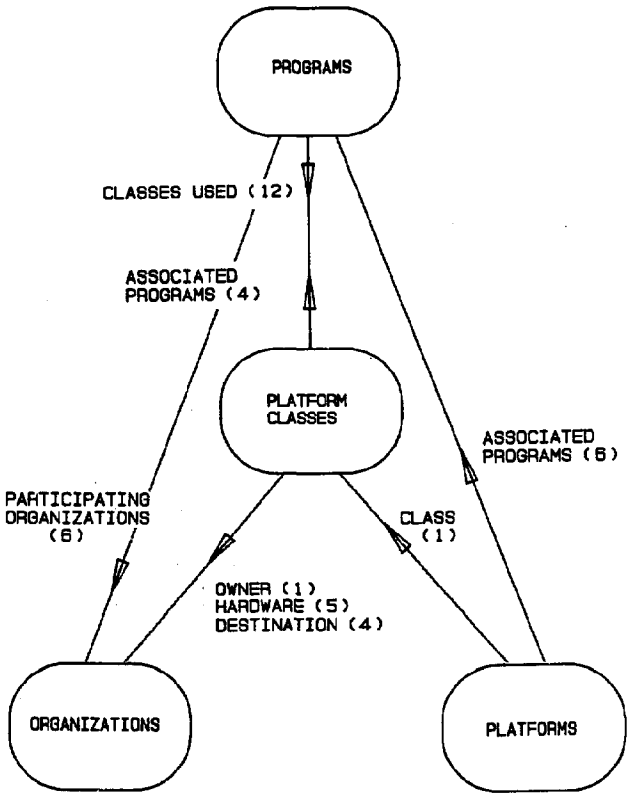

Figure 1. Database File Structure

Class ID 0001 Class Name VOLUNTEER OBSERVING SHIPS
Organization ID 0024
Assoc. Programs 0004
Platform Type Surface Ship Number in Class 745 Application Forecast

Comment THIS IS THE MOST BASIC VOS CLASS, WITH MANUAL RECORDING AND REPORTING OF MET. OBS. VIA RADIO. NOT ALWAYS SYNOPTIC.

Satellite	Real Time yes Radio	Telemetry Synoptic Telephone	GTS Messenger	AFOS Mail	Other
no	yes	no	no	yes	no

Telemetry Descr. PORT METEOR. OFFICER MAILS REPORT
Recorded format STANDARD FORM
Transmit format SHIP SYNOPTIC CODE
How often sent MAILED ON ARRIVAL. RADIOED NOMINALLY 3 HOURS.
Destination ID 0020

Oceanographic Measurement Capability

Parameter	Loc.	Sensor description	Accuracy	Frequency
Temperature				
Temperature	S			
Con./Salinity				
Con./Salinity	S			
Current				
Current	S			
Waves		VISUAL		1-8 HOURS
Water Level				
Other				

S indicates sub-surface sensor. All others are surface.

Figure 2. Sample Platform Class File (continued next page)

Meteorologic Measurement Capability

Parameter	Sensor description	Accuracy	Frequency
Temperature	THERMOMETER		1-8 HOURS
Pressure	BAROGRAPH		1-8 HOURS
Wind Speed	ANEMOMETER (POSSIBLY)		1-8 HOURS
Wind Direction	VANE		1-8 HOURS
Dew Point /R.H.	PSYCHROMETER		1-8 HOURS
Other	ICE, VISIBILITY, CLOUD - VISUAL		1-8 HOURS

Hardware Management

Responsibility	Contact person	Org.	Phone
System operation	NWS - Vince Zegowitz	0024	(301)-427-7724
Calibration	NWS PMOS	0024	
Maintenance	NWS PMOS	0024	
Quality Control	PRIMARY QC BY NMC	0020	
Data Archive	NCDC, IN ASHEVILLE, NC	0017	

Figure 2. Sample Platform Class File

group includes class i.d. number and name as well as references to associated programs and organizations Other groups identify telemetry, measurement capabilities, and individuals/agencies responsible for the class and its data.

The platform file is a list of all class members giving, for each platform, its i.d. number, associated class, associated programs, and location parameters.
The program file contains identifying data on platforms associated with major government oceanographic programs. It includes five information groups listing associated organizations, approximate level of program funding, platform classes used, platform counts by class, and users of platform products. The organization file is a simple list of participating organizations and their addresses.

INVENTORY RESULTS

The primary data sources for the inventory consist of studies of three dozen national programs which include over 500 platforms categorized into five dozen classes. The studies include annual reports, technical reports, catalogs, brochures, charts, tables, records of telephone conversations, and detailed notes taken during technical conferences.

Although the computer database created with these records has been populated only with data from the U.S. federal inventory, it is demonstrating that there are certain areas of the world's oceans that contain very few in situ observing platforms. At the other extreme, the database indicates that there are several ocean monitoring platforms collecting significant amounts of data (at great expense) that are not being used to the maximum possible extent. For example, it was found that some expendable drifting buoys had been released on the Arctic ice pack for research purposes. We believe that the data from these buoys could have benefited operational polar ice forecasting. Similarly, it was discovered that there are both drifting and moored buoys deployed in Equatorial Pacific programs, collecting data that could be of major benefit to the work of NOAA's Climate Analysis Center in improving its realtime ocean models. At the engineering level, the inventory shows that certain sets of useful data are not being ingested by NOAA's weather and marine forecasting models because of incompatible data foremats. Workshops are planned to coordinate and pool the efforts of all agencies that stand to benefit from the sharing of data.

FUTURE DIRECTIONS

Now that the initial inventory has been accomplished and the database established, the inventory will be extended while increasing access to the database. The remaining elements of the ocean observation enhancement effort are envisioned in the following paragraphs:

INTERAGENCY COST REDUCTION PROGRAM - This effort builds upon the substantial information gained during the inventory phase. The inventory provides a useful tool for planning and coordinating system standards, e.g., reliability statistics; organizing government-wide procurement strategies; promoting cost sharing in system operation and maintenance; and providing management information.

A major objective of this activity will be to identify and eliminate redundancies and system deficiencies, providing substantiation of critical needs and optimization of ultimate "mixes" of platforms, sensors and measurement techniques.

REAL-TIME QUALITY CONTROL SYSTEM - This is an effort that can be initiated immediately. Since the majority of marine observations still come from ships at sea participating in the Volunteer Observing Ship Program (now over 7,700 vessels worldwide), and these data undergo only cursory editing at our National Prediction Centers, this database can benefit immediately from several basic procedures (listed below). The same techniques, once they undergo operational testing and are in place, can then be applied to other platforms and sensor systems:

- o Evaluation/Assessment Procedures
  - Comparing to a range of values or climatology
  - Comparing data with previous and later observations
  - Comparing data with nearby observations
  - Checking for internal consistency
- o Action Procedures
  - Maintaining corrector values for each platform and/or sensor
  - Correcting errors, where feasible
  - Editing data before the archival process
  - Informing the system operators, performance monitor, and data users when there is missing or degraded data from individual platform(s) and monitoring of corrective actions needed to restore the platform to full operational effectiveness.

COORDINATION AND INTEGRATION - Because the entire global ocean data set must be uniformly accessible in both the near - real time and retrospective modes, NOAA's global database must be operated and managed as an integral unit. We are aware that compatible technologies in measurement systems, data communications, and data processing are already in use in NOAA or that their procurement should be planned and programmed systematically so as to gain maximum benefit from scarce fiscal resources. Therefore we must act decisively and move ahead on both fronts in a logical, fully coordinated manner.

ACKNOWLEDGMENT

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LEADING LINES FOR THE NINETIES !

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ABSTRACT

Navigation in a channel by observing leading lines is discussed in terms of operational requirements and new signals. Once off the channel's center line, conventional leading lines provide no inherent clues to the ship's lateral position in the channel. Alternative methods of navigating in a channel using vernier lines of light, laser lines in the sky and multiple sector lights are described. The ideal leading line will mark the center line and edges of the channel as an inherent characteristic of the method, and will be usable by navigators who do not have previous experience in the channel. Methods that provide continuous feedback from spatial signals are preferred. Field tests of these alternative methods are described.

INTRODUCTION

Staying on the center line of a channel is not always possible or desirable. Once off the channel's center line, the navigator relies on experience from previous transits and buoy fences for confidence. The need for off center line navigation is an established fact. Leading lines are now being provided for inbound and outbound lanes in some channels to overcome the difficulty of off center line navigation. Use of conventional leading lines (lights and dayboards) is a learned experience for each navigator in each channel. Vernier lines of light (extended light sources) have operational limitations similar to those of conventional lights (point sources), but may have fewer engineering limitations. Laser lines in the sky uniquely mark the center line and both edges of the channel as an inherent characteristic of the method, not as a learned experience. Laser lines originate from a single point on the horizon and pass through the zenith of an observer who is on the channel's center line. Thelaser line is visible from the horizon to the zenith because the atmosphere scatters light out of the laser beam. Multiple sector lights do not give continuous feedback but may be useful in acquiring the entrance to the channel or for navigation in short segments of the channel.

SINGLE STATION LEADING LIGHTS

Single station leading lights with a luminous range over a mile can provide continuous feedback for navigation only with a temporal signal, because the signaling apparatus must be enormous to obtain a resolved spatial display. Interpretations of temporal signals such as counterrotating pencil beams of a light, flash rate changes of a sector light and alternating colored flashes from a sector light are poor navigation tools compared to spatial parallax. Off center line navigation is not an inherent feature of single station leading lights. Light signals that provide an instantaneous, continuous spatial signal are desirable for navigation in a channel.

CONVENTIONAL LEADING LIGHTS

The observer looks toward the horizon when using conventional leading lights. The center line of a channel is operationally located when two point light sources, called "leading lights", appear to be on a vertical line. A line connecting the "leading lights" appears oblique when the observer is off the center line. The angle between a vertical line and the slanted line through the "leading lights" increases with the observer's distance off the channel's center line. Experience in a specific channel is needed to make use of the information provided by "leading lights" that appear to be on an oblique line. Feedback is continuous but no definite channel edge or lane parallel to

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the center line can be located uniquely with "leading lights".

The operational use of "leading lights" is a result of spatial parallax. To achieve parallax the "leading lights" are placed on structures that are built on the channel's extended center line. The upper light is farther away from the end of the channel than the lower light. Use of the "leading lights" to navigate on an off center lane is a learned capability of the operator and not an inherent feature of the "leading lights" method. Buoys enable mariners to navigate with confidence when off the center line.

Two point light sources must have an angular separation of 1.3 milliradians to be easily resolved as separate lights. The line connecting the point lights will have a detectable slant from the vertical when the horizontal angular separation of the point lights is 0.3 milliradians. This minimum detectable slant depends on the relative intensity of the lights and the vertical separation of the lights. Airport Reach Channel on the Columbia River has a width of 300 feet and a far end of channel to front light separation of 10,190 feet and an acceptable off center line awareness distance of 40 feet. The required horizontal and vertical separations of the two lights are 1600 feet and 14 feet, respectively.

Limitations of conventional leading lights are reviewed:

(a) Only the center line of the channel is uniquely determined. Off center line navigation is a learned capability and not an inherent property of the system.

(b) Buoy fences are needed to give mariners confidence for off center line navigation.

(c) The two point light sources must be separated by several thousand feet for a typical range, and the light's locations are critical.

(d) Access cost for the land and the cost of bringing power to the locations can be high.

(e) Lights several thousand feet apart are hard to synchronize.

(f) Rear tower heights of 50 feet or more are common. Towers must support the servicing men and hardware.

(g) Residential and industrial lighting often hinders detection and use of point source leading lights.

VERNIER LINES OF LIGHT

The center line of a channel is operationally located when two vertical lines of light that are at different heights appear to be colinear. This vertical line may have a gap at the junction for some channel positions. The horizontal separation of the two vertical lines increases with the observer's distance off the channel center line with the same convention as for point lights. Only the center line of the channel is inherently marked by use of vernier lines of light. Navigation off the center line is a learned experience. Lines of light will be more conspicuous than points of light and will make leading line lights unique from other aids to navigation lights and commercial lighting.

The two lines of light must have a geometrical configuration similar to the conventional point lights to obtain spatial parallax for navigation in a straight channel. An improvement in navigation can be expected if the lateral alignment sensitivity of two vertical lines, vernier acuity, is greater than the lateral sensitivity for vertical alignment of two point sources. Difference in how the eye responds to points and lines with different separations and apparent intensities and the difference in atmospheric scintillation effects on point sources and extended sources are reasons for expecting increased sensitivity. Another advantage to using extended rather than point light sources is that when viewed through binoculars the lateral alignment sensitivity is increased for lines of light and decreased for points of light. Since binoculars are frequently used this advantage should not be ignored even though leading lines are designed for the unaided eye.

The same operational requirements for the Airport Reach Channel can be achieved with lines of light separated horizontally by 426 feet or less, approximating a single station serving as a leading light. The length of each lighted line should subtend a vertical arc of 1.3 milliradians, which is 15 feet for this example. The tugboat captains like the vernier range installed at Airport Reach. Their only operational complaint is that the range is too sensitive which requires decreasing the 426-foot separation of the lines of light. A vernier range is planned for Curtis Creek Channel in the Chesapeake Bay.

A line of light can be achieved by illuminating the interior of a clear acrylic pipe which has a rectangular cross section with a searchlight. The optical axis of the searchlight and axis of the pipe are made to coincide. Total internal reflection of light at the outside surface of the acrylic walls is achieved for a narrow pencil beam of light that is emitted by the searchlight. A mirror is placed on the end of the pipe opposite the searchlight to reflect the light. The acrylic pipe appears as a uniform lighted surface for lengths of 20 feet. Only a passive vertical acrylic pipe must be supported. Maintenance on the searchlight is done at the base of the tower. Standard Coast Guard searchlights are usable for this application. The lamp can be flashed to produce a pulsating line of light, and filters can be used on the searchlight to make colored lines of light.

The limitations (a) and (b) for conventional point sources still apply for extended line sources. Lines of light must appear as extended sources which requires light source lengths, L =0.0013R, where R is the distance from the light to the end of the channel. Typical lengths are 30 to 60 feet. These lengths can be reduced considerably, by a factor of 7, if binoculars are used. Extended light sources will be less energy efficient than point light sources.

Advantages of vernier ranges are:

(a) Front and rear lights are close together, 100 to 1,000 feet, so a COMMON POWER SOURCE (commercial line, engine generator or battery) can be used, and lights can be hardwire synchronized.

(b) EXPENSIVE TOWERS are not needed. Only the vertical acrylic light pipe must be supported. Servicing personnel need not climb the pipe.

(c) All servicing is done on the searchlight at the base of the pipe and at ground level, for a significant increase in SAFETY.

(d) AIMING of a diffuse, extended light source is not critical.

(e) Extended light sources are CONSPICUOUS and more easily recognized in a background of residential and commercial lights than point lights.

(f) Binoculars increase the lateral alignment sensitivity for lines of light.

LASER LINES IN THE SKY

A laser beam passing through the sky is visible to an observer because the atmosphere scatters light out of the laser beam. The parallax between several horizontal laser lines which are at different heights is usable for navigation in a channel. Polluted air in heavily industrialized ports increases the light scattered which makes the line more visible. Heavy background lighting from the city is no longer a problem because the laser line is aimed over the observer's head and is seen against the night sky.

The Coast Guard performed a laser line in the sky experiment on the St Mary's River, Michigan in 1972. A single horizontal laser line was aimed over the center line of a six mile long channel. The laser beam was 100 feet above river level, and the entire length was visible from scattered light on clear and hazy nights. The beam was visible from all points in the six mile channel. The spatial parallax of the line with the stars and clouds at the observer's zenith was used to navigate on the channel's center line. However, the stars and clouds are so far away that the laser line shifted radically away from the zenith as the observer walked a few feet across the deck away from the channel's center line. The laser line was easy to see but the lateral sensitivity was too great to be useful. This experiment demonstrated that light scattered out of a laser beam by the atmosphere can be used as an aid to navigation. This laser beam had a diameter of 8 inches (23 cm.) and power output of 1 watt in the wavelength interval of 458 to 514 nm. Eye damage risk was low because the power per unit area was reduced to 2.4 milliwatts per square centimeter. The effort was abandoned because of technical problems with the 1 watt output lasers available in 1972.

The observer looks at the zenith, the spot in the sky directly overhead, to use these lines. The center line of a channel is operationally located when two horizontal lines seen in the sky are equidistant from a third horizontal line which is at the observer's zenith. The display is symmetrical about the observer's zenith. The three horizontal lines in the sky are parallel to the channel's center line. The two horizontal, outside lines are in

the same plane, and the line through the zenith is above this plane and in the vertical plane intersecting the channel's center line. Off axis navigation is an inherent feature of the laser line method. The heights and horizontal distance between the lines can be fixed to provide exact identification of the channel's edges and the off axis center lines of inbound and outbound traffic lanes. No experience is needed. Once the observer is off the channel's center line the display is asymmetrical and shifts away from the zenith toward the port or starboard horizon. At the edge of the channel one outside line coincides with the center line so only two lines are seen. The two lines are below and on the same side of the zenith. The spatial parallax between the lines and the spatial parallax of the lines against the stars are effective aids to navigation.

There are two possible objections to laser lines in the sky. A stable platform is needed so the horizontal direction of the beam does not wander causing variations in lateral sensitivity, and the laser beam can blind a pilot who is in the beam and looking toward the source with binoculars. The laser beams will be 75 to 500 feet above sea level which is not an altitude where planes fly. Helicopters would have to be restricted from the area but the danger is minimal. The Coast Guard's demonstration showed that a laser line is visible when the power density is safe for the naked eye.

Advantages of laser lines are reviewed here:

(a) Off center line navigation is inherently provided and edges of the channel are uniquely marked for the operator.

(b) Buoy fences are not needed to give operators confidence.

(c) Background lighting is not a problem since the operator looks at the zenith of the night sky.

(d) Position of lasers from the near end of channel is not important.

(e) Tall towers are not needed since lasers can be aimed upward; this decreases lateral sensitivity at the far end of the channel but does not change the inherent off axis navigation capability.

(f) Laser lines are conspicuous and easily acquired by approaching ships.

(g) The 1972 Coast Guard experiment showed that the laser line has the same apparent brightness over its entire length, and that strong forward scatter of light by the atmosphere occurs since the beam expands from 23 to 46 cm. in 0.75 miles. This is a divergence of 0.29 degrees.

(h) Laser lines are not obstructed by other ships.

MULTIPLE SECTOR LIGHTS

Two colored sector lights can be used to navigate in a segment (about one mile) of a straight channel. Use of more sector lights can extend the navigable segment. The lights must be separated by 1.3 milliradians to be resolved. Spatial parallax plays no part in this method, the sector lights need only be resolved to be useful. Two sector lights will be installed to mark Craighill Entrance Channel in the Cheseapeake Bay. Entering the channel the mariner sees one or two lights changing color from single red, red-red, red-white, white-white, white-green, green-green, single green as the lateral position in the channel changes. The white-white signal has a constant width equal to the horizontal separation of the lights. The other signals are diverging sectors. The alignment of the sectors with the channel's center line and angular width of the sectors determines the sensitivity. The sector lights will be at least 100 feet apart for this 500 foot wide channel. The lateral uncertainty at a sector boundary is between 5 and 17 feet. This method inherently marks the channel's center and edges over a limited segment, but does not provide continuous, instantaneous feedback.

CONCLUSION

New technology may now be available to implement significant improvements in channel navigation. The possible operational advantage of the laser line method is easily recognized. The use of extended light sources as range lights may provide improved conspicuity of the lights and more localization of hardware. Potential cost savings from reducing tower heights and loads and from reducing the number of buoys used may be a side benefit of the proposed navigation systems.

CONTRACT SERVICE OF FEDERAL AIDS TO NAVIGATION

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ABSTRACT

Recently, the United States Coast Guard began a series of contracts for servicing federal aids to navigation. These contracts constitute replacement of the previous government servicing personnel and craft with privately owned and operated vessels. This paper describes the waterway selection criteria, the services being contracted and the results to date.

INTRODUCTION

Today, one of the largest single missions which the Coast Guard performs is the establishment, placement, and maintenance of federal aids to navigation. This system includes an extensive system of buoys, beacons, and lighthouses. There are approximately 49,000 government owned and serviced short range aids to navigation (SRA) which mark this nation's waters, serving military, commercial, and recreational needs. Additionally, the Coast Guard regulates the establishment and maintenance of approximately 44,000 private aids to navigation.

BACKGROUND

The Coast Guard Authorization Act of 1982 amended portions of the legislation governing aids to navigation (14 USC 81) allowing the U.S. Coast Guard to contractually establish, maintain, and operate aids to navigation. One of the outgrowths of that change was a program to test the feasibility of private contractors to service aids to navigation. A Coast Guard Headquarters task group was formed in the Office of Navigation to develop a strategy to evaluate contracting aids to navigation service, which includes:

- Annual inspection
- Biennial mooring inspections
- Relief of buoys
- Recharge of battery powered lighted aids
- Seasonal aid changes
- Building beacons (i.e. SRA structures)
- Lighthouse maintenance
- Discrepancy response
- Establishment and relocation of SRA
- Conversion of primary battery (i.e. not rechargeable) powered aids to solar power
- Conversion of SRA to comply with the International Association of Lighthouse Authorities (IALA) markings

Normal on-station time for a buoy is six years. During that time, it is inspected annually for position accuracy and general operating conditions. Biennially, it is hauled aboard the servicing unit to allow the underwater components and mooring system to be checked and serviced as necessary. Periodically, depending on the light characteristic and hours of operation, the batteries are recharged or replaced. At the end of six years, another buoy is put in its place (relieved), and the old buoy is sent to be completely overhauled. In most waterways, this process is staggered to allow the servicing unit to balance its workload. During each visit, the service routine includes touching up the exterior paint, replacing retroreflective numerals, repairing minor damage, and testing the light and power source. In waterways where the winter climate is extreme, many of the buoys are also removed during the fall and reset in the spring.

The buoys require a lift capability of the servicing vessel, based on the buoy size. The following table breaks down the buoys by type. The terminology used indicates the diameter and overall length of the buoy. For example, an 8x26 is 8 feet in diameter by 26 feet long. The letters after the buoy size connote type (e.g., LBR is lighted, bell, radar reflector). The following abbreviations are used: lighted (L), bell (B), whistle (W), gong (G), radar reflector (R), ice (I). Unlighted buoys are classified according to: class (i.e. 1 thru 6 meaning large thru small); can (C) or nun (N), and construction material, if other than steel: plastic (P), foam (F).

Size	Nominal Weight (tons) (no mooring or power unit)
Lighted	
8x26 LBR	6
8x26 LWR	6
7x17 LR	4

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Size	Nominal Weight (tons) (no mooring or power unit)
6x20 LBR	3
5x11 LR	1.5
Unlighted	
8x26 GR	6
8x26 BR	6
1NR	3
1CR	3
2C	1.5
3C	0.5
5CI	0.5
6CR	0.1

Beacons (i.e. structures) are serviced similarly to buoys, except the biennial mooring and six year relief periods are not performed, for obvious reasons. In their stead, the dayboards and hardware associated with the structure are routinely inspected and periodically refurbished. Also, the visibility of the structure is maintained by brushing-out weeds, trees and other plants that impair the aid's visibility from the waterway.

Although the preventive maintenance program is extensive, discrepancies still occur. In addition to equipment failure, aids are vandalized, damaged due to the weather or struck by ships passing too close. The unit primarily responsible for the aid responds when a failure is reported. Normally, that unit repairs the reported discrepancy, as well as performs the annual service, if appropriately timed. Occasionally, the unit responsible will not be available and a secondary unit responds. In areas where there is extensive damage to the SRA system, due to acts of nature such as floods or hurricanes, several servicing units respond. This minimizes the time during which the waterway has limited availability for marine traffic.

OBJECTIVES

With all this in mind, the Coast Guard embarked on a three year trial of commercially servicing short range aids to navigation (SRA). The objectives of the trial are:

1. Determine the ability of a contractor to provide equivalent service as provided by the Coast Guard unit replaced.

2. Identify the Coast Guard's ability to contract and administer annual contracts. This includes the logistics requirements, contracting expertise, evaluation process, administration, and monitoring workload.

3. Determine the actual cost of contractor servicing and compare it to the historical cost of the Coast Guard to service the contracted aids to navigation.

SELECTION

To accomplish these objectives, a task group developed procedures for selecting the trial contracting candidates. Since all federal waterways are categorized under the Coast Guard's Waterway Analysis Management System (WAMS), this system assisted in targeting eligible waterways. In general, all waterways fall into one or more of the following categories:

Militarily Critical: Waterways which serve military or military essential facilities and are deemed critical for national defense.

Environmentally Critical: Waterways where a degradation of the short range aids to navigation system would present an unacceptable level of risk to the general public safety because of the transport of hazardous materials or dangerous cargoes, as defined in 46CFR and 49CFR.

Navigationally Critical: Waterways where a degradation of the short range aids to navigation system would result in an unacceptable level of risk of a marine accident, due to the physical characteristics of the waterway, difficult navigation conditions, aid establishment difficulties, or a high aid discrepancy rate.

Non-critical: Waterways which serve commercial and recreational interests, where the disruption or degradation of an aid system beyond the normal level of discrepancies will not increase the risk from a marine accident to an unacceptable level.

The selection process for the trial waterways was a three step process. A list of each Coast Guard district's units and the waterways

they service was compiled. The list was broken down by critical waterways/aids versus non-critical waterways/aids. With this breakdown, the units best suited to contract were determined. Since a very large percentage of the Coast Guard buoy tender SRA are in critical waterways, no trials affect these units.

Certain factors were of paramount concern for the final selection: the ability to resume service to any trial area should the contractor default; the ability to continue the other missions which the servicing unit performs; and the desire to minimize the risk to the maritime community. The five waterways selected were:

- The Merrimack River and Ipswich Bay in Massachusetts (First Coast Guard District)

- The Intracoastal Waterway in New Jersey (NJICW in the Fifth Coast Guard District)

- The Inside Passage of the Virginia Intracoastal Waterway (VIP in the Fifth Coast Guard District)

- The Sacramento and San Joaquin Rivers in California (Eleventh Coast Guard District)

- The Snake and Willamette Rivers in Washington and Oregon (Thirteenth Coast Guard District)

A key premise of the trial contracting initiative was that contracts were only to be awarded when the contractor's bid was less than the Coast Guard's current cost of SRA service. This agrees with the privatization principle to contract only where it makes good economic and management sense. In order to permit reasonable cost comparisons, an OMB Circular A-76 type cost comparison was used in order to determine if a contract should be awarded.

STATUS

MERRIMACK RIVER/IPSWICH BAY IN MASSACHUSETTS

This contract involves a portion of the SRA assigned to Aids to Navigation Team (ANT) Boston, the Cutter PENDANT and the Cutter WHITE HEATH (141 of 721 total SRA).

The original contract (RFP) was advertised on 28 February 1986 with 9 lighted buoys, 117 unlighted buoys, 7 light structures, and 8 daybeacons.

The Coast Guard received two responses to the RFP. A technical evaluation board was conducted on 10 July 1986 to evaluate the two candidates. Of the two, only one bidder was found to be qualified, and price negotiations began. On 3 September 1986, the bidder submitted his best and final offer. Although the contract cost greatly exceeded the estimate of the Coast Guard's servicing cost, a decision was made to award this trial contract. This was done because of the difficulties encountered in trying to apportion the marginal cost of the SRA, and because of a desire to gain experience in contract service of. Award was made in late December 1986 with work starting on 1 March 1987.

A summary of the quarterly reports submitted by the First Coast Guard District indicates:

- The contractor is performing at a satisfactory level, however the contractor requested and required a great deal of Coast Guard guidance to initiate his operations. Performance was unsatisfactory for the first four months of the contract.

- The contractor required approximately three months to become accustomed to procedures and reports. This is important since changes to the aid system are broadcast immediately, and published weekly. The contractor remains slow in submitting required reports and paperwork.

- The contractor has not paid the same degree of attention to detail as the Coast Guard servicing unit (i.e. sloppy work, crooked lettering).

- The contractor has been unable to work several aids at different times. This necessitated Coast Guard servicing of those aids.

- Several complaints were received concerning placement of seasonal aids. The contractor had relocated the aids to mark the best water location. The complainants stated the aids

were not in their historic locations as set and published by the Coast Guard.

THE SNAKE AND WILLAMETTE RIVERS IN WASHINGTON AND OREGON

This contract area consists of two tributaries of the Columbia River which were serviced by two separate Coast Guard units. The contract covers 186 of the 588 aids assigned to Coast Guard Cutter BLUEBELL, and 35 of the 150 aids assigned to ANT Bluebell. A total of 127 structures, 4 lighted buoys, 60 unlighted buoys, 12 daybeacons, and 20 survey monuments were included in this contract. All of the lighted buoys are 5x11s, and the majority of unlighted buoys are 5NPR or 5CPR.

A RFP was advertised, and closed on May 15, 1986. Five bidders responded to the RFP, of which three were deemed qualified to perform the work. Best and Final bids were received in September 1986. Although the best and final offers were all higher than the Coast Guard's cost, the decision was made to award the contract. Since the contract included aids from more than one unit there was difficulty in assessing the Coast Guard's cost. The contract was awarded in December 1986, with work beginning in March of 1987.

The winning bidder is a medium sized barge company which is also a primary user of the waterways. The contract is performed using existing equipment, so the initial mobilization and marginal contract costs were small. To execute the contract, Tidewater employs several former Coast Guardsmen with aids to navigation experience. Buoy work is accomplished with a company owned crane barge and tug. The project manager for the contractor is a retired Coast Guard E-7, and the project supervisor is a retired Coast Guard Warrant Officer. To date, the work has been excellent; however the number of discrepancies reported has risen significantly, with the majority being reported by the contractor.

A summary of the quarterly reports submitted to date indicates:

- The contractor is performing quality work.
- No public comments have been received.

THE INTRACOASTAL WATERWAY IN NEW JERSEY

This contract covers aids contained in the New Jersey Intracoastal Waterway which were historically serviced by Aid to Navigation Team (ANT) Hornbeam. The contract service area consists of only a portion of that unit's SRA and includes: 24 lighted buoys, 260 unlighted buoys, 89 daybeacons, and 89 light structures (462 of 745 total). Of these, approximately half require seasonal replacement.

Four proposals were received by the close of bids on 2 October 1986. Best and final bids were received on 13 March 1987. Based on the dollar amounts and scope of work, the contract was negotiated as a fixed firm price contract. Although the contract costs greatly exceeded the estimate of the Coast Guard's current servicing cost, a decision was made to award this trial contract. Again, this was done because of the difficulties encountered in trying to apportion the ANT's marginal cost to the contracted SRA, and because of the need to acquire experience with contracting. Actual contract maintenance began in August 1987.

The contractor is a female-owned, small company which is trying to establish a marketplace in central New Jersey. Prior to this contract, the company was conducting local marine construction in the area around Toms River, N.J. To satisfy the terms of the contract, the contractor has procured a 65 foot vessel and expanded operations. Since the bulk of the effort for the trial contract is in the spring and fall, the company can employ 10 to 15 people year round. Although they did not have any background in aids to navigation, they have obtained the training necessary to properly position and service the aids. To some extent, this has been through trial and error using the Coast Guard provided Computer Assisted Positioning (CAP) program. The contractor was provided the program as part of the contract, but had to procure necessary hardware. The contractor presently uses a commercial distance measuring system for positioning.

A summary of the quarterly reports submitted by the Fifth Coast Guard District indicates the following:

- The contractor has performed most work to the same standards as the Coast Guard.

- The contractor has not been as diligent as the Coast Guard in reporting the location or time for changes to the aid system.

- Initially slow in responding to discrepancies. Some SRA discrepancies were acknowledged and allowed to exist for two months when the terms of the contract state all discrepancies must be corrected no later than seven days after report.

- The contractor required approximately three months to become accustomed to procedures and reports. Slow in submitting complete paperwork.

- Only one public comment was received. The inquiry concerned the removal of seasonal aids as listed in the Light List. The complainant stated the contractor had removed aids at the scheduled time vice leaving them until they were threatened by ice (which was the CG practice).

THE SACRAMENTO AND SAN JOAQUIN RIVERS IN CALIFORNIA

The contract for this waterway offered a clean analysis of the entire work performed by a unit. From the beginning, the contract included the total area covered by ANT Rio Vista (four persons). Sixteen additional buoys were added from those serviced by the buoy tender BLACKHAW in order to form a more representative cross-section of the aid population. The contract includes 216 aids consisting of 5 lighted buoys, 16 unlighted buoys, 184 structures, and 11 daybeacons.

This contract was delayed due to a reorganization of Coast Guard districts, and specifically, the dissolution of the Twelfth Coast Guard District, which had been handling the RFP. Bids closed in October 1987. Three initial responses were received, however only two bidders provided the required technical information. An evaluation board convened 17 November 1987, and found both bidders qualified to perform the work.

At the final analysis, the Coast Guard cost was considerably less than the lowest bid so the solicitation was cancelled.

THE INSIDE PASSAGE OF THE VIRGINIA INTRACOASTAL WATERWAY

This contract area is serviced by Coast Guard Aid to Navigation Team (ANT) Chincoteague.

Initially, the trial contract included 389 SRA in non-critical waterways. This represented 93% of the unit workload (7 personnel). The original contract included 5 lighted buoys, 32 unlighted buoys, 147 light structures and 205 daybeacons. The RFP was scheduled for release in April of 1987. As a result of the earlier contracting experiences, a decision was made in early 1987 to contract the entire unit's SRA workload. This allows the cost for an entire unit to be compared with the bid costs, similar to the ANT Rio Vista contract. Due to this decision, and the Coast Guard's district reorganization, the RFP was delayed until July 1988. As of the date of this article, no details regarding response to the RFP are available.

SUMMARY

The time necessary to prepare, consider and award each contract is summarized below:

Timelines

District	Contract Initiation	Opt.1	Opt. 2	Termination
1	Jan '87	Oct '87	Oct '88	30 Sep '89
5 (NJ)	Aug '87	Oct '87	Oct '88	30 Sep '89
5(VIP)	Nov '88	Oct '89	Oct '90	30 Sep '91
11	Solicitation canceled			
13	Jan '87	Oct '87	Oct '88	30 Sep '89

The costs associated with each contract, except the Virginia Inside Passage, which is

currently being competed, are summarized below:

	Annual Cost Data ($)		
District	CG Service	Best & Final	Actual
1	148,608	343,516	368,448
5 (NJICW)	416,694	704,000	704,000
5 (VIP)	CURRENTLY IN COMPETITION		
11	529,750	657,700	Not awarded
13	259,693	268,023	273,310
Total	1,472,856	** To Be Determined **	
Total for 3 Waterways	824,995	1,315,539	1,345,758

In general, it's become apparent there are tradeoffs when a Coast Guard unit departs a waterway and is replaced by a private contractor. Search and rescue, ice-breaking, law enforcement, port security and support for national defense operations all diminish when a Coast Guard unit leaves. Coast Guard aid to navigation servicing units perform more than the singular tasks involved in maintaining this nation's aids to navigation. A benefit of contracting is the continuity which a private organization can bring by not continually transferring personnel, as the Coast Guard does. However, the corollary to this benefit is the negative aspect that the Coast Guard loses touch with the citizenry and the waterway user's needs. Perhaps the biggest benefit resulting from privatization was best stated by Mark Menchik, a senior analyst for the Advisory Commission on Intergovernmental Relations: "Often one of the best results of privatization is that it forces government to reconsider the nature of the service, the rationale for providing it and the means by which it's provided."[1]

FUTURE POLICY

General results show contractors can perform the work, but it is also apparent that private contractors accomplish the work less economically. In order to gain additional data, this privatization initiative will continue and more Coast Guard units stand to face competition for servicing our federal aids to navigation.

[1] Thomas B. Darr, Pondering Privatization May Be Good For Your Government, **Governing**, November 1987, pp. 42-50.

MARINE RADIONAVIGATION OF THE FUTURE

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ABSTRACT

What will the mariner of tomorrow use to navigate with? He will use some of the same basic elements he does today; however, technology will change the way they are used. Improvements and availability of the long-range aids will play an ever-increasing role. Radiobeacon coverage will be limited to single line availability and used mainly for homing. Omega may be phased out by 2005 unless retained as a backup to satellite navigation. Loran-C will be around until 2015 and maybe longer. Transit will be phased out by 1996. When the Global Positioning System becomes operational, a new era will begin and may prove to be the answer to all of the mariners' navigation needs. However, there is international sentiment to retain a terrestrial system to complement the emerging satellite systems. Will the prudent navigator require both terrestrial and satellite systems? The navigator will continue to find his destination. The navigation systems of the future will help him get to his destination more economically and safer.

1. INTRODUCTION

Modern technology promises a broad range of improvements in marine navigation...accuracy, availability, and reduced operator costs...to name a few. What are the current trends in marine navigation and what will be the mix of marine navigation aids beyond the year 2000? As we look at the evolution of marine navigation we see that we have come a long way from crude beginnings. Even so, many of the old techniques are still effective and used today. As new methods and systems were developed, many of the useful aspects of the older methods were retained, new techniques often augmenting existing ones rather than replacing them. While some of the old marine navigation techniques eventually disappeared, others continue to serve the mariner well. Today we have a broad range of marine navigators, from the very small pleasure boater with little or no navigation equipment to very large merchant vessels and military ships with an array of modern navigation equipment at their disposal.

There have been many developments in the last few decades in short-range aids to navigation. New materials used in buoy construction, new mooring techniques, and the use of new power sources such as solar, wind, wave and even nuclear power to name a few. While more refinements in short-range aids will certainly be made in the future, this paper will only focus on the current trends in the evolution of long-range radionavigation.

The Transportation Systems Center is conducting a radionavigation user survey for the Coast Guard. This survey will help us determine what the future radionavigation user needs will be, what systems mix will best meet those needs and when we can phase out older systems. However, until the survey is complete we can make some educated guesses about the future of radionavigation. Obviously, new satellite systems will have the greatest impact, but existing systems such as Radiobeacons, Loran-C and Omega will not disappear over night. What is the status of these radionavigation systems? What can we expect of radionavigation in the early 21st century?

2. RADIOBEACONS

Marine radiobeacons operate in the 285 to 325 kHz band. While their use as a primary radio aid may be declining, they are still used extensively around the world. Employed usually as a back-up navigation system on larger vessels, they are sometimes the only radionavigation equipment on smaller recreational boats. When first introduced, their long-distance, all-weather capability, provided tremendous improvements in marine navigation. Today there are a number of other systems available that have made radiobeacons rather insignificant in comparison. Still, they provide a cheap and reliable radionavigation aid meeting the needs of many mariners and can be used as a back-up for other, more sophisticated systems.

The Coast Guard currently operates approximately 200 marine radiobeacons. A number of changes to the U.S. radiobeacon system are being made to improve efficiency. Recent studies have shown that radiobeacons are now used mostly for homing. The system will be reconfigured with emphasis on providing a homing service to the user. Sequenced radiobeacons will be eliminated. The operating frequencies of some radiobeacons will be changed. The output power of some will be reduced and many hard to service remote sites will be eliminated. With these changes the U.S. radiobeacon system will be more reliable and cheaper to operate. Since the receivers are relatively inexpensive, we can expect

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that there will be continued user demand for the radiobeacon system. Additionally, the use of radiobeacons to transmit differential information for other radionavigation systems is being considered. We expect to see radiobeacons to be part of the radionavigation mix for some time to come.

3. LORAN-C

Initially a military navigation system, over the years Loran-C has gained a high degree of user acceptance within the maritime community. As coverage increased and receiver costs dropped, the number of Loran-C users grew quickly. The reliability, accuracy, cost and coverage advantages of Loran-C have lead to a continued, steady growth within the marine community and, more recently the aviation community and land users have discovered its advantages. Today there are over 300,000 Marine and 50,000 Aviation users world-wide.

Loran-C is now firmly in place around the world and provides extensive coverage in the northern hemisphere. The Coast Guard operates fifteen Loran-C chains in the U.S. and overseas. Some of our overseas stations are operated by the host nations under bilateral agreements. Other countries, including; Canada, Egypt, France, Saudi Arabia and the Peoples Republic of China, are operating their own Loran-C stations. The Soviets have a system they call "Chayka" which is very similar to Loran-C. In fact, the U.S. and the U.S.S.R. recently signed an agreement to create and jointly operate a Loran-C/Chayka chain. One goal of the agreement is to demonstrate the compatibility of the two systems.

While the Coast Guard is planning to cease operation of our overseas Loran-C stations in 1994, a number of nations are considering retaining the stations when we leave and even adding new ones to increase current Loran-C coverage in their area. This is particularly true in northern Europe, but other nations have shown an interest in retaining or expanding Loran-C coverage as well. Thus, the outlook for Loran-C in the foreseeable future, is bright. Even in light of the newer satellite systems, the present Loran-C user population is large and is expected to continue to grow. The Coast Guard currently has several active projects which could have significant impact on the future of Loran-C.

Mid-continent Expansion Project

The Mid-continent Expansion Project (MEP) is currently the major Coast Guard Loran-C project. Two new Loran-C chains, called the South Central U.S. (SOCUS) and the North Central U.S. (NOCUS) are being built to provide Loran-C coverage in the central United States. This is an aviation-related project and will have little impact on marine users. Funding for the project is being provided by the Federal Aviation Agency. Both of the new chains will be a mix of new stations and existing stations. The new stations will be located in Havre, Montana; Las Cruces, New Mexico; Gillette, Wyoming and Boise City, Oklahoma.

Loran-C/Chayka Joint Chain

At the U.S./Soviet summit in May of 1988, Secretary of State Schultz and Foreign Minister Shevardnadze signed an agreement for our two countries to create and jointly operate a Loran-C/Chayka radionavigation chain in the Bering Sea. Chayka is a Soviet radionavigation system where the operation and signal format are similar to Loran-C. This joint chain will improve marine navigation in the Bering Sea and Northern Pacific Ocean. It will demonstrate the utility and compatibility of the two systems, and the service it will provide will be available to all who wish to use it. There remain differences between the two systems which must be resolved if the chain is to be useful. The agreement calls for subsidiary arrangements to create coordinating committees and to develop operation procedures and other working arrangements.

Creation of the the joint chain is to take place in two stages. Stage one, will link the U.S. Loran-C station at Attu, Alaska with the Soviet Chayka stations at Petropavlosk and Aleksandrovsk. Petropavlosk will be the master station, Aleksandrovsk and Attu will be the secondary stations. Our goal is to complete stage one by the end of 1990. Stage two, to be completed within two years after stage one, will replace the Soviet secondary station at Aleksandrovsk with a station at Kurilsk. (The Kurilsk station is currently, a small, low-power station which the Soviets will upgrade before adding it to the joint chain).

Improved Loran-C Timing

The "Airport and Airway Safety and Capacity Expansion Act of 1987" was signed by President Reagan on December 30, 1987. This act requires that U. S. Loran-C master stations maintain synchronization to Coordinated Universal Time (UTC) within 0.1 microseconds. Currently, the master stations are held to within 2.5 microseconds of UTC. The act also calls for a study of the impact of synchronizing secondary stations to within 0.1 microseconds of UTC. Both the synchronization of the master stations and the study of the secondary stations are to be completed by September 30, 1989. Improved master station timing may benefit Precise Time and Time Interval (PTTI) and aviation users, but may have little effect on marine navigation users. The full user-impact of this law cannot be determined until the study is completed.

4. OMEGA

Omega is an all-weather, global radionavigation system consisting of eight transmitting stations located throughout the world. It is the only system that currently provides worldwide coverage. The Coast Guard operates two of the stations. The other six are operated by partner nations. While the world-wide coverage of Omega is the major advantage of the system, the 2-4 mile accuracy limits its utility. The accuracy provided by Omega is sufficient for most open ocean navigation but not for coastal navigation applications. Accuracy can be improved using differential techniques but

there has been little desire for their development and implementation. The Department of Defense plans to phase out military use of Omega by the end of 1994. Complete phaseout of Omega will probably occur by 2005 unless there is renewed emphasis by civil users or it is identified as a terrestrial back-up for satellite systems. In the meantime, no significant changes to the current Omega operation and eight station configuration are anticipated. Considering the near world-wide coverage of Omega, it is a relatively inexpensive system to operate. However, existing Omega transmitters and antennas are over 20 years old. The system will become increasingly difficult to maintain without recapitalization. The Recapitalization issue is currently being studied. The results of this study will bear significantly on the systems longevity.

5. SATELLITE SYSTEMS

Space-based navigation systems currently hold the greatest promise for the future. Older systems, such as Transit, are being phased out in favor of newer, more accurate systems. Several countries, including the U.S. and the Soviet Union are building new satellite systems. Commercial systems are also being implemented. Global Positioning System (GPS), the new U.S. satellite system, is expected to be declared operational within the next five years.

Transit

Initially established as a military system primarily for support of the Navy Fleet Ballistic Missile Submarines, civilian users of Transit now greatly outnumber DOD users. Today there are approximately 80,000 commercial sets in use. The system is operated by the Navy and currently consists of six active satellites and one spare. Transit provides worldwide coverage but is limited by periodic availability. As GPS becomes operational, Transit will be slowly phased out. There are no plans to continue Transit beyond 1996, either as a Navy operated system or as a civilian system.

Global Positioning System

The Global Positioning System is being touted as the navigation system of the future and indeed, promises to revolutionize navigation. When fully operational, in about 1992, it will provide accurate, full-time, world-wide coverage. Operated by DOD, GPS was designed and is being implemented for military use but will be available to civil users. However, for reasons of national security the accuracy available to civil users will be limited to less than the system is capable of providing.

The accuracy provided to civil GPS users may not be adequate for some marine applications such as, harbor and harbor approach and inland waterway navigation. Studies are being done to determine what those accuracy requirements are and how they can best be provided. Methods being explored include differential Loran-C and differential GPS.

6. SUMMARY

Many of the radionavigation systems used today will be around well into the 21st century. Radiobeacons might be used to transmit differential information to improve the accuracy of other systems. Loran-C is well established as the preferred terrestrial based system. Many countries are planning to continue operation of existing overseas Loran-C stations. Cooperative international efforts to build and operate new Loran-C chains are being discussed. Recapitalization and user demand for Omega will determine the future of the system. Transit will be phased out by 1996. GPS, when fully implemented, will provide the mariner with complete world-wide coverage, 24 hours a day. We can expect that as has happened in the past with other systems, with a drop in receiver cost, the number and type of users of GPS will grow quickly. Clearly, the radionavigation needs of the Mariner will be well served into the 21st century.

7. REFERENCES

1. Federal Radionavigation Plan, Department of Defense and Department of Transportation, DOD 4650.4, DOT-TSC-RSPA-87-3, Washington, D.C., 1986.

2. Captain Nelson H. Keeler, USCG, Maritime Future Navigation Needs and Plans, NAVIGATION, Journal of the Institute of Navigation, Vol. 34, No. 2, Winter 1987, pp. 290-296.

FEDERAL RADIONAVIGATION PLAN OVERVIEW

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Abstract

Significant changes to the Federal Radionavigation Plan (FRP) were made in the 1986 edition. A brief review of FRP history will be presented to establish the foundation for the current federal radionavigation plan policy statement. Special emphasis will be given to the Global Positioning System (GPS) and its impact on other systems, especially long-range, ground based systems. Highlights from the radionavigation users conference held in Washington, D.C. in March 1988 and other user oriented actions will be discussed. Current and future federal requirements for radionavigation systems will be addressed.

1. INTRODUCTION

The formation of the Department of Transportation in 1967 provided the impetus to develop a coordinated national navigation plan. With the Federal Aviation Administration and the Coast Guard providing navigational services in the aeronautical and maritime environments respectively, the planning and studies needed to formulate a national plan proceeded from the humble beginnings of the National Plan for Navigation of the 1970's to Federal Radionavigation Plan that we know today. Early long range radionavigation systems were all ground based and the Transit system's enormous success showed the potential for a satellite based full coverage system. The emergence of the Global Positioning System provided the push for better planning and control over the presumed proliferation of radionavigation systems and emerged into the force that produced the Federal Radionavigation Plan. With the Department of Defense setting the pace for the Global Positioning System for national defense purposes, users and manufacturers began to rally and demand a mix of radionavigation systems that would include ground based as well as satellite systems.

2. HISTORY OF THE FEDERAL RADIONAVIGATION PLAN

In the later half of the 1960's the Department of Transportation and the Department of Defense saw an increased need for better coordination of radionavigation systems development and operations. The Federal Aviation Administration and the U.S. Coast Guard completed studies in 1969 that eventually led the Department of Transportation to the development of a national navigation plan. The first edition of this plan was the DOT National Plan for Navigation (NPN) and was published in May 1970. Military navigation requirements were published in the Joint Chiefs of Staff Master Navigation Plan and were not included in the NPN. The first NPN set national policy, established requirements and presented a basic operating plan for civil radionavigation systems. The last NPN (third edition) was published in 1977 and was a major refinement of the 1970 and 1972 NPN's and the 1974 NPN annex.

The General Accounting Office (GAO) report to the Subcommittee on Coast Guard and Navigation, Committee on Merchant Marine and Fisheries, U.S. House of Representatives, in March 1974, titled "Summary of GAO Study of Radionavigation Systems: Meeting Maritime Needs" endorsed Coast Guard plans that would designate:

- Omega as the most cost-effective solution to the medium accuracy and worldwide coverage requirements for all users on the high seas.
- Loran C as the radionavigation system that can best satisfy the precision navigation requirements resulting from heavy traffic in the coastal confluence and harbors and estuaries, thereby, eliminating the requirement for Loran A.

Additionally, this report noted that space satellite systems were not economical or readily available for civil users. With Loran-C satisfying civil maritime navigation requirements, Loran-A would be phased out, with a period of two years dual Loran-A and Loran-C operations being reasonable for equipment amortization and changeover! This GAO study of radionavigation systems was undertaken because of the presumed proliferation of such systems. Recognition of the differences in requirements between civil and military aviation and maritime communities and the potential number of land users highlighted the need to standardize on the minimum number of long-range radionavigation aids.

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The NPN Annex of July 1974, announced the designation and implementation of Loran-C as the government provided radionavigation system for the U.S. coastal/confluence zone and the deactivation of the Loran-A radionavigation system. The annex provided for a five year phase out period for Loran-A and a two year dual operation of Loran-A and Loran-C.

The last edition of the NPN was promulgated in November 1977. Based on recommendations in the March 1974 GAO report and the work being done by the Office of Telecommunications Policy, this last NPN came closer to being a national radionavigation plan for civil users than those previously. The plan was prepared and approved by the Departments of Transportation, Defense and Commerce and the National Aeronautics and Space Administration. The emerging technology of the Global Positioning System was included and showed great promise as an all weather truly worldwide radionavigation system.

The March 1978 GAO report "Navigation Planning--Need for A New Direction," was more comprehensive than the 1974 study and recommended a government wide radionavigation plan along with a reduction in the number of federally operated systems. The report relied heavily on the potential of the DOD Navigation System using Timing and Ranging (Global Positioning System) to replace most existing long-range radionavigation systems.

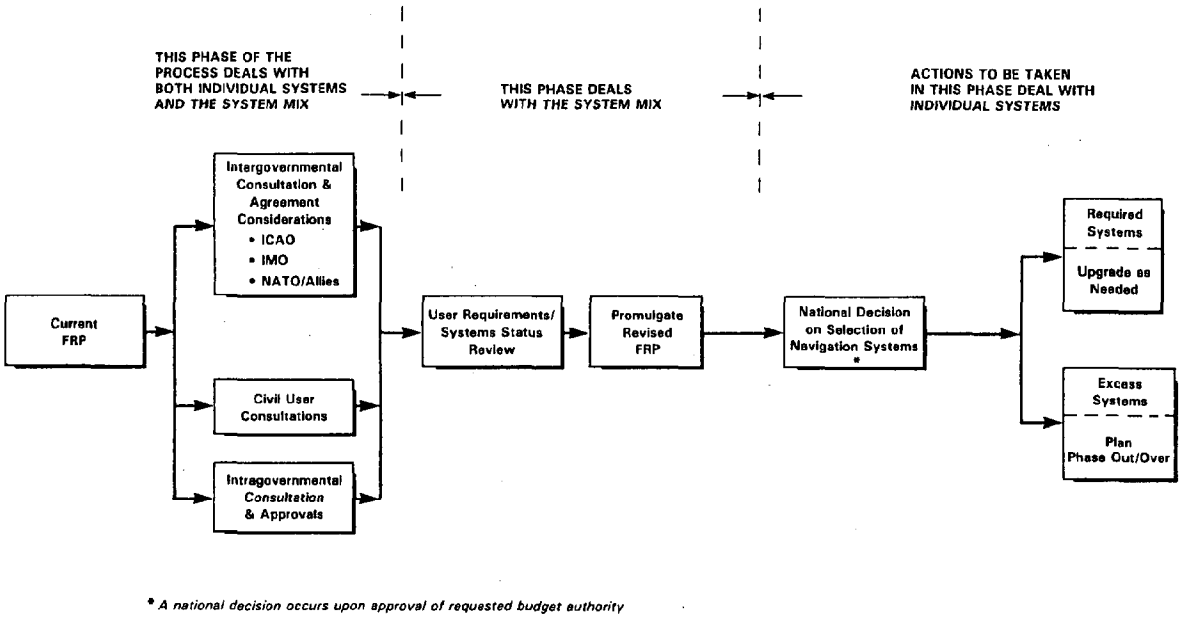
The International Maritime Satellite Telecommunications Act, Public Law 95-564 of November 1978, required the President to submit a government-wide navigation plan to the Congress. An interagency working group, already studying radionavigation planning, developed the first edition of the FRP, jointly published by DOD and DOT in 1980. This new national plan contained policy for national defense as well as civil policy for radionavigation systems. The most significant goal of the plan called for a 1986 decision an optimum radionavigation system mix. This 1986 decision was to be based on the GPS becoming operational in 1987. The system mix decision was to be made based on coordination and consultation with all groups affected by the planned 1986 decision.

The GAO published another report in September 1981 titled, "DOT Should Terminate Further Loran-C Development and Modernization and Exploit the Potential of the Global Positioning System." This report was highly critical of Coast Guard plans for operating and improving the Loran-C system to the year 2000 when the GPS was being deployed to provide coverage by 1986.

The second edition of the FRP was published in 1982 and recognized the need for input from sources other than the Federal Government. Liaison with the private sector was initiated by the Research and Special Programs Administration (RSPA) of DOT.

The 1984 edition of the FRP provided the following preliminary policy on an optimum system mix:

-DOD phase out military air use of Omega and



* A national decision occurs upon approval of requested budget authority

FIGURE 1 DOD/DOT RADIONAVIGATION SYSTEMS PLANNING PROCESS

overseas Loran-C by 1992, VOR/DME and land-based TACAN by 1997 and cease TRANSIT operation in 1994

-Civil user phase out of Loran-C and Omega after certain problems with GPS were resolved

-A 15 year transition period for phase out of Loran-C and Omega as GPS became operational

-Resolution of international commitments.

3. THE 1986 FEDERAL RADIONAVIGATION PLAN

The 1986 FRP, the fourth edition, is structurally a major revision of the 1984 edition. The 1986 FRP consists of one volume containing four chapters and several appendices. The FRP is better organized and easier to read. Redundant materials have been eliminated. However, the basic content of the FRP is consistent with previous editions. To encourage wider audience participation in the civil review process of the FRP, the request for private sector input has been placed in the preface.

In the discussion to follow, I will cover only those areas where FRP content has changed significantly from the 1984 edition. Editorial changes or differences in presentation not accompanied by substantial information additions or deletions will not be addressed. Therefore, the reader should consult the FRP directly to clarify specific areas of interest or concern.

Objectives

The need to consolidate and reduce the number of radionavigation systems is still recognized as the major objective of the FRP. However, due to delays in the GPS operational status and comments from radionavigation system users, a recommendation on the optimal mix of systems has been deferred until after GPS becomes operational and significant questions relating to GPS operation have been satisfactorily resolved for all classes of users. The 1986 FRP has updated the 1984 preliminary decision based on current system plans. Thus, improvements in existing system operating characteristics is not precluded since system lifetimes are most probably in excess of fifteen years.

Policy Considerations

A major change in selecting systems to be part of the system mix is shown in figure 1. Previous editions of the FRP referred to a DOD/DOT final recommendation on selection of navigation systems of the future. The current policy is more dynamic since there is no final recommendation but rather each revision of the FRP provides an updated decision on the current system mix. This process now allows systems to be selected based on user need rather than forcing an artificial selection of systems based on Global Positioning System availability.

Indeed, the 1986 FRP refers to a "long-term goal to establish, through an integrated DOD/DOT planning and budgeting process, a cost-effective, user-sensitive, mix of systems for the post-2000 time frame." Thus, a mix of systems implies that a need for redundancy will be taken into consideration when warranted by user requirements. Although not explicitly stated in the FRP, redundancy of radionavigation systems, strongly expressed during the 1986 and 1988 users conferences, is considered extremely important for safety of navigation. Figure 1 is noteworthy also because of the lack of a time line driving the distinct phases of the planning process. The planning process now extends over the two year period between subsequent editions of the FRP.

The current policy is:

-DOD phase out military air use of Omega and overseas Loran-C by 1994, VOR/DME and land-based TACAN by 1997, and cease TRANSIT operation in 1996. Additionally, DOD will phase out military use of ILS

-Civil user phase out of VOR/DME, Loran-C and Omega continues to depend on resolution of certain problems with GPS

-Establishment of a 15 year transition period

-Resolution of international commitments.

Factors Affecting Selection of the System Mix

The selection of the system mix has not been made for several reasons. The GPS is not operational and will not be operational for several more years. Since a decision on whether to phase out a radionavigation system can have serious consequences, including increased costs for the users of the system, a delayed decision is obviously the best choice. When other factors are considered, such as GPS satellite launch schedule delays, changes in user profiles, changes in dynamic radionavigation technology, and input received during the 1986 civil radionavigation users conferences it becomes readily apparent that government concern for maintainable, economical, and accurate navigation systems that meet current user requirements would force a delay in selection of the system mix. Since any recommendation on an optimal system would be premature before GPS operation for all user classes can be verified, there will be no optimal system recommendation until the GPS is operational.

GPS satellite launch delays are a direct result of the shuttle accident. The changes in users' profiles are attributable to: an expansion of the role of Loran-C in aviation, vehicle location, and timing synchronization applications. Dynamic electronics technology has resulted in the largest increase in users because of the ease of operating newer receivers. Automation of receiver functions, dramatic decreases in receiver costs, internal receiver databases, and use of software to provide additional capabilities (automatic calculation of latitude and longitude, way point calculations, course to steer, etc.) have resulted in a significant increase in the number of users, especially in the marine and land community. Navigation management systems have introduced additional complexity into the system mix selection process, especially for aviation applications. Digital signal processing has resulted in

easier receiver operation, less need and demand for operator training, and a quantum improvement in receiver performance. Strong support for retaining Loran-C was evident at the civil users conferences held in 1986, especially from the marine community.

Role of the Private Sector

Private sector involvement in radionavigation services is briefly discussed in the 1986 FRP. There are no recommendations on the role of the private sector in providing radionavigation services, but several factors are mentioned for consideration. The Federal Communications Commission (FCC) has authorized commercial Radiodetermination Satellite Service (RDSS) and such a service could provide navigation capability, although it is unlikely that RDSS will replace the federal government's role in providing radionavigation services for basic safety of navigation. RDSS systems differ from federal radionavigation systems in that a one or two way communications channel is generally supplied by the RDSS system, thus providing fleet management capabilities, the major RDSS advantage over a pure radionavigation system. Some of the factors remaining to be examined to ensure the appropriate future roles of private and federally operated radionavigation systems are:

- Privately-operated service's impact on usage and resultant demand for federally operated services.
- Resolving competition related questions between private sector services and a federally provided free service.
- Possible private sector operation of phased-out federally-operated services.
- RDSS liability in providing navigation services and the federal government's regulatory role.

These factors could have a significant impact on future radionavigation policy and a detailed examination of the relationship between federal systems and RDSS must be undertaken. However, since RDSS is not presently fully operational, questions relating to these factors cannot be properly answered at this time.

Land Navigation

Land navigation applications are recognized for the first time, however requirements are still in the developmental state. Also there is no designated federal agency to represent the land navigation users. The Research and Special Programs administration is coordinating these requirements with other federal agencies and civil users. The major application is in vehicle navigation systems, however requirements are still in the developmental stage.

Automobile manufacturers are studying the use of GPS or Loran-C based systems for intra-city navigation of automobiles. A differential Omega system has been used for automatic vehicle location with good results. Other commercial activities are engaged in the monitoring of vehicle position using private or federal systems.

Uses Other than Navigation

The FRP recognizes applications other than navigation: these applications include radiolocation in two forms (surveying/site registration and automatic vehicle monitoring/location) and time/frequency dissemination. These applications will further enhance transportation safety, especially in applications dealing with shipments of hazardous cargoes and improved coordination and response to accidents or disasters. Other areas of radionavigation use showing definite economic benefits include wildlife migratory, forestry conservation and crustal motion studies.

4. CURRENT AND FUTURE STATUS OF NAVIGATION SYSTEMS

Loran-C

The domestic Loran-C system expansion in the mid-continent continues on schedule, with full operation planned by 1990. Military requirements for overseas Loran-C will cease in 1994. Present government plans are to turn operation of these overseas stations over to host nations where there is such interest and to shut down the Hawaiian Loran-C chain. The domestic Loran-C system should be in operation well into the next century. Loran-C user population is expected to increase substantially by 1991 as a result of new land based applications and an increased acceptance by the aviation community. Comments from the 1986 and 1988 users conference indicates an increased interest and acceptance of the Loran-C system, especially in land based and timing applications. Differential Loran-C systems are in use today. The Coast Guard is using differential Loran-C to set aids to navigation. State governments are using such systems to monitor ocean dumping practices and procedures.

Omega

The Omega system will see some modernization of station equipment, but no significant change in the system configuration is planned. Use of the aviation trust fund to pay for Omega system improvements was mentioned during the 1988 users conference. Projections of the Omega user population shows no change or only a slight increase in aviation users through 1992. Military air requirement for Omega will cease in 1994, but some naval receivers will remain in operation after 1994. Any decision to phase out the Omega system is not expected to be announced until GPS has been operational for at least three years and only if all requirements currently being met by the Omega system are satisfied by GPS. During the 1988 users conference, a transition period of less than fifteen years was mentioned.

GPS

The first GPS operational satellite is

scheduled to be launched in November 1988. The 21-satellite constellation is scheduled to be in place by 1992. Thus GPS should be fully operational in 1992 in three dimensions for military and civil users. Studies have shown that a constellation of 24 operational GPS satellites is one means to meet civil aviation requirements for sole-means navigation in the national air space. Funding for additional satellites is being considered. A Department of Commerce study estimates a 1995 worldwide civil GPS user population of one-half million, a most optimistic figure, unless a low cost GPS receiver is available. A request from the timing and frequency community of GPS users to leave two GPS satellites on orbit with no selected availability is being considered by the GPS Steering Committee. A 24 satellite constellation will solve the GPS coverage problem for aviation users.

5. CURRENT AND FUTURE RADIONAVIGATION PLANNING

GPS will become operational in 1992 when 18 satellites and three spares are on orbit. Since GPS receivers are not currently economical for most general aviation and the majority of marine users, civil use of GPS will be limited to special user groups. When economical GPS receivers are available, probably within three to five years of GPS being declared operational, the number of GPS users is expected to increase dramatically. Discontinuance of federal funding for domestic Loran-C or worldwide Omega service, in lieu of GPS service, is not likely to occur until sometime in the twenty-first century and not until the following issues are resolved:

-Resolution of GPS accuracy, integrity and financial issues
-GPS meeting the needs of civil air, marine, and land users currently met by existing systems
-Economical GPS receivers becoming available
-Resolution of international commitments
-Designation of an appropriate transition period for any phased out system.

Another matter which must be reconciled is the selection of radionavigation systems by DOT to meet civil requirements. Although the FRP policy statement has, for several issues, indicated that DOT might decide to discontinue federal operation of Loran-C and Omega for the reasons cited above, recall that the selection process calls for a cost-effective, user-sensitive, mix of systems for the post-2000 time frame. Thus one cannot rule out a civil user requirement for redundant systems based on the fundamental rule that the prudent navigator not depend on one system or method for all navigation needs.

The selection process provides for biennial reviews of the current national decision, with any changes being promulgated in a revised FRP. This process was applied to the preliminary decision in the 1984 FRP to reach the decision on the current mix of systems. Because the questions relating to GPS issues cannot be fully answered until the early 1990's, no change in the current mix of systems is anticipated prior to 1992.

Only one user conference was held to obtain civil user input on the 1986 FRP. This public hearing was held in conjunction with the annual FAA user conference in Washington, DC during March 1988. Comments from civil users of radionavigation systems can have a significant impact on the contents of the FRP and accordingly, active participation by the civil sector in providing input into the FRP is highly encouraged. Although private sector input cannot be guaranteed to directly influence the national decision on radionavigation policy, consideration of civil user comments and opinions are very important in the overall planning process to ensure that all user requirements are properly satisfied.

Projection of user populations can markedly affect decisions relating to continued operations of any radionavigation system. User equipment costs will continue to have a direct impact on any future recommendations relating to an optimal radionavigation system mix. The effect of an operational GPS on radionavigation systems will not be fully known until after several years of GPS operation; even then, redundancy requirements could preclude the shutdown of particular systems.

6. CONCLUSIONS

The 1986 FRP did not select an optimum mix of radionavigation systems because of the rapid changes occurring in today's technology. This rapid technological change is evident in Loran-C receiver costs, some now available below five hundred dollars. For GPS to successfully compete as a civil radionavigation system, receivers costing less than one thousand dollars must be readily available to the marine community. The decrease in receiver costs has been of significant importance in fostering the large increase in Loran-C users. Reduction in receiver costs for the other radionavigation systems is probably imminent. Economical receivers will attract more users to a particular system, causing further difficulties in the decision making process to reduce the number of radionavigation systems. With the selection process calling for a mix of systems to meet user requirements, the number of users of a particular system will be a major obstacle in deciding on the final system mix.

With a dynamic process for formulating policy decisions for selection of the optimal mix of federally funded radionavigation systems, civil system user populations will play a major part in shaping the biennial FRP policy statement for domestic systems. The FRP will continue to be updated every two years, allowing for civil review and influence in the radionavigation system selection process. Decisions on the phasing out of current radionavigation systems will not occur until after GPS has been operational for several years and a solid base of GPS users is in place, along with a concurrent decrease in users of other systems. Thus, the middle to late 1990's is the earliest possible date to validly change the current radionavigation system mix for the post year 2000 time frame.

7. REFERENCES

1. National Plan for Navigation, May 1970, Department of Transportation.

2. National Plan for Navigation, April 1972, Department of Transportation.

3. National Plan for Navigation Annex, July 1974, Department of Transportation.

4. National Plan for Navigation, November 1977, Department of Transportation.

5. "Summary of GAO Study of Radionavigation Systems: Meeting Maritime Needs," B-180715, March 26, 1974, General Accounting Office.

6. "Navigation Planning--Need for a New Direction," LCD-77-109, March 21, 1978, General Accounting Office.

7. "Radionavigation Action Plan Summary," DOT-RSPA-DPB-20-79-1, April 1979.

8. "NAVSTAR Should Improve the Effectiveness of Military Missions--Cost has Increased," PSAD-80-21, February 15, 1980, General Accounting Office.

9. "DOT Should Terminate Further LORAN-C Development and Modernization and Exploit the Potential of the NAVSTAR/Global Positioning System," MASAD-81-42, September 18, 1981, General Accounting Office.

10. Federal Radionavigation Plan, July 1980, Volumes I-IV, DOT-TSC-RSPA-80-16, DOD-NO. 4650.4-P.

11. Federal Radionavigation Plan, March 1982, Volumes I-IV, DOT-TSC-RSPA-81-12, DOD-4650.4-P.

12. Federal Radionavigation Plan, 1984, DOT-TSC-RSPA-84-8, DOD-4650.4.

13. Federal Radionavigation Plan, 1986, DOT-TSC-RSPA-87-3, DOD-4650.4.

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COOPERATIVE ELECTRONIC CHART DEVELOPMENT
THE GAADS PROJECT

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ABSTRACT

The National Ocean Service (NOS) is currently supporting the development and implementation of the Graphical Analysis, Archiving and Display Station (GAADS) of the United States Coast Guard (USCG) through the provision of electronic chart prototypes. NOS is working closely with the USCG and is assisting them in the determination of data requirements and feature display density by producing a number of digital nautical chart specific data files. In addition, NOS is developing an efficient method for producing digital data files for the entire suite of NOS nautical charts, if required. This paper will describe the GAADS system, data preparation, and prototype production techniques employed in the compilation of GAADS charts.

1. INTRODUCTION

In 1986, the United States Coast Guard (USCG) Office of Research and Development in Washington, D.C., requested assistance from the National Ocean Service (NOS) Office of Charting and Geodetic Services in Rockville, Maryland, to develop a method of producing digital navigational charts for a USCG electronic piloting and buoy positioning system. Their prototype system, known as the Automated Aids Positioning System (AAPS), had proven successful according to their Office of Navigation and was therefore being considered for production. NOS, in its support of research and development of new technology, responded to the USCG request by agreeing to utilize its digital shoreline and aids to navigation data files as a base to fulfill the USCG requirement of producing digital navigational charts for the AAPS Project. The USCG agreed to provide funding for the NOS development effort along with a loan of all associated hardware and software. In return, NOS would be responsible for developing, producing, and certifying the nautical chart data files required to produce an initial suite of digital navigational charts. While these negotiations were underway, the AAPS Project was replaced by a more sophisticated project undergoing development at the USCG Research and Development Center in Groton, Connecticut. This new project, the Graphical Analysis, Archiving and Display Station (GAADS), not only included AAPS, but also supported several other applications.

GAADS, an Electronic Chart Display System (ECDIS), is menu driven and easy to operate. It allows the user to display and analyze multiple vessel positions, aids to navigation, way points, search patterns, and composite data against digitized nautical charts with scales ranging from 1:20,000 to 1:30,000,000. These charts are loaded using standard chart numbers for easy identification. GAADS uses an algorithm to display the latitude-longitude graticules on a Mercator Projection.[3]

2. COMPUTER SYSTEMS

In order to understand the compilation process of a GAADS nautical chart, it is necessary to identify and describe the computer systems that support the process. The Intergraph Digitizing System is used to compile the graphic portions of a nautical chart digital data file. This System consists of a PDP 11/70 central processor, three 300 megabyte disk drives, and seven graphic workstations. Digital data collected at the Intergraph is processed using a Univac 1100 computer system located in Suitland, Maryland. The software available on the Univac 1100 gives NOS the capability of converting Intergraph x and y table coordinate positions to geographic positions (G.P.'s) or latitude/longitude. The Univac 1100 software also produces a file which is used to plot the digital data on a Calcomp 748 flatbed plotter. These plots are used to verify the accuracy of the digital data collected at the Intergraph. An IBM-AT personal computer with a 30-megabyte hard disk is used as the collection point for the certified data files. A contemporary word processing software package on the IBM-AT allows for last-minute editing of the data prior to transfer to a Hewlett Packard 330 Computer. The GAADS software runs on a Hewlett Packard series 9000, model 330 computer, which has a 12-inch color monitor and a resolution of 512 by 400 pixels. The computer utilizes 4 megabytes of RAM and a 20-megabyte hard disk. The computer has the capability to quickly store, manipulate, and retrieve display screen images. The GAADS software is written in HP BASIC 4.0 and contains 200 separate subprograms offering flexibility and maintenance.[2] The keyboard has 10 menu keys, a numeric key pad, and a knob for positioning the cursor on the screen.[1]

3. GAADS DATA FILE STRUCTURE

In 1987, technical representatives from the USCG R&D Center in Groton, Connecticut, and NOS met in

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Rockville, Maryland, to discuss data structure, specifications, and compilation procedures for the nautical chart data files required to support GAADS. A result of this meeting was an agreement that each GAADS chart compiled by NOS contain four separate and distinct data files: a shoreline file, a linear features file, a discrete point hazards file, and an aids to navigation file. The data in the shoreline and linear features files contain the x and y table coordinate positions, compiled directly from the Intergraph, of all points required to adequately depict these line features. The data in the discrete point hazards and aids to navigation files contain the G.P.'s required to adequately depict all point data in the file. All four files are structured in a vector format. The four files are combined at the Hewlett Packard 330 Computer, utilizing GAADS software, to produce a GAADS chart. In addition, all data files are in ASCII to facilitate the transfer of digital data between the IBM-AT and Hewlett Packard 330.

4. GAADS CHART COMPILATION

A description of each data file, its current specifications, and its compilation will provide some insight into the actual production of a GAADS chart. The shoreline, as defined by NOS, is the Mean High Water line on a nautical chart and includes both natural and man-made features. For GAADS chart compilation, this file must support color fill of all land areas displayed on the GAADS monitor. For the majority of nautical charts at NOS, a shoreline file is readily available in the form of NOS/Exclusive Economic Zone (EEZ) digital shoreline data sets. These sets contain the large-scale digital shoreline of the United States in G.P.'s. The first step in the compilation of a shoreline digital data file for a GAADS chart is to identify which chart is to be compiled and where the data exists within the EEZ digital shoreline data sets. The shoreline data is partitioned from the data set which contains the chart, then converted to x and y table coordinates on the Univac 1100, and downloaded onto the Intergraph System. A raw plot of this file is compared to the most recent published nautical chart drawing, and the shoreline data is edited at the Intergraph workstation to bring the file up to date. A filter routine is run to reduce the size of the file by eliminating all unnecessary points. The shoreline file is processed on the Univac 1100 converting the Intergraph x and y table coordinate data to G.P.'s. This conversion is not a require-ment of GAADS but is used solely by NOS to produce plots to check the accuracy of the data. The converted file is plotted and checked against the most recent published nautical chart drawing. Any additional editing required is performed at the Intergraph workstation. Upon completion of all editing, it is essential to close all shoreline polygons because this file must support color fill of all land areas displayed on the GAADS monitor. To close all shoreline polygons, the line strings are connected on the Intergraph. The file is once again processed on the Univac 1100, plotted, and checked against the most recent published nautical chart drawing. A copy of the completed shoreline file, an Intergraph vector file containing x and y table coordinates, is loaded on the Univac 1100. A printout of the shoreline file is obtained to verify that all shoreline polygons are closed. Any additional editing is performed using the Univac 1100 text editor. The file is downloaded from the Univac 1100 to the IBM-AT over a data line. A contemporary word processing package is used to remove unwanted Univac 1100 commands such as end of file marks and line feed carriage returns from the shoreline file. The file is written to a text file in ASCII format on the IBM-AT. A vector file containing all shoreline data with polygons closed is complete and ready for transfer to the Hewlett Packard 330.

The linear features file contains a selection of lines on the chart other than shoreline. Presently, this file consists of 6, 12, 18, and 30-foot depth curves, all channel lines, spoil and anchorage areas. This file contains nautical chart line features that do not require color fill on the GAADS monitor. This data does not reside in the NOS digital data base, so it must be digitized from the most recent published nautical chart drawing at the Intergraph System. This digital data is processed on the Univac 1100 where it is converted from x and y table coordinates to G.P.'s and plotted. The plot is compared to the chart drawing and edited as necessary at the Intergraph workstation. The file is filtered to eliminate unnecessary points and reduce the size of the file. The file is processed again on the Univac 1100 and plotted to verify the accuracy of the digitizing against the most recent published nautical chart drawing. A copy of the completed Intergraph file, a vector file containing x and y table coordinates representing the linear features digitized, is loaded on the Univac 1100. Any additional editing of the data files is per-formed using the Univac 1100 text editor. From this point, the file is essentially treated like the shoreline file. The file is downloaded to the IBM-AT, edited, and placed in a text file in ASCII format. A vector file containing all linear features required for GAADS chart compilation is complete and ready for transfer to the Hewlett Packard 330.

The discrete point hazards file consists of rocks, piles, islets and other hazards to navigation found on the nautical chart outside the 6-foot depth curve. This point data does not exist in the NOS digital data base so it must be digitized from the most recent published nautical chart drawing at the Intergraph. Upon completion of the digitizing, the Intergraph data file is processed on the Univac 1100, where it is converted to G.P.'s and plotted. The plot is compared to the chart drawing and edited as necessary at the Intergraph workstation. The file is processed again on the Univac 1100 and plotted to verify the accuracy of the digitizing. A copy of the G.P. file, a vector file containing the geographic positions of all discrete point hazards, is loaded on the Univac 1100. Any additional editing is performed using the Univac 1100 text editor. From this point, the file is essentially treated like the shoreline and linear features file. The file is downloaded to the IBM-AT, edited, and

placed in a text file in ASCII format. A vector file containing the G.P.'s of all discrete point hazards for the GAADS chart is complete and ready for transfer to the Hewlett Packard 330.

The aids to navigation file consists of all charted aids to navigation along with the characteristics of all lighted aids and references to the source document which established the position of the aid. This file does exist in the NOS data base on the Univac 1100 and is known as the Discrete Independent Point File (DIPFILE). It is updated as Notice to Mariners and other source documents are received by each nautical chart compilation area team. A software routine is run to partition from the DIPFILE, all aids to navigation which fall on the chart. The file is processed on the Univac 1100, and a plot is made of all the aids that fall on the chart. The plot is compared to the most recent published nautical chart drawing and edited to bring it up to date. All discrepancies are resolved by checking the chart history and Notice to Mariners. The characteristics of all aids are also edited and updated using the USCG Light Lists and/or Notice to Mariners. All editing of the file is performed on the Univac 1100 text editor. Upon certification of the file, the vector file containing the G.P.'s of all aids to navigation for the GAADS chart, is downloaded from the Univac 1100 to the IBM-AT, edited, and placed in a text file in ASCII format. The aids to navigation file is complete and ready for transfer to the Hewlett Packard 330.

5. TRANSFER OF THE DATA FILES

The shoreline, linear features, discrete point hazards, and aids to navigation files are transferred to the Hewlett Packard 330 via an RS-232 interface or floppy diskettes. Upon transfer, the USCG assumes control of the NOS nautical chart data files. The vector files are transformed by the GAADS software for display on the HP-330 color monitor. The GAADS software offers the flexibility to recall the data by individual files, or in any combination, depending upon the functional requirements of the user. The NOS nautical chart data files support the USCG GAADS chart requirements by providing the USCG with a highly accurate product which conforms to paper nautical chart production standards.

6. CONCLUSION

The development of nautical chart data files for the compilation of GAADS chart prototypes continues at NOS. The initial prototype, chart 13213 covering the New London - Groton Connecticut area, has been transferred to the USCG and transformed for display on their GAADS color monitor. At USCG request, NOS is currently compiling additional nautical chart data files for charts covering the St. Marys River, Michigan area. The NOS/USCG cooperative effort continues to provide the USCG with the nautical chart data files required to fully realize the capabilities of the GAADS System.

7. REFERENCES

1. Lamb, Michael J., GAADS User's Manual, Prepared for U.S. Coast Guard Research and Development Center, September 15, 1986, p. 1-1.

2. Poltilove, David L., Development of Digital Chart Products, Proceedings, U.S. Hydrographic Conference '88, April 12-15, 1988, Baltimore, Maryland, p. 190-193.

3. Vorthman, Lt. Cdr. Robert G., Jr., U.S. Coast Guard Alumni Association, The Bulletin, August/ September 1986, p. 32-35.

AUTOMATED NAUTICAL DATA AND CHARTING DEVELOPMENT

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ABSTRACT

The National Ocean Service (NOS) is beginning the development and implementation of an automated system of nautical data evaluation, data base administration, and nautical chart production. This system, the Automated Nautical Charting System II (ANCS II), represents NOS' next generation of automation of the cartographic processes involving nautical data.

The ANCS II will be utilized to evaluate and select data from the many types and forms of source information received and to interactively apply that data to a geographic, product-independent data base. Data will be drawn from this data base and applied to a logically separate data base which will be used to produce approximately 1,000 NOS paper nautical charts. In addition, the system must support requests for digital chart products.

While the initial product load of ANCS II will be chart products, the nautical data base will service the expected growing demand for custom digital data requests. Additional logically separate data bases may be established to service new products.

1. INTRODUCTION

The NOS is required by statute to publish nautical charts and related publications, and otherwise make available information necessary for the safe and efficient transit of the Nation's coastal waters and inland waterways. This information is necessary to support domestic and foreign commercial shipping, private recreational boating, government regulation and defense of the Nation's coastal areas, offshore resource exploration and extraction, and coastal zone planning.

In the late 1960's, NOS recognized the advantages of automating the production process of the traditional nautical product line and the value of creating and maintaining a digital data base of the information represented by these products. The application of digital plotting technology offered the ability to reconstruct current nautical chart products to improve and standardize the construction of the chart base and the depiction of the chart symbology, and offer the capability to reconfigure the chart format as desired. In addition, new chart constructions could be made in a much shorter calendar period. If a multipurpose digital data base were made first to produce data for this digital plotter output, then a source for a whole new generation of digital products would be available.

The NOS developed a digital plotting capability in the late 1960's and early 1970's. In 1975, the design of the Automated Information System (AIS), a storage, retrieval and update system for nautical charting data, was begun. This system was developed and integrated with data collection and processing capabilities, and digital plotting functions, to implement the Automated Nautical Charting System (ANCS) in 1978.

The ANCS includes all the functions to process incoming digital and analog data into the AIS data base and produce NOS nautical charts. A digitizing capability enables analog source documents to be completely or selectively converted to digital form for processing along with NOS digital hydrographic data into the AIS system. Once loaded into the AIS, data can be interactively attributed to reflect application to NOS nautical charts. This data base is geographic and logically continuous. Data is then extracted from the AIS according to parameters describing the dataset or the nautical chart desired. For nautical charts, offline batch processing then constructs a plot dataset compatible with one of many devices available. The ANCS includes electrostatic, flatbed vector, and laser raster plotting capability to produce paper, scribe film, and photographic film plots.

While the production level for ANCS never reached the initial desires, the concepts and value of the digital data base and automated chart production have been demonstrated and a modest level of chart production has been achieved and maintained. Currently, the system fully maintains 70 published nautical charts on the AIS system with digital data collection and plotting support for all chart production except minor corrections and reprints.

The ANCS II is designed to provide the capability and capacity to handle nautical chart production and requests for digital data. The system will take advantage of the tremendous advancements in automated mapping and charting hardware and software technology, and experiences with the current ANCS. A Nautical Information Data Base (NIDB) of data will serve as source data for all nautical products including nautical charts and digital nautical information requests, and a logically separate Chart Graphics Data Base (CGDB) derived from the NIDB will specifically support nautical chart production.

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2. REQUIREMENT

Data for nautical chart application is received from more than 60 sources including NOS, in the form of NOS hydrographic and photogrammetric surveys, the U. S. Coast Guard, U. S. Corps of Engineers, and numerous other public and private organizations. ANCS II must provide for the evaluation, extraction and application of this data to the NIDB according to all product requirements. Approximately 35,000 new source documents must be processed annually. Of these, about 9,000 are typically determined by an initial evaluation to contain information affecting the NIDB. Since only NOS hydrographic surveys, and in the near future NOS photogrammetric surveys, are received in digital form, this number represents physical documents that must be processed.

The legal nature of current and anticipated NOS products necessitates maintaining a complete history of the application of source data. The ANCS II system must provide tracking and status reporting to assure that data is processed and applied on schedule and provide this history of processing activity and disposition of the data. This capability goes far beyond current capabilities in maintaining an inventory of all source documents received and providing management tracking of the progress of application of the document.

Once data is applied to the NIDB according to product specifications, data to produce products or satisfy data requests can be extracted.

The immediate production goal of ANCS II is to support the production of nautical charts and related publications, and to provide critical feedback to the U. S. Coast Guard and the Defense Mapping Agency (DMA) in the form of the Notice to Mariners publications.

Data will be extracted from the NIDB to produce NOS nautical charts according to a regular printing schedule. This data enters the CGDB where it is interactively applied to previously published information to yield a new chart edition. This step also requires a complete history of the application of changes.

Currently NOS publishes approximately 980 nautical charts to fulfill its nautical charting requirement. The design goal for ANCS II is a capability to produce about 500 revised chart editions each year. Nautical charts may include extensions, larger scale insets, and be divided into several panels in order to adequately represent an area. Because of this, approximately 2500 individual chart panels must be maintained.

The reporting of critical conditions, or "Notice," through the U. S. Coast Guard and the DMA Notice to Mariners publications, takes place both during data application to the NIDB and the CGDB. A critical change noted during source application and NIDB update may be reported immediately, but more typically would generate a CGDB application which allows a cartographer to assess the impact of the change on the nautical chart and safe navigation during the compilation process. After this assessment a "Notice" may be issued.

The primary long-term goal of the ANCS II system is to maintain the NIDB as the data source for the CGDB and all nautical products and directly service the growing number of requests for digital data to support scientific and economic studies, electronic charts, and any other navigational uses. A major demand for digital nautical charting data will come from the Department of Defense (DOD) which plans to store nautical data in an all digital form in the early 1990's. The DOD and other government agencies use about half of the approximately 2 million NOS charts distributed each year.

Data and product archiving will be tracked and reported during the process. Data to assist in planning and supporting the acquisition of photogrammetric and hydrographic data within NOS will feed back to those acquisition activities.

The ANCS II must contain the batch processing capability currently provided offline on offsite mainframe and onsite micro computers. Data is currently offloaded from independent systems and transferred by magnetic tape or floppy disk for processing. The ANCS II will have the capability to batch process this data as it passes between logical production steps within the ANCS II Local Area Network (LAN).

Additional processing steps supply special overlays and graphic elements for NOS products which include electronic positioning lattices, magnetic information, services, and boundaries of all types. Other processing supports data evaluation and chart compilation processes such as line generalization, sounding selection, and hydrographic surface modeling. All batch processing requirements will be satisfied within the networked ANCS II system.

3. ANCS II FUNCTIONAL OVERVIEW

The ANCS II system will process selected navigational data from digital and analog source form for inclusion into the NIDB and provide the tools to extract that data for a multitude of products.

Figure 1 is a conceptual overview of the ANCS II system. Two major processes take place within the system. Data from all sources is evaluated, compared to existing data in the NIDB, and applied to the NIDB in the "manage data" process while updating appropriate control files to assure data and task tracking through the system. The "produce charts" process, logically separate from the "manage data" process, extracts data from the NIDB to maintain the CGDB in order to compile digital chart images.

In the "manage data" process an initial evaluation will determine if source information received should be added to or might affect the NIDB. Digital information will be processed into a compatible format and input into the system. Analog documents

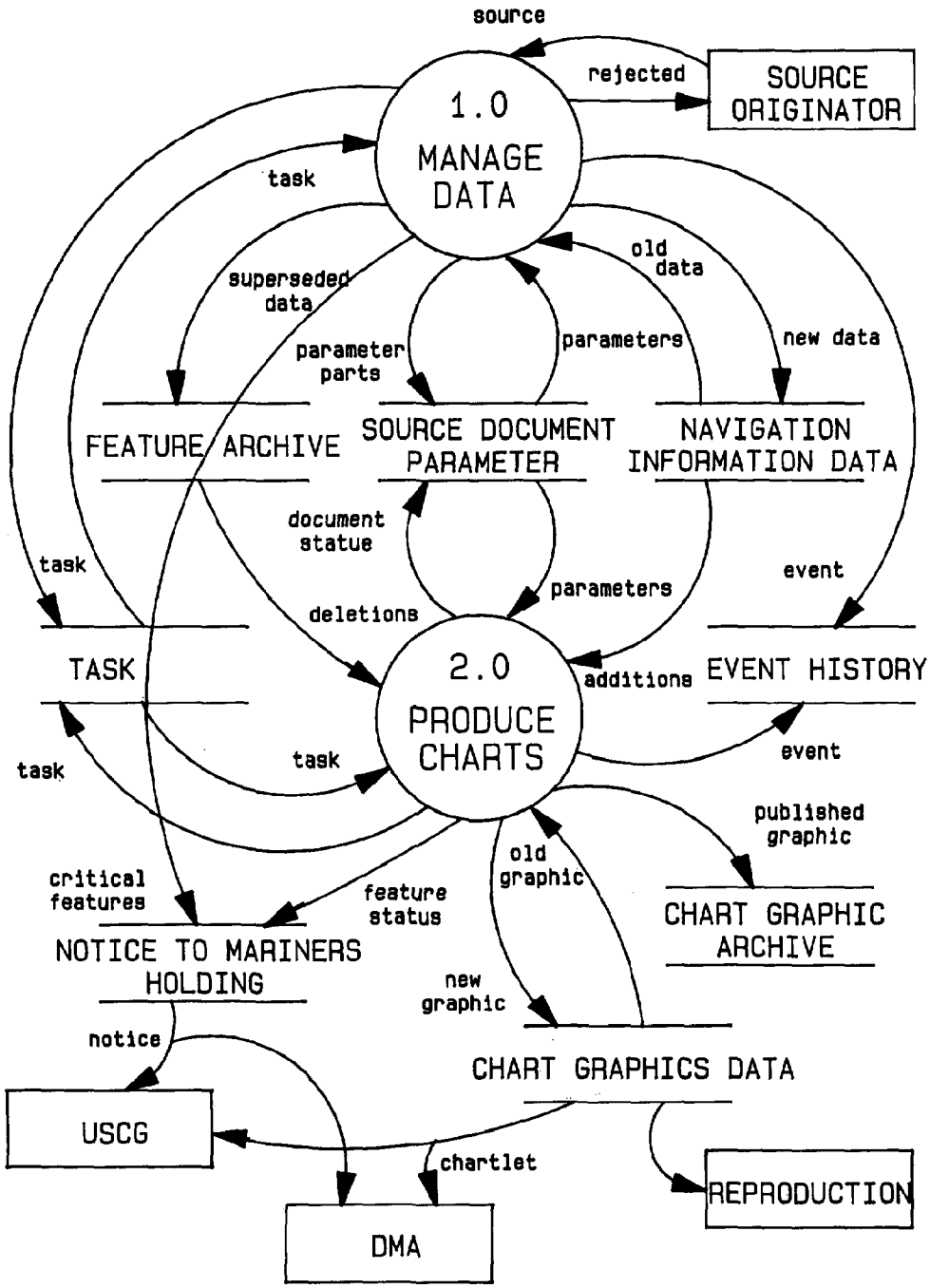

Figure 1.--Automated nautical charting system II conceptual overview.

selected will then be processed by the system. Processing of a document entails a comparison of the data contained to current NIDB data and data specifications to determine changes requiring an NIDB addition or update.

Each change or addition normally requires conversion of the data involved to digital form and an interactive application to the NIDB. A number of the system workstations will be equipped to digitize source information from analog documents. This information is then immediately available for application to the NIDB. A small percentage of documents will require bulk digitizing that would unduly occupy a workstation. This will be done on a peripheral system or on contract.

The current system requires data to be collected offline after selection and then applied to a database in a separate session. The ANCS II will eliminate the multiple handling of documents, breaks in the process flow, and excess data collection inherent in the offline process.

Methods to quickly scan these sources into a raster digital format for display and interactive visual comparison to existing data will be investigated. This method is very attractive as it allows a comparison of the entire source document before resources are expended to convert and attribute individual features that may not be needed. While it is not anticipated that entire documents will be bulk converted by this method, the majority of the documents received which have relatively small numbers of features selected from many could be efficiently handled. Other selection methods typically require more features to be converted than will be used.

Once this process of source document assessment, data selection, and data collection is complete, a workstation session will commence to interactively apply the data to the current NIDB contents. Processing power available to the ANCS II workstations will allow the interactive comparison of source data to data residing in the NIDB, selection of data which changes NIDB contents, and application of this data. ANCS II will contain the full range of compilation and graphic tools to assist the cartographer in this process. Application software such as sounding selection, automatic contouring, surface modeling and line generalization will be used for certain applications. When the process is complete and the necessary quality checks and tracking data are complete, the data is applied to the NIDB through the ANCS II Data Base Management System (DBMS).

The "produce charts" process is the product dependent process to compile and maintain the suite of NOS nautical charts. The ANCS II system will provide for extracting data from the NIDB and processing the application of the data to the CGDB.

The CGDB update task will be independent from NIDB update, initiated by a cartographer/manager. Control file entries established during the NIDB update process, and the chart production schedule will be queried to prioritize possible CGDB updates necessitated by chart printing schedules and application of information critical for the safety of navigation.

This process will incorporate most of the same tools and the same system components used in the NIDB update but be controlled by different product specifications, procedures and rules. This process, too, will maintain control files to provide for management tracking and a permanent history of data application or change to the CGDB.

The logical separation of the CGDB from the NIDB will insure that cartographic modifications to the data for printed or electronic chart depiction of nautical features will not affect NIDB data usage but be confined to the CGDB. This concept is extremely important to maintain the integrity of the NIDB for multiple uses.

These completed chart compilations contained in the CGDB are then available for processing electronic chart and NOS chart graphic requests. Textual and graphic output are necessary for requirements such as the Notice to Mariners publication, and graphic chart output to support NOS traditional paper charting production and electronic chart data requests.

4. HARDWARE

The ANCS II system architecture, currently in the planning stage, may vary from a highly centralized system with database functions, batch processing and much graphics processing residing on one or two large processors networked to single or clustered limited capability workstations, to a highly distributed system with many processors networked to very powerful workstations where database functions and batch processes are distributed and workstations operate independently. A likely configuration is one in which very capable workstations connected by a standard LAN are distributed in the cartographic work areas. The databases would reside on larger processors on the LAN along with batch processing capability. Microcomputer "smart terminals" would be connected to the LAN for management control and reporting and peripheral operations such as word processing, software maintenance, and routine data input.

The current system is hampered by obsolete system hardware. The ANCS II will benefit from tremendous advancements now commonplace to mapping systems. The system will be coupled by a LAN allowing great flexibility in system configuration and placement of equipment while maintaining an integral system. Logically the NIDB, CGDB, and any other required data bases will be centrally supported while workstations distributed in the cartographic areas will function essentially autonomously. The capability of workstation hardware to function within typical office environments and the flexibility of physical placement afforded by LAN's allows the integration of the system functionality into the workplace and the modular growth and reconfiguration to adapt to production and organizational changes.

The system will consist of up to 40 graphics workstations, smart terminals, batch data processing resources, data base processing resources, and peripherals locally networked together. As many as 15 of the 40 workstations may include a precision digitizing capability for direct data entry from graphic source documents. Each workstation will be capable of performing all data entry, NIDB data base, and CGDB chart production functions. Smart terminals will be used for a variety of functions including data entry, development, and management inquiry and reporting.

5. SOFTWARE

The software for the system will include a DBMS, Operating System, mapping routines, and applications. It is anticipated that the majority of the software will be commercially available, proven products.

The DBMS will manage the NIDB, CGDB and other data bases required for the system. While it may be possible that different DBMS software may manage the different data bases, one system is more likely.

Data will be stored in a topological structure to take advantage of relationships between features. Line features in particular can be interrogated according to these relationships for automatic update, error checking, and extraction in logical groupings according to purpose.

The required applications for the ANCS II system will require the bulk of the development effort since these are highly influenced by specific NOS specifications and policies.

6. IMPLEMENTATION

A Request for Proposals (RFP) to procure the ANCS II system was released on January 19, 1988, and closed on April 28, 1988. Responses to the RFP are being evaluated as of this writing with contract award expected in September 1988.

The system will be developed in phases over a period of 3 to 4 years and include a prototype development and demonstration phase, a trial production phase, and a full production implementation phase. The system hardware configuration will be expanded during the phases in four steps culminating in the full configuration at the end of the final phase.

7. SUMMARY

The NOS plans to procure and implement the ANCS II system as part of the modernization of the nautical charting system. The result will be a product independent data base capable of supporting a range of products. Separate databases derived from this product independent data base will support specific product lines including NOS nautical charts and electronic digital charts.

THE CONTINUING NEED FOR ACCURATE POSITIONING IN NAVAL TACTICS

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ABSTRACT

Modern naval warfare has, over the years, resulted in the relegation of accurate positioning and navigation to a second class role. The modern naval officer worries about positioning usually only when concerned with navigation. During the battle he most often conducts his operations in a relative motion sense using relative ranges and bearings. The once widely-respected title of navigator has been replaced by that of the Tactical Action Officer. Despite these lamentable trends, accurate positioning remains as important today as it ever was. The trends toward over-the-horizon targeting/battles and strict Emission Controls (EMCON), coupled with the more traditional tactics in Anti-Submarine Warfare (ASW) and Mine Warfare, continue to require good geographic positioning as a matter of paramount importance.

INTRODUCTION

Naval warfare, as with all other operations at sea, depends heavily on the positions of one's own vessel and those of other contacts in the area. While much activity is conducted in the relative frame of reference using bearings and ranges, it is still necessary to have accurate and current knowledge of one's position on the surface of the earth.

In this discussion on determining one's location we need to review two fundamental definitions. The first is for navigation, which is the art or science of conducting one's self from one place to another. The second is for positioning, the act of determining one's place on the earth to a specific tolerance.

While the two words mean the same thing to many people, there are subtle differences. Fundamentally, the word 'positioning' implies a more accurate knowledge of one's position than is required in navigation. The act of navigation is more dynamic in that it includes movement from one place to another. Positioning reflects a greater interest in one's position as accurately fixed on the surface of the earth. It is very often used in association with activities requiring close tolerances such as in surveying or the offshore oil industry. Positioning is necessary where the mariner wishes to accurately mark a place for return or some future action.

DECLINE IN NAVIGATIONAL AND POSITIONING EXPERIENCE

The term 'Navigator' within the U.S. Navy has lost some of its luster over the years because of two factors. One, improved techniques and equipment have made navigation less difficult to practice but at the same time more accurate. Secondly, the evolution of modern warfare has shifted emphasis from true positioning to a relative frame of reference. A navigator is generally less interested in precision positioning because his ship's motion does not allow him time to take full advantage of multiple or more complex positioning strategies.

Less than a hundred years ago, the title Navigator was one which inspired admiration. Now navigation is something that must be done to keep out of trouble. It's still possible to ruin one's reputation through bad navigation. For this reason, navigation is maintained as a necessary but not altogether desirable skill. Unfortunately, the imperatives of today's fast-moving tactical and battle situations have diluted the emphasis placed on traditional navigation skills.

The modern naval officer must concentrate more on threat indicators and less on finding his position. This lamentable

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state of affairs appears in both the lack of strong and comprehensive navigation training and in the lower priority given its actual practice.

The evolution of modern electronic navigation systems has led to the design of relatively simple-to-use equipment with direct reading displays. One needs only take latitude and longitude readings from the equipment and plot them. This may be well and good in the open sea where the hazards of running into a shoal are less unlikely. However, in restricted waters, or where an accurate position is required, these systems are not always as accurate as manufacturers would like users to think. Potential problems range from what we call range holes, to system failures to poor pattern geometry. Navigation in well-travelled waters, is generally easy because provision has been made for complete and accurate electronic navigation signal coverage. However, in less frequently travelled waters, it becomes more problematic. It is into these waters that our navies must sail and fight. How many of you, ten years ago, would have thought that there would be major actions in such out-of-the-way places as the Falklands and Grenada? In order to position oneself well, one must pay full attention to all the variables.

There are still many operations personnel who find it difficult to adjust to a digital environment because they feel they've lost touch with the real world. They find it difficult at times to interpret the information presented. It's not surprising that we still find the requirement aboard U.S. Navy ships to keep a hard-copy (paper) geographic track plot.

RELATIVE AND GEOGRAPHICAL POSITIONING

One need only look at any tactical radar screen today to get an appreciation for how operational tactics have developed after World War II. Before that, they were always played out on plotting tables using geographic references. Virtually every navigational and tactical radar displays targets in the Plan Position Indicator (PPI) format. With PPI, the radiating ship is positioned in the center. Contacts are located on the screen along radials, at some true or relative bearing, extending from the radiating vessel's blip. Some radars allow radar operators to displace the origin of the cursor to an off-center position to aid in the visualization of the tactical situation. Computations may be made within the equipment to solve for the maneuvering board solutions of targets' courses and speeds thereby reducing relative data to true motion. Similarly, bearings and ranges from one target to another can be determined by moving the cursor origin to a desired blip and rotating the cursor to a third.

Modern tactical operations are normally conducted within a relative motion framework because most weapons systems deal in range and bearing data elements. When contact is made, the target is generally identified by its range and bearing from the detector. The resulting evolution in tactical thinking, therefore, has concentrated almost solely on the relative motion solution. This is a dangerous trend because, with the flood of information now available from all our sensors, there is a higher probability of losing the 'big picture.' That's why, when you see a picture of the Combat Information Center of an Aegis ship, you see a bank of very expensive screens. Unfortunately most ships cannot carry such an expensive suite of equipment and must make do either with small and very limitecd screens or with the more traditional and underdeveloped plotting tables.

Nevertheless, one of the best ways for keeping a clear picture of what is going on is to plot the action on a table. This effectively results in conversion of relative motion into a true motion picture on a geographic plot. The resultant plot then directly relates the action to the real world.

The fact that such solutions are still available, dramatically points to a definitive need for tactical operations officers to get their target information on a true or geographic display. Movement is then unambiguously portraye. Mariners feel at home working tactical solutions in true motion where action is depicted in real world terms. It significantly reduces the complexity and allows for faster decision-making.

The major advantage is that one gets a true appreciation of the interaction of all the participants in an action without having to work out a relative motion solution in one's head. This is particularly advantageous when there are multiple contacts to contend with both true and relative data flows being received.

LARGE AREA BATTLES

Modern weapons systems have longer and longer stand-off ranges. The result is that tacticians have had to consider ever extended detection horizons. The only good method for adequately referring target positions to scattered elements of a task force is on some sort of grid or geographic coordinate system. This is because not all vesssels can support complex, large and expensive detection and tracking sensor suites, or their sensors are limited by EMCON restraints. Ships must rely on other sources of information to learn the whereabouts of the enemy. As with most detection systems, the detection is made in the relative mode but converted into geographic positions for transmission to, and plotting by, other elements.

NTDS AND THE LINK SYSTEMS

Much of these data communications are performed through the Navy Tactical Data System (NTDS) or Link 11 or 14 Systems. These systems pass disposition information on a number of contacts automatically between computers. One weak link in these systems is the frequent inability of data generating ships to position themselves accurately. Any errors in their positions are passed through the system and multiplied by any other errors present at the receiving vessel.

If every ship and aircraft was properly positioned, the problems could be significantly reduced. In a recent exercise, the Link system was observed at one instant to have three contact symbols portraying the same vessel in three different places on the screen. Two of these positions were more than five miles distant from each other. The force was in radar silence and at darken ship. The positions provided the only information by which the ships maintained their stations in the main body and screens. The ship from which we made these observations was carrying a navigation integration system which combined three navigation system inputs with an automated tactical plotting table. We were able to obtain the finest positioning information of any ship in the force. Since we knew the location of our ship to within a hundred meters, we were easily able to see the failings in other ships not possessing good navigation or position information.

A common tactic during periods of EMCON silence is to send a radar aircraft aloft which radiates from a location far removed from its task force. One of the greatest sources of error in the Link system arose from the fact that the helicopter had taken its relative position from the carrier which was in turn not well-positioned. The result was that all the contacts illuminated by the helo, which was the only radar in the EMCON-shrouded force, were in as much error as that of its guide, the carrier. She was, interestingly, the element which had appeared in triplicate (i.e., in error) on the Link screens of the force earlier in the exercise.

When enemy targets are detected by such a mis-positioned helo's radar, then the error is propagated throughout the force. Any ships needing to plot those targets would be in error as would any weapons which were to be fired.

During a similar exercise transit, the Link control ship role was given to one of the screening escorts. It was easy to see that the destroyer, which was also the screen commander, was soon overloaded trying to run the ASW problem against three submarines whilst trying to maintain the tactical data base. When the going got hot, it was obvious which effort was left to languish. We observers noted an early breakdown in the navigation function as disorientation became the rule on the Link system. We believe this occured because the navigation function is not considered critical when compared with the priorities of the battle. This might possibly be considered acceptable in battle there is no need for this to happen. There are systems available which will automatically track the geographic plot for low cost and minimal effort. Positioning information was of paramount importance to other ships in the force when in EMCON.

ATTACK SCENARIOS

Attack scenarios are most often played out on geographic plots because of the clarity of their presentations. This is particularly true in situations where there is a 'time-late' or datum to deal with. The solution to such problems is best found on a geographic frame of reference because the "lost" contact can be fixed to a position on the earth where it was last detected. In this way its projected movement can be easily portrayed. Similarly, it is far easier to set up search and attack patterns on a geographic grid than it is to work in relative motion. This fact becomes even

more true when there are multiple vessels and helos involved in the action.

Traditional Anti-Submarine Warfare (ASW) attack scenarios are traditionally played on a tactical plotting table. The datum or target is plotted with the positions of other participating ships and aircraft. The plot is most critical for the Attack Coordinator who must be able to see the entire situation and call in his forces to maximum effect.

Most modern plotting tables still require the concerted efforts of several persons to keep the plot current. The ship's position is projected by a light source from below and a person must mark its position manually at fixed intervals. Similarly, all other contacts and targets must be similarly tracked. The result is that many persons must lean over the table while hand plotting. Meanwhile, the Attack Coordinator must look over everyone's shoulders to get a clear picture of the unfolding attack. Not only is this method manpower-intensive, but it is prone to human error in the plotting. Very little development has taken place in this area.

Few equipment manufacturers have attempted to automate this function. While there are a number of systems attempting to consolidate all this information on a geographic plot, most equipment tends to be very expensive and complex. Additionally, many operators tend to feel alienated from a strictly digital solution. The plotting table still has an intimacy that is not found from viewing a video screen.

MINE WARFARE

The need for good geographical positioning is even more critical in the area of mine warfare. It is of paramount importance that mine warfare vessels, aircraft, Q-Routes and objects on the seabed be accurately positioned. Each of the elements in the mine warfare equation must be fixed on a common reference frame on which all players may track and display objects of interest. The most common grids are those developed around geographic coordinate systems, whether they be in Latitude/Longitude or Universal Transverse Mercator. Without a common reference frame, the ability to avoid or re-acquire the contacts is significantly reduced.

Precise positioning is of even greater importance in this critical area of naval operations. There is very little margin for error. Many of the larger equipment manufacturers are quick to provide very large and technologically advanced suites of equipment by which they claim to solve many of the mineman's problems. We've found that a far better and less expensive approach is to increase the precision in solving the navigation/positioning challenges. This is a relatively low cost solution with leveraged benefits surpassing those of the 'more and larger' equipment syndrome.

Q-ROUTES

Mine warfare begins with the complete survey of Q-Routes, i.e., the intended routes through restricted waters down which vessels may steam. This concept limits the amount of area needing to be continually searched. The objective is to condition a channel by accurately surveying it and then resurveying it frequently to ensure that no new mine-like objects have appeared. When the initial surveys are undertaken, all objects of interest on the bottom are accurately positioned and identified. These become the reference objects against which future contacts will be compared. It is important that all objects are located in order to reduce future requirements for classification of 'new' contacts.

Q-Routes should be regularly "conditioned'" so that, should war break out, the number of new contacts needing to be classified would be limited. Positioning during these conditioning surveys must be as accurate as possible to provide accurate positions for future comparison with objects previously detected and classified.

Much of this kind of survey work is done with the aid of side scan sonars. These allow operators to sweep a swath of bottom between the survey run lines. There are inherent inaccuracies in the side scan sonar principle which must be considered before the positioning of objects far from the survey run line may be regarded as accurately positioned.

Side scan sonar traces are good reconnaissance tools but there are a number of variables which are often not taken into account when accurate positions are desired. A number of products on the market and in development project the paper side scan trace onto a video screen. This should allow the operator to rapidly classify and "position" objects detected. Many of these systems, however, fail to address

such problems as a display (waterfall) scroll rate tied to ship's speed. This is common on paper recorders but causes distortion on video, leaving doubt as to where the object really is. Other interesting features touted are 'freeze framing' and 'zooming,' which allow the operator to stop the scrolling to better view a contact or blow up its scale. Both these functions serve a useful purpose but obscure the cascading display currently being collected.

Positioning objects detected by side scan sonar is possible, but there are a number of variables which must be addressed. The principal consideration is the position of the towfish at the time of each ping. This is no small problem. Just knowing the position of the towing vessel/aircraft is not good enough when obtaining positions for use in mine warfare. One of the other papers at this conference on the Bathyscan system (in the Acoustics - Side Scan Session) provides an interesting and accurate approach.

MINE HUNTING AND NEUTRALIZATION

Return to a previously-detected mine-like object for neutralization is an extension of the problem discussed above. It's no good just having the objects accurately positioned and charted. The mine hunter must be able to navigate back to the object. Without proper navigation, useless time is wasted looking for the object to be neutralized and the risk is always present that the wrong object will be destroyed. Therefore, as much attention must be paid to positioning the hunter and disposal vessels/aircraft as in the initial survey.

The point being made here is that positioning is the key to good mine warfare tactics from beginning to end. Mine warfare operators cannot be content to be haphazard in their approach to navigation. The best solution is to use more than one positioning system and mathematically evaluate the inputs to reduce the errors. We are not even sure that the GPS will be the final solution to all these problems, though it is supposed to give very accurate positions. Mine warfare personnel cannot afford to be cavalier in their approach to positioning.

Recently we heard a story about some mine forces in the Gulf. They had come up with the traditional "Cocked Hat" problem where three lines of position resulted not in a point but in triangle. Their solution was to turn off one of the three stations in order to reduce any ambiguity. With two lines of position, they had no doubt where they were and they had a point fix. We have no knowledge what criteria they used in selecting the deselected station, but it points to the fact that they really needed more than three lines of position to get a statistical evaluation of their positioning systems. There are too many lives and High Value Targets riding on their efforts. There is an ever greater need to provide for the integration of a number of positioning systems in order to come up with a statistically weighted answer. If nothing else, you will know how bad your position is.

There is an old mappers' axiom that says, "The next battle will be always be fought at the junction of at least two map sheet lines." The extension of this rule in mine warfare is that the next mine will be seen at the outer limits of your radiolocation chain pattern. Minemen will always be on the fringes; out where the coverage is weak and support is weak. That's why they need systems which can be counted upon to give the very best solutions for positioning themselves and the objects they're looking for.

CONCLUSION

We've tried to point out that the evolution of modern naval warfare has drawn us away from the careful and assiduous application of navigation and positioning information. The ease of obtaining a 'fix' and the imperatives of tactical threats have relegated this aspect to a lesser role. Nevertheless, the importance of accurate positioning, whether it be for navigation or some warfare application cannot be dismissed. Only with good positions may naval forces optimize their power.

Without good positions, tracking the battle is made difficult. The lack of a plot makes decision-making difficult. Too much effort is put into making large systems which do everything, with too little attention being paid to the key element, the positioning of the force. Neither can we let the speed of the battle detract from maintaining our positions because they are what we need to deconflict our scenarios in the end.

OCEANOGRAPHIC APPLICATIONS OF THE ARGOS SYSTEM

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ABSTRACT

Since 1978, the Argos Data Collection and Location System (DCLS), operating in bilateral cooperative use of NOAA's TIROS series of polar orbiting satellites, has played a leading role in most major worldwide oceanographic data collection programs. This paper describes the Service Argos/NOAA satellite system, its' policy and operation, and recent Argos system technological advances. Information concerning past, present, and future major United States, North American, and global oceanographic programs is also presented, along with other types of oceanographic applications possible through the use of the Argos system.

INTRODUCTION

The need to acquire oceanographic data to use as a basic tool towards a broader understanding of the global ocean's climate has never been more pressing than it is today. The impact of the southern Pacific oscillations (El Niño) on the world's climate is an example of the importance of understanding oceanographic processes. Today there are satellite system technologies available that support, to an ever increasing extent, the requirement to gather in-situ ocean and atmosphere data.

One of these satellite systems, the Service Argos Data Collection and Location System (Argos DCLS), directly supports NOAA's charter to monitor and predict the environment.

The relationship between NOAA and the French based Argos system is unique. While other national and international agreements exist to provide other than United States instruments for flight on NOAA's satellites, no other agreement includes the instrument provider in the operational processing and distribution of the instrument data to the user.

Development of the Argos system was achieved through a Franco-American agreement among CNES (Centre National d'Etudes Spatiales - the French space agency), NOAA, and NASA, and officially began with the signing of a Memorandum of Understanding (MOU), in 1974. The Argos system, which is reserved for programs involved with the collection of environmental data, became operational in October of 1978 with the successful launch of NOAA's proto-flight satellite, TIROS-N.

Outstanding performance of the Argos system was demonstrated during the Global Weather Experiment, also known as the First GARP (Global Atmospheric Research Program) Global Experiment (FGGE), in 1978 and 1979. NOAA was the lead U. S. organization in this international program which proved the value of using the relatively new concept of oceanographic data collection and transmission by satellite.

The success of FGGE, in a sense, "turned on" the ocean research community, and other global scale ocean research efforts came into being, such as the recent Tropical Ocean Global Atmospheric (TOGA) program directed towards study of the El Niño/ Southern Oscillation. The World's Oceans Circulation Experiment (WOCE), now in the design phase, is another.

INITIAL PROGRAM APPLICATIONS

First GARP Global Experiment (FGGE)

The scientific objectives of the FGGE required observations of pressure, temperature, humidity, and wind velocity over the entire globe from the earth's surface to the low stratosphere. Existing surface observing land stations and ships at sea provided adequate base for satellite data applications in the middle and high latitudes of the Northern Hemisphere. However, in the Southern Hemisphere, a

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special observing system was required to provide the sea surface temperature and atmospheric pressure fields to "anchor" the satellite vertical temperature and humidity profiles.

The FGGE Southern Hemisphere drifting buoy system provided the required surface meteorological information through deployment of 300 drifting buoys, instrumented with atmospheric pressure and sea surface temperature sensors. The buoy data were transmitted and processed through the Argos system and made available for operational use in near real-time. These buoys were contributed by seven nations, including 56 by the United States. The international drifting buoy deployment plan, utilizing ships from 12 different nations and U.S. aircraft, was developed and coordinated by Canada.

Arctic Buoy Program

The Polar Experiment (POLEX), a sub-program of FGGE, saw 15 ice buoys deployed to measure atmospheric pressure and ice drift. Preliminary examination of the POLEX buoy data showed substantial variation in the ice flow along the Canadian Archipelago and north of the Soviet Union, and yielded a better understanding of the upper ocean currents in the Arctic. Use of these data made a positive impact on short term forecasts. Because of the success of this program the National Academy of Sciences recommended continuing it at least 20 more years to establish a climatological data base. With major contributions from Canada, Norway, and several U. S. agencies, the network has now grown to 30 buoys and the technology has advanced to include new sensors for measuring wind, temperature, and sub-surface parameters.

Equatorial Pacific Ocean Climate Studies (EPOCS)

The EPOCS is a continuing NOAA program implemented during FGGE to study the processes in the near surface and deep ocean responsible for the changes in the temperature of the equatorial sea surface. In this program a number of observational systems are used, which include the deployment of about 30 drifting buoys annually to determine surface current and the sea surface temperature field in the eastern equatorial Pacific. Early EPOCS data became a part of the FGGE Data Set, and the program is now an integral part of the Tropical Oceans and Global Atmosphere (TOGA) Program.

TECHNOLOGY TRANSFER

Operational Analysis and Forecasting

In recognition of the potential of drifting buoys for obtaining data so vital to support the implementation of major meteorological and oceanographic programs, a format and code for drifting data buoys (DRIBU), was established through the World Meteorological Organization (WMO) to transmit the data from FGGE, POLEX, and EPOCS over the Global Telecommunications System (GTS). For the first time, reliable in-situ information was available from some of the more remote areas of the Earth.

The Australian Meteorological Service found that there were more numerous, and more intense, low pressure systems in the Southern Hemisphere than previously believed. Post analysis of the Arctic buoy data showed a different location and strength to the Arctic high. These discoveries, and others, resulted in a rethinking of climatology which had been heavily relied upon in some areas for producing weather analysis and forecasting.

In 1980, Canada began a program to study the feasibility of using drifting buoys as part of a system to replace Ocean Weather Station PAPA, a ship located in the Gulf of Alaska, the spawning ground for many of the intense storms that affect North America. The PAPA Alternative Data System (PADS) was a part of the (STREX) Storm Transfer and Response Experiment, an extensive joint United States and Canada field operation to study North Pacific storms.

Although STREX was primarily a research program, 3 buoy groups, in addition to PADS, were deployed on different space scales to determine the usefulness of drifting buoys, and to test new instrumentation for operational weather analysis and forecasting.

Research

While GARP was being conducted, plans were being formulated for a World Climate Research Program (WCRP). The WCRP was formally established in 1980 by an agreement between the WMO and the International Council of Scientific Unions (ICSU). The WCRP encompasses a wide range of interaction between the atmosphere, ocean, ice, and land surface.

Tropical Ocean and Global Atmosphere (TOGA)

Building directly on the FGGE, TOGA is a program within the WCRP that began in 1985 and is scheduled to last for 10 years. Its aim is to explore the predictability of the coupled tropical ocean-atmosphere system and its impact on global climate on time scales of months to years.

The observational domains for the TOGA Program are the tropical oceans (from about 20°N to 20°S), and the global atmosphere. The Argos DCLS is being used extensively to meet the TOGA observational requirements.

Moored and drifting buoy networks are deployed in the tropics to measure surface winds, sea surface temperature, and temperature as a function of depth. A Southern Hemisphere drifting buoy network, similar to the FGGE network, measures surface pressure, air temperature, and sea surface temperature. Some ships of opportunity use the Argos system to relay surface meteorological and expendable bathythermograph (XBT) data.

OTHER OCEANOGRAPHIC APPLICATIONS

In addition to the vanguard FGGE Program, its subsidiary EPOCS and POLEX Programs, and the STREX and TOGA Programs which were formulated and built upon the FGGE experience, Argos technology has been used by the United States and Canada for several other oceanographic research and operational programs. In the last ten years, hundreds of platforms, mainly drifting buoys, have been deployed in nearly every ocean area of the world.

Programs in the Atlantic Ocean have included: studies of the North Equatorial Countercurrent, the Gulf of Maine, the Agulhas Current, the development of the Saragasso Sea thermocline, warm core rings, and the effects of off-shore currents on waste disposal; collection of meteorological and oceanographic data to support operational programs such as the International Ice Patrol and weather analyses and forecasting; and the short and long term monitoring of various physical properties of the ocean for research activities.

Use of the Argos DCLS has allowed new research into the vast data-sparse regions of the Pacific Ocean. Large research programs to study ocean-atmosphere interactions and their influence on weather and climate have been undertaken. In addition to TOGA and EPOCS, the Tropic Heat Program studies the heat flux and storage in the Central Equatorial Pacific and the Ocean Storms Experiment observed upper ocean responses to severe storm forcing. Circulation and physical oceanography experiments include studies of the Gulf of Alaska, processes in the Yellow Sea, California fronts, particle fluxes in the Southern California Bight, the evolution of synoptic and mesoscale eddy fields, and vertical transport and exchange.

Two programs deployed over 40 drifting buoys in the Indian Ocean. These programs, closely related to TOGA, were designed to describe the surface current field, define statistically the time and space scales of the surface current variability, compose model and drifter results for dynamic studies, and study processes which influence sea surface temperature variability.

The Coordinated/Operational Arctic Buoy program (the continuation of POLEX/Arctic Basin Buoy Program) and the Ice Island Trajectories Program collect meteorological and oceanographic data to support operational forecasting and climate research programs in the Arctic Ocean. Physical process and mesocale studies in the marginal ice zone are conducted in the Beaufort, Bering, and Chukchi Seas. Several oceanographic research programs with emphasis on monitoring and developing the technology to measure subsurface parameters, including acoustics, are also being conducted.

Drifting buoys are air-deployed in the Antarctic region to collect meteorological and oceanographic data to support operational and research programs. Another program collects upper ocean and temperature and salinity data in the southern ocean from ice-locked drifters. Several programs are conducted in the U.S. Coastal Areas to study near shore surface circulation and processes off both coasts, the Great Lakes, and the Gulf of Mexico and to test and evaluate new systems.

ARGOS SYSTEM OPERATION

The Argos Subsystems

The Argos system is viewed as five (5) basic components; these are:

(1) The PTTs (Platform Transmitter Terminals), which are used on moving objects such as buoys, ships, balloons, animals, or on fixed environmental data sensing stations.

A PTT transmits without satellite interrogation at preset regular intervals. Individual PTT transmission repetition periods are set between 60 and 200 seconds. Message transmission duration is less than one second. Each message may contain up to 256 bits of sensor data. All PTTs uplink to the satellite at 401.65 MHz. Since there are normally two satellites in operation, seven contacts per day are obtained from a PTT at or near the equator, and up to 28 contacts per day in the polar areas. In the mid-latitudes, ten per day are provided.

(2) The onboard Argos Data Record Unit (DRU) system package included in the TIROS polar orbiting, sun-synchronous satellite payload.

The DRUs receive the messages transmitted by those PTTs within the satellite(s) instantaneous field of view, (approximately a 5000 km diameter "footprint"). Onboard DRU processing consists of:

- identification of the PTT number;

•asynchronization of the transmission time through use of the different repetition periods;

•measurement of the Doppler shift on the transmission frequency;

•"hand-off" of these data, coupled with the platforms' sensor data,to the TIROS Information Processor (TIP) instrument.

(3) The three telemetry receiving stations located at Wallops Island, Virginia, and Fairbanks, Alaska, in the U. S., and Lannion in France.

Each time one of the satellites passes over one of the telemetry receiving stations, the recorded TIP data are transmitted to that station on 1698, 1702.5 or 1707 Mhz at 2.66 mbps.

Each PTT transmission is also rebroadcast in "real-time" by the satellite as soon as it is received. Users with a downlink receiver within range of the satellite can receive data from PTTs that are in the footprint of the satellite at the same time, through either the S-band on 1698 or 1707 MHz at 665.4 kbps, or the VHF beacon on 136.77 or 137.77 MHz at 8.32 kbps.

(4) The NOAA National Environmental Satellite, Data and Information Service (NESDIS) data processing center, located in Suitland, Maryland.

Both the recorded and "real-time" data received from the U. S. receiving stations are then sent via domestic satellites to the NESDIS facility for decommutation. The data from Lannion, France, is rebroadcast through NOAA's geostationary satellite (GOES east) to Wallops Island, Virginia. All of these data are then transmitted to the Service Argos Processing Centers at Landover, Maryland, and Toulouse, France.

(5) The two identical processing centers perform the following:

•decoding of the PTT sensor messages and conversion of data into physical units, as specified by the end user.

•very accurate computation of the satellite(s) orbits.

•PTT location computation using orbital data and Doppler shifts.

•storage of all these results in computer files for user access.

•generation of the archive data base for each program and PTT.

The recorded data processed by the Argos system are available in computer files accessible by telephone or telex through telecommunication networks, generally within 4 hours after satellite reception. The "real-time" data is made available within 20 minutes. Archived data is available on computer compatible tapes, "floppy" disks, or printouts, fortnightly or monthly.

ARGOS SYSTEM ADMINISTRATION

The Argos system is administered by Service Argos, Inc., within the United States, and by CLS/Service Argos, S. A., in France. Argos system usage and performance is monitored by the Argos Operations Committee, a bilateral (France/USA) organization which meets once a year. This committee, comprised of members from CNES, NOAA, and NASA, is responsible for ensuring that the system is managed according to the agreement.

Service Argos is operated on a cost-recovery basis with users contributing a fraction of the running costs proportional to the amount of service required. Government users from the same country can reduce their financial contribution by participating in the "Joint Tariff Agreement".

Joint Tariff Agreement (JTA)

The Franco-American Memorandum of Understanding allows Service Argos, as an agent of CNES, to recover the costs associated with processing the platform sensor data and determining the location of the transmitting platform.

Since 1980, the United States has negotiated a reduced tariff rate for the data processing provided by Service Argos. This reduced rate is predicated on the large use of the system by United States Government sponsored programs, and the ability to guarantee a minimum amount of processing.

In 1982, other countries desiring to use the system were invited to participate in the JTA. The philosophy was that with lower processing costs, more countries could deploy data platforms in remote areas, thus increasing the global data base for operational and research activities. Participation in the JTA is limited to those users who are funded by their national government. Other user organizations which are considered nonprofit-making may also participate.

To negotiate and administer the Agreement, each country or group of countries has a designated Representative Organization for a Country (ROC). The ROC serves as the unique focal point between Service Argos

and that country's users on all matters concerning the JTA. The NOAA Office of Climatic and Atmospheric Research and the Institute for Ocean Sciences, are the ROC's for the U. S. and Canada, respectively.

RECENT ARGOS SYSTEM ENHANCEMENTS

Algorithm Modification

In April 1987, two software algorithm modifications were made to reduce systematic location errors: 1) all the orbitography platforms which are used as fixed precise reference points for location calculations were referenced to the same geocentric system, (World Geodetic System 1984); and 2), the complete Goddard Earth Model 10 (GEM 10) was incorporated, to take resonance coefficients into account.

Argos' Accurate Location System

In the mid-1970's, during the original Argos system design stage, the targeted system location accuracy was approximately one kilometer. However, since the beginning, far more accurate locations were routinely achieved.

Today, the system supports three (3) categories of location accuracy:

(1) Quality, 150m at 1 sigma*

(2) Standard, 350m at 1 sigma

(3) "Not Guaranteed", 1km at 1 sigma

*(1 sigma: meets the criteria for accuracy approximately 68% of the time to within a radius of described meters from true position)

A project by Service Argos to determine the maximum achievable system location accuracy was conducted during 1987.

The project, conducted over a period of time sufficient to generate quantitative conclusions, proved that with a few enhancements, and using retrospective processing, the Argos system could achieve absolute location to within 20 meters, and relative location to within 10 meters. This new location system was implemented during the first quarter of 1988.

Expendable Bathythermograph (XBT) System

In conjunction with the TOGA Experiment, Service Argos developed an end-to-end XBT system. This system enables the results of an XBT sounding to be processed by the Argos system and automatically sent to the Global Telecommunication System (GTS). The data are sent as messages in the required World Meteorological Organization (WMO) code format BATHY. The data acquired from the XBT probes are also made available for Argos system users from the Argos data dissemination computers.

The complete XBT microcomputer based system includes the launcher, the microcomputer interface and computer, the acquisition, bathy-message, and encoding software, and the GTS data processing software resident in the Argos data processing system.

The Institut Français de Recherche pour l'Exploitation de la Mer (IFREMER - the French oceanographic agency) has ordered 15 complete XBT shipboard units which will be progressively implemented by the TOGA network. Forty (40) World Weather Watch (WWW) ships of opportunity will be equipped with these units by 1989.

FUTURE REQUIREMENTS/PROGRAMS

World Climate Research Program (WCRP)
World Weather Watch (WWW) Systems

The WCRP must rely on the operational WWW data acquisition and management to provide longterm time series of global data describing the components of the climate system. It is essential that WWW be maintained at least at the present level of performance or, for some critical components, upgraded to the level of FGGE.

The WCRP atmospheric sampling requirement for drifting buoys calls for:

1) A network of about 100 buoys equipped with, at least, sea-level pressure and sea surface temperature sensors

2) expanding the present polar programs and the development of new atmospheric, oceanic, and sea ice sensors.

This is in addition to the oceanographic buoy and float requirements for specific programs, such as the World Ocean Circulation Experiment.

World Ocean Circulation Experiment (WOCE)

The WOCE is designed to provide the data base for the empirical description required to support long term climate modeling. This will be possible due to the emergence of new global observing systems such as satellite altimetry and advances in in-situ methods such as drifting floats, expendable profilers, fast hydrographic/geochemical sampling and analysis, acoustic tomography, and Doppler current profiling. The WOCE includes an intensive five year monitoring period that is critically dependent upon the successful development and implementation of these observing techniques. The core projects of WOCE will depend upon surface drifting buoys and subsurface floats to determine the global ocean velocity

field. It is envisioned that a network in excess of 1000 drifting buoys will be operating at any given time and nearly 3000 subsurface floats are anticipated during the observational years. These data will be available on the GTS through Argos for operational as well as research use.

Oceanographic and Meteorological Research

Many of the oceanographic research programs now underway or planned, particularly those dealing with circulation and flux measurements, may be encompassed by the WCRP/WOCE. It is envisaged that specialized projects such as marine biological studies, minerals management programs, and sea and ice process studies, will continue to grow and use the Argos system. Large numbers of buoys are also planned for deployment in support of the Navy's Project ERICA, a program to obtain new scientific understanding of the rapid intensification of storms at sea.

Operational Programs

The present operational networks are planned to continue. These include the Arctic Buoy Program, the Canadian Atlantic and Pacific networks, NOAA's rapid response and hurricane drifters, and the Coast Guard's International Ice Patrol. The Navy's experimental data buoy networks in the Atlantic, Pacific, and Arctic Oceans have become operational and are expected to increase dramatically in the next few years. These data will be used to determine surface, subsurface, and boundary layer conditions for inclusion in operational analyses and environmental models to identify, forecast, and provide early warnings of dangerous phenomena, such as tropical and other severe storms.

TECHNICAL ADVANCEMENT

The increasing demand for more intelligent and sophisticated sensor-PTT configurations, fueled to a large extent by the requirements of animal tracking applications, has dramatically affected technical design in terms of solar power, battery life, miniaturization (weight), and other factors. However, costs are down, principally due to the increased demand for transmitters, plus manufacturing efficiencies, and reduced chip and component costs. The incorporation of microprocessor technology into PTTs can be of tremendous value, allowing platforms to be customized to meet specific requirements of the users.

Advances in buoy platform technology are proceeding at a swift pace, and "expendable" air-deployable units are available in the marketplace. Development, test, and evaluation programs are continuously underway to improve on the buoy technology and to produce new sensors and platforms for special purposes. Various thermistor chain and drogue configurations have been developed and tested. Prototype drifting buoys have been successfully deployed in the paths of hurricanes. Deep drifter or "pop-up" type buoys which float at a given depth have been developed. Data relay systems are being developed for future application in major research programs.

New Satellite Instrumentation

In cooperation with NOAA and NASA, Service Argos increased the DCLS data rate between the four (4) Argos DRUs and the Tiros Information Processor (TIP) instrument onboard TIROS series models H, I, and J. This modification was successfully demonstrated with the launch of TIROS H, (NOAA 11), in September, and increased by 20% the number of PTTs able to be received simultaneously onboard the satellite.

TIROS satellite series K through M will see yet another increase in the DRUs-to-TIP data rate, and, the DRU complement will be doubled. These latter modifications will increase the onboard PTT reception capacity by another four-fold.

Service Argos, acting with CNES, and in cooperation with NOAA and NASA, has plans to continue its strong leadership role in the area of environmental data collection and platform location by satellite, through possible current generation add-on's, and the next generation polar orbiting space platforms. Clearly, the Argos/NOAA cooperative arrangement has provided, and will continue to provide a technically proven and financially attractive DCLS service available to regional and worldwide governments' scientific centers, and the commercial sector.

HIGH-VOLTAGE SOLAR-POWERED NAVIGATION RANGE DESIGN

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ABSTRACT

Design, development, and testing of lighting and photovoltaic power systems for a high-voltage offshore navigational range system are discussed. Operational requirements and solar power limitations dictated the selection of lighting components. High-efficiency metal-halide lamps were chosen for the 120-volt daytime system. Photovoltaic array and secondary storage battery configurations were designed to accommodate lighting system power requirements and expected climatic conditions. System design emphasized personnel safety and component reliability in the marine environment. The paper discusses these aspects in detail, giving particular attention to photovoltaic array design and testing.

INTRODUCTION

Navigational ranges provide visual signals to guide mariners down narrow or hazardous channels. A conventional range consists of two lights (and/or dayboards) mounted at separate locations, such that an extension of an imaginary line drawn through the two locations defines the channel centerline. Since the rear range light is higher than the front light by design, the mariner simply attempts to keep the lights lined up vertically as the ship proceeds along the channel. If the ship deviates right (left) from the centerline, spatial parallax causes the rear (higher) range light to appear shifted to the right (left). Mariners judge conventional ranges to be very effective aids to navigation.

PROJECT BACKGROUND

As part of the project to establish a Trident submarine support facility at Kings Bay, Georgia, the Navy asked the Coast Guard to construct two ranges to mark the coastal approach to the St. Mary's River. The two basic operational requirements for both ranges were 24-hour service and effectiveness over six-mile channel segments. Design and construction of the towers was turned over to the Coast Guard Facilities Design and Construction Center (Atlantic). The Acoustics and Optics Section of Headquarters' Ocean Engineering Branch maintained overall project control and designed the power system and signal control scheme. Integration of system components and pre-deployment testing were accomplished by the Coast Guard Research and Development Center.

DAYTIME POWER AND LIGHTING SYSTEM CONSIDERATIONS

To be effective (visible) over the same channel lengths, daytime range lights typically must produce 2,000 to 5,000 times the luminous intensities of nighttime range lights. For the Kings Bay Range systems, this dictated selection of 120-volt lighting equipment since available 12-volt equipment could not achieve the required daytime intensities. The logical choice of optic was the standard Coast Guard 24-inch range lantern, which uses a 24-inch parabolic mirror to project an intense pencil beam, and is normally equipped with two 1,000-watt tungsten-halogen lamps (one burning and one back-up). Range design computations called for two 24-inch lanterns on each rear range tower and one on each front tower.

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Coast Guard lighthouses and other high-power aids to navigation have traditionally relied on submarine cables or on-site diesel generators for electrical power. These familiar options, along with a relative newcomer, solar photovoltaics, were the only systems seriously considered for the primary daytime source of power. Thermoelectric generators were given some thought as back-up power sources, then dismissed as an unnecessary and costly luxury.

Coast Guard diesel generator installations at automated lighthouses have not enjoyed high reliability; rather, they have required (on average) several scheduled maintenance and unscheduled discrepancy visits per year per lighthouse. At best, generator installations are expensive! Two diesel generators are required for redundancy, towers must be sturdier to accommodate the additional weight of generators and fuel tanks, and maintenance costs are high. Trips to remote generator sites (for maintenance, troubleshooting, or refueling) cost $600/hour and $1,600/hour by buoy tender and helicopter, respectively. Diesel generators were judged to be the least reliable and most costly of the three power system options.

Submarine cables have generally been more reliable than diesel generators for automated sites, often providing service over 15 to 25 year life spans. However, they are vulnerable to damage from anchors and fishing nets, dredging operations, and natural causes. Repairs may take days or even weeks to complete. Other major drawbacks with respect to this project were high projected installation cost and the potential for lengthy delays while seeking approval of the required environmental impact statement. The offshore range system would have required cable runs of up to 10 miles and likely would have been prohibitively expensive. The possibility of extended periods without power (while troubleshooting or repairing the cable) was a grave concern.

Solar photovoltaic technology was selected to provide daytime power for a number of reasons. It has had remarkable success in the Coast Guard, with over 10,500 aids to navigation converted to solar power since 1983. Solar modules manufactured to rigorous Coast Guard specifications have proven to be extremely reliable. Emphasis on system design simplicity has produced solar systems that can operate for long periods of time with little or no maintenance. Life-cycle costs are much lower than for diesel generators or submarine cables. Solar power was considered well suited to the Kings Bay project for several reasons:

A. Procurement and installation of solar hardware could be accomplished quickly and easily.
B. Each tower would have an independent, self-contained power system, without reliance on vulnerable cables or refueling vessels.
C. Troubleshooting and maintenance would be much simplified, compared to other power systems.
D. Towers would not have to be specially designed to accommodate heavy loads.

To accommodate selection of solar power and keep array size (and required tower deck space) to a minimum, a nonstandard lamp was chosen for the 24-inch lantern. The 175-watt metal-halide lamp delivers approximately the same luminous output as the 1,000-watt tungsten-halogen lamp at 1/5 the input power. Metal-halide lamps also have longer rated lifetimes. Selection of this lamp necessitated modification to the 24-inch range lantern lampchanging mechanism. As mentioned previously, no provision is made for back-up daytime power. Daytime power and lighting systems are expected to be very reliable. Large fluorescent dayboards on each tower will provide passive daytime range signals. These were designed to provide adequate range signals when viewed through ordinary binoculars.

12-VOLT POWER AND SIGNAL SYSTEMS

Each tower will also have independent low-power 12-volt solar systems for:

A. Nighttime range lights (both ranges).
B. Sound signals (offshore range).
C. Obstruction lights (offshore range).
D. Passing light (inshore range, front tower).

These systems will be similar to standard Coast Guard 12-volt solar installations.

120-VOLT SOLAR SYSTEM DESIGN

The heart of the Kings Bay daytime power system design is the array of rugged solar modules constructed to Coast Guard specifications. To ensure environmental integrity of solar modules, Coast Guard engineers developed the very rigorous Pressure Immersion Temperature (PIT) test several years ago, (Figure 1 depicts the PIT test system). Modules are placed in the test chamber and subjected to repetitive 30-minute cycles of hot (45-degrees C) and cold (5-degrees C) salt

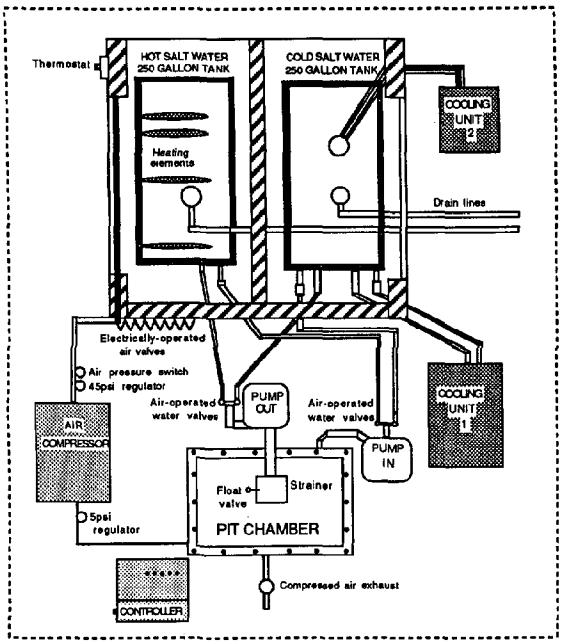

Figure 1; Pressure Immersion Temperature (PIT) test facility.

water immersion, with several superimposed 5-psig pressure cycles. The PIT test simulates the unique combination of stresses present in the marine environment and accelerates solar module degradation by a 45:1 ratio. It has been used effectively to reveal module design problems such as frame corrosion, junction box defects, and substandard cell encapsulation.

Figure 2 depicts the 120-volt daytime system design for the rear tower of each range system. Five parallel strings of ten series-connected 35-watt photovoltaic modules provide power for twin 24-inch range lanterns. Surplus energy charges the 120-volt, 585 ampere-hour battery bank consisting of 60 series-connected 2-volt lead-calcium flooded cells. The initial solar design specified four parallel module strings. An additional 120-volt string was added to maintain the battery bank at a higher average state-of-charge (thereby prolonging battery service life). The extra power will also allow the battery bank to recover much more quickly from long periods of inclement weather. Theoretically, a similar daytime-demand solar system array should be tilted South about 20-degrees (from horizontal) in this location to optimize energy balance throughout the year. In practice, however, a fairly steep slope is required to discourage birds from roosting/nesting on solar modules at sea (a significant concern in this vicinity). Compromising at a 30-degree angle provided an acceptable energy balance as well as a reasonably effective deterrent. A row of

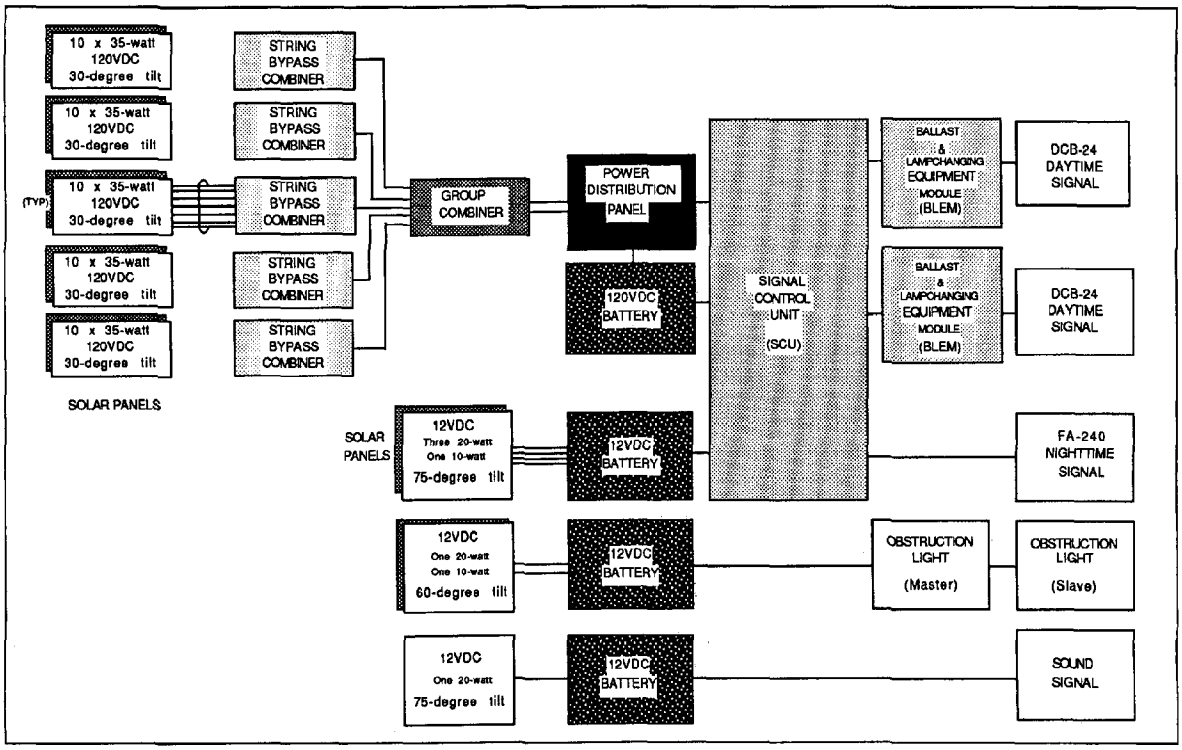

Figure 2; Kings Bay rear range design.

Nixalite bird spikes was attached along the top edge of each solar module string to prevent birds from perching. Extreme care was taken to position the solar arrays so that no shading would occur from other parts of the tower. Figure 3 depicts a typical system layout of the tower platform.

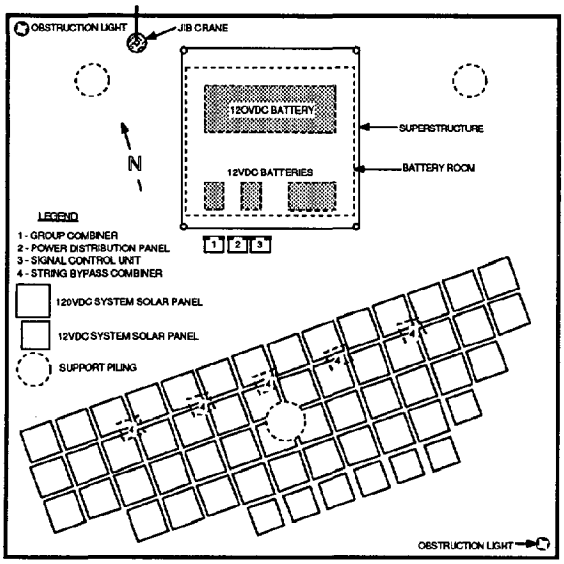

Figure 3; Main deck arrangement.

Blocking diodes were removed from individual modules to increase string voltage; a single blocking diode was substituted at the termination of each 120-volt string inside the group combiner box (blocking diodes prevent the batteries from discharging through the solar modules during periods of low illumination). Longer special-jacketed output cables were installed on the modules to eliminate splices, decrease the potential for corrosion, and minimize resistance. All system wiring was run through teflon coated metal conduit and terminated in Nema-4X enclosures sealed by stuffing tubes.

Bypass diodes were installed in parallel with each module to reduce power losses and prevent damage caused by localized reverse biasing (hot spots). Shading (caused by bird droppings or other obstructions) causes the affected cells to dissipate, rather than generate, electrical power. Without bypass protection, a single shaded silicon cell (in systems over about 50-volts) can cause a significant (30-60%) reduction in power production. Dissipated power is expelled as heat and may cause various degrees of damage to the shaded cell(s). The bypass diodes were hardwired into the string combiner boxes instead of in the individual modules, for added personnel safety. To increase personnel protection, all 120-volt negative components are grounded directly to the structure.

Each string bypass combiner's 120-volt output was connected in parallel by the group combiner. After considering advantages and disadvantages of blocking diode placement, attachment was made on the array side of the parallel connections. The primary advantage of this method is reduced current flow in the bypass circuit. The extent of bypass protection required is directly proportional to circuit current. Most manufacturers advocate one diode for at least each 20 cells because standard practice involves series-parallel connections where high currents are possible. Employing one bypass diode for each 32-cell module under single-string (low predictable current) operation was considered conservative enough for this system. The possibility of an open-circuit fault disabling a string is probably very slight considering the demonstrated reliability of our modules. Single-string design also simplifies servicing procedures; covering 10 modules deenergizes the circuit.

Three module strings are paralleled at the group combiner and are electrically hardwired to the charging/power system at the power distribution panel (PDP). The two remaining strings are similarly paralleled and fed to a switched input of the PDP. To prevent significant battery overcharge, these strings are shed (disconnected) as average battery voltage rises; lowering the charge rate to C/78. Battery banks are expected to last 10 years with minimal annual maintenance.

LABORATORY TESTING OF SYSTEM COMPONENTS

Prior to installation of the range towers, all lighting and power system components were tested thoroughly in the laboratory. Five 175-watt metal-halide lamps and ballasts were subjected to 4-hour on / 1-hour off cycles for 40 consecutive weeks to test reliability. The 24-inch range lantern lampchangers were modified to operate on DC rather than AC power, and reconfigured to accept screw-base metal-halide lamps rather than bi-post tungsten-halogen lamps. Lamp out sensing circuitry was also redesigned to detect reduced current flow rather than an open circuit, since metal halide lamps do not normally create an open circuit during failure. This function was incorporated into the Ballast & Lampchanging Equipment Modules (BLEM's), which were tested extensively for proper switching to the standby lamp

in case of simulated operating lamp failure. Proper day/night switching of the Signal Control Units (SCU's) was confirmed by exposing the photodetectors to periods of light and darkness. String Bypass Combiner boxes and Group Combiner Boxes were thoroughly inspected for continuity of all circuits and proper operation of blocking and bypass diodes.

MAINTENANCE AND TRAINING

Basic system indoctrination was recently provided to servicing personnel by representatives from Coast Guard Headquarters and the Research & Development Center. Very little experience with 120-volt DC solar power exists within the Coast Guard. Servicing personnel regularly work with 12-volt solar/battery combinations, and to a lesser extent 120-volt AC systems. The dangerously high potentials associated with these inherently live DC sources require more safety consciousness than many other systems. An Operation and Maintenance Manual will be published in the near future wherein normal operation, maintenance and troubleshooting of each component will be described. In the interim, servicing personnel will accompany Headquarters and R&D designers to the towers whenever possible.

Generally, the system should require only minimal maintenance to ensure reliable operation. Battery specific gravity will be initially monitored quarterly as the primary indication of overall system integrity. This requirement should be slackened after electrolyte depletion and battery performance trends are established. The only additional preventative maintenance requirements expected are:

A. Replacement of metal-halide lamps semiannually.
B. Replacement of photoresistors annually.
C. Retorquing battery intercell connections and reapplying corrosion preventative annually.
D. Annually examining circuit board terminal strips for corrosion and retorquing connections.
E. Examining Nema-4x enclosure cover gaskets annually.
F. Coating terminal strips and cover gaskets with silicone lubricant before resealing enclosures.

CONCLUSION

The Kings Bay range systems will be operational by Fall of 1988. After all power and lighting hardware is installed on the towers, the battery banks will be brought up to full charge by portable generators. Systems will then be energized for a detailed final inspection and necessary troubleshooting. Frequent inspection trips in the early months will ensure that all systems are operating as designed.

[1] "Design of High Voltage Arrays;" P.A. Lawson and R.R. Addiss, Jr. Fourteenth IEEE Photovoltaic Specialists Conference - 1980, Pgs. 512 - 517.

ACCURACY OF SATELLITE SURVEY MEASUREMENTS ON OFFSHORE PLATFORMS FOR MONITORING SUBSIDENCE

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ABSTRACT

Phillips Petroleum Company Norway measured the progression of subsidence of the Ekofisk Field with a NAVSTAR GPS satellite surveying system. The uncertainty of GPS satellite measurements onshore is compared to the uncertainty of similar offshore subsidence measurements. It was found that the uncertainty of offshore satellite measurements may be slightly higher than for onshore measurements. Computed uncertainties are stated

INTRODUCTION

Ekofisk is an oil and gas field in the southern portion of the Norwegian North Sea. it is one of several such fields operated by Phillips Petroleum Company Norway in that area, such as the nearby Tor, Edda and Albuskjell fields.

Late in 1984, it was noticed that the Ekofisk platform decks were closer to the sea surface than when the platforms were installed. Subsidence was the only logical explanation for these observations. After the subsidence phenomenon was recognized, an accurate measurement method was needed to measure progression of subsidence and the associated subsidence rate. One available system for which no further development was needed, is the NAVSTAR GPS (NAVigation System with Time And Ranging Global Positioning System). The measurements started in March 1985 with Blom A/S as the survey contractor. These surveys were continued after January 1987 by GPS Services A/S. Aero Service provided equipment and specialized expertise to Blom A/S and GPS Services as required after October 1985.
For a period of almost three years this system was the back bone of the methods used to derive subsidence rates and the progression of subsidence. At approximately monthly intervals measured the elevation difference between three bench mark platforms which do not subside (Albuskjell, Edda and Tor) and the subsiding Hotel (2/4H) platform were measured. Figure 1 shows their relative locations.

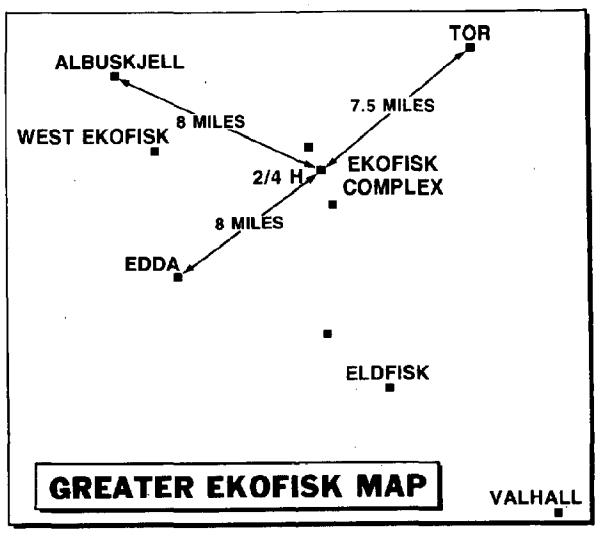

Figure 1
Map of the Greater Ekofisk area.

BACKGROUND OF THE GPS SYSTEM

The GPS is a satellite supported radio navigation system which provides 3-dimensional position and velocity information as well as high precision time information for an unlimited number of suitable equipped users. In the near future the GPS will be available world wide 24 hours per day. Currently, the system is in the late stages of development phase where the design of operational satellites, the operational control segment and prototypes of receivers are tested and finished. At the end of 1990, the system should be completed. In space, 24 satellites should be orbiting with four satellites in each of the six orbit planes. They will operate at approximately 20,000 km height with corresponding orbit period 12 hours sideral time.

The satellites are transmitting signals at two frequencies (L1 and L2). Two different codes, the P-code (P for precise) and the C/A-code, (C/A for coarse acquisition) are modulated on the L1 frequency. The P-code is modulated on the L2 frequency only.

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SINGLE POINT POSITIONING

With knowledge of one of the codes, it is possible to get clock information of the transmissions from the satellite. With that, it is possible to calculate the so-called pseudorange between the satellite and the receiver. The pseudorange is different from the true range because of the receiver clock offset from system time (see Figure 2). By placing one antenna in an unknown position, the pseudoranges can be measured simultaneously to four satellites with one receiver. This information is used to determine the three

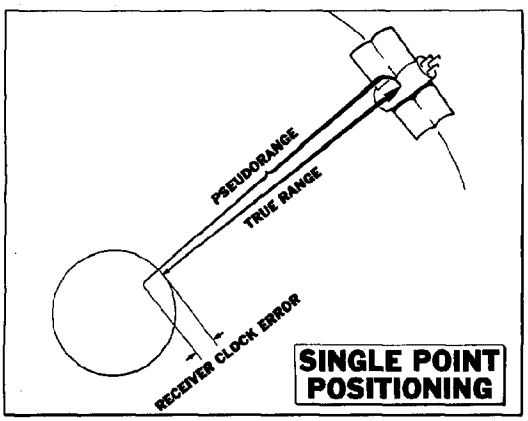

Figure 2
The principle of single point positioning by using pseudoranges.

position coordinates as well as the clock offset of the receiver clock and the satellite clock. Without further refinement, this method today gives results of 30 m uncertainty for the C/A-code and 10 m uncertainty for the P-code. It is mostly used for navigation of moving military objects, where real time positions are needed. The uncertainty quoted in this paper equals three standard deviations of the data concerned.

RELATIVE POSITIONING

To obtain a much more accurate position, at least two GPS receivers used relatively to one another are necessary. The basis of this method is to have one reference station with accepted geographical coordinates, and to determine the coordinates to one or more stations relative to this reference station.

For this type of precision geodetic surveying, the phase of the carrier signal transmitted by the satellite is measured and interpreted. The reason for the higher accuracy is that the carrier signal has a much higher frequency than the code. For performing carrier phase measurements, it is not necessary to have knowledge of the code signal.

The phase measurements are only useful if the carrier beat phase difference between different stations and between satellites is known as a time history. The cycle differences representing an integer number of wave lengths can only be calculated after the receiver has continuously tracked a satellite signal and the phase difference history for typically over half an hour. When the signal is lost for a short time, so-called cycle slips may occur. The receiver starts developing a phase difference history again which may contain an error equal to an integer number of signal periods. The phase difference history can only be corrected in the relative sense for these cycle slips by computation. This causes that this method can only provide a relative position of one station to the other, as absolute, biasfree corrections are impossible.

EQUIPMENT USED

For the subsidence measurements, four Macrometer (R) V-1000 GPS receivers are used. Macrometer is a registered trade mark of Aero Service Division, Western Atlas International. The Macrometer is an interferometric GPS receiver which uses the L-Band frequency of 1575 MHZ to measure the phases. The field unit consists of one antenna and a field receiver/terminal that are connected by coaxial cable of up to 30 meters length during observations. The data have been processed on a special purpose, Model P-1000 Data Processor. This is a desk top system built around the DEC LSI-11 micro computer.

Control measurements by the manufacturer (Aero Service), and independently by the US National Geodetic Survey in the USA, have provided relative vertical uncertainty estimates expressed in the distance between receivers of one to four millionths of this distance. Over a distance of ten kilometers between receivers, a relative uncertainty (three standard deviations) of $\pm$ 45 mm is expected on land under ideal and controlled conditions.

MEASUREMENTS ONSHORE - OFFSHORE

By a simultaneous measurement at the Ekofisk Center and an onshore bench mark reference station called Eikeberg near Stavanger (Norway), the relative position of the Ekofisk Center was determined with an estimated uncertainty of $\pm$ 1.0 meter. During the first nine surveys, measurements were taken onshore as well as offshore to check the system accuracy and repeatability. For all following offshore measurements, the position of the Ekofisk Center was used as reference.

The Ekofisk Hotel platform has shown the largest amount of subsidence. It is located nearest to the center of the reservoir structure. Three other platforms are used as bench mark references. These are the Edda, Tor and Albuskjell platforms. On the Ekofisk Center and on the three bench mark reference platforms, measurements are carried out to obtain a measure for the relative subsidence of the Ekofisk Hotel platform. These measurements have been conducted at approximately monthly intervals from March 1985 through April 1988.

FACTORS INFLUENCING THE UNCERTAINTY

Atmospherical Influence

The GPS phase measurements could be corrected for differential atmospherical influences such as signal delays caused by tropospheric refraction and ionospheric refraction. The tropospheric refraction correction would be based on actual surface weather information such as humidity, barometric pressure and temperature at each measurement station interpreted with a Troposphere model. Corrections for surface weather conditions are not generally applied in GPS processing over distances where weather conditions can be considered as uniform.

The ionospheric correction is not critical to the uncertainty of the solution for base lines 10 km long. It is difficult or near impossible to determine this correction when using single frequency GPS receivers . The ionosphere is situated at a height of approximately 40 - 400 km above the earth surface. For relative measurements and short distances such as 10 km, the ionospheric delays are equal for both stations. A correction for the ionospheric refraction delays are only possible if the measurement system relies on two different frequencies. When measurements rely on one frequency, only approximate and non-exact corrections can be made.

The ionospheric refraction delay variations are largest near polar regions. It increases with sun spot activity. The sun spot activity is expected to be above average large in 1988 to increase to a cycle maximum in 1990-1991. The data analysis must account for these delays as well since possible invisible systematical errors will be introduced in the computed results.

The Satellite's Position

For processing of the raw data, knowledge of the satellite's position is necessary. The coded satellite message contains predictive information about the anticipated satellite position and path as a function of time, the so-called ephemeris. This predictive information about the satellite's position in it's orbit is not very accurate, i.e. the estimated uncertainty in the anticipated position is $\pm$ 20 - 100 m. That corresponds to a relative uncertainty of up to 5 ppm by a distance of 20,000 km between the satellite and the user.

The Macrometer V-1000 data are interpreted by using measured satellite trajectories provided by Aero Service in the United States. Such data usually become available a few days after the measurements via a telephone modem link. These have an uncertainty of about 20 - 50 m, i.e. 1 - 2.5 ppm. Confirmed post-processed ephemerides are available at present from the US Department of Defense and at least one commercial agency.

Multipath and Reflection

The so-called multipath effect occurs when some satellite radio signals reflect off an object before they reach the receiver antenna. Thus the original signal may reach the antenna phase center via different paths at different times. This introduces ambiguities in the measurements which lead to an inaccurate solution. To avoid such effects, a carefully chosen antenna type and antenna position is important. One has to pay attention, especially to metal objects and other conducting surfaces in the vicinity of a GPS antenna that could reflect the radio signals.

A special antenna design reduces the multipath effects to a minimum. For instance, the Macrometer V-1000 has an aluminum plate below the actual antenna to shield the antenna from reflections from below and provide a very stable phase antenna.

Available Field Data and Data Interpretation

Data recorded in the field, consist of phase measurements taken during a five hour long observation period with simultaneous measurements on four platforms. The Macrometer clocks are calibrated before and after the measurements with a portable atomic clock. This gives the connection between the internal Macrometer clock and UTC. Following the measurements, the quality of the data is checked by using the Macrometer as a computer.

The post-processing is done later by GPS Services A/S, using special purpose software developed by Aero Service who

manufactured the system. The data processing is done independently for every baseline. Three dimensional relative coordinates with their co-variance matrix are the results. The uncertainty and the adjustment are used to optimize the solution by iterative means.

The Network Adjustment

After processing each baseline separately, the results are entered in a so-called network adjustment program. The purpose of that is to connect all stations and all measurement periods from several (2 - 4) survey days to one consistent solution.

The network analysis mainly consists of a least square adjustment of the relative coordinates. The sum of the squared residuals is adjusted to a minimum. At least one station has to be chosen as reference station. Its coordinates are kept fixed in the network adjustment process. The calculations provide all adjusted coordinates, and the uncertainty of the information.

EVALUATION OF ACCURACY

Onshore

As a check on the system uncertainty and repeatability, onshore measurements were taken during the first 19 surveys in parallel to the offshore measurements. These were taken on the three onshore stations: Eikeberg 1, Eikeberg 2, and Jåttånuten (see Figure 3). These stations are part of the geologically stable standard Norwegian Geodetic Grid System.

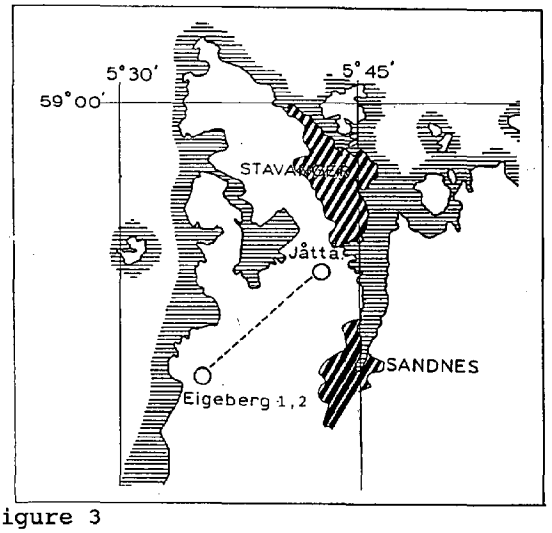

Figure 3
The onshore stations Eikeberget and Jåttånuten near Stavanger.

Eikeberget 1 and 2 are located only 9 meters apart. Therefore, for the assessment of elevation differences from Eikeberget and Jåttånuten (10 km apart) these measurements to Jåttånuten were combined. The deviation of the computed elevation difference to the official difference in elevation is plotted in Figure 4. The standard deviation of these differences is 15 mm, giving an estimated uncertainty in the results of 45 mm.

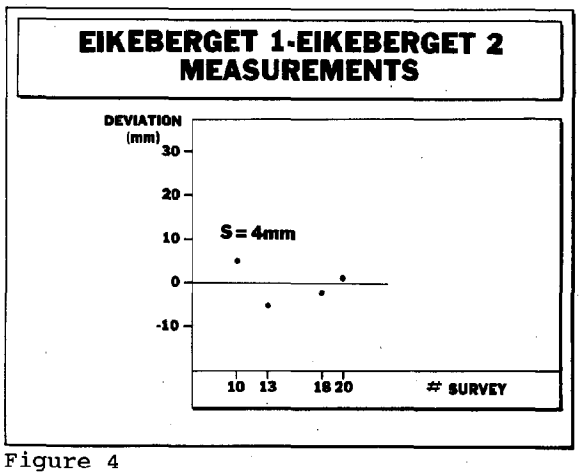

Figure 4
Onshore GPS survey results.

In Figure 5 the computed deviation between the computed and the official difference in elevation between Eikeberget 1 and 2 is shown. The standard deviation of these differences is 4 mm. Because of the proximity of these bench marks, it is believed that most of the spread in their computed elevation differences are caused by ephemerides errors and operational influences.

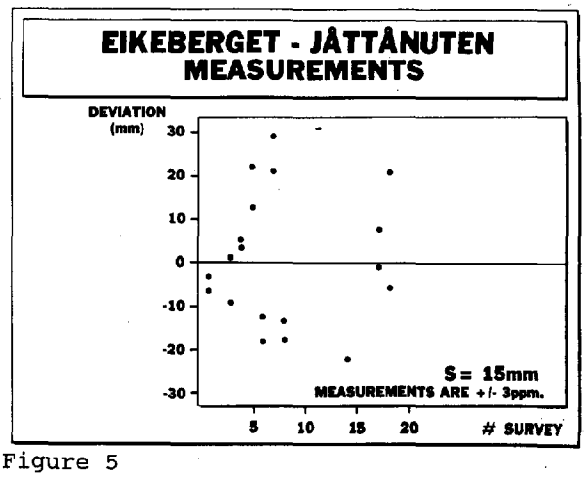

Figure 5
Onshore GPS survey results for the height difference between the Eikeberget 1 to Eikeberget 2 bench marks.

During the initial surveys, personnel operating the equipment and setting up the antennas were inexperienced. Thus these results may include errors caused by inexperience. Nevertheless, we feel that the above results reflect the accuracy attainable under operational conditions very well.

Offshore

The survey results of the 2/4-E Tor, 2/4-F Albuskjell, and 2/7-C Edda benchmark platforms are shown relative to each other in Figure 6:

a) Tor platform 2/4-E relative to Edda platform 2/7-C.
b) Edda platform 2/7-C relative to Albuskjell platform 2/4-F
c) Tor platform 2/4-E relative to Albuskjell platform 2/4-F.

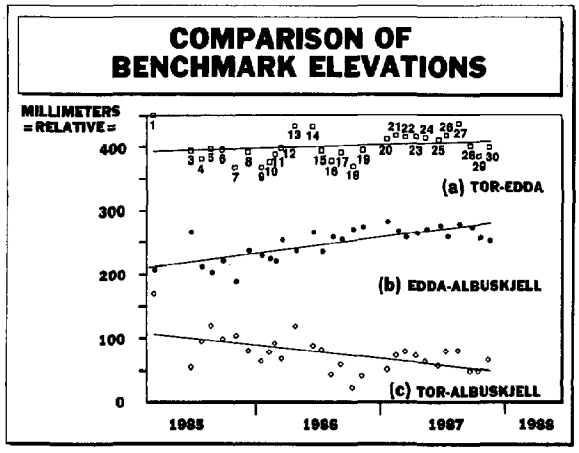

Figure 6
Comparison of survey references for all 30 satellite surveys.

There one can see systematic trends in the elevation differences as well as seemingly random variations. It was found difficult to separate the random variations from any systematical influence. The data are analysed for the apparent uncertainty. A linear regression analysis is used to estimate random variation in the three elevation differences between the three benchmark platforms. The standard deviation in the measurements is computed from offsets from the regression line. The standard deviation of individual measurements from the regression lines are respectively 19, 17 and 25 mm. The mean of these standard deviations is 20 mm. This value includes the effects of possible systematic influences. This is higher than the standard deviation of similar onshore measurements. This corresponds to an uncertainty in the results of 60 mm. After survey no. 18, some of the antenna positions on several platforms were moved because of multipath problems. Therefore, a better estimate of the uncertainty in the measurements can be obtained from the data of survey no. 19 through 30.

a) Tor - Edda (12 $\pm$ 10)mm/year
b) Edda - Albuskjell (14 $\pm$ 7) mm/year
c) Tor - Albuskjell (5 $\pm$ 13) mm/year

The standard deviations of individual measurements from the regression line are found as 11, 8 and 14 mm, respectively. The mean of these standard deviations is 11 mm. This indicates that the uncertainty of Ekofisk offshore GPS measurements is approximately 33 mm. We have used an assumed uncertainty of 40 mm in our own evaluation.

CONCLUSIONS

The uncertainty of offshore GPS satellite measurements of elevation differences of survey points approximately 10 km apart and derived from all measurements is 60 mm. This uncertainty reduced markedly to 33 mm for the latest eleven measurements when different, presumably better, antenna locations were used and the operators had gained experience with the system.

Similar onshore measurements show an uncertainty for all available measurements of 45 mm. This compared to the equivalent uncertainty for offshore measurements of 60 mm indicates that offshore measurements may have a slightly higher uncertainty than onshore measurements.

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Volunteer Observing Ships and the U.S. Government - - A Winning Partnership

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ABSTRACT

The U.S. Government continues to enjoy excellent partnerships within the National Oceanic and Atmospheric Administration (NOAA), private industry, universities, the U.S. Navy, and other Government agencies in the collection of marine meteorological and oceanographic data from the world's oceans. A partnership exists where the maritime industries provide the platforms and personnel and NOAA and Navy provide training, equipment, and logistics support. Data gathered by this partnership and received at the National Prediction and Archive Centers aid the entire maritime industry by improving forecasts and services thus allowing ships to make safer voyages while saving time and money.

This partnership is not limited to U.S. ships but extends to ships of other countries. This international cooperation makes possible the collection of ocean data on a global scale, allowing the world to better understand global environmental changes and their interactions with the oceans.

INTRODUCTION

The level to which we understand the marine environment and the role it plays in our weather and climate depends directly on our ability to observe its structure and variability. Advances in science and technology in the past few years - - particularly in satellite-based sensing and computers - - have given us the capability to collect and transmit marine meteorological and oceanographic data in real-time by an array of space based and conventional platforms. Existing and future satellite systems have increased the need for conventional data to provide surface truth for satellite measurements. These data (sea-level pressure, winds, waves/swell, ice, water levels, surface and subsurface temperature, and currents) are collected by drifting and moored buoys, water level gages, research vessels, and Volunteer Observing Ships (VOS).

This paper focuses on the VOS Program - - a partnership program where the maritime industries provide the platforms and personnel and the U.S. Government supplies equipment, logistics support, and training. Through this Program the Government gains timely, accurate data from data-sparse ocean areas. Shippers share in better marine forecasts for safer, speedier at-sea operations. The following presents a brief history and background of the VOS partnership; describes the present coordination of the VOS Programs in the National Oceanic and Atmospheric Administration (NOAA) and the Navy; and outlines the future direction of the Program.

HISTORY AND BACKGROUND

Ship weather reports have historically been the backbone of the ocean data observational system. The worldwide VOS Program has approximately 7,000 ships from 47 countries. Ships vary in size from large containers/tankers, to university vessels, to small fishing boats. The meteorological reports from these vessels contain up to 19 elements, including sea level pressure, wind velocity and speed, wave height, sea surface temperature, etc. Some ships are also used as platforms for making subsurface measurements such as temperature, conductivity, and currents.

Within the U.S. Government the VOS Program is a coordinated partnership among NOAA's major elements. These elements include the National Weather Service (NWS); the National Ocean Service (NOS); the Office of Oceanic and Atmospheric Research (OAR); the National Environmental Satellite, Data, and Information Service (NESDIS); and the National Marine Fisheries Service (NMFS). Outside NOAA, the partnership extends to the U.S. Navy, U.S. Coast Guard, the Environmental Protection Agency, the U.S. Geological Survey, and universities such as the Scripps Institution of Oceanography (SIO). Key to the U.S. VOS effort are the nearly 1,500 volunteer ships that collect and transmit timely, accurate marine observations from the world's oceans. These ships account for nearly 30,000 marine observations each month.

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The number of ships and the monthly contribution of each U.S. VOS Program range in size from 1,400 ships and 15,000 observations to 3 ships and 100 observations. Table 1 lists the U.S. VOS Programs. Also tabulated are the number of ships, the geographical coverage, and the data transmission capabilities of each program.

Table 1. U.S. VOS Programs

Program	Number of Ships	Coverage	Trans. Capability
NWS	1,400	Global	Radio/SAT
NOS	120	Global	SAT
NAVY	85	Global	Radio/SAT
SIO	34	Pacific	Radio/SAT
OAR	10	Global	SAT
NMFS	3	Atlantic	SAT

While the common goal of each program is to collect and transmit accurate, timely marine data, some programs have unique features. For example, the NWS Program employs Port Meteorological Officers (PMO's) in major U.S. ports. These PMO's are responsible for recruiting ships into the program, administering to and maintaining participating ships, installing and calibrating instrumentation, and instructing ships' officers in observing and recording marine observations. Unique to the Navy's Program of 85 vessels are its strategically stationed support personnel in the U.S., Guam, Japan, Philippines, and Spain. The NOS VOS Program differs from the other Programs in that all 120 ships in this Program have Shipboard Environmental [Data] Acquisition System (SEAS) equipment. Data entered into the SEAS unit are automatically checked, formatted, and transmitted through the Geostationary Operational Environmental Satellite (GOES) system and passed to NWS via NESDIS.

Data collected by all U.S. programs are transmitted to National Prediction Centers (National Meteorological Center and Fleet Numerical Oceanography Center) and National Archive Centers (National Climatic Data Center and National Oceanographic Data Center). The key NOAA partner in this data transfer is NESDIS who makes available and coordinates GOES transmission assignments, and oversees the archive of retrospective data. Real-time and retrospective data are used in support of high seas, offshore, and nearshore marine forecasts; climate and global change studies; environmental monitoring activities; and satellite calibration/validation. Figure 1 depicts the locations of VOS field support personnel and a schematic of data flow.

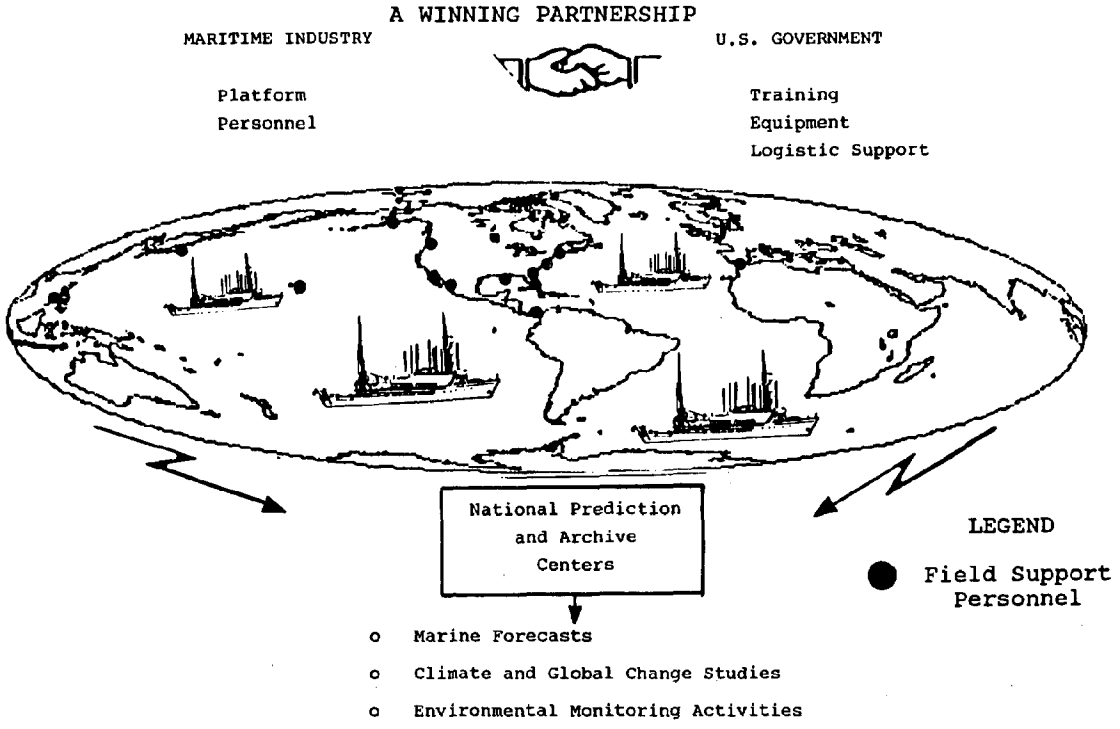

Figure 1. U.S. VOS Partnership, Locations of Field Support Personnel and a schematic of data flow.

PRESENT COORDINATION AMONG PROGRAMS

A high degree of coordination exists in the VOS partnership as evidenced by the joint authorship of this paper. On-going coordinated activities involve user requirements, equipment design and procurement, training and logistics support, and system monitoring.

User Requirements

Selection of VOS vessels for SEAS equipment in the NOS VOS Program is decided by the SEAS Advisory Committee. The committee is composed of a representative from each U.S. VOS program, Canada, and Australia. Based on user requirements (operational and research) this committee recommends and votes on the deployment of SEAS units by electronic mail. Factors considered are: data need, logistics support capabilities, satellite communication coverage, vessel time at sea, area of operation, and existing shipboard equipment.

Equipment Design and Procurement

Coordinated efforts exist on the design and procurement of equipment. Equipment is state-of-the-art, off-the-shelf hardware with standard interfaces that are compatible with equipment throughout the VOS Program. Interfaces which must be designed are coordinated among the various programs. This is a must to ensure the cross utilization of logistics support people among the programs.

Joint procurements have been shared among the programs. For example, the Navy and NOS normally share procurements of expendable bathythermographic probes (XBT's) and the purchase of the central processor for SEAS. NWS and NOS are jointly funding 20 "Lap Top" SEAS units. The automated pressure sensors used on some of the SEAS units also constitute a shared activity. The pressure sensor purchased with NOS funds are calibrated and routinely checked by NWS PMO's.

Training and Logistics Support

Because of rotating schedules, ship personnel often change. The key to a successful VOS program is frequent ship visits and retraining of ship personnel. NWS and NOS schedule annual meetings for briefing and training VOS support personnel on new procedures and data gathering and transmission equipment. At these meetings logistics support personnel from other VOS Programs are invited.

For ship greeting and retraining, the preference is to have the same person greet his/her assigned vessel. This allows the greeter to build a good working relationship with the ship's personnel. Because of changes in ship's schedule this is not always possible. In these situations training is provided by the most geographically convenient trainer, regardless of Programs.

System Monitoring

Shipboard equipment must be monitored to spot problems as soon as they occur. When ship's data are transmitted by the GOES system, monitoring is extremely important. A transmitter malfunction could cause another ship's data not to be received. User agreements with NESDIS require transmitter problems to be corrected within 24 hours.

Data transmitted by the GOES system are monitored by a microcomputer which allows VOS support personnel from NOS, NMFS, and OAR to dial-in and monitor their assigned vessels. During installation the system's transmission capability can be tested via the dial-in monitoring mode. Monthly statistics compiled by the system are shared with participating vessels in a monthly newsletter.

FUTURE DIRECTION

The planned course for the U.S. VOS Program is continued coordinated, shared support; deployment of more shipboard environmental measuring systems with automated oceanographic and meteorological sensors; increased use of satellite telemetry methods; increased effort to interface Government developed data collection software with commercially developed and deployed hardware; and fostering a coordinated international VOS Program.

Shipboard Environmental Measuring Systems

More equipment with automated and state-of-the-art, off-the-shelf, oceanographic and meteorological sensors will be deployed. All systems will have satellite telemetry capability. The move

to fully automated systems will require less time of ship's personnel to take and transmit meteorological and oceanographic observations. For example, winds can be measured by anemometers and fed directly into the ship's central processor. Winds will be automatically adjusted for ship's heading and speed. Automated systems will also allow for more in-line quality control of measured data.

Plans for automated oceanographic and meteorological sensors include acoustic doppler current profilers; expendable conductivity-temperature-depth sensors; and automatic meteorological packages that measure wind speed and direction, relative humidity, air and surface water temperature. Automated sensors and satellite telemetry method will allow for more frequent and more timely observations. The overriding requirements for the equipment are price, compactness, and flexibility for add-on, state-of-the-art sensor packages. The interfacing of the packages will be handled by system software.

Satellite Telemetry Methods

To take advantage of the more than 6,000 ocean-going vessels with International Marine Satellite (INMARSAT) capability, software for shipboard data collection systems is being modified. The INMARSAT capability will allow for the transmission of large volumes of data such as subsurface current data collected by acoustic doppler current profilers. INMARSAT transmission, which is two-way, will make it possible to send marine forecasts and value-added products back to the ship.

The U.S. VOS Program is working with the French on coordinated deployments of equipment to collect subsurface temperature data. The French system - - Service ARGOS System - - transmits data via the polar orbiting TIROS satellite. Rather than modify U.S. shipboard systems to transmit via the TIROS satellite, the U.S. and French are coordinating deployments to take advantage of their respective satellite coverages.

Summarized in Table 2 is the planned direction for the design and depoloyment of VOS equipment.

Table 2. Planned Direction for VOS Shipboard Systems

Equipment

Deploy more Systems
(Less Expensive and Smaller)
Interface with more Sensors
Work with Private Industry

New Sensors

Expendable Conductivity - Temperature - Depth (XCTD)
Acoustic Doppler Current Profilers
Automatic Meteorological Packages

- o Wind Speed and Direction
- o Relative Humidity
- o Air and Surface Water Temperature

Satellite Telemetry

Interface with INMARSAT
Continue Coordinated Deployments with Polar Orbiting French Reporting System

Partnership with Commercially Developed and Deployed Systems

Representatives of the U.S. VOS Program and private industry are working to interface ocean data collection software with commercially developed and deployed systems. This software will run in the "background" of these system and send data via a ship's INMARSAT transmitter.

The U.S. Program is contracting private industry to upgrade (add subsurface data collection capability) to "MET ONLY" systems. The program is also looking to the private sector to interface off-the-shelf, state-of-the-art hardware into SEAS-like systems.

Foster An International, Coordinated VOS Program

The U.S. VOS Program contributes supplies, logistics support, and

equipment to a number of international VOS Programs. These Programs include: Scientific Industrial Research Organization in Australia, Office De La Richerche et Technique Outre-Mer, France; Ministry of Agriculture and Fisheries, New Zealand; and Ocean Science and Surveys/Institute of Ocean Sciences, Canada. In addition, cooperative data collection efforts are underway with Chile, China, Ecuador, Japan, Mexico, Peru, Portugal, Uruguay, and West Germany. Data collected by this international partnership are very important to global programs such as the Tropical Ocean Global Atmosphere (TOGA) and the World Ocean Circulation Experiment (WOCE) programs.

To further the international effort, the U.S. Program shared in the design and distribution of the Integrated Global Ocean Services System (IGOSS) Ship of Opportunity Programme brochure. This brochure describes this worldwide service for rapid collection, exchange, analysis, and dissemination of meteorological and oceanographic data and products. A tear-out, addressed panel of the brochure is included for those who would like to receive more information about the Program and for those who are interested in participating in the Program.

SUMMARY

The VOS partnership with the U.S. Government and private industry is continuing to grow. This partnership, where the maritime industries provide platforms and personnel, is growing to the stage where private industry will more fully share in satellite telemetry and intergrating shipboard data collection equipment. This partnership is headed toward a totally international program. Continuous monitoring of the data collected, formatted, and transmitted by sensors aboard vessels will ensure the collection of accurate, real-time data in the most cost-effective manner.

The net result of this U.S. Government - Private Industry Partnership will be timely data sets that will enable us, as a nation, to better understand global climate change, to develop better predictive models, and to increase our forecast skills thereby saving life and property. **If you are interested in taking part in this partnership please contact either Steve Cook, NOS (408-893-7103), Paul Stevens, U.S. Navy (408-647-4351), or Vince Zegowitz, NWS, (301-427-7724).**

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REFERENCES

Benway, R., 1987: Water Column Thermal Structure Across the Shelf and Slope Southeast of Sandy Hook, NJ in 1987. Northwest Atlantic Fisheries Organization, Ser. No. N1441, 7 p.

Brown, S., 1987: Watch Out For Nelson Eddy. Lamp, Vol. 69, No. 1, 12-17.

Cook, S. and V. Zegowitz, 1983: An Automated Data Acquisition and Satellite Transmission System. Sea Technology, (Oct. issue), 48-49.

Saur, T. and P. Stevens, 1972: Expendable BT Observations from Ships of Opportunity. Mon. Wea. Rev., 16, 1-8.

Stevens, P. and D. McLain, (unpublished manuscript), 1987: Cooperative Oceanographic Observations Program, 18 p.

Szabados, M., C. Roman, and B. Taylor, 1987: Transmission of Real-Time Oceanographic and Meteorological Data From Ships. Proceedings of Oceans 87, Vol. 3, 863-869.

COMPARING U.S. COAST GUARD BUOY TENDER PERFORMANCE USING SIMULATION

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ABSTRACT

The Coast Guard plans to replace its aging fleet of buoy tenders with newly constructed vessels. Many of the vessel designs being considered have never been built, therefore they have no track record. Moreover, the Coast Guard requires a way to compare these vessels against one another for each operating district of consideration in order to choose the best vessel possible. A simulation has been developed which models a single tender working a given field of buoys. The purpose of this model is to evaluate alternative buoy tender designs of differing characteristics in realistic operational environments.

1. INTRODUCTION

A major responsibility of the Coast Guard is to maintain a system of navigational aids to mariners within territorial waters. These aids, otherwise known as buoys and lighthouses, are used to mark navigable waters for various sizes of vessels and also to warn of submerged dangers such as rocks, sandbars, and sunken vessels.

An essential feature of overall buoy tending operations is that the buoys are maintained in a variety of environments which can affect the way in which the tender performs service. An example of this would be the differences between the tenders that service the coastal area of the Pacific around Alaska versus those that service the Long Island Sound region between New York and Cape Cod. The tenders servicing the Alaskan area must travel great distances to reach a particular buoy, whereas tenders in the Long Island Sound area travel much shorter distances. In addition, the aids they service are placed closer together and tend to be in groups. In comparison with the Alaskan region, the aids are smaller and the weather is susceptible to quick changes in the Long Island Sound region.

Servicing aids to navigation and correcting discrepancies is a complicated activity. Otherwise well-planned servicing trips are often altered to accommodate reported discrepancies in the area or because the weather creates unsafe working conditions. At times, several aids become discrepant simultaneously due to weather, collisions, or vandalism, demanding rapid and extraordinary response from servicing units.

The present fleet of buoy tenders used to service these aids are aged. Thus they require ever-increasing amounts of maintenance and are no longer cost efficient. Over the next decade the Coast Guard plans to replace these tenders with a new fleet, possibly of a new design (class). This means that many of the designs to be considered have never been constructed and thus have no historical track record by which the Coast Guard can evaluate their operational performance.

To make performance comparisons of the various tender designs is cost prohibitive. In order to do this, each alternative design would need to be built and tested in each area. As a result, a simulation model has been developed. The purpose of this model is to evaluate alternative buoy tender designs in realistic operational environments. The model (see Fig. 1) is basically a SIMSCRIPT II.5 simulation which can be used to realistically simulate buoy tenders with differing characteristics while they work a field of buoys in a given geographical area. This allows the analyst to measure relative performances of various buoy tender alternatives (new designs). Since no data or experience would be available for new ship designs, the model provides the only means of measuring operational performance of these ships.

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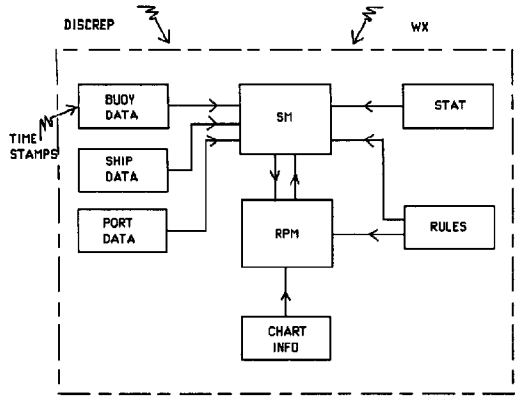

Figure 1. Simulation Model

2. OVERVIEW

The Simulation essentially provides the "driver" for moving the tender around, servicing the field of buoys. The speed of the tender changes as a function of sea state, thereby providing a realistic setting for buoy tender operations. The simulation also keeps track of statistics over time, such as operating hours, response times, buoy and tender downtimes, etc. Resource usage such as fuel and material are also accounted for by the model.

The model addresses a select group of environmental factors that were felt to have an influence on the performance of the tender. For each of these environmental considerations the tender has attributes that designate the operational limits of the tender with respect to each of these factors. The height of waves, and the speed and direction of prevailing winds, have a significant effect on the cruising speeds of the tenders. Moreover, visibility is a factor when positioning a buoy. If reference sites are not visible because of haze or fog, then maintenance and repositioning of the buoys could not be performed.

Uncontrollable environmental factors handled by the model are Navigable Waters and Weather Conditions. Navigable waters are those waters in which the tender can safely travel. Any aid outside the tender's navigable waters cannot be directly accessed by the tender and thus cannot be serviced. Two weather-related uncontrollable factors are wave height and surface visibility. These two factors have a direct bearing on tender's performance.

The Sea State was modeled using wave data from weather buoys local to the area being simulated. This data was obtained from the NOAA Data Buoy Center and Army Wind and Wave Summaries. The Sea State model takes into account total time at a wave height interval as well as the average time at that interval. Visibility was generated using actual readings taken from local airports.

Importantly, surface visibility affects the tender's ability to position buoys after servicing. Their proper positioning is critical to mariners. In positioning a buoy, the tender's crew must take measurements that require certain reference points. Visibility that falls below the minimum level at which the tender can make an accurate placement, means that the tender cannot complete its work until the visibility returns to acceptable levels. This increases the downtime of the buoy and tender under-utilization, thereby degrading performance.

Geographical limitations (navigable waters) are dependent on land obstacles and water depth for a given area. Each tender may have characteristics which limit its ability to travel in some waters. The difference between navigable waters and land and non-navigable water is represented by a boundary polygon. A route consists of a sequence of line segments lying entirely within this polygon. The polygons are derived from a nautical geographical data base for the region to be modeled (see Fig. 2). Importantly, the polygons serve to delimit the area for travel and define the navigable region for the ship. Therefore an individual tender has its area of navigable waters specified by boundaries defined by polygons which can be used to route the tender properly.

In summary, the simulation model can be used to simulate buoy tenders with different attributes such as speed, lifting capacity, draft, length, weight limitations, deck space, etc. This allows the analyst to measure the effectiveness of a new buoy tender design. The measures of effectiveness will be related to output data which reflects quality of service to the mariner, e.g., how long a buoy is out of service.

3. ROUTE PLANNING MODULE

A significant aspect of modeling is that the needs of a ship within a region depend critically on its particular geography. Possible travel routes vary according to which ships can successfully travel them, due to depth of water or weather exposure. Therefore,

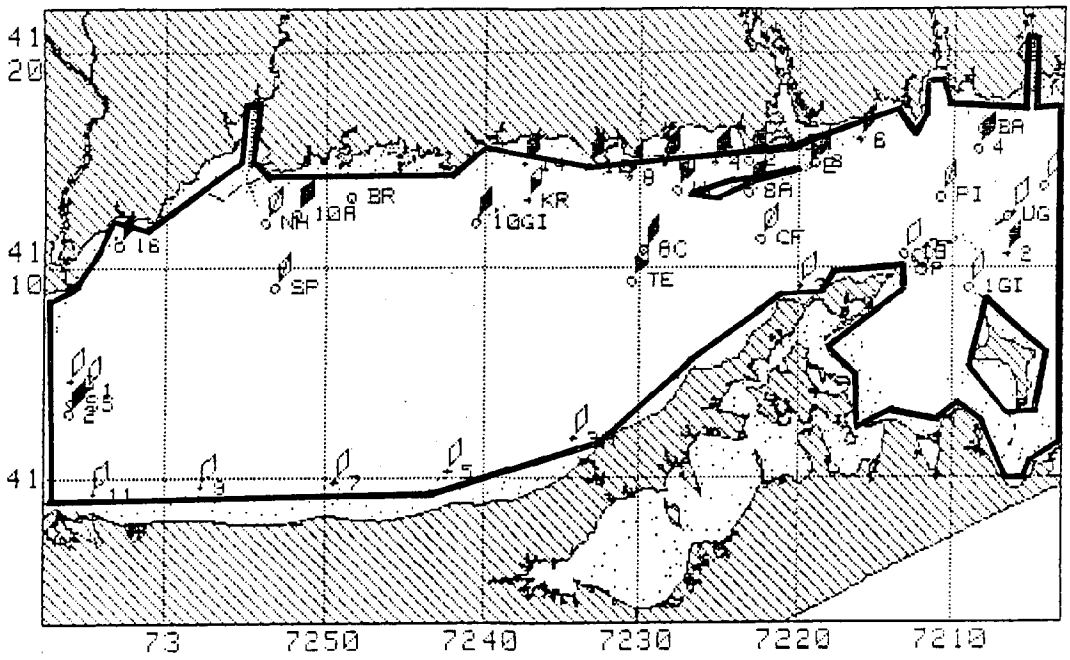

Figure 2. Navigable Waters

the modeling process must take into account geographical constraints such as shoals and islands.

The Route Planning Module (RPM) is called by the simulation model when it is required to plan the tender's travel itinerary. The RPM will select routes based on a multitude of inputs from the simulation model. These include vessel attributes such as; geographic limitations, buoy attributes, weather limitations, and resource requirements such as fuel for the ship. Moreover, the RPM is called when the simulation model generates interrupts of the normal buoy servicing for such things as unscheduled buoy maintenance and responding to emergencies. Upon interrupt, the ship must be reassigned temporarily and then rescheduled from a new starting point to efficiently service the remaining buoys.

Concisely, the route-planning problem can be stated as follows: A base has a single ship and N buoys, where N is too large to be visited on a single trip. The navigable space is defined as the interior of a specified polygon. Islands are represented as polygon "holes" within the outer specified boundary polygon. The capabilities of the ship affect the routing. Therefore, the model must find the least expensive and timely set of trips that visits each buoy once for the length of time required to perform the specified maintenance.

3.1 Subjective Elements of Route Planning

One important set of variables that influence the routes are those derived from human judgement. Ship captains differ in their preferences and their decisions can depend on many variables. To include judgement or preference in the model requires a framework which will reflect the preferences or utility of a particular ship captain.

Two significant factors are thought to be most important in constructing a route based on judgemental factors: timeliness and minimizing the time to complete a route of buoys. Basically, the captain is asked to construct two utility functions which give a measure of timeliness and time to complete service. Judgemental Independence is assumed and the two utility functions are combined additively. By obtaining the most preferred attribute and the scaling weights for the functions, allow one to combine the attributes into a 2-dimensional utility function. Once a set of alternative routes are constructed. The most preferred route, can be selected using the utility function.

This leaves the problem of searching the nodes for feasible sets of routes. This is performed using two linear evaluation functions. The search is performed

depth first and is controlled by using scaling weights on the evaluation functions. A Search tree is created for each buoy. Within a predefined cluster of buoys the next buoy visit selection is made based on applying the evaluation function. The buoy with the highest value resulting from the application of the evaluation function is selected. This process is continued until all the feasible routes have been generated. Finally, the utility function is calculated for each feasible route, resulting in the route's combined utility. The route selection is based on maximizing utility of the routes.

4. EXPERIMENTS

This section will describe an experiment running the model in the Long Island Sound region. This was a comparison between a coastal tender (REDWOOD) and an oceangoing tender (BITTERSWEET). There were 251 buoys assigned to each alternative tender. Eight ports were designated as places the tender can dock. Of the eight, only the homeport was designated with the capability to store buoys and refuel the tender. For these comparison runs, a period of time from April to June, 90 days, was selected as indicative of peak workload.

Wave height data from a NOAA data buoy, which is located just south of Cape Cod, was used in the generation of wave heights for these simulation runs. This buoy data was selected for its proximity to the mouth of Long Island Sound and its completeness of data. Because the data buoy location is in an exposed area, simulated wave height data was biased to rougher wave conditions.

The characteristics of the tenders were based on engineering estimates. The tender's characteristics were set as follows:

REDWOOD

Top economical speed:	10.0 knots
Depth restriction:	10.0 feet
Crane capacity:	20,000 lbs
Payload (buoys on deck):	40,000 lbs
Night buoy operations:	No
Endurance:	5 days
Fuel capacity:	17,620 gals
Fuel usage:	60.00 gals/hour
Maximum wave height for safe tender operation:	1.2 meters

BITTERSWEET

Top economical speed:	10.0 knots
Depth restriction:	15.0 feet
Crane capacity:	40,000 lbs
Payload (buoys on deck):	99,999 lbs
Night buoy operations:	No
Endurance:	120 days
Fuel capacity:	28,000 gals
Fuel usage:	39.47 gals/hour
Maximum wave height for safe tender operation:	3.2 meters

Discrepancy downtime was used as a surrogate for a measure of mission degradation. The response policy currently being used within the simulation gives discrepancies highest priority. That is, unless the tender is currently performing work on a buoy or is in port to satisfy a constraint, the tender will immediately head for the discrepant buoy.

It is possible for buoys to be serviced behind schedule due to such factors as; weather, buoy discrepancies, constraint satisfactions required by the tender, and maintenance of the tender. Any buoys that are worked beyond an acceptable scheduled maintenance date are output in a report in addition to the amount of time beyond the scheduled maintenance date. The acceptable range of time used in current runs was 14 days.

Buoy time stamps for routine buoy maintenance are obtained from the operational offices. These time stamps indicate the type of work required (i.e., replacement) and the date the work should take place. During the course of the simulation run, the time stamps are updated to the next time the work needs to be done according to policy.

4.1 Results of Experiment

As previously mentioned, the measure of buoy tender performance was the average down time of the discrepant buoys. Since the primary objective of buoy tending is to keep buoys in service and operating, it is desirable and of the utmost importance to keep these buoys functioning to reduce the danger to mariners. Importantly, the objective with regard to mission effectiveness is to minimize the down times of the discrepant buoys.

The test data was taken in 90-day intervals. Twenty repetitions of this interval were performed with different samplings of weather, service times and buoy failures. The Measures of Relative

Effectiveness (MORE) was represented by a sample mean and variance of average discrepancy downtimes. A 99% confidence interval of the mean was calculated using the Standard Normal Approximation. Along with the above statistics, a histogram is generated to give a visual idea of the distribution of the MORE.

Figure 3 below presents the MORE results of the experiment. As expected, the

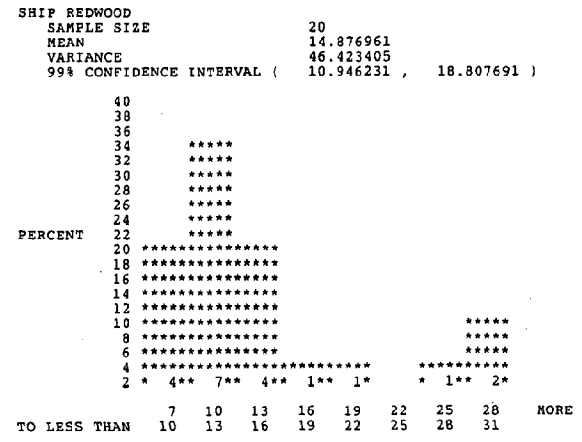

Figure 3a. REDWOOD Run

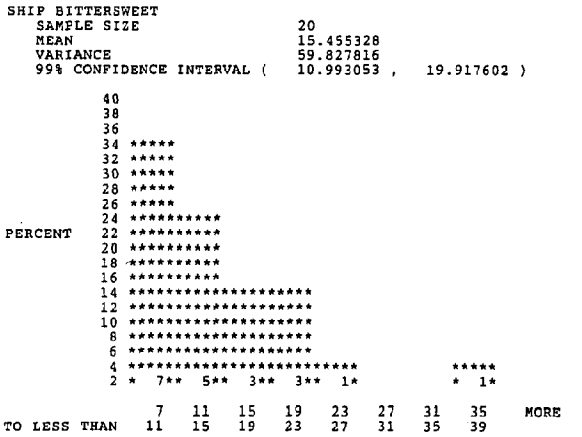

Figure 3b. BITTERSWEET Run

MORE's show that both tenders would perform relatively the same with regard to mission effectiveness. However, the BITTERSWEET, as an oceangoing tender, would be extremely more costly to operate than the REDWOOD in this area given its larger manning and fuel requirements. Moreover, additional output revealed that the BITTERSWEET was unable to service 10 buoys in the 90-day interval due to draft restrictions. This would further add to the cost of operating, because additional resources would be required to service these buoys. Incidentally, since the REDWOOD has been operating in this area for years, one would expect it to be the better choice when tested against current designs.

In order to show that the model does indeed distinguish among tenders, sensitivity runs were performed using the REDWOOD as the baseline tender operating in Long Island Sound. Figure 4 on the next page presents the MORE results of changing the Maximum Allowable Sea State from calm to moderate seas. When the tender is restricted to operate in calm seas, the MORE is 18, while if allowed to operate in moderate seas the MORE is 10. The tender with the smaller MORE is more capable of operating in the established environment. Since the confidence levels do not overlap, there is a significant decrease in the MORE when Maximum Allowable Sea State is increased. This implies that the less capable vessel would allow for more equipment outages and may reduce operational safety compared to the more capable vessel. Of course, tradeoffs must be made with other MOREs such as tender utilization and operating cost before any concrete conclusions could be reached.

5. SUMMARY AND CONCLUSIONS

A simulation model for evaluating various buoy tender designs operating in selected geographical regions has been developed and has produced results which could be used with other supportive evidence to decide on the best design for a particular region. Although the model does not directly use engineering parameters such as heave, pitch and roll, the results indicate that environmental effects and approximations (or surrogates), such as Maximum Allowable Sea State, are able to distinguish significant differences between tender designs. Of course, it is essential that sound engineering judgement is used to select these engineering characteristics.

Finally, it is important to note that the simulation results are only valid when making comparisons between alternative designs within fixed weather patterns, discrepancy rates, service time distributions, and geography. No attempt should be made to extrapolate any of these results beyond their intended purpose. As with all models of this nature, other information (or models) must accompany the analysis before conclusions can be reached concerning the best tender design for a

given region. If viewed in this light, the simulation model can produce results which would not otherwise be available to the decisionmaker, thereby providing a valuable tool for evaluating competing buoy tender designs.

6. REFERENCES

1. Law, A.M., and C.S. Larmey, "An Introduction to Simulation Using Simscript II.5," CACI, Inc. - Federal, 1984.

2. "Winds and Wave Summaries for Selected U.S. Coast Guard Operating Areas," Report No. CG-D-11-83, April 1983.

3. "Diskette Documentation for NCDC's Element Archive Format," Release B - condensed, November 1985.

4. Kuipers, B., "Modeling Spatial Knowledge," Cognitive Science, 2, pp 129-153, 1978.

5. "Kaun, D.T., "Terrain Map Knowledge Representation for Spatial Planning," Proceedings of First Conference on Artificial Intelligence Applications, Denver, CO, December 5-7, 1984, pp 578-583.

6. Kuipers, B. and Alan Cline, "Coast Guard Route Planning," U.S. Coast Guard R&D Center Report, December 1, 1986.


```
SHIP REDWOOD (2 wea)
   SAMPLE SIZE                  20
   MEAN                         16.076307
   VARIANCE                     61.595390
   99% CONFIDENCE INTERVAL (    13.548595 ,    22.604020 )

          40
          38
          36
          34       *****
          32       *****
          30 ***********
          28 ***********
          26 ***********
          24 ***********
PERCENT   22 ***********
          20 ***********
          18 ***********
          16 ***********                                   *****
          14 ***********                                   *****
          12 ***********                                   *****
          10 ***********       *****                       *****
           8 ***********       *****                       *****
           6 ***********       *****       ********************
           4 ***********       *****       ********************
           2 *  6**  7*        *  2*       *  1**  1**  3*

               10    13    16    19    22    25    28    31    MORE
TO LESS THAN   13    16    19    22    25    28    31    34
```

Figure 4a. Sensitivity Output - Limited to Calm Seas

```
SHIP REDWOOD (5 wea)
   SAMPLE SIZE                  20
   MEAN                         10.226603
   VARIANCE                      5.737406
   99% CONFIDENCE INTERVAL (     8.844747 ,    11.608458 )

          40
          38
          36
          34 ***********
          32 ***********
          30 ***********
          28 ***********
          26 ***********
          24 ***********
PERCENT   22 ***********
          20 ***********
          18 ***********
          16 ***********
          14 ****************
          12 ****************
          10 ********************
           8 ********************
           6 ********************
           4 *************************
           2 *  7**  7**  3**  2**  1*

               7     9    11    13    15    17    19    21    MORE
TO LESS THAN   9    11    13    15    17    19    21    23
```

Figure 4b. Sensitivity Output - Moderate Seas

USING SPACEFILLING CURVE TO GENERATE THE FEASIBLE ROUTES FOR THE SET PARTITIONING PROBLEM

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ABSTRACT

The Vehicle Routing Problem, which is a variation of the classical Traveling Salesman Problem, is and has been a topic of much interest. The basic premise of the problem is that of a vehicle that must visit a large group of nodes but is limited by the distance it can travel in one trip. Therefore, several routes must be scheduled in order for the vehicle to visit every node.

Set Partitioning algorithms are a good approach to solving this problem. Up to now, the feasible routes were only able to be generated if the routes were already defined, such as an airline flight schedule. With use of Space Filling Curve Heuristics, feasible routes can now be generated for a random field of nodes thus making Set Partitioning a viable option for the general Vehicle Routing Problem. The heuristic for generating feasible routes that is described in this paper, uses a method of route estimation based on The Space Filling Curve. Route estimation with the Space Filling Curve is fast and relatively accurate.

I. INTRODUCTION

The Vehicle Routing Problem, which is a variation of the classical Traveling Salesman Problem, is and has been a topic of much interest. One approach that is favored by several researchers is the use of set partitioning. In a paper by Marsten and Shepardson[1], several successful applications are presented. As a result, there already exists good algorithms for solving the set partitioning problem. Two examples are the Branch and Bound algorithm[2] and the Enumerated algorithm[3]. However, very little has been written on the method for generating the the feasible routes for the set partitioning problem. In some specific applications,the feasible routes can be efficiently generated but there lacks a general algorithm or heuristic for nodes randomly located in an area.

The next step, therefore, is to develop a method to generate the feasible routes for the set partitioning problem.

The basic premise of the vehicle routing problem that this paper will examine is that a vehicle that must visit a large group of nodes but is limited by the distance it can travel in one trip. Therefore, several routes must be scheduled in order for the vehicle to visit every node with the vehicle returning home in between each trip. An example would be a buoy tender who must service all the buoys in a given area. The tender obviously could not service all the buoys at one time so several trips must be planned. Therefore, the entire schedule for the buoy tender could be generated.

II. SET PARTITIONING

This section contains a brief description of the Set Partitioning problem. It is presented as background for the other sections of this paper. This discussion will not explain any algorithms,but will only describe the set partitioning problem.

The set partitioning problem can be written as an integer program[4] with the basic formulas described in equations(1, 2, and 3) as they apply to this particular problem. These can be expanded as in figure(1).

In these equations x represents a particular feasible route while c represents the length of the route. The ith rows represent a particular node while the jth columns stand for a particular route of nodes, thus the intersection a is used to show if a particular node is contained in a particular feasible route. The a values can be better visualized in matrix form as seen in figure(2).

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$$\min(z) = \sum c_j x_j \qquad (1)$$

$$\sum a_{ij} x_j = 1, \quad i = 1,\ldots,m \qquad (2)$$

$$x_j = 0,1 \quad j = 1,\ldots,n \qquad (3)$$

where

$$x_j = \begin{cases} 1 & \text{if feasible route } j \text{ is used in the partition} \\ 0 & \text{otherwise} \end{cases}$$

$$a_{ij} = \begin{cases} 1 & \text{if node } i \text{ is in feasible route } j \\ 0 & \text{otherwise} \end{cases}$$

c_j is the length of the feasible route j

FIGURE 1.

$$\min(z) = c_1x_1 + c_2x_2 + c_3x_3 + \ldots + c_nx_n$$

subject to

$$a_{11}x_1 + a_{12}x_2 + a_{13}x_3 + \ldots + a_{1n}x_n = 1$$

$$a_{21}x_1 + a_{22}x_2 + a_{23}x_3 + \ldots + a_{2n}x_n = 1$$

$$\ldots$$

$$a_{m1}x_1 + a_{m2}x_2 + a_{m3}x_3 + \ldots + a_{mn}x_n = 1$$

FIGURE 2.

$$\begin{matrix} a_{11} & a_{12} & a_{13} & \ldots & a_{1n} \\ a_{21} & a_{22} & a_{23} & \ldots & a_{2n} \\ a_{31} & a_{32} & a_{33} & \ldots & a_{3n} \\ \ldots & & a_{ij} & & \ldots \\ a_{m1} & a_{m2} & a_{m3} & \ldots & a_{mn} \end{matrix}$$

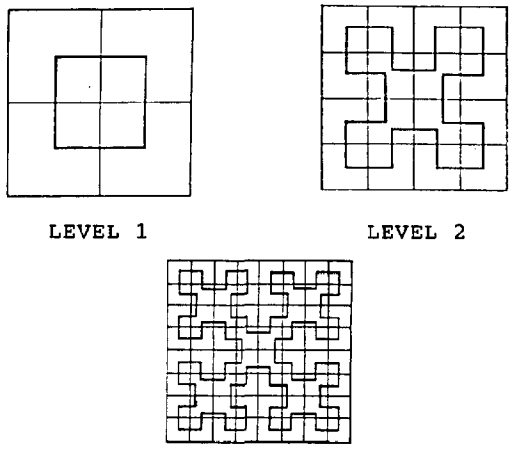
III. SPACEFILLING CURVE

Spacefilling Curves was first introduced by Peano, Hilbert, and Sierpinski in the late 19th and early 20th century. Since then, they have interested many mathematicians for its simplicity, speed of execution, and recursive quality. One popular application of Spacefilling Curves is their use by Mendelbrot in generating Fractal Curves. Spacefilling curves along with the specifics used in this heuristic are discussed extensively by Bartholdi and Platzman[5].

In brief, heuristics based on Spacefilling Curves is a method by which N-dimensional space is mapped to a 1-dimensional line. The space in which the nodes are mapped from tend be a unit square or unit cube etc. Therefore, all values for dimensions are be scaled to unit length. Since vehicle routing occurs on a plane, a 2-dimensional space, a unit square, is used.

The Spacefilling Curve heuristic creates a path through the unit square which visits every space in the plane as seen in figure(3). Where a node is mapped on the 1-dimensional line is dependent on where it is positioned on the Spacefilling Curve. Using the Spacefilling Curve heuristic described by Bartholdi and Platzman, the path is drawn and the node located by dividing the square into quarters and then finding which quarter the node lies. After the node is located, that quarter is divided again into four and the process repeated. This process, which is recursive, continues until the node is in the center of the new divided square. Then the nodes location on the 1-dimensional line is calculated by where it was at each recursion level. The nodes then receive a value from 0 to 1 according to its location on the 1-dimensional line. These nodes are then sorted by value and the route is thus generated. The path the Spacefilling curve takes at the first three recursions are demonstrated in figure(3).

FIGURE 3.

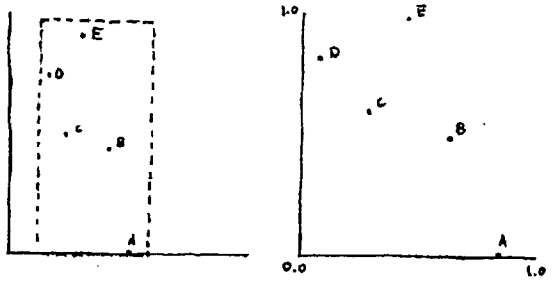


This heuristic creates routes which circle back on themselves. The path that navigates through the unit square begins and ends at the origin, coordinates (0,0). This lends itself quite well to this problem since the vehicle must return at the end of each trip to its base.

For this application, two additional procedures are added to the Spacefilling heuristic to create a Modified Spacefilling Curve Heuristic. These steps are designed to improve the results of the Spacefilling Heuristic. They are framing, and flip-sort optimizer. The framing step is used to translate the nodes into the unit square for the Spacefilling Curve heuristic while the flip-sort optimizer is used to improve the results of the heuristic.

The framing procedure is particularly useful when the nodes that are being routed are only located in one portion of the plane, e.g. just on one side, as seen in figure(4). This generally occurs when nodes that are being considered for a route are all close together or when all the nodes considered are on one half of the plane. In these circumstances, framing can be useful in creating more efficient routes by increasing the circle back effect of the Spacefilling curve.

FIGURE 4.



INITIAL RESULT

The framing step transposes a section of the plane which contains all the nodes to be routed into a unit square. This is done by finding an adjusted minimum(eq. 4) and maximum(eq. 5) of the x and y coordinates and then inserting the location of the nodes into equations(6 and 7) to get the new coordinates in the transposed unit square. These new coordinates are then inserted into the Spacefilling curve heuristic for the new route.

$$adj.min(\alpha) = .95 * MIN(\alpha_1 \ldots \alpha_m) \quad (4)$$

$$adj.max(\alpha) = 1.05 * MAX(\alpha_1 \ldots \alpha_m) \quad (5)$$

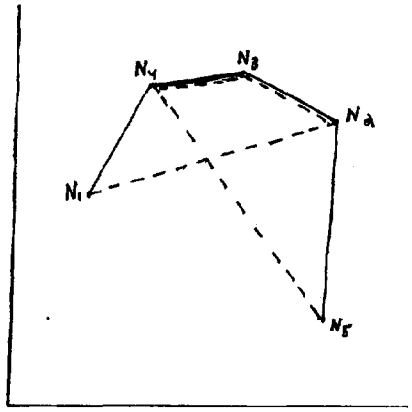
$$Xi = \frac{xi - adj.min.(x)}{adj.max(x) - adj.min.(x)} \quad (6)$$

$$Yi = \frac{yi - adj.min.(y)}{adj.max(y) - adj.min.(y)} \quad (7)$$

Now that the nodes have been sorted with the Spacefilling curve heuristic, the generated route can be optimized. The inefficiencies are primarily caused by the convoluted path by which the Spacefilling curve can take. This is seen in the example in figure(3). At this point, the Flip-Sort is utilized. This new optimizer is similar to the R-optimal method which has been used by Christofedes[6]. In actuality, the R-optimal method may be used in its stead, however, the Flip-Sort optimizer is much faster with an order of growth, O(n).

The Flip-Sort Optimizer differs from the R-optimal method in that the internal order of the nodes which the Optimizer looks at stays the same, the only decision made is whether or not to reverse the entire order of the nodes (see figure(5)). The assumption is that the Spacefilling curve will give a good route for the nodes being examined. The problem lies with the nodes association with its neighbors, therefore, the R-optimal method will not gain you very much for the extra time used.

FIGURE 5.



EXAMPLE

r = 3

Original Path Resulting Path

IF

$$[DIST(N_X, N_{X+1}) + DIST(N_{X+r}, N_{X+r+1})] \quad (8)$$

is greater then

$$[DIST(N_X, N_{X+r}) + DIST(N_{X+1}, N_{X+r+1})] \quad (9)$$

THEN

N_{X+1} through N_{X+r} are "flipped"

FROM N_1, N_2, N_3, N_4, N_5

TO N_1, N_4, N_3, N_2, N_5

The Modified Spacefilling Curve Heuristic is efficient and fast. The Framing Step simply finds the smallest and largest x and y coordinates and then a simple transposition. This has a linear order of growth, O(n). The Spacefilling Curve also has a linear order of growth since each node is processed separately. The last step, the Flip-Sort, has a linear order of growth, O(n), because the nodes that are examined are not reordered. Therefore, the largest order of growth for this algorithm is that of the sorting algorithm which is used once the Spacefilling curve has given the values to each node. This order of growth is O(n log(n)) which is standard for sorting algorithms. As a result, this heuristic has an order of growth of O(n log(n)) due to the sorting algorithm and is therefore quite fast.

IV. FEASIBLE ROUTE GENERATION

The algorithm for routing the vehicle is executed in three steps. The first step is to cluster the nodes, the second is to generate the feasible routes using the clusters, and the third is to partition the feasible routes into sets. The first two steps use the Modified Spacefilling Curve and are the subject of this paper.

Clustering is accomplished by using the Modified Spacefilling Curve discussed in the last section on all nodes to be visited. The path that is generated will be called the clustering route. Each node will then have the distance to its next neighbor calculated(see equation 10). These differences(Δ_i) are then sorted and with an arbitrary percentile, the clustering difference($\tilde{\Delta}$) is found (see equation 11).

$$\Delta_i = \text{Distance between Ni and Ni+1} \quad (10)$$

$$\tilde{\Delta} = \text{P\% of the order } \Delta_i \quad (11)$$

The arbitrary percentile is decided upon by several factors, The important ones includes the maximum size of the feasible routes and the number of nodes to be visited. Even more important is the optimization of the results and the speed of the calculations. The smaller the percentile the fewer the number of different clusters and therefore, the algorithm will be faster but less accurate. A larger percentile will of course have the inverse effect because there will be many more clusters with fewer nodes in them. The most efficient choice would be to divided every node into its own cluster but this would cause a large number of feasible routes to be generated for the set partitioning step. It is likely that The best percentile should be obtained through experimentation in the particular application.

Each pair of nodes with a difference less than or equal to the clustering difference are permanently clustered together. The order of the nodes in each cluster is not important and is not be maintained. However, since these nodes are close enough together they will always be together when generating feasible routes.

The next step is the feasible route generation. This step uses the order of the clusters as they were formed in the clustering route. The same principal is used in that if nodes that are close together are clustered together then clusters that are close together should be routed together.

Starting with the first cluster and later adding the succeeding clusters in order, feasible routes are generated. The length and path of the new route is calculated using the Modified Spacefilling Curve Heuristic. Here is where the framing procedure is most useful. The nodes in the clusters being considered may be only in part of the plane, and therefore a more efficient route may be calculated then using the path of the more general clustering route. The length of the route represents the values(c) used for the columns in the set partitioning problem. At this point, the next cluster in order is added to the previously examined nodes with the length again calculated and another feasible route is generated. This process continues until the length of the route being examined is larger then the vehicle can handle in one trip. This length represents the maximum distance that the vehicle can travel in one trip. After this first group of routes is generated, the next cluster in order is selected as the first cluster in the next group of routes and the process is repeated. This continues until everv cluster is used to start a group of feasible routes.

Now that all the feasible routes are generated, the set partitioning algorithm is applied. Although the algorithm is not discussed, it may be desirable to include certain steps to improve its computing performance. The first step to consider is to eliminate some of the less efficient routes. For example, some of the routes that contain less than one half the total nodes in the largest route starting with the same cluster, could be eliminated. Another possibility is to set up the set

partitioning problem to consider the feasible routes with more nodes in them. Since the larger routes tend to be more efficient because they return home less often and thus the overhead of distance per node visited is less, they should be considered first.

The largest order of growth in the entire route generation lies with the set partitioning algorithm and not with the feasible route generation. If a system can handle a large set partitioning problem already, then the addition of this feasible route generator will make only a minor change in the total amount of computing time.

V. EXAMPLE

In this section, a small example is produced to demonstrate the Algorithm. This example uses twelve nodes which are randomly distributed in a unit square. Since the nodes are already in a unit square, the framing procedure will not be used in creating the clustering route.

The first step is to define several variables along with the location of the nodes. See equations (12 and 13) for a list of these variables. The arbitrary percentile (p%) is set to 40% to give a good balance in clustering.

$$p\% = 40\% \tag{12}$$

$$\text{max. route size} = 2.3 \tag{13}$$

$$\text{number of clusters} = p\% * \text{number of nodes} \tag{14}$$

$$\text{number of clusters} = 5 \tag{15}$$

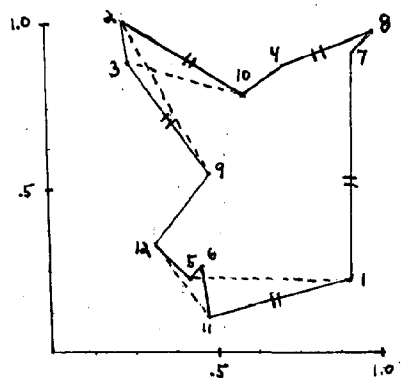
The next step is to generate the clustering route. This is shown in figure(6) and table(1). With this route, ($\tilde{\Delta}$) can be calculated and the clusters formed. ($\tilde{\Delta}$) is shown in equation(16).

$$= .20 \tag{16}$$

With these clusters, the feasible routes are now generated and are shown in table(2). These routes can now be translated into an activity matrix if desired. To simplify the matrix, each row can represent a cluster instead of a node. This will condense the matrix and speed up the set partitioning algorithm. The activity matrix is described in figure(7).

At this point the set partitioning algorithm solves the generated problem with the results shown in figure(8).

FIGURE 6



----- DENOTES ROUTE BEFORE FLIP-SORT.

——— DENOTES FINAL CLUSTER ROUTE.

—||— DENOTES CLUSTER SEPARATION.

TABLE 1

NODE	COOR. X	COOR. Y	SPACE-FILL	CLUSTER ROUTE	Δ_i	CLUSTER
1	.92	.18	.73	9	.47*	4
2	.24	.98	.27	4	.41*	1
3	.25	.85	.28	3	.13	1
4	.68	.83	.46	6	.20*	2
5	.40	.23	.91	12	.13	5
6	.45	.25	.92	11	.05	5
7	.82	.81	.53	8	.64*	3
8	.87	.88	.49	7	.09	3
9	.43	.50	.13	2	.39*	5
10	.57	.74	.39	5	.14	2
11	.46	.11	.93	10	.14	5
12	.33	.34	.10	1	.19	5

* DENOTES CLUSTER SEPARATION DIFFERENCES.

FIGURE 7.

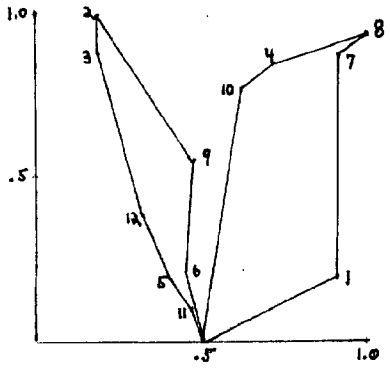
	2.0	1.7	2.0	2.3	1.9	2.1	0.9	1.7	1.1	2.2
1	1	0	0	0	0	0	0	0	0	1
2	0	1	1	1	0	0	0	0	0	0
3	0	0	1	1	1	1	0	0	0	0
4	0	0	0	1	0	1	1	1	0	0
5	0	0	0	0	0	0	0	1	1	1

where

the rows represent the clusters in the feasible route

the columns represent the feasible routes themselves.

FIGURE 8.



VI. CONCLUSION

This heuristic, which uses the Spacefilling Curve, introduces the possibility of using set partitioning in the general case of the vehicle routing problem. Up to now, set partitioning was used when the feasible routes were obtainable in well defined applications. These routes either came pre-defined or were easily discernible. With this heuristic, a random field of nodes can be visited with the feasible routes being generated in a reasonable amount of time.

VII. ACKNOWLEDGMENT

This research was done under contract with the University of New Haven Foundation and the United States Coast Guard Research and Development Center. I wish to give special thanks to Joseph A. Smith of the U.S.C.G. R.& D.C. without whom this paper would not have been possible.

VIII. REFERENCES

1. R. E. MARSTEN and F. SHEPARDSON, "Exact Solution of Crew Scheduling Problems Using the Set Partitioning Model: Recent Successful Applications", Networks, vol. 11, 165-177, (1981).

2. R. E. MARSTEN, "An Algorithm for Set Partitioning Problems", Management Science, Vol. 20, No. 5, (1974).

3. R. S. GARFINKEL and G. L. NEMHAUSER, "Integer Programming", Wiley, 315-318,(1972).

4. R. S. GARFINKEL and G. L. NEMHAUSER, "Integer Programming", Wiley, (1972).

5. J. J. BARTHOLDI, III and L. K. PLATZMAN, "Heuristics Based on the Spacefilling Curves for Combinational Problems on the Plane", PDRC Report Series 84-08, Georgia Institute of Technology.

6. N. CHRISTOFIDES and S. EILON, "Algorithms for Large-scale Traveling Salesman Problems", Op. Res. Quart. 23, 511-518, (1972).

IX. BIBLIOGRAPHY

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RESULTS OF AN EXPERIMENT TO EXAMINE CERTAIN HUMAN FACTORS RELATING TO SEARCHES CONDUCTED WITH MARINE RADAR

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ABSTRACT

As part of a series of Search and Rescue (SAR) experiments sponsored by Transport Canada, an investigation of certain human factors relating to electronic searches using a standard marine radar was conducted using a navigation/radar simulator system. Simulated search operations for weak radar targets partially obscured in a clutter field were carried out by experienced Canadian Coast Guard officers. The interrelated factors of fatigue and motivation and the "area of concentration" within the detection envelope were examined. The results have implications for SAR planning and training.

1.0 INTRODUCTION

The importance of investigating certain human factors affecting electronic searches using marine radar became evident in the initial search and rescue detection experiment conducted by the Canadian Coast Guard (CCG) (Dawe et al., 1986). Of specific concern were:

1. operator look direction selectivity on the radar plan position indicator (PPI); and,
2. the effects of fatigue and motivation on the ability of experienced CCG officers to detect weak radar echoes.

Objective evidence and subjective observations suggested that radar operators tended to concentrate on a relatively small sector of the PPI display centred on the heading marker and that the operators tended to become excessively fatigued after two hours on watch. To shed light on these issues in a short, cost effective manner, an experiment was planned using a Transport Canada Training Institute (TCTI) navigation/radar simulator system. The specific objectives were to:

1. define quantitatively the area(s) of the PPI display that are viewed more frequently and/or with greater concentration by experienced CCG officers; and,
2. examine the time variability of detection success of weak targets in a clutter field.

The results of the experiment are expected to be used to improve search and rescue planning and operations and to provide guidance in SAR training methods for electronic searches using marine radar.

2.0 THE TCTI SOLARTRON NAVIGATION SIMULATOR FACILITY

The system consists of a master control/monitor station and four individual bridge simulator facilities (own ships). Each is equipped with a radar display, navigation equipment, communications gear, and helm control facilities. The equipment is controlled by proprietary software running on a DEC PDP-11/34 computer system. Each "vessel" can be navigated independently or made to follow a prescribed route. A brief summary of system characteristics relevant to the experiment follows directly:

1. Any specified search pattern and vessel speed can be simulated.

2. Up to 24 radar targets can be positioned in any desired location.

3. Target strength and size may be varied in steps allowing relatively weak targets to be simulated. Target characteristics, however, are not adjustable during an individual trial.

4. Clutter simulation is not accurate but its intensity and range can be adjusted. Video levels of the targets and clutter field can be adjusted independently by the system operator during a simulation.

5. The simulated pulse length is menu adjustable between 0.2 microseconds (us) and 3.0 us, and antenna beamwidth is variable between 0.7 and 2.1 degrees to the 3 db point in steps of 0.17 degrees.

6. A flat bed plotter is available to plot track and target positions at virtually any time interval desired.

3.0 THE EXPERIMENT

For the purposes of this experiment each own ship acted as an independent SAR vessel. Track

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patterns were preset and all vessels maintained identical course and speed at all times.

The experiment was run over the five day period in July 1987. Two simulated searches of approximately four hours duration were run each day. Eight CCG officers were made available for the experiment and they were arbitrarily divided into two groups of equal size. The individuals in each group participated as radar operators on the identical series of simulated search patterns.

The CCG officers had either a Watchkeeping Mates Certificate, an Ocean Navigator 2 Certification, or a First Mate Home Trade ticket. Sea time experience ranged from about 1 year to 25 years, with the median being very near three years.

Eight parallel track or creeping line type search patterns, and two expanding square patterns were implemented. Twenty-four targets (the maximum possible) were distributed at random locations within the search area. The area was a function of the leg lengths and the vessel speed. The actual number of detection opportunities varied since some targets became opportunities more than once while others, normally because of their location on the extreme edge of the search area, never did become opportunities for detection.

An attempt was made to use ship parameters which were, more or less, typical of CCG SAR vessels. Simulated search speeds, which were held constant during an individual search, varied between 10 and 15 knots. A radar antenna height of 37 feet (about 11 metres) was selected.

The target "echos" were made as small as the system allowed. Video levels of both the targets and the sea clutter representation were adjusted to make the detection of the targets difficult. The clutter model employed is not indicative of actual sea clutter, the pattern being symetrical with the level decaying gradually with distance from the centre of the PPI display to a minimum at 3 nautical miles. The simulated searches were conducted in deep water out of sight of land. This eliminated the requirement for navigational support.

The simulated searches were run with one CCG officer operating the radar unit in each own ship for the length of the search; normally the duration was approximately four hours. The operators were required to log the time, true bearing and range of each target sighting, and were asked to provide remarks whenever it was deemed appropriate. Since each operator had identical opportunities for detection, no communication regarding the experiment was permitted between the "vessels".

4.0 DATA REDUCTION AND ANALYSIS

The detection envelope is the moving area around a search unit within which a target has a potential for being detected (Edwards et al., 1981). The actual detection envelope for a marine radar system is a complex function of target cross section area, and height above the sea surface, sea state, and radar performance specifications, antenna height, and microwave propagation conditions. For the purposes of this analysis the detection envelope has been defined as the radar range selected by the operator. For the most part, the radar operators elected to use the 6 nautical mile range setting on the PPI display. Since the theoretical radar range of targets very near the sea surface with an antenna height of 11 metres is approximately 7.5 nautical miles, the commonly selected radar range was appropriate. To examine the look direction selectivity on the PPI display, the detection data were binned by bearing, by range, and by range and bearing. Actual and relative frequencies of detection were computed from the binned data.

Investigation of the fatigue/motivation factor was reduced to an examination of the variability of target detection success in relation to time on search. For each operator and search, the ratio of the number of confirmed detections to the total number of opportunities in consecutive ten minute time intervals was determined. The average number of the percentage of targets that were detected for each time bin was computed to show the variability of detection performance with time.

5.0 RESULTS

Table 1 shows a summary of detections by area. The highest percent detected was in the second quadrant; the lowest was in the third quadrant, even though there were approximately 10% more opportunities than in any of the other quadrants. Comparing the port and starboard sides, the highest number and percent detected was on the starboard or right side of the PPI. The percent detected in the forward and aft semi-circles were approximately equal.

With regard to detection range, Figure 1 shows that more detections occurred in the 3 to 4 nautical mile (nmi) range than elsewhere. It is noted that the simulated clutter decreased markedly after 3 nmi. However, a significant number were seen inside the 3 nmi range (area of greatest clutter).

An inverse relationship was noted between the percent of targets detected and the number of opportunities. The effect was removed by dividing the percentage of targets detected by the number of opportunities. Figure 3 shows the results of all operators over all searches. There is an overall increase in detection success at the beginning (less than 1 hour) and towards the end of the searches (time on task of 3 to 3.5 hours).

6.0 DISCUSSION

The tendency to detect more targets in the second quadrant might be explained by the clockwise rotation and the cueing effect of the heading marker. The time delay between the heading marker flash and the operators response to the refreshed image may be such that full concentration may not occur until the second quadrant is being refreshed. By the time the operator had scanned the first and second quadrants and had started to look elsewhere the third quadrant had been already refreshed, phosphor decay had started and full concentration was not achieved until the fourth quarter was being refreshed. Once the heading marker flashes again the cycle repeats itself. A greater concentration on the starboard side may also be related to the regulation regarding risk of collision in crossing situations wherein a vessel which has another vessel on their own starboard side shall keep out of the way of the other vessel.

During the radar target detection experiment undertaken in Placentia Bay, Newfoundland (Dawe et al., 1986) it was found that all the detections occurred in the forward half of the radar displays and that the majority occurred within the $\pm$ 45° of the ships heading. In the simulator experiment there were almost 11% more opportunities in the aft sector. Despite this, the percent detected in each sector is about equal. This confirms the tendency to concentrate on the forward sector as indicated by the 1986 experiment. In the simulator experiments the operators knew they were not on a real vessel, were not concerned about any potential hazards, and were more concerned about detecting targets. Had the situation been more realistic it is quite possible that they would have had an even greater bias towards the forward half.

The detection data suggested that more targets were detected at the outer edge of the major clutter zone. United States Coast Guard (USCG) personnel have noted that past experiments indicated that during visual searches, lookouts tended to look along borders or edges (for example, along the side of a river, along the edge of a forest). This tendency might explain the phenomena seen here. The significant number of targets seen inside the clutter zone is probably an artifact of the poor clutter simulation technique employed.

No obvious explanation has been found for the inverse relationship indicated between the number of opportunities and the percent detected. It might be speculated that the operator thought after an initial period of time he was seeing false targets (too many were detected), thus a reduction in the percent detected occurred in the mid-range after and initial higher percent detection. After a 2 to 3 hour period a "pattern recognition effect" resulted in the operator being able to more definitely recognize true targets, giving a higher detection percentage toward the end of the search.

Another possibility is that the operator started the search at maximum alertness, resulting in more detections, tedium and fatigue then followed, resulting in lower detections. Finally, realizing that the search was coming to an end the operator began to work more diligently.

The normalized time on search trends seem to suggest some residual effects after removal of the "number of opportunities" bias. The overall slight drop in performance level after about an hour or so does give some indication, however small, that an operator should not be placed on radar watch for more than one hour. The slight and temporary improvement around the 2 hour time mark correlates with the coffee break time and indicates that a longer break period is necessary for an operator's performance to return to the first hour level. The rise in performance in the latter period may be an artifact of the "eagerness" effect discussed above. The significance of the peak at one hour is unknown.

7.0 CONCLUSIONS

The simulator experiments showed a number of trends which have significance in terms of a SAR operations using marine radar. The look direction selectivity suggests that with current radar systems, some investigtion is necessary in the need to utilize special search patterns to take into account this factor or some retraining of radar operators to remove it. The use of raster displays might remove some of this look direction bias. The tendency to detect more targets at the edge of the clutter also suggests that some retraining might be necessary for SAR operations.

The significance of the inverse relationship between the number of opportunities and percent detected is unknown in terms of its impact on a SAR operation. The number of opportunities is unrealistically large in terms of a real situation.

The time on search trend does indicate that to maximize radar search performance radar operators should be relieved approximately every hour. A short coffee break is insufficient. The significance of the other trends are unknown.

Many of the trends indicated may have a lot to do with ergonomics and human physiology. Indepth investigations of these factors are clearly beyond the scope of this experiment.

ACKNOWLEDGEMENTS

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REFERENCES

Dawe, B.R., D.S. Bryant, and D.J. Finlayson, 1986. Search and Rescue Detection Experiment Placentia Bay, Nfld. Transport Canada Rpt. No. TP (8028(E).

Edwards, N.C., S.R. Osmer, T.J. Mazour, and G.L. Hover, 1981. Factors Affecting Coast Guard SAR Unit Visual Detection Performance. Rpt. No. CG-D-09-82. U.S. Coast Guard Research and Development Center and Analysis and Technology, Inc.

DISPLAY SECTOR	TOTAL OPPORTUNITIES	TOTAL DETECTIONS	PERCENT DETECTED
First Quadrant (000°-090°)	3339	86	2.58
Second Quadrant (090°-180°)	3672	124	3.38
Third Quadrant (180°-270°)	3969	64	1.61
Fourth Quadrant (270°-360°)	3567	88	2.47
Forward Sector	6906	174	2.52
Aft Sector	7641	188	2.46
Starboard Sector	7011	210	3.00
Port Sector	7536	152	2.00

TABLE 1 Summary of Total Number of Opportunities, Total Number of Detections, and Percent Detected for Various Quadrants and Sectors of the Radar Plan Position Indicator Display

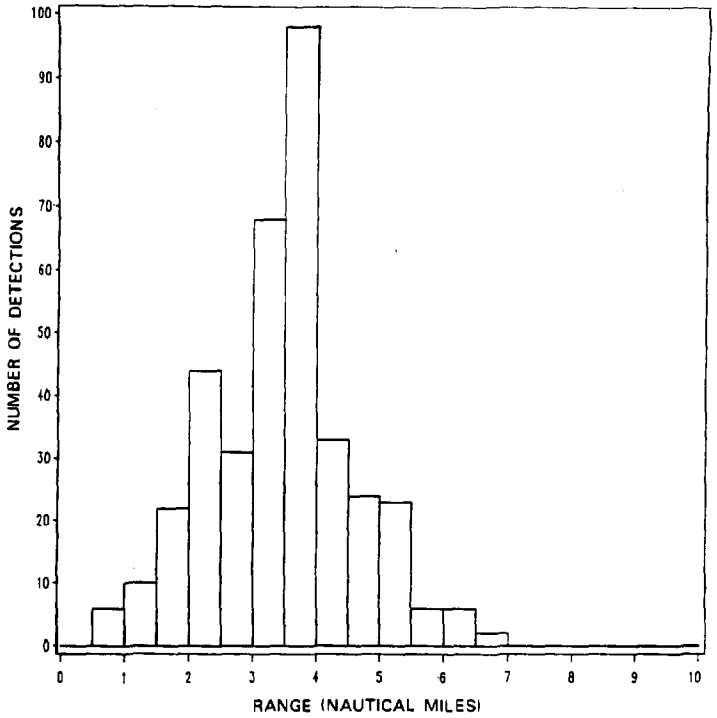

Figure 1 Number of Detections by Range

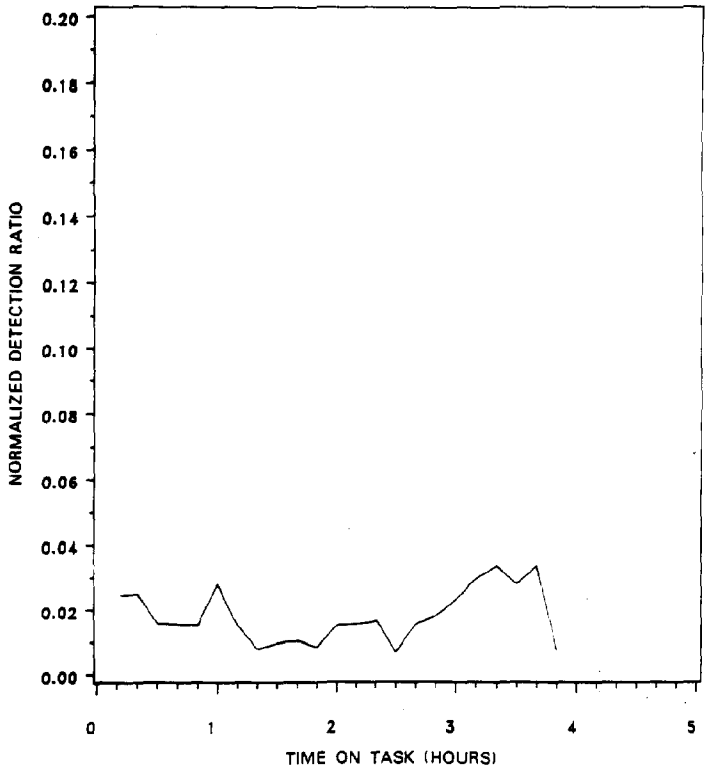

Figure 2 Average Normalized Detection Ratio as a Function of Time

RESULTS OF CANADIAN SHIPBORNE NIGHT SEARCH EXPERIMENTS

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ABSTRACT

In the fall of 1987, a marine shipborne search and rescue detection experiment was undertaken off Nova Scotia employing the Canadian Coast Guard ship "Sir William Alexander". United States Coast Guard (USCG) visual search experiment methodology was employed. The targets were 4 and 6-man life rafts. Night searches for these rafts with lights were carried out by visual observers without visual aids. Night searches were also carried out for unilluminated liferafts using night vision goggles supplied by the USCG.

1.0 INTRODUCTION

During the period from mid October to the last week of November, 1987, a multifaceted ship based search and rescue detection experiment took place on the Canso Bank off Nova Scotia, Canada. The primary objectives of the experiments were to obtain visual sweep width information for Canadian Coast Guard (CCG) vessels under typical Canadian conditions; to add to the United States Coast Guard (USCG) data base on visual detection information for sea states 3 to 5, to determine sweep widths for standard ship's radars against unenhanced and radar reflector equipped life rafts; and to determine the sweep width improvement that might be achieved using marine radars with more sophisticated signal processing. The targets used were commercial 4-man orange canopied life rafts and canopied 6-man yellow military life rafts. In addition to the basic experiment visual night searches were undertaken for life rafts equipped with canopy lights and for unilluminated life rafts using night vision goggles supplied by the USCG. Detection experiments were also conducted utilizing targets equipped with search and rescue x-band radar transponders. This paper provides the results of the night searches for life rafts equipped with canopy lights and for the searches involving unilluminated life rafts using night vision goggles.

2.0 THE EQUIPMENT

The vessel used was the CCGS "Sir William Alexander", a 1100 class Coast Guard buoy tender/ icebreaker. The ship had an overall length of 85 metres (m), a beam of 16 m and a displacement of 3728 tonnes. It was equipped with a flume stabilization system which acted to significantly dampen the natural roll of the vessel.

Table 1 provides a summary of the major system parameters pertinent to the two night vision goggles used.

Precise navigation information was essential to the experiment in order to determine ranges to valid target detections and opportunities. Fortunately the LORAN-C coverage in the area was excellent. A differential hyperbolic LORAN-C navigation system was utilized. A LORAN-C buoy, on loan from the USCG, was moored in the centre of the target area. Because the required accuracy (100 m) was available using the basic LORAN-C coverage, the LORAN-C buoy data was not utilized.

A Datawell non-directional wave rider buoy was deployed near the centre of the area. Onboard processing, display and storage of wave data was achieved through the use of a VHF telemetry link and a portable micro-computer.

Remote reading Weathermeasure Model 5121-B temperature/humidity sensors contained within self-aspirating shields were mounted on either side of the vessel. Measurements of the temperature and humidity on the windward side of the vessel were made very hour.

The ship's own meteorological instrumentation was utilized by trained weather observers to measure, on an hourly basis, temperature, humidity, wind speed and direction, barometric pressure, and sea surface temperature. In addition, these observers recorded sky conditions, prevailing visibility, precipitation, degree of whitecapping, and other pertinent data.

3.0 DATA COLLECTION AND METHODOLOGY

It was considered to be very important that the data collection methodology be standardized and compatible with that utilized by the USCG in similar experiments. This would ensure that the results could be directly utilized by both Canada and the United States and indeed other countries undertaking research in this area. Thus the

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methodology employed is essentially the same as that utilized by the USCG in their visual detection experiments.

Approximately 20 single point target moorings were distributed over the experiment area. Targets were normally placed at 10 of these moorings. The experiment was broken into a series of simulated searches averaging 4 to 5 hours in length. The targets were a mixture of 4 and 6-man life rafts.

After deployment of all the targets the ship was moved to a position well outside the radar and visual horizon. A search pattern was derived. During the search each detection was recorded manually along with the appropriate data (range, bearing, time, system parameters, etc.).

4.0 DATA REDUCTION AND ANALYSIS METHODOLOGY

The analysis methodology that was employed followed, in general, USCG procedures for visual detection experiments and involved a multivariate regression technique to compute a relationship between various independent variables and the probability of search object detection. In addition to lateral range, relevant independent regressors include attributes of the search object, and environmental conditions (for example, significant wave height). Sweep width, the parameter used in search planning is determined by integrating the probability of detection with respect to lateral range for particular values of the significant independent variables.

Prior to performing the analysis, a data reduction task was undertaken. A semi-automated procedure was developed to assist in verifying target detections and for computing the lateral range or closest point of approach (CPA) of the detection opportunities. After manually scrutinizing the detection data, the successfully detected opportunities were flagged in the opportunities files. The data for individual searches were combined by search type forming the following files:

1. Night vision goggles visual opportunity/ detection file,
2. Night search for canopy lights opportunity/ detection file.

The records also contained the observed environmental conditions at the time of detection or, in the case of missed opportunities, at the time of CPA.

The multivariate regression technique was used to determine the statistically significant parameters. The variables were preselected and checked for their significance at the 90 percent confidence level in an interactive procedure. Those variables which did not contribute significantly were rejected from the analysis.

5.0 RESULTS

Night Vision Goggle Searches for unilluminated Life Rafts

The results are based on only 2 searches with a total search time of 11.6 hours.

The factors tested for in the multivariate regression analysis were:

- lateral range
- wind speed
- sea state (significant wave height)
- visibility
- precipitation
- cloud cover
- target type (4- or 6-man life raft)

The analysis showed that only lateral range had a significant effect on the probability of detection (P).

Figure 1 shows the resultant POD versus lateral range curve. The corresponding sweep width is 1.36 nautical miles (nmi).

Night Visual Searches for Life Rafts with Lights

The results are based on only 4 searches with a total search time of 32.5 hours. Although more searches did take place, it was discovered that the canopy lights were not operating at full illumination all the time. Those searches for which the illumination was low were subsequently eliminated from the analysis. The searches were conducted in the same manner as the day light visual searches with the look-outs utilizing binoculars.

The factors tested for in the multivariate regression analysis were:

- lateral range
- wind speed
- sea state (significant wave height)
- visibility
- percent cloud cover
- target type (4- or 6-man life raft).

The analysis showed that lateral range was the only significant factor. Figure 2 shows the probability of detection versus lateral range curve. The derived sweep with is 2.2 nmi. Although this is only based on 4 searches the spread in the data is low so that some confidence can be placed in this result.

6.0 DISCUSSION

It is noted that in the analysis of both these data sets it was seen that either wind speed or sigificant wave height could have been considered significant parameters at slightly lower

confidence levels, say 80% to 85%. This may be attributed to the fact that wind speed and significant wave height are loosely related to each other. It is felt that a larger data set would be required to accurately determine their true significance.

No estimates of sweep width for night searches for life rafts equipped with standard lights have been reported previously. However the National Search and Rescue Manual (DND and CCG, 1985) does provide estimated sweep widths (in darkness) for similar devices. These are compared with the NORDCO result in Table 2. Table 3 shows sweep widths derived by the USCG for white strobe life ring lights. An inspection of Tables 2 and 3 suggests that the National Search and Rescue Manual estimates may be high while the USCG results for life ring strobe lights are more comparable to those of the NORDCO results when the differing variable of ship size, environmental condition, and light height are taken into account.

Another interesting comparison can be made. For the prevailing condition encountered, the sweep width derived for this type of search is greater than the day light visual sweep width (1.2 - 1.5 nmi) now employed operationally.

The searches involving the night vision goggles are believed to be the first of their kind ever undertaken. The small data set and the wide spread in the data suggests that a low level of confidence should be placed in the sweep width value obtained (1.3 nmi). Plus, the particular night vision goggles used were meant to operate with some sky light available. The 100% cloud cover was not optimum for their operation.

In Table 4 a summary of the environmental conditions under which this data was collected is provided.

7.0 ACKNOWLEDGEMENTS

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8.0 REFERENCES

Department of National Defence and Canadian Coast Guard, 1985. National Search and Rescue Manual. Dept. of National Defence B-GA-209-001/FP-001, Canadian Coast Guard TP5421, Ottawa.

Litton Model M-912A/M-915A	
Magnification	1.0 X
Field of View	40 degrees
Resolution (limiting)	.68 Lp/mR
Brightness gain (M-912A)	1000
(M-915A)	1700
Litton Model M-927	
Magnification	1.0 x ± 5%
Field of View	40 degrees
Resolution, on Axis (min)	.68 Lp/mR
Brightness gain	1200

TABLE 1 - NIGHT VISION GOGGLES GENERAL SYSTEM CHARACTERISTICS

DETECTION AID	ESTIMATED SWEEP WIDTH (NAUTICAL MILES)
Life Raft Canopy Light (From NORDCO Experiment)	2.2
Electric Floating Lantern	1.0
Hand Flashlight	3.0
Strobe LifeJacket Light	3.5

Table 2 - Comparison Between NORDCO Limited Derived Sweep Width for Life Raft Canopy Lights and Estimates from the National Search and Rescue Manual for Similar Devices

SEARCH PLATFORM	TIME ON TASK (HOURS)			
	1		3	
	WIND SPEED (KNOTS)			
	6	15	6	15
41 Foot Utility Boat	3.9	2.6	2.1	1.1
82/95 Foot Work Boat	3.9	2.6	2.1	1.1

Mean Experiment Environment Conditions

Cloud Cover (Tenths): 0.6

Significant Wave Height (Feet): 2.4

TABLE 3 Sweep Width Values (NMI) for White Strobe Life Ring Lights Derived from USCG Experiments

Nighttime Visual Searches (Lights On Rafts)				
#	VISIBILITY (nm)	WIND (T,kt)	HS (m)	NOTES
1	15+ BCMG 5	SSE 20 VRG NWLY 8	1.0 INCR 1.4	MAINLY WIND-WAVE
3	10 BCMG 15	SW-W 15	2.0 BCMG 1.4	
24	12 BCMG 15	NNW 32-40	2.5 BCMG 2.3	WIND-WAVE ONLY
25	15	NWLY 25-40	2.2 BCMG 1.9	WIND-WAVE ONLY
Night Vision Goggles Searches				
#	VISIBILITY (nm)	WIND (T,kt)	HS (m)	NOTES
20	4-6	SW 25-30 VRG NW 25	1.8-2.0	WIND-WAVE ONLY
22	15	NW 10 BCMG 20	0.9-1.1	MAINLY SW SWELL

TABLE 4 - ENVIRONMENTAL CONDITIONS

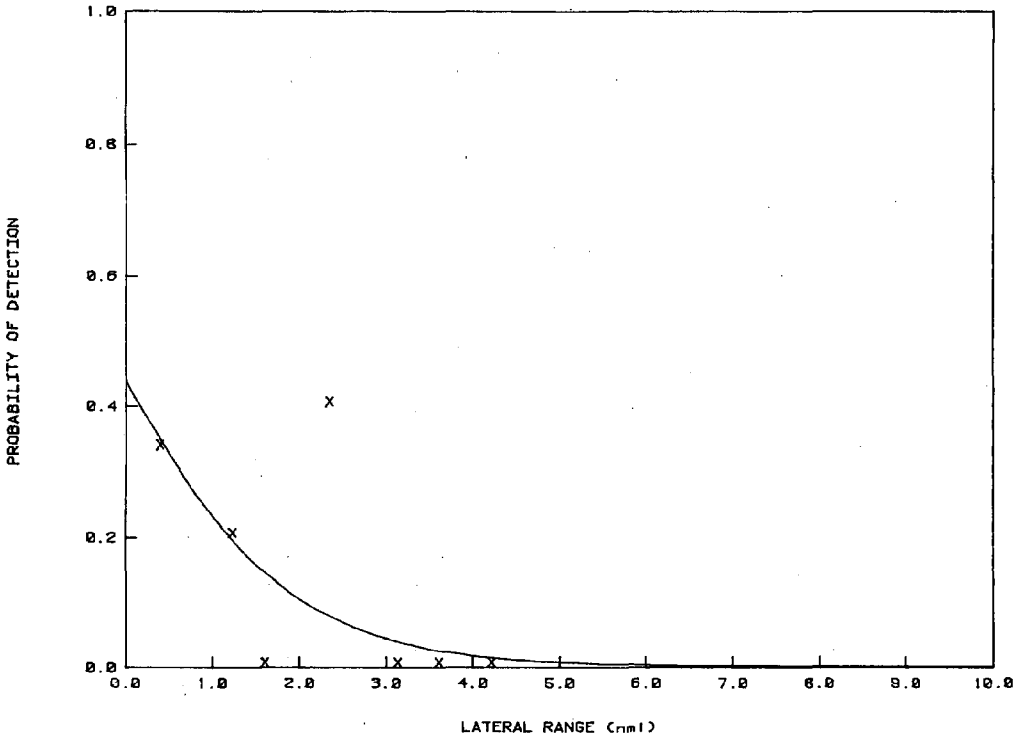

FIGURE 1 Night Vision Goggles Probability of Detection VS Lateral Range Curve

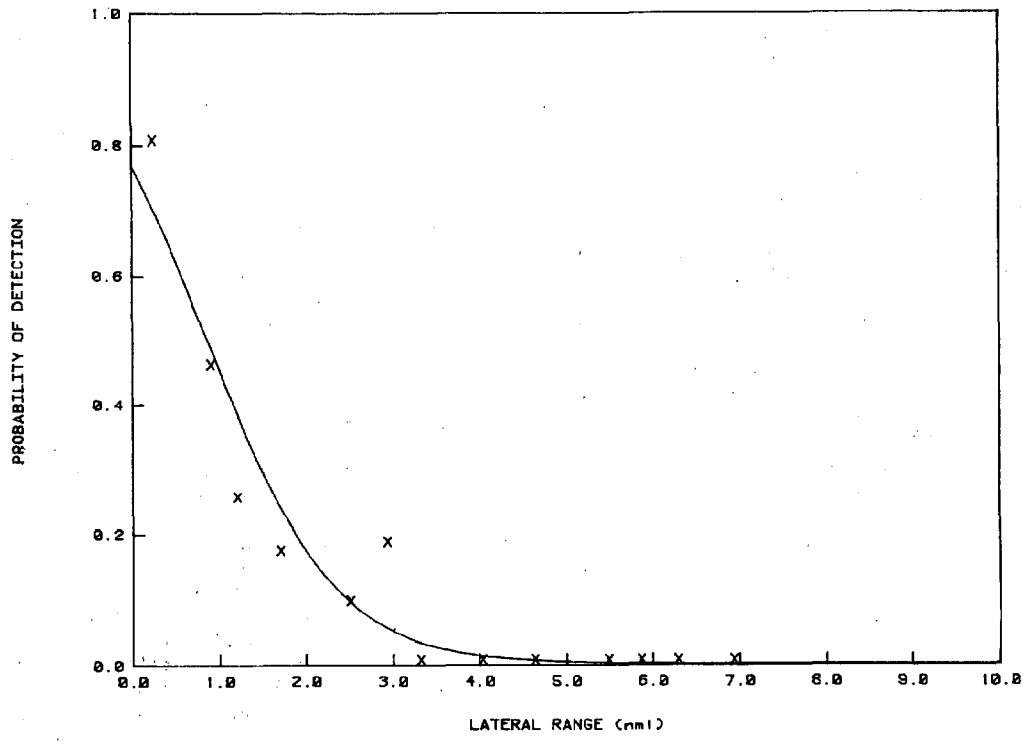

FIGURE 2 Night Search for Lights Probability of Detection VS Lateral Range Curve

RESULTS OF A CANADIAN SHIPBORNE RADAR SEARCH AND RESCUE DETECTION EXPERIMENT

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ABSTRACT

In the fall of 1987, a marine radar shipborne search and rescue detection experiment was undertaken off Nova Scotia employing the Canadian Coast Guard ship "Sir William Alexander". United States Coast Guard (USCG) visual search experiment methodology was employed. The targets were 4 and 6-man life rafts, some with $2m^2$ Lunenburg lenses mounted on high flyer buoys at a height equal to that of the canopy top of 4-man life rafts, and a small search and rescue radar transponder deployed on the ocean surface. The radar systems used were the Sperry 340, the Sperry 4016 and the new Raytheon Pathfinder ST radar. The number of searches and the target type varied for each radar. The sweep widths were very narrow for all but the radar transponder.

1.0 INTRODUCTION

During the period from mid October to the last week of November, 1987, a multifaceted ship based search and rescue detection experiment took place on the Canso Bank off Nova Scotia, Canada. The primary objectives of the experiments were to obtain visual sweep width information for Canadian Coast Guard (CCG) vessels under typical Canadian conditions; to add to the United States Coast Guard (USCG) data base on visual detection information for sea states 3 to 5, to determine sweep widths for standard ship's radars against unenhanced and radar reflector equipped life rafts; and to determine the sweep width improvement that might be achieved using marine radars with more sophisticated signal processing. The targets used were commercial 4-man orange canopied life rafts and canopied 6-man yellow military life rafts. In addition to the basic experiment visual night searches were undertaken for life rafts equipped with canopy lights and for unilluminated life rafts using night vision goggles supplied by the USCG. Detection experiments were also conducted utilizing targets equipped with search and rescue x-band radar transponders. This paper provides the results of the radar experiments.

2.0 THE EQUIPMENT

The vessel used was the CCGS "Sir William Alexander", a 1100 class Coast Guard buoy tender/icebreaker. The ship had an overall length of 85 metres (m), a beam of 16 m and a displacement of 3728 tonnes. It was equipped with a flume stabilization system which acted to significantly dampen the natural roll of the vessel. A large A-Frame support for the ship's crane was located just aft of the fo' c's le. The height of the top of the A-Frame was such that it was just below the height of the radar antenna.

The ship was equipped with 2 Sperry radar systems: a conventional x-band system (Sperry 4016) and a Sperry 340 radar equipped with a Collision Avoidance System. A Raytheon Pathfinder ST radar system was installed for the latter half of the experiment. Table 1 provides a summary of the major system parameters pertinent to each radar. The radars are similar and it is felt that the only significant difference among them is the signal processing utilized.

The passive radar reflectors used were LENSREF (Lunenberg lens type) reflectors made by the Maritime Facilities Co., Ltd. of Japan). The reflectors have a minimum 2 square metre radar cross section in the horizontal plane and have a 25° wide vertical reflection pattern.

The radar transponders were Mitsubishi Electric Corporation MELSWEEP Model H units. The transponder radiated omnidirectionally in the horizontal plane and up to 40° in the vertical plane. The effective radiated power was nominally 400 milliwatts. Once interrogated the unit responds with a signal that sweeps from 9.34 to 9.48 GHZ. A train of radar "blips" are transmitted extending outward from the transponder's position.

Precise navigation information was essential to the experiment in order to determine ranges to valid target detections and opportunities. Fortunately the LORAN-C coverage in the area was excellent. A differential hyperbolic LORAN-C navigation system was utilized. A LORAN-C buoy, on loan from the USCG, was moored in the centre of the target area. Because the required accuracy (100 m) was available using the basic LORAN-C coverage, the LORAN-C buoy data was not utilized.

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A Datawell non-directional wave rider buoy was deployed near the centre of the area. Onboard processing, display and storage of wave data was achieved through the use of a VHF telemetry link and a portable micro-computer.

Remote reading Weathermeasure Model 5121-B temperature/humidity sensors contained within self-aspirating shields were mounted on either side of the vessel. These sensors were to be used to determine the presence or absence of microwave ducting and the subsequent derivation of its effect on the sweep width. Unfortunately both the humidity sensors failed shortly after installation. As a substitute, the humidity derived from the ship's instrumentation was used.

The ship's own meteorological instrumentation was utilized by trained weather observers to measure, on an hourly basis, temperature, humidity, wind speed and direction, barometric pressure, and sea surface temperature. In addition, these observers recorded sky conditions, prevailing visibility, precipitation, degree of whitecapping, and other pertinent data.

3.0 DATA COLLECTION AND METHODOLOGY

It was considered to be very important that the data collection methodology be standardized and compatible with that utilized by the USCG in similar experiments. This would ensure that the results could be directly utilized by both Canada and the United States and indeed other countries undertaking research in this area. Thus the methodology employed is essentially the same as that utilized by the USCG in their visual detection experiments.

Approximately 20 single point target moorings were distributed over the experiment area. Targets were normally placed at 10 of these moorings. The experiment was broken into a series of simulated searches averaging 5 to 6 hours in length. The targets were a mixture of:

1) empty life rafts;
2) life rafts with LENSREF radar reflectors mounted inside (suspended from the canopy);
3) LENSREF reflectors mounted on spare buoys at a height of 1.1 metres (simulating mounting at canopy height), and,
4) radar transponder deployed on the ocean surface.

After deployment of all the targets the ship was moved to a position well outside the radar and visual horizon to any of the targets. A search pattern was derived. Radar operators were deployed at the appropriate radars. Where necessary screening was used to prevent the operators from receiving visual clues. The operator was changed every hour and given a one hour rest. During the search each detection was recorded manually along with the appropriate data (range, bearing, time, system parameters, etc.).

4.0 DATA REDUCTION AND ANALYSIS METHODOLOGY

The analysis methodology that was employed followed, in general, USCG procedures for visual detection experiments and involved a multivariate regression technique to compute a relationship between various independent variables and the probability of search object detection. In addition to lateral range, relevant independent regressors include attributes of the search object, and environmental conditions (for example, significant wave height). Sweep width, the parameter used in search planning is determined by integrating the probability of detection with respect to lateral range for particular values of the significant independent variables.

Prior to performing the analysis, a data reduction task was undertaken. A semi- automated procedure was developed to assist in verifying target detections and for computing the lateral range or closest point of approach (CPA) of the detection opportunities. After manually scrutinizing the detection data, the successfully detected opportunities were flagged in the opportunities files. The data for individual searches were combined in individual files for each radar.

The records also contained the observed environmental conditions at the time of detection or, in the case of missed opportunities, at the time of CPA.

The records were sorted by lateral range then binned using an iterative procedure to ensure that the equal size bins each contained approximately the same number of records and that no bins were empty. Finally, the percentage of targets detected in each bin was calculated.

For the passive radar targets a multivariate linear-regression technique was used to determine the statistically significant parameters. The variables are preselected and checked for their significance at the 90 percent confidence level in an interactive procedure. Those variables which do not contribute significantly are rejected from the analysis.

Plots of the percentage of radar targets detected versus lateral range, however, suggested that the choice of an exponential model normally used for visual detection analysis was not appropriate for each of the radar detection data for all of the target types except the SAR transponder. Indeed, it is clear that the detection process for these passive radar targets is quite different from that of visual detection. The radar operator has to detect the target against a competing noise or clutter background. A number of detections often must occur before the operator can identify a "blip" on the screen as a target. Quite often a "mental pattern recognition - like process" is required to identify the blip as a target. If the target enters the zone of significant sea clutter, surrounding the ship in the near range it quite probably is lost again, and the

probability of detection curve as a function of range may actually decline in this area. Thus, intuitively, a monotonic exponential function is probably not applicable for computation of the probability of detection as a function of lateral range in this case. No other model has been proposed to date, and it was decided that a cubic spline curve fitting routine was the most appropriate to fit a curve to the percent detected data. The curve was extrapolated from the first bin back to zero lateral range. The sweep widths for various target types using the three radar systems were then computed by numerically integrating the area under the empirically derived curves.

Quite often the first detection of the transponder occurred when the first response was received. Had the response not had a series of radial delay lines associated with it the target could no doubt have not been detected by the operator. This distinctive response would also no doubt enable easy detection in sea clutter and no reduction in the probability of detection in clutter. It was quite characteristic for the radar operator to recognize the target at the first detection although it may have only been seen on one sweep. By the time the next single detection occurred (after as much as 5 to 10 full radar scanner sweeps later) the operator was able to obtain a range and bearing to the target. In this manner, with the transponder's distinctive response, the human detection process is the same as that for visual detections. It was therefore considered appropriate to use the exponential curve and the standard visual analysis technique to determine the probability of detection versus lateral range relationship and the resultant sweep width for the transponder.

5.0 RESULTS

The factors tested for each target type in the analysis for each were: lateral range, wind speed, sea state (significant wave height) and the presence of ducting. The analysis showed that lateral range was the only significant factor. Table 2 summarizes the results, giving derived sweep widths for the target types for each radar. Table 3 provides a summary of the environmental conditions encountered. With the exception of the life rafts, for which all three radars were tested, and in which the standard Sperry had a 0.0 sweep width, each pair gave essentially the same sweep width. Figures 1 to 4 show the POD versus lateral range curves for the various radars and targets. As already noted with the exception of the transponder, these are based on splined fits. The fitted curves and even the data points, in most cases, show a reduction in the near range.

Figures 5 and 6 are polar diagrams divided into areas of equal size. The numbers indicate the number of detections. The Sperry radar (both the 340 CAS and the 4016) detections are shown separately from those of the Raytheon radar. The transponder results are not shown. The fewest detections occurred directly ahead where the large A-frame was located. In both figures there were more detections in the first and third quadrants and there were more detections on the starboard side. Overall there were more detections in the aft sections.

6.0 DISCUSSION

General Issues

The sweep width results provided for all but the transponder should be viewed in light of the methodology used to derive the sweep width values. The extrapolation of the curve to zero lateral range is likely to lead to some error in computation of sweep width. Further work will be required to develop an appropriate model for radar detection data.

An examination of the plots of probability of detection versus lateral range indicates that a substantially reduced or zero probability notch will occur around zero lateral range. This, as already noted, is probably due to sea clutter limiting detection and/or the A-Frame structure which might limit radar visibility for short lateral ranges. The question arises as to whether the search track spacing should be sufficiently less than the derived sweep width to provide overlap in the gap. Further investigation is obviously necessary to resolve this issue. For the purposes of the following discussions the sweep width has been kept as is.

It was quite obvious during the experiment that one of the major problems in detecting the radar targets was that they were physically obscured a considerable portion of the time by large waves. This, then, is probably the primary reason for the reflector at canopy height giving the substantial improvement.

Radar operator motivation was clearly a problem. Each operator was relieved after 1 hour in order to obtain the best performance as indicated by the simulator experiment. Some operators liked the Raytheon display while others preferred the standard PPI display. Some operators sometimes became pre-occupied with the Automtic Radar Plotting Aid (ARPA) functions on the Raytheon system, while others were reluctant to adjust any of the displays to ensure optimum detection performance.

Comparison Among Radars

Table 2 summarized the sweep widths derived. It is clear that for the weakest targets the more sophisticated radars outperformed the standard marine radar, although even their sweep widths were probably negligible. For the remainder of the targets there was no significant difference between the Sperry 340 or the Raytheon radar and the standard radar. This would initially suggest that there was no significant difference between the performance of the more advanced radars and

that of the standard radar except in the case of the weakest targets. Since these weak targets were detected at the edge or within the zone of significant sea clutter it would appear that the more advanced processing had its greatest benefit within that zone.

Effect of Passive Reflector Enhancement

Table 2 suggests that placing 2 m^2 passive radar reflectors within life rafts has little benefit over not using a reflector at all. However, placing the reflector at canopy height shows a substantial improvement. In fact, the sweep width derived is greater than that of the normally used visual sweep width for comparable conditions.

Radar Transponder

Both the radars tested gave about the same performance against the transponders. The sweep width is about 6 to 7 times greater than that for a visual search under comparable conditions as specified by the National Search and Rescue Manual.

The high performance of the radar transponder was only due to it being an active device. The detection process, as described earlier was the same as that of visual detection. As noted earlier one of the major problems observed in detecting targets on the radar was that they were physically obscured by waves. It is evident from the passive reflector results that had the transponder been placed at canopy height then a considerably greater sweep width would have been potentially obtained.

Look Direction Selectivity

Simulator experiment (Finlayson et al., 1988) results indicated certain biases as to where the radar operators looked. The small number of detections available from the experiment does make it difficult to make direct comparisons. However, some general comments can be made. The Raytheon System was grouped separately from the other two radars because of its very different raster display.

As with the simulator experiment more targets were detected on the starboard side. The simulator results suggested a slight bias to the forward section. The result here might be partially explained by the large A-frame structure on the ship forward of the radars, which quite likely partially obstructed the view directly head for all three radars. This would have reduced detections in the forward section as is evident from the polar diagrams which show overall minimal detections in the the 30° to 330° sector.

The lowest number of detections overall occurred in the fourth quadrant, while the lowest number in the simulator experiment occured in the third quadrant. The slightly lower number in the second quadrant in the case of the Raytheon radar is likely to have been a direct consequence of the shadow area created by the ship's mast. This mast was behind and slightly to the right of the radar antenna, creating a shadow area covering the 150° - 180° zone.

The radar shadow areas (A-Frame and mast) noted in the preceding paragraphs and the corresponding reductions in the number of detections suggests that such factors will cause variations in the radar sweep width for individual ships.

Finally, no significant differences were found between the detection distribution of the Raytheon raster display and the standard PPI displays. This suggests that display type does not affect operator look direction biases, an indication that training is the primary factor.

ACKNOWLEDGEMENTS

This work was funded by the CCG and the Transportation Development Centre. The authors wish to thank the staff of the CCG, Maritime Region for their support and co-operation, especially Mr. Bernard Leonard and the officers and crew of the CCGS "Sir William Alexander". We also thank the USCG for its support and participation.

REFERENCE

Finlayson, D., D. Bryant, B.R. Dawe, and A.J. Armstrong, 1988. Results of an Experiment to Examine Certain Human Factors Relating to Searches Conducted with Marine Radar - Submitted to Oceans '88.

SYSTEM PARAMETERS	RADAR		
	SPERRY 4016	SPERRY 340	RAYTHEON PATHFINDER
Peak Power (KW)	50	50	25
Wave Guide Loss (db) (Estimated, 2-way)	6	5.5	1.0
Antenna Height (metres)	23.9	20.6	17.9
Beamwidth (3db) Vertical Horizontal	25° 0.8°	25° 0.8°	25° 1°
Pulse Length (US)	0.07/0.25/1.2	0.07/0.25/1.2	0.08/0.25/0.75/1.0
Pulse Repetition Frequency (HZ)	4000/2000/500	3200/1600/530	3000/2000/1000/750
Receiver noise Figure (db)	8.5	8.5	7.5 db
Display	16 inch PPI	16 inch PPI	23 inch raster
Processing		CFAR	Binary pulse to pulse and scan-to-scan correlation

TABLE 1 - Major Characteristics of Marine Radars Used in Experiment

RADAR	SWEEP WIDTH (NMI)			
	RAFT	RAFT WITH REFLECTOR	REFLECTOR ON SPAR BUOY	TRANSPONDER
Sperry 4016 (Standard)	0.0	0.6	1.6	8.8
Sperry 340	0.4	0.5	Not Tested	Not Tested
Raytheon	0.3	Not Tested	1.8	8.7

TABLE 2 - Summary of Marine Radar Sweep Widths Derived From Experiment

RADAR	WIND SPEED (kts)	SIGNIFICANT WAVE HEIGHT (m)
Sperry 4016	Lgt. - 43	0.6 - 3.0
Sperry 340	8 - 43	0.9 - 3.0
Raytheon Pathfinder	Lgt. - 37	0.6 - 2.5
Radar Against Transponders	6 - 30	0.9 - 2.0
Dominant Conditions	20 - 30	1.0 - 2.0

TABLE 3 - Summary of Environmental Conditions

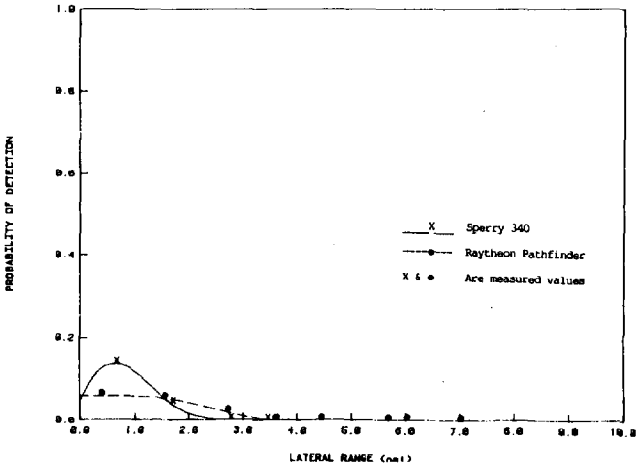

FIGURE 1 Derived Radar Probability of Detection versus Lateral Range Relationship against 4 and 6-man Life Rafts

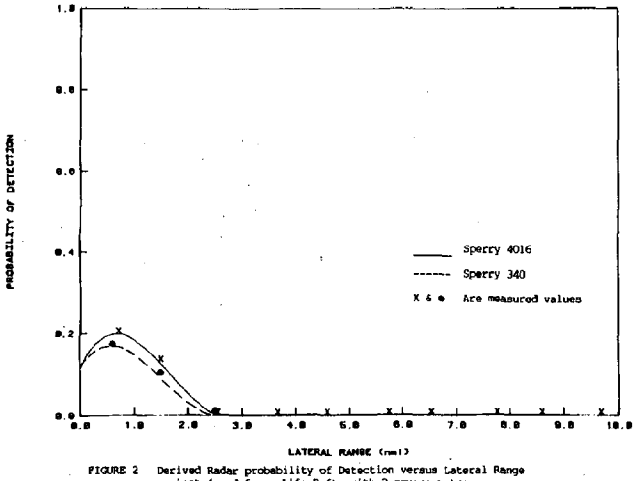

FIGURE 2 Derived Radar probability of Detection versus Lateral Range against 4 and 6-man Life Rafts with 2 square metre Reflectors Mounted Inside

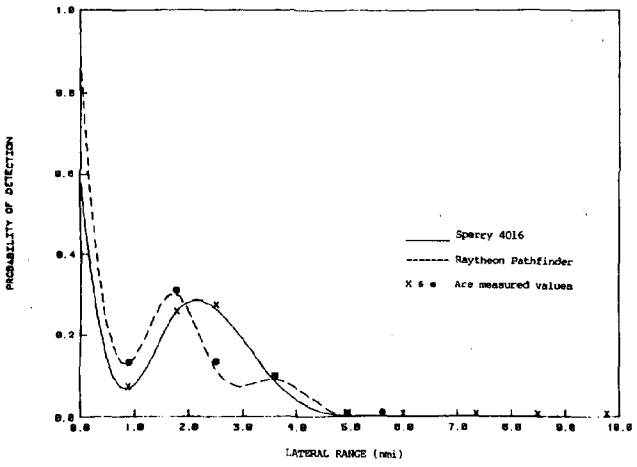

FIGURE 3 Derived Radar Probability of Detection versus Lateral Range against 2 square metre Reflectors Mounted at 4-man Life Raft Canopy Height

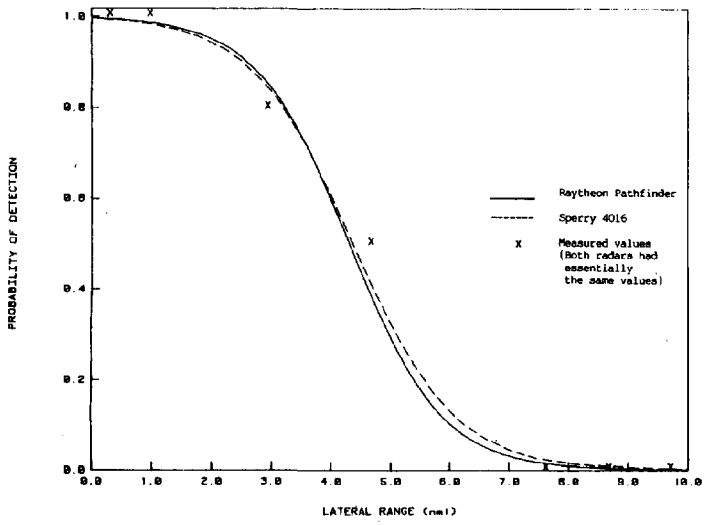

FIGURE 4 Derived Radar Probability of Detection versus Lateral Range Relationship Against Radar Transponders

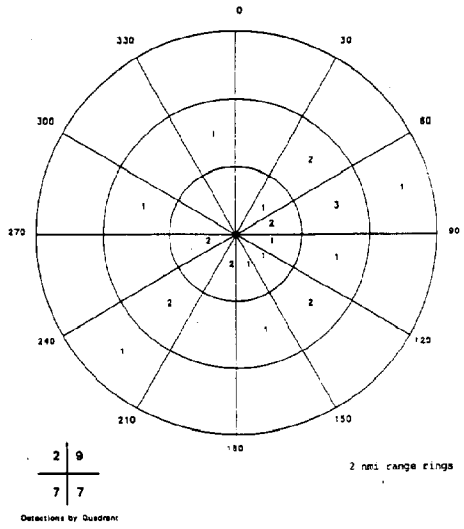

Figure 5 Relative Target Detection Positions for the Sperry 4016 and 340 Radar Systems

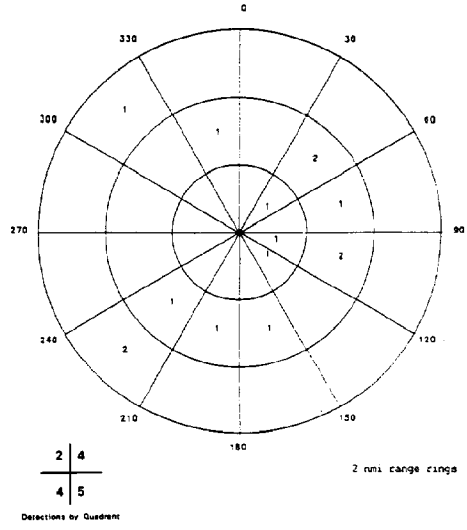

Figure 6 Relative Target Detection Positions for the Raytheon Pathfinder ST Radar System

RESULTS OF A CANADIAN VISUAL SEARCH AND RESCUE DETECTION EXPERIMENT

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ABSTRACT

In the fall of 1987, a marine shipborne search and rescue detection experiment was undertaken off Nova Scotia employing the Canadian Coast Guard ship "Sir William Alexander". United States Coast Guard (USCG) visual search experiment methodology was employed. The targets were 4 and 6-man life rafts. Searches for these rafts were carried out by visual observers.

1.0 INTRODUCTION

During the period from mid October to the last week of November, 1987, a multifaceted ship based search and rescue detection experiment took place on the Canso Bank off Nova Scotia, Canada. The primary objectives of the experiments were to obtain visual sweep width information for Canadian Coast Guard (CCG) vessels under typical Canadian conditions; to add to the United States Coast Guard (USCG) data base on visual detection information for sea states 3 to 5, to determine sweep widths for standard ship's radars against unenhanced and radar reflector equipped life rafts; and to determine the sweep width improvement that might be achieved using marine radars with more sophisticated signal processing. The targets used were commercial 4-man orange canopied life rafts and canopied 6-man yellow military life rafts. In addition to the basic experiment visual night searches were undertaken for life rafts equipped with canopy lights and for unilluminated life rafts using night vision goggles supplied by the USCG. Detection experiments were also conducted utilizing targets equipped with search and rescue x-band radar transponders. This paper provides the results of the visual searches for life rafts.

2.0 THE EQUIPMENT

The vessel used was the CCGS "Sir William Alexander", a 1100 class Coast Guard buoy tender/ icebreaker. The ship had an overall length of 85 metres (m), a beam of 16 m and a displacement of 3728 tonnes. It was equipped with a flume stabilization system which acted to significantly damp the natural roll of the vessel.

Precise navigation information was essential to the experiment in order to determine ranges to valid target detections and opportunities. A differential hyperbolic LORAN-C navigation system was utilized. A LORAN-C buoy, on loan from the USCG, was moored in the centre of the target area. Because the required accuracy (100 m) was available using the basic LORAN-C coverage, the LORAN-C buoy data was not utilized.

A Datawell non-directional wave rider buoy was deployed near the centre of the area. Onboard processing, display and storage of wave data was achieved through the use of a VHF telemetry link and a portable micro-computer.

Remote reading Weathermeasure Model 5121-B temperature/humidity sensors contained within self-aspirating shields were mounted on either side of the vessel. Measurements of the temperature and humidity on the windward side of the vessel were madeevery hour.

The ship's own meteorological instrumentation was utilized by trained weather observers to measure, on an hourly basis, temperature, humidity, wind speed and direction, barometric pressure, and sea surface temperature. In addition, these observers recorded sky conditions, prevailing visibility, precipitation, degree of whitecapping, and other pertinent data.

3.0 DATA COLLECTION AND METHODOLOGY

It was considered to be very important that the data collection methodology be standardized and compatible with that utilized by the USCG in similar experiments. This would ensure that the results could be directly utilized by both Canada and the United States and indeed, other countries undertaking research in this area or using derived sweep widths in SAR missions. Thus the methodology employed is essentially the same as that utilized by the USCG in their visual detection experiments.

Approximately 20 single point target moorings were distributed over the experiment area. Targets were normally placed at 10 of these moorings. The experiment was broken into a series of simulated searches averaging 4 to 5 hours in length. The targets were a mixture of 4 and 6-man life rafts.

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After deployment of all the targets the ship was moved to a position well outside the radar and visual horizon. A search pattern was derived. During the search each detection was recorded manually along with the appropriate data (range, bearing, time, system parameters, etc.).

4.0 DATA REDUCTION AND ANALYSIS METHODOLOGY

The analysis methodology that was employed followed, in general, USCG procedures for visual detection experiments and involved a multivariate regression technique to compute a relationship between various independent variables and the probability of search object detection. In addition to lateral range, relevant independent regressors include attributes of the search object, and environmental conditions (for example, significant wave height). Sweep width, the parameter used in search planning is determined by integrating the probability of detection with respect to lateral range for particular values of the significant independent variables.

Prior to performing the analysis, a data reduction task was undertaken. A semi-automated procedure was developed to assist in verifying target detections and for computing the lateral range or closest point of approach (CPA) of the detection opportunities. After manually scrutinizing the detection data, the successfully detected opportunities were flagged in the opportunities files. The opportunity/detection data for individual searches were combined by search type; the file records also contained the observed environmental conditions at the time of detection or, in the case of missed opportunities, at the time of CPA.

The multivariate regression technique was used to determine the statistically significant parameters. The variables were preselected and checked for their significance at the 90 percent confidence level in an interactive procedure. Those variables which did not contribute significantly were rejected from the analysis.

5.0 RESULTS

The factors tested for significance in the multivariate regression analysis for the day light visual searches were:

- lateral range
- wind speed
- sea state (significant wave height)
- visibility
- precipitation
- cloud cover
- target type (4- or 6-man life raft)

The analysis showed that the optimum regression model in the maximum log-likelihood sense consisted of lateral range, visibility, significant wave height, and raft type.

Table 1 shows a comparison of sweep width values obtained using this model with USCG sweep widths for various values of the regression parameters.

6.0 DISCUSSION

Table 1 shows newly derived sweep width values developed by the USCG from experimental results which are to be incorporated in Canada's National Search and Rescue Manual. Referring to Table 2 it can be seen that the environmental conditions for this experiment are generally closer to the higher wind speed and sea state conditions listed in the table. It can be seen from Table 1 that the NORDCO Limited derived sweep widths under all conditions are approximately a factor of two greater than the values derived by the USCG for smaller vessels. A great deal of confidence may be placed in this result as the maximum log-likelihood model used for analysis shows a near perfect fit has been obtained. The major difference between the USCG experiments and this experiment is the size, stability, and overall seakindliness of the vessel. The CCG vessel was much larger than the USCG 90 ft. work boats and was equipped with an efficient flume stabilization system. The results indicate that a more stable search platform greatly enhances search detection performance.

An interesting result here is the significance of the raft type parameter which was specified as either a 4 or a 6 to represent the number of men each raft was designed to support. The larger 6-man life raft was constructed of yellow fabric while the 4-man life raft was international orange in colour. Further work needs to be conducted to determine the significance of the size and colour of the search object.

7.0 ACKNOWLEDGEMENTS

This work was funded by the CCG and the Transportation Development Centre. The authors wish to thank the staff of the CCG, Maritime Region for their support and co-operation, especially Mr. Bernard Leonard and the officers and crew of the CCGS "Sir William Alexander". We also thank the USCG for its support and participation.

8.0 REFERENCES

Department of National Defence and Canadian Coast Guard, 1985. National Search and Rescue Manual. Dept. of National Defence B-GA-209-001/FP-001, Canadian Coast Guard TP5421, Ottawa.

SWEEP WIDTH SOURCE	VISIBILITY (NAUTICAL MILES)	WINDS 15 KNOTS SEA 2-3 FEET		WINDS 25 KNOTS SEAS > 4 FEET	
		4-MAN RAFT	6-MAN RAFT	4-MAN RAFT	6-MAN RAFT
USCG (90 Foot Work Boat)	10	2.0	2.4	1.0	1.2
	15	2.3	2.8	1.2	1.4
NORDCO (280 Foot Icebreakers/ Buoy Tender)	10	3.7	5.1	2.5	3.8
	15	5.4	7.0	4.1	5.5

NOTE: Significant Wave Height for NORDCO Derived Sweep Width was set at 3 Feet and 5 Feet, Respectively for this Comparison

TABLE 1 Comparison of USCG Derived Sweep Widths (Nautical Miles) with those Derived from NORDCO Experiment for Similar Conditions

#	VISIBILITY (NM)	WIND (T, kt)	HS (m)	NOTES
2	15+	NW 10	1.7-1.9	MAINLY SE SWELL
4	15	SWLY 10	1.0-1.3	MAINLY SE SWELL
5	8 INCR 15	NW 25-43	1.5 INCR 2.7-3.0	WIND-WAVE ONLY
7	15+	WNW 15-20	1.0 INCR 1.5-1.7	
8	15+	SWLY 25-30	1.2 INCR 1.4	WIND-WAVE ONLY
9	15 BCMG 12	SWLY 20	1.4	WIND-WAVE ONLY
10	15+	SSE 20-28	1.1 INCR 1.4	
11	15	1.4-1.6	WIND-WAVE ONLY	
12	15+	NWLY 22-30	1.9-2.3	1.3-1.8m WIND WAVE + SELY SWELL
13	15+	LGT & VRBL	0.9-1.0	WSW SWELL ONLY
16	15+	SELY 18-28	0.9-1.1	WIND-WAVE ONLY
17	15+ BCMG 9	SELY 17-25	1.2 INCR 1.5	WIND-WAVE ONLY
18	2 BCMG 1/8	SSE 40 VRG SLY 20-25	2.3 INCR 3.0	WIND-WAVE ONLY
19	12 BCMG 5	SLY 25-30 BCMG SW15	1.6-1.8	
21	12 INCR 15	NNWLY 6-12	1.2-1.4	MAINLY SWLY SWELL
23	8 BCMG 5	NE 20-25	1.5	WIND-WAVE ONLY
26	15	NWLY 25-36	2.0-2.2	WIND-WAVE ONLY
29	15	WLY 15 BCMG SW 15-20	0.6 INCR 1.0	WIND-WAVE ONLY
30	1/8 INCR 15+	WSW 15 VRG WNW 15	2.2-2.4	MAINLY SSW SWELL
31	15	LGT & VRBL	1.8-2.1	MAINLY SSW SWELL
32	15+	SW 17-24	1.5-1.8	MAINLY SSW SWELL

TABLE 2 Environmental Conditions

A NEW COAST GUARD SEARCH TECHNIQUE

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For three years the U.S. Coast Guard Research and Development Center has been pursuing a new airborne search technique. It shows promise of detecting liferafts with a greater than 95 percent probability at a search rate of 250 square nmi per hour.

Historically the Coast Guard has used two search sensors, the eye in daytime for small objects and radar in day or nighttime for large objects. Search by aircraft has provided area coverage rates many times as great as search by boats.

However, searching by eye in an aircraft produces high levels of stress because of the area coverage rates required. Searching for a liferaft from a jet aircraft might be compared to searching the area of a slide projection for an object of dimensions only 1/300'th of the width of the screen. In addition to possibly containing the target object, the screen is filled with wave clutter. If the aircraft is flying at 2000 ft at a speed of 250 knots, the searcher must search the full area every five seconds. Because of the difficulty of performing this search in the required time, the probability of detection is typically 60 to 75 percent for a single pass, and repeated passes must be carried out if this probability is to be increased. Ofttimes the availability of equipment and personnel does not permit this.

Search for larger objects with radar is less taxing for the operator. Here the target "blip" may subtend 1/100'th of the screen dimension, and the time requirement for searching a frame is relaxed to 250 seconds.

Evidently any improved technique for searching for small objects must utilize aircraft, must have automated detection -- with a high detection probability, and must operate day or night. At the R&D Center active and passive optical techniques have been considered. It was found that the amplitudes of wave clutter are drastically reduced in the Mid and Far Infrared wavelength region. In the Far IR wave clutter signals are typically small in comparison to target self emission signals out to nadir angles of 60 degrees. Thus in a passive system automating detection is reduced to thresholding of signals and determining if the object sensed possesses the characteristics of the target desired.

Fortunately passive Far IR imaging apparatus has been developed for many applications. The apparatus nearest to the Coast Guard's search requirements is the Navy's high performance line scan IR reconnaissance equipment. Since this was developed for reconnaissance, readout is on film, which must be developed.

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However, the Coast Guard requirement is for real time imaging, which requires the addition of a real time TV presentation to this equipment. Since the number of scene pixels covered in a line scan is several times the number which can be presented in a TV display line, it has been necessary to sense the presence of a target automatically and then automatically to provide the operator with a zoomed TV presentation of the target. Thus the actions of the operator are reduced from performing a continuous taxing search to indicating occasionally if a target is the type desired.

To test the utility of this approach, services of Rochester Institute of Technology to fly an Infrared scanner plane over targets on Lake Erie were contracted. The electrical signals from the scanner were recorded on magnetic tape. This was replayed at the laboratory into an apparatus of the type mentioned. When the signals met the amplitude and length criteria, an operator cueing ("target high lighting") bar was added to the video. Targets were a 41 ft Search and Rescue boat with two liferafts tethered to the stern. Figures 1 and 2 show a sample frame of a full field video image and a zoomed portion of this field.

Current theoretical efforts include modelling probabilities of detection of small targets in different types of weather conditions. For this a model giving the temperature difference between a liferaft canopy and the sea under different atmospheric and time conditions is being developed. To this expected clutter and noise signals will be added to give probabilities of detection and false alarms.

The current experimental effort includes having the Naval Air Development Center modify a high performance IR scanner to record on magnetic tape. The equipment will be flown in a P3 over Block Island Sound under a variety of weather conditions. Then the taped signals will be replayed into a laboratory imaging apparatus intended to simulate an aircraft search station. With this the effectiveness of the overall technique will be judged. If this is favorable, equipment of this type will likely be installed in Coast Guard search aircraft.

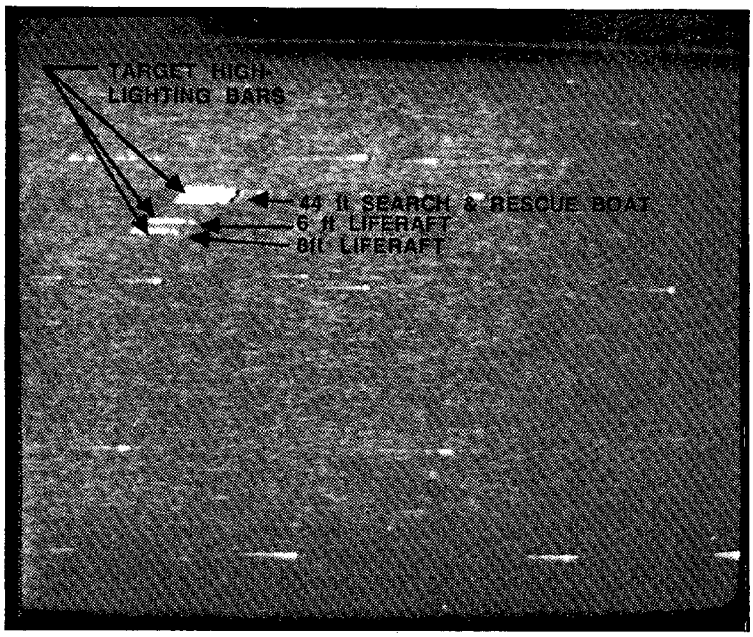

FIGURE 1. Infrared Map Showing Search and Rescue Boat and Two Liferafts.

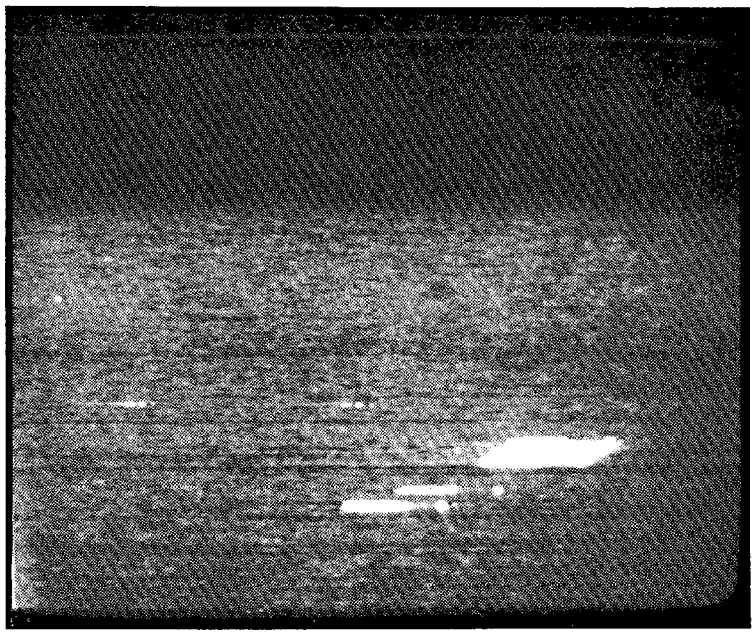

FIGURE 2. Zoomed Portion of Figure 1

ALASKA SAR FACILITY ARCHIVE AND OPERATIONS SYSTEM

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ABSTRACT

The Jet Propulsion Laboratory and the University of Alaska Geophysical Institute have initiated a task to receive, record, process, and archive Synthetic Aperature Radar (SAR) and optical images at the Fairbanks campus. Data will be acquired from the European Space Agency (ESA) E-ERS-1 and the National Space Development Agency of Japan (NASDA) J-ERS-1 spacecraft.

JPL is currently developing the Alaska SAR Facility (ASF), consisting of the Receiving Ground Station, the SAR Processing System, and the Archive and Operations System. This paper focuses on the Archiving and Operations System which catalogs and archives signal data and derived data products and provides an interactive product order function for users.

In addition, a Mission Planning Subsystem provides the capability to predict satellite swath coverage of the spacecraft, manages data acquisition requests, and produces an operations schedule for the Receiving Ground Station and the SAR Processing System.

Data products processed and archived at ASF will be available throughout the NASA research community, as well as to non-NASA researchers.

1. INTRODUCTION

The National Aeronautics and Space Administration (NASA) has issued a Memorandum Of Understanding with the European Space Agency (ESA) [1] and the National Space Development Agency of Japan (NASDA) [2] to record and process Synthetic Aperature Radar (SAR) and optical data at the University of Alaska Geophysical Institute (UAF GI) in Fairbanks. In order to implement this memorandum, JPL is currently developing the Alaska SAR Facility (ASF).

Early in 1990 the European Space Agency will launch a Remote Earth Sensing Satellite, E-ERS-1 [3] and in 1992 NASDA will launch a Japanese Earth Resources Satellite, J-ERS-1 [4]. Characteristics of the spacecraft and SAR instrument parameters are shown in Table 1. The optical sensor parameters for the J-ERS-1 spacecraft will be found in [7].

The ASF will operate 24 hours per day for at least 3 years beginning with the launch of E-ERS-1, with the goal of remaining operable for product ordering up to 10 years after the end of the last satellite transmission. The ASF will receive 5 minutes of real time SAR data from E-ERS-1, 10 minutes of real time SAR and optical data from J-ERS-1, and up to 80 minutes of J-ERS-1 recorded SAR and optical dump for NASDA.

Table 1. Spacecraft and SAR Parameters

CHARACTERISTIC	E-ERS-1	J-ERS-1
Orbit Altitude (km)	800	600
Orbit Period (min)	90	85
Orbit Inclination (deg)	98	98
Downlink Data Rate (Mbps)	105	60
Radar Transmit Frequency (GHz)	5.3 (C-band)	1.3 (L-band)
Swath Width (km)	80	75
Mbps=Megabits/sec		

2. SYSTEM DESIGN

Fig. 1 shows the ASF functional block diagram. The Receiving Ground Station (RGS) tracks the satellites based on predicted satellite locations and captures and records data specified by approved data acquisition requests and operational schedules. The SAR Processing System (SPS), which is based on an Advanced Digital SAR Processor developed at JPL [5][6], processes the data into images. These SAR products are then cataloged and archived by the AOS either on tape, magnetic disk, or 12" digital optical disk (DOD).

A Geophysical Processor System (GPS) is currently being designed and implemented at JPL and emphasis is on the SAR Ice Ocean portion (see note below). This processor will provide automated analysis of SAR imagery acquired by the ASF. In particular, the GPS will produce products for ice motion vector maps and ice classification maps. These products will be archived and distributed by the AOS. The GPS will be available to local UAF personnel and visiting science team members.

An Interactive Image Analysis System (IIAS) is a general purpose workstation co-located with the ASF which will receive data products from the AOS. This system will support research investigations by local science team members and visiting researchers at UAF. The IIAS is being developed by UAF.

The Image Processor for Optical Data (IPOD) [7] [8] is a system which will be co-located with the ASF to process data from the J-ERS-1 optical sensor and to provide for distribution of the resulting products. Only a small portion of the optical data will be processed into final products at ASF. Users will be able to order these products through the product order function of the AOS.

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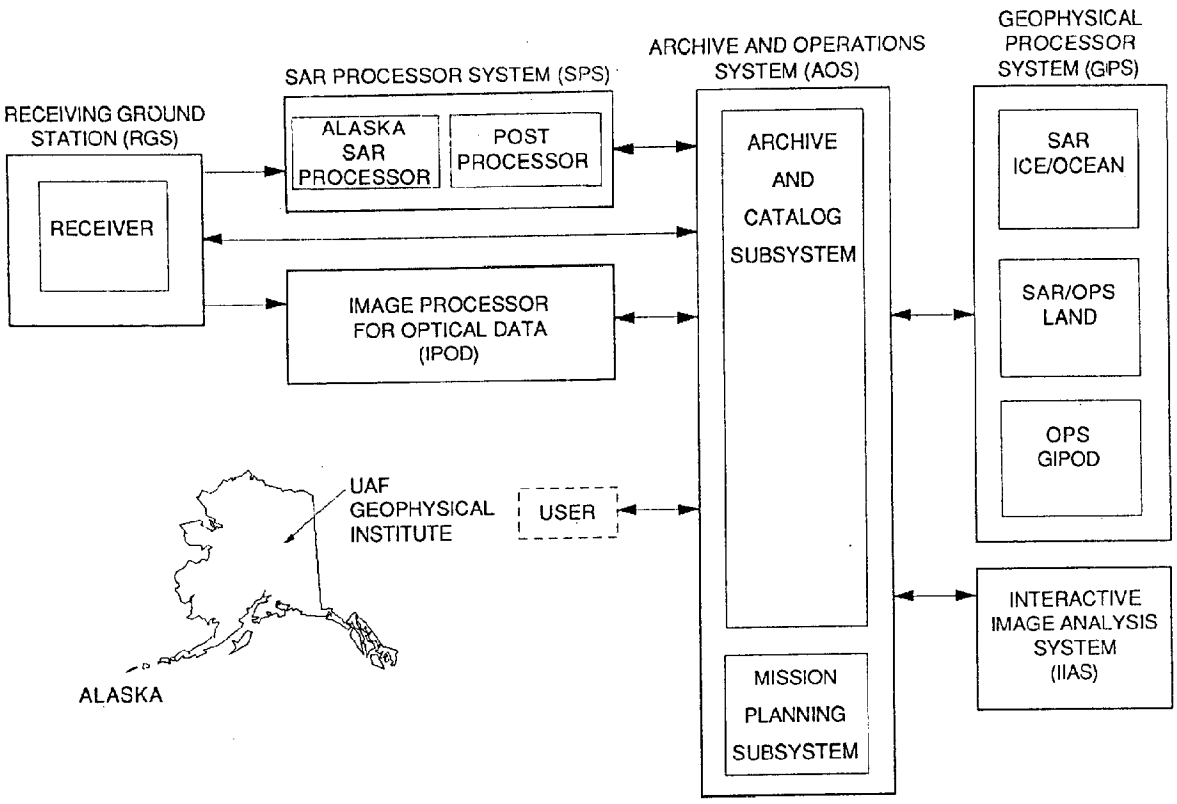

Fig. 1 ASF Functional Block Diagram

The AOS consists of an Archive and Catalog Subsystem (ACS) and a Mission Planning Subsystem (MPS) [9]. The ACS archives SAR data and products, manages information about the SAR data, products, and optical data, and also provides means to order the SAR and optical products. The MPS predicts swath coverage of the spacecraft, prepares data acquisition requests in a multi-mission environment, and provides for multi-satellite conflict analysis. The MPS also provides operational schedules for the RGS to obtain data and for the SPS to plan its activities.

The AOS software architecture will be based on the concept of a catalog system. Conceptually, a catalog system consists of directory, catalog, and inventory levels.

The directory is a level which provides the user with a brief description of what data are available at each node. These descriptions help to make an initial determination of the potential usefulness of a data set for a user's application. Information on the location of more detailed descriptions and/or the data set itself will be found in a directory.

A catalog is the next level of information granularity down from the directory and is physically located at each node. The user can gain access to the catalog from the directory. Typically, the catalog contains detailed information about whole data sets specific to a discipline, data center, and/or other facility.

The inventory provides information about data set granules usually used to identify or locate the granule(s) (see below), given the specification of the independent variable range(s).

A granule is a set of data samples. For example, a granule may be the unit of data storage in a physical medium such as magnetic tape (one tape file) or a paper chart.

The inventory is the main operational level of the ACS. The inventory is being designed with a menu driven interface which presents the user with a series of menus, or screens, which prompts and guides the user through a menu network. These menus allow the user to enter search criteria for

selecting, assessing, and ordering data. Search criteria include items such as 1) location and time of datatake, 2) image id (a unique number given to the product when generated), and 3) site name (assigned by a user for later reference). These criteria allow the user to view a list of products (both images and photos) which meet these input search parameters.

From this product list, the user can then select one or more of these products and have descriptions of each product displayed on the screen. These descriptions include the percentage of mutual coverage of the image and the user's site area, and an earth coordinate vs. image pixel number display. At this time, the user can place an order for any of these products.

The design of the searching and ordering capabilities of optical data and GPS products is still preliminary. However, the procedures of the inventory are expected to operate in a similar manner to that of SAR products.

Note: Funding for implementation of IPOD and the CIPOD (Geophysical IPOD) and SAR/OPS portions of the GPS is not approved at this time.

3. PRODUCTS

3.1 SAR Products

Standard products are produced by the SPS for all SAR signal data recorded by the RGS. Special products are generated by the SPS and the AOS in response to user requests only. Standard, reprocessed, and geocoded full-res photos are generated from the corresponding image data by means of a FIRE recorder. Lo-res photos are produced from a lo-res image data file using a Lasertechnics camera. The lo-res photo products are negative and positive transparencies and a positive print.

The characteristics for these products are shown in Tables 2 and 3 and are defined as follows:

Standard Products:

1. Full-res image: 4 looks, <30 m resolution, 12.5 m pixel spacing
2. Lo-res image (+ photos): derived from full-res image by 8x8 averaging of the pixels, approximately 60 looks, <240 m resolution, 100m pixel spacing

Special (by request) Products:

1. Full-res photos
2. Computer compatible signal data: Converted raw signal data suitable for recording onto a Computer Compatible Tape for processing by users
3. Complex image data: an image in which the Doppler phase information at natural pixel spacing has been retained
4. Geocoded full-res image (+photos): Produced by rotating a full-res image to grid north and projecting the image on a base map (usually Universal Transverse Mercator or Polar Stereographic projection)
5. Geocoded lo-res image (+ photos): Produced by rotating a lo-res image to grid north and projecting the image on a base map (usually Universal Transverse Mercator or Polar Stereographic projection)
6. Reprocessed full-res and lo-res images (+photos): User can request reprocessing of signal data to full-res and lo-res images by specifying parameters different from standard processing. Useful for centering features and highlighting certain characteristics.

The AOS is designed to archive 465 SAR and film products daily as a result of recording and processing data throughout the mission lifetimes of E-ERS-1 and J-ERS-1. This archiving will require storage facilities consisting of 294 Gigabytes on 12" DOD for lo-res, Geocoded full-res, and Geocoded lo-res images, 3 Gigabytes on magnetic disk for the catalog and inventory, 11,200 Gigabytes on magnetic tape cassetes for raw signal data, full-res, and complex images, plus a library for storing approximately 112,000 photo packets.

3.2 Optical Products

Optical products are processed and archived by the IPOD and ordered through the inventory function of the AOS. Distribution of full-res, lo-res, Digital Terrain Maps, and Custom Produced Products is on CCT and 5.25" digital optical disk. Browse images are produced for any product and is routed through the AOS to the user's workstation.

The characteristics for optical products are shown in Table 4 and are defined as follows (these definitions were taken from reference [7]):

1. Full-res image: an image including all correction data and raw video
2. Lo-res image: a subsampled, subbanded product providing browseable images. This product will have a binary cloud cover mask
3. Digital Terrain Map: an elevation image map derived from stereo pairs. These are produced at user-selected spatial resolutions up to the source resolution of 18x24.2 meters
4. Custom Produced Product: a variety of customized products based on user specified parameters
5. Browse Product: compressed images of any image product residing in the IPOD archive

Table 2. SAR Image Product Characteristics

SAR PRODUCT	DAILY QUANTITY	IMAGE RESOLUTION (M)	PIXEL SPACING (M)	FRAME SIZE (KM)	FILE SIZE (MBYTES)
Full-res image	25 (E) 50 (J)	<30	12.5	100X100	64
Lo-res image	5 (E) 10 (J)	<240	100	100X100	1
Geocoded full-res image	1	<30	12.5	100X100	128
Geocoded lo-res image	10	<240	100	100X100	128
Reprocessed full-res image	15	<30	12.5	100X100	64
Reprocessed lo-res image	15	<240	100	100X100	1
GPS full-res product	6	TBD	TBD	TBD	TBD
GPS lo-res product	60	TBD	TBD	TBD	TBD
Complex image	1	<10	NATU-RAL	30X50	100
(E)=E-ERS-1, (J)=J-ERS-1, TBD=to be determined					

Table 3. SAR Photo Product Characteristics

PHOTO PRODUCT	DAILY QUANTITY	MAP SCALE
Full-res	5 (E) 10 (J)	1:500,000
Lo-res	25 (E) 50 (J)	1:500,000
Geocoded full-res	1	1:500,000
Geocoded lo-res	10	1:1,000,000
Reprocessed full-res	15	1:500,000
Reprocessed lo-res	15	1:500,000
E=E-ERS-1, J=J-ERS-1		

Table 4. Optical Image Product Characteristics

OPTICAL PRODUCT	DAILY QUANTITY	SIZE (MB)	GEOGRAPHICAL COVERAGE
Full-res	2	305	75kmx225km
Lo-res	2	60	full swath
Digital Terrain Map	3	7	75kmx75km
Custom Produced	75	variable	user selectable
Browse	150	65	variable
Browse products are variable according to product compressed Quantities based on 10 minutes of data acquisition/day processed The quantities represent one option considered in the Phase B study [7]. Exact amounts of optical image products are to be determined.			

4. PRODUCT FORMATS AND MEDIA

The SAR data will be distributed in the format consistent with the Committee on Earth Observation Satellites (CEOS) [10]. This format organizes the data into 1) a Volume Directory File, 2) a SARLEADER file, and 3) a SARTRAILER file.

Distribution of SAR and optical products will be on Computer Compatible Tape (CCT) and 5.25" digital optical disk.

5. FUTURE ENHANCEMENTS

Browse Images:

In addition to ordering data through the product order function, the user will be able to request browse images. which are full-res and lo-res images which have been compressed in size suitable for electronic transmission to the requestor's remote work station. Once a compressed image has reached the user's workstation, it can subsequently be decoded, or uncompressed, and displayed in its (approximately) original form.

Future Data Ordering:

A user will be able to request data to be taken at some future time from a particular satellite and sensor. These data acquisition requests, entered interactively from a user's workstation, will specify target location, observation period, datatake repeat interval, and whether the datatake is to be from an ascending or a descending orbit. Requests will be entered into a database which the mission planner will use to merge them with previous requests and resolve multi-satellite conflicts. Updated data acquisition requests will be submitted to flight agencies for approval.

6. CONCLUSIONS

The Archive and Operations System (AOS) is designed to archive Synthetic Aperature Radar (SAR) data products produced and derived by an advanced digital SAR processor and to inventory data products produced by the Image Processor for Optical Data. The AOS will also provide a data management system whereby the scientific community can interactively search the inventory and order data products. Geophysical products pertaining to ice motion vector maps and classified ice maps will be available to users through the inventory and product order function as well.

The Mission Planning Subsystem is designed to provide users with ordering of data takes of interest from future fly-bys of the satellites over the Alaska station mask. The MPS also provides schedules of datatakes for ASF station personnel to plan antenna activities for receiving and recording incoming data and to assist the SPS operator in its activities.

The ASF is an integrated system designed specifically for receiving data, producing products, and distributing these products to the scientific community. The functions of the ASF represent a major advancement from current systems for processing and distribution of data products. Data gathered within the Alaskan station mask will support studies and scientific analyses in oceanography of the open ocean and ice margins, glaciology, geologic processes of river and delta formation, and seasonal vegetation changes [11].

7. ACKNOWLEDGEMENT

The work described in this paper was carried out at the Jet Propulsion Laboratory of the California Institute of Technology, and supported under a contract with the National Aeronautics and Space Administration.

8. REFERENCES

[1] "Memorandum of Understanding between NASA and ESA on the Reception of E-ERS-1 Data at Fairbanks", January 1986.

[2] "Memorandum of Understanding between NASA and NASDA Concerning the Direct Reception of JERS-1 Data at the Fairbanks Station", January, 1988.

[3] Erich, U. and D.H. Gottschalk, "ERS-1 and Its Potential for Industrial Utilization", Earth-Oriented Applications of Space Technology, Vol. 4, No. 4, pp 211-219, 1984.

[4] Y. Horikawa and H. Ohba, "Studies on Japan's Earth Resources Satellite-1", Earth-Oriented Applications of Space Technology, Vol. 5, No. 3, pp 185-192, 1985.

[5] "Computer Sciences and Data Systems", Vol.2, p. 248, Proceedings of a Symposium held at the National Conference Center in Williamsburg, Virginia, NASA Conference Publication 2459, November 18-20, 1986

[6] Carande, R. and B. Charny, "Alaska SAR Processor", IGARSS'88, Edinburgh, Scotland, September 13-16, 1988.

[7] "J-ERS-1 Optical Sensor Image Processing System Phase A Study Draft Report", Goddard Space Flight Center, December 1987.

[8] "J-ERS Optical Sensor Image Processing System Conceptual Design Draft Report", Goddard Space Flight Center, December 1987.

[9] J. Hilland, "ASF AOS FRD", JPL D-4738, September 1987 (a JPL internal document)

[10] Final Report on SAR Data Product Format Standards by the CEOS Working Group on SAR Data Standards, November 1987.

[11] Carsey, F. "Alaska SAR Facility Science Requirements", JPL Internal Document D-3668, January 1988.

THE SEARCH FOR SOUTH AFRICAN AIRWAYS FLIGHT 295

Michael K. Kutzleb

Steadfast Oceaneering, Inc.

Steadfast Oceaneering, Inc. recently performed a successful search operation for a South African Airways 747 aircraft that had crashed in the Indian Ocean. Using a special deep ocean sonar system, the Steadfast search team located the aircraft in less than 14 hours of sonar search in water depths of over 4400 meters. Steadfast is the prime contractor for search operations for the U.S. Navy's Supervisor of Salvage office. The tiny island of Mauritius served as the base of operations for mobilization and deployment of all search assets. This is believed to be the deepest successful search operation on record-deeper even than the TITANIC operation of 1986.

On 28 November 1987, South African Airways Flight 295 enroute from Taiwan to Mauritius disappeared into the Indian Ocean shortly before its scheduled arrival. The Boeing 747 Combi aircraft, which was carrying passengers as well as cargo, had reported smoke in the aircraft and had just completed an emergency descent to 14,000 feet when communications were lost. Floating debris was located the following day approximately 135 miles northeast of Mauritius.

Based upon the U.S. Navy's success in locating the pingers from the Air India 747 in 1985, the South African Government requested the U.S. Navy Supervisor of Salvage assistance. An agreement was signed on 3 December 1987, after favorable determination under Section 607 (a) of the Foreign Assistance act of 1961, and further legal determination that use of U.S. Navy assets for humanitarian purposes would not violate the terms of the comprehensive Anti-Apartheid Act of 1986. The SUPSALV office administers several civilian contracts for the provision of specialized search and salvage services for various projects. For this task, the services of Steadfast Oceaneering, Inc., the Navy's prime contractor for underwater search and recovery operations, were required.

Steadfast Oceaneering Inc., with offices in Falls Church, VA and Fort Lauderdale, FL, is a leader in the field of underwater search and recovery, and specializes in deepwater operations. Steadfast was the prime contractor for the search for KAL Flight 007, the Air India 747, and the space shuttle CHALLENGER. Since its incorpration in August 1979, Steadfast has conducted over 100 other search tasks around the world for both military and civilian customers, in addition to performing numerous routine survey tasks in deep and shallow water. Steadfast is a wholly owned subsidiary of Oceaneering International, one of the world's largest underwater services company providing diving, Remote Operated Vehicles, and engineering services to both oilfield and government customers worldwide.

PRE-TASK PLANNING

The first order of business was to identify what assets were required and where to commence the search. Both the Cockpit Voice Recorder (CVR) and the Flight Data Recorder (FDR) on SAA Flight 295 were equipped with Dukane 37 kHz underwater beacons. These beacons are activated upon immersion in water, and are designed to survive an aircraft crash and help pinpoint the location of the flight reorders using underwater acoustic locator equipment. With theoretical detection ranges for these beacons of up to two miles, large areas can be covered fairly quickly using suitable pinger locator systems.

Based on this, it was decided that Phase I of the search would concentrate on listening for the beacons, while Phase II would involve the use of side scan sonar either to map the debris if Phase I was successful, or to continue the search if the pingers were not located during Phase I.

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PHASE I

The Supervisor of Salvage keeps two pinger locator systems in their inventory for use in locating downed military aircraft, and provided them for use on this task in reponse to an official request from the South African government. Each system consists of a towed hydrophone, a cable, and a topside processing/display console. The hydrophone and underwater electronics housing are pressure rated to 10,000 psi, and could therefore be towed at a sufficient depth to ensure detection of the beacons in the water depths in the search area, which ranged from 2500 to 4500 meters. Previous tests using these locator systems had shown a maximum detection range of approximately 3700 meters under ideal conditions.

A team of U. S. Navy and Steadfast personnel, headed by Captain Bartholomew of the SUPSALV office, departed for Mauritius on 4 December to meet with DCA and SAA personnel. Captain Bartholomew, along with Tom Salmon and Bill Walker of the SUPSALV office, assisted the DCA Executive Committee in the planning phase of the search. The organizational experience that the SUPSALV personnel gained in projects such as the Air India and CHALLENGER search and recovery tasks was of immense assistance in the preliminary phases of this effort.

Mike Kutzleb, President of Steadfast and in overall charge of the Steadfast Project Team, together with Dr. Johan Strumpfer of the South African Institute for Maritime Technology, collected all available loss data for analysis. Using metereological data and positions of floating wreckage obtained by various search aircraft over a two day period following the accident, debris set and drift were calculated to derive a projected impact position. This position was then compared to other data such as the projected flight path to define a preliminary search area for the Phase I search.

The search was truly an international effort. Equipment came in from around the world, and had to be cleared through customs, transported across the island to Port Louis, unpacked, set up, and tested. Pinger locator systems, navigation systems, winches, and A-frames were needed for each of the two vessels, and had to be ferried to the ships at anchor since all berths in the port were full. Retrieval of floating debris by commercial and South African Naval vessels was still an ongoing effort.

Two ocean-going salvage tugs from Pentow Marine in South Africa, the WOLRAAD WOLTEMADE and the JOHN ROSS, were provided as platforms for the first phase of the search. A German research vessel that was operating in the area, the SONNE, was tasked to conduct a bathymetric survey of the search area using a SeaBeam survey system. This information proved to be invaluable throughout both phases of the search effort. The SONNE also had a video sled aboard capable of obtaining photos of the seafloor in water depths of up to 6000 meters. The R/V AFRICANA, a South African fisheries research vessel outfitted with a hull-mounted acoustic listening system, was also used during the Phase I pinger search.

An ARGO navigation chain, using shore sites on Mauritius, Rodriguez, and Cocos Island, was set up and operated by Geoteam, a Norwegian survey company. The ARGO system could only be used during the day, since ranges to two of the sites exceeded the maximum night time range of the system. This resulted in the use of GPS satellite positioning during the night after the ARGO signals were lost. With the two systems, accurate positioning was possible approximately 18 hours per day.

The WOLRAAD WOLTEMADE got underway on 11 December, with the JOHN ROSS joining the search the following day. A test pinger was dropped near the area in 3600 meters of water, both to test the locator systems used and to serve as a standard to compare with the sounds actually detected during the operation. The AFRICANA arrived on scene to assist on 17 December.

Trial runs conducted on the test pinger confirmed that the towed locator systems were indeed capable of detecting the pingers in the prevailing water depths. A consistent detection envelope of one mile was observed, which resulted in the selection of one mile spacing for the search tracks. This gave an overlap 100% to ensure that all areas were covered.

Phase I continued until 2 January 1988, when it was felt that the batteries in the pingers would have been exhausted. Several possible sound sources were heard, but none of them were determined to be definite pinger sounds. A total of 1005 square miles was covered by the three ships during this phase.

PHASE II

Once Phase I was completed, it was decided to demobilize all assets and plan for Phase II - the side scan sonar search. All of the data used in the preliminary analysis was reviewed and refined, and new bits of information were added. During one of the SONNE'S video runs, newspapers and several pieces of mail were observed on the bottom in one area. This area was along the calculated debris drift axis, coincided with the flight path, and also fit in well with the best estimates of the projected impact position of the aircraft. Based on this information, an area of high probability, measuring four by ten miles, was selected as the primary area of interest for the Phase II sonar search.

The search vessels used during the pinger locator phase were not suitable as platforms for a deep sonar search due to their inability to maintain the slow search speeds needed and the lack of adequate deck space required for installation of the deep ocean winch and the sonar A-frame and handling system. The OMEGA 801, a 65 meter supply type vessel with variable pitch propellors and a large open deck, was chartered to serve as the platform for the sonar search.

During the break between Phases I and Phase II, it was decided to replace the ARGO navigation system with a system that would provide reliable navigation around the clock. A GEOLOC system, owned and operated by CGG, a French geophysical survey company, was contracted to provide the high accuracy positioning required during the Phase II sonar search. GEOLOC, which is manufactured by Sercel, operates in the 2 mHz band using a spread spectrum technique, and has a maximum range of approximately 1000 km. Radiated signal strengths are kept below the ambient noise level to eliminate interference, and the system is immune to the tropospheric and sky wave interferences so common to other medium and long range precise navigation systems.

The sonar system used for the search was built around the Klein Smartfish, a dual frequency (50 or 100 kHz) full ocean depth towfish. The signals were multiplexed at the towfish and passed through a 9000 meter coaxial towcable to the Klein topside processing, recording, and display equipment. The winch consisted of a traction unit/power pack and a take up reel capable of storing up to 14,000 meters of towcable. A hydraulically operated A-frame was used for launch and recovery of the towfish, with an oceanographic sheave for fairleading the towcable over the stern.

The search team got underway on 22 January and arrived in the primary area the following morning. High winds and rough seas from a nearby tropical depression prevented the sonar fish from being launched for the next 36 hours, so this time was used to lock in and calibrate the GEOLOC navigation system. By Sunday evening, 24 January, the weather had abated sufficiently to permit launch of the sonar fish, and the first line was started just after midnight. Towing a sonar fish 45 meters off the bottom in 4500 meters of water at the end of a 9000 meter wire is no small feat; thus the first search line was run in an area of relatively flat topography. This allowed the operators to become familiar with system control and response before tackling the more difficult, central portion of the area where the aircraft wreckage was believed to be located. The SeaBeam charts of this high probability, central area showed several peaks rising 600 to 1500 meters off the seafloor amidst generally rough terrain.

The 50 kHz sonar operating on a scale of 300 meters per side was used for the search. Lane spacing of 300 meters was chosen to give a theoretical overlap of 100 percent, subject to steering errors, navigation system error, and an anticipated offset in the towfish track relative to the search vessel. This track offset was actually observed to vary from 0 to 200 meters during the course of the search.

The second search line was run through the center of the area, and a promising contract was noted on the sonar records. Subsequent runs over the next two days showed a typical aircraft debris pattern, with pieces spread out over a 1000 meter square section of the bottom. News of the discovery was passed to the DCA Executive Search Committee on 27 January. Sonar mapping continued for another week using shorter range scales and the 100 kHz system for higher resolution and greater detail of the various pieces of debris. The largest piece in the debris field measured 40 meters long by approximately 5 meters wide, with most pieces measuring less than 5 meters in overall size.

The water depth at the site where

the wreckage was located was 4450 meters. Rocky terrain existed within two miles east and west of the crash site, with mountains rising 700 to 1500 meters from the ocean floor. At the site itself, the bottom was flat and featureless, which greatly assisted the search team in mapping the area and flying the towfish at the low altitudes required for the high resolution sonar imaging.

Although the sonar portion of the search was almost immediately successful, it was by no means an easy task. Steadfast personnel had conducted numerous search tasks in water depths ranging from 2000 to 3000 meters, but had never searched in depths of 4500 meters. As a guage to measure the complexity of this task, consider that the deepest location of a lost object to date was the TITANIC discovery in 1985. The TITANIC, close to 300 meters in length, was located in less than 4000 meters of water, or over 500 meters shallower than the SAA 747. The entire fuselage of a 747 aircraft measures only 69 meters in overall length, and from previous experience it was predicted that the aircraft would be broken up into numerous small places and spread out over the bottom, thus making detection difficult at best. The wreckage was indeed broken up and spread out as predicted, but the experience of the sonar operators in interpreting the records, as well as the excellent quality of the records themselves, resulted in the successful completion of the task in spite of difficult operating conditions in water depths previously considered unreachable.

PERFORMANCE OF COAST GUARD MEDIUM RANGE SURVEILLANCE (MRS) AIRCRAFT RADARS IN SEARCH AND RESCUE (SAR) MISSIONS

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ABSTRACT

During June 1987, the U.S. Coast Guard conducted a series of tests to determine the ability of two airborne radar systems, mounted aboard a Coast Guard MRS aircraft (HU-25A), to detect small SAR-type objects. The two radar systems which were evaluated were the AN/APS-127 forward-looking airborne radar (FLAR) and the AN/APS-131 side-looking airborne radar (SLAR).

Realistic radar searches were conducted to collect data using unalerted sensor operators and standard search patterns.

Analysis of the detection data confirmed that the probability of detecting these targets varied with significant wave height, search altitude, and target size as well as lateral range to the target.

1. INTRODUCTION

During June 1987, the U.S. Coast Guard Research and Development Center (R&D Center), together with units of the CG Seventh District and the Seventh District CG Auxiliary, conducted a 4-week experiment to evaluate and measure the ability of the crew of a CG MRS aircraft (HU-25A) to detect SAR-type objects using the aircraft's FLAR (AN/APS-127) and SLAR (AN/APS-131) sensors. The SAR-type objects used were 6- to 10-person life rafts of commercial types and pleasure boats in the 24- to 43-foot range. The test was designed to collect data under as realistic a set of circumstances as possible. The capabilities of the whole system including radar operators, radars, signal processing/display, and aircraft was included in the evaluation.

Since early 1978 the R&D Center at Groton, Connecticut, has conducted at-sea experiments designed to produce visual and electronic search guidance for use in U.S. Coast Guard SAR planning and operations. Prior to this research program, Coast Guard planners used visual search data developed during World War II together with a limited amount of detection data collected in 1955 (reference 1). Field experiments conducted before 1978 collected relatively few samples, ignored significant variables and did not account for missed targets. No reliable search guidance was available for searches using electronic sensors prior to the current series of experiments.

2. EXPERIMENT DESCRIPTION

The site used for the experiment was a 15- by 30-nautical mile area located in the Atlantic Ocean off Ft. Pierce, Florida. All SAR objects were located in this area. Actual search tracks assigned to the aircraft for different data collection objectives were not limited to this area. Allowance was made for the aircraft to fly beyond the test area so that the aircraft would be parallel to the major axis, wings level prior to it entering the experiment area. For longer range data collection/detection opportunities, the flight track was parallel to, but seaward of the search area.

Three types of life rafts and ten different boats were used as search objects/radar targets during the experiment. The boats used provided a good variety of vessel types, 24 to 43 feet in length overall. This range of vessel length was selected as representative of the vessel size expected to be encountered in a majority of search and rescue cases. The vessels were constructed of fiberglass except for a 41-foot aluminum hull Coast Guard utility boat. The boats and rafts were not outfitted with radar reflectors. Target boat radars were not operating during the experiment period.

Target locations and aircraft positions were monitored using an automated microwave tracking system (MTS)

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consisting of a Motorola Falcon 492 system coupled with an HP350 computer. This system, developed by the Coast Guard R&D Center for the SAR Project, provided target and search unit positioning and search track reconstruction accurate to better than 0.1 nautical miles. The MTS master station, for this experiment, was located in Ft. Pierce, Florida. Two fixed reference stations were located to the north and south of the master station. These locations provided line-of-sight tracking of searcher and target positions.

The trackline of the HU-25A often took it beyond the range of the MTS. When this occurred, the position of the aircraft, as displayed on the onboard navigation computer, was used to reconstruct the track. These positions were recorded once per minute while outside MTS coverage area and were recorded as a navigation tie-in two or three times on each search leg while within MTS coverage. During data reconstruction all aircraft positions were converted to the MTS coordinate base.

Target and aircraft (when within MTS range) positions were recorded continuously by the computerized tracking system, displayed in real time on the CRT and recorded on a microcomputer hard disk every 15 to 30 seconds.

Recorded target and aircraft position data were used to generate an 8- by 12-inch hard copy plot of each search. Target locations were marked on these plots with letters. The aircraft tracks were plotted with a "+" to designate every fifth position fix. A hard copy chronology of the search and target craft positions was also generated to accompany the plot of each search. Using these plots and the detection logs, accurate lateral range measurements and detection/miss determinations could be made. A target was considered an opportunity for detection on any given search leg if the aircraft passed it within the selected radar range scale distance. If a logged target detection could be correlated with the target's position, it was considered a detection. Otherwise, a miss was recorded for the target on that particular search leg. These detections and misses, along with associated search parameters and environmental conditions, were compiled into computer data files for analysis.

3. HU-25A RADAR SYSTEM DESCRIPTIONS

The HU-25A Guardian is a Falcon 20 jet aircraft specially modified to perform the medium-range surveillance missions of the U.S. Coast Guard. These missions include SAR, law enforcement, fisheries patrol, and marine environmental protection. A limited number of these Guardian aircraft are equipped with both the AN/APS-127 FLAR and the AN/ASD-6 AIREYE multisensor surveillance system. The AIREYE system includes the AN/APS-131 SLAR. Both of the Guardian's airborne radars were evaluated during this experiment.

The AN/APS-127 FLAR is an X-band air-to-surface search radar developed to detect small targets in a sea clutter environment. The radar operates at a peak power of 200 KW, scan rate of 720 deg/sec, and a beam width of 5.0 degrees horizontal and 6.5 degrees vertical. A 7-inch plan position indicator (PPI) is used for a radar display . This PPI is designed primarily for operation in the search mode and was used for all FLAR data collection. The FLAR system contains special selectable features that may enhance system performance when used correctly. Range scales are selectable from 5 to 160 nautical miles with the option of moving the display origin from its normal centered position to any location on the PPI. Only the results on the 10 nmi ranges were used in this report.

The AN/APS-127 offers three distinct display modes: heading stabilized, ground stabilized, and north stabilized. The heading-stabilized display provides a PPI presentation wherein targets and terrain move relative to the sweep origin, which represents aircraft position. North stabilization aligns the display with magnetic north, and the degree marks around the scope represent magnetic bearings from the aircraft. The ground-stabilized display provides a PPI presentation that is an unchanging view of the earth's surface as long as the selected area remains within radar range. This stabilization mode provides a greater signal gain than the other modes and has been determined to be the best mode for small target search (reference 2).

Previous AN/APS-127 experiments were performed in 1983 and 1984 using Coast Guard HU-25A aircraft. The evaluations of these experiments were found in references 2 and 3. System parameter settings that appear to optimize small target detection performance were determined during these evaluations and used during this experiment.

The AN/APS-131 SLAR is an X-band surveillance and oil slick detection system capable of operation in all weather conditions, day or night. The AN/APS-131 is one of five components that comprise the AN/ASD-6 AIREYE system. The vertically polarized radar operates at a peak power of 200 KW with a beam width of 0.4 degrees in the horizontal and an elevation of -4 to -45 degrees vertically measured from the horizontal. The SLAR produces an aerial map containing an imagery swath width of up to 160 nautical miles centered on the aircraft's ground track. This map is produced in a near-real time video format using the AIREYE multipurpose display (MPD) or on a permanent copy dry-silver film. Both display methods include annotations of critical flight data, aircraft position, and target position (MPD only). AN/APS-131 imagery can be recorded from the AIREYE MPD for post-operation viewing and processing.

The SLAR radar antenna is designed to provide wide coverage in elevation and very narrow coverage in azimuth. The SLAR antenna is mounted on the aircraft so that it radiates nearly broadside to the aircraft centerline. The imagery produced by this system includes a blind zone centered on the aircraft's ground track. The width of this blind zone is approximately twice the aircraft's altitude.

An evaluation of a similar radar, the AN/APS-135 SLAR, was performed in 1985 using an HC-130 aircraft. The AN/APS-135 is nearly identical to the AN/APS-131 with the major difference being use of a 16-foot vice an 8-foot antenna. A summary of this evaluation can be found in reference 4. Parameter settings determined to optimize small target detection performance were chosen based upon this evaluation.

4. RANGE OF PARAMETERS TESTED

The range of potentially significant parameters tested for each sensor includes controllable aircraft/sensor parameters (time on task, altitude, range scale), environmental parameters expected to influence radar performance (wind speed and wave height), and target type/size.

Search speed was held constant at 250 knots indicated air speed (IAS) for all data collection.

Although wind speeds ranged from 0 to 18 knots and wave heights ranged from 0.5 to 5 feet, it should be noted that the most severe of these conditions occurred on the first day of data collection, June 8, when wave heights were 3 to 5 feet and winds were 12 to 18 knots. During the remaining 7 days of data collection, significant wave heights ran 0.5 to 3 feet and winds were 0 to 11 knots.

Range scale and search altitude were the only selectable parameters varied during data collection so that statistically significant sample sizes could be generated. Other sensor parameters were optimized by the radar operators as needed.

The only potentially significant human factor investigated for its influence on detection performance was time on task.

5. ANALYSIS APPROACH

The primary performance measure currently used by SAR mission coordinators to plan searches is sweep width (W). Since this radar evaluation was intended to support improved Coast Guard SAR mission planning, W was chosen as the measure of radar search performance to be developed during data analysis. Sweep width is a single-number summation of a more complex range/detection probability relationship. Mathematically,

$$\text{Sweep Width (W)} = \int_{-\infty}^{+\infty} P(x)dx$$

where

x = lateral range or closest point of approach to targets of opportunity (see figure 1), and

P(x) = probability of detection at lateral range x

Figure 2 shows a typical P(x) curve as a function of lateral range. In Figure 2, (x) is the lateral range of detection opportunities.

Conceptually, sweep width is the numerical value obtained by choosing a value of lateral range less than the maximum detection distance for any given sweep so that scattered targets that may be detected beyond the limits of W are equal in number to those that may be missed within those limits.

6. ANALYSIS

The influence of interactions among the primary search parameters of interest was investigated using a sophisticated binary, multivariate regression analysis technique. The detection data were combined into a set with all variables

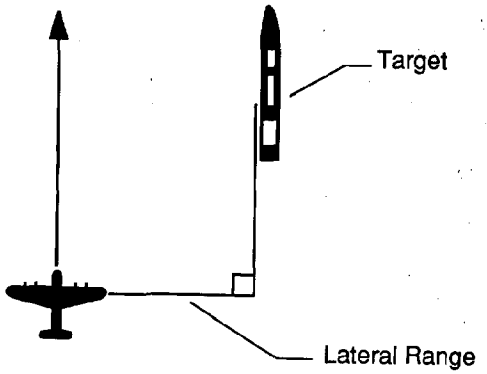

Figure 1. Definition of Lateral Range

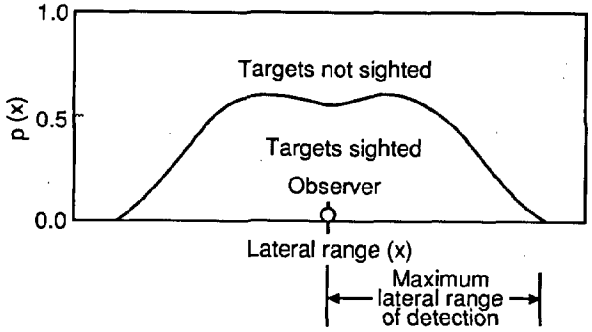

Figure 2. Relationship of Targets Detected to Targets Not Detected

of interest included. This data set was divided into statistically significant subgroups based on this multivariate analysis technique. Data groups which were not significantly different were combined. For each data grouping a function which represents the probability of detection versus lateral range was established. Sweepwidth can be calculated by integrating this function. Inspection of the raw data for many target/sensor/range scale combinations indicated that the multivariate analysis model as constrained by the need for a monotonic functional relationship, would not adequately represent the observed radar detection performance as a function of lateral range.

In order to fit a lateral range curve to the detection data that exhibited unimodal response, an appropriate fitting function had to be identified. The function

$$P(x) = \frac{A^C}{\left[(x-B)^2 + A^D\right]}$$

was selected where A,B,C, and D are regression variables and x is lateral range.

7. TEST RESULTS

A total of 904 valid sensor-target interactions were reconstructed from the experiment. Data quantities are categorized by sensor, and target type for the 10-nmi range scale in Table 1. Data quantities pertaining to the SLAR reflect elimination of targets occurring within the assumed 0.8-nmi blind zone to either side of the aircraft.

Table 1. Number of Searcher/ Target Interactions

RADAR SYSTEM	LIFE RAFT TARGETS	BOAT TARGETS
	10-nmi Range Scale	10-nmi Range Scale
AN/APS-127 FLAR	224	412
AN/APS-131 SLAR	83	185

7.1 FLAR Detection of Life Rafts

Figures 3 and 4 depict the raw detection data and least-squares fitted lateral range curves for FLAR detection of life rafts when the 10-nmi range scale was used. Significant wave height was the only search variable in the data set that was found to exert significant influence on target detection probability. Figure 3 provides the lateral range curve for significant wave heights less than 2 feet, and Figure 4 provides the lateral range curve for 2- to 3-foot significant wave heights.

Inspection of the two lateral range curves indicates that detection performance against these small targets degraded markedly with even a small increase in sea return. It should be noted that only a small data set was collected in the higher sea conditions, resulting in a rather uncertain lateral range curve fit (the 90-percent confidence limits are extremely wide).

7.2 FLAR Detection of Boats

Figures 5 to 7 depict the raw detection data and least-squares fitted lateral

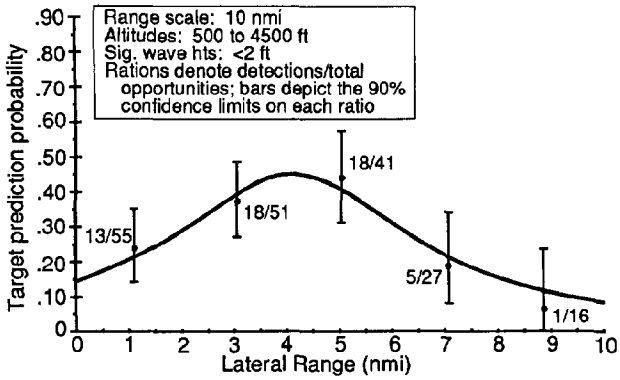

Figure 3. APS-127 FLAR Detection of Life Rafts (10-nmi range scale; seas <2 feet)

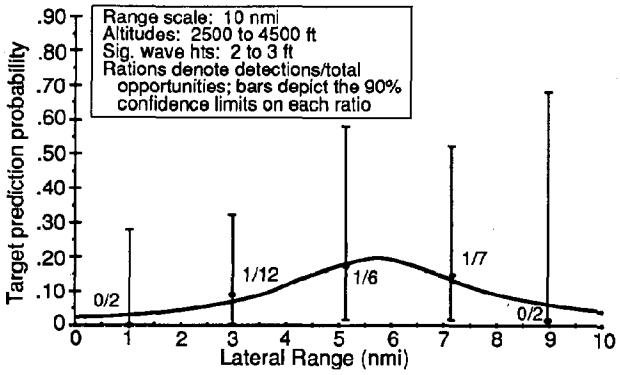

Figure 4. APS-127 FLAR Detection of Life Rafts (10-nmi range scale; seas 2 to 3 feet)

range curves for FLAR detection of 24-to 43-foot boats when the 10-nmi range scale was used. Significant wave height and search altitude were the search variables found to exert significant influence on target detection probability.

Figures 6 to 7 provide lateral range curves for significant wave heights less than 2 feet and 2 to 5 feet, respectively, when 2500- to 5000-foot search altitudes were used. Comparison indicates that a moderate increase in sea return resulted in approximately a 30-percent reduction in boat target detection probability near the middle of the 10-nmi lateral range curve. Near the inner and outer limits of the 10-nmi curve, target detection probability was not affected by the increase in sea return.

7.3 SLAR Detection of Life Rafts

Figure 8 depicts the raw detection data and least-squares lateral range curve fit for SLAR detection of life rafts

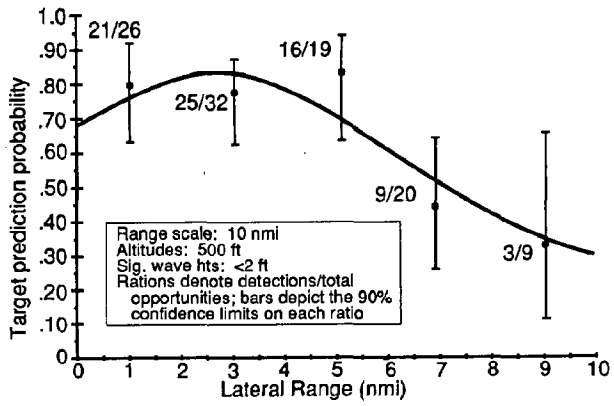

Figure 5. APS-127 FLAR Detection of 24-to 43-foot Boats (10-nmi range scale; seas <2 feet; 500-foot altitude)

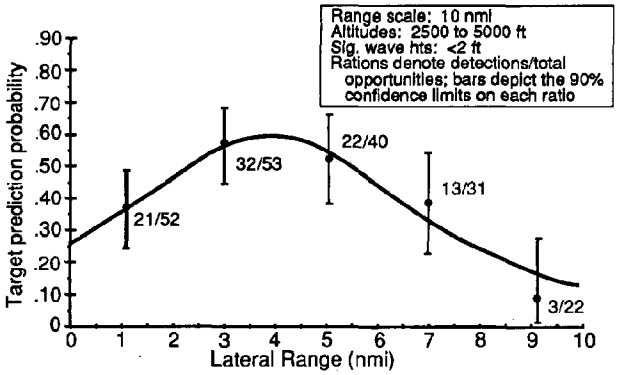

Figure 6. APS-127 FLAR Detection of 24-to 43-foot Boats (10-nmi range scale; seas <2 feet; 2500- to 5000-foot altitudes)

when the 10-nmi range scale was used. None of the search variables were found to exert a statistically significant influence on life raft detection probability. This result is not surprising in light of the narrow range of significant wave height and search altitude represented in the data set.

The APS-131 SLAR was designed to be a high-altitude, wide-area surveillance radar, thus, it was not tested at the 500-foot altitude. Based on a 1985 test of the APS-135 SLAR using alerted operators and an analog film display (reference 4), the 2500- to 4000-foot search altitude was expected to yield much better life raft detection performance than is indicated by Figure 8. During the earlier experiment, detection probabilities of 60 to 80 percent were achieved with 10-person life rafts. The use of unalerted operators, high operator workload (including real-time target logging), and the introduction of the MPD video

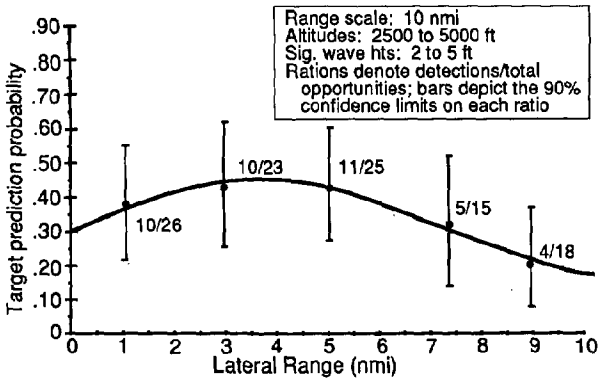

Figure 7. APS-127 FLAR Detection of 24- to 43-foot Boats (10-nmi range scale; seas 2 to 5 feet; 2500- to 5000-foot altitude)

display vice a film display are potential factors in explaining this degradation in SLAR detection performance. Additional data collection will be required to better identify the cause of the degraded detection performance and to investigate the effect of using a 500-foot SLAR search altitude for small targets.

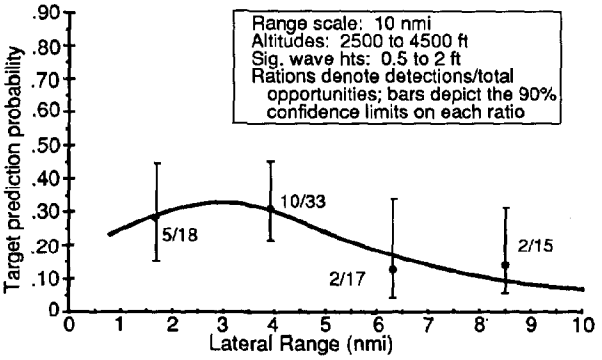

Figure 8. APS-131 SLAR Detection of Life Rafts (10-nmi range scale; all data)

7.4 SLAR Detection of Boats

Figure 9 depicts the raw detection data and lateral range curve fits for SLAR detection of 24- to 43-foot boats when the 10-nmi range scale was used. As with the life raft targets, none of the search variables evaluated in the regression analysis exerted a statistically significant influence on boat detection probability. The most notable feature of the lateral range curve in Figure 9 is that target detection probability increases steadily with lateral range, implying that the

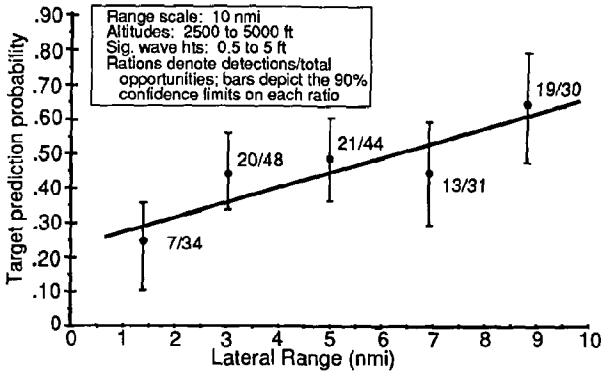

Figure 9. APS-131 SLAR Detection of 24- to 43-foot Boats (10-nmi range scale; all data)

10-nmi scale does not accommodate the full range of SLAR capability to detect 24- to 43-foot boats.

8. REFERENCES

1. Richardson, W.H., Empirical Sweep Width Analysis (Air to Surface), SIO Reference 68-30, Visibility Lab, Scripps Institute of Oceanography, University of California, San Diego, California (October 1968).

2. Ketchen, H.G., St. Martin, J., Hover, G.L., and Mazour, T.J., Evaluation of U.S. Coast Guard Forward-Looking Airborne Radars, Report No. CG-D-17-84, U.S. Coast Guard Research and Development Center and Analysis & Technology, Inc., March 1984.

3. Ketchen, H.G., Nash, L., and Hover, G.L., Analysis of U.S. Coast Guard HU-25A Visual and Radar Detection Performance, Report No. CG-D-29-83, U.S. Coast Guard Research and Development Center and Analysis & Technology, Inc., June 1983.

4. Robe, R.Q., Edwards, N.C. Jr., Murphy, D.L., Thayer, N., Hover, G.L., Kop, M.E., Evaluation of Surface Craft and Ice Target Detection Performance by the AN/APS-135 Side-Looking Airborne Radar (SLAR), Report No. CG-D-30-86, U.S. Coast Guard Research and Development Center, International Ice Patrol, and Analysis & Technology, Inc., December 1985.

SEA BASED AEROSTATS (SBA): EFFECTIVE SURVEILLANCE FOR MARITIME INTERDICTION

James B. Brewster, LT., USCGR

United States Coast Guard

In any war, forces cannot be effectively used until the enemy is located. In the war on drugs, narcotics traffickers cannot be captured until they are spotted. The Sea Based Aerostat (SBA) is efficient, effective and inexpensive in locating and causing the apprehension of traffickers. The SBA can:

Determine general vessel size.
Screen probable traffickers from innocents mariners.
Conserve cutter fuel and search time.
Extend cutter on scene endurance by UNREP.
Provide deterrence value.

SBAs are providing inexpensive operational intelligence that is making a difference in maritime interdiction

Mariners transiting the Caribbean Sea lately, have often spotted something similar to the Goodyear blimp. As they got closer they discovered that the blimp was tethered to a ship by a long cable. Frequently, the mariner would spot a United States Coast Guard Cutter and/or a Coast Guard helicopter operating in the vicinity of this blimp. What the mariner saw was a Sea Based Aerostat, the latest Coast Guard tool for combatting maritime narcotics trafficking.

In 1982 narcotics trafficking into the United States had reached alarming proportions. Responding to the public outcry for action, the President set up the South Florida Task Force under the supervision of Vice President Bush. The Task Force was directed to formulate a comprehensive strategy to combat narcotics trafficking into the United States. The strategy developed was based upon the three major phases of narcotics trafficking: Production, Transportation, and Distribution.

It set up a three pronged attack to combat the specific phases and involved:

1. Eradication/Elimination of the narcotics supply - aimed at production
2. Interception and seizure of drug stockpiles - aimed at transportation and distribution
3. Reduction of consumer demand - to effect whole system

The question was where to effectively use US law enforcement personnel.

During production, if narcotics can be detected and destroyed, the supply will be reduced. However, this activity is beyond the capability of law enforcement agencies whose jurisdiction is inside the United States. This must be left to the State Department, Drug Enforcement Agency (DEA, primarily an undercover investigative agency) and the cooperation of production countries.

During transportation large quantities can be seized if the trafficker can be detected. However, law enforcement agencies must seperate the trafficker from among legitimate commerce. This is laborious and difficult but the kind of work law enforcement personnel do daily. Given proper detection and interdiction assets, results can be seen immediately in this phase.

Distribution networks are usually destroyed through undercover work. While effective, these operations require long time frames and historically catch people. The narcotics seized here is small compared to the transportation phase.

The South Florida Task Force recommended concentrating law enforcement activities against the transportation phase as the most effective means to intercept and seize narcotics. This was called the Border Interdiction Strategy. The agencies involved in implementing this strategy are: US Customs, US Immigration and Naturalization Service, and the Coast Guard. Customs was designated as the lead agency ashore, the Coast Guard was designated the lead agency for Maritime Interdiction and the two agencies would jointly share responsibility for air interdiction.

The primary purpose of the Border Interdiction Strategy is to detect and intercept narcotics during shipment. This is the area in which the trafficker is most vulnerable. The trafficker cannot hide his movements. He must put his contraband on some form of conveyance to get them to market. Most importantly, for drugs grown or produced outside the United States, the trafficker cross the border zone before he can

 United States Government work not protected by copyright

get to market. In doing this, the trafficker risks coming under the watchful eye of law enforcement personnel. The Border Interdiction Strategy has proven to be a very effective way to intercept and seize large quantities of narcotics. During fiscal year 1987, the DEA recorded 616 marijuana seizures each involving over 200 pounds. A total 1018 tons was seized. 82% of those seizures occurred in the border interdiction zone during the transportation phase. This accounted for 81% of the total seized. In the same time period, the DEA recorded 1613 cocaine seizures each involving a minimum of one kilogram. While only 39% of the seizures occurred in the border interdiction zone, it accounted for 64% of the quantity seized.

Narcotics traffickers must first be DETECTED. After being detected they must be IDENTIFIED. Once identified as a probable trafficker, a law enforcement unit must be able to INTERCEPT the trafficker. Only in this manner can a trafficker be arrested and his contraband seized. The United States has manpower and equipment to intercept traffickers once they have been detected. The crucial step has always been in detecting the trafficker.

As lead agency for maritime interdiction, the Coast Guard analyzed the maritime aspects of narcotics transportation. Our concern was how to use our fleet to efficiently and economically patrol the Caribbean Sea. The solution was obvious. All maritime traffic entering or leaving the Caribbean Sea must transit through an island pass. This concentrates or funnels all maritime traffic through an area of manageable size. These are referred to as "Choke Points". The Caribbean Sea has four principle choke points: The Yucatan Strait, Windward Passage, Mona Passage and the Sombrero Passage (called The Anegada). This phenomenon is advantageous for efficiently interdicting contraband. The choke points reduce area that a patrolling cutter has to cover and concentrates traffic. This reduces search time, saves funds and greatly increases the probability of detecting a smuggler.

Patrolling choke points has proven to be a successful concept, however, the major problem continues to be one of detection. Radars on our largest cutters can only see 15-20NM. The largest choke point, the Yucatan Strait, is 114NM across. The cutters did not have radars with sufficient range to see across the pass.

Smugglers could use planes to determine what side of the Strait the cutter was on and then direct their trafficker to the opposite side. If the cutter transited from side to side, hoping to stumble upon a vessel, their unprogrammed movements might confuse the spotters or it just might waste fuel. Interception was mainly dependent on luck since the cutter did not have the entire picture of the traffic in the pass.

The Coast Guard began to investigate options that could provide greater, sustained radar coverage of the choke points. The requirement was for a radar with at least 60NM range. C-130s, E-2C Hawkeyes and airships were considered and rejected because the aircraft radar platforms were not as effective on slow moving targets like ships which required more extensive on station time than these platforms were capable of. The Sea Based Aerostat was considered to have the best potential and was selected.

The SBA is a radar surveillance, and command and control platform. It consists of an Aerostat (an aerodynamically shaped balloon), a Radar, a Command and Control Center, and a Platform Vessel.

The AEROSTAT is an aerodynamic helium filled balloon. It looks like a blimp and is tethered to the platform vessel. It has a diaphragm, called a ballonet, that maintains constant pressure inside the Aerostat in response to changes in atmospheric pressure and altitude. In this manner the Aerostat maintains it shape and provides lift. The radar is suspended underneath the Aerostat. The helium filled aerostat can elevate the radar to a height of 2500'. The aerostat is 109FT long, has a diameter of 37FT, and holds 56,000 CU FT of helium.

The RADAR is suspended under the Aerostat and is protected by a fabric wind screen. It is a surface search radar that can spot small wooden vessels (30') up to 60NM away. Range is a function of the square root of the altitude, times 1.25. Thus the range of the radar is increased by suspending it beneath the balloon. At an altitude of 2500FT the range of the radar horizon is 63NM. The aerostat is the primary factor allowing the radar to see as far as it does.

The COMMAND AND CONTROL CENTER is the operations center for the whole system. It consists of the radar repeater, radio communications gear, Aerostat monitor display and Target Information Processing System (TIPS). All radar data is received, viewed, and analyzed in the Command and Control Center. The data is then transmitted to operational commanders for action.

The PLATFORM VESSEL is a 192' long offshore supply vessel. It houses the crew, functions as the aerostat mooring platform and can remain on station for 30 days. It also carries fuel, water, and food to extend the on station time of other interdiction cutters.

The Coast Guard stated its requirements for an SBA that would properly operate in the open ocean environment, and in all temperatures and conditions, from 55 degrees North to 55 degrees South latitude with the following limitations:

AEROSTAT

a. Altitude: 0-2500' feet above sea level.
b. Winds:
   Peak sustained: 50 knots relative.
   Gusts: 70 knots relative.
c. Seas 15 feet.
d. Be winchable in 50 knots relative wind.
e. Be winchable at a minimum speed of 200 ft/min and stoppable at any point between 20 and 2500 feet.
f. Use helium as the lighter-than-air gas.

RADAR

a. Have a weather detection mode.
b. Detect a small wooden vessel in sea state three from 3-60NM.
c. Have a probability of detection of 50% per sweep.
d. Radiate and rotate continuously 27 days each month.

When tested, the SBA was able to meet the foregoing criteria and proved capable of electronically seeing at one time all the traffic in the widest Caribbean passage, Yucatan Strait.

Coast Guard interdiction operations have become more efficient as a result of deploying the SBA. When operating with an SBA a cutter commanding officer does not have to waste time in the detection phase of interdiction operations. The SBA detects traffic in a choke point and produces a picture of the traffic. This picture is electronically sent to the cutter. The commanding officer can then use this information to produce a "plan of attack" to identify the contacts. If he has a helicopter, he can direct his helicopter to fly over each contact. If a contact should be identified as a probable trafficker, the commanding officer can intercept the vessel. This maximizes the on station cutter time in active interdiction.

In addition to providing detection services to the cutter, the SBA crew can also make some determinations about the contacts. This helps the Commanding Officer screen out legitimate traffic from probable smugglers. With it's 60NM range, the SBA can observe a contact for a while and make some assumptions about it. SBA operators can determine the contact's general size from the radar scope. By coupling general size with the observed trackline some contacts can be determined to be commercial traffic and not worth trying to identify. This only enhances the efficiency with which the Commanding Officer can pursue contacts.

The SBA crew records and stores all radar data. This data is later analyzed. From this data, the Coast Guard has been able to discern trackline patterns that indicate a high probability that the vessel is a trafficker. When such a trackline pattern is observed, the SBA immediately notifies the cutter and a direct intercept is plotted. What is humorous is the trafficker thinks he is avoiding detection. In reality, he has given himself away. This type of intelligence further aids the Commanding Officer in selecting and pursuing contacts that have the highest probability of being a trafficker.

Deterrence is a value that is hard to measure. In the case of the SBA, its deterrence value is measurable. When on station, vessel traffic cannot get around the SBA. The only way to avoid detection by the SBA is to move through another choke point. SBA crews continue to observe a large drop in vessel traffic within five days of arriving on station. This appears to represent a tactical response by traffickers to switch to a choke point not covered by an aerostat or to wait and ship their narcotics after the SBA leaves. It is an intangible result and is therefore hardest to defend. Analysts/program reviewers like to see results (eg do a cost benefit analysis of the value of narcotics seized against dollars spent). If the SBA provides 100% deterrence, no narcotics are seized. This creates the appearance of not being effective. In reality the SBA is being extremely effective. Another case did demonstrate and prove 100% deterrence. The SBA was deployed to enforce a closed fishing area. Fishermen commonly fished right through the closed area realizing that there was no one to catch them. The night the SBA arrived on station the crew observed fishing traffic moving into and out of the closed area. During the next day, word got to the fishing community that the Coast Guard was on duty. That night fishing traffic stayed clear of the closed area. The SBA crew could see on the radar, fisherman moving up to the edge of the closed area and then reversing course away from the closed area.

Since May 1984, Coast Guard SBAs provided intelligence to cutters that was instrumental in thirty-three seizures.

Marijuana	Cocaine	Haitian Migration
27 Seizures	2 Seizures	8 seizures
247,865 lbs	3010 lbs	792 Haitians

In addition to its primary role as an interdiction resource, the SBA can also act as a mother ship and service other cutters with fuel, water, and stores. These supplies are routinely transfered to cutters on station eliminating the need for a cutter to make a port call for fuel and water. This allows the cutter to become more efficient in using its deployment time for interdiction and has proven to be extremely cost effective. The Coast Guard has only one aerostat on duty at this time. Four additional aerostats are being procured by the Coast Guard. These are expected to be in operations in February of 1989. With five SBAs, the Coast Guard will be able to more effectively seal the passages to the Caribbean Sea.

INNOVATIVE TECHNOLOGY APPLIED TO MAXIMIZE A PORT'S LIFELINE: A CASE HISTORY FOR THE SEA LANES OF THE CHESAPEAKE BAY

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ABSTRACT

A consortium of public and private marine interests have worked together to maximize the available finite navigational resources that serve the Port of Baltimore. The port needed to make maximum use of the Chesapeake Bay ship channel and of the Chesapeake and Delaware Canal as its short cut to and from the Atlantic. Thus a number of conventional and non-conventional improvements were undertaken to increase the vertical clearance (air gaps) in the canal and the water depths of the channels. This paper deals with the new technological improvements which involve remote data sensing and real time transmission and the application of this information to the maneuvering of the larger ships entering the port. The net benefit of the improved technology and increased shipping is national in scope since it makes the export of U.S. commodities more competitive in the world wide market.

I. INTRODUCTION

In order to keep the Port of Baltimore more competitive, there has been a concerted effort by many private, state and federal agencies to maximize use of the available shipping channels. Both conventional and non-conventional methods are being used today to increase the size of ships entering the port. This paper deals with some of the non-conventional methods which have proven to be very cost effective. The economical, navigational and operational considerations of these new technologies are discussed as they apply to the Chesapeake Bay and Chesapeake and Delaware (C&D) Canal, although they are equally applicable to all major harbors.

A. Economic Considerations

The Chesapeake Bay Ship Channel is nearly 150 miles long, requiring an average 10-hour transit from the mouth of the bay to Baltimore. On the other hand the C&D Canal connects Chesapeake and Delaware Bays and is the Port of Baltimore's "short cut" to and from Philadelphia, New York and northern Europe. This sixteen nautical mile waterway can save a large, new container ship up to seven hours of "steaming" time and approximately $12,000 per voyage by use of the canal. The adage that "time is money" is particularly appropriate for present container ship services where, as a result of intense competition, profit margins are thin. Large steamship companies have responded by building new ships which carry fewer crew members, more cargo and are faster and more energy efficient. Even with such improvements, container steamship lines are constantly "rationalizing" ports of call which means basically that fewer ports are served in order to maximize use of the large investment in vessel capital costs and to diminish unnecessary transit time and related operating expenses. Modern ship costs can run $35,000 - $50,000 per day so making effective use of the C&D Canal becomes of paramount importance to the Port of Baltimore. In terms of economic impact, some eleven jobs are created for each 1,000 containers and some $57 are created for each container ton (1). Thus ports keenly compete for this valuable cargo.

In the March, 1988 issue of American Shipper magazine, Dr. John Hayes of NOAA notes that the tidal gauges in the federal system also allows for more efficient use of large bulk carriers. He notes that while the primary use of the 225 tidal gauges in the U.S. system in the past was to provide data for oceanographic research and historical documentation, the new use of tidal datapermitting increased shiploads through use of this information has both economic, safety and therefore environmental benefits. The economics of this situation are such that one additional foot of draft on some large Cape Class ships can equal 3600 tons of additional coal handled. Through March of 1988, U.S. average coal prices equaled some $42 per ton (2) so this extra foot provides an ability to move $151,200 worth of additional coal with little additional cost.

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B. Navigational Considerations

Of the nearly 200 miles of waterways in the Chesapeake Bay serving oceangoing commerce and the Port of Baltimore approximately 100 miles are dredged channels. These channels vary in size from the fully restricted (i.e. a canal with walls) Chesapeake and Delaware Canal with a 450-foot width through a variety of channel configurations of various widths up to the 1000-foot width channel at the Bay entrance. In addition, the C&D Canal is crossed by five bridges of heights varying from 136.4 to 140.9 feet above mean high water (MHW). In order to maximize the use of the channel system in view of the increasing size of ships serving the port, a clear need arose to develop a system which would provide water level data and vertical bridge clearance data so that a rational policy could be developed regarding water draft and air draft for the two different approaches to the Port of Baltimore.

1. Water Depths and Bottom Changes

The channel bottom, the water levels and the ships draft (and elevation) are all variable in time and space. Only the bridge elevations are fixed in elevation. The Chesapeake Bay ship channel has a guaranteed depth of 42 feet below mean low water (MLW) while the C&D Canal has a guaranteed depth of 35 feet (MLW). However over a period of time, sediments will be deposited in the channels. Consequently frequent hydrographic surveys and dredging are required to monitor and maintain the published depths.

2. Sea Surface Variability

Of considerable more variability in both time and space is the sea surface. The astronomical spring tidal height ranges from a height of 3.4 feet at Cape Henry (VA) and 6.0 feet at Reedy PT (DE), at the eastern end of the C&D Canal, to a low of 1.3 feet in Baltimore Harbor. The water depth and the vertical clearance (air gap) can change as much as 6 to 7 feet in 12.5 hours at the Reedy Point Bridge during the period of spring tides. Fortunately the astronomical tides are predictable and allowances can be made beforehand for these tidal height changes.

A less frequent, but random change in water level occurs in response to passing weather systems, which can result in either a significant increase or decrease in water level depending on the wind speed and direction. At its maximum values, the wind tide exceeds the astronomical tide by a factor of 2 or 3 and since it is independent of the astronomical tide, it can superimpose on the latter to produce even greater extremes of water elevations.

Wind tide elevations can be predicted on a short-term basis (a few days), but the accuracy of this forecast depends on the accuracy of the weather forecast and also on the availability of a well-calibrated, numerical-hydrodynamical model. This forecast system has not been developed for the Chesapeake Bay area to date. Fortunately, due to the slow response of the Chesapeake and Delaware Bays to the strong wind velocity, a lag time of 6-12 hours exists before major water level changes occur and the change in water level can be anticipated before it occurs and monitored as it develops. Since the wind tide is not easily predicted and since it can cause considerable change in either the air gap or the channel depths, it is a major contributor to the amount of underkeel or vertical clearance that the pilots require in navigating large ships in these water ways. This unknown variable could reduce the effective operating draft or bridge clearance for ships entering the Port of Baltimore. These are some of the natural variations affecting the water depths of the Chesapeake Bay and C&D Canal. Ship loading and maneuvering can also alter the "effective" water depth of these waterways.

C. Ship Handling Considerations

The establishment in the last century of conventions limiting overloading of vessels led to the familiar Plimsol Mark or load line in order to protect against life and property loss at sea. Today's increase in vessel size has out-distanced the ability of many ports to increase channel depths to accommodate fully loaded ships. hence large bulk carriers and container ships rarely are able to load to their Plimsol Marks, but seek guidance to load cargo to some maximum safe draft for channel transit. In order to determine maximum safe draft, several factors must be considered in addition to the above navigational considerations including, vessel trim, vessel maneuvering characteristics, vessel roll and pitch in exposed seaways, and the vessel hydrodynamic phenomenon known as ship sinkage or squat.

Vessels transitting channels exposed to the open sea at the mouth of the Chesapeake Bay will experience to some degree pitch and roll (heel) and other forms of motion induced by long period swell.

A ship moving through the water also generates large pressure differentials around the hull which interact with the channel banks and bottom and with other vessels in meeting and overtaking. These pressure changes also cause a ship to sink bodily

in the water and, for a deeply laden ship with a large block coefficient, to trim by the bow, effectively causing an increase in draft and reducing underkeel clearance. This phenomena has variously been called sinkage or squat and is influenced by hull form, water depth, ship speed and other factors. Investigator's analyses of squat provide another guide in determining draft limits and operational requirements.

II. TECHNOLOGICAL DEVELOPMENTS

The advent of inexpensive microprocessors and simplified telecommunications systems has made rapid data transmission possible with the finished data products available within minutes of data acquisition to the product's users. In turn, the user has responded by increasing his willingness to accept deeper draft ships by using this information to take advantage of favorable water level conditions and to adjust accordingly to unfavorable conditions. Some of the new technological developments are briefly discussed.

A. Real-time Navigational Information

Two real-time navigational systems have recently been installed in the Chesapeake Bay and C&D Canal shipping lanes. These two systems are NOAA's TIDES ABC and EHI's TAGMOS (Tide and Air Gap Monitoring System) programs which provide similar types of measurements, but the results are used for different purposes. In the C&D Canal the lowest of the five bridges in Maryland is at Chesapeake City which has a 140.9-foot clearance above MHW and in Delaware at Reedy Pt near Delaware City which has a 136.4-foot clearance. In the spring of 1986, the Association of Maryland Pilots, through a grant from the Maryland Port Administration, contracted Evans-Hamilton, Inc. to install a TAGMOS on the C&D Canal at Chesapeake City (MD). In June 1988 in cooperation with the Pilot's Association for the Bay and River Delaware, the TAGMOS system was expanded to Reedy Pt (DE) as shown in Figure 1. The two systems can be interrogated by a personal computer at any of the pilot's offices in Baltimore, Philadelphia, Lewes (DE), Chesapeake City and Cape Henry (VA).

The TAGMOS system operation is straight forward. The water level is measured by both a Leupold & Stevens float gauge and a Sensotec pressure gauge, and the data are automatically processed and stored in a microprocessor for 24-hours. Upon interrogation using a standard phone connection, the water level data of either gauge are transmitted to the pilot's PC where the past 24-hours are graphically displayed. The PC also computes and displays the predicted tidal height elevations for the corresponding and the succeeding 24-hour periods. The differences between the elevations are the result of the non-tidal components, primarily the wind tide; thus, the pilot is forewarned of any anomalous water level condition prior to entering the canal. The user can select either the air gap mode to provide the clearance beneath the bridge or the tide mode to provide the water depth of the canal.

Quality control and reliability are maintained several ways. The TAGMOS system is calibrated at each maintenance trip. The gauges are checked daily by phone for operation, and the measured water level is compared to the predicted tide level and any anomaly verified. The two gauges at each location are compared weekly. The newer system at Reedy Pt. has been upgraded so that the field controller PC can be programmed by phone, thus permitting more rapid restoration of service. Finally, the redundant gauges provide backup in the event of a gauge failure.

The Chesapeake City TAGMOS has had less than 3% downtime in 24 months of operation with the lost data being mostly due to power surging from lightning and poor commercial power. The system has been proven to be reliable and accurate.

A typical TAGMOS graph of the predicted and observed water levels is shown in Figure 2 for a major winter storm. The graph shows an increase in water elevation of 2.3 feet above high water (air gap decreased to 138.3 feet) associated with an approaching storm. This wind tide stayed above 2.0 feet for several days. On another occassion, the wind tide decreased to 3.8 feet below the predicted tide level when the winds shifted to the northwest.

While the air gap is of interest to large vessels using the north route to Baltimore, the water depth in the ship channel in the Chesapeake Bay is of primary concern to those ships arriving from the south. Consequently, in 1986 the National Ocean Service (NOS) of NOAA installed real-time water level monitoring gauges at strategic locations in the Chesapeake Bay near the dredged ship channels as shown in Figure 1. These gauges are part of NOS's larger program of "real-time" or "now" tidal gauges which have been placed in operation in several major shipping ports. The NOS system is described in more detail in a paper by Parker (3). A software package developed by NOS called TIDES-ABC (4) is used to interrogate the tidal gauges and to process and display the measured water levels and predicted tidal elevations.

The TIDES-ABC and the TAGMOS systems have basically the same configuration of tide gauges, field data micro-processors, modems and the user's PC type graphic/-tabular displays. However, the hardware components and the software programs are indigenous to each system. The NOS gauges have also been installed in Delaware Bay at Lewes, Cape May and Philadelphia and are used by the Delaware pilots bringing ships into the C&D Canal. NOS maintains a comparable quality assurance program of daily checks and periodic calibrations of their gauges.

Figure 3 shows a typical NOS display of the predicted and observed water levels in Baltimore Harbor following the passage of a strong storm off the east coast of the U.S. The water levels dropped over 3.5 feet below the predicted tide level and 3 feet below MLW. Water elevation persisted below normal values for several days.

B. Ship Maneuvering/Operations

Since introduction of the new technology providing both predicted and actual tides and air gap in real-time, maximum transit drafts have been increased incrementally from 39.5 feet to 41 and in some cases 42 feet. As pilots gained experience with larger and deeper draft vessels and as they became convinced of the realiability of the tide and air-gap acquisition system, the "productivity" of the channel system was increased while maintaining safe clearances.

1. Ride the Tide

The astronomical tide wave enters the Chesapeake Bay and travels northward at an average speed of about 12 knots. With the cooperation of shipowners and operators, deep laden, inbound vessel arrivals at the Bay entrance are timed so that northbound transits can be made with the incoming tide. If a ship maintains an average speed of 12 knots it can arrive in the Baltimore approach channels, where shallower channel sections exist, at high water. While this practice of transiting on a rising tide is not unusual in many ports, the new real-time tidal data provides immediate information on actual conditions before and during transit of the waterway. Since the tidal level in the Chesapeake and especially Baltimore Harbor is very sensitive to changes in wind velocity and direction, this information is essential if vessel movements are to be made safely.

2. Ship Maneuvering

Vessel maneuvering characteristics depend largely on water depth/ship draft ratio and ship speed through the water. The hydrodynamic forces generated by a moving vessel, will vary approximately as the square of the ship's speed, hence a modest speed reduction does much to reduce these effects. If, for example a ship moving at 13 knots reduces speed to 9 knots, the magnitude of the hydrodynamic forces can be reduced by nearly 50% . Speed reductions, however, are also accompanied by a certain degradation of maneuverability, especially in strong cross currents or high winds. A minimum underkeel clearance must also be maintained for proper steering and control. A balance must be struck between navigational considerations and maximizing vessel loads. By knowing water levels prior to and during time of passage, proper assessment of these elements can ensure safe transit.

III. RESULTS OF THE TECHNOLOGY

A. Improved Ship Operations

Real-time tidal and air gap data is used in two important ways for improving ship operations. By examining historical data, long range policy regarding draft can be established. By examining immediate conditions an informed decision can be made as to the advisability of channel transit at deep draft on a particular voyage. If conditions do not warrant departure from the berth or entrance from the sea vessels are delayed until conditions improve. Vessel owners, agents and operators have agreed to this policy and operational decisions are made based upon probability of delays, length of delays, economic benefits of increased draft and concern for safety.

B. Less Restrictive Navigational Requirements

The use of NOAA's TIDES-ABC and EHI's TAGMOS has considerably reduced guesswork in channel navigation regarding underkeel and vertical clearances. Excessive underkeel clearances due to uncertainties in water levels have been reduced as a direct result of the new technology. The reluctance of certain vessels to use the Chesapeake and Delaware Canal due to uncertainties in bridge clearance have been overcome by demonstrating the reliability of the system to shipping officials. New ship calls into the Port of Baltimore are in part the result of these new technological innovations.

IV. SUMMARY

Technological innovations have contributed to deeper draft and taller structured ships entering the Port of Baltimore, resulting in more economical shipping

costs and increased attractiveness of the port as a major transportation center. These gains in navigational capabilities were achieved at a relatively small capital cost which was less than the income generated from one new container ship arrival or one deeper loaded bulk ship departure. While these gains have been achieved at a nominal cost, other agencies have been working in this partnership of marine interests to improve ship operations at the port using more conventional techniques. The U. S. Army Corps of Engineers is in the process of constructing the new 50-foot Baltimore Channel Project as well as maintaining and improving the C & D Canal. The U. S. Coast Guard Aids to Navigation Section has worked with the other marine interests to provide improved navigational aids and to relocate of channel buoys for safer ship operations.

In summary, the enhancement of the shipping channels and canal into the port of Baltimore is being achieved through a partnership of marine interests working together at the federal, state and private industry levels using both innovative and conventional techniques to exploit the full potential of these waterways while maintaining safety for the equipment and personnel and respect for the environment.

REFERENCES

1. Martin Associates, The Economic Impact of the Port of Baltimore, Maryland Port Administration and the Greater Baltimore Committee, January, 1988.

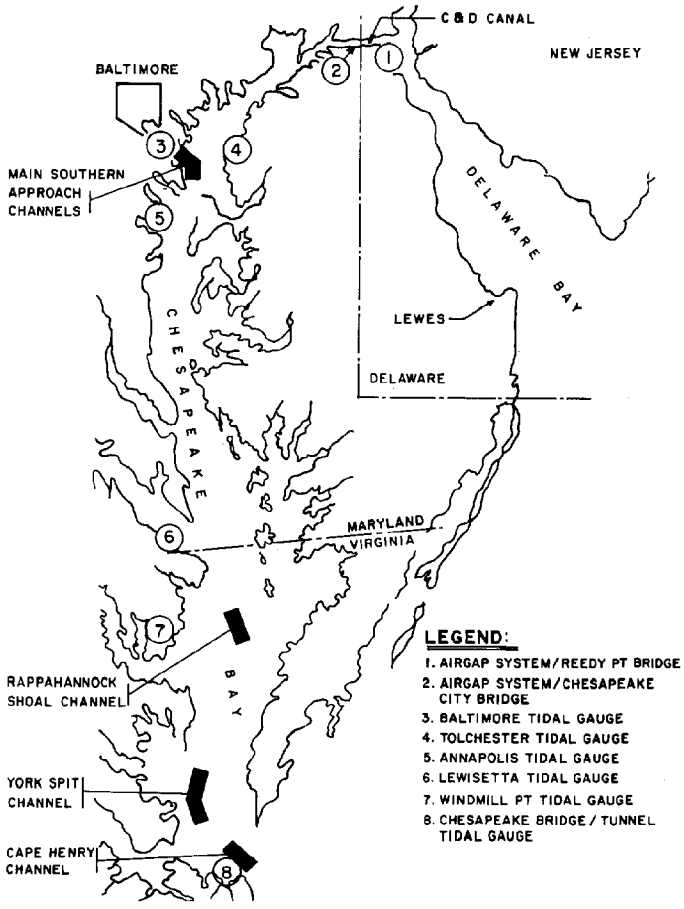
2. Energy Information Administration, Weekly Coal Production, Week of June 18, 1988, Washington DC.

3. Parker, Bruce B, Application of Real-Time Data Systems to the Forecasting of Water Levels and Circulation, Proc. Oceans 86, Vol 5, pp. 1401-1406, Sept. 23-25, 1986.

4. U. S. Dept of Commerce, TIDES-ABC Version 3.14, NOAA, National Ocean Survey, Rockville, MD 20852, Dec. 2, 1985.

Figure 1

LOCATION OF CHANNELS, TIDAL AND AIRGAP MEASURING STATIONS / CHESAPEAKE BAY-C&D CANAL



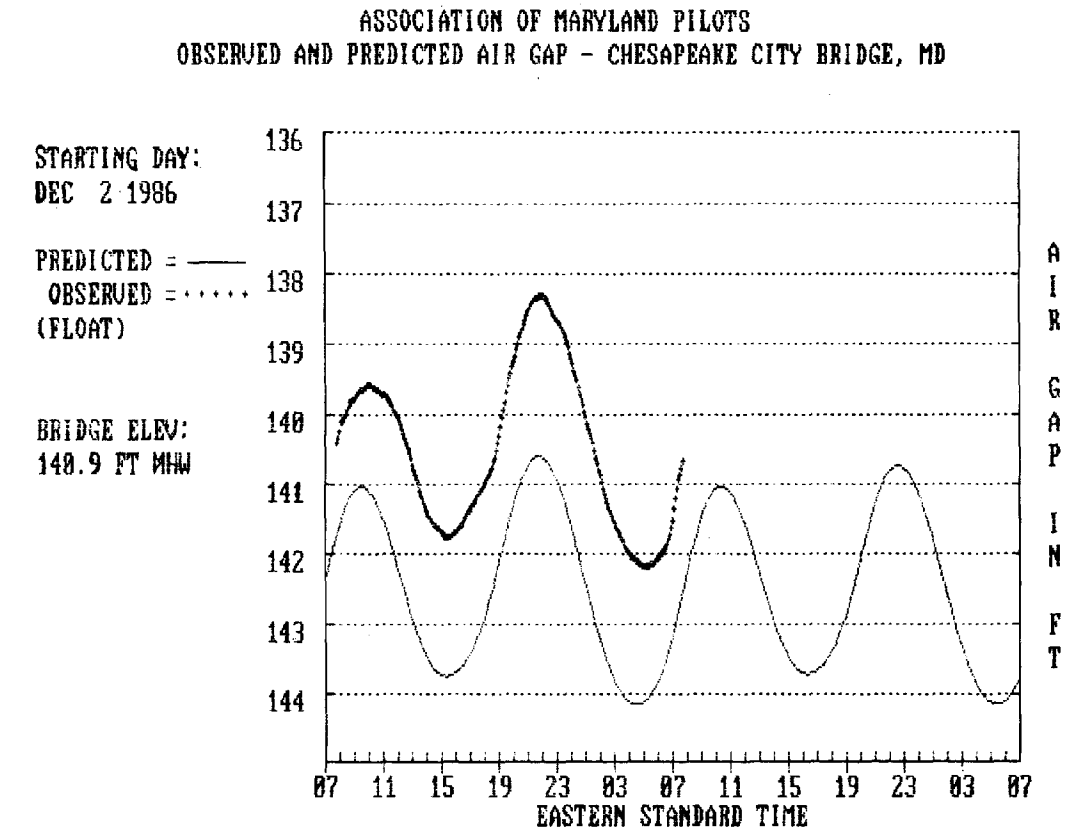


Figure 2. Example of a Typical TAGMOS PC Graphic Display.

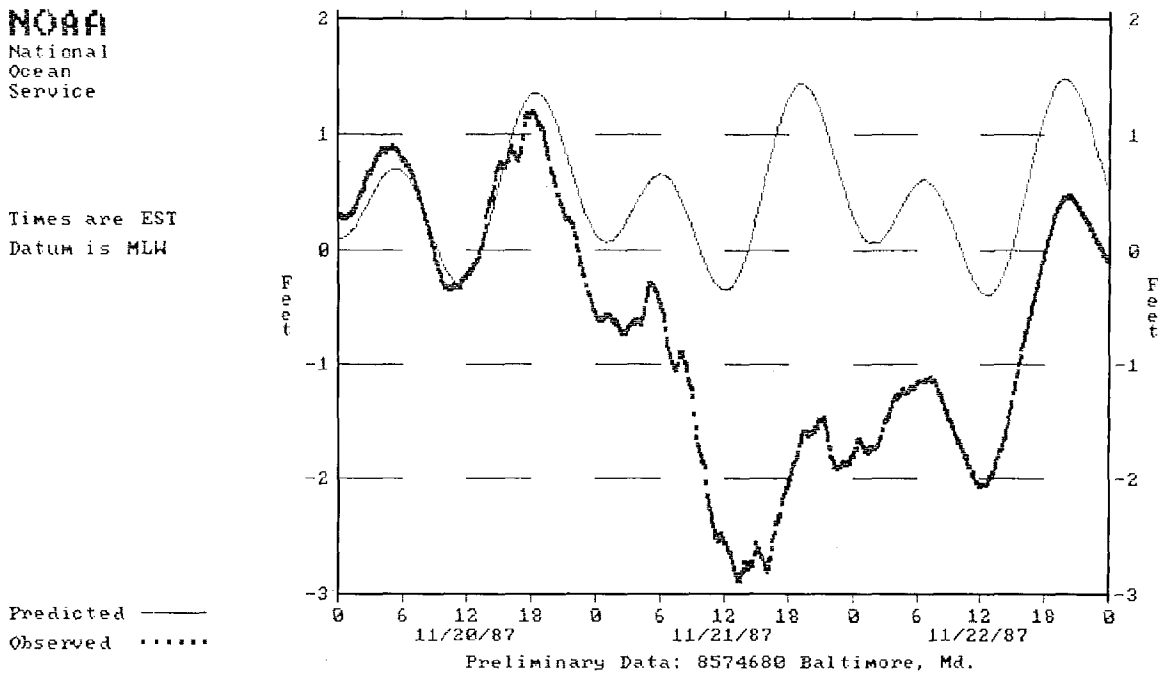


Figure 3. Example of a Typical TIDES-ABC PC Graphic Display.

THE MULTI-AGENCY MOU ON PORT SECURITY: A MODEL FOR CONFLICT RESOLUTION

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ABSTRACT

Channels of communication and coordination between marine law enforcement and defense agencies exhibit the same potential for misunderstanding, disruption, and inefficiency that often exist between other multiple-interest marine entities. Specifically, the diverse military, law enforcement and commercial interests in port security as represented by the U.S. Navy, Coast Guard, Maritime Administration and other agencies offer the opportunity for a fruitful analysis of a model of conflict resolution applicable across a wide spectrum of marine policy concerns. It is the object of this paper to demonstrate that the devolution of policy formulation and implementation to the local level where historical factors so allow is, in fact, the best national level policy for marine interest group conflict resolution.

The United States is critically dependent on the security of its waterborne channels and marine terminals.

As one element in the coastal defense community since its formal establishment in 1915 as "an armed service", the Coast Guard has been a military force-in-being as well as a maritime law enforcement agency. In this formation, port safety and security became specific responsibilities of the Coast Guard, and the Coast Guard Captain of the Port (COTP) was charged with the safe passage of military and non-military waterborne vessels and cargoes.

Most of the port security work of the Coast Guard in wartime has contributed significant expertise and resources which had been developed and accumulated during peacetime. It is because the port security mission has been executed in both peace and war that certain ambiguities in authority exist, and with them potential coordination problems.

Besides joint Navy - Coast Guard port security planning and operations, the Coast Guard must deal with other military and civilian agencies in the execution of its port security mission. The mission of port security is a shared one and is critical to national security. These complex aspects of port security have introduced controversy and discussion in both interagency and intergovernmental relations. This controversy, in turn, has generated difficulties in the port security planning and coordination process. It appears that interagency coordination with regard to port security and related mission areas has proceeded more effectively in the last decade than during any previous time in history; yet, important areas of coordination remain to be addressed and associated issues resolved. Indications are that these areas will be carefully fine tuned in such a manner that they may serve as a model for interagency and perhaps intergovernmental coordination in the future.

It is the central argument of this study that the past and probable future success of such coordination has been and will be due to the establishment of local port readiness committees (PRC's), the creation of a milestone in interagency understanding. The Coast Guard's assumption of the chairmanship of these committees is a logical outgrowth of its long history of activity in the mission area and its concern for optimum cooperation and coordination. The effectiveness of local PRC's demonstrates the wisdom of allowing the largely local nature of port security coordination concerns to control the manner in which they are addressed. It will be argued that the continued successful coordination of port readiness and security interests and resolution of difficulties, as practiced in the PRC's, is predicated upon the devolution of policy formulation and implementation to the local level.

By implication, this suggests that much of what falls under the rubric of marine policy may be most efficiently implemented by allowing the necessarily diverse interagency and intergovernmental interests in the marine environment to provide policy directions as close to the specific area of contention as possible. Port security as a policy issue demonstrates the correctness of this hypothesis, and by extension, its applicability to other areas of marine policy. None of this is to deny the appropriateness of national level strategic planning where such efforts are logically required to initiate local coordination bodies. It is only maintained that once macro-level steering

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groups have performed their important function, they permit local entities to bring their inherent efficiencies into the policy process.

Questions of Coordination

Early in the 1980's, prodded by renewed interest in national defense preparedness, a number of officials in Congress and in the Administration, began to voice concern that previous initiatives to insure interagency coordination in port security related matters were inadequate and ineffective.

Typical of marine agency comments at that time is the following:

> MARAD and the Coast Guard appear to have distinct areas of responsibility regarding the smooth operation of ports in wartime. The duties of the Captain of the Port are specifically spelled out in statute. However, the Port Controller function only exists during wartime, thus hampering peacetime coordination and planning efforts between the COTP and the Port Controller in each locale.[1]

(The Port Controller is the Maritime Administration's (MARAD) local agent during mobilization.)

In considering the manner in which the diverse interests in port security have addressed the coordination issue, insight will be gained in resolving similar difficulties in other areas of marine policy.

Historical Authorities

Legal authorities for port security consist of statutes, executive orders, and more recently, international agreements. Statutory authority, as first developed during World War I, was originally designed to meet immediate wartime and/or emergency threats. Executive orders issued in conjunction with these threats continued the linking of direct federal involvement in port security with emergency contingencies. This state of affairs continued until the initiation of hostilities in Korea and U.S. - Soviet polarization during the Cold War prompted Congress to adopt a landmark piece of legislation on 9 August 1950, the Magnuson Act, 50 U.S.C. 191. The Magnuson Act amended the Espionage Act of 1917 (the first statute concerned with port security) by permitting the President to institute measures pursuant to port protection without having to first issue a declaration of national emergency.

The decoupling of port security from national emergency declaration was an important shift in the program's evolution. It provided the basis for some standing authority to perform port security duties, and led to the legislation of the 1970's that granted permanent statutory status to the program.

Further development in port security missions occurred as new concerns surfaced relating to environmental protection in the 60's and 70's. Ultimately the Coast Guard recognized these related concerns by organizing its Port and Environmental Safety Program (PES) in May 1980. The new program consisted of port safety, port security, and environmental protection.

Naval Coordination Issues

Port security coordination issues between the Navy and the Coast Guard are best approached by first citing the institution of Maritime Defense Zones (MDZ's) in 1984.

Subsequent to the signing of an MOA between the Coast Guard, Department of Transportation, and Navy officials in 1984 that formally established the Maritime Defense Zones, a number of MOU's, ad hoc committees, working groups, and the like on all planning levels, active and reserve, have sprung up involving Coast Guard, Navy, and other agencies of the federal government. Before considering these initiatives, a brief excursus on potential problems between the Navy and Coast Guard is in order.

Whether proceeding from the orders of the President himself, the National Security Council, defense secretaries, or the Chief of Naval Operations, the executive branch and its military instrumentalities have historically issued directives that have shaped large portions of the mission known as port security today. Recently, Congress has become much more aggressive in designing the Coast Guard's role in port security, although traditionally less active in policy formulation in the mission area.

As with many of Congress' other efforts to be a more equal partner in policy development since the early 1970's, its initiatives in port security have obtained both a more solid basis for mission performance and the potential for serious conflicts in the event of national emergency or war mobilization between executive branch managers and field officers whose responsibilities must include a proper regard for purely statutory duties. Such conflicts, left unaddressed or unrecognized, can only tend to produce potentially dangerous inefficiencies in coordination under crisis conditions.

Without doubt, the most comprehensive authority conferred specifically upon the U.S. Coast Guard by Congress for port security and safety was the Ports and Waterways Safety Act of 1972, as amended by the Port and Tanker Safety Act of 1978 and subsequently. Bearing close similarity to the regulations promulgated by the Magnuson Act of 1950, the provisions of implementing regulations grant specific, statutory authority to the Coast Guard Captains of the Port, under the Commandant and District Commanders, to regulate broad areas of vessel and waterfront facility operations.

The Role of the Captain of the Port (COTP)

In the execution of the port security authorities granted to the Coast Guard, whether statutory or in time of mobilization (and therefore also under the naval MDZ

commands), it is the Coast Guard Captain of the Port who bears the immediate responsibility for the mission area. Previous to the Ports and Waterways Safety Act of 1972, responsibilities of the COTP had been codified by executive orders, as well as by World War II legislation and naval assignments.

Passage of the 1972 legislation did broaden COTP authorities; the 1978 legislation went further by defining the applicable marine environment to include the 200-mile fishery management zone and Outer Continental Shelf waters. Most importantly, however, both pieces of legislation fully institutionalized, in effect, the COTP organization by making its activities immune from rescission by executive authority.

Federal regulations which specifically implement provisions of the Ports and Waterways Safety Act stipulate that the COTP's authority includes the management of vessel operation and anchoring when, among other conditions, "The District Commander or Captain of the Port has determined that such order is justified in the interest of safety by reason of weather, visibility, sea conditions, temporary port congestion, other temporary hazardous circumstances, or the condition of the vessel."[2] Inasmuch as a recent NAVGARD Working Group on Port Security report said, "The greatest vulnerability, even during mobilization, is damage from accidents. . . . Historical data bear this out"[3], it would appear as if the COTP's statutory authority over vessel movement might even be greater in war than during peace.

COTP concerns are, in effect, being divided between MDZ-related naval planning functions and statutory ones. Indeed, potential conflicts in both planning and operations might appear to be inevitable, with or without additional resources.

The Convergence of Statutory and Naval Warfare Missions - Flow or Impact?

The distinct but related responsibilities involved in the performance of statutory and naval warfare missions clearly converge, at the operational/port level, in the person of the Coast Guard Captain of the Port. Congress expressed its firm conviction that the COTP ought to possess permanent, unequivocal authority to protect U.S. ports and waterways in order to assure safe and expedient passage of waterborne cargoes. Various executive branch agencies and the U.S. Navy have concurred, along with the Coast Guard, that the COTP office is the proper and logical level to exercise important naval port and coastal defense missions. While opportunities for interservice coordination are thereby enhanced in the execution of the port security mission between the Coast Guard and the Navy, it is equally apparent that, depending on other factors, increased opportunity for confusion and conflict also exist.

While,

> . . . under "posse comitatus" provisions, DOD cannot normally perform law enforcement functions. Thus, DOD has no legal basis to task the Coast Guard to perform law enforcement functions as a military/warfare mission.[4]

And,

> DOD planning assumes the Coast Guard will continue to perform its regulatory and law enforcement missions as tasked by statute and Executive Order.[5]

DOD planning intentions and COTP operational realities may not be as harmonious under crisis conditions as intended.

Even in peacetime planning, the question as to how the military harbor defense mission is distinguishable from the statutory port security mission is problematic. The two highly complementary missions were discussed in a NAVGARD Port Security Working Group report; the following excerpts of that discussion are illustrative of the potential for real disruption of coordination between Navy and Coast Guard concerns:

> A member of an armed force is generally free to use deadly force against an enemy while a law enforcement officer uses force in a graduated manner against a suspected criminal . . . The Rules of Engagement for military action differ substantially from the Use of Force policy for law enforcement. Although there are some clear distinctions between Harbor Defense and Port Security, there will also be an overlap . . . The contrast between what Navy units/personnel can do and what Coast Guard units/personnel can do suggests that the distinction between Harbor Defense and Port Security should reflect the statutory authority of the armed force concerned . . . Port Security, as a Coast Guard specialized mission, must include all law enforcement related activities and may include military activities. In practice these distinctions will not be clear when action is taken.[6]

According to a recent statement by a reserve Coast Guard officer, "Coastal defense is a U.S. Navy mission."[7] One's political sense as to whether executive or legislative agencies should prevail in port security planning and one's perspective on the larger question as to what really constitutes "peace" or "war" (and the proper way for a democratic society to design and implement its public policy in a world frought with crisis and danger) affects one's perception of the issues discussed here. One will either perceive the foregoing as a call to denounce the statutory basis for port security, or an opportunity to further delineate the wisdom in crafting a maritime policy dealing with potential crisis management on the basis of a firm deliberational foundation. Indeed, whether civil marine policy and military naval policy converge and flow or impact depends ultimately

upon deeper constitutional issues.

Whatever one's opinion, it is undoubtably true that the greater the attempts to provide explicit channels of communication and coordination, the greater the probability of success in achieving some measure of harmony. The U.S. Coast Guard and U.S. Navy have begun that process at a number of interagency levels. We turn now to other agencies who have begun talking together about port security, and the implications for marine policy conflict resolution in general.

In the event of wartime mobilization, a number of military and civilian federal agencies would be responsible for various aspects of the overall task of acquiring the necessary vessels and port facilities for emergency shipping, as well as the management of those vessels and the waterways they must ply for the safe and efficient transfer of military and economic cargoes between the United States and its diffuse overseas forces and allies. State and local port and law enforcement/emergency personnel would also need to be organized so as to support the objectives of the national authorities. These include the Maritime Administration (MARAD) and its National Shipping Authority (NSA), the Military Traffic Management Command (MTMC) of the U.S. Army, the U.S. Army Corps of Engineers, the Military Sealift Command (MSC), the Naval Control of Shipping Organization (NCSORG), the Federal Emergency Management Agency (FEMA), and even the Environmental Protection Agency (EPA).

All the above organizations have been assigned emergency/mobilization responsibilities by Executive Order 11490 - without the benefit of that comprehensive and rational analysis that would have clearly delineated the unambiguous domain of each. The object here will be to discover the degree to which these organizations have sought to examine their roles during mobilization and negotiate with the others a clear understanding of the respective responsibilities of each, with the objective of attaining efficient and effective use of waterborne assets. Coordination activities in local port readiness working groups will be featured as a reasonable cause for optimism in any future contingency requiring port-level cooperation.

The Multi-Agency Memorandum of Understanding on Port Readiness

Largely as a result of signing of an MTMC - Coast Guard memorandum, a number of other federal agencies with port readiness concerns began to approach MTMC and the Coast Guard with an eye toward participating in an extended formal agreement. There was a clear need for a comprehensive, multi-agency understanding that would address the broad sweep of issues that would likely arise during national mobilization. As a result, an ad hoc port readiness working group formed in June 1983 and comprised of representatives from each of six agencies responsible for various aspects of emergency marine transportation, both civilian and military, finally developed a memorandum, which was signed by them in December 1984. This Multi-Agency MOU on Port Readiness was endorsed by the Departments of Defense and Transportation in January 1985. In the words of the Coast Guard Commandant, "For the first time, responsibilities of key federal agencies involved in port throughput of strategic cargo are presented in a single document."[8]

The signatories realized that merely documenting the roles and authorities of the participating agencies, as they were then understood, could not of itself insure their efficient and effective coordination in the stress of a crisis management contingency. For this reason, the MOU also mandated the creation of a Port Readiness Steering Group which, in turn, established a Port Readiness Working Group (PRWG) "to develop guidance and manage actions to accomplish the MOU's objective."[9] The Port Readiness Working Group recommended that the chairmanship of local Port Readiness Committees, which were mandated by the multi-agency MOU for the purpose of coordination of local concerns, be assumed by the Coast Guard Captains of the Port (COTP).

The basic reason for the selection of the Coast Guard COTP as the local committee chairman was simply but eloquently expressed by MTMC in an intra-agency memorandum:

> A COTP is permanently present in the specified ports and provides a standardized focal point for committee coordination . . . Although the COTP is the chairman, the committee is an organization of equals. The chairman's role is to coordinate communications and action.[10]

While emphasizing overall committee membership equality, MTMC never forgot the Coast Guard's special capabilities, developed from nearly 15 years of statutory responsibility for port security and local port awareness in general, as well as decades of port presence derived from executive department authority.

With the establishment of the national steering and working groups, and the local port readiness committees, it would seem an ideal forum has been developed wherein important players in the emergency marine transportation field can address, and correct, some of the serious potential problems in coordination that existed at the beginning of the present decade. There is insufficient space to discuss all the issues the various federal signatories of the multi-agency MOU have faced.

While the ultimate judgement as to the success of the local working groups may have to wait that unsought occasion for which they have prepared, it seems that much of value has occurred in the few years in which the

multi-agency MOU has been in existence.

Summary and Conclusions

It now remains to determine just how well the port security mission is being addressed by MOU participants and what organizational perspectives and insights might assist policy and program analysts to craft the most effective and efficient approach to the mission of port security, and similar marine policy issues.

Evaluation of the execution of the port security mission must proceed in two distinct, if related, contexts. First, the military character of the mission must be considered along with its special relationship to both the U.S. Navy and Coast Guard. This military aspect, in dialectical tension with statutory responsibilities as a maritime law enforcement concern, provides one focus for evaluation. Second, the largely civilian character of the multi-agency MOU on Port Readiness and its non-naval aspect in emergency maritime transportation planning provides another perspective for analysis. These different contexts for involvement in port security will render diverse assessments as to how well interagency coordination is being effected in the mission area.

In its relationship to the U.S. Navy, the Coast Guard would have to fulfill two distinct mandates during mobilization. These two mandates are a direct function of the constitutional division of power between the executive and legislative branches. Under its executive branch mandate, the Coast Guard must assume the character of a naval service in its own right during national mobilization or emergency. Under the mandate imposed upon it by Congress, the Coast Guard must also maintain its status as a maritime law enforcement agency with statutory duties during both peacetime and mobilization.

Even as Congress and the President frequently argue over various points of national policy, so do those agencies and organizations which view themselves as primarily executing either Congressional intent or Presidential operating authority. Recent events associated with the Iran/Contra affair demonstrate most vividly the strong potential for misunderstanding and fractured national policy that exists when executive branch operatives and statutory considerations run counter to one another.

With both day-to-day operational expertise applicable to inshore naval missions and a clear law enforcement mission, the COTP must necessarily serve two masters during wartime. It is clearly an irregular boundary between general maritime and national defense/naval policy with which the COTP must contend, and there appears to be little guidance available to the COTP in this regard from Congress or high executive officials.

It must be acknowledged, on the other hand, that the Coast Guard's military relationship with the Navy has indisputably never been better. The formalization of that relationship within the context of the Maritime Defense Zone command structure, and the excellent forum for planning functions related to the MDZ's (as well as other military and non-military concerns) provided by the formation of local Port Readiness Committees augers well for the future. Ultimately, it will most likely be the low-level but powerful influence of the relationships forged in local PRC's that will provide the best opportunity for the Navy and Coast Guard to work out its potential conflicts rather than the high-level but often ineffective attempts to set things in order conducted from Washington.

Examination of the difficulties and opportunities involved in the coordination of Naval - Coast Guard concerns in port security will now focus on the PRC's. Analysis of the dynamics within the PRC's will proceed upon the insights of organizational theory. The existence of "good faith" relationships within the context of a military command structure are also important, but the scope of the analysis must transcend such considerations as well as recognize the dynamic and fluid nature of port security as one policy issue within a total, synergistic governmental process. This "fluidity" is reflected in a situation in which information flows from the external environment (such as threat assessment data and the demands of public and special interest groups) to the federal agency as well as between the impacted marine agencies themselves.[11] The public policy responsibilities requiring cognizance of rapidly changing conditions, of correctly interpreting those conditions, and finally of effectively responding to them impose special demands and insights on policymakers.

A degree of managerial flexibility has been developing which is inconsistent with the centralized model. According to organizational theorist Donald P. Warwick, highly interdependent agencies whose decision making processes are centralized at a relatively high level of hierarchy usually experience information "buck up" and subsequent inefficiency in the policy process.[12] In addition, such interagency entities are generally resistant to necessary structural changes as external conditions shift in both nature and intensity.[13] In the fluid world of port security, policy development and mission management cannot afford the kind of inefficiencies inherent in this centralized model.

Interestingly, Warwick discusses organizational development initiatives of the past quarter century designed to remedy the problems of centralized management that closely resemble the local PRC's philosophy and approach.[14] From sensitivity training to organizational feedback and problem-solving sessions, Warwick describes those very

elements that have been central features of the PRC's modus operandi. While it is not possible to document the degree to which organizational theory was or was not consciously employed by the framers of the local PRC's, it is significant such insights find their reflection in these local entities.[15]

Summarizing the first part of our evaluation of the port security mission, it may be concluded that although potentially serious problems in coordination do exist between the Navy and the Coast Guard, the pace of efforts of the two services to understand each other's perspectives which have been ongoing since before the beginning of the 1980's (and especially since the establishment of local PRC's) is likely to result in a satisfactory mobilization relationship within the next five to ten years, certainly before the end of the century. The MOU which attempts to integrate the naval, Coast Guard, and general interagency perspective and functional structure has been mutually declared to be a "living document", and it would seem that there is truly an organic character to the relationships that have been forged in connection with its preparation and execution. By continuing to design and implement its own resolution of executive-statutory conflicts at the local level, local PRC's, chaired in the main by Coast Guard officers, do appear to offer the best opportunity for Navy - Coast Guard coordination requirements to find suitable satisfaction.

Turning now to the non-naval aspect of the emergency maritime transportation planning efforts of the multi-agency MOU signatories, an extension of the foregoing analysis would be appropriate. Inasmuch as the relationship of the non-naval signatories is, unlike that of the relationship to the naval command structure, a largely negotiated affair among equal but separate partners, the dynamics of coordination tend to produce more open-ended results. This "indeterminate" quality of interagency linkage compels one to adopt a more conservative prognosis for future coordination efforts than was the case with the Navy and the Coast Guard.

One key interagency relationship which must be maintained is that which concerns the Maritime Administration. Commenting on the role of MARAD and its designated port representative, the Federal Port Controller, Hugh W. Stephens wrote,

> . . . MARAD representatives believe their agency will assume a predominant role in coordinating federal agency interaction with port authorities during the surge phase of mobilization. MARAD may indeed assume this during the initial stages of mobilization, but, given the primacy of military needs in general, and MTMC's responsibilities in particular, it is questionable that DoT (Department of Transportation) interpretations will prevail over those of a DoD (Department of Defense) component.[16]

Indeed, Dr. Stephens indicated that MARAD port representatives would require a lot of help from other quarters.

In actuality, another approach to the role of the FPC may be more useful. According to Mr. Joseph Corban, Military Liaison/Special Operations Officer with the State Port Security Office at the Port of Wilmington, North Carolina, the appropriate model for the Federal Port Controller is the Joint Chiefs of Staff, whose directorship is likened to that of a coordinator, whose overall purpose is to achieve maximum efficiency of operation.

One danger which the agencies involved in port mobilization planning need to avoid is the possible tendency to erect inefficient hierarchical structures in attempting to execute their intertwined responsibilities thereby negating the central benefit of the local PRC's. According to Warwick, public bureaucracies, especially those which need to operate in a multi-agency environment, tend to promulgate elaborate structures as a response to uncertain signals in the external environment.[17]

The potential for inefficiency inherent in a hierarchical environment has been discussed. The remedy would appear to be the acquisition and maintenance of realistic threat assessments, response criterion, and communication channels; in other words, the external signals need to be well defined and good working relationships must be maintained in the local PRC's. Although the special impetus provided by military command structures does not exist between the naval and non-naval multi-agency MOU co-signatories, the forum provided by the local Port Readiness Committees can be a source of important interaction and adjustment.

In the main, the interagency coordination efforts in the execution of the port security mission have improved markedly since the beginning of the decade. The outcome of interagency deliberation in the early 1980's exhibits the wisdom both of perceiving mutual needs at high levels of administration and then of allowing the resolution of those issues at the regional and local level wherever possible. Marine agencies must strive to utilize the opportunities this shift in policy formulation and management style affords them.

Thus far, interagency efforts to engender significant cooperative relationships and understandings have been most exemplary. Though not without important difficulties yet to be resolved, the dynamics and trend of the interagency coordination process as implemented in local PRC's will likely render a working model by which other intergovernmental processes will be evaluated in the future. By developing local fora for

conflict resolution, with suitable national direction, as necessary, and identifying relevant historic factors in the conduct of those fora, planners in port security throughout government have designed a management system worthy of consideration by those groups whose concerns include meshing military and non-military interests in marine policy.

NOTES

1) U.S. Department of Transportation, Office of the Secretary of Transportation, Coast Guard Roles and Missions, Staff Working Papers, Washington, D.C., March 1982, p. 504.
2) 33 CFR 160.111(c).
3) Port Security Working Group, "Report of the NAVGARD Board", 25 June 1986, p.6. (Emphasis added).
4) U.S. Coast Guard, Port Security Branch, "Operating Program Plan (OPP) - Emergency Preparedness Goal, Goal Number 1", 10 April 1987, p. 11.
5) Ibid.
6) Port Security Working Group, "Report of the NAVGARD Board", 25 June 1986, pp. 2-3.
7) LCDR Edward A. Moritz, USCG(R), "Coastal Defense", U.S. Naval Proceedings, June 1985, p. 48.
8) U.S. Department of Transportation, U.S. Coast Guard, Commandant Instruction 16601.5, dated 3 July 1985, Item No. 4.a.(2); also Lieutenant Mike Ditto, USCG, "Information Paper", 1 August 1984.
9) Commandant Instruction 16601.6, dated 9 February 1987, Item No. 3.a.
10) Charles A. Vickery, Brigadier General, USAF, MTMC Vice Commander, Department of the Army, dated 18 March 1987, Item No. 4. (Emphasis added).
11) "There is a unique and diverse range of groups and institutions in the inter-governmental public policy arena whose claims, counter-claims and concerns are factored into any policy equations or strategies being considered by governmental or ocean industry corporate decision-makers." Edward W. Cannon in "National Ocean Policy 'Octagon'", Sea Technology, January 1985, p. 50.
12) Donald P. Warwick, A Theory of Public Bureaucracy, (Cambridge, MA: Harvard University Press, 1975), pp. 66-67, 192.
13) Ibid, p. 167.
14) Ibid, p. 196-7.
15) It is noteworthy that other areas of marine policy have experienced or are experiencing similar shifts to local and regional management schemes, perhaps the most important example being the establishment of regional fisheries councils mandated by the Magnuson Act of 1975. An equally important trend in marine affairs is the increased level of discussion and coordination that occurs in the Ocean Principals Group. Founded by the USCG in 1978, this executive level group, whose membership includes agencies as diverse as the National Security Council and EPA, strives to create an environment in which constructive activity can occur without the dampening effects of "superagency" oversight.
16) Hugh W. Stephens, "U.S. Ports and National Defense Strategies", Defense Transportation Journal, December 1986, p. 67.
17) H. Brinton Milward and Hal G. Rainey, commenting upon Warwick in "Public Organizations", in Organizational Theory & Public Policy, edited by Richard H. Hall and Robert E. Quinn, (Beverly Hills, CA: Sage Publications, 1983), p. 136.

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MITIGATION PLANNING FOR PORT DEVELOPMENT

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ABSTRACT

Port expansions frequently result in adverse environmental impacts that require mitigation to preserve living marine resources. A systems analysis approach was used to select the location and design of an artificial reef that was part of the mitigation required for redevelopment of the Port of Wilmington, Delaware.

Multiple Attribute Decision Making (MADM) and decision risk analysis (via network simulation) were among the methods used to plan cost-effective and reliable mitigation. This approach allowed decision makers to adjust attribute weighing factors and evaluate the uncertainty inherent in the application of this new technology. The results suggest that these methods can be used to assist in resolving the complex problems common in mitigation planning.

PORT MITIGATION REQUIREMENTS

Port redevelopments and expansions frequently result in localized adverse environmental impacts that may require mitigation to preserve living estuarine or marine resources. In many areas, however, mitigation options are both limited and expensive due to extensive land development and multiple use conflicts with other on-the-water activities.

Port development often requires dredging and land reclamation to increase or maintain capacities or adapt to new cost-effective shipping and transfer technologies. These actions may result in the loss or degradation of wetland, reef, or shallow water habitat that is critical to maintaining fish or shellfish resources and the vitality of the local ecosystem. Concern over the loss of this habitat and its associated resources has resulted in increasing efforts to maintain the carrying capacity of our coastal areas. As a consequence, mitigation for unavoidable adverse impacts is now frequently required as a permit condition for port development activities.

A number of options exist for creating or augmenting wetland or shallow water habitats impacted by proposed development activities. These include construction of artificial wetlands, rehabilitation of existing degraded wetlands, establishment of submerged aquatic vegetation (SAV) or kelp, excavation of existing shore sites to create open water, and construction of artificial reefs. The decisions associated with deciding whether or not mitigation is required, the performance requirements to be met, and the site, type, and scale of mitigation are complex interagency problems. Applying a systems approach to support these decisions can serve to improve the probability that a decision acceptable to the various agencies and interest groups can be achieved in a cost-effective and timely manner.

APPLYING SYSTEMS ANALYSIS TOOLS FOR DECISION SUPPORT

The purpose of applying a systems approach to mitigation planning is to clearly establish the assumptions, criteria, and decision factors used to make judgments. Once this is accomplished, it is somewhat easier to rationally debate the problem. This is particularly helpful when, as with most mitigation projects, decisions are being made by groups of individuals from different agencies that reflect different concerns and disciplines.

Systems analysis is a decision making process in which competing alternatives are analyzed for the purpose of selecting the one that best satisfies some predetermined set of requirements, in this case, the requirement would be the mitigation of adverse impacts. Before applying the systems analysis process to aid decision makers, however, two basic questions must be answered: What requirement, and "best" in what way? How these central questions are answered is vital to the successful application of the analytic tools. Objectives must be carefully selected, and suitable performance measures must be clearly specified before the benefits of the systems approach can be fully realized.

There are basically six elements to a systems analysis, they include:

- The selection of useful objectives.
- A listing of all feasible alternatives.
- An examination of expenditures associated with the alternatives.

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- o An effectiveness scale for each attribute
- o Estimates of effectiveness of various alternatives
- o Criteria that functionally relate expenditures and performance

Each of these elements is significant to the decision making process; failure to fully address them is often the cause of controversy and delays in the environmental decision making process. Since delays frequently result in cost increases, they may adversely affect project completion and, if fixed funding has been allocated for the project, may reduce the scope or effectiveness of the final project.

The first step any analysis should be the selection of useful objectives. This should result in a clear statement of the problem. The objectives must both satisfy the basic requirements and not conflict with organizational goals. This may may appear to be a simple task. However, when more than one set of organizational goals are involved or a new conceptual objective is contemplated, this task may require considerable discussion and compromise to arrive at a mutually acceptable set of objectives.

The second step is the listing of all feasible alternatives. A feasible alternative is one that satisfies all objectives within the limited resources that are available. The resources that may be limiting factors include funding, material, people, time, and information. For environmental projects, information may be limited to a degree that results in some measure of uncertainty with respect to the ultimate decision. It is very important to clearly state this uncertainty so that it can be accounted for in the decision making process. The analyst must define the real-world situation as accurately as possible in order to determine which alternatives are valid.

The third step is cost analysis and estimation wherein the expenditures required to fully implement each of the alternatives must be assessed. An important point to remember here is that if any of the alternatives are developmental (not fully operational, tested, and proven) the costs as well as performance are bound to be uncertain as well.

The next step in the process is the development of an effectiveness scale that indicates the degree to which each alternative achieves the objectives specified. This is a critical problem in analysis and is one where errors are frequently made. Since effectiveness is rarely measured by a single attribute, methods to combine readings from a multiplicity of effectiveness scales are often required. Reliance on simple parametric cost estimates is a very risky approach and should be avoided.

Determining where on the effectiveness scale each alternative lies is the next step in the analysis. Effectiveness is a comparative measure of the degree of attainment of the stated objective by competing alternatives. Considered together, the effectiveness scale and effectiveness are referred to as the "measure of effectiveness" or "objective function."

The final step in the analysis process is the criterion that is simply a statement about cost and effectiveness that determines choice. Cost and effectiveness are functionally related. Therefore, an effort to maximize effectiveness and minimize cost is relatively meaningless. In most cases, either cost or performance must be defined by thresholds or bands while the other is maximized.

One advantage of applying a systems approach to mitigation planning is that it serves to create an audit trail for the decision making process. Since many environmental decisions may ultimately be reviewed by all interested parties, the public, and possibly the courts, it is definitely advantageous to have applied a rational and open approach to the problem that can be defended logically and, if necessary, legally. The systems approach is particularly useful for complex problems involving new approaches and more than one organization.

DECISION SUPPORT METHODS

A range of methods are available to systems analysts and others interested in solving real-world environmental and natural resources problems. It is, however, essential to apply the correct methods and to be aware of the requirements and assumptions inherent in their use. As with any set of decision support tools, these methods must be carefully applied in a manner consistent with the decision maker's project objectives and institutional goals. Misapplied, such analytic tools can create the illusion that a "ideal solution" has been found when, in fact, it has not.

Project Objectives

Although obtaining the decision maker's objectives would appear to be a straight-forward problem, this is not always the case. Often objectives are not clearly stated, or multiple and possibly conflicting objectives exist. This frequently occurs in mitigation projects that require concurrence of numerous federal and state agencies. To allow for the widest range of feasible alternatives, objectives should be functionally described in a manner that allows clear performance measures to be established.

Alternatives

Developing a list of feasible alternatives may require the advice of specialists from a number of fields. For mitigation planning, what is feasible depends on site-specific conditions. Frequently the information needed to fully examine feasible

alternatives is limited which introduced an element or risk into the process. Developing a listing of alternatives acceptable to all parties can be facilitated by applying group decision making tools designed to apply social choice theory to group expert judgment. These range from traditional "brainstorming" and Delphi methods to methods using the Borda function or Successive Proportional Additive Numeration (SPAN) (MacKinnon, 1966). These methods can function to incorporate a range of group input to arrive at a consensus.

Cost

Cost is also dependent on local conditions and available information. The approach that should be used here is the concept of "life cycle cost," which incorporates the total cost of selecting an alternative over its life expectancy. Alternatives should be compared based on an economic analysis that considers acquisition, maintenance, and replacement costs as well as all other costs which may be associated with fully implementing that alternative over the period of performance required for the project. Failure to consider the life cycle costs often leads to decision errors. Simply comparing initial acquisition costs does not consider variations in functional life expectancy and the future requirements to replace and/or maintain alternatives.

Measure of Effectiveness

The development of a scale to measure each alternative's relative effectiveness is frequently the most difficult problem in analysis. In almost all cases, effectiveness is not measured by a single attribute and the problem of how to combine the readings from a multiplicity of attribute effectiveness scales is difficult particularly when some amount of uncertainty is involved in the individual scores. The basic problems include:

- o Multi-attribute effectiveness
- o Measurability
- o Commensurability
- o Importance
- o Sensitivity
- o Uncertainty

Alternative effectiveness is typically a function of many characteristics; this is certainly the case in mitigation performance. The problem arises from the fact that the underlying relationship among these operating characteristics is not always clear. Sensitivity analysis can be used to determine which attributes are not worth considering in terms of their relative impact on the decision. Measurability is especially a problem for nonquantifiable attributes that cannot be put on a cardinal scale. The development of interval measurement scales for these attributes using group decision making methods can help address this problem.

If meaningful scales can be developed for each attribute, the problem then becomes one of how to combine the readings from each scale for each alternative. The question of commensurability of these scales relates to whether of not they are directly comparable. If they can be converted to comparable scales, the question of the relative importance of each attribute to overall performance becomes the next problem. This is usually addressed by developing weighting factors that reflect the decision maker's perception of importance.

The problem of uncertainty about the effectiveness of any developmental system or one that has not been applied under the specific circumstances being considered is inherently probabilistic. This is especially true for new mitigation methods applied in new areas. In incidences where the distribution of each activity can be estimated, network simulation methods can be used to obtain a frequency distribution for the overall system performance an cost.

Multiple Attribute Decision Making (MADM) methods that aid in addressing the problems of importance, commensurability, and uncertainty have been applied to resource development and siting problems for some time. Some of these methods such as the the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) (Yoon and Hwang, 1985) or Hierarchical Additive Weighting Method (HAWN) (Saaty, 1978) can aid in reconciling disagreement among compromise solutions. These are robust techniques which permit decision makers to examine the significance of individual criteria, weighting, or uncertainty factors.

Although a detailed description of the application of a systems analysis approach is beyond the scope of this paper, our objective here is to present a framework that can aid decision makers to resolve the complex problems associated with mitigation and to illustrate briefly how this approach was used in a case study. Our experience with recommending the application of a new technology for a controversial project suggests that this approach can help focus discussion on real issues and expedite the decision making process. It is particularly useful in interactive group situations where it can be used to illustrate the consequences of attribute weighting and uncertainty variations.

CASE STUDY: THE PORT OF WILMINGTON, DELAWARE

As part of a proposed project to maintain authorized channel depths in the Wilmington Harbor Federal Navigation channel adjacent to the Wilmington Marine Terminal in order to accommodate current and projected waterborne commerce levels at the Por Wilmington, the construction of a disposal area at the Wilmington Harbor South Site was proposed.

This plan would also leave open opportunities for on-site port relocation and expansion to accommodate projected growth. One of the primary areas of environmental concern associated with the preferred plan was the filling of 326 acres that comprised approximately 87 acres of uplands, 12

acres of wetland vegetation, 85 acres of intertidal mudflat, and 142 acres of shallow water habitat. To address these losses, a plan for proposed mitigation to compensate for the losses of aquatic habitat was developed through interagency coordination (Corps of Engineers, 1985). This conceptual mitigation plan called for the use of artificial reefs in the Delaware Bay.

The application of artificial reefs for mitigation is a relatively new approach based on the introduction of designed and prefabricated artificial reef technology in the U.S. (Sheehy, 1979; Aquabio, 1980), and the results of testing and evaluation of this technology in Florida (Aquabio, 1981). Properly sited and designed artificial reefs have significant advantages over scrap material and rock reefs for mitigation applications (Sheehy and Vik, 1983; Sheehy, 1984).

The description of this case study will focus on the application of designed prefabricated reefs to illustrate the application of a systems approach to resolving some of the problems associated with the use of this relatively new technology for a nonstandard application.

Some of the methods briefly described in the earlier section were applied to this project by Aquabio, Inc., which provided consulting services to both the State of Delaware and the U.S. Army Corps of Engineers. The data base used to support this study was developed by Aquabio and was based on extensive field and laboratory studies in Japan and Taiwan on prefabricated reefs and literature and field studies throughout the U.S. The specific approaches and methods are presented here as examples tailored to the needs of this project and are not necessarily suitable to all mitigation projects.

Application of a Systems Approach to the Case Study

Aquabio applied some of the approaches commonly used in systems analysis to address some of the multiattribute problems associated with selecting artificial reef sites and designs, and conducted a feasibility study to estimate costs. The flow of events is illustrated in Figure 1.

The project requirements were to select suitable reef sites and then select designs appropriate for the site conditions and target species. Therefore the major emphasis of the case study application of systems approaches was focused on the measurement of effectiveness which includes establishing an effectiveness scale, determining effectiveness of each alternative, and then ranking the alternatives in terms of their overall preference.

Defining Objectives. The initial objective of mitigation/habitat compensation for losses identified in the impact statement was not sufficient to establish functional performance criteria for the reefs. To resolve this problem, discussions were

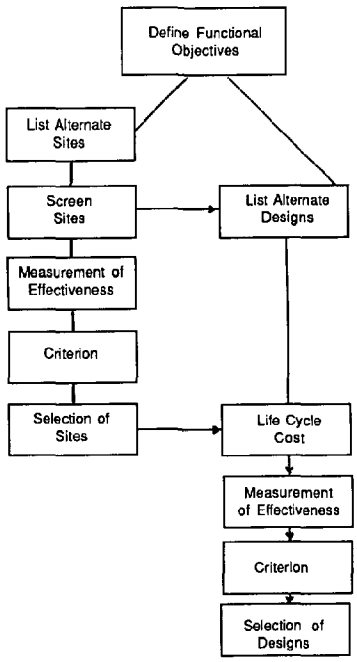

Figure 1. Reef site and design selection process

held with the interagency group established to guide this effort. These discussions resulted in the development of a set of objectives that focused the mitigation on provision of compensatory habitat for a selected group of target species. This refinement permitted the application of existing information on ranges, food habits, shelter, spawning, and nursery requirements for each of the species to be used to screen sites for consideration. Once sites were selected, data on the oceanographic and substrate conditions could be used to help select appropriate designs ("design to site").

Discussions with the Division of Fish and Wildlife indicated that, in addition to the habitat compensation objective, enhancement of recreational fishing opportunities was a secondary objective to be considered in the siting and design of the reefs. This reflected the concern by fishermen that continued development on the bay would adversely impact fishing opportunities and success.

The objectives were thus reduced to clear functional statements that had the concurrence of each of the participating agencies. Some compromises were made due to questions about long-term performance; however, a consensus was reached that enabled the project to proceed.

The basic objectives were to provide an artificial reef that would:

- Have an effective life expectancy of at least 50 years.

- o Increase local carrying capacities for selected fish and shellfish.
- o Be structurally stable and non-leaching.
- o Provide a effective surface area for epibenthic communities.
- o Be accessable to recreational fishermen.

Alternative Identification. Alternative selection reflected a two phase process. The first step was to identify potential sites that met the conditions suitable for the target species, would provide stable conditions, and would avoid conflicts with other water use activities. A hierarchical screening method was used to select sites efficiently. The exclusionary screening was based on established (e.g. shipping channels) or derived (e.g. ice scour regions) exclusion zones. Next more detailed information such as fish habitat requirements or preferences and access areas for recreational fishermen was considered.

Feasible design alternatives were examined to determine if they complied with all the basic objectives. Initial screening eliminated developmental designs without performance data to support claims of stability, life expectancy, or effectiveness. This eliminated certain types of reefs including scrap material units and units which were originally developed for other purposes (e.g., erosion control or submerged well head protection). The feasible alternatives were a series of prefabricated units which have been proven and tested.

Cost Estimation. Due to the recent introduction of prefabricated artificial reef technology in the U.S., and the fact that only small-scale projects have been completed here, cost estimates were required as part of the feasibility study. Since a number of the units under consideration were originally developed in Japan, it was necessary to conduct aspects of the cost analysis in Japan where hundreds of such reefs have been built for commercial fisheries development. A review of the current costs of components, labor and material requirements, and logistic constraints that might affect deployment in Delaware Bay was conducted. Cost projections were made for those units which appeared to have the greatest potential for mitigation applications in Delaware Bay.

The resulting data was used in conjunction with predictions of reef unit effective life expectancy at the proposed sites in Delaware Bay. These predictions were based on wave data, substrate conditions and current velocities at the proposed sites by using drag and lift coefficients for the configuration most suitable for that site.

All costs associated with the acquisition, deployment, and maintenance of a reef system were credited to that system. Since some of the reefs required different labor skills and equipment for erection and placement, this approach assured that what was being compared was the best estimate for the desired overall performance.

Effectiveness Scale. For each attribute identified as important to reef siting or design performance, a scale and weighting system was developed by a team of experienced reef specialists. Where actual data was judged adequate (e.g. water depth or reef height), it was used. Where some subjective judgment was required to evaluate an attribute (e.g., effective surface areas/unit), expert opinion was collected by using one of the group decision making methods discussed earlier. All attribute effectiveness scales were at least interval. In some cases, such as stability, a number of factors were combined to produce an overall stability scale.

Effectiveness. Table 1 illustrates the type of data used in the final MADM analysis for selecting reef sites. This type of decision matrix was used to rank the final sites in order of preference based on weighting and uncertainty factors derived from case studies and expert opinion. A similar approach was used with the selection of final reef designs (Table 2). In both cases, the number of alternatives was reduced by initial screening.

The MADM methods applied permitted us to conduct a sensitivity analysis on the rankings by varying weighting, certainty, and individual score values.

This resulted in the selection of a set of sites and designs that met all the criteria and had the lowest probability of failure.

Criterion. Criterion that related cost to performance were developed and used to aid in the final selection reef sites and designs. The cost performance relationship was extended in time; this affected the decision by indicating that some sites or designs exhibited a differential reduction in performance over time. Final recomendations were based on the outcome decision risk analysis conducted using network simulation models which reflected potential uncertainties in cost, performance, and schedule. The combination of MADM and Decision Risk Analysis methods resulted in the recommendation of reefs that were proven and tested and had a high probability of successfully meeting the mitigation performance objectives.

CONCLUSIONS

A systems approach to mitigation planning provided a rational framework for addressing the multiple attribute problems associated with siting and designing of artificial reefs. Results suggest that decision errors can be avoided by clearly defining objectives in terms of functional performance requirements, applying life-cycle cost estimates, and properly considering the relative importance and uncertainty of the multiple attributes used to evaluate the alternatives. Risk analysis, using network simulation methods, is useful in assessing the long-term reliability of mitigation options.

Table 1. Decision matrix for final site ranking

	Weight	Uncertainty	Site A	Site B	Site C	Site D	Site E	Site F
Substrate type	High	10	2.1	4.5	6.7	2.3	4.3	4.1
Proximity to ramps	Low	0	4.5	3.2	4.2	2.1	4.7	5.6
Hydrographic	High	35	4.6	6.3	5.2	4.5	6.0	7.1
Water quality	Medium	15	5.6	7.9	6.5	6.8	7.6	8.3
User conflict pot.	Medium	25	7.8	5.6	2.8	5.3	5.5	3.0
Biologic factors	High	60	5.4	8.9	5.3	3.5	7.9	4.4
Score			2.2-7.1	4.0-8.4	2.7-7.6	2.8-7.6	3.2-7.7	2.4-7.2
Rank			6	1	3	3	2	5

Table 2. Decision matrix for final reef design ranking

	Weight	Uncertainty	Reef 1	Reef 2	Reef 3	Reef 4	Reef 5	Reef 6
Stability	High	15	4.0	5.6	7.5	3.2	8.3	5.5
Life cycle cost	Medium	35	7.0	8.2	5.2	8.9	3.7	5.7
Reliability	High	25	4.0	10.0	6.2	7.5	8.4	4.3
Effective surface	Medium	5	3.4	7.5	6.9	5.9	5.0	3.5
Fishability	Low	10	7.8	4.3	6.7	3.4	5.7	3.6
Benthic fish	Medium	45	4.0	6.9	6.5	4.3	8.0	6.7
Pelagic fish	Medium	20	4.1	7.6	7.2	5.2	3.5	4.1
Shellfish	Low	15	3.1	6.3	5.5	4.3	6.3	5.5
Design flexibility	Low	0	3.1	8.9	7.8	3.2	5.2	4.2
Score			2.5-6.4	5.4-8.6	4.6-8.5	3.3-6.9	4.2-7.8	2.8-6.7
Rank			6	1	2	4	3	5

REFERENCES

Aquabio, Inc. 1980. Artificial Reefs as a Means of Marine Mitigation in Southern California. Aquabio 80-TT-720: 75 pp.

Aquabio, Inc. 1981. Japanese Artificial Reef Technology. D.J. Sheehy and S.F. Vik eds. Aquabio 81-TR-604: 392 pp.

MacKinnon, W.J. 1969. Development of the SPAN Technique for Making Decision, in Human Groups. Am. Beh. Sci. 9(9):9-19.

Satty, T.L. 1977. A Scaling Method for Priorities in Hierarchical Structure. J. Math. Psych. 15(3):234-281.

Sheehy, D.J. 1979. Fisheries Development: Japan. Water Spectrum (Winter 1979-1980):1-9.

Sheehy, D.J. and S.F. Vik. 1983. Recent Advances in Artificial Reef Technology. In. Proceedings of Oceans '83 Vol. II: 957-960.

Sheehy, D.J. 1984. The Application of Designed Artificial Reefs in Coastal Mitigation/ Compensation and Fisheries Development Projects. In: Proceedings of the Ninth Annual Conference of the Coastal Society: 331-338.

U.S. Army Corps of Engineers. 1985. Final Environmental Impact Statement. Wilmington Harbor Federal Navigation Project.

Yoon, K. and C.L. Hwang. 1985. Manufacturing Plant Location Analysis by Multiple Attribute Decision Making. Int. J. Prod. Res. 23(2):345-359.

COAST GUARD RECREATIONAL BOATING PRODUCT ASSURANCE PROGRAM

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ABSTRACT

The purpose of the Coast Guard Recreational Boating Product Assurance program is to improve the safety of boats and associated equipment sold to the recreational boating public and thereby reducing injuries and deaths on the nations waterways. The program stems from laws enacted as early as 1940. Initially these laws prescribed limited standards for motorboat equipment. Today's Recreational Boating Product Assurance program involves approximately 3000 companies manufacturing and importing more than 2.5 million units annually.

In the 1960s, two laws affected noncommercial boats on the navigable waters of the United States. The Motorboat Act of 1940 prescribed limited standards for motorboating equipment. The Federal Boating Act of 1958 was primarily a boat numbering statute. Both of these Acts applied to the boat operator only. In many cases manufacturers would build boats in accordance with such requirements as backfire flame control or ventilation; however, for manufacturers who chose not to do so, only the person who operated the boat could be cited for a violation of the law.

Several considerations lent a sense of urgency to early passage of a new bill promoting boating safety. For one, annual fatalities in boating accidents were averaging four per day and many more boaters were involved in serious accidents which resulted in injuries and severe property damage. During the months of May through September of 1968 alone, the casualties were 195 persons killed in May, 169 killed in June, 198 killed in July, 158 killed in August, and 130 killed in September. Those were a lot of casualties and only involved fatalities.

The Coast Guard's present involvement with recreational boating product safety began with the enactment of the Federal Boat Safety Act (hereafter "The Act" or "FBSA") on August 11, 1971, which became a part of the United States Code. The biggest problem with previous boating legislation in the United States was that each requirement was part of the law passed by Congress. This meant that it took an act of Congress to change, improve or add new requirements as the need arose. Among other things, the FBSA authorized the Coast Guard to establish national construction and performance standards applicable to manufacturers of boats and associated equipment.

Each regulation the Coast Guard has issued under the FBSA has related to safety. That is, each was developed in response to a demonstrated need. Section 5 of the FBSA specifically directs that the regulations be stated in terms of performance. This gives the manufacturer the widest discretion in designing and improving products, which still meet the required level of safety. Therefore, it is unlikely that the Coast Guard will ever issue boating safety standards relating to the fit and size of components. If accident statistics indicate a problem in such an area, then a performance standard may be issued. By "performance" we mean specifying the load which a fitting must withstand, as opposed to specifying the dimensions of that fitting or the thickness of the material from which the fitting is constructed.

In establishing a need to develop and prescribe regulations and standards, the Coast Guard:

(1) considers the need for and extent to which requirements imposed on manufacturers will contribute to boating safety;

(2) considers relevant available boating safety standards, statistics and data, including public and private research and development, testing and evaluation;

(3) considers whether any proposed manufacturer requirement is reasonable and appropriate for the particular type of boat or associated equipment for which it is prescribed; and

(4) consults with the National Boating Safety Advisory Council (NBSAC).

NATIONAL BOATING SAFETY ADVISORY COUNCIL

After the Coast Guard is reasonably certain that a regulation is needed, the matter is brought to the attention of the National Boating Safety Advisory Council, established under the authority of section 33 of the FBSA, for their advice and concurrence. The Council was established to further insure that all boat safety regulations are needed and are reasonable, considering the hazard which is being addressed by the regulation. NBSAC consists of 21 members divided equally among State Boating officials, representatives from the boating industry and representatives of the boating public. The public members are usually members of boat owners associations or have some other

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wide interest in boating, from the point of view of the consumer. NBSAC normally meets twice per year. The members are reimbursed for their travel expenses.

Often NBSAC wishes to maintain close liaison with the Coast Guard during the development of a particular regulation. In these instances, NBSAC appoints several members to a subcommittee or panel. These members attend frequent meetings and briefings with the Coast Guard project officers who are working on the regulation. They are invited to attend demonstrations and boat testing sessions. In this way they are completely acquainted with the solution of the problem as it is developed.

EARLY REGULATIONS AND STANDARDS

The first regulations and standards applicable to manufacturers were adopted from industry standards published by the American Boat and Yacht Council (ABYC) and the Boating Industry Associations. The Coast Guard issued final rules in the Federal Register on August 4, 1972 covering Defect Notification and Boat Identification for all boats and safety standards covering Safe Loading, Safe Powering, and Flotation for boats less than 20 feet in length. Later, standards covering Level Flotation, Electrical Systems, Fuel Systems, Ventilation and Start-In-Gear Protection were published.

Following are brief explanations of the present Coast Guard regulations and safety standards applicable to manufacturers and importers of recreational boats:

HULL IDENTIFICATION NUMBER

The Hull Identification Number regulations apply to all recreational boats manufactured in or imported into the United States. Each Hull Identification Number (HIN) is a 12-character label which must be placed on the stern or transom of every boat hull above the water line. The first three characters are a manufacturer identification code assigned by the Coast Guard. The next five characters in the HIN are the manufacturer's serial number. The last four characters in the HIN indicate the date of certification and the model year. The HIN is used by the Coast Guard and various Federal and State agencies to identify boats subject to recall, to identify boats being registered, to identify boats involved in accidents and to trace lost, stolen or abandoned boats.

DISPLAY OF CAPACITY INFORMATION

The Display of Capacity Information Standard, Safe Loading Standard and Safe Powering Standard are part of a continuing effort by the Coast Guard to reduce the number of drownings associated with recreational boating. Drownings which accounted for over 90 percent of all boating deaths, were most often the result of the sinking or capsizing of boats less than 20 feet in length. Manufacturers of boats subject to the Safe Loading and/or Safe Powering Standards must affix a U.S. Coast Guard Maximum Capacities label. The Safe Loading Standard applies to monohull boats less than 20 feet in length, except sailboats, canoes, kayaks and inflatables. The Safe Powering Standard applies to monohull boats less than 20 feet in length that use one or more outboard motors for propulsion, except sailboats, canoes, kayaks and inflatables.

The U.S. Coast Guard Maximum Capacities label must display Maximum Horsepower (if an outboard boat), the Maximum Persons Capacity in pounds and the number of people and the Maximum Weight Capacity (persons, motor and gear for outboards) (persons and gear for inboards, inboard-outdrives and boats without mechanical propulsion). The manufacturer tests a boat and calculates the capacities to be displayed on the label in accordance with the specific requirements in each of the standards.

SAFE LOADING STANDARD

The Safe Loading Standard and requirement for the display of loading information provide a guide to selecting appropriate weight capacities. A careless or inexperienced boat operator might crowd too many people or too much portable gear into a boat, thereby reducing its stability and freeboard and making it more susceptible to capsizing and swamping. Capsizings frequently occur because of the simple fact that a small boat hull can physically accommodate a much greater load than the boat can safely carry.

SAFE POWERING STANDARD

The regulation governing horsepower capacity for outboard boats was taken directly from the voluntary industry standard used in the United States for a number of years. In this regulation, horsepower capacity is a function of boat length and transom width. The boat length in feet is multiplied by the transom width in feet to obtain a factor. The horsepower capacity allowed for various factors is listed in a table in the regulations. Generally, boats equipped with remote steering and a transom height of at least 20 inches qualify for larger horsepower capacities than boats which lack remote steering or a smaller transom height. A further reduction in horsepower is required if a boat has a flat bottom with a sharp square chine.

A recent amendment to the Safe Powering Standard allows manufacturers of certain small outboard runabouts less than 13 feet in length to use optional performance test methods as an alternative to the existing calculation method. Boats capable of less than 35 miles per hour must successfully complete a Quick Turn Test in which the boat operator performs a 180 degree of the wheel at top speed. Boats capable of 35 miles per hour or more must successfully complete both a Quick Turn Test and a Safe Maneuvering Speed Test in which the boat is steered through a test course with progressively sharper turns, depending upon the boat's top speed. When the performance tests are used, a boat's maximum horsepower capacity may not exceed 40 horsepower. Both performance tests were adopted from the ABYC powering standard.

FLOTATION STANDARD

The Flotation Standard applies to monohull boats less than 20 feet in length, except sailboats, canoes, kayaks and inflatables. The amount of flotation required and the attitude in which the boat must float when swamped, depends upon whether the boat is powered by an inboard engine, an outboard motor greater than two horsepower, or an outbooard motor of two horsepower or less or manual propulsion. Boats less than 20 feet in length powered by inboards and sterndrives must be equipped with "basic flotation." Outboard powered boats and manually propelled boats must be equipped with "level flotation."

BASIC FLOTATION

The original "basic" flotation standard, effective in August 1973 (1974 model year), reflected the existing industry practice for emergency flotation. From 1968-70 there were 218 deaths, 51 injuries, and over $1 million in property damage resulting from boats sinking. At the time, it was felt that a boat which would float when flooded gave its occupants a greater chance of survival because it would be available to grasp until assistance arrived. For search and rescue purposes, it was considered far easier to find a boat than individuals in the water.

The basic flotation regulations require a boat to contain an amount of flotation that is determined from a complicated formula based on the estimated weights and densities of its different components. Experience had shown however, that the use of basic flotation in outboard powered boats was not satisfactory. Outboard powered boats equipped with basic flotation had a tendency to capsize and float bow high when swamped. This made it difficult for survivors to hang onto and remain with the boat and almost impossible for them to right the boat and climb back on board.

Faced with this situation, the Coast Guard began an analysis of reports and statistical data pertaining to fatalities that resulted from boats capsizing, flooding, sinking, or striking floating objects. The results of the analysis showed that a large percentage of the fatalities investigated during the analysis period would not have occurred had the boats involved in the accidents been equipped with "level flotation." In response to the findings of the analysis, the level flotation regulations removed the major difficulties experienced with the basic flotation standard.

LEVEL FLOTATION

The "level flotation" regulations are designed to greatly increase both the visibility and the survivability of individuals following a boating accident by making the boat a safety platform from which rescue can be effected. When the level flotation regulations were established, it was estimated they would save approximately 210 lives annually.

The level flotation regulations apply to monohull outboard powered boats — the most common type of boat used on America's waterways. These boats must be constructed with enough properly placed flotation to cause them to float in an approximately level attitude when submerged with occupants on board. This "level flotation" standard is substantially more stringent than the "basic flotation" standard.

In general, outboard powered boats equipped with level flotation have these advantages:

(1) They will float in a level attitude when swamped, thus providing a platform on which the occupants can remain safe until rescued.

(2) Occupants can remain in the swamped boat with approximately 50 percent of their bodies out of the water, thus lessening the danger of hypothermia (subnormal body temperature resulting from exposure to cold water).

(3) The powerhead of the motor, in most cases, will remain out of the water when the boat is swamped. If the motor can be started with a pull starter, the boat and its occupants may be able to return safely to shore under the boat's own power.

FUEL AND ELECTRICAL SYSTEM STANDARDS

The Coast Guard Fuel and Electrical System Standards apply to gasoline powered inboard boats and boats with permanently installed gasoline powered auxiliary engines. The standards do not apply to outboard engines, portable engines or portable fuel tanks. Accident statistics on fires and explosions have shown that inboard powered boats are 43 times more likely to have a fire or explosion than outboard powered boats. Even when outboard powered boats have a problem it is usually a fire, result-

ing in fewer injuries, while the inboard boat typically explodes.

Both of these regulations were exposed to the broadest and most comprehensive discussion and analysis by a subcommittee of the National Boating Safety Advisory Council. A Fuel and Electrical Panel was established by the Council to review the regulations. The panel included representatives from independent testing laboratories, marine surveyors, boat builders, engine builders, and State Boating Law Administrators. The technical aspects of the proposed regulations were scrutinized by the panel in meetings open to the public. The regulations were based on the existing American Boat and Yacht Council (ABYC) standards and on the standards of the National Fire Protection Association (NFPA).

Some of the major requirements in the Fuel System Standard are:

(1) The use of terneplate (lead-tin alloy coated steel) for permanently installed fuel tanks is prohibited due to its susceptibility to deterioration from exposure to salt water.

(2) Fuel tanks must be physically tested for shock and vibration.

(3) Tanks larger than 200 gallons must also be subjected to a slosh test — designed to detect weaknesses in the fastening of baffle plates inside the tank.

(4) All components in the fuel system must be capable of withstanding exposure to the flames of gasoline for 2-1/2 minutes.

(5) Fuel pumps of the diaphragm type, commonly used on automotive and marine engines, are not permitted to be vented into the engine room.

(6) The principle innovation in the Electrical System Standard is a requirement that all components used within the engine room must be externally ignition-proofed. This means that these electrical components must be able to operate in an explosive atmosphere without igniting the vapors.

(7) The electrical wiring specifications are a combination of those published by the Society of Automotive Engineers and Underwriter's Laboratories.

VENTILATION STANDARD

The Coast Guard Ventilation Standard applies to boats having gasoline engines for propulsion or electrical generation. Existing ventilation regulations required gasoline powered motorboats or motor vessels to have "at least 2 ventilation ducts fitted with cowls or their equivalent, for the efficient removal of explosive or flammable gases from the bilges of every engine and fuel tank compartment." The effectiveness of this type of natural ventilation method was questioned in a 1975 report based upon information from two independent research projects. The report showed that a natural ventilation system is effective only when a boat is moving fast enough to force air through the ventilation ducts, or when the wind is at sufficient velocity and direction to blow through the ducts. The report concluded that there is a definite need for some type of forced ventilation on boats to remove flammable and explosive gases before the engine is started. Boating accident statistics indicate that most fires and explosions occur while the boat is dead in the water after fueling. A forced ventilation system assures that engine compartments are properly ventilated before the engine is started.

Among the major features of the Coast Guard Ventilation Standard are:

(1) The term, "open to the atmosphere," is defined for the purposes of identifying compartments which do not require ventilation: A compartment is open to the atmosphere if there is at least 15 square inches of open area directly exposed to the atmosphere for each cubic foot of net compartment volume.

(2) A powered ventilation system must be installed in any compartment (not open to the atmosphere) which contains a permanently installed gasoline engine with a cranking motor.

(3) Minimum air flow capacities for blowers are specified.

(4) A natural ventilation system is req. ired for each compartment which contains a permanently installed gasoline engine, contains a permanently installed fuel tank and an electrical component that is not ignition protected, contains a fuel tank that vents into that compartment or contains a non-metallic fuel tank exceeding acceptable permeability.

(5) Intake ducts must be above the normal accumulation of bilge water and low enough in a compartment to draw fuel vapors which are heavier than air.

(6) A label must be displayed advising the boat operator to run the blower for at least 4 minutes prior to starting a gasoline engine.

(7) Minimum internal cross-sectional areas for supply openings and supply ducts and exhaust openings and exhaust ducts in natural ventilation systems are specified.

START-IN-GEAR PROTECTION STANDARD

The Coast Guard Start-In-Gear Protection standard applies to outboard engines which are capable of developing a static thrust of 115 pounds or more. A review of Coast Guard accident statistics had found that when an outboard motor is started in gear it frequently produces a sudden movement of the boat which causes its occupants to either fall inside the boat or be thrown overboard. The standard requires these motors and any controls for such motors to be equipped with a device to prevent such accidents.

MANUFACTURER CERTIFICATION

An important feature of regulations issued under the FBSA is the regulation which requires Manufacturer Certification that a boat complies with applicable regulations without the previous approval of the Coast Guard or the Government. Behind this policy is a presumption that reputable manufacturers will not risk the imposition of the penalties provided under the Act, nor do they wish to expose themselves to civil liabilities arising from their failure to supply a legally complying product to the retail customer.

DEFECT NOTIFICATION

The most revolutionary provision of the FBSA are the Defect Notification Regulations which require manufacturers to notify all boat owners of any safety related defect in their boats, and repair these safety related defects at the manufacturer's "sole cost and expense". This requirement to pay for repair of defects was the first such requirement in U. S. product and consumer law. The law establishing safety regulations for automobiles simply requires that the manufacturer notify the owner of the need for repair. However, in practice, most automobile manufacturers have voluntarily made those repairs free of charge to the customer. The FBSA definition of "manufacturer" includes importers of foreign made boats and engines. It is impossible for the Coast Guard to enforce regulations on boat builders who are outside the United States. Therefore the responsibility for meeting the requirements of the FBSA falls directly on the person who imports these marine products.

Manufacturers of boats and engines are required to notify all purchasers of defects which create a substantial risk of personal injury to the public, as well as notifying customers of defects arising from failure to comply with an applicable regulation. In either case, the manufacturer is required to pay for the cost of repairing the defect or correcting a failure to comply. At that level, there is practically no difference between costs to repair a safety related defect or a failure to comply with a regulation. The significant difference is that failure to comply with a regulation might expose the manufacturer to the assessment of a penalty under the terms of the FBSA. There is no specific penalty for a safety defect other than the cost of repairing that defect.

The FBSA states that the manufacturer should provide notification for any defect, "which creates a substantial risk of personalinjury to the public". The current policy of the Coast Guard is to consider each case on its own merits. In general, a safety related defect must be the primary cause of a condition which can create the injury. It must occur substantially without warning, which precludes normal wear on a product. For example the mere fact that an engine fails to function is not necessarily a safety related defect. While the failure of an engine could allow the boat to drift into danger, the assumption is that the operator would normally have options available to cure such a condition, including an anchor to stop the boat from drifting. If engine failure were considered to be a safety related defect, then an empty fuel tank could also be considered a safety related defect. However, if an engine fails because of a broken connecting rod or piston which breaks through the side of the engine block, it is conceivable that flying engine parts could cause an injury. Therefore, such a failure might be considered a safety related defect.

ENFORCEMENT

The Coast Guard has four principal methods for detecting manufacturer or importer violations of the boating safety regulations:

(1) Coast Guard Marine Safety Office and Marine Inspection Office personnel perform Factory Visits where they examine the boats, with the dual purpose of detecting violations and educating the boat manufacturer in the requirements of the regulation. These field personnel also recommend boats to be tested in the laboratory to detect violations which cannot be determined visually, such as the maximum weight capacity displayed on a boat.

(2) The Coast Guard also purchases boats on the open market for Compliance Testing by independent testing laboratories under contract to the Coast Guard. This method is particularly appropriate for determining compliance with the flotation regulations and the safe loading regulations, wherein the boat must be immersed in a test tank of water. Boats are selected for testing on the basis of suspected irregularities. This means a high percentage of the boats tested fail to pass one or more of the applicable regulations. In 1987 149 boats were purchased and tested for compliance with the Safe Loading and Flotation Standards and 74 failed one or more of the tests.

(3) Manufacturers and boat builders who discover that they have failed to comply with boating safety regulations, usually report their violations voluntarily to the Coast Guard in order to reduce any possible penalty and in order to place themselves in a better position to defend civil liability law suits that might arise from the violation.

(4) Manufacturers also report their competitors' violations of boating safety regulations to the Coast Guard. Manufacturers who are posting legal weight limits on their products are naturally quite perturbed when they discover that competitors are unlawfully posting higher weight capacities on their own comparable products.

PENALTIES

The FBSA provides for penalties of as much as $2,000 for each violation of a regulation on each boat produced up to a maximum of $100,000 for a series of related violations. These penalties would apply to the manufacturer in the United States or to the U.S. importer of a foreign made article.

The Coast Guard normally considers the relative seriousness of a violation of a boating safety regulation when determining the amount of any penalty. Conscientious efforts by themanufacturer to correct the defect quickly and to ensure that all purchasers of products containing the defect are notified are factors tending to mitigate the penalty assessed. We have found that most manufacturers are anxious to correct defects in the shortest possible time. They have cooperated with the Coast Guard to the extent that most penalties have been for a relatively small percentage of the maximum penalty which could have been assessed. The Coast Guard considers that its primary duty is to achieve safe boats. The penalty provisions of the FBSA are viewed only as an aid for achieving safe boats and associated equipment. We believe that excessively harsh and unsympathetic application of the penalties would only encourage manufacturers to attempt to hide their problems instead of openly cooperating with the Coast Guard in the correction of those problems.

DETERMINING HORSEPOWER LIMITS ON RECREATIONAL BOATS

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ABSTRACT

The Coast Guard regulates maximum allowable horsepower on recreational outboard boats up to 20 feet in length. Improved methods of determining the proper amount of horsepower have been proposed, including a new "dry land" formula based on lateral acceleration. A test program was conducted which evaluated the power-related performance of 25 outboard boats of various designs. From this information it was determined that lateral acceleration was not sufficient to set horsepower levels and that a fairly complex formula would be needed to adequately assess the powering-related behavior of the wide variety of hull designs currently available to the consumer.

1. INTRODUCTION

The issue of limiting horsepower on recreational outboard boats has been discussed and debated since the Coast Guard began regulating power in the early 1970s. Opinions range from questioning the need for such a regulation to a desire for more strict controls on the current limits. Since the adoption of the Federal Boating Safety Act of 1971, in particular 33 CFR 183.53 (D) - Horsepower Capacity, the Coast Guard has been mandated responsibility in this area. The current regulation, which simply relates maximum horsepower to principal boat dimensions, applies only to outboard motorboats 20 feet in length or less. It is the purpose of this paper to describe the history behind the current regulation, discuss some of the alternatives that have been investigated, and describe the current thinking on the subject of horsepower limits.

2. BACKGROUND

The Coast Guard regulation has its roots in early work done by the American Boat and Yacht Council (ABYC). This organization was founded in 1954 and charged with developing and implementing safety standards relating to recreational boating. A Hull Division was formed which is responsible for a variety of topics, one of which is powering. The Hull Performance Committee, formed in the early '70s, picked up on the powering subject begun in the '50s where the basis of the present length/width formula was developed and called the "Ralph Brown Curve" after its originator. Industry standards making organizations, the Outboard Boating Club (OBC) and the Boating Industry Association (BIA), worked with and amplified on the basic formula. Compliance with the standards set by the ABYC has been mandatory for those manufacturers participating in the organizations. However, participation in the organizations themselves was voluntary. Thus, prior to 1970, compliance with any standard was strictly a matter of choice.

During the 1950's and 60's, when the data for the ABYC standard was developed, there were primarily family, fishing and skiing boats. There was a significant performance gap before the category of "race boat" was reached. It is important to note that the current standard was developed at that time as a guide for a family boat with a beginning or novice driver. Times have changed. With the advances in fiberglass construction making possible a wide variety of new hull designs, new outboard designs and features, in particular power trim and high performance propellers, and power availability quadrupled, the entire range of recreational boat performance has broadened greatly. Step V bottom hulls have been developed which offer a soft but fast ride but bring with them the instability known as "chine walking". The bass boat craze brings high speeds in low-sided boats which often run in obstacle-infested waters.

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Gone is the gap between a family and a high performance boat.

3. CURRENT COAST GUARD REGULATIONS

When the Federal Boating Safety Act was enacted, the Coast Guard borrowed the ABYC formula, H-26. The method of calculation is shown on Figure 1. Basically, a factor is determined by multiplying the boat length by transom width. This factor is then used to determine maximum horsepower according to the table in Figure 1. Not long after this standard was adopted, however, it was realized that it did not apply to a variety of situations. Some manufacturers of high performance boats began adding lightweight "beaks" to their bows for added length and wing-like extensions to achieve the highest possible formula power rating.

In order to research other methods of determining horsepower limits, the Coast Guard contracted with Wyle Laboratories to investigate the present standard, test course methods and any alternate proposals. The primary test course used for this study was the one developed a number of years previously and adopted by the ABYC, the so-called Avoidance Course. It is shown on Figure 2. Wyle's final report, issued in March 1974, presented results which showed 53% of all outboard boats are underpowered when horsepower capacity is restricted to formula horsepower as compared to results from avoidance course tests. This implies that the other half of the outboard population is overpowered and thus the current formula gives only an average value of horsepower capacity.

What, then, could offer a more accurate method for determining horsepower limits? This question is not easily answered. For one thing, there is no simple criteria to use to determine how much horsepower is appropriate. The issue involves maintaining adequate maneuverability at high speeds without serious jarring of those in the boat. The current formula does not relate power, speed and maneuverability. Moreover a formula, such as the one currently in use, makes it possible for a boat builder to put a boat on the market that has not undergone adequate, or in the worst case, any, water testing yet is in full compliance with the Coast Guard regulation.

The current Coast Guard procedure does allow for exemptions to be granted in cases where a manufacturer feels his boat is being underpowered. For instance, according to the present regulation, the "sport boats", which are small boats 12 feet in length or less, remotely steered and designed for a maximum of 2 persons, cannot carry sufficient power to get them up on plane. Their power limit is now obtained by successful completion of the Avoidance Course.

In spite of the potential misuse, a "dry land" formula is desirable for reasons that it can be simple to use and requires no subjective interpretation. In 1982 the Coast Guard contracted with Ideamatics, Inc., to try to develop a more complete standard which would still be easy for the manufacturers to use. The Ideamatics effort involved a relating powering, speed and turning radius to a quantifiable variable, lateral acceleration. Their premise was based on the statistical information which indicates that falls overboard are a major cause of recreational boating fatalities and that lateral acceleration is a measure of the force needed to cause this. The Ideamatics formula uses length, beam, weight and deadrise to predict maximum attainable speed and turning radius. These predictions are combined to calculate maximum lateral acceleration.

The formulas were developed by using a number of different boat hulls with various engines, and measuring the physical parameters and the speeds, turning radii and lateral accelerations obtained on the test course. Regression analysis was then used to fit the data and develop the formulas. It was hoped that ultimately this formula could serve as a replacement for the current standard.

The Coast Guard Research and Development Center became involved in this work in 1984. They were tasked with getting a number of boat hulls representative of various categories and testing them to see if the Ideamatics formula could be used as a replacement. Field tests were conducted at the Mercury Marine facility in Oshkosh, Wisconsin, during May of 1985 and 1986. In all 25 boats were tested in the categories of jon, bass, semi-vee, deep-vee, trihull, tunnel hull, cathedral hull and "sport" boats.

The boats were measured for beam, length, deadrise, transom height and width, and for some hulls, complete offsets were taken. Afterwards, the boats were run through the avoidance test course with their current maximum horsepower, a turn radius test was conducted to determine maximum radius, and lateral acceleration measurements were taken. For some of the hulls, roll angle, pitch, longitudinal and vertical

acceleration, heading, and rudder angle were also measured. These additional quantities were measured so that if the Ideamatics formula did not prove valid, additional information would be available to try another formulation.

An additional test used in this series is called the Quick Turn Test. This is used by the ABYC to determine maximum maneuvering speed for any remotely steered boat; inboard, outboard, and any length including those over 20 feet. As used by the ABYC, whenever a boat cannot remain under satisfactory control when put in a one-half steering wheel rotation snap turn at wide open throttle, a placard is affixed to the dashboard which states at what speed that turn can be negotiated. This was developed as an alternative to the Avoidance Course, since no marker buoys need be used and there is less driver influence. We used it to compare lateral accelerations from the Avoidance Course.

After comparing the two years field data it became apparent that the Ideamatics formula was not sufficiently accurate in predicting the relationship between engine power and lateral acceleration. It was decided to suspend any further validation at that point.

As mentioned previously, additional data was taken in the course of the test program to use in the event that the Ideamatics formula did not prove valid. Stevens Institute of Technology was tasked to examine the results of the field tests and to investigate the possibility of another formula based on easily measured boat parameters. They did make an preliminary formulation, however, much work remains to be done to determine its range of applicability and accuracy as a predictive tool.

4. FUTURE PLANS

As this work was being finished, several things occurred which have delayed further development in the area of maximum horsepower determination for recreational powerboats. First is the recognition that an improved dry land formula which is both simple to use and applicable to the wide range of hull types available may not be achievable. At the same time the Coast Guard has experienced the budget cuts and reprioritization that so many government agencies have. Also, the area of overpowering is quite subjective and other areas of compliance, such as adequate flotation and the new alcohol and boating laws have refocused boating safety issues. It is unlikely at the present time that further work towards an improved "dry land" formula will be done. However, if the interest in this area is renewed, it is likely that an investigation into the use of a test course approach will be pursued.

TITLE 33 - Navigation and Navigable Waters

CHAPTER I - COAST GUARD, DEPARTMENT OF TRANSPORTATION (CGD 73-250)

Part 183 - BOATS AND ASSOCIATED EQUIPMENT

183.51 - Safe Powering

183.51 Applicability

This subpart applies to monohull boats less than 20 feet in length, except sailboats, canoes, kayaks, and inflatable boats, that are designed or intended to use one or more outboard motors for propulsion.

183.53 Horsepower capacity

The maximum horsepower marked on a boat must not exceed the horsepower capacity determined as follows:

(a) Compute a factor by multiplying the boat length in feet by the maximum transom width in feet excluding handles, and other similar fittings, attachments, and extensions. If the boat does not have a full transom, the transom width is the broadest beam in the aftermost quarter length of the boat.

(b) Locate horsepower capacity corresponding to the factor in Table 183.53.

(c) If the horsepower capacity in Table 183.53 is not an even multiple of 5, it may be raised to the next even multiple of 5.

(d) For flat bottom hard chine boats with a factor of 52 or less, the horsepower capacity must be reduced by one horsepower capacity increment in Table 183.53.

Table 183.53 - Outboard Boat Horsepower Capacity

COMPUTE: FACTOR = BOAT LENGTH X TRANSOM WIDTH

If factor (nearest integer) is	0-35	36-39	40-42	43-45	46-52
Horsepower capacity is.....	3	5	7½	10	15

Note: For flat bottom hard chine boats, with factor of 52 or less, reduce one capacity increment (e.g., 5 to 3)

		No remote steering, or less than 20" transom	
If factor is over 52.5 and the boat has	Remove steering and at least 20" transom height	For flat bottom hard chine boats	For other boats
Horsepower capacity is (raise to nearest multiple of 5).....	(2X Factor)-90	(0.5X Factor)-15	(0.8X Factor)-25

Figure 1. Current Standard

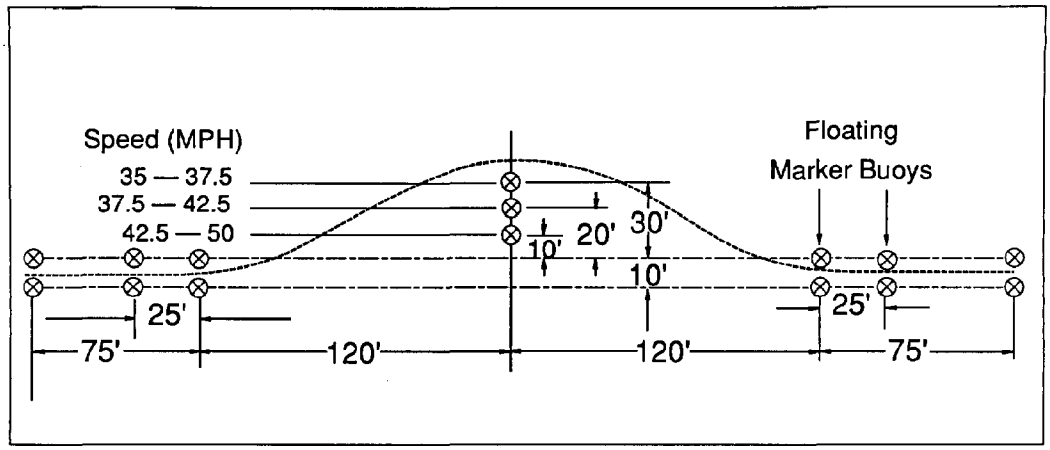

Figure 2. Avoidance Course — 35 to 50 MPH

REGULATION OF PASSENGER CARRYING SUBMERSIBLES

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ABSTRACT

This paper is a history of commercial passenger carrying submersibles and the United States Coast Guard regulatory efforts to ensure their safe operation. A description of a typical operation and vessel is given with emphasis on safety features. Safety guidelines and procedures for certification are described.

INTRODUCTION

There is a growing interest in operating submersibles in the tourist sightseeing business. This interest now centers in the Caribbean with operations in the Cayman Islands, Barbados, and the U.S. Virgin Islands. Operations have also begun recently in Hawaii and the Mariana Islands. The leader in this business has been Subaquatics of Vancouver, BC with two 28 passenger submersibles, ATLANTIS I AND II, in the Cayman Islands and Barbados and two 47 passenger submersibles, ATLANTIS III AND IV, in St Thomas, USVI and Hawaii respectively. ATLANTIS III was built in Vancouver, BC under Coast Guard inspection. ATLANTIS IV was built under Coast Guard inspection in Washington State. Two other passenger submersibles have come under U.S. jurisdiction recently. MARIEA I, a 46 passenger submersible built in Finland, is now operating in Saipan under Panamanian flag and the U.S. control verification program for foreign passenger vessels operating within U.S jurisdiction. LOOKING GLASS, built in Scotland, has recently been U.S. Coast Guard certificated for carriage of 48 passengers in St. Thomas. MARIEA I and LOOKING GLASS were designed by Fluid Energy Ltd. of Scotland.

The basic operations of these attractions are similar. They are located in a strong tourist market with interesting dive sites. A typical excursion begins with a brief ferry ride from a convenient shoreside base.

At the dive site the passengers embark the submersible for a 45 minute dive. Each passenger sits with access to a viewport on one side of the vessel. The dive follows a predetermined standard course at 50 to 200 foot depths. Commentary on the underwater attractions observable during the dive is given by the pilot or attendant over a PA system. During the dive a support vessel patrols the dive site maintaining communications and possibly visual contact with the submersible. A scuba diver from the support vessel may dive to the submersible to provide entertainment such as feeding fish. At the conclusion of the dive the passengers disembark to the ferry which has picked up another load of passengers at the shore base. Ten or more dives may be completed during a day's operations and an evening or night dive may also be offered if the submersible is equipped with suitable lighting.

The submersible pressure hulls are cylinders with hemispherical heads. Two hatches are located on top of the cylinder at the ends. Overall hull lengths range from 50 to 65 feet. Acrylic viewports are fitted along both sides of the cylinder portion of the hull and large acrylic hemispherical viewports are fitted at one or both ends. The forward viewport is for the pilot and the after viewport, if fitted, is for passenger viewing. An exostructure is affixed to the hull which includes the embarkation deck, skids, protective guards and fairing. Attachments to the exostructure include hard and soft ballast tanks, trim tanks, propulsion units, jettison weights, lights, liferails, and emergency locating devices. Power for propulsion is provided by rechargeable batteries. The interior is fitted with a deck and seating arranged for passenger viewing out of the viewports. The batteries are usually located in a compartment below the deck. Ladders to the hatches are usually stowed up out of the way to make room for additional passenger seating. Pilot controls are located in the forward hemispherical head. Toilet facilities may be installed depending on voyage length.

This new business is on the verge of expanding from several operations to possibly dozens throughout the United States. These tourist attractions have been very popular and are potentially very lucrative for their owners. The Coast Guard, as the maritime safety regulatory agency, has the responsibility for ensuring the safety of the passengers and crew of these vessels.

HISTORY

Considerable research and development has been conducted relative to the safe design, construction, and operation of small manned submersibles. These efforts involved the participation of the Navy, the Coast Guard, the submersible industry, the classification societies and other interest groups such as the Marine Technology Society (MTS).

The Navy has always been involved with the safety of military submersibles. The loss of THRESHER in 1963 intensified the Navy efforts and resulted in special safety programs. With the advent of the deep research

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vehicles such as TRIESTE and ALVIN, the Navy took action to establish the safety of Naval personnel when embarked on manned noncombatant submersibles. The military certification requirements were applied as appropriate. Other requirements were applied as dictated by the submersible's specialized design and use.

SECNAV Instruction 9290-1 was issued in 1966 establishing the Navy safety policy and assigning responsibility for action to CNO. This responsibility covered: the competency of operations; the planning of operations; and the materials adequacy of the submersibles.

The Naval Ship Systems Command (now NAVSEA) was delegated responsibility for development and promulgation of the evaluation and certification criteria. The Navy published "Material Certification Procedures and Criteria Manual for Manned, Non-combatant Submersibles" in 1968. This manual was considered both broad and strict. The Navy certification program was open to innovation and new technology by acceptance of new features which were demonstrated safe.

The Navy's certification program is now published in NAVMAT P-9290, "Systems Certification Procedures and Criteria Manual for Deep Submergence Systems". This certification program applies to all noncombatant submersibles which are employed carrying Navy personnel. The Navy still has a number of submersibles to which the certification program applies including ALVIN, the first research submersible certificated by the Navy.

In the mid-1960s, ABS was approached by industry representatives regarding the practicality of preparing standards for the design and construction of commercial submersibles. Because of the limited experience in operation of commercial submersibles and because of the unknown variety of their uses at that time, ABS felt that specific Rules would be premature. Accordingly, a Guide for Classification of Manned Submersibles was prepared and published in 1968. The Guide was for use during the period of accumulation of actual operating experience. The Rules were written with the small research, industrial, and experimental submersibles in mind.

In the decade to follow, there was a dynamic growth in the submersible industry. Builders, operators, and ABS (the Navy and Coast Guard as well) gained extensive experience relative to small submersibles, primarily those for research, industrial, and experimental service. Consequently, ABS was able to publish "Rules for Underwater Systems and Vehicles" in 1979. The Coast Guard participated in the development of these Rules.

MTS conducted three studies and published three sets of guidelines for submersible safety during the period from 1968 to 1979. The guidelines address design, operations, personnel, maintenance, procedures, and equipment. The Coast Guard participated in the studies and provided funding.

The Coast Guard established the Underwater Safety Project (USP) on July 15, 1968 in reaction to what appeared at the time to be a strong near-term need for Coast Guard regulation of underwater vehicles and stations. At the time, there were about 50 civilian submersibles in existence in the U.S. In a decade of submersible operations, there had been only three major accidents resulting in the loss of one life. Nevertheless, to ensure at least a minimum standard of safety was maintained, the Coast Guard proposed legislation in bills introduced in both the House and Senate to obtain authorization for regulation of non-military submersibles regardless of size, service, or number of passengers.

In preparation for the legislative proposal, the Coast Guard developed a regulatory concept which would prescribe a reasonable standard of safety but not hinder development of submersible technology. The intention was to produce performance standards for submersible vessel systems which would lead to low-level initial regulations for implementation. Highly specific regulations would not be promulgated until undersea technology passed beyond the developmental stage. Indications at the time were that a slow and deliberate effort would be possible. Research and development efforts were initiated to determine some of the more basic requirements for submersible regulations. Liaison with the industry and standards organizations was established to develop policy, codes, and guidelines for submersibles. Submersibles requiring certification under existing laws and regulations were to be handled on an individual basis making extensive use of provisions for determining "equivalent safety."

Not long after the Coast Guard Underwater Safety Project Team was formed, the priority of the project became questionable. The Bills in Congress had not passed and the anticipated demand for submersibles had not materialized. Although there had been steady involvement in the advancement of submersible technology, the industry itself had experienced the same decline as the marine industry in general. The use of submersibles for other than industrial, experimental or research applications did not until recently appear probable. This being the case, Coast Guard efforts tapered off with the termination of the Underwater Safety Project (USP) in the late 1970's.

Non-military submersibles have now been used for several decades; however, until 1984 had not been used in any service for which the existing Coast Guard inspection statutes and regulations would apply.

In 1984 Subaquatics first contacted the the Coast Guard about their plans to build and operate passenger carrying submersibles. Their first two vessels, ATLANTIS I and II, built from 1984 to 1986, were designed to carry 28 passengers and two crewmen on short voyages to a depth of 150 feet. These two vessels are now operating in Barbados and the Cayman Islands. With the success of these vessels, Subaquatics then approached the Coast Guard with a proposal for a 47 passenger submersible to be operated within U.S jurisdiction in the U.S. Virgin Islands. The Coast Guard worked closely with Subaquatics to define the basic safety requirements and determine acceptable design and operational features necessary to ensure the safety of passengers and crew at a level equivalent to that of a small passenger vessel of similar capacity. This submersible, ATLANTIS III, was certificated in July 1987 and has been operating successfully in St. Thomas, USVI.

COAST GUARD CERTIFICATION

The Coast Guard has taken a systems approach to certificating submersibles, evaluating the combined design, operation, dive site, and operator qualifications from the conceptual stages through the initial operations. After initial certification, the Coast Guard monitors the operations and periodically inspects the vessel. Each operation is evaluated individually because of the developing nature of the business and absence of

specific regulations for submersibles.

The regulations that are the basis for passenger submersible certification are found in 46 CFR Subchapter T-Small Passenger Vessels (less than 100 gross tons). Since these regulations were developed primarily with surface craft in mind, many of the requirements cannot be applied to or may otherwise be inappropriate for submersibles. The Coast Guard's approach to the novel design and unique operational hazards of passenger submersibles is to attain a level of safety at least equal to that required for a surface craft of similar size and service and otherwise minimize any inherent hazards of underwater operation. The failure of any single piece of equipment should not result in a "fatal" or unsafe situation. This is accomplished in part through a combination of design requirements, operational restrictions, and redundant systems.

Passenger submersibles over 100 gross tons would be subject to 46 CFR Subchapter H-Passenger Vessels which is a more detailed and comprehensive set of regulations than Subchapter T; however, like Subchapter T it does not address submersibles. No submersibles are likely to be built to Subchapter H in the near future.

A small submersible, carrying six or less passengers for hire, is an "uninspected vessel" as defined by 46 United States Code (USC) 2101 (42). Such vessels are not subject to Coast Guard inspection regulations but are subject to regulations for uninspected vessels, 46 CFR Subchapter C-Uninspected Vessels, or recreational boats, 33 CFR Subchapter S-Boating Safety. These regulations do not address submersibles and do not provide for periodic inspection after the vessel has been manufactured. Due to the potentially hazardous nature of operating a submersible vessel, the local Coast Guard Captain of the Port having jurisdiction over the operating area may make special operational requirements under authority of 33 USC Chapter 25 - Ports and Waterways Safety Program, and 33 CFR part 160 - Ports and Waterways Safety - General. Concerns of the Captain of the Port include special operational restrictions, navigational safety, and port security considerations.

FOREIGN FLAG VESSELS

Foreign flag vessels may operate in certain U.S. waters as discussed in the Documentation section below. A foreign flag submersible inspected and certificated by a country having inspection laws and standards similar to those of the U.S. will be inspected (control verification) to ensure that the condition of the vessel is as stated in its certificates. A foreign country is considered to have inspection laws and standards similar to those of the U.S. if that country is a party to the International Convention for Safety of Life at Sea (SOLAS).

Generally, the vessels current certificates of inspection will be accepted as evidence of lawful inspection; however, the Coast Guard must be aware of and in agreement with the design and inspection standards applied. If the Flag Administration issues SOLAS Passenger Vessel Certificates to the vessel, as we would prefer, certain exemptions will be necessary. The SOLAS Regulations, like U.S. regulations, were written primarily with surface craft in mind. Thus, there are many regulations which cannot be applied to or may otherwise be inappropriate for submersibles. Other measures to attain an equivalent level of safety will be necessary. Exemptions to the SOLAS Regulations must be coordinated with and accepted by the U.S. Coast Guard if the vessel will be operating in U.S. waters (SOLAS Chapter I, Regulation 4(b)). Requests for consideration of exemptions can be made to Commandant (G-MVI). If the Flag Administration issues its own certificate of inspection, the Coast Guard needs to know the standards and requirements that were applied before accepting the vessel. Early identification and contact with the Flag Administration is necessary. The degree of Coast Guard inspection will depend on its country of registry and the degree of inspection performed by the Flag Administration.

DOCUMENTATION

U.S. Customs Service has determined that vessels operating to carry passengers or cargo between U.S. ports or from one U.S. port to a point within the territorial waters and back to the same port are considered to be operating in coastwise trade. Vessels engaging in coastwise trade must be documented under the laws of the United States with a coastwise license. Such vessels, in addition to being owned and operated by qualified citizens, must also have been built in the United States, and must never have been sold to a non-citizen of the United States, registered under the laws of any foreign country, or (if greater than 500 gross tons) rebuilt abroad. The foreign built and foreign flag passenger submersibles currently in operation are an exception to these requirements because the U.S. Virgin Islands and the Mariana Islands are not covered by the coastwise laws.

COAST GUARD PLAN REVIEW

Normally small vessel plan review for Coast Guard approval is done by the cognizant Officer in Charge, Marine Inspection (OCMI) who has the responsibility of inspecting vessels within his jurisdiction. However, because passenger submersibles are novel, detailed plan review is done by the Marine Safety Center (G-MSC), located at 2100 Second St. S.W., Washington, D.C. 20593-0100. Plan submittal procedures should, however, be discussed with the OCMI as well. Detailed plan review will not be performed before jurisdiction (evidence that Coast Guard inspection is required) has been established and a contract has been awarded for construction. Concept review prior to this is usually appropriate and can be accomplished by submitting a proposal addressing the design and operation of the vessel to Commandant (G-MTH), 2100 Second St. S.W., Washington, D.C. 20593-0001. A written operations manual/safety plan giving details of the normal and emergency operational procedures is submitted to the Coast Guard early in the planning stage for conceptual review and approval.

Plans required to be reviewed by the Coast Guard are listed in 46 CFR Subchapter T, Section 177.05, and include the following: midship section, outboard and inboard profiles, arrangement of decks, machinery and electrical installations, fuel tanks, piping systems, hull penetrations and shell connections.

In addition to the plans required in Subchapter T, the following are required for detailed plan review of submersibles:

- Pressure hull construction, strength calculations, and tolerances; including windows, hatches, penetrations and attachments.

- Life Support systems/equipment.
  (1) Air filtration
  (2) Sensors and monitoring equipment
  (3) Oxygen system
  (4) Emergency breathing
- Fire Protection systems/equipment.
- Bilge system.
- Ballast system plans and calculations.
- Weight, stability and buoyancy data and calculations, including emergency surfacing capability. A surface and submerged inclining will be required for which a proposed procedure is to be submitted.
- Intact and damage freeboard and limits of heel/trim calculations.
- Control Systems plans.
- Quality control and testing procedures.
- Material identification.

Considering the unique operating parameters of a submersible, there are certain areas where the Coast Guard will focus particular attention during plan review and inspection. Some examples are:

- Escape and rescue from a submarine will be difficult and hazardous, so the means for returning to the surface in both the normal and emergency modes will be reviewed. The submersible must be capable of returning to the surface in the event of failure of any system except the main pressure hull. Redundant systems can make this possible.
- Access to lifesaving equipment and means of exiting the submersible once on the surface may also be difficult. The Coast Guard requires that adequate freeboard and stability be available on the surface to permit the safe debarkation of passengers under the worst expected surface conditions in the designated operating area.
- Review of calculations which demonstrate adequate subdivision and stability to permit the vessel to surface in a timely manner, while maintaining an upright attitude after receiving damage which penetrates the hull or damage to any ballast tanks.
- Provisions for personnel protection, during the time it takes to surface and evacuate, from hazards such as smoke or toxic vapors in the event of a fire or from flooding in the case of hull damage.
- Differences between submerged and surface operations including restricted visibility, undetectability by surface craft, and modifications to the required emergency instructions must be considered.
- Vital systems, such as those necessary for the vessel to surface, to deploy lifesaving equipment, or to debark personnel, must be shown to have an acceptable level of reliability, a manual override control, or redundancy.
- The oxygen system will be subject to special review due to the increased potential for fire.

DESIGN

Compliance with the ABS rules and ABS classification have been important factors in the Coast Guard's acceptance of the design of all the submersibles mentioned above. The ABS Rules provide a good base for evaluating a submersible vessel. The vessel's certification is also dependent on its operational plan and dive site which are evaluated along with the submersible vessel. A submersible design certificated for operation in one location might not be acceptable in another location or for a different operation such as a longer dive because of the close association of the vessel design and its operation.

Hull Structure

The hull structure should be designed to and will be reviewed to the standards of the American Society of Mechanical Engineers (ASME) Code for Pressure Vessels for Human Occupancy (PVHO) or the standards of the American Bureau of Shipping (ABS) Rules for Building and Classing Underwater Systems and Vehicles. Proposals to use other established standards for underwater vehicles may be submitted for consideration by Commandant (G-MTH). Plan submission must identify the standard utilized and the pertinent design parameters such as maximum operating depth and structural safety factor.

Since submersibles are more susceptible to rapid and catastrophic flooding than surface vessels, additional requirements to those in 46 CFR Subchapter T may be necessary. The following are examples of features which may need to be incorporated depending on the design and whether or not an equivalent level of safety is achieved by the operational procedures addressed in the operations manual/safety plan.

- A protective cover over the exterior and interior of windows to protect them from impact and chemical cleaning agents.
- Windows, designed to the PVHO standards or equivalent, are to be reasonably protected in case of underwater collision (during normal or emergency operations) with natural formations or man-made obstructions in the operating area.
- Quality control during construction (including 100 percent weld X-ray).

Subdivision and Stability

Subdivision is not a requirement for vessels less than 100 gross tons, less than 65 feet LOA measured over the weather deck, carrying no more than 49 passengers, and operating on other than ocean waters. Subdivision has not been required for any of the submersibles mentioned above, but may be required for any submersible designed to exceed any of the constraints listed here or for isolation of hull penetrations not adequately designed to prevent flooding.

Stability must be adequate for both surface and submerged conditions. While surfaced, the stability must be sufficient to safely withstand heeling moments caused by wind, waves, and passenger movement. Hatch coamings must be high enough to prevent flooding by waves, and the embarkation deck must be high enough to be reasonably dry for embarking passengers. The passenger submersibles built to date have been quite stable on the surface.

The significant stability hazard while submerged is the large trimming moment that can be generated by passenger movement. A submerged stability test is

required to determine the vertical distance between the centers of gravity and buoyancy in order to evaluate the submersible's stability in loaded conditions.

Passenger Accommodations

Unless they carry more than 150 passengers, there are no specific rules for structural fire protection. However, 46 CFR Subchapter T, Section 177.10-5 states that the "...general construction of the vessel shall be such as to minimize fire hazards insofar as reasonable and practicable." This means that a designer or builder should minimize the amount of flame, smoke, and toxic gas producing materials within the submersible to reduce the risk to passengers and crew. The fit and installation of the materials must be to the satisfaction of the cognizant Officer in Charge, Marine Inspection.

Separation (e.g., a partition) to prevent passengers from interferring with operator performance is required between the passenger and pilot sections.

Lifesaving Equipment

Alternatives to on board stowage of required primary lifesaving equipment (e.g., liferafts) must be addressed. Liferaft stowage on board the support vessel has been accepted.

Coast Guard approved life preservers will be required for everyone on board, including children. Coast Guard approved inflatable life preservers are available and may be used on submersibles. Life preservers must be stowed on board.

Fire Protection Equipment

Required fire protection equipment is limited to portable non-toxic extinguishers approved by the U.S. Coast Guard. Fixed Halon 1301 systems are typically installed and are in addition to the required portable extinguishers. Fixed systems must be approved. Fire detection is not required, but a detection system is usually installed. If installed a detection system must have an approval from a nationally recognized testing laboratory as well as plan approval by the Marine Safety Center. A fire pump and firemain system are not required.

Machinery Installation

Marine engineering systems are subject to the requirements of 46 CFR Subchapter T and Subchapter F as appropriate. The following are certain specific items which must be considered and addressed in the design; however, this list is not all inclusive.

Pressure vessels (other than the main hull) which are permanently installed on board the vessel are subject to 46 CFR 54.01-5. Portable pressure vessels for use on board, but serviced/refilled ashore and remaining in commerce, are considered ship's stores and must be Department of Transportation (DOT) approved (46 CFR 147.04). DOT cylinders which are modified in any way are no longer considered DOT approved and must be shown to be equivalent to the appropriate pressure vessel standards.

Hydraulic and pneumatic systems must meet 46 CFR 58.30.

Air conditioning systems must meet 46 CFR 58.20.

A system for dewatering must be addressed.

Lifesupport Systems

ABS lifesupport standards are considered by the Coast Guard to be adequate for passenger submersible certification.

Electrical Installation

The electrical system must meet the requirements of 46 CFR Subchapter T and Subchapter J as appropriate. The following are some of the specific items which must be considered and addressed in the design; however, this list is not all inclusive.

Either marine shipboard cables or low smoke cables would be acceptable. The low smoke cables provide a degree of safety surpassing that provided by the standard shipboard cables and their use is encouraged.

An emergency power source must be provided. It must be independent of the main power source and must be sized to supply all connected loads for at least twice the duration of the voyage. At the end of this period the voltage of the battery must not be less than eighty eight per cent of the nominal battery voltage. Emergency lighting must be automatically activated upon loss of the main power source. Emergency lights may have a means to turn them off to conserve power, but such means should not be accessible to the passengers. Other emergency loads must be capable of being connected to the emergency power source. There must be a means to indicate a low charge on the emergency batteries.

All batteries must be protected from salt water contamination, yet remain accessible for regular servicing. Hydrogen gas generation must be monitored.

Battery charging procedures and equipment must be addressed from the standpoint of hydrogen generation and sources of ignition.

INSPECTION

The inspection and certification requirements are addressed in 46 CFR Part 176. Application for Inspection (CG-3752) should be submitted to the Officer in Charge, Marine Inspection (OCMI) having responsibility for the location at which the vessel is being built. Normally, inspection for certification is conducted only on U.S. flag vessels. Generally, inspection will begin when requested after there are approved plans by which to conduct the inspection. The schedule of inspection is to be worked out with the OCMI.

For a U.S. flag vessel built overseas, the ultimate aim will be a degree of inspection during construction equivalent to that which would be attained if the vessel were built in the U.S. The Coast Guard maintains only a limited number of inspectors overseas, hence overseas inspections may be complicated by delays in communications and inspector availability. Additionally, overseas inspections of U.S. vessels are subject to reimbursement.

MANNING

Since the Coast Guard does not presently have regulations which specifically address licensing and manning of passenger carrying submersibles, a proposal must be submitted to Commandant (G-MVP), via the cognizant OCMI. This proposal must address the level of training and qualification and number of personnel necessary for safe operation of the vessel. Each licensed

operator will also be required to meet additional requirements and receive a special license endorsement for passenger submersibles. The number of unlicensed deckhands required, if any, will be determined after evaluation of the manning proposal and operational safety plan. ATLANTIS III is required to be manned by a licensed operator, a pilot trainee and a deckhand.

OPERATIONS

Since a submersible is usually not as self sufficient as a surface vessel, special consideration will be given to the overall system of operations, support and maintenance in view of the environment in which the submersible will operate. Depending on the location of operation, certain conditions such as strong tidal currents or hazards presented by other vessels or underwater obstructions may be cause for certain operating restrictions, additional design features, or possibly prohibiting operations altogether.

Submersibles will be restricted to operations in waters no deeper than the designed and certified maximum operating depth of the vessel.

Certification will be for a particular operating location, and operations in other locations will not be permitted without specific Coast Guard approval. All aspects of the intended operations must be discussed with the cognizant OCMI and Captain of the Port (COTP) for the proposed operating area early in the planning stage. The written operational safety plan would be useful as a basis for that discussion.

The operations manual/safety plan should address at least the following aspects of the operation. In the planning stages and during review, a draft manual/plan is acceptable. Ultimately, the manual/plan must be finalized and adhered to. Changes may be made subject to approval of the OCMI and COTP.

- Support craft functions and capabilities including: submersible shadowing, diver availability and capabilities, and emergency lift capability.
- Normal operational procedures for: submerging and surfacing, surface operations, underwater operations (visibility, currents, communications, surface traffic, etc.), and ferrying and transferring passengers (vessels carrying more than six passengers to and from the submersible are also subject to Coast Guard inspection).
- Emergency procedures for scenarios such as: inability to surface, loss of power, controllable leakage of hull, collision, evacuation out of and off the vessel.
- Mooring and operational area proposal.
- Dive site location.

Search and Rescue (SAR)

Also important to the safe design and operation of submersibles is a rescue capability should it ever be needed. Although the Coast Guard search and rescue responsibilities extend under, as well as on, the surface of the sea, there was, when the USP first formed, no facilities in existence designed for underwater rescue from non-military submersibles. A Mutual Assistance Rescue and Salvage Plan (MARSAP), whereby other submersible owners would provide all possible assistance, was proposed by the industry but never formalized. Navy assistance when available will be utilized through an agreement between the Coast Guard and the Navy. The Coast Guard underwater SAR policy and guidance is published in the National Search and Rescue Manual.

FUTURE PLANS

The Coast Guard is presently working with the Transportation Systems Center (Department of Transportation), Cambridge, Massachusetts, in the development of a sytems safety analysis of a typical passenger submersible operation. This analysis will provide the basis for a more systematic safety evaluation of future proposals. The analysis should be completed in early 1989.

The Marine Board of the National Research Council has shown interest in this area and in cooperation with the Coast Guard may conduct a study of the safety of passenger submersible systems during 1989.

The results of these two studies will be used by the Coast Guard in the development of appropriate guidance or regulations for passenger submersible builders, operators and owners. If this emerging business continues to grow it will be necessary to have a uniform set of safety requirements in order to effectively guarantee the safety of the crews and the hundreds of thousands of passengers that will take the thrilling excursions these vessels can offer.

RECREATIONAL BOATING ACCIDENTS IN OCEAN WATERS

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ABSTRACT

The U.S. Coast Guard's Boating Accident Report file contains reports of 6,860 boats involved in 4,781 recreational boating accidents occurring between 1969 and 1987 on the oceans, the Gulf of Mexico, and Long Island Sound. These accidents accounted for an average of 74 fatalities, 71 reported injuries, and $2,380,000 in reported property damage annually for those nineteen years. Because of the considerable difference between the environments of these waters and inland waters, differences are also expected in the characteristics of recreational accidents.

Fatalities on the oceans have dropped from 93 fatalities per year in the 1969 to 1973 period to 48 per year in the current five-year period. The most frequent (45%) type of fatal accident is capsizing. Falling overboard is responsible for another 17% per cent of the fatalities.

INTRODUCTION

Since 1960 the Coast Guard has been collecting and publishing statistics annually on recreational boating accidents. Data on reported accidents occurring since 1969 are in a computer file that is updated as each year's statistics are published. This paper analyzes those accidents that are coded as occurring on the oceans, which also include, for our purposes, Long Island Sound and the Gulf of Mexico. Because the data base contains no indication of the distance of the accident from shore, we do not know the number of these accidents which occurred on the open seas.

ALL RECREATIONAL ACCIDENTS

Boating Statistics, U. S. Coast Guard publication COMDTPUB P16754.1, shows that the number of fatalities in recreational boating has been decreasing for approximately fifteen years. Since 1971 the fatality rate has decreased from 20.2 fatalities per hundred thousand boats to 6.1 fatalities in 1987. In 1973 the peak number of 1,754 fatalities occurred. Last year 1,036 people died in boating accidents, the lowest number since the Coast Guard began keeping records in 1960.

Regulations under the Federal Boat Safety Act of 1971 have helped considerably in this reduction of fatalities. The regulations have covered electrical systems, engines, boat flotation, personal flotation devices (PFD), other safety equipment, and safe operation. Despite the growth in the number of participants and the increase in congestion in popular areas, the overall danger in recreational boating is being reduced each year. This reduction is a result of the production of safer boats and life saving appliances and an increase in educational efforts and public promotion of boating safety.

STATE RANKINGS

For many years Florida and California have reported the greatest total number of accidents occurring on all waters. Since both have long shorelines and are populous, they also have accounted for the most accidents occurring on the oceans (and the Gulf of Mexico). The top six states and the number of reported accidents on the oceans from 1969 through 1987 are:

STATE	ACCIDENTS
California	1,451
Florida	1,266
New Jersey	348
New York	239
Hawaii	185
Oregon	177

The list of the top states in the number of fatalities occurring on the oceans shows the same two states at the top.

STATE	FATALITIES
California	422
Florida	323
Oregon	77
New York	71
Washington	64
New Jersey	59

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The top two states reverse their order when the states are ranked by the number of reported injuries occurring on the oceans.

STATE	INJURIES
Florida	421
California	372
New Jersey	121
Oregon	65
New York	63
Hawaii	49

The ranking of the states according to the amount of reported property damage in thousands of dollars follows. The figures are not adjusted for inflation, so the ranking is weighted towards the more recent years.

STATE	PROPERTY DAMAGE ($000)
California	14,877
Florida	11,667
New Jersey	3,271
Hawaii	2,984
North Carolina	2,323
Oregon	1,341

CAUSES OF ACCIDENTS

The Coast Guard's Boating Accident Report file allows for three codes describing the sequence of events for each boat involved in an accident. This analysis of all accidents from 1969 through 1987 concerns only the first code. For instance, many capsizings occur after the boat has flooded. Such accidents are analyzed as floodings.

As one would expect, accidents occurring on the ocean are different from the accidents occurring on lakes, rivers, or other bodies of water. Grounding is more frequent among accidents on the oceans than on inland waters. There are proportionately fewer collisions reported with other boats or with fixed objects since boats have more room to maneuver. Reports of falls overboard are proportionately less frequent, probably due to the limited use of small boats on the ocean. People in the water are not reported to be struck by boats or propellers as often because water skiers, swimmers, and divers are not as common far from the ocean beaches. These statements on the frequency of reported accidents do not account for any differences in the type or length of use of boats on the oceans versus those on other waters. Fatalities from falling overboard, colliding with another boat, and striking a fixed object are proportionately fewer on the oceans.

The Boating Accident Report file allows for three causes of accidents to be coded for each boat. This analysis concerns only the first code. If more than one cause is blamed for the accident, they are coded in the order of their impact on the casualty.

Among the twenty-eight causes of accidents which are listed in Boating Statistics, the proportion of accidents on the ocean caused by failure of the steering, throttle, or other non-power equipment is the most significantly increased over that proportion found on all waters. Instead of four per cent of the reported boats having such a failure, 7.9% of the boats on the ocean had equipment failures. Speeding shows the most significant decrease. Only 1.2% of ocean operators caused their accidents by speeding, whereas more than four per cent of operators in reported accidents on all waters caused them by speeding.

In analyzing fatalities we find that inattention or carelessness is blamed for proportionately fewer fatalities on the oceans than on all waters. A wave or wake striking the boat is the cause for proportionately more fatalities on the oceans. This finding agrees with the finding that fatalities when boats capsize, which is one of the results of being struck by a wave, are proportionately more frequent on the oceans.

BOATS

Most boats involved in reported accidents on the ocean from 1969 to 1987 are open motorboats. The median length of all boats involved in reported accidents on the ocean is 24 feet, but the most common length is sixteen feet. For those boats involved in fatal accidents, the median length is nineteen feet. The most common length for boats involved in fatal accidents is also sixteen feet. On the oceans, as on all waters, fatalities are more likely on smaller boats.

The median horsepower of boats reported to be involved in accidents on the ocean between 1969 and 1987 is 120 for powered boats. A steady rise over the years in the power used on boats has increased the median for accidents occurring in 1987 to 140 horsepower. In fatal accidents the median is 70 horsepower, again showing the greater likelihood of fatalities on smaller boats. In the last four years the median for fatal accidents has fallen to 50 horsepower. No explanation for the decrease is apparent.

ACCIDENT CHARACTERISTICS

For each item of information that is coded for each accident, including the boat, operator, and the environment, some of the characteristics which occur significantly more or significantly less frequently on the oceans than on all waters combined will be stated. Statistics for all waters used in the statistical testing covered only the year 1986, when there were 1,066 fatalities and 6,407 reported accidents. Most characteristics do not change much from year to year, so that the 1986 statistics are appropriate for general comparisons.

When the frequencies of occurrence of reported accidents are discussed, we must remember that

accidents are rare events. Associated characteristics do not necessarily reflect the same proportions as one might observe in recreational boating experience or through surveys because the probability of an accident occurring is the product of risk and exposure. Knowledgeable people usually have an idea of the relative risks, but not about the overall exposure of segments of the boat population under various conditions. Therefore, we can not be too specific in analyzing accident statistics, but must talk more generally. Another problem is that only a small fraction of accidents are believed to be reported. Analysts must use their experience to interpret the results meaningfully. The following paragraphs in this section consider those characteristics of reported accidents which are more likely or less likely on the oceans than on all waters combined.

According to this analysis, boats are less likely to be maneuvered or used for water skiing on the oceans. Cruising while the passengers are fishing is more popular on the oceans. The proportion of cabin motorboats and auxiliary sailboats is greater on the ocean and open motorboats are less common. Boats on the ocean are more likely to have inboard engines and they are longer.

Based on accident reports, operators of boats on the ocean are older, with a higher percentage over 50 years old and a lower percentage under 26. More operators have more than 500 hours of experience and fewer operators have operated boats of the same type for less than 20 hours. People in accidents on the ocean are less likely to be alone on the boat. They are also more likely to have taken a safety course with the Coast Guard Auxiliary or the U.S. Power Squadrons. Fewer operators have had no safety instruction. When the boat has an accident, the personal flotation devices are more likely to be used.

Environmental conditions on the oceans are different because rough and very rough conditions are more likely. Moderate winds are more common. Water temperature from 50 to 59 degrees Fahrenheit is overrepresented in ocean accidents, while temperatures of 70 degrees and above are underrepresented.

The proportion of accidents occurring in the early evening on the oceans are less frequent than on all waters, but the early morning hours from 6:30 to 10:30 account for more accidents. June and July, the usual peak months of recreational boating activity, do not see as high an accident peak on the oceans. Rental boats account for a lower proportion of accidents on the ocean than on other waters.

TRENDS

The total number of fatalities occurring on the oceans, Long Island Sound, and the Gulf of Mexico is on a significant trend downwards at a rate of approximately five per cent per year. However, since the total number of fatalities on all waters is also trending down, there is no immediate reason to suspect that there is anything affecting ocean fatalities that is not affecting all recreational boating fatalities.

Since the number of fatalities on recreational boats on the oceans is declining, the usual analysis will find many downward trends. In order to produce more useful results, the statistical calculations are performed on the ratio of the number of fatalities having each characteristic to the number of all ocean fatalities year by year. Such an analysis will, instead of finding that the number of capsizings is in a downward trend, compare the capsizing fatalities to the downward trend of the total number of fatalities. In the case of capsizing, there is no downward trend in the relationship to all ocean fatalities, even though capsizing fatalities have dropped from 37 per year in the 1969-1973 period to twenty in the current period.

The most significant trend is a rise in fatalities in accidents caused by the loss of stability in strong current, weather, rapids, white water, etc. It appears that this cause was not usually considered for ocean accidents before 1976, when there is a sharp break in the number of fatalities each year. This is possible because the different Boating Accident Report forms which the states print have limited room to list causes. So the coder must choose from our list of 48 cause codes depending on how the events of the accident are understood.

The second most significant trend is a decline in the percentage of fatalities on wooden boats. This is a direct result of the popularity of fiberglass over wood for new boat construction. In 1969, 31% of the registered boats were wooden. By 1987 this percentage has dropped to 4.6. In contrast, fiberglass boats increased from 33% of all those registered in 1969 to 52% today.

Fatalities have not occurred on boats using exactly 75 horsepower since 1978. In the ten preceding years 39 fatalities had occurred. In the eight years from 1969 to 1976, 38 of those fatalities occurred, for an average of almost five per year. The sharp contrast between this average and no fatalities in the present time may be the result of boat owners scrapping their previously high-powered engines of 75 HP for larger ones. In fact, there is a significant increasing trend of fatalities on boats powered with exactly 150 HP.

Fatalities occurring in accidents where the sea temperature is from 70 to 79 degrees Fahrenheit are increasing significantly. This trend, and two less significant trends for temperatures in the 50's and 60's, is explained by a trend toward fewer fatalities in accidents where the sea temperature is unknown. The investigators

of fatal accidents seem to be recording the temperatures more often now than they did years ago.

The percentage of ocean accident fatalities found to have been using Personal Flotation Devices (PFD) is on a downward trend. There are several explanations possible. One is that search and rescue is becoming more effective, thereby saving those who do use flotation. Another is that the PFD's themselves have become more effective. The criticism, over the past several years, of the effectiveness of the most comfortable PFD's may be discouraging some boaters from using their PFD's. Another less likely reason is reduced use of the oceans by those who are likely to wear PFD's.

Water entering the boat over the transom, gunwale, or bow is declining as a cause of fatalities on the ocean. This may be partly due to the ability of small boats built under the level flotation regulation to remain level on the surface even when flooded. The regulation covers only boats under twenty feet in length. (Remember that the median length of boats involved in fatal accidents on the ocean is nineteen feet.) However, only one other cause, wave or wake striking the boat, among those that should be affected by the same boat capability, also shows a significant downward trend. Deeper investigation into the accident files may determine if there is a more probable reason.

The number of ocean fatalities that have occurred in fog has been very low since 1981, when there were 13. There have been only thirteen more in the six following years.

Equipment failure is becoming a thing of the past in causing fatalities on the ocean. There has not been one recorded since 1984. In the period 1969 through 1976, an average of more than six fatalities per year were blamed on equipment failure.

There are other trends that are statistically significant for the period from 1969 to 1987. However, those which were described are the most significant.

ACCIDENT CHARACTERIZATION

Some statements will be made about the most common accidents, based on the length of the boat involved and the type of accident, in order to supply a little more detail about how accidents occur. Reports of the most recent accidents in each group were read to find what the accidents had in common. In general, capsizings are responsible for the greater proportion of fatalities. Collisions with another boat are responsible for very few fatalities, but many injuries.

Collisions of 25' Boats With Other Boats

Seven collisions of a 25 foot boat with another boat occurred in 1987. Another four occurred in 1986. Six of these eleven accidents occurred at some distance offshore. The five known distances from land are a quarter to a half mile, 1900 yards, one and a half miles, two miles, and three miles. In three of the eleven accidents, the environment (fog, darkness, and 3 to 6 foot seas) was a factor in causing the accident. However, attentive operators would have avoided all three collisions. Another seven were caused by inattention or carelessness or not obeying the Rules of the Road. Five sailboats, (two 25 foot sailboats hit each other) were hit while they were under sail.

Capsizings of 16' Boats

Of the twelve capsizings of sixteen foot boats which I will discuss, three occurred in 1987, three occurred in 1986, and six occurred in 1985. Two of the three in 1987 occurred while small craft warnings were in effect. Seven of the twelve occurred in surf or close to shore or at the entrance to a harbor, where waves were at least three feet. Two boats were kayaks on the Pacific Ocean off the coast of California. One of the kayaks was three miles away, the other was sighted one eighth of a mile from a harbor before the victim was lost by the observer. Four of the twelve accident reports cited the distance of the boat from shore. The distances are 150 yards, 1/8 mile, 1/2 mile, and three miles. None of the other eight reports indicated that the boats were far offshore, so they probably were pretty close. The motors of two boats stopped, allowing the boats to drift into the surf of three feet or more. Three of the operators were trying to reach shore in bad weather and water conditions.

Capsizings of 14' Boats

With information on four of the nine capsizings of fourteen foot boats occurring from 1985 through 1987, the distances from shore were six hundred yards, three hundred yards, and two boats just off a beach. Two catamarans capsized in Hawaii, one just getting underway at a beach, the other on trying to return to the beach.

CONCLUSION

Recreational boating accidents which occur on the oceans, the Gulf of Mexico, or Long Island Sound are different in some of their characteristics. However, no matter where people use their boats, one thing above all remains the same. Operators, and their passengers, could avoid many accidents if they were more attentive and careful.

TRIBUTYLTIN AND WATER QUALITY: A QUESTION OF ENVIRONMENTAL SIGNIFICANCE

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ABSTRACT

The most critical scientific issues that have caused strict regulation of tributyltin (TBT) antifouling paints were reviewed. It was determined that the evidence cited by scientists and regulators as most significant is equivocal. Unreal expectations that science can provide definitive answers in a short time have been established through increased environmental awareness, and politics. The regulatory process has accelerated decisions using less-than-optimum scientific data with abnormally high degrees of uncertainty. Research has been driven to develop quick-response tests to quantify effects only and not explain why they occur. At parts-per-million (mg/l) cause-and-effects levels with simple contaminants, these regulatory approaches were cost effective, and conservative approximations. However, faced with effects in the parts-per-trillion range (ng/l), these regulatory approaches appear to be inappropriate. They have perpetuated many interpretations of the available data and many unresolved questions of environmental significance. This paper reviews the scientific data utilized by regulatory agencies to establish criteria for the use of TBT in antifoulant paints.

INTRODUCTION

Mariners have battled fouling organisms on boat bottoms since the first days of sail. Phoenicians nailed copper strips to their wooden hulls as along ago as 300 B.C. Copper-based antifouling paints were introduced in the early 1800's and have been the predominant bottom coating for over 150 years. The first organotin-based paints were developed in 1961 and were not used in significant quantities for at least 10 years (1, 2). Organotin antifouling paints can provide protection for up to 7 years compared with 2 years for copper-based paints. However, the future use of tributyltin (TBT) compounds in antifouling paints will be severely limited in many countries. There is little doubt that unregulated use of TBT in antifouling paints has generated environmentally unsafe levels in many marinas. However, there are many unresolved questions of environmental effects in areas removed from marinas. Where TBT concentrations are low, problems of interpretation are due, at least in part, to a highly accelerated collection and analysis of scientifically questionable organotin data used for regulatory purposes. Assuming unlimited time and resources, even the best environmental data has some scientific uncertainty. Given the accelerated time requirements of the regulatory process, these data have even higher levels of uncertainty. The environmental impact of new regulations are also unknown.

Most of the evidence considered by the regulatory process to be most significant comes from bivalve molluscs. This has occurred for a variety of reasons. First, it is generally believed that molluscs are more sensitive than other animal groups to TBT, the primary toxic component of organotin antifouling paints. Second, many bivalves have a cosmopolitan distribution and are commonly maintained in the laboratory. Third, filter-feeding bivalves may be more susceptible to TBT due to their feeding strategy. Fourth, many bivalves have an economic importance in the commercial shellfish industry. One significant point that should be made here is the subtle distinction between the environmental impact of TBT on the shellfish industry and the environmental impact of TBT on natural populations. However, it should be noted that effects on cultured shellfish do not necessarily demonstrate similar ecological effects in a typical natural situation. This issue becomes particularly relevant when oysters are raised in the vicinity of marinas or high vessel densities. Even if TBT were not present, it is difficult to understand selecting culture areas immediately adjacent to marinas and boatyards with many other contaminant problems. Furthermore, marinas which are usually located in protected areas with low flushing rates, other contaminants, and high silt loads do not have optimum conditions for culturing filter-feeding bivalves.

Nevertheless, this paper will focus on the scientific aspects of data that the regulatory process has chosen as the most important evidence against organotin antifouling paints. In Europe, the critical evidence was associated with shell thickening in oysters (Crassostrea gigas) and imposex in dogwhelks (Nucella lapillus). In the U.S., the critical evidence was associated with three laboratory studies that reportedly demonstrated unacceptable effects on growth and development in oysters (C. gigas, Ostrea edulis) and clams (Mercenaria mercenaria). All of this evidence is based on only four species, a similar number of laboratory tests and field observations, generally unsupported by chemical measurements. In general, the laboratory

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studies utilized questionable methodology and field studies were little more than casual observations.

The collection of this type of data was apparently driven by the short-term, crisis type needs of the regulatory process. Regulatory offices in the U.S. do not generally fund research, but only solicit data and information from users, product manufacturers and other interested parties. In effect the information requirements of the regulatory process monopolize many research resources in an attempt to get the information needed for policy and decision-making. The result with TBT appears to be an abundance of scientific information that is not effective in predicting environmental effects. The regulatory process is forced to be even more conservative because of the abnormally high scientific uncertainty in the data.

SHELL THICKENING IN C. GIGAS

The European Experience

By 1976 French and U.K. scientists had observed an abnormal thickening in the shells of Pacific oysters, C. gigas (3) The first difficulty in interpreting these field observations of shell thickening is that this species is not native to Europe. It had been introduced to France in 1968 and to the U.K. in 1972 (4, 5), about the same time TBT antifouling paints were becoming more widely used. There was very little baseline data on "normal" growth of this exotic (non-native) species before the anomalies were reportedly associated with TBT. The second difficulty was that existing analytical methods were insufficient to support the early French work with appropriate chemical measurements. Field studies were generally not conducted by commonly accepted procedures (6). This environmental work appears to have been conducted in essentially scientific isolation. Most of the evidence was largely correlative and therefore the interpretation was subjective (1). Supporters of the 1982 French ban point to the marked improvement in spatfall and reduced shell thickening in Arcachon Bay but fail to discuss that LaRochelle Bay showed little improvement after the ban (7). Alzieu (3) does report some measurements of heavy metals in Arcachon Bay but suggests no correlation with shell thickening. It is interesting to note that the concentrations of copper in Arcachon Bay are an order of magnitude above TBT levels and are within the range reported to reduce growth (8) and cause shell deformities (9) in mussels.

In the U.K., thickening was first attributed to suspended sediment by Key et al. (10). Waldock and Thain (11), conducted a laboratory study to determine whether this shell thickening phenomenon was induced by suspended sediment or TBT. They found that "clean" sediment did not cause shell thickening. TBT alone and sediment contaminated with TBT both induced thickening. As with the Key et al. study, this only shows a correlation, and does not prove a cause-and-effect relationship in the field.

Other contaminants in the sediment were not measured. If sorbed on sediment surfaces they could have been a contributing factor to the observed shell thickening in addition to the stressful laboratory test conditions. It should be mentioned that corroborating field measurements only establish another correlation with shell thickening. This does not disprove the field correlation with suspended sediment documented by Key et al. (10). Further, the Waldock and Thain laboratory study is questionable due to abnormally small sample size (10 animals/replicate), artificial seawater, carrier solvents, artificial algal diets, static conditions, and no statistical analysis. Additionally, all comparisons were made relative to a seawater control rather than comparing suspended sediment treatments with a clean suspended sediment control.

Due to the different methods and procedures used to study the effects of organotin compounds in many studies like this, the National Oceanic and Atmospheric Administration in the U. S. sponsored an Interagency Workshop on Aquatic Monitoring and Analysis of Organotin Compounds in 1986 to review and recommend standardized procedures for field studies (12).

Thain and Waldock (13) suggest that TBT is at least a contributory factor and probably a major factor in the failure of O. edulis to reproduce naturally in the Crouch estuary. Thain also points out that the natural population fluctuates widely and has been decimated by harsh winters, over fishing and disease. The last major collapse followed the harsh winter of 1962-1963 (14). It is well known that the chance of repopulation diminishes when stocks are low.

After the natural failure of the natural population of O. edulis, a number of species were introduced, unsuccessfully. These include Crassostrea angulata, Crassostrea virginica, Ostrea lutaria and Ostrea chilensis (4, 15, 16). This should not be surprising since Mann (15) has concluded that "The introduction of a exotic (non-native) species can be a highly unpredictable and potentially harmful act, with results ranging from total failure to reproduce to practically uncontrolled proliferation of the species in the new environment". After over 50 years of culture of C. gigas on the Pacific coast of North America, its future as a self-sustaining species in that region is still uncertain.

It also seems too coincidental that the decrease in spat from Japan and British Columbia was concurrent with the first reports of shell thickening in France and the U.K. Although hatcheries provide a large number of progeny from a small number of broodstock and a source of spat without natural breeding, there is a significant potential problem. Mann (15, 16) has suggested that the impact of exotic species on the environment may not be evident for many years. In the context of TBT and simultaneous introduction of C. gigas, it is likely that the natural effects of the environment on the oyster may not be evident for many years. C. gigas has a tendency toward homozygosity and, without clear genetic lines to promote vigorous heterozygotes, the progeny may be more susceptible to any environmental perturbations. It should be remembered that the main reason for introducing C. gigas was the failure of a natural population from natural causes.

The U.S. Experience

The concern created by the European experience has had a profound effect on expediting the U.S. regulatory process. Without waiting for the national regulation, several states have already placed strict limits on the use of TBT. The results from TBT use in France and the U.K. most likely caused EPA to be more conservative, lowering their TBT criteria below the calculated values. Data were used from three tests that have significant limitations and should not be used for environmental prediction. EPA has acknowledged that they did not properly scrutinize methodology or results (7) due to regulatory deadlines and the inadequacy of the data. It is interesting to note the coincidence in the literature cited for significant effects at 20 ng/l TBT and the original 20 ng/l TBT EQT (Environmental Quality Target) in the U. K. Again, commercially important species are emphasized and the environmental significance in the typical natural situation is only implied.

Shell thickening studies with C. gigas in the U.S. have been driven by the European experience and a need for organotin field data. This shell thickening index has been used by Wolniakowski et al. (17) in Oregon, and Stephenson et al. (18, 19) in California. Its validity as a reliable bioindicator in any environment has never been scrutinized. It is important to recognize how pressures of the regulatory process have limited and focused science in such a narrow direction. The reported specificity of the shell thickening index is also its weakness.

The first International Organotin Symposium was held in Washington, D.C. in 1986. One obvious question asked was; Is there anything other than TBT that can cause shell thickening? European scientists reported that nothing they had tested induced shell thickening in C. gigas. None of these results have ever been published however, so there has been no peer or regulatory review. At the 1987 International Organotin Symposium in Halifax, Nova Scotia, a panel discussion addressed two similar questions. (1) Is there anything else that might cause shell thickening? (2) Why have there been no reports of shell thickening from Japan where C. gigas is a native species? European scientists present at the meeting dismissed these concerns even though TBT use in Japan is widespread.

The Japanese Connection

In 1987, the first reference to shell thickening in C. gigas from Japan appeared in an international journal. Okoshi et al. (20) reported that there were distinct differences in propensity for shell thickening in two local races of the Japanese oyster C. gigas. The Miyagi race has a genetic tendency for shell thickening. This race was primarily exported to Europe and the U. S. (15, 16). Contrary to what had been reported in the U.K., Okoshi et al. (20) found no correlation between chambering and either shell height or flesh weight. Furthermore, they did not consider shell thickening to be a serious problem for the oyster industry because meats are sold out of the shell. The thickened shell was regarded as a trivial problem. They also cite papers that report shell chambering in C. gigas from Japan before the introduction of TBT paints. Similar early accounts of shell thickening that were apparently unrelated to TBT have been reported in British Columbia (21). Chambering in O. edulis was reported as early as 1916 (22, 23). European biologists generally agreed that chambering was caused by body shrinkage and deposition of partitions to occupy the unused space (24, 25, 26). Although TBT was not measured in the transplant experiments, Okoshi et al. (20) doubt whether a relation exists between shell thickening and TBT antifouling paints. They do believe that there is a significant genetic and environmental component responsible for the observed thickening response.

Since C. gigas does not reproduce naturally in the U.K. and Japan has not exported seed since 1978, all laboratory and field test animals come from hatchery operations that produce animals with uncertain genetic backgrounds. It seems likely that inbreeding has occurred over the years and the resulting oyster may be even more prone to thickening than the original Japanese Miyagi race. In numerous studies of natural and hatchery populations, heterozygote deficiencies have been reported for over two dozen bivalves species including Mytilus edulis, C. gigas and O. edulis (27, 28). This tendency toward homozygosity has been correlated with low growth rates and high mortality (29). Hatchery reared animals, particularly C. gigas, tend to have a genetic as well as an environmental liability. First, offspring tend to lack hybrid vigor due to homozygous tendencies. Second, hatchery animals are conditioned to grow well in the hatchery and not necessarily in nature. Natural stocks generally grow faster, exhibit higher survival and are less susceptible to environmental changes than their hatchery cohorts (30).

Although this work on shell thickening in C. gigas from Japan was not reported in the international literature until 1987, the actual research was completed in 1984. Since they had predicted potentially catastrophic effects on the oyster industry, it seems odd that European scientists did not contact Japanese scientists. The possibility of hatchery deficiencies was apparently disregarded, even though oyster inbreeding is well known in the scientific community.

MOLLUSCAN GROWTH EFFECTS

Imposex in Nucella lapillus

Another reportedly TBT-specific bioindicator that has influenced the bans in Europe and the TBT advisory in the U.S. (7) is imposex in dogwhelks (N. lapillus), i.e., the imposition of male sexual characteristics on the female of the species. It is unclear whether TBT is the only chemical that can induce this phenomenon, particularly when this tendency toward hermaphroditism is quite common in gastropods. Severe imposex can apparently affect

the population but the degree of imposex and the TBT concentration that induces these effects remains unclear. The laboratory studies have extrapolated effects from TBT concentrations beyond analytical capabilities and reported corroboration by casual field observations that is highly speculative (31, 32). Further, in similar studies on a closely related species, Smith (33, 34, 35, 36) reports that other chemicals like organoleads might induce the same phenomenon in Nassarius obsoletus and that imposex does not necessarily have any significant impact on the population. The other important factor to consider is the genetic propensity for imposex. Just like inbreeding and resulting homozygosity in C. gigas, dogwhelks have a very strong tendency to inbreed. N. lapillus, particularly, spend their entire lives in a very limited area and there are no pelagic larvae. There is very little genetic exchange. A recent study on Nucella lamellosa has shown the greatest population subdivisions reported for a marine gastropod (37). This generally supports the theory that these particular gastropods with limited larval and adult dispersal have genetically fragmented populations that would be very susceptible to environmental changes.

The two most significant findings that led to bans in France and the U.K. could be attributed to potentially large genetic deficiencies in two molluscan species, C. gigas and N. lapillus. One is a non-native species that is cultured for consumption. The other is naturally occurring but appears to be at an evolutionary standstill due to its inability to exchange and distribute genetic information. If the philosophy of regulatory criteria is to protect 95% of the species, dogwhelks and oysters with potentially large genetic limitations do not seem like appropriately representative species. The Japanese paper (20) has stressed the importance of genetics and environment in explaining observed thickening effects. The importance of genetics (stock) and environment (site) has also been stressed in explaining mortality and growth in a number of bivalve species including M. edulis, O. edulis, C. virginica (38, 39, 40, 41). Additionally, the data from questionable laboratory studies and casual field observations with minimal chemical measurements precludes establishing a clear cause-and-effect relationship.

Regulatory Procedures

The majority of laboratory testing in the U.K. has been on the oyster C. gigas. Although this work was intended to corroborate field observations in Europe, the results are subject to a variety of interpretations and unresolved questions of environmental significance. Nevertheless, these and similar studies were used by EPA to lower their organotin advisory criteria calculated by a precise formula from 47 ng/l to 10 ng/l TBT. More importantly, EPA chose to regulate the use of TBT antifouling paints by inference of unacceptable effects on larval and juvenile clams and oysters. Reductions in growth and development were reported near 20 ng/l TBT in laboratory studies. These studies violate EPA's own criteria for acceptable data, but were used for proposed national regulation. The conservative lowering of the advisory in itself suggests that the regulatory process is flawed if limited data are available. For purposes of this discussion, it will be assumed that the calculation of the Final Acute Value was valid and only the reduction of the calculated value will be scrutinized.

The major problems with larval and juvenile bivalve bioassays are unrealistic test conditions (static renewal, artificial seawater, unialgal feeding, carrier solvents), unmeasured test concentrations and extreme variability in aliquots used to represent survival. Additionally, TBT adsorption to particles could make them less bioavailable for bivalve larvae as previously suggested (42). The unrealistic test conditions might represent what Carpenter and Huggett (43) have referred to as "biogeochemical quackery" in assuming that experimental conditions are similar to those in the field. Unmeasured test concentrations are unacceptable when testing in the parts-per- trillion range.

The EPA calculated the advisory concentration based on a pre-determined mathematical formula and then lowered it based on "other considerations." Several steps in this scenario are flawed and suggest that unresolved questions of understanding environmental significance are being perpetuated by the regulatory process. The derivation of the Final Acute Value based on the four most sensitive species tested for saltwater will not be discussed here. No bivalves were used in the calculation even though the advisory was lowered because of reported effects on bivalves. It will be assumed that the acute value, approximately 500 ng/l is correct. It should be remembered that this value is a function of the most sensitive species tested to date. The next critical step is determining the acute/chronic ratio. Under the EPA guidelines, acceptable studies for determining this value are only available for two freshwater species and one saltwater species. It is important to note that although the saltwater mysid is the most sensitive species used in the calculation, the acute/chronic ratio is significantly higher for the less sensitive species. This ratio is more a function of procedures than the actual effects of tributyltin. The Daphnia tests were conducted for only two days. According to the EPA guidelines (44), this is the maximum time they could be kept alive without feeding. This gives an artificially high acute value. If the animals were exposed for a longer period of time, e.g., 96 hours, the acute value and thus, the ratio would be significantly lower. The animals were fed during chronic tests and a more reasonable estimate of projected effects in nature was obtained. It should be noted that the chronic values for mysids and Daphnia are quite similar. It might be expected that the acute values would be similar if the Daphnia were fed and the test conducted for 96 hours as with the mysids.

The EPA also suggested that the freshwater numbers can be used to calculate the acute/chronic ratio for the saltwater advisory concentration. However, the most sensitive and the most resistant of freshwater organisms differ by a factor of 20 as compared to a factor of 463 for saltwater organisms. Additionally, the calculated advisory concentration

for freshwater is only half of the calculated value for saltwater.

Interestingly, over 5 years ago, preliminary static tests with mysids provided a 96-hour LC-50 estimate of approximately 500 ng/l TBT. At the time, this was one of the most sensitive species tested. In preparing the Navy's Environmental Assessment (45) that number was divided by a safety factor of 10 to estimate 50 ng/l as a safe level. Although a gross estimate, it is amazing that 5 years later with sophisticated mathematical manipulation of significantly more data from a variety of species, the regulatory process would produce a number that is virtually identical (47 ng/l). This also suggests that only a few key species have a large impact on the criteria and that greater care should be exercised in the interpretation of those bioassays in particular.

Larval and Juvenile Bivalve Growth

However, the regulatory process suggests that there are unacceptable effects on commercially important bivalves at concentrations less than this calculated value. EPA cites reductions in growth and rate of development in three different species. Previously White and Champ (46) have discussed the shortcomings of bioassays in general for predicting environmental impact and their questionable use by the regulatory process. Cunningham (47) has enumerated essential factors in the design and conduct of experiments using bivalves. The environmental significance and interpretation of organotin bioassays have been discussed with an emphasis on understanding bioavailability (42). The three bioassays cited by EPA are subject to the same problems noted in other bioassays, but the test conditions are so extreme that they warrant further scrutiny and interpretation.

All three tests were conducted under static renewal conditions, which are more realistic than static, but not representative of the environment. All three tests used an approximation of seawater which was either artificial seawater, and/or seawater that had been filtered and sterilized in addition to stock algal cultures as food. These test conditions are so far from natural conditions it is difficult to believe that animals in nature would respond similarly. The use of carrier solvents and filtered seawater may have increased bioavailability by concentrating TBT on food particles.

Bivalves could be more sensitive to TBT because they filter and retain bacteria, algae and sediment as food with the associated TBT. Laboratory studies have shown that TBT rapidly binds to suspended sediment particles, algal cells and bacterial cells (48, 49, 50, 51), and that suspended particulates enhance TBT bioaccumulation in mussels (42, 48) and oysters (42, 11).

The EPA regulatory Protocol has suggested that only native species be used in predicting environmental effects (7). The unpublished Springborn Bionomics study (52) violates this criterion by using *C. gigas* larvae. The validity of the experimental design should be scrutinized. Although effects were reported at 25 ng/l TBT, these concentrations were not measured as they were below their limits of detection. This violates another of EPA's criteria for accepting data, i.e., measured test concentrations (44). In addition there was extreme variability in estimated survival from aliquots with different results on different sampling days. More than half of the solvent controls has significantly different survival than the seawater control. Test validity is questioned because control survival was only 3% at the end of the test. Further, larvae from adults "conditioned" on a diet of corn starch and algae were probably under stress passed on from the adults (53, 54, 55).

The second test that was used to lower the U.S. advisory was conducted by Thain and Waldock (56) on *O. edulis*, another species not native to North America. The results could be rejected on the basis of non-native species and unmeasured test concentrations. These tests were conducted under static conditions, using artificial seawater, artificial algal diets, and solvent controls, all of which either separately or in combination could significantly affect the results. There was no replication and no statistical analysis. The authors suggest that significant reductions in growth occurred at 60 ng/l TBT. EPA selected 20 ng/l TBT as a critical concentration because growth was slightly lower than the controls. In a conservative regulatory scenario it seems reasonable that any statistically significant reduction of growth rates in nature could be considered environmentally significant. Any reduction in laboratory growth, statistically significant or not, should be interpreted with extreme caution, In this case, no statistics were used.

The only study used to lower the advisory in which test concentrations were measured at levels of reported effects was in the most recent study conducted by Laughlin et al. (57). Observed effects at 25 ng/l TBT were considered significant by EPA even though the authors reported significant effects at 50 ng/l TBT. Solvent carriers were used which may reduce survival and increase bioavailability. This study suffers from many of the same problems of the other tests, partly due to difficulties in maintaining larvae in the laboratory. Static conditions must be used because there are no techniques available to maintain them under flow through conditions. The algal species used as food were much different than field populations. In addition, this was an uncontrolled experiment without replication that defies statistical analysis. If replicate containers had been counted at each sampling time, a statistical variance could be associated with the results. Another problem was the utilization of rarefied data. That is, only animals that grew were included in the growth rate computations. This biases the results in favor of finding a difference between test concentrations. It does not account for a natural distribution where some animals grow slowly but survive to grow when conditions improve. Larvae were obtained from an experimental hatchery with potentially the same inherent problems previously discussed.

As with the European experience, EPA did not scrutinize the three studies it used to lower the advisory (44). Particularly, EPA did not consider problems in methodology or analysis. Further, the potential genetic and environmental deficiency of hatchery-reared animals and their offspring were not considered.

ANALYTICAL LIMITATIONS AND BIOAVAILABILITY

There has been a rapid improvement in development of analytical techniques to measure the various species of butyltins and progress in identifying the species that are most toxic. Bioavailability has yet to be quantified in any study. How can environmental effects be predicted when there still is not a definitive method for reliably measuring the bioavailability of TBT in nature? Partitioning experiments have reported TBT associated with particulates from 3 to 70 % in nature (58, 59). This demonstrates a high degree of natural variability and the inability of the detector to distinguish between truly dissolved TBT and TBT associated with paint dust. Since these measurements were made in different types of estuaries, at different times of the year, with different levels of suspended solids and only by differentiating a small fraction of particles, the environmental significance is unclear. To predict environmental effects, this relationship must be more clearly defined and it cannot be measured by chemical measurements alone. It is still not clear if TBT measured by detectors is equivalent to TBT available to organisms and how bioavailability varies by species.

Laughlin et al. (48) have shown that lab values are not reliable measures of the bioaccumulation process for mussels and have suggested that accumulation under field conditions is necessary for accurate predictions of environmental effects. This has been confirmed in a recent field study (60). Previous work by others on heavy metal accumulation by mussels has shown that bioaccumulation is affected by age, sex, season, tidal height, and animal condition (61, 47). It is well established that organic complexes reduce the toxicity of metals to phytoplankton and zooplankton. These same complexes may enhance the bioavailability and toxicity of metals to filter-feeding bivalves (62, 63, 64, 65). Organic complexes may also increase the bioavailability of TBT for bivalves and reduce the bioavailability of TBT for phytoplankton and zooplankton.

The early laboratory work suggests bivalve growth rates are directly affected by accumulated TBT (14, 66, 11). Recent work (60) shows that very low growth rates are associated with high TBT concentrations in mussel tissues and that below 1.5 ug TBT/g tissue there is no clear correlation between TBT in mussel tissues and mussel growth rates. Salazar and Salazar (60) have questioned the utility of extrapolating environmental effects from tissue levels, extrapolating seawater TBT concentrations from tissue levels, or using field data to verify laboratory data (13, 59, 67, 68, 69, 32, 66).

Davies et al. (68) have shown that TBT accumulation by oysters in the field is generally higher than in the laboratory and it takes longer to reach equilibrium. This field study also casts doubt on the validity of laboratory studies which were used to lower the advisory values. Thain and Waldock (56) reported equilibrium after only 14 days where Davies et al. (68) report equilibrium in C. gigas after 16 weeks. Part of these differences could be attributed to stressed animals in the laboratory. Stress in the laboratory can be caused by maintenance under unnatural conditions (53, 54, 55). Stress in the field could be attributed to TBT, other contaminants or physical/chemical factors (70).

Kiorboe et al. (71) suggested that growth rates in optimum laboratory studies do not approach growth rates in the field primarily because M. edulis derives additional nutrition from suspended particulates. They may also accumulate additional TBT from these suspended particulates.

Mysids exposed to TBT survived better with bottom sediment than without sediment (72) while the presence of suspended sediment appears to enhance the deleterious effects of TBT on oyster spat (11). Henderson suggests that TBT did not bind to phytoplankton, but two species of coral had significantly higher mortality when exposed to TBT with phytoplankton than without (73). Laughlin (48) found that phytoplankton enhanced TBT accumulation in mussels. Waldock and Thain (11) showed that TBT with sediment particles reduced growth more in C. gigas than TBT alone. These three bioassays demonstrate that TBT binds to bottom sediment and that sediment and feeding type affect bioavailability.

FIELD STUDIES

Given the high degree of scientific uncertainty in the laboratory studies previously discussed, it is not reassuring that field studies and field monitoring of TBT have an even higher level of uncertainty. Environmental complexity and variability have precluded establishing a clear cause-and-effect relationship between measured TBT concentrations and observed effects in the field. This caused Stebbing to conclude as late as 1985 that "While the weight of evidence strongly implicates organotins, strictly speaking the case remains inconclusive." Stephenson (19) reported significant reductions in bivalve growth along an increasing TBT gradient but other conditions along that gradient were not documented and the control site could not reasonably be called a true control. Further, few chemical measurements were made to establish a true gradient.

These shortcomings were addressed at Oceans '87 (70) and Stephenson acknowledged that these methods could not be used as previously suggested. Similar criticisms could be made of the European experience in the field. Now the validity of the shell thickening index has also been questioned as inappropriate. The failure to bring this information to the attention of the scientific and regulatory

communities has resulted in potential overestimates of TBT effects in nature and a regulatory response which is likely overly conservative.

A number of authors have discussed the questionable value of single chemical measurements at a point in space or time but there are few meaningful measurements available for TBT on a real-time basis. This is absolutely necessary for field experimentation and environmental prediction. Otherwise, the "mindless monitoring" and "biogeochemical quackery" discussed by Carpenter and Huggett (43) are approached.

This is particularly true of chemical measurements reported from the U.K. Most samples were taken at slack water low tide which can overestimate actual concentrations. The number of measurements that exceed the arbitrary EQT of 20 ng/l has also been reported and emphasized. Order of magnitude differences in TBT concentrations have been reported to vary with tidal flow (74) and in weekly survey samples (60). Further, that relatively short time of slack water low tide represents a small fraction of the time that animals are exposed to the highest concentrations. It has yet to be demonstrated that animals respond to mean TBT concentrations over the entire tidal cycle or just the extreme highs. Any valid environmental assessment should include means as well as extremes with some integration of exposure over time that is commensurate with the natural temporal and spatial variability of the ecosystem in question. It has also been shown that surface samples are generally much higher in TBT concentration than deeper samples (75, 60), so it hardly seems representative to use one water sample taken near the surface at slack water low tide to represent the entire tidal cycle and all water within the basin.

SUMMARY

Studies have reported that TBT exposure produce the following effects: (1) shell thickening in C. gigas, (2) imposex in N. lapillus, (3) growth reductions in larval C. gigas and M. mercenaria as well as juvenile O. edulis. Data from a limited number of laboratory tests and field observations were used to regulate TBT antifouling paints in Europe and the U.S. A careful review of the scientific methodologies used in these studies shows that these critical bivalve test results remain equivocal and that a true cause-and-effect relationship in nature remains unproven. The data may also have been biased by emphasizing reported effects on cultured, non-native species with possible genetic deficiencies. It has been acknowledged that the information reported for most studies and time constraints did not allow a thorough evaluation of the methodology or the results. Most of the laboratory tests did not follow commonly accepted procedures. Most of the field studies report mostly anecdotal information without measuring other factors that could have affected molluscan growth. Furthermore, baseline studies to clearly demonstrate growth effects or existing environmental conditions before the introduction of both TBT and C. gigas were not conducted.

In the U.S., results from studies on C. gigas and N. lapillus could be rejected as non-native species and results from the three larval and juvenile studies on C. gigas, M. mercenaria and O. edulis rejected for not adhering to commonly accepted guidelines for toxicant testing. In Europe, the question of environmental importance was overwhelmed by the significance of the oyster industry. Everywhere, scientists and regulators were pressured for quick results. If not, advisories might not have been lowered in both the U.K. and U.S. and TBT might not have been so severely restricted. In short, the existing regulatory process may not be appropriate for evaluating environmental effects in the low parts-per-trillion ranges. Regulatory agencies should consider holding an international review of the protocols for regulating toxicants with ng/l level effects. Perhaps GESAMP or NAS/NRC could coordinate such an effort on an international basis.

It seems that at least some of the problem in perpetuating these unresolved questions of environmental significance can be attributed to advocacy instead of science, and conducting most of the early work in virtual scientific isolation without peer review. Some of the problem can also be attributed to the regulatory process accelerating decisions using less-than-optimum scientific data with abnormally high degrees of uncertainty. This has perpetuated many interpretations of the available data, many unresolved questions of environmental significance and many overly conservative regulations. The remainder of the problem can be attributed to the uncertainty of environmental science. For TBT, this uncertainty appears much higher than acceptable, much higher than it could have been.

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REFERENCES

1. Stebbing, A. R. D. 1985. Organotins and water quality - some lessons to be learned. Mar. Poll. Bull. 16(10) 383-390.

2. Champ, M. A. and F. L. Lovenstein. 1987. TBT: The dilemma of high-technology antifouling paints. Oceanus 30(3):69-77.

3. Alzieu, C. 1986. TBT detrimental effects on oyster culture in France - Evolution since antifouling paint regulation. In: Proceedings, Oceans 1986 Conference, Washington, D. C., 23-25 Sept 1986, Organotin Symposium, Vol. 4, pp. 1130- 1134.

4. Walne, P. R. and M. M. Helm. 1979. Introduction of Crassostrea gigas into the United Kingdom. In: R. Mann (Ed.), Exotic Species in Mariculture, MIT Press, Cambridge, Massachusetts. Proceedings of a Symposium of Exotic Species in Mariculture: Case Histories of the Japanese Oyster Crassostrea gigas, Woods Hole, 1978. pp. 83-105.

5. Maurin, C. and J. LeDantec. 1979. The culture of Crassostrea gigas in France. In: R. Mann (Ed.), Exotic Species in Mariculture, MIT Press, Cambridge, Massachusetts. Proceedings of a Symposium of Exotic Species in Mariculture: Case Histories of the Japanese Oyster Crassostrea gigas, Woods Hole, 1978. pp. 106-122.

6. Popham, J. D. and J. M. D'Auria. 1983. Combined effect of body size, season, and location on trace element levels in mussels (Mytilus edulis). Archs. Envir. Contam. Toxic. 12:1-14.

7. Environmental Protection Agency. 1987. Tributyltin Technical Support Document, Position Document 2/3. Office of Pesticides Programs, Office of Pesticides and Toxic Substances, U. S. Environmental Protection Agency, October 1987.

8. Manley, A. R., L. D. Gruffydd and P. C. Almada-Villela. 1984. The effect of copper and zinc on the shell growth of Mytilus edulis measured by a laser diffraction technique. J. Mar. Biol. Assoc. U K. 64:417-427.

9. Sunila, I. and R. Lindstrom. 1985. Survival, growth and shell deformities of copper- and cadmium-exposed mussels (Mytilus edulis L.) in brackish water. Estuar. Coastal. Shelf Sci. 21:555-565.

10. Key, D. R. S. Nunny, P. E. Davidson, and M. A. Leonard. 1976. Abnormal shell growth in the Pacific oyster (Crassostrea gigas): Some preliminary results from experiments undertaken in 1975. ICES Paper CM 1976/K:11, International Council for the Exploration of the Sea, Copenhagen.

11. Waldock, M. J. and J. E. Thain. 1983. Shell thickening in Crassostrea gigas: organotin antifouling or sediment induced? Mar. Poll. Bull. 14(11):411-415.

12. Landy, R. B., S. T. Holm, W. G. Conner. 1986. Intragency workshop on aquatic monitoring and analysis for organotin compounds. NOAA/National Ocean Service National Marine Pollution Program Office, July 1986.

13. Thain, J. E. and M. J. Waldock. 1986. The impact of tributyl tin (TBT) antifouling paints on molluscan fisheries. Wat. Sci. Tech. 18:193-202.

14. Thain, J. E. 1986. Toxicity of TBT to bivalves: Effects on reproduction, growth and survival. In: Proceedings, Oceans 1986 Conference, Washington, D. C., 23-25 Sept 1986, Organotin Symposium, Vol. 4, pp. 1306-1313.

15. Mann, R. 1979. Exotic species in aquaculture. Oceanus 22(1):29-35.

16. Mann, R. 1983. The role of introduced bivalve mollusc species in mariculture. J. World Maricul. Soc. 14:546-559.

17. Wolniakowski, K. U., M. D. Stephenson and G. S. Ichikawa. 1987. Tributyltin concentrations and Pacific oyster deformations in Coos Bay, Oregon. In: Proceedings, Oceans 1987, Halifax, Nova Scotia, Canada, September 28 October 1, 1987, Organotin Symposium, Vol. 4:1438-1442.

18. Stephenson, M. D., D. R. Smith, J. Goetzl, G. Ichikawa and M. Martin. 1986. Growth abnormalities in mussels and oysters from areas with high levels of tributyltin in San Diego Bay. In: Proceedings, Oceans 1986 Conference, Washington D. C., 23-25 Sept 1986, Organotin Symposium, Vol. 4, pp. 1246-1251.

19. Smith, D. R., M. D. Stephenson, J. Goetzl, G. Ichikawa and M. Martin. 1987. The use of transplanted juvenile oysters to monitor the toxic effects of tributyltin in California waters. In: Proceedings, Oceans 1987 Conference, Halifax, Nova Scotia, Canada, 28 Sept 1 Oct 1987, Organotin Symposium. Vol. 4, pp. 1511-1516.

20. Okoshi, K., K. Mori and T. Nomura. 1987. Characteristics of shell chamber formation between the two local races in the Japanese oyster, Crassostrea gigas. Aquaculture 67:313-320.

21. Quayle, D. B. 1969. Pacific oyster culture in British Columbia. Fish. Res. Bd. Can Bull. 169. 193 pp.

22. Houlbert, C. and C. Galaine. 1916. Sur le chambrage des huitres et sur l'infection possible des chanbres par le fait d'une Annelide tubicole parasite de la coquille. Comptes Rendus Hebdomadaires des Seances de l'Academie des Sciences, Vol. 162:54-56.

23. Houlbert, C. and C. Galaine. 1916. Sur les causes du chambrage et sur l'entretien raisonne des bancs d'huitres naturels. Comptes Rendus Hebdomadaires des Seances de l'Academie des Sciences, Vol. 162:301-304.

24. Korringa, P. 1951. On the nature and function of "chalky" deposits in the shell of Ostrea edulis Linneaus. Proceedings of the California Academy of Sciences Series 4, Vol. 27(5):133-158.

25. Orton, J. H. and C. Amirthalingam. 1927. Notes on shell- depositions in oysters. J. Mar. Biol. Assoc. U. K. 14:935-953.

26. Worsnop, E. and J. H. Orton. 1923. The cause of chambering in oysters and other lamellibranchs. Nature 3(2775):14-15.

27. Zouros, E. and D. W. Foltz. 1984. Possible explanations of heterozygote deficiency in bivalve molluscs. Malacologia 25(2):583-591.

28. Fujio, Y. 1982. A correlation of heterozygosity with growth rate in the Pacific oyster, Crassostrea gigas. Tohoku J. Agri. Res. 33(2):66-75.

29. Gaffney, P. M. and T. M. Scott. 1984. Genetic heterozygosity and production traits in natural and hatchery populations of bivalves. Aquaculture 42:289-302.

30. Wilkins, N. P. 1976. Genic variability in marine bivalvia: implications and applications in molluscan mariculture. In: G. Persoone and E. Jaspers (Eds.), Proceedings, 10th European Symposium on Marine Biology, Ostend, Belgium, Sept. 17-23, 1975. Vol. 1:549-563.

31. Bryan, G. W., P. E. Gibbs, L. G. Hummerstone and G. R. Burt. 1986. The decline of the gastropod Nucella lapillus around south- west England: evidence for the effect of tributyltin from antifouling paints. J. Mar. Biol. Assoc. U. K. 66:611-640.

32. Bryan, G. W., P. E. Gibbs, G. R. Burt and L. G. Hummerstone. 1987. The effects of tributyltin (TBT) accumulation on adult dog-whelks, Nucella lapillus: long-term field and laboratory experiments. J. Mar. Biol. Assoc. U. K. 67(3):525-544.

33. Smith, B. S. 1980. The estuarine mud snail, Nassarius obsoletus: Abnormalities in the reproductive system. J. Moll. Stud. 46:247-256.

34. Smith, B. S. 1981. Reproductive anomalies in Stenoglossan snails related to pollution from marinas. J. Applied Toxic. 1(1):15-21.

35. Smith, B. S. 1981. Male characteristics on female mud snails caused by antifouling bottom paints. J. Applied Toxic. 1(1):22-25.

36. Smith, B. S. 1981. Tributyltin compounds induce male characteristics on female mud snails Nassarius obsoletus = Ilyanassa obsoleta. J. Applied Toxic. 1(3):141-144.

37. Grant, W. S. and F. M. Utter. 1988. Genetic heterogeneity on different geographic scales in Nucella lamellosa (Prosobranchia, Thaididae). Malacologia 28(1-2):275-287.

38. Dickie, L. M., P.R. Boudreau and K. R. Freeman. 1984. Influences of stock and site on growth and mortality in the blue mussel (Mytilus edulis). Can. J. Fish. Aquat. Sci. 41:134-140.

39. Mallet, A. L. and L. E. Haley. 1983. Growth rate and survival in pure population matings and crosses of the oyster Crassostrea virginica. Can. J. Fish. Aquat. Sci. 40:948-954.

40. Lannan, J. E. 1980. Broodstock management of Crassostrea gigas. I. Genetic and environmental variation in survival in the larval rearing system. Aquaculture 21:323-336.

41. Newkirk, G. F. and L. E. Haley. 1983. Selection for growth rate in the European oyster, Ostrea edulis: response of second generation groups. Aquaculture 33:149-155.

42. Salazar, M. H. 1986. Environmental significance and interpretation of organotin bioassays. In: Proceedings, Oceans 1986 Conference, Washington D. C., 23-25 Sept 1986, Organotin Symposium, Vol. 4, pp. 1240-1245.

43. Carpenter, J. H. and R. J. Huggett. 1984. Meaningful chemical measurements in the marine environment transition metals. In: H. H. White (Ed.), Concepts in Marine Pollution Measurements. Maryland Sea Grant Publication, University of Maryland, College Park, pp. 379-403.

44. Environmental Protection Agency. 1987. Ambient aquatic life water quality advisories for tributyltin. U. S. Environmental Protection Agency, Office of Research and Development, Environmental Research Laboratories, Duluth, Minnesota, Narragansett, Rhode Island.

45. United States Naval Sea Systems Command. 1984. Environmental Assessment for Fleetwide use of organotin antifouling paint. U. S. Navy, Code 56YP, Washington D. C.

46. White, H. H. and M. A. Champ. 1983. The great bioassay hoax, and alternatives. In: R. A. Conway and W. P. Gulledge (Eds.), Hazardous and Industrial Solid Waste Testing: Second Symposium. ASTM STP 805. American Society for Testing and Materials. pp. 299-312.

47. Cunningham, P. A. 1979. The use of bivalve molluscs in heavy metal pollution research. In: W. B. Vernberg, A. Calabrese, F. P. Thurberg, F. J. Vernberg (Eds.), Marine Pollution: Functional Responses. Academic Press, New York, pp. 183-221.

48. Laughlin, R. B., Jr., W. French and H. E. Guard. 1986. Accumulation of bis(tributyltin) oxide by the marine mussel Mytilus edulis. Environ. Sci. Tech. 20:884-890.

49. Yamada, J., K. Tatsuguchi and T. Watanabe. 1978. Uptake of tripropyltin chloride by Escherichia coli. Agric. Biol. Chem. 42:1867-1870.

50. Blair, W. R., G. J. Olson, F. E. Brinckman and W. P. Iverson. 1982. Accumulation and fate of tri-n-butyltin cation in estuarine bacteria. Microb. Ecol. 8:241-251.

51. Dooley, C. A. and V. Homer. 1983. Organotin compounds in the marine environment: Uptake and sorption behavior. Naval Ocean Systems Center Technical Report #917.

52. Springborn Bionomics, Inc. 1984. Chronic toxicity of tributyltin fluoride to the Pacific oyster (Crassostrea gigas Thunberg). Report Number BP-84-8-66, Project Number 1462.8000, Springborn Bionomics, Inc., Pensacola, Florida, August 1984.

53. Bayne, B. L. and R. J. Thompson. 1970. Some physiological consequences of keeping Mytilus edulis in the laboratory. Helgo. Meeres. 20:526-552.

54. Bayne, B. L., P. A. Gabbott and J. Widdows. 1975. Some effects of stress in the adult on the eggs and larvae of Mytilus edulis L. J. Mar. Biol. Assoc. U. K. 55:675-689.

55. Bayne, B. L., D. L. Holland, M. N. Moore, D. M. Lowe and J. Widdows. 1978. Further studies on the effects of stress in the adult on the eggs of Mytilus edulis. J. Mar. Biol. Assoc. U. K. 58:825-841.

56. Thain, J. E. and M. J. Waldock. 1985. The growth of bivalve spat exposed to organotin leachates from antifouling paints. ICES Paper CM 1985/E:28, International Council for the Exploration of the Sea, Copenhagen.

57. Laughlin, R. B., Jr., P. Pendoley and R. G. Gustafson. 1987. Sublethal effects of tributyltin on the hard shell clam, Mercenaria mercenaria. In: Proceedings, Oceans 1987 Conference, Halifax, Nova Scotia, Canada, 28 Sept 1 Oct 1987, Organotin Symposium, Vol. 4, pp. 1494-1498.

58. Valkirs, A. O., P. F. Seligman, and R. F. Lee. 1986. Butyltin partitioning in marine waters and sediments. In: Proceedings, Oceans 1986 Conference, Washington D. C., 23-25 Sept 1986, Organotin Symposium, Vol. 4, pp. 1165-1170.

59. Waldock, M. J., J. E. Thain and M. E. Waite. 1987. The distribution and potential toxic effects of TBT in UK estuaries during 1986. Appl. Organomet. Chem. 1:287-301.

60. Salazar, M. H. and S. M. Salazar. 1988. Tributyltin and mussel growth in San Diego Bay. Proceedings, Oceans '88, This Conference.

61. Phillips, D. J. H. 1980. Qualitative Aquatic Biological Indicators. Applied Science Publishers, Ltd., London. 488 pp.

62. George, S. G. and T. L. Coombs. 1977. The effects of chelating agents on the uptake and accumulation of cadmium by Mytilus edulis. Mar. Biol. 39:261-268.

63. Harrison, F. L. 1979. Effect of the physicochemical form of trace metals on their accumulation by bivalve molluscs. Am. Chem. Soc., Symp. Ser. 93:611-634.

64. Luoma, S. N. 1983. Bioavailability of trace metals to aquatic organisms a review. Science Tot. Environ. 28:1-22.

65. Martincic, D., H. W. Nurnberg and M. Branica. 1986. Bioaccumulation of heavy metals by bivalves from Limski Kanal (North Adriatic Sea). II. Copper distribution between oysters, Ostrea edulis, and ambient water. Mar. Chem. 18:299-319.

66. Thain, J. E., M. J. Waldock and M. E. Waite. 1987. Toxicity and degradation studies of tributyltin (TBT) and dibutyltin (DBT) in the aquatic environment. In: Proceedings, Oceans 1987 Conference, Halifax, Nova Scotia, Canada, 28 Sept - 1 Oct 1987, Organotin Symposium, Vol. 4, pp. 1398- 1402.

67. Waldock, M. J. 1986. TBT in UK estuaries, 1982-86. Evaluation of the environmental problem. In: Proceedings, Oceans 1986 Conference, Washington, D. C., 23-25 Sept 1986, Organotin Symposium, Vol. 4, pp. 1324-1330.

68. Davies, I. M., J. C. McKie and J. D. Paul. 1986. Accumulation of tin and tributyltin from anti-fouling paint by cultivated scallops (Pecten maximus) and Pacific oysters (Crassostrea gigas). Aquaculture 55(2):103-114.

69. Thain, J. E., M. J. Waldock and M. Helm. 1986. The effect of tri-butyl-tin on the reproduction of the oyster Ostrea edulis. ICES Paper CM 1986/E:14, International Council for the Exploration of the Sea, Copenhagen.

70. Salazar, M. H. and S. M. Salazar. 1987. TBT effects on juvenile mussel growth. In: Proceedings, Oceans 1987 Conference, Halifax, Nova Scotia, Canada, 28 Sept 1 Oct 1987, Organotin Symposium. Vol. 4 pp. 1504-1510.

71. Kiorboe, T. F. Mohlenberg and O. Nohr. 1981. Effect of suspended bottom material on growth and energetics in Mytilus edulis. Mar. Biol. 61:283-288.

72. Salazar, M. H. and S. M. Salazar. 1985. The effects of sediment on the survival of mysids exposed to organotins. Proceedings, 11th U.S. - Japan Experts Meeting on Management of Sediments Containing Toxic Substances, November 4-6, 1985, Seattle, Washington. pp. 176-192.

73. Henderson, R. S. 1985. Effects of tributyltin antifouling paint leachates on Pearl Harbor organisms. Naval Ocean Systems Center Technical Report #1079.

74. Clavell, C., P. F. Seligman, P. M. Stang. 1986. Automated analysis of organotin compounds: a method for monitoring butyltins in the marine environment. In: Proceedings, Oceans 1986 Conference, Washington D. C., 23-25 Sept 1986, Organotin Symposium, Vol. 4, pp. 1152-1154.

75. Seligman, P. F., A. O. Valkirs and R. F. Lee. 1986. Degradation of tributyltin in marine and estuarine waters. In: Proceedings, Oceans 1986 Conference, Washington D. C., 23-25 Sept 1986, Organotin Symposium, Vol. 4, pp. 1189-1195.

REDUCING PLASTIC POLLUTION IN THE MARINE ENVIRONMENT: THE U.S. COAST GUARD AND IMPLEMENTATION OF ANNEX V OF MARPOL 73/78

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ABSTRACT

This paper explores the U.S. Coast Guard's efforts to reduce ocean pollution by plastics and other ship-generated refuse. Implementation of Annex V of the International Convention for the Prevention of Pollution by Ships, 1973 (MARPOL 73/78) will outlaw dumping of plastics at sea from vessels of signatory nations. It will also severely restrict vessels from discharging other types of garbage at sea and will require nations which are party to the Convention to provide adequate reception facilities for ships' refuse. This paper discusses the problems caused by ship-generated garbage and traces the Coast Guard's role in reducing marine pollution through MARPOL 73/78 and particularly through Annex V.

I. THE COAST GUARD AND MARINE ENVIRONMENTAL PROTECTION

Marine environmental protection is a relatively new mission in the almost two hundred year history of the U.S. Coast Guard. Yet this new task is closely aligned to other Coast Guard mission areas, for preservation of the marine environment assures continuity of the very medium on which all mariners rely. It was not until after World War II, when the Coast Guard inherited the duties of the Bureau of Marine Inspection and Navigation, did it begin to enforce a panoply of arcane marine pollution laws. Among these were the Refuse Act of 1899 and the Oil Pollution Acts of 1924 and 1961. These laws were almost impossible to enforce: either they authorized only meager fines which did not deter violators or they were filled with loopholes. By the late 1960's, worldwide attention was fixed on the need for effective marine pollution controls after events such as the catastrophic oil spill following the grounding of the tankship *Torrey Canyon*. The growing importance of marine environmental protection within the Coast Guard was formally recognized in 1971 with the creation of the Office of Marine Environment and Systems.

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II. MARPOL 73/78: THE INTERNATIONAL FRAMEWORK

The *Torrey Canyon* disaster, along with several other major environmental debacles, convinced the Coast Guard leadership that an enforceable international maritime pollution treaty was essential to protect our coastal resources. The U.S. Coast Guard firmly believed that an international approach was required, because domestic law could not effectively control the great number of foreign flag ships after they left U.S. ports and ventured into our coastal waters. By the early 1970's, almost 95% of petroleum products entering the United States were transported in foreign bottoms. Domestic political pressures, combined with a growing awareness on the part of the European shipping nations, finally led to acceptance of the International Convention for the Prevention of Pollution by Ships, 1973 (also known as MARPOL, for Marine Pollution).

Although the 1973 Convention was a watershed event in international maritime cooperation, the United States believed the 1973 Convention's ship construction standards were too lax. Many other maritime nations agreed: by 1976, only three others had accepted the 1973 Convention. The Coast Guard's vision of a strong and effective international convention seemed far from reality until a series of fifteen major marine disasters struck within a three month period. In December 1976, the tanker *Argo Merchant* foundered off the coast of Massachusetts and threatened the abundant George's Bank fishing grounds. Only two days later, the *Torrey Canyon's* sister ship, *Sansinena,* exploded at her berth in Los Angeles. These domestic tragedies prompted the U.S government to threaten unilateral enforcement of strict safety standards on all ships entering U.S. waters. Faced with this threat, the maritime nations of the world agreed to convene an international Conference on Tanker Safety and Pollution Prevention in London in October 1977. The resulting agreement, which the United States ratified, was the Protocol of 1978 and it amended the 1973 Convention. MARPOL 73/78 was born.

MARPOL 73/78 addresses the problem of operational pollution from ships on a global scale and consists of five Annexes, each of which is designed to combat a specific type of marine pollution. Annexes I and II address shipboard pollution by oil and noxious liquid substances (bulk liquid chemicals) and were the first to be enforced internationally. Annexes III, IV and V are optional to Party states, and address ship-generated pollution by packaged hazardous materials, sewage and garbage. By terms of the Convention, these annexes only enter into force one year from the date on which at least fifteen nations (which must cumulatively represent fifty per cent of world shipping tonnage) have ratified them.

As an international legal instrument, MARPOL 73/78 is acknowledged as being very successful. Unlike its ineffective predecessors, MARPOL took into account the economics of international shipping. The Convention had some unusual, yet effective, terms for signatory

nations. Nations which ratified the Convention agreed to enforce its provisions on all ships which entered their waters. This removed any economic advantage to those shipping nations which failed to ratify the Convention and discouraged them from switching to flags of convenience to avoid compliance. MARPOL 73/78 also required Party states to ensure that shoreside reception facilities for certain MARPOL pollutants were available at ports and terminals. This assured ship operators that there would be a site to dispose of these wastes once the ship arrived in port and also served as an incentive for compliance.

Through the late 1970's, technical experts from the Coast Guard led U.S. delegations to the Marine Environmental Protection Committee of the International Maritime Organization in London. At this specialized body of the United Nations, the U.S. Coast Guard negotiated the ship construction standards and other technical details for the MARPOL annexes. In 1980, after these details had been agreed upon internationally, the United States government formally enacted MARPOL 73/78 into domestic law with passage of the "Act to Prevent Pollution from Ships, 1980" (33 U.S.C. 1901 et seq.). By 1987, Annexes I and II were in force internationally and had significantly reduced pollution by ships from oil and bulk liquid chemicals. With the first two Annexes of MARPOL 73/78 in place, the stage was set for implementing Annex V, which targeted operational pollution of the oceans by plastics and other ship-generated refuse.

III. PLASTICS: ENVIRONMENTAL AND ECONOMIC IMPACTS

As early as the 1973 Convention, it was recognized that garbage from ships, especially plastics and synthetic fishing nets, posed a multitude of problems. The unregulated dumping of plastics at sea menaced marine life, was a safety hazard to mariners and was an affront to our aesthetic values. Although the disposal of ship-generated garbage at sea has been the norm for commercial and military vessels for millennia, this practice has had severe environmental and economic effects. A 1975 study by the National Academy of Sciences indicated that 6.4 million metric tons of refuse were discharged annually into the oceans from commercial merchant ships, naval vessels, fishing vessels, oil rigs and offshore platforms. About one million metric tons of this was estimated to be plastic debris. Over fourteen million U.S recreational boats also compound the problem by depositing garbage into the inland waters of the United States. The accumulation of plastics in the marine environment is also exacerbated by their persistency: non-biodegradable plastic "six-pack" beverage yokes are believed to have a life at sea of several hundred years.

The central environmental concerns surrounding the discharge of plastics at sea are entanglement and ingestion. Entanglement by various marine species in synthetic fishing nets and monofilament fishing lines severely reduces

their mobility to avoid predators and inhibits their ability to feed. Juvenile sea creatures can become entangled in small packing bands or six-pack beverage yokes, which constrict as they grow, resulting in strangulation, infected lesions or starvation. Likewise, ingestion of persistent debris is a serious problem for all types of marine life. Turtles often ingest plastic sheeting materials and bags mistaking them for jellyfish, one of their favorite delicacies. Birds ingest small plastic resin pellets which block digestive tracts, impair the absorption of nutrients and can cause bacterial infections. When plastics are continually ingested, the eventual outcome is often death.

While data detailing the effects of persistent marine debris are becoming more available for certain species, the aggregate effect of plastics on marine life is not fully understood. Populations of the Northern Fur Seal on the Pribilof Islands and the Hawaiian Monk Seal have precipitously declined during the same timeframe in which the use of synthetic fishing nets became prevalent. Many scientists feel confident that the ubiquity of plastics in the marine environment is directly related to these and other unexplained population declines.

Ship-generated garbage also causes adverse economic effects through the depletion of fishery resources, vessel damage and degradation of our beaches. One of the most expensive economic impacts is on the commercial fishing industry, both in terms of the loss of fishing gear and the depletion of fishery stocks. Fishermen have reported substantial losses of fishing gear and have attributed these to fouling hooks and lines on discarded or lost gill nets. According to one small passenger boat operator association in New England, approximately $50,000 worth of hooks, synthetic lines and lures and one million dollars in operating expenses are lost every year in dealing with monofilament gill nets in the Gulf of Maine alone. Lost fishing nets and traps are also believed to deplete stocks of commercially valuable species of fish, lobster and crabs. Recent research indicates that abandoned or lost gillnets remaining in the ocean can continue to entangle fish for months, indiscriminately killing fish and other economically significant marine life.

The impact of persistent marine debris on the economies of coastal communities is also noteworthy. The Padre Island National Seashore Park in Texas spends over $10,000 annually on beach cleaning efforts, primarily concentrating on a one half-mile stretch of beach frequented by the public. The beaches of Long Island, New York were closed to swimming in June 1976, as were many beaches between Virginia and Massachusetts in the summers of 1987 and 1988, when unusual amounts of floating debris washed ashore. The total economic impact on the tourist industry (including loss of revenues to restaurants, pier fishing, bait and tackle shops and in reduction of beach attendance) has been estimated in the hundreds of millions of dollars annually.

IV. POLITICAL PRESSURES AND A SOLUTION: ANNEX V OF MARPOL 73/78

While environmental groups had been pressing the federal government for a legislative answer to the hazards of entanglement and ingestion of plastics, researchers around the world convened at the 1984 "Workshop on the Fate and Impact of Marine Debris." They presented research which confirmed the damage being done to the marine environment and identified new areas for future research.

Within the United States, economic concerns prompted several powerful states to join in the call for legislative action. Texas, New Jersey, and other coastal states were fearful at the prospect of declining tourist revenues because of unprecedented accumulations of beach litter. By the spring of 1987, over thirty U.S. Senators were so aroused that they wrote to the President of the United States outlining the severity of the marine debris problem and asked him to take action. A federal Interagency Task Force on Persistent Marine Debris was directed to study the dilemma and to report back to the President's Domestic Policy Council. Shortly afterwards, Congressman Studds of Massachusetts introduced legislation to prevent plastics from being discharged into the ocean. Rear Admiral J. William Kime, Chief of the Coast Guard's Office of Marine Safety, Security and Environmental Protection, strongly supported the legislation. He convinced Studds and other lawmakers that the only hope of an effective solution to this problem was through an international agreement, and that Annex V of MARPOL 73/78 was the best mechanism to accomplish this. Kime testified before Congress several times over the summer and fall of 1987. He persuaded them to apply the discharge prohibitions of Annex V to the internal waters of the U.S. as well, thus providing an effective enforcement tool to replace the Refuse Act of 1899. The U.S. Senate gave its advise and consent to ratify Annex V in November 1987 and President Reagan signed the "Marine Plastic Pollution Research and Control Act of 1987" into law on December 29, 1987. With U.S. ratification of Annex V, the Convention's entry into force requirements were fulfilled, and as a consequence, Annex V would be in effect throughout the world on December 31, 1988.

V. ANNEX V OF MARPOL 73/78

Annex V of MARPOL 73/78 is designed to reduce the introduction of ship-generated garbage into the marine environment. It particularly aims at preventing the discharge of plastics, including synthetic fishing nets, into the marine environment.

Annex V has three mandates. First, it prohibits discharge of any plastic materials at sea by ships. Second, it limits the locations at sea where other types of non-plastic garbage can be discharged. The Annex accomplishes this by setting minimum distances from land where certain types of garbage can be discharged. For instance, large floatable items such as dunnage, packing and lining materials may only be

discharged outside twenty-five miles from land. Similarly, other refuse, such as crockery, food wastes, paper products, and bottles may only be discharged outside twelve miles from land, unless they have been "comminuted" or ground so that they can pass through a mesh screen with openings no greater than twenty-five millimeters (about one inch). In this case, they may be discharged outside three miles from nearest land. Strict limitations are also imposed on oil rigs and platforms: they can only discharge food wastes when outside twelve miles from nearest land. "Special Areas" are also established in which only comminuted food wastes may be discharged outside of twelve miles. Special Areas are waters which must receive extra attention because of peculiar oceanographic conditions or because of their present polluted state. There are now five Special Areas under Annex V: the Mediterranean Sea, Black Sea, Baltic Sea, Persian Gulf and Red Sea. Because of the vast amount of ship and oil industry related garbage accumulating in the Gulf of Mexico, the United States Coast Guard is considering the designation of the Gulf as a new Special Area.

Finally, the Annex requires that party nations ensure that ports and terminals provide reception facilities for ships' garbage, so that plastics and other garbage can be brought ashore and that ships will not be delayed in ports. As provided by the Act to Prevent Pollution from Ships, the U.S. Coast Guard is empowered to deny entry to a ship if the port or terminal it is bound for does not provide the required reception facilities.

VI. THE FUTURE

Just as the oil pollution prevention laws of the early 1970's enforced a radical change with past practice, so will implementation of Annex V of MARPOL 73/78. Effective implementation of the Annex will take several years before measurable results can be detected and will require the cooperative efforts of government, mariners, private citizens, port and terminal operators and shipping related industries.

Moreover, significant efforts will have to be undertaken in the areas of shipboard engineering, enforcement and education. Ships undergoing construction and some existing ships will have to be fitted with compactors, incinerators, grinders or other equipment to enable them to meet the discharge requirements of Annex V. Cooperative enforcement mechanisms must also
be put into place which can make the most effective use of the combined resources of various federal, state and local law enforcement agencies.

Finally, a series of educational campaigns must be targeted at commercial fishermen, merchant seamen and recreational boaters. The concern and strong sense of partnership displayed to date by a multitude of marine interests strongly suggest that solving this serious environmental dilemma can become a reality in the near future.

THE PRODUCTION OF MENHADEN SURIMI

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INTRODUCTION

The world's catch of fish and shellfish reached 92.2 million metric tons (mmt) in 1986 with about 30% or 28 mmt processed into fish meal and oil.

Non-traditional sources of low cost high quality fish protein are needed to meet both the consumer and institutional markets worldwide. There is strong commercial interest in many countries to use industrial fish and under-utilized species for human consumption. Part of the basis for this interest is a growing movement world-wide, especially in developing countries, to limit the amount of fish that can be used in the production of fish meal and oil even though, at the present time, few commercially viable products for human consumption can be made from them. And finally, new uses for these under-utilized species may be vital to survival of the fish meal industry. The value of fish meal is in direct relationship to soybean prices. Wide fluctuations in the price of commodities over the last few years has led to financial problems in the industry. In fact, because of low prices, several countries now burn as much as 40% of their fish oil as fuel.

THE MENHADEN FISHERY

Various species of fish, found along the Atlantic, Gulf and Pacific Northwest/ Alaskan coasts of the U.S. may be used as raw material for surimi. Alaskan pollock has been the major resource used for surimi by the Japanese because of its abundance, low price and physical properties. Gulf croaker, Atlantic and Gulf menhaden, Atlantic mackerel, Pacific whiting and red hake are among other species which offer possibilities. Of all of these, menhaden representing around 40% of the total U.S. landings offers not only unique possibilities for further development but also some major challenges to its utilization as food.

Commercial landings by U.S. fishermen at ports in the 50 states were 3.1 mmt in 1987. This was composed of 1.8 mmt of edible fish and shellfish and 1.3 mmt of fish for reduction to meal and oil. Menhaden represented 92% (1.2 mmt) of the fish used for reduction. An 8 year history of the U.S. menhaden catch appears in Table 1.

Menhaden are small, oily, herring-like fish similar in appearance to the alewife and shad. They are dark blue to brown in color with silver along the sides. They are distinguished from other fish of the herring family by the presence of a dark shoulder spot on both sides of the body. Menhaden are migratory fish. They appear in dense schools in the open waters of large bays and along the shores of the Atlantic and Gulf coasts of the U.S. The menhaden are pelagic and feed primarily on plankton which they convert to

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energy and store as fat.

DEMONSTRATION PLANT

During what has been described as the Age of Engineered Seafoods, 1975-1986, U.S. imports of surimi products rose from 5.9 to over 100 million pounds. The period 1985 to 1987 has seen a slower increase in consumption of these surimi based analogs, but now we are beginning to see interest from other segments of the food industry. Table 2 shows the phenomenal growth in the consumption of surimi products in the U.S. for the period 1975-1987. The period since 1985 is now being described as the Age of Engineered Foods. With the continued promotion of the health benefits of seafood, research is currently underway to engineer new food concepts produced from basic building blocks. Interest in omega 3 fatty acids and surimi from red fleshed, oily species as a possible source of these fatty acids has sparked new interest from the red meat industry as well. Table 3 shows the unique omega 3 fatty acid composition of both a high fat and low fat surimi produced from Atlantic menhaden.

And so economic stresses on the menhaden fishing industry, increased market demands for traditional food fish and emphasis on full utilization of our fishery resources have directed attention to the higher value utilization of the menhaden resource. With the possibility for new market opportunities for surimi and fish mince, counterbalanced by the unique challenges associated with red fleshed species, the U.S. menhaden industry requested technical assistance from both academic and government groups.

In response, the Congress of the U.S. designated increased FY1985 funding for menhaden research and development in the conversion of whole menhaden into surimi and minced forms. The NMFS in cooperation with industry was directed to use the funds to achieve the following objectives: 1. determine the economic and technical feasibility of producing menhaden surimi, 2. produce developmental quantities of test menhaden surimi material for formulation and evaluation of end products by public and private sector food scientists and, 3. determine onboard and inplant procedures necessary to convert menhaden to human food products.

On February 20, 1986, Zapata Haynie Corp., the largest processor of menhaden in the U.S., signed a contract with the National Marine Fisheries Service (NMFS) to conduct a two-year, $2 million pilot project designed to determine the most efficient way of making surimi from menhaden. Under the terms of the contract, the NMFS provided $1.4 million, with Zapata Haynie providing the additional $600,000. Since that time, Zapata Haynie's contribution has increased well beyond that initial committment. Although the original contract ended in February, 1988, an extension was arranged to permit continuation of the project during the 1988 fishing season and further evaluate improvements involving harvesting and process optimization.

CONTRACT

Under the terms of the contract, each party has specific responsibilites:

Zapata Haynie must provide:

1. An appropriate physical site, 2. An appropriate food grade building, 3. Refrigerated holding facilities, 4. A plate freezer, 5. Frozen storage facilities, 6. Utilities, 7. Fresh food grade menhaden, 8. Disposal of all processing wastes.

U.S. Government Funds Are Used For:

1. Purchasing, installing and maintaining fish handling and processing equipment, 2. Plant operating expenses, 3. Collection of data, 4. Storage and distribution of test products, 5. Preparation of reports, 6. Public access/technology transfer, 7. Overhead costs.

The contract calls for a plant capable of producing at least 1 ton of finished surimi per 8 hour day. The contract spells out the steps needed to produce surimi, however it recognizes that the processing requirements to make a quality surimi from menhaden are not well defined and calls for a plant design that includes sufficient flexibility to allow the evaluation of a number of different processing options through experimental runs. It was expected that the processing options would lead to an alternate method of producing surimi from menhaden.

Based on contract requirements, Zapata Haynie initially set up the traditional Japanese surimi production process as the baseline method for producing surimi from menhaden, this process is outlined in Figure 1. The steps involve removal of the head, tail and viscera followed by removal of the skin and large bones. The meat fraction is then washed 3 times until the majority of the fat and water soluble proteins are removed. Finally, the meat is refined through a 1 mm screen to remove fine pin bones, scales and some of the dark meat. The refined meat is then pressed to obtain the desired moisture content and finally mixed with cryoprotectants before freezing. Waste is generated at almost every step of the process. A fish meal plant or some process for treatment of the solid and liquid waste is essential to the success of such a plant.

The plant was designed with enough flexibility to allow design changes for improvement of the product and process through a series of experimental runs. These runs were designed to determine the technical feasibility of the processing options, provide data on preliminary cost estimates and provide products and by-products for evaluation. Product quality and yields were major factors for the development of operating procedures for subsequent production runs.

OVERVIEW OF THE PROCESS WITH MENHADEN

The surimi process is essentially a series of processing steps designed to isolate the undenatured muscle protein of the fish from the other components of the flesh. How well these steps perform and at what cost in yield will determine the eventual economic and technical feasibility of producing surimi from red fleshed species such as menhaden.

In general terms, protein will increase as we proceed through the process as more non-protein wastes are removed, but will drop in the surimi block because of the addition of 8% cryoprotectants, which appear as carbohydrate material.

The fat drops as we proceed through the process eventually leveling off at 0.5-1.0% in the final surimi block.

In addition to the isolation of muscle protein, the process removes pigment, blood, and some dark flesh. Color is measured on the Hunter Scale. The L value stands for lightness (white-black), A for redness (red-green), and B for yellowness (yellow-blue). The raw mince is very red, and the process tends to increase the lightness (L value) and decrease the red color (A value), but so far we have had very little effect on the yellow color (B value). In fact over several hundred observations, the B value (yellowness) has deviated very little regardless of process changes. Yellowness may be species specific.

Because of large variations in fish size we experienced wide fluctuations in yield, in spite of on line fillet machine adjustments. Fish sorting before filleting should improve yield significantly. Yields can also be affected both positively and negatively by process equipment changes.

During the first year, the technical program of experimental work was broken down into two major tasks.

TASK I: HARVESTING AND PRE-PROCESS HANDLING.

Bulk handling methods for food grade menhaden were developed. Menhaden vessels with some modifications were utilized. In addition to the menhaden vessels, arrangements were made with local trap net fishermen so that an alternate source of locally caught menhaden were available. In most instances, these fish are less than 6 hours old. Alternate methods of harvest included the small local snapper rigs or single vessel purse seiners. These normally fish in shallow waters and are available as an alternate source of fish. Since these vessels do not have refrigeration systems, chilled sea water and slush ice systems were tested.

Since the plant is set back away from the water, fish were unloaded into insulated containers and trucked to the surimi plant. After delivery, the fish containers were drained, refilled with fresh refrigerated water and held in the plant's refrigerated storage facility. A major question was how long menhaden could be held in refrigerated water on shore without adversely affecting the surimi quality.

Results from the 1987 fishing season indicated that in order for fish quality to be acceptable for next day processing to surimi : 1. chilling must begin immediately after harvest and bring the fish temperature down to 50°F. within 4 hours 2. chilling must then continue to approximately 34°F. and held and 3. if the initial chilling takes longer than 4 hours, then the fish will appear good but will be unacceptable for surimi within 12 hours.

TASK II. PROCESSING

Processing covers the range from sorting through final storage of the finished surimi.

CUTTING PROCESS

Cutting is the first major processing step in the production of surimi. The cutting step is critical to the process, since it has a lasting effect on the economics of the overall process. Edible meat lost in this step cannot be recovered as surimi at the end of the process. Three different types of cuts were evaluated; heading and gutting, filleting, and scalping (lateral cut along the top of the backbone). In each case, cutting was done with commercial equipment, except that in the case of the scalp cut, it was done manually. The scalp cut simulated separation of red and white meat and should be a good predictor of what skinning might do. Table 4 shows the composition of red and white meat from 3 different batches of fish. Fat is significantly higher in the red meat while moisture is lower. We made several runs of scalped fish. Results indicated that a significant improvement in the Hunter A and B values could be obtained if we could mechanically separate white and dark meat. It was not possible to obtain a good headed and gutted fish with our cutting machine, so this option was dropped.

MINCING

The mincing process (deboning) is designed to separate fish flesh from bones, skin and scales. Different sized screens in the deboner and different belt tensions have an effect on yield and quality of the mince. Different cuts of fish will behave differently in the deboner, and will also give different yields depending upon cut and screen size.

Our Bibun deboner is equipped with a 5 mm screen. We looked at several variations in the mincing operation. With a lighter belt tension color improved slightly, protein and fat were significantly improved but unfortunately, surimi yields were significantly lower. And while orienting the fillet meat side down lowered the A and B values, it also lowered the L value. With the plant configuration, orienting the fillet meat side down was not possible however this could be done under full scale commercial conditions.

WASHING

Washing of the mince is another critical step in the production of surimi. Washing removes water soluble proteins and other undesireable constituents from the mince.

The initial process called for a batch wash system: 3 cycles, 5 to 1 ratio water to fish with a dewatering screen at the end. We looked at ratios of 3, 5 and 10 to 1 and 4 wash steps at a 3 to 1 ratio. There was very little change in color between 5:1 and 10:1 but both were improved over the 3:1 ratio. Four batch wash steps at 3:1 were similar to 3 steps at a 5:1 ratio.

In late July 1987 we began evaluating the Alfa Laval inline wash system. This consists of a pump, a variable length of stainless steel pipe made up into loops with inline static mixers, and an Alfa Laval NX 414 decanter. Deboned, refined, unwashed mince is mixed with water and pumped through the wash loops to the decanter where the water and solids are separated. The wet solids are then pressed before mixing with cryoprotectants. While there doesn't appear to be much of an improvement in the quality of the surimi, yields are improved, water usage is cut and there is a definite savings in labor.

REFINING

Zapata Haynie decided on a refining step instead of the traditional straining step for removal of pin bones, scales, dark meat and skin particles. The refiner handles wet meat, so less heat is generated and bench scale research at North Carolina State Univ. indicated that it might be possible to separate red meat from white meat.

We evaluated several different machines as refiners. The Bibun refiner was difficult to control, required additional water and did not have sufficient capacity to meet the plant's needs. We evaluated a Beehive, Yield Master and a strainer as substitutes for the Bibun. The Beehive gave the best combination of results, had a greater capacity and could handle a dryer product. We also looked at placement of the refiner in the process either before or after the wash cycle and found that before the wash cycle gave the best operational results. At this point, pin bones and scales were completely removed and this helped with the rest of the process. We were not successful in separating red meat from white meat in the refiner.

DEHYDRATION OR PRESSING

Since the purpose of the dehydration step is to remove water and maintain a product at 75-80% moisture, dehydration studies consisted of achieving this moisture level under the various test conditions.

We also evaluated single and double pressing. There was very little difference in product color between the two methods however double pressing did improve protein and lower fat.

MIXING

In addition to the normal addition of cryoprotectants i.e. sugar, sorbitol and sodium tripolyphosphate, we evaluated different levels and types of cryoprotectants.

Because of the unique challenges that are associated with surimi from menhaden, Zapata formed a technical advisory committee consisting of researchers from several universities, government and industry technical staff, as well as Zapata technical staff. This committee has, among other things, advised the surimi plant on experiments, test runs and needed data. In addition, several of the members of this committee have supplemental research grants designed to complement the data generated by the surimi

plant. These efforts show a unique cooperation between private industry, the Federal Government, the Sea Grant College Program and the Fisheries Development Foundations.

1986 AND 1987 FISHING SEASONS

Plant construction was completed on October 6, 1986. A full scale production run was made on November 19, 1986. The run demonstrated the 1 ton per day capacity of the plant, as defined in the contract. The 1986 fishing season ended on November 21. The 1986 winter work was done with frozen fillets and provided us with the opportunity to test the technical structure of the program as well as the operation of the various pieces of equipment.

Production in the plant actually began in May 1987. A series of bench scale experiments defined the initial benchmark for menhaden surimi. In early June 1987 we made our first series of extended production runs. These were followed by a series of experimental runs to determine the optimum operating parameters for deboning as well as washing.

We also experimented with skinning machines during 1987 but were unable to find a satisfactory machine for handling the menhaden. Since separation of the red meat will be critical to producing a lighter colored, lower fat product, we continue to explore this type of equipment.

The project progressed rapidly during the 1987 fishing season but as with most projects of this type, it raised many questions which formed the experimental basis for the 1988 fishing season.

1. A modified process utilizing the in-line wash system with pre-refining although defined still must demonstrate a product of consistent quality over the wide range of fish composition available during the season. A series of continuous production runs are needed.

2. Based on these runs a set of possible specifications must be developed for menhaden surimi. These specifications must be reproducible in the plant.

3. Fat in surimi can either be an advantage or disadvantage. If the block can be stabilized then menhaden surimi will be able to offer not only funtionality but also a source of omega-3 fatty acids.

4. If the residual fat in the surimi presents stability problems, then additional research will be needed to release the fat from the meat since it appears to be bound to the proteins.

5. The relationship of the 3 color values for surimi must be evaluated. Higher L values seem to be associated with higher A and B values. Skinning may offer a solution to this problem.

6. Finally, the yield must be optimized without adversely affecting quality.

1988 FISHING SEASON

Based on the 1987 experimental results a modified process for the production of surimi from menhaden was developed. A flow diagram of this new modified process appears in Figure 2.

The 1988 fishing season began in May of this year. A number of modifications were made in the plant to improve fish handling and processing.

On the harvesting side, we have modified a menhaden vessel to deliver food grade Atlantic menhaden to the surimi plant. The surimi plant has been modified to handle the bulk unloading of menhaden from the vessels directly into 5500 gallon stainless steel insulated tankwagons. These vehicles are then used to transport the fish in slush ice to the plant and to act as storage containers for supplying fish to the plant. The tank wagons are loaded from the vessel and unloaded at the plant with wet fish pumps. The pumps operate on a pulsed cycle, vacuum unloading the fish in a mass of water to a sealed tank and then pumping the fish and water under pressure to the tankwagon. The fish enter the plant pass over a dewatering screen and onto a weigh belt.

The only other modifications to the original process was the inline washing with a pre-refining step. The only mechanical sorter available for trial was a Patco 3500. It separated fish according to body thickness at the widest point, just behind the gills. While a favorable correlation exists between fish size and this cross dimension, the machine was not capable of handling the volume needed by the process. The menhaden had a tendency to wedge in the channels, blocking the machine and restricting fish flow. We are still looking for a sorting machine. We recently purchased a Trio Skinning machine and are evaluating different deboner screen sizes to see if the refining step can be dropped. We anticipate further modifications to the process after the 1988 fishing season.

Research on menhaden surimi is also underway at a number of Universities in the U.S.. North Carolina State Univ., which did much of the original bench scale work on menhaden surimi along with researchers at the NMFS Laboratory in Charleston, SC, is currently investigating the use of a flavor mask developed by the Ogawa Company to extend the use of menhaden surimi in analog products. They are also evaluating the presence of a protease that affects the functionality of surimi in certain foods. In cooperation with the National Fisheries Institute they have helped standardize the methods of analysis to be used for testing surimi. Researchers at Cornell Univ. are evaluating surimi and intermediate minces in a number of products and have evaluated several anti-oxidants that might be used to stabilize the fat. Researchers at the Univ. of Massachusetts Seafood Lab in Gloucester, Mass. are evaluating the basic lipid chemistry of menhaden surimi. Virginia Tech. Univ. scientists are evaluating a number of convenience and fast food type products that can use menhaden surimi. Univ. of Georgia scientists have produced pasta type products with menhaden. Rhode Island Univ. researchers are evaluating process modifications and the North Carolina State Univ. Seafood Laboratory is evaluating ultrafiltration as a means of recovering valuable proteins from the waste waters.

In addition to the University research, a number of food companies both in the analog business and in other areas of the food industry have been evaluating the product for some time. The recent precedent setting approval of surimi for use in a cured meat blend by the U.S. Department of Agriculture will open up a new arena of opportunity for surimi producers. The first product approved was for "Spicey Bites" breaded pork nuggets with 15% surimi produced by the Alaska Fisheries Development Foundation. A second product "Southwest-Style Golden Morsels" developed by Manning, Batson and Associates of Phoenix, Arizona was also approved. According to the company, the product is low in fat, adequate for either commercial market or restricted diet programs and is less expensive to manufacture than similar all-meat products. They have also successfully used menhaden surimi in some of the test formulations.

In the future we will see snack foods, drinks, luncheon meats, hot dogs and many other foods which will utilize the unique functional properties of surimi. The Age of Engineered Foods is now.

BIBLIOGRAPHY

1. Sonu, Sunee C. ,"Surimi", NOAA Technical Memorandum, NMFS, January 1986, NOAA-TM-NMFS-SWR-013, .

2. Anonymous, Surimi: The Explosive Blended Seafood Market, Cos Cob, Connecticut, 06807-0398, Seafood Management Corporation, 1984.

3. Suzuki, Taneko, Fish and Krill Protein, Processing Technology, London, Applied Science Publishers, 1981.

4. Dreosti, G.M., and T. J. Billy, "Potential Food Products From Industrial Fish", IAFMM Technical Report No. 1, January 1983.

5. Anonymous, "The Surimi Explosion", Seafood Business, Vol 5, No 3, May/June 1986.

6. Anonymous, "Surimi Sensation", Seafood International, March 1986, pg 25.

7. Vondruska, John, "Blue Crab Markets and Analog Products", Paper presented to the National Blue Crab Industry Association's Annual meeting, Feb. 26-28, 1986.

8. Vondruska, John, "Market Trends and Outlook for Surimi-Based Foods", Paper presented at the International Symposium on Engineered Seafoods, Seattle, Washington, Nov. 19-21, 1985.

9. Lanier, Tyre C., Roy E. Martin, and Anthony P. Bimbo, "Nutritional Implications of Increased Consumption of Engineered Seafoods", Food Technology 42(5); 162, 1988.

10. Vondruska, John, W. S. Otwell, and R. E. Martin, "Seafood Consumption,

Availability and Quality", Food Technology 42(5); 168, 1988.

11. Bimbo, Anthony P. "U.S. Menhaden Surimi Production: First Interim Report", Paper presented at the 26th Annual Meeting of the International Association of Fish Meal Manufacturers, October 8, 1986.

12. "Proceedings of the International Symposium on Engineered Seafood Including Surimi", Edited by Roy E. Martin, National Fisheries Institute, Washington, D.C., November 19-21, 1985.

13. Anonymous, "Alfa Laval Decanter-Based Surimi Production", Bulletin PB 40984E/8610, Alfa Laval Fish and Meat Engineering A/S.

14. Andres, Cal, "Surimi Poised For Next Step Forward", Food Processing, August 1987, pg. 28.

15. Martin, Roy E., "Surimi Products A Review", Paper presented at the 194th National Meeting of the American Chemical Society, September 2, 1987.

16. Bimbo, Anthony P., "U.S. Menhaden Surimi Production: Second Interim Report", Paper presented at the 27th Annual Meeting of the International Association of Fish Meal Manufacturers, October 7, 1987.

17. Bimbo, Anthony P., et. al. "U.S. Menhaden Surimi Production: A Progress Report", Paper presented at the National Technical Conference: Fatty Fish Utilization: Upgrading from Food to Feed, Raleigh, NC, December 10, 1987.

18. Moore, Raymond E., et. al. "Harvesting and Pre-Process Handling of Food Grade Menhaden- An Interim Report", Paper presented at the National Technical Conference: Fatty Fish Utilization: Upgrading from Food to Feed, Raleigh, NC, December 10, 1987.

19. Martin, Roy E., "Surimi", Proceedings of the IFT Short Course on Seafood Technology- Preparing for Future Opportunities, New Orleans, LA, June 19, 1988.

20. Bimbo, Anthony P., "Fish Oils", Proceedings of the IFT Short Course on Seafood Technology- Preparing for Future Opportunities, New Orleans, LA, June 19, 1988.

TABLE 1. US AVAILABILITY OF FISH, SHELLFISH AND MENHADEN, 1980-1987, IN 1000 METRIC TONS.

	FISH AND SHELLFISH	ATLANTIC MENHADEN	GULF MENHADEN	TOTAL MENHADEN
1980	2940	430	702	1132
1981	2711	402	553	955
1982	2888	400	854	1255
1983	2921	420	924	1344
1984	2920	329	983	1311
1985	2839	359	884	1243
1986	2736	256	829	1085
1987	3128	323	907	1230

SOURCE: FISHERIES OF THE UNITED STATES, 1980-1987.

TABLE 2. ESTIMATED US SUPPLY OF SURIMI PRODUCTS

YEAR	CONSUMPTION
	MILLION POUNDS COOKED EDIBLE WEIGHT
1975	5.6
1976	4.7
1977	5.8
1978	4.8
1979	4.9
1980	6.1
1981	9.1
1982	20.6
1983	39.9
1984	69
1985	90.6
1986	99
1987	110.2

SOURCE: VONDRUSKA, J. SYMPOSIUM ON MARKETS FOR SEAFOOD AND AQUACULTURAL PRODUCTS, 1987.

TABLE 3. N-3 FATTY ACID COMPOSITION OF MENHADEN SURIMI.

FATTY ACID	LOW RANGE	HIGH RANGE
EXPRESSED IN MG PER 100 GRAMS OF RAW EDIBLE PRODUCT.		
16:3N-3	3.5	11.4
16:4N-3	5.1	16.4
18:3N-3	6.1	19.6
18:4N-3	18.8	60.6
20:3N-3	0.93	3
20:4N-3	8.74	28.2
20:5N-3	57.85	186.6
21:5N-3	3.41	11
22:5N-3	14.14	45.6
22:6N-3	106.08	342.2

SOURCE: ZAPATA HAYNIE CORP. INTERNAL DATA.

TABLE 4. PROXIMATE COMPOSITION OF MENHADEN RED AND WHITE MEAT.

		PROTEIN	FAT	ASH	MOISTURE
BATCH A	RED MEAT	16.43	18.47	0.77	63.90
BATCH A	WHITE MEAT	17.97	10.56	1.30	70.05
BATCH B	RED MEAT	18.12	7.14	1.79	72.31
BATCH B	WHITE MEAT	18.70	3.46	1.62	76.68
BATCH C	RED MEAT	16.82	15.27	1.48	65.83
BATCH C	WHITE MEAT	18.80	8.43	1.42	72.06

SOURCE: ZAPATA HAYNIE CORP. INTERNAL DATA.

FIGURE 1 ORIGINAL PROCESS

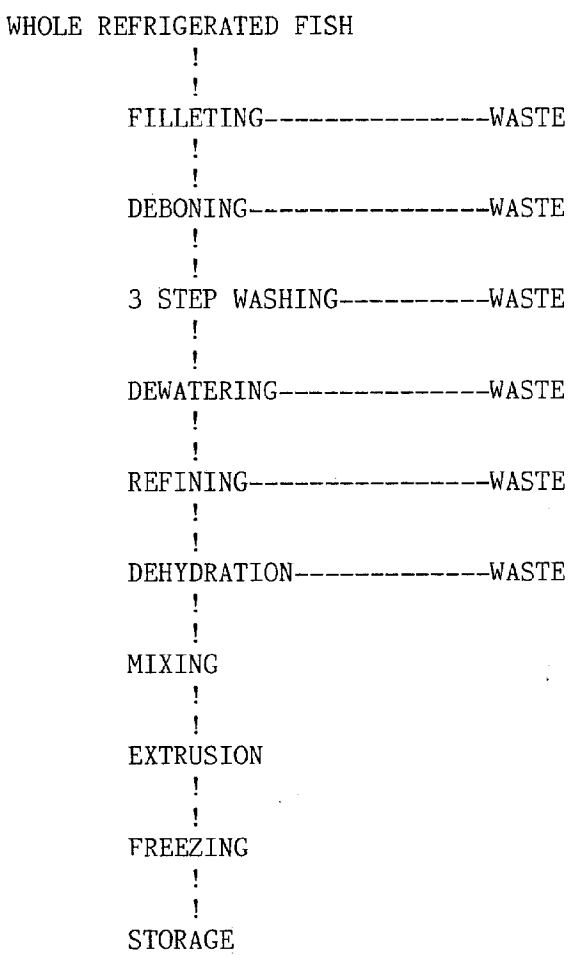
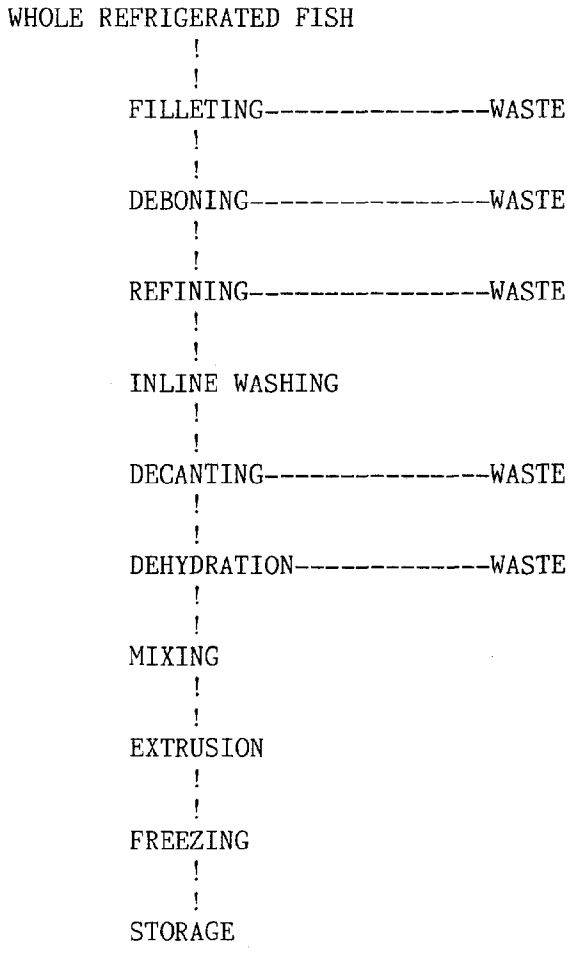


FIGURE 2 MODIFIED PROCESS



AN EXPERIMENTAL ESTUARINE SALINITY GRADIENT

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Abstract

For the last decade, we have operated 14 large marine mesocosms (13 m^3) to model a well-mixed, high salinity (30 °/₀₀) coastal system. Mid-Narragansett Bay, R.I. has been the natural reference station. These systems, however, are capable of being adapted to simulate other natural situations. Recent interest in the behavior of low salinity estuaries has led us to develop a salinity gradient model suitable for biogeochemical experiments.

We adapted 4 mesocosm tanks to create a salinity gradient. River water was introduced at one end of the system and seawater (30 °/₀₀) was introduced at the other. Dilute salinities of 5 °/₀₀, 10 °/₀₀ and 30 °/₀₀ were maintained between these two extremes. Air driven displacement pumps that are non-destructive to plankton were designed to transfer water "up" and "down" the gradient and calibrated to maintain a 27 day turnover time in each tank. In this design the same equipment allows a wide range of operating conditions.

INTRODUCTION

Marine mesocosms are more than research aquaria; they are experimental ecosystems created to behave as analogs of the larger natural systems from which they are derived. By design they are interactive systems that contain feedback networks found within ecosystems and are thus self-sustaining and ecologically durable. Mesocosms serve as unique environmental research tools and are an important bridge between field and laboratory studies. They are cost effective when compared to the cost of obtaining a similar data set in the field. Of more significance, they can be operated at a level of experimental control and replication that is not possible in the field. Field experiments in the marine environment are confused by advection and the difficulty in locating valid control sites. Bioassay type laboratory experiments while useful in their ability to efficiently project the response of a species to a perturbant, are not capable of predicting a whole system effect. Mesocosms can be operated for relatively long periods of time over seasonal and annual cycles and because of this feature ecosystem responses such as adaptation, and succession of communities can be observed. This capacity has made mesocosms ideal for investigation of chronic, low-level pollution effects.

The Marine Ecosystem Research Laboratory (MERL) is a mesocosm facility at the University of Rhode Island's Graduate School of Oceanography. A 560 m^2 building serves as a support laboratory and operations center for large experimental ecosystems. Fourteen cylindrical tanks 1.8 m in diameter and 5.5 m in depth are arranged along an access deck outside and adjacent to the building. The facility has laboratories for biology, organic, trace metal and nutrient chemistry, and radioisotope tracer studies.

The mesocosms (Figure 1) contain 13 m^3 of Narragansett Bay water with associated pelagic community. Benthic communities from Narragansett Bay are removed, as undisturbed as possible, with a box core, loaded in trays and placed in the bottom of each mesocosm. Physical parameters such as mixing, water turnover and temperature can be scaled to simulate natural conditions. MERL has typically operated these parameters to simulate the "average" conditions of mid-Narragansett Bay. The water column is stirred to simulate wind and tidal mixing (Nixon et al., 1980). Mixing is by a vertically rotating plunger, 60 cm dia. with a 60 cm travel, run at 5 rpm, 2 h on : 4 h off. Seawater from Narragansett Bay is pumped to a head tank by diaphragm pumps which are nondestructive to plankton. The head tank periodically (120 l/tank, 4 times a day) delivers seawater by gravity feed through a manifold to the mesocosms providing the tanks with a 27-day turnover time; the average turnover time of Narragansett Bay (Pilson, 1985). Temperature within the tanks is controlled and maintained at the average daily ambient bay temperature with heat exhangers placed in each tank. An IBM-PC and compatable digital/analog input/output interface device is used to control many of these operations.

Over the last decade numerous experiments have been completed at MERL with this "average" model of Narragansasett Bay. Long-term experiments of a duration greater than a year have been conducted to observe ecosystems under the influence of hydrocarbons, enhanced nutrients, nutrient ratios, sewage sludge and effluent, and polluted sediments. Many short-term experiments have been run either within the context of long-term experiments or as separate studies. These experiments have been diverse and include radioisotope studies and specific organic, hydro-

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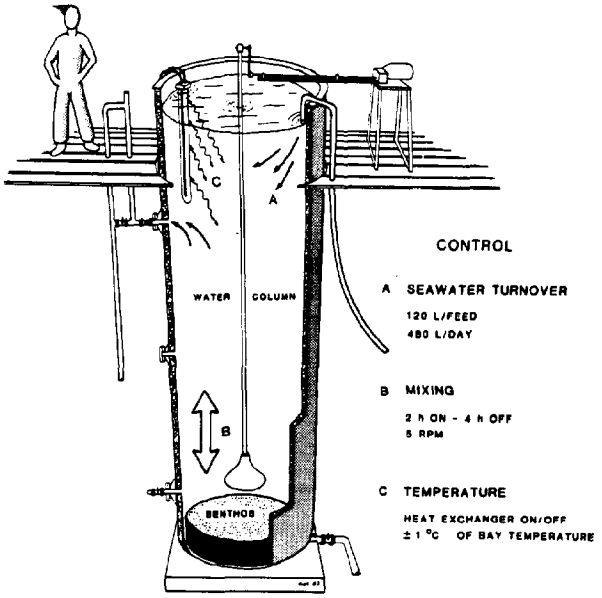

Figure 1. A MERL Mesocosm

carbon and metal spikes. On several occasions natural conditions other than Narragansett Bay have been investigated. In one experiment several tanks were stratified to simulate an offshore ecosystem with a strong pycnocline (Fox and Kester, 1985). Recent interest in low-salinity estuaries led us to attempt construction of an experimental estuarine salinity gradient making use of our existing mesocosms. This work was done in the latter part of 1987 as a feasibility study and initial examination of contained ecosystems at low salinity.

Design Concept and Goal

A simplified and conceptual view of an estuary was generated initially to set design criteria for the experimental salinity gradient mesocosm (Figure 2a). This view is not unlike those represented in many textbooks. Seawater enters the estuary at the bottom by tidal forcing and is mixed and diluted with freshwater entering from a river at the opposite end. There is a net flow of freshwater out of the estuary observed as lower salinity. Mixing within the estuary is both horizontal and vertical and the rate of mixing is a function of tidal currents and wind shear.

This view of an estuary was used to define an overall design goal making use of available tanks, equipment and resources (Figure 2b). We decided that this initial experiment would be vertically well mixed - the gradient would be strictly horizontal - and mixing would be the same magnitude as in most other MERL experiments. A benthic community would be included. Tank temperature would be monitored and maintained as in other experiments and the tanks would be cleaned on a regular schedule. The only deviations from our normal operations was the introduction of river water with seawater to produce dilute salinities and our final goal of connecting tanks together so that water could move "up" and "down" the gradient. Four conditions were selected: freshwater (0 °/₀₀), 5 °/₀₀ and 10 °/₀₀ low salinities in the middle and seawater (30 °/₀₀). Tank turnover was kept the same as previous experiments - 27 days.

The Pawcatuck River in western RI (Figure 3) was selected as the reference. The estuarine part of the river is about 8 km long - from Westerly to Watch Hill - and opens into Little Narragansett Bay to the south. Salinities in the estuary vary primarily in relation to the amount of freshwater input but typically there is a clear salinity gradient in the estuary from entirely fresh at Westerly to around 30 °/₀₀ at Watch Hill. There are two sewage treatment plants along the river about 2 km south of Westerly on opposite banks serving a modest population of around 10,000. Although this input represents a measurable nutrient enrichment (Nowicki, unpublished data) there is little industrial discharge and water quality is satisfactory (Sisson, RI Dept. Environmental Management, personal communication).

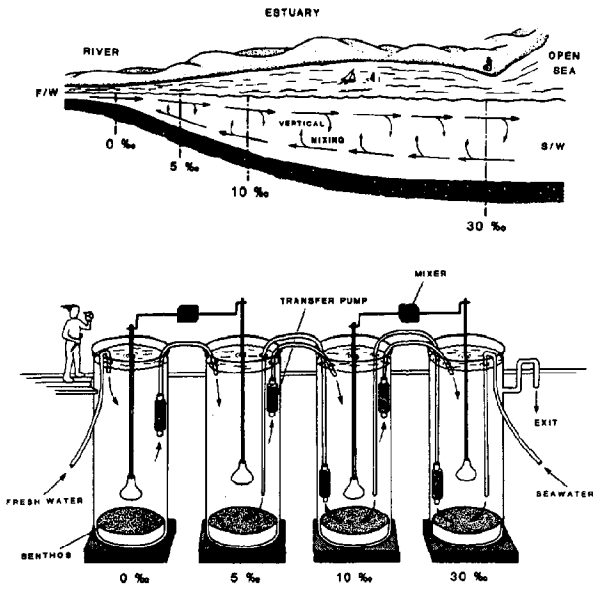

Figure 2.
(a) Conceptual view of an estuary.
(b) Experimental estuarine salinity gradient. Freshwater and seawater are introduced at either end. Mixing is a function of tides and wind in the estuary, and transfer pumps and mechanical mixing in the mesocosm.

The Pawcatuck River was examined on several occasions to locate suitable sediment sites and measure salinity and other water quality variables. (A larger unpublished salinity data set over 1 year was made available to us by Sisson, RI-DEM.) Sediments in the estuary are mostly fine silt-sand. Low salinity (3-20 °/₀₀) and high salinity (22-30 °/₀₀) stations (Figure 3) were selected as the sediment sources for the experimental benthic communities.

METHODS

Experiment Initiation

In early September, 1987, four sediment trays were loaded by the standard MERL method with sediments from the Pawcatuck River - 3 from the low and 1 from the high salinity station. These were transported to MERL and each lowered to the bottom of an empty tank. Seawater and river water were added to each tank in the proportion required to bring each tank to its set salinity. Mixers and heat exchangers were placed in the tanks and water feed systems were turned on. After a one week "equilibration" period routine monitoring and sampling commenced.

Mesocosm Design

Mesocosm design goal was accomplished in two phases. In the first phase tanks were operated independently. Freshwater and seawater end members were introduced into each tank at the proper rate to maintain set salinity. Our intent was to first observe the behavior of low salinity ecosystems run under the same protocol as other MERL experiments with salinity as the only variable. This allowed a more straightforward analysis of their condition. In the second phase, four independent tank systems were converted into a single estuarine "system" with four compartments. Freshwater and seawater were introduced only at the ends of the model and transfer pumps were installed to move tank water "up" and "down" the gradient.

River water was delivered to us periodically - about every 2 or 3 weeks - via tank truck (E.H. Benn & Sons) in ca. 20 m^3 volume shipments and was pumped into two mesocosm tanks set aside for use as a freshwater reservoir.

Phase I design required a new method of controlling the feed into the tanks; both freshwater and seawater. Experience at MERL has taught us that from a single source equal flow rates among tanks is the best way of insuring an equal split of plankton. (Different flow rates may transport different plankton concentrations (per unit volume) from a single source.) There is subtlety to this problem: just having equal flow rates to tanks is insufficient. The splitting manifold must be constructed with each path geometrically equal (Vargo, unpublished data). This situation is in part due to the condition of laminar flow maintained in the feed system (Reynolds No. Ca. 2 x 10^3). Although fully turbulent flow (Reynolds No. > 10^4) may be more desirable for flow control, we do not feel this is good for plankton.

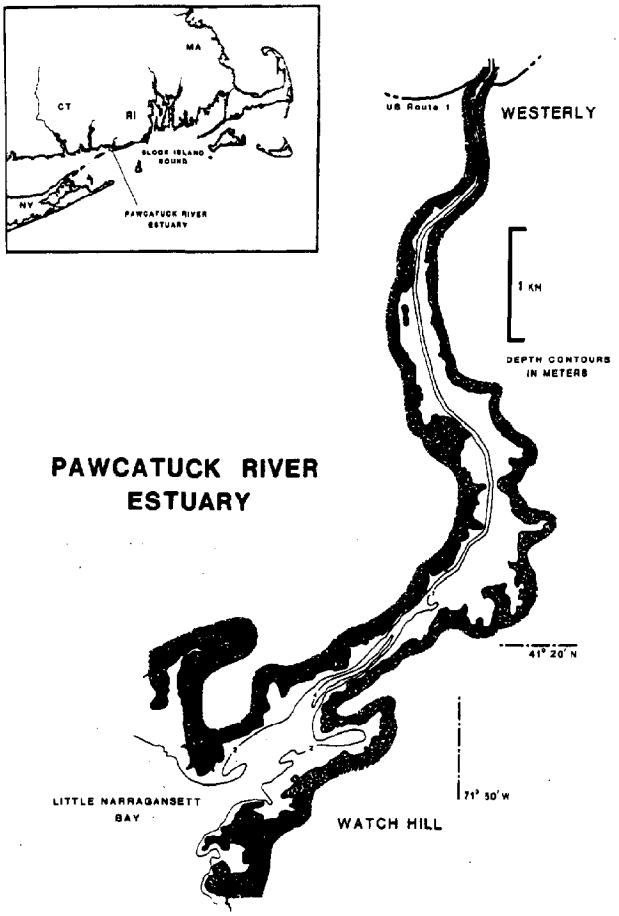

Figure 3. The Pawcatuck River estuary.

The seawater feed manifold in use at MERL is constructed of PVC and designed to have an equal path from the head tank inflow to the outlet for each tank. This feature, and equal length lines to each tank provide an even distribution of plankton to the tanks at equal flow rates. When not in the process of feeding tanks the manifold and feed lines are drained to prevent freezing and fouling. In previous experiments all tanks received the same volume input (480 l d^{-1}) and only 1 control point was necessary. This design was expanded for this experiment with installation of 2.5 cm dia. spring return pneumatic actuator valves (Chemtrol, mfg.) to allow individual on:off control for each of the salinity gradient tanks. This particular valve is interchangeable with the standard manual ball valves used with other tanks and has the same pressure drop.

Actuation with air at 80 psig turns the pneumatic valve against a spring. When pressure is removed the spring returns the valve to its initial state. Valves were configured to be normally closed. Air pressure was supplied from the MERL compressor (Joy, mfg. : 20 hp., 80 SCFM) and was directed either to the pneumatic valve or vented with .64 cm dia. 3-way solenoid valves (ASCO, mfg.). The action of the solenoid valve was controlled with a relay that received its signal from a computer driven digital output module.

The freshwater manifold incorporated the same general design principles as the seawater system. One important difference: 1.3 dia. 2-way solenoid valves (normally closed) were used directly to control water flow. This was done, in part, to compare the performance of solenoid vs. pneumatic valves in the same application. As with seawater flow, freshwater valves were directed by computer.

The total amount of water fed to each tank to provide a 27 d turnover time is 480 l per day, or 120 l each feed cycle. An equal amount of tank water drains through an overflow pipe. The amount of freshwater and seawater required each feed to maintain set salinities can be determined by a simple proportioning of known and selected salinity times the total flow rate:

$$J_s = \frac{S_e}{S_s} \times 120 \text{ l feed}^{-1} \qquad (1)$$

where:

J_s = volume flow rate of seawater
S_e = Tank salinity, °/₀₀
S_s = Salinity of seawater, 30 °/₀₀

Flow rates through the seawater system averaged 16.5 l min^{-1} $tank^{-1}$. Flow rates through the freshwater system were slightly lower: 14.5 l min^{-1} $tank^{-1}$. These flow rates were translated into a feed system "ON" schedule by calculating the time required to supply the necessary volume to each tank each feed cycle. Tanks were fed 4 times each day; at 0300, 0900, 1500 and 2100. Both seawater and freshwater were added at the same time.

Phase II - the interconnection of 4 tanks into a single estuarine system - involved the use of pumps to transfer water between tanks. In this phase salinity within a tank would be the result of input from adjacent tanks. Seawater and freshwater end members were added only at the end of the experiment (Figure 2b).

Several pump designs were examined for their ability to transfer zooplankton undamaged. Other desirable qualities were that the pump be non-contaminating, self-priming, draw minimal power and require minimal connecting plumbing. We concluded that our best choice was a pump of our own design. A prototype was fabricated and tested. Concentrated zooplankton samples discharged through this pump were indistinguishable from control samples (Sullivan, personal communication). Other criteria were satisfied and it was relatively inexpensive to fabricate in our shop.

The submersible transfer pump works by displacing water flooded into the pump chamber with air. PVC check valves direct the flow of water out of the pump and into the next tank. A 2 s on : 2 s off cycle of air was supplied to each pump with 3-way solenoid valves of the same type used with the seawater manifold. Five pumps were independently controlled to attain the circulation shown in Figure 2b. Each tank except the 0 °/₀₀ treatment received water from two sources.

Determination of flow rate proportions that maintain salinity and supply a 27 d turnover time for each tank is more elaborate for an interconnected system than a single compartment model. It was necessary to have an overflow from each tank. The volume fed to a tank from one source during each feed was calculated as follows:

$$J_1 = \frac{S_e - S_2}{S_1 - S_2} \times 120 \text{ l feed}^{-1} \qquad (2)$$

where:

J_1 = Volume flow rate, of first source
S_e = Tank Salinity, °/₀₀
S_2 = Salinity of second source, °/₀₀
S_1 = Salinity of first source, °/₀₀

Flow rates from transfer pumps averaged 10.2 l min^{-1}. Seawater and freshwater end members averaged 16.5 and 20.2 l min^{-1} respectively. A new schedule for timing feed was programmed. All feeds were added simultaneously 4 times a day at the same time as before.

Analytic Methods

Salinity was monitored daily with a refractometer with a calibrated precision of ± .5 °/₀₀. Samples were taken after feeds and during mixing to ensure that they were representative. Several times a Beckman induction salinometer was used to look for vertical salinity structure during and following feeds. This salinometer had a precision of ± .05 °/₀₀ and was additionally useful as a check of refractometer accuracy. On two occasions high precision (± .005 °/₀₀) measurements with an Autosal were made to study small scale vertical structure during feed with transfer pumps. Bay salinity was measured routinely and at times, over a tidal cycle.

Flow rates were measured volumetrically about

every week. Measurement precision was ± .05 l min^{-1}. Flow rates among tanks through the freshwater and seawater manifolds varied up to ± 1 l min^{-1} from the mean. Flow rates through transfer pumps varied up to ± .5 l min^{-1}. Timing of individual feeds allowed us to correct for individual differences. Total system precision was estimated to be 5 to 8%.

Ecosystem behavior was monitored by other members of the MERL staff. The following parameters were measured weekly in the tanks as part of the ongoing MERL mesocosm sampling program:

1. Phytoplankton biomass (as chlorophyll)
2. Zooplankton abundance
3. Total system metabolism
4. Dissolved inorganic nitrogen, phosphorus and silicate
5. Particulate nitrogen and carbon
6. Dissolved and particulate iron.

Methods for these analyses are described in Lambert and Oviatt, 1986.

RESULTS

Salinity varied ± 1 °/₀₀ in the mesocosms over the duration of the experiment (102 days). What changes in salinity did occur were gradual over a period of days or weeks. Such drift was corrected with minor adjustments in the feed schedule and the system allowed to drift back to its set salinity. Because tank salinity was a function of flow rate such adjustments (at least theoretically) increased the precision of turnover time.

Differences in flow rate between actual and that used to set schedules accounted for this drift. The pneumatic ball valves were superior to solenoid valves in controlling water flow. The solenoid valves were diaphram seated and easily trapped matter flowing through the valve on the seat when closed thus allowing some leakage. Ball valves, because they rotate across the seat when closing, tend to wipe off any accumulated matter.

Vertical salinity profiles taken during both phases of the experiment indicated that there were virtually no gradients within a tank. Samples taken within 30 cm of an input during feed revealed differences from tank salinity < .5 °/₀₀ but these were rapidly mixed out following a feed. The transfer pumps did not apparently entrain newly added water and overflows were always whole tank salinity.

Ecosystem Behavior

Data obtained from routine tank monitoring suggested that in a general way the experimental estuary behaved like the natural one. Table 1 characterizes the ecosystem in the different treatments (Oviatt, unpublished data). Divers observed that the benthic community in each treatment was viable and similar in appearance to the collection site throughout the experiment. The 0 °/₀₀, 5 °/₀₀, and 10 °/₀₀ benthic communities were impoverished (a condition observed in nature). Less macrofauna may in part explain the greater abundance of zooplankton in the low treatments. The greater filter feeding community in the high salinity tank may have removed phytoplankton at the expense of zooplankton. The ratio of dissolved inorganic nitrogen:phosphorus (DIN/DIP) suggested phosphorus limitation of phytoplankton in the 0 °/₀₀, 5 °/₀₀, and 10 °/₀₀ tanks and nitrogen limitation in the 30 °/₀₀ tank (Suttle and Harrison, 1988). While the mechanism of this shift in limiting factors is not fully understood, it appears in nature and was present in the mesocosm.

Table 1. Condition of the experimental ecosystem

	0°/₀₀	5°/₀₀	10°/₀₀	30°/₀₀
Production ($gO_2m^{-2}d^{-1}$)	1.0	1.0	1.5	1.6
Respiration ($gO_2m^{-2}d^{-1}$)	0.5	0.3	0.6	1.2
P/R	2.0	3.3	2.5	1.3
Zooplankton (no. l^{-1})	17.0	40.0	22.5	4.0
DIN/DIP	165.9	161.8	53.4	3.2

DISCUSSION

For more than a decade mesocosms have been developed for a number of marine environments. The substantial diversity of mesocosm designs mirrors the different underlying concepts from which these designs were generated. Banse (1982), Grice and Reeve (1982), Pilson and Nixon (1980), Steele (1979), Davies and Gamble (1979) and others have reviewed and compared some of the larger and more prominent of these systems. At present there are at least a dozen major types of design. They range in volume up to 1300 m^3. Some of these systems have been deployed at sea as large plastic enclosures attempting to trap the local water community as in the CEPEX experiments (Menzel and Case, 1977). Living models of such diverse ecosystems as coral reefs (Adey, 1982) and estuaries with strong salinity gradients (Cooper and Copeland, 1973) have been constructed. Many marine mesocosms have only isolated part of the water column, but some like MERL have coupled their systems to the benthos. All of these efforts have had to come to terms with a fundamental problem: as you isolate a piece of the ecosystem from nature you are removing it from its physical environment and must provide for that with mechanical systems.

Perhaps in some situations containment alone is sufficient. Light, flushing, turbulence and

temperature, however, are important forcing functions in the marine environment that require consideration. Scaling of physical forcing functions to mimic nature is an important design concept. If physical parameters are scaled to relative magnitudes, the biological components should behave naturally (Perez et al., 1977; Oviatt et al., 1977). The technology for constructing and operating mesocosms is not sophisticated; the challenge is how to apply it. The behavior of experimental ecosystems is linked to physical design in much the same way that natural systems are coupled with their physical environment. Mechanical structure and function are managed more or less to the researchers specification.

Design can be changed, scale can be adjusted, and a range of conditions may be created that simulate different natural conditions. For example, varying the speed of mechanical stirrers has been shown to influence plankton community structure and function in tanks (Oviatt, 1981; Donaghay and Klos, 1985).

An experimental estuarine salinity gradient was established by blending freshwater and seawater in different proportions. An ecosystem not unlike the reference estuary was maintained throughout the experiment. The results have demonstrated the feasability of operating mesocosms to these specifications for longer periods of time and for more complex experimentation, for example adding nutrients to a parallel system. Conversion to a vertically stratified salinity gradient is a future goal and will incorporate methods applied previously to maintain strata in single tank systems. Managing flow between compartments will become more complex however.

Tanks linked together to produce a multicompartment mesocosm offer unique research opportunities. The compartments are interactive at rates that can be controlled. Estuarine box models which describe replacement time and transport through a non-homogeneous environment can be applied directly to an experiment. It has not escaped our notice that by allowing tank overflows when the tanks were connected complicates calculation of mass balances and other factors. We allowed overflows so that each tank had an equal turnover time at its selected salinity. A decision to have water exit only the high salinity end of the experiment would have resulted in each of the tanks turning over at different rates. We chose the former option for this experiment for comparison with past work. It is not clear at this point which option is more desirable or if different types of investigation are best operated differently.

With the advent of microcomputers and compatible interface devices, process control has changed dramatically. Electro-mechanical hardware must have the same power wiring no matter how it is controlled, but with use of a computer, control is by written program. This approach has the potential to be more flexible and less expensive than traditional electromechanical controls. Following an initial investment in this equipment, the cost and effort of radically changing the operation of a process like a MERL mesocosm can be minimized.

There are many types of estuaries: low salinity (relatively high river input) or high salinity (relatively low river input) and well mixed or vertically stratified is one simple classification scheme. In this experiment we have modelled one possibility. We recognize that in nature there is awesome complexity and variability both within and between estuaries in everything from sediment type to the prevalence of internal waves. This should not discourage mesocosm development - it should serve as an invitation to explore.

ACKNOWLEDGEMENTS

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REFERENCES

Adey, W.H. 1982. The microcosm: A new tool for reef research. Coral Reefs 1:193-201.

Banse, Karl. 1982. 2. Experimental marine ecosystem enclosures in historical perspective. In: Marine Mesocosms, G.D. Grice and M.R. Reeve (eds). Springer Verlag, pp. 11-24.

Cooper, D.C. and B.J. Copeland. 1973. Responses of continuous-series estuarine microecosystems to point source input variations. Ecol. Monogr. 43:213-236.

Davies, J.M. and J.C. Gamble. 1979. Experiments with large enclosed ecosystems. Phil. Trans. R. Soc. Lond. B. 286, 523-544.

Donaghay, P.L. and E. Klos. 1985. Physical, chemical and biological responses to simulated wind and tidal mixing in experimental marine ecosystems. Mar. Ecol. Prog. Ser. 26: 35-45.

Fox, M.F. and D.R. Kester. 1985. Fate of ocean-dumped acid iron waste in a stratified microcosm. In: Duedell, I.W., B.H. Ketchum, P.K. Park, and D.R. Kester, (eds.), Wastes in the Ocean, Vol. 5, Wiley-Interscience, N.Y., pp. 171-185.

Grice, G. and M. Reeve. 1982. Introduction and description of experimental ecosystems. In: G. Grice and M. Reeve (eds.), Marine Mesocosms; Biological and Chemical Research in Experimental Ecosystems, Springer-Verlag, NY, pp. 1-9.

Lambert, C.E., and C.A. Oviatt. 1986. Manual of biological and geochemical techniques in coastal areas. MERL Series, Report No. 1, Second Edition, The University of Rhode Island, Kingston, RI.

Menzel. D.W. and J. Case. 1977. Concept and design: controlled ecosystem pollution experiment. Bull. Mar. Sci. 27(1):1-7.

Nixon, S.W., D. Alonso, M.E.Q. Pilson, and B.A. Buckley. 1980. Turbulent mixing in aquatic microcosms. In: John P. Giesy, Jr. (ed.), Microcosms in Ecological Research, U.S. Technical Information Center, U.S. DOE Symposium Series 52 (CONF-781101), pp. 818-849.

Oviatt, C.A. 1981. Effects of different mixing schedules on phytoplankton, zooplankton and nutrients in marine microcosms. Mar. Ecol. Prog. Ser. 4:57-67.

Oviatt, C.A., K.T. Perez and S.W. Nixon. 1977. Multivariate analysis of experimental marine ecosystems. Helgolander wiss. Meeresunters 30:30-46.

Perez, K.T., G.M. Morrison, N.F. Lakie, C.A. Oviatt, S.W. Nixon, B.A. Buckley and J.F. Heltshe. 1977. The importance of physical and biotic scaling to the experimental simulation of a coastal marine ecosystem. Helglander wiss. Meeresunters 30:144-162.

Pilson, M.E.Q. 1985. On the residence time of water in Narragansett Bay. Estuaries 8:2-14.

Pilson, M.E.Q. and S.W. Nixon. 1980. Marine microcosms in ecological research. In: John P. Giesy, Jr. (ed.), Microcosms in Ecological Research, U.S. Technical Information Center, USDOE. Symposium Series 52 (CONF-781101), pp. 724-741.

Suttle, C.A. and P.J. Harrison. 1988. Amonium and phosphate uptake rates, N:P supply ratios, and evidence for N and P limitation in some oligotrophic lakes. Limnol. Oceanogr. 33(1): 186-202.

DEPURATION OF OYSTERS IN A CLOSED RECIRCULATING SYSTEM

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ABSTRACT

A pilot scale depuration facility for Crassostrea virginica has been established in a heavily-industrialized suburb of New Orleans. This facility consists of five 10,000 liter holding tanks with a capacity of 200 bushels per 48 hour period. Because of its location, tanks are prepared with well water and synthetic sea salts to achieve the proper salinity. Effluent water is circulated through a series of treatment steps and eventually contacted with a form of advanced photoxidation (APO) in order to eradicate pathogenic bacteria and reduce accumulation of toxic metabolites.

1. INTRODUCTION

Depuration, also known as controlled purification, is a process whereby the number of pathogenic organisms that may be present in shellfish harvested from polluted (restricted) waters is reduced to levels considered safe for human consumption.

Research on depuration began in the late nineteenth century and has continued over the years with basic and applied research on bacterial assimilation/removal and physiological effects of a wide variety of physical, chemical and environmental water quality parameters (1). Recent developments in environmental pollution and dwindling resources have accelerated this research and caused all government regulatory agencies to consider requiring depuration of all shellfish, possibly within the next five years.

Purification of oyster tissue via the depuration process is a function of acclimation of the animal to environmental conditions existing in the depuration tank (temperature, salinity; (2), (3), (4). It is directly associated with pumping activity of the oyster and is typically manifested by shell activity in conjunction with release of feces and pseudofeces into the water. Monitoring of pumping activity is usually accomplished via soluble and insoluble nitrogen, dissolved oxygen, and turbidity sampling at various points in the system. Various mechanisms have been developed to directly monitor shell activity (5); but this measurement cannot be conclusively correlated to production of feces.

The present methodology for determining end point quality in depurated oyster tissue is the recognized procedure for fecal coliforms (6). This methodology is quite slow (96 hours), and requires either wet storage or refrigerated storage of product until the product has been determined to be in conformance with State guidelines. Current Louisiana regulations regarding water quality and end point criteria for tissue are shown in Table 1.

Currently there is only one commercial-scale, certified, oyster depuration plant operating in the United States. This paper presents the various technologies used to achieve end point criteria for successful depuration of Louisiana oysters in a semi-closed, recirculating system located in an industrial section of a large city (New Orleans, Louisiana). It also shows results from a typical run in which compliance with regulations for end-point criteria were met.

2. ADVANCED PHOTO-OXIDATION TREATMENT

Depuration of oysters is accomplished by addition of an oxidizing gas known as Photozone (TM) to the water. The process by which oxygen is converted to a greater activity level is known as advanced photo-oxidation (APO). This is accomplished by passing either ambient air or oxygen through a PVC housing or quartz sleeve, containing a patented ultraviolet lamp with a spectral emission of 185 nM light. Gas stream analysis by mass spectrometer shows that of the 1.8% oxygen converted to Photozone

Table 1. Depuration Standards

Parameter	Concentration
dissolved oxygen	greater than 50% saturation
coliform bacteria (mpn/100 ml)	less than 1.8
salinity (ppt)	+/- 20% source
temperature (°C)	10 - 25
pH	7.0 - 8.4
turbidity (JTU*)	less than 20
mean fecal coliform (mpn/100 g tissue)	less than 20
mean fecal coliforms for upper 10%	less than 70

* Verified for individual facilities

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(TM), 65% is negatively-charged ozone, 14.7% hydroxal radical, 6.3% hydrogen dioxide, 5.9% hydrogen peroxide, 4.4% atomic oxygen, and less than 0.1% nitrogen oxides. This gas carries an oxidation potential of 2.60 volts compared to classical ozone (96.4% ozone, 3.3% nitrogen oxides) at 2.07 volts. Because of its long half-life in water (approximately two hours,) it can be easily recirculated.

Photozone (TM) is usually injected into water via an air compressor or liquid oxygen dispenser. The actual mechanism by which it is injected varies; by venturi injector, air diffusion tubing, micropore airstones, static mixer devices or oxygen solubilizers. Two types of gas generators are used on the Water Management depuration facility: a gas-phase generator consisting of a metal or PVC cell containing less than 180 or 200 nM lamp or a gas-liquid generator that utilizes both UV treatment and Photozone (TM) treatment. The latter generator utilizes a quartz sleeve to separate gas and liquid phases. Photozone (TM) is created by passing the source gas between the lamp and the quartz sleeve. It is then injected into a hydraulic line entering the cell and passing between the steel jacket of the cell and the outer surface of the quartz sleeve.

3. DESCRIPTION OF SYSTEM

Because of the location of the facility, the depuration process requires a recirculating hydraulic flow utilizing Activated Oxygen for water treatment. A flow schematic of the process is shown in Figure 1. Other depuration plants currently use flow-through systems and UV for disinfection. The closed loop design optimizes water use, provides water quality surpassing process water standards and year-round operation in a controlled environment.

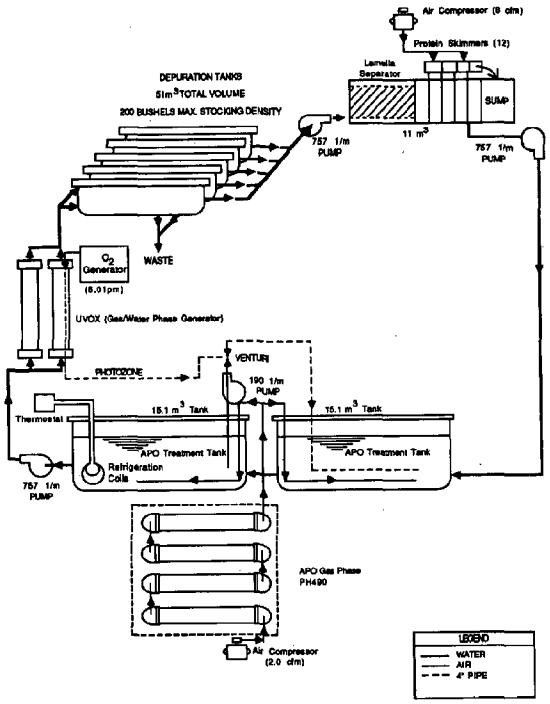
This facility has a depuration capacity of 200 bushels every forty-eight hours. Both the National Shellfish Sanitation Program regulations and Louisiana State regulations require a flow rate of 3.785 liters per bushel per minute, which provides 151 liters per minute to each tank. There are five depuration tanks in the system, each holding 40 bushels of oysters and 10.2 metric tons of artificial seawater. The design criteria for the plant are shown in Table 2.

4. SHELLSTOCK PRE-TREATMENT

Before oysters are placed in the depuration tanks, they are culled to remove heavy accumulations of fouling organisms and dead oysters or oysters in broken or cracked shells and then washed to remove mud and detritus. After the pre-treatment process, the oysters are arranged in trays with layers no more than 3 inches thick. The trays are stacked four trays high in the depuration tanks resting on pallets made of pvc to allow bottom circulation. The trays are configured in each tank so that a

FIGURE 1.

OYSTER DEPURATION PLANT FLOW SCHEMATIC



maximum of three trays wide by seven trays long exists. This allows for a minimum of three inches clearance on all sides of each tray (FDA, 1987).

5. DEPURATION PROCESS DESCRIPTION

The depuration process begins with purified water entering each tank via a 2" PVC manifold situated at the base of the tank. Holes drilled in the pipe assure a uniform flow of water is dispersed into all areas of the tank. Together, all depuration tanks operate as one process system. The tank size, tray configuration, water circulation rate and flow pattern are identical for each tank in the treatment system.

The water treatment process begins with the water from each depuration tank overflowing

Table 2. Design Criteria

Parameter	Criterion
Oyster Capacity/Tank	40 bushels
Oyster Capacity Total	200 bushels
Tank Circulation Rate	151 lpm/tank
Total Circulation Rate	757 lpm/tank
Depuration Rate	3.785 lpm/bushel*
Depuration Time	48 hours
Temperature	20°C
Salinity	20 ppt

* 1 Bushel = 120 to 133 oysters = 2/3 sack

into a top skimmer drain with simultaneous removal via a bottom drain. This water is pumped into a lamella tube separation chamber for settling of larger solids. From there it flows into a second chamber containing a parallel arrangement of protein fractionation columns which assist in removal of suspended solids (bacteria), dissolved solids, and soluble nitrogen. Aeration in the skimmers is provided at a flow rate of 0.5 cfm per column diffusor. Foam from the protein fractionators is concentrated down into a sump, chlorinated after each run, and wasted into the local sewer system. All water that passes into subsequent sections of the facility must pass through this protein fractionation column. Columns are designed to process a hydraulic flow of 64 lpm.

Water from the protein fractionators is pumped into the first of two 15,000 liter Photozone (TM) treatment tanks through a 90 elbow at the base of the tank wall oriented to create clockwise circulation. The circular flow pattern assures that there is no short-circuiting in the treatment process. Photozone (TM) for this contact tank is produced by four gas-phase generators driven by a small 0.5 hp compressor. Photozone (TM) from the generators is added to the water by a series of connected concentric rings of 1.27 cm weighted diffusor tubing. This treatment also serves to aerate the water and provide sufficient oxygen for the oysters. Additional treatment is introduced into this contact tank via a recirculating venturi arrangement from the second treatment tank.

Water then flows into a second 15,000 liter treatment tank from a 4 inch lateral standpipe. This tank receives the same type of Photozone (TM) treatment as the first contact tank. There is a refrigeration coil in this tank used to maintain the process water temperature at 20°C. The treatment water is then pumped from the contact tanks through a parallel arrangement of two gas-water generator units and 1 parallel UV sterilizer unit. These units have a hydraulic capacity of 151 lpm (APO) and 302 lpm, respectively. A small bypass of 151 lpm does not receive the previous UV treatment and is mixed with treated water and returned via a manifold distribution system to the depuration holding tanks. Flow into these tanks is regulated by hydraulic flow meters/valve arrangements (one per tank).

6. DEPURATION RESULTS

Typically, a depuration run will last 48-72 hours. Monitoring of physical and chemical water parameters takes place at 0, 24 and 48 hours. Tissue bacteriological samples are taken from each oyster depuration tank at the same time. Water bacteria samples (total coliforms, fecal coliforms) are taken from a port immediately prior to water recirculating back into the depuration tanks) at similar times. Typical total coliform levels in recirculating water and fecal coliform levels in oyster tissue are shown in Figures 2a and 2b, respectively for one run during the summer of 1988.

As can be seen in Figure 2a, there is an increase in tank total coliform bacteria at the 24-hour sampling point, followed by a decrease to less than 1.8 mpn/100 ml at the 48-hour sampling point. Samples taken in the recirculation line past the UV port show only a slight increase at the 24-hour sampling point that decreases to less than 1.8 mpn at 48 hours.

Results from fecal coliform sampling of oyster tissue (Figure 2b) show a high 0-hour level (92,000 mpn/100g), followed by a decrease to less than 18 mpn/100g at both the 24-hour and 48-hour sampling points.

Figure 2a. Depuration Results (total coliform bacteria)

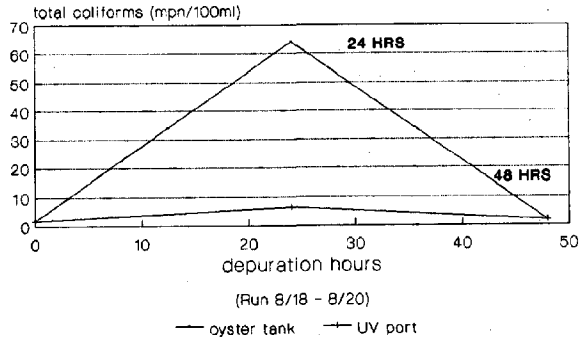


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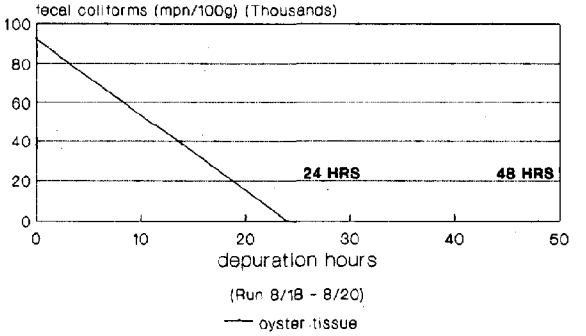
Figure 2b. Depuration Results (fecal coliform bacteria)



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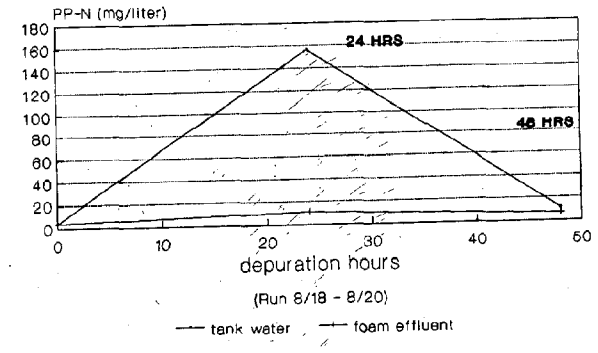
Sampling of insoluble nitrogen as protein particulate nitrogen (PP-N) from protein fractionation unit effluent (condensed foam) showed concentrations of 3.9 mg/liter, 156.3 mg/liter, and 10.5 mg/liter at 0-, 24-, and 48-hour sampling points. This data is shown in Figure 3.

Figure 3. Fractionation Effluent (protein particulate nitrogen)



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7. DISCUSSION

As can be seen from the previous results, there is a general decrease in tissue fecal coliform concentration over the 48-hour depuration period. The decrease to compliance level, as seen in most successful depuration trials, is usually achieved within 24 hours post-stocking of tanks. The increase in total coliforms in tank water can probably be explained by either release of bacteria (both fecal and total) from oysters as part of the depuration process or by release from sediment associated with the shell of the oyster. As is seen in the results, protein particulate nitrogen concentration increased in fractionation column effluent in correspondence with a similar increase in total coliform bacteria in tank water. Apparently, protein fractionation units can serve a useful function in reducing total coliform bacteria in recirculating systems. Because of the relatively low cost of construction of such columns, their use could mean a substantial reduction in overall capital outlay for UV or oxidation equipment.

What must be emphasized in developing or evaluating oyster depuration systems is the ability to sequentially decrease both particulate and soluble materials as either bacteria or substrates for bacterial growth by very simple and cost effective means prior to contact with UV sterilization and/or ozone oxidation equipment. Strict maintenance procedures allowing for cleaning of system build-up or biofouling of tanks, lines, UV lamps and other equipment must be incorporated into operational schedules. The ability to depurate oysters in any system will inevitably be a function of shell and tissue bacterial status for 0-hour oysters, oyster biomass, the maintenance of physical conditions conducive to depuration within holding tanks, system processing efficiency, and treatment time. The development of more-rapid and accurate methodologies for determination of end point tissue quality in conjunction with statistically verifiable levels of sampling could assist in determining the status of individual lots of oysters prior to removal from the depuration system. This would ultimately result in increased depuration capacity and decreased storage time of product awaiting verification of end point quality prior to market release.

REFERENCES

1. Richards, G. P. Microbial purification of shellfish: A review of depuration and relaying. Journal of Food Protection. 1988. Vol. 51:(3): 218-247.

2. Banoub, S., N. J. Blake and G. E. Roderick. Final Report: Studies concerning the cleansing mechanisms of non-01 Vibrio cholerae and V. vulnificus in Florida shellfish. DOC/NOAA Award No. NA 83-GA-H-0007. February, 1985. 63 pgs.

3. Rowse, A. J. and G. H. Fleet. Effects of water temperature and salinity on elimination of Salmonella charity and Escherichia coli from Sydney rock oysters (Crassostrea commercialis). Appl. Environ. Microbiol. 1984. Vol. 48: 1061-1063.

4. Fufari, S. A. Shellfish purification: A review of current technology. FAO Tech. Conf. on Aquaculture, Publ. FIR: AQ/Conf/ R.11. Kyoto, Japan. 1976. 16 pgs.

5. Soniat, T. A microcomputer based shell activity monitor for oysters. Proceedings of the National Shellfish Association Conference, June 27 - June 30, 1988, New Orleans, Louisiana. 1988.

6. American Public Health Association. Laboratory Procedures for the Examination of Sea Water and Shellfish. 5th edition. Chapter 3. Procedures for the Bacteriological Examination of Water and Shellfish. 1985: 37-63.

ON RAY TRAJECTORIES AND PATHTIMES FOR ACOUSTIC PROPAGATION IN A MEDIUM WITH VELOCITY GRADIENTS

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ABSTRACT

Sound, in addition to its traditional role for communication and sensing in the ocean environment, serves now also for tomographic determination of the spatial distribution of some medium parameters. This paper contributes new expressions and insights for paths and pathtimes of rays in volume cells of the medium for which the sound velocity can be characterized in terms of a point velocity and a constant velocity gradient. Such a parametrization permits the use of relatively large cells in the segmentation of the medium, this having the consequence that the dimensional complexity of the tomographic formulation and inversion is significantly reduced. In the case of a small number of segmentwise ramping vertical velocities, including velocity reversals, the profile parametrization enables the computational determination of arrival point targeted (APT) or eigenrays, the rays from a given source point to a specified arrival point.

1. INTRODUCTION

Important questions posed by climatologists and oceanographers point to the need for sensing and mapping of ocean current and temperature fields and their dynamics, on various spatial and temporal scales. A promising approach for such large scale sensing has been pioneered by Munk and Wunsch [1-3], ocean acoustic tomography (OAT), whereby traveltime information of sound signals passing through the medium is processed to yield estimates of the spatial sound propagation distribution at the time of probing. Temperatures can be inferred from the sound velocity information, whereas the time differential of oppositely directed sound signals gives information about currents, gyres, or eddies. A key component of the OAT method is the tracing of rays, transmitter to receiver through the heterogeneous medium, including multipaths due to bottom and surface reflections and due to velocity gradient reversals (deep sound channel).

The ocean, as a sound transmitting medium, is inherently heterogeneous, and the objective of OAT is to retrieve detail of the spatial sound velocity distribution. This calls, in principle, for sound transmission experiments between many sources and receivers, and for finely gridded ocean cells with associated cellwise constant sound velocities, for the purpose of ray tracing and mathematical inversing of the traveltime information. Such many source/receiver probing being as yet not practically feasible, it is appropriate to ponder the implications of medium heterogeneity on signal travel paths and travel times, and to contemplate the use of larger volume cells, say with constant gradient velocity models (ramp velocity models). These will be concerns to be addressed in this paper.

2. HETEROGENEITY AND VELOCITY AGGREGATIONS

In OAT it is the discerned propagation time of the sound signal from a source to a receiver which encapsulates information about raypath geometry and about the local propagation velocity at every incremental of the paths. For the ray model idealization the important aggregation variables are pathlength ℓ, pathtime t, and a velocity-pathlength product $v_P\ell$, which can be represented as line integrals or partitions thereof as follows [4]:

$$\ell = \int_\zeta d\zeta = \int_\zeta v(\zeta)dt(\zeta) = v_T t = \int_{\zeta 1} + \int_{\zeta 2} + \ldots \quad (1)$$

$$t = \int_\zeta dt(\zeta) = \int_\zeta \frac{1}{v(\zeta)}\, d\zeta = \frac{\ell}{v_T} = \int_{\zeta 1} + \int_{\zeta 2} + \ldots \quad (2)$$

$$v_P\ell = \int_\zeta v(\zeta)d\zeta = \int_\zeta v^2(\zeta)dt(\zeta) = v_G^2 t = \int_{\zeta 1} + \int_{\zeta 2} + \ldots = v_P v_T t \quad (3)$$

It is seen that the above variables for the raypath traversed define time-average velocity $v_T = \ell/t$, path-average velocity $v_P = (v_P\ell)/\ell$, and a geometric mean velocity

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$v_G = [(v_p\ell)/t]^{1/2} = [v_p v_T]^{1/2}$. In seismic usage this latter is known as the RMS or root-mean-squared velocity. It is only for a homogeneous medium and attendant straight line raypaths that the above three velocities have the same numerical value. The dimensionless ratio $v_p/v_T = h > 1.0$ is a quantitative measure of the velocity heterogeneity encountered along the path [4]. It has attributes somewhat like a variance; the larger the value above the base value of unity, the larger is the velocity variation.

The line integrals may be arbitrarily partitioned, say corresponding to the boundaries of a medium segmentation into cells with which the raypath interacts. Clearly, any medium heterogeneity within a cell will give rise again to numerically different time- and path-average velocities for the pathsegment through the cell. Most important however, is that the components in the partitions of the variables ℓ, t, $v_p\ell$ in equations (1) to (3) may be arbitrarily permuted without affecting variable values, or without affecting numerical values of v_T, v_p, v_G, or h.

For further clarification of the effects of medium velocity heterogeneity, we consider a medium segment sufficiently small so that it is only heterogeneous in one dimension, say in the vertical [4]. This is then a Snell's medium, i.e. Snell's law applies for raypaths. Figures 1(a) and 1(b) respectively display a velocity profile and an associated raypath for some given ray parameter value (the solid curves). A partition of this profile and the Snell's law associated raypath at z_γ, say, and a reordering of profile and path segments (the broken curves) will not affect any aggregation variables or velocities along the raypath or for the profile which relate to the total transitions, provided that rays are monotonic. Figure 2 displays a strongly vertically heterogeneous profile. By extension of the situation in Figure 1, this profile may be finely partitioned, and the partition parts reordered to generate the monotonically increasing profile as shown without affecting any of the profile or path aggregation variable values or velocity and heterogeneity parameters [4]. The canonical profile is in fact the cummulative form of the velocity distribution function for the profile. The ramp trend in the canonical (monotonic) profile suggests that a ramp velocity profile can be an appropriate approximator for medium segments which have inhomogeneity of consequence.

3. RAMP VELOCITY PROFILE

The ramp velocity profile model is relevant and important as a segmentwise approximator for some characteristic deep ocean sound speed profiles like the SOFAR channel, in addition to its role as the simplest of approximators for modeling medium heterogeneity. In this section we summarize and extend somewhat the basic relationships which have relevance for tracing of rays through a medium cell with a velocity distribution which can be modelled by a ramp velocity profile. For tractability the relationships are given for the simplest case, for velocity ramping by a constant gradient g in the vertical direction, and for the x vs. z plane origin positioned at the starting point of a ray. As indicated in Figure 3, variables and parameters pertaining to the ray commencement point are subscripted by α, those pertaining to the ray arrival point by β, those along the ray locus may be unsubscripted or they may be qualified by (z) or (x,z), as appropriate. We have thus at the starting point, $(x_\alpha{=}0, z_\alpha{=}0, v_\alpha, \theta_\alpha)$; at the terminal point $(x_\beta, z_\beta, v_\beta, \theta_\beta)$; along the raypath $(x,z,v(z),\theta(x,z))$. Coordinate axes for z and x are directed downward and to the right respectively; all angles are measured counter-clockwise from the z-axis, but geometrically identical angles may also be used to simplify representations. Snell's law holds at the end points and at all points along a ray, thus the equivalent ray parameter expressions

$$p = \cos\theta(x,z)\,\frac{d\theta(x,z)}{dv(x)} = \frac{\sin\theta(x,z)}{v(x)} = \frac{\sin\theta_\alpha}{v_\alpha} = \frac{\sin\theta_\beta}{v_\beta} = p_\alpha \quad . \tag{5}$$

Along an incremental ray segment $d\zeta$, path geometrical and time incrementals are related by

$$\begin{aligned} d\zeta &= v(z)dt \\ dx &= \sin\theta(x,z)d\zeta \\ dz &= \cos\theta(x,z)d\zeta \quad . \end{aligned} \tag{6}$$

The gradient of the linearly ramping velocity in the vertical direction is g, so that the profile function takes the form

$$v(z) = v_\alpha + gz \quad \text{for } -\infty < z < +\infty \; z_\alpha = 0 \quad . \tag{7}$$

With (5) and (7), incremental relationships (6) can be integrated to give explicit expressions for raypath points and time as

$$z(p,\theta_\alpha) = \frac{1}{pg}\,(\sin\theta(x,z) - \sin\theta_\alpha) \tag{8}$$

$$x(p,\theta_\alpha) = \frac{1}{pg}\,(\cos\theta_\alpha - \cos\theta(x,z)) \tag{9}$$

$$t(x,z,\theta_\alpha) = \frac{1}{g}\,\ell n\left(\frac{\sin\theta(x,z)(1+\cos\theta_\alpha)}{\sin\theta_\alpha(1+\cos\theta(x,z))}\right) \tag{10a}$$

$$= \frac{1}{g}\,\ell n\left(\frac{\tan(\theta(x,z)/2)}{\tan(\theta_\alpha/2)}\right) \quad . \tag{10b}$$

Summing $\sin^2\theta(x,z)$ and $\cos^2\theta(x,z)$ from (8) and (9), one obtains the well-known circular raypath locus, its coordinates of the centre and radius being transparent, as

$$\left(x - \frac{v_\alpha}{g\tan\theta_\alpha}\right)^2 + \left(z + \frac{v_\alpha}{g}\right)^2 = \left(\frac{v_\alpha}{g\sin\theta_\alpha}\right)^2 \quad . \tag{11}$$

Some rearrangement of (11) leads to an expression which gives the ray departure angle

$\theta_\alpha(x,z)$ for an arrival point targeted ray or APT ray at (x,z) as

$$\frac{1}{\tan\theta_\alpha(x,z)} = \frac{(x^2 + z^2 + 2v_\alpha z/g)}{2v_\alpha x/g} \qquad (12)$$

It can be frequently convienent to use ray endpoint-specific parameters, as complements to the (v_α, g) parameter pair, namely a profile or vertical ray path-average velocity v_{PN} and a ramp profile contrast factor q. The defining relationships and various other parameters relating to these are then as follows [4]:

$$v(x,z) = v(z) = v_\alpha + gz \quad \text{at} \quad (x,z) \text{ on ray} \qquad (13)$$

(ray point velocity)

$$v_{PN}(z) = (v_\alpha + v(z))/2 = v_\alpha + gz/2 \qquad (14)$$

(profile or vertical path-average velocity)

$$q(z) = \frac{v(z) - v_\alpha}{v(z) + v_\alpha} = \frac{gz}{2v_{PN}(z)} \qquad (15)$$

(ramp contrast factor)

$$t_N(x,z) = \frac{1}{g}\ln\left(\frac{v(z)}{v_\alpha}\right) = \frac{z}{v_{PN}(z)}\ln\left(\frac{1+q}{1-q}\right)/2q \qquad (16)$$

(vertical ray time-average velocity)
note $q = (q(x,z)) = q(z)$

$$h_N(z) = \frac{v_{PN}(z)}{v_{TN}(z)} = \left(\ln\left(\frac{1+q}{1-q}\right)\right)/2q \qquad (17)$$

$$= \left(1 + \frac{q^2}{3} + \frac{q^4}{5} + \frac{q^6}{7} + \ldots\right)$$

(profile or vertical ray heterogenance)

The arrival point targeted ray parameter and cumulative variable expressions can then be obtained as follows:

$$p(x,z;v_\alpha,g) = \frac{x/z}{v_{PN}\left[\left(1 + \left(\frac{x}{z}\right)^2\right)\left(1+\left(q\,\frac{x}{z}\right)^2\right]^{1/2}} \qquad (18)$$

(ray parameter; note $q = q(z)$, $v_{PN} = v_{PN}(z)$)

$$\ell(x,z;v_\alpha,g) = \frac{1}{pg}\left(\sin^{-1}(pv(x,z)) - \sin^{-1}(pv_\alpha)\right) \qquad (19)$$

$$t(x,z;v_\alpha,g) = \frac{1}{g}\ln\left(\frac{\left[1+\left(q\frac{x}{z}\right)^2\right]^{1/2} + q\left[1 + \left(\frac{x}{z}\right)^2\right]^{1/2}}{\left[1+\left(q\frac{x}{z}\right)^2\right]^{1/2} - q\left[1 + \left(\frac{x}{z}\right)^2\right]^{1/2}}\right) \qquad (20)$$

$$[v_P\ell](x,z;v_\alpha,g) = \frac{x}{p} \qquad (21)$$

$$= zv_{PN}\left[\left(1 + \left(\frac{x}{z}\right)^2\right)\left(1 + \left(q\,\frac{x}{z}\right)^2\right)\right]^{1/2}.$$

Likewise expression (12) and the related expression for $1/\tan\theta(x,z)$, with $\theta(x,z)$ at a raypoint (x,z), take forms

$$\frac{1}{\tan\theta_\alpha(x,z)} = \frac{1 - q\left(\frac{x}{z}\right)^2}{(1+q)\frac{x}{z}} = \frac{1}{\tan(\phi(x,z) + \alpha(x,z))} \qquad (22)$$

$$\frac{1}{\tan\theta(x,z)} = \frac{1 + q\left(\frac{x}{z}\right)^2}{(1-q)\frac{x}{z}} = \frac{1}{\tan(\phi(x,z) - \alpha(x,z))}. \qquad (23)$$

We have introduced here decompositions of the ray departure angle $\theta_\alpha = (\phi - \alpha)$ and ray arrival angle $\theta(x,z) = (\phi + \alpha)$, ϕ being the angle of the chord and α being the angle between the chord and the tangent to the raypath at the endpoints $(x_\alpha=0,\ z_\alpha = 0)$ and (x,z), as shown in Figure 3. Angles α and ϕ are linked through the simple but important relationship

$$\tan\alpha = q\tan\phi = q\,\frac{x}{z}\,. \qquad (24)$$

The consequence of these decompositions is that the straight line chord can facilitate thinking and analytical relationships pertaining to the attendant circular arc raypath.

For the ramp velocity model being considered, a ray departing at $(x_\alpha=0, z_\alpha=0)$ at an angle $\theta_\alpha = \theta_{\alpha TURN}$ will eventually reach its depth extremum at $(x_{TURN}, z_{TURN}, \theta(x_{TURN}, z_{TURN}) = \frac{\pi}{2})$. Relevant relationships linking these turning ray angle and coordinate values include the following:

$$x_{TURN} = \frac{v_\alpha}{g\tan\theta_{\alpha TURN}} \qquad (25)$$

$$z_{TURN} = \frac{v_\alpha}{g}\left(\left[1 + 1/\tan^2\theta_{\alpha TURN}\right]^{1/2} - 1\right) \qquad (26)$$

$$\tan\phi_{TURN} = \frac{x_{TURN}}{z_{TURN}} = \frac{1}{[q_{TURN}]^{1/2}} \qquad (27)$$

4. RAY TRACING AND APT-RAYS

From the above, it is seen that the ramp velocity model gives rise to simple and tractable raypath related relationships. These can serve for the ray tracing task through a conjunction of medium cells, where profile parameters for each are presumed known and ray direction at entry is known from ray direction at exit from the adjacent cell. Relationship (23) among others, in conjunction with geometry expressions for cell boundaries can serve for obtaining directly the

ray exit point from the cell. Appropriate translations and rotations of coordinate axes in the 3-D space enable the above results to be adapted for ray tracing through 3-D cells in the general 3-D medium. In the ocean environment, ramp velocity models would apply for relatively large medium cells, making these then attractive for OAT by virtue of the small count of parameters to be determined from the applicable perturbation equations.

For a single ramp velocity profile segment, relationships which have been detailed unable the direct determination of arrival point targeted or APT rays (also variously referred to as eigen-rays), plus their ancillary detail of raylength, raytime, etc. For two or three ramp segments and horizontal reflecting boundaries, applicable expressions can be combined with boundary and interface constraints to give low order polynominal equations for the x-coordinates of ray segment transitions. The root solutions of these equations allow then again construction of the APT-rays and segmentwise evaluation of their raytimes. Simulation results demonstrate feasibility and computational efficiency for direct and multipaths in shallow channels and in deep sound channels from velocity gradient reversals.

Figure 4 exemplifies up-starting soundpaths in a shallow channel of 200 m, over horizontal range of 2000 m, $v_{SURFACE}$ = 1480 and g = .1 (m/sec)/ sec . Figure 5 exemplifies rays in the deep channel, over a horizontal range of 100 km, with $v_{THERMOCLINE}$ = 1475 at 1000 m, g_{UP} = .04, g_{DOWN} = .01, z_{TRANS}= 950 m, z_{REC} = 1100 m.

5. REFERENCES

[1] W. Munk and C. Wunsch (1979): Ocean Acoustic Tomography - A Scheme for Large Scale Monitoring; Deep-Sea Research, 26A, pp. 123-161.

[2] Munk, W. and C. Wunsch, (1982): Observing the Ocean in the 1990's; Philosophical Transactions of the Royal Society of London, Vol. A 307, pp. 439-464.

[3] Ocean Tomography Group, The, (1982): A Demonstration of Ocean Acoustic Tomography; Nature, Vol. 299, 9 September 1982, pp. 121-125.

[4] W.J. Vetter (1987): Vertical Heterogeneity and Moveout in the One-Dimensional Medium; Geophysical Prospecting, 35, pp. 700-717.

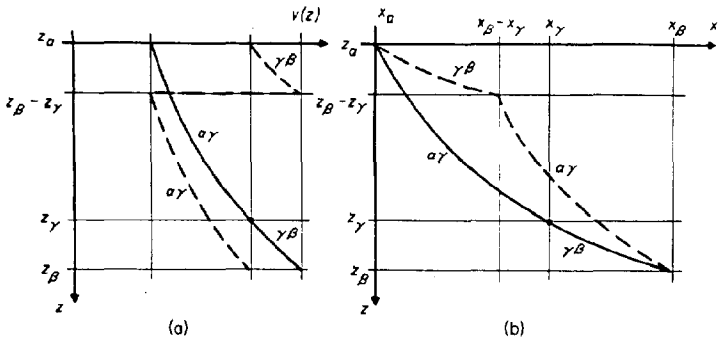
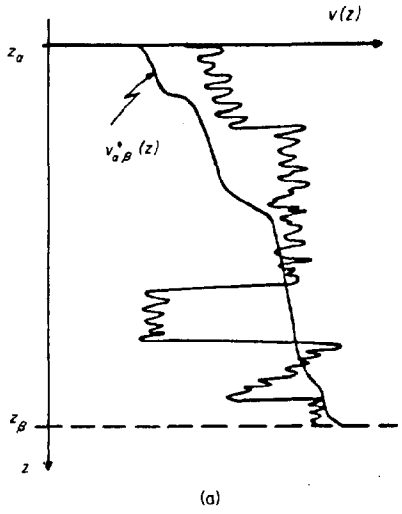


Fig. 1: Raytime and raylength invariance for profile and trajectory segment permutation.
(a) Profile, (b) trajectory.



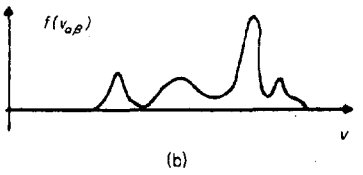


Fig. 2: Canonical Profile. (a) Profile segment and canonical profile, (b) velocity distribution.

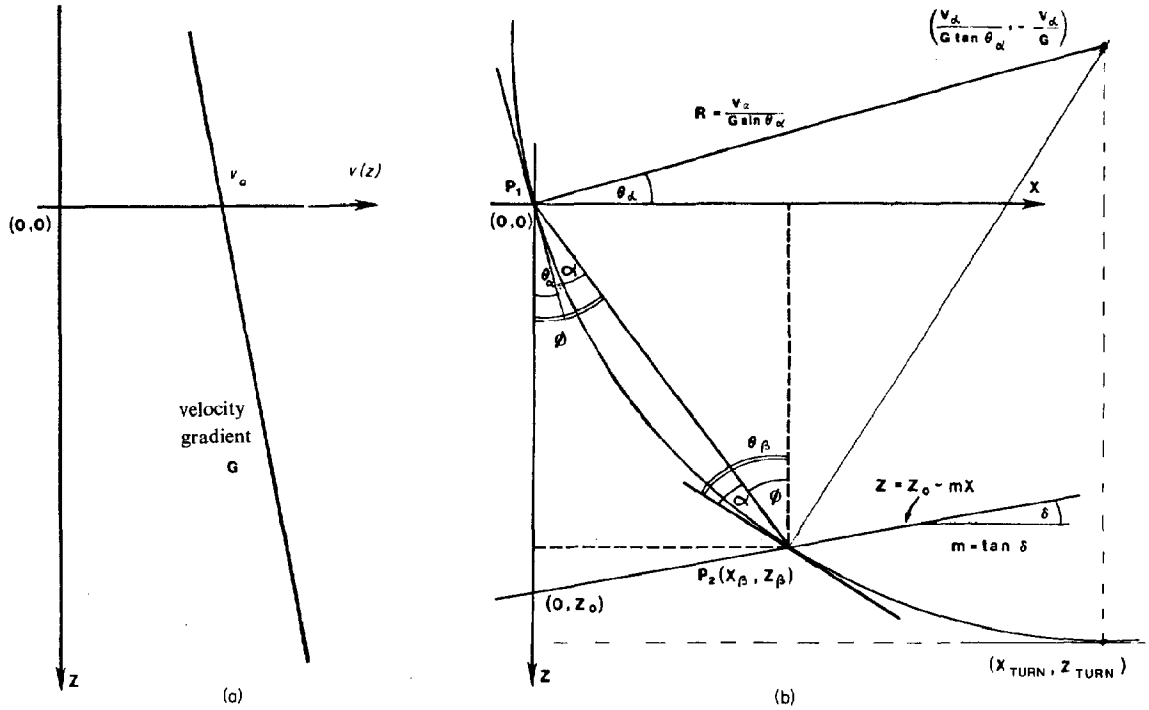


Fig. 3: (a) Ramp velocity profile, (b) raypath geometry

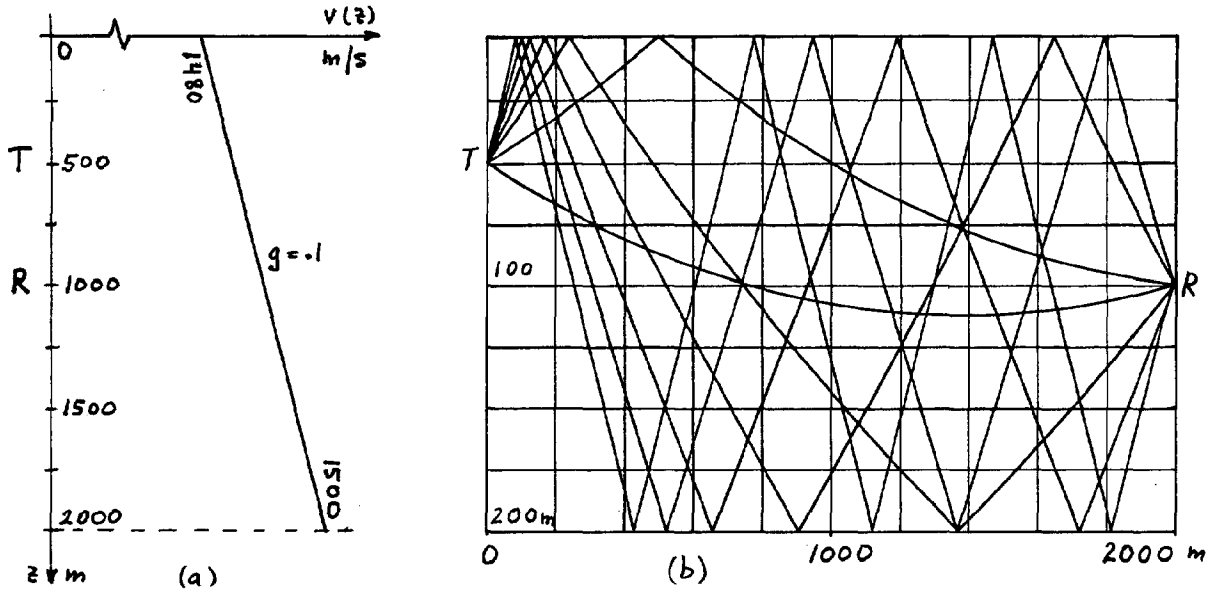


Fig. 4: APT rays in single ramp segment shallow sound channel
(a) profile, (b) arrival point targeted rays

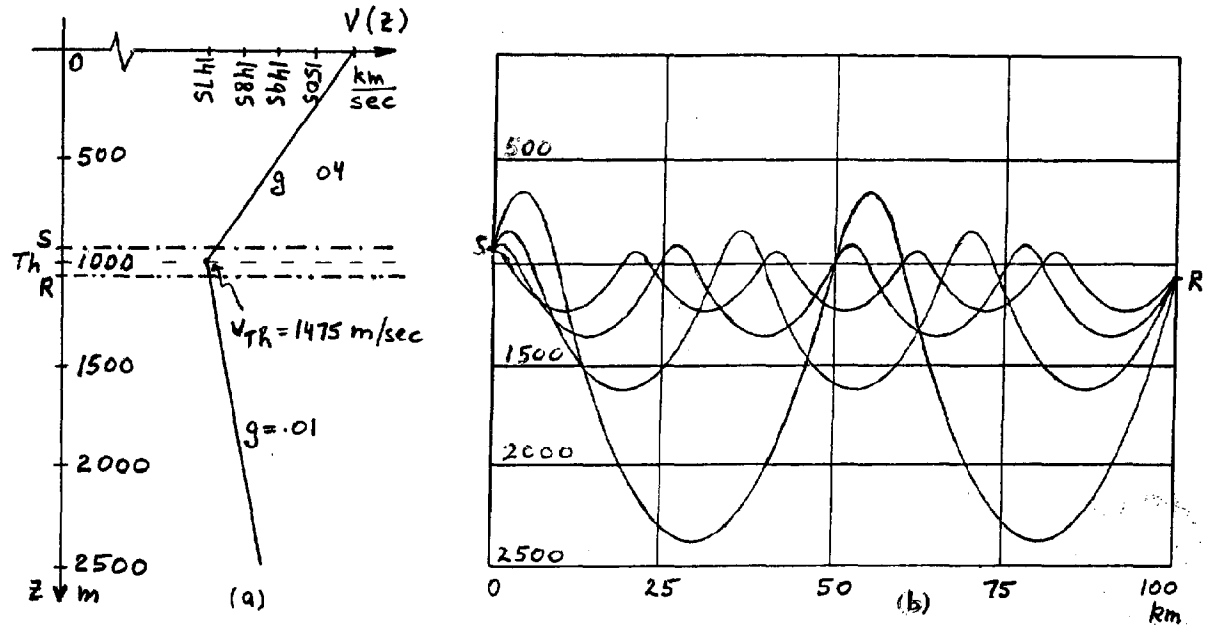


Fig. 5: APT rays in 2 ramp segment deep sound channel
(a) profile, (b) arrival point targeted rays

THE DEPENDENCE OF THE MICROWAVE RADAR CROSS SECTION ON OCEAN SURFACE VARIABLES DURING THE FASINEX EXPERIMENT

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ABSTRACT

A measurement program, to develop more precise relationships between the microwave (Ku-band) radar cross section and the ocean surface variables that affect the roughness and reflectivity, is in progress. An extensive data set was obtained during the Frontal Air-Sea Interaction Experiment (FASINEX) during the Winter of 1986 in the Atlantic south of Bermuda. Of interest in this study are the airborne Scatterometer measurements that were coincident with surface wind speed and stress measurements from aircraft and ships, and the directional surface wave spectrum. The airborne radar data set spans several different flights (typically at an altitude of 3000 feet) during which there were a variety of different atmospheric and ocean conditions. This also includes a variety of radar parameters such as incidence angle of the radar beam, the polarization and a circular sweep of look direction relative to the wind vector. The goal of this research is to explain the properties of the Ku-band radar cross section of the ocean (as a function of incidence angle, azimuth angle and wind speed) in terms of the physical forces and variables, such as surface stress and currents, long wave tilting and hydrodynamic modulation of the short Bragg waves. Current theoretical models based on Bragg scattering are being tested. In situations where the Bragg scattering theory does not agree with the measured radar cross section (magnitude and azimuth dependence), revisions of the theory are proposed.

1. INTRODUCTION

The Frontal Air-Sea Interaction Experiment (FASINEX) was a cooperative program to investigate the role of horizontal variability in air-sea interaction. It took place during the Winter-Spring of 1985-86. The region selected for study was an oceanic front in the subtropical convergence zone southwest of Bermuda. The operations involved numerous agencies and research organizations [Stage and Weller, 1985]. Observations and measurements were made from buoys, ships, aircraft and spacecraft. The scientific objectives spanned a wide range of subjects and included: the role of atmospheric forcing in maintaining the subtropical front; changes in surface roughness, stress and drag coefficients across the front; and mean marine atmospheric boundary-layer structure in the area [Stage and Weller, 1986].

The goal of this study is to improve the understanding of the relationships between microwave radar backscatter from the ocean and basic geophysical parameters of interest to oceanography and meteorology, such as surface winds and stress. The uniqueness of this experiment is that for the first time it is possible to quantitatively examine the combined effect of ocean surface winds and stress, air-sea temperature, sea surface wave spectrum, and total mean square slope on the measured radar cross section as a function incidence and azimuth angles, because of the near simultaneous manner in which these measurements were conducted.

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Empirical [Wentz, 1984] and physically based model functions [Fung and Lee, 1982] have had their successes and shortcomings when compared to satellite and aircraft scatterometer data. Newer RCS model functions [Plant, 1986; Donelan & Pierson, 1987] based on more detailed physical effects and related experimental results have appeared recently. They merit application and evaluation to determine their ability to account for the observed RCS data characteristics. The FASINEX data set is the best available collection for providing atmospheric and sea measurements to be used with the theoretical model functions for RCS predictions, for comparison with the data.

2. BACKROUND

This study involves the analysis of the NASA-JPL Scatterometer (AMSCAT) data obtained from 10 measurement flights during FASINEX. A total of approximately 30 hours of data were collected, for a wide range of sea and environmental conditions. The radar incidence angle ranged from 0 to 60 deg., and for each case the azimuthal scan was close to 360 deg. (within a time duration such that the aircraft traveled 12 km along a straight flight path). Winds encountered over this experiment period ranged from 2 to 20 m/s. The supporting data on sea and atmospheric conditions will be obtained from several sources. Other aircraft that often flew in the same formation with the C-130 were the NCAR Electra (wind and wind stress, temperatures, and wind fluctuations), the Navy-NRL P-3 (with winds, stresses and radar backscatter measurements), and the NASA P-3 (with the surface contour radar for wave sprectrum measurments) [Friehe and Williams,1988]. Ships and buoys also provided surface measurements.

On each day the C-130B aircraft that carried the AMSCAT Scatterometer followed a planned flight pattern that usually consisted of 80 to 100 km straight segments that crossed the frontal boundary several times. The altitude was 3600 feet. The variation in azimuth angle was performed by a conical scan rotation of the antenna mounted on the underside of the fuselage of the C-130B. The antenna (dual linear polarizations, 3.5 deg. beam width) was rotated by a gimbal system; every 4 seconds the antenna was slewed by 10 degrees for a total azimuth range of 330 deg. This rotation can be completed in about 130 seconds. Therefore local (13 km regions) and short duration estimates of the physical variables that affect the RCS can be studied. The accuracy in the estimate of the radar cross section is believed be 0.5 dB or better. Features in this data such as upwind/downwind asymmetry and spacing between maxima and between minima are of interest as well the variations measured across the front. Figure 1 is diagram indicating the a typical 3-aircaft flight formation. The C-130 carrying the Scatterometer is the lead aircraft, followed by the NCAR Electra conducting gust probe measurements of the mean and fluctuating wind that yield stress measurements and u . The last aircraft is the NASA Wallops P-3. Onboard is the Surface Contour Radar that measures the two-dimensional spectrum of the long wave field. It also carries the Goddard ROWS short pulse radar that measures the total mean-square slope (and at higher altitudes the directional wave spectrum). Fig. 2 shows the general structure of the flight lines on Feb. 18. The numbers next to each line indicate the time sequence in which they occured. The sea surface temperature front running east and west is indicated by the solid line.

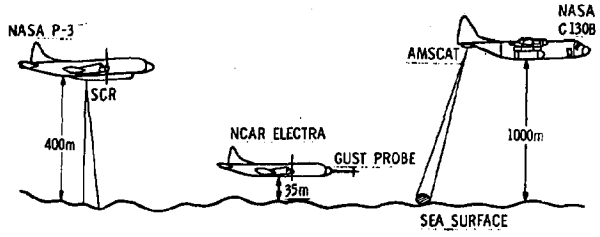

Figure 1. The aircraft relative positions and altitudes of the three different aircraft are shown.

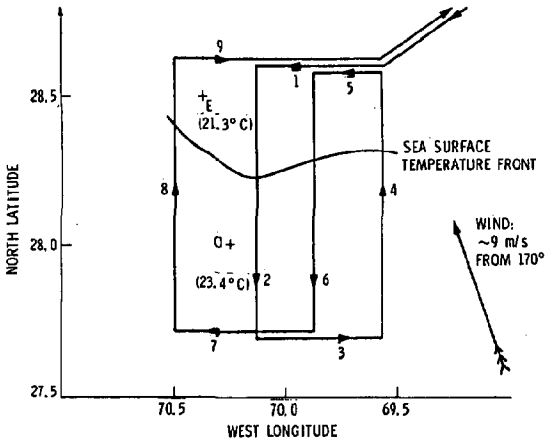

Figure 2. The flight pattern of the airplanes on Feb. 18 is shown, the arrows and numbers in each segment indicate the flight directions and the relative sequence. The curved line indicates the sea surface temperature front. A wind arrow for conditions south of the front (at a particular time) is given. The "E" and "O" are the locations of the ships Endeavor and Oceanus.

3. DATA ANALYSIS

This study is providing an evaluation of the relative and absolute accuracy of these RCS models over a wide range of radar angles and environmental conditions. In addition, whenever possible, errors in the theoretical predictions will be examined with the purpose of identifying those aspects of the theory that might be modified to yield better results. For example: the FASINEX data & theory comparisons shows that Plant's model provides good agreement with the measured V-Pol RCS results (see Fig. 3), but does not fully account for the 4 dB change in RCS ocean the ocean front (see Table 1 - sequence of antenna circles for Run 2, from 1 to 7). In addition, the measured H-Pol RCS is noticeably higher (3 dB) than the theory for incidence angles above 40 deg. (for the 50 and 60 deg. data; see Fig. 4). This latter situation (a slower decline in the measured RCS with incidence angle) has been seen in other studies [Donelan & Pierson, 1987; Fung & Lee, 1982]. Plant's theory contains a modulation transfer function term that is based on measurements of the hydrodynamic interaction; this term is important for RCS estimation.

Detailed comparisons between theory and experiment will continue to be conducted over a wide range of wind and sea conditions. Specific tests will be made to separate experimental situations where only one important quantity changes over a flight line, such as: winds (and/or stress), the long wave spectrum (from surface contour radar data) or the total mean square slope (from the ROWS radar). Comparisons between the theoretical and measured changes should give an excellent test of some of the specific terms in the theoretical equations.

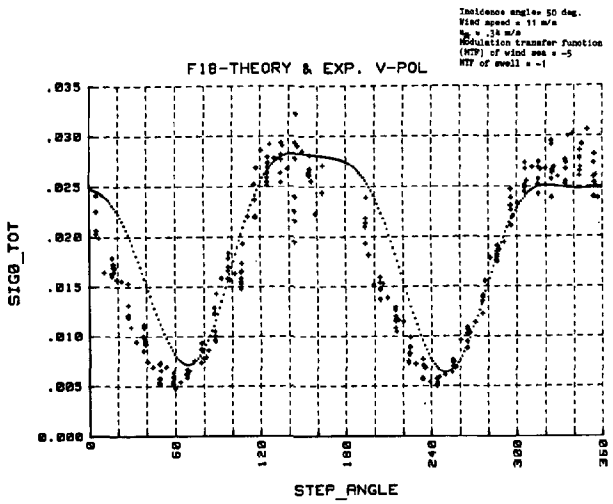

Figure 3. RCS data (V-Pol), on a linear scale, from the last cycle of Run 2 on Feb. 18 (south of the front) is given with a theoretical calculation using Plant's model modified to include two other swell wave components.

Wave slope information is an important part of all the theoretical models of RCS. Mean square wave slope measurements were made with a Ku-band broad beam radar altimeter [Jackson, et. al. 1987]. This instrument measures the total mean square slope (averaged over all azimuth angles).

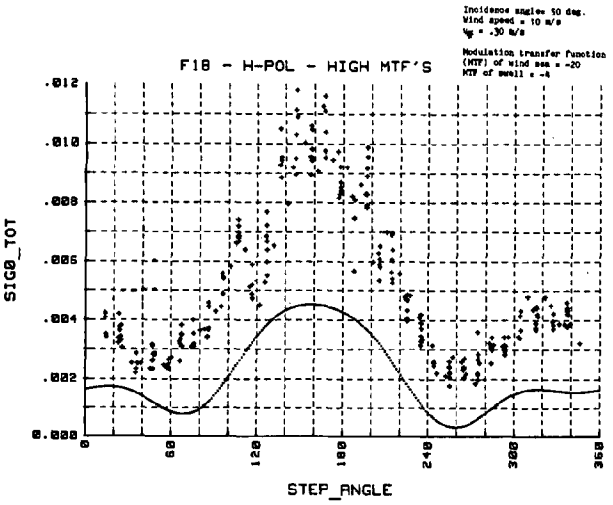

Figure 4. RCS data (H-Pol), on a linear scale, from the 4th cycle of Run 4 on Feb. 18 (south of the front) is given with a theoretical calculation using Plant's model modified to include two other swell wave components.

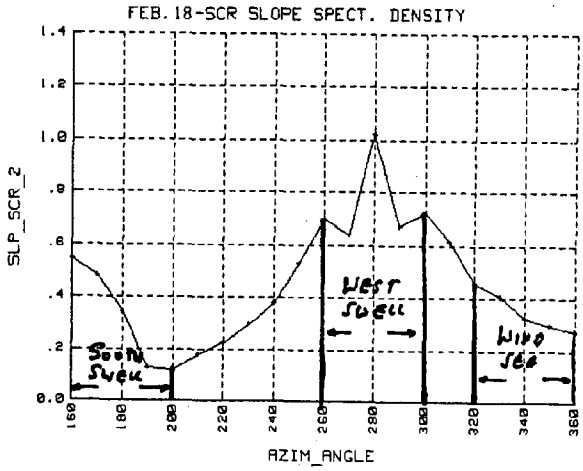

Figure 5. The integral of the two-dimensional slope spectrum (from Fig. 5) over all wavenumbers in each direction vs. direction. The wind is coming from 160 deg. and the spectrum between 320 and 360 is labeled as the associated wave field.

More detailed long wave height and direction information was measured by the surface contour radar (SCR) [Walsh, et. al., 1988, Walsh, et. al., 1985] on many of the days that the Scatterometer conducted measurements. These directional measurements clearly show the extent of other wave systems (such as swell on Feb. 18), on the total wave field. We have data files for all of the SCR wave spectra during FASINEX. From these it can be determined when other wave systems (in addition to the wind wave field) can affect the RCS. The SCR provides a measurement of the two-dimensional height power spectral density of the long wave part of the sea spectrum in a polar format, S(k,). A slope spectral density (with respect to angle only) is used in this study; it is defined as the integral of the standard 2-D slope PSD over all "long" wavenumbers, up to k=0.2. Thus this slope spectral density, SLP_D is:

$$SLP\_D = \int_0^{0.2} k^2 \left[S(k,\alpha) \cdot k \right] dk$$

If the sea consisted of a single wind driven, narrow spectrum, the graph of SLP_D vs angle would show a single prominence in the wave direction. On Feb. 18, the swell conditions relatively strong and Fig. 5 shows that the swell slope SLP_D traveling towards 280 deg. is larger than the wind sea slope traveling towards 340 deg. It is then possible to estimate the contributions to the total slope of the separate wave systems identified by the 2-D contour diagrams [Walsh, et. al.,1988]. The theoretical calculation of Fig. 3&4 (dotted curves) uses a sum of contributions from the separate areas identified in Fig. 5, along with estimates of the modulation transfer function. The incidence angle was 50 deg. Table 1 summarizes some of the Feb. 18 results. During Flight #4 (on Feb. 24) the Scatterometer measurements were at a 40 deg. incidence angle. We see that the V-Pol (Fig. 6) theory is slightly high, and the H-Pol theory is higher than the measurements by about 1.5 dB (Fig. 7).

'SIG0' - COMPARISON BETWEEN MEASUREMENTS AND THEORY

FEB. 18 (50 DEG. INCIDENCE)

RUN 2

SUB#	LAT	MEAS.(V-POL)	THEORY RCS	u*(cm/s)
1	28.6	0.013		29
	28.5		0.020	29
2	28.4	0.015		
3	28.3	0.023		
4	28.2	0.028		
5	28.1	0.028	0.029	35
6	28.0	0.030		
7	27.9	0.029		
	27.8		0.028	29

RUN 4 MEAS.(H-POL)

1	27.8	0.0073		
2	28.0	0.0090		
3	28.1	0.0080		
4	28.2	0.010	0.0038	30
5	28.4	0.0087	0.0030-0.0033	24
6	28.5	0.0055		
	28.6		0.0028	24

Table 1: Radar cross section measurements (at up-wind maximum) for individual scatterometer azimuth cycles (labeled Sub# 1 to #7 for Run 2 and #1 to #6 for Run 4) are listed and compared with theoretical estimates based on long wave mean square slope and u*

The important conclusion here, consistent with other theoretical comparisons with measurements [Fung and Lee, 1982; Wentz, et. al., 1984], is that for the larger incidence angles (> 40 deg) the measured H-Pol RCS is higher than the theory. In order to explain this discrepancy it is proposed to re-evaluate one of the important theoretical terms that is common to all of the theoretical models. This is the term in the RCS model that is referred to as the "quasi-specular term" that arises from the scalar approximation to the Kirchoff (Physical Optics) method [Ulaby, Moore and Fung, 1982, Chapt. 12]. The usual assumption has been that the sea surface height and slopes are independent (the latter being much less than 1) and have Gaussian statistics [Ulaby, et. al., 1982; Durden, 1986]. The RCS formula for this term is a Fourier transform of a Gaussian joint probability density function and thus has a Gaussian form which decays very rapidly with incidence angle. There is ample evidence that Gaussian height and slope statistics is only an approximation [Cox & Munk, 1954; Tang & Shemdin, 1983; Wu, 1975].

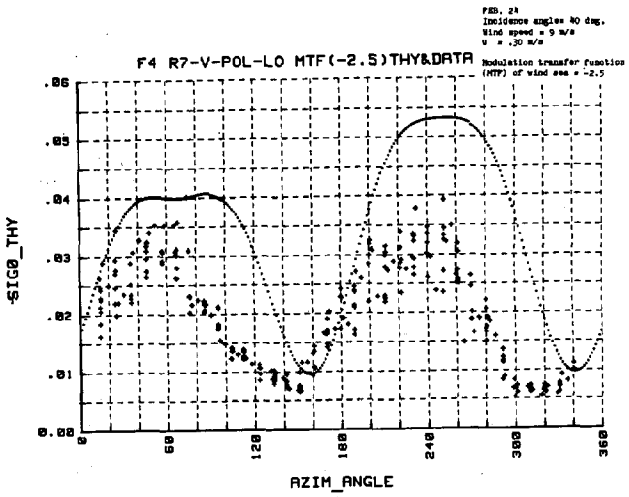

Figure 6. Comparison of V-Pol RCS with theory, from Feb. 24 data. Incidence angle is 40 deg.

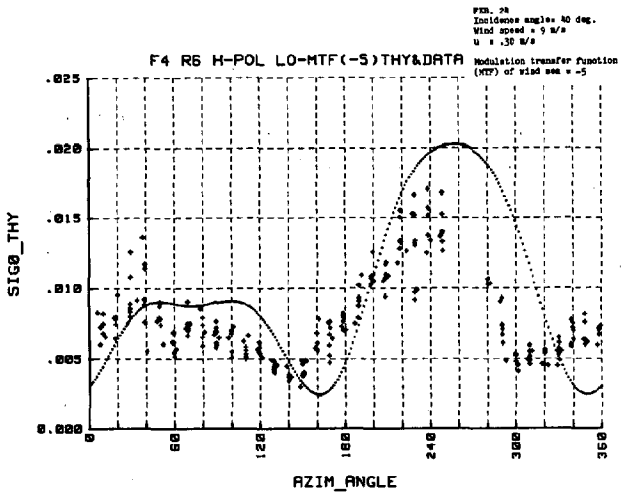

Figure 7. Comparison of H-Pol RCS with theory, from Feb. 24 data. Incidence angle is 40 deg.

Measurements of the height PDF have shown departures from Gaussian statistics at higher winds and slopes [Huang, et. al. 1983]. This is the cause of the well known electromagnetic bias effect that must be compensated for on satellite altimeter measurements. Furthermore, the measurements by Tang & Shemdin show that slope magnitude is correlated with the long wave height, contrary to the usual assumption in deriving the radar cross section from the Kirchoff integral. It is possible that departures of the actual surface from the Gaussian PDF could have an appreciable impact on the H-Pol RCS at the higher incidence angles where the

Bragg scattering term is relatively small (35 dB below the nadir RCS). The V-Pol backscatter is usually 4 to 6 dB higher than the H-Pol so it would not be affected by this additional contribution to the RCS as much as the H-Pol will be. Recent H-Pol X-band radar measurements in the NRL wavetank also find this same discrepancy at high wind speeds.

Measurement at 20 deg. incidence angle on Feb. 18 show interesting features. In Fig. 8 & 9 (V-Pol and H-Pol respectively) there are very little directional effects in these azimuth scans taken south of the frontal boundary. These show *no* maximum in the radar cross section looking upwind. However other scans along the same flight line do show a small up/cross ratio of about 2 or less. The Bragg theory (dotted curves in Fig. 8 & 9) gives a good estimate of the average RCS, but not of the up/crosswind ratios. The possible role of "physical optics" scattering will be examined for this case.

It is intended to continue theoretical and numerical investigations of the consequences of non-Gaussian surface properties, on the "quasi-specular" term in the RCS at higher incidence angles. If this effect can be proved and explained it could have important ramifications for future Scatterometer measurements and other radar techniques of ocean remote sensing.

The continuation of the analysis of Scatterometer data from FASINEX will also proceed to explore the wide range of incidence angles and wind speeds encountered during this program, and carry out more comparisons with the theory under these varying conditions.

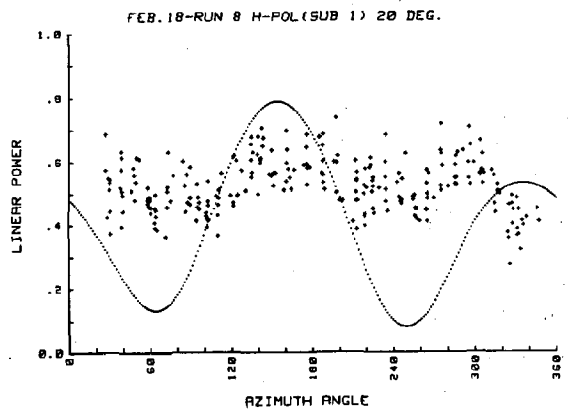

Figure 8. Comparison of H-Pol RCS with theory, from Feb. 18, south of front. 20 deg. incidence.

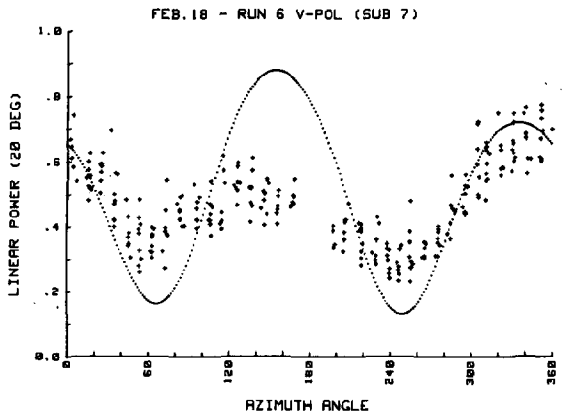

Figure 9. Comparison of V-Pol RCS with theory, from Feb. 18, south of front. 20 deg. incidence.

4. DISCUSSION

This project is advancing the understanding of the relationship of the wind stress on the ocean, atmospheric turbulence, the long wave two-dimensional spatial spectrum and the mean square slope to the average radar cross section as a function of polarization, the incidence angle and azimuthal angle. Future applications of Scatterometer data, whether from space or aircraft will greatly benefit from a better physical understanding of these relationships.

The FASINEX data from the airborne Scatterometers and the related atmospheric and ocean measurements are the "state-of-the-art" in terms of their accuracy, time and spatial coincidence, and range of conditions. The issue of the higher measured H-Pol backscatter (at the higher incidence angles) has been a puzzle for some time [Donelan & Pierson, 1987]. This study offers some new opportunities and ideas to pursue better answers to the questions about 1) the higher levels of H-Pol backscatter at the higher incidence angles (> 40 deg.) and 2) the effect of the long wave field (and the modulation transfer function) on the RCS function, at various wind speeds. For example, it has been suggested (Lyzenga, et. al., 1983) that the coherent scattering from wedges and surface elements with small radii of curvature may make an appreciable contibution to the total backscatter at the higher incidence angles. This study suggests an alternate view; that the incoherent scattering should be re-examined, but with attention to the character of the statistics and probability density functions of the ocean surface wave heights and slopes. Then it

will determined how these can affect the Kirchoff integral and the quasi-specular RCS theoretical term.

The 20 deg. data for Feb. 18 and other days will also be very useful in comparing theory based on Bragg scattering vs. quasi-specular (physical optics) scattering.

5. ACKNOWLEDGEMENT

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This is FASINEX Contribution No. 66

6. REFERENCES

Cox, C.S. and W.H. Munk, Statistics of sea surface derived from the sun glitter, J. Mar. Res., Vol. 13, pp 198-227, 1954

Donelan, M.A. and W.J. Pierson, Radar scattering and equilibrium ranges in wind generated waves with applications to scatterometry, J. Geophys. Res., Vol. 82, No. C5, pp. 4971-5030, 1987

Durden, S., Microwave scattering from the ocean surface, Center for Radar Astronomy, Stanford University, Sci. Rept. No. D901-1986-1, June 1986

Friehe, C.A., and E.R. Williams, Aircraft measurements in Fasinex, Proceedings of the 7th Conference on Ocean-Atmosphere Interaction, Amer. Meteor. Soc., Anaheim, CA., pp 38-40, Feb. 1-5, 1988

Fung, A.K., and K.K. Lee, A Semi-empirical sea-spectrum model for scattering coefficient estimation, IEEE J. Oceanic Engg., Vol. OE-7, No. 4, pp. 166-176, 1982

Huang, N.E., S.R. Long, C.C. Tung, Y. Yuan, L.F. Bliven, A non-Gaussian statistical model for surface elevation of non-linear random wave fields, J. Geophys. Res., Vol. 88, No. C12, pp 7597-7606, 1983

Jackson, F.C., W.T. Walton, B.A. Walter, and C.Y. Peng, Sea-surface mean square slope from Ku-band backscatter data, Submitted to J. Geophys. Res., 1987

Keller, M., Naval Research Laboratory (private communication).

Lyzenga, D.R., A.L. Maffett and R.A. Shuchman, The contribution of wedge scattering to the radar cross section of the ocean surface, IEEE Trans. Geosci. Remote Sensing, Vol. GE-21, No. 4, pp 502-505, 1983

Masuko, H., K. Okamoto, M. Shimada, and S. Niwa, Measurements of the Microwave Backscattering Signature of the Ocean Surface Using X-band and Ka-band Airborne Scatterometers, J. Geophys. Res., Vol. 91, pp. 13,065-13,083, 1986

Plant, W.J., A Two-Scale Model of Short Wind-Generated Waves and Scatterometry, J. Geophys. Res., Vol. 91, No. C9, pp. 10,735- 10,749, 1986

Schroeder, L,C., P.R. Schaffner, J.L. Mitchell, W.L. Jones, AAFE RADSCAT 13.9 GHz Mesaurements and Analysis: Wind-Speed Signature of the Ocean, IEEE J. Oceanic Engg, Vol. OE-10, No. 4, pp 346-357 No. C11, pp 13,063-13,083, 1985

Stage, S.A., and R.A. Weller, The Frontal Air-Sea Interaction Experiment (FASINEX); Part I: Backround and Scientific Objectives, Bull. of Amer. Met. Soc., Vol. 66, No. 12, Dec. 1985

Stage, S.A., and R.A. Weller, The Frontal Air-Sea Interaction Experiment (FASINEX); Part II: Experiment Plan, Bull. of Amer. Met. Soc., Vol. 67, No. 1, Jan. 1986

Tang, S. and O.H. Shemdin, Measurement of high frequency waves using a wave follower, J. Geophys. Res., Vol. 88, No. C14, pp 9832-9840, 1983

Ulaby, F.T., R.K. Moore, and A.K. Fung, Microwave remote sensing: active and passive, Vol. II, Addison-Wesley 1982

Walsh, E.J., D.W. Hancock III, D.E. Hines, R.N. Swift and J.F. Scott, Directional wave spectra measured with the surface contour radar, J. Phys. Oceanog., Vol. 15, No. 5, pp 566-591, 1985

Walsh, E.J.., D.W. Hancock III, D.E. Hines, R.N. Swift and J.F. Scott, Surface contour radar observations of the directional wave spectrum during FASINEX, Proceedings of the 7th Conference on Ocean-Atmosphere Interaction, Amer. Meteor. Soc., Anaheim, CA., pp 103-106, Feb. 1-5, 1988

Wentz, F.J., S. Peterherych and L.A. Thomas, A Model Function for Ocean Radar Cross Section at 14.6 GHz, J. Geophys. Res., Vol. 89, No. C3, pp 3689-3704, 1984

Wu, J., Correlation of micro and macroscopic structures of wind waves, Proceedings of IEEE OCEANS '75, pp 321-326

OONA: AN INTELLIGENT DSS FOR THE U.S. COAST GUARD

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Abstract: This paper describes Oona, an intelligent decision support system (DSS) developed at the University of Pennsylvania for the U.S. Coast Guard, in conjunction with the Coast Guard R. & D. Center, Groton, CT. As a DSS, Oona is a software tool that integrates data and models into a coherent system, thereby permitting more effective and economical use of application data and models. Data and models for support of vessel acquisition decisions are the primary application models currently available in Oona. These data and models are useful for cost analysis, performance analysis, and for forecasting costs and requirements. Although Oona was built with extensive use of artificial intelligence programming techniques, Oona is, in many ways, traditional in concept for a DSS. We envision substantial feature enhancements for Oona, which enhancements are facilitated by our having built Oona using artificial intelligence programming techniques.

1.0 INTRODUCTION

Oona is a prototype DSS. She is written mainly in Prolog, runs in the VAX VMS environment, and addresses VT240 terminals. Oona was developed for the purpose of supporting analyses of competing vessels by the Coast Guard's Office of Acquisition. The purpose of this paper is to describe and discuss Oona briefly, to review the main, general lessons we have learned from building and experimenting with her, and to discuss our plans for future releases of Oona, and other DSSs, in light of these lessons.

2.0 OONA

As in any DSS, the primary job of Oona is to facilitate the exploring and exercising of data and models. The particular data and models that Oona currently works with include vessel performance models (SAR and ELT) and vessel cost models (CASHWHARS). Significantly, SAR and ELT are Fortran models that were written well before Oona was envisioned, and CASHWHARS is—like Oona—written in Prolog. Thus, Oona has proved able to integrate disparate models into a single coherent system, in spite of the fact that some of these models were never intended to be used this way.

Besides her ability to integrate models from different sources, Oona has a number of distinctive features. We shall now discuss several of these.

First, Oona is more than a particular DSS, she is what we call a *DSS shell* [4], a software system providing DSS features and functionality in a ge-neric, reusable way. A particular DSS consists of applica-tion–specific data and models, plus software for manipulating, exercising, exploring and reporting on the data and models. In our design for Oona we have managed to make this latter software generic, so that the specific data and models may be removed and replaced with other, very different, data and models, and the feature set for manipulating, exercising, exploring and reporting on them will remain in place. By carefully developing and reusing the shell software in Oona, we anticipate that enormous benefits will be realized, including: lower incremental costs for building new particular DSSs; decreased user training costs and user resistance to computer systems due to user familiarity with the generic shell; and lower software maintenance costs due to reuse of debugged code.

Second, Oona is written in Prolog, employing programming techniques normally associated with expert systems. A typical, basic expert system consists of a domain–specific *knowledge base* that holds the system's knowledge about the application at hand, and a domain–independent (generic) *inference engine* for extracting information from the knowledge base. Because the inference engine and other system routines (e.g., for screen management) may be used for more than one expert system application, they are often referred to collectively as an *expert system shell*. Oona works as a DSS shell precisely because her software architecture resembles that for an expert system, although it is much more elaborate. Oona in fact consists of a high–level inference engine (the *meta–level*

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control), several inference engines devoted to particular tasks (e.g., for differentiating symbolic expressions), and several distinct knowledge bases, some of which are generic and some of which contain information about the data and models in this specific DSS. The job of the meta–level control is to task work out to the other inference engines as appropriate (a technique pioneered in the symbolic mathematics program, PRESS [6]). New data and models may be added simply by declaring them in the appropriate knowledge bases; the previously–existing inference engines are then automatically available to operate upon the new knowledge in the system. Further, this software architecture allows both standard procedural models (e.g., SAR and ELT) and *deductive models* (as in expert systems) to reside comfortably in a common system.

Third, Oona contains an elementary, but powerful, symbolic mathematical modeling language. Models expressed in this language may be evaluated and manipulated by a variety of the built–in inference engines.

Fourth, like its prototype predecessors [3], Oona makes essential use of a multiattribute utility model in order to integrate the cost and performance models mathematically. Significantly, the multiattribute utility model is expressed internally in Oona's symbolic modeling language.

Fifth, Oona exploits her symbolic, declarative–style programming to deliver a hypertext user interface with many of the links between information items (nodes) generated automatically by the system. Once a model (or data item) is declared in an appropriate knowledge base, generic commands are available for displaying the model (or datum) in symbolic form and for further exploration of the symbols constituting a particular model. As noted above, three models—SAR, ELT, and CASHWHARS—are integrated mathematically by a multiattribute utility model expressed in the system's modeling language. At one level, a user might see, for example, the utility model expressing the overall value of a given ship:

```
u(ship1) = k(1)*u(1,sar(ship1)) +

           k(2)*u(2,elt(ship1)) +

           k(3)*u(3,cost(ship1))                (1)
```

Note that the model is presented symbolically to the user. At this point, *generic* commands are available for exploring, and for obtaining information on, any symbol in the model. The user simply issues an `explore` command and types the symbol of interest and the system retrieves and reports on the knowledge it has of the symbol. These and related commands are part of Oona's shell and will work on *any* symbol that is part of a particular DSS.

3.0 LESSONS FROM OONA

Our purpose in this section is briefly to discuss the main lessons we have gleaned from Oona. These shall serve to motivate the discussion that follows.

(1) The use of symbolic programming proved instrumental in delivering the generic features of the shell part of Oona. (2) Expert systems programming techniques also proved key to providing a rich feature set in a modular, expandable way. We want to emphasize that Oona is not an expert system. Instead, she has been written making extensive use of declarative knowledge bases and domain–independent inference engines. The expertise encoded into Oona is expertise about how to manipulate models, how to put together a report, and so forth. None of this knowledge had to be extracted from an expert and engineered. Instead, it is mostly common, public, and—most significantly—static knowledge. (It is static because, for example, the rules of differentiation are fixed and will never change. Such stasis yields a tremendous maintenance benefit and helps promote the reuse of coded knowledge, precisely what the shell concept was intended to achieve.)

(3) We consider our experiment here with command–driven—rather than mouse–based point and click—hyper-text to be a success. Of course, a much better display system could be built, given a hardware and software environment for building user interfaces that is more sophisticated than a VT240 terminal (e.g. Macintosh

[2]). The essential point, however, is that the design concept motivating hypertext—variously described as discretionary display of information (DDI), knowledge on demand (KOD), and what you want when you want it (WYWWYWI)—has been shown, we find, to be immensely useful and valuable. In the future, no DSS should be without it.

(4) The fourth lesson we draw from our experience with Oona has to do with a significant conceptual shortcoming we discovered in operating the system. In spite of the innovative technical approaches used to implement Oona and certain of the resulting features made possible, Oona remains in concept a traditional DSS; she is a friendly environment for exploring data and exercising models interactively. All that is well and good, but more is needed and what that is may be briefly described as follows.

Arriving at a decision in a rational and considered manner amounts, we believe, essentially to developing and comparing competing arguments (or reasons) for alternative courses of action. This is called the *argumentation theory of decision support* [5]. This point of view is reflected nicely, we believe, in federal procedures guiding major decisions, for example in the A109 circular (Office of Management and Budget) that outlines procedures for major systems acquisitions. The conceptual shortcoming we find in (the current version of) Oona and in traditional DSSs is that they focus on the trees—on exercising sets of data and models—and fail to help the user see the forest—i.e., the arguments for competing courses of action, which need to be constructed and evaluated. Put another way, a major systems acquisition is a very large, lengthy project. Making particular cost or performance or configuration models available to an analyst or decision maker is useful and to be welcomed, but that leaves unsupported the critical task of *managing the process of arriving at a decision.* Consequently, we are developing a broader DSS concept and plan to incorporate it into future versions of Oona and other DSSs we are developing for the Office of Acquisition [2]. In §4.1, below, we briefly describe our expanded DSS concept.

(5) Oona has a rudimentary, but powerful, model management system (MMS), which provides the basis for very many of her interesting and useful features. Our fifth lesson is that our exploratory development of a declarative–style model management system has worked extremely well and merits significant additional development. We now turn to a more general discussion of model management in DSS.

4.0 MMS DESIGN CONCEPTS

The purpose of this section is to describe briefly some of the central model management system (MMS) design concepts implemented and/or planned for Oona, as well as other DSSs we are building for the Coast Guard.

4.1 PROCESS–ORIENTED DSS

Early on in the development of the field of DSS, it was found that DSSs in general and DSS features in particular can be categorized as either *data–oriented* or *model–oriented* [Alter 1977]. However correct this may be as a description of actual practice, it is our finding that a third orientation needs to be provided for in DSS. Assuming the argumentation theory, DSSs should be explicitly oriented towards the process of coming to a decision, and that process—tempered by case–specific requirements, e.g., the A109 process—is basically one of developing and evaluating arguments for competing courses of action. We see the requirement, then, for *argumentation–* or *process–oriented DSS* and we are actively designing and developing implementations.

Our process–oriented concept, with regard to providing DSS shell support for the Office of Acquisition, exploits and enhances concepts from the field of project management and is, briefly, this. The Office of Acquisition (in conformance with the OMB A109 circular) has carefully articulated what it wants done during a major systems acquisition project. Phases, key decision points, and so forth are identified and sequenced. Our concept is to model—in a declarative, knowledge–based system fashion—this process, both as it is set out by policy and as it actually unfolds in a particular project. This process model, a kind of deductive model, would then be available to the DSS shell, and hence to the DSS users, who could inquire as to project status, discover, e.g., what decisions were made and by whom, add information as the project goes forward, and develop project reports in the DSS.

These reports would then have full access to the sorts of models and data traditionally associated with a DSS. In our current design, we distinguish between *process-level* entities—e.g. processes that report on how the decision process is doing—and *subject-level* entities—e.g. data and models having to do with the particular subject matter of the acquisition project, such as helicopters or types of cutters. The DSS is arranged so that the user has the feel of being, at any given moment, "in" a certain step of the acquisition process. Given the user's location in the process model, certain process-level functions and certain subject-level functions will be available, and the user can then proceed with the business of contributing to the progress of the project. In sum, the goal is for the DSS to serve as a central respository of project information, which information is available to the DSS to be reasoned about for the sake of controlling and comprehending what is going on in the project. Space does not permit a full discussion of the potential benefits of such a concept, but we strongly believe that it can be instrumental in contributing to a solution of the institutional memory problem for lengthy decision processes.

4.2 FUNCTIONS OF AN MMS

Oona is meant to be an integrated modeling system that handles various modeling techniques (mathematical models, deductive models, decision analysis models, and data models), for solving problems in several domains (e.g. financial analysis, vessel acquisition, capital budgeting), across different phases in the modeling life cycle (e.g. formulating models, solving them, interpreting their results), and usable by users with varying degrees of domain knowledge and computer skills. In developing a feature set for model management, we begin by defining the different user roles that such a system must support, and which of the modeling activities they perform.

Broadly speaking, we see three user roles: 1) model builders, who construct the models and express the domain knowledge that enables the MMS to perform its functions in that domain, 2) model users and analysts, who exercise the models, solve or analyze real-world problems by providing the data, and create reports based on their analyses, and 3) browsers, or decision makers, who browse through various reports and models, make decisions based on these analyses, and seek justification for their decisions. To support these users, we define the following feature categories for a model management system.

1. Construct. New models need to be added to the model base by model builders. The system can support this task by reporting on existing models, and providing a facility to input models and solution techniques in a very natural form (particularly for mathematical expressions). Models are expressed symbolically in a model declaration language, analogous in some ways to a database data definition language. The model definition language is declarative so that, for example, builders need only declare the mathematical form of a function instead of specifying a procedure to compute it.

2. Formulate. The system will assist users in formulating models to solve their problems. This has two parts, identifying the model(s) to be used, and obtaining a symbolic formulation for the model. The first task includes identifying the problem type or context, determining a set of appropriate models, and selecting from this set. The second involves partial instantiation of the chosen models by identifying model parameters and variables for the particular problem, and obtaining a symbolic form for the model. In the example in §2 (expression (1)), the first step involves determining that the overall value of a ship is calculated by using a utility model, and the second step involves identifying the parameters for the model to obtain the form of expression (1), in §2.

3. Instantiate. Once a model has been obtained in a symbolic form, it can be used to solve different problems of the same type by instantiating it (fully or partially) to problem-specific data. Thus we distinguish between a model and a model instance. The system will use the symbolic knowledge about models to assist users in creating model instances. For the ship model, this requires instantiation of the `k(i)`'s and cost and performance parameters, which may themselves be obtained from other models.

4. Exercise. Once models have been formulated, they may be exercised or executed to obtain solutions. This includes evaluating a model (e.g. drawing a set of con-

clusions, or computing model outputs), performing symbolic manipulations (e.g. rewriting in a different form, or differentiating a model), and executing queries on a model. Depending on circumstances, and the kind of execution, model parameters will need to be fully instantiated, partially instantiated, or completely instantiated, and the system will use knowledge about the relevant models to manage this task. Models may be solved by internal solvers (as in the utility model) or by external solvers (e.g. SAR and ELT).

5. Analyze. Modeling is generally an iterative activity, since problem characteristics, problem data, etc. can change, and/or not be known with certainty. The system should assist in answering questions about these changes by supporting ad hoc post–execution analysis, which can be analytical (e.g. computing derivatives to understand the implications of changes in some parameters) or numerical. A useful feature would be the ability to generate a list of all the models and parameters affected by a change in some value, so that users are aware of the implications of the change.

6. Explain. An important requirement of a good DSS is that it be able to explain its results, so that users can form arguments to support decisions made using these results. This involves the ability to explain the models themselves, as well as the algorithms used, and how parameter values were obtained. For example, the justification for selecting a particular ship may be that it had the highest utility, which was computed using the model of §2, and so on.

7. Describe. At any stage in the modeling life cycle, different kinds of users will need information about the models they are working with, so that they may understand the model better, or determine whether or not it is appropriate for their problem. The system should be able to generate such descriptions from its knowledge about the models.

8. Validate. At various stages in the process of modeling, the system may need to get inputs from the user. These might be data values for parameters (e.g. `k(1)`), or the choice of a model to obtain values for some parameter. In either case, the system can perform checks to see if the input is valid (e.g. checking that the dimensions are consistent).

9. Maintain. Models and data need to be stored and maintained. In the case of data, scenarios (or cases) may need to be altered (in which case links to outputs need to be revised), deleted, and created. Models need to be created, edited, deleted. Further, for both data and models, additional (often meta–level) information will need to be added, altered, or deleted. Model maintenance involves a tradeoff between regenerating every value (i.e. wasteful computations), and storing results (which requires setting appropriate links so that the effects of changes are automatically managed, and the values are always updated).

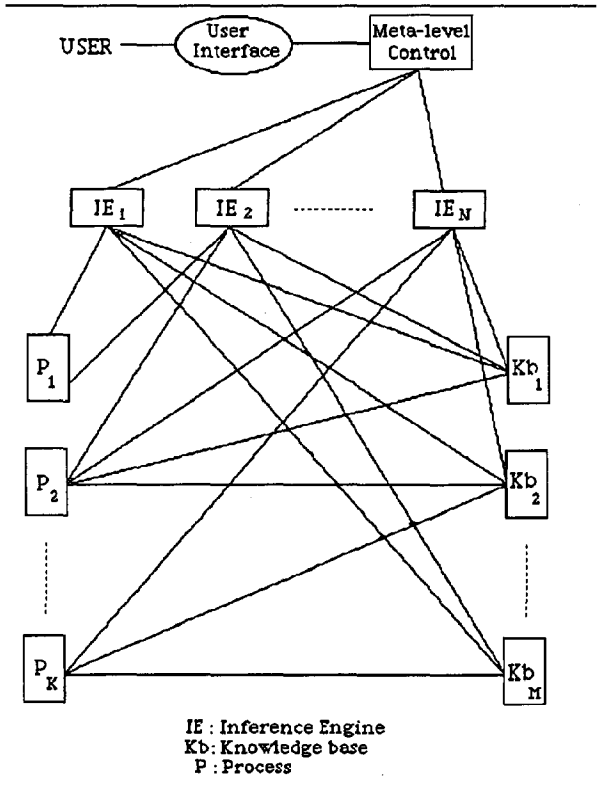
4.3 SOFTWARE DESIGN

The application of modeling techniques to solve decision problems involves a multi–step progression from the general to the specific. For example, the system might infer from a user's description of a problem that it requires minimization of shipment costs subject to satisfying demand and supply constraints, and may select to formulate it as a linear program. The final form will be a fully instantiated problem which was obtained (by instantiating index sets and coefficients) from a general product shipment problem which is a special case (with specific forms for constraints and objective function) of a linear program. For each step in this process, the system has inference engines to perform the required inferences (interacting with the user, if necessary), and there are meta–interpreters controlling the application of inference engines (since in general, there is no pre-determined procedure for using the inference engines). The inferences are performed on knowledge resident in various knowledge bases. This knowledge is obtained from users either explicitly through statements in a (model) declaration language, or through interactions between the system and users.

The system performs each of the functions in §4.2 by using inference rules that manipulate knowledge about models, obtained through a declaration language, and stored in knowledge bases. For example, the same equational form of a model would be used in describing it,

executing it, and explaining its results. In general, the system will have several inference engines that use a combination of inference rules that operate on a set of knowledge bases. Hence there is a many–to–many relationship between inference engines and knowledge bases, which is depicted in the system schematic design, Figure 1.

Figure 1



REFERENCES

[1] Alter, S. "A Taxonomy of Decision Support Systems," *Sloan Management Review,* **19**, no. 1 (Fall 1977) 39-56.

[2] Bhargava, Hemant, Michael Bieber, and Steven O. Kimbrough, "Oona, Max and the WYWWYWI Principle: Hypertext and Model Management in a Symbolic Programming Environment," *Proceedings of the Nineth International Conference on Information Systems,* 1988.

[3] Kimbrough, Steven O., et al. "A Decision Support System for Evaluation of Advanced Marine Vehicles," *Transactions of DSS-86, Sixth International Conference on Decision Support Systems,* Jane Fedorowics, ed., Washington, D.C. (April 21-4, 1986) 15-26.

[4] Kimbrough, Steven O., "On Shells for Decision Support Systems," University of Pennsylvania, Department of Decision Sciences working paper, 1986.

[5] Kimbrough, Steven O., "The Argumentation Theory for Decision Support," University of Pennsylvania, Department of Decision Sciences working paper, 1987.

[6] Silver, Bernard, *Meta–Level Inference,* North–Holland, Amsterdam, 1986.

THE ZENO ALLIANCE NETWORK: A DUAL-LOOP FIBER OPTIC INSTRUMENTATION NETWORK FOR SHIPS

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ABSTRACT

The *ZENO ALLIANCE Network* is a dual-fiber, fiber optic ring connecting any number of intelligent sensor interface (ISI) units to a central controller. Network devices transmit three-layer messages simultaneously in opposite directions around the loop, and each device has the ability to accept a message from either direction. In this way the loop is immune to breakage. Each ISI unit responds to its own address or to 'global' commands. ISIs are capable of extensive data compression and operate on the network at 9600 baud. Thus collisions are rare, easily detectable, and resolvable.

A recent ZAN installation is described. Four ISIs collect statistics of wind, air temperature, relative humidity, barometric pressure, and solar radiation from 3 different locations on the ship. The data are collected in a Microvax 2000 with a sophisticated data base management system (DBMS). Ship information is collected concurrently.

1. INTRODUCTION

ZENO ALLIANCE Network (ZAN) is a local area network (LAN) made up of ZENO data acquisition devices. Fiber optic inter-connections assure immunity from electromagnetic interference and wide bandwidth data transmission over long distances. Our first complete ship installation was a satellite ground meteorology verification system for the new NATO research vessel the *R/V ALLIANCE*. ZAN is a next-generation shipboard data system that emphasizes flexibility and expandability. Figure 1 shows the final installation of the meteorological instrumentation on the foremast of *ALLIANCE*. This paper will discuss the basic concepts of ZAN and present details of the installation.

ZAN consists of a number of *Intelligent Sensor Interfaces* (ISIs) and a *Central Computer Facility* (CCF) connected with a dual, fiber optic loop (Figure 2). Each ISI operates its own set of instrumentation with its own particular software package with common communication protocol. An earlier loop protocol which has been successful in the oceanographic community is SAIL (Serial ASCII Instrumentation Loop) which was originally developed for shipboard applications.

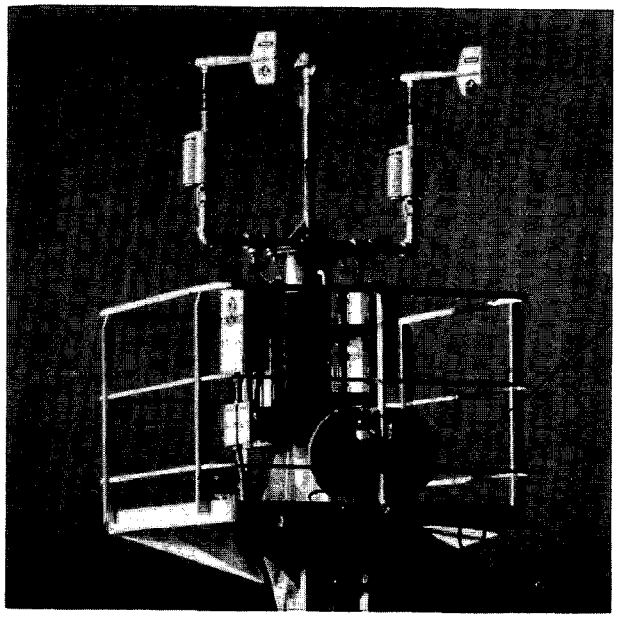

Figure 1: Photo of the sensors and intelligent interface assemblies on the foremast of the *R/V ALLIANCE*. The fiber optic and power cables are protected in flexible coated metal conduit. *Photo courtesy of Dr. Peter Minnett*

ZAN devices use a peer-to-peer communication protocol called *Carrier Sense Multiple Access with Collision Detection* (CSMA/CD) which is similar to Ethernet. Devices monitor both inputs for transmissions and switch to the active line. A ZAN message is comprised of an attention character (#), an address, a return address, the message string, a checksum, and an end of transmission character. The Central Computer Facility (CCF) is responsible for interrogating each ISI and collecting the various data.

The CCF operates a comprehensive *Data Base Management System* (DBMS) which maintains and operates the network. The DBMS software retrieves and archives data from the ISIs as a background procedure. In the foreground, the user can use the DBMS to examine data, create output reports, and run processing or plotting programs. The DBMS allows one to create and schedule customized

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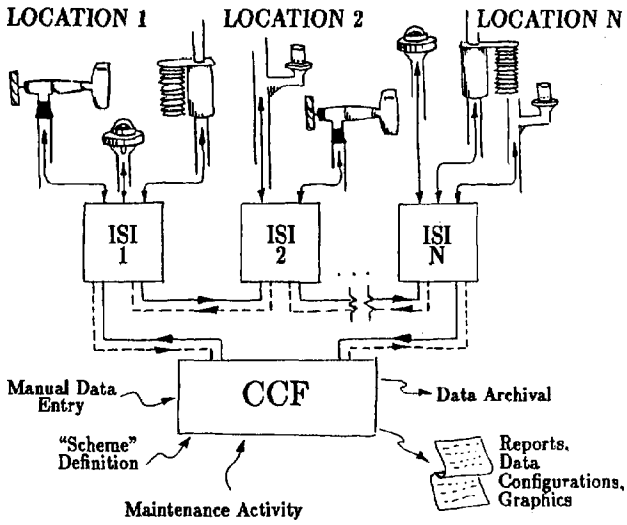

Figure 2: Sketch of a ZAN system. The dual fiber, fiber optic cable connects the CCF to all ISIs in a loop configuration. The sensors at remote sites are processed by the ISIs using individually tailored software.

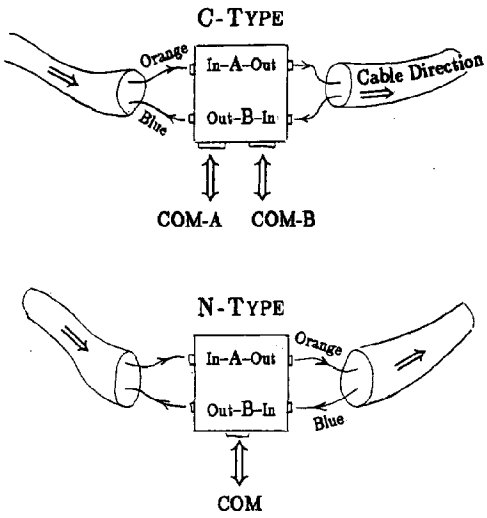

Figure 3: The fiber optic interface box and the direction of signals in the fiber optic cables. The orientation of the cable corresponds to the direction of the light in the orange (*A*) fiber.

sampling schemes. When the time for a particular scheme comes, the CCF automatically reconfigures all ISIs and begins collecting the new data. All data are marked according to the current sampling configuration.

Devices in a ZAN system communicate over dual-fiber, fiber optic cables. Each fiber optic serial port on an ISI is in effect a half-duplex port. Figure 3 shows two different types of fiber interfaces and how signals travel on the LAN. The direction of the light in the fibers is in opposite directions. The forward direction is called the *A* fiber and the reverse direction is called the *B* fiber. Actually there is no real distinction in the two but for practical purposes it is useful to distinguish between them.

Signals can arrive at the ISI on either the *A* or *B* fibers. An ISI can have one or two UART buffers. In the former case it will collect characters from only one input but will switch between buffers automatically. If it is monitoring the *A* input when a transmission comes on *B*, it will switch with no loss of data and begin monitoring that input. Signals received at any input will be re-transmitted down the corresponding fiber. When an ISI transmits an internally generated message it will transmit over both *A* and *B* fibers simultaneously.

The *Controller* is the part of the CCF that communicates and manages the LAN. The Controller uses a special type of fiber optic interface box (FOIB) to communicate onto the LAN (Type-C in Figure 3). The fiber optic interface box is a dual RS232-to-fiber optic converter. Each RS232 port is a full duplex port that transmits onto one fiber and receives from the other. Thus the Controller can communicate in either direction. In the present configuration, all signals stop at the Controller interface box.

Many different network configurations are possible with ZAN hardware. Figure 4 shows examples of *star* and *loop* configurations. The loop configuration is the most reliable configuration as it allows any device to talk to any other device and assures that the Controller can communicate with any device, even when the loop is broken or a node device has failed.

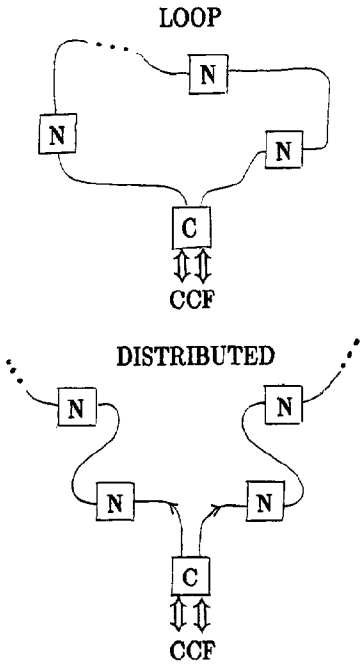

Figure 4: Two different fiber optic networks possible with ZAN hardware. The loop is the most reliable because it will operate even if the loop is completely severed at a spot. The distributed configuration is easier to install but not as failsafe.

Section 2 presents details of a ZAN network and describes the various ZAN hardware available from Coastal Climate Company. Section 3 describes the installation of this equipment on the *R/V ALLIANCE*. Finally, Section 4 is a brief description the future of the ZAN and planned new hardware.

2. BASIC CONCEPTS

2.1 *ZAN Protocol*

ZAN is designed for the interconnection of oceanographic and meteorological instrumentation on a single dual-loop LAN although other applications are in no way ruled out by this emphasis. It is an extension of the earlier SAIL protocol (IEEE,1985). Primary differences between the two protocols are: (*a*) Messages are bi-directional with forward and return addresses; (*b*) Messages are terminated with a checksum and ending character; and (*c*) Baud rates can be up to 19,200 baud.

As in any serial communication there are two states, the *mark* and the *space*. A mark or logical one is defined as the presence of light in the cable sufficient to drive the receiver circuits to a positive output. A space or logical zero is the case of zero light. The duty cycle for messages is low and the majority of time there will be no light. This is different than standard fiber optic convention but conserves power for battery powered devices. Special circuitry in the ISI interface distinguishes between true communication signal and random light from an exposed fiber.

All communication within the ZAN system is asynchronous ASCII and will use the 256 character IBM standard character set including control characters. Each character has 10 bits consisting a start bit, 8 data bits (no parity), and one stop bit. No parity bit is required. The use of an end-of-message checksum provides ample checking of the message. If any device uses or requires parity, it is up to the communicating equipment to deal with that requirement.

In loop operation, the Controller communicates through two full duplex serial ports, *COM1* and *COM2*. One port transmits on the *A* fiber and receives from the *B* fiber. The other port uses the reverse order. Signals transmitted from one port travel directly through each ISI around the loop and are received at the other port. The Controller can assess loop health and pinpoint any faults using a logical process of elimination. If the loop is broken or if a star configuration is used, the Controller treats each network as a separate full duplex communication port.

ZAN protocol permits any device on the LAN to exchange data with any other device. This uncontrolled usage can lead to conflict when two devices transmit at the same time. High baud rates and short messages are recommended to reduce the probability of a conflict . The use of a message checksum will reduce the probability of an error.

The Controller can check its own message and re-transmit if it is bad. If a loop break is encountered, the Controller can switch to the other loop. The ISI cannot check its own message; instead it waits a nominal time for acknowledgement from the addressed device.

A *message* is any exchange of information from one device to another. A message can be one of two types: a *request* or a *reply*. Messages will have one of two formats: *formatted messages* or *unformatted messages*. Dialog between two devices begins with a formatted request. Two devices can agree to go into an unformatted or *open* state by a formatted exchange.

A formatted message consists of six parts: an attention character, an address, a return address, the message string, a checksum, and ending character.

The '#' (ASCII decimal 35) is the *attention character* for all elements of the ZAN. When any device receives #, it begins monitoring the incoming string. Simpler devices must suspend sampling to do this but multi-tasking devices can collect data and monitor the LAN simultaneously.

A *device address* will be 4 numeric characters. We recommend that device addresses and device serial numbers be the same as this facilitates configuration control and configuration archival. The ISI checks each numeric character and compares to its address. The moment the incoming address disagrees with the ISI programmed address, it returns to waiting for #.

If the first character after # is one of the letters *A-Z*, then all ISIs will check the message to see if it is one of their programmed *global commands*. Global commands are given by the Controller. They are interpreted by all devices. Since all devices obey the global command they do not usually issue a reply. Global commands can be used to set the clock, change baud rates, or other such communal operations. Two global commands are:

`BDbbbb`	Sets the baud rate to bbbb.
`TMyymmddhhmmss`	Sets the device clock to year, month, day, hour, minute, and second specified.

The *return address*, the four digit address of the sending device, is the next 4 characters in the message string after the device address. This will be the address for any reply messages. A responding ISI will invert the device address and the return address in its reply.

The *message string* is any string of characters that will be interpreted by the receiving device in a particular way. The string can be a simple command or it can be an extensive data output with embedded control characters. The attention character (#) and the ending character (^D) are not allowed to be in any message string.

The *checksum* is two decimal numbers which are computed by adding the ASCII value of all characters following and not including the attention character. Only the last two digits of the sum are transmitted.

$$Checksum = \sum(\text{ASCII characters}) \bmod 100$$

Finally the last character in the entire message string is the *end-of-transmission* character. In ZAN, the ending character is the control-D, written ^D, whose ASCII value is 3.

When the address, checksum, and ending character all agree, the addressed device interprets the command string and replies with the appropriate responses. The addressed device must respond within two seconds and the mean time to respond should be less than one second. The response time should be as short as possible to reduce the time the loop is committed. All responses to a formatted command message will be formatted reply messages. In the case of global commands, the global command, checksum, and ending character must agree for the device to respond.

A *null message* is a command message with no message string, that is there is an attention character, address, return address, checksum, and end character only. On receipt of a null message the ISI will enter into an *open state* where communication is not formatted and straight serial communication is possible. As an example, if the address of an ISI is 1111 and the address of the sending device is 0000, then the null message would be:

#1111000088<^D>

On entering the open state the ISI sends a formatted reply of:

#00001111OPEN94<^D>.

In the open state, the two devices will be able to communicate on the LAN in a half- or full-duplex mode depending on the connections to the LAN. ISI software provides a menu oriented operating system that allows the operator to change software parameters, test sensor operation, read status or down-load data. From the open state it is possible to re-load software or change code. Since ISIs are often placed in un-sheltered locations, this is a major advantage.

The open state ends if: (*a*) a command is given from the command device; (*b*) a # occurs on the LAN; or (*c*) a BREAK occurs. The BREAK is a pulse of light with a width between 120 msec and 150 msec. It causes a complete LAN reset.

2.2 *Intelligent Sensor Interfaces*

A block diagram of the major components of a Coastal Climate Company ISI are shown in Figure 5. The major components are the two fiber optic interface circuits, transient relief and power regulation circuit, digital interface circuit, analog-to-digital (A/D) circuit, CPU, and power supply.

The ISI can be powered in three ways. An external 9-18 volt DC power source can be connected to terminals in the sensor input connector. Typical current drain is less than 75 mA including fiber optic communication. Standard 105-115 volt AC power, 50-60 Hz, can be supplied via a separate AC power connector. The power line has 'hot', 'neutral', and ground terminations. Each ISI has power protection capable of withstanding 2500 V 50-μsecond voltage transients and thus will withstand all expected power surges. The equipment should be safe if operated with the ship's standard power although if protected power is available it should be used. The transient protection circuit combines capacitors and protection diodes as a combined RF filter

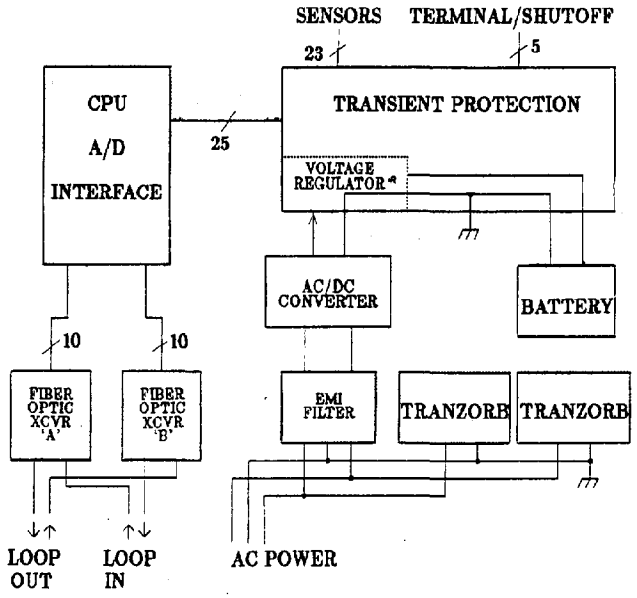

Figure 5: Block diagram of the Intelligent Sensor Interface.

and high-voltage shunt. Finally a 2.1 A-hr internal battery protects the ISI from line surges and fluctuations and maintains operation in the case of external power failure.

The fiber optic receivers and transmitters are made by Hewlett Packard Co. The transmitter (HFBR-1404) contains a planar 820 nm GaAs emitter and the receiver (HP HFBR-2402) incorporates a monolithic photo-IC which contains a photodetector and DC amplifier. All fiber optic connections are SMA connectors and the fiber optic cable used is 50/125 μm glass fiber.

The fiber optical power budget is as follows: The optical transmission power into the cable is rated at - 17.5 dBm. The receiver requires at least - 11.2 dBm to operate reliably. Thus about 6.3 dBm surplus light is available. At -40 °C temperature this figure is degraded by approximately 2 dB.

The fiber optic connectors degrade the signal by about 0.5 dB each and feed-thru connectors degrade the signal by as much as 1 dB. The attenuation in the 50 μm glass fiber is less than 5 dB/Km. Our longest run will less than 0.2 Km. Thus we expect a surplus light power of 3.3 dBm typically and 1.3 dBm in the coldest conditions.

The fiber optic connectors are soldered directly to the fiber optic interface printed circuit boards and protrude through the wall of the ISI housing. O-rings seal the holes and provide mechanical support to the connectors.

ISIs can accept 3 different types of data signals: analog voltages, frequency variable sine or square waves, and RS232 serial signals. Resident software in the ISI determines how the data signals are sampled and converted to final numbers. Data are stored as fully calibrated floating point numbers. In this way complicated data manipulations at the CCF are reduced and overall flexibility is enhanced.

Two identical frequency circuits are provided. Each is

designed to read the AC signal from an R.M. Young wind monitor. The wind monitor output is a sinusoidal voltage whose frequency is proportional to wind speed and whose amplitude varies from about 10 mV at near-stall speeds to about 1 V at high winds. When other types of inputs are required, the input buffer circuitry is easily modified.

There are eight analog inputs. The number can be expanded if necessary as the A/D circuit boards are stackable and addressable. The A/D circuit uses an ADC1205 12-bit A/D integrated circuit. A free-running oscillator provides a conversion clock to the circuit. Reference voltage is generated by a precision reference and voltage-follower amplifier. The analog input signals are buffered in low-pass filters and multiplexed under CPU control.

There are two serial RS232 inputs: COM1 and COM2. COM1 is used by the LAN and optionally by the terminal. COM2 is available in the sensor connector and can be used for any variety of inputs. One example is to operate a digital barometer such as the Paroscientific Digiquartz barometer. The COM2 port has four signal lines: transmit line; receive line; Data Terminal Ready line (DTR); and ground. The DTR line is a bi-directional 0–5 V high-impedance digital i/o signal line.

2.3 *ISI Software*

The above descriptions of ZAN protocol and the ISI hardware provide a nucleus of an operational network. The specific software in the ISIs determine how they will be able to function as an integrated system. ISIs are capable of running distinct sets of software. In fact any intelligent device such as a PC can operate as an ISI as long as it follows the few simple guidelines.

ISI commands follow a menu oriented syntax. There are four menus: *main*, *data*, *parameter*, and *test*. They are designated by M>, D>, P>, and T>, respectively. The menu domain is entered via the main menu. If you are in a particular menu and want a command from that menu, simply enter the request syntax. If you want a command from another menu you must first transfer to the correct menu by typing the menu letter. Commands can be concatenated into one long command string but menu jumps must be made correctly.

Fundamental to the operation of ISI software is the concept of *parameters*. Each ISI maintains a parameter array of numbers (Currently there are 30 32-bit numbers possible.) that can be used to control timing, sampling options, or data conversions in the ISI. They can act as flags signalling the presence of certain sensors. Parameters are designated by the symbol P_i, $i = 1, \ldots, 30$.

Parameters are read and written in the parameter menu. Parameters are altered in RAM memory with the syntax Pn/m where n is the parameter number and m is the desired value. Parameters can be stored permanently in the CPU EEPROM using the command E.

Example: The message string P1/20ETI *changes parameter 1 to the value of 20, stores all current parameters in EEPROM, then moves to the test menu and requests internal temperature.*

A *setup* is a particular assignment of values for the specific parameters which control sampling and averaging in a particular ISI (parameters 1-5, see below). The user defines one or more setups for all ISIs in the DBMS. Setups can be given names such as 'one_minute' or 'on_station'. A *scheme* is a particular group of setups for one or more of the ISIs defined in the ZAN DBMS. The scheme can be defined in the DBMS by a unique name. One or more schemes can be defined.

A DBMS table allows the user to schedule when different schemes are to be initialized. This feature is one of the most powerful aspects of the ZAN DBMS. It is possible to partition a complete cruise for satellite overpasses, intercomparison times, and less intensive periods in advance. All current parameter values are collected from each ISI whenever data are collected.

Certain of the parameters have specific functions in the Coastal Climate ZAN: Parameters P_1–P_5 are used exclusively for the sampling schedule. Parameter P_{28} contains the ISI four-digit address. Parameters P_{29} and P_{30} contain the date and time of the initiation of the present scheme. The CCF Controller transfers P_1–P_5 and P_{29}–P_{30} to each ISI as part of a scheme initialization. Each time the controller collects data from an ISI it also reads back the entire parameter list and compares the date-time to the date-time of the current scheme. If they do not agree, then the data will not be logged into the data base. It is felt that this cross checking is essential to insure a maximally un-corrupted data set.

Another important concept in the ISI-DBMS interaction is the concept of *fields*. The ISI stores computed statistics (samples, means, standard deviations) in memory as individual ASCII lines. Each line begins with the date and time of the line followed by a string of data separated by commas. The line is terminated by a carriage return and line feed. The comma separators define data fields. Each field for each ISI is defined in the DBMS. As the data are collected they are stored in the DBMS measurement table according to their definition in the DBMS. All data are stored in association with the scheme, parameters, time, and ZAN setup that was current at that time.

Communication between a terminal and the ISI is possible over the fiber optic cables or with the terminal connection. To speak directly to an ISI over the LAN simply plug a terminal or computer into the fiber optic interface box. Either the *A* or the *B* loop can be used. A terminal can be programmed to send formatted commands to individual ISIs or it can send a null message and open up a particular ISI for unformatted communication. With a terminal you will be able to: (*a*) set calibration coefficients; (*b*) set ISI addresses; (*c*) sample all sensors for calibration or checkout; (*d*) set the clock; (*e*) set sampling duration, interval, and time or; (*f*) re-program the ISI partially or completely.

2.4 *Central Computer Facility*

The complete computer system is called the *Central*

Computer Facility (CCF) and the Controller is the part that maintains communication with the ZAN devices. The Controller can be a piece of hardware in a distributed processor system or it can be a background procedure in a multitasking computer. The CCF described here uses the latter approach with a MicroVax 2000 computer and peripherals (Figure 6). Our CCF software can be implemented in AT, IBM mini, or HP environments as well as Digital Equipment Corporation's VMS.

The software in the CCF is a combination of continuously running system programs and programs which are called by others on a predetermined schedule. Figure 7 shows the interaction of the different components of the software. Rectangles represent batch jobs that run concurrently and interact with the DBMS. Tilting parallelograms represent processes that are initiated, run to completion, and terminate. These processes are usually called as VMS jobs by the VMS Controller. Disk files are represented by the cylinders.

The Data Base Management System (DBMS) is the heart of the ZAN CCF. Of several options we have chosen the FOCUS software package from Information Builders Incorporated for the nucleus of the DBMS. FOCUS stores information in a relational data base so that any data can be related to other data through defined pointers. The DBMS provides a quickly assimilated hierarchy of menus with which one can configure the network, schedule schemes and VMS procedures, and print out reports of past data. The window/menu technique though somewhat slower to manipulate then direct commands, provides an easy system for occasional users.

For more sophisticated reporting and data manipulation, the advanced user must become familiar with the FOCUS database command structure. With this he will have immense processing capability including most statistical procedures. Alternatively, the user can write out selected data to ASCII archival files on tape or hard disk and process them with individual software packages.

Great thought and care was given to DBMS architecture with the following guidelines: (*a*) The DBMS must allow complete flexibility for the addition of diverse instrumentation and sampling characteristics. As an example, occasional data from an expendable bathythermograph should be as easily entered as data from regularly sampled air temperature sensors. (*b*) The DBMS should provide complete configuration control and archival. The ZAN configuration at any moment must be part of the DBMS and all data in the DBMS must be associated with the ZAN configuration at the time it was measured. This includes hardware serial numbers, parameter settings, calibration coefficients, and, of course, time. (*c*) The DBMS must provide for the casual user and the non-sophisticated user. We decided on a menu oriented multi-table DBMS which leads the user through all steps of the system operation. If this is frustrating to an

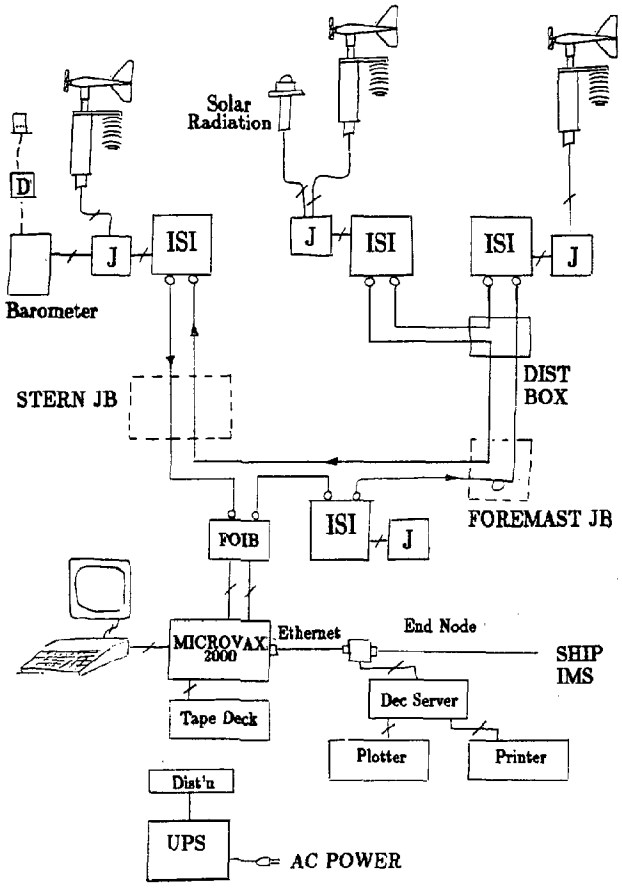

Figure 6: Sketch of ZAN installation on the NATO Research ship *R/V ALLIANCE*.

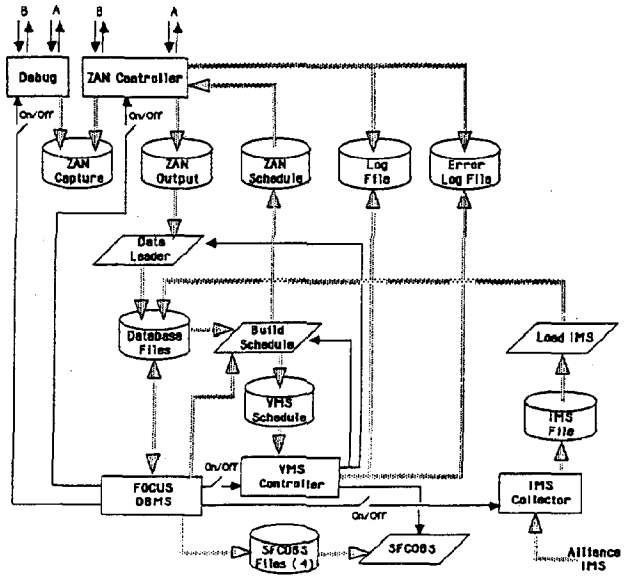

Figure 7: Block diagram of the Central Computer Facility software. Rectangles are continuously running programs; slanted parallelograms are called procedures; cylinders represent disk files. Solid lines are lines of control and hashed lines represent data flow.

expert user, they may work directly with FOCUS command language. However, the scientist who comes on board once in six months or the ship technician will find the menu operation with its checks and cross-checks infinitely useful.

There are actually two controllers in the VMS system; the ZAN Controller which up to now we have called the Controller, and the VMS Controller. The ZAN Controller communicates messages onto and receives responses from the ISIs on the LAN. Messages for the LAN are stored in the *schedule file*. The schedule file is a text list of times and activities for the next several hours. The schedule file is routinely updated by a VMS procedure called in the VMS schedule file. In this way the process is self-perpetuating. An activity might be a command message for a particular ISI and it might be a global command for all ISIs. Data received by the Controller are stored in the LAN data file.

The ZAN Controller codes out-going messages with addresses, checksums, and start/stop characters. It decodes incoming messages. The Controller handles collision errors, LAN faults, and other management functions.

Routinely a VMS procedure loads the data into the data base. When the *capture mode* is on, all LAN communications are also stored in the Capture file. If a received response does not check out, the Controller will repeat the request. The operator can select how many times the Controller will try to get a good message. Currently, with one repeat try a 99% data recovery is achieved. If the LAN is broken, the Controller will send and receive on different loops and notify the operator of the problem.

The VMS Controller operates in a manner similar to the ZAN Controller and allows system batch jobs to be scheduled and run via the DBMS. A *procedure* is a VMS job that is initiated and runs to completion. Procedures can be scheduled in the DBMS. In this case they will be entered into the VMS schedule file and then are called by the VMS Controller. They can be run on request by a call directly from the DBMS. Procedures may be command language files, executable files, or a combination. Users can write and execute their own procedures using the DBMS commands table. Thus plotting, report writing, and archival activities can be run routinely by the system. The VMS Controller reads the VMS schedule file for time and activity. At the appropriate times, the Controller launches VMS batch jobs or processes. Jobs can run periodically (1-minute, 5-minute,...,hourly, 3-hourly,..., daily), on request, or 1-time only.

We define the ship's *Information Management System* as a single computer port which provides all current ship operational information: position, ship speed, heading, gyro information, and engine status. The IMS collector software periodically reads data from the IMS and formats them for the DBMS as though they came from an ISI on the LAN. An ISI could perform this task in the case when an IMS is not present.

The *Debug* software allows the operator direct control of the LAN from the CCF monitor. The Debug program first turns off the ZAN Controller and then allows the user direct access to the network. The user can communicate directly in unformatted text or he can send and receive formatted messages. Debug allows direct contact with each device on the network.

Hourly coded meteorological surface observations are prepared by a sophisticated melding of all available data. The code conforms to the World Meteorological Organization (WMO) synoptic code for ships at sea. The software that does this is called SFCOBS. SFCOBS uses DBMS application routines to create 5 data files for the past ten minutes of data from the database. Files 1-3 are meteorological measurements from three different locations on the ship. Three different sets of instrumentation can be defined with a DBMS table. Thus there can be a 'port', 'starboard', and 'stern' location of instruments. The DBMS allows the operator the flexibility to specify each sensor and also to designate for what relative wind directions each sensor is valid. (i.e. Ignore a sensor when it is leeward of an obstacle.) File 4 is the IMS data collected during the past ten minutes and File 5 is information from the SFCOBS setup table of the DBMS.

The process of melding the four time series into one is involved. All time series are filtered and resampled onto a common one-second sample period. All valid relative wind directions are reduced into a single direction for each second and these directions are used as criterion with the DBMS table to compress the three time series to a single 'best' relative time series. Next, the ship speed and directions and the relative winds are used to compute a true wind vector time series. Finally, the ten-minute second-by-second final time series of all meteorological variables are averaged and the WMO weather code is produced.

3. R/V *ALLIANCE* Installation

We have recently installed a ZAN system on the research vessel *ALLIANCE*. The ship is operated by the Undersea Research Centre of the Supreme Allied Commander Atlantic (SACLANT), located in La Spezia Italy. *ALLIANCE* is 93 m long, displaces 2450 tonnes, has a sustained speed of 16.3 kts, has a crew of 10 officers and 17 crew, and supports a scientific staff of 23 persons. Figure 6 is a diagram showing the ISI locations and sensors.

For *ALLIANCE*, ZAN is sub-divided into seven major sub-assemblies: (1) Foremast sensor mast; (2) Foremast ISI plate for starboard sensors; (3) Foremast ISI plate for the port sensors; (4) Stern sensor mast; (5) Stern ISI plate; (6) Lab ISI plate (a spare system); and (7) Central Computer Facility.

Figure 1 is a photo showing the foremast mast assembly and ISI plates. The foremast provides an excellent platform for measuring surface layer conditions in uncontaminated air over a broad forward sector (relative wind directions from 230° to 120°). Instruments at the top of the foremast will be approximately 16 m above the sea surface.

The foremast sensor mast assembly includes the mast structure, the sensor mounting hardware, and the sensor

assemblies. The foremast mast is mounted on the foremast pedestal. It holds the port and starboard meteorological sensors and the radiation sensors. A completely redundant set of instrumentation is installed on the foremast for maximum reliability. The short-wave downward radiation measurement is not redundant and is measured with the starboard ISI.

Each 'plate' assembly is a heavy aluminum plate on which are mounted the ISI, sensor junction box, and any additional item for that particular location.

The LAB ISI is located in the ship laboratory. At this time there are no sensors attached to it. It will serve as a spare ISI. Sensors can be attached to it over time and the data will be collected into the data base.

The wind monitor and temperature-relative humidity sensors are combined into a single interchangeable module called the *WEATHERPAK*. Coastal Climate Company manufactures WEATHERPAK in a variety of configurations of intelligence, memory, and sensors. The model used in ZAN combines an R.M. Young wind monitor and a modified Rotronic temperature-RH sensor into a single module with transient protection and radio frequency filtering on all signal and sensor power connections. Figure 8 is an exploded view of WEATHERPAK. All components of the system use sealed connectors and can be removed or replaced with little trouble.

Air temperature and relative humidity (RH) are measured with the Rotronics MP-100 hygromer sensor. The air temperature is measured by two different sensors. A platinum RTD sensor is used by the RH circuit for temperature compensation but while the RTD has excellent long-term stability, the linearization circuitry used by Rotronics is only accurate to about $\pm 0.8°C$. For better temperature accuracy, Coastal Climate Company has modified the MP-100 by adding a thermistor bridge circuit to the MP-100. The thermistor is the Yellow Springs Inc. (YSI) bridge Model 44212, interchangeable to 0.2 °C .

Complete electromagnetic shielding is provided with the WEATHERPAK. The Rotronic T-RH sensor is mounted inside a metal tube and then inside the radiation screen. All sensor signals and power lines are protected from transients and EMI by circuitry including resistor-capacitor filters and ferrite toroids. Lightening and corona transients are shunted by transient protection 'transorb' diodes.

The WEATHERPAK mounts to a special clamping base which incorporates the unique 'Kamlok' fitting. The Kamlok fitting was originally designed for high pressure hoses in fire fighting and tanker industries. Its cam-shaped locking arms press the mating insert down onto an internal gasket making a water-tight seal. We have added an internal cylinder with additional o-ring seal to the Kamlok fitting. The internal cylinder supports a 10-pin connector that connects the WEATHERPAK to the ISI. All electrical wiring is entirely enclosed in metal tubing, either in side the mast or in flexible coated metal conduit.

Barometric pressure is measured with a Paroscientific intelligent pressure sensor at the stern location. All calibration coefficients for the barometer are stored in the sensor EEPROM, and it can be altered with a computer connection. In all barometers the most typical error will be an offset; the unit will track pressure changes correctly, but will be offset by a constant amount. We have provided an ISI parameter to correct for offset error in the barometer. Thus it is easy to correct the barometer during a cruise or in inclement conditions.

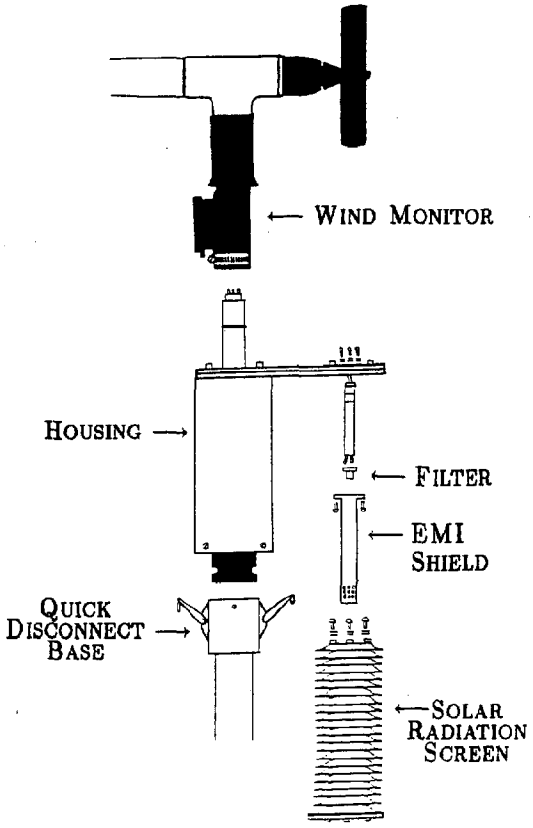

Figure 8: Exploded view sketch of the WEATHERPAK sensor package. The wind monitor plugs directly into a connector with o-ring seals. The temperature-RH sensors are covered with a teflon particle filter and the entire electronic package is shielded with a metal cover. With the Kamlok clamping base the unit is easily removed or replaced.

Solar insolation is measured at the foremast starboard location. The black-and-white pyronometer has a conversion gain of 10 μvolts/Wm^{-2} and in full sunlight the sensor output will be about 10 millivolts. Preamplification by a factor of 200 is required to convert the sensor output to the nominal 2 V input required by the ISI. A very low noise instrumentation amplifier, MAX420, is installed in the foremast mast just under the radiation sensor. By amplifying as close as possible to the sensor and keeping electrical wires inside the mast and conduit we have eliminated any detectable noise in the data.

4.0 Conclusions and Future Developments

The ZENO ALLIANCE Network was developed so that a network of ZENO data collection platforms could be connected together in a peer-to-peer local area network. We use fiber optic connections because it provides noise-free reliable operation at high baud rates over long distances.

The installation on the *R/V ALLIANCE* met or exceeded all expectations. We routed the fiber optic cables in two days. The fiber optic connectors were installed after the cables were pulled through the ship wireways. They were made in place; on the deck or the lab. Ship's technicians learned to make the connectors in a couple of hours. Each connector was assembled in less than 20 minutes and the failure rate was about one in ten.

After the entire network was configured and operating we added the fourth ISI in the laboratory. This involved only making the fiber optic connections and editing the DBMS configuration tables. The entire process was completed in less than thirty minutes.

The data have been completely free of ship induced noise. Even though the foremast mast is placed in front of two ship radars and one end of the ship's HF radio antenna connects just below it, we have not seen the slightest electromagnetic contamination. Any one who is familiar with ship instrumentation installations will recognize the threat these noise sources pose.

We are just beginning to collect long data sets with this installation. During a test cruise the redundant instruments on the foremast tracked perfectly. The temperatures were within 0.1 °C of each other and the RH sensors were within 3%. Vector averages of wind speed were within 0.1 ms^{-1} and directions within 2 degrees. The stern instruments tracked almost as well but for obvious reasons differed somewhat.

With any new development, there are enhancements that will be developed in the near future. Coastal Climate Company is actively pursuing the following improvements:

- Expendable bathythermograph (XBT) reader ISI connects to an XBT launcher and logs each profile for entry to the DBMS.
- ISI interface to an infrared detecting sea surface temperature sensor.
- ISI display device. This unit will connect into the network and collect data for display. The display will be able to interrogate any ISI or the CCF for data to display. The display will be a plasma display with touch screen control for operator convenience. It will be water resistant and can be placed in unsheltered locations.

We believe that ZAN is an ideal extension to the SAIL principle. It is time that all research ships begin using a common data management in an organized effort to upgrade the quality and the availability of ship data. ZAN is a system which will provide this needed next step.

Acknowledgements

The ZAN system concept has been on these author's minds for some time but it required an act of faith by the scientists of the SACLANT Undersea Research Centre to bring it to reality. In particular we appreciate the help and effort by Dr. Peter Minnett, the chief scientist for the project. The chief engineer Mr. Frederico De Strobel and his technicians Roberto della Maggiora and Antonio d'Augustino provided much help in the installation.

References

Atallah, Deif N. (1988) Peer-to-peer protocol facilitates real-time communications. *Electronic Design News, Aug 18,* 179-186.

IEEE Standard ANSI/IEEE Std 997-1985.

ENVIRONMENTAL CONDITIONS IN NEW YORK BIGHT, JULY-AUGUST, 1987

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ABSTRACT

During the summer of 1987 the coastal area of New Jersey experienced short periods of local and regional anomalies in coastal and offshore characteristics of water and flow during the period of late July and early August. Intervals of warmer-than-normal surface waters occurred, associated with slightly higher-than-normal salinity. Short periods (up to ten days) of wind direction blowing from the northeast and onshore may have created conditions which would favor onshore transport. Large-scale systematic abnormality of the environment in the New Jersey coastal region is not evident.

1. INTRODUCTION

To describe the environmental situation along the mid-Atlantic coast during the months preceding events of interest in August 1987, we utilized selected standard information collected by NOAA through three of its Line Offices: observed and modeled winds from National Weather Service (NWS), water temperature and salinity from National Ocean Service (NOS), and satellite sea surface temperatures from National Environmental Satellite, Data, and Information Service (NESDIS).

2. AIR TEMPERATURE AND PRECIPITATION

During June and July 1987, coastal stations from Bridgeport, CT, to Cape Hatteras, NC, experienced warmer-than-normal air temperatures. In August this regime changed with stations north of Atlantic City, NJ, recording below-normal temperatures. In the middle region, including Maryland and Delaware temperatures were near normal, and to the south temperatures remained above normal for August. Boston recorded lower-than-normal average monthly temperatures for the entire year until September 1987, a pattern possibly related to the presence of a cold pool of water east and southeast of the New England states.

From June through August the area experienced predominantly drier-than-normal conditions. Several stations experienced drought conditions during this period. The exceptions were Kennedy Airport at the apex of the New York Bight, which had near-normal or excess rains, and Atlantic City and Baltimore, which received at least 25 percent more than normal amounts of precipitation during July.

3. WINDS

Wind data for the area are available in several forms. Climatological analyses provide monthly means of temperature and winds averaged over large areas. The National Climatic Data Center (1987) publishes Local Climatological Data giving daily values as well as summaries for each month for each NWS station. The predicted wind field from the NWS Limited-area Fine Mesh model archived at NCDC provides still another estimate of the surface wind values for the region, particularly over the ocean.

Observed Winds

Long-term average surface winds in this region flow from the south and slightly offshore during this period of the year (Williams and Godshall, 1977; Bishop, 1980). South and southwest winds will produce offshore movement of surface waters along the New Jersey coast. Williams and Godshall give only July data in this summary form. These authors have rated the summer constancy of the winds near 40 percent, which is relatively steady compared to the spring or fall periods and is slightly less constant than the values found for winter. Bishop displays both July and August summaries in wind roses, whose mean values agree well with Williams and Godshall.

NWS observations from Atlantic City, NJ, show the winds, as indicated by the 'fastest mile', predominantly onshore during July 1987, then southward alongshore during early and middle August 1987 (Figure 1a). The remainder of August winds were highly variable, trending generally shoreward. These "fastest mile" winds probably include a strong measure of sea breeze.

A simple analysis cannot easily separate the wind induced by the general circulation from the effects of sea breeze generated by the differential heating and cooling of land and

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ocean. During this period the land was experiencing warmer-than-normal air temperatures and lower-than-normal precipitation. Such conditions may have contributed to a stronger-than-normal evening onshore breeze, in turn creating a 'fastest mile' predominantly reflecting the sea breeze, not the general circulation. Studies have shown the perils of using land-based wind measurements over water (Overland and Gemmill, 1977). Other detailed wind velocity measurements were not available for the study. One must exercise extreme caution in any attempt to apply these Atlantic City winds to infer movement of surface waters offshore.

Modeled Winds

The NWS' Limited-area Fine-Mesh Model II (LFM) forecasts winds for grid points over North America at eleven levels (Gerrity, 1977). Boundary layer winds in this archive are roughly the lowest 50 millibars of the atmosphere and include the effects of friction over the water. Values are chosen at six hours after model initialization, in order that the winds and the atmospheric pressure systems are in dynamic equilibrium and spurious transient surface wind patterns generated from the widely-spaced observations used for initial conditions will have damped out (Reeves and Pytlowany, 1985).

The dataset comprises the most recent ten years of modeled winds. Since wind observations over water are sparse, these modeled winds are the best available estimate of what the instantaneous wind field was over the water, provided modeled data can be related to observed data. Hess and Pytlowany (1987) studied the statistical relationship between the modeled winds and observed winds for two stations in Chesapeake Bay. Modeled variables explained between 50 and 71 percent of the variance, hence, these winds represent reasonable estimates of the wind fields for this region.

The mean monthly wind field from the LFM model compares favorably with the climatology of Williams and Godshall. No consistent anomaly appears for the summer of 1987, nor even for a single month. However, examination of the daily values of the modeled winds reveal patterns of a week to ten days duration which created surface flow quite different from normal monthly averages.

The LFM wind displacement plotted as two percent of the wind speed shows two periods when winds were northeasterly, from 05-08 August and again from 12-16 August (Figure 1b). Northeast winds normally will create conditions of onshore surface drift. Coincidentally garbage washed onto the New Jersey shore during each of these periods. Climatological data for the region suggest consistent northeast winds during the late summer is unusual.

4. SURFACE TEMPERATURE AND SALINITY

The NOS maintains observations of surface salinity and temperature at selected coastal stations. The data are published periodically in the series Surface Water Temperature and Density, Atlantic Coast, North and South America (Department of Commerce, 1968). The NOS has updated these averages for station data requested individually. In the mid-Atlantic Bight area stations at Montauk, NY, Ventnor, NJ, and Chesapeake Bay Bridge-Tunnel, VA, are sufficiently open to coastal oceanic influence to provide information on events in the mid-Atlantic Bight.

The daily salinity for summer 1987 at both Montauk, NY, and Chesapeake Bay Bridge-Tunnel, VA, followed the normal seasonal march of salinity during this period. The values for Ventnor, NJ, however, did not follow the seasonal march and remained above normal throughout the summer. Of the three coastal stations only Ventnor recorded monthly water temperatures consistently above normal during July and August.

5. REGIONAL OCEAN TEMPERATURE SUMMARY

Regional sea surface temperature data are summarized by NWS from ships' observations, buoys, and satellite data, and are published monthly in the Oceanographic Monthly Summary (National Weather Service, 1987). Off the New Jersey coast sea surface temperatures ranged from near normal in June to 2°C above normal in July and August, 1987. No large water temperature anomaly was present in the New York Bight, though water far offshore was below normal through much of the summer, and water temperatures far south off the South Carolina coast in August were higher-than-normal.

During August 1987, average surface temperatures over the region were mixed, with large areas above-normal, large areas below-normal, and much of the intervening area near-normal. Along the coast, summer warming continued quite strongly in the Carolinas, where water temperatures reached more than 4°C above normal.

South of Nova Scotia and southeast of New England was a large mass of water nearly 4°C below normal centered near 41°N, 66°W. The depth of this cool pool is not available without additional shipboard measurements. This pool persisted from July into September. Warming in the Gulf of Maine continued, however, and in September the warmed surface waters extended throughout the Gulf and south of New England, effectively separating the continent from the cold pool offshore.

7. SURFACE CURRENTS

Seasonal mean surface currents in the region are fairly constant in the nearshore region within 30 kilometers of the coast (Bishop, 1980). Ship current measurements and surface drifter computations indicate a mean southward surface drift in the nearshore region during the summer months. The rates are on the order of 10 cm/sec. Farther offshore the drift is highly variable due to both shifting wind structure and movement of eddies and Gulf Stream meanders through the area.

The NWS Limited-area Fine-Mesh Model (LFM) output for the wind field are applied with the equations by N. Huang (1979) to approximate surface drift and integrated mass transport. Transport was shoreward over the entire Mid-Atlantic Bight for the period of 09-15 August 1987, a pattern which is unusual at this time of year.

8. CONCLUSIONS

During summer of 1987, coastal New Jersey experienced short periods of local and regional anomalies in coastal and offshore water characteristics and flow during the period of late July and early August. Intervals of warmer-than-normal surface waters occurred, associated with slightly higher-than-normal salinities. A large-scale systematic abnormality of the ocean environment in the New Jersey coastal region is not evident, although surface water temperature anomalies occurred far offshore in the ocean southeast of Cape Cod (cold water anomaly) and well south off the coast of South Carolina (warm water anomaly).

The analysis suggests short periods (up to ten days) of northeast winds may have created conditions which localized the appearance of floatables and garbage on the beach. Any debris floating offshore may have drifted onto the beaches when the wind-driven surface currents flowed onshore during two short periods of early August. Surface drift computations indicate the garbage could have reached shore between the 6th and 8th of August and again between the 10th and 15th of August, from areas just offshore to as far as 50 km offshore.

9. REFERENCES

Bishop, Joseph M. A Climatological Oil Spill Planning Guide, No. 1, The New York Bight. National Oceanic and Atmospheric Administration, 1980.

Environmental Science Services Administration, Coast & Geodetic Survey, U.S. Department of Commerce, 1968.

Gerrity, J. F. The LFM model--1976: a documentation. NOAA Technical Memorandum NWS NMC 60, 1977.

Hess, Kurt W., and Peter J. Pytlowany. Predicted Winds for Chesapeake Bay from LFM and Observational Data. NOAA Technical Memorandum NESDIS AISC 11, 1987.

Huang, Norden. A simple model of ocean surface drift current, in The Physical Behavior of Oil in the Marine Environment. MIT Press, 1979.

National Weather Service. Oceanographic Monthly Summary. National Oceanic and Atmospheric Administration, U.S. Department of Commerce, 1987.

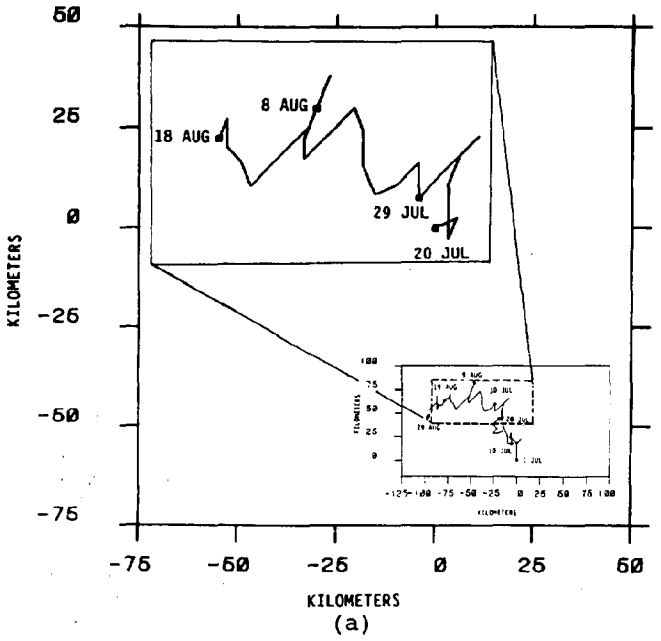
National Climatic Data Center. Local Climatological Data, Atlantic City, New Jersey. National Oceanic and Atmospheric Administration, U.S. Department of Commerce, 1987.

Overland, J. E., and W. H. Gemmill. Prediction of marine winds of the New York Bight. Monthly Weather Review, 105(8), August 1977.

Reeves, Robert W., and Peter J. Pytlowany. Comparison of Boundary Layer Winds from NWS LFM Output and Instrumented Buoys, NOAA Technical Memorandum NESDIS AISC 2, 1985.

U.S. Department of Commerce. Surface Water Temperature and Density, Atlantic Coast, North and South America, C&GS Publication 31-1, Third Edition.

Williams, Robert G., and Fredric A. Godshall. Summarization and Interpretation of Historical Physical Oceanographic and Meteorological Information for the Mid-Atlantic Region. National Oceanic and Atmospheric Administration, U.S. Department of Commerce, 1977.



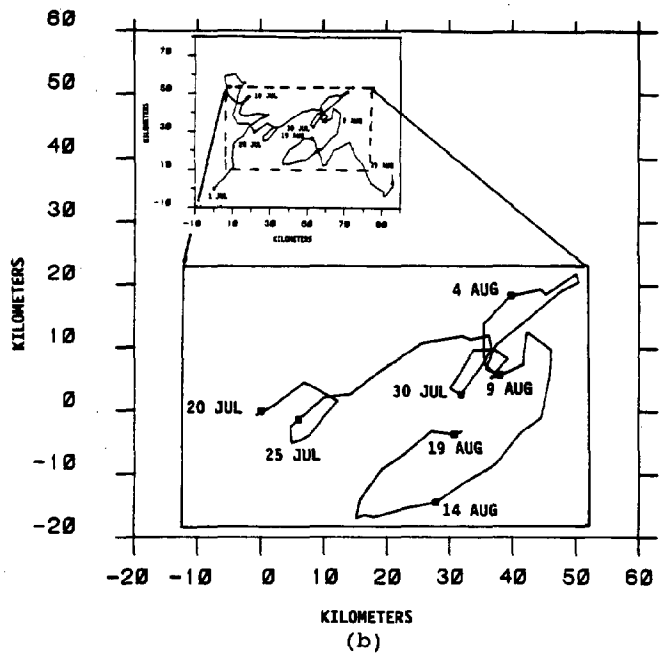


Figure 1. Progressive wind displacement diagrams for a) Fastest mile at Atlantic City, NJ, July-August 1987; and b) LFM winds at grid point located at 39°07'42" N, 72°22'49"W, July - August 1987.

DEVELOPMENT OF DEEP WATER TECHNOLOGY AS IT RELATES TO FUTURE SALVAGE

Andre Galerne

International Underwater Contractors, Inc.

At a time when technology in deep water research has made tremendous progress, the author will review the options available in deep water archeology and treasure salvage in terms of survey, identification and recovery.

This paper will cover not only diving but also various other equipment including tethered and/or untethered ROVs, manned submersibles, and support vessels.

The development of deep water technology and the improvement of the surface support ship will undoubtedly thrust the USA toward a new salvage era.

In more recent years, the most publicized salvage was performed by Mel Fisher in very shallow water, maximum 60'. He spent 17 years of his life researching, locating and doing the salvage. It was a very long and tedious job.

Numerous individuals and groups have spent millions for this same type of research with some success. In fact, there's been some very special but unpublished salvage work during the last quarter century.

After World War I, a Royal Navy ship "Laurentic" which was sunk by a mine near Greenland, led to a salvage of very little publicity, bringing up 14 tons of gold worth $550,000,000 at current value in the form of 3,211 ingots, leaving only 25 ingots behind.

In the 30's, a substantial amount of gold was salvaged from a sunken ship, the "Egypt", by Sorina, a private Italian company. The salvage yielded 5 1/2 tons of gold and 42 tons of silver, worth a total of $78,000,000 at current value.

During World War II, the British used an old decrepit ship, the " Niagara" , to transport gold from Singapore to Australia. They felt the Japanese would never fire on an old ship. They were wrong, it was sunk and this led to a salvage in waters beyond diver depth by a remarkable salvor, Sir Williams, to retrieve a multimillion dollar cargo, using an observation bell.

In Russian waters in depths of 850', using new technology and improved diver capability , a salvage was made with great success, with an alleged profit of $80,000,000.

Normally, the salvage process is an orderly progression of steps in which a salvor (1) acquires or performs research on a target, (2) attempts to locate the target, (3) performs an initial verification, (4) attempts to establish rights, (5) launches a full-scale salvage effort, (6) brings the cargo to market, (7) sells and distributes the proceeds.

Research into potential targets will take many forms. It may include (a) obtaining certain information concerning the circumstances of the casualty, its approximate location and environmental conditions at the time of the loss, (b) obtaining a cargo manifest, and (c) determining the possibility of salvage based on technical considerations, an evaluation of the cargo's marketability, projections of the economic return on the salvage, a determination of the liklihood of a previous successful salvage attempt, and, finally, the possibility of establishing rights to the salvaged cargo.

Once a wreck's "file" is in place, the location phase may begin. Estimated location offset by known wind, current, and tidal conditions can be marked off to approximate the likely boundaries of the ship's initial resting place on the ocean floor. Using state-of-the-art remote sensing tools, such as side scan sonar, magnetometer, and sub-bottom profiler, one can develop a hard copy image of the

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area in an effort to identify the target. These surveying techniques are tied to geodetic positioning references and deliver coordinates of potential targets to further investigate.

The products of the above survey are used for an initial verification process in which the targets are investigated through the use of diving techniques, remotely operated vehicles (ROVs), and manned submersible intervention depending on the specific circumatances. This operation is to identify the vessel and then to verify the cargo's manifest in both the qualitative and quantitative aspects with emphasis on completing; (1) confirmation of cargo, (2) initial sight survey to establish optimum salvage plan, and (3) obtaining a sample of cargo or artifacts to assist in establishing rights and value.

Legal work will begin to establish rights and possible claimants (if any) to the salvaged cargo. This is sometimes a lengthy process depending on the wreck's geographic location, reported cargo and recent publicity.

Upon the recovery of the cargo, it must be evaluated from the aspect of its archeological worth. Some cargoes must be treated to avoid spoilage, or restored, depending on its contents. The cargo must be stored and valued while a distribution network is established.

Successful salvage depends a great deal upon the experience of the salvor and resources that are available to it.

I've just narrated the ideal salvage procedure for a modern ship. But it's not that simple. For years, I've been working on developing a technique to retrieve cargo in deep water. A salvor trying to perform this type of task faces huge problems. The first one, but not the least, is to locate the wreck and determine its cargo. If the wreck dates back to the 16th, 17th or 18th century, navigation being very imprecise and communications being non existent, many ships disappeared without a trace and only vague information is found in old archives. If, after a long struggle in difficult-to-read archives, one is successful in finding a cargo of interest, there remains the task of trying to find its location. Remember that at that time maps were often a national secret and the published ones were often misleading. In fact, if one reads old books, some navigators reported sighting islands that we now know are non existent.

Many legends also muddied the water (pun not intended). For instance, legends of a race of giants in South America reporting people to be 10 feet tall were common. No trace has been found of this race of giants. And legends of sunken ships may, in reality, have been ships that had been mutinized and their cargo stolen.

But we do know, in fact, that many important cargoes are on the bottom of the sea. The new age of electronics will give us the possibility to locate these treasures.

Thousands of cargo ships sank during World War II in the Atlantic. If you search for one, you will invariably find two or three others. Many have no commercial value. Nevertheless, people have always been interested in the adventure of the treasure hunt.

Being in the diving business since 1946, I must say that I am amazed at the gigantic progress made in this industry. The hard hat was king of the road for nearly a century but was slowly replaced by the invention of SCUBA. The first patent talking about a self contained underwater breathing apparatus was by a Mr. Denerouz in the late 19th century.

In 1933, Commandant Yves Le Prieur developed a SCUBA system with a full face mask and free flow system. The real breakthrough was the Cousteau-Gagnan system developed in 1942. This equipment was a true revolution. Suddenly, man became free to swim and explore underwater.

Today, divers using sophisticated mixutures go to 1500 ft and hope to go deeper on hydrogen/oxygen mixutres which are currently being tested by Comex.

Not only did the diver make tremendous progress but the appearance of the manned submersible brought our industry to another threshhold. However, it did get off to a rather slow start. We had to wait for Perry to develop a relatively small exploratory submersible. One of the first was the PC3B which was used to locate the sunken atomic bomb off Spain. I subsequently purchased the PC3B and used it on different jobs. It was really a crude piece of equipment, and, in fact, I recently donated it to a marine museum.

From that first sub to the highly sophisticated Woods Hole "Alvin" and Ifremer's "Nautile", submersibles capable of diving to 20,000 ft now are

being surpassed by two new Russian submersibles built in Finland, and Japan is preparing one to dive to 21,000 ft. These subs are capable of exploring 97% of the bottom of the sea. The remaining 3% to 35,000 ft is not really worth the excess cost needed for development of the necessary technology. However, a recent panel for NOAA recommended the construction of a 10,000 meter submersible for the 90's.

Manned submersibles are often limited to 1,000 meters. Very few have been built to go deeper and often they have been one of a kind. An exception was the Canadian company, Hyco, which built a series of Pisces. These subs were very useful in developing deep water technology. For five years, my Pisces 6 was on the drilling ship "Discoverer Seven Seas" roaming the world making dives to 6,000 ft. It was in the forefront of deep water oil work development.

The ROV made a modest debut. The eyeball RCV 225 became widely used. Now there are so many different types that Frank Busby, the man who tries to track and publish new developments in manned submersibles and ROVs, has a hard time keeping up with the new equipment.

From their original capability of an eyeball view, ROVs have progressed to some very sophisticated equipment, like AT&T's "Scarab" capable of cutting and burying cable, digging trenches, and making surveys. These are becoming the backbone of deep water research and work.

Other hybrid ROVs, like the Mantis, also have the dual capability of being used with a pilot and/or as an ROV. Some can perform these tasks simultaneously.

All this underwater technology has also been helped by the development of a new class of ships - the SWATH - small water area twin hull. The SWATH made a very slow debut into this market. I purchased the former "Duplus", renamed "Twin Drill". Like the semi submersible drilling ship, as long as the wave does not reach its flotation, the ship is very stable. There are only a few SWATHs in existence today. The Japanese have one -"Kascio". The U S Navy has three now under construction. I believe that in the 1990s, all research vessels will be of a SWATH design, providing a more stable work platform and more comfortable quarters.

Many salvors underestimate the importance of the surface support equipment. In fact, if you look at the accident rate in this area, you will often find the cause to be the lack of a stable work platform.

From another technological standpoint, I also can foresee the development of a new generation of equipment able to locate and pinpoint wrecks with valuable cargo. A highly sophisticated underwater sled was instrumental in showing Woods Hole Dr. Ballard and Ifremer the first pictures of the lost "Titanic".

Many, many wrecks are buried and this new technology will make the difference in being able to find them. And if you consider that many old wrecks are made of wood with bronze cannons which offer very little magnetic deviation, you will understand the magnitude of the needed technology. Something must be developed to find precious metal. There is some hope that the satelite can be of great help. This is not a far fetched idea.

Although, the development of this technology is not an easy problem to solve, there is a more difficult obstacle to overcome and that is the legal aspect.

After a wreck has been located, then the legal maze begins. Maritime laws are very complex and not too well defined. One can be in international waters and still face the wrath of various groups; i.e. the French going back to the "Titanic" instigated protestation in the U S congress. Yet Peter Gimble diving on the "Andrea Doria" stirred no protest. (Our company supported his first movie on this vessel.) If a wreck is close to shore within the 3 mile limit in state controlled waters, permission is needed. More red tape. There is now in the works a tentative law to extend the 3 mile limit to 12 miles. This will increase the power of the states.

Salvors recognize and respect that archeological finds must be handled with great care, but all underwater research can come to a halt with all these restrictions. If this comes to pass, an entire segment of our past history will be unknown to us forever. But this is another story.

ART AND TECHNOLOGY ON 20th-CENTURY VESSELS

Carol Olsen

Olsen and Associates
- Art for Marine Architecture -

Part of the $14 billion Americans spent last year on pleasure boating was for hull carvings and graphics. New technology now revolutionizes the ways in which vessels are personalized, posing new competition for the few remaining American shipcarvers.

Based on a photographic survey from many ports, this paper shows how the American spirit is diversely expressed on a broad range of vessels, including military craft, commercial fishing and passenger vessels, and pleasure craft. Contrast is also made with commercial vessels from other nations, which show some of the finest innovations in modern hull ornamentation. Some of the social, political, economic, ideologic, and artistic influences on vessel decoration are also considered.

New materials and techniques have created better opportunities to decorate military, cargo, passenger, fishing, and pleasure vessels than ever before in the 5,000 year history of seafaring.

Among the most innovative designs in recent years are the 25,000-piece glass mosaics on the bows of some Fred. Olsen ships in Norway (Fig. 1). The strength of these artworks was first tested for six months by placing samples of the glass and adhesives at the waterline of an Olsen Line ship sailing in frigid northern waters, and success with those experiments led to commissioning the full bow work.

The Fred. Olsen Lines has commissioned over 50 bow ornaments for their ships since 1936; most have been bronze sculptures by the best artists available (Fig. 2). It appears that the immense added recognition of these ships because of their decorations has off-set the financial investment for the artwork.

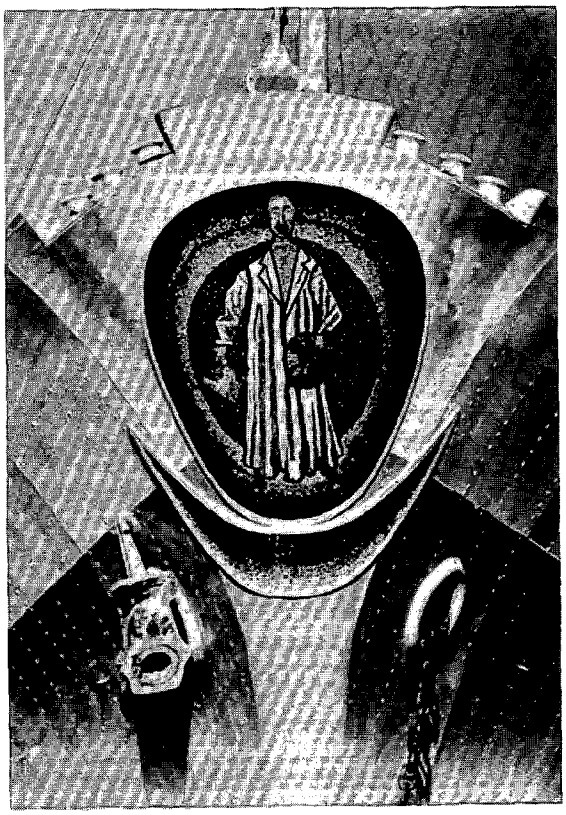

Fig. 1. In 1961 M.S. BONNARD carries a mosaic bow shield, made of 25,000 pieces of glass secured to a curved steel plate which is welded to the ship. Depicting the Impressionist painter Pierre Bonnard, the shimmering glass conveys the effect of an Impressionistic play of light. (Photo: Fred. Olsen & Co.)

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In fact, throughout history, nations have often employed their best artists as naval sculptors. One of America's best examples is the bronze Victory on the U.S.S. OLYMPIA, put on the bow after Commodore (later Admiral) George Dewey's victorious return from the Spanish-American War (Fig. 3). Other particularly noteworthy American efforts include works by William Rush, who created figureheads for America's first Navy vessels in the late 18th-century; his work on early 19th-century American merchant ships caused artists in foreign ports to study and sketch his work.[1]

Also, an extraordinary eagle, weighing 3200 pounds and with nearly a 20-foot wing span, was carved in 1881 by John Haley Bellamy for the U.S.S. LANCASTER and is one of the masterpiece marine sculptures produced in our country. It is now on display at The Mariners' Museum in Newport News. Also the beautifully graceful eagle on the bow of SHENANDOAH, a passenger vessel sailing from New England, is one of the best at sea today.

In the 17th-century, court artists such as the famous Pierre Puget were partially responsible for decorating ships.[2] Jean-Baptiste Colbert, Finance Minister to Louis XIV, said, "Nothing can be more impressive, nor serve more to exalt the majesty of the King, than that his ships should be more beautifully decorated than any others at sea." [3]

The importance of the appearance of nations' ships is still significant. When vessels gather in parades such as Operation Sail 76, Operation Sail 86, and for the 1988 Australian anniversary, photographs published in books and articles around the world not only document for posterity the quality of naval architecture, but also the level of art considered acceptable at the bow.

It should be a matter of national pride for the best artwork possible to be on United States ships such as the U.S. Coast Guard's EAGLE which so frequently represents our great nation in ports around the world.

One of the most interesting Coast Guard figureheads was on the cutter BEAR. Before becoming a Coast Guard ship, this was the vessel on which naval officer and polar explorer Admiral Richard E. Byrd sailed, and her original polar bear figurehead is in The Mariners' Museum collection at Newport News, VA.

In some cases, it has been appropriate for military vessels to have more playful decorations. For example, at Admiral Arleigh Burke's request, cartoonist Fred

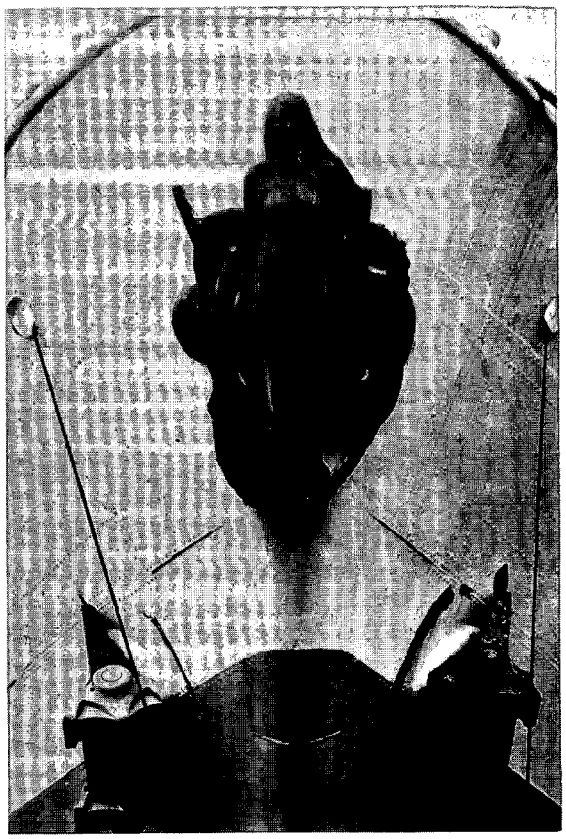

Fig. 2. Bronze sculpture by Gunnar Janson on bow of M.S. BOREALIS, 1948. (Photo: Fred. Olsen & Co.)

Harman developed a logo for Destroyer Squadron 23, based on the Indian character Little Beaver from the Red Rider comic strip.[4] Thereafter this became known as the Little Beaver Squadron. The design was painted on the side of the bridge wing on the CHARLES AUSBURNE, and Harman's original artwork is in the Navy Yard Museum in Washington, D.C.

A very animated look is achieved by the painted shark's teeth and eyes on the submarine U.S.S. TORSK, docked in the Baltimore, Maryland harbor. According to Henry Lingenfelder, Director of the TORSK now on display to the public, this echoes the shark mouth design used on the Flying Tigers P-40 fighter planes, which were flown by the American Volunteer Group in 1941 and 1942, under the command of Claire L. Chennault. TORSK has carried this design since at least 1970.[5]

Interestingly, this popular motif is also seen on a recently developed low-cost ROV [6], as well as a Dutch-built passenger-carrying hydrofoil vessel.[7]

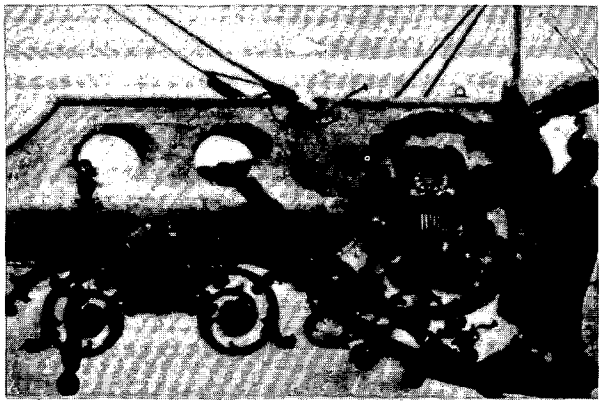

Fig.3 Classical bronze figurehead on Cruiser U.S.S. OLYMPIA, turn of 20th century. Photo in National Maritime Museum, San Francisco.

Surprising to some perhaps, issues such as water pollution have influenced boat decorations. For example, to help raise funds to clean up the Hudson River in New York, the day-sailing passenger vessel CLEARWATER hosts concerts by singers such as Pete Seeger. One of the volunteer crew members, Pete Lintene, carved one of his favorite birds, a Canada goose, as a figurehead, which he describes as "a symbol of a free, healthy environment."[8]

Elsewhere, commercial fishermen and their families create some of the most colorful decorations to be seen anywhere, for the blessing of fleets held along United States shores. The work involved is sometimes monumental, taking weeks to prepare large numbers of elaborate paper flowers, papier mache seahorses, cardboard cartoon characters, and other imaginative displays. Galveston shrimper Johnny Patane has covered his boat with Mickey Mouse and other cartoon characters in recent years, and Joel and Cheryl Coward in Kemah, Texas took first prize in 1984 for a dragon figurehead that breathed smoke; it was rigged to a CO2 cartridge.

On Stonington, Connecticut lobster boats, there have been excellent paper sculpture renderings of Mother Goose subjects such as the Old Lady Who Lived in a Shoe, and Humpty Dumpty Who Sat on a Wall. Fleet blessing decorations have also lightly nodded toward national interests; in 1983, one Galveston, Texas fishing family created a Shrimp Shuttle in the image of the Space Shuttle.

When the paper decorations come off, permanent carvings may be found on some fishing boats, such as the Chesapeake Bay skipjacks which have trailboards showing American flags, eagles, and cannons. More often one sees painted graphics. In Seattle's Fishermen's Terminal they vary for example, from images of Pacific Northwest art to jumping dolphins to the logo of the Seattle Seahawks football team.

Images that people choose for hull decorations usually have important meanings to them. For example, oyster fisherman George Carmines of Poquoson, Virginia, had a modest little portrait of his wife's grandfather painted on the boat that he named for the fine old man, Capt Henry. The artwork was added after Henry died, and it shows him puffing away on a cigar, one of the vices he loved but was told to avoid for health reasons. Captain Carmines' voice softens to admit that some of their favorite times together were long hours spent smoking and talking about the sea and those with whom they share it.

Tribute is often paid to heroes through boat decorations. For example, the Seattle, Washington commercial fishing vessel GJOA is named for the exploration vessel upon which the Norwegian explorer Roald Amundsen made the first voyage through the Northwest Passage and around the northern Canadian coast. On the bow is painted a Viking; the owner himself is Scandinavian.

And in Virginia, sport fisherman Curtis Reeves considers Francis Marion one of the great American heroes; his boat carries Marion's nickname SWAMP FOX, earned not only for his ability to successfuly engage British troops, but particularly for avoiding them by hiding in the South Carolina swamps. A cartoon graphic on the transom shows a fox riding a fish, a combination used merely because the owner is also one of the millions of Americans who also greatly enjoys fishing.

Forbes magazine recently reported that approximately $14 billion was spent on pleasure boating in 1987. Part of that revenue covered paintings (Figs. 4, 5), sculpture (Fig. 6) and vinyl-cut names and graphics for boats.

At least a dozen shipcarvers can still be found at work in the United States, producing hand-carved nameboards and other work in the long-standing tradition of this craft. Also, as in the past, some are itinerant, while others prosper in established locations; both do work other than shipcarving for their full income.[9]

The success of those who still survive in the slim shipcarving trade is challenged a little more by the approximately 5-year old revolution in computer-aided graphics for boat lettering and hulls. Today drawn artwork can very easily and quickly be

computer copied and duplicated in high-performance vinyl. This means that custom and stock graphics are speedily available at reasonable cost, and boatowners usually can install the work themselves with very little effort.[10]

The range of boat decorations chosen by Americans is fascinating to consider. A few examples are the carved wood portraits of twin baby daughters, Sarah and Molly Morfew, on MEKA II in North Carolina. On the Florida-based yacht named LUCKY DUCK belonging to Mr. and Mrs. Philip Ross, there is a painted duck head as a family

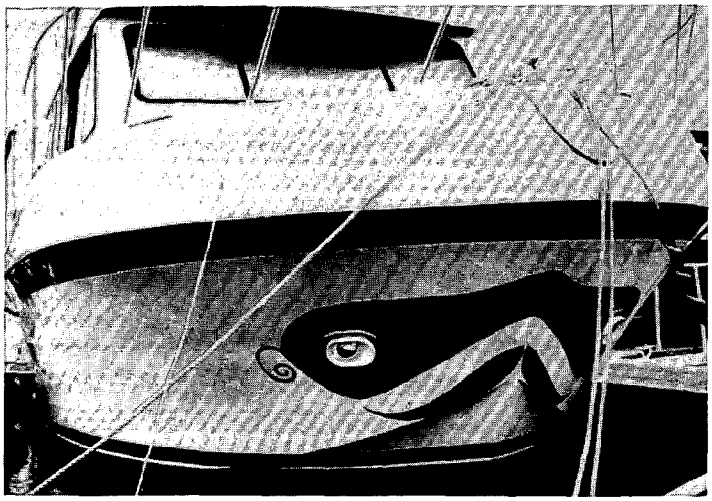

Fig. 4. Custom painted graphics adorn many American pleasure boats. Custom and stock vinyl graphics are also increasingly popular because of the economy and ease with which they are prepared and applied. (Photo: C.Olsen)

reminder of their children's favorite story, MAKE WAY FOR DUCKLINGS. Carved trailboards on the boat of Wendell Crosby of Beverly Farms, Massachusetts shows a special ivy motif; it had been one of the decorations at his daughter's wedding. Just for fun, Wilson Downs of Texas copied a cartoon frog from a cereal box for his boat GRIBBET, and the training vessel PILGRIM in California carries an image of Richard Henry Dana holding the text of TWO YEARS BEFORE THE MAST, the 19th-century book written to acquaint the public with the hardships of the common seaman.

Additionally, as Americans embrace the maritime traditions of other countries, some of those decorations become part of our heritage. Just within the last few years, the International Dragon Boat Races in Hong Kong have greatly captured the interest of athletes throughout the United States who now practice in 48-foot long, 2000-pound teak boats which are complete with carved dragon heads and tails. Spring-time competitions between teams from New York, Virginia, Pennsylvania, Illinois, and elsewhere are held in Philadelphia and the winning team goes to Hong Kong to compete in the International races in June. At both the American and Far East events, the competition is begun with a colorful ceremony conducted by a Taoist priest, to open the eyes of the brightly painted wooden dragon figureheads and bring good luck to the Dragon Boat races.[11]

Fig. 5. Decorative paintings on hulls are a 5,000-year old tradition. This work on the bow of T.T. BORGHOLM, 1959, is by Tore Heramb. (Photo: Fred. Olsen & Co.)

Art symbols express an attitude toward life and the ideals one strives to attain. Malvina Hoffman wrote, in part, "The study of art is the study of life..."[12], and there are many reasons for decorations on ships. They help in ship identification; figurehead descriptions were, in fact, part of official 19th-century custom house records.[13] They increase the value of a ship [14], and give added prestige to nations, businesses (Fig. 7), and particularly to individuals represented.

Perhaps more than anything else, figureheads have been associated with good luck, both on ships and off. In fact, at the United States Naval Academy in Annapolis, Maryland, a replica of the U.S.S. DELAWARE's portrait figurehead of the Indian leader Tamanend has long been called the God of 2.5 - the passing grade at the Academy; a new system has now changed the standard to 3.0. Before exams, some cadets still pitch coins up to the Indian figurehead, considering it good luck if the coin stays up on the figure, rather than dropping off.[15]

Ship decorations have also served as gestures of good will. In one instance, the 6100-ton German vessel HENRIETTE SCHULTE gave its approximately 6-foot long and 4-foot wide bow emblem bearing a city emblem to the City of Newport News, Virginia, in appreciation for repeatedly excellent harbor facilities and assistance. [16]

One story of friendship though is particularly remarkable.[17] In 1891, the DICTATOR was coming up from Florida, loaded with lumber. Hit by one storm after another, she finally sank off of Virginia Beach, Virginia. The local people grieved that the captain's young wife and son were among those lost, and when the ship's wooden figurehead of a woman washed ashore, it was set up to look out over the sight as a memorial.

But decades later, due to more storms and the ravages of tourists and time, little remained of the original carving. Then an amazing thing happened. A whole new generation of people at Virginia Beach still felt it was important to have a memorial, and arrangements were made for Ornulf Bast of Norway to create a new bronze figure to replace the original figurehead. The bronze was erected not only in Virginia Beach, Virginia, but also in Moss, Norway, the homeport of DICTATOR. Today the two figures are said to look out across the ocean to each other. Additionally, Moss and Virginia Beach are officially sister cities, and even have had a student exchange program.

The story of ship decoration throughout history is immensely rich. If one imagines that for about 5,000 years on the world's lakes, rivers, and oceans, maritime cultures have each been decorating vessels differently and in ways that express something of their social, political, economic, technological, ideological and artistic uniqueness, then the scope of the subject begins to suggest itself.

Thus, as the world's scientists and leaders struggle today with critical

Fig. 6. Bronze or carved wood figureheads can be designed for all bow shapes.

questions of marine management and policies and sea technology and safety,[18] there is one area of the ocean's history that is always uplifting to consider. The ways in which people have decorated ships is fascinating, showing national pride, personal heroes, allusions to literature, a sense of humor, and more, and new technologies suggest that there will be continued and fuller chapters in art for marine architecture to more fully express the seafaring spirit of our people.

For those who are working with today's ships and who have the opportunity and interest to develop some type of hull decoration, whether a painted or vinyl graphic, or a wood, bronze, or glass ornament, please feel welcome to contact Carol Olsen of Olsen and Associates, in Washington, D.C., a business that specializes in art for marine architecture. This business was established so that the marine art traditions of the past, coupled with innovations of the present and future, will be readily available to the maritime community. Naval artwork is part of our living maritime legacy and it can be awe-inspiring, as one author observed:

And when a ship with sails outspread
Came up the bay like a bird awing
Inanimate the figurehead
Seemed yet a living, breathing thing.

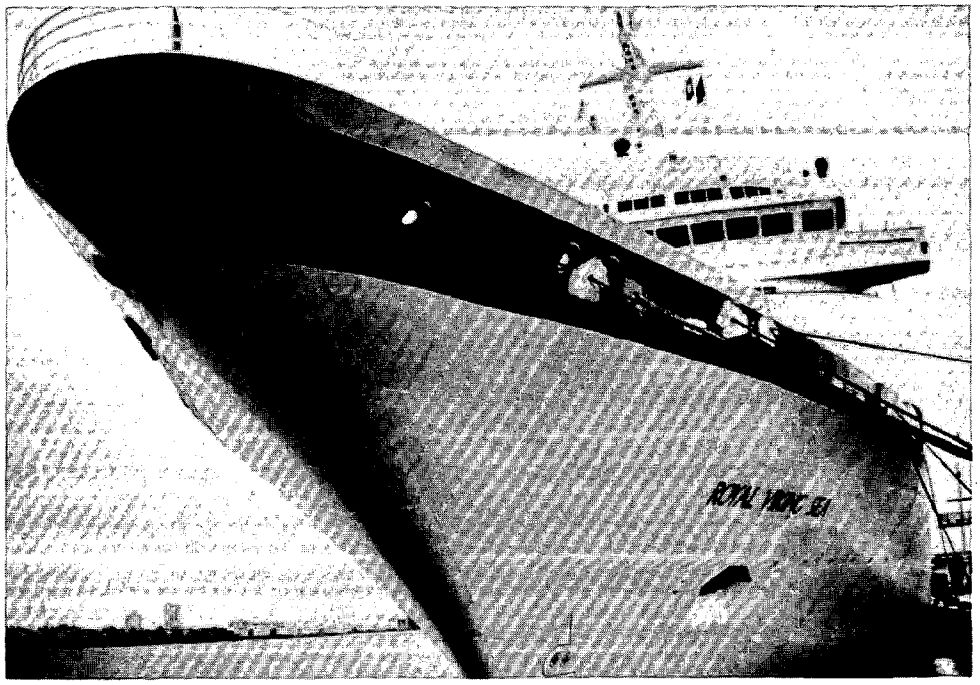

Fig.7. Company logos enhance the bows of some ships.

NOTES

[1] H. Marceau, WILLIAM RUSH, 1756-1833 THE FIRST NATIVE AMERICAN SCULPTOR (Philadelphia 1937).

[2] P. Norton, SHIPS' FIGUREHEADS (New York, 1976) 60-62.

[3] Maurice Michael and Martin Grass, trans.,THE SWEDISH WARSHIP WASA, n.d.

[4] Mr. John Riley, Ships History Branch, Navy Yard, Washington, D.C., personal communication.

[5] H. Lingenfelder, Sept.1988, personal communication.

[6] R. Frank Busby, "Low Cost ROVs-Some Early Returns," SEA TECHNOLOGY Feb.1987, p.11.

[7] THE MARINE PHOTOGRAPHY OF PETER BARLOW (New York, 1972, Motor Boating and Sailing Books), p.106.

[8] All information in this essay concerning modern boat decorations is based on personal communication within the last decade with the boatowner and/or the artist.

[9] In addition to shipcarvers already working, many academically trained artists are available to do naval sculpture and would like to receive these commissions.

[10] The equipment most frequently used for boat lettering and graphics is by Gerber Scientific Products, Inc.

[11] The U..S Dragon Boat Association is currently headed by Mr. Jack Seitz of Ambler, Pennsylvania.

[12] M. Hoffman, SCULPTURE INSIDE AND OUT (New York, 1939).

[13] See, for example, the Custom House records at the Newport Historical Society, Rhode Island.

[14] W. Baker, A MARITIME HISTORY OF BATH, MAINE AND THE KENNEBEC RIVER REGION (Bath, 1973).

[15] The Indian's quiver is solid, so it is not possible for the pennies to be pitched into it as some sources have described.

[16] The Mariners' Museum, Curatorial records, OB9.

[17] Every March the Ladies Auxiliary to the volunteer and paid Virginia Beach Fire Department commemorates the DICTATOR with a ceremony that includes placing a wreath in the ocean. Also see William Foss, THE NORWEGIAN LADY AND THE WRECK OF THE DICTATOR (Norfolk, 1970).

[18] "The Dirty Seas," TIME magazine, August 1, 1988, 44-50.

SELECTED BIBLIOGRAPHY in addition to sources shown above.

Brewington, M.V., SHIPCARVERS OF NORTH AMERICA (1962, Barre, Massachusetts)

Laughton, L.G.C., OLD SHIP FIGURE-HEADS AND STERNS (1925, London)

Pennsylvania Academy of the Fine Arts, WILLIAM RUSH AMERICAN SCULPTOR (1982, Pennsylvania)

Pinckney, P.A., AMERICAN FIGUREHEADS AND THEIR CARVERS (1940, New York)

MARITIME TRAINING AND OCEAN EDUCATION

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INTRODUCTION

An intrinsic part of the future is undeniably the ocean and its resources. The impact of the ocean environment on the civilizations of the world is taught to young students from the very start of their education.

Maritime education does exist in the United States. The education process in this field has for many years followed the industry. The key word being used here is "followed". Could the old cliche apply in this case? Have we found ourselves being followers rather than leaders?

I believe that the time has come for educators to modify techniques and adjust the curriculums of the maritime education process. The academicians need to join with the industry and design the education of the next generation rather than waiting until the future is upon us and then trying to catch up as best we can but never actually doing it.

OCEAN EDUCATION

Maritime education, as it is being applied and taught at present, is in a transitional state. Undoubtedly the first requirement of the maritime training is to provide the student with a strong back ground in the practical skills needed to competently perform the jobs at sea. The second aspect of the education, and what I referred to as part of the transition, has to do with an ocean oriented education. This term implies an intentionally broad field of study. The personnel who have been practically trained need, now, to go beyond wheelhouse and join more fully in the scientific, political, economical, and managerial aspects of the changing marine and ocean environment.

Companies, organizations, societies, regulatory authorities and individuals who, in some way, are connected to the ocean environment are all troubled by a common factor. That is, where do you find qualified personnel to work in and around the extreme environment of the world's oceans? I suggest that students need to be taught the practical skills of seafaring and then provided with a selected series of classes and topics that will enhance the students' potential. By doing so the graduate becomes an asset, both to himself and to the industry in general. Their horizons are broadened to enable them to see the multitude of factors affecting the international maritime environment.

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CURRICULUM

At the Maritime Academy in Castine, Maine, we have undertaken the task of broadening our curriculum and going beyond the skill and task-based training that has seemingly ruled curriculum development in the past.

Once we targeted our goal, we listened to various sectors of the ocean oriented community, one being the shipping companies and associated services, and the other being maritime and management colleges and universities. We observed and researched the development of transportation oriented curriculums and, by combining these two facets, were able, during the early nineteen eighties, to develop and implement a marine transportation track within the standing navigation and nautical science curriculum base.

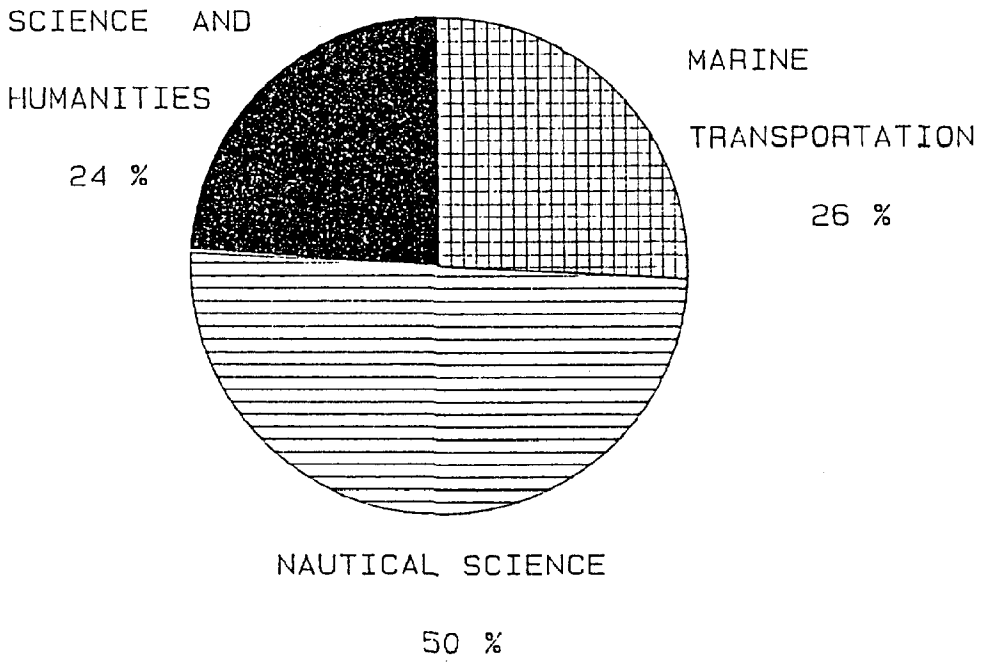
A priority was to maintain a strong practical-based curriculum. This stems back to the mission and objective of the college which is, in essence, to carry on Maine's heritage of the sea. This happens to be the mission of our college but I firmly believe that it needs to be the mission and directive force of all maritime education in this country. In the coming spring we will be graduating the first of these students into the industry. Each individual has an expansive practical background in ship operations, and also carries with him or her a broad understanding of the various managerial aspects of the industry in its entirety.

Figure (1) depicts the percentage allotment of the various courses being taught to the undergraduates. Note that the Nautical Science courses reflect a 50% contribution to the entire curriculum. These are the true professional-license courses students take during their matriculation. They include topics ranging from Terrestrial and Celestial Navigation to Vessel Stability and Cargo Handling Procedures.

Marine Transportation is shown as having a 26% share of the curriculum. These courses represent our effort to round out the undergraduates' studies in ocean education. Naturally, we have slanted our courses to reflect a transportation-directed series of classes, and each successive course builds on its predecessor.

We start teaching Marine Transportation basics at the beginning of the freshman semester in an introductory level course. It is a current overview of the maritime industry, what it consists of, terms, definitions, and the basic concepts prevailing in the maritime world. This course prepares the student for a detailed study of each of the listed topics in greater detail during the college career.

Maritime Shipping Finance is a study of decisions and actions that affect the value of a firm. Current and long-term assets, liabilities, financing, and capital structure decisions are considered, along with a study of financial management in the maritime environment. A



(figure 1)

separate course has been developed to study the theory and case analysis of maritime economic issues. Topics in this class include vessel acquisition and disposal, chartering, and pricing along with the study of the government and international regulatory organizations and policies impacting the maritime community.

An ever important facet of the shipping industry is the management of human resources and labor relations. In this course the students analyze the functions performed in organizations which facilitate the effective use of people to achieve organizational goals.

Maritime insurance and salvage is an economic consideration of growing importance for the maritime world. Our students review liability, risk, protection and indemnity, and salvage. This course is complimented by an admiralty and international law course which introduces the student to international conventions, national legislation, and general maritime law.

In addition to the topics and course I have listed, the students will complete a series of traditional undergraduate management courses covering the basic management techniques common to all industry, plus the more specialized aspects of maritime marketing management, seaport management, and shipyard management.

We also offer a course in Managerial Leadership in which students identify the management skills commonly believed

to belong to recognized leaders and exploring the issues concerning the same. It also should be emphasized that the structure of a maritime college is regimented and, by its very nature, these skills are learned and practiced as students live and work within the college community.

The remaining 24% of our curriculum provides the undergraduate with a solid mathematics and science background, accompanied by a series of courses in literature, composition, and oceanography, to name a few. It is important to note that even within the science and humanities departments an effort is constantly being made to address the needs of the maritime industry. An example of this effort is revealed in our composition course which emphasizes technical writing as it pertains to the maritime industries. We additionally offer a mathematics course designed for business management. Topics addressed include optimization techniques, probability, and decision-making theory.

The result of this effort is a graduate who is cross-trained in a variety of ocean related subjects; one who is specifically trained in the operation and management of the merchant marine industries, solidly educated in navigation and related subjects and, additional possesses an interest and exposure to the ocean environment from a firsthand, multi-perspective viewpoint.

ADVANTAGES

I firmly believe that the graduate of Maine Maritime Academy, or of any other college which teaches this type of curriculum, is what is needed to lead us in the coming developmental years as international advancements are made in all the various disciplines that influence the ocean environment.
Many graduates will find employment within a few months after graduation from institutions such as ours. There are many opportunities for these young people. They will staff the vessels of the world, operate merchant vessels, research vessels, and exploratory vessels.

Some will target other specific areas of ocean related employment. Such a decision would likely lead to postgraduate work. These young men and women thus find themselves in a very desirable position. They have already been exposed to a number of ocean oriented subjects which will undoubtedly help them in making a career decision. They additionally possess the practical seafaring background which will constantly serve them in their coming years.

Consider, as an example, an individual who, after graduation from a maritime college, goes on to a graduate degree and then to a doctorate. At some time in the future he finds himself preparing to enter the world of deep ocean remote-sensing research. Part of the research application will be conducted from a three-man submergible to be launched from a ship platform

900 miles at sea. On the planned day of the launch, weather conditions are predicted to deteriorate making recovery difficult and dangerous. Decisions must be made. Our individual has experienced these conditions before. Remembering the days before graduate school, he assesses the situation correctly, uses his expertise, and continues with a successful launch and recovery of the submergible craft. The illustration is melodramatic but the point is that the individual's prior practical experience and education served him well.

All sectors of the maritime world will benefit from individuals who possess the qualities described in the previous paragraphs. Whether one is profit motivated, a private business, or a government agency, all will be best served by an individual with the practical skills of seafaring combined with the complementing knowledge of a specific area of study.

CONCLUSION

Ocean education is the key. Cross-training at the undergraduate level should be supported by all the various sectors of the maritime and ocean community.

Changes are upon us. We, as a society, will turn to the ocean as a source of energy, minerals, and sustenance. Who is going to lead us into this forthcoming era? Who will oversee the application of the current technology and who will work to prepare for advancements that are only this day being spoken of for the first time? Technology will come, but it will be the application of the technology that makes the difference. A source from which to draw the individuals that will be needed in the environmental conditions of the ocean, and to provide leadership in the coming century can be found in the various academic institutions that exist today.

SUMMARY

I suggest three guidelines as we move in this direction:

I. Academic institutions need the flexibility to adjust their curriculums as technology advances; not in such a way that makes them followers of industry, but rather to be leaders of technology.

II. Financial support of the world's ocean-oriented colleges and universities from both the public and the private sector is a primary requisite for advancement in realizing and then utilizing the potential of the world's oceans.

III. Conferences such as OCEANS 88 help us to chart the best course as we move into the coming century. Identification of the issues at this preliminary stage will determine the success of ocean education, research and development, and their impact on world society.

THE NEXT GENERATION WATER LEVEL MEASUREMENT SYSTEM: THE NEXT STEP IN REAL-TIME DATA FOR NAVIGATION

Daniel W. Farrell[1]

ABSTRACT

The Sutron Corporation was recently awarded a contract to develop the Next Generation Water Level Measurement System (NGWLMS) for the National Ocean Service (NOS), an agency of the National Oceanic and Atmospheric Administration (NOAA). The NGWLMS system will integrate existing sea level and Great Lakes measurement networks and modernize them with state-of-the-art sensors, satellite transmission, and centralized data receiving/processing.

The NGWLMS consists of five functional subsystems:

- o sensor/measurement subsystems;
- o data collection and recording subsystem;
- o data transmission subsystem;
- o data processing and analysis subsystem; and
- o data and information dissemination subsystem.

The integration effort will include near real-time capability and links with other NOAA centers and systems for ocean, weather, and climate services.

The NGWLMS was designed to upgrade the operation and maintenance of the National Water Level Observation Network (NWLON), a network of approximately 225 permanent stations and approximately 150 temporary stations. The NWLON was established to aid in measuring, collecting, analyzing and disseminating water level data and related products. The technology used to support the NWLON is aging and largely obsolete; therefore, NOS determined to upgrade it with a more modernized system. The NGWLMS system provides a major upgrade of the existing system through complete end-to-end replacement with technological advances made during the past decade.

NGWLMS will apply state-of-the-art technological capabilities to upgrade and augment the existing system's capabilities. NGWLMS uses acoustic ranging and silicon strain gauge pressure sensors and microprocessor-based data collection and recording subsystems designed to improve data quality as well as to collect data quality assurance parameters. A self-calibrating acoustic sensor that takes 181 samples in three minutes (centered at six-minute intervals) will be used. All data quality assurance parameters will be stored every six minutes.

Such multiple sampling will greatly increase the reliability of each of the six-minute measured values. Moreover, because the acoustic sensor will be leveled directly, an observer will no longer be necessary. The NGWLMS will relay data, every

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three hours, from a data collection platform (DCP) to an OMA central computer facility in Rockville, Maryland, through NOAA's Geostationary Operational Environmental Satellite (GOES).

The new capabilities of the NGWLMS will include:

- o acquisition of near real-time water-level data from the system and full automated data processing;
- o accommodations by the DCP of as many as 11 ancillary sensors for observations including air and water temperatures, water density, conductivity, current speed, current direction, wind speed and direction, and barometric pressure;
- o capability of real-time water-level data for navigation;
- o capability of line-of-site radio links to ships supporting real-time hydrography operations and harbor traffic control;
- o automated acquisition of data and dissemination of products through computer network links;
- o acquisition of ancillary meteorological and oceanographic data for use in real-time by the National Weather Service's Storm Surge and Tsunami Warning Systems; and
- o application to other new NOAA systems to determine absolute changes in sea level by correlating with the Global Positioning System (GPS) and Very Long Baseline Interferometric measurements (VLBI) for climate and long-term sea level applications.

These new capabilities will center around shortened response times to user requests, for example:

- o a few minutes for hydrographic and other navigation applications (present response time, 30-60 days);
- o a few hours for automatic detection and preliminary diagnosis of malfunctioning field equipment (present response time, 60 days);
- o 1-7 days response to requests from general users for basic data (present response time, 90 days); and
- o 7-30 days beyond the data collection time required for tidal data computations (present response time, 3-6 months).

Implementation of the NGWLMS is already underway. The first 20 prototype field units, provided by The Sutron Corporation, were installed last year and have been under evaluation since June 1986. The locations of these prototypes were selected to include a wide range of environmental and tidal conditions. Evaluations to date indicate satisfactory performance and an extremely successful rate of data return. An additional 50 field units are being installed in 1988. The installation of the central computer facility in Rockville, Maryland, is also underway. Completion of the entire NGWLMS is expected within about three years.

Electronic Chart Display Information Systems: Operational, Policy and Legal Issues

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Unlike paper charts, electronic charts are dynamic information systems which can be manipulated to support specific user requirements and, by incorporating other electronic navigation equipment, provide real-time navigation.

The potential exists to enhance marine safety through adoption and use of electronic chart display and information systems (ECDIS). However, how navigators access, interpret and act upon the information will determine whether or not ECDIS is a blessing or a menace.

This paper highlights issues related to ECDIS and its users. It reports on the first Canadian seminar devoted to ECDIS, organized by IITOPS on behalf of the Marine Advisory Board and the Canadian Hydrographic Service, held in June, 1988 at the Marine Institute in St. John's, Newfoundland.

1. INTRODUCTION AND HISTORY

At a relatively early stage in their development, Canada has attained a great deal of experience in electronic charts (ECs) and electronic display and information systems (ECDIS). The reasons for this are varied. In some respects they were fortuitous: the right people coming together at the right time. In others certain applications peculiar to Canada favour the development of new navigation systems, such as the number of areas which are difficult to navigate using traditional means, e.g., the Arctic.

The result is that Canada hosts one of the few companies in the world, Offshore Systems Ltd. (OSL), which has a viable electronic navigation display system operating in a commercial context on the Marine Atlantic ferry, the MV Caribou. OSL developed its first system, a Precise Navigating System (PNS), which used microwave transponders to get ships in and out of narrowly defined channels in the arctic.(Note) Its second-generation system, a Precise Integrated Navigation System (PINS) which incorporated an electronic colour-filled chart display, is used on the Caribou and 13 other vessels. OSL is currently developing a Shipboard Integrated Navigation and Display System (SINADS) which will add a radar overlay to an improved electronic chart display. SINADS will also be able to incorporate positioning systems such as LORAN-C. OSL is also developing a passive precise radar positioning system called NAVFIX to replace the active microwave transponders.

What does and ECDIS do? An ECDIS provides real-time navigation for a vessel. It gives the master an accurate, contemporaneous picture of a vessel's position (through the use of a positioning system such as SATNAV or LORAN or, soon, GPS) on an up-to-date chart (which, potentially, will be kept current through automatic updating) and reflects the real circumstances of the vessel by integrating radar returns, including ARPA.

2. THE TECHNOLOGY

The technology in terms of hardware and software for an ECDIS is here now. Several companies internationally, in addition to Canada's OSL, are marketing operational ECDIS.[1] Each system employs its own software to manipulate the chart data and navigating information to produce its display. Already we have seen several generations of this type of system come and go. As has been previously noted, OSL is presently developing its third generation system. The refinements in these systems are generally designed to make them more accessible, user-friendly, safer, and more independent.

Apart from the purely technical advances — new microchips, etc. — the primary concerns in this are ergonomic. What are the most effective consols ("knobology"); what are the most effective colour displays (colour perception).

The other aspect of technology important to an ECDIS is positioning. A breakthrough in this area is expected when Global Positioning System (GPS) comes on stream. It has been delayed by the hold-up in deploying the necessary satellites due to the "Challenger" space shuttle disaster. With the advent of GPS it will be possible for civilian vessels to obtain a position within ± 100 m and, with differential GPS within ± 2 m. The ability to position a vessel accurately is critical.

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3. INFORMATION

Having developed the hardware to display the EC and the software to manipulate the data, what is then needed is the "grist for the mill". In Canada, the Canadian Hydrographic Service (CHS) is now processing its data digitally but the end product is still a paper chart. The CHS is responsible for 993 charts. The information for each chart is collected on field sheets (there may be up to 20 field sheets in one chart) plus information gathered from plans of wharves, dredging surveys, engineering plans, hydro and cable plans, etc. All of this information has to be considered in developing and electronic chart information base (ECIB) which will be used to create charts, both electronic or paper.

George Macdonald, Manager of chart production for the CHS, commented at the recent seminar that, from his region, at the current rate of 12 charts per year it would be 2003 before the 202 charts for that region where digitalized and 2013 before the 702 field sheets used to create those charts were in digital form.

Internationally, the International Maritime Organization (IMO) and the International Hydrographic Organization (IHO) have jointly formed the Harmonization Group on ECDIS (HGE) to formulate standards/regulations concerning ECs and ECDIS. The HGE has stated that the national hydrographic offices (HOs) should continue to be charged with the production of official charts. The reason for this is two fold; first, to ensure accurate safe charts: and, second, to facilitate exchange of information through the implementation of uniform standards in this area. However, as has been noted, there are ECDIS on the market. Where are they getting their data?

Most manufacturers are taking charts produced by the HOs and digitizing them. This fact identifies one of the critical aspects of ECs and ECDIS.

To date, one reason users have been generally reluctant to consider ECDIS in their operations is a lack of relevant ECs. To the potential user this limits its utility. Those are using an ECDIS have mostly been involved in situations, like the CARIBOU, where they are employing it in a restricted situation (access to a difficult harbour often obscured by fog) so they do not require in extensive EC and where the benefits far outweigh the costs. If this is a case of "seeing is believing", until users are convinced of the value of ECDIS there will be little demand (and consequent resources available) for the HOs to produce the data necessary. Despite this, HOs, and the CHS in particular, are going ahead on the belief the demand will be forthcoming and, judging from the reaction of Marine Atlantic and other present users, they will be proven correct in their prediction.

4. CHARTING AND THE LAW

To this is added the consideration as to the legal status of ECs and ECDIS. Until the IMO/IHO through the HGE agree on their recommendations/standards, the courts will have very little to go by in deciding the status of these systems. Internationally, the SOLAS Convention (Safety of Life at Sea) requires that vessels carry paper charts; the Regulations passed pursuant to the Canada Shipping Act require that vessels carry **and use** paper charts.[2]

As the courts decide, so the insurance industry will adhere.

It was noted at the seminar, however, that it was unlikely that Marine Atlantic, which operates the Caribou, would have been able to obtain coverage on that vessel operating under those conditions without the PINS.

One aspect of this technology which the insurance industry has already picked-up is the "black box". As in aircraft, some ships are already being fitted with a device which will record their activities and serve as a after-the-fact record in the event of a disaster.

Premiums and litigation are only one legal concern.

ECs and ECDIS have introduced a new player to the scene, the ECDIS manufacturer. Before liability was divided between the HOs and the vessel. Now the manufacturer of the ECDIS exercises control over the information as well (through the hardware, software and, if they digitize the chart, the data).

One final legal issue to be mentioned is copyright. In Canada courts have accepted that software is a suitable subject of copyright. It has yet to be determined either in the courts or by legislation whether charts or databases may be copyright. As Capt. Mukherjee noted at the MAB/CHS Seminar, "It is well known that the objective of copyright control is to ensure safe distribution and use of charts. The same objective can be secured by other means" (eg., regulation or licensing).

5. THE 'WILD CARD'

There is one user group who has already embraced the ECDIS and that is the recreational boater. It has been reckoned there are 45,000 vessels worldwide which would come under the IMO-IHO regulations when they are adopted: in the US alone there are in the vicinity of 16,000,000 registered pleasure craft.

The potential of this market speaks for itself. Recreational ECDIS are already available for less that $10,000, and with the general reduction in prices for micro-computer technology the probability is that these will be half that price in the foreseeable future. These people are less constrained by budget or the need to justify the purchase of such a system in economic terms.

Pleasure boaters are not regulated as stringently as commercial vessels.

This is a market which, generally, is not as skilled or as practised in navigation as the commercial practitioners. This is both good and bad. On the

positive side, an ECDIS may compensate for a lack of experience or knowledge; on the negative side, it may promote an undue confidence in the system.

The consequence of the ECDIS market developing in this are is that standards and systems will be market driven and regulators will have to accommodate a multiplicity of established systems which may not be the best all round.

Ultimately the need for information will be the same whether it originates with commercial or recreational users.

6. OPERATIONAL AND TRAINING ISSUES

Too often the human dimension of technological change is neglected in the rush to gain a perceived operational advantage and many aspects relating to the application and use of innovative systems are either neglected or left to chance. ECDIS depends on the capacity of users to access and correctly interpret information. Given the costs associated with navigational errors, it is imperative to identify user needs in tandem with the development of ECDIS hardware and software.

From an operational perspective, ECDIS are revolutionary navigational aids enabling mariners to access and manipulate relevant information for different purposes simultaneously. For example, dual display capability allows navigators to monitor the ship's route on a real-time basis and to examine options for advance routing. In addition, most systems have the capacity to store historical navigational data which can be retrieved for both planning and documentation purposes.

Canadian mariners who have used ECs are generally enthusiastic about the potential of ECDIS to enhance marine safety, particularly in close manoeuvring situations and during icebreaking. Although ECs are regarded as being a significant addition to the kit-bag of navigational aids, most mariners do not foresee that they are likely to become a single, all-purpose navigational tool. Radar, for example, provides essential information about vessel traffic. Participants at the 1988 seminar in St. John's were of the opinion that radar overlays should be incorporated into ECDIS design.

Mariners are often described as being extremely conservative, sceptical and slow to innovate. The expression, "if it ain't broke don't fix it," describes the attitude of the seafaring community towards change. However, the introduction of ECDIS technology aboard Canadian ships has not encountered significant opposition, probably because navigators do not perceive the technology as a threat to job security or professional competence. Unlike technologies which transfer functions originally performed by human operators to machine, ECDIS do not eliminate the requirement for experienced and properly qualified navigation personnel aboard ship. Canadian Coast Guard experience with ECDIS in the Laurentian region indicates that mariners are receptive to this innovative technology because it adds another dimension to their repertoire of navigational skills.

According to experienced EC users, reliability is the single most important benefit derived from the acquisition of electronic navigation technology. Electronics facilitate precision navigation and reduce the margin of error associated with manual calculations and observations. When navigators gain confidence in the accuracy of information provided, they are better able to concentrate on manoeuvring operations. In turn, the ability to concentrate relieves some of the stress and fatigue induced by uncertainty.

Mariners are also cognizant that lack of understanding or over-confidence in system capabilities may result in excessive risk taking. Whereas equipment manufacturers bear responsibilities to inform users about system limitations, ultimate responsibility for ship safety rests with the Master. Therefore, discussions about data inputs and system capacities are integral components of ECDIS training exercises.

In 1987, the Canadian Coast Guard issued a Ship Safety Bulletin advising mariners that existing ECDIS should be used with caution and are not to be regarded as an acceptable equivalent to conventional charts: "The safe use of these displays for navigation purposes depends on a number of factors including the existence of an adequate data base, the accuracy of digital information, the availability of satisfactory means of updating that base and the subsequent provision of safe and comprehensive methods of data selection for display."[3]

To date, questions about training mariners to use ECDIS safely and responsibly have been overshadowed by debates about data acquisition, specifications and system administration.[4] The 1988 Marine Advisory Board seminar provided a unique opportunity for mariners, hydrographers, commercial operators and regulatory agency representatives to assess their collective experience with ECDIS and to identify future training needs. Navigators with hands-on experience argued that competence in "knobology" was achievable in a relatively short timeframe, that is, given a good introduction to an on-board system and access to a reference manual (backed up by a system "help" menu). competent personnel should be capable of operating an ECDIS. However, a majority of these users argued that there are two levels of training: Level 1 training involves the study of system principles and focuses on knowledge, comprehension and judgement. Level 2 training concentrates on enhancing operational skills. Responsibility for Level 1 training rests with schools and professional nautical training institutes, while Level 2 training is probably best provided by equipment manufacturers.

Instructors from several marine training institutes expressed frustration with the current system of training and testing marine personnel. Because curriculum changes are linked to regulatory development, nautical education tends to lag behind technology and commercial practice. Thus, individuals may earn qualifying certificates that do not.

in fact, adequately prepare personnel for working in the dynamic environment of commercial shipping. Although most seminar participants shared the view that it was premature to add ECDIS to nautical curricula immediately, there was consensus that instruction in precise positioning systems was probably overdue. Of course, when international standards for ECDIS are accepted by national regulatory agencies, training institutes will then be compelled to instruct students in the use of such systems.

Possibly the most vehemently argued point by mariner participants at the MAB seminar was the need to involve users at all stages of system development. Although there is no evidence that mariners have been deliberately excluded from ECDIS R & D activity nationally, the Canadian Hydrographic Service and manufacturers have assumed leading roles in system design, testing and standards-setting. An important outcome of the seminar was the follow-up action taken by the Canadian Coast Guard Superintendent of Navigation Safety, Mr. Tom Brooks, who distributed copies of the draft ECDIS performance standards prepared by the IMO/IHO Harmonization Group (NAV-HGE) and solicited comments from all interested parties.[5] Thus, one tangible result of the MAB/CHS Seminar was the expansion of the ECDIS "constituency" in Canada.

7. THE MAB/CHS SEMINAR

The following points about the introduction of ECDIS in Canada emerged in the final session of the MAB/CHS seminar:

* It was felt that uniform standards for electronic navigation displays should be developed internationally in order to ensure safety and ease of access to information, which would enhance commercial viability. However, there was general agreement that more hands-on experience is needed before standards are "cast in stone".

* The rate at which electronic navigation displays will develop is not clear given the lack of international standards and the uncertainty as to when GPS will be available and with what accuracy.

* Another factor hampering the development of electronic navigation displays at this stage is a lack of user demand which would generate the government resources necessary to provide the chart information needed to operate the systems. One reason users are reluctant to install systems is because there is no government chart information with which to operate systems.

* There is a need to establish a clear vocabulary in relation to this field.

* There is a need to realign thinking from a mere electronic representation of a paper chart to a true concept of equivalency, ie. a system that will provide information for safe, accurate navigation. At the same time there was agreement that all the information contained on the paper chart should be accessible to the mariner. The critical question is achieving a proper balance between a minimum amount of information which should be displayed at all times and the mariner's ability to avoid "clutter" by selecting from the total information available those items necessary to create a meaningful display. Thought should be given either to allowing mariners to create their own charts by providing information/database and allowing them to build up a composite display based on what they need to know in a given situation, or a minimum data set (default setting) should be provided with the ability to add or delete information as needed.

* Mariners present stressed the importance of good, user-friendly design. Perceptual, as well as ergonomic, considerations were mentioned.

* The focus should be changed from concentrating on display standards to database/information standards.

* Speakers supported the use of EC test beds as a means of improving technology and, more importantly, gaining practical experience. The use of test beds, or simulators, in Nautical Training Institutes was also endorsed.

* As an ancillary issue, resulting from the CHS' statement that sufficient funds were not available to proceed with the speedy digitization of data, there was some discussion of the concept of "user pay". In this context the recreational user was identified as possibly an extremely lucrative market.

* Although electronic navigation display systems would be of great value in commercial shipping, from a user perspective the largest market would be recreational boaters who are generally not as stringently regulated as the commercial sector.

* There was some discussion about the infrastructure required to support electronic navigation, including: digital data from the Hydrographic Service: the ways and means to update navigational information; and differential GPS broadcast from the Canadian Coast Guard.

* It would be useful to try to foster a continuing process of user input into the development of electronic navigation displays. In the same area it may be useful to consider separately the issue of training/retraining.

8. CONCLUSION

Ultimately, the successful introduction of ECDIS in Canada will depend on whether it answers a need of the marine community. There is no question that it has proven itself extremely capable in certain

specific situations and, no doubt, will continue to do so. The question is will it find a more general acceptance.

The hardware and the software required to prove the benefits of ECDIS to the user are now available. They have been relatively easy to develop. It is more difficult (i.e., costly because of the labour involved) to produce the data required to operate these systems.

Commercial interests are holding back because of the lack of certainty in the areas of standards and liability. Recreational users are seen as a potentially profitable way of stimulating demand for this service which will benefit all sectors of the marine community.

The development of ECDIS technology offers an unparalleled opportunity for cooperative activity among different sectors of the marine community. The gaps between hydrographers and mariners, for example, can be bridged if conscientious efforts are taken to involve all interested parties from the earliest stages of design through to decisions about system application and administration. To date, mariners have not resisted the introduction of ECDIS because they perceive ECDIS as a tool to enhance precision of navigation. However, the experience and concerns of the user community must be incorporated into the development process to promote acceptance of this new technology and maximize the potential benefits associated with ECDIS.

Questions about training and certification should be addressed prior to widespread shipboard application of ECDIS. Too often training follows regulation but, given the rapid advances in ECDIS technology, the need to anticipate training needs is paramount and should not be permitted to lag behind legislative/regulatory development.

Certainly it is the CHS's contention, based on their experience with ECDIS, that when the demand comes it will be big.

9. REFERENCES

1. eg. "Geonav" is manufactured by Navonics in Italy; ChartNav 20/20 by Laser Plot Inc. in the US; Disc Navigation by Disc Navigation Sales A/S in Norway; and NavPlus by ComGrafix Inc. in the US.

2. C.R.C. 1978, c. 1415.

3. Canadian Coast Guard. 1987 Ship Survey Bulletin, No. 2/87, 29 January.

4. Kerr, A.J., R.M. Eaton, and N.M. Anderson. 1986. "The Electronic Chart: Present Status and Future Problems", Journal of Navigation, Vol. 39, pp. 24-31.

5. IMO/IHO Harmonization Group (NAV-HGE). 1988. "Performance Standards for Electronic Chart Display System (first draft). Hamburg, FRG.

A Computer Navigation System using Kalman Filter Smoothing

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ABSTRACT

The University of Rhode Islands Graduate School of Oceanography and the URI/GSO Technical Service Department are building a general shipboard data collection system for the R/V Endeavor. The collection system is implemented on a DEC MicroVax II running VMS.

This paper describes the computer software comprising the navigation data collection portion of the overall system.

The navigation software collects, logs and processes information from a diverse set of electronic navigation aids.

A "smoothed best guess" set of navigation parameters is continuously produced using a Kalman filter system.

1. DRIVERS

The device specific portions acquire data from the navigation devices, convert it into a "common format", and hand it off to the router/logger. They are designed to allow multiple processes to access interactive navigation devices.

Navigation devices come in two flavors; those that require bidirectional interaction with the host, and those that passively "dump" data. For the former type, the device specific portion consists of a device command process and device query process; the latter type is implemented with a simple device grabber process.

The device command and device query processes work in concert to extract and process data from their device. The command process implements any device specific command protocols and data translations between the host and navigation device. It is designed to allow several processes to issue commands to the device without interfering with each other.

The device query process is a client of the device command process. It knows all about the device specific commands and the data contained therein, but does not have to worry about the other device specifics. Its job is to do those things required to collect navigation position and quality data, convert the data into a standard format, and send the "standardized" and raw data to the logger/router.

The grabber process simply catches the ejected data, tacks on a "standardized" translation, and sends it and the raw data to the logger/router.

2. LOGGER / ROUTER

The logger/router logs all incoming data to a daily file, distributes new data to other processes, and keeps track of currently active devices.

There are two classes of clients of the logger/router; the "producers" who send data for logging and/or distribution, and the "consumers" who want to examine the data. Generally, the device specific processes are the producers and user processes are the consumers. A process may be both producer and consumer; the kalman filter process consumes data from devices like a user process and produces navigation data like a device.

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The device clients of the logger/router hand it some device specific information when they "connect" to it. This data is available to other clients who may wish to examine data from the device.

The "consumer" services offered by the logger/router range from a log file to continuous delivery of the latest data from selected devices. The device information service of the logger/router acts as the "yellow pages" of the active "producers". Included in this information is the "producers" unique name. A consumer receives data from a producer by sending the producers name to the logger/router. It may request one fix or sign up to receive all fixes as they come in. There can be many real-time consumers of a single producers data.

The log file and data from the logger/router is in ascii.

3. KALMAN FILTER

The Kalman filter is the heart of the whole system. It takes the output from all navigation devices and produces as "best guess" smoothed output.

Each navigation device in the system is assign a "weight" that allows the filter system to make allowances for the accuracy of the device. These weights are currently chosen by the informed user of the navigation system. When a new reading is entered the filter system makes a prediction (based on previous readings) of navigation parameters and combines the new reading with its predicted position according to the weight of the navigation device and the weight of the predicted position. This produces a "maximum likelihood" set of current navigation parameters.

The filter system is designed to allow the user to change its operating parameters on the fly. It uses an ascii configuration file to describe device input format and the processed navigation output.

The filter system can process navigation data either in real-time or in a batch mode since it obtains all time data from the navigation message it is processing. Output from the system is produced whenever it receives a special "output data" message.

4. REMOTE ACCESS

Remote access to the device command servers and logger/router is available through TCP/IP and DECNET. Special server processes running on the host field network requests, routing them through the appropriate server and back to the requesting node.

5. UTILITIES

There are several utilities that use the navigation services. The time server updates the system time using the GPS clock time. The navigation plotter produces plots of current or previous fix data.

6. SOFTWARE FRAMEWORK

To make a system of this type maintainable and flexible the software has been designed and written in "layers". The following is a description of these layers and how they are used.

For starters, all device io is device independent. All io is done via a set of standard calls. This helps remove device and operating system dependence from the navigation system. A device can be reconfigure to run on a different io system without making any code changes.

Navigation device dependence is pretty well confined to the navigation device specific drivers. Adding a new navigation device to the system requires a driver specific for that device and some configuration changes to the Kalman filter startup file.

All the processing involved with making the logical connections between "server" and "client" processes exists in a template form. This means that writing a new device command process, device grabber process, or device query process requires filling in the software blanks.

A fully implemented set of commands is available for all supported interactive devices. Direct command access to a device is as easy as calling an init routine and then calling the specific command routines.

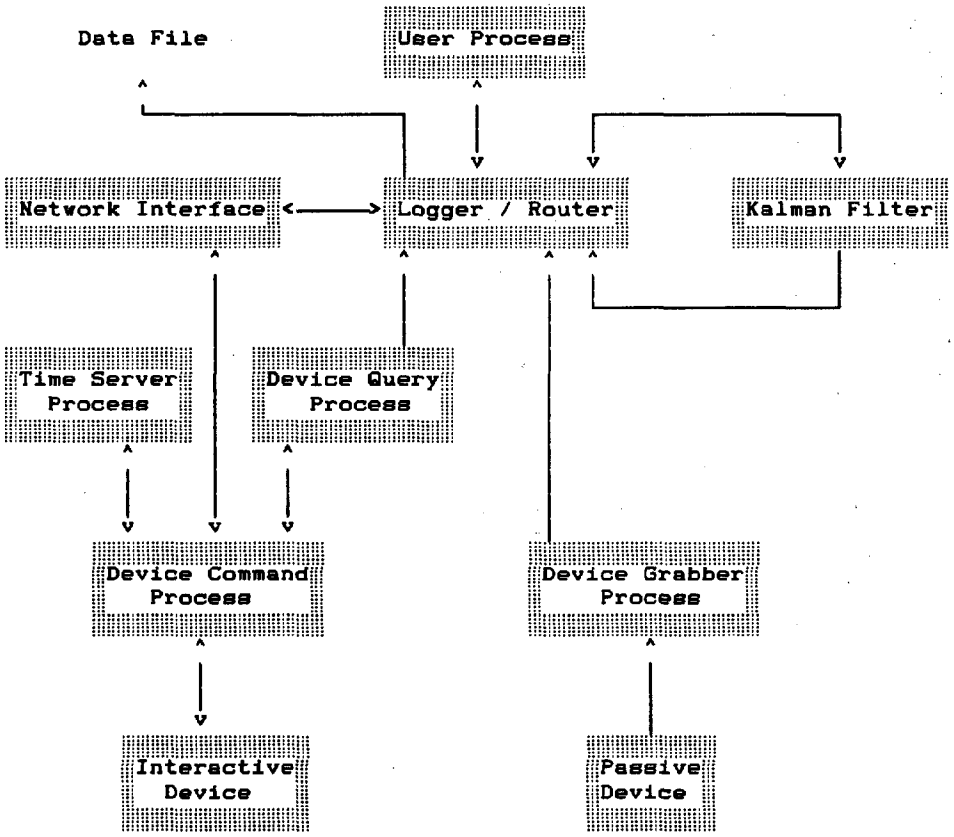
Interprocess communication is done via mailboxes. The operating system dependent calls are confined to a mailbox module for portability purposes. There are many ways to implement interprocess communication; mailboxes were chosen because they seemed to offer the greatest ease of portability.

Error handling is done by a yet another process that receives error messages from the other processes. When things go wrong or when a routine wants to log some event, it send a message to the error logger. The logger records the time, date, process name, id, error, image name, source file, software version, source code error line, compile date, and an auxiliary error message in a file. Depending on the severity of the error and upon the desires of the reporting process, it remains silent, flashes the panic light, catches fire ... etc. All error messages must be "registered" with the error logger. This means at least a minimum effort by the unruly programmer to "document" the error types and messages in the program. It also leaves a trail of what went wrong, when, and where. This makes it easier to debug over the horn ... no weird messages that print cryptic messages and then scroll into the void.

7. CONCLUSION

The result is a flexible, easy to use system that runs with a minimum of operator intervention and provides continuous navigation data.

Process Interconnection in the Navigation System



AWAKENING THE CONSCIOUSNESS OF THE BOATING PUBLIC REGARDING POLLUTION, INTOXICATION, AND COMMON SENSE SAFETY ON THE NATIONS WATERWAYS

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ABSTRACT

Possibly the least regulated of all forms of transportation occurs on our nations rivers, lakes, bays and oceans in the form of recreational boating. The amount of environmental damage and relative safety of these waters is left largely to the individual boater, and yet, the relative damage which can be done to the planet, animal life and fellow humans is staggering. This paper deals with the problem of changing public attitude to a more responsible perspective. These problems include lack of funds, motivation, and direction.

The roles of government, associations, federations, industry, retailers, media, educators, and law enforcement are considered in this uncharted process of change. Those involved with education are often overwhelmed by the vast number of issues they are tasked to address with little or no support material to help them. Looking at specific programs undertaken by national nonprofit organizations, industry and government,one can see a very plausible model which can be expanded by cooperative efforts of various groups. The objectives are basically simple and are centered around educating the public through short messages, involvement and interaction to not only be aware of potential problems but empowered to intervene in preventing them and, thus, awakening the consciousness of the boating public.

INTRODUCTION

The purpose of this paper is to explore the current status of one of the nation's most unregulated transportation activities and to assess some options relative to dealing with negative aspects of it. Each year over 1,000 people die in recreational boating accidents which is over 90% of the water transportation fatalities. When we get right down to analyzing the data, we really do not know precisely how many people have been injured or otherwise been involved in some sort of boating accident. Likewise, we have little more than the garbage and debris on the shore lines to help us speculate on the environmental damage of recreational boating. We can only make an educated guess, based on experience with small microcosms, as to these effects and try to forecast what will happen if nothing is done while substantial growth continues.

Anyone who remembers their basic grade school earth science class recalls the importance of the water cycle and how delicate the balance maintained by Mother Nature. Being candid, we are literally playing on the lifeline of mankind, water. The impact has not appeared in truly catastrophic terms and is not defined simply as a recreational, commercial or residential problem. In some areas we are witnessing more severe effects than others. Are these examples of more general conditions that we can expect as our re-creating on the water increases? One of the primary reasons many of us are here at this meeting is because of our concern for the ecology of our planet and the delicate balances that we know exist. Unfortunately there are many others who do not know of these concerns and use and consume our nations waterways with little or no regard for these issues.

There seems to be little comprehension of the fact that our garbage outlives us. Soda cans, beer cans, bottles, potato chip bags, plastic bags and wrappers all live many times longer than the average human being. It is all out of sight out of mind, until a prop becomes hopelessly entangled, marine animals ingest it thinking its food, animals become caught in it or a storm washes it ashore. The aggregate effect of this garbage accumulation may leave an unfortunate legacy for our children's children, moving closer and closer to the headwaters of our rivers and covering the bottoms of our estuaries.

COMMON SENSE AND RESPONSIBILITY

So far we have been lucky. The majority of boaters exhibit common sense and common courtesy as they use the nations waterways. They respect the environment and the safety of their fellow boaters. We may

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however not be so lucky in the future. We take for granted that people will use common sense. Many, however, don't know what it is, and we cannot assume that everyone has it. I will define common sense as: Having the knowledge to do what is best for the safety and common good of others as well as oneself. We would assume that the father who took his family and friends to view the fireworks this past July Fourth would have had the common sense to know that it is unsafe to put 15 people in a 20 foot boat to go for a cruise on a busy harbor. We might also assume that operators of the two high speed boats which passed close to this overloaded craft should have had the common sense to know that their wakes could have caused an accident.

We expect boaters to exhibit a great deal of common sense. Unlike the automotive market place, the prospective boat buyer is often asked to piece together the boating system that he or she wants for the intended areas and activities the boat is to be used. This may mean buying a hull and propulsion system separately, or adding on consoles, instrumentation, and a whole host of aftermarket items which may effect the performance of the vessel depending upon placement adjustment etc. Because a boat is an expensive item, many will buy a basic boat and add to it each year as they get the money. The industry only assumes responsibility for the specialized components it makes. The dealer is often overwhelmed by the quantity and variety of items that he is being asked sell and may or may not know the best choice for the intended purpose. When these choices are made they are most often driven by concern for performance and not concern for safety or the environment. The boater is expected to use his or her vessel in waters appropriate for the vessel, yet many operators will "push the envelope" of the vessel in pursuit of more challenging activity in rougher water. We expect boaters will go out prepared to meet sudden changes in the environment such as wind, rain, currents, tides and changes in temperature. How often have we heard the story of the fisherman who goes out and at the end of the day can't get the motor started and spends several hours or the night drifting farther away from the intended destination? In addition to exhibiting common sense and knowing their craft we expect boaters to be good and courteous seaman, which includes being concerned for the impact of their boats and related activities to the environment.

The intent here is to show that the operator not only has to have common sense but an innate sense of responsibility as well. No amount of enforcement is going to foster this sense of responsibility. Unfortunately, enforcement will continue to be needed to remove those who persist in operating vessels in an unsafe manner to satisfy their own ego. However, the majority of boaters will be headed for the waterways in search of fun and relaxation but not knowing enough to be truly responsible boaters. Who will be the conscience of mankind and who will influence boaters to adopt behaviors which will embrace good "common sense?"

THE MODEL

What is heartening is that an embryonic model exists for implementing this "common sense approach." In some areas of the country it is more widely developed than others. It is a model that has within it the flexibility to address specific needs of geographic areas and populations. The generating of a common sense base means the instilling of an awareness that it is needed, then a program of information to support it with constant reminders through role modeling and endorsement of the need to be responsible and use it. This goes beyond just offering classroom training or providing public service messages. It means weaving it into the cultural fabric which includes entertainment, social activities, advertising, and folklore. With primarily volunteer horse power the boating organizations and the national boating federations have sought to do all of this. It is time consuming long term work fraught with many frustrating experiences. The intention is there but the funding and the person power to support it are woefully lacking.

INFORMATION - THE KEY ELEMENT

For years people have realized that education and information dissemination are key elements to preventing accidents and promoting safe behaviors. How often have we heard the accident victim say "I didn't know..." Various nonprofit, national, state, local, and commercial groups have sought to educate the public in one way or another in safe boating practices. The efforts of these organizations vary in scope in different geographic areas largely a factor of the number of personnel, particularly volunteers, involved with the program. On a national level these organizations have banded together in the forums of the National Safe Boating Council, the National Association of Boating Law Administrators and the National Water Safety Congress, to exchange ideas and generate some common programs such as the National Safe Boating Week campaign. These national federations are run on the dedication of leaders who donate time apart from their

regular jobs to make these organizations function. While the efforts of these organizations have grown phenomenally in the past 3 years, it has not kept pace with the increase in size of the boating public. The National Safe Boating Week program, for example, has grown by a factor of at least ten, but it is estimated that this effort is reaching only twenty percent of the boating population.

The boating industry has verbally been in support of educating the public. Jeff Napier, president of the National Marine Manufacturers Association, stated "The teaching of boat operation techniques and safety measures should be as common place in our nation's school systems as is the teaching of ground strokes for tennis... Boating has an enviable safety record: of the 70 million people who go boating every year, only 6,000 are involved in accidents resulting in 1,036 fatalities or a fatality rate of 6.1 per 100,000 boats.... Despite the small number of fatalities or the dropping fatality rate, our industry recognizes that by seizing the initiative we can better prepare our future boat owners for more enjoyable and safer hours on the water." While statements made by industry representatives reflect an awareness that growth may create problems in the future and an honest desire to become involved, there is a hesitancy to go all out and create complete boating education or information programs to support their endorsements. There are the factors of time, money and the differing levels of commitment of the 1,500 manufacturers, but in this author's opinion, the problem is related to specifically what to do and how to get it into the system.

It is a given that no boating safety education course or information program will adequately cover all areas boat handling, first aid, seamanship, navigation, regulations and environmental impact. There is always more to learn, some of which is dependent upon the type of boat and waters that are used. The Minimum Education Guidelines established by the National Association of Boating Law Administrators does offer some help in narrowing the field of possible topics, but it would still be a monumental task to come up with a program that all manufactures would support. In addition to this problem, each educational system has its own standards and associated review and selection process. How many school systems would make the same choice as the industry?

In fairness to the industry, it should be pointed out that this problem exists for all the organizations who have developed or are creating public education programs for boaters. At this point some would opt for a bureaucratic solution which would legally mandate boating education through legislation at the state level. While this is one option that has the advantage of guaranteeing funding for a program, it still does not assure that the boater actually has the information he or she needs to be operating the particular boat that is being used.

ALTERNATIVES

Like boating, learning to play a musical instrument is a difficult task requiring knowledge of musical signs, note values, key signatures, rhythms, etc. Yamaha Music Corporation developed a pre-instrumental program, with the aid of psychologists, educators and musicians that gives a student many of the basics before ever touching an instrument and enhancing the ability of the individual to master it more rapidly. Because Yamaha had a rigorous instructor training program, complete media and material support, and a certification process, the program was assimilated into a number of school systems. With some adaptation, a similar model could be developed for a boating education program.

Another approach was taken by Kaiser Permanente to educate youth on certain health hazards. Small acting companies were hired to perform informative plays depicting the various hazards in an entertaining way. The companies traveled from school to school putting on assembly programs geared at different age levels. Similarly, a team of experts could be assembled to develop dramatic productions on boating.

With the computer age comes possibilities that are truly innovative. Computer assisted training modules have been successfully developed for other subjects. Why not boating? Video games teaching navigation as well as safety information would seem a natural.

Automobile seat belt campaigns and anti drug campaigns offer yet another avenue of approach. The media blitz is an unaffordable task for most nonprofit and government agencies. As a part of advertising and public service campaigns industry could promote various aspects of boating safety. Alcohol is as significant a problem on the water as it is on the highway. Several breweries have been forthright enough to publish brochures on the subject but more is possible.

One element of alcohol awareness programs is intervention. Too often when people see an unsafe behavior or a problem related to intoxication they just watch.

Most people do not know how to effectively intervene. Parents will snatch children from the jaws of death but will often not know how to prevent it from happening again. Programs have been developed to address the communications skills that are needed to effectively intervene but they are not well known and are not well funded.

There are a range of possibilities for industry involvement. Some might also be exercised by other organizations with the sophistication to develop a funding base. The bottom line seems to be the development of a product. Those organizations that are conducting education and information programs successfully are doing so because they have the support materials and personnel for training instructors as well as the materials to conduct the program.

It is not necessary for industry or any other group to go back to square one and start with a whole new program. There are many organizations which have programs in various forms and levels of proficiency. Some are kept more current than others. A few have gained the acceptance of school systems. By gathering representatives from some of the larger member organizations of the National Safe Boating Council it may be possible to provide support for existing programs and allow for a quantum leap in the evolution of these programs and broader use.

THE OPPORTUNITY AND THE CHALLENGE

The exciting element is that boating and water sports are perceived as fun. The growth in the marine market is just one indicator. Advertisements, movies and TV shows are often staged on the water because of this perception. Learning how to deal with the water environment also offers the opportunity to present standard english, mathematics and science programs with a practical application and appeal. It offers opportunities for the development of communications and teambuilding skills. The issue is we are not exploiting a golden opportunity.

It is a question of nurturing the "common sense base" which is a part of many current programs and providing the funding so they may flourish. It means influencing the media; the movie makers, TV producers, story writers, advertisers and textbook writers to take a responsible approach when depicting the water environment. By providing role models that reinforce safe and responsible practices, a subliminal message can be sent that may far exceed the effectiveness of any training program. By creating short messages which provide leading information, a motivation to pursue more indepth knowledge can be generated. Government and industry will need to provide leadership, some funding and coordination to facilitate the development of new programs and keep duplication of effort to a minimum. It is a strategy that presumes that everyone will accept more responsibility rather than waiting for infamous accidents to color our approach and produce costly legal mandates. The decision makers of government, industry and boating related organizations will have to develop a common commitment so we can begin to weave responsible boating into our cultural fabric. We have an opportunity to effect significant behavioral change to preserve the environmental integrity and the safety of our waterways for future generations without imposing legal hoops and wickets we may not have the ability to enforce.

GEOLOGY AND HYDROLOGY OF REEFS AND BANKS OFFSHORE TEXAS AND LOUISIANA

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From 1967 to 1983 the Department of Oceanography at Texas A&M University was involved in research on reefs and banks off Texas and Louisiana. Funding was originally provided by Texas A&M University, University of Texas Flower Garden Ocean Research Center, and NOAA/Sea Grant College Program. Beginning in 1974, funding was provided by the U.S.D.O.I. Bureau of Land Management (now Minerals Management Service). Studies were conducted on the geologic structure, sediment distribution, biological zonation, and water and sediment dynamics at over 30 reefs and banks. Geological studies utilized precision navigation, high resolution subbottom profilers, and side-scan sonar to produce accurate bathymetric and structural maps. Grab samplers were used to obtain sediment samples. Direct observations of the seafloor and the sampling of rock outcrops were accomplished by use of the DRV DIAPHUS. Video cassette recordings of the seafloor were made on all submersible dives. Hydrologic data was obtained by long term moorings of current meters and temperature sensors. In addition, profiles of temperature, salinity, horizontal current velocities, and transmissivity were obtained on seasonal cruises. The results of the research show an intimate relationship between geologic, biologic, and hydrologic processes and each has a direct influence on the other two.

LAUNCH AND RETRIEVAL OF A 1000 TON BARGE-SHAPED VESSEL FROM A CONVENTIONAL TANKER

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This paper describes the successful application of ship salvage technology to solve the problem of transferring a 1000 ton Single Anchor Leg Mooring (SALM) Base from the deck of a conventional tanker to the water and back to the deck. Hydraulic Linear winches, long popular with salvors, are used to haul in or pay out the SALM Base on Nylatron lined skid beams at the rate of 1.5 fpm. The skid beams have hinged sections which open out during the launch and retrieval operations. The skid beams slope at an angle of 12 degrees and the entire tanker itself is heeled over to about 12 degrees during launch and retrieval operations.

DEVELOPMENT OF EXPERIMENTAL ECOSYSTEMS FOR THE STUDY OF COASTAL LAGOONS

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Much of the world coastline is characterized by shallow, macrophyte-dominated lagoons that increasingly are subjected to pollutant inputs. A major concern on the R.I. coast is eutrophication possibly caused by nitrate enriched groundwater entering such lagoons from increasing numbers of individual sewage systems or leach fields. In order to examine this problem, we have designed and constructed ten replicate lagoon mesocosms, each 2.3 m x 1.8 m x 1.1 m deep (4.1 m^2 surface area, 4.55 m^3 volume). The bottom of each mesocosm is covered partially (45%) by unvegetated, organic-rich sediments, 45% by lower organic sediments with eelgrass, and 10% by clean sand. This ratio is similar to that of natural R.I. lagoons. Sediments were carefully collected from the field (to about 30 cm deep) to preserve their vertical structure. Water for the systems is collected regularly from a natural lagoon, trucked to the mesocosm site, and stored in large tanks. The mesocosms are run as open systems with flushing rates of 5% per day. Water circulation is provided by large transparent plastic paddle wheels. Several species of small fish, crabs and shrimp, as well as macroalgae have been added. After an initial study of replication among the ten systems, three different levels of daily nitrate additions will be started to observe the responses of plankton, seagrasses, macroalgae, and animal growth rates. An automatic oxygen sampling system allows frequent measurement of total system and water column metabolism.

IMPROVING SEARCH SUCCESS; REAL-TIME DATA COLLECTION AND TRANSFER TO USER

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ABSTRACT

To improve the probability of detection of the target in search and rescue (SAR), the USCG R&D Center is conducting research to determine sweep widths for search platforms and sensors such as Night Vision Goggles and new radars (including side and forward-looking and synthetic aperture radars). Research in measurement of currents in real time to hindcast and nowcast target movement includes development of Loran-C position transmitting buoys, satellite image analysis to initialize a current field in a search area and a search planning test bed utilizing desktop computers to analyze and transmit this information to the rescue command center. This SAR planning system is to be included as an ocean module in a ports and waterways management information system (PAWMIS). PAWMIS utilizes a microcomputer-based automated information system which will provide information required for emergency response, port security, vessel traffic management, aids to navigation management and permit review by means of computer-generated site-specific charts, databases and video response-planning images. The modules of PAWMIS are designed for use by Marine Safety Officers, Captains of the Port, Operations Centers and others. It will permit access to mainframe databases as necessary.

NEW APPROACHES FOR INDICES/MONITORING MICROBIAL PATHOGENS IN SEAFOOD

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Assessment of the public health safety of seafood requires microbiological monitoring, either for the presence of potentially pathogenic microorganisms or of indicator species. Culture methods used for microbiological analyses are, historically, recognized to be limited in accuracy and reliability. Most probable number (MPN) of coliforms, fecal coliforms and related enteric bacteria yields an estimate of the number of such bacteria in a sample but does not offer precision or accuracy. Furthermore, the coliform group has been used to indicate the probable presence of human pathogens, e.g., Salmonella, Shigella, Hepatitis virus, etc. The inadequacy of the coliform MPN test has been decried widely in the literature. However, until recently, suitable alternative methods have not been available. Recent discovery of the viable, but nonculturable phenomenon, characteristic of many Gram negative bacteria and nonspore-forming Gram positive bacteria (Roszak and Colwell, 1987) and first demonstrated in Vibrio cholerae, poses a new challenge to the standard methods approach. The phenomenon, briefly stated, is a viable stage, whereby cells can be demonstrated to be endogenously respiring, responsive to substrates, but not culturable by ordinary microbiological methods. Such cells can be cultured when passaged through animals, e.g., the rabbit illeal loop, in the case of Vibrio cholerae. The viable but nonculturable stage has also been documented for Campylobacter and Legionella. New methods have been devised to detect bacteria in the viable but nonculturable stage. Research is needed to determine the occurrence of these forms in seafood and to assess their public health significance.

INFORMATION IN A CHANGING MANAGEMENT CONTEXT: THE OCEAN DUMPING EXAMPLE

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Policy toward ocean dumping as expressed in legislation, regulation, and judicial interpretation has shifted. In addition multimedium management and assimilative capacity, concepts introduced after passage of the law, have further affected perceptions about appropriate policy. As a result the information relevant to measuring success in program implementation has been redefined.

Policy relevant information in reports for the Congress has been reviewed. Initially, policy was directed toward the magnitude of the materials dumped in the ocean, but units of and techniques for the measurement of amounts are not consistent. The magnitudes of other anthropogenic sources are ignored. Nonetheless, ocean dumped dredged material and industrial/chemical wastes show a decline while sewage sludge dumping is increasing.

Since passage of the law, policy has shifted from a proposed elimination of sewage sludges to restricting only those sludges that might unreasonably degrade the ocean. After these refinements, agency success may be measured in avoidance of unreasonable degradation or through the other considerations introduced by multimedium management or assimilative capacity. The changes redefine policy relevant information and place greater emphasis on composition, fates, and effects of materials proposed for the ocean.

A BIOTECHNOLOGICAL SYSTEM FOR THE UTILIZATION OF WASTE PRODUCTS OF THE SEAFOOD AND CHEESE MANUFACTURING INDUSTRIES

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The U. S. Shellfish and Cheese Manufacturing Industries are producing huge amounts of wastes and they have serious problems with their proper disposal. The value of the nutrients lost by dumping the unused byproducts is estimated to be in excess of $500 million annually. Although the cost for cleaning the environment is difficult to assess in terms of dollars, a conservative figure may be well over one billion dollars. The main reason for the underutilization of whey is that it contains a high quantity of lactose. Nearly 80 percent of the world's population is lactose intolerant, an incident which is similar for most species of animals. Since lactase is not an inducible enzyme in most animals, the main problem is how to increase the ability of an individual to digest larger amounts of lactose in the diet. Using chitinous products in diets containing high amounts of whey, we were able to overcome the lactose intolerance in economically important animal species. The enzymatic breakdown of chitin (in the shellfish processings) in the gastrointestinal tract, releases bioactive growth-promoting compounds (such as Beta-N-acetyl-D-glucosamine glycosides and oligosaccharides) which stimulate the growth of beneficial lactase-producing bifidobacteria in the gut. The manipulation of these bacteria in the gut supplied indirectly the needed lactase and enabled us to feed broiler chickens up to 8 times more whey than it is possible without the chitinous supplement. These and other nutritional as well as enzymological studies will be presented and discussed.

EPA's RESPONSE TO THE FLOTABLES INCIDENTS OF THE SUMMER OF 1987

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Office of Marine and Estuarine Protection
U.S. EPA

Summary of EPA actions to identify sources of flotables problems in New York Bight. How EPA plans to use its various authorities (MPRSA, CWA and RCRA) to reduce future flotable problems. How EPA plans to work with state/local governments and other federal agencies to handle future flotable incidents that occur.

LOW COST ROVS FOR SCIENCE

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NOAA's National Undersea Research Program at the University of Connecticut, Avery Point, is the national center for test and evaluation of low cost ROVs for scientific applications. LCROVs were viewed as easily transportable and deployable undersea platforms that could deliver specially designed sampling devices and cameras to depths of 330 meters. Since 1984, we have evaluated and developed procedures and tools for utilizing ROV technology to address a wide variety of sampling tasks. Operations in 1988 include a dedicated ROV science program supporting 21 research missions covering a multitude of scientific tasks. Examples of research missions include: herring egg bed studies in the northern Gulf of Maine; juvenile finfish and crustacean habitat definition on the southern New England shelf; hypoxia effects in Long Island Sound; hydrothermal activity in Yellowstone Lake; macrozooplankton migration and sediment transport in the U.S. Great Lakes; deep sound scattering layer definition in the Gulf of Alaska; and the ecology of the deep basins of the East African Rift Lakes system.

THE HYDROCARBON POTENTIAL OF THE FEDERAL OCS, OFFSHORE NORTHERN CALIFORNIA

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A series of four sedimentary depositional basins, extending from Cape Mendocino to Point Conception, underlie much of the Federal OCS and State Tidelands. These basins, the Point Arena Basin, the Bodega-La Honda Basin, the Ano Nuevo Basin, and the Santa Maria Basin, are closely related in their stratigraphic and structural framework.

The first exploration efforts concentrated in the onshore portions of the basins, most notably in the Santa Maria and La Honda Basins. Offshore exploration began in the Federal OCS following the 1963 Lease Sale. Early inconclusive results were followed up by the recent successes in the offshore Santa Maria Basin.

Natural oil seeps and exposed oil-bearing strata are present at many locations along the coastline, and suggest that hydrocarbon-rich rocks also occur in the offshore basins. In the 1960's, the principal exploration targets were sandstones of Pliocene age. Currently, exploration emphasis is placed on older Miocene-aged rocks, especially the Monterey Formation.

The Monterey Formation, and its equivalents, are prolific source rocks. Its arguable quality as an economic reservoir rock onshore suggested to many geologists that it would not be a viable exploration target offshore. However, discoveries on Lease Sale 48 and 53 tracts in Miocene rocks of the Santa Maria basin suggest that Miocene rocks in the other offshore basin may also contain hydrocarbon reservoirs.

WILSON ROCK FIELD: A CASE HISTORY

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Wilson Rock Field is located in the Santa Barbara Channel, approximately 20 miles southwest of Gaviota, California. The blocks containing the field were leased during OCS Lease Sale 48 in June 1979 for bonus bids totaling $32,922,144. The discovery well was spudded in July 1983 from a semisubmersible in 1,547' of water. Sediments ranging in age from Pleistocene to Cretaceous were penetrated. Drill stem tests produced 43 API gravity oil and gas at cumulative rates of approximately 600 BOPD and 700 MCFPD.

The Wilson Rock Unit was formed in August 1984 to facilitate development of the field. Constraints on development included water depth, distance from shore, estimated recoverable resources and declining oil prices. Analysis of the available data indicates that these factors prohibited development under the prevailing economic conditions, resulting in the termination of the leases in June 1987. The Wilson Rock Field is an ideal example of recoverable resources that remain undeveloped due to technological considerations and changing economic conditions.

OUTER CONTINENTAL SHELF FISHERIES AND RESOURCES IN THE GULF OF MEXICO

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About 44 percent of the total Gulf commercial landings came from the Outer Continental Shelf (OCS) in 1986. OCS landings in this region are dominated by shrimp trawling and menhaden purse seining operations. In 1986, 134.7 million pounds of shrimp were taken in the OCS, almost 45 percent of the entire Gulf shrimp catch. The shrimp fisheries off Texas harvested 79.2 million pounds, followed by Louisiana with 22.8 million pounds. The Louisiana and Texas shrimp fleet is comprised of approximately 3,400 vessels and 4,000 boats employing 16,000 full- and part-time fishermen. Menhaden landings of 821.3 million pounds, all from off Louisiana, dominated the commercial OCS finfish harvest in 1986 volume. Snappers, groupers, and king and Spanish mackerel were the dominant finfish catch from the Florida OCS; snappers and flounders in Alabama; snappers in Mississippi; and snappers, groupers, and tuna species dominated the Texas OCS finfish harvest.

The total estimated 1986 recreational harvest from the Gulf OCS was 27.9 million pounds, about 33 percent of the Gulf-wide catch. Catches of spotted seatrout, Spanish mackerel, snappers and groups dominated the harvest. In total, almost 4 million recreational anglers made 17.9 million trips in the Gulf in 1986.

Since 1984, the National Marine Fisheries Service has obtained data on the association of recreational fishing with oil and gas structures. In the Gulf OCS off Louisiana, up to 70 percent of all recreational fishing trips took place within 200 yards of a structure, although there was no significant difference in the number of fish caught per trip compared to fishing away from structures.

AN INEXPENSIVE MOBILE SELF-CONTAINED HABITAT SYSTEM FOR MARINE RESEARCH

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A mobile, self-contained habitat system has been developed for marine research by Perry Offshore, Inc. and the Caribbean Marine Research Center. The habitat is a two-person ambient system measuring 9ft x 7ft x 6½ft with full-size flat windows on three sides. Initially, power has been provided by a battery pod set on the bottom allowing the habitat to be completely free of surface support. The batteries provide 60 amps at 24 volts to power a 002 scrubber, internal lights, exterior lights and auxiliary outlets for instrumentation. A solid polymer fuel cell producing 40 amps at 36 volts is in the final stages of development as an alternate source of power. The habitat system is highly mobile, designed to be launched and retrieved from the deck of a vessel in less than two hours. Decompression can be conducted in a deck chamber, while the habitat is being moved from one location to another.

CUMULATIVE ENVIRONMENTAL EFFECTS OF THE DEPARTMENT OF THE INTERIOR'S OFFSHORE OIL AND GAS PROGRAM: 1987 REPORT TO CONGRESS

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As part of the Minerals Management Service's (MMS's) responsibilities for administering oil gas leasing and development activities on the Outer Continental Shelf (OCS) and in the Exclusive Economic Zone, the MMS prepares an annual report on the cumulative effects of the program on the environment. As the first cumulative effects report, the 1987 report traces the effects of offshore oil and gas activities since the program's inception in 1954. Studies sponsored by the MMS and effects observed and reported in the literature indicate that acute effects of oil and gas development activities to marine biota and habitats are both highly localized and short lived. Follow-up investigations on recovery of marine and nearshore habitats following oil spills have revealed a remarkable resilience by many species and rapid recovery of affected areas. No chronic, low level, long term effects attributable to offshore oil and gas activities have been noted, although the MMS continues to monitor for these effects through the Environmental Studies Program.

LEGAL AND POLICY ISSUES AT STAKE IN THE CURRENT 5-YEAR PROGRAM

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The current 5-Year OCS Oil and Gas Program was approved by the Secretary of the Interior in July 1987 and immediately litigation was filed against it, asserting that the program was deficient and in violation of the OCS Lands Act in several respects. The ruling of the U.S. Court of Appeals of the District of Columbia is expected in fall 1989.

If the Court has ruled by the Oceans 88 Conference, the paper will focus the Court opinion and its implications. If the Court has not ruled, the paper will outline some of the issues and the key arguments (in laymens language) of the Federal Government and the petitioners in the case. Also, the paper will address evolving policy issues confronting the OCS leasing program with emphasis on the Department of Interior's efforts in conflict resolution.

A SHALLOW WATER SONAR PERFORMANCE PREDICTION SYSTEM

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Standard Navy sonar system performance prediction models have typically focused on deep water applications. Mission Sciences' has developed a family of ray based shallow water prediction models which form a physically realistic, consistent and robust system for the prediction of system signal, noise and reverberation levels. The embedded propagation loss model, SMART, has tested well against several difficult ocean data sets. This paper describes the shallow water prediction system including comparisons with measurement and other prediction models.

A VCR BASED DIGITAL DATA RECORDER FOR UNDERWATER ACOUSTICS MULTIPATH MEASUREMENTS

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A family of multichannel underwater acoustic data acquisition systems which are deployed to the ocean floor and utilize Video Cassette Recorders as a digital data storage medium have been developed. One of these systems, the Acoustic Transient Recording Buoy (ATRB), was used recently as part of an ocean boundary-interaction acoustic measurement program. Explosive SUS charges were used as a source of transient high energy wide band acoustic signals and the direct, surface, and bottom-interacting multipath arrivals from the detonation of these charges were recorded by the bottom moored ATRB system. Acoustic data obtained from the first two deployments of ATRB are of very high quality with wider bandwidth and dynamic range than data sets acquired during earlier experiments using analog recording methods. The ATRB recording system is described in this paper and some of the acoustic data collected during the measurement program are presented.

Funding for the development of the ATRB system was provided by the ONR AEAS Program (K. Dial, program manager).

AN INTRODUCTION TO THE PHYSICS OF UNDERWATER SOUND AND THEIR APPLICATION TO PASSIVE ANTI-SUBMARINE WARFARE

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The importance and interaction of the physical aspects of underwater sound to the United States' passive anti-submarine warfare effort has been recognized and well documented. The United States involvement in the undersea warfare effort is linked directly to the massive Soviet build-up of its subsurface force. We have recognized the need for a thorough understanding of the basic principles of underwater sound as the primary phenomena governing our application of passive anti-submarine warfare. This material displays the principle basics of underwater acoustics and its association with the undersea warfare effort.

In addition, this paper presents some highlights of the present state-of-the-art applications in passive anti-submarine warfare and gives some possible future directions that this field might pursue.

REALTIME SIDE SCAN SONAR TARGET ANALYSIS

Ray Gandy and Steven Paulet

SEAQUEST
Niantic, CT.

Sonar records require analysis by experienced personnel who can identify potential targets from the surrounding natural features and other seabed debris. The data required in an anomaly analysis is generally obtained from a topographical representation of the seafloor using manual measuring techniques, i.e. rulers, calipers, etc. Consequently the anomaly analysis is routinely performed at a location remote from the actual sonar scanning location and often occurs several days after an area of interest has been mapped. Furthermore, the manual measurement procedure and computation of the relative location of an identified target is often very inaccurate. Subsequent attempts to observe and/or retrieve the object associated with the identified anomaly at the computed latitude and longitude can be very time consuming and possibly unsuccessful.

It is the intent of this paper to present and discuss a revolutionary method of analyzing Side Scan Sonar records. The Instant Target Analysis Computer (INTAC) System enhances target analysis in two ways. The first speeds up the analysis procedure by avoiding tedious manual measurements of a sonar contact. The second enhancement is the ability of INTAC to determine the position in latitude and longitude of a sonar target. This position can then be used to guide submersibles or divers to the exact location of the target for investigation or recovery purposes. This instant target analysis is performed realtime, thus avoiding costly project delays.

HARDWARE/SOFTWARE PACKAGE FOR CTD DATA ACQUISITION WITH A NEIL BROWN CTD

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INTRODUCTION

The Institute of Marine Science (IMS), University of Alaska, has built a low cost hardware/software CTD system to replace an aging Neil Brown CTD deck unit and 9 track tape drive. The new IMS CTD Deck System includes a commercial power supply, a small hardware package and microcomputer software which provides enhanced features such as data acquisition concurrent with real-time computer screen plotting of the cast. The package demonstrates that a versatile, reliable, computer based system can provide low cost redundancy and serve most CTD data collection needs. The software and hardware schematics will be provided at no cost to interested institutions.

BACKGROUND

The policy at the Institute has been to maintain redundancy for sea going CTD components for the sake of reliability. Since we had a MARK III Neil Brown deck unit, it was decided that to add a new model would not only be expensive, but would leave us with two different model deck systems.

The first step was to build electronics to interface the Neil Brown deck unit with an RS-232 computer interface. The software package was designed to meet our various needs but has been kept modular and flexible by the use of ASCII configuration files that sit outside of the compiled program. Once the software was tested and proven, new deck hardware was built that eliminated the need for the Neil Brown deck unit. The complete system is comprised of an IBM-XT/AT or clone, a rack mounted power supply and a compact, 8"x8"x2 1/2" case containing the CTD deck hardware.

THE SYSTEM

Major concerns driving the design of the system are that it be simple to operate, reliable as far as data acquisition is concerned , and easy to maintain. While development costs were somewhat higher than originally anticipated, all the above goals have been met.

The software package has been designed so that it will lead an operator through a series of menus. It has taken only few casts for a person who has only minimal knowledge of CTD cast operations to become competent with the system. The software has been constructed so that only authorized responses are accepted; others are ignored (with a beep). This makes the system difficult to lock up. Critical operations (such as halting data collection) require a specific, simultaneous two-key response. The capabilities of the system include cast preparation, data collection to hard disk while viewing real-time data, dumping plots or data to a

printer, collecting calibration information, and plotting or listing previously collected data. There is an option to select a series of stations and then have them plotted or listed automatically. Up to three parameters can be simultaneously plotted on the screen; the user can alter both plotting scales and parameters to suit changing needs. (A detailed list of features for the IMS CTD Deck System Software are available on request.)

The software is written in Microsoft QuickBASIC 4.0 and is documented within the program. Both compiled and source codes are available. The software does not include Microsoft QuickBASIC, but the compiled version operates as a standalone. Code modification will require Microsoft QuickBASIC.

Evaluation of many of the system features (exclusive of data collection) are possible by using the software without the hardware or CTD connected; test CTD data will be supplied.

Raw data are recorded to hard disk during data collection. One-meter averaged data are computed (ASCII) after the cast is terminated, and can be used to speed subsequent shipboard analysis. An alterable batch file is run after each cast that allows raw or one-meter averaged data to be copied to floppy, streaming tape or other preferred means of storage for redundant data security. Because of the low cost, exclusive of the MS-DOS computer ($200 plus labor for signal demodulator and $800 for a power supply) it is possible to obtain affordable redundancy with this system. In addition, since the computer (or two computers, if you wish complete redundancy) is not dedicated, it may be used for a variety of other data processing tasks.

The hardware consists of two components; the signal demodulator and a power supply. The demodulator has been designed to be minimal with emphasis on simplicity, placing most of the system sophistication in software. This was done to allow easy enhancement without having to return to the electronics shop for soldering iron and parts, as well as to ensure maintainability in the field. The design for the demodulator uses simple circuitry and modern componentry. Functionally, it replaces the Neil Brown MARK III deck unit. The compact circuit design has proven highly stable, requiring minimal adjustment. The cost of fabricating of the demodulator can be under $200 plus labor. Schematics will be provided at no cost to those who wish to build their own signal demodulator.

A Hewlett Packard 6443B power supply ($1300) was chosen to drive our CTD system, providing sufficient power for add-on devices such as a fluorometer. It is a constant voltage/constant current supply with meters which aid in system diagnostics. We feel that these added capabilities justify the additional cost of a more sophisticated power supply. A less elegant power supply will meet the basic needs of the system for under $800.

It's possible to use the software module with a Neil Brown MARK III deck unit with no modifications to the NB deck unit except a level shifting adapter to match the TTY output to RS-232.

COMPUTER REQUIREMENTS

An IBM-XT/AT or clone is needed, with two floppies or one floppy and a hard drive, one serial port for data input and a CGA or EGA video adapter. The software was

originally developed with Microsoft QuickBASIC versions 2.1 and 3 which do not support Hercules Monochrome graphics or VGA resolution. Only CGA is currently supported. Since QuickBASIC 4.0 does support Hercules and VGA standards, our plans include an upgrade to support these standards. A parallel port is needed for screen dumps or for listing data. The preferred configuration is an AT operating at 8 MHz (or above) with a hard drive and one or more floppy drives. If many casts are normally taken per cruise, it may be desirable to add a Bernoulli drive or a demountable hard drive (or optical disk?) for transporting data from the ship.

ADDITIONAL PROCESSING OF DATA

There presently is no data processing capability beyond that described above. We expect to build limited plotting capabilities to expand the simple screen dump and listings already provided. This might include such things as parameter/depth, T-S and cross-sections plots. There is no commitment on the part of the Institute of Marine Science to provide processing capabilities beyond those present in the original software package.

Applications programs can be developed to interface with both One-meter averaged files and raw data files (one-meter averaged files are presently ASCII; raw data are binary). Users are free to develop their own applications programs in any language they wish since applications do not interact directly with the acquisition program, but rather with MS-DOS data files.

ACKNOWLEDGMENTS

This project was financed primarily with funding from National Science Foundation grant OCE 8619385. Supplemental funding was provided by the Institute of Marine Science. We also wish to thank the many users of the system, David Leech in particular, who have provided the feedback necessary for us to build a better system.

OUTER CONTINENTAL SHELF FISHERIES AND RESOURCES IN THE NORTHEAST REGION

Darryl Christensen

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Department of Commerce

About 39 percent (517.7 million pounds) of the total commercial landings from the Northeast Region were harvested from the Outer Continental Shelf (OCS) in 1986. These landings had a total value of $367.4 million, of which Massachusetts contributed over 48 percent. The predominant landings in the Region were Atlantic cod, pollock, flounder, surf clams, sea scallops and ocean quahogs, which comprised 57 percent of the OCS harvest by weight and 69 percent by dollars. Sea scallops were the most valuable fishery at $86.1 million, while flounder comprised the greatest quantity at 73.9 million pounds. The commercial fishing fleet is comprised of approximately 4,604 vessels and 45,748 boats employing 80,450 full- and part-time fishermen.

The total estimated 1986 recreational harvest from the Northeast Region OCS was 58.4 million pounds, about 38 percent of the total marine recreational landings. Catches of black sea bass, bluefish, Atlantic mackerel, weakfish, and scup were the most popular, composing 42 percent of the harvest. In total, almost 4 million marine recreational anglers made over 28 million trips in the Northeast during 1986.

OCEAN SENSING CAPABILITIES ON LANDSAT 6

Matthew R. Willard

Earth Observation Satellite Company
Lanham, MD

The Earth Observation Satellite Company (EOSAT), in conjunction with NASA and the U.S. Navy, will fly a Sea-Wide-Field-Of-View Sensor (SeaWiFS) on Landsat 6. SeaWiFS builds on the heritage of NASA's Coastal Zone Color Scanner (CZCS) and NOAA's Advanced Very High Resolution Radiometer (AVHRR), and will provide real-time ocean color and thermal data in the early 1990s.

Some of the potential uses of SeaWiFS data by operational and commercial users include: locating fish populations, optimizing ship routing, and assisting in design of offshore oil platforms.

SeaWIFS data will also be used by the oceans research community to support global research projects involving: quantative evaluation of the ocean's role in the global carbon cycle and other major biogeochemical cycles; determination of the magnitude and variability of annual primary production by marine phytoplankton on a global scale; and study of marine optical properties and upwelling patterns on a regional and global basis.

In sum, the SeaWIFS mission will provide an unique oceans data set in the early 1990s essential to a number of global oceans research missions as well as being essential to improving the cost-effectiveness of a wide range of ocean industry users.

AN INEXPENSIVE INTERACTIVE PROCESSING SYSTEM FOR NOAA SATELLITE IMAGE

W. B. Campbell and M. L. Weaks

NOAA/NESDIS
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A PC based image processing system has been produced to enhance the image analysis functions within NOAA and to facilitate high quality product creation and rapid dissemination. It uses basic commercially available components and NOAA written software. This system allows for display of mapped, gridded, full 11-bit resolution image information from LAC, GAC, or GOES images. The dynamic color enhancement utilities allow for easy interpretation of ocean thermal structure details because each area of an image can be custom enhanced with as many or as few color intervals as necessary and annotated on separable non-destructive overlay planes for future use or direct distribution. The software is menu driven and quite simple to operate.

CONSEQUENCES OF THE ABANDONED SHIPWRECK ACT: THE NORTH CAROLINA EXAMPLE

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One of the uncertainties surrounding the "Abandoned Shipwreck Act", should it be passed, is how the various states would manage their shipwreck resources. Perhaps the best way to answer this question is to look at state with existing submerged cultural resource programs.

This paper will examine North Carolina's underwater archaeology program, which has been active for over twenty years, and how the Underwater Archaeology Unit manages the state's shipwrecks, and deals with such issues as diver access to shipwrecks, recovery and salvage permits, and treatment of recovered artifacts. Particular attention will be given to the contribution that sport divers and volunteers have made in discovering and preserving our maritime heritage.

LONG-TERM ABRASION AND CORROSION DAMAGE TO THE HAWAII DEEP WATER POWER CABLE

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National Science Foundation
Washington, DC

A 300 kV deepsea power cable is being designed and tested for possible deployment between the islands of Oahu and Hawaii. Part of the deep ocean section of the route includes regions with steep lava ledges washed by strong tidal currents. It is anticipated that sections of cable could become suspended between ledges and be moved back and forth by tidal drag forces. Then abrasion and abrasion-corrosion become potential failure mechanisms. In this paper we evaluate literature data and corrosion test results for both armor wire samples and prototype cable specimens exposed in both surface and deep ocean Hawaiian waters. The results are combined with abrasion and friction data for armor wire-lava rock combinations to develop an estimate of the expected worst-case damage in an 30-year design life. According to this estimate the greatest damage will occur for a cable catenary which, being sufficiently short to avoid tension fracture (<60 m) or long-term fatigue of the lead sheath (<40 m), has a contact load of 100 kg at mid-point, a corresponding friction-limited excursion of 0.38 m and a 30-year distance of travel over the rock of 33 km. Here, the expected wear is 7 mm and general corrosion is 2 mm, leaving about 3 mm before the rock face comes in contact with the lead sheath. On this basis, it is concluded that the cable most probably will survive damage due to abrasion-corrosion.

UPWELLING MONITORING OFF WESTERN SAHARA

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Upwelling off the northwestern coast of Africa occurs year around mainly as a response to prevailing northerly winds which parallel the coastline. Bottom topography and non-local large scale atmospheric events have also been cited as important upwelling factors in this region, one of the most important commercial fishing grounds in the world. A database of sea surface temperatures (SST) has been produced for the Canary Islands waters ant the African coast between 21N and 30N to study the ocurrence, satellite detectability, and temporal variability of upwelling activity in the region. Thermal infrared data from the advanced very high resolution radiometer (AVHRR) aboard the NOAA 9 satellite was used to produce atmospherically corrected SST maps. A particularly important fishing ground for the spanish fishing fleet based in the Canary Is. lies between 24N and 25 N off the coast of Western Sahara. This area has been selected for a detailed study of SST variability. A time series of STT over a 1/2 degree latitude by 1/2 degree longitude area was produced for a one year period, summer 1986 to summer 1987, utilizing the available cloud-free data. The data shows that while SST's are generally cooler during the winter and spring months, relatively strong upwelling events occur troughout the entire year. On the other hand, decreased upwelling activity is observed twice in the year during early October and mid-March.

OPTIUM TECHNIQUES FOR TRACKING PLUMES IN THE OCEAN: A CASE STUDY OF SLUDGE PLUME DISPERSION AT THE 106-MILE SITE

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With increased public concern for pollution of the marine environment, ocean disposal of manmade wastes has become a topic of growing interest. Under contract to the U.S. Environmental Protection Agency, Battelle Ocean Sciences is conducting an oceanographic monitoring program at the 106-Mile Deepwater Municipal Sludge Site to determine the fate and effects of sewage sludge dumped at the site. A series of cruises has been conducted to collect physical oceanographic and chemical data from within sludge plumes to determine rates of plume dilution and the effect on water quality within and around the site.

The success of the recent studies has been due to an integration of physical and chemical sampling techniques which allows 1) tracking of sludge plumes for periods up to 1 day, 2) collection of hydrographic and current data to resolve plume advection and dilution, and 3) directed water sampling within the plumes for analyses of trace metals and organic compounds. The optimum measurement tool for tracking sludge plumes is an in situ transmissometer interfaced to a CTD profiler and Loran-C navigation system to provide real-time, 3-dimensional information on plume turbidity. Results from these field studies will be presented, and the use of this measurement capability for other pollution monitoring programs will be discussed.

A MONITORING PLAN FOR DISPOSAL OF SEWAGE SLUDGE AT THE 106- MILE SITE

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The 106-Mile Deepwater Municipal Sludge Site (106-Mile Site), located approximately 120 nmi southeast of the Ambrose Light, New York, beyond the edge of the continental shelf, is currently designated for the disposal of sewage sludge originating from 19 sewage treatment plants in the New York metropolitan area. A monitoring program for the 106-Mile Site has been designed which will generate data to be used by site managers to make decisions about site redesignation or dedesignation, and continuation, termination, or modification of dumping permits.

The monitoring plan for the program describes the regulatory basis of monitoring, and how site and waste characteristics have been used to predict possible impacts of sludge disposal and to formulate null hypotheses that these predictions suggest.

The impacts of sludge disposal have been organized into an implementation framework of tiers. The tiered approach organizes the null hypotheses into a hierarchy, whereby data collected in each tier are required as the foundation for the design and extent of monitoring activities in the next tier. The four tiers included in the monitoring program are (1) Sludge Characteristics and Disposal Operations, (2) Nearfield Fate and Short-term Effects, (3) Farfield Fate, and (4) Long-Term Effects.

MONITORING WATER QUALITY CHARACTERISTICS DURING DISPOSAL OF SEWAGE SLUDGE AT THE 106-MILE SITE

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Regulation of sewage sludge disposal at the 106-Mile Deepwater Municipal Sludge Site is contingent upon achieving Environmental Protection Agency saltwater quality criteria (WQC) or limiting permissible concentrations (LPC) within four hours of disposal. These criteria must be met in less time if the plume is transported across the site boundary in less than four hours. Verification of whether WQC are being met requires sample collection from within the plume. Collecting these samples presents several difficulties, including positioning of the sampling platform within the plume, location of the maximum concentrations of the plume at depth, and collecting the samples from within this maximum. Combining in situ sensors, including CTD and transmissometry, with realtime shipboard display of data, and high-volume pumping systems has provided the necessary direction and control over sample depths to successfully sample sewage plumes for up to 8 hours following disposal. This capability allowed collection of water samples for several parameters useful for tracing the dispersion and dilution of the sludges in addition to determining concentrations relative to marine WQC. The results from samples collected in several plumes during September 1987, indicate dumping rates currently used at the 106-Mile Site may be affected if permits to dump at the site are issued.

HYPOXIA IN LONG ISLAND SOUND (LIS), SUMMER OF 1987

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The seasonal depletion of oxygen in western LIS in summer, 1987, reached the lowest levels heretofore documented for the area. Deficits in waters below the pycnocline began in the westernmost basin in mid-June, and hypoxic conditions (< 3ppm) spread eastward to encompass most of the western half of the Sound by mid-August. The area of deepwater affected in 1987 was similar to that in 1986. In 1987, however, a dinoflagellate bloom developed in mid-July, aggravating the deepwater situation to the point of causing anoxia in the mainstem of the system, linking the mass of hypoxic deepwater to hypoxic water in the adjoining embayments, and causing unusually severe kills of fish and invertebrates. The widespread hypoxia in 1986 is believed to have resulted from the eutrophying effects of nutrient additions from sewage treatment plants (STP). The extreme conditions brought on by the dinoflagellate bloom in 1987 are believed to have resulted from a coupling of unusually stable meteorological conditions to regular STP additions plus additional STP failures.

EPIDEMIOLOGY OF BOTTLENOSE DOLPHIN DISEASE --U.S. ATLANTIC COAST, 1987-1988

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This paper describes the history of the epidemiologic investigation into the bottlenose dolphin disease which ranged from northern New Jersey to Central Florida in 1987-1988. A simultaneous die-off of dolphins occurred in New Jersey and Virginia in July 1987. An interagency team was formed which examined animals for biotoxins, pollutants, viruses and bacteria in an extensive pathobiology investigation. Results of the several lines of investigation are presented and an epidemiologic synthesis is discussed.

DRIFT CURRENT MEASUREMENTS FROM A SUBMARINE

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A simple, accurate technique for measuring ocean currents from the set and drift of a submarine is described. The drift current is the vector difference between two velocity vectors: the inertial velocity determined from navigation data and the relative velocity, which is calculated from the electromagnetic speed log and the gyrocompass heading. Drift currents may be calculated routinely and displayed for submarines underway with a modest amount of computation or calculated from data recorded on tape.

An example of submarine drift current calculations is presented from a multi-ship exercise in the Sargasso Sea, including a cold-core, Gulf Stream ring. These data illustrate the capability of the technique for resolving the complex current structure of the region and demonstrate that the current estimates from different ships are consistent to within a few tenths of a knot or less.

IMPLICATIONS OF USING A WIDE SWATHE SOUNDING SYSTEM

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There is an ever growing evidence that surveys of the seabed obtained by means of echo sounding does no longer meet the stringent demands for greater positive identification of navigational and seabed engineering hazards and for a quality assurance of the data. Although sidscan sonar has been able to assist the surveyor over the last couple of decades, it has required an interpretative skill, not always available to the busy operator, and has proved somewhat subjective as a consequence.

Interferometric swathe sounding has enabled the generation of depth data in a uniform density pattern across the survey area thereby removing the orientation bias inherent in echo sounding surveying. The widths of the swathes achieved are such that it is operationally possible to ensure sufficient overlaps, and thus duplication of data, so that objective quality control procedures can be applied. Using the procedures has resulted in evidence that hitherto sometimes unsuspected inadequate performances of complementary instrumentation, or insufficiently precise environmental data, can be monitored, quantified and, if need be, corrected.

The data rates are greatly augmented thereby improving the resolving capacity of the survey in terms of identification and delineation of seabed features. The other side of the coin is that the high data rates require the application of a strict discipline in data base management while also providing opportunities to supply the customer with much more detailed environmental information wherever he wants, or needs, it. The proposition is that several versions of the data base should be available, each being tailored to the specific requirements of major customer type groups. In this way data will be used for fully if selectively enhancing the cost benefit derived from the original survey operation.

DEVELOPMENT OF SEPARATOR TRAWL TECHNOLOGY

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A project to develop a shrimp separator trawl (SST) has resulted in a number of viable designs that catch shrimp without catching or retaining unwanted fish species. A body of knowledge on net development strategies as well as on fish reactions to various net configurations has also been assembled. All designs tested as possible SST configurations will be described. Also explained will be the evolution of the various techniques used to comparitively evaluate the wide variety of designs tested. Experience with "trouser trawls" of various designs will be emphasized.

RECENT WAVE ENERGY RESEARCH IN SWEDEN

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Technocean AB
Gothenburg, Sweden

Wave energy research has been carried out in Sweden since 1976. About $6 000 000 have been spent - one half by a governmental research programme and one half by Swedish industry.

The main aim of governmental program is to evaluate if wave energy could contribute to the future Swedish energy supply - especially in the light of the decision that the nuclear power shall be settled before 2010.

There are three industrial projects:

- The IPS-buoy (Interproject Service AB). A prototype was built in 1979 and tests were carried out at sea in 1980 and 1981. In 1985 a smaller buoy, for navigation purposes was tested.
- The hose pump concept (Celsius Industries AB). Sea trials have been carried out in 1983 and 1984. A small light-buoy was also tested in 1985. Calculated cost for large scale power plants is less than 4 ¢/kWh.
- The Wave Rotor is a new promising concept of which only small models have been tested yet.

THE SSV CORWITH CRAMER: SEA EDUCATION ASSOCIATION'S NEW SAILING RESEARCH VESSEL

R. Jude Wilber, Charles E. Lea and Susan E. Humphris

Sea Education Association
Woods Hole, MA

With the launching of the SSV Corwith Cramer the Sea Education Association of Woods Hole, MA now operates two sailing vessels which serve as research platforms for Sea Semester. This program, using the 125' schooner Westward, has provided practical, at-sea experience in oceanography to over 2000 undergraduates over the past 17 years. The Cramer, which is the first vessel built to meet U.S. Coast Guard regulations for Sailing School Vessels, is modeled closely after Westward. A variety of design modifications and equipment changes greatly improve her performance as a research vessel. Cramer's greater length (135 feet) and beam (26 feet) serve to increase speed, stability and working deck area. The dry lab amidships is nearly twice the size of Westward's and designed specifically for the type of research projects conducted during Sea Semester. The vessel's on-board research equipment consists of standard oceanographic sampling gear such as plankton nets, trawls, cores, dredges, and Nisken bottles. Sampling gear is deployed amidship over either side of the vessel using a 9 hp variable speed winch carrying 500 m of ¼" hydrowire. In addition, the Cramer carries a variety of modern sampling and analytic gear including a 3.5 and 12 kHz PDR, digital recording BT and CTD, salinometer, fluorometer, spectrophotometer and four micro-computers for data recovery, processing and storage.

With its new design and equipment the SSV Corwith Cramer provides SEA with an economical, stable and well-equipped research platform which will continue to provide students with a practical introduction to oceanography for many years to come.

HAZARDOUS MATERIALS IN MARINE SALVAGE OPERATIONS

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Hazardous materials are on board ships in abundance. In addition, materials that are normally benign may become hazardous when exposed to heat, air, water or undergo a chemical reaction. Materials long held as being safe have been found to be hazardous or toxic; for example, cellulube is carcinogenic. Similarly, statutes and regulations, handling, reporting, transporting and disposal requirements are dynamic and of tremendous impact on any operation involving hazardous/toxic materials. The problems of managing hazardous materials and hazardous situations have grown in scope and complexity. Recent salvage cases worldwide have demonstrated this. Most salvors have very little knowledge, and even less experience, with operations involving hazardous materials. Training is almost non-existent, and the available documentation was not written towards the salvor. Similarly, the salvor normally does not have the equipment readily available to react to a hazardous situation. Any hazardous material operation may very likely tie to a pollution or firefighting operation or both. Other issues such as generator designation, liability, disposal, etc. can add enormous complexity, risks and expense to an operation.

This paper addresses the issues a salvor must confront when faced with an operation that involves hazardous or toxic materials.

THE FUTURE OF THE TOURIST SUBMARINE INDUSTRY

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The market for underwater sightseeing aboard submersibles specifically designed for it has been well established, and competition is underway. Sites for operations are being developed worldwide. Eventually the number of people going on submarine rides in the coastal oceans of the world could exceed 40,000 per day.

Because they are becoming mass transport vehicles for recreation, tourist submersibles will suffer the accidents that befall such operations eventually. Unlike other kinds of transportation, an accident with loss of life could totally discourage the market. The future of tourist submersibles will likely be strongly affected by the position and cohesiveness of the industry when an accident occurs.

An outline is presented of a predictive approach that utilizes three separate but similar models from the literature. They are a technology assessment, an industry competition analysis, and a behavioral stimulus-response model of one particarly important regulatory agency, the U.S. Coast Guard. The models are used as overlays on a complex picture to help identify significant features and their interactions. The most apparent scenarios for the future of the tourist submersible industry are described.

HYDRODYNAMIC AND MASS TRANSPORT MODELING OF NAVY HARBORS

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Hydrodynamic water quality modeling of eight U.S. Navy harbors is being performed to acertain the effects of organotins on harbor life. Organotins are the essential constituents in a fairly new family of powerful anti-fouling nautical paints that have proven very effective against biofouling when applied to seaborne vessels, and have thus resulted in significant associated fuel and maintenance cost savings. DYNHYD (hydrodynamics) and TOXIWASP (mass transport) are being used to model the hydrodynamics and the transport and fate of these organotins within the following harbors: Mayport - Jacksonville, FL; Pearl Harbor, HI; Puget Sound, WA; Charleston, SC; Long Beach, CA; Philadelphia, PA; Portsmouth, NH; and Alameda, CA. For each harbor a detailed link-node network is established, hydrologic and hydraulic data is collected, calibration and verification of the DYNHYD model, and dispersion calibration of the TOXIWASP model is performed. DYNHYD modeling characterizes the movement of water in the area of interest under alternative climatic conditions. TOXIWASP modeling determines parameter dispersion throughout the water and sediment layers of the system. The modeling is intended as a support to the design and implementation of monitoring efforts and as a general support tool for the Navy's water quality program.

SCHEDULING PATROLS USING A HYBRID INTEGER PROGRAMMING/RULE-BASED SYSTEM APPROACH

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Formal mathematical programming algorithms have been developed for many scheduling problems of interest to the maritime community, but computational complexity often restricts their use to disappointingly small problems. An interactive system which uses a rule base and advice from the scheduler to formulate constraints for an integer program will be discussed. The interaction results in fixing the values of many decision variables, thus considerably reducing the size of the decision space, and consequently, the computational burden. As a sample problem, the task of scheduling U.S. Coast Guard Atlantic Area cutters is addressed. Some 30 ships are involved, with varying patrol lengths, maintenance and training requirements, and capabilities. The system illustrates the coupling of symbolic computing techniques with a high-level math programming language (GAMS).

SHIPBOARD TECHNICIAN PROGRAM OF THE NATIONAL SCIENCE FOUNDATION

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National Science Foundation
Washington, DC

The NSF Shipboard Technician Program of the Ocean Sciences Division provides support for basic technical support services on research vessels. Technician support grants are provided to institutions specifically for the support of NSF-sponsored research projects scheduled on those research vessels operated by the institutions, and are concurrent with an award for Ship Operations.

The Shipboard Technician Program has two components: an at-sea component and an ashore component. The at-sea component consists of instructing scientific personnel in the use of shared shipboard equipment; maintenance, repair, and calibration of scientific instrumentation; instruction and supervision of deck operations; and providing logistics assistance to on-coming and off-going scientific parties. On-shore activities include the maintenance, repair, and calibration of shared use seagoing equipment and assisting scientific personnel in preparing for field work on the vessel. Shipboard technicians funded by this Program have broad responsibilities for providing the coordination and technical assistance needed for the successful completion of research projects at sea.

CHRONIC EXPOSURE EFFECTS OF TRIBUTYLTIN ON PEARL HARBOR ORGANISMS

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Several species of harbor organisms were exposed in a chronic, flowthrough experiment to environmentally relevant tributyltin (TBT) concentrations in the range of about 10 to 100 ng/liter. Effects were seen only at the highest mean level of exposure (100 ng/liter) and included depressed condition indices of adult oysters (Crassostrea virginica) and reduced settlement of two endemic oyster species. The settlement and growth of 15 common fouling organisms and survival of anchovy baitfish and portunid crabs were unaffected by all TBT exposures. Oysters, anchovies and crabs were sampled periodically for future analysis of TBT tissue burdens. The results of this experiment reaffirm observations from previous site-specific flowthrough tests in Pearl Harbor that show that chronic exposures to TBT levels of about 80 to 100 ng/liter and higher cause significant deleterious effects on sensitive marine epifauna.

CONTROLLED DEPRESSOR TOWED SENSOR PLATFORM -- THE U.S. NAVY'S Mk28 SEARCH SYSTEM

Michael Higgins and Roger Whyte

Eastport International, Inc.
Upper Marlboro, MD

Eastport International, under contract to and direction of the U.S. Navy's Explosive Ordinance Disposal Technical Center, has developed, tested and delivered to the Navy a towed search system based on entirely new techniques and technology. The Mk 28, Mod 0 Search System, offers the Navy unequaled shallow water capabilities in locating objects using marine magnetrometers and, eventually, side scan sonar. The development and testing of high performance naval search systems is the subject of this paper.

The Mk 28 is a fully integrated system composed of: an actively controlled towed depressor fish, a small tow winch and cable, surface control consoles, an integrated navigation system, and the search sensor and its processing equipment. The towfish has remotely controlled depressor wings which permit the fish and sensors to be flown at either a constant depth or a constant altitude. The fish also incorporates an acoustic positioning beacon and the ability to support side scan sonar.

This paper will address the development and testing of the innovative features of the system, mainly: the controllable depressor wing, control algorithms (with hydrodynamic analysis), the integrated navigation system, and the sensor integration. Substantial use of the Navy's technical sea testing data will be used to support the paper.

DEVELOPMENT AND TESTING OF A HEAVY-DUTY WORK ROV FOR 10,000 FOOT SERVICE

Michael Higgins, Bill Lawson and Bill Field

Eastport International, Inc.
Upper Marlboro, MD

EASTPORT INTERNATIONAL has upgraded the depth capability of the entire GEMINI ROV system for 10,000 feet bringing the GEMINI into the vanguard of deep-ocean commercial ROV systems. The GEMINI development used designs at the forefront of today's submersible technology, including: a fiber optic umbilical cable, dual spatially-correspondent heavyduty manipulators, and an air-transportable aluminum handling system.

The development and testing, due to be complete in mid 1988 is expected to be completely successful. This paper addresses and describes the engineering development and systems integration. Specific areas of discussion include: telemetry system design and integration for this great depth, cable design, power system engineering, vehicle sensor and manipulators/tools specification and integration, and handling system design. Sea testing is also addressed with a focus on operational problems and solutions when working in 10,000 foot depths.

Deep ROV system technology has many useful applications in supporting offshore oil and gas exploration, drilling, and production, and cable and pipeline support. Development of a 10,000 foot submersible proves the capability exists to support commercial operations to this extreme depth.

DESIGN AND APPLICATIONS OF SEATRAC, AN INTEGRATED NAVIGATION AND DATA MANAGEMENT SYSTEM

Ray Gandy and Steven Paulet

Structured Technology Corporation
Niantic, CT

Typically, position data processing equipment is manufactured to interface with particular positioning sensors or devices. In addition, the data processing and its overall effectiveness can be somewhat limited in particular applications. The need for the integration of navigation equipment along with enhanced data management capabilities has been evident for some time in the offshore industry. This need has been recognized in developing the state-of-the-art integrated navigation and data management system known as, SEATRAC.

SEATRAC combines two primary functions incorporating the latest in microprocessor technology. The first is to integrate the signals from a variety of offshore positioning devices and optional digital data. The second function is to manage the collected data for visual display and permanent storage. The interface versatility and increased data processing capabilities make SEATRAC an affordable integrated system for offshore use as a shipboard display, plotting and recording system.

Mission operations can be more readily evaluated with multicolor simultaneous display of ship and submersible position and track history. This results in instant recognition of prior and future positions. The operating area video presentation can be changed from an overall perspective to a close-up view with the push of a button. Beacons, anchors, pingers, markers, etc., can be visually displayed as desired. Position fix colors even change when the automatic dead reckoning position mode is activated.

This paper details the design and applications of SEATRAC as a high-tech, low-cost alternative in providing integrated navigation and data management.

THE MEASUREMENT OF PRECIPITATION AT NATIONAL DATA BUOY CENTER STATION

Eduardo D. Michelena

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NSTL, MS

An operational capability to measure precipitation at shore stations and deployed buoys is being developed at the National Data Buoy Center (NDBC). Measurement accuracy and sensor reliability are of prime importance in this program.

The design and field evaluation of several precipitation sensors is described. Included are sensors specially developed and built for NDBC, as well as some commercially available instruments. NDBC's experience with tipping-bucket rain gauges, including laboratory calibration and use on shore stations and ocean platforms, is presented. The installation on a large discus buoy of an optical precipitation-rate sensor and a new design of rain-accumulation-type gauge is explained. Inter-comparison data from both land and at-sea test installations of several precipitation gauges are evaluated.

MINI-DRIFTER TEST DEPLOYMENT DATA -- GULF OF MEXICO, SPRING 1988

Ralph R. Miller and Raymond Canada

Computer Sciences Corporation
Moorestown, NJ

A dozen mini-drifter meteorological buoys were tested in field conditions in the Gulf of Mexico in the spring of this year. This paper presents a summary of the data in terms of data quality, sensor stability, and sensor accuracy. The buoy data are compared with NWS data. Conclusions are presented reflecting our assessment of the state of development of the mini-drifter meteorological buoy.

A SURVEY OF RADIONAVIGATION SYSTEM USERS

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U. S. Coast Guard
Washington, DC

In these times where cost-effectiveness is being emphasized in all government programs, the Coast Guard is reviewing the status of federally-operated radionavigation (RA) systems to support a recommendation to the Department of Transportation on the optimal mix of RA systems. To conduct a thorough review, the Coast Guard believes that direct input from the users of these systems (marine and terrestrial [land/offshore]) must play an integral part. However, there is a lack of available valid baseline data on current RA system users. This necessitated the sponsorship by the Coast Guard Headquarters Radionavigation Division of a comprehensive nationwide RA system user survey to accomplish the following:

a) receive feedback on each system's effectiveness;
b) determine each system's extent and method of use;
c) determine the impact on the user of each system's discontinuance;
d) determine the impact upon these systems of changing user needs and technology advancements; and
e) provide an estimate of and categorize the marine user population.

This paper will provide a description of the survey (including antecedent data collection efforts - estimation of the respondent universe, sampling methodology, copy of each questionnaire type, etc.), analysis of the results, and publication plans.

EXPERIMENTAL MANIPULATIONS OF DRAINAGE IN A GEORGIA SALTMARSH: LESSONS LEARNED

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ABSTRACT

In two separate studies of factors controlling primary productivity of Spartina alterniflora, subsurface water movement was increased in stands of intermediate and short Spartina. The objective of the manipulation was to simulate conditions found in creekbank marsh, where productivity was 2-4 times higher than in the experimental areas. The small-scale pilot study had resulted in a two-fold increase in aboveground biomass in one growing season and in shifts in belowground chemical conditions toward those typical of creekbank marsh. In the large-scale experiment, belowground chemistry changed as expected, but although plant biomass increased at all sites during the first growing season, it declined steadily during the next three years. In addition to those contradictory results, substantial site-to-site variation was observed in the large-scale study. These results demonstrate the need for caution in making broad generalizations about salt marshes and their response to disturbance, and the value of long-term studies in determining the effects of disturbance.

INTRODUCTION

Spartina alterniflora Loisel., which dominates the intertidal marshes along much of the East and Gulf Coasts of the United States, displays a striking heterogeneity in growth form which corresponds to a major physical differentiation in habitat. The highly productive "tall Spartina" is invariably found growing on and immediately behind the levees bordering the meandering tidal creeks which intersect the marsh, while "short Spartina" occupies the remainder of the marsh area, usually called the high marsh (see 13 for a detailed description of these zones). While short Spartina exhibits considerable variability in productivity and height, nowhere does it equal that of the grass growing in the creek bank-levee zone. Interstitial water moves through the levee and creekbank sediment relatively rapidly under the influence of the hydraulic forces created by the rising and falling tides (4), while horizontal sediment water movement in the high marsh is virtually nonexistent (11). Thus productivity is correlated with the amount of sediment water movement.

There are a number of differences in the chemistry of the sediments in these two zones which result from the difference in interstitial water movement in combination with plant and microbial activity (8, 7). Although the heterogeneity in productivity in the two areas has been correlated with a number of features (e.g., water flow, free sulfide, interstitial salinity, available Fe2+), there has been no clear demonstration of the factor or combination of factors which control productivity of S. alterniflora (1).

Soil drainage has been suggested by several investigators (9, 7, 15) to be an important factor controlling productivity of S. alterniflora. Patterns of heterogeneity in grass height, standing crop and productivity have also been correlated with interstitial salinity (10), iron availability (12), nitrogen availability (8) and sediment redox (7, 9), all of which are affected by drainage.

Here I report the results of two studies, similar in design but different in scale, designed to determine the effects of increased drainage on Spartina productivity. The results of the first, small-scale study have been reported in detail by Wiegert et al. (15) and King et al. (7), and are only summarized here.

The site for the small-scale study, conducted in 1980-81, was in a stand of intermediate height S. alterniflora on the southern end of Sapelo Island, GA. For the large-scale study, conducted in 1983-86, four study sites were selected in short S. alterniflora marshes, two in the Airport Marsh (AP 1 and AP 2), one of the most studied marshes on Sapelo Island (12), one in a relatively new marsh at Raccoon Bluff (RB1) on the eastern side of the island and the fourth near the north end (NE) of the island.

At each site three plots were marked out and designated as undisturbed control (UDC), disturbed control (DC) and drained (Dr). Plot size in the pilot study was 5 m X 5 m and 10 m X 10 m in the large-scale study. For the large-scale study drainage systems were installed in the drained and disturbed control plots, but the outflow pipes in the disturbed control plots were capped so that no drainage would take place. For the small-scale study, trenches were dug in the DC plot to simulate the disturbance of installing a drainage system, but were refilled without burying any pipes. The design of the drainage systems is reported in detail in Chalmers et al. (ms. submitted to Ecological Monographs).

During late September or early October of each year, aboveground biomass was clipped from 0.25 m2 quadrats in each plot at each site. The culms were washed, stripped of dead leaves, sorted into 25 cm height classes and dried to constant weight at 60°C. Dead material was also washed and dried.

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Belowground chemistry was sampled once during the small-scale study and at 3-4 month intervals throughout the later study. Acrylic dialysis samplers with Gelman Versapor-200 acrylic copolymer membranes (pore size 0.2μm) were used to obtain interstitial water samples (5). One sampler was placed in each plot and allowed to equilibrate for two to three weeks. Salinity, pH, redox potential and the concentration of sulfide were measured at 4 cm depth intervals. Details of the chemical analyses are reported in Chalmers et al. (ms. submitted).

RESULTS AND DISCUSSION

In the pilot project experimentally increased drainage caused, in one growing season, a two-fold increase in end-of-the-year biomass in a stand of intermediate height S. alterniflora (15). Average culm height also increased. Sulfide concentrations were lower and soluble iron concentrations were higher in the experimental plot than in the control area (7). Interstitial salinity was also lower in the drained plot than in the undisturbed control area. All of these results were consistent with a shift of conditions toward those found in creekbank marsh.

In the large-scale study, interstitial salinity was lower in the drained and DC plots than in the undisturbed controls. The average reduction in salinity over the upper 24 cm (root/rhizome zone) ranged from 1.7 ppt at the North End to 7 ppt at the Airport 2 site. The salinity decrease in the large-scale study was not as large as expected based on the results of the pilot project. The reduction in salinity caused by increased infiltration of tidal water may have been counteracted in the later study by increased evapotranspiration in the higher elevation short Spartina marshes.

Increased movement of water through the sediment raised the redox potential at each site. At Raccoon Bluff the experimental manipulation had the least effect; redox potential was higher in the undisturbed control there than at any other site and nearly the same as in the Dr and draining DC plots at the other three sites. The depth profiles of redox show steep gradients in the upper 8 - 20 cm of the undisturbed marsh at each of the sites. In contrast, redox increased just below the surface in each of the Dr plots.

There was also a marked increase in the acidity of the interstitial water at the two Airport Marsh sites. The effect was less pronounced at Raccoon Bluff and the North End, but was nonetheless evident in the depth profiles. The greatest reduction in pH occurred between 10 and 18 cm deep in the sediment at each site, which corresponds to the zone with the largest biomass of roots and rhizomes. Values as low as 2.9 were measured in the drained plots at the two Airport sites; data from January and July 1986 show that pH in the original drained plots is returning to levels similar to those in the undisturbed plots.

The marked decrease in pH observed in the drained plots during the later study indicates that increased oxidation was an important drainage effect. The lower pH's are consistent with oxidation of reduced sulfur compounds and the release of protons (3). At each site the increased acidity was greatest at depths of 10 - 18 cm, near the bottom of the root zone. Although we do not know how deep air penetrated into the sediment, we do know that the depth of the water table at low tide was deeper than that at which the maximum decrease in pH occurred, and might assume that some air penetrated to the depth of maximum acidity. Apparently the peak of increased acidity was due to oxidation of reduced sulfur compounds which were accumulated at that depth. Sulfate/chloride ratios and differences between pyrite concentrations in drained and undisturbed control plots also support this hypothesis (Chalmers, in prep.).

At all four sites, sulfide concentrations were lower in the drained plots than in the undisturbed marsh, although the differences at Raccoon Bluff were small. In the undisturbed plots concentrations were low at the surface and increased with depth.

Aboveground biomass increased in the Dr plots at each site during the first year of increased drainage, although the increases were small at all sites but AP 1. During the remainder of the study, however, aboveground biomass in the Dr plots declined at every site, while that in the UDC plots remained relatively constant. There was little change in aboveground biomass in the DC plots during the first year of the study except at AP 1, where it increased slightly. At AP 1 it continued to increase during the next two years, but decreased substantially at the AP 2 and NE sites. At three of the four study sites, aboveground biomass in the Dr and DC plots was lower at the end of the study than it had been before the drainage systems were installed. Mean plant height increased at the two Airport sites as a result of the increased drainage, but changed only slightly at the other two sites.

Drainage was clearly increased by the experimental manipulation. In both studies, we could easily see the differences in the marsh surface caused by drainage; in the undisturbed marsh, water covered the surface at low tide as a thin film and as pools filling small depressions, but not in the drained plots. Water ran out of the outflow pipes at a slow but steady rate throughout the low-tide period of exposure of the ends of the pipes. In fact, during some summer neap tide periods, the surface sediment at the NE site at times became so dry that cracks and fissures developed and it took on a powdery appearance. Similar but less severe drying was occasionally observed at Raccoon Bluff, but not at either of the Airport sites or at the pilot project site. Such extremes of dryness could undoubtedly cause a degree of water stress for Spartina that would counterbalance or outweigh the beneficial effects of lower salinity and more oxidized root zone. Although the frequency of inundation was the same at all sites, duration varied from site to site because of differences in elevation. Thus, there were small but possibly significant differences from site to site, even in the undisturbed control plots, in the length of time the sediment surface was wet or covered with water and in natural rates of drainage.

Although there were initial increases in aboveground biomass in the Dr plots at each site in

the large-scale study, the decline in productivity during succeeding years demonstrates that drainage alone does not determine the productivity of S. alterniflora. Clearly, a number of factors interactively control plant growth in the salt marsh, but the pilot project which preceded this study suggested that the amount of drainage determined how favorable for growth the interaction of controlling factors would be. Simply increasing the drainage doubled the aboveground biomass in one growing season. Why then were the results of the later study so different?

The first experimental drainage was done in intermediate height S. alterniflora, a type with higher initial rates of drainage than those of short-form grass. Our selection of four short-form Spartina sites for the present study was made deliberately in the expectation that what was good for partially-drained marsh would be even better for stagnant (interstitially) marsh. In retrospect, this was clearly a naive expectation. Adjacent to the laboratory building at Sapelo Island is a large area of marsh which was, many years ago, drained in the expectation of using it as cultivatable land. When resultant soil conditions prevented its use, it was returned to its original intertidal condition. The outcome of this "experiment" should have warned or enlightened us.

During the course of this study we found that there are substantial differences within the marshes adjacent to Sapelo Island in the natural rates of drainage. Of the four sites used for the present study, the site with the largest amount of natural drainage was Raccoon Bluff, where there was almost no plant response to increased drainage. The Airport 1 site had the smallest amount of natural drainage, yet was the only site where aboveground biomass in the drained plot was higher at the end of the study than prior to installation of the drainage systems. Had the study been limited to these two sites we might have concluded that some degree of increased drainage could be beneficial to growth in stands of short Spartina.

The Airport 2 site most closely resembled the site of the earlier project visually, yet aboveground biomass in the drained plot at AP 2 increased only slightly (12%) during the first growing season, and decreased by 75% over the course of the experiment. At the North End site, which had more natural drainage than either of the two Airport sites, biomass declined by more than 80% during the study. The sustained increase in drainage was clearly detrimental to plant growth at these sites.

There was less change in sediment chemistry at Raccoon Bluff than at the other sites, but water stress should have been most severe there, even under natural conditions. Its relatively high elevation results in high natural drainage and less frequent and less prolonged tidal inundation than at either Airport site, and its sandy sediment holds less water than those with high clay content found at the other three sites. The lack of response to increased drainage, either positive or negative, suggests that the plants at Raccoon Bluff were already adapted to severe water stress.

It is clear that prolonged increased drainage can have an adverse effect on growth of S. alterniflora. But it is also clear that similar perturbations in apparently similar sites can produce quite different effects. There is to date no evidence that prolonged increased drainage has been detrimental at either the AP 1 or the Raccoon Bluff site. At Airport 1 productivity in the drained plots continues to be higher than in the undisturbed control, due perhaps to lower natural drainage and more frequent and/or prolonged tidal inundation.

The ability of S. alterniflora to alter its own belowground environment (6), especially insofar as it controls movements of the water table and the potential for air entry into the sediment (2) could be of great importance, but the age of the marsh and its sediment type or the source of its sediments also are important in determining belowground chemistry. Because of the large site-to-site differences that can occur even in a small geographical area, broad generalizations about typical high marsh or typical low marsh sediment chemistry should be approached with caution. The aboveground appearance of a S. alterniflora marsh, in particular the height of its grass, is not necessarily an indication of a single specific aspect of the belowground chemistry.

Drainage alone does not control primary productivity in S. alterniflora marshes and can, in fact, be detrimental in some circumstances. When drainage rates are high, water stress, which is generally considered to be a function of salinity in salt marshes, can become a more serious problem than interstitial salinity alone would indicate it to be. On and near creek banks, where drainage is naturally high, tidal period and hydrological dynamics of the marsh combine to prevent the excessively dry conditions that increase water stress in plants. In those circumstances it is sediment water movement, or flushing of interstitial water, rather than drainage per se that creates conditions so favorable for S. alterniflora growth. Similarly, at AP 1, where elevation was low and sediment drying was not so great as at other sites, the increase in sediment water movement, rather than the increase in drainage in the drained plots, was the cause of increased productivity.

The dramatic difference in the conclusions that would have been drawn about the effects of increased drainage if the large-scale experiment had ended at the end of the first post-drainage growing season (1984) and those drawn after three growing seasons demonstrates the need for long-term studies, particularly when large-scale disturbances are part of the experimental design. The site-to-site differences in response to increased drainage demonstrate the dangers of generalizing about marsh response to disturbance or alteration. Although all S. alterniflora marshes may be similar in appearance, there can be substantial differences, even within a small geographical area, in controls on important ecosystem-level processes and susceptibility to disturbance.

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REFERENCES

1. Chalmers, A. G. Soil dynamics and the productivity of Spartina alterniflora. In: Estuarine Comparisons, V. S. Kennedy, (ed.), Academic Press. 1982. pp. 231-242.
2. Dacey, J. W. H., and B. L. Howes. Water uptake by roots controls water table movement and sediment oxidation in short Spartina marsh. Science. 1984. 24: 487-489.
3. Giblin, A. E., and R. W. Howarth. Porewater evidence for a dynamic sedimentary iron cycle in salt marshes. Limnology and Oceanography. 1984. 29: 47-63.
4. Harvey, J. W., P. F. Harvey, and W. E. Odum. Geomorphological control of subsurface hydrology in the creekbank zone of tidal marshes. Estuarine, Coastal and Shelf Science. 1987. 25: 677-691.
5. Hesslein, R. H. In situ sampler for close-interval pore water studies. Limnol. Oceanogr. 1976. 21: 912 - 914.
6. Howes, B. L., R. W. Howarth, J. M. Teal, and I. Valiela. Oxidation- reduction potentials in a salt marsh: Spatial patterns and interactions with primary production. Limnol. Oceanogr. 1981. 26: 350-360.
7. King, G. M., M. J. Klug, R. G. Wiegert, and A. G. Chalmers. Relation of soil water movement and sulfide concentration to Spartina alterniflora production in a Georgia salt marsh. Science 1982. 218: 61-63.
8. Mendelssohn, I. A. Nitrogen metabolism in the height forms of Spartina alterniflora in North Carolina. Ecology. 1979. 60: 574-584.
9. Mendelssohn, I. A., K. L. McKee, and W. H. Patrick, Jr. Oxygen deficiency in Spartina alterniflora roots: metabolic adaptation to anoxia. Science. 1981. 214: 439-441.
10. Nestler, J. Interstitial salinity as a cause of ecophenic variation in Spartina alterniflora. Estuarine and Coastal Marine Science. 1977. 5: 707-714.
11. Nestler, J. A preliminary study of the sediment hydrology of a Georgia salt marsh using rhodamine WT as a tracer. Southeastern Geol. 1977. 18: 265-271.
12. Nixon, S. W., and C. A. Oviatt. Analysis of local variation in the standing crop of Spartina alterniflora. Botanica Marina. 1973. 26:103-109.
13. Pomeroy, L. R., W. M. Darley, E. L. Dunn, J. L. Gallagher, E. B. Haines, and D. M. Whitney. Primary production. In: The Ecology of a Salt Marsh, L. R. Pomeroy and R. G. Wiegert, (eds.), Springer-Verlag, New York. 1981. pp. 39-67.
14. Pomeroy, L. R., and R. G. Wiegert. The Ecology of a Salt Marsh. Springer-Verlag, New York. 1981. 271 pages.
15. Wiegert, R. G., A. G. Chalmers, and P. F. Randerson. Productivity gradients in salt marshes: the response of Spartina alterniflora to experimentally manipulated soil water movement. Oikos. 1983. 41: 1-6.

BUTYLTIN RELEASES TO HARBOR WATER FROM SHIP PAINTING IN A DRY DOCK

by
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ABSTRACT

The results of a study to determine the release of butyltins into harbor waters from shipyard painting of the underwater hull of USS *Badger* (FF 1071) are presented. The study was part of a Congressionally mandated program to conduct a two-harbor case study to ascertain the fate and effects of organotin in marine waters resulting from the application and use of organotin antifouling paints. Implementation of the program involves development of a mathematical model of Pearl Harbor, documenting the shipyard activities involved in the application of the paint, monitoring the concentration of organotin in the harbor waters following undocking of the ship, and studying the environmental fate and toxicity of organotin in Pearl Harbor waters.

The shipyard took extraordinary steps to contain and collect the paint overspray in the drydock. We found that more than 99% of the paint overspray was collected from the drydock floor before the ship was undocked. The remaining overspray and the initial release of tributyltin from the freshly painted hull resulted in a release of approximately 15 grams of tributyltin from the drydock. The release did not cause a measurable increase in the concentration of tributyltin in adjacent harbor waters over the background concentration of 15 to 20 ng/L. The release of butyltins into the marine environment from shipyard activities can be reduced to negligible levels, but practical means to achieve that reduction within the constraints of shipyard operating procedures are required.

INTRODUCTION

The U.S. Navy has been authorized by Congress to conduct a two-harbor case study involving the application of organotin antifouling paint to Navy ships.[1] This study will provide data for the Environmental Protection Agency's (EPA) Special Review and for evaluating the effects of the Navy's use of tributyltin (TBT) paints. Organotin-based antifouling paints have been applied to only 13 active Navy ships for testing purposes. Three ships were painted at Pearl Harbor Naval Shipyard during Fiscal Year 1987 under the two-harbor case study.

Pearl Habor and Mayport, Florida, the other harbor in this study, were selected as the sites for the study because they are used predominantly by the Navy. Therefore, the Navy can control and monitor TBT use at these sites. The presence of unknown and uncontrolled TBT mass loadings from non-Navy sources would make it difficult to accurately relate TBT concentrations resulting from Navy sources. An implementation plan for the entire Pearl Harbor phase of the two-harbor case study describes the joint DTNSRDC/NOSC effort.[2]

Base line surveys of organotin concentrations in Pearl Harbor were conducted in 1984.[3] The surveys show low to undetectable levels of butyltin compounds present in water (5 ng/L TBT) and low to undetectable levels of extractable tin in sediment (<50 ng/g) and oyster tissue samples (<400 ng/g). Conversely, Honolulu Harbor, with heavy commercial and private use, showed significant impact from tributyltin inputs averaging 97 ng/L TBT in water and elevated levels of extractable tin in tissues and sediment.

This paper presents the results from sampling of drydock and harbor waters during and after the painting and undocking of the first ship painted at Pearl Harbor Naval Shipyard, USS *Badger* (FF 1071).

There are two pathways by which butyltin compounds associated wth antifouling paints can enter the estuarine environment. The first pathway, the release of butyltin compounds from the underwater hull of the vessel, is most significant when the vessel is docked or anchored and represents a continuous source of release. The second, the release of butyltin compounds associated with the painting and cleaning of underwater hulls, represents an intermittent discrete release at the point of boatyard or shipyard activities.

In the past 3 years, a great deal of effort has been devoted to describing the first pathway. Concentrations of butyltin compounds in estuaries and, in particular, in pleasure craft marinas have been determined. The rate at which butyltin compounds are released from antifouling coatings has been measured, and attempts have been made to relate the concentrations in the marinas to the rate at which the butyltin compounds are released from the coatings. However, no known attempts have been made to describe the second pathway, either from small boatyards or from large shipyards. This paper describes the first attempt to measure the release of butyltins into adjoining harbor waters during the painting and undocking of a ship.

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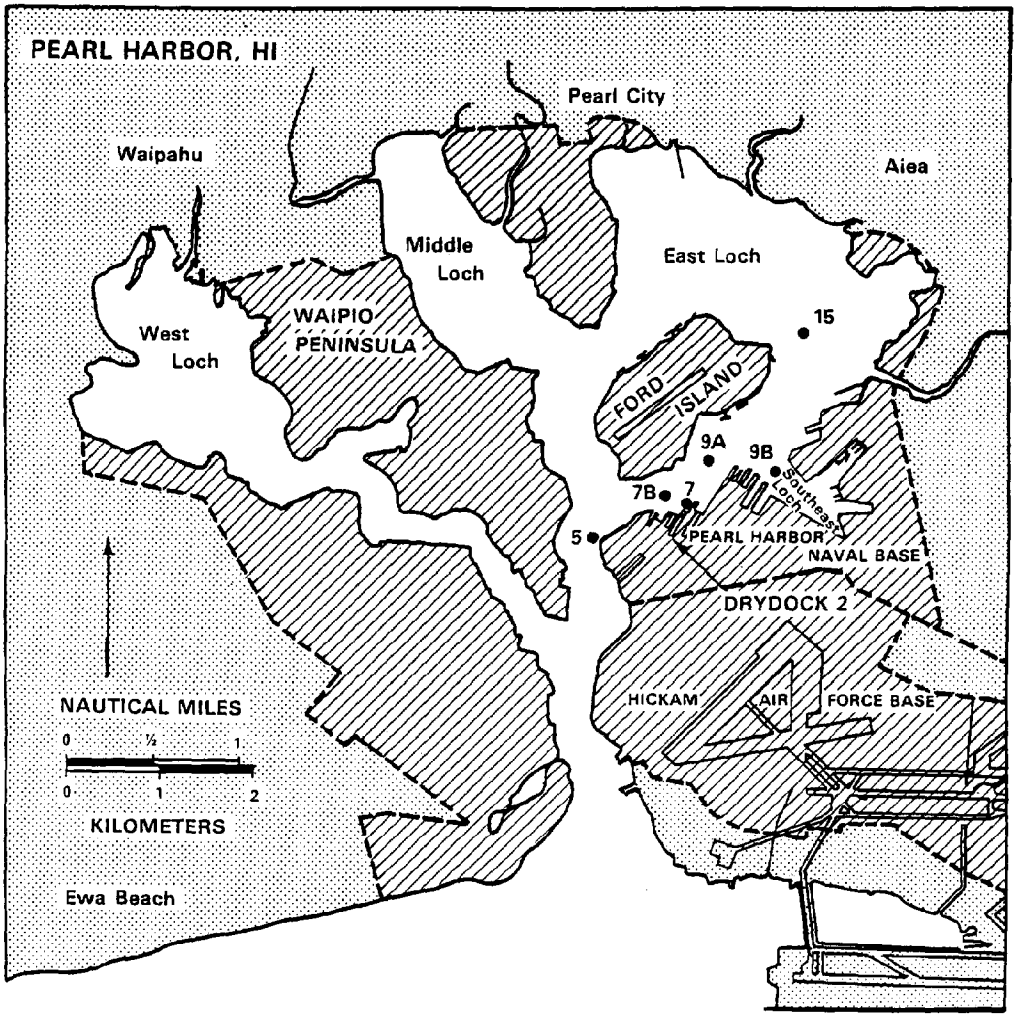

Fig. 1. Map of Pearl Harbor.

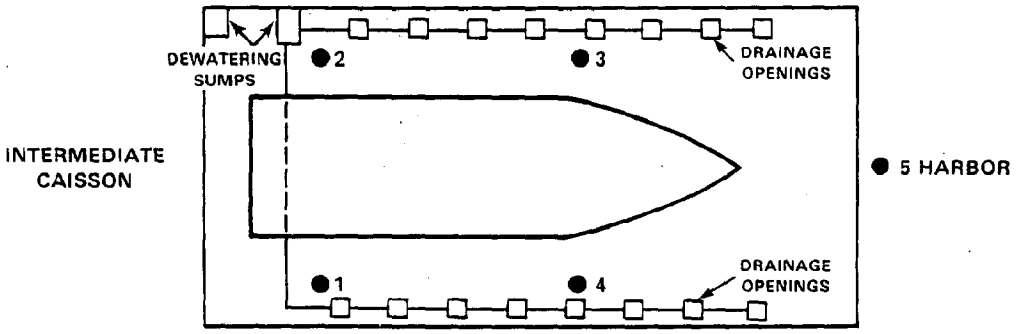

Fig. 2. Drydock water sample locations; schematic of drydock drainage system.

METHODS AND MATERIALS

Site Description

The ship was painted at the Pearl Harbor Naval Shipyard in one of its four graving drydocks* (see Figure 1). This drydock has an intermediate caisson which divides the drydock into two separate sections which are independent of each other. The section of the drydock used was approximately 500 ft long by 140 ft wide (153 × 43 m). The drydock floor has 4-in.-wide by 2-in.-deep (10.2- × 5.1-cm) lateral drainage trenches on 6-ft (1.8-m) centers, which are designed to transport precipitation and infiltration water to one of the longitudinal drains located on each side of the drydock (see Figure 2). There are eight openings to each of the two longitudinal drains. The longitudinal drains discharge into one of two sumps which empty into a common pump well from which the drydock water is pumped into the harbor.

USS *Badger* (FF 1071) with approximately 22,500 ft^2 (2090 m^2) of underwater surface area was painted. It is 438 ft long (134 m) and has a 46.8-ft beam (14 m). The ship was approximately centered in the drydock with the stern 20 ft (6 m) from the intermediate caisson and the bow 40 ft (12 m) from the seaward caisson. The ship rested on concrete dock blocks at the center line and bilge keels about 10 ft (3 m) above the drydock floor. The water line was 15 ft (5 m) below the top of the drydock wall.

Drydock Preparations

The shipyard took unusual and substantial efforts to contain and collect the overspray in the drydock in order to minimize the amount of overspray that could enter the harbor. Four of the openings to each of the longitudinal drains were covered completely during painting. The other four were fitted with 1/4-in. mesh steel screens lined with cheese cloth to filter particulates from the water. The sump which collected the water from the longitudinal drains was isolated from the pump well, and two diaphragm pumps were used to pump the water from the sump to the sanitary sewer. The other sump was covered and used to discharge ship's cooling water through the normal pump well. The portion of the drydock floor directly under the ship and extending out 20 ft (6 m) toward the drydock walls (representing approximately 50% of the drydock floor) was covered with Herculite,† a phenolformaldehyde reinforced plastic cloth. It is very durable and will not tear if mechanical equipment runs over it during painting operations. The bilge and keel blocks were covered completely also. The staging, caissons, painting baskets, and ship brows were masked so that shipyard personnel would not inadvertently contact an organotin painted surface.#

* A graving drydock is a large hole in the shoreline into which the ship is floated. The harbor end of the drydock is sealed with a caisson and then the water is pumped from the drydock so that repairs can be made to the underwater hull of the ship. Alternatively, repairs can be made to the ship in a floating drydock which lifts the ship out of the water.

† Herculite is a trade name of Herculite Products, Inc., 1107 Broadway, New York, NY 10010.

To our knowledge, no one has established whether these personnel safety precautions were necessary, i.e., whether skin contact with a dry organotin coating is harmful.

Drydock Cleanup

Three coats of paint were applied to the ship over a 3-day period; then protective materials containing the overspray in the drydock were collected. First, the masking of the bilge and keel dock blocks and the staging was removed and then, the Herculite on the drydock floor was cut into 4- to 5-ft (1.2- to 1.5-m) strips, rolled, and placed in 55-gallon drums for disposal. Next, the drainage trenches and tunnels were cleaned manually using narrow shovels. Finally, the entire drydock floor was vacuum-swept using industrial-sized manually operated vacuum sweepers.

The drydock preparations and cleanup described above, although successful, were costly; other engineering approaches must be evaluated to minimize the release of paint overspray into the harbor when the ship is undocked.

Drydock Sampling

Sampling in and about the drydock was designed to provide a complete picture of the release of butyltins during painting and undocking of the ship. We took samples to quantify the amount of antifouling paint which fell to the drydock floor during the painting process, the amount that was discharged to the sanitary sewer system during painting and cleanup, and the amount released to the harbor while the ship was being undocked.

Paint Overspray

ABC-2, an organotin antifouling paint manufactured by DeVoe-Reynolds Corp., was applied to the ship using airless spray equipment in three coats of 5-mils (5 mils = 0.005 in. ≈ 0.13 mm) dry film thickness, for a total antifouling coating of 15 mils. A 4-mil-thick polyethylene sheet was wrapped around 8- × 8- × 1/8-in. (20- × 20- × 0.3-cm) aluminum panels to measure the overspray from the painting; 22 of these panels were placed on the drydock floor and six on the top of the drydock wall. The panels were placed on the drydock floor prior to the start of painting and picked up at the completion of painting each of the 3 days to prevent redistribution of the overspray by wind or rain. After the first and second coats of paint, a circular piece of the black polyethylene with a surface area of 1.25 cm^2 was excised from six of the panels in a transect across the dock. A 1.25-cm^2 circular piece was excised from each of the panels after the last coat of paint was applied.

Drydock Discharge During Painting and Cleanup

Infiltration or leakage into the drydock and precipitation are pumped continuously from the drydock. We sampled this discharge before the painting began to establish the background level of butyltins. This discharge was diverted to the sanitary sewer while the ship was being painted and while the drydock was being cleaned. Daily samples of the water discharged to the sewer were collected from the time that painting began until the ship was undocked. These samples were collected in 1-L polycarbonate containers by submerging the container in the sump water. A daily discharge of approximately 60,000 gallons (227 m^3) was estimated for the 10-day period.

Drydock Release During Ship Undocking

The drydock is flooded with water from the adjacent harbor to facilitate undocking of the ship. The caisson is removed when the drydock has been filled with water, and the ship is floated out of the drydock. Then, the caisson is replaced, and the drydock is pumped out in preparation for the next ship. We collected samples from the drydock at the locations shown in Figure 2 after the drydock was flooded before the caisson was removed, and again after the ship was removed and the caisson was replaced. Approximately 23 hr elapsed between the two samplings in this particular instance, because high winds prevented the caisson from being replaced immediately after the ship was undocked. The samples were collected at three depths (0.5, 6, and 12 m) using a 1.5-L Kemmerer sampler with Teflon* wetted surfaces. Triplicate samples were taken at each depth at Location 2 to estimate sample variability. A second set of triplicate samples was taken at each depth at Location 2 and filtered within 4 hr. through nominal 0.45-μm glass fiber filters using a polycarbonate filtering apparatus to minimize butyltin losses to surfaces. The apparatus was rinsed with methanol between samples. The filter and filtrate were retained for butyltin analysis to determine if the butyltins were associated with particulates or were dissolved. A third set of triplicate samples was drawn at each depth at Location 2 to analyze for total suspended solids. A composite sample of the harbor water adjacent to the drydock was collected before the drydock was flooded to determine the background concentration. All butyltin water samples and filters were placed in a freezer within 4 hr after sample collection or filtration.

The drydock water was sampled again at the pump well while the drydock was being pumped out, which occurred over a 1 1/2-hr period immediately following the second sampling of the flooded drydock. Samples were collected at 15-minute intervals. Triplicate samples were taken at the 15- and 75-minute sampling points. Simultaneously, samples also were taken and filtered for suspended solids and butyltins, as described above.

Harbor Sampling

Harbor water was sampled three times; twice before and once after the ship was undocked. The former was to provide background organotin concentrations which may be attributed to ships and pleasure craft located in Pearl Harbor before the ship was painted. Sampling stations were selected to correspond to stations used for Navy base line organotin surveys.[3] Six sampling stations concentrated in the main and south channels of Pearl Harbor were selected for the survey. We collected the background samples at high slack tide the day before the scheduled undocking of the ship. Mechanical problems with the ship delayed the scheduled undocking, so we took a second set of background samples at low slack water 5 days later. Four tidal cycles (2 days) after undocking, we took samples at the six stations to describe the plume of TBT that resulted from the undocking of the ship. Sampling was delayed 1 day because the drydock was not pumped out until the day after undocking of the ship.

Triplicate water samples were collected 1/2 m below the surface and 1 to 2 m above the bottom, using a 1.5-L Teflon Kemmerer sampler, and were transferred to 1-L polycarbonate bottles. Water quality measurements were taken at each station prior to water sample collection. Parameters we measured included salinity, pH, temperature, and dissolved oxygen to determine the extent of stratification. Additional samples were collected at several stations to be filtered and were used to evaluate the partitioning of TBT to suspended particulates in the water column. Split samples were taken at approximately 10% of the stations for quality control purposes. All samples were chilled in ice chests during sampling and placed in a freezer within 4 hr of collection.

ANALYTICAL METHODS

Water

All samples were collected in 500-mL or 1-L polycarbonate bottles and frozen at −20°C within 4 hr of collection. The samples remained frozen until they were thawed for analysis. Seawater samples preserved in this manner have been shown to be stable up to 3 months.[4] The samples were thawed and analyzed by gas chromatographic separation followed by flame photometric detection (GC-FPD).[5] Sample preparation consisted of taking a 200-mL aliquot of seawater, spiking it with a dipropyltin dichloride internal standard, adding dichloromethane and sodium tetraborate III, and shaking the sample for 10 minutes. The dichloromethane layer is removed, another 4 mL of dichloromethane is added, and the extraction is repeated. This sample preparation converts the organotin compounds to the more volatile and hydrophobic organotin hydrides and isolates them from the seawater matrix. The combined dichloromethane layers are evaporated to less than 100 μL, of which 5 μL are injected into a gas chromatograph equipped with a tin-sensitive flame photometric detector. The chromatograph separates the organotins and quantifies them by peak area comparisons with standards prepared in the same manner. A detection limit for tributyltin of 2 ng/L can be achieved.

Filters

Nominal 0.45-μm glass fiber filters[6] were used to filter samples for butyltin analysis. We analyzed six dibutyltin and tributyltin standards, three at 100 ng/L and three at 1000 ng/L, filtered through these filters, and found that less than 5% of either butyltin species is adsorbed onto the filter.

Filters were frozen at −20°C within 4 hr of collection. First, the thawed filters were Soxhlet-extracted for 6 hr with methanol. Then, we added 10 mL of the methanol to 200 mL of water and analyzed the solution in the same manner as the water samples. The detection limit for tributyltin was 5 ng.

Overspray

Pain overspray samples were prepared for analysis by dissolving the paint with dichloromethane. Toluene was added and the dichloromethane was allowed to evaporate. The samples were analyzed for total tin by graphite furnace atomic absorption spectrophotometry. Three of the samples were dissolved in dichloromethane and speciated to determine the types of organotin in the paint. The results are shown in Table 1.

* Teflon is a trade name of E.I. DuPont de Nemours & Co., 1007 Market St., Wilmington, DE 19898.

Table 1. Distribution of butyltin in paint overspray.

Paint Overspray Sample No.	Monobutyltin/Tributyltin	Dibutyltin/Tributyltin
8	0.17	0.26
9	0.08	0.28
11	0.06	0.14
Average	0.10	0.23

Suspended Solids

Samples for suspended solids were taken in 1-L polycarbonate bottles. The samples were analyzed within 8 hr of collection by filtering the entire contents of the 1-L polycarbonate sample bottle through a 0.45-μm glass fiber filter in accordance with "Standard Methods."[6]

Quality Control

Several quality control measures were taken to ensure that the results obtained were accurate. Chromatagraphically pure quality control standards prepared by the National Bureau of Standards were analyzed daily to ensure that the GC-FPD was operating within ±25% of the historical tributyltin value for these samples. Twenty samples were split and analyzed by personnel from the National Bureau of Standards (NBS) and this Center. There was no significant difference in the results. Split samples that contained more than 20 ng/L were within 65% of each other with a mean difference of 22%. Split samples that contained less than 20 ng/L were within 5 ng/L with two exceptions.

In addition, we conducted replicate analyses on 26 samples. Replicate analyses that contained more than 20 ng/L were within 26% of each other with a mean difference of 15%. Replicate analyses that contained less than 20 ng/L were within 7 ng/L.

Nineteen samples were spiked with 50 ng/L of tributyltin. The recovery ranged from 66% to 150%, with an average recovery of 102.5%. Similarly, when 13 samples were spiked with 50 ng of dibutyltin, the recovery ranged from 65% to 138%, with an average recovery of 90.6%.

RESULTS AND DISCUSSION

Paint Overspray

Approximately 68 kg of TBT were applied to the ship. Figure 3 shows the distribution of solvent-extractable organotin on the drydock floor. Analysis of the paint overspray showed a dibutyltin to tributyltin ratio of 0.23. The total mass of organotin on the drydock floor after painting of the ship was approximately 5.4 kg or 8% of the TBT applied to the underwater hull. Interestingly, this is within the 5% to 9% range reported by Adema and Schatzberg.[7]

The concentration of TBT at the harbor end of the drydock indicates that only very small amounts of TBT could have entered the adjacent harbor waters as a result of paint overspray due to the predominant wind direction, as shown in Figure 4. These results also indicate that even with the relatively windy conditions that existed at the time of painting, more than 90% of the overspray was collected on dropcloths placed under the ship.

Drydock Discharge During Painting and Cleanup

Table 2 shows the concentration of butyltin in the drydock discharge. The total mass of TBT discharged to the sanitary sewer was approximately 20.5 g. An average daily drydock discharge of 60,000 gallons (227 m^3) was diluted in the average daily sewage treatment plant flow of 5.64 million gallons (21,300 m^3) so that the average TBT concentration entering the sewage treatment plant was approximately 80 ng/L. The results clearly show the effects of cleaning the drydock in that the concentration of butyltins in the drydock discharge were reduced by approximately an order of magnitude after cleanup was complete. The results also indicate that an insignificant amount of overspray is washed from the drydock by transient rain showers; rain occurred at four different times during the painting and cleanup of the drydock, and the discharge concentration showed no significant difference on those days.

Drydock Release During Ship Undocking

The flooded drydock samples show the concentration of butyltins resulting from paint overspray remaining after the cleanup and from the initial release of butyltins from the underwater hull of the ship. The organotin release rate of the Devoe-Reynolds ABC-2 paint was measured using the method specified by the U.S. Environmental Protection Agency (EPA).[8] The results are shown in Table 3.

We used the sum of the initial release (0 to 10 minutes) and the 10-minute to 3-hr release rate to calculate the mass of TBT released from the underwater hull prior to sampling and estimated that 3.1 g of TBT would be released, resulting in a concentration of 34 ng/L in the 90,000 m^3 of water in the drydock. Table 4 shows the initial concentration of butyltins in the drydock prior to ship undocking.

The average TBT concentration in the drydock was 180 ng/L. Of the 180 ng/L, 17 ng/L was contributed as background by the harbor water and approximately 34 ng/L was contributed by the initial release from the ship hull. Therefore, approximately 130 ng/L or 11.7 g of TBT remained from the paint overspray, which represents a cleanup of 99.8%.

Three samples out of 21 contained a particle of paint. This was evident in the elevated concentration and in the chromatogram for the sample (Figure 4). Those samples

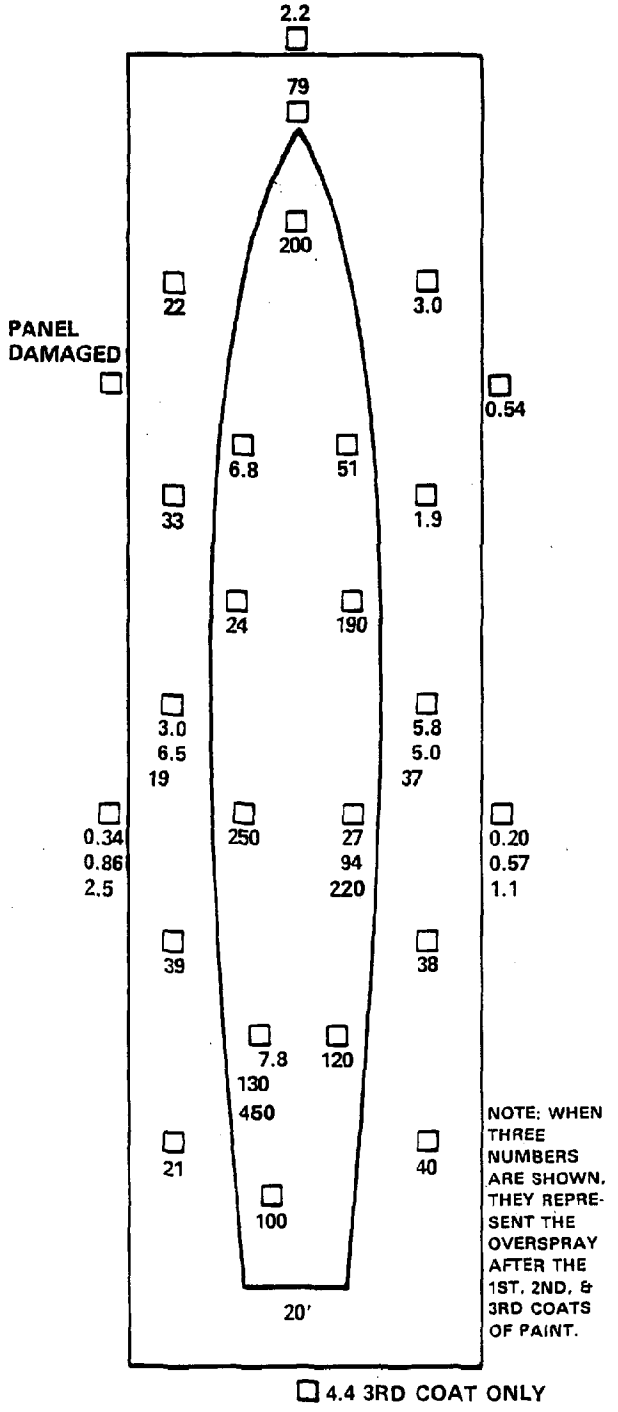

Fig. 3. Distribution of dichloromethane extractable tin (μg TBT/cm^2).

which contain paint particles were not included in the calculation of average concentrations because the paint particle disproportionately affects the bulk water concentration. The environmental effects of TBT are dependent upon its bioavailability; i.e., it must be dissolved in the water column. The samples containing paint particles also

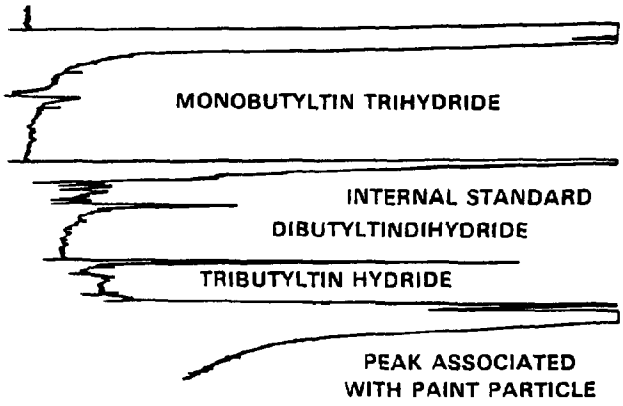

Fig. 4. Typical chromatogram of sample containing paint particle.

had a DBT/TBT ratio that was closer to the 0.23 ratio found in the paint overspray samples. The high concentration of DBT in the samples which did not contain a paint particle may be because DBT is being released from the coating more rapidly than the TBT, which causes a high DBT/TBT ratio.

Table 5 shows a comparison of filtered and unfiltered samples with the associated suspended solids concentrations from Drydock Station 2.

The filtered samples indicate that approximately 16% of the dibutyltin and 47% of the tributyltin is associated with suspended solids even when the sample does not contain paint particles. The sum of filter and filtrate is about equal to the results of whole water samples. This indicates that the analytical method allows recovery of the butyltins from the suspended solids.

Drydock water samples collected after the caisson was replaced show approximately 24% of the TBT that was present in the drydock before the caisson was removed 22 hr before, and only 23 ng/L higher than the harbor background of 17 ng/L shown in Table 4; see Table 6.

Note that it is unusual for the caisson to be left out of the drydock for this long. Typically, the caisson is replaced immediately after the ship is undocked, but in this case high winds prevented its replacement in the drydock until the following day.

Concentrations of TBT in the drydock averaged 40 ng/L after the caisson was replaced. The average DBT/TBT ratio was 0.6 compared to 2.2 in samples taken before the caisson was removed. Filtered samples indicate that 76% of the TBT and 83% of the DBT is associated with particulates; see Table 7. However, the sum of filter and filtrate is 5 to 6 times higher than the results from whole water samples. This indicates that the butyltins are irreversibly attached to the particulate within 1 day and the higher absorption of dibutyltin would account for the lower DBT/TBT ratio of the samples shown in Table 6.

The results of drydock water samples collected at the pump while the water was being pumped out are shown in Table 8. The higher concentrations of butyltins at the beginning and end of the pumpout appear to correlate with the higher suspended solids concentrations found at these times during the pumpout. However, we could not verify this correlation statistically. As with the second set of flooded drydock samples, the combined TBT from the filter and

Table 2. Butyltin concentration in drydock fluids discharged to the sewage treatment plant (ng/L).

Day	Drydock Operation	Butyltin Concentration		Climatological Conditions
		Dibutyltin	Tributyltin	
1	Prior to painting	17, 14	15, 30	
3		4	6	Rain
4	Painting	11,000	16,000	11 to 12 mph average winds from the northeast
		4,200	750	
5		2,700	6,000	
		3,000	8,500	
6	Cleanup	2,200	13,000	Rain
		5,600; 5,000	17,000; 6,000	
7		1,500	8,000	Rain
8		5,600	12,500	
9		2,600	24,000	
10		1,600	3,100	
11		4,200	6,200	Rain
12		2,500	2,450	
13		2,600	6,000	
14	After cleanup	1,400	200	
15		800	1,250	
16		4,200	170	
17	Drydock flooded			

Table 3. Release rate of organotin by EPA Method.

Time After Paint was First Exposed to Water During which Measurement was Made	Release Rate (μg TBT/cm^2/day)	
	Mean*	Standard Deviation*
0 to 10 min	2.83	0.34
10 min to 3 hr	1.01	0.22
4 to 6 hr	0.83	0.18
24 to 30 hr	0.78	0.06
2 days**	1.11	0.05
3 days	1.39	0.18
7 days	1.75	0.08
15 days	2.79	0.05
24 days	1.80	0.05
28 days	1.66	0.07
31 days	2.36	0.09
56 days	1.96	0.04
77 days	1.89	0.09
93 days	2.53	0.03
128 days	1.71	0.16

*Mean and standard deviation are based on the three cylinders painted with the same paint as required by the EPA Method.
**The measurement is taken over a 6-hr period on the days shown.

Table 4. Butyltin concentration of drydock water before the cassion was removed.

Location	Depth (m)	Butyltin Concentration (ng/L)		Dibutyltin/ Tributyltin Ratio
		Dibutyltin	Tributyltin	
Harbor	12.0	48	17	2.8
Drydock Station 1	0.5	1500	2500**	0.6
	6.0	220	120	1.8
	12.0	140	84	1.7
Drydock Station 2*	0.5	470	140	3.4
	6.0	280	160	1.8
	12.0	310	160	1.9
Drydock Station 3	0.5	1000	400	2.5
	6.0	730	320	2.3
	12.0	290	220	1.3
Drydock Station 4	0.5	120	63	1.9
	6.0	390	150	2.6
	12.0	350	140	2.5
Drydock Average	0.5	530	200	2.7
	6.0	410	190	2.2
	12.0	270	150	1.8
Drydock Average, All Depths		390	180	2.2

*Drydock Station 2 samples were taken in triplicate.
**Sample contained paint particle and was excluded from average.

Table 5. Butyltin concentrations of filtered and unfiltered samples with associated suspended solids concentrations at Drydock Station 2 before the caisson was removed.

Depth (m)	Butyltin Concentration (ng/L)								Suspended Solids Concentration (mg/L)
	Filtered						Unfiltered		
	Water		Filter		Total				
	DBT	TBT	DBT	TBT	DBT	TBT	DBT	TBT	
0.5	600	3100*	58	47			170	65	
	200	38	42	110			690	2600**	
	550	210	50	60			550	210	
Average	375	124	50	72	425	196	360	138	24
0.6	365	53	35	190			280	54	
	200	60	36	110			290	340	
	170	41	46	37			265	88	
Average	245	51	39	112	284	163	278	161	22
12.0	29	30	47	42			120	100	
	155	170	10	21			300	85	
	140	56	90	80			500	295	
Average	108	85	49	48	157	133	307	160	22
Average, All Depths	243	87	46	77	289	164	315	153	

*Sample contained paint particle and was excluded from average.

Table 6. Butyltin concentrations of the drydock water after the caisson was replaced.

Location	Depth (m)	Butyltin Concentration (ng/L)		Dibutyltin/ Tributyltin Ratio
		Dibutyltin	Tributyltin	
Drydock Station 1	0.5	20	30	0.7
	6.0	12	19	0.6
	12.0	8	28	0.3
Drydock Station 2*	0.5	19	24	0.8
	6.0	10	24	0.4
	12.0	13	20	0.7
Drydock Station 3	0.5	13	5	-
	6.0	40	38	1.1
	12.0	9	32	0.3
Drydock Station 4	0.5	80	85	0.8
	6.0	50	50	1.0
	12.0	24	120	0.2
Drydock Average	0.5	33	36	0.9
	6.0	28	33	0.8
	12.0	14	50	0.3
	Drydock Average, All Depths	25	40	0.6

*Drydock Station 2 samples were taken in triplicate.

Table 7. Butyltin concentrations of filtered and unfiltered samples with associated suspended solids concentrations at Drydock Station 2 after the caisson was replaced.

Depth (m)	Butyltin Concentration (ng/L)								Suspended Solids Concentration (mg/L)
	Filtered						Unfiltered		
	Water		Filter		Total				
	DBT	TBT	DBT	TBT	DBT	TBT	DBT	TBT	
0.5	28	20*	350	200			18	26	
	5	8	730	3100*			10	20	
	10	16	16	35			29	25	
Average	14	15	183	117	197	132	19	24	18
6.0	32	50	97	95			12	35	
	15	19	39	99			9	18	
	21	20	47	82			10	20	
Average	23	30	61	92	84	122	10	24	17
12.0	770	300*	130	82			20	35	
	45	70	14	7			11	21	
	10	25	110	160			8	4	
Average	28	48	85	83	113	131	13	20	14
Average, All Depths	22	31	109	97	131	128	14	23	

*Sample contained paint particle and was excluded from average.

Table 8. Butyltin concentration in drydock water during pumpout.

Time from Start of pumpout (min)	Butyltin Concentration (ng/L)								Suspended Solids Concentration (mg/L)
	Filtered						Unfiltered		
	Water		Filter		Total				
	DBT	TBT	DBT	TBT	DBT	TBT	DBT	TBT	
15	70	120	110	140			1000	800	17
	140	300	160	520			82	225	29
	34	335	62	100			13	116	27
Average	81	251	110	250	191	501	48	170	24
30	70	90	11	5			52	38	21
45	21	35	ND	ND*			31	29	19
60	38	45	7080	1270*			57	39	17
75	140	120	1760	4600*			60	50	57
	400	148	160	110			950	5000*	48
	384	153	470	310			540	5000*	31
Average	308	140	315	210	623	350	-	-	45
85	570	280	720	1400			1500	510	54

Table 9. Butyltin concentration prior to and following the undocking of the ship (ng/L) (± standard deviation).

Station		5 Days Before		1 Day Before		2 Days After	
		DBT	TBT	DBT	TBT	DBT	TBT
5	Surface	14	15	3	8	13	13
	Bottom	4	5	12	8	5	4
7	Surface	18	18	19	22	29	22
	Bottom	7	6*	2	4	16	28
7B	Surface	2	2	5	12	14	14*
	Bottom	6	4	5	21	22	17*
9A	Surface	7	5	-	-	8	5
	Bottom	12	13	6	1	18	34*
9B	Surface	4	6	9	38	14	11
	Bottom	9	3	4	12	6	6
15	Surface	7	6	2	2	42	24
	Bottom	11	10	3	24	23	20
Average	Surface	11±8	9±9	8±6	16±13	20±23	15±11
	Bottom	8±6	7±8	5±3	12±8	11±14	17±20
Average All Stations		9±7	7±7	6±5	14±11	17±19	16±16

*One sample apparently contained a paint particle.

filtrate was about four times greater than the amount of TBT in whole water samples. A comparison of the amount of butyltin present in the flooded drydock to that present during pumpout is not possible because the pumping rate varied and was not recorded. However, the observed lower water concentration after replacement of the caisson apparently is due to two factors: mixing with the water and settling of suspended solids to the drydock floor.

Harbor Water

Samples of harbor water were taken twice before the ship was undocked and once 2 days after the ship was undocked. All harbor water samples were taken in triplicate. The results are shown in Table 9.

Harbor water samples from Stations 5, 7, and 7B were filtered. The results for samples collected 5 days before ship

undocking and 1 day after ship undocking are shown in Table 10. Table 11 compares the two sets of samples shown in Table 10.

The stations where samples were collected represent the portion of Pearl Harbor adjacent to the naval station and shipyard. Although the results shown in Table 9 exhibit considerable variability, the average concentration of TBT in that portion of the harbor after the undocking of the ship is not statistically different than before the undocking. The results shown in Table 11 reflect the same phenomenon seen in the flooded drydock samples taken after the caisson was replaced (Table 7); specifically, there is some discrepancy between the filtered and whole water analyses. The discrepancy appears related to the butyltin collected on the filters associated with the suspended solids in the water column. A partition coefficient of approximately 70,000 was calculated using the average water, filter, and suspended solids concentrations. This is significantly higher than the 3,000 to 4,000 reported by Valkirs[9] and Slesinger.[10] Additional work would be required to identify the cause of this difference, but it may be due to a difference in the nature of the suspended solids in Pearl Harbor or possibly a difference in the recovery efficiency of the analytical techniques.

Table 10. Butyltin concentrations in filtered and unfiltered samples and corresponding suspended solids concentrations in harbor water samples.

Station		Butyltin Concentration (ng/L)								Suspended Solids Concentration (mg/L)
		Filtered						Unfiltered		
		Water		Filter		Total				
		DBT	TBT	DBT	TBT	DBT	TBT	DBT	TBT	
Before Undocking of the Ship										
5	Surface	7	25	8	110	15	135	14	15	9
	Bottom	6	42	17	92	23	134	4	5	25
7	Surface	10	10	260	2100*			5	10	
		6	9	150	84			33	33	
		14	10	11	28			17	11	
	Average	10	10	140	56	150	66	18	18	15
	Bottom	4	4	11	25			6	7	
		8	12	11	28			8	4	
		3	2	-	-			110	210	
	Average	5	6	11	27	16	33	42	74	17
7B	Surface	2	10	4200	7600*			2	2	20
	Bottom	2	5	4	11			6	4	15
After Undocking of the Ship										
5	Surface	6	4	84	60	90	64	46	13	19
	Bottom	10	10	17	42	27	52	5	4	20
7	Surface	8	10	110	26	118	36	32	24	
		15	25	10	13	25	38	42	33	
		16	35	20	47	36	82	12	10	
	Average	13	23	47	29	60	52	29	22	20
	Bottom	33	37	24	22	57	59	6	65	
		4	12	140	14	144	26	10	10	
		12	12	51	14	63	26	16	8	
	Average	16	20	72	17	88	37	11	28	21
7B	Surface	12	20	28	14	40	34	12	56	16
	Bottom	120	200	51	150	171	350	18	17*	15

*Sample contained a paint particle and was excluded from the average.

Table 11. Comparison of filtered samples collected before and after undocking of the ship.

	Average % on Filter		Ratio of Total Tributyltin in Filtered Sample Versus Whole Water Sample
	Dibutyltin	Tributyltin	
Before Undocking	72	79	5 - 6*
After Undocking	69	56	2**

*Excluding bottom at Station 7.
**Excluding bottom at Station 7B.

CONCLUSIONS

The release of butyltins into the marine environment from shipyard drydock activities can be controlled and reduced to a very low level, as low as 15 g during the undocking of a ship. This release resulted in an unmeasurable increase of tributyltin in the vicinity of the shipyard 2 days after undocking of the ship. Therefore, if extraordinary precautions are taken, the contribution to the marine environment from shipyard activities can be minimized, and the environmental effect of organotin resulting from these activities can be negligible. The techniques used in this case to minimize the release of TBT were those that were available; they are not practical for routine use. Additional work is required to identify the practical means by which the release of butyltins can be minimized within the constraints of shipyard operating procedures.

ACKNOWLEDGMENTS

We gratefully acknowledge the assistance of Mr. Gordon Smith for his assistance in the collection of samples. We also appreciate the cooperation and assistance provided by the Pearl Harbor Naval Shipyard during the sampling program.

LIST OF ABBREVIATIONS

°C	Degrees Celsius
cm	Centimeters
cm^2	Square centimeters
DBT	Dibutyltin
EPA	Environmental Protection Agency
ft^3	Cubic feet
m	Meters
m^3	Cubic meters
GC-FPD	Gas chromatographic separation followed by flame photometric detection
mm	Millimeters
g	Grams
kg	Kilograms
L	Liters
µg	Micrograms
µL	Microliters
µm	Micrometers
mg/L	Milligrams per liter
mL	Milliliters
min	Minutes
ng/L	Nanograms per liter
NBS	National Bureau of Standards
NOSC	Naval Ocean Systems Center
TBT	Tributyltin

REFERENCES

1. House of Representatives Appropriation Committee Conference Report 99-1005 (15 Oct 1986).

2. Seligman, P.F., J. Grovhoug, and C.M. Adema, "Implementation Plan for Pearl Harbor Phase of Navy Organotin Two-Harbor Case Study," NOSC/DTNSRDC (Dec 1986).

3. Grovhoug, J.G., et al, "Baseline Measurements of Butyltin in U.S. Harbors and Estuaries," Proceedings of the Organotin Symposium of the Oceans '86 Conference, Washington, DC (23-25 Sep 1986).

4. Valkirs, A.O., P.F. Seligman, G.D. Olson, F.E. Brinkman, C.L. Matthias, and J.M. Bellama, "Di- and Tributyltin Species in Marine and Estuarine Waters. Interlaboratory Comparison of Two Ultratrace Analytical Methods Employing Hydride Generation and Atomic Absorption or Flame Photometric Detection," *Analyst*, Vol. 112, pp. 17-21 (1987).

5. Matthias, C.L., G.D. Olson, F.E. Brinkman, and J.M. Bellama, "A Comprehensive Method for Determination of Aquatic Butyltin and Butylmethyltin Species at Ultratrace Levels Using Simultaneous Hydridization/Extraction with Gas Chromatography-Flame Photometric Detection," *Environ. Sci. Technol.*, Vol. 20, No. 6, pp. 609-615 (1986).

6. American Public Health Association, American Water Works Association, and Water Pollution Control Federation, *Standard Methods for the Examination of Water and Wastewater 209D*, 15th Ed. (1980).

7. Adema, C.M., and P. Schatzberg, "Organotin Antifouling Paints and the Environment — Drydock Phase," *Naval Engineers Journal* (May 1984).

8. U.S. Environmental Protection Agency, "Data Call-In Notice for Data on Tributyltins Used in Paint Antifoulants," Washington, DC (29 July 1986).

9. Valkirs, A.O., P.F. Seligman, and R.F. Lee, "Butyltin Partitioning in Marine Waters and Sediments," Proceedings of the Organotin Symposium of the Oceans '86 Conference, Washington, DC (23-25 Sep 1986).

10. Slesinger, A.E., "The Distribution of Organotins in the Workplace and the Environment," 23rd Annual Marine and Offshore Coatings Conference, Baltimore, MD (11-13 May 1983).

ACCUMULATION AND FATE OF TRIBUTYLTIN SPECIES IN MICROBIAL BIOFILMS

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ABSTRACT

Microbial biofilms, composed of microorganisms originally obtained from estuarine harbor-exposed commercial organotin-painted panels, accumulated tributyltin (TBT) spiked into estuarine water. Algal or bacterial-dominated biofilms were grown by varying nutrient conditions. Both types of microbial communities accumulated TBT in excess of 300 ng/mg biomass (dry weight basis) from estuarine water solutions containing 50 μg/L TBT, corresponding to bioconcentration factors of over 7000. No degradation of TBT to dibutyltin (DBT) species was detected, either in the biofilm material or in the surrounding solution. Thus, the microbial biofilms concentrated but did not degrade TBT. These results suggest that microbial films on TBT-painted structures in marine environments concentrate TBT at materials surfaces, thereby acting as "capacitors". Such effects might make practical the use of paints with extremely low TBT release rates delivering antifouling service with reduced environmental hazard.

1. INTRODUCTION

Organotin-based antifouling coatings are in world-wide use to prevent attachment of marine life to ship hulls, saving time, fuel, and maintenance costs (1). The U.S. Navy has an interest in painting its fleet with advanced controlled release (CR) polymer coatings which provide antifouling protection for six years or longer (2). However, tributyltin (TBT), the most widely used organotin compound for CR antifouling activity, is extremely toxic to some non-target marine life (3,4). A number of countries including France and the United Kingdom, and more recently individual states and the Environmental Protection Agency in the United States, have imposed or are considering restrictions on the use of these materials on recreational vessels (5,6).

The actual mechanism by which TBT repels fouling organisms is unclear. Microbial biofilms rapidly develop on TBT-painted hull surfaces, but higher forms of life (i.e. barnacles) are effectively repelled (7). The role of the microbial biofilm in concentrating or affecting the release rate and form of the TBT toxicant has received very little attention. Loeb and colleagues (unpublished data) found that the presence of microbial biofilms on TBT-painted panels affected the release rate of the TBT into surrounding solutions. Laughlin and co-workers (7) found that microbial biofilms growing on TBT painted panels accumulated TBT. They suggested the microbial biofilm may contribute to paint performance by reducing organotin loss, in effect acting as a secondary controlled release medium, as well as having protective functions toward non-target marine life. The extent of bioaccumulation of TBT in microbial biofilms and its possible transformations remain uncertain, because it is difficult to measure and speciate organotins within the biofilm matrix. The problem is further complicated by the difficulty of removing biofilm from painted surfaces without also removing some of the paint coating below.

Our earlier studies showed that estuarine heterotrophic bacteria can rapidly accumulate TBT from solution without TBT molecular transformation (8). The purpose of the current research was to determine the extent of TBT accumulation and transformation in microbial biofilms. Methodology developed for speciation of TBT in waters and sediments (9,10) was applied to the analysis of butyltins in the biofilm matrix. We grew biofilms on glass slides and exposed them to TBT in solution. While this does not precisely mimic the leaching of TBT from a painted surface, it does offer a reliable system in which we could be certain that none of the TBT observed in the biofilm had been physically removed from paint. We assumed that films capable of accumulating TBT leached from paint would also be able to accumulate TBT from surrounding free solutions, if grown on a surface not painted with TBT. In addition, we investigated using organotin-fluorescent ligand combinations and epifluorescence microscopy to directly detect organotins on biofilms (11,12). We did not find a fluorescent probe for TBT but monobutyltin in a microbial biofilm was detected using epifluorescence microscopy.

2. EXPERIMENTAL

2.1 Biofilm Growth

All biofilm experiments employed a mixed culture of estuarine microorganisms originally obtained from the surface of a steel panel painted with a

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commercial ablative copper and TBT-containing antifouling paint (International Hysol BFA-254 copolymer). The panel had been immersed in the Severn River at Annapolis, MD for 6.5 months at an average salinity of approximately 8-10 parts per thousand (ppt) (J. Mihm, David Taylor Research Center, Annapolis, personal communication). The panel displayed some green growth on the surface, suggesting the presence of algae. Upon removal from the river, the panel was gently rinsed with 0.5 L of Chesapeake Bay water (salinity 10 ppt), made sterile by autoclaving at 121°C for 15 min. The panel was then gently scraped with a sterile teflon spatula over a 10 x 10 cm area, and the scraped material was washed into a sterile polycarbonate bottle with 100 mL of sterile Chesapeake Bay water. The wash water was immediately transported to the laboratory, where 30 mL of the suspension was inoculated into a conical flask (250 mL) containing 170 mL of sterilized Bay water having 10 mM ammonium chloride and 2 mM dibasic potassium phosphate as nutrients. This flask was placed under fluorescent lamps (intensity 350-400 foot candles) at 22°C. Another 30 mL of wash water was inoculated into a flask containing 170 mL of water containing 0.03% yeast extract and 0.03% polypeptone (Difco). These samples were incubated at 28°C on a gyratory shaker at 200 r.p.m. (New Brunswick model G76). After one week of incubation, the contents of both flasks were mixed and centrifuged (6000xg, 20 min). The supernatant was poured off and the pellet containing cells was resuspended in 70 mL of sterile Bay water. Sterile glycerol (7.7 ml) was added, the cell suspension was continuously stirred to mix the contents, and 1.0 mL aliquots were removed and added to each of 60 sterile 1.5 mL plastic screw-capped vials designed for cryogenic sample preservation. The vials were transported to the American Type Culture Collection (ATCC, Rockville, MD), where they were frozen and stored under liquid nitrogen. The cell suspensions contained 2.0 x 10^8 cells/mL (Petroff-Hauser counting chamber) and 4.3 x 10^7 colony forming units/mL when spread on to peptone-yeast extract (0.03% concentration of each) agar and incubated at 28°C for one week.

Microbial biofilms were grown on glass microscope slides (2.5 x 7.5 cm) immersed vertically in a small glass tank (Figure 1) containing 500 mL of sterile Chesapeake Bay water amended with peptone and yeast extract (0.05% of each), or ammonium chloride and dibasic potassium phosphate (10 and 2 mM, respectively) . The Bay water had been collected in a 50 L polyethylene carboy from 1.0 m depth at the mouth of the Severn River. The sample was passed through a 35 μm filter during collection. It was stored in the dark at room temperature in the laboratory, and aliquots were removed and autoclaved as needed for biofilm experiments. The inoculum was prepared from frozen cells in storage at ATCC. The cells were quickly thawed in warm water (30°C) and added to the biofilm growth tank. A sterile teflon stir bar was added to the tank and the tank was placed on a magnetic stirrer in the dark or under fluorescent lamps (intensity 350-400 foot candles), depending on the experiment.

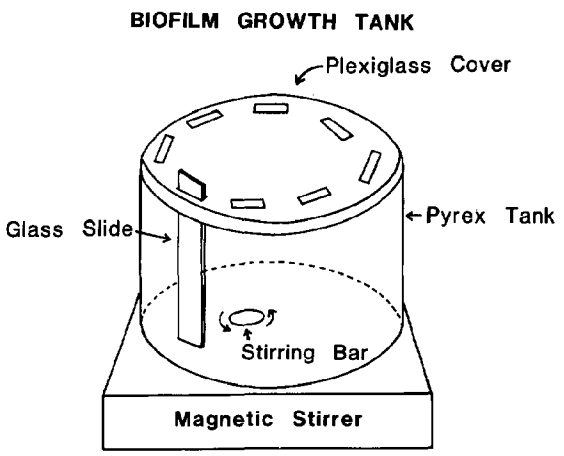

Figure 1. Apparatus used to grow microbial biofilms on glass slides.

2.2 Tributyltin Uptake on Biofilms

After several weeks, glass slides containing biofilms were removed from the growth tank and immersed in smaller growth cylinders of pyrex glass containing sterile Bay water amended with 50 μg/L TBT (as the cation). Additionally, two groups of control slides were included, which consisted of clean glass slides placed into TBT solutions and biofilm slides placed into sterile Bay water minus the TBT spike. Small teflon stir bars were added to the cylinders and the solutions were held in the dark or under fluorescent lamps at room temperature. After incubation, the slides were dipped twice into Bay water free of TBT and scraped with a clean razor blade. A small volume of water was used to rinse the scraped material into 15-mL glass centrifuge tubes. Scrapings from the duplicate or triplicate biofilm slides incubated with TBT were pooled in one centrifuge tube. Aliquots were removed to separate tubes for spiking with butyltin compounds (method of additions quantitation) and for dry weight determinations.

2.3 Butyltin Extraction and Analysis

The procedure is a modification of a method for extraction of TBT from sediment (10). All concentrations of organotins are listed on a weight basis in terms of the cations. Approximately 200 μL of the pooled biofilm suspension was added to a 150-mL round bottom flask along with an internal standard consisting of 50 uL of tripropyltin chloride (1.5 μg/uL in methanol). Concentrated HCl (0.5 mL) followed by methanol (25 mL) was added and the mixture was refluxed for 30 min at 80-85°C. The sample was cooled to room temperature and was extracted twice with 5-mL aliquots of cyclohexane in a 125-mL separatory funnel with shaking (10 min) on a wrist action shaker (Burrell). The combined cyclohexane layers were evaporated to about 2 mL under a gentle stream of air and then shaken for

45 min with 1.0 mL of 4% (w/v) aqueous $NaBH_4$. A small aliquot of the cyclohexane layer was injected into a gas chromatograph equipped with a flame photometric detector operated in a tin-selective mode as described previously for detection of DBT and TBT (9,10).

2.4 Epifluorescence Imaging

Spectrophotometric detection of monobutyltin adsorbed to the biofilm was successfully demonstrated by epifluorescence microscopy (11). Monobutyltin, which has a more intense fluorescence emission than tributyltin when complexed with flavonol (11), was chosen for this experiment to demonstrate that the concept of visual imaging of adsorbed organotins on the biofilm was practical. Glass slides covered with a well developed biofilm growth were exposed to a solution of monobutyltin in ethanol (4.5×10^{-4} M concentration) for approximately 1 hour. The slides were then rinsed with ethanol and exposed to an ethanol solution of flavonol (1.4×10^{-4} M concentration) for 15 min. Control slides, either exposed to monobutyltin but not to flavonol, or exposed to flavonol but not to monobutyltin, were also prepared.

Following the above treatment, the slides were examined by epifluorescence microscopy. The UV excitation frequency was set at 366 nm with a 28 nm bandpass. A barrier filter was used to eliminate any radiation at wavelengths over 400 nm.

The following compounds were tested for their abilities to chelate to butyltin species and generate luminescent emission: 3-hydroxyflavone, morin, apigenin, galangin, emodin, flavone, chrysin, 4',5,7-trihydroxyflavone. All of these compounds were purchased from a commercial source (Aldrich Chemical Co., Milwaukee, WI).

3. RESULTS AND DISCUSSION

Preliminary experiments showed that microbial biofilms accumulated 331-784 ng TBT/mg (dry weight) on exposure of films to Chesapeake Bay water containing 0.344 mg TBT/L for 28 hr. Subsequent experiments were performed at lower (50 μg/L) TBT concentrations and comparably substantial quantities of TBT were also bound to biofilms in these experiments. The first experiment involved biofilms grown in the dark, then immersed in the spiked Bay water and held in the dark. After four days incubation the pooled biofilm sample contained 353 ng TBT/mg (dry weight; Table 1, Figure 2). This represents a bioconcentration factor of 7060. Each glass slide contained an average of 0.43 mg of biofilm material (dry weight) over an area of 25 cm^2. The concentration of TBT in the film was determined by standard additions of di- and tributyltin chlorides to aliquots of the pooled biofilm sample. These were then carried through the entire extraction procedure. Samples of the solution of Chesapeake Bay water were analyzed periodically and showed no biodegradation of TBT to DBT, nor was any DBT detected in the biofilm material. Control slides (clean slides exposed to TBT, or biofilm slides minus TBT) gave no butyltin peaks in the chromatograms.

TABLE 1

Bioaccumulation of TBT by Microbial Biofilms

Incubation	TBT Soln. Conc.	TBT Accum. Conc.	Bioconc. Factor (dry wt)
Dark, 97 hr	50 μg/L	353 μg/g	7060
Light, 168 hr	50 μg/L	373 μg/g	7460

Another experiment was run using biofilms that had been grown under fluorescent lamps. These biofilms contained a large proportion of algae, as evidenced by their green color and large numbers of red autofluorescing cells visible under epifluorescence microscopy using 365 nm excitation (owing to chlorophyll in the cells). These films were incubated under fluorescent lamps for 7 days and analyzed for TBT and DBT as

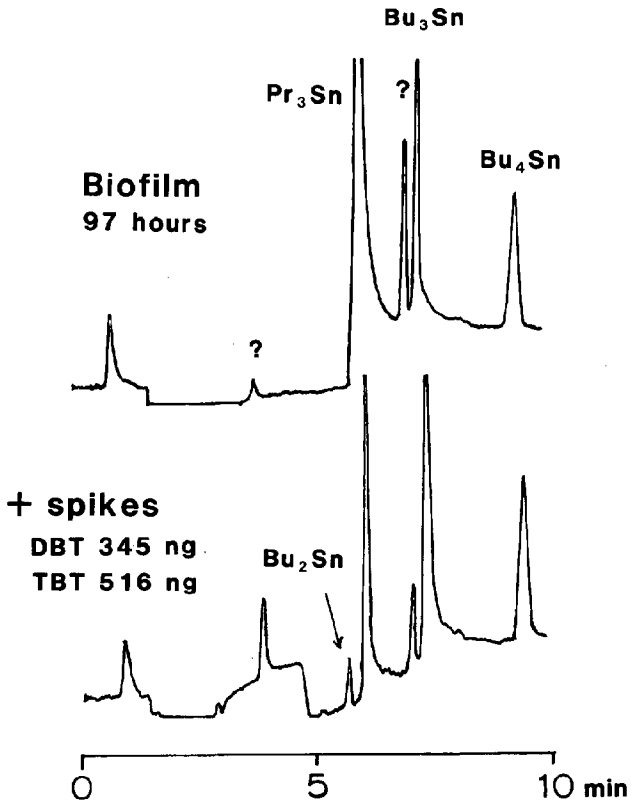

Figure 2. Chromatograms showing the bioaccumulation of TBT in microbial biofilms after 97 hours incubation (top). Spikes of tributyltin and dibutyltin species into the biofilm matrix are shown at bottom.

above. This biofilm material contained 373 ng TBT/mg (dry weight; Table 1). This corresponds to a bioconcentration factor of 7460. Again, there was no evidence of light- or dark-induced degradation of TBT to DBT either in the biofilm material or in solution during the course of the experiment.

Tetrabutyltin was detected in biofilms run in the first (dark incubated) experiment (Figure 2). This compound was detected as a contaminant in reagent TBT used as a spike and was evidently bioaccumulated. This peak was not seen in the light incubated experiments where a chromatographically purified source of TBT was employed which did not contain tetrabutyltin.

The concentration of TBT used in these bioaccumulation studies (50 μg/L) greatly exceeds concentrations of TBT reported in bulk water in aquatic environments. However, bioaccumulation of TBT in more dilute samples is also likely, especially since biofilms accumulated nearly as much TBT from solution at 50 μg/L as at 0.344 mg/L (see above). In addition, it is likely that the concentration of TBT in the interstitial water of a microbial biofilm on an organotin-painted ship hull is considerably higher than in surrounding open waters. We therefore do not believe 50 μg TBT/L to be an unrealistic concentration to illustrate potential microbial biofilm effects.

The TBT bioaccumulation results are similar to our previous findings with isolated strains of estuarine bacteria (8). In that study we found that the organisms accumulated TBT to 3.7 to 7.7 μg/mg (dry weight; bioconcentration factors in the hundreds). There was no measurable degradation of TBT to DBT. Laughlin et al. (7) found that a microbial biofilm on a TBT painted panel contained 20-60 μg/mg (wet weight), substantially greater than the concentration we observed in our biofilms. This is not surprising, given the quite different experimental systems between that study and the present investigation. Laughlin et al. employed TBT painted panels immersed for four months in San Francisco Bay and removed biofilm by lightly scraping the film from the painted surface. However, both studies show that microbial biofilms bioaccumulate TBT to a significant extent.

Previous studies have shown that TBT is degraded to DBT in the environment, with half-lives on the order of 1-2 weeks (13,14). In some cases, microalgae have been implicated in the biodegradation process (14). However, the current experiments show that biodegradation of TBT did not occur in the microbial biofilm composed of organisms originally obtained from a panel painted with TBT-containing paint. We believe that our past and current results indicate biodegradation is not a common mechanism of TBT resistance in estuarine bacteria.

Table 2 summarizes results employing EMI to detect monobutyltin in microbial biofilms. The biofilm slide exposed to both monobutyltin and

TABLE 2

Detection by EMI of Monobutyltin Bioaccumulation

SLIDE	EMISSION MAXIMUM	RELATIVE INTENSITY
No cells- no tin no ligand	435	8.58 +/- 0.25
Biofilm- no tin no ligand	435	8.54 +/- 0.27
Biofilm- with $BuSn^{3+}$ no ligand	436	9.03 +/- 0.28
Biofilm- with ligand no $BuSn^{3+}$	458	7.85 +/- 0.19
Biofilm- with $BuSn^{3+}$ with ligand	452	30.39 +/- 0.87

flavonol had significantly greater fluorescence intensity than any of the control slides. Visual examination of this slide under the epifluorescence microscope revealed a dark blue-black background with localized areas of bright blue fluorescence, characteristic of the monobutyltin-flavonol complex. These images suggest that the monobutyltin moiety is not homogeneously retained in the biofilm, but additional studies will be required to determine whether the organotin is adsorbed chiefly by viable cells or by exocellular adhesive polymers.

Only 3-hydroxyflavone, morin and galangin ligands form complexes which emit sufficiently for consideration as "fluorogenic ligands" for tin species (data not shown). In each of these cases, Bu_3Sn^+ had a fluorescence of only about 1/100 of that of the other tin species, perhaps due to the UV degradation of TBT to more fluorescent species (12). It therefore seems very unlikely that any of these ligands could be a sensitive, selective reagent for the detection of tributyltin species in mixtures of organotins. However, it seems reasonable to employ the EMI technique to survey biofilm communities for the presence of TBT degradation compounds. In conjunction with electron microscopy with element specific energy dispersive microanalysis, questions could be answered concerning the location of organotin species in the biofilm (cell mass or exocellular polymer).

It is interesting to note that reproducible results indicate that the relative intensity of emissions of either morin or 3-hydroxyflavone complexes of butyltin species in EtOH follow the trend:

$$BuSn^{3+} > Bu_2Sn^{2+} > Sn^{4+} > Bu_3Sn^+$$

This trend differs from the relative intensities reported for butyltin compounds in aqueous solution (10). The $EtOH/H_2O$ ratio (v/v) greatly

affects the relative emission intensities of these samples. There may be a solubility or miscibility problem in the case of organotin-flavanoid complexes in a highly aqueous environment. This may hinder analyses of "in-vivo" samples which require an aqueous environment. The best use of the EMI may be to detect tin species on a solid surface, after chromatography has been performed (i.e. paper chromatography, TLC).

4. SUMMARY AND CONCLUSIONS

Biofilms containing microorganisms obtained from organotin painted panels accumulated relatively large amounts of TBT from solution. There was no detectable biodegradation of TBT to DBT in the films or in the surrounding solutions. The films may thus influence the action of organotin coatings. Microbial biofilms may concentrate TBT on the surface of painted ship hulls. In this manner it is conceivable that the TBT charged microbial biofilms act as the primary repellent to settling larvae of hard fouling organisms. If so, then organotin paints with extremely low release rates may still provide antifouling protection by virtue of a TBT enriched surface biofilm, and may release very little TBT to surrounding waters. Such paints would minimize environmental impacts of the use of TBT-containing antifouling paints. Additional experiments involving exposure of TBT enriched biofilms to macrofouling organisms are warranted. Epifluorescence microscope imaging of monobutyltin in microbial biofilms was demonstrated. The technique may be useful for the detection of such TBT degradation products. Direct detection of TBT in solution or in biomass will require the development of a ligand which specifically chelates to TBT, yielding a complex which fluoresces with reasonable quantum efficiencies. Selected commercially available materials were found to be unsatisfactory for these requirements.

5. ACKNOWLEDGMENTS

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6. REFERENCES

1. Ludgate, J.W. Jr., in Proc. Internat. Organotin Symp., Oceans 87', Sept. 29 to October 1, 1987, Halifax, Nova Scotia, IEEE, Piscataway, NJ, pp. 1309-1313 (1987).

2. Schatzberg, P., in Proc. Internat. Organotin Symp., Oceans 87', Sept. 29 to October 1, 1987, Halifax, Nova Scotia, IEEE, Piscataway, NJ, pp. 1324-1333 (1987).

3. Champ, M.A. and Lowenstein, F.L. Oceanus, 30, 69-77 (1987).

4. Maguire, R.J. Appl. Organometallic Chem. 1, 475-498 (1987).

5. Champ, M.A. and Pugh, W.L. in Proc. Internat. Organotin Symp., Oceans 87', Sept. 29 to October 1, 1987, Halifax, Nova Scotia, IEEE, Piscataway, NJ, pp. 1296-1308 (1987).

6. Champ, M.A. and Bell, D.F. Research Needs Concerning Organotin Compounds Used in Antifouling Paints in Coastal Environments, Report to NOAA/National Marine Pollution Office, Rockville, MD, March 1988, 133 pp.

7. Laughlin, R.B. Jr., Cobet, A.B. and Guard, H.E. in Proc. Internat. Conf. Marine Biodeterioration, in press.

8. Blair, W.R., Olson, G.J., Brinckman, F.E. and Iverson, W.P. Microbial Ecol. 8, 241-251 (1982).

9. Matthias, C.L. Bellama, J.M., Olson G.J. and Brinckman, F.E. Environ. Sci. Technol. 20, 609-615 (1986).

10. Matthias, C.L., Olson, G.J., Brinckman, F.E. and Bellama, J.M. Internat. J. Environ. Anal. Chem., submitted.

11. Blair, W.R., Parks, E.J., Olson, G.J. and Brinckman, F.E. J. Chromatogr. 410, 383-394 (1987).

12. Trout, T.K., Olson, G.J., Brinckman, F.E., Bellama, J.M. and Faltynek, R.M., submitted.

13. Seligman, P.F., Valkirs, A.O. and Lee, R.F. Environ. Sci. Technol. 20, 1229-1235 (1986).

14. Olson, G.J. and Brinckman, F.E. in Proc. Organotin Symp., Oceans 86', September 23-25, Washington, DC, vol. 4, IEEE, Piscataway, NJ, pp. 1196-1201 (1986).

UPDATE OF OCCURRENCE RATES FOR ACCIDENTAL OIL SPILLS ON THE U.S. OUTER CONTINENTAL SHELF

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ABSTRACT

The Minerals Management Service estimates the likelihood of oil spills of 1,000 barrels or greater occurring in association with the production and transportation of offshore oil on the U.S. Outer Continental Shelf (OCS). The estimation process uses a spill rate constant, based on historical accidents, expressed in terms of number of spills per billion barrels of oil produced or transported. The mean spill occurrence estimate is obtained by multiplying the rate constant by the volume of oil projected to be handled. The mean number of spills is then applied to a Poisson process to further estimate the probability of one or more spills occurring in a given production period. The calculated occurrence rates of 0.60 spills per billion barrels produced on U.S. OCS platforms and 0.67 spills per billion barrels transported in U.S. OCS pipelines represent a decline of 40 and 58 percent, respectively, since last evaluated in 1983. Spill occurrence rates for worldwide tanker transport remain unchanged, since last evaluated in 1983, at 0.90 for "at-sea" spills and 0.40 for "in-port" spills.

INTRODUCTION

The Minerals Management Service (MMS) of the U.S. Department of the Interior (DOI) conducts oil and gas leasing on the U.S. Outer Continental Shelf (OCS) and regulates activities on tracts that have been leased. The MMS normally prepares an Environmental Impact Statement (EIS) for each offshore lease sale. Within each EIS, MMS must evaluate the potential risks of oil spills occurring and contacting environmentally sensitive resources.

The Oil Spill Risk Analysis (OSRA) model was developed in 1975 by DOI as a tool to assist in the evaluation of offshore oil-spill risks (Smith et al., 1982). This model is used primarily to provide environmental impact analysts with probabilistic estimates of oil-spill occurrence and contact with biologic and economic resources located on the U.S. OCS. The trajectory portion of the model uses seasonal surface current and local wind conditions to simulate many trajectories from potential offshore spill sites. Results of the trajectory runs are then used to estimate the statistics of potential contact. The OSRA also addresses the likelihood of oil spills occurring during the production and transportation of offshore oil. A realistic, objective methodology for estimating oil spill occurrence rates is needed for this application of the oil spill risk analysis.

SPILL RATE DEFINITION

This paper presents the results of analyses of oil spill occurrence rates (hereafter referred to simply as "spill rates") for U.S. OCS platforms and pipelines and worldwide spills from tankers. Spill rates are expressed in terms of number of spills per billion barrels of oil handled. Only spills of 1,000 barrels and greater are addressed, since the OSRA is used primarily to estimate contacts over days, not hours, without consideration of explicit spreading or weathering of oil. Consequently, only those spills that are large enough to travel long distances on the ocean surface and that could persist for several days or longer are appropriate for simulation by this model. Another consideration is that a large spill is unlikely to go unnoticed; therefore, reporting records should be more reliable. The 1,000-barrel cutoff meets the above requirements. In addition, the estimation of the size of an oil spill is generally an inexact measurement, which is often rounded up or down by onsite observers to the nearest 500 or 1,000 gallons, barrels, or metric tons. Therefore, spills near 1,000 barrels are likely to be reported as 1,000 barrels. Large spills account for less than 1 percent of all spill events on the U.S. OCS; almost all smaller spills (98 percent) are less than 10 barrels in size. These smaller spills do not lend themselves to trajectory modeling. Any further reference to "spills" in this paper should be assumed to be "spills of 1,000 barrels or greater" unless otherwise specified.

POISSON DISTRIBUTION FOR ESTIMATION OF SPILL OCCURRENCE

Efforts to estimate the probability of a spill occurring are part of MMS's assessment of potential environmental impacts. In the past, the occurrence of spills has been modeled as a Poisson process (Smith et al., 1982). Using the updated database, we have reexamined the assumptions necessary to use this distribution and have determined that they are still applicable.

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Since spill occurrences do meet the criteria for a Poisson process, we use the following equations in our estimation of spill rates. The estimated volume of oil handled is the exposure variable. Smith et al. (1982), using Bayesian inference techniques, presented a derivation of this process assuming the probability of n spills over some future exposure t is assumed to occur at random with some frequency specified by equation 1a:

$$P[n \text{ spills over future exposure } t] = \frac{(\lambda t)^n e^{-\lambda t}}{n!} \quad (1a)$$

where λ is the true rate of spill occurrence per unit exposure. The predicted probability takes the form of a negative binomial distribution:

$$P(n) = \frac{(n+\nu-1)!\,t^n \tau^\nu}{n!(\nu-1)(t+\tau)^{n+\nu}} \quad (1b)$$

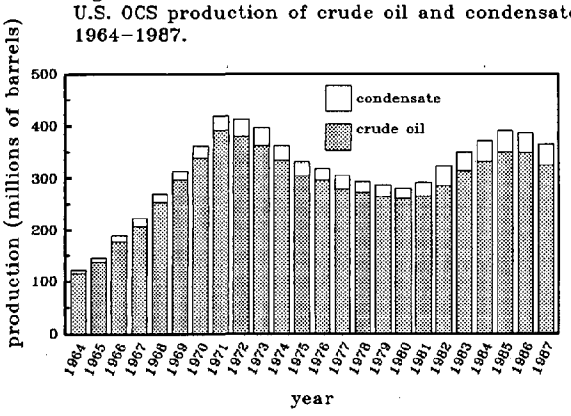
where τ is past exposure and ν is the number of spills observed in the past. The negative binomial is then shown to converge over time to the Poisson with λ estimated using equation 1c (Smith et al., 1982):

$$\lambda = \nu/\tau \quad (1c)$$

SELECTION OF EXPOSURE VARIABLE

Two basic criteria for selecting an exposure variable are that the exposure should be simple to measure, and it should be a quantity which is predictable. Volume of oil handled is the chosen exposure variable primarily for these reasons. Past production is well documented, as shown in figure 1. Volume of oil handled makes the calculation of the spill rate simple--the ratio of the number of historic spills to volume of oil handled--in the form of equation 1c. Volume is also predictable. Estimates of volume are prepared by the Resource Evaluation Program within MMS, whose function and expertise is in the assessment of oil resources using comprehensive geological and geophysical databases and related models. In addition, almost all other exposure variables that could be used--number of platforms, number of tanker trips, etc.--are currently estimated by MMS as a function of oil handled.

Figure 1
U.S. OCS production of crude oil and condensate, 1964–1987.



Sources: MMS 88-0010, 1988a and 1988b.

The spill rate, λ, is expressed in the form of equation 1c as the number of spills per billion barrels of oil handled. In the case of platforms and pipelines, MMS addresses the U.S. OCS experience exclusively. The advantages of this approach are that the rates will better reflect the magnitude of spill occurrence under U.S. regulation and operational controls and that the individual spill and production records are readily accessible to MMS. The disadvantages include the limitations involved in analyzing a small number of observations. This precludes cross-sectional analysis of possible rate variations that may exist between the northern Pacific or Alaska waters versus the Gulf of Mexico and Southern California, where the majority of the U.S. OCS experience has occurred. The rates should not be adjusted based on the intuition that more hostile environments are riskier. The more hostile environments have more stringent engineering and procedural regulations, which may offset or even reduce the risk of a spill occurring relative to historic OCS experience.

RATES FOR SPILLS OF 1,000 BARRELS OR GREATER

We separately addressed three sources of oil spills: platforms, pipelines, and tankers. Only spills of the size of 1,000 barrels or greater were rigorously analyzed. Platform and pipeline spills were analyzed based upon U.S. OCS experience from 1964 through 1987. Tanker spills were based on worldwide data from 1974 through 1985. In each analysis, each spill event record was examined and verified to the extent possible. Each spill was classified based on its applicability to the analysis in terms of size, product spilled, and spill source.

There are only 11 and 8 spill observations, respectively, for platform and pipeline spills; see tables 1 and 2. Nonparametric tests were applied to determine whether these observations were random and independent. In both cases, the volume of oil handled between spills appeared to be nonrandom and increased over time. This indicated that the spill rate, based on volume of oil handled, had declined over time.

Table 1
Oil spills of 1,000 barrels or greater from platforms on the U.S. OCS, 1964–1987.

Date	Area	Size (barrels)	Cause
04/08-09/64	Eugene Island	2,559	Collision, fire.
10/03-19/64	Ship Shoal/Eug. Isl.	11,869	Hurricane, blowout.*
07/19-26/65	Ship Shoal	1,688**	Blowout.
01/28-02/06/69	Santa Barbara	77,000	Blowout.
03/16-19/69	Ship Shoal	2,500	Collision, blowout.
02/10-03/31/70	Main Pass	30,000	Fire.
12/1/70-4/17/71	South Timbalier	53,000	Blowout, fire.
01/09/73	West Delta	9,935	Storage tank rupture
01/26/73	South Pelto	7,000	Storage barge leak.
11/23/79	Main Pass	1,500***	Collision with rig.
11/14/80	High Island	1,456	Tank overflow.

Sources: MMS 88-0010, MMS 88-0011. (Santa Barbara estimates vary, 10,000-77,000 BBLS.)
* 5 platforms, includes 1,589 BBL storage oil.
** Condensate.
*** Diesel.

Table 2
Oil spills of 1,000 barrels or greater from pipelines on the U.S. OCS, 1964–1987.

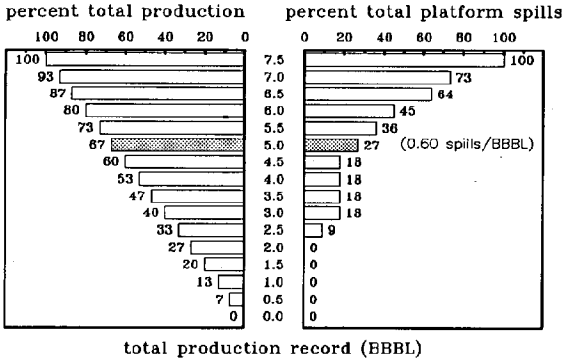
Date	Area	Size (barrels)	Cause
10/15-27/67	West Delta	160,638	Anchor dragging.
03/12/68	South Timbalier	6,000	Anchor dragging.
02/11-16/69	Main Pass	7,532	Cause unknown.
05/12/73	West Delta	5,000	Internal corrosion.
04/18/74	Eugene Island	19,833	Anchor dragging.
09/11/74	Main Pass	3,500	Hurricane.
12/18/76	Eugene Island	4,000	Trawler dragging.
12/11/81	South Pass	5,100	Anchor dragging.

Source: MMS 86-0011.

To properly examine the data, uniform intervals based on volume of production, rather than time, were selected. Interval lengths were calculated to maximize the percentage of intervals with a single spill occurrence. This minimized misleading observations of zero spill intervals created by using production intervals of such short length that it was highly unlikely that a spill would be observed. Historical spill rates were calculated cumulatively from the first available interval forward through 1987, dropping the previous interval's record. The spill rate was selected by indentifying the point in the database where major decreases in the spill rate are no longer apparent while trying to maximize the amount of the historical record used.

Spill rates of 0.60 and 0.67 spills per billion barrels were selected for U.S. OCS platforms and pipelines, respectively. These rates were selected because they reflect the observed decline compared to the intervals based on the longest records, and they are based on the most recent 60 percent or more of the historical record. Figures 2 and 3 illustrate the comparison of the historical production record against the spill record, showing

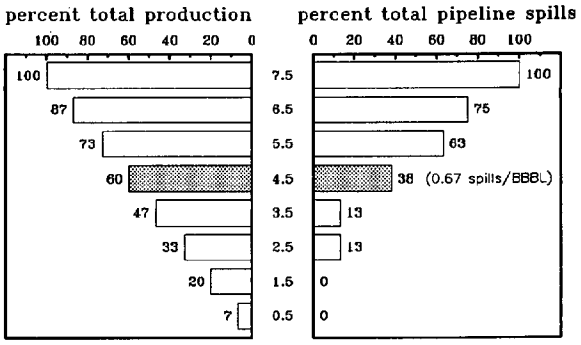
Figure 2
Percent of production and platform spills in the record disregarding previous 0.5 BBBL intervals.



Production includes crude oil and condensate.

100% includes entire U.S. OCS record, 1964–87. Subsequent percents represent distribution as the oldest 0.5 BBBL intervals are disregarded.

Figure 3
Percent of production and pipeline spills in the record disregarding previous 1.0 BBBL intervals.



Production includes crude oil and condensate.

100% includes entire U.S. OCS record, 1964–87. Subsequent percents represent distribution as the oldest 1.0 BBBL intervals are disregarded.

the percentages of the record included as the oldest data are dropped in increments of 0.5 and 1.0 billion barrel production intervals for platforms and pipelines, respectively. The shaded area indicates the percentage of the record included in our final spill rate selections. For example, figure 2 indicates that the selected 0.60 platform spill rate is based on the most recent 67 percent of the production record, which includes only 27 percent of the total number of historical spills. This means that by dropping the record for the first 2.5 billion barrels of production, 73 percent of the spills occurred during this early production and are discounted. Likewise, figure 3 indicates that the 0.67 pipeline spill rate is based upon the most recent 60 percent of the OCS production record, which contains only 38 percent of the historical spills.

The database of worldwide tanker spills provided substantially more observations than the U.S. OCS pipeline and platform data. Rates for tanker spills of 1,000 barrels or greater were calculated directly from the data and were relatively constant over the entire time period from 1974 through 1985. Spill rates for spills occurring "at-sea" were calculated separately from those occurring "in-port" based on an exposure of 107.8 billion barrels transported. These spill rates were 0.9 and 0.4 per billion barrels, which were based on 97 "at-sea" and 43 "in-port" spills, respectively.

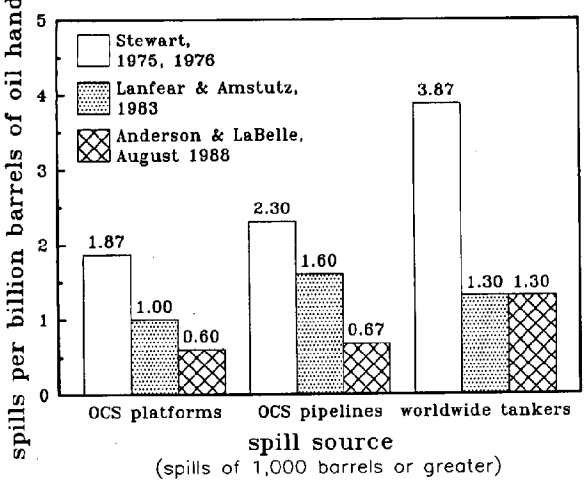
SPILL RATES FOR SPILLS OF 10,000 BARRELS OR GREATER

Rates for spills of 10,000 barrels or greater were calculated by applying the percentage of historical spills equal to or greater than 10,000 barrels against the 1,000 barrel or greater spill rate. This resulted in a rate of 0.24 spills per billion barrels of oil produced and/or handled for platforms and 0.17 for pipelines. The 10,000 barrel and greater spill rates are 0.55 for "at-sea" tanker spills and 0.16 for "in-port" tanker spills.

CONCLUSIONS

The updated platform and pipeline spill occurrence rates are significantly reduced from those of Stewart (1975, 1976) and Lanfear and Amstutz (1983). This may be due to improvements in technology and stricter safety regulation over time, combined with overall gains in experience in offshore oil production. A comparison of how the rates have changed since 1983 is shown in figure 4. The primary reason for these reductions is the low incidence of spill occurrence since 1980.

Figure 4
OSRA Model oil spill rates, 1988 revision compared with previous rates.



REFERENCES

Lanfear, K.J., and Amstutz, D.E., 1983. A Reexamination of Occurrence Rates for Accidental Oil Spills on the U.S. Outer Continental Shelf: Oil Spill Conference, 1983, Proceedings, 5 pp.

Smith, R.A., Slack, J.R., Wyant, T., and Lanfear, K.J., 1982. The Oil Spill Risk Analysis Model of the U.S. Geological Survey: U.S.G.S. Professional Paper 1227, 40 pp.

Stewart, R.J., 1975. Oil Spillage Associated with the Development of Offshore Petroleum Resources. Report to Organization for Economic Cooperation and Development, 49 pp.

Stewart, R.J., 1976. A Survey and Critical Review of U.S. Oil Spill Data Resources, with Application to the Tanker/Pipeline Controversy. Report to the U.S. Interior Department: Cambridge, MA, Martingale, Inc., 75 pp.

U.S. Department of the Interior, Minerals Management Service, 1988. Federal Offshore Statistics: 1986: OCS Report No. MMS 88-0010, 95 pp.

U.S. Department of the Interior, Minerals Management Service, 1988. Accidents Associated with Oil & Gas Operations: OCS Report No. MMS 88-0011, 264 pp.

U.S. Department of the Interior, Minerals Management Service, 1988a. Communication with MMS Pacific Region for 1985-86 OCS crude oil and condensate production figures.

U.S. Department of the Interior, Minerals Management Service, 1988b. Communication with MMS Gulf of Mexico Region for 1985-86 crude oil and condensate production figures.

MYTH AND MANAGEMENT--The Shipwreck Management Act

Jack Fullmer, Legislative Committee, N.J.C.D.C.

Congress recently passed the Abandoned Shipwreck Act and this has caused a great deal of concern in the sport diving community. As legislative Committee Chairman of the N.J. Council of Diving Clubs, I was asked to formulate a position for our Council and took an active part in trying to change the wording of the bill. Eventually this effort led to testimony before the Senate Subcommittee on Public Lands, National Parks, and Forest. The changed wording of the Senate Bill eventually became law.

The purpose of this paper is to examine some common myths about shipwrecks and shipwreck management, to look at some of the wording in the Shipwreck Management Bill, and to show how some of the positive concepts in the law can be used at the state level to build a framework that will both protect historic shipwrecks and fully utilize this multipurpose resource.

The rise of sport diving in the second half of the century along with advances in marine electronics have changed the role that shipwrecks play in our society. At one time shipwrecks were looked upon only as objects of salvage. It was difficult to find them and difficult to dive on them. Modern SCUBA gear and advanced electronics have changed all that. But the myths and stereotypes that arose during that era when shipwrecks were looked at as treasure trove are still around us along with a few new myths generated by the media.

Perhaps the most common myth is that shipwrecks are mainly important for salvage and, more recently, for underwater archaeology. Certainly most of the T.V. and news coverage on shipwrecks portrays this role. Yet treasure wrecks probably constitute less than 1% of the total resource, while historic shipwrecks are estimated to constitute about 5%. A historic shipwreck is a wreck that could meet National Register criteria.

The predominate importance of almost all shipwrecks in marine waters is for fishing and sport diving value, or what is often referred to as reef value. For example, in New Jersey 70% of all sport diving is done on shipwrecks. Party and charter fishing boats fish the wrecks extensively, for the wrecks are concentration or focal points for bottom fish, lobsters, and other marine life in an otherwise barren seafloor. Every day during the season a whole fleet of fishing and dive boats visit the wrecks off the Jersey coast.

Another myth that may have instigated the Shipwreck Management Bill is the belief that salvage is the most serious threat to shipwrecks. Yet the traditional cause for the destruction of shipwrecks in our rivers, harbors, and bays is dredging and large scale construction projects. Trawlers and draggers account for much of the damage in the oceans. It is interesting to note that this sort of damage is accidental, and if the location of the wreck were well known, the damage could be avoided.

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Natural causes such as storms, hurricanes, worms, and corrosion eventually doom all shipwrecks in the marine environment, some at faster rates than others. One Revolutionary War wreck had laid on the bottom of the Mullica River in south Jersey in a fair state of preservation. But within the last 10 years a 30 foot deep channel has meandered into it causing the wreck to tip over into the channel at a precarious angle. Large timbers are now falling off the wreck and are being washed away by the current.

All shipwrecks should be viewed as transient resources. It is important to locate those historic shipwrecks that have entered periods of accelerated deterioration so that archaeological work can be done before it is too late. Salvage as a factor in the destruction of shipwrecks is rather minor.

Another misconception that crops up in the Shipwreck Management Act is the belief that an embedded wreck is probably an old or historic shipwreck. The simple fact is that whereas most historic shipwrecks are embedded, so are most non-historic shipwrecks. Almost all wrecks are embedded in the normal sense of the word, as shifting sands and storms will embed a wreck in as short a period of time as a couple of years.

Yet another misconception is that states will make good managers of shipwrecks because they have archaeologists on staff that are interested in shipwrecks. In New Jersey not one dime of Historic Preservation Funds or discretionary grant funds has ever been used to fund an underwater archaeology project. Nor is there a single person in the agency that is designated for historic preservation in N.J. that dives or has ever seen a shipwreck underwater.

On the other side of the coin the N.J. Dept. of Marine Fisheries has undertaken an ambitious program to increase the number of wrecks (artificial reefs) with little available funding, a program that will benefit both fishermen and sportdivers, and replace a transient resource. The fact is that some states have taken an active interest in shipwrecks while others have shown little or no interest. This can even vary between departments within a state whose jurisdictions both involve shipwrecks.

Another interesting point is that states must approve dredging projects in rivers, harbors, and bays, and have inadvertently been responsible for much of the destruction of historic shipwrecks in this country. Sometimes the location of historic research information is known to sport divers but this information is not known to state officials that issue permits for dredging or other large scale projects. A similar situation took place in 1983 in N.J. when a memorandum of agreement was reached on a proposed bridge across the Crosswicks Creek near Bordentown; all of the state and federal officials had overlooked the fact that an entire Revolutionary War fleet of merchant vessels and privateers (22 vessels) had been sunk by the British in the immediate area of that proposed bridge, and it took some sport divers and amateur archaeologists to bring that point home.

Another prevalent assumption is that state and federal agencies find most shipwrecks. Nothing could be further from the truth. Sport divers, dive boat captains, and charter and party boat captains, who often ask sport divers to check them out, find almost all wrecks, including historic shipwrecks. State officials are almost totally dependent on these sources, or on publications, usually by sport divers, for information about the locations of shipwrecks.

Strangely enough the logical assumption that archaeologists and historians are responsible for most historic research about shipwrecks is also correct. Most historic research on shipwrecks is done by sport divers, who also write numerous local histories about shipwrecks in books and for newspapers, and magazines. This is also true for mapping and drawing of shipwrecks, and much of what passes for underwater archaeology in this country is handled advocationally by interested sport divers.

The last myth that needs some comment is the idea that shipwrecks are fragile resources. This fallacy even occurs in the House report language on the Shipwreck Management Act. Shipwrecks may be fragile in the sense that pollution could affect their ecosystem, but common sense should tell anyone that a wreck that can survive the violence of numerous hurricanes is not going to be affected by a sport diver swimming over it.

MANAGEMENT

The previous discussion suggests certain logical principles that should be involved in any shipwreck management program.

The first and very obvious point is that shipwrecks should be treated as a total resource (multipurpose) and not just as an historic resource, which is actually a very minor aspect of the resource. Treating shipwrecks as a multipurpose resource means that you take a close look at how they are actually utilized in our society, what purposes they serve, and who are the people who utilize them. You consider the large numbers of fishermen and sport divers that visit them every year. You consider the lobster fisherman that sets his traps near a shipwreck, but tries to avoid entangling them in the wreck. You consider the trawler captains that are trying to avoid hitting them. You also consider the very tiny number of underwater archaeologists and salvors that make a living from shipwrecks.

The Shipwreck Management Act does recognize some of these different uses of shipwrecks. In Sections Four and Five of the Act, it mentions habitat value, tourism, recreational exploration, underwater parks, and historic research and salvage. Strangely absent is the almost total lack of reference to recreational fishermen and commercial fishing interests, which is one of the main uses of the resource.

Another thing that suggests that the Act was not intended to take a total resource point of view is its jurisdiction. The categories of shipwrecks transferred to states (National Register vessels and those vessels embedded in submerged lands of a state so that tools of excavation are required...) would indicate that the law is oriented to historic and/or digging up vessels that could be historic. The impression one gets is that the law was first aimed at historic shipwrecks, and then the legislators, after hearing testimony, decided that it might be important to mention other uses as well.

The concern sport divers have repeatedly expressed is that almost all shipwrecks are embedded in the normal meaning of that word. Yet states are given the mistaken impression that there is some special importance to an embedded wreck. Tools of excavation probably refers to power dredging equipment, and the act of removing substantial amounts of sediment from the bottom would also be of environmental concern. Yet that is not made clear anywhere else in the Bill. In hindsight, the Act should have given jurisdiction to all abandoned shipwrecks in state waters, or to just historic shipwrecks, and not become involved in the embedded mystery. I have enclosed a letter from a Congressman that states his belief that Admiralty Courts still have jurisdiction over some wrecks in state waters.

The second principle of management, which follows logically from the first, is that state management of shipwreck resources should not be solely vested in historic preservation offices, but should reflect the interests of sport divers, fishermen, salvors and other groups that utilize the resource. The idea of management by the utilizers of the resource is not a new idea. It occurs in the N.J. Marine Fisheries Council, in the N.J. Boat Regulation Commission, and in other such regulatory agencies. It is particularly important in a resource that is only seen and utilized by a small segment of the population. For example, 99% of the people that actually dive and can see shipwrecks fall into the sport diver category. If this group were to be excluded from its management, a state would have very little information and input about the resource and, in addition, it would have no handle on the feelings or concerns of that segment.

Furthermore, the people that are most likely to understand the issues and problems relating to shipwrecks are those that are familar with shipwrecks. By involving the utilizers of the resource, a state is less likely to run into a situation where the managers of the resource have never seen a shipwreck, a situation that is bound to foster myth and ill conceived regulations.

The type of management form could be a commission which would accurately reflect the number and involvement of these different groups with shipwrecks. Thus it might have a large portion of fishermen and sport divers as well as a salvor, archaeologist, and a few representatives of state agencies involved with shipwrecks.

The Shipwreck Management Act suggests that sport divers, fishermen, archaeologists, salvors and other interests be involved in the management of shipwrecks at the state and federal level in Section Five, and this was a key aspect of the testimony of the N.J.C.D.C. before the Senate. Unfortunately it occurs in a section of the Act that asks the National Park Service to draw up guidelines. The N.J.C.D.C. suggested to the National Park Service that they appoint sport divers and fishermen to serve on the Committee to draw up these guidelines. This idea was refused by the Park Service, and apparently the only persons that will serve on this committee will be historic preservation professionals who will listen to testimony at hearings. The question is how sport divers and fishermen are supposed to manage shipwrecks at the federal and state level if they are not allowed to serve on the advisory committee. Where else at the Federal level could they serve in a management capacity.

In Section Five, the word "partnership" is written in conjunction with the idea of management. The testimony of the N.J. Council of Diving Clubs intended partnership to have a wider meaning. Partnership refers to a cooperative effort between sport divers, fishermen, archaeologists, salvors, and (inferred) state agencies to not only manage shipwrecks, but to work together to fully realize the potential of this resource. For historic shipwrecks, partnership means that sport divers and state officials work together to identify historic shipwrecks, especially those that may be threatened by natural or other factors. It means cooperation between sport divers and archaeologists to map and study these wrecks It means sharing information about the location of historic shipwrecks with trawler captains so that they can avoid them.

For our shipwreck reefs, partnership means sport divers working with the marine fisheries agency to monitor fish kills, to conduct fish surveys and water sampling, and to help out with other scientific endeavors where the numbers of sport divers can do what the small numbers of scientists cannot do. Partnership means fishermen and sport divers working with the State to replenish our shipwrecks through artificial reef programs. Partnership means sharing the location of shipwrecks so that they become a truly public resource, not hidden as secret loran numbers known only to a few.

Partnership is not helped by the attitude of some archaeologists and "historic preservation professionals" that tries to limit access to historic shipwrecks. This elitist approach (that only a select few with degrees should be permitted on shipwrecks) ignores the statistics that most historic shipwrecks are not found by archaeologists, are not initially explored by them, are not mapped by them, and that most historic research is not done by them. Yet this elitist philosophy, which contradicts the voted on policy of Congress, is reflected in the House Language Report.

Since there are very few underwater archaeologists in this country and few states employ any, the direction that historic preservation is going to take for shipwrecks is not a professional archaeological approach, but is going to stress mapping, National Register nominations, and historic research by paraprofessionals. Several surveys have already been conducted in New Jersey in this manner, and have been highly successful. A state might consider hiring an underwater archaeologist to help lead these sport diver volunteers.

Partnership, therefore, is based on guaranteed access. Not only is this the voted policy of Congress, but common sense would indicate that no sport diver would report the location of a historic shipwreck if a state had a policy to then deny access to it. Access is also important because historic shipwrecks, unlike land sites, may also be important sport diving and fishing reefs. New Jersey has many old shipwrecks that are important sport diving wrecks. Even for important archaeological sites, states have alternatives to denial of access.

Report language is both Houses suggest that states hide the location of historic shipwrecks by issuing vague descriptions of their location. This foolish policy would not only increase the risk of trawlers hitting them, but also ignores the fact that it is the diving public that normally finds them. This public would probably return the favor by hiding the location from the state, and this is not a partnership relationship.

Finally states should stress education and innovative designs over fear of penalities when trying to protect historic shipwrecks. In a paper by Alan B. Albright of the Institute of Archaeology and Anthropology, University of South Carolina called the Law and the Amatuer in Resource Management, Mr. Albright stresses that cooperation is far more effective than confrontation and threats of law enforcement. He cites the cooperation that his state has received from sport divers and the numerous finds that are archaeologically important that have been reported by sport divers. He mentions that enforcement is always time consuming, expensive, and tends to establish an adversary relationship. Voluntary compliance, a product of education, understanding, and compromise, is less expensive, self motivating, and establishes cooperation as the norm.

Maryland recently passed a law that calls for an educational program for the training of interested members of the public (sport divers) in the identification and registration of submerged archaeological property. New Jersey is considering draft legislation that will include advocational mapping of shipwrecks. Sport Divers are already mapping historic shipwrecks in the Mullica River, and Amateur involvement is a very large part of archaeological efforts in the Crosswicks Creek. Organizations such as the Atlantic Alliance with notable archaeologists such as Duncan Mathewson are

sponsoring underwater archaeological training programs for sport divers. Consideration is being given to inserting positive incentives such as an annual awards program for the best mapping and nomination of historic shipwrecks in the N.J. Shipwreck Management Bill.

I could go on and on about what the Shipwreck Management Act did and did not do, and what principles of management offer the most promise for the full utilization of this multipurpose resource. The fact is that the national law allows for a great deal of latitude for states to shape their own management programs.

The sport diving community needs to meet the challenge of overcoming the myths and stereotypes that cloud this resource. It must defeat elitist ideas that try to hide or deny access to historic shipwrecks. Since 99% of the people that actually dive on and see shipwrecks are sport divers, the sport diving community has a unique opportunity to take a lead role in the partnership that will manage this important resource. This should be a positive role that stresses sport diver involvement in scientific and archaeological programs, and a cooperative effort with fishermen, archaeologists, and state agencies to map, explore, and replenish this multipurpose resource.

The N.J. Council of Diving Clubs believes that shipwrecks are a public resource and should be open to the public. We believe that shipwrecks are not the exclusive monolopy of archaeologists, salvors, or anyone else, but that openness and cooperative effort is what will best serve the development and preservation of the resource. State programs should encourage innovative designs to reach this goal.

THE CONTINUING NEED FOR ACCURATE POSITIONING IN NAVAL TACTICS

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ABSTRACT

Modern naval warfare has, over the years, resulted in the relegation of accurate positioning and navigation to a second class role. The modern naval officer worries about positioning usually only when concerned with navigation. During the battle he most often conducts his operations in a relative motion sense using relative ranges and bearings. The once widely-respected title of navigator has been replaced by that of the Tactical Action Officer. Despite these lamentable trends, accurate positioning remains as important today as it ever was. The trends toward over-the-horizon targeting/battles and strict Emission Controls (EMCON), coupled with the more traditional tactics in Anti-Submarine Warfare (ASW) and Mine Warfare, continue to require good geographic positioning as a matter of paramount importance.

INTRODUCTION

Naval warfare, as with all other operations at sea, depends heavily on the positions of one's own vessel and those of other contacts in the area. While much activity is conducted in the relative frame of reference using bearings and ranges, it is still necessary to have accurate and current knowledge of one's position on the surface of the earth.

In this discussion on determining one's location we need to review two fundamental definitions. The first is for *navigation*, which is the art or science of conducting one's self from one place to another. The second is for *positioning*, the act of determining one's place on the earth to a specific tolerance.

While the two words mean the same thing to many people, there are subtle differences. Fundamentally, the word 'positioning' implies a more accurate knowledge of one's position than is required in navigation. The act of navigation is more dynamic in that it includes movement from one place to another. Positioning reflects a greater interest in one's position as accurately fixed on the surface of the earth. It is very often used in association with activities requiring close tolerances such as in surveying or the offshore oil industry. Positioning is necessary where the mariner wishes to accurately mark a place for return or some future action.

DECLINE IN NAVIGATIONAL AND POSITIONING EXPERIENCE

The term 'Navigator' within the U.S. Navy has lost some of its luster over the years because of two factors. One, improved techniques and equipment have made navigation less difficult to practice but at the same time more accurate. Secondly, the evolution of modern warfare has shifted emphasis from true positioning to a relative frame of reference. A navigator is generally less interested in precision positioning because his ship's motion does not allow him time to take full advantage of multiple or more complex positioning strategies.

Less than a hundred years ago, the title Navigator was one which inspired admiration. Now navigation is something that must be done to keep out of trouble. It's still possible to ruin

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one's reputation through bad navigation. For this reason, navigation is maintained as a necessary but not altogether desirable skill. Unfortunately, the imperatives of today's fast-moving tactical and battle situations have diluted the emphasis placed on traditional navigation skills.

The modern naval officer must concentrate more on threat indicators and less on finding his position. This lamentable state of affairs appears in both the lack of strong and comprehensive navigation training and in the lower priority given its actual practice.

The evolution of modern electronic navigation systems has led to the design of relatively simple-to-use equipment with direct reading displays. One needs only take latitude and longitude readings from the equipment and plot them. This may be well and good in the open sea where the hazards of running into a shoal are less unlikely. However, in restricted waters, or where an accurate position is required, these systems are not always as accurate as manufacturers would like users to think. Potential problems range from what we call range holes, to system failures to poor pattern geometry. Navigation in well-travelled waters, is generally easy because provision has been made for complete and accurate electronic navigation signal coverage. However, in less frequently travelled waters, it becomes more problematic. It is into these waters that our navies must sail and fight. How many of you, ten years ago, would have thought that there would be major actions in such out-of-the-way places as the Falklands and Grenada? In order to position oneself well, one must pay full attention to all the variables.

There are still many operations personnel who find it difficult to adjust to a digital environment because they feel they've lost touch with the real world. They find it difficult at times to interpret the information presented. It's not surprising that we still find the requirement aboard U.S. Navy ships to keep a hard-copy (paper) geographic track plot.

RELATIVE AND GEOGRAPHICAL POSITIONING

One need only look at any tactical radar screen today to get an appreciation for how operational tactics have developed after World War II. Before that, they were always played out on plotting tables using geographic references. Virtually every navigational and tactical radar displays targets in the Plan Position Indicator (PPI) format. With PPI, the radiating ship is positioned in the center. Contacts are located on the screen along radials, at some true or relative bearing, extending from the radiating vessel's blip. Some radars allow radar operators to displace the origin of the cursor to an off-center position to aid in the visualization of the tactical situation. Computations may be made within the equipment to solve for the maneuvering board solutions of targets' courses and speeds thereby reducing relative data to true motion. Similarly, bearings and ranges from one target to another can be determined by moving the cursor origin to a desired blip and rotating the cursor to a third.

Modern tactical operations are normally conducted within a relative motion framework because most weapons systems deal in range and bearing data elements. When contact is made, the target is generally identified by its range and bearing from the detector. The resulting evolution in tactical thinking, therefore, has concentrated almost solely on the relative motion solution. This is a dangerous trend because, with the flood of information now available from all our sensors, there is a higher probability of losing the 'big picture.' That's why, when you see a picture of the Combat Information Center of an Aegis ship, you see a bank of very expensive screens. Unfortunately most ships cannot carry such an expensive suite of equipment and must make do either with small and very limitecd screens or with the more traditional and underdeveloped plotting tables.

Nevertheless, one of the best ways for keeping a clear picture of what is going on is to plot the action on a table. This effectively results in conversion of relative motion into a true motion picture on a geographic plot. The resultant plot then directly relates the action to the real world.

The fact that such solutions are still available, dramatically points to a definitive need for tactical operations officers to get their target information on a true or geographic display. Movement is then unambiguously portraye. Mariners feel at home working tactical solutions in true motion where action is depicted in real world terms. It significantly reduces the complexity and allows for faster decision-making.

The major advantage is that one gets a true appreciation of the interaction of all the participants in an action without having to work out a relative motion solution in one's head. This is particularly advantageous when there are multiple contacts to contend with both true and relative data flows being received.

LARGE AREA BATTLES

Modern weapons systems have longer and longer stand-off ranges. The result is that tacticians have had to consider ever extended detection horizons. The only good method for adequately referring target positions to scattered elements of a task force is on some sort of grid or geographic coordinate system. This is because not all vesssels can support complex, large and expensive detection and tracking sensor suites, or their sensors are limited by EMCON restraints. Ships must rely on other sources of information to learn the whereabouts of the enemy. As with most detection systems, the detection is made in the relative mode but converted into geographic positions for transmission to, and plotting by, other elements.

NTDS AND THE LINK SYSTEMS

Much of these data communications are performed through the Navy Tactical Data System (NTDS) or Link 11 or 14 Systems. These systems pass disposition information on a number of contacts automatically between computers. One weak link in these systems is the frequent inability of data generating ships to position themselves accurately. Any errors in their positions are passed through the system and multiplied by any other errors present at the receiving vessel.

If every ship and aircraft was properly positioned, the problems could be significantly reduced. In a recent exercise, the Link system was observed at one instant to have three contact symbols portraying the same vessel in three different places on the screen. Two of these positions were more than five miles distant from each other. The force was in radar silence and at darken ship. The positions provided the only information by which the ships maintained their stations in the main body and screens. The ship from which we made these observations was carrying a navigation integration system which combined three navigation system inputs with an automated tactical plotting table. We were able to obtain the finest positioning information of any ship in the force. Since we knew the location of our ship to within a hundred meters, we were easily able to see the failings in other ships not possessing good navigation or position information.

A common tactic during periods of EMCON silence is to send a radar aircraft aloft which radiates from a location far removed from its task force. One of the greatest sources of error in the Link system arose from the fact that the helicopter had taken its relative position from the carrier which was in turn not well-positioned. The result was that all the contacts illuminated by the helo, which was the only radar in the EMCON-shrouded force, were in as much error as that of its guide, the carrier. She was, interestingly, the element which had appeared in triplicate (i.e., in error) on the Link screens of the force earlier in the exercise.

When enemy targets are detected by such a mispositioned helo's radar, then the error is propagated throughout the force. Any ships needing to plot those targets would be in error as would any weapons which were to be fired.

During a similar exercise transit, the Link control ship role was given to one of the screening escorts. It was easy to see that the destroyer, which was also the screen commander, was soon overloaded trying to run the ASW problem against three submarines whilst trying to maintain the tactical data base. When the going got hot, it was obvious which effort was left to languish. We observers noted an early breakdown in the navigation function as disorientation became the rule on the Link system. We believe this occured because the navigation function is not considered critical when compared with the priorities of the battle. This might possibly be considered acceptable in battle there is no need for this to happen. There are systems available which will automatically track the geographic plot for low cost and minimal effort. Positioning information was of paramount importance to other ships in the force when in EMCON.

ATTACK SCENARIOS

Attack scenarios are most often played out on geographic plots because of the clarity of their presentations. This is particularly true in situations where there is a 'time-late' or datum to deal with. The solution to such problems is best found on a geographic frame of reference because the "lost" contact can be fixed to a position on the earth where it was last detected. In this way its projected movement can be easily portrayed. Similarly, it is far easier to set up search and attack patterns on a geographic grid than it is to work in relative motion. This fact becomes even more true when there are multiple vessels and helos involved in the action.

Traditional Anti-Submarine Warfare (ASW) attack scenarios are traditionally played on a tactical plotting table. The datum or target is plotted with the positions of other participating ships and aircraft. The plot is most critical for the Attack Coordinator who must be able to see the entire situation and call in his forces to maximum effect.

Most modern plotting tables still require the concerted efforts of several persons to keep the plot current. The ship's position is projected by a light source from below and a person must mark its position manually at fixed intervals. Similarly, all other contacts and targets must be similarly tracked. The result is that many persons must lean over the table while hand plotting. Meanwhile, the Attack Coordinator must look over everyone's shoulders to get a clear picture of the unfolding attack. Not only is this method manpower-intensive, but it is prone to human error in the plotting. Very little development has taken place in this area.

Few equipment manufacturers have attempted to automate this function. While there are a number of systems attempting to consolidate all this information on a geographic plot, most equipment tends to be very expensive and complex. Additionally, many operators tend to feel alienated from a strictly digital solution. The plotting table still has an intimacy that is not found from viewing a video screen.

MINE WARFARE

The need for good geographical positioning is even more critical in the area of mine warfare. It is of paramount importance that mine warfare vessels, aircraft, Q-Routes and objects on the seabed be accurately positioned. Each of the elements in the mine warfare equation must be fixed on a common reference frame on which all players may track and display objects of interest. The most common grids are those developed around geographic coordinate systems, whether they be in Latitude/Longitude or Universal Transverse Mercator. Without a common reference frame, the ability to avoid or re-acquire the contacts is significantly reduced.

Precise positioning is of even greater importance in this critical area of naval operations. There is very little margin for error. Many of the larger equipment manufacturers are quick to provide very large and technologically advanced suites of equipment by which they claim to solve many of the mineman's problems. We've found that a far better and less expensive approach is to increase the precision in solving the navigation/positioning challenges. This is a relatively low cost solution with leveraged benefits surpassing those of the 'more and larger' equipment syndrome.

Q-ROUTES

Mine warfare begins with the complete survey of Q-Routes, i.e., the intended routes through restricted waters down which vessels may steam. This concept limits the amount of area needing to be continually searched. The objective is to condition a channel by accurately surveying it and then resurveying it frequently to ensure that no new mine-like objects have appeared. When the initial surveys are undertaken, all objects of interest on the bottom are accurately positioned and identified. These become the reference objects against which future contacts will be compared. It is important that all objects are located in order to reduce future requirements for classification of 'new' contacts.

Q-Routes should be regularly "conditioned'" so that, should war break out, the number of new contacts needing to be classified would be limited. Positioning during these conditioning surveys must be as accurate as possible to provide accurate positions for future comparison with objects previously detected and classified.

Much of this kind of survey work is done with the aid of side scan sonars. These allow operators to sweep a swath of bottom between the survey run lines. There are inherent inaccuracies in the side scan sonar principle which must be considered before the positioning of objects far from the survey run line may be regarded as accurately positioned.

Side scan sonar traces are good reconnaissance tools but there are a number of variables which are often not taken into account when accurate positions are desired. A number of products on the market and in development project the paper side scan trace onto a video screen. This should allow the operator to rapidly classify and "position" objects detected. Many of these systems, however, fail to address such problems as a display (waterfall) scroll rate tied to ship's speed. This is common on paper recorders but causes distortion on video, leaving doubt as to where the object really is. Other interesting features touted are 'freeze framing' and 'zooming,' which allow the operator to stop the scrolling to better view a contact or blow up its scale. Both these functions serve a useful purpose but obscure the cascading display currently being collected.

Positioning objects detected by side scan sonar is possible, but there are a number of variables which must be addressed. The principal consideration is the position of the towfish at the time of each ping. This is no small problem. Just knowing the position of the towing vessel/aircraft is not good enough when obtaining positions for use in mine warfare. One of the other papers at this conference on the Bathyscan system (in the Acoustics - Side Scan Session) provides an interesting and accurate approach.

MINE HUNTING AND NEUTRALIZATION

Return to a previously-detected mine-like object for neutralization is an extension of the problem discussed above. It's no good just having the objects accurately positioned and charted. The mine hunter must be able to navigate back to the object. Without proper navigation, useless time is wasted looking for the object to be neutralized and the risk is always present that the wrong object will be destroyed. Therefore, as much attention must be paid to

positioning the hunter and disposal vessels/aircraft as in the initial survey.

The point being made here is that positioning is the key to good mine warfare tactics from beginning to end. Mine warfare operators cannot be content to be haphazard in their approach to navigation. The best solution is to use more than one positioning system and mathematically evaluate the inputs to reduce the errors. We are not even sure that the GPS will be the final solution to all these problems, though it is supposed to give very accurate positions. Mine warfare personnel cannot afford to be cavalier in their approach to positioning.

Recently we heard a story about some mine forces in the Gulf. They had come up with the traditional "Cocked Hat" problem where three lines of position resulted not in a point but in triangle. Their solution was to turn off one of the three stations in order to reduce any ambiguity. With two lines of position, they had no doubt where they were and they had a point fix. We have no knowledge what criteria they used in selecting the deselected station, but it points to the fact that they really needed more than three lines of position to get a statistical evaluation of their positioning systems. There are too many lives and High Value Targets riding on their efforts. There is an ever greater need to provide for the integration of a number of positioning systems in order to come up with a statistically weighted answer. If nothing else, you will know how bad your position is.

There is an old mappers' axiom that says, "The next battle will be always be fought at the junction of at least two map sheet lines." The extension of this rule in mine warfare is that the next mine will be seen at the outer limits of your radiolocation chain pattern. Minemen will always be on the fringes; out where the coverage is weak and support is weak. That's why they need systems which can be counted upon to give the very best solutions for positioning themselves and the objects they're looking for.

CONCLUSION

We've tried to point out that the evolution of modern naval warfare has drawn us away from the careful and assiduous application of navigation and positioning information. The ease of obtaining a 'fix' and the imperatives of tactical threats have relegated this aspect to a lesser role. Nevertheless, the importance of accurate positioning, whether it be for navigation or some warfare application cannot be dismissed. Only with good positions may naval forces optimize their power.

Without good positions, tracking the battle is made difficult. The lack of a plot makes decision-making difficult. Too much effort is put into making large systems which do everything, with too little attention being paid to the key element, the positioning of the force. Neither can we let the speed of the battle detract from maintaining our positions because they are what we need to deconflict our scenarios in the end.

ECONOMIC IMPACTS FROM COAL EXPORTS: THROUGH THE PORT OF BALTIMORE AND THE PORT OF NORFOLK

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ABSTRACT

Paper presented at the OCEANS '88 Conference and Exposition on 'A Partnership of Marine Interest' co-sponsored by The Marine Technology Society and The Institute of Electrical and Electronics Engineers--Ocean Engineering Society, in cooperation with the Port of Baltimore, 31 October - 2 November 1988, Baltimore, Maryland. Paper summarizes the results of using a multiregional input-output methodology, developed by economists at the U.S. Army Engineer Institute for Water Resources, to conduct an economic impact analysis of the export shipment of coal through the Port of Baltimore and the Port of Norfolk, respectively. Paper is based on research and other work conducted by the authors in their pursuit of the use of regional science and economic structural analysis in the planning and development of federal navigation projects. An earlier version of this paper was delivered at the 27th Annual Meeting of the Southern Regional Science Association, 14-16 April 1988, Morgantown, WV. This paper does not necessarily reflect the official policies and deliberations of the U.S. Army Corps of Engineers.

1. INTRODUCTION

This paper exhibits the efficacy of using of a multiregional input-output (MRIO) methodology to assess the economic impacts attributable to the exports of a commodity through one port or another. In this instance, the commodity is coal and the ports are Baltimore, Maryland, and Norfolk, Virginia. The economic impacts are expressed in terms of output, value added, income (wages and salaries), and employment (person-years). All results are expressed in 1984 prices.

Navigation planning in the U.S. Army Corps of Engineers is characteristically conducted in conformity with the Corps navigation planning requirement (as stipulated in the Principles and Guidelines for Water and Related Land Resources Planning, published by the U.S. Water Resources Council) that commodity movements be identified and traced. Thus, the economists at the U.S. Army Engineer Institute for Water Resources used a multiregional input-output (MRIO) methodology to identify, trace, and provide an assessment of the economic impacts of the export coal movements through the ports of Baltimore and Norfolk.

One should remember, however, that an impact assessment constitutes only one of the many sets of socioeconomic inputs to the political decision-making process by which scarce Federal and state resources, such as the dredging of harbors, are distributed. One aspect, for example, of determining whether a port should be dredged at a given point in time is to show with geographic and sectoral specificity how movements of commodities through that port contribute to regional and national economies.

This impact assessment makes use of three major assumptions: (1) economic impacts of shipping one million tons of export coal through each port, respectively, can be analyzed to provide the impacts attributable to the first unit million ton shipment as well as successive unit million-ton shipments; (2) economic impacts of shipping coal through each port can be derived by multiplying the actual many millions of tons of export coal handled by each port in the year 1986 by the economic impacts of the unit million-ton shipment of export coal; and (3) coal exported through either port will come from mines in the 8-state coal shed defined below.

At this juncture, let us view our input data in a time perspective.[2] An average 1984 mine mouth price of $34.70 per ton for coal was derived, as discussed below, from executing the MRIO models with 1980 data in 1977 prices and then expressing the 1980 results in 1984 prices. Then 1986 waterborne traffic data (Waterborne Commerce of the United States, Calendar Year 1986: Department of the Army, May 1988, p. 74 and p. 83) for each port were reduced to million-ton units and multiplied by the unit million-ton impact data for each port in order to derive the total economic impacts for each port in the year 1986, the most recent year for which export coal traffic data are available.

2. METHODOLOGY

The MRIO methodology was selected because it provides explicit information on the trade among states, and on exports and imports. The source data, used in the model, is the 1977 Jack Faucett Accounts for the United States which were created on a state-by-state basis. These accounts provide the latest consistent estimates of production, consumption, and trade among the 50 states. The 1977 Jack Faucett Accounts were derived from data

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in the 1977 Economic Censuses pertaining to production, consumption, and trade among the industrial sectors within each state. The 1977 Jack Faucett Accounts are also consistent with the 1977 National Input-Output Accounts compiled by the U.S. Bureau of Economic Analysis.

The twenty five sectors listed below are utilized to provide the requisite industry detail.

1. Agriculture
2. Forestry & Commercial Fishing
3. Other Mining (Non-coal)
4. Coal Mining
5. Crude Petroleum & Natural Gas
6. Contract Construction
7. Food & Kindred Products
8. Apparel & Textiles
9. Lumber & Other Wood Products
10. Paper & Printed Products
11. Chemicals
12. Plastics, Rubber & Leather
13. Petroleum Refining
14. Stone, Clay & Glass Products
15. Iron/Steel Fabricated/Structural Products
16. Other Metallic Products
17. Non-Elect. Machinery & Equipment
18. Electrical Machinery & Equipment
19. Transportation Equipment
20. All Other Manufacturing
21. Transportation & Communications
22. Utilities
23. Wholesale & Retail Trade
24. F.I.R.E. & Services
25. Government Enterprises

The model is configured in a way that identifies each of the 8 states which contribute most of the export coal shipped through Norfolk Port and Baltimore Port, and the remaining 42 states are aggregated into a single region, giving a total of 9 regions which are defined below:

Region Number	State Name
1	Maryland
2	Virginia
3	West Virginia
4	Pennsylvania
5	Kentucky
6	Ohio
7	Tennessee
8	Illinois
9	Rest of U.S.A.

Multiregional input output models replicate the transactions among sectors and regions. There are 5 major categories of transactions data:

Interindustry Transactions - sales by one sector to another in the intermediate stages of production

Value Added - payments made for wages, management and to capital

Imports - purchases from foreign sources used for production of goods and services or for consumption

Final Demand - sales by each sector for consumption or capital formation

Exports - sales to foreign customers

In the transactions matrix, the sum of each row (interindustry and final demand) gives total gross output. The sum of each column (industry transactions and value added) gives total gross outlay. In balance, total outlays equal total outputs, and the model provides a complete description of an economy. A particular value of the use of input-output models is the industry detail they provide (as well as regional detail in multiregional models) and the capability to estimate direct and indirect economic impacts due to a change in final demand (which may include exports).

In matrix notation, the impact model is as follows:

$$\triangle X = (I-TA)^{-1}T\triangle Y$$

where:
X = Total Output,
I = Identity matrix,
T = Trade coefficient matrix,
A = Technical matrix, and
Y = Final demand

The multiregional input-output methodology used in this analysis is designed to evaluate the economic impact of one million tons of coal exported through Baltimore Port or Norfolk Port based on:

* Direct Sales by coal and transportation industries
* Total Output of all industries
* Value Added by all industries
* Employment

The major inputs to the model, expressed in 1977 prices for coal shipments by truck and rail to the Norfolk Port or Baltimore Port from each coal producing state in the 9-state region, are:

* Coal sales
* Associated transportation costs which include port costs, handling costs and vessel services

Although the model provides detail on 9 regions and 25 industrial sectors, the following discussion simplifies the presentation by emphasizing the 5 major states that ship coal through each port, and the remaining 45 states, depending on the port in question. The following sections summarize the results of the impact analysis.

3. FINAL DEMAND CHANGES

A shipment of coal increases the demand for goods and services throughout the United States, especially and primarily in the coal producing regions. The MRIO methodology is used to calculate the effects of producing and shipping a unit million tons of export coal through the Ports of Baltimore and Norfolk, respectively, by appropriately making changes in the final demand for the coal sector and the transportation sector. Coal

export tonnage for each port for the year 1986 (the most current export data available) expressed as million-ton units (24.177 million tons for Norfolk Port and 6.177 million tons for Baltimore Port) was multiplied by the corresponding unit million-ton impact factors for each port.

According to the most recent data available from the Norfolk and Baltimore Engineer Districts, the regional distribution of the coal sales through each port, in 1984 prices by originating state, is shown in Table 1.[3]

Table 1

REGIONAL DISTRIBUTION OF THE SOURCES OF THE EXPORT SHIPMENT OF ONE MILLION TONS OF COAL

PORT	MD	WV	PA	OTHER REGIONS	ALL
BALTO.	34.0%	38.5%	26.1%	1.4%	100.0%

PORT	VA	WV	KY	OTHER REGIONS	ALL
NORFOLK	37.0%	43.1%	17.1%	2.8%	100.0%

According to the same reference sources cited above, the regional distribution of the mine mouth prices per ton of export coal, in 1984 prices by originating state, is as shown in Table 2.

Generally, trucks haul coal to rail loading facilities and railroads transport the coal to each port. Ports add handling costs for transferring the coal to ships, fuel costs, and the cost of providing other services to the ships, to the average price of coal per ton. Rail costs are distributed according to the distance traveled in each state and handling costs are allocated to the port sector in each port state.

For the year 1980, it was estimated that truck conveyor and rail haul to the rail loading tipples cost $2 per ton and rail transportation costs to each port range from $14 to $15 per ton.[4] Port handling costs are estimated to be $0.75 per ton. The 1980 costs of fuel and supplies, provided by the port to coal-carrying ships, average $3.78 per ton of coal. Thus, the total 1980 port cost is$4.53 per ton, which is $5.58 per ton in 1984 prices.[5]

Average transportation costs for both ports add slightly more than $25.90 per ton to the $34.70 average mine mouth value per ton resulting in a total loaded-on-ship value of approximately $60.60 per ton of export coal in 1984 prices. The total U.S. transportation and handling costs for coal exported through Norfolk Port or Baltimore Port, are apportioned as follows:

Rail	75%
Port	18%
Truck	7%
Total	100%

Of course, the total costs per ton of coal to foreign customers will increase by the costs of the ocean voyage, unloading, and transhipment.

4. OUTPUT IMPACTS

The overall impact on output of shipping through Baltimore Port is $113.5 million per million tons of coal and $769.2 million for 6.778 million tons of coal. For Norfolk Port, the overall change in total output is $115.9 million per million tons of coals and $2,802.6 million for 24.177 million tons of coal.

Total industrial output impacts exceed the amount of direct sales to export coal customers by about 2 times. This multiplier effect is due mainly to the indirect impact on other industries of the purchases by the coal industry and the transportation industry. The multiregional input-output model solves directly the overall equilibrium impact of the sequence of rounds of interindustry impacts.

Economic impacts accruing to states other than Maryland, Virginia, West Virginia, Kentucky, and Pennsylvania (the states primarily involved in production and transportation of coal) are about 25% or more of the total increase in output attributable to export of coal through either port.

Table 2

REGIONAL DISTRIBUTION OF MINE MOUTH
PRICES PER TON AND MINE MOUTH VALUE OF ONE MILLION TONS OF EXPORT COAL

Mine Mouth Prices Per Ton Through (1984 Prices)

PORT OF BALTO.	MD	WV	PA	OTHER REGIONS	ALL REGIONS
	$30.43	$37.29	$32.43	$36.09	$33.67

PORT OF NORFOLK	VA	WV	KY	OTHER REGIONS	ALL REGIONS
	$36.76	$37.12	$30.71	$31.25	$35.73

Mine Mouth Value Of A Million Tons Through (Millions of 1984 Dollars)

PORT OF BALTO.	MD	WV	PA	OTHER REGIONS	ALL REGIONS
	$10.35	$14.36	$8.47	$0.51	$33.67

PORT OF NORFOLK	VA	WV	KY	OTHER REGIONS	ALL REGIONS
	$13.60	$16.00	$5.25	$0.88	$35.73

Table 3

REGIONAL DISTRIBUTION OF THE TOTAL MINE-TO-LOADED-ON-SHIP TRANSPORTATION COST AND VALUE OF ONE MILLION TONS OF EXPORT COAL

(Millions of 1984 Dollars)

Total Mine-To-Loaded-On-Ship Transportation Cost Of A Million Ton Export Shipment

PORT OF BALTO.	MD	WV	PA	OTHER REGIONS	ALL REGIONS	PORT OF NORFOLK	VA	WV	KY	OTHER REGIONS	ALL REGIONS
Rail	12.39	4.78	0.90	0.12	18.19	Rail	12.13	4.72	0.87	0.12	17.85
Truck	0.79	0.89	0.64	0.03	2.35	Truck	0.85	0.99	0.40	0.07	2.31
Port	5.58	NONE	NONE	NONE	5.58	Port	5.58	NONE	NONE	NONE	5.58
Total	18.76	5.68	1.54	0.15	26.12	Total	18.57	5.72	1.27	0.19	25.74
	71.8%	21.7%	5.9%	0.6%	100.0%		72.1%	22.2%	4.9%	0.7%	100.0%

Total Mine-To-Loaded-On-Ship Value Of A Million Ton Export Shipment

PORT OF BALTO.	MD	WV	PA	OTHER REGIONS	ALL REGIONS	PORT OF NORFOLK	VA	WV	KY	OTHER REGIONS	ALL REGIONS
MM Val.	10.35	14.36	8.47	0.51	33.67	MM Val.	13.60	16.00	5.25	0.88	35.73
Transp.	18.76	5.68	1.54	0.15	26.12	Transp.	18.57	5.72	1.27	0.19	25.74
Total	29.11	20.03	10.00	0.66	59.80	Total	32.17	21.71	6.52	1.06	61.47
	48.7%	33.5%	16.7%	1.1%	100.0%		52.3%	35.3%	10.6%	1.7%	100.0%

Depending upon the economic (structural) composition of each state, indirect impacts vary, since different sectors have varying multipliers.

5. VALUE ADDED IMPACTS

Value added is a fundamental indicator of the benefits attributable to economic impacts. Value added represents returns (payments) to employees, managers, and capital investments due to increased output. Additions to value-added total $63.14 million per year per million tons of coal exported through Norfolk port and $62.96 million when exported through Baltimore port. The corresponding value added totals for the 1986 traffic are $1,526.6 million for 24.177 millions tons through Norfolk Port and $426.8 million for 6.778 million tons through Baltimore Port. The major impact states (Maryland, Virginia, West Virginia, and Pennsylvania) receive about 80 percent of the value added for shipment through either port.

6. EMPLOYMENT IMPACTS

Export coal provides jobs in coal mining, transportation, and other industries. Estimates of the full time equivalent job impacts are shown in the following table. In the 9 regions, based on the $60.60 average loaded-on-ship coal value per ton in 1984 prices, the million-ton shipment of export coal through the Norfolk port will generate 1,089 jobs, and through the Baltimore port will generate 1,066 jobs. In terms of the 1986 export traffic data, the employment impacts are 26,323 person-years for export shipment of 24.177 million tons of coal through Norfolk Port and 7,228 person-years for export shipment of 6.778 million tons of coal through Baltimore Port.

The 23-job difference in the employment totals (about 2% of either total) for the unit million-ton shipment, is well within the margin of error for this type of analysis. Such differences in total employment, if actual, would be due to the differences in the output-per-employee estimates for the transportation and manufacturing sectors in the impact states. Since we do not know the actual routes of the coal from the mines to the ports, however, we also do not know the actual aggregation of employment impacts that are attributable to the transportation sectors of the impact states along the routes of the component shipments. Consequently, the lack of detail in the transportation input data necessitates our viewing the 23-job difference as being too small to give either port an actual employment advantage. We suggest that the actual employment impact stemming from the difference in the total employment generated by a unit million-ton shipment through each port is likely to be much smaller.

7. IMPACTS BY INDUSTRY SECTOR

Where, one may inquire, besides the direct impacts on coal mining and transportation sectors, do the impacts accrue? For shipment through Norfolk Port, about 35 percent of the total employment

Table 4

REGIONAL DISTRIBUTION OF FINAL DEMAND CHANGE IMPACTS LARGER THAN THREE PERCENT STEMMING FROM EXPORT COAL SHIPMENTS THROUGH BALTIMORE PORT AND NORFOLK PORT

(USA Total Impacts In 1984 Prices And Person-Years)

REGION	OUTPUT	VAL ADD	INCOME	EMPLOYMENT
One Million Tons Through Baltimore Port				
	$Millions			Person-yrs
MD	39.01	23.80	13.12	443.3
WV	28.94	16.64	9.97	257.7
PA	17.06	8.85	5.17	142.8
REST/SHED	6.74	3.21	1.71	62.4
REST/USA	21.72	10.46	3.55	160.2
Total	113.48	62.96	33.51	1,066.4
	Percentage Analysis			
MD	34.4%	37.8%	39.2%	41.6%
WV	25.5%	26.4%	29.7%	24.2%
PA	15.0%	14.1%	15.4%	13.4%
REST/SHED	5.9%	5.1%	5.1%	5.8%
REST/USA	19.1%	16.6%	10.6%	15.0%
Total	100.0%	100.0%	100.0%	100.0%
6.778 Million Tons Through Baltimore Port				
	$Millions			Person-yrs
MD	264.44	161.32	88.96	443.3
WV	196.19	112.82	67.55	257.7
PA	115.64	60.01	35.01	142.8
REST/SHED	45.71	21.74	11.59	0.0
REST/USA	147.23	70.89	24.03	160.2
Total	769.21	426.77	227.15	1,066.4

REGION	OUTPUT	VAL ADD	INCOME	EMPLOYMENT
One Million Tons Through Norfolk Port				
	$Millions			Person-yrs
VA	43.42	24.76	14.87	476.5
WV	31.21	17.92	10.69	274.5
KY	10.13	5.67	2.99	84.0
REST/SHED	8.95	4.15	2.37	85.4
REST/USA	22.21	10.64	3.72	168.4
Total	115.92	63.14	34.64	1,088.8
	Percentage Analysis			
VA	37.5%	39.2%	42.9%	43.8%
WV	26.9%	28.4%	30.9%	25.2%
KY	8.7%	9.0%	8.6%	7.7%
REST/SHED	7.7%	6.6%	6.8%	7.8%
REST/USA	19.2%	16.8%	10.7%	15.5%
Total	100.0%	100.0%	100.0%	100.0%
24.177 Million Tons Through Norfolk Port				
	$Millions			Person-yrs
VA	1,049.70	598.60	359.42	11,520.4
WV	754.70	433.24	258.45	6,637.0
KY	244.88	137.19	72.30	2,030.2
REST/SHED	216.37	100.42	57.26	2,063.8
REST/USA	536.95	257.18	90.02	4,072.0
Total	2,802.60	1,526.63	837.46	26,323.3

impacts are in sectors other than coal mining and transportation, about 31 percent of total value added impacts are in the other sectors, and about 35 percent of total output impacts are in the other sectors. Table 5 provides greater detail on total output shares by sector and port.

8. FINDINGS

Exporting coal through the Ports of Baltimore and Norfolk generates direct impacts in the 5 regions which are major coal producing states and indirect impacts in all regions. Differences in the indirect impacts are due to trade and production patterns. The largest impacts are induced in the states which produce coal and provide transportation and port handling of cargo. Overall impacts, however, are significant in other regions of the United States. The port states receive about 35 percent or more of all of the impacts, while West Virginia receives more than 25 percent of all impacts attributable to shipment through either port. Non-coal-producing states receive over 20 percent of the output impacts.

Generally, we recommend that one should be cautious in extending these preliminary results. Although our knowledge of the sources, quantities, and prices of the coal shipped through each port appears quite good, we must emphasize that we have virtually no information concerning the actual routes of the coal from the mines to the ports. To the extent, from a theoretical perspective, that the data on the coal shipments and associated transportation costs used in this analysis reflect the actual tonnages and associated transportation costs of specific component shipments from source-region to port, we find it appropriate to attribute the attendant impact differences to the differences in the output-per-employee estimates.

Calculation of employment totals, the natural basis of the difference in employment totals, is dependent in part upon the output-per-employee

Table 5

SECTORAL DISTRIBUTION OF FINAL DEMAND CHANGE IMPACTS LARGER THAN THREE PERCENT STEMMING FROM EXPORT COAL SHIPMENTS THROUGH BALTIMORE PORT AND NORFOLK PORT

(USA Total Impacts In 1984 Prices And Person-Years)

INDUSTRY	OUTPUT	VAL ADD	INCOME	EMPLOYMENT
One Million Tons Through Baltimore Port				
	$Million			Person-yrs
Coal Min'g	40.17	23.01	12.34	268.8
Crude Pet.	5.96	4.48	0.50	20.1
Pet.Refin.	6.31	0.87	0.23	6.4
Trans/Com.	32.94	20.56	13.24	430.2
FIRE/Serv.	8.16	5.42	2.14	138.5
All Other	19.94	8.62	5.05	202.5
Total	113.48	62.96	33.51	1,066.4
	Percentage Analysis			
Coal Min'g	35.4%	36.5%	36.8%	25.2%
Crude Pet.	5.3%	7.1%	1.5%	1.9%
Pet.Refin.	5.6%	1.4%	0.7%	0.6%
Trans/Com.	29.0%	32.7%	39.5%	40.3%
FIRE/Serv.	7.2%	8.6%	6.4%	13.0%
All Other	17.6%	13.7%	15.1%	19.0%
Total	100.0%	100.0%	100.0%	100.0%

INDUSTRY	OUTPUT	VAL ADD	INCOME	EMPLOYMENT
One Million Tons Through Norfolk Port				
	$Millions			Person-yrs
Coal Min'g	42.19	23.61	12.96	282.3
Crude Pet.	5.70	4.28	0.48	19.2
Pet.Refin.	5.96	0.81	0.20	6.0
Trans/Com.	32.32	19.67	13.49	422.1
FIRE/Serv.	8.42	5.56	2.14	142.8
All Other	21.32	9.21	5.36	216.3
Total	115.92	63.14	34.64	1,088.8
	Percentage Analysis			
Coal Min'g	36.4%	37.4%	37.4%	25.9%
Crude Pet.	4.9%	6.8%	1.4%	1.8%
Pet.Refin.	5.1%	1.3%	0.6%	0.6%
Trans/Com.	27.9%	31.2%	39.0%	38.8%
FIRE/Serv.	7.3%	8.8%	6.2%	13.1%
All Other	18.4%	14.6%	15.5%	19.9%
Total	100.0%	100.0%	100.0%	100.0%

INDUSTRY	OUTPUT	VAL ADD	INCOME	EMPLOYMENT
6.778 Million Tons Through Baltimore Port				
	$Millions			Person-yrs
Coal Min'g	272.28	155.94	83.66	1,821.6
Crude Pet.	40.41	30.39	3.41	136.2
Pet.Refin.	42.76	5.90	1.55	43.2
Trans/Com.	223.27	139.38	89.77	2,916.0
FIRE/Serv.	55.33	36.72	14.51	938.4
All Other	135.16	58.43	34.24	1,372.5
Total	769.21	426.77	227.15	7,228.0

INDUSTRY	OUTPUT	VAL ADD	INCOME	EMPLOYMENT
24.177 Million Tons Through Norfolk Port				
	$Millions			Person-yrs
Coal Min'g	1,020.17	570.81	313.33	6,825.1
Crude Pet.	137.72	103.60	11.62	464.2
Pet.Refin.	144.09	19.53	4.84	145.5
Trans/Com.	781.50	475.58	326.26	10,206.1
FIRE/Serv.	203.60	134.40	51.83	3,453.0
All Other	515.52	222.71	129.58	5,229.4
Total	2,802.60	1,526.63	837.46	26,323.3

estimates in the sectors of the impacted regions. Actual employment totals would also be based on detail actual transportation data that show the actual routes of coal shipments from mines to ports. Data on actual routes of component shipments would be used to aggregate actual transportation costs and derive actual transportation cost totals.

The significance of this lack of detailed transportation data is apparent in the example in which the export of a million tons of coal through Norfolk Port generates an estimated total employment that is 23 full-time jobs larger than the estimated total employment stemming from the export of a million tons coal through Baltimore Port. Additionally, please remember that the 23-job difference is approximately two percent of the total employment impact of a million-ton coal shipment through either port; therefore, it is an estimate that is well within the margin of error for this type of analysis. Consequently, our lack of access to detailed transportation input data also necessitates our reiterating our opinion that the 23-job difference (for the unit million-ton basis or the 1986 actual tonnage basis) is too small to be significant.

Even without the benefit of detailed transportation data, however, it is apparent that the MRIO methodology can be used to readily quantify (at least in relative orders of magnitude when detail transportation data are unavailable) the interdependence (expressed as economic impacts) of all states in the U.S. economy when a bulk commodity is exported through an American port.

ENDNOTES

[1]Economists in the Navigation Analysis Division at the U.S. Army Engineer Institute for Water Resources, Fort Belvoir, Virginia 22060-5586; telephone: (202) 355-2240.

[2]Due to a paucity of data and time, technologies from different years were consciously aggregated to derive results that are primarily useful as indicators of relative orders of magnitude. When detailed data on actual transportation costs, for specific shipments of export coal from mine to port, become available, results which are more definitive will be produced.

[3]Booz Allen and Hamilton, Transporting Export Coal from Appalachia, a report prepared for the U.S. Department of Energy (November 1982).

[4]Ibid., November 1982.

[5]Siberman and Yochums, The Economic Impact of Virginia's Ports on the Commonwealth.

Interpretation of SEASAT Radar Altimeter Returns from An Overflight of Ice in the Beaufort Sea

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ABSTRACT

SEASAT radar altimeter data are examined for the effects of sea ice on the returns during an overflight of the Beaufort Sea. Waveform parameters and their statistics are combined to form a parameter sensitive to the presence of sea ice. Variations in the value of this ice parameter are compared with ice charts obtained from the Canadian Atmospheric Environment Service. Particular attention is paid to the sensitivity of the radar altimeter to the open-ocean sea ice boundary.

INTRODUCTION

The satellite-borne microwave radar altimeter is an all-weather high-resolution instrument. Estimates of surface roughness and variations in surface topography are determinable from the returned-pulse waveforms. Figure 1 illustrates the expected waveform from the ocean surface as determined by rough-surface scattering, based on specular point theory [*Barrick*, 1972]. In the figure, gate number 0 defines the mean surface position; for ocean returns, this is approximately at the half-power point of the waveform. Gate numbers less than 0 are indicative of ranges closer to the radar and therefore above the mean surface level. Gate numbers greater than 0 indicate ranges farther from the radar, and signals in these gates come from off-nadir reflections (and also from below the mean surface level in the presence of waves). The rise-time parameter of the leading edge, t_p, is a function of rms elevation (height roughness). This time constant is defined to be

$$t_p = \frac{2}{c}\sqrt{\chi_w^2 + 2h^2} \qquad (1)$$

where c is the speed of light, $\chi_w = c\tau/[4(\ln 2)^{1/2}]$, τ is the transmitted (compressed) pulsewidth, and h is the rms surface elevation; for SEASAT $\chi_w \sim 28$ cm.

† On assignment at the NOAA/ERL Wave Propagation Laboratory

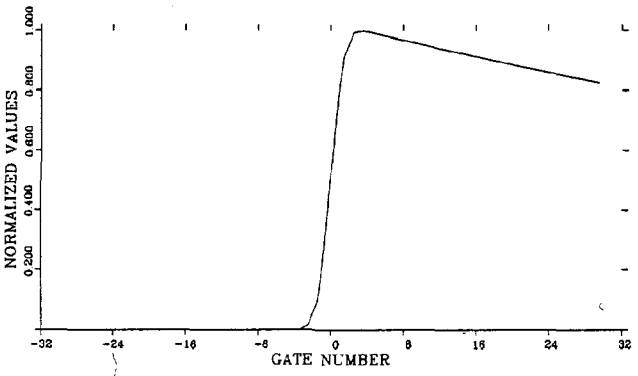

Figure 1. Modeled radar altimeter waveform response to ocean waves. SEASAT parameters were used for input. The significant wave height used was 2 m.

t_p is a function of the radar characteristics and the surface height roughness but not the altitude of the instrument above the surface. The time constant of the trailing edge-decay of the waveform, t_s, is the two-way time of flight difference between the suborbital point and the edge of the effective scattering region:

$$t_s = \frac{2H}{c}\psi_e^2 \qquad (2)$$

where H is the effective height of the instrument above the surface, $1/\psi_e^2 \sim [(8\ln 2)/\psi_B^2] + [1/s^2]$, ψ_B is the half-power beamwidth of the radar antenna, and s is the rms surface slope. For most ocean returns $s > \psi_B$ so that $\psi_e \sim \psi_B/\sqrt{8\ln 2}$ and t_s is nearly constant. For the SEASAT altimeter, $\psi_e \sim s$ when $s \leq 0.003$ radians. Since $s \sim 0.07$ for an open-ocean local wind of 1 m/s [*Fedor and Brown*, 1982] the surface winds would have to be virtually nonexistent before the altimeter waveform would exhibit a response in t_s significantly smaller than that determined solely by the beamwidth.

The functional form of the received power from a

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rough surface, to first order, is given as [*Fedor et al.*, 1979]

$$P_R(t) = K\frac{\lambda_0^2}{H^4}[2\pi^{3/2}\chi_w H\frac{|R_R(0)|^2}{s^2}\mathcal{F}(t)] \qquad (3)$$

where K contains the radar constants including the transmitted power and antenna gain; λ_0 is the radar wavelength; χ_w, H, and s have been defined previously; $|R_R(0)|^2$ is the rough-surface Fresnel reflection coefficient; and

$$\mathcal{F}(t) = [1 + \mathrm{erf}(\frac{t}{t_p})]\exp(-\frac{2t}{t_s})$$

is the waveform function with a value of ~ 2 at its maximum. The parameters t_p and t_s are described earlier, and $\mathrm{erf}(x)$ is the error function with argument x. The surface effect on the magnitude of the received power is primarily influenced by the average backscatter cross section per unit area at normal incidence, $\sigma^0 = (|R_R(0)|^2)/s^2$. We concentrate our discussion on the surface effects of sea ice on σ^0, t_p, and t_s.

Altimeter Returns from Sea Ice

Earlier studies note that radar returns from sea ice are characterized by narrow waveforms and by greater signal strength than returns from ocean waves [*Brown*, 1982; *Dwyer and Godin*, 1980]. From the previous discussion we note that the waveforms may be made more narrow relative to ocean returns by reducing the slope roughness of the surface. In the extreme, assume that the surface is perfectly smooth. Then the power received at the radar will have the form

$$P_I = K\frac{\lambda_0^2}{H^4}[\pi H^2|R_I(0)|^2] \qquad (4)$$

where $|R_I(0)|^2$ is the Fresnel reflection coefficient of the smooth surface, and all other parameters are as defined previously. Thus, the signal is returned to the radar as if reflected from a smooth sphere of radius H, the shape of the returned pulse being the same as the transmitted pulse. In contrast to ocean returns, note that the position on the waveform for locating the range to the surface occurs at the maximum of the return rather than near the half-power point.

Figure 2 illustrates the interaction of the radar pulse with a smooth surface. The top of the figure shows the vertical plane, with sixteen positions of the spherically expanding pulse indicated, as it advances toward the surface. The position at which the pulse just begins to interact with the surface is blackened. The vertical scale is magnified by a factor of 400 with respect to the cross-track scale, and the apparent off-nadir angles are correspondingly distorted. The bottom of the figure shows a plan view of the area illuminated by the pulse for two of the pulse positions indicated above.

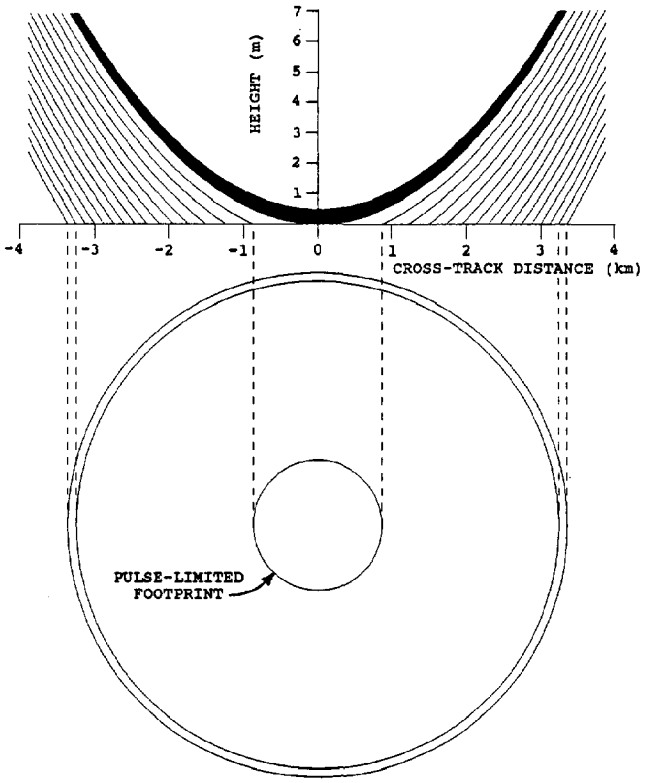

Figure 2. Top: Schematic of a radar altimeter pulse advancing toward a smooth surface. The pulse (blackened) is just beginning to reach the surface. The vertical scale is magnified by a factor of 400 relative to the cross-track scale, so the incidence angles are distorted. Bottom: Plan view of the area illuminated by the pulse.

Only those portions of the pulse that are incident on facets of the surface oriented normal to the direction of propagation are reflected back to the radar. This occurs only at the nadir point for a perfectly smooth surface. Any off-nadir returns require that the surface be tilted toward the radar. If we define $\mathcal{M}$ as the ratio of power received from a smooth surface to the power received from an ocean surface at the waveform maximum, then

$$\mathcal{M} = \frac{\sigma_s^0}{\sigma^0} \qquad (5)$$

where

$$\sigma_s^0 = \frac{H}{2\pi^{1/2}\chi_w}|R_I(0)|^2 .$$

Using SEASAT values, we find $H \sim 800$ km and $\chi_w \sim 28$ cm, and the coefficient multiplying $|R_I(0)|^2$ is 59 dB. For the open ocean the Fresnel reflection

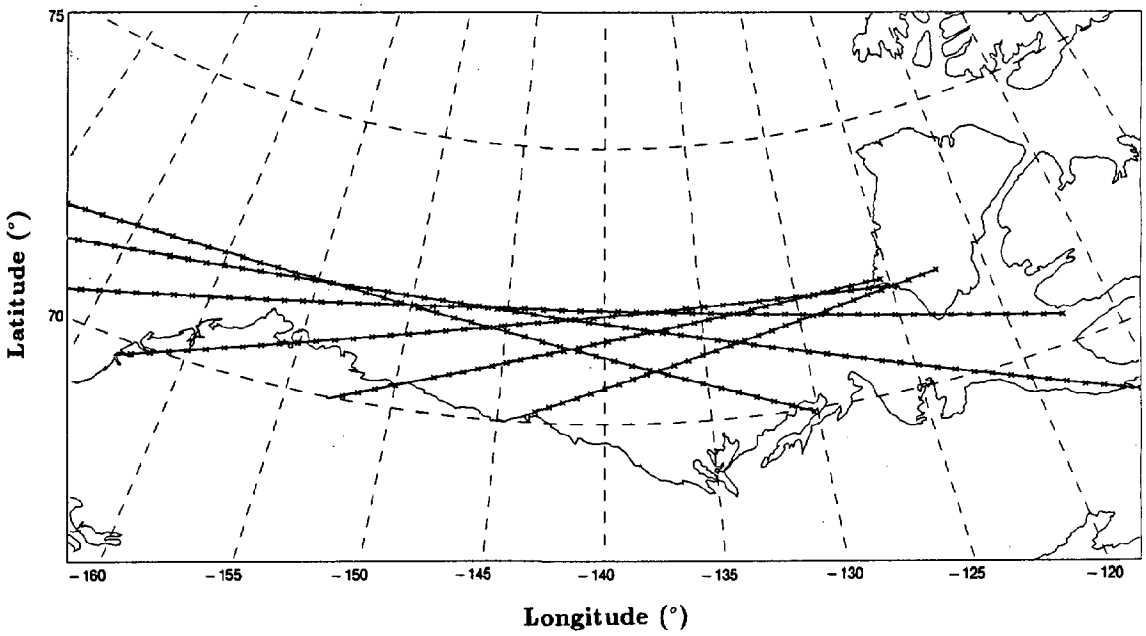

Figure 3. SEASAT 3-day repeat suborbital tracks for the Beaufort Sea. The tracks are limited to less than 72°N by the orbit inclination angle.

coefficient is approximately −2.1 dB. If we use 0.005 as the value for s^2 (for surface winds $\sim$ 1 m/s)the average backscatter cross section per unit area is about 21 dB. Thus, even for a poor reflector such as first-year sea ice, which has a Fresnel reflection coefficient of −11 dB [*Brown*, 1982], a smooth surface will greatly enhance the returned power; that is, $\mathcal{M} \sim 27$ dB.

To explain the appearance of the waveform shape and its magnitude the radar returns from sea ice indicate that there must be a high probability of flat surfaces at the satellite subpoint [*Brown*, 1982]. Off-nadir returns would result if portions of the surface were rough and/or if there were flat surfaces tilted toward the radar. Using parameters that are estimated routinely during processing of over-ocean radar returns, we define an ice parameter $\mathcal{I}$, that is sensitive to the non-ocean-surface response expected from a surface with sea ice present. The quantity $\mathcal{I}$ is given as

$$\mathcal{I} = 100 \frac{t_p}{t_s} \frac{S_P}{P} \sigma^0_{max} \qquad (6)$$

where S_P is the standard deviation of five waveform values, beginning with the waveform maximum, about their mean value P; σ^0_{max} is the average backscatter cross section estimated at the waveform maximum; t_s and t_p are as defined earlier; and the coefficient 100 is a scaling factor. This quantity $\mathcal{I}$ is responsive to flat surfaces both through the ratio t_p/t_s and through the relative standard deviation S_P/P. The value for σ^0_{max} in decibels is used in the computation.

SEASAT Data Over Sea Ice

During the last month of its lifetime SEASAT was in a 3-day repeat-orbit mode. In this period, from the end of September to the middle of October 1978, we obtained several data sets over the Beaufort Sea. Figure 3 shows the Beaufort Sea area and the SEASAT suborbital tracks for this repeat-orbit period. Since the radar altimeter is a nadir-looking instrument, the tracks also are indicative of the altimeter coverage of the Beaufort Sea. Although this results in large areas where there is no data coverage, the radar altimeter can still provide a cost-effective means for long-term monitoring of sea ice dynamics by providing detailed information over the same set of ground tracks every few days.

We selected SEASAT radar altimeter data from orbit number 1439 obtained on 5 October 1978 to illustrate the effects of sea ice on the radar returns. In Figure 4, we show a schematic of the ice conditions on this day that was derived from ice charts compiled by the Canadian Atmospheric Environment Service. The region marked as new ice, extending from Banks Island in the east to approximately Point Barrow in the west, is no more than a week old. The ice chart compiled in the previous week, dated 28 September (not shown), indicates that this whole region is open water. Superimposed on the ice chart is the satellite suborbital track. The middle part of the track is over

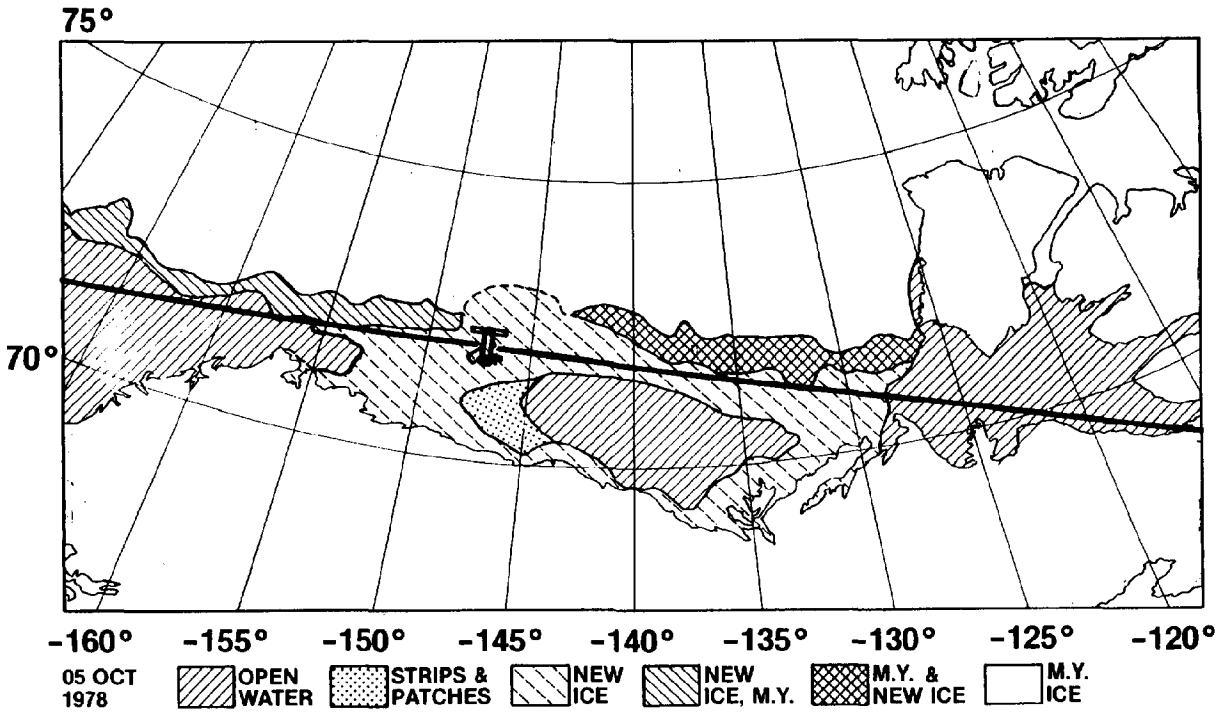

Figure 4. Schematic of the Canadian Atmospheric Environment Service ice chart for 5 October 1978. Solid diagonal hatching is new ice with some multiyear ice present. Cross-hatching is multiyear ice with some new ice present. Superimposed on the chart is the SEASAT suborbital track for orbit 1439.

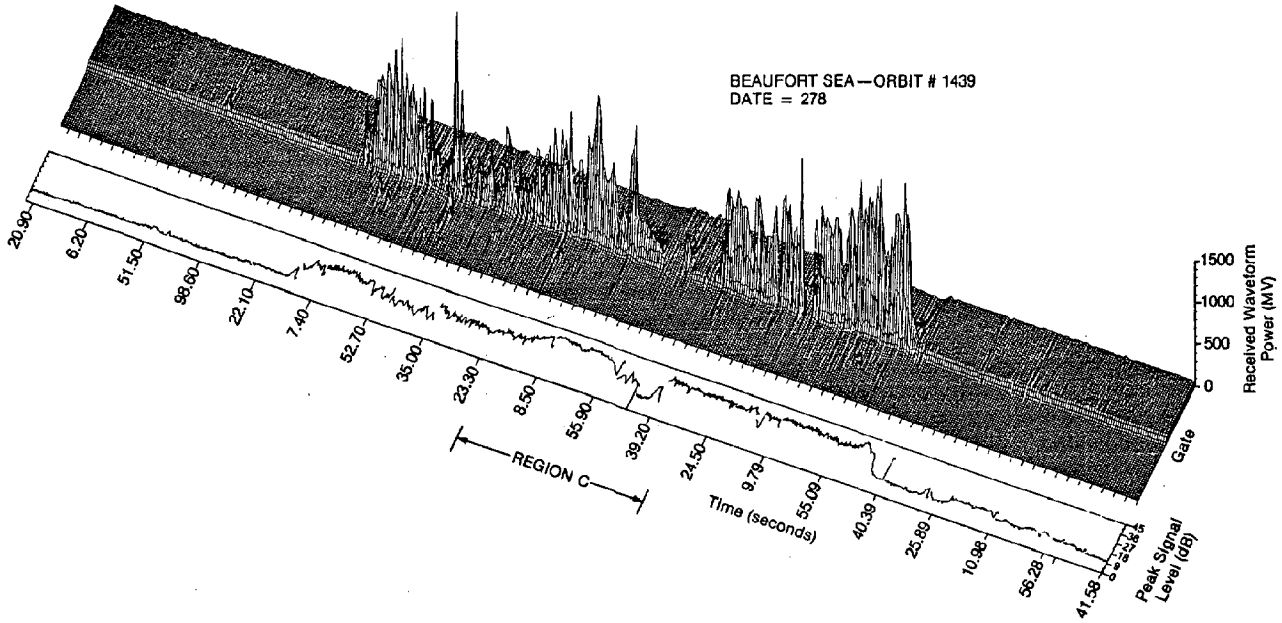

Figure 5. Three-dimensional radar altimeter waveform plot for orbit 1439. Time (in seconds after the beginning time of 1528:41.58 GMT) increases from right to left. Radar range increases toward the upper right hand corner of the figure. Below the waveforms is a reference plot of σ^0_{max}.

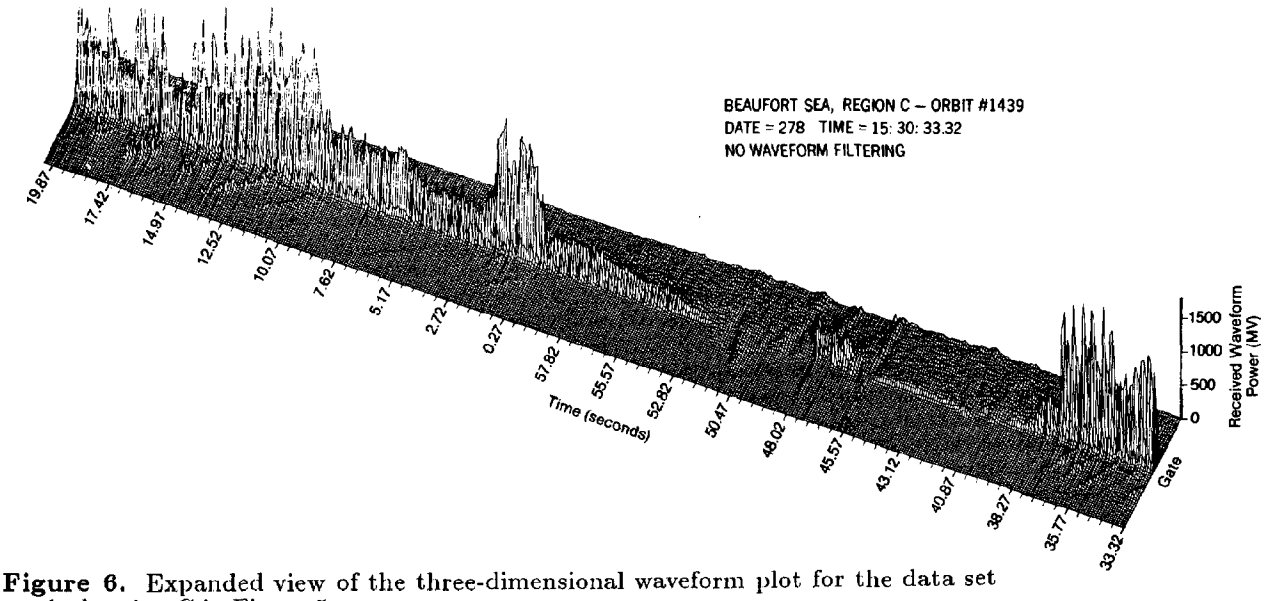

Figure 6. Expanded view of the three-dimensional waveform plot for the data set marked region C in Figure 5.

this new ice region, whereas the parts of the track over the Amundsen Gulf and the Chukchi Sea are mostly open water.

The presence of sea ice in the radar altimeter signals is clearly demonstrated in Figure 5, which shows a three-dimensional plot of the altimeter waveforms as a function of time. The time axis is labeled in seconds after the beginning time of 1528:41.58 GMT, with time increasing from lower right to upper left. Each waveform used in the plot represents 100 pulses averaged on board the satellite. The waveform sampling time is approximately every 0.1 s. The axis labeled Gate represents the position of the waveform sampling gates; the center of the axis denotes the mean surface level. Increasing range from the radar follows the axis toward the upper right side of the figure. The power in the gates is plotted on the vertical axis. As mentioned previously, the first and last minutes of data are open-ocean returns. The waveforms in these regions are as shown in Figure 1. Their amplitudes are relatively small because of the vertical scale that was necessary to accommodate the over-ice returns dominating the center of the figure. Each waveform is normalized to have equal area, to prevent overwhelming of the over-ocean waveforms by the over-sea-ice waveforms. This feature is demonstrated more clearly in the plot of σ^0_{max} along the bottom of the figure. The over ice returns are at the 40 dB level whereas the over water returns are at the 10 dB level. The waveform shape about the maximum for the over ice returns is much as we described previously for a smooth surface. Still, the off-nadir returns visible behind the maxima are not negligible. The reduced levels, to around 25-30 dB, at 1531:35.00 GMT are probably due to the presence of multiyear floes (see Figure 4).

Other features in Figure 5 can be seen more clearly in the expansion of the area labeled region C (Figure 6). There are numerous regular patterns of apparent signals that appear above the mean surface level (at lower gates) that decrease in radar range as a function of time. These signals are a result of the sampling filter gate response to the strong sharp signal (John L. MacArthur, The Johns Hopkins University, Applied Physics Laboratory, private communication) and are not a physical phenomenon. However, although there is a feature occurring at 1530:51 GMT where smooth ice is not present (no strong main return), there is a signal beginning some 17 gates above the surface (8.0 m). The along track extent of this feature is about 0.8 s (5.28 km). We believe that this feature is a large ice island sensed by the altimeter. The ice island T-3, northwest of Banks Island, was observed by the SEASAT Synthetic Aperature Radar on orbit 1438 (W. J. Campbell, United States Coast and Geodetic Survey, private communication). Other features in this mixture of sea ice and open water extending a few gates above mean surface level are inferred to be multiyear floes. The features at 1530:45.57 and 1530:48.02 are data dropouts.

Ice Parameter

A test of the proposed ice parameter's response to sea ice is shown in Figure 7. For reference, the average backscatter cross section is plotted above the satellite suborbital track and $\mathcal{I}$ is plotted below the track. The maximum value for $\mathcal{I}$ on the plot is 2000. The over-open-water values are less than 10.

We refer to the right-hand portion of the figure, where sea ice is first encountered. We note that σ^0_{max} increases in value before there is a corresponding response in $\mathcal{I}$. Comparison of σ^0_{max} with the waveform

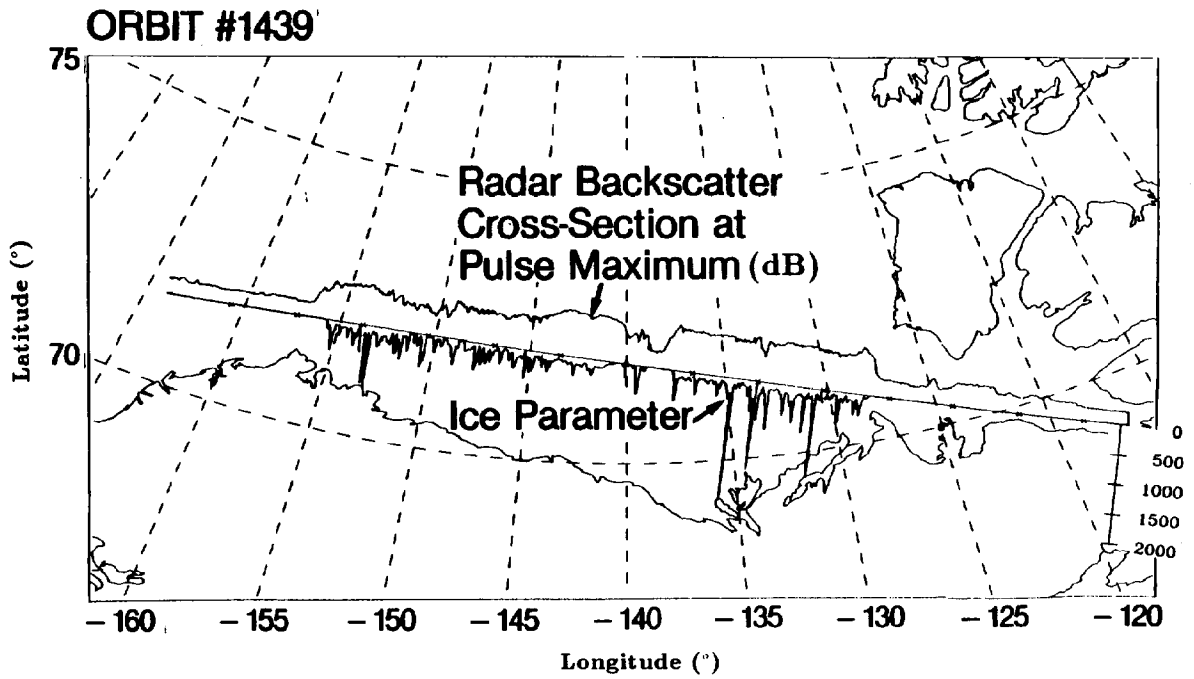

Figure 7. Calculated ice parameter $\mathcal{I}$ for orbit 1439 (plotted below the track). σ^0_{max} is plotted above the track for reference.

plot in Figure 5 shows a similar behavior; that is, the waveform shape is similar to a normal open-water response. Furthermore, the response of $\mathcal{I}$ agrees well with the ice chart in Figure 4. Either, the surface near the ice edge is calm relative to the open ocean earlier in the track, or there are an insufficient flat surfaces oriented toward the radar to compensate for a water-dominated mixture. From this point until the track crosses 138°W longitude, the surface is dominated by very flat structure. This is indicated by the large values of $\mathcal{I}$ as well as the high values in σ^0_{max}. Next there is an open- water area clearly marked by both altimeter parameters and the waveforms. The satellite suborbital track is well away from the open-water region indicated on the ice chart. We believe that the altimeter correctly "sees" open water and that this difference from the ice chart is indicative of the dynamic conditions of the region. The ice charts are composited from a series of aircraft reconnaissance flights during the week prior to the given date. These aircraft flights are similar to the the 3-day repeat-tracks shown in Figure 3, but more restricted in extent and duration. Since the flight track data is than interpolated in order to complete the charts it is reasonable to expect that their accuracy would not be sufficent for our purposes. Other ground truth that would be available is Landsat imagery but that was not pursued at this time.

Beyond this open-water region is evidence of the multiyear floes discussed previously. From 144°W to 155.5°W the altimeter parameters are again indicative of ice. Now, however, the character of $\mathcal{I}$ is different, without large excursions, but having a more rapid variation along track; σ^0_{max} is also reduced in magnitude. These characteristics are all indicative of rougher surface conditions but with a considerable number of flat surfaces. In contrast to results in the ice chart, the altimeter responses west of 155.5°W indicate that the ice did not extend down to the satellite track.

Concluding Remarks

The ice parameter $\mathcal{I}$, as defined here,provides a reasonable estimator of the presence of sea ice in the returned radar altimeter signals. It is empirically based on the waveform shape and magnitude expected of returns from a linear combination of smooth and rough surfaces. It is expected that, as the ice undergoes stresses and rafting, surface tilting will enhance or degrade the returns. Hummocking will further reduce the number of reflecting facets as the ice grows older even though weathering smooths the rough edges. We have shown data suspected of indicating multiyear ice; here the signal signature is sufficiently different from the expected open ocean response to give a significant value for $\mathcal{I}$. The major limitation of the discussion is lack of high-quality ground-truth. The ice charts are valuable but lack the unique one-to-one evidence that is needed.

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References

Barrick, D.E., Remote sensing of sea state by radar, Chapter 12, *Remote Sensing of the Troposphere*, edited by V.E. Derr, NOAA Wave Propagation Laboratory, Boulder, Colo., 1972.

Brown, G.S., A theory for near-normal incidence microwave scattering from first-year sea ice, *Radio Sci., 17*, 233-243, 1982.

Dwyer, R.E., and R.H. Godin, Determining sea-ice boundaries and ice roughness using GEOS-3 altimeter data, *NASA Contract Rep. CR-156862*, 1980.

Fedor, L.S., and G.S. Brown, Waveheight and wind speed measurements from the SEASAT radar altimeter, *J. Geophys. Res., 87*, 3254-3260, 1982.

Fedor, L.S., T.W. Godbey, J.F.R. Gower, R. Guptil, G.S. Hayne, C.L. Rufenach, and E.J. Walsh, Satellite altimeter measurements of sea state–An algorithm comparison, *J. Geophys. Res., 84*, 3991-4002, 1979.

Airborne Pulse-Limited Radar Altimeter Return Waveform Characteristics Over Ice in the Beaufort Sea

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Abstract

Pulse-limited radar data taken in March 1978 with the 13.9 GHz AAFE altimeter from 1500 m altitude over ice in the Beaufort Sea are registered to high quality photography. The variations of the radar return waveform shape and signal level are correlated with the variation of the ice type determined from photography.

Introduction

During mid-March 1978, the NASA C-130 aircraft was deployed to Eielson Air Force Base in Fairbanks, Alaska, to make a series of flights over ice in the Beaufort Sea. The radar altimeter data analyzed here were obtained northeast of Mackenzie Bay on March 14th in the vicinity of 69.9°N, 134.2°W (Fig. 1). The data were taken with a 13.9 GHz radar altimeter developed under the NASA Advanced Applications Flight Experiments (AAFE) Program [Hughes Aircraft Company, 1976]. This airborne radar was built as a forerunner of the SEASAT radar altimeter and utilized the same pulse compression technique. It has the same pulse compression ratio (1000 : 1) as the SEASAT altimeter and approximately the same range resolution (0.417 m versus 0.469 m for SEASAT). One significant difference was that the AAFE altimeter has only 24 range gates instead of the 60 that SEASAT had.

AAFE Altimeter Return Waveforms

In the two flight lines analyzed in this paper, the aircraft altitude deviated only about 1 m from its mean value (1524 m and 1566 m). The top of Fig. 2 shows the position in space occupied by a radar pulse (darkened region) transmitted from 1545 m altitude just as it begins interacting with a flat sea surface. Also indicated are the next 12 positions that the transmitted pulse sequentially occupies at time

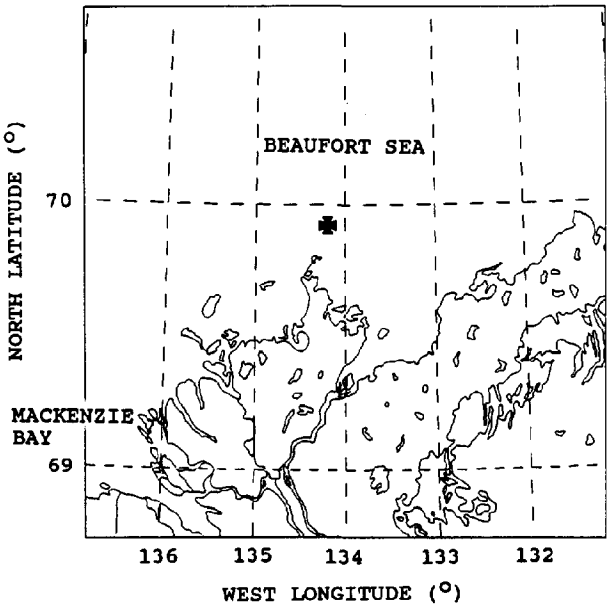

Figure 1. Region (indicated by the formée cross) of the AAFE altimeter data acquisition March 14, 1978.

intervals equal to the pulse duration as it spherically expands within the antenna pattern.

The bottom of Fig. 2 shows a plan view of the area illuminated on the flat surface for two of the pulse positions. As the pulse advances from the darkened position to the next one, the illuminated area increases from zero to its maximum value and thereafter remains constant. As the pulse continues to advance, the illuminated area becomes an annulus, which increases in radius but narrows in width, the two trends compensate to maintain the illuminated area equal to that of the pulse-limited circle.

If the range to the mean surface is in its nominal position, centered in the 24 range gates of the AAFE altimeter, then only the last 12 gates (indicated in Fig. 2) would probe a flat surface. It is apparent from Fig. 2 that under these circumstances the maximum

† On assignment at the NOAA/ERL Wave Propagation Laboratory

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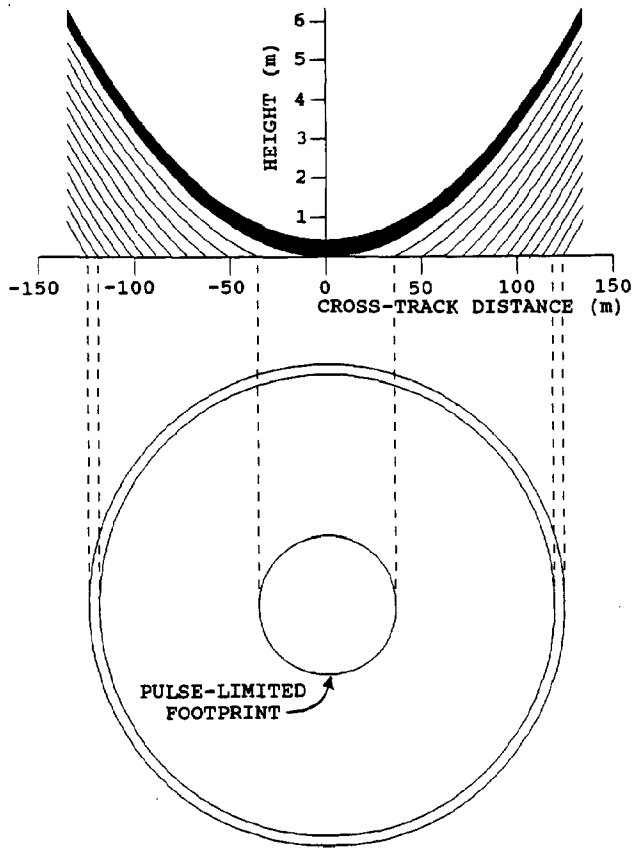

Figure 2. Schematic illustration of the interaction of radar altimeter pulses with a smooth surface. The upper part of the figure shows the position in space of a pulse (darkened region) transmitted from an altitude of 1545 m altitude just as it reaches the surface. The lower part of the figure is a plan view of the area illuminated on the surface for two of the pulse positions.

width of the swath interrogated on the surface would be approximately 250 m. On the other hand, a highly specular surface would return a signal to the radar only from the nadir point, and the effective area contributing to the return would be much smaller in diameter.

The monostatic horn antenna used by the AAFE altimeter had a 3 dB beamwidth of 15°, so the two-way beamwidth was 10.6° and signals from 5.3° off-nadir would be reduced by half. Figure 3 shows what the return waveform would look like if the AAFE altimeter were at 1545 m altitude over a flat, diffusely scattering surface. The four waveforms essentially show the variation with off-nadir pointing of the antenna gain pattern as a function of range to the surface. The curves past gate 12 are shown dashed as a reminder that the AAFE altimeter would generally have only 12 of its gates probing the surface if the return from nadir were centered in its 24 gates. Since the pitch attitude of the aircraft would be very stable as the C-130 maintained a constant altitude, antenna-pointing variation during the flight lines being analyzed would essentially be caused by aircraft roll attitude variation. Analysis of the photography indicates that the roll attitude variation was typically within ±1°. That means that the return signal from a surface whose scattering is independent of incidence angle would be down to about 65% of the maximum by the 12th gate past the nadir return (3.3° off-nadir). But we shall see that when the surface is highly specular, the entire return signal can rise and fall within two adjacent gates.

Data Analysis

High-quality photography was taken simultaneously with the radar data, using a 9-inch format Zeiss camera with a 6-inch lens. Figures 4, 5, and 6 each show two noncontiguous segments of approximately 30-s duration where the photography has been registered to the variation of the radar signal level and the return waveforms. In each segment, time increases from left to right and the average return waveforms are at the top, normalized to their respective peaks. Below the waveforms is the variation (in dB) of the signal level at the peak of the return. The AAFE altimeter was not absolutely calibrated and the indicated power values are relative. Below the signal level variation is the photography of the swath interrogated by the radar.

The AAFE altimeter pre-averages the return waveforms and outputs average returns at about a 10-Hz rate. The pulse repetition frequency (PRF) used for the data under analysis was 476 Hz, and each output waveform was the average of 52 returns. In Figures 4, 5, and 6, each waveform shown is a nonoverlapping average of 10 output waveforms spanning a time interval of 1.09 s and representing 520 transmitted pulses. The standard deviation of the fluctuations in

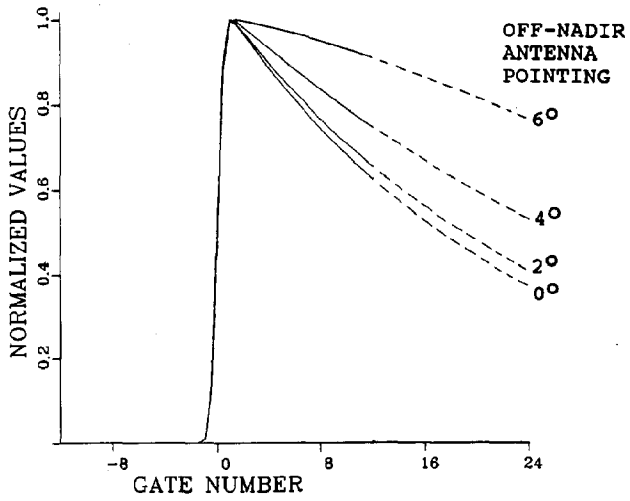

Figure 3. Modeled returned waveforms for the AAFE altimeter at 1545 m altitude. The four waveforms show the effect of varying the off-nadir pointing angle of the antenna over a surface whose scattering is independent of incidence angle.

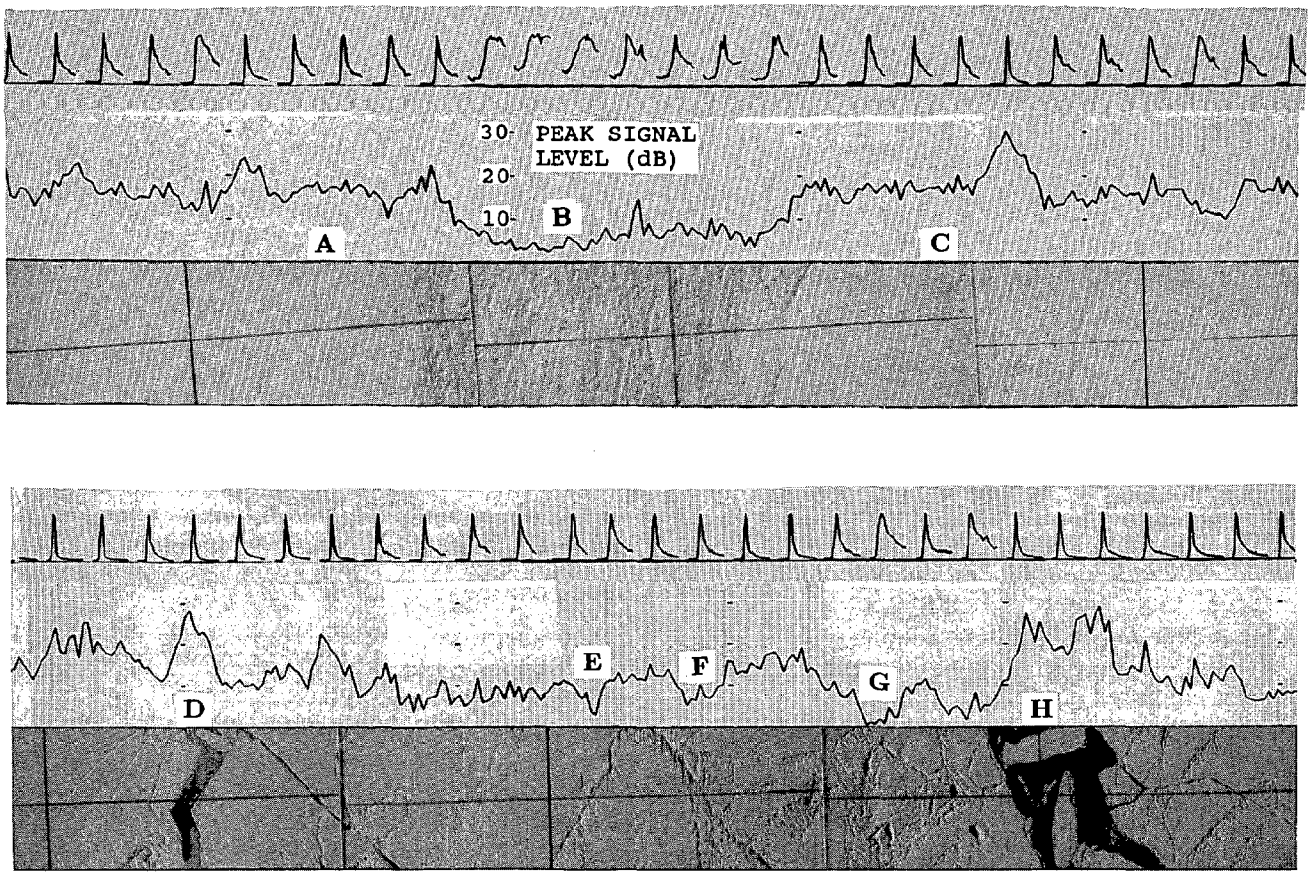

Figure 4. The response of the AAFE altimeter to ice returns. Each of the two noncontiguous data segments shown displays the returned waveforms at the top, the AGC power in the middle, and the corresponding photography at the bottom.

these average returns due to Rayleigh fading would be only about 5% of the mean value at each point on the waveform.

The aircraft ground speed was approximately 76 m/s and the length of each of the segments in Figures 4, 5 and 6 was about 2.3 km. The cross-track width of the photographic images is 250 m, the diameter of the region nominally interrogated by the altimeter (Fig. 2). Letters are used to identify specific features. The registration of the radar data to the photography was made as close as possible but should not be considered exact.

In the top segment of Fig. 4, the aircraft traversed a shear zone that was probably caused by the Beaufort gyre. The width of the zone was about 625 m and the AAFE altimeter indicated that the mean elevation within this rubble field was approximately 1 m higher than the surrounding area. The radar return peak power in this region was 10-15 dB lower than the surrounding areas, and the return waveforms indicate that the surface was scattering diffusely. The waveforms in the surrounding area (A,C) of homogeneous first year white ice (thicker than 30 cm; refer to [Steffen, 1986] generally exhibit both the sharp peak at nadir indicative of specular scattering and the slow decay following the antenna pattern (Fig. 3) in the later gates, which indicates diffuse scattering. The waveforms from the area of lowest backscattered power in the shear zone (B) had a signal level of approximately 3 dB and showed virtually no decay in the plateau region. The absence of a plateau falloff seems to suggest that the backscattered signal may actually have increased off-nadir, compensating for the falloff of the antenna gain (Fig. 3) to maintain the return signal level constant.

The bottom segment of Fig. 4 shows that the returned power could reach levels about 20 dB higher than the surrounding areas when the radar encountered gray (10-15 cm thickness) and gray-white ice (15-30 cm thickness) either at a refrozen lead (D) or in a matrix of white ice flows (H). Notice that the response of the radar to the refrozen lead (D) is strong even though the width of the lead is smaller

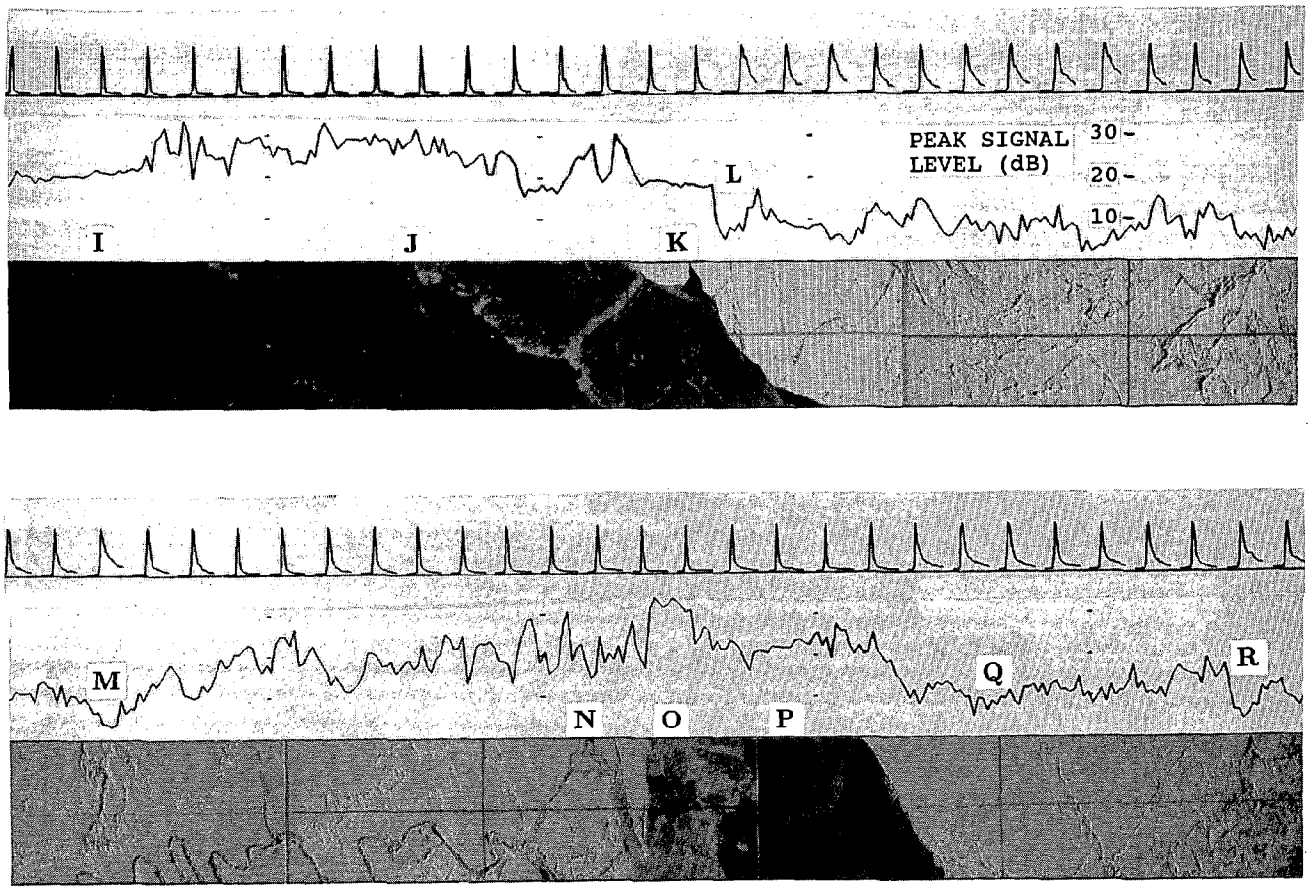

Figure 5. Two additional noncontiguous data segments in the same format as Fig. 4.

than the altimeter pulse-limited footprint (Fig. 2). On the other hand, the radar signal evidences sharp decreases when it encounters compression ridges (E,F,G) formed by the buckling, bending, or local crushing of colliding ice features.

The top segment of Fig. 5 shows the radar response to regions of gray ice (10-15 cm thick) and light nilas (5-10 cm in thickness). The uniform regions of gray ice (I,K) produced a highly specular signal of about 20 dB. In these regions the return signal rose and fell within a few range gates, and there was relatively little energy in the later gates. The signal from the light nilas (J) was almost 30 dB. The radar signal fell abruptly when the first-year ice was encountered (L) and thereafter maintained an average level of about 9 dB. The return waveforms in this region generally exhibited both specular and diffuse scattering components.

The bottom of Fig. 5 indicates that localized areas of old rafting (M,R) can produce signal levels in the 5-dB range. It also shows that visually similar smooth areas of first-year ice could produce significantly different average signal levels, for example, 20 dB at (N) and 10 dB at (Q). The recent finger rafting in evidence just past (M) on the lower half of the photography suggests that the first-year ice on the left side of this segment may be thinner than the ice on the right side.

Because of the rapid cross-track variation of the ice structure occurring in the gray ice and light nilas at (O), it is difficult to assess what is causing the signal to be 10 dB higher than in the more uniform region of light nilas at (P), which exhibits some rafting.

The region (S) of dark nilas (less than 5 cm thickness) on the left side of the top segment of Fig. 6 has a typical signal level of 32 dB as well as the highest value seen in the data set (37 dB just before the first-year ice is encountered at the right of the area). The waveforms are also the most specular of any of the data shown. The gray ice on the right side of the top segment (T) produced a signal level of about 25 dB, and the narrow bands of dark nilas (U,V) in the matrix of flows beside it have backscattered signal levels of about 30 dB.

The bottom segment in Fig. 6 demonstrates just how small a break in the first-year ice can cause a significant response in the radar signal level. The very small fracture at (W) is only about 3 m wide, yet it produces a peak response of 18 dB, about 10 dB higher than the surrounding area. The narrow area of dark nilas at (X) produces a signal level just as high as the broad area at (S) because part of it is at nadir. But the light nilas and gray ice at (Z) produce no response because they do not quite extend to the radar nadir point. As a result, the signal level at (Z) is 15 dB lower than at (X). As is the case throughout,

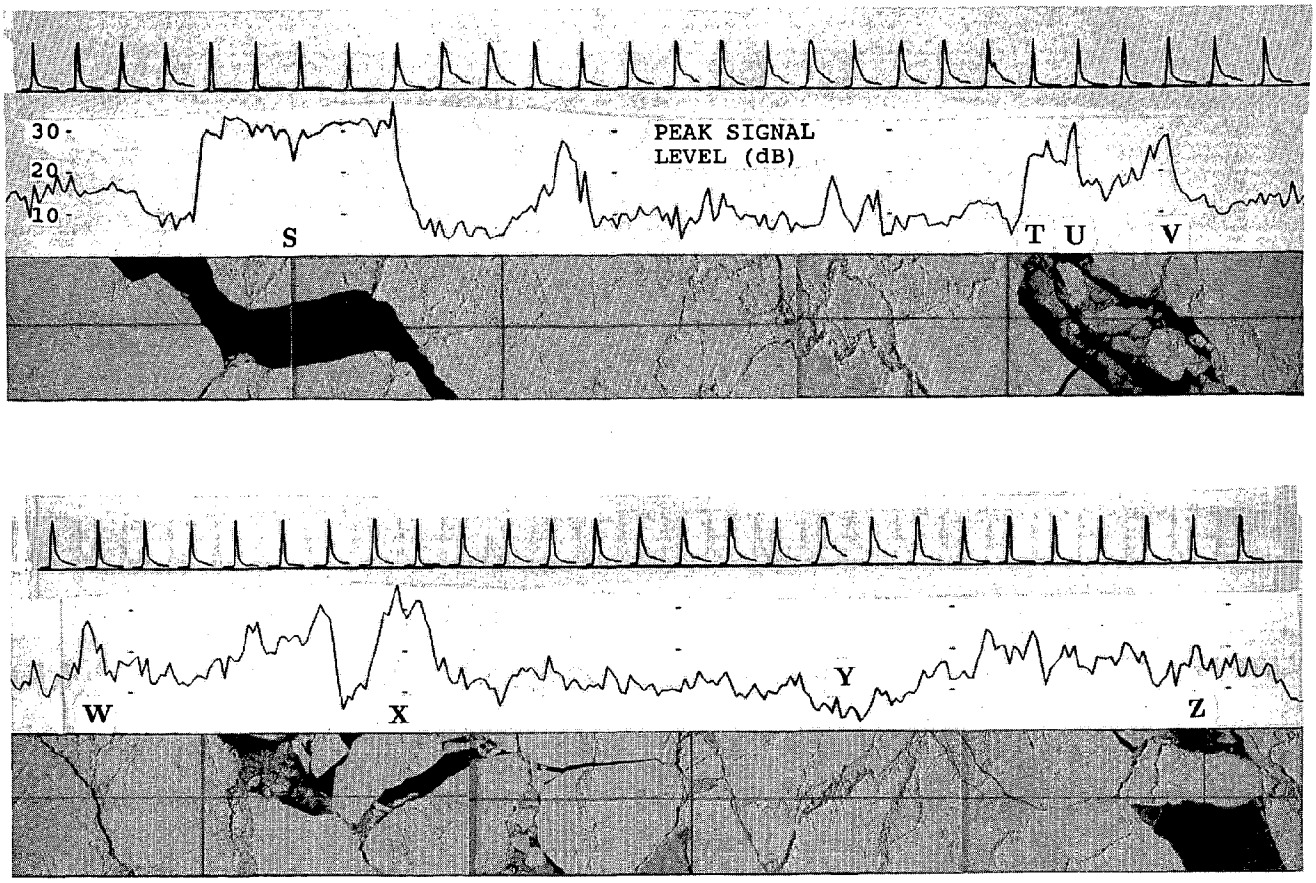

Figure 6. Two additional noncontiguous data segments in the same format as Fig. 4.

the radar signal level is depressed to about 5 dB whenever a region of significant ridging such as (Y) is encountered.

The ten-output-waveform averages displayed in Figs. 4, 5, and 6 give a very good impression of the composition of the backscattered signal as far as diffuse and specular scatter is concerned. But because they are averages over 1.09 s, the aircraft has moved approximately 83 m and the response to some very localized phenomena would be smoothed over. Figs. 7 and 8 present every output waveform for four short segments of the data already discussed so the altimeter response at a 0.109-s rate can be observed. Since the aircraft moved only 8.3 m during this interval, there would be very little smoothing of the response, even for highly specular returns. Even at this highest output rate of the AAFE altimeter, the returns are the average of 52 return pulses. The standard deviation caused by Rayleigh fading in the radar signal would be only 14% of the mean value at each point on the return waveform.

The top segment of Fig. 7 shows the region near (B) in Fig. 4. The waveforms are plotted to provide a three-dimensional effect. The vertical axis is linear in returned power to give an immediate impression of the relative strength of the returns. The axis parallel to the aircraft ground track can be thought of as either the distance or the time interval between output waveforms. The major tick marks along this axis are every ten waveforms and represent the averaging interval utilized in Figs. 4, 5, and 6. The axis labeled GATE is the radar range in the return waveform (0.417-m interval). The display has 60 gate positions along this axis because the program used to generate these three-dimensional plots was orginally developed to analyze SEASAT altimeter data. The AAFE altimeter waveforms occupy the central 24 gates in the display.

The return waveforms are plotted twice (Figs. 7-8). Below the photography, range increases toward the upper left. In plots of the same waveforms above the photography range decreases toward the upper left. This allows one to view the backs of the waveforms, which are hidden in the bottom plot. It is similar to holding a mirror behind a three-dimensional model to look at the rear face. As in the case of Figs. 4 through 6, the width of the photography is the 250 m cross-track distance nominally interrogated by the 12 range gates of the AAFE altimeter past the range to the nadir point (Fig. 2). This segment demonstrates that the off-nadir scattering in the last AAFE altimeter gate decreased by only a factor of 2 over the shear zone relative to the region outside the zone. However, the near nadir scattering was greatly reduced.

The bottom segment of Fig. 7 shows the region

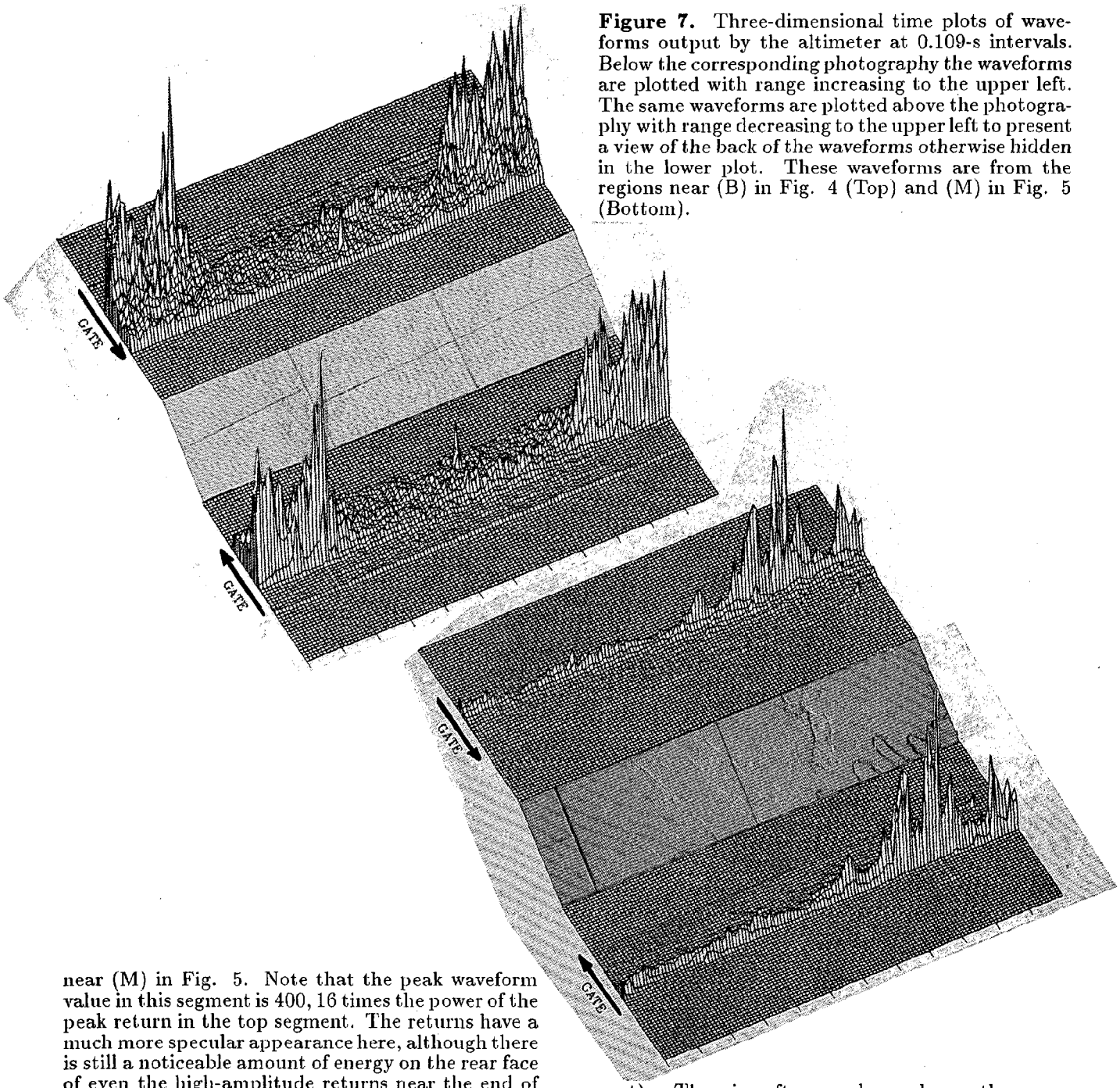

Figure 7. Three-dimensional time plots of waveforms output by the altimeter at 0.109-s intervals. Below the corresponding photography the waveforms are plotted with range increasing to the upper left. The same waveforms are plotted above the photography with range decreasing to the upper left to present a view of the back of the waveforms otherwise hidden in the lower plot. These waveforms are from the regions near (B) in Fig. 4 (Top) and (M) in Fig. 5 (Bottom).

near (M) in Fig. 5. Note that the peak waveform value in this segment is 400, 16 times the power of the peak return in the top segment. The returns have a much more specular appearance here, although there is still a noticeable amount of energy on the rear face of even the high-amplitude returns near the end of the segment.

The top segment of Fig. 8 encompasses the (N)-through-(R) region of Fig. 5. The peak value is 2,000, 5 times higher than the peak of the bottom segment of Fig. 7. The returns are highly specular and show almost no indication of off-nadir scattering.

The bottom segment of Fig. 8 shows the region near (S) in Fig. 6. It contains the highest amplitude return waveform seen in the data set (5,000). The high-amplitude returns in this segment generally rise and fall within two range gates (three at the most). The aircraft ground speed was the same at the nominal value of the aircraft airspeed, and the photography over the 1-min interval surrounding this segment indicated that the aircraft had virtually no drift angle. This combination indicates that the wind speed at the aircraft altitude was negligible, and suggests that it was also negligible at the surface. The structure apparent in the photography indicates that the highly specular region contains dark nilas (up to 5 cm thick), but the possibility that there was also some very smooth open water cannot be ruled out.

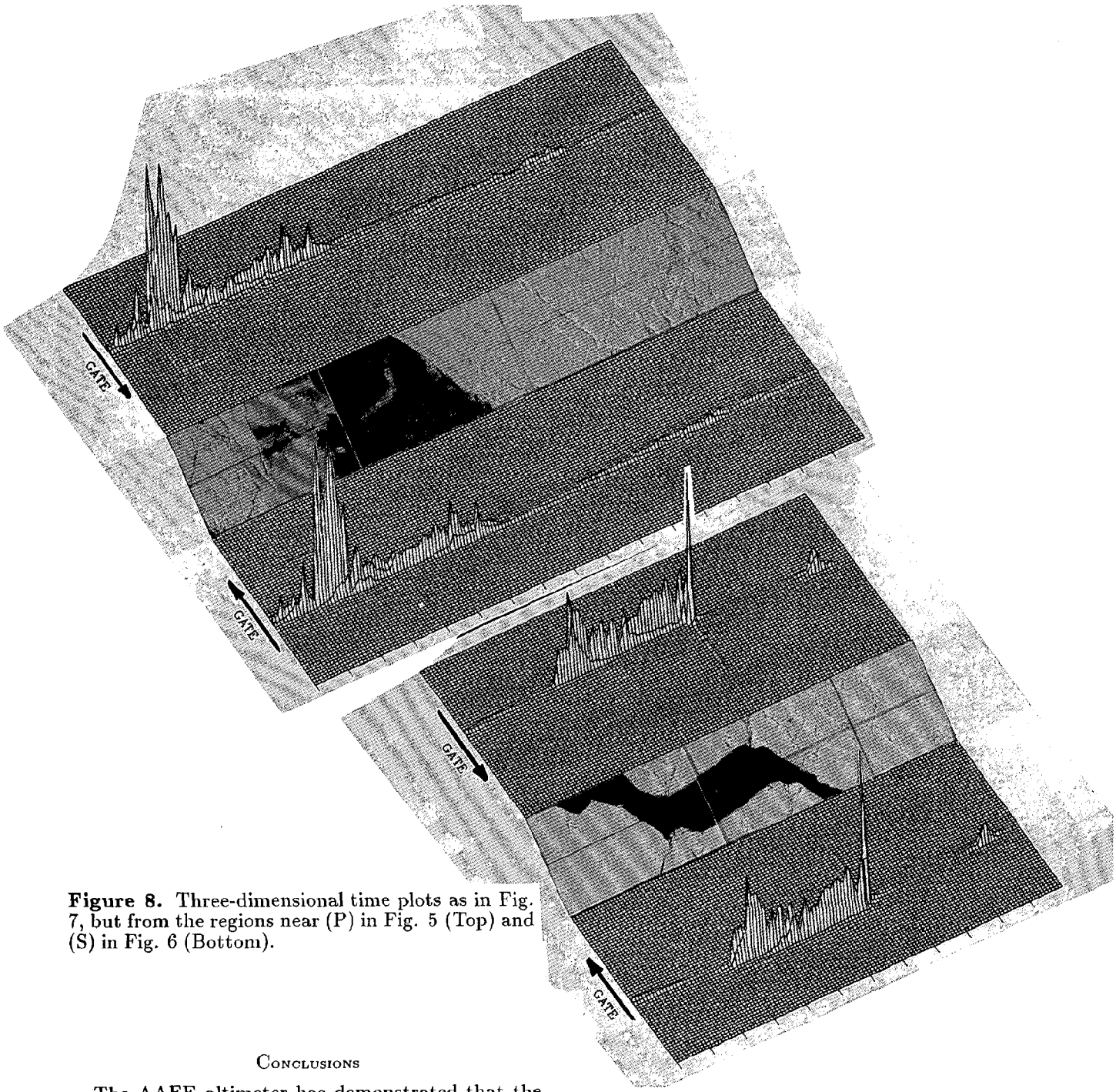

Figure 8. Three-dimensional time plots as in Fig. 7, but from the regions near (P) in Fig. 5 (Top) and (S) in Fig. 6 (Bottom).

Conclusions

The AAFE altimeter has demonstrated that the return waveform shape and signal level of an airborne pulse- limited altimeter at 13.9 GHz respond to sea ice type. The signal level responded dramatically to even a very small fracture in the ice as long as it occurred directly at the altimeter nadir point. Shear zones and regions of significant compression ridging consistently produced low signal levels. The return waveforms frequently evidenced the characteristics of both specular and diffuse scattering, and there was an indication that the power backscattered at 3° off-nadir in a shear zone was actually somewhat higher than that from nadir.

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References

Hughes Aircraft Company, Ground Systems Group, "Final Report of the Advanced Application Flight Experiment Breadboard Pulse Compression Radar Altimeter Program," *NASA CR-141411*, August 1976.

Steffen, K., "Atlas of the Sea Ice Types, Deformation Processes, and Openings in the Ice," North Water Project, *Zürcher Geographische Schriften, Heft 20*, Zürich 1986.

SEA GRANT FACES OCEANS OF PLASTIC

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ABSTRACT

The National Sea Grant College Program (NSGCP) is well-suited to serve as a partner in marine plastic debris education and problem-solving due to its unique character. A non-regulatory, university-based organization, it can reach segments of the population which national campaigns cannot. Sea Grant's greatest strengths are the ability to nurture innovative educational efforts and hand them on to local groups, its experienced corps of marine advisory agents, and a built-in national network. Marine debris is not a key area on Sea Grant's research agenda, with the possible exception of aiding applied research into the usefulness and effects of alternative materials in the marine environment.

INTRODUCTION

The advantages of plastic products are well known. They are durable, inexpensive, and versatile. It is almost inconceivable that any marine enterprise could survive in the modern world without the benefits of this ubiquitous material.

But plastic has a darker side in the marine environment. Six-pack yokes, strapping bands, and lost fishing gear, when dropped into the ocean, may disable fishing vessels and entangle, starve or maim wildlife. On the beaches, plastic trash has the same potential for harming wildlife and is, in addition an aesthetic eyesore that may harm a local tourist industry.

The specific impacts of plastic debris on fish, turtles, marine mammals, and birds have not been quantified, nor have the economic impacts on fishermen and coastal communities. Information from beach clean-ups and research tell us that the sources and composition of plastic trash are very different around the country. Fishing vessels are the largest source in the North Pacific, while along the Gulf of Mexico and the north Atlantic seaboard, the major culprits are commercial vessel traffic and non-point shore-based sources, respectively.

MARPOL Annex V and the Marine Plastic Pollution Research and Control Act of 1987 (MPPRCA), which prohibit the disposal of plastics at sea, will begin to address the overall problem by minimizing vessel sources of plastic trash. However, as recognized in the *Interagency Task Force Report on Persistent Marine Debris*, which builds significantly on a specially designed Sea Grant workshop[1] and working papers, enforcement at sea is difficult and costly; therefore, the best approach to reducing plastic trash impacts is education to change public behavior.[2]

The National Sea Grant College Program has been aware of the issue since 1984, when the Pacific Sea Grant College Program (PSGCP, composed of Sea Grant college programs in states bordering the Pacific Ocean) helped support an international workshop in Honolulu on the fate and

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effect of marine debris. More specifically, PSGCP was responsible for publishing the proceedings, which have become the basic reference document on this subject.[3] Texas and Oregon Sea Grants became involved in specific local efforts to tackle the problem, and as awareness of the issue spread, other Sea Grant programs incorporated the concern about plastic debris into their ongoing education and advisory efforts.[4] Most of these efforts have been undertaken cooperatively with the NMFS Marine Entanglement Research Program (MERP), state and local governments and private organizations such as the Center for Environmental Education (CEE).

WHAT IS SEA GRANT?

The National Sea Grant College Program is a cooperative research, education and advisory network supported by funds from the National Oceanic and Atmospheric Administration (NOAA) together with matching public and private funds from the participating states. It comprises 30 programs involving more than 300 colleges, universities, and affiliated institutions in the coastal and Great Lakes states and territories. Created by an act of Congress in 1966 and modeled in part after the Land Grant College system, the mission of the Sea Grant Program is to foster the wise use, development, and conservation of marine resources. Sea Grant programs use three tools to carry out their mission — research, education and and the marine advisory service.

WHY SEA GRANT?

Sea Grant's marine plastic debris education program has been carried out primarily by marine advisory services. Patterned after the Land Grant system's Extension Service, the marine advisory service is a network of marine agents and specialists who work with many varied marine activities, such as seafood processing, commercial and recreational fisheries, port management, aquaculture, tourism, and waterfront development. Housed at Sea Grant universities, the field agents and specialists serve as a bridge between the academic researchers and the users of the marine environment. They serve both as advisors to marine industries and as educators promoting environmental stewardship.

Not affiliated with any regulatory agency or single constitutency, advisory agents actively seek to remain neutral and provide information upon which the public can make better decisions. The agents also work closely with Sea Grant's extensive Communications network, which provides a broad publications and outreach capability, considerably extending the educational effort. Their unique position enables Sea Grant to extend educational programs to marine user groups not easily reached by national campaigns.

Several Sea Grant programs have developed expertise regarding this issue, which they try to share nationally throughout the network. The first and most concerted marine debris education projects began at the Texas and Oregon Sea Grant programs, and both demonstrate the slow-growing but potent networking effect common to Sea Grant nationally.

The Newport, Oregon marine debris disposal project, funded by NMFS, developed from contact between Oregon Sea Grant and MERP. At MERP's request, Oregon Sea Grant wrote a proposal for funding, and helped to find and train the manager who so successfully carried out the project. The Port of Newport, MERP, Oregon Sea Grant and the fishing community succeeded in providing more accessible waste handling facilities and a recycling program which actually lowered port waste handling costs, while simultaneously involving the entire community and creating a new attitude of stewardship toward the ocean.[5]

In Texas, the successful and nationally visible Adopt-A-Beach program was developed by the state based on marine advisory agent Charles Moss's active beach adoption program in Brazoria county. One of Sea Grant's strengths is that it is able to nurture new ideas and fund innovative programs which can then be taken over by community activists. These programs tend

to be more successful in the long run, since they are locally "owned" and controlled.

Most of the 30 state Sea Grant programs are now incorporating marine debris educational materials in their in their advisory and education efforts. They have written newsletter articles and issued press releases informing the public how to make a difference. Several programs have developed posters warning about the hazards of marine debris and have cooperated with state agencies to coin catchy slogans as well as to run public service announcements in the media.

THE EDUCATION CAMPAIGN

The list of major Sea Grant publications on marine plastic debris is short: the *Texas Shores* [6] summer 1987 issue on marine plastic trash, the *Oceans of Plastic* workshop proceedings,[7] *Plastic in the Ocean:What are we doing to clean it up?* [8] and a condensed version of the *Interagency Task Force Report* .[9] However, they are distributed widely and have a slow but profound effect as network builders, helping people in small communities to share information and minimize duplication of efforts. Some of these publications are being used and reused, either in full or in part, with adaptations for specific local audiences.

Workshops are another form of strategic talent-sharing. The *Oceans of Plastic* workshop in February, 1988, brought together experts to discuss aspects of fisheries-related marine debris problems. Aside from producing a report about the importance of educational efforts vis-a-vis increasing enforcement mechanisms, the workshop generated many personal ties and several spin-off effects. Marine debris disposal projects will be established at two Texas ports in the coming year (with Saltonstall-Kennedy funds), and the state of Alaska has increased its activity with regard to its small and isolated fishing ports. Topics for future workshops might include alternative fishing gear construction, or small port and terminal marine debris reception facilities.

Another recent Washington Sea Grant activity has had similar impacts. Members of our staff have been actively involved with the Washington State Marine Plastic Debris Task Force, convened by state Public Lands Commissioner Brian Boyle in January of 1988. Task Force members (including representatives of state agencies, community groups, legislative staff, educational institutions, public and private sector organizations) developed a report for the Commissioner, outlining how the state should go about increasing public sensitivity to the marine debris issue, enforcing the MPPRCA and mitigating plastic debris problems in a coordinated and cost-effective manner. Washington Sea Grant may play a larger role in the state's response to this issue if it is designated the state's clearinghouse for marine plastic debris information.[10]

Other Sea Grant activities include a port debris disposal project in Bellingham, Washington, similar to the MERP-funded project in Newport, Oregon, but different in a number of ways: the Sea Grant agents are acting in an advisory capacity to the Port of Bellingham, whereas in Newport the project manager was a port employee; the fishing fleet comprises primarily seiners and gillnetters, not trawlers; and there was more prior knowledge and interest among fishing community leaders in Newport than in Bellingham.

Gear type makes a significant difference. Whereas the Newport fleet of trawlers fish in Alaska as well as near home, and often make extended fishing trips, the Washington fleet of seiners and gillnetters are primarily overnighters or day fishermen. They do not need to do repairs at sea, and their gear is too cumbersome to do so. Wildlife entanglement problems are not so visible or acute here as in Alaska, and fishermen have an antagonistic relationship with harbor seals due to their poaching of catch. For all of these reasons, formulating an effective educational campaign is more complex in Bellingham, as the fishermen perceive themselves to be less of a problem and have little self-motivation to change. Funded partially by a Puget Sound Water Quality Authority (PSWQA) public involvement and

education grant, this project is part of a larger effort to educate the citizens of Puget Sound about water quality management.

Sea Grant is also helping to produce educational videos about marine plastic debris. Alaska Sea Grant has cooperated with Saltwater Productions to produce a MERP-funded video, "Trashing the Oceans", for general audiences. They plan to collaborate again in the future to produce a video targeted at Alaska fishermen.

Some Sea Grant programs are very involved with local and state beach clean-ups. For example, Georgia, North Carolina, and Louisiana are compiling databases on the nature and origins of the plastic debris found during beach sweeps. This information should help focus educational programs more closely on the primary sources of the trash. It is also useful for legislative testimony when legislators attempt to make new policies regarding marine debris.[11]

Although the port project in Newport, Oregon is no longer receiving NMFS funding, the port is continuing the debris disposal and recycling program and Oregon Sea Grant has picked up the education and advisory role. The educational materials developed during the course of the project are available through Oregon Sea Grant, and they continue to publicize the efforts of individual fishermen who haul their trash to shore. In future educational materials, Oregon Sea Grant will target charterboat operators and recreational fishermen.

The Saltonstall-Kennedy (S-K) grant program is funding another outgrowth of the Newport project. Former project manager Fran Recht, based at the Pacific Marine Fisheries Commission, will be serving as roving advisor to small ports on the West coast as they come into compliance with the Coast Guard's regulations implementing the MPPRCA. Her expertise will be shared by a larger audience both in this manner, and through a guide published by NMFS.[12]

THE BROADER CONTEXT

The marine plastic debris issue is strategic in that it provides an easy opening to discuss larger and, in the long term, more significant issues, such as deteriorating coastal and estuarine water quality and the national solid waste disposal crisis. The public relates immediately to images of fur seals entangled in trawl gear, or to sea turtles choking on plastic bags. Attention may then be drawn to the larger issues inherent in any discussion of marine plastic debris. In this sense, marine plastic debris is a key piece of any advisory educational program that attempts to promote the wise use and conservation of our natural resources.

A RESEARCH ROLE?

The Interagency Task Force recommended several broad areas for future research: fish and wildlife impacts; economic impacts; improved knowledge of the contribution of sea-based versus shore-based debris sources; and cooperation with the fishing and gear manufacturing industries to reduce gear loss, improve gear recovery, and develop recycling opportunities for used gear. The Task Force also recommended research on degradability for specific plastic products. These research subjects are by and large best addressed as augmentations to ongoing work by NOAA, the U.S. Fish and Wildlife Service, state and local governments, and the plastic industry itself. Very specialized academic research organizations have evolved which deal with the more technical research issues of plastic recycling and degradability.[13]

Sea Grant may have a role to play if the plastics or fishing gear industries are able to develop alternative materials or gear configurations. Sea Grant could then forge the link between users and industry to test new applications in the environment, while relating this work to existing resource management research.

CONCLUSION

The major activities that Sea Grant will emphasize over the next few years with respect to marine plastic debris are to:

a) Continue networking, among Sea Grant programs, user groups, and other interested bodies.

b) Target public education with publications, workshops and problem solving activities.

c) Identify problem areas where additional policy development is needed.

No single organization can carry the entire marine plastic debris educational effort. As evidenced by ongoing projects, many different organizations contribute funds, ideas and expertise. By working together, projects that start small are able to reach much broader audiences and have a greater effect. We must continue to expand the educational network—locally, regionally and nationally—in order to increase our reach yet further. And we must also continue to emphasize the marine plastic debris problem in the context of broader water quality, resource management and environmental concerns.

I would like to thank Mr. Ron Dearborn, Director, Alaska Sea Grant for the thoughts and ideas he shared with me in the preparation of this paper.

REFERENCES

[1]Oceans of Plastic; A Workshop on Fisheries Generated Marine Debris and Derelict Fishing Gear, Portland, Oregon, February 9-11, 1988.

[2]*Report of the Interagency Task Force on Persistent Marine Debris*, printed by the Department of Commerce, National Oceanic and Atmospheric Administration, 1988, p. 141.

[3]Shomura, R.S. and H.O. Yoshida (ed.s), *Proceedings of the Workshop on the Fate and Effect of Marine Debris*. NOAA TM-NMFS-SWFC-54 and UNIHI-SEAGRANT-CR-85-04, 1985:580 pp.

[4]For a good description of the initial Sea Grant debris programs and ongoing efforts throughout the Sea Grant network, see Guthrie, D., "Castoff Plastic Debris," *Oceanus* 31(3):pp 29-36.

[5]For more information about the Newport Marine Refuse Disposal Project, see Recht, F., *Report on a port-based project to reduce marine debris*. NOAA-NWAFC Processed Report 88-13, July 1988:75 pp.

[6]Texas Sea Grant College Program. Marine Litter. *Texas Shores* Summer 1987:28pp.

[7]Alaska Sea Grant. *Oceans of Plastic; Workshop Proceedings* (forthcoming).

[8]Augerot, X. *Plastic in the ocean; what are we doing to clean it up?* WSG-AS-88-6, 1988:8pp.

[9]Interagency Task Force on Persistent Marine Debris. *Summary of Report to Congress*. Alaska Sea Grant (forthcoming).

[10]Washington State Marine Plastic Debris Task Force. *Marine Plastic Debris Action Plan for Washington State*. October 1988:65 pp.

[11]Dearborn, R.K., Director, Alaska Sea Grant, *Statement regarding marine plastic debris, on behalf of the Sea Grant Association* and Liffman,M.M., Assistant Director, Louisiana Sea Grant, *Testimony concerning marine plastic debris*, before the National Ocean Policy Study, U.S. Senate Committee on Commerce, Science, and Transportation, July 29, 1988.

[12]Recht, F.. *Dealing with Annex V — a reference guide for ports*. NMFS MERP 1988.

[13]Michigan State University's School of Packaging, Rutgers Center for Plastics Recycling Research and the Stevens Institute of Technology's Polymer Processing Institute, for example.

ANALYTICAL CHEMISTRY OF BUTYLTINS

K.W. Michael Siu, James W. McLaren, Paulette S. Maxwell, Graeme J. Gardner, Shier S. Berman

The common analytical technique for butyltins involves extracting the species as halides, derivatizing to hydrides or tetraalkyltins, separating by using gas chromatography, and quantitating with flame photometry or atomic absorption spectrometry. To arrive at certified concentrations of butyltins in standard reference materials (SRMs), it is, however, imperative to have results from at least two independent analytical techniques.

In order to satisfy this requirement, analytical techniques have been developed for the determination of butyltins in a harbour sediment SRM, PACS-1. These are: (1) Gas chromatography - flame photometric detection (GC-FPD) of butyltins as chlorides, (2) High performance liquid chromatography - inductively coupled plasma mass spectrometry (HPLC-ICPMS), and (3) Ion spray mass spectrometry / mass spectrometry (ISMS/MS). In GC-FPD, butyltins are extracted from the sediment as chlorides, and separated and quantitated with gas chromatography as such. Two extractants may be used: toluene/iso-butyl acetate/tropolone and hexane/iso-butyl acetate. Extracted butyltins are separated by cation exchange in HPLC-ICPMS using citrate buffers and determined on-line with ICPMS. ISMS/MS is only applicable to tributyltin (TBT) determination. The TBT ion is evaporated from the extract by ion spraying, separated from matrix ions by the first MS stage (no chromatography is necessary), and quantified by using the second MS stage with selected reaction monitoring.

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'The U.S. Coast Guard: A Prototype for
National and International Ocean Policy Implementation

Presented by

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and

Executive Director
Oceans '88 Conference and Exposition
Baltimore, Maryland

October 31, 1988

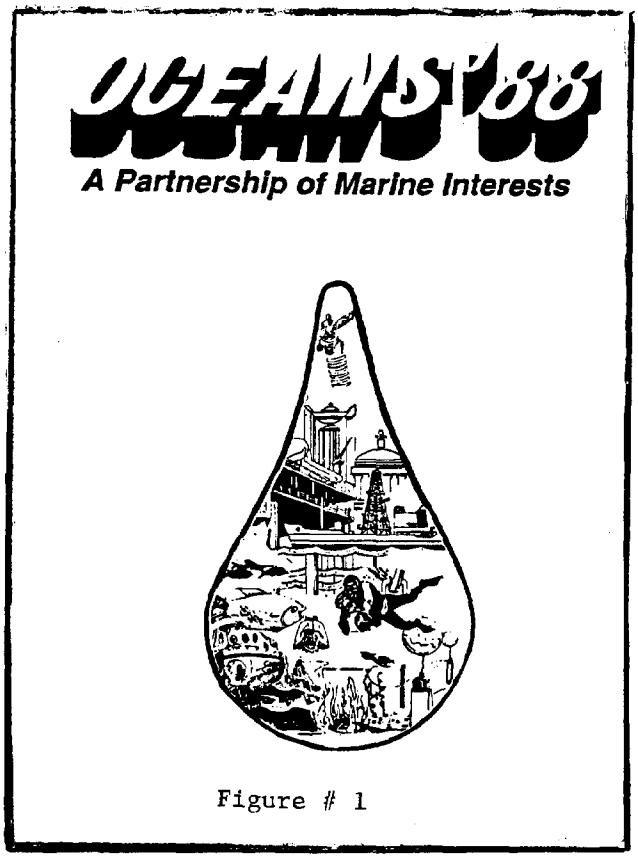

Figure # 1

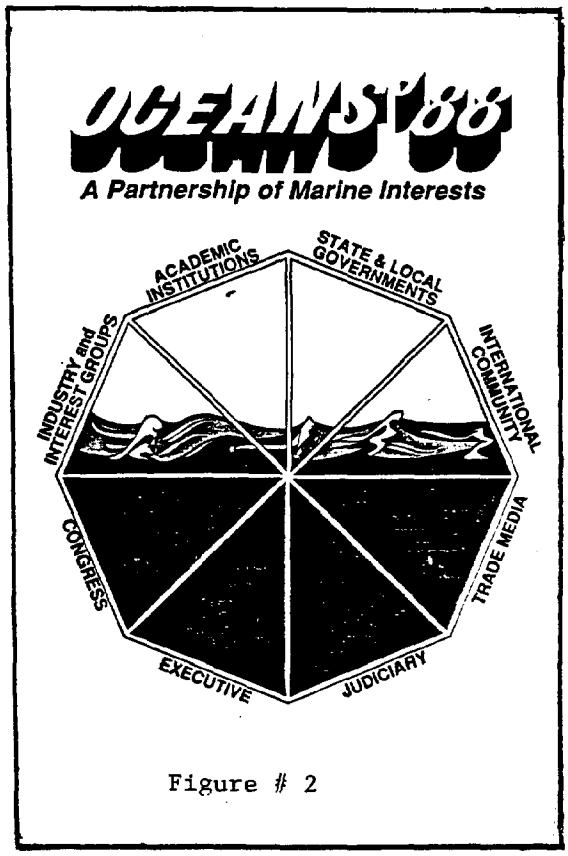

Figure # 2

INTRODUCTION and THE RELEVANCE OF THE OCEANS '88 THEME

In the tandem roles as Chief, Governmental Affairs Staff, U.S. Coast Guard, and the Executive Director of the Oceans '88 Conference and Exposition, a managerial responsibility I was honored to undertake, there are many policy, programmatic and operational issues and perspectives I could convey with respect to the U.S. Coast Guard; to what has been called 'ocean policy'; or to their combined relevance to Oceans '88 and its theme of consensus construction within the most comprehensive parameters which might yet be postulated for a major policy and technical forum.

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There is an intended correlation between the theme of the Oceans '88 Conference and Exposition, 'A Partnership of Marine Interests' and the thesis that the U.S. Coast Guard represents a unique prototype for the cost-effective implementation of both national and U.S. foreign policy goals. There is an additional relationship between the overall conference theme and this paper's later recommendation that the U. S. Coast Guard, as well as other Federal agencies, can be more responsive to their multiple constituencies, and reciprocally assure a better stake in Federal budgetary allocations, if these agencies can adopt what I call the 'External Affairs' model.

Indeed both the logos precisely designed for Oceans '88 are depicted to convey these themes; i.e., the Marine Partnership, and the notion of consensus involving all interested players in the oceans policy/ocean technology ballgame; the reality that relevant structures are helpful to comprehend and pursue individual and joint, Federal interagency and intergovernmental strategies; and the necessity to assure more harmonious conflict use resolution. The themes are also crafted to assist in rallying the support necessary to attract national attention to the national, inland marine, coastal, oceanic and related atmospheric needs of this nation. In commercial chatter, it's called institutional advertising for long-term, market retention. If you want attention, utilize the most sophisticated, creative and professional ideas which can be marshalled to support your cause.

The single droplet of water illustrated in Figure #1, and suspended in the water column radiating photosynthesis, suggests the scientific-atmospheric integration. The mosaic of ocean uses within the droplet signifies both harmony and diversity, peaceful conflict resolution, and the premise that any one ocean use or concern is, in an Aristotolian sense, as significant as the others for their respective constituencies.
The 'octagon' logo illustrated in Figure #2 is designed as a more permanent symbol to represent all the categories of the participants in Oceans '88, as well as all of the participants involved in any modern nation-state's policy formulation process. Those participants include what I call the '8 Estates of Government': Congress; the Executive Branch; the Judiciary; the Trade Media, historically called the 4th Estate of Government; a combine of Industry and Interest Groups as the Fifth Estate, an aggregate of Academic Institutions and Professional (or Disciplinary-Oriented) Institutions as the Sixth Estate; State and Local Governments as the Seventh Estate; and the International Community as the 'Eighth Estate' involved in any individual, nation-states' policy formulation.

In a larger public policy context, it can be predicated that a local government initiative such as California's Proposition #13, bilateral agreements such as the recent US-Canada Trade Agreement, or the role of the media, the 'Fourth Estate' in public diplomacy, can have profound consequences on national ocean policy formulation.

The private sector, public and special interest groups, academic entities, state and local governments and indeed international representatives, all lobby before the Congress; and, the general and trade media print and electronic, in turn report upon those interactions and influence both the 'inside the Beltway' and 'outside the Beltway' citizens, voters and decision-makers. Unless a federal agency, as well as Governmental Affairs components of corporations, national associations and other institutions, comprehend this precise networking, as well as the prescriptions in the U.S. Code regulating lobbying activity, their efforts at advancing from the 'reactive mode' to the 'proactive mode' can only be marginal; and, in some cases their obsolete organizational styles can be counterproductive. Public policy strategies cannot be optimized without rational and constituent-responsive structures.

THE U.S. COAST GUARD AS A PROTOTYPE

So much for a primer on the symbols of Oceans '88; now, to their symbiosis with the U.S. Coast Guard itself, and how it has been utilized, and can further be refined, as a remarkable prototype for the National interest. The Coast Guard is a multi-faceted model in which its delegated missions require the agency to be an active participant in a plethora of interagency, intergovernmental and international programs, events, task forces, conferences and proceedings, ranging from the National Narcotics Border Interdiction System to the UN/IMO, to the Federal Ocean Principals Group, to the American Oceanic Organization, to EXPO '86 in Vancouver, to the Marine Technology Society and the Chairmanship of Oceans '88.

My window or personal perspective of the U.S. Coast Guard is as a unique, and traditional, yet dynamic, Federal agency and Armed Service, implementing U.S. domestic law as well as international covenants, in the inland waterways, coastal zones, and high seas as well as in a record of visits to other national ports of call. It is an agency which not only presents a unique 'peace and defense model' similar in texture perhaps to NATO's Committee on the Challenges of Modern Society, but one which is committed to both national needs and international interchange ... one which, as I hope to describe, has operated quietly yet efficiently across the intergovernmental spectrum, across the 'Eight Estates of Government' ... as will be elaborated. Thus, the U.S. Coast Guard: 'A Prototype for National and International Ocean Policy Implementation". Thus the utility of the 'Partnership of Marine Interests' and 'Octagon' logos to fit the needs of both the Coast Guard and Oceans '88.

The U.S. Coast Guard has been continually involved in the process of charting both contemporary and emerging ocean-related needs since its origin as the Revenue Cutter Service in 1790 when Secretary of the Treasury Hamilton petitioned the Congress for a fleet of cutters to assure import revenues for the infant Nation. The agency was established in name in 1915 when it was merged with the Life Saving Service. It became part of the newly formed Department of Transportation in 1967. Its current and 18th Commandant is Admiral Paul A. Yost who assumed command in May 1986.

The U.S. Cost Guard, is the nation's historic maritime law enforcement agency and has a major operational presence, with a myraid of functions in the coastal, offshore and high seas as well as inland waterway areas. Many of those missions and activities are familiar to many of the attendees at Oceans '88 and the readers of its formal Proceedings. Thus, they will only be briefly enumerated and described.

The Coast Guard is an agency which maintains traditional safety-at-sea and national defense functions, yet continually evolves in response to national and international needs. Much of the direction of its current missions, programs and activities emanate from the last 16 years of both Legislatiave and Executive initiatives which have included the following:

- o National Environmental Policy Act (1970)
- o Water Quality Improvement Act (1970)
- o Port and Waterways Safety Act (1970)
- o Coastal Zone Management Act (1970)
- o Federal Boat Safety Act (1971)
- o Marine Protection, Research, and Sanctuaries Act (1972)
- o Amendments to the Oil Pollution Act (1973)
- o Fisheries Conservation and Management Act (1976)
- o Executive Initiative on Oil Pollution (1973)

- o Executive Initiative on Drug Law Enforcement (1973)
- o Clean Water Act of 1977 (Amendments to Federal Water Pollution Control Act)
- o Presidential Order on Interdiction of Illegal Migrants (1981)
- o Vice Presidential Task Force on South Florida Crime (1982)
- o National Narcotics Border Interdiction System (1983)
- o Presidential Proclamation for a 200-mile Exclusive Economic Zone (1983)
- o Maritime Defense Zone enactment (1984) ... and the
- o Anti-Drug Abuse Act (1986)

The synergistic effect has been the expansion of some traditional missions and entry into new areas such as Marine Environmental Protection and working closely with the states and jurisdictions in a joint education and enforcement effort for its Recreational, Boating Safety program. Innovations in development of the 'Pollution Strike Force' concept, have become internationally known. These newer responsibilities, combined with its historic roles, have led the service to structure, as modern management systems require, a statement of strategic objectives; which includes the responsibilities:

To minimize the loss of life, personal injuries, and property damage on, over, and under the seas and waters subject to U.S. jurisdiction. 'Help Others - Help Yourself' is one recruiting message which attracts young men and women to this humanitarian role;

To facilitate waterborne activity in support of national economic, scientific, defense, and social needs;

To maintain an armed force prepared to carry out specific naval or military tasks in time of war or emergency; the Coast Guard, is, as another recruiting ad conveys, 'An Armed Service and More;'

To assure safe and secure ports, waterways, and shoreside facilities;

To enforce federal laws and international agreements on and under those waters subject to U.S. jurisdiction and on and under high seas where authorized;

To maintain or improve the quality of the marine environment; and

To cooperate with other governmental agencies - Federal, state and local - so as to assure efficient use of public resources. This latter responsibility, as well as Executive mandates such as the Presidential Task Force on Private Sector Initiatives, established to link Federal with intergovernmental resources in the pursuit of the National interest, provide the rationale for the Coast Guard Chairmanship of Oceans '88.

The Executive initiative for an Exclusive Economic Zone (Presidential Proclamation #5050 of March 10, 1983) represented an expansion of U.S. national resource management over a spacial area of some 3.4 million miles, estimated to be over one and one-half the total land mass in the United States. And, although this act essentially recognized both the judicial framework and legality of ongoing, offshore activities evolved as the result of customary international law, and has in the short term primarily required major research attention by both NOAA and the Department of the Interior, the U.S. Coast Guard must also consider in its planning whatever private sector, public sector, interest group or academic forecasts will be projected for offshore resource development within that zone The agency must factor these inputs into what I call a 'Long-Term Perspective' so 'event management' can be related cohesively to 'Trend Management'; so reaction can be reconciled with proaction to assure that the proper level of resources will be allocated; and to also guarantee that the Coast Guard's multiple constituencies are adequately and cost-effectively served.

However, for the foreseeable future, a major portion of the Coast Guard's resources must be committed to the national effort to reduce the supply side of the narcotics equation through sea-air interdiction. Yet, in the current mix of priorities, three mission areas will remain paramount: Maritime Law Enforcement, Maritime Safety, and Defense Readiness. As activity is generated from increased hydrocarbon expoloration and extraction, ocean transportation, fisheries development, offshore mining, specific Arctic offshore and onshore development, recreational boating, disposal of oil and other hazardous substances, such as plastic harnesses and toxic medical waste, and the possible scenarios for waterborne terrorism, the Coast Guard's role and mission base must be expanded. Its statutory responsibilities have evolved in terms of inland marine and coastal as well as high seas or 'trans-oceanic' functions beyond the jurisdictional shores of the United States ... and they extend beyond the economic factoring to include general law enforcement, safety-at-sea, environmental protection and national defense activities. The specific, current programs as derived from law and Executive direction, currently include:

Search and Rescue ... in which the agency must maintain a 24-hour, 'real time' operational infrastructure of small boats, cutters, aircraft, communications facilities and Operations Centers ... and in which under international agreement, it provides the search and rescue coordination for 21 million square miles of ocean ... that's already a sizeable segment of both the EEZ's seawater and the high seas to supervise.

Unquestionably, as resource limitations are imposed upon the public sector, another significant element or question which has arisen is the issue of what degree of current governmental activity can be transferred, at reduced cost and without loss in the threshold of public safety, to the private sector. In addition, to its ongoing extensive Office of Management and Budget A-76 reviews, the U.S. Coast Guard issued a classification of non-emergency towing policy in June 1983. It is proceeding with a new system in which assistance cases, which are clearly of a non-emergency nature, are transferred to the private sector via local lists of available towers and salvors. However, the infrastructure for response to both inshore and offshore emergency cases must still be maintained; and, as both distant offshore and Arctic activity expand .. given the time, weather and expense variables, it remains highly uncertain what degree of private sector enterprise would be available for those locales. There is a threshold of public response which must be maintained. The strategy is for public and private sectors to work together and more creatively in the national and foreign policy interest.

Search and Rescue, the most publicly known mission of the Coast Guard, ranges from removal of hazards to navigation to flood relief in tranquil waters, to firefighting, to response to offshore boaters (72% of the life saving missions involve recreational boats and almost 95% of all rescue missions take place within 20 miles of shore), to high seas rescues, to helo/medevac operations ... all requiring skilled seamanship and exposure to mariner hazards. And passenger vessels are included as well.
Search and Rescue is an international obligation. In March 1987 the Coast Guard rescued the merchant seaman of the Soviet disabled vessel, the Komsomolets Kirgizii, foundering in the Atlantic. In July 1986, three Coast Guard cutters (Farallon, Mau, Cape Gull) and three Dolphin choppers helped extinguish fires and airlifted passengers when an explosion occurred on the cruise ship SS EMERALD SEA offshore a resort island in the Bahamas. From 1979 to 1984, the Coast Guard annually averaged 6000 lives saved and over a billion dollars in property loss prevention.

In a more systemized format for international safety-at-sea, the Coast Guard operates the AMVER program, or Automated Mutual Assistance Vessel Rescue System, from its Third Coast Guard District Headquarters on Governors Island in New York. Participating flag merchant vessels send both sail plans and periodic position reports to the AMVER computer. In an emergency, a recognized Rescue Center of any nation may obtain a computer-predicted list of ships in the vicinity of an emergency. An AMVER mock-up has been displayed at the Oceans '88 Exhibit.

Enforcement of Laws and Treaties ... In the year 1990, the U.S. Coast Guard will celebrate its bi-centennial of service as the primary Federal agency for maritime law enforcement ... which includes not just the enforcement of those domestic laws within the 200-mile Fisheries Conservation and Management Act, but other domestic laws and international agreements extending to interdiction of drugs, other controlled substances and contraband, waterborne movements of illegal migrants, and a variant of laws relating to protection of endangered

species, marine mammals and marine sanctuaries. In this effort the service participates in a unique, intergovernmental coordination within the National Narcotics Border Interdiction System, comprising the Coast Guard, Customs Service, Drug Enforcement Administration, U.S. Navy and at times up to 27 different local, state, and Federal agencies, depending on the specific mission. The effort is part of a multi-faceted, national program reaching from crop substitution to crop eradication ... to seizure at or prior to exportation ... to land, air and sea interdiction ... to education and elimination of drugs in the workplace and school ... to continuing drug research ... to stricter penalties for drug abuse ... to increased international cooperation as well as cooperation between the public and private sectors to reduce consumption.

The U.S. Coast Guard has primary responsibility for the at-sea enforcement of over 20 different fishery management plans and associated enforcement regulations which regulate domestic and foreign fishing in the U.S. EEZ pursuant to the Magnuson Fisheries Conservation and Management Act. In addition, the U.S. Coast Guard is tasked with monitoring compliance with endangered species and marine sanctuary regulations, as well as certain international fishing agreements in waters beyond the limits of the EEZ. Fisheries enforcement is also a close interagency effort; concurrent jurisdiction is shared with the National Oceanic and Atmospheric Administration of the U.S. Department of Commerce for the enforcement of the Magnuson Act provisions.

The fourth significant program area is Port and Environmental Safety and Security. In this decentralized effort, under the Ports and Waterways Safety Act and earlier legislation, Coast Guard officers acting as Captains of the Port (COTP's) in 47 port cities, are authorized to enforce rules and regulations governing the safety and security of ports and the anchorage and movement of vessels in the U.S. waters. Port safety and security functions include supervising cargo transfer operations, both storage and stowage, conducting harbor patrols and waterfront facility inspections, establishing security zones as required, and the control of vessel movements. In the reality of potential for terrorism, this role is also evolving as evidenced by the large fleet of small patrol boats on duty in 1984 at Olympic Village along Long Beach, California.

Merchant Marine Safety ... in which the U.S. Coast Guard assures the safety of the nation's ports and inspected merchant vessel fleet. Vessel safety standards are established for construction, maintenance and repair, machinery, electrical systems, lifesaving equipment and the manning of vessels.

In addition the service must also review and approve plans for vessel construction, repair and alteration; establish merchant marine qualification standards and investigate maritime casualties and incidents involving merchant marine personnel. To assist the Coast Guard in meeting these responsibilities, memoranda of understanding are now in effect with the American Bureau of Shipping, the National Cargo Bureau, Underwriters Laboratories and other related certification organizations. International obligations for merchant marine safety, the related environmental safeguards, and the allied responses to waterborne terrorism are standardized through the United Nations' Intergovernmental Maritime Organization in London.

Ice Operations ... in which the U.S. Coast Guard maintains the sole Federal capability for icebreaking in both domestic waters and polar regions. In its domestic ice operations, certainly the increased focus on Alaskan/Arctic resource development will continue to increase in importance. In another interagency effort, the agency provides assistance to ships and assists the U.S. Army Corps of Engineers in the prevention, mitigation or relief of flooding caused by ice accumulation in waterways. This opening involves ice-blocked waters in the Northwestern United States, the Great Lakes - St. Lawrence Seaway System, the Upper Mississippi River Basin and Sub-arctic Alaska. In addition to maintenance of a domestic fleet of buoy tenders and tugs with icebreaking capabilities, the U.S. Coast Guard operates polar icebreakers to support resupply for the Department of Defense in the Arctic and to support the National Science Foundation and other Federal interests for resupply and scientific investigation in the Antarctic. The icebreakers must meet the personnel and equipment standards to meet those continuing treaty obligations. Yet, the icebreaker fleet has been greatly reduced; and, as this writer submits, only a coordinated, 'External Affairs' approach can help alleviate this Coast Guard and national shortfall.

Marine Environmental Response ... The U.S. Coast Guard is responsible for enforcing the Federal Water Pollution Control Act and related legislation on the navigable waters of the United States and tributaries to ensure that public health and welfare are protected. Plastic harnesses and hazardous medical waste are two emergent problems in which the agency is involved in cooperative interagency activities.

Pollution monitoring and response is again another Federal interagency effort in which the U.S. Coast Guard shares on-scene coordinator responsibilities with the Environmental Protection Agency, depending on whether the spill has occurred in the inland waterways or coastal/offshore areas. And, the agency views the Marine Environmental Protection responsibility in a systematic fashion extending from preventive measures in the operation of vessel traffic systems and anchorages, the enforcement of laws governing weaterfront facility safety, and the stowage of explosives, oil and hazardous cargo on board vessels ... to the remedial responsibilities for responding to oil spills and the release of other harmful substances in the inland marine, coastal and offshore area.

Closely related to the Ports and Waterways, Safety and Environmental Protection responsibilities is a designated Bridge Administration program. The Coast Guard assumed responsibility for administering bridges over navigable U.S. waters in 1967, shortly after the Department of Transportation was formed. This encompasses approximately 18,000 bridges in the U.S. from foot bridges to the Verrazano. The Coast Guard is charged with ensuring safe and unobstructed navigation through or under bridges, while meeting the needs of other modes of transportation, such as car and truck traffic on the bridges. This program may soon be transferred to the U.S. Corps of Engineers; and, hopefully, more resources can then be directed to coastal and other bluewater concerns.

Recreational Boating Safety - In 1980, 81.8% of the population lived in America's coastal states and the current projections indicate an increasing movement of population concentrations to the Coastal Zone cities, and clusters of beaches, bays and harbors in the megalopolitan corridors. Concomitant with this trend is a rapid growth in recreational boating, now a national maritime pastime with about 70 million boaters (Operators, passengers, skiers, hunters and fishermen) and over 15 million recreational vessels. To meet this national recreational and economic activity, the U.S. Coast Guard administers a comprehensive program of assuring manufacturers' compliance with standards, and facilitates safe operation and enforcement through dual Recreational Boating educational programs. These tasks are pursued through the 40,000 member Coast Guard Auxiliary in the form of formal public education courses, courtesy boat examinations, and regatta patrols, as well as a $30 million financial grant system to the states and jurisdictions for carrying out the significant education and enforcement efforts. Given the size of the constituency, this is a significant, intergovernmental responsibility in which the Coast Guard's role is largely managerial and less asset-intensive. However, the boating population remains the Coast Guard's largest, most identifiable constituency.

Defense Readiness ... is a fundamental underlying mission and the U.S. Coast Guard is the Nation's oldest continuous seagoing service with a record of participation in every defense encounter since the birth of the nation. Federal law requires that the U.S. Coast Guard be at all times a military service and a branch of the Armed Forces within the Department of Transportation. The only exceptions are in time of war or as directed by the President when it operates as part of the U.S. Navy. In 1984, following a Memorandum of Understanding between the Secretary of Transportation and the Secretary of the Navy, Coast Guard Atlantic Area and Pacific Area Commanders were designated by the U.S. Navy as Maritime Defense Zone Commanders for their respective coastal area. They are tasked by CINCLANTFLT and CINCPACFLT to exercise command and control over DOD and Coast Guard forces supporting maritime defense. Coast Guard Area Commanders assume additional responsibilities to plan, direct and conduct defensive operations in the safety of ports, harbors and navigable waters. In addition, they will support other commands and agencies in anti-submarine warfare, mine countermeasures, protection of shipping, intelligence, civil defense and related matters.

To support and complement the Defense Readiness mission, the U.S. Coast Guard maintains a 13,000 member Reserve Program, including men and women, to provide qualified individuals and trained units for active duty in time of war or national emergency. In addition to its role in national defense, the Reserve augments the active service in the performance of peacetime missions during domestic emergencies and during routine and peak operations.

Research and Development - In support of all Coast Guard operational programs, a modest but mission-specific, engineering, research and development program has been deigned to apply state-of-the-art technology to the agency's needs.

The Coast Guard's R&D support tasks, like its operational program, are characterized by both an intergovernmental and international perspective. Interagency cooperation increases the pool of expertise, and reduces redundancy and costs in research and development. There has been a significant measure of US-Canadian cooperation in this support program.

In addition to its R&D effort, the U.S. Coast Guard maintains a separate Marine Science Activities program, which is entirely applied oceanography in support of Coast Guard missions. It includes the conduct of the International Ice Patrol, begun in 1914 following the TITANIC disaster, to detect and chart iceberg movement into shipping lanes; operational support for NOAA's data buoy project; early marine and coastal weather observation and reporting from 124 Coast Guard shore stations and 81 cutters; and several other Federal

interagency projects such as ocean sounding. The Coast Guard has been involved in SEASAT, the ocean-observing satellites, participating in the operational requirements for the Alaskan Synthetic Operative Radar (SAR) Facility for sea ice and iceberg reconnaissance. Operational ocean products from future satellites will be used to assist in predicting surface object drift in the ocean for Search and Rescue, International Ice Patrol, Marine Environmental Protection and Response, and Law Enforcement.

Infrastructure: Budget and Personnel:

To carry out the foregoing missions the U.S. Coast Guard received an estimated $2.5 billion in its FY88 budget, including some 1.8 billion in operating expenses. Its manpower level is just over 38,000 military with an officer corps of 5,000. It has a civilian complement of about 5,000 and is assisted part time by some 40,000 Coast Guard Auxiliarists. Women are significant in the Coast Guard; the Academy was the first to accept women cadets and the service was the first in assigning women as CO's of armed vessels. It now has approximately 190 female officers and over 2,300 women enlisted personnel.

International Participation:

In addition to the international involvement previously cited, the U.S. Coast Guard is a major participant in international affairs, both in the furtherance of U.S. foreign policy as well as in the interest of the international ocean community at-large. The Coast Guard assists other nation's marine agencies under the provision of over 50 international instruments, exclusive of an additional number of international fisheries agreements.

The Coast Guard has assisted these other maritime agencies in training foreign nationals within the U.S. from over 60 nations ranging from Argentina to Zaire. This training includes, but is not limited to, cooperation with the Department of Defense's Military Assistance Program and training in accordance with LORAN agreements between the U.S. and other nations. It has provided mobile training teams to nations such as Jordan, Saudi Arabia and Haiti and all in the varied training areas of search and rescue, merchant marine safety, port security, law enforcement and aids to navigation. In addition to those forms of cooperation identifiable as 'training assistance,' "operational" forms of assistance have also been provided, such as dispatching oil pollution strike forces to the Straits of Malacca and Magellan and elsewhere.

Whether one acknowledges the marine scientific and operational functions of conducting the International Ice Patrols, providing operational and technical direction to LORAN stations overseas (under various treaties and agreements), comprehensive participation in major UN/IMO subcommittees, or representation within the special inter-American Port and Harbor conferences and the UNCLOS itself, the U.S. Coast Guard's international, socio-technical assistance is extremely broad. The international involvement is also performed within a healthy interagency arrangement with EPA, NOAA, the National Science Foundation, the Department of State and other Exectuive components. However, the Federal interagency and international participation must, at some point, be more cohesively and consistenly organized within the Coast Guard itself and in a policy-integrated manner, if the agency's fullest measure of 'External Affairs' benefit is to be achieved.

In July of 1986, a Coast Guard flight crew flew a C-130 to the Peoples Republic of China to demonstrate its Search and Rescue capabilities to senior military and government officials. The PRC's SAR interest has been motivated by the start of offshore drilling operation for oil in the South China Sea and some severe accidents they have experienced in ferrying people from the mainland to the rigs. The Coast Guard Captain who headed the project was born in Beijing and is fluent in Chinese.

On the more diplomatic and mini-Olympian front, the Coast Guard was a major participant in the SAR week, Marine Commerce Week, and 'Sea the Future' Symposium of EXPO the '86 World's Fair in Vancouver, B.C. The participation in sporting events with the other nations' Coast Guard forces, and the visits of helicopters and the cutters MORGENTHAU and BOUTWELL, were designed to accommodate that fair's theme of 'Man in Motion ... Man in Touch' with an operational presence. Yet, these aforementioned activities are only a few of the intergovernmental and international cooperative projects in which the U.S. Coast Guard is involved.

THE U.S. COAST GUARD AND NATIONAL OCEAN POLICY

The Coast Guard is an 'Armed Service and More.' And, to accommodate all of these responsibilities, it must employ a multi-mission system of management which is designed to effect the optimum utility of whatever level of physical, financial and personnel resources is available. Also, to perform the multiple range of missions, the vessels and aircraft must be so equipped with the necessary hardware and state-of-the-art technology; and its personnel must have a corresponding measure of expertise and versatility in their training. So, it seems that the sum total and key elements to this management challenge, at least for the remainder of this millennium, may be 'productivity, and professionalism.' Those twin goals and attributes will apply to both the public sector and private sector. 'Productivity' will become a significant byword and basic barometer of performance. And productivity can be enhanced in a critical path network when interagency and intergovernmental partnerships are maximized.

The Coast Guard's programs reach to the full range of those parameters enveloping in what is circumscribed within the Exclusive Economic Zone; and, in which its mission frame of reference must include policy considerations for maritime safety, transportation, maritime law enforcement, national defense, environmental protection, and of course all other functional policies inherent in its responsibilities for the overall facilitation of waterborne transportation. Those policy considerations will more and more involve interagency, intergovernmental and international coordination as budgetary limitations are imposed; and, national and international oceanic wants and needs are multiplied. To assess these newer dimensions of national ocean policy, the Coast Guard must, like its motto, be 'always prepared'; and such preparation will necessitate fine tuning its key, policy-oriented, and multi-programmatic staffs so they are postured for the future.

Because the U.S. Coast Guard has been a respondent to many initiatives and issues addressed in the name of 'National Ocean Policy,' it had to respond accordingly. For example, in responses to various inquiries and initiatives regarding the extent of interagency cooperation and coordination, it submitted a straw definition to the National Advisory Committee on Oceans and Atmosphere (1971-1985) i.e., it stated generally that "ocean policy is a reflection of energy policy, transportation policy, fisheries development and other forms of economic policy, foreign policy, defense policy, fiscal policy, law policy." That definition, like the theme of a 'Partnership of Marine Interests' designed for Oceans '88, and the octagon logo of intergovernmental players, was fashioned to guarantee apertures for participation by all concerned parties in the national ocean policy formulation process. The agency prototype is based on promoting the highest degrees of interagency and intergovernmental consensus.

In 1978, to provide a model for interagency cooperation, the U.S. Coast Guard established the 'Ocean Principals Group' as an ad hoc forum within the Executive Branch - to discuss marine interagency issues which have become mutual commonality and concern. That forum still meets for quarterly luncheon discussions and includes as members 'Principals' from the Office of Science and Technology Policy, the National Security Council, the Coast Guard, NOAA, the Navy, MARAD, the Army Corps of Engineers, the U.S. Geological Survey, the Minerals Management Service, the Environmental Protection Agency, NASA, the National Science Foundation, the Energy Department and State Department. The Coast Guard, as founder, remains as Executive Secretary; however, the chair is rotated quarterly with the meetings. It works because it has a comprehensive roster of all the Federal interests, is objective, and is one high-level arena and captive audience where emerging interagency problems can be headed off or mitigated; and where each agency's concerns can be introduced - and, it takes place within a very informal setting.

Because the U.S. Coast Guard implements such a variety of inland marine, coastal and trans-oceanic, national and international activites - with an extensive multi-mission infracture of over 200 helicopers and fixed wing aircraft, over 240 large vessels, over 2,000 small boats and over 1,200 shore stations, and shares interagency concurrent jurisdiction for many of its statutory responsibilities, it interacts closely with all the players in the intergovernmental arena. The Ocean Principals is informal; there are other informal arrangements.

To assure appropriate networking with other agencies and the private sector, it has at last count, over 80 memoranda of understanding with entities ranging from the American Bureau of Shipping to the Veterans Administration, from the states of Texas and Florida to Environment Canada and other nations.

To participate formally with industry and education in the intergovernmental arena, the U.S. Coast Guard has both chaired and directed the marketing and press operations for the biennial, Washington-based "Oceans" conferences. Those conferences have been identified as germane Federal participation under the Presidential Task Force on Private Sector Initiatives, and heralded a lasting 'Industry-Government-Education' partnership. The theme has ranged from 'Partners in Progress', to 'Designs for the Future', to 'Science, Engineering and Adventure,' to this year's theme of 'A Partnership of Marine Interests.'

Returning again to the nature of ocean policy and the notion of a unique interagency and international perspective, it is my view that national government policy formulation is evolving into a newer, 'state-of-the-art' process. We can thank the French for recognizing the press as the Fourth estate of government. In recent years the public policy pundits have discerned the interest groups, or 'gatekeepers,' as tantamount to the Fifth Estate. Now, I think we might recognize the roles of the private sector and public and special interest groups in the national public policy process as the Fifth Estate; the roles of think-tank et. al. educational groups as the Sixth Estate; the states and localities as the Seventh Estate; and the international community of interests as the Eighth Estate. We might indeed call the configuration an 'Ocean Policy Octagon.' The array is again depicted in Figure #2. Whatever value in such modeling, the bottom line is that institutionalized cooperation is far better than the episodes of intransigent confrontation which can occur if all concerned interests are not consulted..

A POSSIBLE DIRECTION FOR THE COAST GUARD IN INTERNATIONAL AFFAIRS

Given such an expanded perspective within the Coast Guard, and given the origination and nurturing of a 'Partnership of Marine Interests,' a major initiative is suggested to posture the Coast Guard as a more viable instrument of foreign policy. It is stated as follows:

given the myriad of national missions with which the agency has been tasked;

given the experience of working with many mechanisms for national interagency and intergovernmental and international cooperation;

given the extensive involvement of the U.S. Coast Guard in the area of international marine technical assistance, as manifested in cooperative projects with a myriad of nations; and given its unique 'white ship' receptivity in international participation in SAR agreements and other multilateral events (EXPO '86, etc.); ... how might the Coast Guard's utility as a significant instrument of American foreign policy be more properly recognized and utilized in the furtherance of overall foreign policy and defense objectives?

Can the military/bluewater mission base be further enhanced by greater technical and operational assistance to coastal nations, particularly developing states now acceding to various zones of coastal control, and in return gain support for U.S. seapower and other national and allied objectives? Is there a future national defense role where an expanded Coast Guard can provide such 'transfer of expertise' and 'transfer of technology' in close cooperation with private sector firms such as TRACOR Industries, now involved in the design of a master coastal surveillance system for the Government of Indonesia? Might this also be a variation of the original mandate of the Presidential Task Force on Private Sector Initiatives? Might it provide some of the agency's share of privatization overtures and offset the displacement or dilution of other needed resources?
To reinforce this national and international initiative, perhaps the Coast Guard could also, as a follow-on to its EXPO '86 participation, take the leadership for establishing an 'International Association of Coast Guards?'

THE CONCEPT OF EXTERNAL AFFAIRS FOR THE U.S. COAST GUARD

During the remainder of this millennium, the United states, as well as other seafaring nations, will advance their focus on the coastal regions and oceans in order to satisfy emerging economic and recreational needs, meet national defense requirements, and concurrently plan for the significant socio-environmental concerns associated with accelerated ocean resource and ocean space development. Oceans '88 has been offered as a major milestone in this coastal and offshore evolution. The U.S. Coast Guard can also be a major milestone in the continuing national ocean policy evolution, but its internal organization must match the external world with far greater compatability.

Given the complexity of the managerial challenges ahead, and the reality that budgetary resources must be utilized prudently, my perspective is that a new 'Partnership of Marine Interests,' integrating the diverse industrial interests, Federal interagency particpants, the state governments, the range of comprehensive intergovernmental groups and the relevant international interests should be pursued by the Coast Guard as well as the ocean community at-large. A more precise integration of external activities must take place within the Coast Guard if it is to match its internal organization with the challenges and opportunities presented in the external ocean policy arena.

If the Coast Guard is to come of age and develop any carefully considered, proactive strategies to survive in an increasingly austere, national budgetary environment, it should establish: first, an 'External Affairs Secretariat;' and later when oportune, an External Affairs staff directed by a flag officer.

Such an organizational component should integrate its Congressional Affairs Staff, Governmental Affairs Staff (the integrated Federal interagency and ('within the Beltway' groups), International Affairs Staff and Public Affairs Staff (Media Relations, internal communications and 'Beyond the Beltway' community affairs functions), so that their respective directors can discuss external interrelationships more cohesively.

Such a senior staff is further necessary: to relate internal management to the reality of how policy is formulated and budgets are orchestrated in the external world; to provide a continuum of critical analysis and insights on 'Within the Beltway' interest group initiatives and needs; to provide the integrated feedback and necessary recommendations for the Commandant's decision-making; to design responses and innovations to relate short-term, reactive 'Event Management' to longer term, proactive 'Trend Management' ... or indeed 'Survival Management in Strategic Planning;' to articulate a more consistent voice and posture with key Legislative, interagency and intergovernmental groupss; to chart the future mission base of the Coast Guard in closer communion with its critical support groups; and, enhance its resource base to implement, and take fullest advantage of, the evolution of inland marine, coastal and trans-oceanic needs.

The Coast Guard can be a leader and designer of the marine policy agenda, help draft new mission areas, and concurrently enhance its status in the budgetary allocation area. To paraphrase Franklin Delano Roosevelt, it must generate "the will to prosper as well as to survive."

CONCLUSION

I close my paper with the notion that the more we meet, within international fora such as Oceans '88 for professional and purposeful exchanges and the associated camaraderie, we will recognize that the short-term decisions we make for immediacy, visibility and independent needs, sooner or later can and must be reconciled with the longer-term decisions for imagination vision and interdependent needs. Federalist James Madison may have observed that man is inclined toward factions, but fellow Bostonian John Adams expressed more profoundly that, "if we don't all hang together surely, we will all hang separately."

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This article is an elaboration of my presentation before the 'Sea The Future' symposium of the EXPO '86 World's Fair, Vancouver, B.C., September 14, 1986.

The views offered are solely my own and do not necessarily reflect any current official position of the United States, the U.S. Coast Guard/Department of Transportation or other federal entities. I do not suggest however, that the government would have any occasion to disfavor the loyal and presumably positive, accurate and - I trust - helpful thoughts I have conveyed for my colleagues in that public policy domain we call the "ocean community." -- Edward W. Cannon

THE UNSPOKEN YET VITAL PARTNERSHIP BETWEEN THE UNITED STATES COAST GUARD RESERVE AND THE PUBLIC SECTOR AT LARGE

Petty Officer Second Class Louise A. Berney, USCGR

There is a component of each branch of our armed forces known as the reserve. The intention here is to focus upon the United States Coast Guard Reserve.

The words "reserve" or "reservist", within the USCG, are in many ways misnomers. The USCG is the singlemost counterpart of all the branches of the armed forces whose missions dictate constant contact with the public *. This is also true of a Coast Guard Reservist in an IDT (weekend drill) status. However, let's carry that several steps further. The interaction amongst USCG reservists and the public does not end at 1700 on a sunday at the close of an IDT weekend. A reservist does not "reserve" his USCG - public partnership activities to two days per month. It operates on a daily basis in an "unofficial" capacity throughout the remainder of the month.

The members of the USCGR bring their Coast Guard know-how to the public daily. The premise is that, in this, there is an exchange of ideas, expertise and understanding between the USCG and the public that goes beyond the reservists' official military capacity. This is the unspoken partnership. It does exist. It is beneficial to both the USCG and the public. It is not a funded function yet has positive econimic ramifications as well as positive public relations benefits. It does deserve to be brought to the forefront.

The intricacies and varieties of the exchanges between reservist and public have been observed for nearly five years. They have been scrutinized, questioned, ruminated upon, dissected and even participated in by this author. This has included speaking with over 250 reservists from every state and Puerto Rico. Perhaps this may not statistically be considered a large cross section out of approximately 12,000 members of the USCGR. However, direct conversation and detached observation has provided candid, unsolicited input.

Of the 250 plus reservists, their civilian occupations included science, academia, law enforcement, firefighting, indusrty, technology, naval archictecture and engineering, environmental consulting, port operations, diving, government and recreation. There is a two way street that has developed between the reservists' USCG role and their civilian (public) roles. Each of these 250 reservists were examples of mutual benefit to the USCG and the public. It evolves naturally with the reservist serving as the catalyst and enabler for the partnership pathway.

The following examples will serve as a representative sampling. No statistics have been included since this good will and exchange of expertise cannot be quantified, nor for the intended purpose of this expose should it be statistically manipulated.

(* For purposes of this expose, public is defined as all academic, industrial, governmental, scientific, maritime/marine, persons and business entities outside of the USCG and USCGR.)

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A reservist on a civilian business trip stops by a USCG district office to visit. This sparks a dialogue amongst USCG personnel and the reservist. It so happens, coincidentally, that there has been a significant pollution incident at a petrochemical plant that handles the same products as the plant the reservist manages. The outcome of this "unofficial" dialogue resulted in the USCG personnel gaining new insights into the realities of daily plant operations and of non-intentional pollution incidents that occur at facilities who are typically in compliance with regulations. This occurred in such a manner where none of the parties in the dialogue had to act defensively. On the other hand, the reservist gained new insights as the the position and responsibilities of the USCG in such a matter. He could then use this to foster ongoing cooperation and understanding between plants such as his and the USCG. The perspectives gained by both entities were "unofficial", yet valuable.

A group of reservists have been invited to visit a Coast Guard cutter. In the engine room, one reservist noticed a USCG junior officer intently working on a problem with an engine component. After several moments of observation, the reservist engaged in a casual conversation with the officer. Soon after, they were approaching the technical problem together. The reservist happened to be a naval engineer/architect who designed engine rooms such as the one on the cutter. The officer learned valuable "tips" on the quirks of the system. The reservist then returned to his company to relate to them the temperment of the engine system in the field under actual daily operation. Another partnership develops.

Several local police officers (reservists) patrol a major port area which is also under the jurisdiction of the local USCG Marine Safety Office. The police officers and MSO personnel are found discussing access to the port facilities. The police officers (reservists) know the most rapid access from the shoreside. The MSO personnel know every little nook and cranny of the port facilities and waterside access. This conversation resulted in the MSO personnel becoming aware of alternate and more rapid access that they had no opportunity to previously explore. The police officer (reservists) learned of the more minute details of the port area and thereby could be more effective to the public.

"No way" shouted a reservist in a class being attended by 29 persons (14 active duty USCG and 15 reservists) and being taught by a combination of regulars and reservists. The outspoken reservist was a vessel agent. The discussion involved the economic realities of the shipping industry versus the Codes of Federal Regulation overseen by the USCG. Reasonable solutions and new perspectives considering both economic reality and regulatory obligation develop. The active duty personnel will be more aware of this in future inspections. The reservists in their civilian roles will be cognizant of regulatory responsibility. In the field, both entities will use these insights to accomodate needs and responsibilities. The instructors can then pass this on to future classes, thus enhancing the learning process.

A company president approaches an employee (a reservist), posing a question about planned bridge construction on a major highway project. The bridge will cross navigable waters. The reservist has patrolled these waters during drill weekends. She then calls USCG Captain of the Port for the particulars of a permit process. COTP personnel explain the criteria to the reservist and do so easliy since the reservsist is familiar with the area due to her USCGR patrols and knowledge of USCG terminology and regulation processes

and understands the USCG terminology and basic policies On the other hand, the COTP personnel query her to explain more on how a major thoroughfare's bridge crossings come into being from the earliest stages to completion. The engineers at the reservist's consulting firm are confident of the information from the USCG that she passes to them since they are aware of her dual perspective in the matter. Partnership once again develops.

These are but a few examples cited to show such "unofficial" exchanges between the USCG and the public occur on a daily basis. These are partnerships far more common and beneficial than we realize. The dual perspective (reservist as civilian and reservist as Coast Guardsman) lends itself well to fostering true understanding since exchanges are casual (without the defensiveness that develops in many official exchanges) and are candid. Best of all, it is of great economic benefit. These parnerships require no purchase orders and no budgeting and save time. The economic benefits are inestimable.

The unspoken and unofficial role of the United States Coast Guard Reservist is truly that of educator, arbitrator and facilitator. There is a dual perspective and combined knowledge (USCG and public) that reservists possess due to their duality of roles. They bring this to both the United States Coast Guard and to the public. They are not "officially" ordered or obligated to do so, nor are they paid to do so. It simply develops and is for the benefit of all concerned. Herein lies a true partnership of marine interests.

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