UNOLS Small Research Vessel Compendium

2004

INTRODUCTION
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The Oceanographic community, as represented by University National Oceanographic Laboratory System (UNOLS), has provided myriad documents on research vessels. The Fleet Improvement Committee (FIC) has investigated new ship designs and developed Science Mission Requirements (SMRs) for ship classes I through IV. Missing in the FIC studies has been a comprehensive look at “small” research vessels. It is difficult to develop mission requirements that would fit all or even most cases because small vessels are most often designed for a specific mission or are designed peculiar to a specific area. Recognizing this, the UNOLS Research Vessel Operators’ Committee (RVOC) took on the challenge to write a compendium for small research vessels. This compendium or primer is provided in the papers that follow.

The authors of the papers contained herein were volunteers from the marine industry and academic oceanographic community. They represent hundreds of years of experience in research vessel operations and provide a broad perspective on vessel design, construction, safety, outfitting, and operations.

The opening paper titled Requirements and Capabilities sets the stage for this primer providing the procedure for small vessel designs. Regulatory requirements, an important consideration in building and operating a small research vessel, follows. Small boat safety followed by a comprehensive treatise on marine insurance and liability, by Dennis Nixon, provides a legal perspective to small vessel operations.

One paper on stability and one on sea-keeping for small research vessels provide an in-depth study on these subjects. Vessels of 30 feet to over 100 feet in length are addressed in the conversion paper. A generous listing of successful conversions to research vessels is provided. A list of outfitting for small research vessels, divided into three sizes of boats follows. A paper on propulsion systems for small research vessels is next.

The following three papers deal with various hull forms for small research vessels. These include monohull, small SWATH vessels and small catamaran R/V designs. The final paper is a study of research vessel procurement.

Each paper stands on its own. Together they comprise a broad spectrum of information about small research vessels. This primer is provided as a resource for the entire oceanographic community and is posted on the UNOLS web site to permit access for all interested persons.

You can access the inventory of Small Research Vessels at UNOLS Institutions on the UNOLS Website, by searching "UNOLS Small Research Vessel Inventory" in the Document Search Feature.

Section Title
Author

SECTION 1
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REQUIREMENTS AND CAPABILITIES

The requirements (and capabilities) for a research vessel usually are set out in two general categories: Platform Requirements and Scientific Requirements. The former category includes size, speed, accommodations, habitability, construction, propulsion, endurance, electronics, regulatory factors, and so on. Science requirements often overlap with platform requirements but go on to include mission definitions, laboratories, work decks, deck equipment, instrumentation, etc. Often not explicitly stated but of driving importance is cost, both construction and operating cost. This discussion will be concerned chiefly with science mission requirements and will address platform requirements only where they are affected by science requirements.

Whereas the science mission requirements for larger seagoing research vessels generally are similar, the requirements for small vessels can differ considerably due to varying coastal environments and specific priorities of the operating lab (training, disciplines and scope of operations).

In planning for a new (or conversion) research vessel, the usual sequence of events is as follows:

- Mission Definition
- Mission Requirements
- Concept Design
- Preliminary Design
- Final (Contract) Design

The "Mission Definition" and "Mission Requirements" should be prepared by the prospective operator in conjunction with user scientists. The design phases should be undertaken by a qualified naval architect with oversight by a committee of intended users.

Mission Definition

The Mission Definition or Profile is a brief statement setting out the principal use (or uses) of the proposed vessel, intended area of operations (and environment), scientific disciplines, operating capabilities and scientific accommodations.

An example of a Mission Profile is that prepared by the Woods Hole Oceanographic Institution for a small SWATH coastal research vessel.

- *Operational capability during all seasons off the Northeast Coast, making short cruises of up to ten days and distances no further than Bermuda* (650 *miles).*
- *Coastal science studies in bays and gulfs including multi-anchor moored stations. Open sea operations in all science disciplines including net tows, deep sampling, ROVs, diving support, seismics, coring and buoy work.*
- *Equipment and instrument testing during development stage needing platform capability (size and stability) simulating larger ships where equipment ultimately will be used*
- *Student training and practicum.*
- *Rapid response to oceanographic and atmospheric " events " possibly involving heavy weather transits at reasonable speed*
- *High flexibility in science outfitting -all winches, cranes, .frames, etc. to be totally portable through the use of deck boltdowns.*
- *Seakeeping of paramount importance and performance on-stations (including dynamic positioning) -stopped or slow speed- being more important than cruising. Lab and berthing accommodations to support J* 2 *science personnel.*
- *Total science payload (may reach* 20 *Ltons) highly variable and may include winches, vans, ROVs, cranes, and itinerant deck I~ such as buoy moorings.*

The Mission Definition is the starting point in the development of the vessel requirements. It is a brief but important statement. If the subsequent design development proves too costly or incongruous to the intended vessel, design review should include the mission profiles and be amended accordingly. The next step in the design process is Mission Requirements.

Mission Requirements

Following the mission definition, the Mission Requirements become the guidelines for directing the design (or conversion) of a research vessel. The science requirements define vessel and shipboard needs for operational capabilities, working environment, science accommodations, and outfitting. From the requirements can be deduced the size, speed, endurance, and overall capability .Additional aspects -habitability , safety , and cost are important factors and can have a significant impact on ship design, but these are either mandatory or statutory and usually are defined elsewhere

The UNOLS Fleet Improvement Committee has established a standard format for presenting science mission requirements. It includes the following categories:

- *General*
- *Size*
- *Endurance*
- *Accommodations*
- *Speed*
- *Seakeeping*
- *Station Keeping*
- *Ice Strengthening*
- *Deck Working Area*
- *Cranes*
- *Winches*
- *Overside Handling*
- *Towing*
- *Laboratories*
- *Special*
- *Science Facilities*
- *Vans*
- *Workboats*
- *Science Storage*
- *Acoustical Systems*
- *Navigation! Positioning*
- *Internal Communications*
- *Exterior Communications*
- *Ship Control*
- *Instrumentation*

In order to suit any particular application, these categories may be expanded or reduced. This is especially true in the case of smaller vessels where many of the categories may not be applicable, and special needs may dictate others.

Each of these categories is discussed briefly in the following sections:

General -This is a restatement of the Mission Profile along with any other design requirements. For smaller day, or short cruise, vessels, the educational use is often important and should be emphasized here or in a separate category.

Size -Although size ultimately is determined by the requirements, the prospective operator may consider it important to state a limiting size either in length, draft, or tonnage, or all three. Regulatory aspects often are a factor in a size limitation.

Endurance -This is based upon scope of intended cruising and nature of operations. The endurance formula should include a percentage of cruising and on-station work. The cruising range can be stated here.

Accommodations Here are stated the intended number of scientific personnel and provision for berthing arrangements. The current trend is for two person staterooms with a common WC between two staterooms. Crew size usually is an outgrowth of the design and or regulatory factors, but may be stated here as a limiting number.

Speed -Speed can be a scientific requirement when the duration (and cost) of a cruise becomes an important factor. There are current instances where higher speeds (greater than 20 knots) have been a major design requirement. An optimum speed can be calculated using cruise costs (fuel, etc.) vs. "time" consumed. It comes, however, at an additional "price". The design often results in a narrow beam, uncomfortable vessel not otherwise suited to work or cruising in a seaway. In heavy seas such hulls cannot make the intended speed and the greater cost and engine size is wasted. Furthermore, experience has shown that most research vessels carry greater loads with deeper drafts than the naval architect designed for with the result that the design speed cannot be achieved

Careful attention should be given to all factors when a high cruising speed is considered.

Seakeeping -There is almost full agreement by seagoing scientists that seakeeping, both underway and on-station is one of the most important of requirements. Seakeeping is often misnamed "stability". The latter is a safety tenn and not necessarily a measure of a stable environment for which seakeeping is a preferred term. A stiff vessel, i.e. one which rolls rapidly with high accelerations, can have high stability but afford poor seakeeping.

Seakeeping is important to ensure that work can be carried out safely, effectively, and continuously, both on deck and in the lab. This is especially true in smaller vessels on short cruises where excessive motion can render the entire cruise unproductive.

A reasonable seakeeping goal for a research vessel of 80-100 ft. is to maintain headway and/or science operations in sea state 4 (4-8 ft. seas) and limited work in higher sea states. (See Appendix B) In new construction, seakeeping should be a principal consideration of the naval architect. Improvements in conversions can be achieved by ballasting, larger rolling chocks (bilge keels) and other roll suppression systems such as anti-roll tanks, active fins, and paravanes (flopper-stoppers).

Station-keeping -Although related to seakeeping, station-keeping includes the added element of ship control at the best, or desired, heading on station or along a given track line. This is a function of the maneuverability of the vessel including propulsors and control systems. On smaller vessels this traditionally has been accomplished manually using the screws and bow thruster (if available) by the mate on watch. Success usually depends upon the skill of the operator, twin screws, and the effectiveness of the bow thruster.

A typical station keeping requirement is to maintain station at best heading in 25 knot wind, sea state 4, and one-knot current.

A bow-thruster is desirable but not without controversy. The two chief uses, mooring and station keeping can dictate different installations and power. For the former, a simple tunnel thruster with 50-100 hp itinerant operations usually is adequate. For station keeping, twice the power with continuous operation and an azimuthing thruster may be needed. Experience has shown that on a small vessel a bow thruster is noisy, is located close to the sleeping quarters, and generally is not used. In order to be effective, a bow thruster should be readily available. When better station heading is needed (e.g. bow thruster), starting it from the conn should be available so it is not neccessary to wake up the engineer to start another generator to place the bow thruster on line.

Dynamic positioning, becoming more common on larger vessels, is now getting attention by small vessel operators. Here the added requirement for excursions no greater than 50 meters and plus/minus 5 degree heading, requires automatic propulsion control systems with input from GPS or acoustical beacons. Experience has shown that dynamic positioning without a stern thruster or azmuthing propellers is unsuccessful, and that the quick response of smaller hulls is difficult to control. Until more experience is gained using dynamic positioning on smaller vessels, a requirement for its use should be viewed with caution. A stem thruster, however, might be well considered even to the exclusion of a bow thruster. Norwegian vessels frequently have stern-thrusters only and report good results especially in acoustics where a bow thruster may be a chronic problem for echo sounding.

Ice Strengthening -This is a matter of regional consideration and inclusion as a requirement should stem from the mission definition. If ice strengthening is considered necessary, the various ice classes defined by the American Bureau of Shipping should be consulted. If work in ice (and cold weather) is a requirement, then additional requirements for protecting personnel and work on deck should be considered.

Deck Working Area -The layout of the science work deck is extremely important in the design of any research vessel. In a small vessel, the tradeoffs between deckhouse and open deck area must be carefully considered. As a general rule, one-third of the main deck area should be given over to science work. This usually is the stern area although several successful R/V's have had the work area in the waist or forward area. However, in view of lesser vertical accelerations in the after area, and towing requirements, a stern work deck is preferable. Important requirements for the work deck include"

- .It should be as uncluttered as possible; hatches should be flush; equipment such as capstans, bitts, cranes, frames, winches, etc should be portable.
- .Deck should be flat or have minimum camber.
- There should be bulwarks with cleats and tiedowns at frequent intervals. Pipe railings should be avoided. Several (if not all) bulwark sections should be removable.
- .One inch threaded boltdown sockets should be installed on a 2-ft. grid pattern for the installation of portable equipment.
- The stern quarters should be as square as possible in order to provide maximum railing and workspace.
- All workdeck(s) should have multiple access for power, fresh & sea water, air, and hydraulics, and cableways for data & communication lines.

Cranes -A crane (or cranes) is an essential item of R/V shipboard outfit. It should be specified to match the vessel size and anticipated uses. A typical installation is a main crane located at the forward end of the work deck or on the 01 deck overlooking the work deck and able to reach most of the work deck. It should be able to handle weights up to, say, 5,000 lbs over the side and 1,000 lbs. fully extended over the stem.

Cranes can be either telescoping or articulated with the choice usually at the operator's preference. A telescoping crane usually has a greater capacity and reach for its weight, but an *r* ~ articulated crane is more versatile and eliminates the danger of pendulous weights when working at sea. A telescoping crane when properly braced can be used for fairleading overside wires and towing equipment. Such work will shorten the life of an articulated crane and/or damage it.

In addition to the main crane, a smaller auxiliary crane is useful -usually as a portable articulated type able to be placed at several locations on the work deck or even forward.

Winches -Oceanographic winches are the primary tools of a research vessel. The kind and sizes of winches along with the installed wires and cables determine the ships basic capability for work at sea. Science requirements should state the type, number, and size of winches to be installed. Common terminology used in describing oceanographic winches and wire includes:

- **Hydrographic Winch** -A winch carrying mechanical wire, usually 3/16" or 1/4", used chiefly for sampling in the vertical water column with Nansen or Nisken bottles. Also for small net tows or bottom sampling grabs-
- **CTD Winch** -A winch usually similar or identical to the Hydro Winch but equipped with conducting cable usually 1/4" or 5/16" (0.322) used for electrical or electronic instruments connected to deck units via the conducting cable and slip rings. These include crus, rosettes, small sampling nets, thermal probes, etc. CTD winches and Hydro winches often are interchangeable.
- **Trawl Winch** -A heavier winch used for trawling, dredging, or coring and equipped with mechanical wire usually 3/8" to *1/2* (or 9/16" on larger vessels). As the use of electronic instrumentation becomes more prevalent, many operators elect to carry conducting cable on the Trawl winch for use with large controllable

nets (MOCNESS) and towed vehicles. Larger vessels are now outfitted with dual storage drums so that either wire can be used on the same winch. On some vessels the heavier winch by tradition is termed Coring Winch.

The foregoing comprises the basic suite of winches common to most research vessels. This, of course, can be varied widely according to the mission profile and special needs of the users. A key element in any small research vessel is flexibility where portable winches can be brought on and off depending on cruise needs. Important here are the deck boltdowns and power sources.

Two common types of winches are Traction Winches and Drum Winches. The former have tandem driving wheels and the wire or cable is led to separate storage drums. A drum winch both pulls and stores the wire on the same drum. Traction winches usually have better control and the cable is not stored under heavy tension. They are, however larger and more expensive than drum winches and are seldom applied to small vessels. Drum winches are more common on small R/V's. When selecting the appropriate winch for a small R/V .The following factors should be considered:

- **Winch Size** -The common hydro/CTD winch found on large R/V's usually has a capacity for 10,000 meters of 5/16" cable and 75 to 100 hp. The trawl winch is rated for 10,000 meters of 9/16 wire rope or 8,000 meters of 0.68" electromechanical cable. These sizes usually are excessive for a small R/V unless there is a compelling requirement for deep sea capability .A more typical winch arrangement for a coastal research vessel of 75-90 ft. might be two similar hydro/CTD winches carrying 2,000 meters of 3/16- *1/4"* wire rope on one winch and 2,000 meters of l/4-5/16" conducting cable on the other; and a trawl winch with 1,500 meters of 3/8-1/2" wire rope or conducting cable. Flexibility can be achieved by having interchangeable drums.
- **Electric V5. hydraulic power** -Either can be suitable depending on the vessel's power system. Hydraulic power is the more common in smaller vessels. The power source can be an electro-hydraulic power unit or power takeoffs (PTO) from an engine, or both.
- **Level Winding** -For winches spooling more than 500 meters of wire, a level winding device is essential. The most common is a diamond thread; others are available-
- **Wire Monitoring** -This includes metering devices to measure and display the wire out, line speed, and tension. Wire out metering is mandatory in all winches. Others are desirable but not essential on a small R/V .
- **Winch Controls** -On small vessels, the winches usually are controlled from deck stations at or near the winch. There is an increasing requirement that the winch also be controlled from the lab. This capability should be included in all new vessels.

Additional, and important information is contained in the publication ***Handbook of Oceanographic Winch, Wire and Cable Technology,*** 2nd Edition, NSF/ONR, 1989.

Overside Handling -Various frames, davits and other handling gear are required to launch and retrieve overside instrumentation, and are an essential adjunct to the winch arrangement. The most common installations are the overstern A-frame and A- or J-frames for side lowerings. The size and capacity of the frames should match the wires and cables in use. The frames should be ram operated and special attention should be given to adequate inboard and outboard reaches, and to the horizontal and vertical clearances.
It is important that the ultimate strength of overside handling equipment be greater that the breaking strength of the wires or cables in use.

Towing -Net tows and dredging are traditional requirements for a small coastal R/V. More recent requirements that should be planned for include Multiple Opening and Closing nets (MOCNESS), side scan acoustic imagers, and towed vehicles. These and other new equipment require special handling arrangements, deck space, and fine winch speed and ship speed controls.

Laboratories -Along with the work deck and winches, shipboard scientific laboratories are the objects that set research vessels apart from others. Planning for a lab should include the following elements:

- Good Location with suitable access to the work deck and other labs. The Main Lab preferably should be on the Main Deck with direct access to the work deck and to the Wet Lab.
- Size should be determined by the mission profile taking into consideration the number of scientific personnel, anticipated cruise duration, and work use. A typical 90-ft general purpose R/V would have a 400 sq.ft. main lab and a 150 sq. ft. wet lab. Use of the lab as a fore & aft passageway should be avoided; experience has shown that when a lab is used as a passageway, 25% of the available space may be lost.

- Environment including Air Conditioning, Ventilation, lighting, noise levels, and vibration suppression should be carefully planned.
- Flexibility should be planned for including moving benches, cabinetry , sinks and instrumentation on and off from cruise to cruise-
- Cabinetry should be of the highest quality .Experience shows that cheap metal cabinetry deteriorates quickly.
- Electrical Outlets both ships service and clean power should be abundantly located.
- Sink Drains should not go to the ship's sanitary system but should go to a separate neutralizing tank and/or directly overboard.
- Cleanliness should be ensured through the use of suitable materials.

Special Science Facilities -Equipment or installations to support specialized projects as recommended by and agreed upon prospective users should be made part of the Mission Requirements Phase. Examples of these are:

- Science workshop.
- Centerwell .
- Scuba support facility .
- Aquaria
- ROV and AUV support
- Incubators
- Photo Lab.
- Meteorological tower .
- Stern Ramp.
- Coring facility

Vans -Vans can be viewed as a specialized science facility (i.e. "clean lab", scuba support, etc) or can be treated as regular shipboard outfit used as a lab annex, storage, or extra science berthing. They are widely used on larger R/V's and have limited adaptability to smaller vessels, if weight and space are available. If vans are intended for use, they should be explicitly stated as a mission requirement and not become an afterthought. The traditional van is an 8x20 ft. container van converted for shipboard use: insulation, interior sheathing, power outlets, HVAC, cabinetry, etc. They must have at least two exits and must meet other safety standards.

Berthing vans are now required to be approved by Coast Guard. As a general rule, berthing vans should not be carried on the Main Deck.

Workboats -In most cases, a science workboat will be required, if not as part of the permanent outfit, then as requirement for selected cruises (SCUBA support, beach landings) and therefore should be considered in the mission requirements. Stowage location and launching & recovery are the major elements although motor & gas stowage and communications should be included. The rigid hull inflatable (RIB) is the most popular boat in use today although the straight inflatable often may be more appropriate for smaller vessels.

Science Storage -Adequate stowage of scientific equipment and samples is one of the greatest deficiencies in small R/V designs. Storage space in small vessels takes away from other much needed space and usually receives a low priority. It should, however, be included as a mission requirement. The amount of storage space depends on the size of the vessel and average cruise duration. As a general rule the need can be equated to 10% of the laboratory space. A requirement by users for refrigerated storage can be expected.

Acoustical Systems -The provision for science echo sounding and any other acoustical systems should be included in the Mission Requirements. All small R/V's should carry a survey grade echo sounder. A dual channel 12/50 kHz instrument with a paper recorder is frequently used. To this can be added additional systems recommended by prospective users. These include:

- **Precision Depth Recorders** which may require additional transducer(s) and lab space. Ordinarily on small vessels these should be carried only as part of a cruise project.
- **Sub-Bottom Profller** usually a 3.5 kHz system. Experience has shown that such *0! Q* systems are not very successful on smaller vessels. If required, a towed transducer is recommended.

- **Acoustic Doppler Current Profiler (ADCP)** again has not proven successful when installed in shallow draft, light displacement vessels. Some small vessels have used a portable ADCP extended downward over the side while stopped or towed slowly.
- **Shallow Water Multi-Beam System** is a current requirement for small survey vessels. It is, however, expensive and requires elaborate transducer mounts and specially trained operators and data processors.
- **Side Scan Sonar** has proven highly successful as a towed system on small vessels.

- **Color Fish Finders** are popular in the pilot house and are finding increasing use during science work.

Acoustical systems are greatly affected by ship generated noise and bubble sweepdown along the hull. As such, machinery types and mounts, the placement of transducers, and bow shape can be an important factor, and the naval architect should be accordingly cautioned.

Planning should include one or more spare transducer openings in the hull to accommodate new and special project instrumentation.

Navigation/ Positioning -The primary requirement here is for accurate navigation data as an input to the various data systems and to ship control processors. To do this a dedicated GPS is required to be integral with the science navigation system. The advent of the three dimension GPS attitude ("e.g. Ashtech") system can provide stabilized platform reference for multi-beam and ADCP systems. Other advances in electronic navigation may pose requirements in this area. Also, acoustic navigation systems for precise positioning and AUV/ROV tracking may be recommended.

Internal Communications An adequate internal communication system should be provided for commensurate with the size of the vessel. This includes:
- High quality voice communication s throughout all science spaces and working areas.
- Data transmission, monitoring, and recording system available throughout science spaces.
- Closed circuit television monitoring of outside working areas including subsurface performance of equipment.
- Monitoring of all ship control, navigation, environmental parameters, science and equipment performance.

Exterior Communications -A suitable communication system is required for communications with shore stations (including home lab) and other vessels. Depending on the size of vessel and operating areas, this can be accomplished by UHF, VHF, and satellite communications as well as cellular phones. Provision also should be available for facsimile communications and hard copy text. The need for high-speed communication links to shore stations and other vessels should be examined.

Ship Control -A chief requirement is maximum visibility of deck work areas and adjacent sea surface during science operations both from the pilot house and from science control stations (winches, cranes, ROV's, etc).

The functions, communications, and layout of the ship control station(s) should be designed to enhance the interaction of ship and science operations. For example, course, speed, and positioning will often be integrated with scientific operations which require control to be exercised from a laboratory or deck station.

Instrumentation -The science outfit which a small R/V should te prepared to carry and handle should be examined to ensure that there are provisions to install, operate, maintain, and stow the equipment. This applies both to instrumentation carried on board permanently or portable instruments used as needed for a cruise. These include, but are not limited to, the following:

Permanently Installed

- Echo sounders
- CTD System
- Water sampling bottles
- Rosette system
- Expendable bathythermograph
- Surface thermosalinograph
- Fume hood(s)
- Salinometer
- *R/O* distilled water maker Autoclave
- Water deionizer
- Meteorological system

Portable

- XBT probes
- Gravity corers
- Piston corers
- Bottom dredges
- Sampling nets
- Pingers

A description of equipment to be carried on a research vessel is important in arriving at a suitable design. There is a long history of naval architects not being aware of the full extent of equipment ultimately brought on board, with the result that the vessel is more heavy, deeper, slower, and more cluttered than planned for.

Sample Requirements

The UNOLS Fleet Improvement Committee has compiled a set of scienctific mission requirements for various types and sizes of research vessels. In Appendix A, following, the requirements for a small general purpose research ship are reproduced.

Priorities

In any statement of requirements an ordering of priorities is important for the guidance of follow on activities leading to the design phases. In the case of research vessels, the UNOLS Fleet Improvement Committee made a comprehensive survey of the relative importance of mission requirements. The views of many practicing investigators from all disciplines were solicited. The following is the majority viewpoint.

Priorities for Research Vessel Requirements

- Seakeeping
  - Stationkeeping
- Work Environment
  - Lab Spaces and Arrangements
  - Deck Working Area: overside handling, winches & wire
  - Flexibility
- Endurance
  - Cruising Range
  - Days at Sea
- Science Complement
- Operating Economy
- Acoustical Characteristics
- Speed
  - Ship Control
- Payload
  - Science Storage
  - Weight Handling

Most respondents agreed that seakeeping, particularly on station, and work environment were the two top priorities. But the remaining requirements were ranked so closely together that they become of equal importance. The stated requirements then become threshold levels, and any characteristic that falls below the threshold becomes a high priority. For example, speed which is ranked relatively low, above, would become a high priority if a proposed vessel showed a design speed below the required, or threshold, level.

This emphasizes the importance of assigning genuine, realistic requirements. The acceptance of a design characteristic less than the original requirement signifies either that the original requirement was flawed, or that the vessel will not measure up to its intended service.

Concept Design

The concept design stage is the first step in translating the stated requirements into the actual design process. It is a technical and engineering effort done by a qualified naval architect to develop the hull form, machinery, and general arrangements that integrate the various scientific requirements, combining laboratory arrangements, deck handling, outfit, storage and ship control into a single shipboard system. Here the requirements of the regulatory agencies (USCG & ABS) are defined. From the concept design, the prospective operator and users can evaluate whether the vessel thus described is what was really intended.

The scope of a concept design includes:

- Technical description of the design.
- Discussion of the vessel design and its responsiveness to the requirements.
- Summary of vessel specifications
- General arrangement plans.
- Inboard and outboard profile plans.
- Scientific arrangement.
- Machinery arrangement.
- Operating characteristics, including costs.
- Estimated construction cost.
- Artists concept drawing.

The concept design provides the opportunity *for* feedback into the requirements and the testing of the comments and suggestions that ought to be forthcoming at, this stage of the design. It is doubtful whether the next stage of the design process, the preliminary design, will closely resemble the concept design, but the concept design will have served its purpose if it has tested the requirements and permits the next stage to start with any reasonable degree of confidence.

Summary

The foregoing descriptions of the Mission Definition, Science Mission Requirements, and Concept Design are the key elements in the initial planning phases of a research vessel design for new construction or conversion. Because of the greater diversity of missions and sizes of small coastal research vessels, much of this information may not be applicable or may require modification, and additional material may need to be inserted. The main thrust of what is presented, however, has been developed by numerous experienced seagoing investigators and has produced many successful designs.

Attachments

Appendix A

Scientific Mission Requirements for Small General-Purpose Oceanographic Research Ship", UNOLS 1988

Appendix B

Sea State Table

Appendix A

July 1988

Research Scientific Mission Requirements for Small General-Purpose Oceanographic Ship

General: This monohull ship will serve as a general-purpose research vessel with_limited endurance and maximum flexibility of operations. It is fully capable of continuous 24-hour operations. The primary design requirement is to combine multi-disciplinary capability with small size and cost effectiveness. Vessels of this size often serve educational programs in addition to their research work. For this vessel, endurance and cruising speed are secondary to broad operational capabilities and seakeeping qualities.

Size: LOA = less than 150 ft.; BEAM = not less than 30 ft.; DISPLACEMENT =_500 to 650 tons; GROSS TONNAGE = <300 tons; DRAFI' = 7 to lOft.

Endurance: 21 days. Endurance formula should include 50% cruising and 50% on-station. RANGE = 5,000 nautical miles.

Accommodations: 12 to 16 scientific personnel in two-person cabins, under research cruise I conditions. Expandable to 24 with a van. Up to 40 personnel on day trip basis. Crew size < 10.

Speed: 12-13 knots cruising~ sustain 10 knots through sea state 4. Maximum speed = 14 knots. Speed control plus/minus .1 knot in speed range from i 0 to 6 knots. Design trade-offs should favor seakeeping over speed.

Seakeeping: Maintain science operations at these speeds and sea states:

9 knots in sea state 4
7 knots in sea state 5
4 knots in sea state 6

Station-keeping: Maintain station and over-the-side vertical operdtions in sea state 4, without dynamic positioning. Bow thruster.

Ice Strengthening: ABS Class C (ability to transit loose pack ice) may be desirable for one or more vessels of this class, but distinct from a dedicated, ice-strengthened, high-latitude research vessel.

Deck Working Area: Approximately 1500 sq. ft. with contiguous work area along starboard waist =_8 ft. x 20 ft. minimum for CTD and rosette sampler handling. Deck loading at 15001bs./sq.ft."

Heavy duty hold-downs on 2-ft. cente~. Able to accommodate at least one (preferably two) 8 ft. by 20 ft. van yet retaining clear access to stem and waist work areas. Removable bulwarks with hinged freeing ports to provide dry deck conditions in beam or quartering seas.

All working decks with multiple access for power, fresh and salt water, air and cableways for data and voice communications lines. Low freeboard at fantail (3to 5 ft.). No stem ramp.

Cranes: -One articulated crane to handle large and heavy (up to 8,000 lbs.) gear_over both sides, on station and underway, with lateral motion damping, and an outboard reach of 14 ft. on one side. This crane also capable of reaching all working deck arras for-loading and off-loading of equipment (including empty van). Man-rated for launch and recovery of small submersibles. A second, smaller crane with re-location sites forward, midships and aft; articulated for work at deck level and at the sea surface, with weights up to I4,000 Ibs., also usable as over-the-side, cable fairlead for vertical work and light towing

Winches: Two modem winches with state-of-the-art controls providing fine control (0.5 m/min); constant tensioning or with tension accumulator. Wire monitoring systems on both winches, with readouts on laboratory panels and shipboard recording systems, as well as on the bridge. Local and remote control boards. Winches to be re-locatable (in port) to allow reconfiguration of deck layout. Capable of transferring winch drums at sea.

Hydrowinch with interchangeable drums capable of handling up to 30,000 ft. of wire rope, synthetic line or electromechanical cables having diameters from 1/4" to 3/8" or 11 mm standard (e.g. Markey DESSS-5 or equivalent). Slip rings with six conductors.

Trawling winch capable of handling 20,000 ft. of *1/2"* trawling or coring wire or 20,000 ft. of 0.68" electromechanical cable (up to 10 KV A power transmission) or fiber optics cable. Can be operated with interchangeable drums. Slip rings with six conductors. A traction winch. is a possible alternative.

All weather winch control station(s) located for optimum operator visibility of work area and overside gear, with fail-safe communications to deck level, laboratories, and bridge A-frame controls included.

Overside Handling: Various frames, davits and other handling gear to accommodate wire, cable and free-launched arrays. Matched to work with winch and crane locations, and with moveable capstans, but able to be relocated as necessary.

Stem A-frame to have 15-ft. throat (horizontal width at deck level and up to 15 ft. off deck) and 20-ft. vertical clearance, 12-ft. inboard and outboard reaches. Man-rated for launch and recovery of small submersibles. Safe working load of 20,000 lbs. Controls to be located at A-frame and at winch control station.

Towing: Capable of towing midwater and benthic gear at speeds up to 4 knots with line tensions of 20,000 lbs.

Laboratories : Minimum of 1,000 sq. ft. of laboratory space allocated: 75% main lab (including separate electronics lab capability), and re configuration into smaller specialized labs. Wet lab to be located contiguous to sampling areas; main lab with temperature and humidity precisely controlled.

Labs to be located so that none serve as general passageways. Access between labs to be convenient. Dry lab and electronics lab areas with door sills to keep water out. Main lab access to be large enough to accommodate transfer of large equipment items.

Labs to be fabricated using uncontaminated and "clean" materials and constructed so they can be easily maintained in an uncontaminated condition.

Furnishings, HVAC, doors, hatches, cab1e runs, plumbing, and fittings to be planned for maximum lab cleanliness.

Fume hood to be installed permanently in wet lab. Main lab to have provision for temporary installation of fume hood. Hood flues able to withstand acid fumes and situated so no fumes can be drawn back to occupied areas inside or on deck.

Cabinetry shall be of high-grade laboratory quality including flexibility through the use of unistruts and deck boltdowns on 1 ft. centers.

Heating, ventilation, and air conditioning (HV AC) capabilities as follows: labs shall maintain temperature of 70- 75° F in all weather conditions; 25% relative humidity; and 9-11 air changes per hour. Each lab area to have a separate electrical circuit on a clean bus with continuous delivery capability of at least 40-volt amperes per square foot of lab deck area. Labs to be furnished with 110 v and 220 v AC. Maximum estimated laboratory power demand is 50 KV A. Uncontaminated sea water supply to wet and dry labs, and deck areas (including anywhere on the fantail). Compressed air supply to all labs and deck area; supply to be clean and oil free, with lOO Ibs. Service pressure at outlets.

Special Science Facilities: Science shop with workbench, vise, and basic hand and power tools.

Scientific freezer space = 36 cubic ft. @ -20° C, and 50 cubic ft. @ -5° C.

SCUBA support facilities- compressor, water entry platform and ladder, tank storage racks.

Space and capability for setting up an operating station for a small ROY; with deck space for cable payout and coiling, launch and recovery .ROY control center with video monitor, recording gear and communications in the main lab or on the bridge.

Undisturbed air-flow at bow *for* air-sea interaction studies

Van: Capable of handling and carrying at least one standard 8 ft. by 20 ft. portable deck van, which may be laboratory , berthing, storage or other specialized use. Hookup provision for power, HV AC, fresh water, uncontaminated sea water, compressed air, drains, communications, data and shipboard monitoring systems. Van should have close, if not direct access to ship's interior. Ship should be capable of loading and offloading empty van using its own crane at dockside.

Workboats: One 16 ft. rigid hull boat with inboard or outboard power, and at least one 12 !0 16 ft. inflatable boat with outboard power .

Science Storage: Readily accessible 1250 cubic ft. minimum for operator's science support gear and resident technician's stores. Accessible safe storage for chemical reagents and hazardous (non-radioactive) materials.

Acoustical Systems: Ship to be as acoustically quiet as possible in the choice of all shipboard systems and their location and installation. Ship to have conventional 12 kHz, and 3.5 kHz echo sounding systems and provision for additional systems as needed. Transducers to be mounted so as to provide clean transmission and reception from both lateral (tracking) and vertical signals. Three transducer wells with at sea access for servicing and installation.

Navigation/ Positioning: Differential Global Positional System (DGPS) and Loran C with appropriate interfaces to data systems in lab and ship control processors**.**

Short baseline acoustic navigation system,

Internal Communications : Internal communication system providing high quality voice communications throughout all science spaces and working areas.

Data transmission, monitoring, and recording system available throughout science space including van and key working areas.

Closed circuit television monitoring of all outside working areas including subsurface performance of equipment and its handling.

Monitors for all ship control, environmental parameters, science and overside equipment performance to be available in all, or most, science spaces.

Exterior Communications: Reliable voice channels for continuous communications to shore stations (including home laboratories), other ships, boats and aircraft. This includes satellite, VHF and UHF .

Facsimile communications to transmit high-speed graphics and hard-copy text on regular schedules.

High speed data communications links to shore labs and other ships on a continuous basis.

Capability to receive real-time satellite imagery.

Ship Control: Chief requirement is maximum visibility of deck work areas and adjacent sea surface, during science operations and especially during deployment and retrieval of equipment.

The functions, communications, and layout of the ship control station should be carefully designed to enhance the interaction of ship and science operations. For example, ship course, speed, attitude, and positioning will often be integrated with scientific operations requiring control to be exercised from a laboratory or deck working area.

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Appendix B

Sea State		*Height*	
	Description	*Feet*	*Meters*
0	Calm-glassy	0	0
1	Calm-rippled	0 to ½	0 to 0.1
2	Smooth-wavelets	½ to 1 ½	0.1 to 0.5
3	Slight	1 ½ to 4	0.5 to 1.25
4	Moderate	4 to 8	1.25 to 2.5
5	Rough	8 to 13	2.5 to 4
6	Very rough	13 to 20	4 to 6
7	High	20 to 30	6 to 9
8	Very high	30 to 45	9 to 14
9	Phenomenal	Over 45	Over 14

SECTION 2
George Ireland
Regulatory Scheme

30 March 1998

Introduction

The purpose of these notes is to describe the regulatory scheme administered by the Coast Guard that applies to small Oceanographic Research Vessels (ORVs). In general, these regulatory standards address safety, pollution prevention and pollution response. The safety blanket covers safety of persons as well as seaworthiness of vessels.

Background

Regulatory standards are contained in U.S. law (US Code) and regulation (Code of Federal Regulations) and are found in Titles 33 (Navigation) and 46 (Shipping). In general, congress provides enabling legislation for executive branch agencies to implement specific regulations. Therefore, nearly all regulatory standards of concern to a marine manager can be found in the Code of Federal Regulations. While the Coast Guard is the primary agency that deals with Navigation and Shipping, there are about 15 other agencies that enter this arena from time to time. Examples are FCC for communications, HHS for drug testing, EPA for spill response, and NOAA for marine sanctuaries.

The Safety System

Safety standards apply to vessels, crew and marine environment and in this regard can be viewed as a system. Each element is important; failure of any one element can result in failure of the system. For this reason the regulatory scheme addresses each of these three elements. Historically, the Coast Guard has concentrated on design and equipment of vessels and paid less attention to crews. More recently however that emphasis has changed course and competency of crews is receiving much more regulatory attention than before.

Where Do Standards Come From ?

Regulatory standards of concern to marine managers (other than standards for recreational vessels) flow from three sources; international conventions (treaties), lessons learned from casualties, and advances in technology. In every case the regulatory agency must have authority to implement new regulations.

International agreements

There are several international agreements that impact U.S. regulation. A short list (names are abbreviated) of relevant international agreements includes the following:

SOLAS 74 (includes the ISM Code)
MARPOL 73/78
LOAD LINE, 1966
STCW 95
TONNAGE MEASUREMENT OF SHIPS, 1969

The International Maritime Organization, a specialized agency of the United Nations, is the international agency that deals with marine matters. The international agreements listed above were brought about by diplomatic conventions that were ratified by a sufficient number of countries representing enough of the world's tonnage to bring those standards into force. Technical work is constantly done under the auspices of IMO to enhance implementation and upgrade conventions. The Coast Guard, together with representatives from industry and other government agencies, provides technical representation for the US on several delegations to IMO committee meetings.

Lessons learned from casualties

There is always an urge to react and prevent reoccurrence of a serious marine casualty. That is why investigations are conducted. Perhaps the best example of reaction to a marine casualty is the regulatory impact resulting from the oil spill from EXXON VALDEZ. That casualty resulted in over 40 regulatory projects initiated by the Coast Guard. Other agencies had their fair share. Loss of several commercial fishing vessels in the 80's, and a number of more recent casualties involving the towing industry have caused the Coast Guard to address those sectors of our industry through the regulatory process.

Advances in technology

Perhaps the greatest change due to technological advances is in the area of satellite communications. The Global Maritime Distress and Safety System (GMDSS), agreed upon internationally, is structured around world-wide satellite communications, has replaced use of Morse code on 500 KC and is nearing full implementation. Immersion suits, inflatable life rafts, fire detection devices, and non-combustible materials are other examples of technology that have enhanced regulatory standards.

How are standards administered?

Implementation of new federal regulations must follow procedures set forth in the Administrative Procedures Act. Elements of these procedures include:

- Publishing Proposed Regulations in the Federal Register along with appropriate economic and environmental impact statements.
- Solicitation of comments from the public as well as impacted industry.
- Consideration of comments by the agency.
- Publishing Final Rules in the Federal Register along with agency response to comments and rationale for decision-making.

The Federal Register is published daily by the National Archives and Records Administration. Final rules published in the Federal Register are incorporated into the texts of the Code of Federal Regulations when those volumes are reprinted each year. For that reason, it is important to keep the most recent issue on hand. Of historical note, agency explanations that accompany printing of proposed and final rules in the Federal Register get left behind - only the regulatory text is printed in the CFRs. The Federal Register can be accessed on line via http://www.access.gpo.gov/nara.

Who is responsible for Enforcement?

Ship owners, operators, Masters and others are ultimately responsible for compliance with regulatory standards. The Coast Guard is the primary agency in the United States charged with regulatory enforcement of navigation and shipping regulations. Some states have recently extended their marine law enforcement jurisdiction from recreational boating to commercial vessels - these efforts are generally related to the transportation of oil.

The Coast Guard will routinely board 'inspected' vessels during drydockings and when a Certificate of Inspection is due for renewal. Coast Guard personnel will also board commercial vessels to examine compliance with oil transfer regulations, various pollution standards, and navigation safety regulations. Because the regulatory scheme applies to inspected and uninspected vessels, the Coast Guard boards vessels from all sectors of the industry, including foreign flag vessels where there is jurisdiction.

Non-compliance is addressed by the Coast Guard in at least three ways: action against the license or Merchant Mariner's Document (MMD) held by a person alleged to be at fault, a civil penalty against the company/operator of the vessel, or criminal charges. When action against a person's license of MMD is deemed appropriate, the Coast Guard presents the case before an Administrative Law Judge who hears evidence, the mariner's response, and then renders a decision and order.

Traditionally, non-compliance involving safety equipment aboard an inspected vessel results in issuance of a Coast Guard form CG-835 that sets forth the deficiency and provides a date when compliance must be achieved.

Much of the Coast Guard's inspection efforts for inspected vessels, particularly in technical areas, is now done by the American Bureau of Shipping per a Memorandum of Understanding between the two entities.

What is an inspected vessel?

Certain vessels are required by law and regulation to be 'inspected' and thus must conform to exact standards regarding vessel construction, stability, safety equipment, manning, and operation. Such vessels are issued a Certificate of Inspection that is usually valid for two years. Factors that determine whether a vessel is subject to inspection are size (measured in gross tons), route (inland or oceans for example), cargo (all oil tankers are inspected), and risk to personnel (vessels that carry more than 6 passengers are inspected).

There is now less distinction between inspected and uninspected vessels than just 10 years ago. Some vessel types have sections of the CFR dedicated to them yet they remain 'uninspected'. Commercial fishing vessels and towing vessels are in this category. Subchapter C of the CFR which addressees uninspected vessels, has 46 pages dedicated to commercial fishing vessels. Uninspected towing vessels are in the process of receiving similar attention.

Where do *SMALL* Oceanographic Research Vessels (ORVs) fit in this regulatory scheme?

An ORV, unlike any other vessel, must be designated as an ORV by the Coast Guard. Criteria and procedures are set forth in 46 CFR 3.05-3 and 3.10-1 which state among other things that the vessel must be employed 'exclusively in oceanographic instruction, limnologic instruction, oceanographic research, or limnologic research. Once satisfied the vessel is used for that purpose, the Coast Guard (Marine Safety Office) issues a *Letter of Designation* to an uninspected ORV that is valid for 2 years.

Seagoing Oceanographic Research Vessels over 300 gross tons are subject to inspection by the Coast Guard in accordance with Subchapter U (46 CFR 188-196). This assumes the vessel is propelled by motor (not steam). Seagoing means the vessel would navigate on the high seas i.e. beyond the Boundary Line.

ORVs of less than 300 gross tons are not subject to inspection but like other uninspected vessels must conform to several other regulatory standards such as load lines, admeasurement, and qualifications for certain members of the crew.

ORVs are unique in that they take *scientists* to sea. Scientists are neither crew nor passengers and therefore ORVs are treated separately by the regulatory scheme. Where this treatment is most apparent is with regard to fire protection. The fire protection standards for ORVs is a blend of technical standards for passenger vessels and cargo vessels. Obviously, those who constructed these standards took account that scientists are active persons with some knowledge and experience regarding ships, more than passengers, and perhaps less than some professional merchant mariners. The Letter of Designation is evidence the Coast Guard acknowledges the vessel carries scientists and not passengers.

Some significant ‘breakpoints’ for application of regulatory standards include:

- SOLAS 74 applies to vessels of 500 gross tons and more.

- MARPOL 73/78 has several tonnage threshold values, the lowest being 400 gross tons.

- Breakpoints, or thresholds, occur at 100, 200, 300, 400, 500 and 1600 gross tons., Conformance is required with whatever standard is required for vessels of that greater size. Tonnage values for ships are often 99, 198, etc for this reason.

- Load Line regulations are applicable to vessels over 79’ in length. This is one of the few standards where length of a vessel is an important determinant.

- Manning. The subject of manning is complicated and application of manning statutes are difficult to interpret. A decision by the US Court of Appeals, 9th Circuit in 1981 decided that “..for purposes of manning statutes, definition of merchant vessels encompasses oceanographic research vessels. The court took account of the fact that the vessels involved were not carrying freight or passengers for hire (my words). Decided were that 65% of the deck crew must be qualified as AB, a 3 watch system was required, and persons were subject to certain qualification standards. Simply put, this court in 1981 decided that manning standards for merchant vessels apply to oceanographic research vessels. The question that I believe remains today is whether that decision should be interpreted broadly or narrowly.

- Documentation. 46 CFR 188.05-10 contains a provision stating that in effect says regulations within Subchapter U that apply to vessels on an international voyage do not apply to a vessel that is numbered in accordance with the Federal Boat Safety Act.. As a consequence many oceanographic research vessels are numbered by states rather than being documented under the federal system. I’m uncertain what benefits accrue from this exemption today.

- In my opinion, the greatest challenge facing operators of smaller oceanographic vessels today is compliance with STCW. STCW applies to any seagoing vessel (that goes seaward of the Boundary Line) regardless of size. The Coast Guard has administratively exempted certain US vessels of less than 200 gross tons from STCW because of their domestic routes and participation in equivalent programs such as AWO’s Responsible Carrier Program. I don’t know any reason why an ORV of less than 200 gross tons that makes an international voyage would be exempt from the provisions of STCW.

Summary

Oceanographic research vessels are unique vessels in many ways, including their fit in the regulatory scheme. The role of scientists is particularly unique in this industry.

Manning standards are complicated. Perhaps they shouldn't be, but they are. If you are uncertain about compliance, take time to insure your vessel is properly manned. Routes, gross tonnage, and length of voyage can influence manning requirements. .

Finally, implementation of STCW applies to many oceanographic research vessels. While implying more work, improving the qualifications of seafarers usually makes sense.

SECTION 3

Tom Smith

Small Boat Safety

I. General

Small boat safety covers a wide variety of boats. A small boat can range in size from a vessel of just less than 100 gross tons to a small open boat propelled by an outboard engine. Because of this variance, the safety regulations that apply to small boats also widely differ. To accurately determine what safety regulations apply to a specific boat, the vessel's size and/or its employment needs to be established. If the vessel is documented, its documentation papers will cite the employment (fishing, small passenger vessel, tanker, etc.) in which it is authorized to work. If it is not documented, then the regulations governing uninspected vessels will most likely apply.

II. Types of Small Boats

Motor Vessel. A vessel more than 65 feet in length that is equipped with propulsion machinery .

Motorboat. Motorboats are classified as: Class A -less than 16 ft.; Class 1 -16 to 26 ft.; Class 2 -26 to 40 ft.; and Class 3 -40 to 65 ft. Most undocumented boats, defined as small boats by this manual, will be this type of vessel.

Documented Vessel. A vessel greater than 5 net tons which is registered, enrolled or licensed as a vessel of the United States. This is a requirement for a vessel that will engage in trade or commerce. UNOLS research vessels are not engaged in trade or commerce but commercial vessels ordinarily are. Charter vessels, other than motor boats, would normally be a documented vessel.

Undocumented Vessel. Any vessel which is not required to, and does not have a marine document issued by the USCG.

Inspected Vessels. One inspected and certificated by the USCG. Motor vessels, tank vessels, passenger vessels and most vessels over 300 gross tons are required to be inspected.

Uninspected Vessel. A vessel not certified under the inspection laws or subjected to regular inspections by the USCG. Most motor boats, fishing boats and oceanographic research vessels under 300 gross tons will be this type vessel. Uninspected vessels, however, are still subject to the rules for safety cited in section III below that apply and, in some cases, the rules for licensed personnel.

Oceanographic Research Vessel. A vessel which the USCG determines is exclusively employed in instruction in oceanography or in oceanographic research.

Numbered Vessel. A vessel is numbered under the provisions of the Federal Boat Safety Act of 1971. Oceanographic research vessels not engaged in commerce are not required to be documented and may be a numbered vessel (except if owned by a State or the Federal Government). All undocumented motorboats are numbered unless owned by the State or Federal Government.

Public Vessel. A vessel which is owned, or chartered, and operated by the US Government and not engaged in commerce. (e.g. USCG & NOAA vessels)

III. Applicable Regulations

Based on the type of boat, its size and/or its employment, some or all of the below federal regulations will apply.

The Motor Boat Act of 1940. This law covers many aspects of safety for small crafts. This would include powered rafts and inflatables, small skiffs and other uninspected vessels 65 feet or less in length.

The Federal Boat Safety Act of 1971. This act sets forth certain safety and documentation requirements for small crafts. The regulations to carry out the intent of this Act and the Motor Boat Act, cited above, are found in 46CFR24 (Subchapter C -Uninspected Vessels). Most but not all motor boats will be governed by the provisions of this chapter.

Commercial Fishing Vessel Safety Act of 1988. This was enacted to stem the high accident and loss of life experienced aboard fishing vessels, and fishing support vessels. A vessel documented as a fishing vessel will be required to adhere to these regulations. The regulations to carry out this act are found in 46CFR188.

Passenger Carrying Vessel. A vessel whose documentation cites its employment as a passenger vessel will be required to adhere to the regulations contained in 46CFR175-187 (Subchapter T - Small Passenger Vessels Under 100 gross tons).

Research Vessel. A vessel whose documentation cites its employment as a research vessel will be required to adhere 46CFRl88-196 (Subchapter U -Oceanographic Research Vessels).

IV. Safety Requirements

All boats used for research by UNOLS institutions will comply with the US Coast Guard Regulations that are applicable to the vessel's size and employment.

Small boats that will be used by UNOLS institutions will have either a current US Coast Guard safety inspection or be inspected by the institute ' s marine staff to insure that the vessel does meet the required safety regulations. A marine staff s inspection will not be accepted as a substitute for an "inspected vessel's" mandated US Coast Guard inspection.

Small boats that are chartered by UNOLS institutions will also meet the requirements of section 17 of the Research Vessel Safety Standards. Chartered boats will be either documented or numbered except for a chartered vessel that is classed as a public vessel.

All personnel aboard open boats (boats with no cabins) or when working on deck with over the side equipment will wear personnel flotation devices, work vests, exposure suits or float coats. The type of flotation will be dictated by the work environment.

Personnel engaged in launching/retrieving over the side equipment or moving weights on deck by cranes, booms, winches, davits, etc. will wear hard hats.

All science parties using a boat will prepare a float or cruise plan. This plan will be prepared by the person in charge of the science party and disseminated prior to departure. The plan will consist of at least the following;

1. Names of all personnel embarked on the vessel.
2. A brief statement of the work being performed.
3. The location of the research area and a brief description of the tracks the vessel intends to follow to and from the research area.
4. The estimated time of the boat to;
    - depart the dock enroute the research area,
    - reach the research area,
    - depart the research area enroute back to the dock, and return to the dock.
5. The type of communications devices aboard and the frequencies monitored or cell phone number.
6. The float plan will be disseminated to the Institute's marine staff and to a person ashore who will be responsible for monitoring the cruise's progress and alerting the science parties home institution, the US Coast Guard, harbor master or other marine safety organizations if the boat is more than 2 hours overdue from its estimated return to the dock.

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7. The person in charge of the science party will communicate to the above individual any major changes (more than 1 hour) in its estimated return time, major breakdowns in propulsion equipment, emergencies, or change to the planned research work area. They shall also notify this person when they return ashore.

Vessels operating north of 32 Degrees North or South latitude in the Atlantic or between 35 Degrees North or South latitude in other waters will have an immersion suit aboard for each person embarked on the vessel(33CFR192.41).

Unless required to carry immersion suits, all boats will carry a US Coast Guard approved personal flotation device (PFD) for each person aboard. The specific type of PFD will be determined by the regulations applicable to the vessel (See 46CFR28.l05 for specific requirements).

All PFDs, life rings, inflatable rafts, and life floats will be marked with the vessel' s name (46CFR28.135).

Life ring, personal flotation devices, life rafts, and life floats carried aboard a vessel will have retro-reflective tape applied as specified in Navigation and Vessel Inspection Circular 1-87 (Published by US Coast Guard).

A1l vessels operating beyond the coastal waters (3 miles offshore), will carry an EPIRB (46CFR28.150, 46CFR25.26).

All inboard gasoline engines will be equipped with a flame arrestor (46CFR25).

Engines fueled with gasoline require extra precaution. Prior to fueling gasoline-powered boats which have built in fuel tanks, bilges should be first checked for the presence of gasoline fumes and then ventilation blowers run. When fueling portable gasoline tanks, insure the fueling nozzle is in contact with the tank's fill port prior to starting and during the pumping of fuel. This will prevent a static electricity charge from being generated during fueling.

Vessel operators must be qualified as competent to operate the vessel. This is best met by requiring the operator to hold a current US Coast Guard license for a deck officer and for such license to be of sufficient tonnage to meet or exceed the gross tonnage of the vessel being operated. Institutions, however, may certify an operator is qualified to operate a small boat if the institution is satisfied that the operator has demonstrated sufficient experience to safely operate the boat.

The operator of a vessel will not operate a vessel for more than 12 hours in anyone day. To exceed this limit, a second qualified operator is required to be aboard.

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The manning of any vessel w]l be sufficient to insure safe, efficient operations for the size vessel being operated and the type work being performed. The institution should make this determination prior to any voyage. A US Coast Guard inspected vessel (inspected under Subchapter T) must comply with the manning requirements listed on its Certificate of Inspection.

Personnel aboard a vessel should not exceed its passenger carrying capacity. .This can be difficult to determine. Most motorboats will have a plate attached to the hull by the manufacturer that states the maximum number of people that the vessel can safely carry .A passenger carrying vessel, that carries more than six passengers for hire, will be inspected by the US Coast Guard and the number of passengers it can carry will be listed on its Certificate of Inspection. Un-inspected vessels cannot legally carry more than six passengers. Under 46CFR188.05-33 (Subchapter U), members of a science party are considered as "persons" and not counted as crew or passengers. This ruling, however, applies only to a vessel whose employment is as an oceanographic research vessel. If a vessel's documents do not list its employment as an oceanographic vessel then the science party is viewed as passengers. This limits the number of people aboard any uninspected, non- research vessels to six people or less. A problem exists with a vessel that is uninspected, does not have a manufacture's plate that states the maximum number of people it can carry, and its employment is shown as oceanographic vessel. Because the science party is not considered as either crew or passengers, a definite limit for personnel aboard cannot be established. Under such a situation, the limit must be logically established. The capacity of the vessel's life rafts, the number of personal flotation devices, the number of built in berths, and the carrying capacity of similar size vessels should all be considered to determine the vessel's carrying capacity .

All small boats are required to carry the below types of USCG approved distress signals (pyrotechnics). The expiration date stamped on the pyrotechnics will not be exceeded during the voyage. (46CFR28.145)

Area Q.f Operations	*Signals Required*
More than 50 miles offshore	Parachute Flares -3 ea. Hand Flares -6 ea. Smoke Signals -3 ea.
Between 3 and 50 miles offshore	Parachute Flares -3 ea. Hand Flares -3 ea. Smoke Signals -3 ea.
Inside of 3 miles from shore	Electric distress light or 3 flares Distress Flag or 3 smoke signals

Vessels will carry at least the below fire extinguishing equipment (46CFR25.30);

Vessel Length	*No. of BI Tvpe Fire Extinguishers*
Uninspected Vessel	
Under 16 feet	One
16 feet but less than 26 feet	One
26 feet but less then 40 feet	Two but only 1 if fixed system in engine room.
40 feet to 65 feet	Three but only 2 if fixed system in engine room.
Over 65 feet	See Subchapter T and 46CFR25.30.
Inspected Vessel	Listed on Certificate of Inspection

All vessels 26 feet or more in length are required to post an oil pollution and garbage placard. A vessel 40 or more feet that is deployed on an ocean voyage (12 miles offshore) must have a written solid waste disposal plan (33CFR151.155).

All installed marine toilet facilities must be a US Coast Guard approved Marine Sanitation Device (MSD) (33CFR159).

If a vessel has Coast Guard licensed personnel aboard, the Master must notify the US Coast Guard if any casualty listed in 46CFR4.05 occurs. This includes groundings which cause a hazard to navigation, the environment or vessel safety, loss of maneuvering capability, injury rendering a person unfit for duty, or an occurrence resulting in property damage in excess of $25,000. If a vessel is involved in a serious marine incident, it must be reported to the US Coast Guard whether licensed personnel are aboard or not. A serious marine incident consists of death, injury requiring professional medical treatment, property damage in excess of $100,000, an oil discharge into the water of 10,000 gallons or more, or the discharge of a hazardous substance into the water. All personnel involved in a serious marine incident are subject to drug testing.

The regulations that require a vessel to carry a survival raft (life raft or boat) varies widely with the area of operation, type of employment, type of environment, and the number of people aboard. See 46CFR28.120 for the correct requirements.

At least one throwable flotation device is required aboard all vessels 16 feet and longer. See 46CFR28.115 for the correct requirements for a specific vessel.

Vessels operating outside the boundary line, as defined in 46CFR Part 7, that is to seaward of the coastline or entrances to small bays, inlets or rivers, must meet the following additional requirements;

> A documented fishing boat or one with 16 or more people aboard, that has ammonia refrigerant, must carry a fireman's outfit and two self contained breathing apparatuses (46CFR28.200).

All vessels will carry charts, a first aid kit, navigational publications and charts for their operating area, an anchor, a radar reflector, a compass, a general alarm system, a high water alarm, and a bilge pumping system (46CFR28.210-255).

Vessels over 79 feet or having their keel laid after September 15, 1991 or undergoing major structural changes since September 15, 1991, should possess either a load line certificate or a current US Coast Guard Stability letter.

All boats will be equipped with a communications device that is of sufficient power to permit it to communicate ashore from the maximum distance offshore where the boat will operate. This can be satisfied by cell phone, portable VHF, SSB radio, etc. as long as the device's range will communicate from the maximum offshore distance that the vessel will reach. Vessels operating outside the boundary line will also comply with the communications regulations governing its type of vessel (46CFR28.245, 28.375; 33CFR26.03; 47CFR80).

All vessels 79 feet or longer must be equipped with an electronic positioning device (i.e. SATNAV, GPS, LORAN, OMEGA or RDF) (48CFR28.260). All vessels operating outside the boundary line will be so equipped.

A vessel less than 12 meters in length must carry an efficient sound signal. If more than 12 meters in length, a bell and whistle are required. All vessel will also have aboard the proper navigational lights and shapes required for the type of boat (33CFR81).

SECTION 4
Dennis Nixon
Marine Insurance

Marine Insurance, Dennis Nixon, UNOLS Risk Manager and Legal Advisor

Small research vessels present the same liability and risk issues as the biggest vessels in the fleet: equipment can be lost or damaged, the vessel may need the services of a salvor, and crew and scientists aboard can be injured or killed. Depending on the type of coverage purchased, each of the above risks may be covered.

There are two principal types of marine insurance policies: (1) hull, and (2) protection and indemnity (P&I). Very simply, the hull policy generally protects the value of the property itself, while the P&I policy covers damage done to others by the vessel and its operators. In the research vessel community, the purchase of hull insurance depends upon the legal status of the vessel in question. If it is owned by the federal government and operated under charter by an academic institution, the operator may not purchase hull insurance using federal funds. Why? The federal government, as a matter of policy, has chosen to self-insure all property risks. If the vessel is privately owned but federally funded for operations, the hull insurance may be paid as an overhead expense (if approved by federal auditors). The government's rationale is that it can afford to self-insure. P&I insurance, on the other hand, is required of all small research vessels funded by NSF in the amount of $15 million, with a minimum deductible of $10,000. With that as a general introduction, each policy will now be examined in more detail.

The Hull Policy

It is a brave soul who has attempted to read his vessel's hull insurance policy. It has been variously described as "obscurity itself" by a noted admiralty scholar, and a "labyrinth of verbiage" by a federal circuit court judge. An important point to realize is that a hull policy is not an "all risk" insurance contract; rather, it only insures against loss from a list of "named perils." Another critical issue is that courts consider the contract of marine insurance to be uberrimae fidei -- a little bit of Latin for "of utmost good faith." That means that the court expects full and honest disclosure of all material facts related to the condition of the vessel. If you are not completely up front when the vessel is first insured, the contract can be voided if the material misstatement leads to a loss. In one reported case, a vessel owner "forgot" to notify his insurance carrier that he had begun to store gasoline for a tender in one of the ship's water tanks. When the tank leaked and the vessel burned, the contract was invalidated because the owner had failed to reveal this significant change.

The subject of valuation on a hull policy can be problematic. A new vessel is commonly insured for its construction cost. After a few years, however, as the vessel ages, the owner and underwriter must come to an "agreed value" which will be paid if the vessel is lost. The reason for this depreciated "agreed value" is to eliminate what is known in marine insurance as a "moral hazard" when the owner would actually benefit more by sinking his vessel than selling it.

After the hull value is agreed upon, navigation limits will be specified. If one's plans do not include extensive voyaging, seek relatively confined navigation limits (say, no more than 25-50 miles from a safe harbor), and your premium will be lower. The rate charged is expressed as a percentage of the vessel's agreed market value. Previous claims on the vessel and the size of the deductible have a large part in the pricing decision as well.

The heart of any hull policy is the so-called "Perils Clause." It commonly reads:

> Touching the Adventures and Perils which the Underwriters are contented to bear and take upon themselves, they are of the Waters named herein, Fire, Lightning, Earthquake, Assailing Thieves, Jettisons, Barratry of the Master and Mariners and all other like Perils that shall come to the Hurt, Detriment, or Damage of the Vessel.

That language is lifted from a policy first used on the good ship *Tiger* in 1613. (This is a business very slow to change.) The first category mentioned, perils of the seas, is the most important in the policy. Generally, courts have found that perils of the seas are of an extraordinary nature or arise from irresistible force or overwhelming power and cannot be guarded against by the ordinary exertions of human skill and prudence. This is the classic "heavy weather" loss. Damage caused through natural decay, worms, or ordinary wear and tear would not be covered under this clause. The concepts of fire, lightning, and earthquakes causing damage are easily understood; the term "Assailing Thieves" covers losses occasioned by the criminal acts of those who gain access to the vessel by force. "Jettison" refers to the intentional act of throwing some part of the vessel or its cargo overboard for a sound reason. For example, if a primary winch broke free and was crashing around the deck causing collateral damage and could not be secured without risking injury to the crew, it could be allowed to slide overboard and be a compensable loss. "Barratry" has been defined to mean any unlawful act committed by the master or crew, contrary to their duty to the vessel's owner, whereby the latter suffers injury.

In subsequent years, an "Additional Perils" clause was added to include losses from latent defects and the negligence of the crew -- as long as the owner has used "due diligence" to provide a seaworthy vessel. Undermanning and the failure to follow up on a surveyor's list of required changes are examples of cases where courts have found a failure of the due diligence requirement.

The collision clause is unusual in that it applies to the damage caused to another vessel in a collision for which the insured vessel is found liable. (Damages to the insured vessel are covered in the Perils clause discussed above). The amount of coverage is limited to the agreed value of the insured vessel. It does not extend to loss of life, personal injury, or damage to shoreside structures -- that liability is picked up in the P&I policy. Vessels normally purchase "Excess Collision" insurance as well for those instances when the physical damages caused are in excess of the valued hull policy. Another alternative, particularly if the vessel is government owned and cannot purchase hull insurance, is to transfer all collision liability to the P&I policy.

The war risk clause is designed to exclude coverage for damage as a result of wars, strikes, or other civil commotions. War risks are broadly defined to include everything from seizure of the vessel to damage sustained from torpedoes and mines dragged from the bottom. Since much of a research vessel's time is spent dragging equipment across the bottom, it is important to add a war risk rider to the basic hull policy.

Finally, the hull policy also contains the closely related "Salvage" and "Sue and Labor" clauses. The Salvage clause simply states that the underwriters will be responsible for salvage charges incurred to preserve the insured property. The purpose of the Sue and Labor clause is to encourage the assured to take all reasonable steps that a prudent uninsured owner would take to protect the insured property. If only P&I insurance is purchased because the vessel is owned by the federal government, both of these clauses can be added to the P&I policy.

The Protection and Indemnity Policy

The traditional name given to the insurance of third-party liabilities which arise in connection with the operation of a vessel is protection and indemnity (P&I) insurance. It is a much more recent type of insurance, dating from the mid-19th century, and thus the basic language and concepts are much easier to understand than the hull policy.

Five categories of loss are covered under the P&I policy. The first category is by far the most important and the principal reason this type of policy was first developed: compensation and medical expenses for the injuries or death of the crew, scientific party, or other individuals aboard the vessel. Members of the crew are entitled to what has become known as "the blessed trinity" of remedies: maintenance and cure, the Jones Act, and the unseaworthiness doctrine. Maintenance and cure is ancient legal remedy provided to seamen, defined as the legal obligation of the vessel owner to "maintain and cure" a seaman injured or taken ill in the service of the vessel. Congress recognized the limitations of this concept in 1920, when it passed the Jones Act, giving seamen injured through the negligence of their vessel owner the right to sue the vessel owner in federal court for damages. Today, however, the most important legal remedy for an injured seaman or scientist is the doctrine of unseaworthiness, which allows recovery against the vessel if the injury was caused by an unseaworthy condition of the vessel, its equipment, or crew. This is true whether or not the unseaworthy condition is caused by the negligence of the vessel owner, the standard required under the Jones Act. Under the terms of the Oceanographic Research Vessel Act of 1965, members of the scientific party may not sue under the terms of the Jones Act, but courts have held that they may recover using the powerful doctrine of unseaworthiness.

The second category of loss under the P&I policy involves damage caused by the vessel to "any fixed or movable object or property of whatever nature." The language includes damage to docks and piers from collision, excessive wakes, and even damage to stationary fishing gear.

The third category is known as "wreck removal" and covers the expenses of removing the vessel if that removal is required by law -- typically when sunk in shallow water or in a channel.

The fourth category involves fines levied against the vessel by any state, federal, or foreign government as the result of some violation of laws, but this clause will not apply if they result "directly or indirectly from the failure, neglect, or default of the assured ... to exercise the highest degree of diligence to prevent a violation of any such laws." Thus, a fine for negligent operation would be paid if the assured had no knowledge that his crew was negligent or reckless and had made every effort to find crew members who were competent and qualified.

Finally, the last category is for the costs of investigating and/or defending claims arising out of a liability of the assured covered by the P&I policy. This is of tremendous importance in the area of crew injuries, where the costs of defending against such claims can be substantial.

Conclusion

The operation of a small research vessel involves most of the same risks as the operation of a large, blue-water vessel, and thus the operator must seek protection with an appropriate level of insurance. If the vessel is privately owned, both hull and P&I insurance should be acquired. If owned by the federal government, hull insurance may not be purchased, but most charter agreements require the purchase of at least $15 million in P&I coverage with a minimum deductible of $10,000. Proof of adequate insurance must be provided to NSF or ONR on an annual basis.

Like a good survey, adequate insurance cover can provide a vessel owner with at least some peace of mind when the vessel goes to sea. Since insurance is typically a vessel's third largest operating expense (after crew and fuel), it pays to know just what one is paying for.

SECTION 5

Jim Yagle

Stability

Jim Yagle graduated from the University of Michigan in 1988 with a B.S.E. degree in Naval Architecture and Marine Engineering. He worked for Elliott Bay Design Group for 9 years as a naval architect and is now with Delta Marine Industries. Mr. Yagle's area of expertise is vessel stability. He has performed inclining experiments and stability analyses on a variety of vessels including the 76' oceanographic vessel for the University of Connecticut, a 100' fisheries vessel for the National Biological Service, and fishing boats from 70' longliners to 270' factory trawlers.

The stability of a vessel refers to its ability to float upright and is governed primarily by the two major forces exerted on any floating object: buoyancy and weight. As long as the buoyancy is greater than the weight, the vessel will float. How well it floats, i.e. how resistant it is to tipping over (its stability), is dictated by where these two basic forces act on the vessel.

Buoyancy

The buoyancy of a vessel is determined by the shape of the immersed hull form. The larger the hull, the more weight it can support. Stability, however, is dictated by the distribution of that hull volume. For example, beam has a much larger impact on stability than length. As a general rule, the wider the vessel, the more stable it is. A deeper hull will also be more stable than a shallow one. The center of buoyancy is the point at which all the vectors of the floating forces of the vessel can be said to act vertically upward.

The designer usually has a great deal of control of a vessel's stability characteristics while it is still being designed. Good practice includes designing a stability margin into the hull before the vessel is built. Unfortunately, features that make a vessel more stable are often in direct conflict with the other aspects of the design. While it may be tempting to simply enlarge the beam to increase stability, this will also increase construction cost as well as increase the propulsion resistance of the hull. Increased resistance in turn drives up fuel consumption and operating costs over the life of the vessel. As with all good designs, a balance between the design criteria and operational requirements must be reached.

Weight

The hull, machinery, outfitting, and cargo load determine vessel weight. As vessel cargo load is increased, the hull will settle deeper in the water until the buoyancy equals the weight. While this may intuitively seem to increase stability, adequate freeboard is also essential. Freeboard is the distance between the water and the working deck of the vessel. If the deck edge goes under water when the vessel heels, the danger of capsizing is increased. An overloaded vessel will have too low a freeboard, and the deck may submerge with even a light heel.

Equally important to the overall weight of the loaded vessel is how that weight is distributed. The center of gravity is the point at which the vector of the whole weight of the vessel can be said to act vertically downward. As a general rule, a lower center of gravity means a more stable vessel. A vessel with a high center of gravity is said to be "top heavy." When a vessel lists or heels to one side, the center of gravity pushes down in the direction of the list.

The designer also has a great deal of control of a vessel's weight characteristics during the design phase. A detailed weight estimate is an essential part of any design package. The equipment selection and arrangements must be constantly monitored to ensure that the vessel stays close to its target weight and center of gravity. Margins on weight and center of gravity should also be included in the calculations to account for the inevitable overlooked objects or estimating errors.

Unlike the buoyant volume of the hull, the vessel weight and center of gravity change constantly as vessel loading changes. For example, a heavy object placed high on a deck will produce a higher center of gravity - and less stability - than a load stored below deck. Similarly, removing a load from low in the vessel, such as burning fuel oil, will cause an increase in the vessel's center of gravity, thus reducing stability.

Additionally, vessels gain weight over their lifetimes as equipment is added or other changes are made to the arrangements. A good design will allow for some weight growth, but careful attention must be paid to modifications to the vessel to ensure that it continues to meet the applicable stability requirements.

Stability

Stability is one of the more quantitative aspects of how a floating object behaves in water. There are a number of calculated values that together determine the stability of a vessel.

Initial stability concerns a vessel's initial resistance to being pushed over. The GM, or metacentric height, is the term used to measure initial stability. GM is measured in meters or feet; a larger value indicates greater stability. A "stiff boat" has a higher GM than a "slow roller." Too little GM results in a vessel with a long, slow roll that, while comfortable, could lead to capsizing. Excessive GM, however, results in a vessel with uncomfortable, snappy, motions in heavy seas that contributes to seasickness and can actually damage equipment as it "whips" the vessel upright after being pushed over by a wave.

Righting energy is the term used to describe a vessel's ability to right itself after being heeled over. As the vessel heels, the vertical vector of the center of buoyancy moves away from that of the center of gravity. The distance between vectors, called the righting arm or GZ, varies as the vessel heels and is measured in meters or feet. Typically, righting arms are plotted on the vertical axis of a graph with the heel angle on the horizontal axis. The area under the curve so generated represents the amount of righting energy. A properly-loaded vessel should have positive righting energy to a heel of at least 50 degrees. The magnitude of the largest righting arm is also an indication of a vessel's stability.

Because of the relationship between weight and buoyancy of a given hull shape, both GM and righting energy vary significantly with the weight and center of gravity of the loaded vessel. This means that how a vessel is loaded has the largest impact on the stability of the vessel.

The previous paragraphs have discussed vessel stability characteristics in the intact state. They also apply to a damaged vessel. However, the buoyant force and center of buoyancy of the damaged hull will differ significantly from that of the intact hull, depending on hull compartmentation as well as the location and extent of damage.

Stability Regulations

A variety of stability criteria have been developed to answer the question "how much stability is enough?" Which criteria apply depends upon the regulatory environment of the vessel - there are different criteria for passenger vessels, tugs, barges, and tankers, to name a few. Research vessels also have their own regulations. The applicable stability criteria are also dependent on the vessel size and location of operations. It is common for a vessel to have to meet separate criteria for rough seas, high winds, towing a trawl or other submerged object, and for crane lifting operations.

Effects of Operations on Stability

Many of the daily operations of a vessel have significant impacts on its stability.

An area of particular concern in operations is the free surface effect. When a vessel with full tanks heels over, the contents of the tank do not shift. The tank's center of gravity does not change, so it does not affect the vessel's stability. In a partially filled tank or fish hold, the contents will shift with the movement of the boat. The center of gravity moves over to the side, making the vessel less stable. This "free surface effect" reduces stability and increases the danger of capsizing. Good initial vessel design can minimize this effect by avoiding large, wide tanks. Good operational practice can minimize this effect by keeping the number of slack tanks and holds to an absolute minimum.

Loading and unloading operations have a dramatic effect on stability. For example, when a heavy load is lifted clear of the water it has the same effect on the vessel's center of gravity as if the weight were located at the tip of the boom. The vessel will also heel. Good design and operational guidance should include crane or boom load limits.

Heavy icing due to weather will also seriously affect stability by adding weight high on the vessel superstructure and masts. In severe conditions, it is very dangerous and it may be necessary to either remove the ice or head downwind to reduce the accumulation.

Stability Guidance

Proper operational guidance to the Master is critical to ensure the vessel maintains adequate stability. This guidance can take several forms. A Stability Letter listing the basic operational limits and guidance in a few pages is common for smaller vessels and is typically posted in the wheelhouse. A Trim and Stability Booklet contains more detailed instructions and includes forms for the Master to actually calculate the weight and center of gravity of the vessel. Curves of the maximum allowable center of gravity are then used to determine if the loaded condition meets the required criteria.

Conclusions

Proper application of both weight and buoyancy margins throughout the design phase, coupled with close monitoring of weight growth once the vessel is in operation, will help a vessel maintain adequate stability throughout its life. Ensuring adequate stability in a vessel is a combination of many factors including recognizing the loading limits of a given hull form and operating within those limits at all times. Stability considerations must always take precedence over operational requirements to ensure the safety of the crew and passengers and to prevent the loss of the vessel and cargo.

Figure 1.

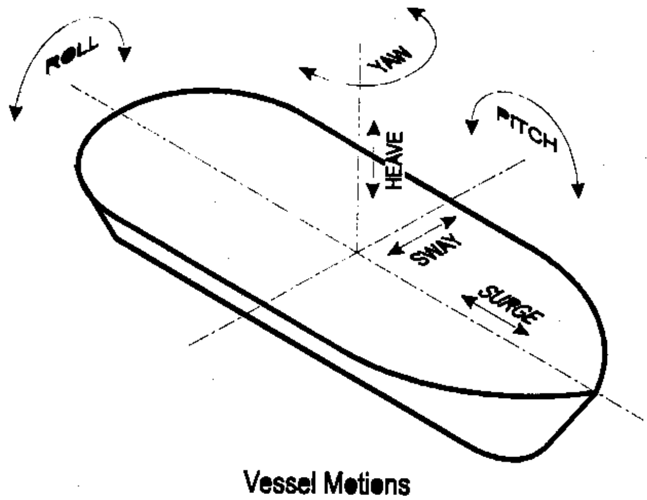


Figure 2.

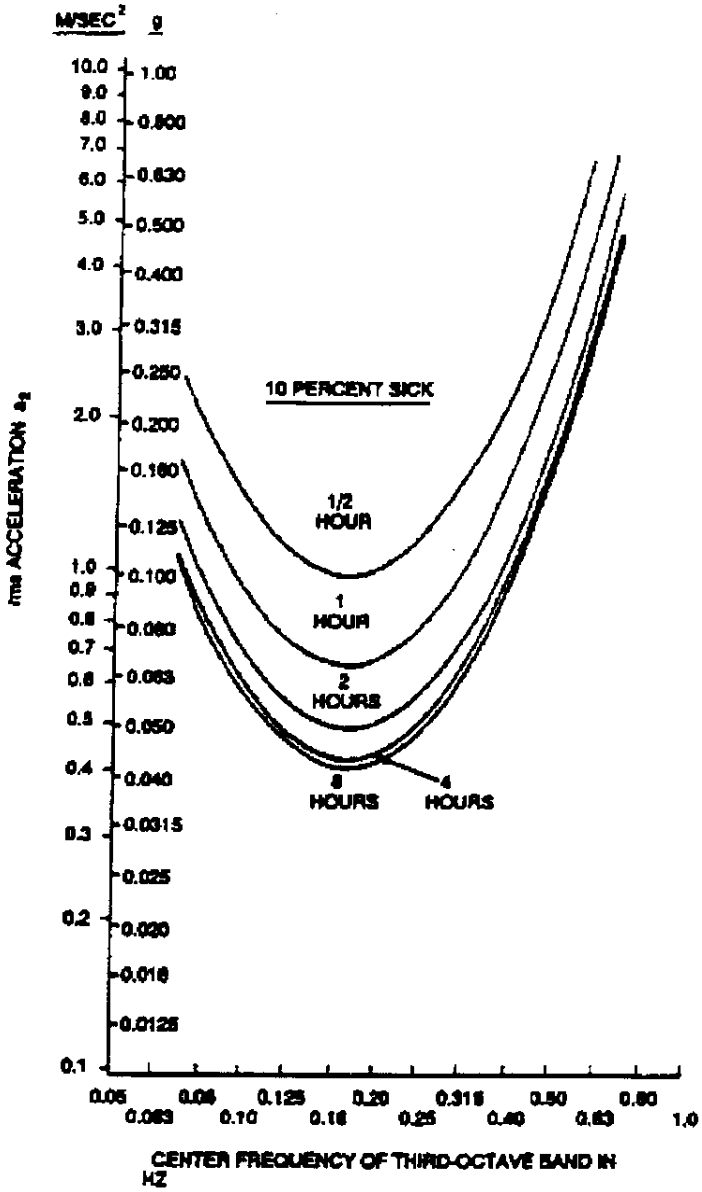


FIG. 98 The 90 % Motion Sickness Protection Limits for Human Exposure to Very Low Frequency Vibration

Figure 3.

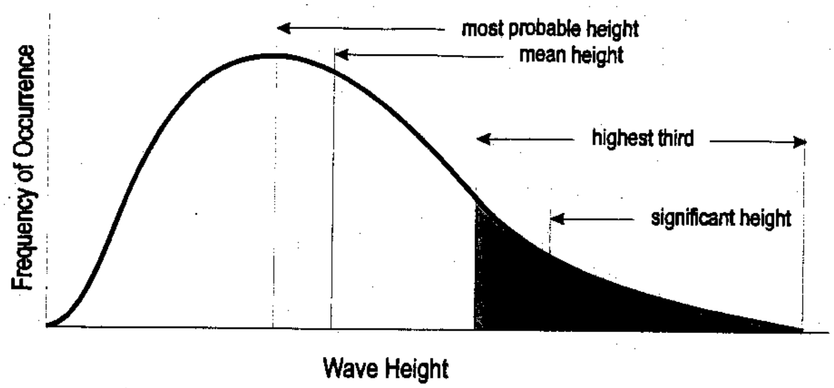

most probable height
mean height
highest third
significant height
Frequency of Occurrence
Wave Height

Figure 4.

WIND AND SEA SCALE FOR FULLY ARISEN SEA

Sea-General: Sea State [1]	Description [2]	Wind [3]: Beaufort Wind Force	Description	Range (Knots)	Wind Velocity (Knots)	Sea [3]: Wave Height (Feet): Average	Significant	Average 1/10 Highest	Significant Range of Periods (Seconds)	Period of Maximum Energy of Spectrum	Average Period	Average Wave Length	Minimum Fetch (Nautical Miles)	Minimum Duration (Hours)
0	Sea like a mirror.	0	Calm	Less than 1	0	0	0	0	-	-	-	-	-	-
	Ripples with the appearance of scales are formed, but without foam crests.	1	Light Airs	1 - 3	2	0.05	0.08	0.10	up to 1.2 sec	0.7	0.5	10 in.	5	18 min.
1	Small wavelets, still short but more pronounced; crests have a glassy appearance, but do not break.	2	Light Breeze	4 - 6	5	0.18	0.29	0.37	0.4-2.8	2.0	1.4	6.7 ft	8	39 min.
	Large wavelets, crests begin to break. Foam of glassy appearance. Perhaps scattered white horses.	3	Gentle Breeze	7 - 10	8.5	0.6	1.0	1.2	0.8-5.0	3.4	2.4	20	9.8	1.7 hrs
					10	0.88	1.4	1.8	1.0-6.0	4	2.9	27	10	2.4
2	Small waves, becoming larger; fairly frequent white horses.	4	Moderate Breeze	11-16	12	1.4	2.2	2.8	1.0-7.0	4.8	3.4	40	18	3.8
					13.5	1.8	2.9	3.7	1.4-7.6	5.4	3.9	52	24	4.8
3					14	2.0	3.3	4.2	1.5-7.8	5.6	4.0	59	28	5.2
					16	2.9	4.6	5.8	2.0-8.8	6.5	4.6	71	40	6.6
4	Moderate waves, taking a more pronounced long form; many white horses are formed. (Chance of some spray).	5	Fresh Breeze	17-21	18	3.8	6.1	7.8	2.5-10.0	7.2	5.1	90	55	8.3
					19	4.3	6.9	8.7	2.8-10.6	7.7	5.4	99	65	9.2
					20	5.0	8.0	10	3.0-11.1	8.1	5.7	111	75	10
5	Large waves begin to form; the white foam crests are more extensive everywhere. (Probably some spray).	6	Strong Breeze	22-27	22	6.4	10	13	3.4-12.2	8.9	6.3	134	100	12
					24	7.9	12	16	3.7-13.5	9.7	6.8	160	130	14
					24.5	8.2	13	17	3.8-13.6	9.9	7.0	164	140	15
6					26	9.6	15	20	4.0-14.5	10.5	7.4	188	180	17
	Sea heaps up and white foam from breaking waves begins to be blown in streaks along the direction of the wind. (Spindrift begins to be seen).	7	Moderate Gale	28-33	28	11	18	23	4.5-15.5	11.3	7.9	212	230	20
					30	14	22	28	4.7-16.7	12.1	8.6	250	280	23
					30.5	14	23	29	4.8-17.0	12.4	8.7	258	290	24
					32	16	26	33	5.0-17.5	12.9	9.1	285	340	27
7	Moderately high waves of greater length; edges of crests break into spindrift. The foam is blown in well marked streaks along the direction of the wind. Spray affects visibility.	8	Fresh Gale	34-40	34	19	30	38	5.5-18.5	13.6	9.7	322	420	30
					36	21	35	44	5.8-19.7	14.5	10.3	363	500	34
					37	23	37	46.7	6-20.5	14.9	10.5	376	530	37
					38	25	40	50	6.2-20.8	15.4	10.7	392	600	38
					40	28	45	58	6.5-21.7	16.1	11.4	444	710	42
8	High waves. Dense streaks of foam along the direction of the wind. Sea begins to roll. Visibility affected.	9	Strong Gale	41-47	42	31	50	64	7-23	17.0	12.0	492	830	47
					44	36	58	73	7-24.2	17.7	12.5	534	960	52
					46	40	64	81	7-25	18.6	13.1	590	1110	57
	Very high waves with long overhanging crests. The resulting foam is in great patches and is blown in dense white streaks along the direction of the wind. On the whole the surface of the sea takes a white appearance. The rolling of the sea becomes heavy and shocklike. Visibility is affected.	10	Whole Gale*	48-55	48	44	71	90	7.5-26	19.4	13.8	650	1250	63
					50	49	78	99	7.5-27	20.2	14.3	700	1420	69
					51.5	52	83	106	8-28.2	20.8	14.7	736	1560	73
9					52	54	87	110	8-28.5	21.0	14.8	750	1610	75
					54	59	95	121	8-29.5	21.8	15.4	810	1800	81
	Exceptionally high waves (Small and medium-sized ships might for a long time be lost to view behind the waves.) The sea is completely covered with long white patches of foam lying along the direction of the wind. Everywhere the edges of the wave crests are blown into froth. Visibility affected.	11	Storm*	56-63	56	64	103	130	8.5-31	22.6	16.3	910	2100	88
					59.5	73	116	148	10-32	24	17.0	985	2500	101
	Air filled with foam and spray. Sea completely white with driving spray; visibility very seriously affected.	12	Hurricane*	64-71	>64	>80[4]	>128[4]	>164[4]	10-(35)	(26)	(18)	~	~	~

*For hurricane winds (and often whole gale and storm winds) required durations and fetches are rarely attained. Seas are therefore not fully arisen.

A heavy box around this value means that the values tabulated are at the center of the Beaufort range.

[4] For such high winds, the seas are confused. The wave crests blow off, and the water and the air mix.

[1] Encyclopedia of Nautical Knowledge, W.A. McEwen and A.H. Lewis, Cornell Maritime Press, Cambridge, Maryland, 1953, p. 483

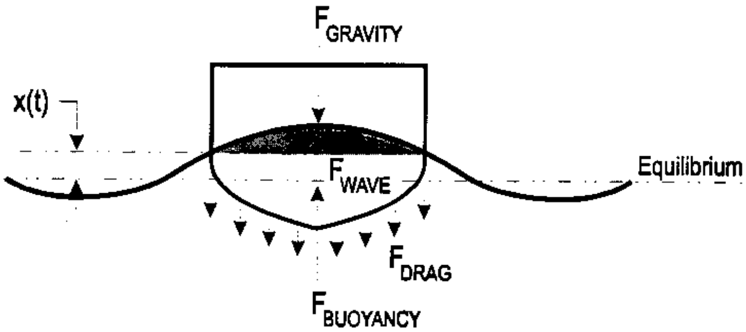
[2] Manual of Seamanship, Volume II, Admiralty, London, H.M. Stationery Office, 1952, pp. 717-718

[3] Practical Methods for observing and forecasting Ocean Waves, Pierson, Neumann, James, N.Y. Univ. College of Engin. 1953.

Based on the Neumann Spectrum

This table compiled by Wilbur Marks, David Taylor Model Basin, 1956

Figure 5.



SECTION 6
John W. Waterhouse
Seakeeping

John W. Waterhouse, P.E. received his B.S. in Mechanical Engineering from U.C. Berkeley in 1979 and his M.S. in Naval Architecture and Marine Engineering from M.I.T. in 1984. Before forming EBDG, John worked for Nickum & Spaulding Associates as part of their preliminary design group. Mr. Waterhouse's research vessel experience includes preparing the preliminary design for a 67m research vessel for the Taiwan Fisheries Research Institute. The vessel was designed to China Registry of Shipping regulations. He was also a member of the project design team for a 200-foot sailing research vessel for pelagic physical oceanography.

Seakeeping refers to motions of a vessel in waves. "Sea kindliness" is a characteristic sought after for research vessels. A sea kindly vessel is easy on its crew and easy on its gear. Trying to define seakindly is difficult. The deep sea mariner may use qualitative descriptions such as "an easy roll" or "a wet boat". The vessel designer and marine scientist must look for quantitative descriptions.

There are six degrees of motion in a vessel, three are linear (surge, heave, and sway) three are rotational (pitch, roll, and yaw). See Fig.1. Each of these degrees of motion has associated values of amplitude, velocity, and acceleration. For example, a vessel in a beam sea can be rolling up to 30 degrees (amplitude). The associated acceleration could be 0.5 g or 1 g. To a designer, the accelerations are usually the key value since they translate into forces on equipment and people. Motion sickness is a function of acceleration levels and periodicity. See Fig. 2 for the ASTM standards motion sickness graph.

The energy input for motions comes from waves. There are several terms that need to be considered. Each distinct wave has a height (distance between trough and crest) and a period (time between succeeding crests). The sea is a spectrum of waves, that is a variety of waves of different heights and periods. The spectrum can be characterized by two terms, the significant wave height and the modal period. If we collect a thousand observations of wave heights and periods we can produce a graph similar to Fig. 3. If we take the average height of the one third highest waves that number represents the significant wave height. This method quantifies what people have historically observed qualitatively. The modal period is determined by finding the average value of the wave periods.

Other factors that affect waves are the fetch and the water depth. Fetch is the distance of open water available for a wave system to develop. A protected bay has little fetch and waves cannot fully develop, regardless of the wind strength. Water depth can produce larger waves, especially when the depth of water is less than 1/2 the wavelength. A good example of this occurs at harbor entrances where a bar or local shallowing can develop. Such a bar can produce larger than ordinary waves as the wave energy is compressed by the rising ocean bottom.

In extreme seas two other characteristics come into play. These are deck wetness and slamming. Deck wetness refers to the presence of green water on deck, not just spray. Having waves board the vessel clearly limits the crew's ability to handle equipment or to safely move around. Deck wetness can be used as a good criteria for limiting operation.
Slamming is more serious. A vessel slams when the bow area is struck by or comes down on a wave. Slamming is characterized by zones of high pressure on the hull and associated shaking of the vessel. When slamming occurs the operator must reduce speed in order to prevent structural damage to the hull.

Mariners have long known that if the wind begins to blow on a open, calm sea, after a while waves will develop and build until an equilibrium condition is reached. This phenomena was categorized by the 19th century English sailor, Beaufort. This so called Beaufort scale matches wind velocities to wave conditions or Sea States as shown in Fig. 4. This terminology has been adopted to define design conditions for vessels.

For the designer of the vessel the sea kindliness or ride quality must be expressed as a set of standards. Because of the varying nature of winds, operating areas, seasons of the year, resistance to motion sickness, etc. this usually means that statistics must be used. To say that a vessel has to work through sea state 3 and survive a sea state 5 is not precise. Before defining the governing sea state one must consider where the vessel is to operate, what kinds of seas are prevalent at what times of the year, and what type of work will be done with the vessel. For example a vessel handling a plankton net over the side can operate in higher sea states than one that will be handling an ROV. The designer and the scientists must both understand the mission and the vessel's limitations.

Having looked at the environment which provides the energy input to cause vessel motions, we next look at the vessel responses. The vessel system can be modelled as a linear mass spring system with a dampener. See Fig. 5. The vessel is the mass, the spring is buoyancy to restore the vessel to its equilibrium position as the waves passes under it, and the dampener is the sum of friction, turbulence, and drag. The equation of a linear system takes the form of $F(t) = mg + mA + cV + kD$ where:

$F(t)$ = force varying over time
m = mass
g = acceleration due to gravity
A = acceleration of the vessel
c = damping coefficient
V = velocity of the vessel
k = buoyancy
D = distance the vessel moves

Note that the vessel mass is a key factor in the equation. For a given wave height a heavy vessel will have lower accelerations, or move less, than a light weight vessel. Another factor is the damping coefficient. For example adding bilge keels to a vessel increases the drag and turbulence when a vessel rolls, and hence reduces the motion.
Finally, the buoyancy constant is proportional to the amount of waterplane area of the vessel. A slender spar buoy will move less than a fat can buoy.

This equation applies to each of the six degrees of freedom. Given the difficulties in solving 6 simultaneous differential equations some standard simplifications are used. First, surge and sway are typically ignored since their magnitudes are usually small compared to the other motions. Yaw can be assumed to be countered by rudder steering forces. This leaves roll, pitch, and heave as the primary motions of concern. There are some differences between these motions and the above equation. For example in roll the "spring" is the vessel righting arm. A low center of gravity due to weight in the form of ballast will produce a different ride from the same weight carried as deck cargo. Whether the ride will be better or worse will depend on factors such as hull shape, the wave spectrum, and how the weight is distributed. For the latter consider an ice skater spinning around. By changing the position of the arms the speed of the spinning can be altered, with the arms tucked in close to the body causing the highest rate of rotation. Similarly, the distribution of weight on a vessel can affect the pitch and roll performance.

Many different approaches have been tried to improve seakeeping, from fundamental differences in hull shape to active or passive appendages. A brief discussion of each of these follows:

SWATH Hull - This type of vessel, a Small Waterplane Area Twin Hull, has excellent seakeeping characteristics. The design consists of two submerged hulls with slender struts rising through the water's surface to support a cross-structure. Because the buoyant hulls are well below the water's surface and by keeping the struts as slender as possible there is little opportunity for the waves to act on the vessel. The main vulnerability is slamming on the cross structure when the waves get large enough.

Catamaran Hull - This type of vessel has some limits for seakeeping imposed by the hull design. If the wave period is twice the spacing of the hulls then the natural frequency in roll creates a resonant condition and extreme motions. Further, the cross structure is vulnerable to slamming if the wave heights are large enough. Finally, due to the relatively short hull length for the displacement, catamarans can experience significant pitch motions.

Monohull - The traditional monohull has been the subject of much investigation for seakeeping. What we have learned is that long slender hulls have less pitching behavior while short fat hulls are typically better in roll and heave. Deck wetness can be limited through good bow shape and hull flare. A round bilge hull will have less roll dampening than a hard chined hull. Hard chine boats can be subject to slamming in the bow area depending on the wave height and the vessel's forward speed.

Anti-roll tank - To combat vessel rolling people have used different designs of tanks holding water ballast. By placing such tanks up high on a vessel and by tuning them to the vessel's natural roll period, significant improvement in motions can be achieved. The disadvantage of such tanks is that they need to be located in prime parts of the ship to be effective. A particular advantage of such tanks is that they are effective at a range of vessel speeds.

Fin Stabilizers - By using airfoil shaped fins mounted low in the hull amidships, significant roll reduction can be achieved when the vessel is underway. Such fin stabilizers use a motion sensing controller that signals the fin to change its angle of attack to the water, thus producing a countering force to the wave motion. Fin stabilizers typically are electro-hydraulic units and are more effective the faster the vessel is moving.

Centerboards - Some research vessels have tried using centerboards with good effect. These boards are typically of an airfoil shape with a mechanism allowing them to be retracted into the hull. Placed at approximately 30% of the waterline length back from the bow they dampen rolling motion and incidentally allow sonar transducers to be placed well away from noise sources in the hull.

Bilge keels - These passive devices have typically been used to add damping in roll. A fixed plate running approximately 40% of the vessel's length along either side of the hull the bilge keel must be placed to maximize hydrodynamic drag in roll and minimize hydrodynamic drag while underway. A drawback of bilge keel is that gear being worked over the side can potentially foul on the bilge keels.

Active Rudders - Similar to the fin stabilizers, an active rudder system will turn the rudders to generate a counter force to vessel roll. This allows the use of existing equipment but obviously suffers in efficiency with comparison to fin stabilizers.

Bulbous bows - These were originally developed as a means of reducing vessel resistance. Later, researchers observed that depending on the bulb's size and shape it could improve pitch resistance. However, in extreme seas when the forefoot of the vessel emerges, an improperly designed bulb can contribute to slamming.

Section 7
Steve Rabalais

Conversions VS New Construction

It is only within the last century that vessels have been designed and built as oceanographic research platforms. Up until this time all research vessels were converted from some other service. The H.M.S. *Challenger* like its predecessor the H.M.S. *Beagle* was built as a warship for the English Navy. The *Beagle* was a 10 gun brig belonging to a class of vessels nicknamed the "coffin brig" because it was more likely to sink then complete 2 successful circumnavigation's of the earth.

Modem interest in exploring the world's oceans has generated the need for more specialized, and safer platforms and forever changed the practice of modifying existing vessels to meet the needs of ocean scientists. Still there are many converted trawlers, US Government T -boats and oil field supply vessels in use today as R/V's and most perform well. The majority of these vessels are < 100' LOA and are typically used in coastal or near-shore habitats. They are used to support all types of ocean science and education on both coasts, the Great Lakes and the Gulf of Mexico.

How these vessels found lives as R/V's is varied. Some were built as R/V's from designs that were already in production as commercial or pleasure craft. Many were convened into R/V's after they were declared surplus by the federal government or after they had ended useful lives as fishing vessels, oil field service vessels, or in many cases legitimate commercial vessels convened to drug runners. :

The relative advantages to converting an existing vessel or vessel design to a R/V depends on many factors not the least of which are the type and age of vessel being convened and the intended service after conversion. Shallow draft oilfield crew boats are easily convened to inshore and near coastal day boats. US Army T- Boats have been used by many institutions to meet the scientific needs in near coastal waters on extended cruises of up to 8 days. It should be noted that some vessels are difficult to convert to R/V's and special consideration should be given before convening these boats. For example, high speed military craft, river gun boats, USCG cutters, landing craft, etc. are available through federal surplus, but these are very specialized vessels with characteristic that are often incompatible with most marine science requirements. But these are the exception and most vessel types in common use today can be convened to RN's.

Converting an existing vessel or vessel design is almost always cheaper than building a new boat Architectural fees, design costs, certification and classification, and testing fees have already been paid. These costs can account for as much as 25% of the final costs of a new vessel, and if the vessel is U.S.C.G. Inspected or built to a classification standard (American Bureau of Shipping, Lloyds, Veritas, etc.) these costs will increase significantly

Convening an existing vessel allows the buyer to benefit from material cost at the time of construction as opposed to the inflated cost associated with a new build. Indirect costs associated with the normal maintenance of design and construction facilities are avoided when purchasing a used vessel.
I

The cost savings associated with a conversion can not be understated and typically allow buyers to stretch their dollar and buy-up into larger, more capable vessels. For example, Bermuda Biological Station for Research, Inc. purchased the *Weatherbird II* in 1989 for $375,000. The vessel, at the time of purchase would have exceeded $3,000,000.

The time lapse between deciding to build a new vessel and delivery is significant when compared to conversion. During periods of vessel surpluses the prospective owner of a converted R/V can be operational in a matter of months; whereas, new builds generally take years from the point of conceptual design to finished product. Once again, the type of vessel and in the case of a new build the decision to meet regulatory standards can have a major impact on the amount of time required to build or convert a vessel. In most cases vessels could begin work as an RN after the addition of a few simple pieces of deck equipment and minor changes to the interior of the vessel to accommodate scientists and there needs for on-board laboratories. In other cases, like the *Weatherbird* II, extensive modifications were made before the vessel was capable of supporting the demands of ocean science.

The buyer of used stock vessels also benefits more directly from the experiences of the builder and previous owners. The right match between propulsion machinery and hull designs are sometimes gained only through trial and error. Over the years of production, boat builders will modify their vessel designs to achieve maximum benefits from their product and these improved will become apparent in later versions of a stock hull.

Conversions are almost always cheaper up front, but there are hidden costs that must be taken into consideration when making the decision to buy a used boat. Obsolete or discontinued machinery may drive up maintenance costs on older vessels. The presence of asbestos products in insulation, overhead and bulkhead sheathing, and deck coverings and, PCB's in transformers and fluorescent lighting fixtures can made repairs and modifications expensive. A thorough survey by a competent marine surveyor should always be conducted before purchasing a used vessel.

Used vessels are available from a number of sources. Marine brokers are available to assist prospective buyers, but there are costs associated with their services. Commercial publications like National Fisherman , and Boats and Harbors carry extensive listing of boats for sale. Vessels are also available through government surplus and are often advertised for auction through the various agencies surplus services.

Following is a list of the most common R/V conversions in use today. This is by no means a complete list and anyone interested in converting a vessel to an R/V would benefit by contacting the operators of the vessels listed before making a decision to convert a particular type of vessel for use as an R/V.

Oil Field Service Vessels

These vessels are used to service the offshore oil production industry. Built to haul passenger, supplies, or consumables (water, fuel, liquid mud, etc.) these vessels typically are not equipped with any deck gear or load handling equipment. They are generally built in Gulf of Mexico yards to some regulatory standard, such as American Bureau of Shipping or United States Coast Guard. These vessels were available in large numbers after the collapse of the oil industry in the Gulf of Mexico in the early 1980's. During this time oil field service vessels, in good condition were available for pennies on the dollar. The revitalization of the oil industry in the Gulf has created a shortage of vessels and good buys no longer exist.

Two types of oil field service vessels are in common use as converted R/V's. Work boats, which are usually > 100' LOA and inland crew boats. General characteristics of these vessels and how they have been converted follows:

Work Boat

Sometimes referred to as a supply vessel, utility boat, or standby boat (Fig. I). The term utility boat and supply vessel can be used interchangeably to describe vessels used to service offshore production facilities. A standby boat is identical to the other 2 categories with the exception that is usually smaller, does not make routine voyages back to port for the purpose of transporting personnel or supplies and is equipped with a fire monitor. A standby boat is usually deployed to an offshore production field and remains on location for weeks and in some cases months. During these periods it is available to respond to emergencies i.e. fight fires, or occasionally make routine personnel transfers between production pla tforms in the field.

Characteristics

-Hard chine displacement hulls.
-Usually larger than 100' LOA I Standby boats for near shore fields may be <100" LOA)
-Typically all steel construction
-May be built to some regulatory standard, usually Americ an Bureau of Shipping but typically operated as un-inspected vessels.
-Wheel house forward and slightly above foc'sle deck which houses some berthing, galley and mess/lounge area.
-Large back deck and deck loading capacity
-Beamy, > 4: 1 length width ratio.
-Large below deck tankage for transporting fuel, water, and drilling mud. Some vessels are equipped with "P" tanks (pressure tanks) for transporting pressurized cargo, i.e. dry cement.
-Limited or no deck equipment. Some vessels may have large anchor handling winches, and capstans for anchor handling.
-Always with at least 2 main propulsion engines w/direct drive transmissions, typically OM in older smaller vessels or EMD or Caterpillar in larger vessels.
-Generator packages are typically small and capable of accommodating the limited demands for lighting, climate control in the habitable spaces, and low amperage service equipment. Typically without power take off options for hydraulics or other ancillary power supply equipment.
-Bow thrusters, or controllable pitch propeller are not common on these vessels -To enhance the loading capacity on the vessels the rear cargo deck are low to the water.
-These vessels were available in large numbers and in good condition prior to the mid 1990's. Now most are back in service in the oil field and it is difficult to find boats in good condition that are for sale.

Conversions

The *Robert Gordon Sproul* from Scripps Institute of Oceanography and the *Weatherbird* II from Bermuda Biological Station for research are both examples of work boats that have successfully been convened into research vessels. The *Sproul* is 125' x 32' and was built in 1981 and convened to an R/V in 1984. She can accommodate 12 scientists and has an endurance of about 14 days. A dry lab, wet lab, science staterooms, a'1d mess and galley are located on the main deck with crew quarters and wheel house on the upper deck (Fig 2).

The *Weatherbird* II is 115' x 28' and was built in 1982 in Alabama at Bosarge Marine. The vessel was bought in 1989 for $375,000 and converted to an RN at Quality Shipyard in Houma, La. at a cost of $500,000. At this time new ships electronics, an aft A frame and side gallows, a cm winch (donated from Woods Hole Oceanographic Institute, a new hydraulic system and a 20' lab van were added (Fig. 3). A second "conversion" was accomplished in 1993 to increase the scientific capabilities of the vessel. This effort that included the addition of a 02 deck, installation of a bow thruster, an increase in berthing space and modifications to deck equipment and the addition of a CTD garage cost about $1,000,000. Following is a comprehensive list of modifications made to the vessel during the 1993 "conversion" (Fig. 4):

-Add 02 deck to include wheel house and aft control station
-Convert forward ballast tanks into bow thruster room and install omni-directional bow thruster
-Remove 2 fuel tanks to add six bunks and 1 head -Convert 1 main deck cabin into 1 dry lab -Install main lab on main deck
-Install CTD garage on main deck and relocated side gallows -Add 4 bunks on 01 deck

-Add damage control locker on 01 deck
-Replace all wooden walls in vessel with metal studs and fire-retardant panels -Install chilled water HV AC system.
-Remove 2-50 KW generators and install 2-75 KW generators -Replaced crane and power pack
-Installed deck grating and additional deck tie-downs -Installed new DUSH-5 CTD winch

These conversions increased significantly the scientific complement of the vessel by the removal of fuel tanks and addition of science staterooms and increased the station keeping capabilities by the addition of a bow thruster. The loss in endurance was not significant given that the vessel typically operates within a few days steam from her home port. Total cost for the acquisition and all modifications to the vessel (<$2M) is significantly less than the original construction cost of a vessel of this type and allowed the operating Institution to meet the needs of her scientific clientele without the lengthy delays associated with design and construction of a new vessel.

Crew Boats

There are 2 class of crew boats, larger vessels 85' -120' (Fig. 5) that are used to transport personnel and supplies to offshore facilities (beyond barrier islands) and smaller inshore vessels typically 45'-65' LOA (Fig. 6). Both types are designed and built for speed and are therefore not as economical to operate as the slower deeper draft work for. In addition they are not very sea-kindly and are not designed for carrying heavy loads and handling gear over the side. For these reasons offshore crew boat do not make good oceanographic R/V's. lnland crew boats on the other hand have been converted to high speed inshore research vessel with very good results. Therefore, the offshore crew boats will not be addressed in this discussion.

Characteristics

-Hard chine planing hulls without keel. Exposed shaft, hanger, propeller, and unsupported rudder. The exposed running gear typical on these vessel limits their utility where shallow drafts are needed. Although they are used extensively in the bays and shallow estuaries of Louisiana, but the bottoms in these areas are typically soft mud which accommodates routine groundings.
-Usually 45'-65' LOA
-Typically all aluminum construction but some all steel vessels are in use today. Wooden (plywood) vessels were typical prior to 1950 but most of these boats are out of service or have been converted to inshore fishing vessel (trawlers). -Average speed 15-25 kts.
-Most of these vessels are built to USGC Sub-Chapter T requirements for passenger carrying vessels within 100 miles of the coast.
-Cabin forward located above the foc'sle which may house limited berthing (2-4 persons) and galley space.
-Aft cabin usually fitted with bus style setting and in some cases tables and benches.
-Back decks open with pipe railings around the perimeters. Access to engine room and rudder rooms are usually located on the back deck. These hatches limit the area available for locating deck gear and loading scientific packages. -No tankage for transporting fluids as with work boats.
-These vessels are usually used for short day runs to oil field facilities in local bays and sounds and therefore do not have large fuel or fresh water tanks.
-Usually 2 engines and gear drive transmission. Most with GM, but some later models may be equipped with Caterpillars, or Cummins. -Limited wheel house electronics
-Small (20kW) generators sets with no power take-offs and no hydraulic systems available on the boat.
-Older aluminum vessels may suffer from extensive corrosion caused by.improperly grounded electric systems. A competent marine surveyor familiar. With aluminum vessels should be consulted before purchasing any alul1llnum vessel.

Conversions

The 52' steel hulled *Orion* and the 65' aluminum *Aquarius* (Fig. 7), both owned and operated by the University of Maryland, Center for Environmental and Estuarine Studies are typical of inland crew boat convened to R/V's.

The *Orion* was built by Sewart Seacraft in Berwick, LA in 1965 using their stock design for a 50' Hawk Class crew boat. The design was stretched 2' before construction in order to increase aft deck space. Cabinets, lab counters, and a galley were added in the aft section of the cabin, and passenger seating was removed. An engine-mounted power take-off and hydraulic pump were added to power a double drum trawl winch on the main deck.

The hydraulic system, winch, and mast and double boom arrangement for deploying scientific equipment were cross-decked from another University of Maryland vessel. The vessel was completed in February 1965 for a total cost of $61,755.

The *Aquarius* was also built by Sewart Seacraft After she was launched in 1964 the vessel was operated as a crew boat in the Gulf of Mexico until it was purchased by the University in 1972. Prior to departing Louisiana, structural modifications were made to strengthen the aft deck to allow for the installation of a trawl winch, mast and double boom. A "round-down" was welded to the transom to facilitate the handling of bottom and mid-water trawls. In Maryland the University personnel removed passenger seats and installed a galley and laboratory in the after section of the cabin and installed a new mast and double boom arrangement, double drum trawl winch and a hydraulic power system.

The University purchased the vessel for $69,500 in 1972 and spent approximately $7,000 at Teledyne Seacraft to accomplish the structural and aft deck modifications. Approximately $8,500 was spent for the materials to complete the modifications performed in Maryland. Total costs for the vessel and modifications, exclusive of labor costs associated with the Maryland conversions was $85,000. *Aquarius* was fully equipped and ready for service approximately 6 months after it was acquired by the University.

The speed, shallow draft, maneuverability and general configuration, of the crew boat design allow them to adapt into versatile research platforms. They are especially well suited for use as RN's in the protected shallow water environments of bays, estuaries, and sounds. The *Orion* has been in service as a research vessel for 33 years and the *Aquarius* is nearly 33 years old. Both vessels are still in service.

Commercial Fishing Vessels

Fishing vessels come in many sizes, shapes, and configurations. But, as with work boats they can be grouped into 2 general classes, large offshore displacement hull vessels (trawlers) and fast inshore planning and semi displacement hull vessels. In general fishing vessel are not built to any regulatory standards and as with many large steel hulled trawlers are built at small yards with poor quality control. But fishing vessels are designed for handling over the side packages and for this reason are sometimes easily convel1ed to research vessels.

Trawlers

Trawlers or bottom draggers are the most common fishing vessel used in the R/V fleet. These craft are typically > 50' LOA and almost always< 100' LOA. Most of the trawlers converted to R/V's were built and operated as shrimp trawlers along the Gulf and South Atlantic coasts. They are used in most instances to meet the need of scientists working inside of the shelf break and inshore water deep enough to accommodate deep draft displacement hulled vessels. Some R/V's were built using stock designs as is the case with R/V *Katy* but other are convened from operating commercial vessels. Typically these vessels are confiscated drug runners that are acquired from the federal government and convened into R/V's, as is the case with the R/V *Edgerton* at the Massachusetts Maritime Academy.

Characteristics

-Displacement hulls > 50' LOA and < 100' LOA round bottom except steel vessels which usually are hard chined
-Constructed of wood, fiberglass, or steel but never aluminum
-Gulf shrimp trawler most common design. These vessels are equipped with large "outriggers" or "booms" that are used to deploy nets and stabilizers. These vessels are equipped with a single double drum winch which fairleads through blocks at the ends of the booms. This arrangement is not suitable for anything other than trawling and some other accommodation must be made for deploying typical scientific gear. North Atlantic trawlers however are usually equipped to deploy gear over the stern and in some cases are equipped with stern ramps. Winches on these vessels are not equipped with slip rings and winches to handle electromechanical cable should be included in conversion.
-Single slow turning diesel engine. Some larger Gulf trawlers are equipped with two engines and in some cases tunnels which allow the vessels to operate in shallower water and nozzles which increase efficiency and enhance thrust.
-Generators typically undersized in comparison with similar-sized research vessels.
-Older vessels may lack HV AC systems and heads. Household or recreational vehicle type AC units common.
-Fire control systems are rare on these vessels.
-Hydraulics systems are available to power trawl winch -No bow thrusters.

-Many of these vessels are one-off or home built vessels and the workmanship in these boats can be very poor. Some companies do specialize in the construction of Gulf trawlers and have built reputation for quality. Diesel Engines Sales Co. (DESCO) of St. Augustine, Fla. were a major producer of Gulf trawlers and some of these wooden and fiberglass vessels are still in existence.

-Stability criteria for these vessels are unknown and in most cases plans and blueprints do not exist

-wiring may be substandard

-Sewage treatment systems substandard or non-existent

-High freeboards with dry decks

-All living quarters on main deck. Engine room, ice hold, and rope lockers below decks. Ice holds have been convened to staterooms or laboratories with some success.

Conversions

The 68' R/V *Edgerton* at the Massachusetts Maritime Academy is typical of a Gulf trawler converted to an R/V. This DESCO vessel, built in the late 1960's is a good example if the earlier fiberglass vessels built at this St Augustine shipyard. She was convel1ed from a Gulf trawler to a stem trawler after she was seized for running drugs. A stem ramp was added along with a hydraulic net real and a 3/4 Yankee trawl. The vessel is equipped with a small (10' x 15') laboratory and galley. Unlike most Gulf trawlers which are powered by a single OM 671 NA diesel this boat has a 365 HP Cummins main engine. But, like most of the early built fiberglass DESCO boat she is too lightly built and rolls badly.

The 72' *Blue Fin* (Fig. 8) at the Skidaway Institute of Oceanography was designed as a yacht but is similar in many ways to a other wooden trawlers in use in the commercial fleet. She was built in 1972 as a trawler yacht and converted to a research vessel in 1974. To increase space below decks for staterooms the engine was removed from its original bed amid ships and moved further aft. This required the installation of a z drive unit which was later replaced with a hydraulic drive unit. This system has been difficult to maintain. For this reason and the fact that the wooden hull is aging and difficult to maintain plans are under away to replace the *Blue Fin* with a new $2,000,000 custom-built fiberglass vessel.

The R/V *Katy* a 57' fiberglass boat built by Thompson Trawlers of Titusvile, Ronda is another example of a commercial trawler hull converted to pleasure yacht and operated as a research vessel. Unlike the *Blue Fin,* the *Katy* was built to spec for the University of Texas Marine Science Institute- Problems associated with convel1ing an existing hull were avoided and the vessel has become an integral part of the research programs in the shallow bays and estuaries along the south Texas coast. The vessel sleeps 6 in below deck staterooms and is equipped with a stern A frame and a semi-sheltered lab on the main deck.

Planing and Semi-displacement Hulls

Smaller planing or semi-displacement hulled fishing vessels < 50" LOA are common among the fleet of R/V's at most marine institutions. Because of their size and the need to limit weight in order to maintain speed characteristics these vessels do not have large cabin or heavy lift equipment. Typical among this type of vessel is the New England lobster boat and the Gulf of Mexico Lafitte skiff.

Characteristics

-Typically < 50' LOA

-Hard chined, shallow draft vessels with no keel and exposed running gear.

-Single high speed diesel engine

-Almost always fiberglass construction. Hull may be solid fiberglass, laminate fiberglass/balsa wood, or combination of both, and occasionally plywood covered with fiberglass. Fiberglass over plywood is often used in the decks and cabins. Improperly sealed penetrations and failures in the fiberglass weather coating can allow water damage to plywood or other laminate materials. Care should be taken to seal these areas and buyers should be cautioned to conduct surveys to determine if vessels have been maintained against this type of failure. -Usually not built to regulatory standards.

-Deck gear limited to hydraulic pot haulers on lobster boats and D.C. electric and sometime hydraulic powered trawl winches and cat heads on Lafitte skiffs.

-Usually with a small cabin forward and large open aft deck with raised gunwales.

-Small generators with hydraulics packages usually available on lobster boats.

Conversions The most common high-speed lobster type vessel in the research fleet are vessel built by Bruno and Stillman. These small, 30'-45' are used by many institution to support science in inshore waters where speed is critical. The 35' Bruno and Stillman at Moss Landing Marine Lab has been in service since 1978 and plans are to continue operating the vessel for local (within 15-20nm) service.

The University of Texas in Port Aransas, TX maintains a fleet of small high-speed vessels 3 of which are Lafitte skiffs built by Jefferson Fiberglass in New Orleans, La.. The smaller (21 ') vessel is powered by a 140 hp outboard and the larger boats (24' and 32') a7re powered by Cobra inboard/outboards. Only the laI.ger boat is equipped with a cabin and A.C. power.

Government Surplus Vessel

These are government built vessels available through the federal surplus system surplus. As indicated above most of these are specialized vessels and do not lend themselves to conversion to general purpose research vessel The exception is the US Army T -Boat The T -Boat is the quintessential government surplus vesseV convened to an RV. The first T Boats were wooden and built between 1940 and 1951. Steel T -Boats replaced wood vessels in 1951 and continued in production until 1953 when the last steel T -Boat was launched. During this time 110 steel T boats were constructed to be used as personnel transports, and harbor towing and lightening vessels. Three yards built steel T Boats, Missouri Valley Steel located in Leavenworth, Kansas, National Steel and Shipbuilding Corp., in San Diego, California, and Higgins Co. in Louisiana.

These vessels were given to Universities to use as research vessels but ownership resided with the US Army. A number of these vessel are still in service including the *Tirsiops* at the Florida Institute of Technology, the *U Conn* operated by the University of Connecticut, the NOAA ship *Benthos,* and the *Linwood Holton* at Old Dominion. The *Hilton* is still in use, the *U CO1ll1* is being replace by a new vessel built as an RN and the *Benthos* has just been acquired by NOAA and is in the process of conversion to a research vessel.

Characteristics

-65' LOA 18.5' beam, 7' draft steel construction
-cabin aft with forward cargo hold and for'scle containing 4 berths and galley with diesel stove and DC refrigerator
-seating for 24 passengers in cabin with 1 berth in wheelhouse
-Main engine either Caterpillar D 375 or Budda 1878 4 cylinder -Generator 5 kW DC and Hercules fire pump -All electrical in vessel DC
-48" x 36" three blade prop with 3-1/2" shaft
-Head, shower, and sink in main cabin and below decks
-2-700 gal fuel tanks
-Designed to carry 30 tons of cargo
-Well built, frames all continuously welded

Conversions

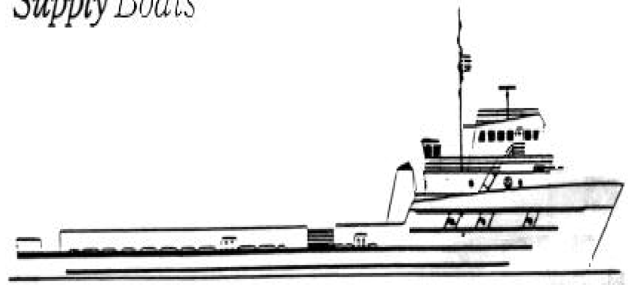
Typical of T boats converted to research vessels are the *U CONN* and the *Linwood Holton.* The *U CONN* was built in San Diego in 1953 and leased to Scripps Institute where it was used for seismic surveys in southern California and the Gulf of Mexico. This vessel was unique in that it was never used by the military or moth balled, it was built and immediately leased to Scripps. The Budda main engine was removed and a Caterpillar D 375 was installed" The vessel is equipped with 2-20kw 110V DC generators and 2-AC generators. The Cargo hold was converted to a berthing area and 8 bunks were added. On the main deck the seating area behind the wheel house was converted to a 110 sq., ft. laboratory with running seawater. The *U CONN* is used for coastal and offshore research in Long Island Sound.

The *Linwood Holton* was built at Higgins in New Orleans, La and was acquired by Old Dominion in 1970. The Budda main engine was removed and a OM 12- 71 was added. The DC power system was removed and AC was provided via a 30 KW generator driven by a OM 371. As with the *U CONN* the seating area on the main deck was convened to a lab and the cargo area below deck was convened into an 8 person berthing area. Deck equipment includes a Tyco 1500 lb. capacity crane, 2 hydro winches and a small boat davit. The crane is used to deploy over the side equipment including trawls and box corers.

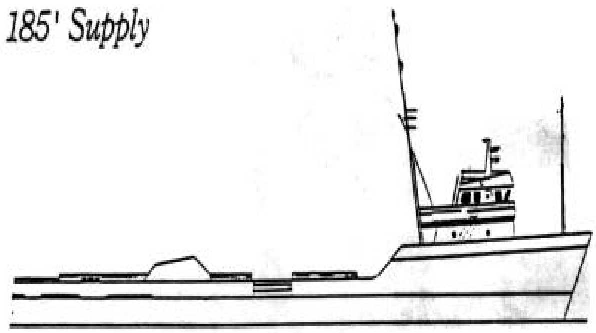
In general, the US Army T -Boat has served science well. These vessels were built to high standards and have lasted beyond the normal life expectancy of vessels of this type. They are very seaworthy although they do have a tendency to roll in heavy seas. Given the age of this class it is unlikely that new conversions will be accomplished in the future.

Fig. 1

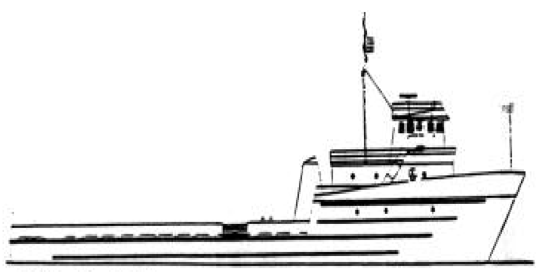
Supply Boats



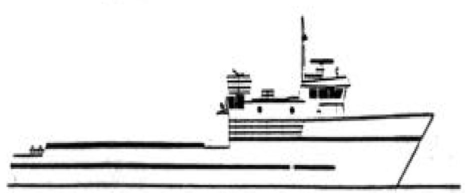
185' Supply



166' Anchor Handling/Supply Vessel

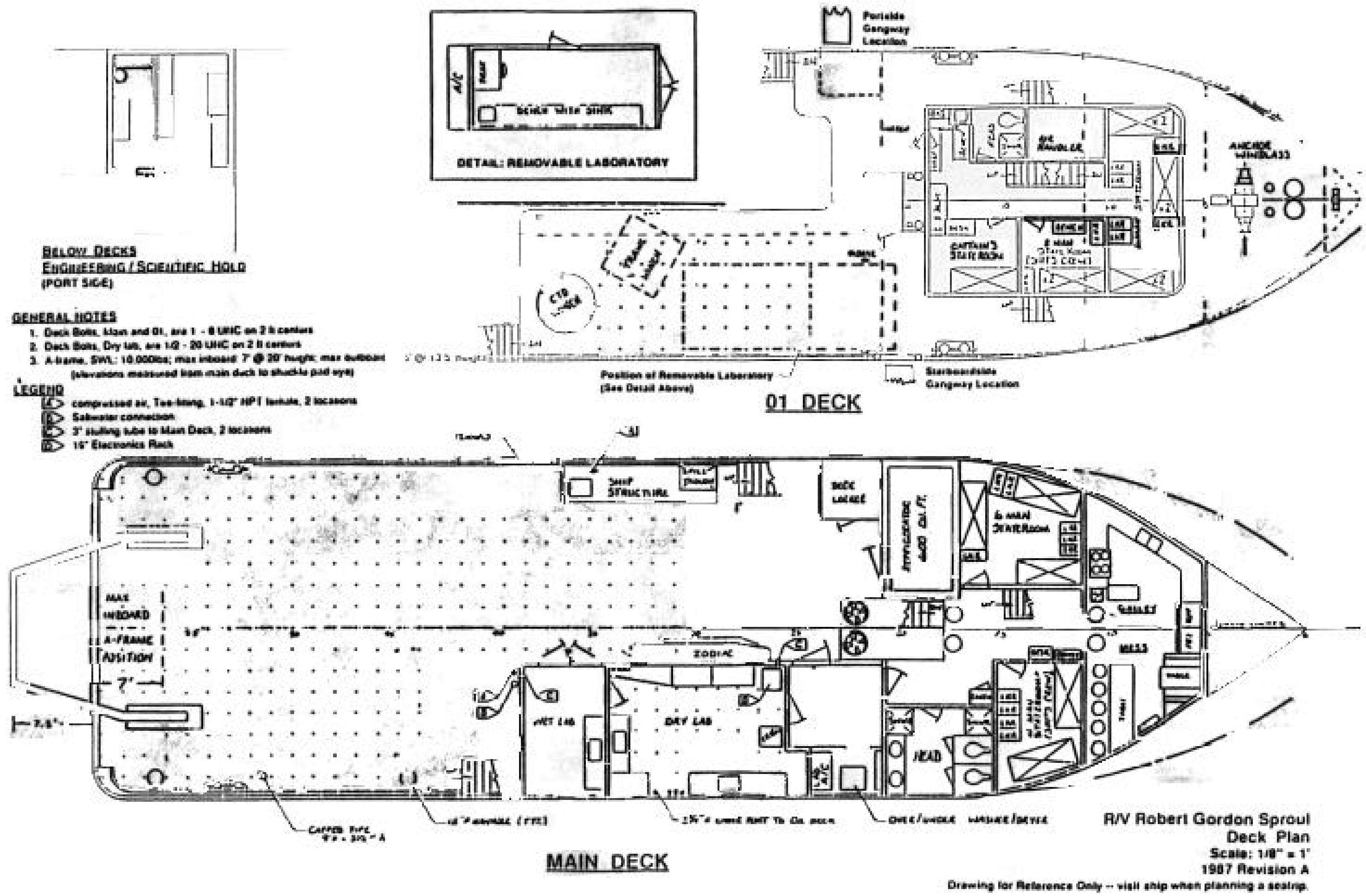


125 Supply

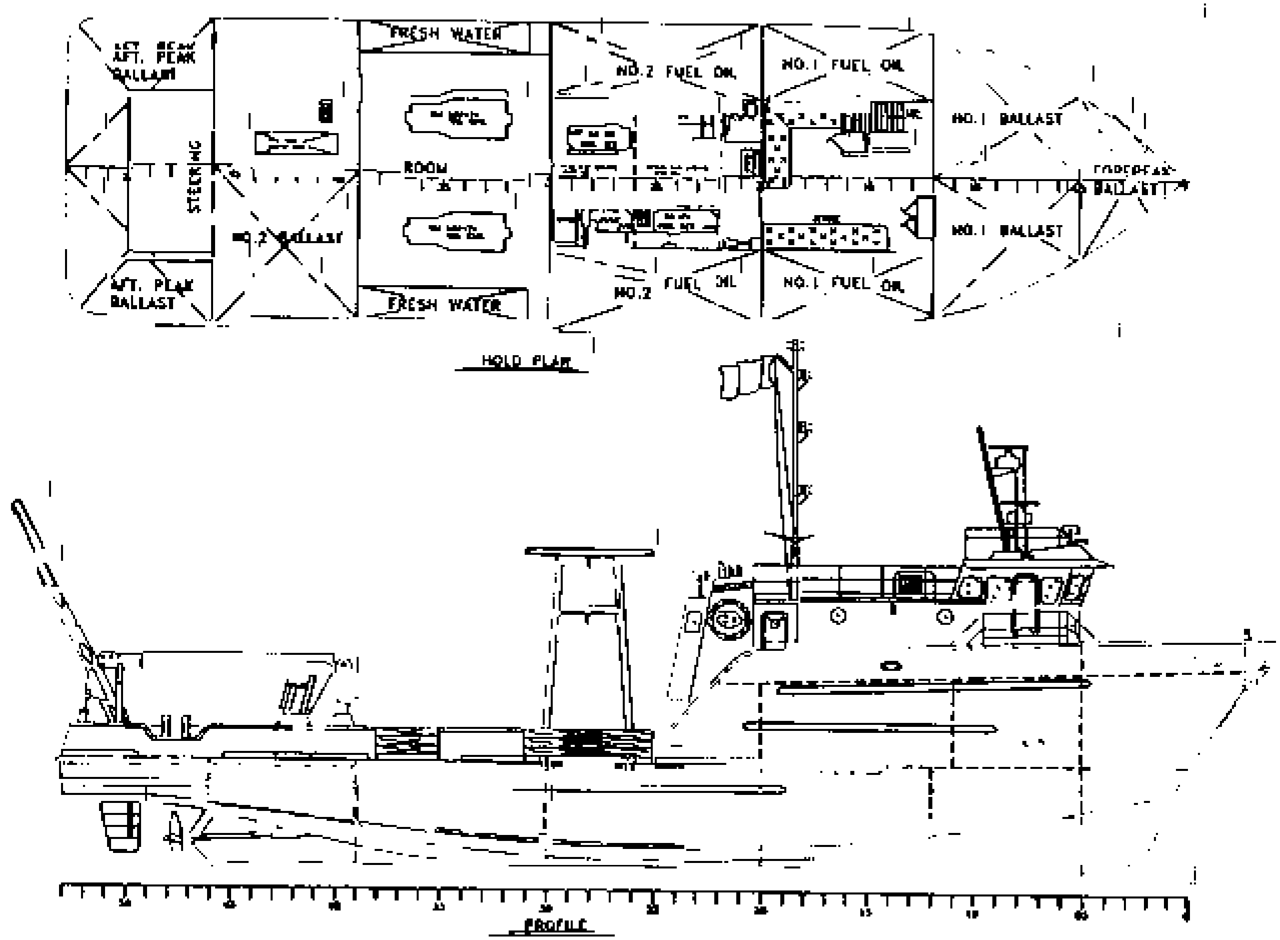


115' Utility Boat

Fig. 2



BELOW DECKS
ENGINEERING / SCIENTIFIC HOLD
(PORT SIDE)
GENERAL NOTES
LEGEND
compressed air, Tee-fitting, 1-1/2" NPT female, 2 locations
Saltwater connection
15" Electronics Rack
DETAIL: REMOVABLE LABORATORY
BENCH WITH SINK
A/C
Portside Gangway Location
ANCHOR WINDLASS
CAPTAIN'S STATEROOM
Position of Removable Laboratory (See Detail Above)
Starboardside Gangway Location
01 DECK
SHIP STRUCTURE
DECK LOCKER
6-MAN STATEROOM
GALLEY
MESS
ZODIAC
DRY LAB
WET LAB
HEAD
MAX INBOARD A-FRAME POSITION
7'
MAIN DECK
R/V Robert Gordon Sproul
Deck Plan
Scale: 1/8" = 1'
1987 Revision A
Drawing for Reference Only -- visit ship when planning a seatrip.



R/V WEATHERBIRD

Fig. 3

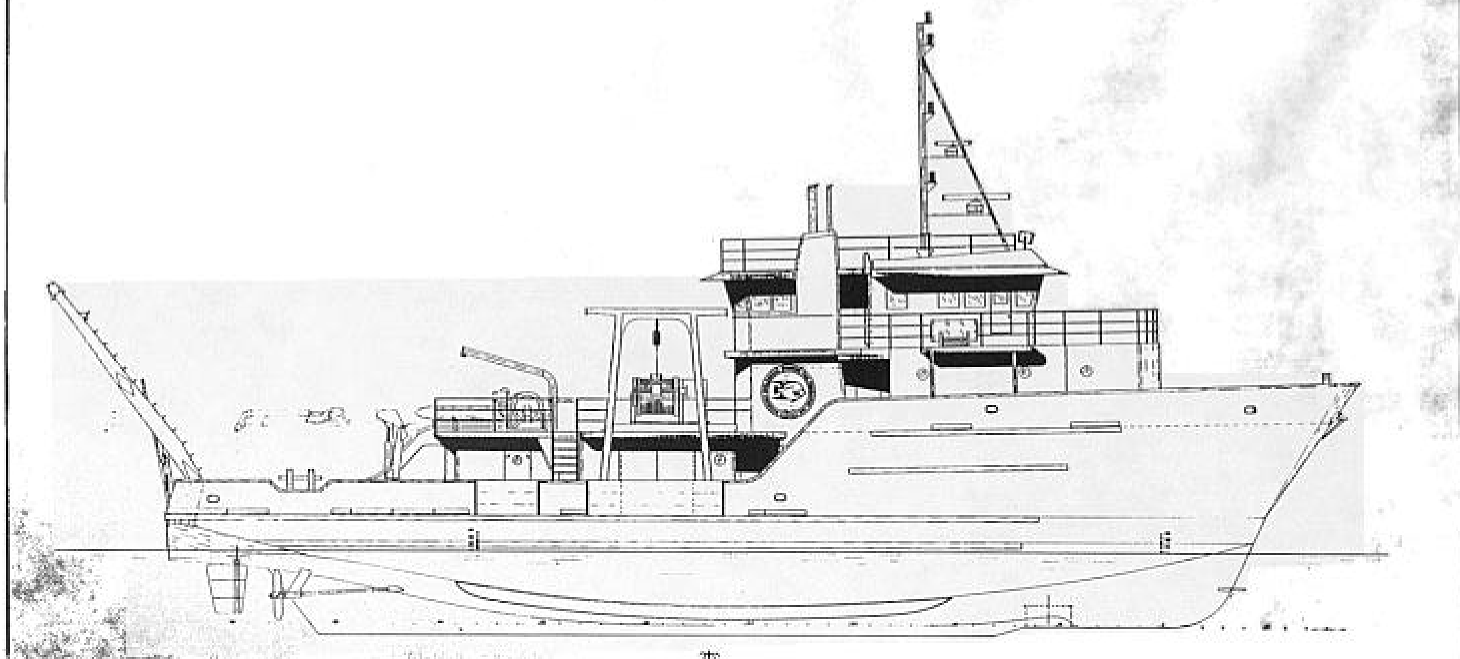
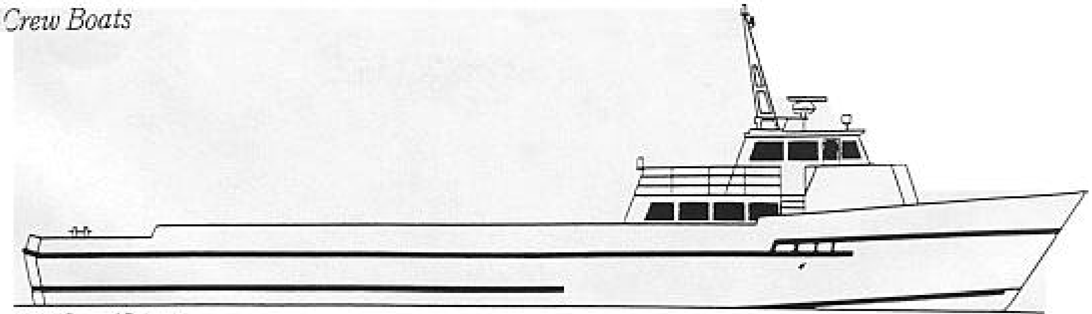


Fig. 4

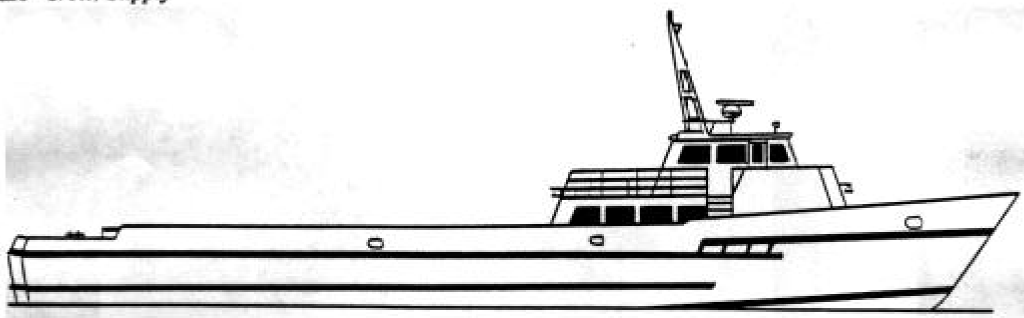
R/V *Weatherbird* after second conversion

Fig. 5

Crew Boats



120' Crew/Supply



115' Crew Boat

110' Crew Boat

105' Crew Boats

Fig. 6

Typical 50' inshore crewboat

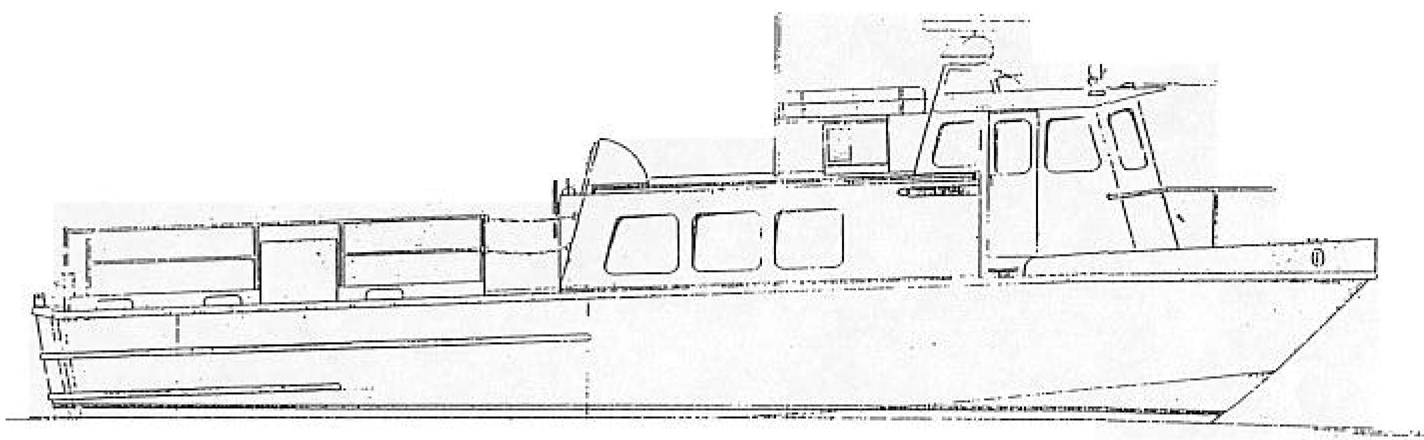
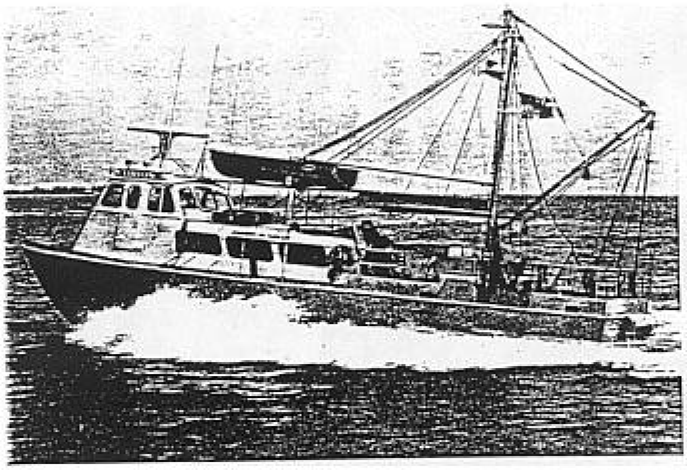
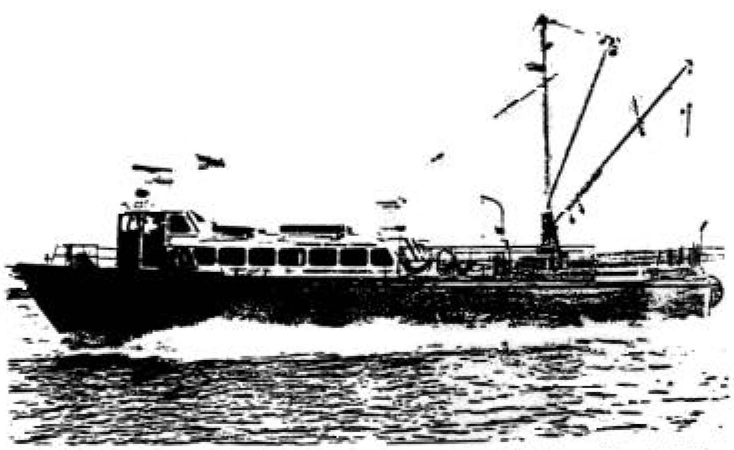


Fig. 7



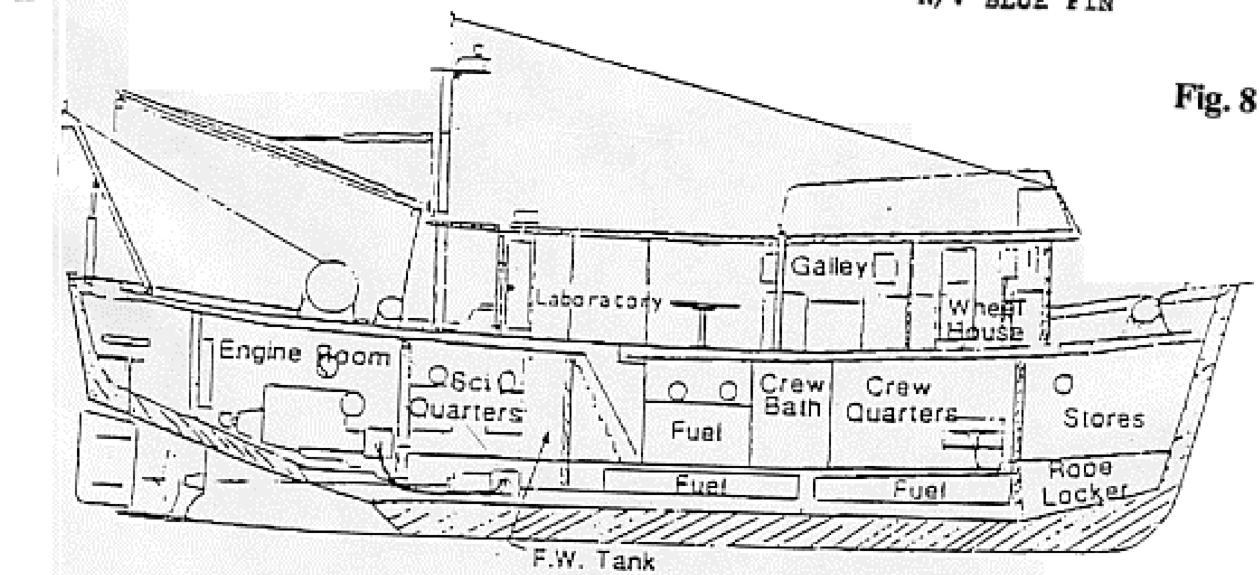
The steel-hulled Orion cruises the entire Bay and is capable of the same types of field work as the Aquarius, although she is not licensed for ocean work. Her draft is less than that of the Aquarius, enabling penetration of shallower waters—an important consideration when dealing with an estuary such as the Chesapeake. For light sampling in very shallow water, a fourteen foot aluminum skiff powered with a ten horsepower outboard motor is carried in a cradle on the Orion's cabin.

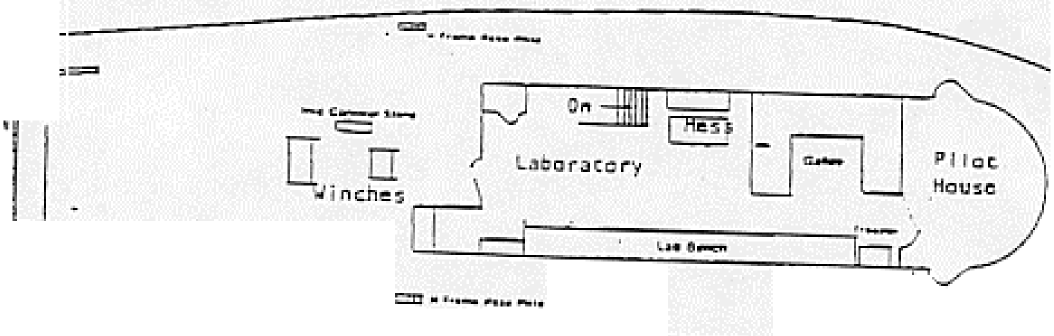


The Fleet's largest vessel, the aluminum-hulled Aquarius, cruises from tidal freshwater to the mouth of the Chesapeake Bay and up to 50 miles out into the Atlantic. Her greater speed and ample laboratory and deck space make her an extremely versatile and able craft, capable of handling most types of research in the varied conditions of the Chesapeake. The capability for carrying large groups makes her particularly useful for student training and public information cruises.

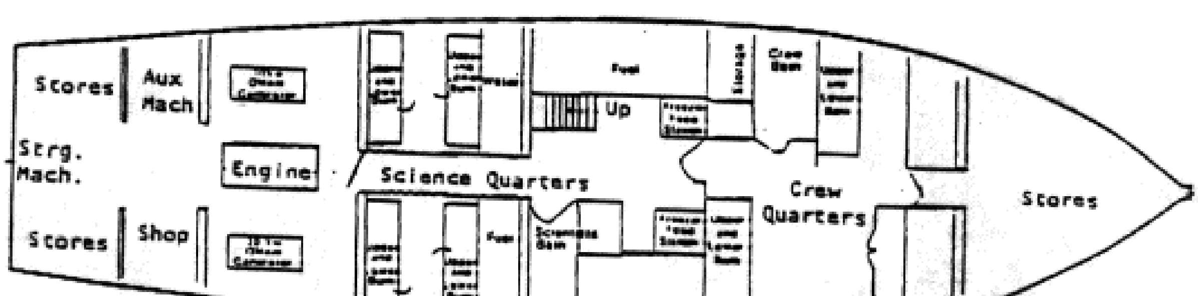
R/V BLUE FIN

Fig. 8





Deck Level



Lower Level

PRIMER ON SMALL RESEARCH VESSELS
OUTFITTING AND EQUIPMENT

Outfitting Items	Below 65 Feet	65 - 85 Feet	86 - 105 Feet
Laboratories (wet and dry area)	50 - 100 sq. ft.	100 - 400 sq. ft.	400 - 700 sq. ft.
Benches	5-10 feet	10-15 feet	15-20 feet
Fume Hood	Optional	Yes	Yes
Sink	Yes	Yes	Yes (2)
Refrigerator	Yes	Yes	Yes
Freezer	In Refrigerator	5-10 cubic feet	10-18 cubic feet
Running Sea Water	Yes	Yes	Yes
Uncontaminated Sea Water	Optional	Yes	Yes
Hot and Cold Fresh Water	Yes	Yes	Yes
Compressed Air	Optional	Optional	Yes
Intraship Communications	Yes	Yes	Yes
Hold Downs and Unistrut	Optional	Yes	Yes
Navigation Equipment (for science)			
DGPS w/ Charting	Yes	Yes	Yes
Gyroscope	Yes	Yes	Yes
Depth Sounder	Yes	Yes	Yes
Speed Log	Optional	Yes	Yes
RDF for Mooring Beacons	Yes	Yes	Yes
Scientific Instrumentation			
Scientific Data Logger (SAIL)	Yes	Yes	Yes
Meteorological System	Wind, Temp, BP, SST	+ RH, Light	+RH, Light
CTD	Internally Recording	Standard	Standard
Transmissometer	Yes	Yes	Yes
Flouorometer	Yes	Yes	Yes
ADCP	Optional	Optional	Yes
Water Sampling Bottles	Yes	Yes	Yes
Rosette System	Optional	Yes	Yes
Salinometer	Optional	Yes	Yes
Pinger(s)	Optional	Yes	Yes
Plankton Net, gravity corer	Yes	Yes	Yes
Outfitting Items	Below 65 Feet	65 - 85 Feet	86 - 105 Feet
Winches (minimum requirements)			
Hydrographic	500 meters 3/16"	1500 meters 3/16"	3000 meters 1/4"
CTD	Optional	2000 meter .322"	3000 meters .322"
Trawl	N/A	2000 meters 3/8"	3000 meters 1/2"
Capstan	Optional	Yes	Yes
Line Monitoring	Optional	Yes	Yes
Frames and Cranes			
Side Frame/Davit	Yes	Yes	Yes
Stern Frame	Optional	Yes	Yes
Deck Crane	N/A	Optional	Yes
Communications (for science)			
Cellular w/Fax	Yes	Yes	Yes
Msat Satellite Phone	N/A	Optional	Yes
INMARSAT Standard C	N/A	Optional	Yes
INMARSAT A, B, or M	N/A	N/A	Optional

Electrical Power			
115 VAC	15 - 25 amps	25-35 amps	35 - 50 amps
208/220 VAC	10 amps	20 amps	30 amps
208/220/480 VAC 3 phase	10 amps	20 amps	30 amps
12/24 VDC	5 amps	10 amps	15 amps
Clean/Uninterrruptable Power	1.5 kVA	1.5-3 kVA	3-7 kVA
Miscellaneous			
Van Capability	N/A	Optional	Yes
SCUBA Platform	Yes	Optional	Optional
Inflatable/Work Boat & Motor	Yes	Yes	Yes
Science Berthing	5 -7	8 - 10	10 - 12
Endurance (days)	5	10	15
Bow Thruster	N/A	Optional	Yes
Weather Deck Working Area	100 - 250 sq. ft.	250 - 450 sq. ft.	450 - 600 sq. ft.

SECTION 9
Brian W. King
Propulsion Systems

Brian W. King, P.E. graduated from the United States Merchant Marine Academy in 1981 with a B.S. degree in Marine Engineering. He worked as an operating marine engineer aboard ships, primarily the solid rocket booster retrieval and research ships home ported at the Kennedy Space Center in Florida. He joined Elliott Bay Design Group in 1988 and currently is their Chief Marine Engineer. He is a U.S. Coast Guard licensed Chief Engineer of Motor Vessels of any Horsepower and Third Assistant Engineer of Steam Vessels of any Horsepower. He is also a Professional Engineer of Mechanical Engineering, and Naval Architecture and Marine Engineering registered in Washington.

THE THRUST END

Disregarding the possibility of paddlewheels or sail, the only practical alternatives for putting thrust to the water are propellers and waterjets. Each have their inherent strengths and weaknesses. The best choice for the small research vessel depends largely on the intended mission profile. Generally, waterjet drives have found the most applications on semi planing or planing boats intended to go over 25 knots. Propellers are more often applied to slower speed vessels with displacement or semi planing hulls.

To understand when each is used, one must understand a little about their principles of operation. The propeller screws its way through the water. As propeller RPM varies, so does propeller thrust and vessel speed. The jet drive is an axial flow or mixed flow pump. The amount of thrust it develops is independent of the waterjet drive RPM. The distinguishing characteristics of a propeller-driven vessel at the propeller are large diameter, large propulsion system momentum, large water flow, low flow velocity, and low propeller RPM. Propellers are very good at maintaining a relatively constant vessel speed when the vessel is being slammed by waves and gusting winds. As hull speeds increase, the shaft support and rudder appendages cause increasing drag and the propulsive efficiency goes down. The distinguishing characteristics of a waterjet-driven vessel at the waterjet are small diameter, small propulsion system momentum, low water flow, high flow velocity, and high waterjet RPM. Waterjet drives are much more sensitive to varying wave and wind forces. As hull load varies due to wind and wave forces, waterjet thrust varies and a constant vessel speed is harder to maintain. Waterjet drives have little or no appendages, so as vessel speed increases, there is no increasing appendage drag affecting propulsive efficiency.

Conventional Shaft and Propeller

A conventional, fixed-pitch propeller, when driven by a high speed diesel engine with reversing reduction gear and shaft, is perhaps the most economical and mechanically least complex of the small research vessel's propulsion system options. (Illustration 1). The conventional system is well proven and reliable. Most shipyards have experience installing a conventional propulsion system and can do it without a high degree of technical sophistication, not necessarily true of the other propulsion system options. Repair parts and technical support for the major equipment are, for the most part, readily available throughout the world. Over a fairly narrow designed speed range, the conventional propulsion system provides the highest overall propulsive efficiency of all propulsion systems available to the small vessel operator. The hull form for a conventional propeller with rudder may be configured so that the vessel is suitable for shallow draft operation or at least presents no delicate appendages below the bottom of the vessel.

When a propeller has been selected to provide the best cruising characteristics, it will not allow the vessel to go slow without constant attention from the operator. An 1800 RPM rated engine may have an idle RPM of 650. This corresponds proportionally to thrust at the propeller. This lack of ability to go slow may present a significant problem for some research vessel operational requirements. Another significant disadvantage is the propellers and the requisite rudder's ability, even talent, at fouling any lines or umbilicals that may be hanging over the side. The conventional propulsion system does not lend itself readily to dynamic positioning.

There are variations of the conventional propulsion system that make it more suited to the small research vessel operational needs. First to consider is use of a controllable pitch propeller system. It adds complexity and a higher initial cost, but it does provide the operator almost infinite speed variation from nearly zero thrust right up to the vessel's rated speed. The reduction gear is simpler because no reversing gear and clutch is required. A controllable pitch propeller system lends itself more readily to dynamic positioning, provided there is also a thruster and, it too, is part of the dynamic positioning system. Many small vessel controllable pitch propeller systems are well-proven, very reliable, and do not significantly increase operational costs or maintenance requirements. Other options to overcome the fixed pitch propellers lacking low speed control are slipping clutch systems or two-speed reduction gears.

Placing a propeller in a nozzle will generally increase low speed thrust. This may be important if the vessel operational requirements include towing. Over 10 to 12 knots, nozzles increase drag and will likely decrease the cruising performance. Nozzles have the added advantage of protecting the propeller and rudder from impacts and may reduce the probability of a propeller fouling with lines.

Waterjet Propulsion

Once waterjets were used exclusively for small, high-speed boats. They, in fact, are more efficient than conventional propellers when speeds are over 25 knots. (Illustration 2). Waterjets now are being built for work boats that need to go slow. Like the conventional fixed-pitch propeller, they lack very-low-speed thrust modulation. Unlike the propeller though, they can moderate their thrust by partially engaging reversing buckets so that they do have the ability to go very slow. Depending upon the configuration, the waterjet drive usually includes a clutch but often does not require a reduction gear. Occasionally a reversing reduction gear is installed to allow back flushing of the waterjet.

Waterjet propulsion lends itself to shallow water operation. Boats can generally be beached or sit on the bottom without damage to the propulsion system. Waterjet propulsion is safer to divers than any of the other propulsion options and is least likely to foul lines and umbilicals.

Z-Drives
Z-drives are so named because of their drive shaft configuration, horizontal off the engine, vertical through the hull, and horizontal again at the propeller hub. (Illustration 3). Modern Z-drives are proving themselves robust and reliable and are now the preferred propulsion system for most ship-assist and line-haul tugs. Initial cost and operational maintenance costs are higher than either the conventional propeller or the waterjet propulsion systems. Z-drives are available in fixed-pitch or controllable-pitch propeller versions and with open propellers or in nozzles. Z-drives may vector their thrust in any direction, making the vessels in which they are installed extremely maneuverable. Rudders are not used with Z-drive installations. Of all propulsion systems available, they are the system most suited for dynamic positioning.

For Z-drives to work effectively, they need to extend below the hull on a small vessel so their thrust is not blocked. This gives the vessel a comparatively deep draft and vulnerable appendages making the Z-drives unsuited to shallow draft work. As with a tug, Z-drives may be tucked under the stern, giving them some protection against bottom impacts, but this does reduce their all-around thrust vectoring capability.

Cycloidal Drives
Cycloidal drives orient their propeller blades vertically and generate lift over them much as an airplane wing does. (Illustration 4). Like Z-drive propulsion installations, cycloidal drives may vector their thrust in any direction and do not use rudders. Cycloidal drives are installed with a docking platform built under them and a skeg around which the vessel pivots, this allows some protection from bottom impacts. Cycloidal-drive vessels have comparatively deep drafts; they are less suitable for shallow water than some other forms of propulsion. Only recently, proportional electro-mechanical control systems have been developed for cycloidal drives making them suitable for interfacing with dynamic positioning systems and autopilots. Cycloidal drives have a higher initial cost and higher operating maintenance costs than the other propulsion system options described here. Cycloidal drive systems have generally proven themselves to be extremely robust and reliable.

Steerable Thrusters
Steerable thruster systems are available and are entirely flush with the hull. They work by ducting in water, either through ports in the bottom or in the side of the hull, increasing its velocity pressure through an impeller and then discharging it out through the bottom through a directable nozzle or steering vane assembly. (Illustration 5). They are well-suited to shallow water work and work where divers, lines and umbilicals may be in near proximity to the vessel. They are well-suited for dynamic positioning systems.

Steerable thrusters should be considered as auxiliary propulsion and take-home propulsion as they are too slow and inefficient to be effective main propulsion. By themselves, steerable thrusters may be suitable for propelling the vessel up to about 6 knots cruising speed.

THE PRIME MOVER END

At the end opposite the thrust end in the propulsion system, is a diesel engine, gas turbine, or electric motor. Due to its very good power-to-weight ratio, the gas turbine has found application on high-speed vessels particularly in combination with a waterjet. The gas turbine has found little application on vessel projects wherein high power-to-weight ratio is not a driving criteria and low cost is a driving criteria. Thus, they are not typically found on the small research vessel. More typical for the small research vessel, and discussed here, are diesel- and diesel-electric drive installations.

Diesel Drive

The most common propulsion installation is the direct diesel drive. (Illustration 1). As used herein, this is a diesel engine coupled to a reversing reduction gear, coupled to a shaft that drives a fixed-pitch propeller. Ahead or astern thrust is determined by the propeller rotation which is changed by which clutch and portion of the gears are engaged in the reduction gear. Changing the speed signal to the diesel engine governor controls propeller thrust and vessel speed. The diesel engine, the reduction gear, and the shaft supports are all typically bolted to the vessel's primary structure (the engine girder).

The direct drive diesel engine/reduction gear installation is comparatively low-cost, simple to install, and is reliable and simple to operate. As discussed previously, it has some disadvantages for low-speed operation. Most often the speed control of the direct diesel drive is enhanced by the use of a controllable-pitch propeller. With a controllable- pitch propeller, direction of thrust is controlled by reversing the propeller blade pitch, not by reversing the direction of rotation of the propeller; thus the reversing clutch and gear portion of the reduction gear may be eliminated. Instead, a hydraulic and mechanical means of propeller pitch control is added to the installation. With a controllable-pitch propeller system, the propeller thrust and vessel speed are controlled by combination of changing the speed signal to the engine governor and by varying the propeller blade pitch.

The direct-drive diesel engine, when rigidly coupled to the reduction gear and shaft, must maintain near-perfect alignment between each of the main components, or premature failure of the equipment will occur. Alignment is maintained by bolting the equipment to the engine girder. The engine girder extends under the engine and reduction gear and often is integral with structure supporting the shaft bearings, stern tube, propeller strut bearing and the rudder. It is massive and rigid, and part of the vessel's primary structure. The engine girder, in part, is designed to maintain alignment between the propulsion system equipment even with the hull flexing in a seaway and, in part, it supports and spreads the propulsion system static and dynamic loads to the vessel's other structure. This direct attachment of the equipment to each other and to the vessel structure also means though that the equipment vibrations, torsional and otherwise, have a method of transmission to each other and throughout the vessel's structure. If not carefully considered in the design and selection of equipment, these vibrations may have a detrimental (sometimes dramatic and catastrophic) effect to the well-being of the other equipment.

Additionally, the vibrations will be felt and heard as structural-borne noise, both within the ship and in the surrounding sea. A research vessel which must keep habitable working and living conditions for its crew and scientists, and a minimally intrusive profile in the marine environment, must have designed-in measures to reduce the propulsion system's noise. An effective way to dramatically reduce structural-borne noise is by resiliently mounting the engine and reduction gear to the engine girder and by putting a coupling able to take a certain amount of motion between the reduction gear and shaft. Other methods of reducing noise include sound insulation, and proper design and selection of equipment for the vessel's systems. Resiliently-mounted engines add considerable cost and complexity to the direct-drive diesel installation.

Diesel-Electric Drive

The diesel-electric drive propulsion system is a favored approach for larger research vessels with shaft horsepower of 1000 and more. (Illustration 6). In the past, the diesel-electric drive system complexity and cost has generally precluded their application for smaller vessels. Recent technological advances, however, have lowered the size of vessel for which it is a practical alternative. The electrical connection between the diesel generator and the propulsion motor offers design flexibility not possible with the direct-diesel drive. The typical installation is to have several diesel-driven generators providing power to an electrical bus which provides both ship's service power and propulsion electrical power. The propulsion prime mover in such an installation is then an electric motor. Propulsion motors may either be alternating current or direct-current, with direct-current motors being much more common on smaller installations. With either motor, propeller thrust is controlled by varying the motor RPM. Thrust direction is controlled by reversing motor direction. In the direct-current motor installation, speed is controlled by altering the motor voltage. In an alternating-current motor installation, speed is controlled by altering the frequency to the motor. With either motor type, speed is continuously variable from zero RPM to the rated RPM of the motor. More than any other attribute, it is the fine speed control of the diesel-electric system that makes it popular for research vessels. Unlike the direct-drive diesel system, there is little need for controllable-pitch propellers or reversing reduction gears with a diesel-electric drive system, although reduction gears with no reversing function are often installed between the motor and shaft to allow use of a smaller, high-speed motor.

In a modern installation, power converters are used to change the constant frequency output of the diesel generator to the direct current used by the direct-current motor or the changeable frequency for the alternating-current motor. The power converters introduce harmonic currents to the otherwise clean sine wave of alternating current on the electrical bus. These harmonic currents are notoriously damaging to the sensitive electronic equipment found in the laboratory or in the wheelhouse.

A diesel-electric vessel must either split the propulsion electrical bus from the ship’s service power electrical bus, or it must include equipment that isolates and filters the harmonic currents from the clean power sine wave. In a split bus configuration, separate diesel generators are connected to the propulsion bus and to the ship’s service power bus with no electrical connection between the two busses.

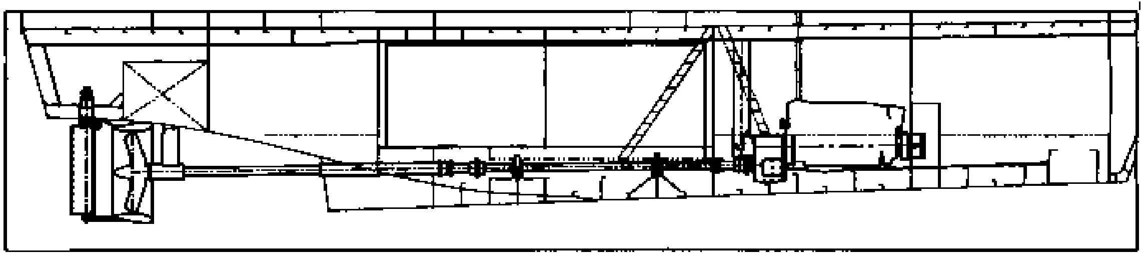


Illustration 1
Conventional Shaft & Propeller

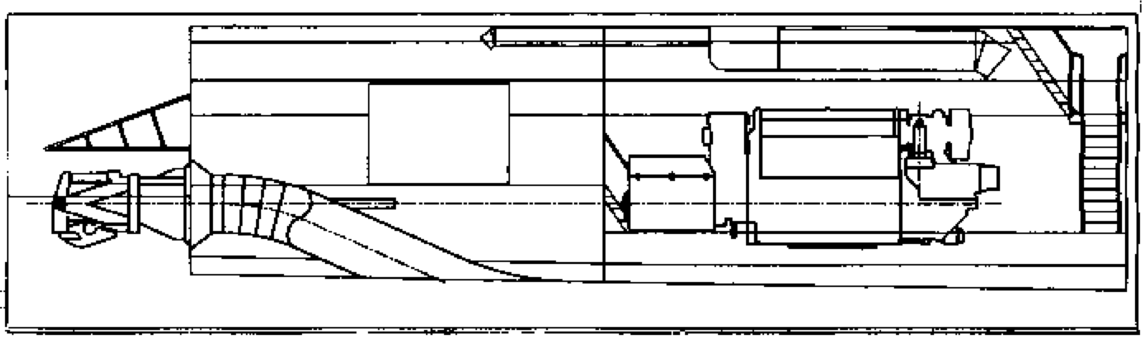


Illustration 2
Waterjet Propulsion

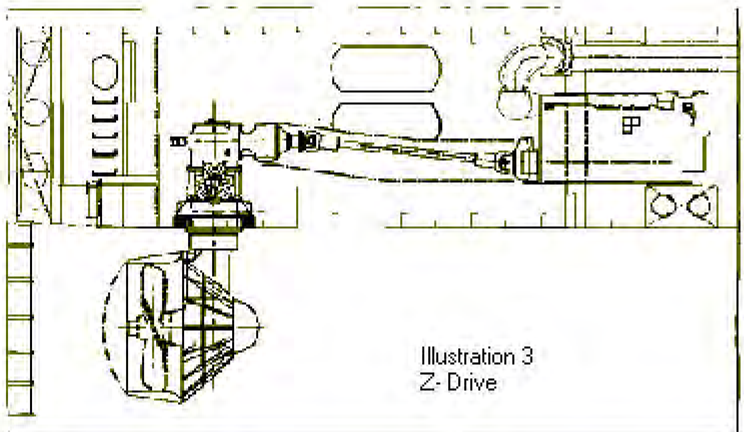


Illustration 3
Z- Drive

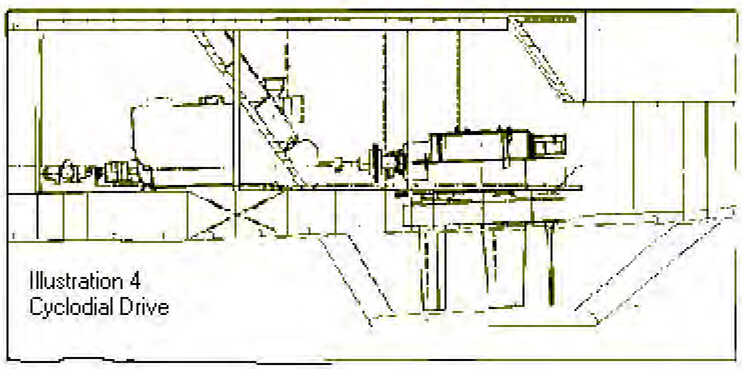


Illustration 4
Cyclodial Drive

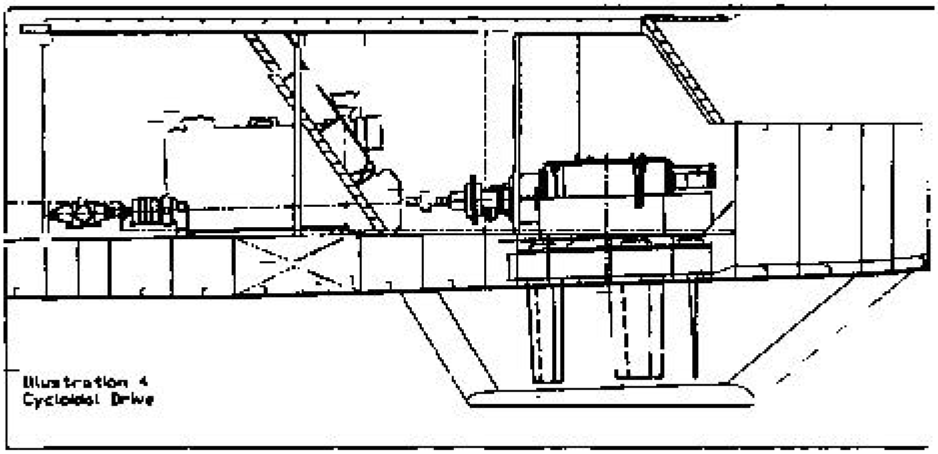


Illustration 4
Cycloidal Drive

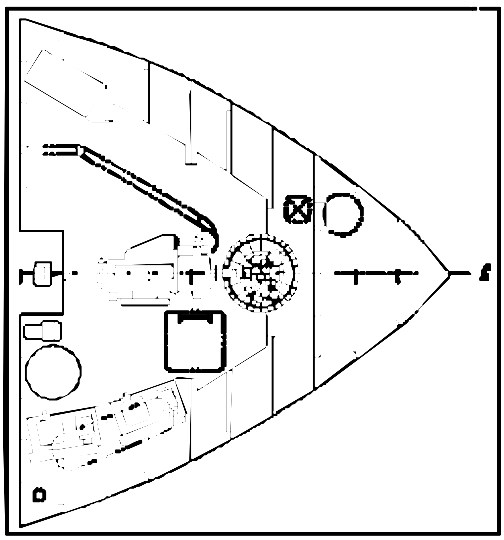


Illustration 5
Steerable Thruster

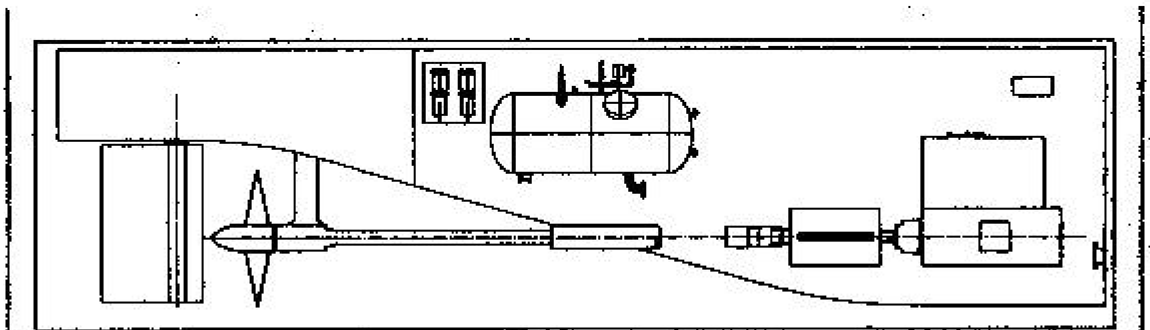


Illustration 6
Diesel-Electric Drive

SECTION 10
Douglas Wolff
Monohull Design and Construction

Monohulls as research vessels have represented the stock-in-trade from the fifteenth century European voyages of exploration until the late twentieth century. Even now, the monohull concept has significant advantages over other hullforms in many applications. Although the SWATH, catamaran, and other "modern" hull forms are increasingly common, the versatility and economy of the monohull design ensure that it will continue to play a major role in the fleet of small research vessels.

Significant advantages of the monohull as compared to SWATH and multihull designs include:

- Low acquisition cost
- Efficient use of enclosed volume
- Propulsion system flexibility
- Excellent maneuverability
- Low relative maintenance

Acquisition Costs

Addition of a new vessel to the fleet requires a careful analysis to determine if the market will support the capital and operating costs. Without delving into the "demand side" issues, it is clear that a lower capital investment will enable the operator to be more price competitive in a slow (buyer's) market, and to recoup the investment faster in an active (seller's) market. Monohulls offer lower cost per unit volume than other hull configurations. This is due to the relationship between hull surface area and volume. This ratio is minimized in the case of a monohull, thereby reducing the quantity of materials and the amount of labor required to assemble the hull. In addition, machinery costs are increased in the case of a multihull due to the redundancy required for multiple propulsion and ballast systems, and are difficulty involved in machinery installation in cramped spaces.

Hull Volume Utilization

Because the enclosed volume is in a single hull, the monohull offers excellent flexibility in layout of machinery and accommodations spaces located below deck. For example, the machinery space can be located aft to reduce shafting length, or forward to permit accommodations or laboratories amidships where the ride is more comfortable. If a cargo hold is required, a monohull has maximum usable volume for an amidships or aft hold.

Propulsion Flexibility

With regard to propulsion machinery, the monohull allows the choice of either single or twin propulsors. Each option has advantages: a single propulsor occupies less space and will be lighter and less expensive; twin propulsors provide better maneuverability as well as take-home power in the event of a propulsor failure. Only the monohull design allows for the advantages a single propulsor offers.

Dynamic Positioning
Dynamic positioning (DP) has become commonplace in monohull will typically be fitted with forward and aft jet thrusters for 360^o directional control. A twin propulsor vessel may be able to dispense with the aft thruster, working the two propulsors against each other as required to obtain the required thrust in conjunction with the forward thrusters. In either case, DP control is available to suit the mission requirements.

Maneuverability, Access and Maintenance
The relatively narrow beam and large waterplane area of the monohull vessel also offer advantages. Many areas served by small research vessels have limited port and repair facilities; the narrow beam allows access into smaller marinas, marine railways and dry-docks that may be accessible to multihulls vessels. Maintenance is reduced due to reduces wetted surface areas and fewer sea chests installed in a monohull.

Large waterplane area can be advantageous in that the vessel draft will be less affected by weight growth than will the draft of a vessel with less waterplane area; i.e. a monohull will be less weight sensitive than a multihull of comparable length.

Having discussed the advantages of the monohull design, it is now appropriate to touch on the disadvantages, which are:

- Seakeeping
- Deck area
- Perception

Seakeeping
The relatively large waterplane area, an advantage when considering weight growth, is a negative factor when considering the issue of seakeeping. Greatly simplified, we can generalize that a vessel will react to the dynamic input of swells and waves proportional to the waterplane area - increased area will result in increased ship motions. Methods for reducing motion are well established and include both active and passive systems. Active systems include fin stabilizers and rudder control, both of which are controlled by sensors measuring and responding to vessel motions. These active systems are very effective when the vessel is operating at speed, but the effectiveness is greatly reduced as vessel speeds are reduced. The complexity and cost of active roll reduction systems have generally precluded their use in small research vessels.

Passive roll reduction systems include bilge keels, a deep centerline keel, a centerboard or daggerboard, flopper-stoppers and anti-roll tank. Bilge keels (also called rolling chocks) are widely used because of their simplicity, low cost and effectiveness at all vessels speeds. Properly designed bilge keels create minimal drag and increase roll period while reducing roll amplitude; poorly designed bilge keels can reduce vessel speed while providing little reduction in roll amplitude. At the cost of reduced effectiveness, bilge keels can be made discontinuous in way of over-the-side launching operations to minimize the risk of fouling.

A deep centerline keel is very inexpensive, but is somewhat less effective in than bilge keels and increases in draft, a problem for shallow water operations. Course keeping is enhanced while maneuverability is reduced; increased resistance to transverse forces by wind and waves may enhance dynamic positioning.

Centerboards and daggerboards offer great flexibility and effectiveness in roll reduction and draft control. They also provide an excellent location for transducers well below boundary layer flow. The major disadvantages of high cost and impact on interior arrangements make these systems generally unacceptable on smaller vessels.

Flopper-stoppers are common on small fishing vessels and are very effective for roll reduction at minimal cost. Their use on research vessels is usually impractical due to the requirement for over-the-side booms, entailing a complicated mast and rigging arrangement, along with the increased potential for fouling scientific equipment on the in-the-water units.

Anti-roll tanks are probably the most effective method for passive roll reduction, but the expense, weight, and space requirements prohibit their use on small vessels.

Deck Area

Working deck area and laboratory space are the premier commodities on any research vessel. For equal length vessels, multihulls have a clear advantage, often up to 30%, in working deck area and lab space.

Perception

Despite their numerous advantages, monohulls suffer from the perseption that multihulls represent the state-of-the-art and are therefore inherently safer, more comfortable, faster or just plain better. Perceptions, true or not, play an important role in completely marketing a vessel; monohull operators must work harder to convince the market of the advantages of their vessel for the proposed operations.

Conclusions

There is no optimum hull form for small research vessels. Viewed as a platform for conducting research, the hull will be subject to numerous compromises affecting cost, range, seakeeping, payload, complement, maneuverability, data collection and analysis, capability, even esthetics. It is incumbent upon the vessel design and selection committee to become educated in these areas so that rational decisions can be made, resulting in the acquisition of a vessel best suited for the intended operations budget.

SECTION 11
Robertson Dinsmore
Small SWATH Research Vessels

The application of SWATH technology for small research vessels should be considered during the planning phase of new or replacement ships. The Small Waterplane Area Twin Hull (SWATH), or semi-submerged ship, is a relatively recent development in ship design. Although patents employing this concept show up in 1905, 1932, and 1946, it was not until 1972 that an 89-foot prototype model was built. The principle of the SWATH ship is that submerged hulls do not follow surface wave motion, and struts supporting an above water platform have a small cross-section (waterplane) which result in longer natural periods and reduced buoyancy force changes. Hull fins further dampen motions and provide dynamic stabilization when underway. The result of all this is that SWATH ships, both in theory and performance, demonstrate a remarkably stable environment and platform configuration which is highly attractive for science and engineering operations at sea. Flexibility of SWATH technology size and configuration allow a wide range of applications both in open ocean and coastal regimes. It is time that the oceanographic community takes a hard look at what a SWATH can offer.

The design concept of SWATH ships consists of two hulls or pontoons submerged beneath the water's surface and connected to the upper hulls by thin single or tandem struts. A cross structure connects the struts above the upper hulls and supports the superstructure (Fig. 1).

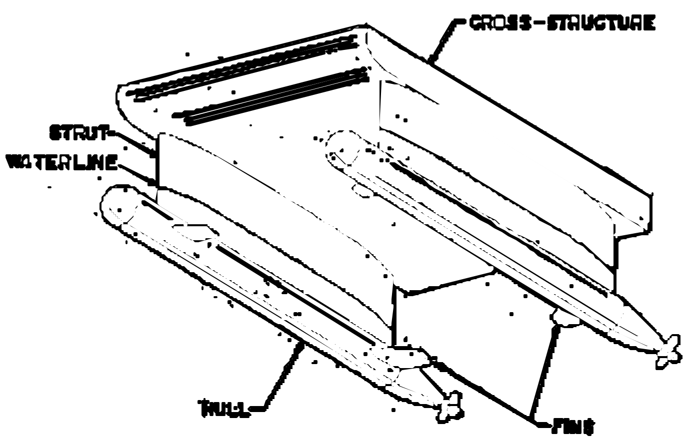


Fig. 1 - SWATH Configuration and Nomenclature

Substantially all the buoyancy for the vessel is provided by the two submerged pontoons with reserve buoyancy maintained in the upper hulls. Draft, for operations at sea, can be 50 percent of the total displacement volume typically is in the lower hulls and the remainder in the submerged section of the vertical struts. This configuration results in dramatically reduced motions because it tends to decouple the ship from surface waves. The two submerged lower hulls do not follow surface wave motion; and the waterplane area (that is, the cross-sectional area of the thin struts at the waterline) is small. Conversely, a monohull of equal size has much larger waterplane area and no benefit to deeply sunken hulls to reduce buoyancy force changes. Monohull vessels are characterized by seasickness, slamming, shipping of green water, and degraded performance in developed seaways due to large pitch and roll motions and with high accelerations. Monohull vessels must avoid beam and quartering seas minimize these effects which is not always possible on science missions. However, the pitch and roll motions of SWATH vessels are low in both magnitude and acceleration. They can maintain course and speed in higher sea states than a monohull or catamaran of comparable or larger size.

In addition to providing an extremely steady platform, the SWATH offers highly usable and flexible deck working space and laboratory arrangements. At the present time (2000), there are about 50 SWATH ships worldwide in operation or under construction. Of these, about 12 are under 100-ft. in length and in use as yachts, ferries, pilot boats, workboats, and research vessels.

Performance

As noted, the chief attribute of SWATH is its seakeeping performance. The flexibility of SWATH geometry allows a selection of hull forms having natural periods which shift ship responses away from the wave frequencies likely to be encountered. SWATH vessels are characterized by small waterplane areas and relatively long natural periods of motion. If the natural periods of a ship are substantially longer than the prevailing ocean waves, then the ship will experience little motion during the station keeping operations which are required for oceanographic work. SWATH configurations provide the most feasible means of obtaining the desired long heave, pitch and roll periods in a relatively small ship.

Both in operating experience and in comparative tests, the superiority of SWATH ships over monohull vessels has been amply demonstrated. Side-by-side tests in an open seaway were carried out with the 89-ft. SWATH *Kaimalino*, a 378-ft. USCG cutter and a 95-ft. cutter. The results over a three-day period showed that the motion of the SWATH in terms of roll, pitch, heave, and accelerations compared favorably with larger monohulls. This is shown on the following graphs.

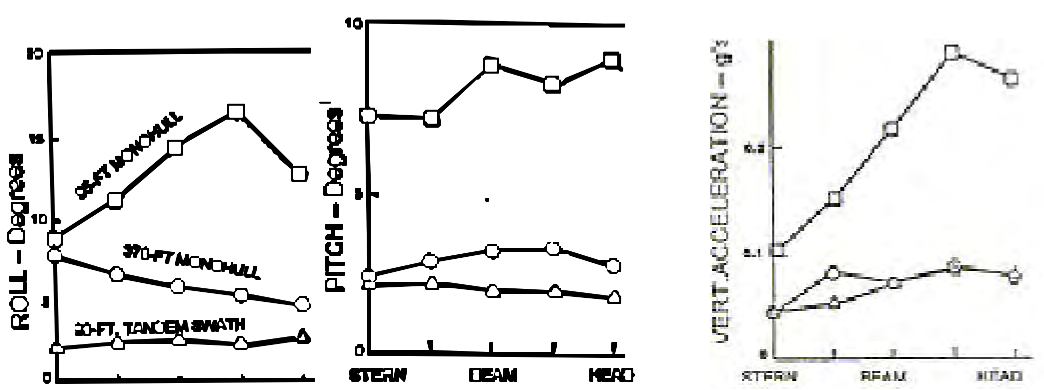


Fig. 2 - Comparative Performance of SWATH and Larger Monohulls

These results have been borne out repeatedly in the use of the *Kaimalino* by practicing oceanographic investigators.

In other areas of performance, SWATH ships have been found to be more acoustically quiet and vibration-free than equivalent monohulls or catamarans.

SWATH Configuration and Variations

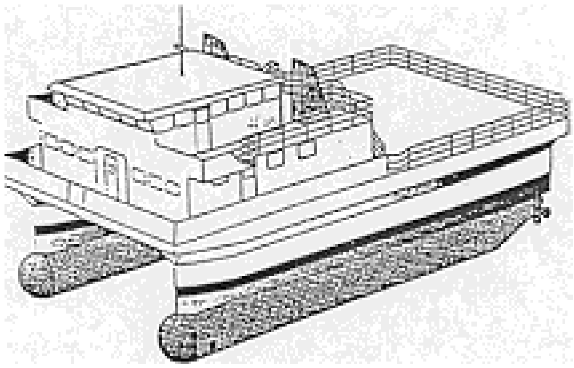
The nature of SWATH geometry permit a wide range of hull form and strut configurations. Unlike conventional hulls, changes in the SWATH waterplane area curve do not impact the entire design. The struts and the lower hulls can, to some extent, be designed independently and modifications in one will not necessarily require modifications in the other. Since the waterplane area is relatively small and can be distributed in many ways, relatively small changes in the waterplane result in relatively large changes in the heave and pitch natural periods and the response characteristics. Consequently, this gives the designer a flexibility to meet other design requirements so that a hull form with good seakeeping characteristics can be selected.

Perhaps the greatest variation in generic SWATH design is in the single strut and tandem strut configurations. This has resulted in no little controversy over which has the superior performance. For on the station (or stopped) work, theory favors tandem strut designs. However, the single strut per side designs are the most frequently used version, especially for applications where the primary mission is carried out when underway. Structurally, the single strut version may be simpler, although the tandem version is preferred if a large center well is required. Model tests and analyses indicate that the drag of optimized single and tandem strut versions are about the same, although the tandem versions tend to require more hull shaping. Also, tandem strut SWATHs generally have a shorter turn radius than single-strut versions. In summary, it appears that the selection of single or tandem struts per side depends upon the particular application

since neither is inherently better than the other for all situations. Some of the factors governing strut selection can be seen in the following table.

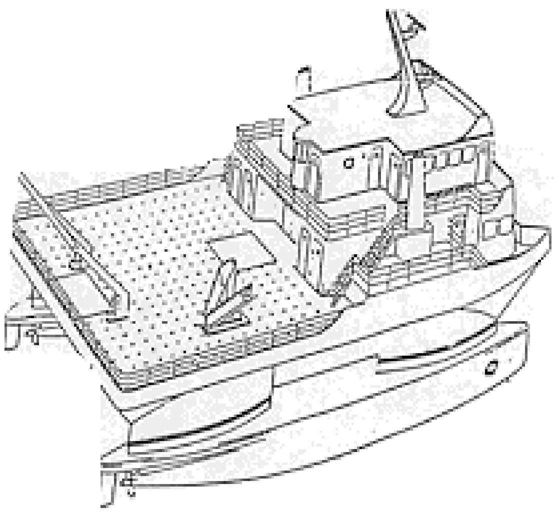
PARAMETER	SINGLE	TANDEM
Resistance	Simple	Complex
Beam	Smaller	Larger
Length	Longer	Shorter
Waterplane Area	Larger	Smaller
Deck Loading	Better	Worse
Pitch Loading	Worse	Better
Overside Loading	Better	Worse
Length/Beam Ratio	2.1 to 2.6	1.8 to 2.1
At Rest Motions	Worse	Better
Stationkeeping Drag	Worse	Better

Examples of both designs are shown by the concept designs of a 90-ft. SWATH research vessel in Figs. 3 and 4.



Single Strut Design

Fig. 3 - SAIC Maritime Services, Alexandria, VA



Tandem Strut Design

Fig. 4 - BSM Joint Venture, Houston, TX

A highly attractive variation in semi-submersible applications is the variable draft SWATH. Here the ship is designed for sufficient ballast transfer to enable it to vary its draft under all load conditions. This permits the ship to transit at reduced draft for better propulsion efficiency or enter shallow harbors where traditional deep draft SWATH ships are excluded. Ballasting down gives steadiest platform for on-station or slow speed operations in moderate to high sea states. It also places the main deck at optimum height for overside handling. For coastal zone research, the variable draft SWATH should be especially attractive. It provides a steady platform for offshore work but allows operations in shallow bays and estuaries where it is even possible to ballast down and bring the ship to rest on a shallow sea floor. A design for a 90-ft. variable draft R/V with operating drafts from 8 to 13.5 ft. is shown in Fig. 5.

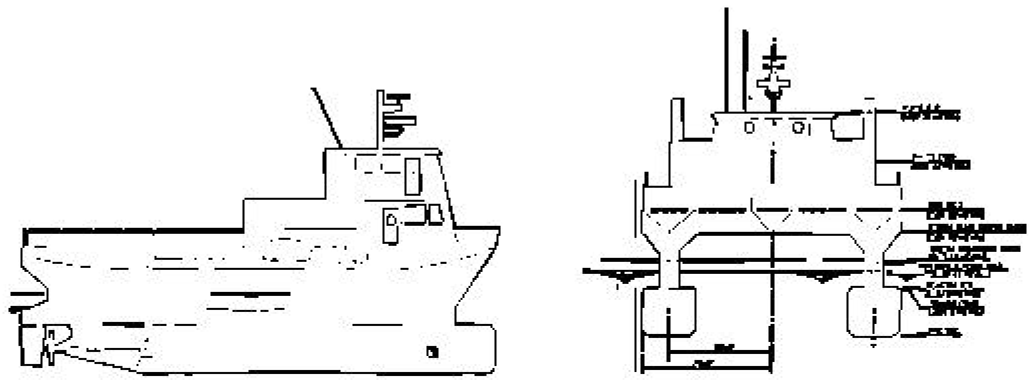


Fig. 5 - 93-ft. Variable Draft SWATH R/V (Blue Sea Corp.)

A unique approach is that which is utilized by NAVATEK Ships, Inc. The carrier vessel and superstructure are two independent ship structural components.

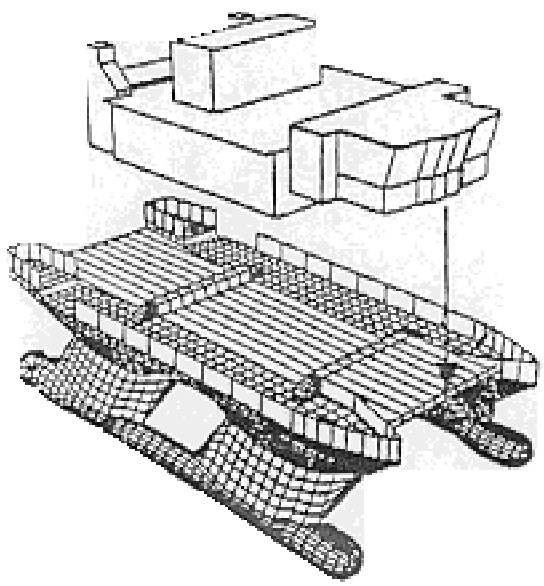


Fig. 6 - SWATH Carrier Vessel Concept

The carrier vessel is comprised of the lower hulls, the water-piercing canted struts, sponson and cross-structure, and accommodates all hydrostatic hydrodynamic loadings exerted on the vessel. The superstructure is added to the carrier vessel and does not contribute to the overall structural integrity of the vessel. By use of this configuration, the carrier vessel can accommodate a wide variety of superstructures with little or no modification.

It is common in smaller SWATHs (under 40m meters) to carry active motion control systems in the fins and canards. These provide further reductions in pitch and roll chiefly at higher speeds. The larger and more boxlike hulls in the variable draft SWATH design provide sufficient damping without resorting to fins.

Other design factors when considering a SWATH ship for oceanographic research are the broad beam, high freeboard, interferences from the lower hulls for overside operations, motion dampening, and maneuverability.

The wide boxlike upper hull and superstructure is highly adaptable to the deck working area and laboratories. A typical SWATH R/V can accommodate science spaces equivalent to a monohull twice its length. The beam and general SWATH configuration allows for a center well of usable size. Experience has shown that science work through a SWATH center well results in smaller wire angles because the wire overboards at the point of least motion. Further, the overboard wire actually is at a greater distance from the hulls than in overside work. This results in reduced interference with the hulls and significantly less sample contamination.

SWATH Ships as Small R/Vs

Of the SWATH vessels which have been operated as R/Vs, the size range 60-70 ft. appears to be a threshold for achieving the full effectiveness attributed to SWATH designs. Hull sizes less than this will tend to become wave followers with reduced seakeeping. Weight sensitivity would be more pronounced, even intolerable. Engine spaces would obstruct deck area and the propulsion drive train becomes cumbersome.

The deep draft, inherent with SWATH design, is a disadvantage for operations in bays and estuaries where shallow draft is needed. This can be overcome by the variable draft design which permits the hulls to be deballasted to a draft almost half of the deep water draft. Operating in this mode allows access to shallow regions and harbors.

Advantages and disadvantages of SWATH ships can be summarized by the following.

Advantages:

Steadiness in a disturbed seaway. It is well confirmed that a properly designed and built SWATH ship will substantially reduce motions induced by moderate to high wave conditions. SWATH ships can be designed to suffer only one-half to one-fifth of the heave, pitch, and roll motions of a monohull of equal displacement in seas driven by wind speeds over 20 knots. Furthermore, SWATH ships can be configured such that motions are nearly independent of wave direction relative to the heading of the ship, both underway and deadin-the-water.

More useable enclosed volume and deck space. The most advantageous SWATH hull form is such that its greater beam leads to large deck area and usable volume in respect to total displacement.

Ability to maintain speed in high sea states. The amelioration of slamming by high waves allows SWATH ships to steam at speeds not possible in comparable monohulls. The submerged hulls running below wave motion, and the main hull elevated by the slender small waterplane columns (struts), together with some other design tradeoffs can make moderate size vessels relatively immune to slamming.

Disadvantages:

Excessive draft. Since the chief benefit of SWATH designs depends on having their buoyancy compartments well below the disturbed sea surface, a deeper draft is required for similar sized monohulls. This can be lessened by the variable draft design.

High propulsion power. The greater wetted surface of the submerged hulls causes greater frictional resistance and total drag at low and moderate speeds. At higher speeds, the lower wave-making drag of a properly designed SWATH lessens this disadvantage.

Weight sensitivity. Because of the small waterplane area and wide separation of its buoyancy compartments, a SWATH design will tend to have larger trim and heel excursions than will have a monohull. The SWATH ship also will experience greater draft changes (about four times greater) than an equivalent monohull. SWATH vessels have a very limited ability to accept a wide variety of science mission loadings. Since such wide variation in mission equipment is characteristic of oceanography, this limitation may be a significant disadvantage.

Science Mission Requirements

As part of an overall effort to examine and improve research vessel capabilities, the University-National Oceanographic Laboratory System (UNOLS) developed a set of Science Mission Requirements for small SWATH vessels. These are reproduced as Appendix A. Although not necessarily applicable to every size or operating region, it serves as guidelines for developing SWATH concepts to meet specific mission objectives.

Selected Designs

The following three sheets illustrates concept, and in some cases actual, designs of small SWATH R/Vs ranging from 60-ft. to 100-ft. Both single and tandem strut designs are included as well as variable draft. For further information, contact the design firm listed.

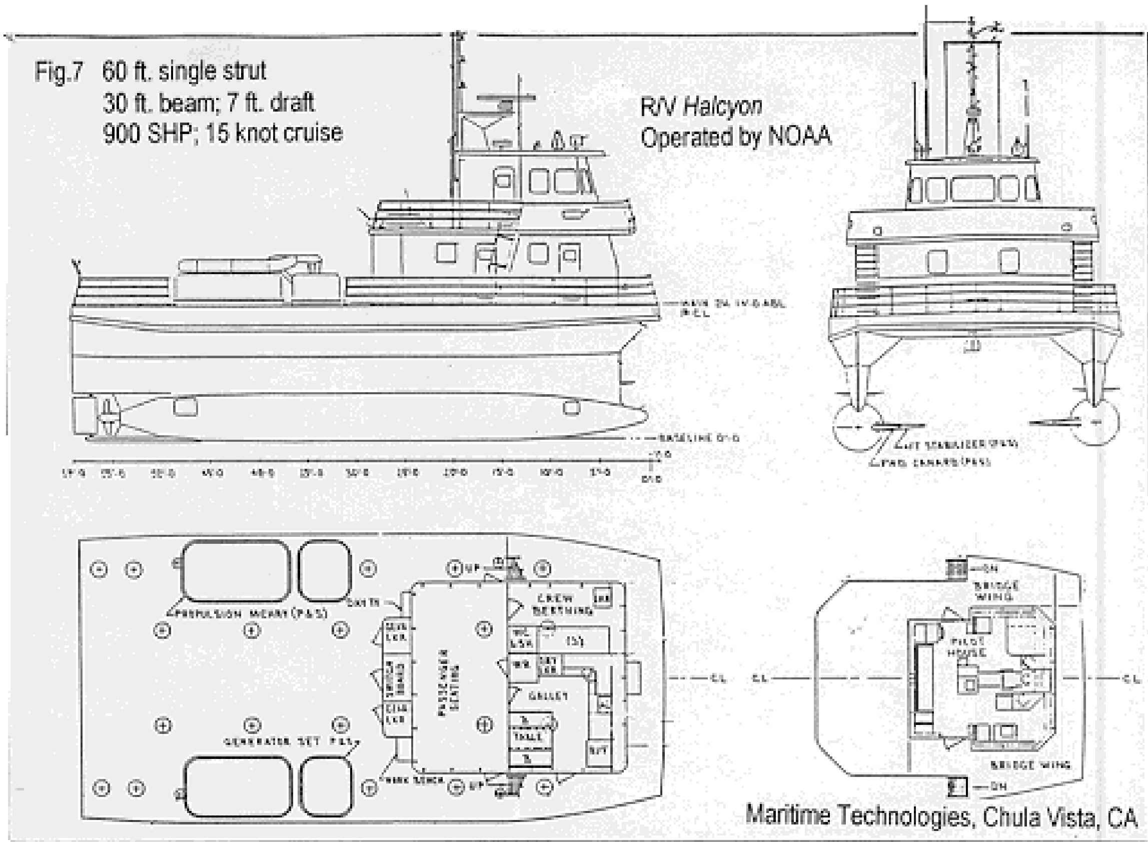


Fig.7

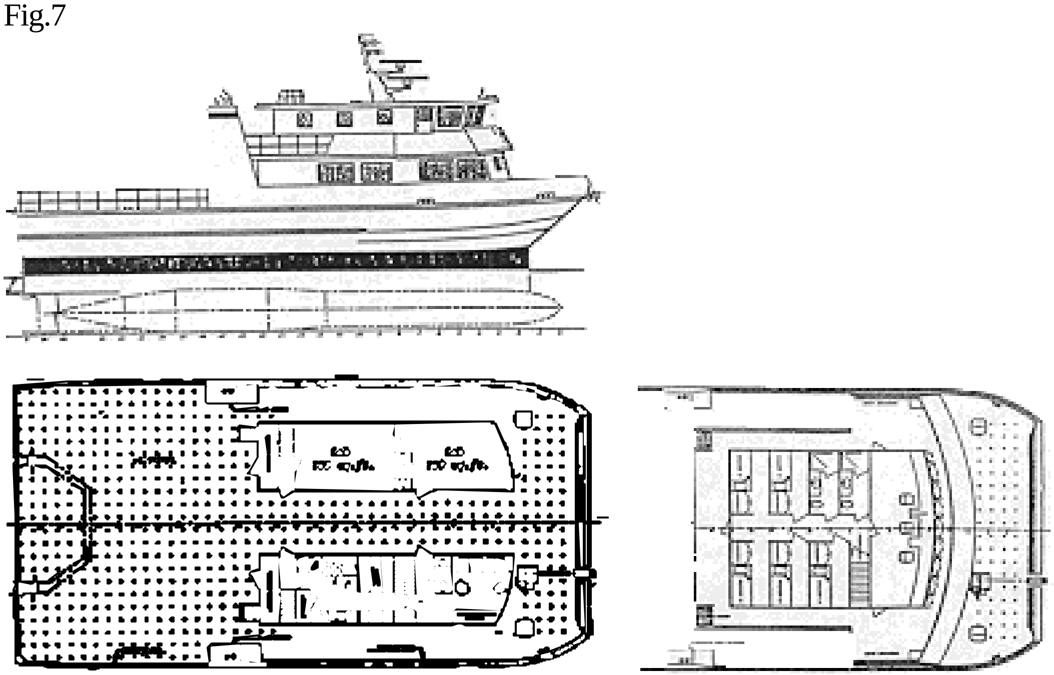


Fig. 8 100 ft. single strut
50 ft. beam, 12 ft. draft
15 knot cruise

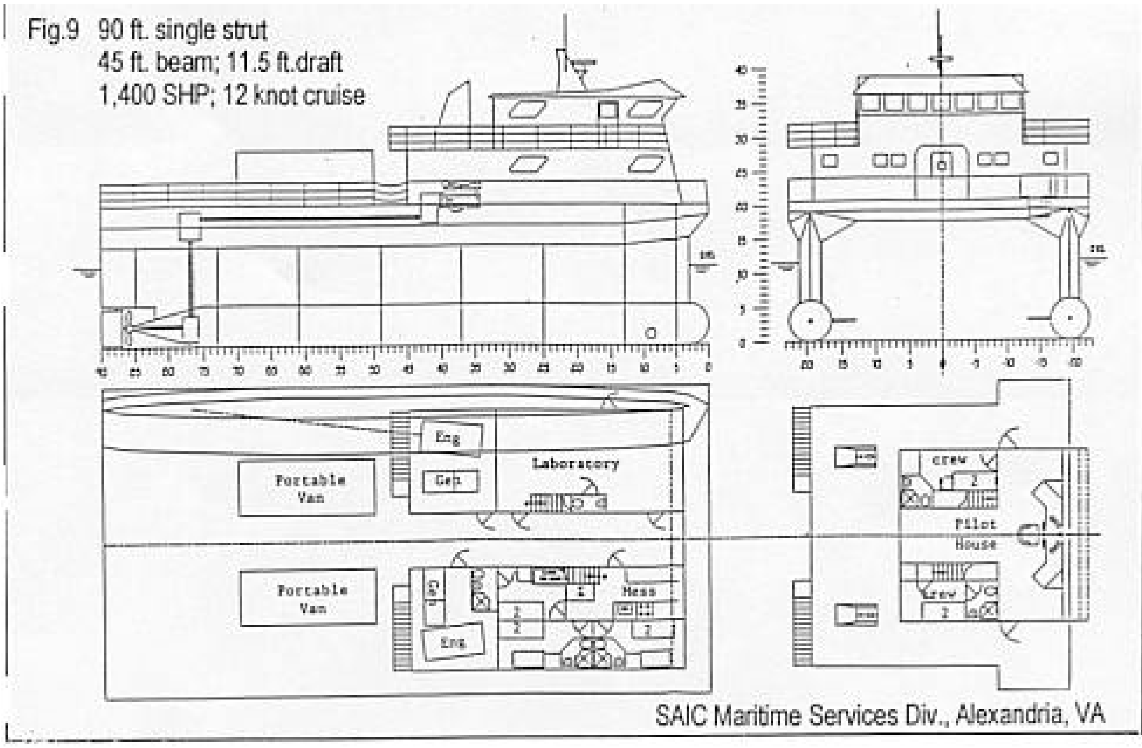


Fig.9 90 ft. single strut
45 ft. beam; 11.5 ft.draft
1,400 SHP; 12 knot cruise
Eng
Portable Van
Gen
Laboratory
crew
Pilot House
Mess
SAIC Maritime Services Div., Alexandria, VA

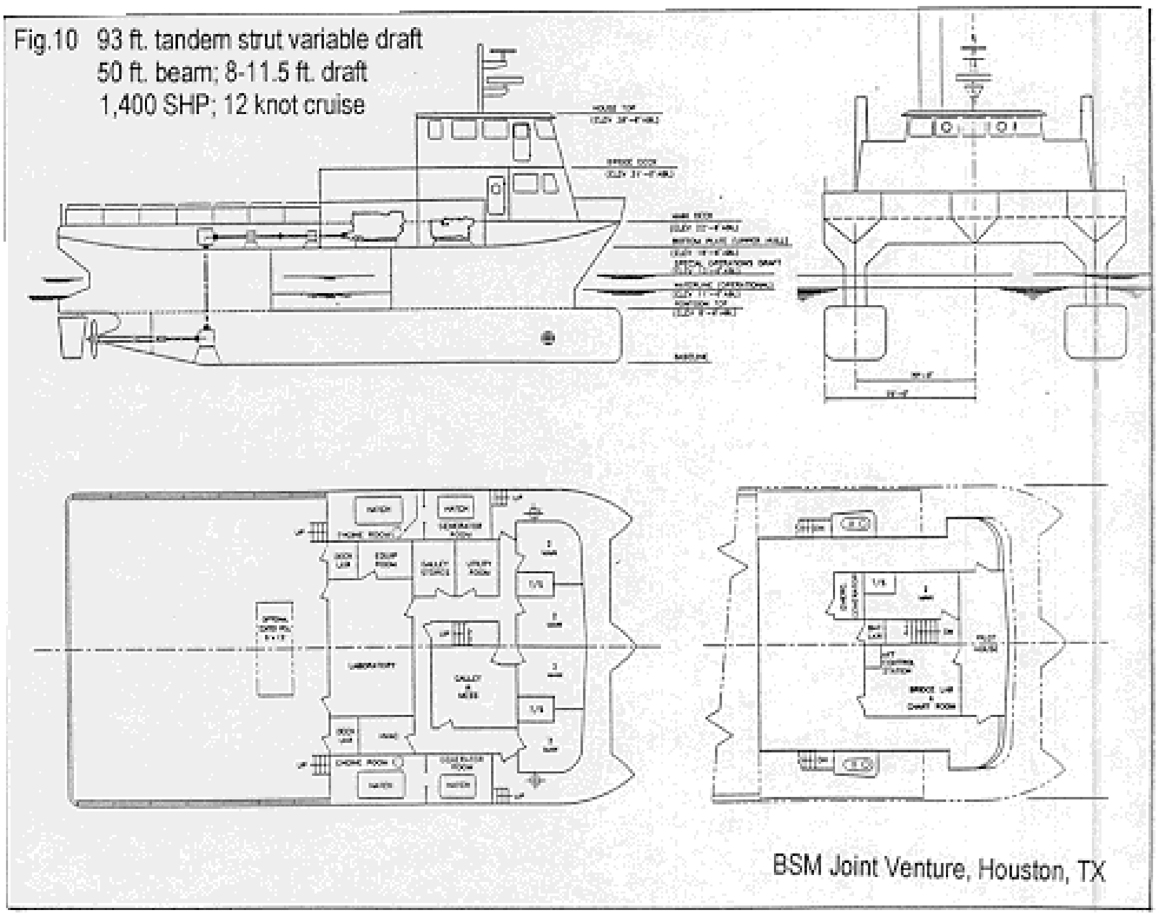


Fig.10 93 ft. tandem strut variable draft
50 ft. beam; 8-11.5 ft. draft
1,400 SHP; 12 knot cruise
BSM Joint Venture, Houston, TX

Fig.10

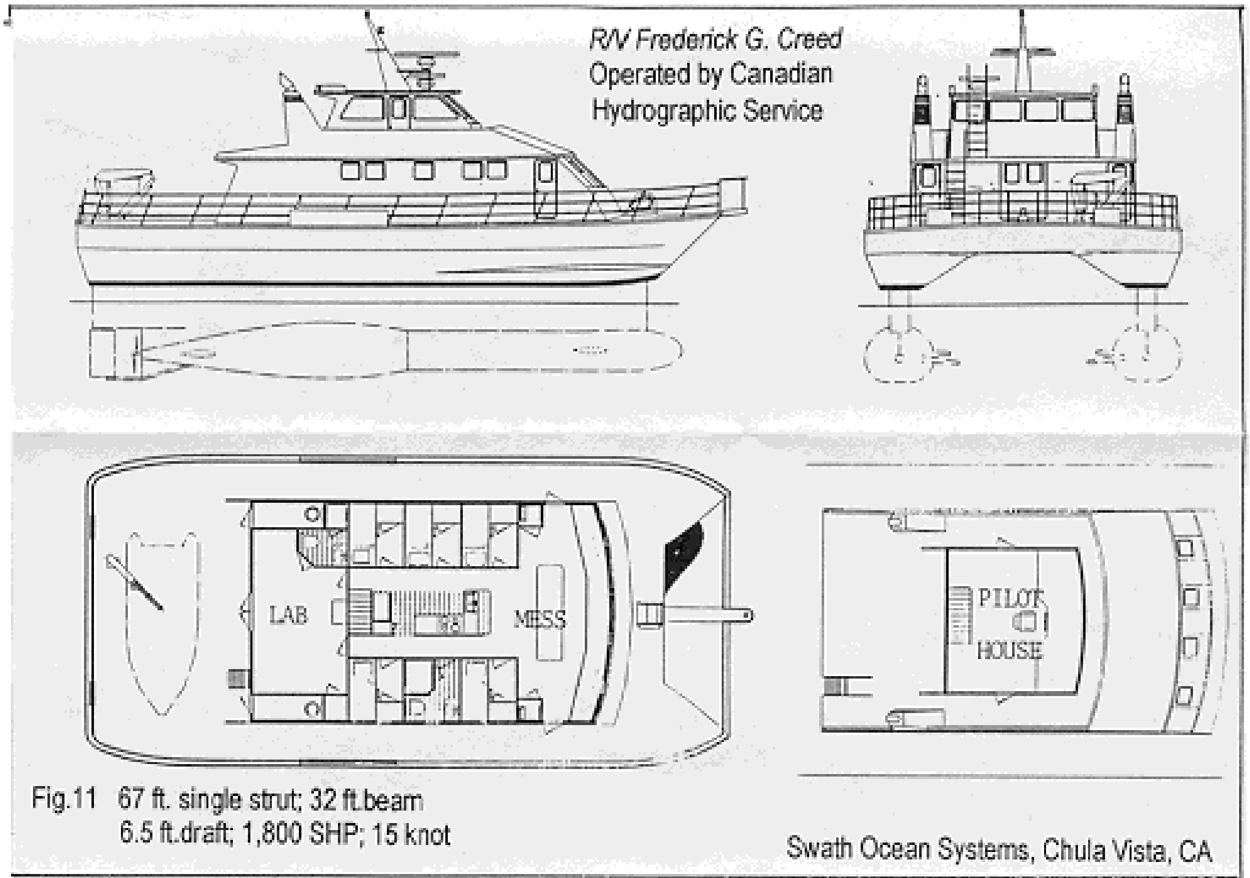

R/V Frederick G. Creed
Operated by Canadian
Hydrographic Service
LAB
MESS
PILOT
HOUSE
Fig.11 67 ft. single strut; 32 ft.beam
6.5 ft.draft; 1,800 SHP; 15 knot
Swath Ocean Systems, Chula Vista, CA

Fig.11

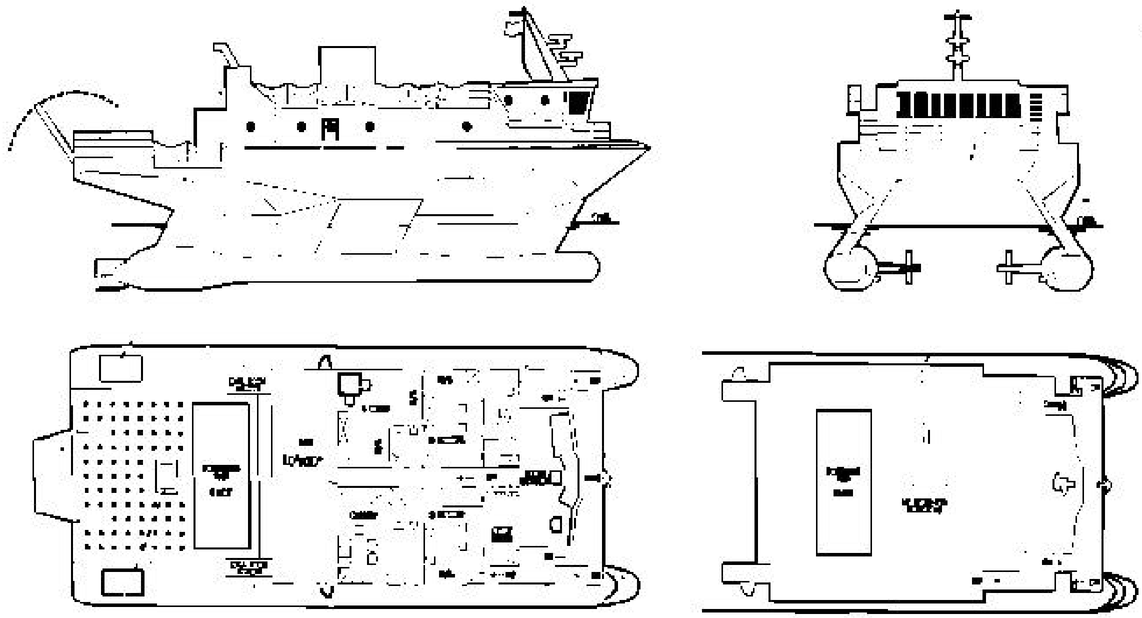


Fig 12 82 ft. tandem strut
28 ft. beam, 9 ft. draft
1,100 SHP; 14 knot cruise

Navatek Ships Ltd. Honolulu, HA

Conclusion

For applications to meet the mission requirements of small oceanographic research vessels, the advantages stated above outweigh the disadvantages. Improved seakeeping is the primary advantage of the SWATH hull form. The motions of SWATH vessels can be equivalent to those of monohulls many times larger. Increased interior volume and clear deck space make SWATH designs highly attractive for small and intermediate research vessels. Adverse characteristics inherent in SWATH design such as weight sensitivity, draft, and trim moments can be overcome by a prudent selection of design technology. Increased experience as new SWATH vessels are launched and operated will further the technology. The demand by the scientific community for access to high performance, yet reasonable sized vessels, should cause strong consideration of SWATH technology.

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Scientific Requirements for Small General-purpose Oceanographic Research Ship, Small Waterplane Area Twin Hull (SWATH)

General:	The general aim of this study is to design a SWATH vessel that will provide a more stable platform in higher sea states and have a higher cruising speed (15 knots in sea state 5). On the other hand, this SWATH will be weight-limited; its payload will only be 50 LT including winches, cranes, and frames, but not fuel.
Size:	The size is determined by the requirements for a 15-knot cruising speed and a 2,000 mile range. It is expected that the size of the "box" will be approximately 100 ft long.
Endurance:	7 days; 2000 mile range.
Accommodations:	12 scientific personnel.
Speed:	18 knots in sea state 4; 15 knots cruising; sustainable through sea state 5; fine speed control between 0-6 knots.
Station Keeping:	Maintain station and work through sea state 5; limited work in SS 6.
Ice Strengthening:	None
Deck Working Area:	Spacious work area - 2,000 sq ft minimum with contiguous waist work area along one side 12 x 50 ft minimum. Provide for deck loading up to 1,200 lbs/sq ft in selected areas and an aggregate total of 50 tons. A 15 x 25 ft centerwell to be provided. Holddowns on 2-ft centers. Highly flexible to accommodate large but not necessarily heavy equipment A deck at the bottom of the centerwell to be 10 ft or less above waterline. All working decks accessible for power, water, air, and data and voice communication ports.
Cranes:	A modem crane to handle heavy and large equipment capable of reaching working deck areas and offload vans and heavy equipment up to 8,000 lbs to 20 ft. Crane to have servo controls and motion compensation and be usable as overside cable fairleads at sea.

Winches: New generation of oceanographic winch systems providing fine control (0.5 m/min); constant tensioning and constant parameter. Wire monitoring systems with inputs to laboratory panels and shipboard recording system. Local and remote controls.

Removable general purpose winches will include:

Hydrowinch with interchangeable drums capable of handling 30,000 ft of wire rope, Kevlar synthetic line or electromechanical cables having diameters from 3/16" to 5/16" (Markey DESS-3 or equivalent) weight with wire 5 tons.

Capable of loading and using portable winches such as a double drum winch with 15,000 ft of 1/2" trawling wire on each drum for large mid-water net towing.

Portable shelters available to winch work areas for instrument adjustments and repairs. Two winch control stations located for optimum operator visibility with reliable communications to laboratories and ship control stations.

Overside Handling: Various frames and other handling gear and more versatile than present to accommodate wire, cable and free launched arrays. Matched to work with winch and crane locations but able to be relocated as necessary.

Stem A-frame to have 15-ft minimum horizontal and 20-ft vertical clearance; 15-ft inboard and outboard reaches.

Provision to carry additional overside handling rigs along working decks from bow to stern.

Control station(s) to give operator protection and operations monitoring and be located to provide maximum visibility of overside work.

Laboratories: Approximately 1,200 sq ft of laboratory space including: Main lab area (700 sq ft) flexible for subdivision providing smaller specialized labs; Wet lab (300 sq ft) both located contiguous to sampling areas; plus Electronics/Computer lab and associated users space (300 sq ft); and freezer (100 sq ft).

Access between labs should be convenient.

Labs to be fabricated using uncontaminated and "clean" materials and constructed to be maintained as such. Furnishings, HVAC, doors, hatches, cable runs, and fittings to be planned for maximum lab cleanliness.

Cabinetry shall be laboratory grade including flexibility through the use of unistruts and deck boltdowns.

HVAC: Heating, ventilation, and air conditioning appropriate to laboratories, vans, and other science spaces being served. Laboratories shall maintain temperature of 70-75 deg F, 50% relative humidity, and 9-11 air changes per hour.

Power:	Each lab area to have a separate electrical circuit on a clean bus with continuous delivery capability of at least 40-volt amperes per square foot of lab deck area. Labs to be furnished with 110 v and 220 v AC. Total estimated laboratory power demand is 40 KVA.
Sea water:	Uncontaminated sea water supply to most laboratories and deck areas.
Vans:	To carry one or two standardized 8 ft by 20 ft portable vans which may be laboratory, berthing, storage, or other specialized use. Hookup provision for power, fresh water, drains, communications, data and shipboard monitoring systems.
Workboats:	One 16-ft inflatable (or semirigid) boat located for ease of launching and recovery.
Science storage:	Science storage space should be provided as feasible.
Acoustical Systems:	Ship to be as acoustically quiet as practical. Ship to have 12 kHz and 3.5 kHz echo sounding systems and provision for additional systems.
Navigation/ Positioning:	Global positioning System (GPS) with appropriate interfaces to data systems and ship control processors. Short baseline acoustic navigation system.
Internal Communi-cations:	Internal communication system providing high-quality voice communications throughout all science spaces and working areas. Data transmission, monitoring, and recording system available throughout science space including vans and key working areas. Closed-circuit television monitoring and recording of all working areas including subsurface performance of equipment and its handling. Monitors for all ship control, environmental parameters, science and overside equipment performance to be available in all, or most, science spaces.
External Communi-cations:	Reliable voice channels for continuous communications to shore stations (including home laboratories), other ships, boats, and aircraft. This includes satellite, VHF and UHF. Facsimile communications to transmit high-speed graphics and hard-copy text on

regular schedules.

High-speed data communications (56 K Baud) links to shore labs and other ships on a continuous basis.

Capability to receive realtime or near realtime satellite imagery.

Ship Control: Chief requirement is maximum visibility of deck work areas during science operations and especially during deployment and retrieval of equipment.

The functions, communications, and layout of the ship control station should be carefully designed to enhance the interaction of ship and science operations. For example, ship course, speed, altitude, and positioning will often be integrated with scientific operations requiring control to be exercised from a laboratory area.

Sea State			**Height**
	Description	**Feet**	**Meters**
0	Calm-glassy	0	0
1	Calm-rippled	0 to 0.5	0 to 0.1
2	Smooth-wavelets	0.5 to 1.5	0.1 to 0.5
3	Slight	1.5 to 4	0.5 to 1.25
4	Moderate	4 to 8	1.25 to 2.5
5	Rough	8 to 13	2.5 to 4
6	Very rough	13 to 20	4 to 6
7	High	20 to 30	6 to 9
8	Very high	30 to 45	9 to 17
9	Phenomenal	Over 45	Over 14

SECTION 12

John Van Leer

Small Catamaran Research Vessels

Commercial catamaran vessels have been steadily evolving over the last 35 to 40 years, with the guidance and the continuing evolution of Det Norske Veritas rules. Hundreds of commercial catamarans have been built, and continue to be built world wide under these rules primarily in Norway, France and Australia progressing through several generations of ever lighter, ever stronger, ever faster catamarans. Down through the centuries, catamaran users have realized that catamarans make poor freighters. As a result, recent design directions have stressed either high speed, semi- planing, passenger ferries, which are refueled daily, or displacement motor/sailing passenger vessels for longer duration cruising. Both of these applications stress enhanced sea keeping over cargo hauling with two distinctly different approaches. The UNOLS fleet includes about two dozen single hulled ships well suited to carrying substantial freight. Thus we will not discuss the duplication of this capability in a catamaran hull here.

In the first part of this chapter, a brief discussion of catamaran history is presented. Secondly, a general discussion of the most significant characteristics and tradeoffs in catamaran design parameters is set forth. Thirdly, a design for a catamaran research vessel optimized around a center well is presented to illustrate one set of logically consistent choices. Lastly, this conceptual catamaran is applied to supporting four innovative motion isolation systems well suited to remote sensing and direct sensing observations. These motion isolation systems and a number of applications give a preview of how the author thinks a 21st century robotic ship might look and work.

Early Background -The Polynesian Period

The catamaran vessels of today are the direct descendants of the highly evolved Polynesian sailing vessels. These vessels were used to colonize every habitable island in the vast area of the tropical and subtropical Pacific and Indian oceans, referred to as Oceania (see Canoes of Oceania by Hadden & Hornell 1936, 1937 & 1938). The colonization of this region started about three thousand year ago from Asia and was essentially completed in Hawaii about one thousand years ago. In 1774 Capt. James Cook had the lines taken off a 108' long catamaran (Brown 1938). Catamarans may seem new and exotic to many in the western oceanographic community, but they are traditional in the other half of the world.

Western Catamaran Developments During the last 350 years

Early western attempts at building Catamarans include Sir William Petty's Double Bottom in 1662 (Brown 1938). She beat all comers in a race in Dublin establishing the speed potential of catamarans in the Western Hemisphere. Most early steamboats including Fulton's 1812 ferry boat Jersey were catamarans where the paddle wheel was protected between the hulls (Brown 1938). The connecting structure between the hulls was used for navigation and became known as "the bridge". The first steam powered war ship, the 156' Demologos, was a double-hulled steamer built for the war of 1812. Steam catamarans remained popular in America, Europe, and

Australia until the screw propeller replaced the paddle wheel around the time of the American Civil War. In all, Brown lists about 130 large western catamarans before 1938.

Western Perception of Catamarans Shaped by Yachting

The brilliant naval architect Nathaniel Green Herreshoff designed at least 7 catamarans including the Amaryllis which beat all comers at the New York Yacht Club's Centennial Regatta in 1876. This victory lead to catamarans being classified as freaks by the yachting establishment and thus excluded from "proper yacht" racing for about a century.

Since Dennis Connors successfully defended the America's Cup in a catamaran, against a mono-hull twice her size, catamarans have become more accepted in the U.S.A. In last year's Miami in Water Sail Boat Show, multi-hull cruising vessels outnumbered conventional cruising vessels for the first time. Similar growth is beginning to be seen in powered catamaran yachts. This explosive growth has also led to a number of poorly designed vessels by inexperienced multi-hull designers getting in on the trend. Thus a considerable shakedown period will be needed.

In the United States only limited commercial catamaran use has occurred during the last decade. The commercial trends overseas suggest that the time for building a catamaran research vessel optimized to take advantage of the catamaran's positive attributes has arrived. However, past mistakes, like the heavy designs of the R/V Ridgely Warfield (106' LOA and 162 L T displacement) and R/V Hayes 35 years ago, have made the oceanographic community understandably wary of catamaran research vessels.

Western interest, materials and technologies have expanded the possible catamaran design envelope. The most significant progress has followed the evolution of modern metals, resins, and fibers, post World War II. The experience of most marine scientists has been limited to the capabilities of mono-hulled vessels designed in the western cargo/fishing traditions with very limited experience with multihulled vessels. This accounts for the above mistakes by past ship design committees. (see VanLeer 1982). Catamaran research vessels are potentially among the most useful but frequently misapplied vessels for research at sea.

Catamaran Research Vessels

The design of any vessel is a series of compromises which trade off one property for another. Catamarans are particularly appropriate in the size range from 45 to 170 feet, where they offer many of the advantages o f considerably longer conventional vessels in a shorter, wider, shallower draft, fuel efficient package. The R/V Sunbird (46 feet LOA) operated out of Lizard Island, Australia, has been an effective, comfortable, rugged vessel for use on the Great Barrier Reef and Coral Sea. In order to gain the greatest research benefit from the catamaran hull form, we will first examine those applications where modern catamarans have enjoyed the greatest commercial success.

High-speed passenger ferry and tourist catamarans have become dominant in many overseas commercial markets. These applications take advantage of shallow draft, large deck areas, high propulsion efficiencies, excellent seakeeping and maneuverability afforded by slender, widely separated hulls and propulsion. These applications clearly stress excellent seakeeping rather than freight hauling applications. Most of the passenger ferries have relatively short ranges with fuel readily available on a daily basis. This reduces fuel loading and permits cruising speeds of 15 to
50 knots with semi-planing or wave piercing hull forms. High speeds doppler shift the encounter frequency of surface gravity waves above natural pitching resonance dramatically smoothing out the ride.

However, for long range oceanographic vessels, fuel loads increase so that slender displacement hull shapes are favored and water plane area must be reduced to improve seakeeping at low speed. Oceanographic vessels spend a lot of time on station near zero speed and thus can't benefit from the above doppler shift. The 73 foot D MB pearl fishing catamaran (Crowther Design #73) stays out for two weeks and spends most of its working life at anchor on station, so it's design is based upon a slender displacement hull form evolved for sailing. This vessel carries 13 long tons (LT) of pearl shells and seawater with a range of 1350 nautical miles at 9 to 10 knots and is described in Crowther (1982). Designing and using modern catamarans is lot like designing and using aircraft where strength/weight considerations are crucial. Weight control is essential for good and safe performance offshore. Blind application of monohull design ideas has lead to the creation of a number of needlessly heavy (and thus expensive) catamarans with poor seakeeping. Fuel load takes the place o f science cargo as the primary weight to be hauled, which in turn requires larger engines to achieve the design speed and range, which requires more fuel and so on. The design spiral then diverges from well-proven wholesome, catamaran design practice. The resulting vessel has a semi- planing hull but insufficient power to "get over the hump" and plane. See Harris (1998) and Band Lewis (1999).

Multihulls or Fundamentally Different in Stability from Monohulls

In monohull design, the form of the hull is essential in determining the stability of the vessel so that there are strong limits on the fineness ratio (hull length/hull beam at the waterline). Destroyers, for example, are near the upper fineness ratio limit in order to gain a greater hull speed and fuel economy, but suffer poor roll stability and are thus notoriously uncomfortable in rough conditions. Twin hulled vessels gain their essential stability by two widely spaced hulls and to a lesser degree by the shape of the individual hulls. The most essential decisions the catamaran designer must make are the fineness ratio of the individual hulls and the overall weight (including all permanent science equipment, science cargo, fuel, machinery, finishings, fire protection etc.).

Many commercial catamaran hulls have a fineness ratio of 20 without significant stability problems. In fact, some SW A TH vessels (.Small WAterplane Twin Hulled vessels) have fineness ratios well beyond 20, trading almost all of the high inherent catamaran stability in favor of enhanced seakeeping in moderate sea states. However, SWATH vessels are deeply rooted in the water and might become dangerous in extremely large, breaking seas if the vessel loses power and becomes aligned with the wave crests. A large breaking sea striking such a disabled SW A TH vessel a'beam could overcome the vessels modest stability. By contrast, light displacement, shallow draft catamarans will slide sideways rather than capsize under the same conditions as clearly demonstrated in Crowther catamaran Model Testing films simulating hurricane conditions.

At the other extreme, some heavy displacement catamarans have been built with a fineness ratio of less than 7 to gain greater capacity to carry cargo. While such a vessel is somewhat dryer on deck, this choice results in a very rough ride due to excessive stability giving rise to unpleasant snap rolling and pitching motions. This was demonstrated by Harris (1998) and (1999) Band Levis model test series with accelerations approaching one g in 4 to 8' head seas measured at the bow. Hull fineness ratios near 12 seem to offer the best compromise, retaining both good seakeeping and reasonable cargo carrying capabilities as demonstrated by the successful operation of DMB (Crowther 1983). A semi-circular, immersed hull form is frequently used to reduce wetted surface and its attendant skin friction losses in slender displacement hulls. Such a hull form also provides reasonably shallow draft with modest skegs (with grounding shoes as seen in figure 3) for extreme shallow water operation and reasonable puncture protection.

Catamarans Have Large Deck Areas Which Invite Overloading

Because the area between the hulls can be used for science, unusually large deck areas and laboratory spaces are potentially available. There is a natural temptation to fill the entire area between the hulls with solid decking. However, weight in the ends of the vessel increases its moment of inertia about the pitch axis and increases the tendency of the vessel to develop a violent pitching motion as above. If the vessel hulls are nearly symmetrical about the pitch axis, as in the R/V Hayes, the tendency toward large amplitude synchronous pitching is aggravated. Therefore, the R/V Hayes was retrofitted with an immersed foil between the hulls well forward of the pitch axis to damp this tendency. Large areas of solid foredecks not only increase the pitching and slamming tendencies, but also act as scoops for boarding head seas in heavy weather, and thus should be avoided for safety reasons (see Band Lavis 1999). Excessive superstructure height can have much the same effect. Large weights like engines and tankage should be carried as near the pitch axis as convenient, and low in the hulls. Amidships weight in the hulls tends to lengthen the roll period which is usually a benefit. State rooms are often placed in the hulls above the tankage to make more space on the working deck for labs, open decks, center wells and common areas like the galley/mess.

Under Wing Clearance and Space Between the Hulls

Wave motion on the sea surface between the hulls contains not only natural surface gravity waves, but also the wake emerging from the bow of each individual hull. Consequently, the space between the hulls should be adequate for wave passage without colliding the underside of the connecting structure between the hulls (slamming). The intersecting bow wave patterns produce humps and valleys in the sea surface between the hulls which move aft as speed increases, leading to significant variations in the propulsion power as a function of increasing speed from the expected square law dependence. So, for a given hull shape and spacing, there may be preferred operation speed ranges where enhanced efficiency is possible. Bows which extend beyond the superstructure by about 30% of the ship's length, allow the vessel to rise to an oncoming sea before it encounters the wing structure (see Band Lavis, 1999). Bulbous bows have been used by Crowther and others to suppress bow waves and damp pitching motions.

If each hull is symmetrical about its center line, the space between the hulls becomes progressively narrower aft of the bow, creating a convergent channel which will amplify waves approaching from the bow. This undesirable effect becomes more pronounced as the hull fineness ratio is reduced. In some extreme cases, the space between the hulls is less than each hull beam measured at the waterline resulting in more than doubling of oncoming wave amplitudes. Unless such a vessel is slowed dramatically in head seas, it will slam frequently (see Band Lavis 1999). Most offshore catamarans employ netting between the hulls forward of the main connecting structure so that breaking wave crests can pass through without overloading and depressing the bow from above or slamming from below.

Adequate underwing clearance will reduce the chance of slamming. Five percent of the catamaran's length is considered minimum clearance in the fully loaded condition with full fuel. Overloading will not only increase vessel stresses, but reduce the underwing clearance, and reduce propulsion efficiencies (see Band Lavis 1999). In a monohull, maximum load is frequently limited by reduced stability. However, a catamaran becomes more stable with load. Clearly, common sense is required when loading a catamaran, by conforming to the designed full load specification (see Band Lavis 1999). With today's easy shipment of containerized cargo, it is no longer necessary to carry everything which will be used on a multi-legged cruise for the duration of the cruise. In coastal regions with reasonable fuel availability, it is likewise not required to carry fuel for an entire multi-legged cruise.

The Center Well Option - A Primary Reason to Choose a Catamaran

It is possible to arrange a catamaran to permit a true center well at the pitch and roll center of the vessel without cutting into the ship's bottom. This location is at the point of minimum motion and acceleration and is useful for drilling, coring and general purpose wire lowered instrumentation. The catamaran R/V Lu Lu operated by W.H.O.I. for many years had a makeshift hull design based upon two extraordinarily heavy pontoons available from Navy surplus, but it did have a fully functional center well with an elevator to launch the deep submersible, Alvin. The author had the pleasure of using this center well to launch and recover instrumentation in rough conditions while Alvin was on a dive. The convenience and safety of the center well was so great it lead the author to wonder why all catamaran research vessels didn't launch their gear through true center wells. The R/V Hayes deploys an extremely large and complex acoustic array through its ample center well, with excellent results. Clearly, there is a compelling reason why all deep sea drilling vessels have center wells. In a catamaran with widely spaced hulls, a large center well is more practical because it avoids problems with surge common within hull piercing center wells, and the added parasitic drag of a large opening in the bottom of the hull.

To test the dynamic response of wire lowered gear in center wells, the author built a center well in his 36' catamaran, straddled by a tripod which had a turning block located near the pitch and roll center of the vessel. This general arrangement, included a self breaking, air driven winch, permitted the safe launching/recovery of 660 lb. anchors from this 4,000 pound vessel in 4 to 6 foot seas. The motion of the anchor was s o gentle that restraining lines were scarcely needed. This is a stark contrast to the danger of handling such a weight over the side or stern of a conventional vessel of similar size in 4 to 6 foot seas.

An Optimized Catamaran Research Vessel Designed by Crowther

Until Hubble, astronomers had to settle for blurred images seen through a turbulent attenuating atmosphere. Oceanographers and meteorologists have begun to image the ocean and the atmosphere from ships through a variety of sensor systems. They too have had to cope with turbulent attenuating media, but the motion of their observing platform, the ship, has had far greater noise producing effects than typical satellite or aircraft platforms. Described here is a catamaran ship designed by Crowther Multihulls to accommodate a set of four related motion reduction techniques for a frontal attack on ship motion induced errors, stresses and hazards.

This vessel relies on four distinct techniques to reduce motion. The large scale of these devices also makes them useful for direct sensing of the ocean, atmosphere, and bottom. Manipulators of appropriate size are suggested to bring the maximum capabilities of the ship to bear on projects, while isolating undesirable effects of ship motion. This will enhance the quality of observations, while introducing a whole new level of safety as scientific personnel are removed from "hero platforms" and replaced by robotic devices. Simultaneous stabilized measurements can be made above and below the sea surface from a common motion stabilized pendulum.

These devices are: (1) A Motion Compensated Pendulum (MCP) deployed through the center well at the pitch and roll center of the vessel (Figure 2). (2) A motion compensated A-Frame Mast (Figure 1). (3) A system of 4 spuds for stable shallow water anchoring as (Figure 2 and 3). (4) A Motion Control System with four inboard control fins to reduce pitching and heaving motions about 50% while underway. The four systems described here will complement and/or enhance the performance o f most sensing and sampling systems. The A-Frame Mast can also support a significant sail plan for passive motion damping, silent operation underway, and increased range.

The proposed motion compensation devices will support existing technology and provide a platform which is easily adapted to emerging technologies which might otherwise go unsupported in seagoing applications. The motion compensation properties, desired to gain the greatest advantage from modern oceanographic and meteorological remote sensing and direct sensing instrumentation, are a result of the entire system designed from the hull upward including the four new systems described here.

An Optimized Catamaran Ship

The 22 meter catamaran vessel used to support these motion isolation devices was designed by Crowther Multihulls in Australia and is presented with Brett Crowther's permission (Crowther Design # 247B). The Crowther design shown in figures 1, 2, and 3 was scaled up from the pearl fishing catamaran DMB which has a fineness ratio of 11.68 and a flared hull shape. This true displacement type hull shape was evolved for sailing to minimize excessive motion which otherwise would disturb the air flow over the sails. This reduction of motion was a result of reduced water plane area, bulbous bows, and relatively broad transoms. This design maximizes usable cabin space within the hull and reduces the tendency toward pitch or roll resonance. Clearly the hull shape will be the first stage of our motion compensation approach. The computer modeling work such as that performed by Marine Dynamics discussed in section four below would aid the naval architect to inexpensively test seakeeping alternatives.

Layout Dictated by Center Well

Most ship designs are adapted from other uses with observation techniques adapted to an existing hull. By contrast, our general arrangement has been optimized for robotic, remote, and direct sensing requirements. In effect, our layout has been built around the observation techniques. Thus, the sweetest spot, the pitch and roll center, has been dedicated to a true center well and the robotic devices to be operated there. Like other research vessels, there are reinforced spots for crane, winch, and A-frame foundations. On our vessel design there are an additional four reinforced areas at the corners of the catamaran's central box structure for spud and/or davit foundations (seen in figures 2, and 3) and two reinforced supports for a central A frame or motion compensated pendulum described below. Ten scientist/crew bunks are located within each hull forward of the engine room which are accessed by two sets of stairs from the main deck. By putting accommodations within the hulls, the main deck is reserved for laboratory space over the central accommodations and engine room. The working deck aft is continuous with the center well deck under the bridge with vertical clearance for a standard 20' shipping container under the raised aft bridge and fore and aft 50' deep.

The raised aft bridge is located overlooking the two principal work areas; the deck, aft, and the center deck. Thus only one set of controls is required for navigation. Winch, center well hatch cover, spud, motion compensated pendulum (MCP), and motion compensated A-Frame Mast controls are located on the bridge. In this way, crew scientists and technicians are remote from gear launching dangers and winch and wire accidents. If roller furling sails are deployed from the A-frame/mast, the bridge is in the perfect location to observe their trim and function. Both winches and the crane are located on the 02 deck for safety and visibility from the bridge.

Straight piping and wiring ways are located in the joint between the working deck and the hull from stem to stern with direct access to all parts of the ship including deck areas, labs, state rooms and engine rooms (seen in figure 3). An additional wireway connects the individual wire ways in each hull (through the bridge deck) for power, signals, and the main electric control panel can be located on the bridge. A second connecting duct passes through the main deck between engine rooms for hydraulic and other plumbing.

Galley and mess areas are on the main deck ahead of the center deck and between the wet and dry lab spaces (Figure 2). The aft sections of the wet or dry lab can be configured for handicapped access stateroom when needed, with wheelchair access to the main deck. Stairs down through each transom give easy diver access to the water.

The Crowther design described here will meet all the UNOLS requirements for a Small Expeditionary Vessel as defined at the Fleet Improvement Committee Meeting on Coastal Oceanography in Williamsburg in early 1993. See table I below:

<u>Table 1</u>

<u>Specifications for Crowther Design #247JB</u>

Length over all	79'
Extreme Beam	34 $_{2}$
Hull Beam @ Waterline	Approximately 6.5'
Draft	4 to 4.5' Depending on Load
Full Load Displacement	62 Long Tons
Science Cargo	10 Long Tons
2 Winches Crane & Aft Frame	2 Long Tons
Center Well @ Pitch & Roll Center	8' Wide x 10.8' Long
Under Deck Clearance to Waterline 4'	Minimum @ Full Load
Scientists	16
Crew	4
Range	1,250n Miles @ 12 Knots
Duration	2 Weeks
Spud Mounting Strong Points	Set of 4 as Show in Figures 2&3
(For Lifting Vessel or Anchoring)	(In 4-15' Depths in up to 3' waves)
Marine Grade Aluminum	5083 H116 Scantlings per Det Norke Veritas
Bottom Plate Thickness	3/8"
Deck Tie Downs	1/2" NC bolt Holes on 2' Centers
Speed (Maximum)	13 Knots Power Only 20 Plus Motor Sailing
Power	Twin Diesels
Propellers (2)	Controllable Pitch
Working Deck Area Aft	450 Square Feet
Center Deck Including Well	350 Square Feet
Lab Space	640 Square Feet in Wet & Dry Labs
Optional Center Lab Module	350 Square Feet
Mooring Weights	Up to 5,000 lbs. At Stern or Center Well
Drilling and Coring	Through Center Well

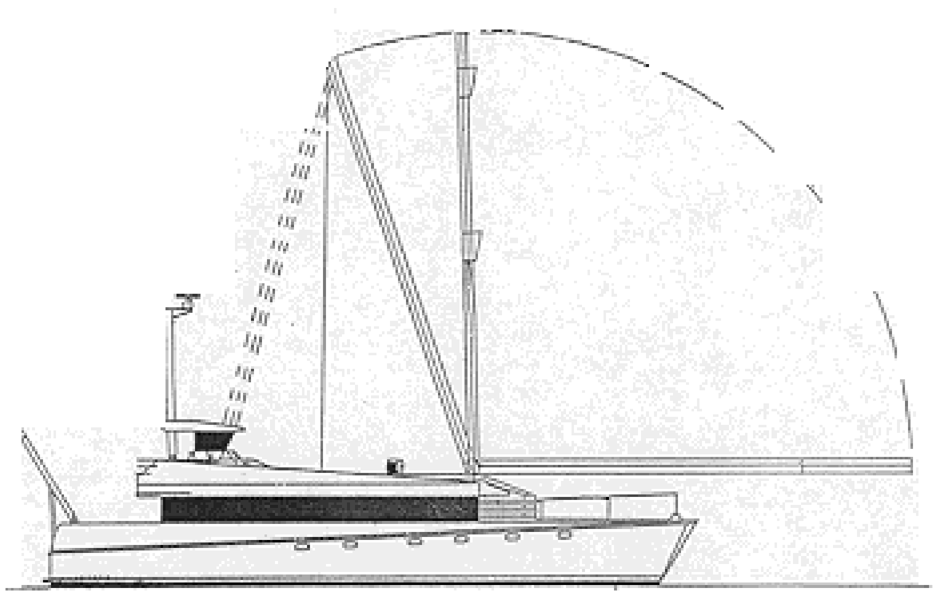
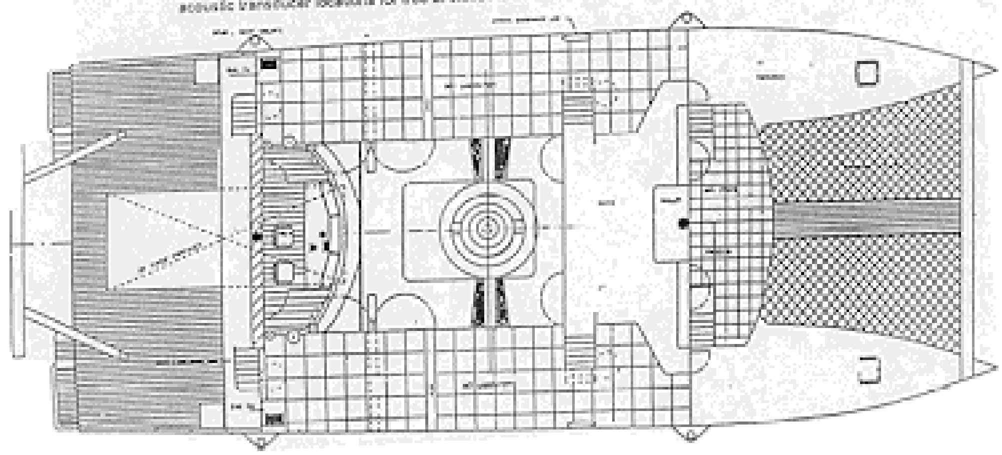


Figure 1. Profile of 79' Crowther catamaran research vessel. A-frame mast pivots about base from 20° aft to horizontal forward. In aft position A-frame may be supported by a compression strut (dashed) to the bridge top to form a tripod for heavy loads 50' over center well. In horizontal position, A-frame reaches 10 meters ahead of the vessel to deploy sensors or a conductor wire over bow for 500 lb. loads. A-frame may be hydraulically controlled in a $\pm$ 15° sector to suppress pitching motion. Top of pendulum is seen in raised position (dashed) and lowered position solid. Note clean forward hull profile for minimum interference with A-frame or pendulum deployed sensor systems.

Figure 2. An 8' wide x 10'8" long well is at the pitch and roll center. Hydraulic controls fold the well cover against the forward bulkhead when the well is open. The deck surrounding the well is protected on 3 sides for work in advanced seastates. "T" shaped working deck is 34' wide aft 16' wide forward by 50' deep. Wet and dry labs have 320 square feet each and have double doors with overhead trolley onto the working deck. A 16' wide x 20' long drop in lab/accommodation module completely fills the working deck when the center well is not needed giving up to 1,000 square feet of total lab space when needed. Notice the four spud locations at the corners of the labs and the four acoustic transducer locations for true bi-static ADCP.



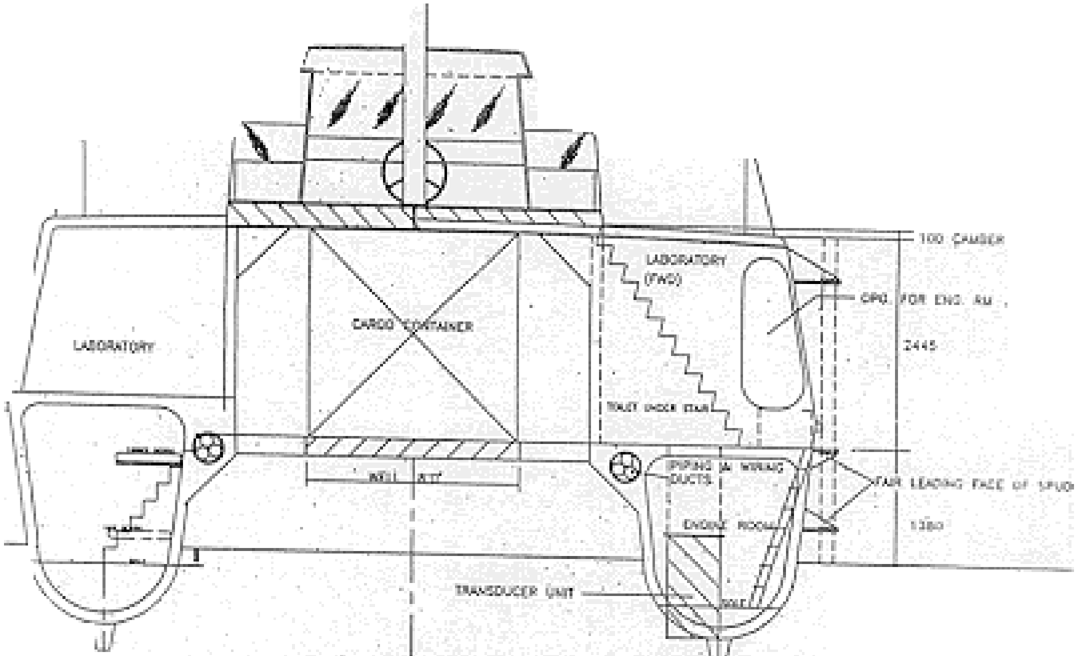


Figure 3. Mid Ship Cross Section. Note aft bridge has clearance for a standard 20' shipping container underneath. Three bolt on mounting brackets are shown for each spud/davit. Aft lab over the engine room has extra head room. In hull accommodations are under the lab with standard head room. Protective skegs/keel coolers, guard hull, propellers and tankage from grounding damage. Four 3' I.D. transducer wells are located inboard of the skegs, permitting bi-static ADCP geometry.

1) <u>Motion Compensated Pendulum for Pitch. Roll & Heave</u>

The pendulum system will motion compensate remote sensing devices of up to 1,000 pounds in the atmosphere, high enough to look over the forward elements of the vessel superstructure, and up to 5,000 pounds below the hulls of the vessel. Our object is to reduce the pendulum's pitch, roll, and heave motions to less than 10 percent of those experienced by the ship as a whole while operating in 4' to 8' seas. A wide variety of science missions are described below which are enhanced by the pendulum. These include: a high frequency swath mapping transducer array, side scan sonar, atmospheric radar and acoustic gear, and a small scientific drilling rig for carbonate sampling in shallow water. Conventional wire lowered instrumentation such as CTD's will also produce data with higher signal/noise and with less chance of damage or loss when handled from the pendulum.

A variety of oceanographic and meteorological sensing systems may be attached to the upper and lower ends of a motion compensated pendulum. This pendulum is located at the pitch and roll center of the conceptual catamaran. The pendulum pivots about two axes on gimbals located about 20' above the water at the 02 deck level (as seen in Figure 2). The vertical distribution of weight is such that the pendulum remains stable in a nearly vertical position when operated in a passive condition. There are mechanical stops at about +1-30 degrees in roll and +45 degrees (for towing) and -30 degrees in pitch. The pendulum will be actively controlled by hydraulic cylinders acting through the gimbal set to maintain the pendulum in a preset position in a near vertical attitude as the ship pitches and rolls around it. Pendulum inertia increases its own stability.

<u>Pendulum Reference Data Needed for Attitude and Heave Control</u>

A GPS Attitude Determination Unit such as the ADU2, produced by ASHTECH Inc., can allow us to measure the attitude (pitch and roll to ± .08° and azimuth to ±.04°) of the catamaran at least twice per second. These measurements are derived entirely from differential GPS data thus they are independent of the accelerations being experienced by the ship. These data are a required input to the motion compensated pendulum system and are now available for less than $20K. Such GPS systems have many uses, including the continuous calibration of the conventional gyro and magnetic compass systems, and precise location of other general purpose data. We also require the real time differential feature needed to determine position with ±1 meter accuracy and velocity to ±.1 knots for ADCP corrections.

Angle resolvers mounted on the gimbals can continuously measure the attitude of the pendulum relative to the ship to within about one tenth of a degree, and are combined with ADU2 data to develop the error signals required to hydraulically maintain the pendulum in a stable vertical or inclined attitude. The addition of an accelerometer aligned with the pendulum axis allows us to develop an error signal required to hydraulically attenuate heave motion. The ADU2 is provided with a 1 meter square antenna array which is small enough to be mounted atop the A-frame mast so that it will be the highest object on the ship to avoid structural interference with satellite signals.

Trunnion Carriage

The two part (port and starboard) structure which supports the outer set of gimbal bearings is called the trunnion carriage. This carriage structurally supports a large pair of self-aligning bearings with spherical shells that hold the trunnion stubs. These stubs protrude from the port and starboard side of the outermost gimbal to permit motions about the pitch axis. It reduces the unsupported span across the center well deck so the gimbals can be smaller. An individual trunnion carriage will be needed to mount the MCP in each individual ship, or a set of adapter plates/fixtures will be required to transfer loads into the structure of each individual ship surrounding its center well or moon pool. In cases like the prototype catamaran, the trunnion carriage structure is minimized by building supporting structures into the bulkheads and decks surrounding the center well. The bulk of the carriage and gimbals are located on the 02 deck to keep the working deck clear of hardware and moving machinery. This built-in structure could alternatively support a conventional A-frame which spans this well mounted on the 02 deck, giving a 25 foot vertical working deck clearance.

The second function of the trunnion carriage is to anchor the double-acting hydraulic cylinders which move the gimbals to compensate for ship motion, friction, and hydrodynamic drag of wind or water. Control valves, hydraulic hoses, compressed air, power and signal connections, will be protected by conduits within the carriage structure with appropriate quick disconnects for easy installation/removal. Lastly when the MCP i s removed from the ship, by dock crane, the trunnion carriage then becomes a storage stand simply by locking the gimbal set and the pendulum.

Other Uses for the Motion Compensated Pendulum

A lift capacity of 5,000 pounds is set for the motion compensated pendulum in order to conform to the UNOLS small expeditionary vessel heavy lifting specification. This new pendulum device is the subject of a separate patent application with the University of Miami. Since the pitch and roll center has the minimum motion on the vessel this is the ideal location to handle the heaviest loads.

A) Drilling and Coring Through the Center Well

The center well is also needed for the optimum placement of a small scientific drilling rig like the one operated by Dr. Richard Fairbanks at Lamont. His commercially produced Acker Bush Master rig has already demonstrated an additional heave compensation system (designed at Lamont) in 10' seas. His system can drill 2" diameter cores about 40 meters into carbonate sediments in water depths of 100 meters. All successful seagoing drill rigs either jack up, or are semi-submersible and/or have a true center well drilling capability.

Twenty-one foot standard lengths of drill string may be lifted from a pipe stand under the elevated aft bridge and hoisted at the top with a crown block hung at the apex of the tripod (Figure I). A system of up to four spuds is used to anchor the conceptual vessel in calm water of depths up to 5 meters, which are commonly found on the Bahama Banks and in

Florida Bay and Biscayne Bay. The MCP system can support the Acker Rig and its motion compensating system, thus reducing heaving motions another order of magnitude. A bottom plate bolted onto the pendulum base can be placed directly on the bottom in very shallow water and act as a drilling template and at the same time support the rig on the sea bed with compression loads through the pendulum body. The ship is constrained horizontally by spuds and the drill rig is free to move vertically within the gimbal sleeve. In deeper water a four anchor spread, or dynamic positioning could be implemented.

B) Five-beam Bi-Static ADCP

A downward oriented narrow beam acoustic transducer mounted at the base of a motion stabilized pendulum will make it possible to measure vertical velocities in shallow water from a moving ship. Such observations would be beneficial to a wide range of physical oceanographic, geological and biological process studies.

The advantages of the vertical transmitter beam and bi-static receiver geometry are (1) clean measurements of the vertical velocity w down to the bottom with minimal contamination from side lobes and (2) the ability to estimate the Reynolds stress (<u'w'>, <v'w'>) if the turbulent velocity (u', v', w') can be resolved. Only the vertical beam allows observations o f wand backscatter strength (related to suspended sediment and/or zooplankton) of the entire benthic boundary layer. Observations of coherent structures such as Langmuir cells, in the surface and benthic boundary layers become feasible with a bi-static ADCP. Other applications include the study of secondary circulation's related to varying bathymetry and observations of organized turbulence (Viekman et al 1994).

Because vertical velocities tend to be small, their measurement by an ADCP mounted on a moving vessel is difficult. Even small deviations from vertical orientation of the ADCP can induce an unacceptably large bias in the sensed w. This bias changes with the trim of the ship. A catamaran with a stabilized pendulum in the center well and a GPS-based attitude system will allow monitoring the orientation of the ADCP to fractions of a degree and make shipborne observations of small w feasible. Residual vertical velocity errors can be corrected with the vertical accelerometer data above or bottom reflection information.

Mounting an ADCP in the center well of a catamaran has additional benefits. There is less flow distortion than with ADCP's mounted on the bottom of the hull, there is less of a problem with bubble clouds obstructing the sound transmission, and there is minimum heave. ADCP data would clearly have much better signal/noise under rough conditions. The transducers can also be located at a shallow depth between the hulls such that measurements can reach closer to the surface than in a conventional mount or be lowered below surface bubble clouds.

C) CTD/Rossette and Other Wire Lowered Applications

Wire lowered sensors, such as CTD systems, would benefit from these motion isolation features. We can motion compensate conventional winch systems by mounting a turning block atop the pendulum with a long horizontal run of wire on the 02 deck to assure small fleeting angles. Vertical motions of the MCP produce minimal changes in long horizontal wire runs. The wire is then lead down through the center of the MCP to the CTD below. Vertical resolution would improve, mixing effects would be reduced and launching damage and personnel safety problems would be virtually eliminated. During launch/retrieval the CTD is snugged up against a compliant spring/shock absorber mounted on the base of the MCP. A conventional A-frame can be mounted on the MCP foundations, when the MCP system is not in use. Three or more restraining lines, from all sides can hold the CTD from swinging, when it is launched through the center well.

D) Diver, AUV and ROV Support Applications

Dive support platforms can be lowered by cable from the pendulum and held nearly motionless near the bottom while supplying ship resources. Examples include: two tons of steady lift, electric power, compressed air, hydraulic power and fiber optic cable for TV monitors control signals and data transmissions. Such a system would be particularly convenient to handle loads safely during underwater construction projects, which have been marginally safe in rough conditions with conventional vessels and cranes. Shark cages, decompression chambers for bell diving with decompression later on deck or other bulky safety devices could be stabilized at depths convenient to the divers mission. ROV's or AUV's could be launched through the surface under complete pendulum control (in a clamping fixture) and released at a depth of 25 feet and lowered by wire to greater depth. Retrieval is also under full pendulum control.

As an example of past problems, caused by a lack of motion compensation, both Peter Weibe and Bob Ballard of WHOI have lost ROV equipment either due to excessive wave induced strains on the tether system or collision with the ship. Sensor systems or ROV's can be held in a fixture at the base of the pendulum, until well below keel depth where wave orbital velocities are reduced and thus should escape damage. Numerous oceanographic sensors, such as CTD's, have been damaged by colliding with the hull at high velocity during launching. In order to prevent such damage, scientists, technicians and students frequently stand in harms way on a "hero platform" or under suspended loads while hanging over the side. A serious winch and wire accident involving serious inquiry has occurred in South Florida on average every 5 years.

Launching gear from the bottom of the pendulum is a robotic rather than human activity, thus personnel are remote from gear failures and gear/hull collisions. Hull/wire or wire/propeller interactions are also avoided. There will be a host of pendulum accessories, for different missions, including those yet to be conceived.

A simple pipe flange is welded to the bottom of the pendulum where the largest loads are handled. A similar bolt on flange at the top is used where atmospheric sensors can be mounted each with the same standard bolt pattern.

E) Examples of Accessories to be Developed

A water damped shock absorber/grabber, to gently capture wire lowered devices, like CTD's/Rossettes. This device would be similar to water damped mooring stops used for years on Cyclesonde moorings.

Large box cores or large diameter piston cores, for water depths 10 meters or less can be directly mounted on the MCP. These devices are pushed into the bottom, with a force supplied by the rack and pinion mechanism, which moves the pendulum vertically or a hydraulic cylinder.

F) Meteorological Pendulum Applications

The MCP would provide a unique capacity for atmospheric remote sensing. Albrecht's group currently operates a 915Mhz wind profiler and a 94GHz Doppler radar for cloud and boundary layer studies on land. Both of these systems require stabilization for ship-board applications. The 915Mhz profiler has a phased array antenna, that forms a vertical-pointing beam and two beams pointing 15° off the vertical. Winds from near the surface to 3-4 km are obtained from Doppler velocities measured along these beams. Since ship movements contaminate these velocities, stabilization is needed to ensure proper operation on a ship. The 94GHz Doppler radar is used in a vertically-pointed mode, to study cloud properties using reflectivity and the Doppler spectrum. It too requires stabilization for ship operations, since the relatively strong horizontal wind components can easily contaminate the vertical velocities, as the radar points off vertical. The MCP would have more than adequate capacity to handle these remote-sensing systems.

2) A Frame Mast for Forward Instrument Deployment -Pitch Stabilized

As part of the suite of motion compensation capabilities, an A-Frame Mast system is proposed for our conceptual catamaran ship. This system will enhance: meteorological observation, remote surface sensing, geological sampling, line of sight communication, chemical/optical sampling, acoustic noise abatement, near reef piloting, propulsion efficiency, speed and sea keeping capabilities of our conceptual vessel. Like other catamaran enhancements, the A-Frame Mast is removable. The structures to support this A-Frame Mast system are the forward spud foundations. When inclined forward, to the horizontal position, a pair o f hydraulic cylinders, bearing on the foredecks, may be controlled to remove about 90% of the pitching motion while the vessel is at rest in 4 to 8 foot seas

A) Meteorological instrument readings are adversely influenced by a ship's structure, by its disturbance of the wind field. Instruments are typically placed high on a mast to reduce these influences, but even in this case, significant corrections are often required and ship motions are amplified. Needless to say, an aft bridge location will greatly improve both direct and remote sensing meteorological of our conceptual ship. An A-Frame Mast is an extremely tall A-Frame, extending to heights of 20 meters above the water. Very narrow instrument towers can be supported from the apex, since the tower does not need to support compression loads. An A-Frame Mast, minimally obstructs the view dead ahead or above, for the bridge or for remote sensing transducer mounted on the motion compensated pendulum system. Like ordinary A-Frames, this mast is equipped with pivots, where the legs meet the deck and can be moved by hydraulic cylinders fore and aft. The legs are pivoted on the same type large self-aligning, bearings used on the gimbals. The same type of angle resolvers and double-acting hydraulic cylinder control the A-Frame Mast. A vertical sensor mast could be suspended in tension from above and lowered down to the sea surface or even below the surface. A-Frame Masts can have sufficient structural strength that they can be used without the complication and interference of stabilizing shrouds associated with conventional masts.

B) Additional Applications for a Pitch-Controlled A-Frame Mast

The use of a tall A-frame gives the flexibility of extending the measuring point well ahead of the ship and its disturbance to both atmospheric and oceanic boundary layers. Air-sea interaction measurements involve the accurate resolution of wave properties and turbulence on both sides of the interface. On conventional ships the problems (in this regard) are of two types: a) contamination o f measurements due to the motion of the ship (e.g., Katsaros et al., 1993); b) disturbance of the flow past the ship. The motion-compensated A-frame concept greatly reduces the severity of these problems, by moving the measuring point well ahead of the ship and compensating for heave and pitch of the ship.

Some of the air-sea interaction measurements that will be greatly facilitated by this motion-compensated A-frame are:

a) Wave directional spectra using an array of remote (laser) ranging devices (Donelan et al., 1996).
b) Momentum, heat and mass fluxes across the interface.
c) Infra-red sensing of the surface skin.
d) Wave breaking statistics.
e) Turbulence structure on both sides of the interface +/- 5 m (Terray et al., 1996).

C) Geological Sampling Uses of an A-Frame Mast

In the aft position, the apex of the A-Frame Mast would be directly over the center well and could be used to support a crown block to hoist standard 21' sections of drill string for Fairbank's heave compensated drill rig. For heavier loads, like vibra-coring, a compression strut could be installed from the top of the bridge deck to join the A-Frame to form a very rigid tripod. (see Figure 1) The greater mast height could provide exceptionally long core capability in soft sediment environments (up to 2 O meters or more) when the vessel is spudded in place.

D) A Third Wire Deployed Forward for Chemistry and Optics

In a forward position, a third wire for loads up to 500 pounds could be rigged through a block at the A-Frame's apex. This would permit the deployment of wire lowered sensors 10 meters ahead of the ship's influence. This would reduce ship shadow for effects optical sensors such as those deployed by Rod Zika or Ken Voss. If the forward section of the ship is primarily netting rather than solid structure, there will be even less influence by the ships shadow. This third wire conforms to a small expeditionary vessel specification by UNOLS to be able to deploy up to three, widely separated, wires simultaneously for independent experiments. In this way three independent groups with different wire requirements could make complementary measurements without interference. One wire i s deployed over the stern A-frame, the second wire is deployed through the center well, and the third wire is deployed over the bow supported by the A-Frame mast. This would give about IS to 20 meters separation between the wires. The A-Frame Mast would be much simpler to use than conventional outriggers since it is little more than an oversized A-Frame. These wire-lowered sensors would also be stabilized in pitch ahead of the vessel.

E) Navigational. Propulsion and Seakeeping With an A-Frame Mast

In the horizontal position, the A-Frame Mast can pass under low bridges. A pivoting crows nest, can support an observer ahead of the ship when navigating coral strewn waters to look downward for obstructions without critical angle of reflection problems typically experienced from the bridge. At night, underwater lights looking forward from the bulbous bows of each hull, will provide illumination at a time when ships are typically blind underwater.

The upper crows nest would provide a convenient mount for instruments and a convenient platform to service: the crown block, upper bearings for roller furling gear, and scientific instruments. A tensile member is located along the aft edge of each mast extrusion (not shown in Figure I) to support the mast in its extreme forward position. Compressive struts between the tensile member and the mast will be spaced at convenient intervals to form steps to climb the A-Frame Mast, with a track for a clip-on safety harness to protect workers aloft.

When not in use for remote sensing, the A-Frame Mast could support a significant sail plan. This offers a capability of taking acoustic data with complete silence from rotating machinery. Seismic or bio-acoustic uses are possible with minimum noise while underway. This would be a unique capability in the entire UNOLS fleet. Sails will result in greatly improved catamaran seakeeping, which will be invaluable when crossing or working in the Gulf Stream during strong North winds. Comfort and range will be improved while making long transit legs to or from the Caribbean Sea across the trade-winds, or crossing from Key West to Cuba after it opens up. John Adams, President of Motion Dynamics Inc., believes Catamaran motion reduction by sails is a re-emerging technology, which may prove more effective than computer controlled fins at low speed (personal communication). Motion Dynamics can do computerized sea keeping model runs including sails to demonstrate their effectiveness quantitatively. Intelligent use of sails while motor sailing will improve speed (about 50% under favorable conditions) and increase the range of the vessel, without burdening the catamaran with added tonnage of fuel.

Recently, a mono-hulled concept boat "Amoco Procyon", has demonstrated a similar full height bi-pod mast. This reduced weight aloft by 25% and windage aloft by taking advantage of carbon fiber in a system designed, built and patented by Eric and Ben Hall at Hall Spars. This system can be raised and lowered, to allow a 30 meter mast to be lowered to 20 feet above the water, to permit passage under low fixed bridges. This bi-pod mast permits hydraulic roller furled sails for both jib and mainsail for ease of short handed sailing on this 65' long high performance boat. Hydraulic roller furling on all sails greatly reduces crewing requirements on motor sailing vessels, so that they are about the same as powered vessels. The Procyon carries 40% more sail area than comparable boats and has greater mainsail efficiency because it is not in the turbulent wake of a conventional mast. The above improvements are calculated to increase boat speed about 10% compared to other ULDB boats.

The advantage of motor sailing would be far greater on a catamaran with 34 foot beam for a wider A-Frame Mast foundation plus much wider sheeting angles. The righting moment is calculated to be a 2 million + ft-lb. and a much higher 25 + knots hull speed. See Van Leer (1982) for a more detailed discussion of Sailing Catamaran Research Vessels.

3) Shallow Water Motion Stabilization With Spuds - A Proven Technique

Barge-like hulls have been traditionally used in shallow water to minimize draft and maximize payload. As long as the footprint of the barge is large enough to span several wave lengths of the dominant gravity waves, the motion response of this platform will be minimal. The ultimate improvement in shallow water barge motion can be had by jacking-up the barge so that the hull is raised completely above the gravity wave crests. This approach has been successfully used at RSMAS by Dr. R.N. Ginsburg and others to drill on the Bahama Banks in the self-propelled Jack-up Mobile Platform (JUMP). However the maintenance of this specialized platform, or the marshaling costs to bring such a vessel from Louisiana prior to each use, precludes ownership or use, except by a large scale project with enough recurring use to keep the platform employed nearly full time. See Van Leer (1985) for other jack-up catamaran ideas.

In Biscayne Bay, construction barges are anchored by using two or more spuds. These spuds are typically long steel pipes, deployed through a clear hole in the deck, lined with a larger internal diameter pipe, which passes through the barge and out the bottom. A central crane on the barge, lifts each spud clear of the bottom so it may be locked in the up position before the barge is moved to a new position by tug boat. We describe a similar spud system to anchor our catamaran below.

Spud Anchoring System for Shallow Water Motion Stabilization

Our concept of a shallow water anchoring system, consists of a set of two or more spuds, carried within fixtures which bolt on any or all o f the four corners of the catamarans rigid central structure, as seen in Figures 2 and 3. A simple sleeve style bolt on fixture can be designed to transfer the load from each spud into the catamaran structure. Each spud is equipped with a rack and pinion drive to move the spud up and down. Hydraulic controls may be located on the bridge and/or directly next to spud mount, on the 02 deck. The pinion drives a rack which is welded to the side of the spud. In this way, a crane and operator is not needed, to deploy or recover the spud, since a crew of two may be called upon to operate our vessel.

For the first generation system described here, we will use standard design small sized jack-up platform legs, made of aluminum, with a single standard hydraulic planetary gear drive and locking mechanism. The wall thickness of the tubular spud, will be chosen, so that it will bend or break before damaging the vessel's structure. A small water pipe can be built into the center of each spud, to break any vacuum which might prevent the spud from being extracted, or to bury the spud end to a depth of a foot or two. We suggest bolting on these spuds to:

a) prevent a bent spud from jamming in a hole through the deck, since it may be unbolted and removed by crane,

b) completely remove spuds when not in use, to reduce the science cargo in favor of other instrumentation or equipment,

c) install other devices like: air gun davits, large outriggers, folding antenna's for OSCR (Ocean Surface Current Radar), king posts for trawling, or large acoustic transducer mounts could be temporarily installed. The same NATO/UNOLS standard 2' square bolt pattern will be built into the side of the vessel's main box structure as are found on working decks. We envision using spuds in protected waters, or in conditions where wave heights are less than 3 feet and water depths are less than 5 meters. If four spuds with rack and pinion drives are installed, the vessel could be jacked up for maintenance or operations in calm conditions. Most large catamaran and swath vessels have four reinforced strong points so they may be lifted by slings for launching. There are frequently width limits in marine railways and ready availability of large cranes in most seaports.

4) Controlled Fins as an Active Part of a Motion Isolation S):stem

SWATH style vessels are widely regarded as having the best seakeeping properties. It should be noted that seakeeping on most SWATH vessels, while underway, is improved significantly by four or more stabilizing fins. These fins are hydraulically actuated and computer controlled, such as those used the Monterey Bay Aquarium SWATH. Such systems are designed commercially by Maritime Dynamics Inc. in Maryland. About 50 systems, delivered by Maritime Dynamics, were installed on conventional high-speed catamarans, where their computer modeling is highly evolved. Heave and pitch motions are said to be reduced by about 50%. Costs for systems appropriate for catamarans in our size and speed range vary between $250K and $350K. Such a fin system should be considered for extensive high speed underway surveying applications. We suggest the installation of such a system in our conceptual catamaran vessel. The computer modeling part and design o f this system is essential to the design of the remaining 3 motion isolation systems. Since the hardware is well proven, the structure needed to mount the fins can be built in at reasonable cost with additional funding later for complete installation. Response of our chosen hull form, to random wave excitation, will need to be modeled on five representative courses relative to the dominant wave direction. These response functions will be essential to the design of the MCP and A-Frame Mast control systems as their first stage of motion compensation. These response functions will also help us plan operations in ways that take the greatest advantage of what a well- designed catamaran has to offer. Ultimately after the fins are installed, data from their controller will be available to our controllers through the

LAN. At speeds of a few knots, the fins become ineffective aside from a little passive damping.

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Figure 3. Mid Ship Cross Section. Note aft bridge has clearance for a standard 20' shipping container underneath. Three bolt on mounting brackets are shown for each spud/davit. Aft lab over the engine room has extra head room. In hull accommodations are under the lab with standard head room. Protective skegs/keel coolers, guard hull, propellers and tankage from grounding damage. Four 2' I.D. transducer wells are located inboard of the skegs, permitting bi-static ADCP geometry.

SECTION 13
Roger Long
RESEARCH VESSEL PROCUREMENT STUDY

Resource Materials for Selection of Basic Vessel Type

This report contains materials intended to assist the Skidaway Institute of Oceanography in making a decision about the basic type of vessel that will best serve as a replacement for the "R/V Bluefin". These materials were prepared to be specifically relevant to the situation of this single institution and are not intended for use by other organizations or to be a general guide to ORV selection.

This analysis assumes a budget for vessel procurement of $1,500,000. It describes four different vessel concepts. Budget numbers are obviously quite rough at this stage of vessel definition. There is a reasonable expectation that a vessel similar to any of the four described could be obtained for the budget figure. It is less certain that the vessel would have the quality, features, and equipment ultimately desired. This report incorporates a great deal of author's judgment to keep many invisible factors roughly equivalent so that a type choice made at this point will remain valid even though size, budget, and configuration may be adjusted later in the design process.

This report considers only monohull vessels. Exotic types such as Swaths and catamarans will probably become an important part of the research vessel fleet -eventually. Their successful use will depend as much on changing the way that research is conducted as on tinkering with the design of the vessels themselves. Many problems with these vessels are yet to be solved. Given the importance of outside investigators, whose equipment and methods are adapted to standard vessels, development of a new type does not appear to be an appropriate path for Skidaway.

The influence of speed on vessel configuration is so great that: a decision about: basic vessel type is primarily one of the speed regime in which it will operate. The hydrodynamics of hulls of the same shape and different size are equ1valant only If the ratios of square root of waterline length to speed are the same. The appropriate hull configurations for various speed length ratios do not change in a smooth fashion with increasing speed but in fairly abrupt jumps at: a few points. This produces three genera of vessels, each of which is described here; with two alternative powering methods for one of them. Dollars per unit weight tends to be the best predictor of vessel cost at this stage of analysis. Weight, at this point in the design process, is roughly estimated according to the product of a proposed vessel's overall dimensions .

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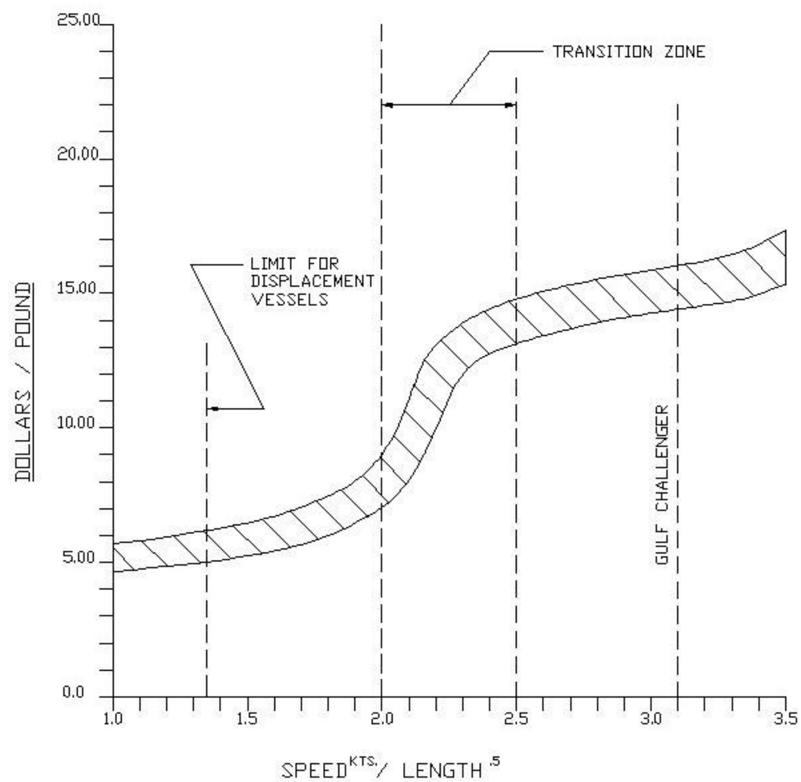
This makes the weight method generally equivalent to the "cubic" method often used. Figure 1, on page 3, is a graph of dollars per pound vs. the non-dimensionalized ratio of speed / length. It will be no surprise that speed is expensive but the magnitude of the difference may be. Note the line labeled "Limit for displacement vessels". This is a practical speed limit for vessels of the hull form typical of fishing draggers, offshore supply, and most research vessels. Operation at higher speeds requires, not just additional power, but significant changes in hull shape and weight to direct the power into increased speed and not just increases in trim angle and wake size.

There is a large jump in cost in the region labeled "Transition Zone", due primarily to the need for aluminum or other exotic construction. Design of a vessel in this region would be a poor option. First, operation in the transition from semi-displacement to full planing tends produce a wallowing, struggling, motion as well as the poorest trade-offs between fuel consumption and distance covered. Second, a vessel configured to operate in this reg1on with reasonable power and fuel consumption will have already paid most of the costs of higher speed. Little but sufficient horsepower will be necessary to gain the benefits of fast operation. The additional expense of larger engines will not be a significant percentage of the total vessel cost.

Figure 2 on page 4 shows a graph with the speed/length ratio on the horizontal axis and a non-dimensionalized ratio of weight to length on the vertical axis. The design lane drawn on this graph is a prediction of how on-station seakeeping and similar requirements would influence a design. Three concept design points are marked on the graph. From these two pages it is possible, given a budgetary cost assumption, to determine a weight and length for each of the concepts. Hereafter, the three concepts will be referred to as "Slow", "Medium", and "Fast". A waterjet drive version of the "Fast" concept will be referred to as "Jet".



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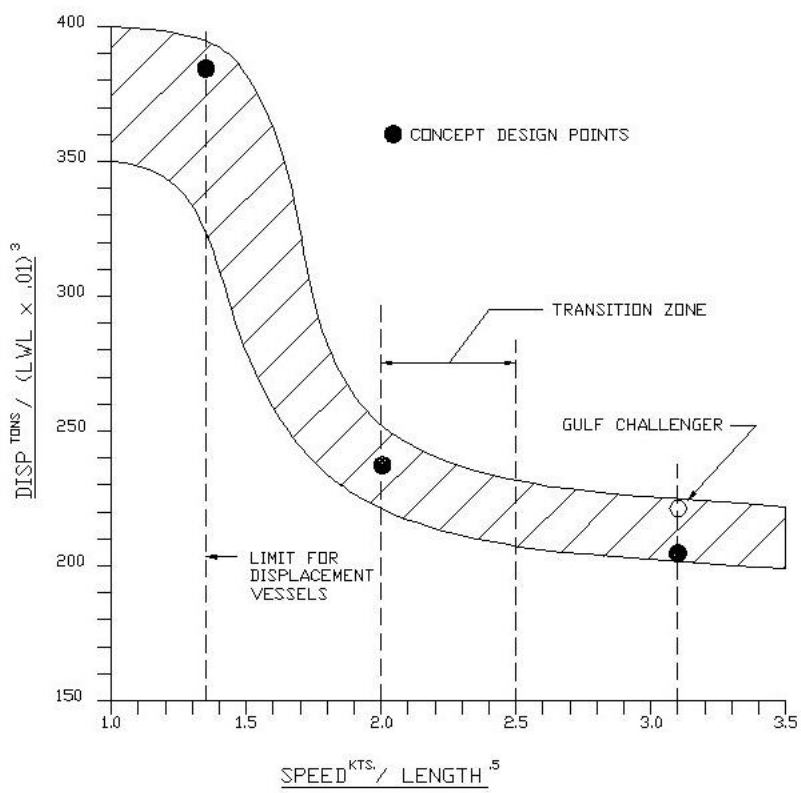

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The appendix contains sketches of the four vessel concepts. These are not conceptual proposals for each vessel but scale "cartoons" that illustrate the general volumes, areas, and characteristics obtainable in each type. A spreadsheet of the principal characteristics of each vessel type will be found on the following page. When comparing lab, deck, and accommodations areas It should be remembered that these areas can be apportioned in different ways. The figures given are the author's estimate of the proportions that would be chosen in a fully developed design. Comparisons of the overall capacity of each type will be more accurate than comparisons of lab or accommodations area alone. Berth numbers can also be varied according to the degree of comfort and privacy desired.

The "Installed Horsepower" numbers are based on Detroit Diesel DDEC engines which are currently the best choice for a research vessel. DDEC engines are much like modern automotive engines in that sensors work through a computer to adjust several aspects of engine operation rather than a single component such as an injector rack or throttle plate. Each cylinder is operated separately with independent control of air and fuel. The result is a very clean burning engine that is able to tolerate the long periods of low power operation typical of research vessel operation. DDEC engines can idle at about half the RPM of a mechanically governed engine due to the instantaneous response of the computer. Fuel/air ratio and other factors can be nearly optimum through out the power range rather than just at a single point as in the normal diesel. The "wet stacking" and carbon production problems of diesels run for long periods at low power output are considerably reduced. Other manufacturers will catch up on this technology within a few years but, for now, the choice of engine supplier is an easy one.

The engines for the Slow and Medium concepts would be rated for "Continuous" operation, permitting top speed to be maintained 24 hours a day. The Fast vessel would have engines operating at the higher power output of an "Intermittent" rating. Operation at full power would be limited to about an hour. At the higher speeds, and in the type of mission profile that would favor selection of the fast vessel type, an hour of operation can be significant. The planing vessel in a seaway also needs the power reserves to push through patches of rougher water and get back over the hump into full planing mode. The Jet concept engines would be rated at the s1ightly higher " Intermittent-Maximum" rating since jets are less stressful to the engines than are props.

C-192 SKIDAWAY INSTITUTE OF OCEANOGRAPHY
RESEARCH VESSEL SPEED TYPE COMPARISON
$1.5 MILLION DOLLAR VESSELS

	SLOW	MEDIUM	FAST	JET
POTENTIAL SPEED LENGTH RATIO	1.35	2.00	> 3.00	> 3.00
DISPLACEMENT LENGTH RATIO	385	240	210	210
DOLLARS / LB. DISPLACEMENT	$5.25	$8.00	$16.00	$16.00
LENGTH OVERALL	76.50	75.75	63.50	63.5
LENGTH ON DWL	69.96	70.39	58.42	58.42
BEAM	26.00	21.00	20.00	20.00
HULL DEPTH	10.50	8.50	8.00	8.00
KEEL DRAFT	8.50	8.00	6.25	4.00
LIGHT SHIP DISP. (LT)	131.80	83.71	41.85	41.85
CREW & EFFECTS	1.00	1.00	0.75	0.75
SCIENCE PAYLOAD	15.00	10.00	5.00	5.00
FUEL OIL	19.00	16.00	7.00	6.00
FRESH WATER	1.00	1.00	0.50	0.50
READY FOR SEA DISPLACEMENT	167.80	111.71	55.10	54.10
HALF LOAD DISPLACEMENT	149.80	97.71	48.48	47.98
INSTALLED HORSEPOWER	840	1680	2120	3540
TOP SPEED (@ HALF LOAD)	11.25	16.00	23.00	27.50
SPEED LENGTH RATIO	1.35	1.91	3.01	3.6
CRUISING SPEED	10.50	14.50	19.50	24.50
GAL/MILE @ TOP SPEED	4.31	5.81	5.21	5.58
GAL/MILE @ CRUISING SPEED	4.00	5.51	4.94	5.06
RANGE @ CRUISING SPEED	1300	800	400	340
HULL MATERIAL	STEEL	STEEL	ALUMINUM	ALUMINUM
LABORATORY AREA	340	210	100	100
ACCOMMODATIONS AREA	630	550	280	280
TOTAL DECK AREA	800	580	600	600
NUMBER OF BERTHS	11	10	10	10

Descriptions of the four vessel concepts follow:

Slow Vessel Concept

The sketch for the slow vessel concept shows a burdensome vessel optimized for seakeeping. Additional weight can be easily accommodated and there is little fuel penalty in carrying it. The vessel can therefore carry large superstructure, payload, and positioning thrusters. The thrusters shown should be able to hold the vessel sideways in a 25 knot wind and provide back up propulsion at a speed of about four knots. The vessel would be designed to create the optimum on-station motion characteristics for handling of heavy objects on deck and minimizing breakage of deep wires. A byproduct of this hull type is tremendous stability and lifting capacity. This vessel could be equipped to safely lift greater weights with its A-frame than it would be prudent or practical to manage once they were on deck. This vessel should be capable of occasional offshore trips as far as Bermuda.

There are separate wet and dry lab areas and vans could be set up to serve as extensions of the wet lab. The sleeping accommodations are in the middle of the vessel, the area of least motion. A vessel of this type could maneuver in any attitude with no exposed, rotating, underwater machinery. The thrusters shown have very low suction head and present little hazard to divers or ROV tethers.

Medium Speed Concept

The medium speed vessel would be of similar length but the hull shape changes necessary to operate at the higher speeds would require a significant reduction in hull volume, and thus, weight. The weight would be saved in two areas, superstructure and machinery. Thrusters, other than low power docking aids, are probably not feasible in this type of vessel so twin screws become mandatory. Use of aluminum could save a good deal of weight but would increase cost and reduce the overall size of the vessel in this comparison.

The twin screw configuration requires that the accommodations be forward of the engine room. Motion will be greater in the forward location and the higher speed of the vessel would create greater pitching forces.

The motion characteristics of this vessel would probably not be as good, as the slow concept but the differences would not be significant. Lifting capacity would be similarly reduced but still in excess of any normal requirement for a vessel of this class.

Fast Vessel Concept

The fast vessel concept shows rather starkly the cost of speed. However the additional lab and accommodations space of the slower concepts is advantageous only if it is consistently used. All else being equal, the faster vessel will do more science and produce better data in synoptic studies. If the capacity of the fast boat is close to what you would generally utilize in the slower types, it can provide significant schedule flexibility.

Operation of a 50 foot vessel of this type by the University of New Hampshire has been very successful and the boat has proven itself an excellent platform for deployment of oceanographic moorings weighing up to four tons. The concept shown is three times the displacement and should be able to lift weights of well over 10,000 pounds.

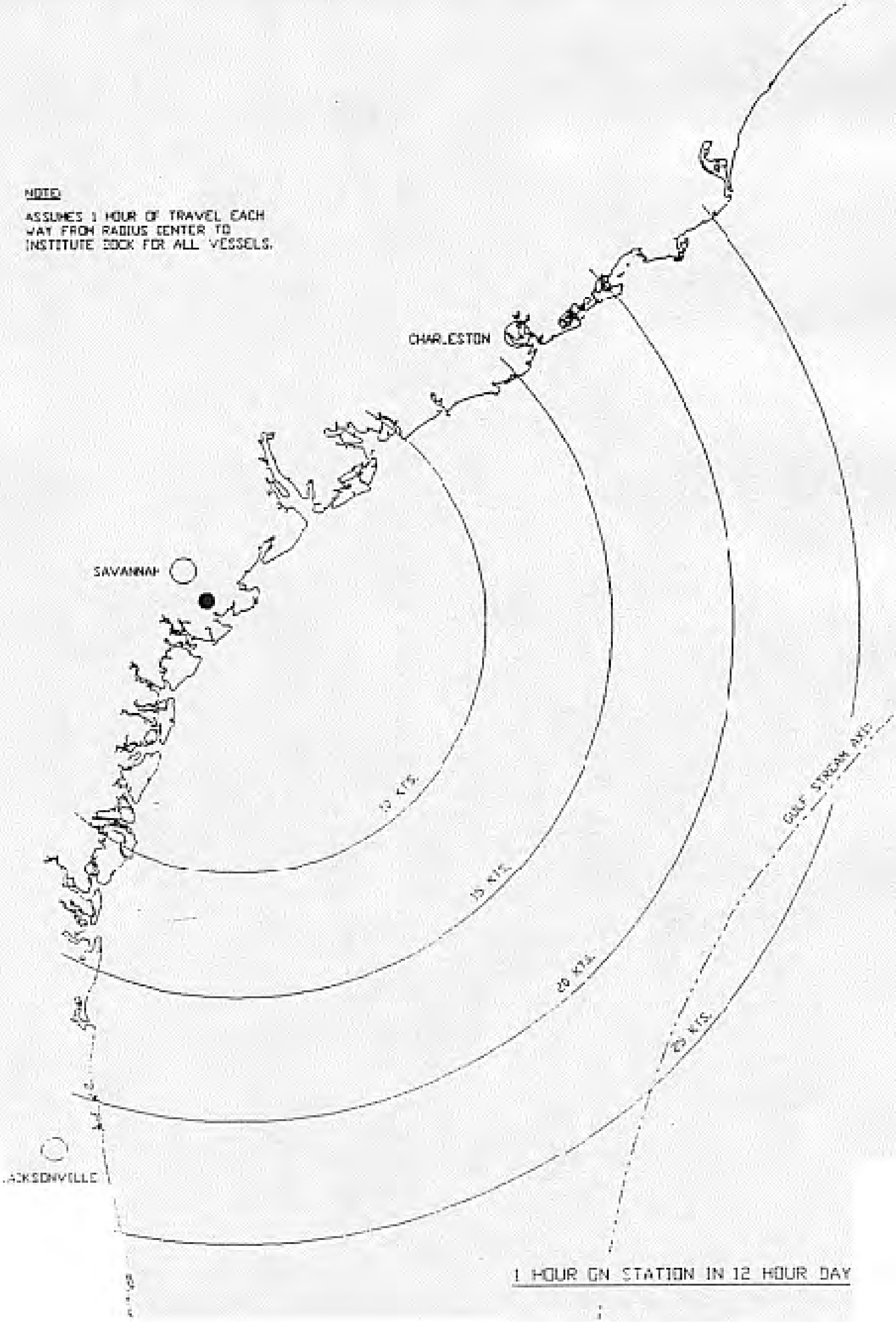
The number of berths is similar to the other vessels but most berths would be in common areas rather than in staterooms as in the other concepts. The lab and galley areas would be adjacent so that the galley could serve as additional lab area on short trips. This has worked well on the UNH boat.

Jet Boat Concept

This concept would differ from the fast concept primarily in the propulsion system. Waterjets would provide significantly reduced draft and increased maneuverability. Jets are most efficient at speeds over 25 knots so higher horsepower would be installed to gain the maximum benefit from the fast vessel concept. Three engines would be installed. The center engine would be a non-steering booster that would not provide propulsion while on station or at slow speeds. This engine would be used to provide hydraulic and, possibly, electric power while on station.

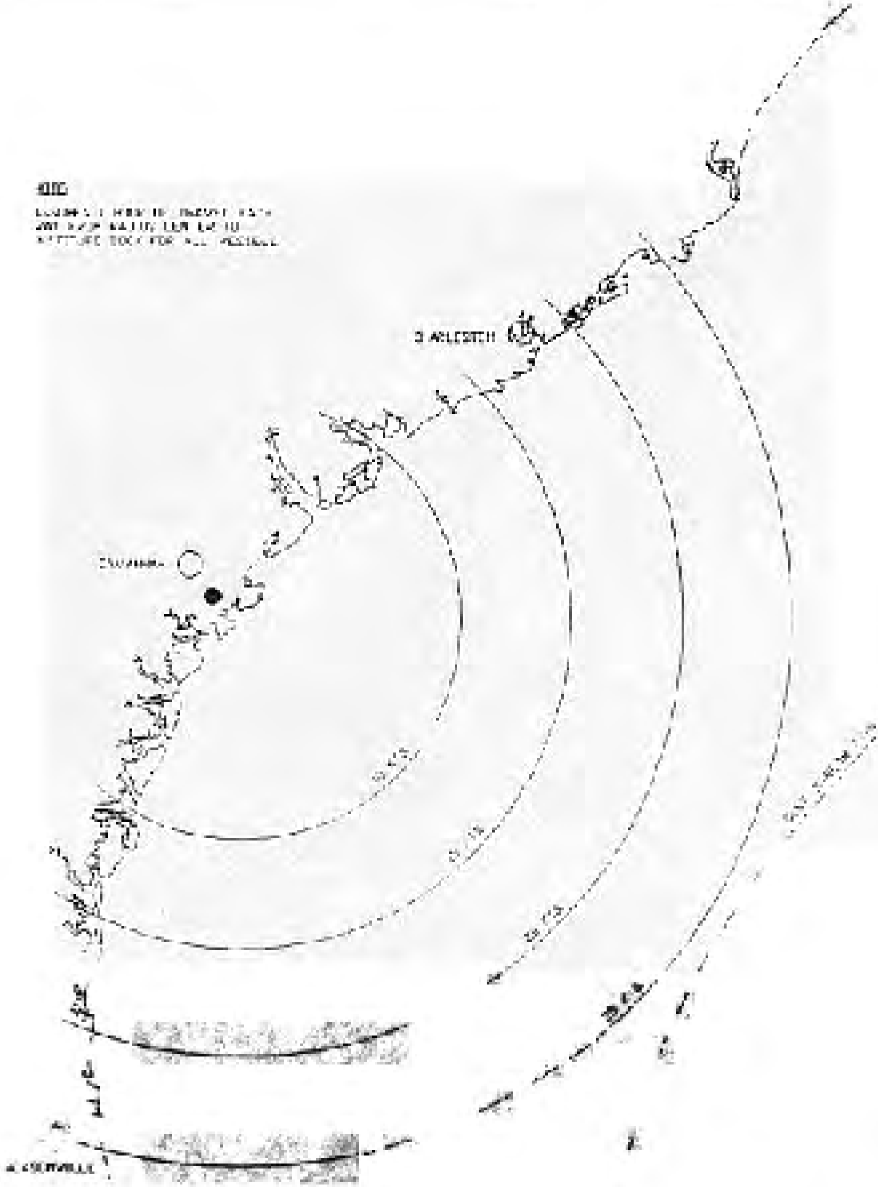
Operational Analysis Materials

The fast vessel concept operates at the greatest economic advantage on trips of twelve hours or less duration. Coast Guard regulations require additional licensed crew for longer trips. The savings in salary on short trips can be very significant. The following pages show map of the area that can be covered in a twelve hour day by vessels of various speeds .

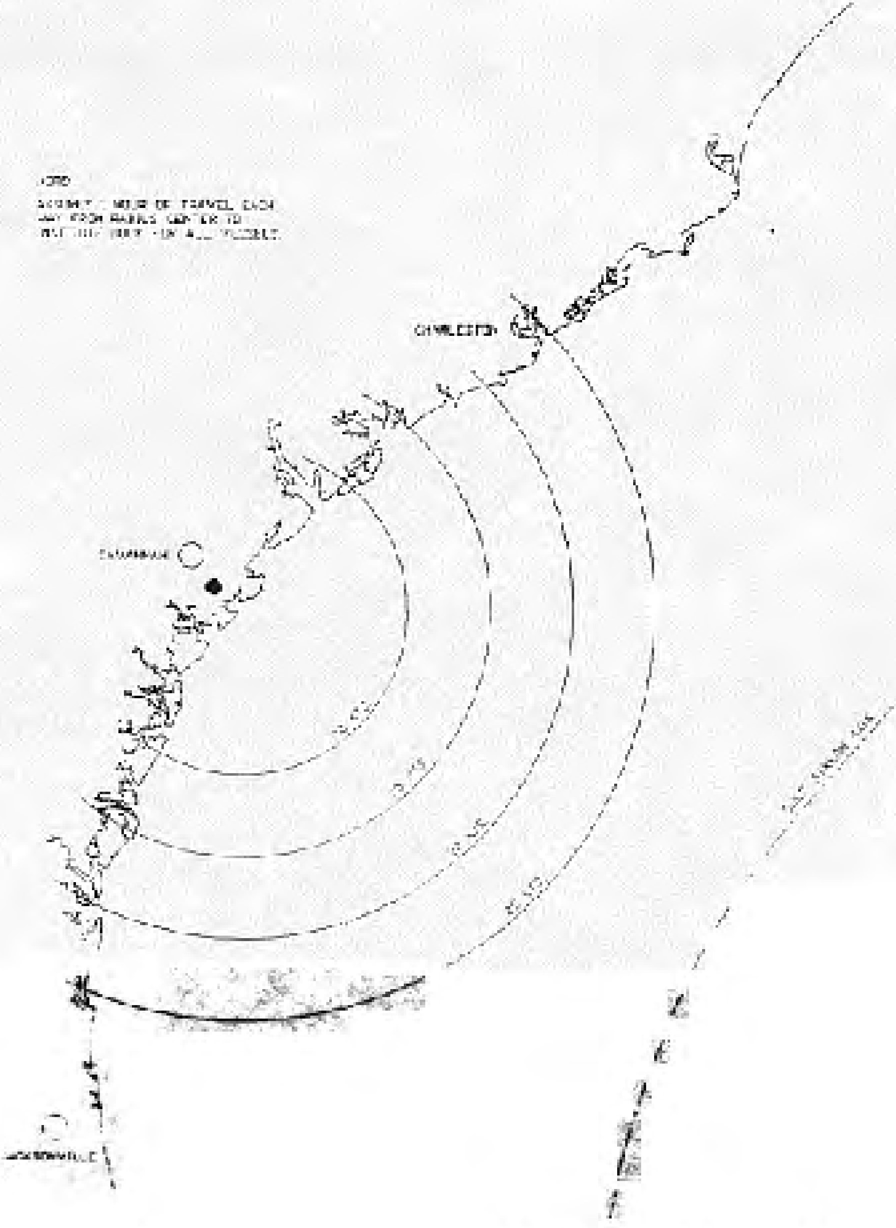


1 HOUR ON STATION IN 12 HOUR DAY

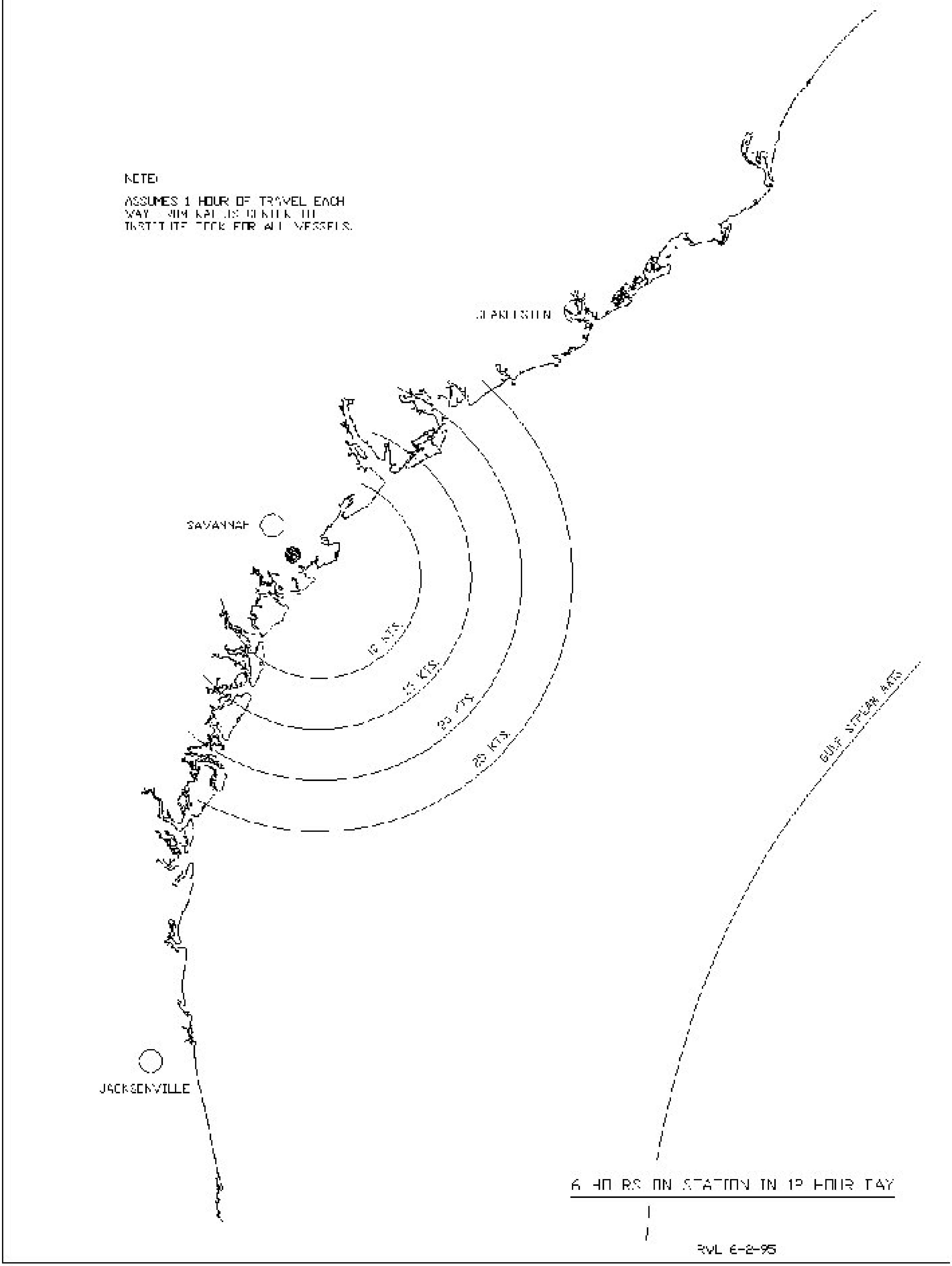
RVL 6-2-95



2 HOURS ON STATION IN 12 HOUR DAY



9 HOURS ON STATION IN 12 HOUR DAY



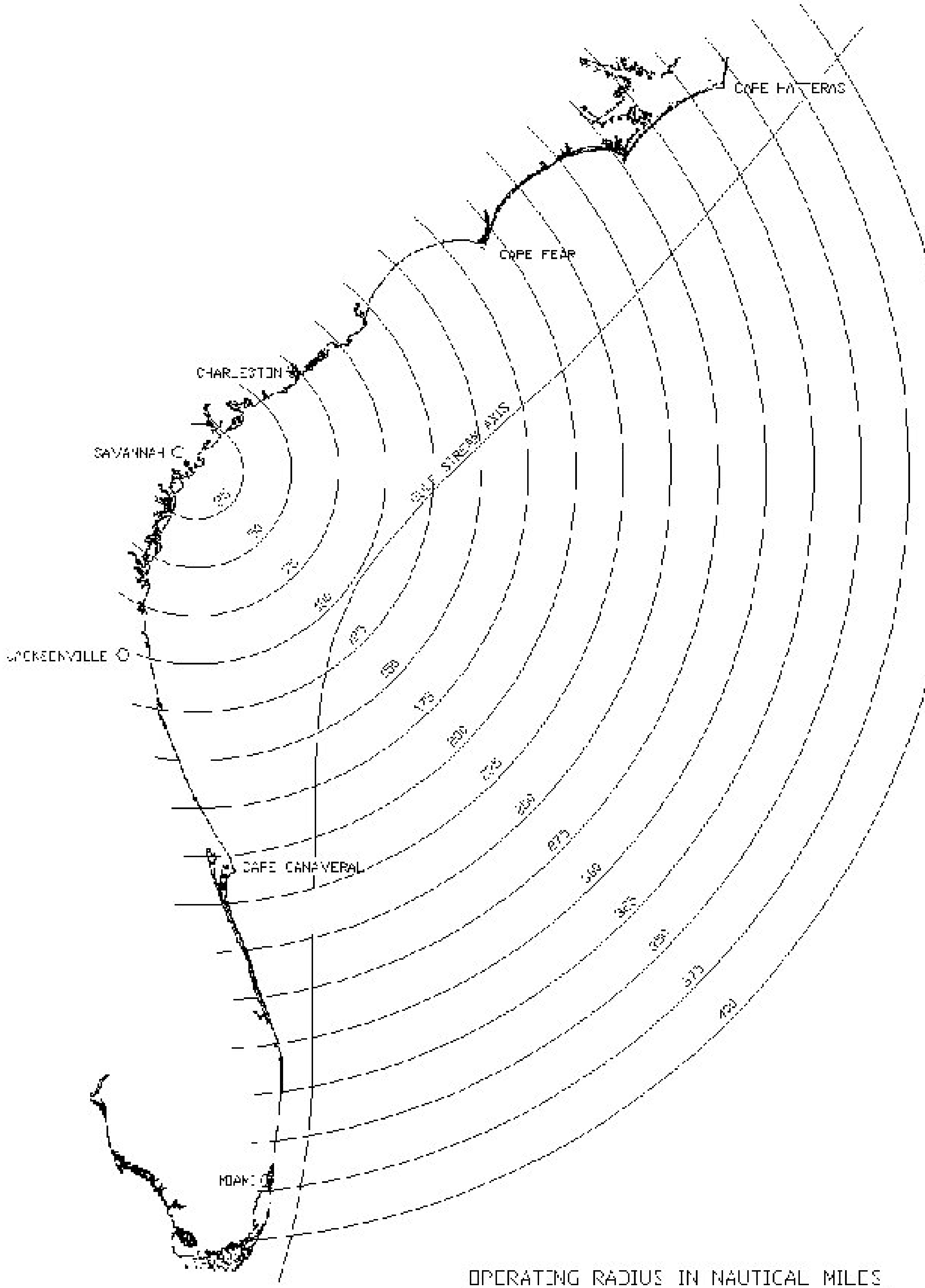
NOTE:
ASSUMES 1 HOUR OF TRAVEL EACH
FOR ALL VESSELS.
CHARLESTON
SAVANNAH
JACKSONVILLE
10 KTS.
15 KTS.
20 KTS.
25 KTS.
GULF STREAM AXIS
6 HOURS ON STATION IN 12 HOUR DAY
RVL 6-2-95

C-1.92 Report. No. 1 to Skidaway Inst1tute of Oceanography Resource Materials for Selection of Basic Vessel Type

The following five pages show a map with distances from Skidaway and sheets giving time and fuel consumption figures for the four vessel concepts.

The primary objective of a research vessel is to provide on-station time, i.e. time spent e1ther motionless or at speeds under five knots. This is the productive time so it is instructive to look at fuel consumption as a function of hours on station. Spreadsheets on page 19 and 20 show the fuel consumption figures for the four concepts. Annual operation is considered as one big trip with a total number of station hours and a total length of cruise track.
Figures for six combinations are given. Within the range of probable operations, fuel consumption can be seen to be a not particularly significant issue.

The most significant numbers on pages 19 and 20 are the
total operating hours. A small institution with just one boat crew on salary can expect about 2000 hours of work from that crew. The difference between this number and the total operating hours is the time available for this crew to perform maintenance and other shoreside duties. This is where the best rational for trading speed for overall space and capacity may be found.



OPERATING RADIUS IN NAUTICAL MILES

RWL 6-2-95

C-192 SKIDAWAY INSTITUTE OF OCEANOGRAPHY

SLOW VESSEL WITH 16V-92 ENGINE

TOP SPEED = 11.25 GAL./MILE = 4.31

CRUISING SPEED = 10.50 GAL./MILE = 4.00

	TOP SPEED		CRUISING SPEED	
RADIUS	HOURS	GALLONS	HOURS	GALLONS
20	3.56	172.40	3.81	160.00
40	7.11	344.80	7.62	320.00
60	10.67	517.20	11.43	480.00
80	14.22	689.60	15.24	640.00
100	17.78	862.00	19.05	800.00
120	21.33	1034.40	22.86	960.00
140	24.89	1206.80	26.67	1120.00
160	28.44	1379.20	30.48	1280.00
180	32.00	1551.60	34.29	1440.00
200	35.56	1724.00	38.10	1600.00
220	39.11	1896.40	41.90	1760.00
240	42.67	2068.80	45.71	1920.00
260	46.22	2241.20	49.52	2080.00
280	49.78	2413.60	53.33	2240.00
300	53.33	2586.00	57.14	2400.00
310	55.11	2672.20	59.05	2480.00
320	56.89	2758.40	60.95	2560.00
340	60.44	2930.80	64.76	2720.00
360	64.00	3103.20	68.57	2880.00
380	67.56	3275.60	72.38	3040.00
400	71.11	3448.00	76.19	3200.00
410	72.89	3534.20	78.10	3280.00

RADIUS	TOP SPEED HOURS	GALLONS	CRUISING SPEED HOURS	GALLONS
420	74.67	3620.40	80.00	3360.00
440	78.22	3792.80	83.81	3520.00
460	81.78	3965.20	87.62	3680.00
480	85.33	4137.60	91.43	3840.00
500	88.89	4310.00	95.24	4000.00

Note:
.All figures are for round trip.

C-192 SKIDAWAY INSTITUTE OF OCEANOGRAPHY

MEDIUM SPEED VESSEL WITH TWO 16V-92 ENGINES

TOP SPEED = 16.00 GAL./MILE = 5.81

CRUISING SPEED = 14.50 GAL./MILE = 5.51

RADIUS	TOP SPEED HOURS	GALLONS	CRUISING SPEED HOURS	GALLONS :
20	2.50	232.40	2.76	220.40
40	5.00	464.80	5.52	440.80
60	7.50	697.20	8.28	661.20
80	10.00	929.60	11.03	881.60
100	12.50	1162.00	13.79	1102.00
120	15.00	1394.40	16.55	1322.40
140	17.50	1626.80	19.31	1542.80
160	20.00	1859.20	22.07	1763.20
180	22.50	2091.60	24.83	1983.60
200	25.00	2324.00	27.59	2204.00
220	27.50	2556.40	30.34	2424.40
240	30.00	2788.80	33.10	2644.80
260	32.50	3021.20	35.86	2865.20
280	35.00	3253.60	38.62	3085.60
300	37.50	3486.00	41.38	3306.00
310	38.75	3602.20	42.76	3416.20
320	40.00	3718.40	44.14	3526.40
340	42.50	3950.80	46.90	3746.80
360	45.00	4183.20	49.66	3967.20
380	47.50	4415.60	52.41	4187.60
400	50.00	4648.00	55.17	4408.00
410	51.25	4764.20	56.55	4518.20

RADIUS	TOP SPEED HOURS	GALLONS	CRUISING SPEED HOURS	GALLONS :
420	52.50	4880.40	57.93	4628.40
440	55.00	5112.80	60.69	4848.80
460	57.50	5345.20	63.45	5069.20
480	60.00	5577.60	66.21	5289.60
500	62.50	5810.00	68.97	5510.00

Note:
All figures are for round trip

C-192 SKIDAWAY INSTITUTE OF OCEANOGRAPHY

FAST VESSEL WITH TWO 16V-92 ENGINES

TOP SPEED = 23.00 GAL./MILE = 5.21

CRUISING SPEED = 19.50 GAL./MILE = 4.94

	TOP SPEED		CRUISING SPEED	
RADIUS	HOURS	GALLONS	HOURS	GALLONS :
20	1.74	208.40	2.05	197.60
40			4.10	395.20
60			6.15	592.80
80			8.21	790.40
100			10.26	988.00
120			12.31	1185.60
160			16.41	1580.80
180			18.46	1778.40
200			20.51	1976.00
220			22.56	2173.60
240				
260				
280				
300				
310				
320				
340				
360				
380				
400				
410				
420				
440				
460				
480				
500				

Note: All figures are for round trip

C-192 SKIDAWAY INSTITUTE OF OCEANOGRAPHY

JET VESSEL WITH THREE 12V-92 ENGINES

TOP SPEED = 27.50 GAL./MILE = 5.58

CRUISING SPEED = 24.50 GAL./MILE = 5.53

	TOP SPEED		CRUISING SPEED	
RADIUS	HOURS	GALLONS	HOURS	GALLONS :
20	1.45	223.20	1.63	221.20
40			3.27	442.40
60			4.90	663.60
80			6.53	884.80
100			8.16	1106.00
120			9.80	1327.20
140			11.43	1548.40
160				
180				
200				
220				
240				
260				
280				
300				
310				
320				
340				
360 -500				

Note:
All figures are for round trip.

C-192 SKIDAWAY INSTITUTE OF OCEANOGRAPHY

GALLONS PER STATION HOUR $1.5 MILLON VESSELS

VESSEL TYPE	SLOW	MEDIUM	FAST	JET
LENGTH ON DWL	69.96	70.39	58.42	58.42
DISPLACEMENT (HALF LOAD)	149.80	97.71	48.48	47.98
PROPULSION	(1) PROP	(2) PROP	(2) PROP	(3) JETS
NUMBER OF ENGINES	1	2	2	3
ENGINE TYPE	16V-92	16V-92	16V-92	12V-92
RATING	CONT.	CONT.	INTERM.	INT.-MAX
HORSEPOWER (CRUISING)	700	700	849	739
GALLONS PER HOUR (CRUISE)	38.00	38.00	46.20	40.00
TOTAL HORSEPOWER (CRUISE)	700	1400	1698	2217
TOTAL GALLONS PER HOUR	42.00	80.00	96.40	124.00
SPEED	10.50	14.50	19.50	24.50
SPEED / LENGTH RATIO	1.26	1.73	2.55	3.21
GALLONS PER MILE	4.00	5.52	4.94	5.06
GPH ON STATION	14.00	10.00	8.00	8.00

TIME ON STATION = 1000 HOURS (ANNUAL TOTAL)
CRUISE TRACK = 10000 NAUTICAL MILES (ANNUAL TOTAL)

TOTAL TRANSIT TIME	952	690	513	408
TOTAL OPERATING HOURS	1952	1690	1513	1408
TOTAL FUEL CONSUMPTION	54000	65172	57436	58612
GALLONS / HOURS ON STATION	54.00	65.17	57.44	58.61

TIME ON STATION = 1500 HOURS (ANNUAL TOTAL)
CRUISE TRACK = 10000 NAUTICAL MILES (ANNUAL TOTAL)

TOTAL TRANSIT TIME	952	690	513	408
TOTAL OPERATING HOURS	2452	2190	2013	1908
TOTAL FUEL CONSUMPTION	61000	70172	61436	62612
GALLONS ; ~OURS ON STATION	40.67	46.78	40.96	41.74

VESSEL TYPE	SLOW	MEDIUM	FAST	JET

TIME ON STATION = 1000 HOURS (ANNUAL TOTAL)
CRUISE TRACK = 15000 NAUTICAL MILES (ANNUAL TOTAL)

TOTAL TRANSIT TIME	1429	1034	769	612
TOTAL OPERATING HOURS	2429	2034	1769	1612
TOTAL FUEL CONSUMPTION	74000	92759	82154	83918
GALLONS / HOURS ON STATION	74.00	92.76	82.15	83.92

TIME ON STATION = 1500 HOURS (ANNUAL TOTAL)
CRUISE TRACK = 15000 NAUTICAL MILES (ANNUAL TOTAL)

TOTAL TRANSIT TIME	1429	1034	769	612
TOTAL OPERATING HOURS	2929	2534	2269	2112
TOTAL FUEL CONSUMPTION	81000	97759	86154	87918
GALLONS / HOURS ON STATION	54.00	65.17	57.44	58.61

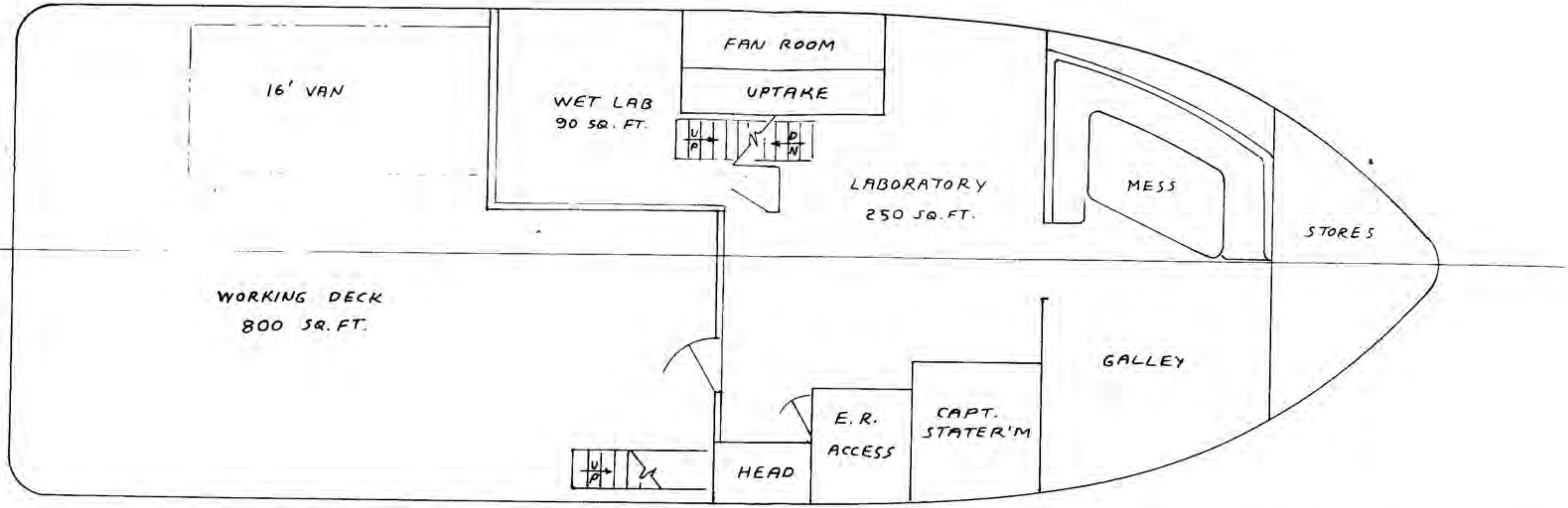
TIME ON STATION = 1000 HOURS (ANNUAL TOTAL)
CRUISE TRACK = 20000 NAUTICAL MILES (ANNUAL TOTAL)

TOTAL TRANSIT TIME	1905	1379	1026	816
TOTAL OPERATING HOURS	2905	2379	2026	1816
TOTAL FUEL CONSUMPTION	94000	120345	106872	109224
GALLONS / HOURS ON STATION	94.00	120.34	106.87	109.22

TIME ON STATION = 1500 HOURS (ANNUAL TOTAL)
CRUISE TRACK = 20000 NAUTICAL MILES (ANNUAL TOTAL)

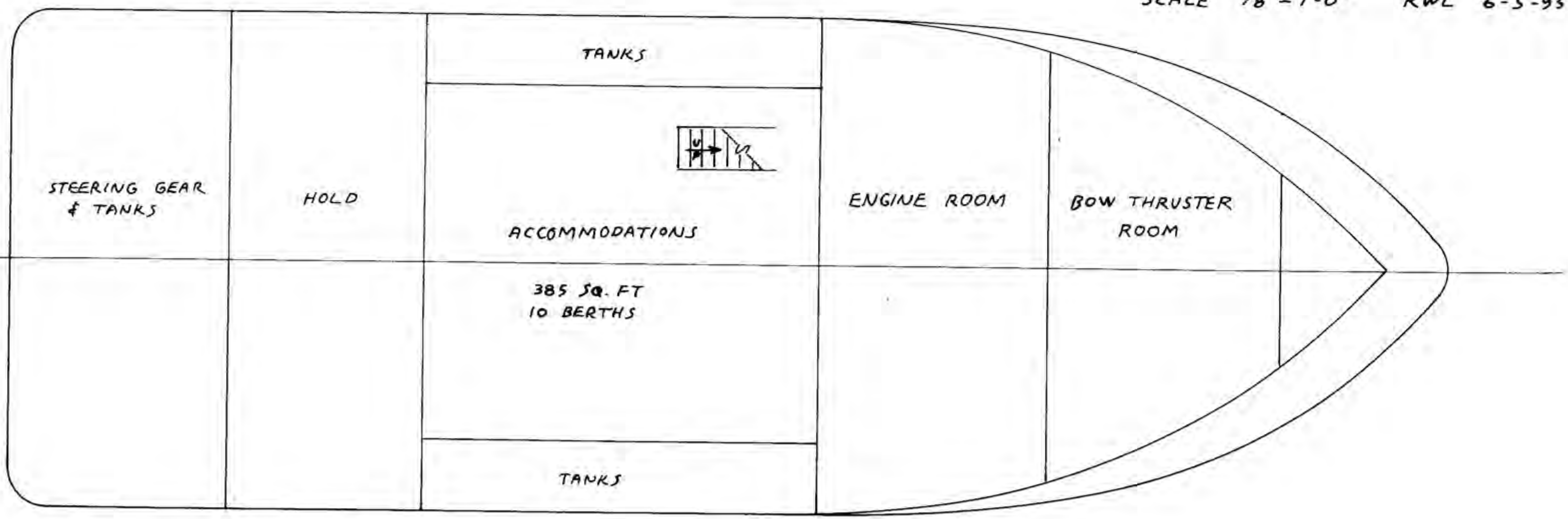
TOTAL TRANSIT TIME	1905	1379	1026	816
TOTAL OPERATING HOURS	3405	2879	2526	2316
TOTAL FUEL CONSUMPTION	101000	125345	110872	113224
GALLONS; HOURS ON STATION	67.33	83.56	73.91	75.48

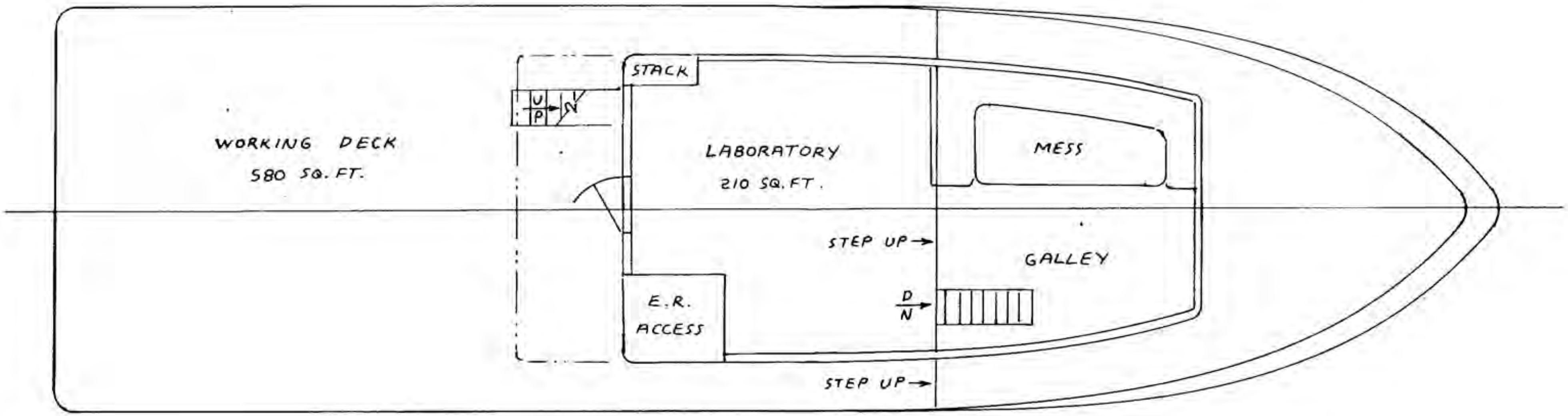
Appendix

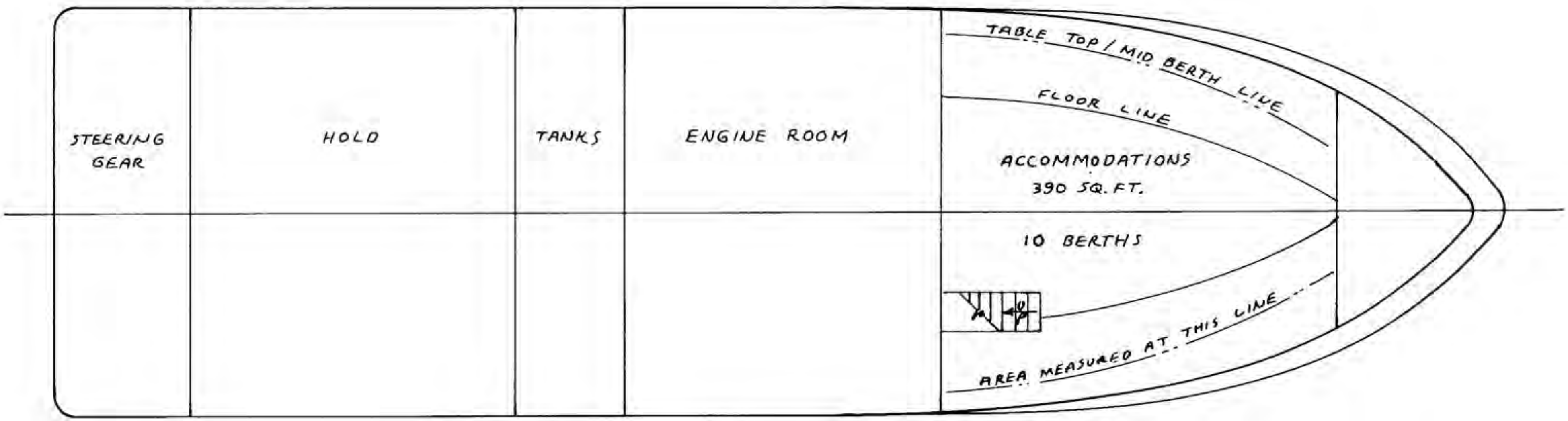


SLOW VESSEL CONCEPT

SCALE 1/8" = 1'-0"   RWL 6-5-95

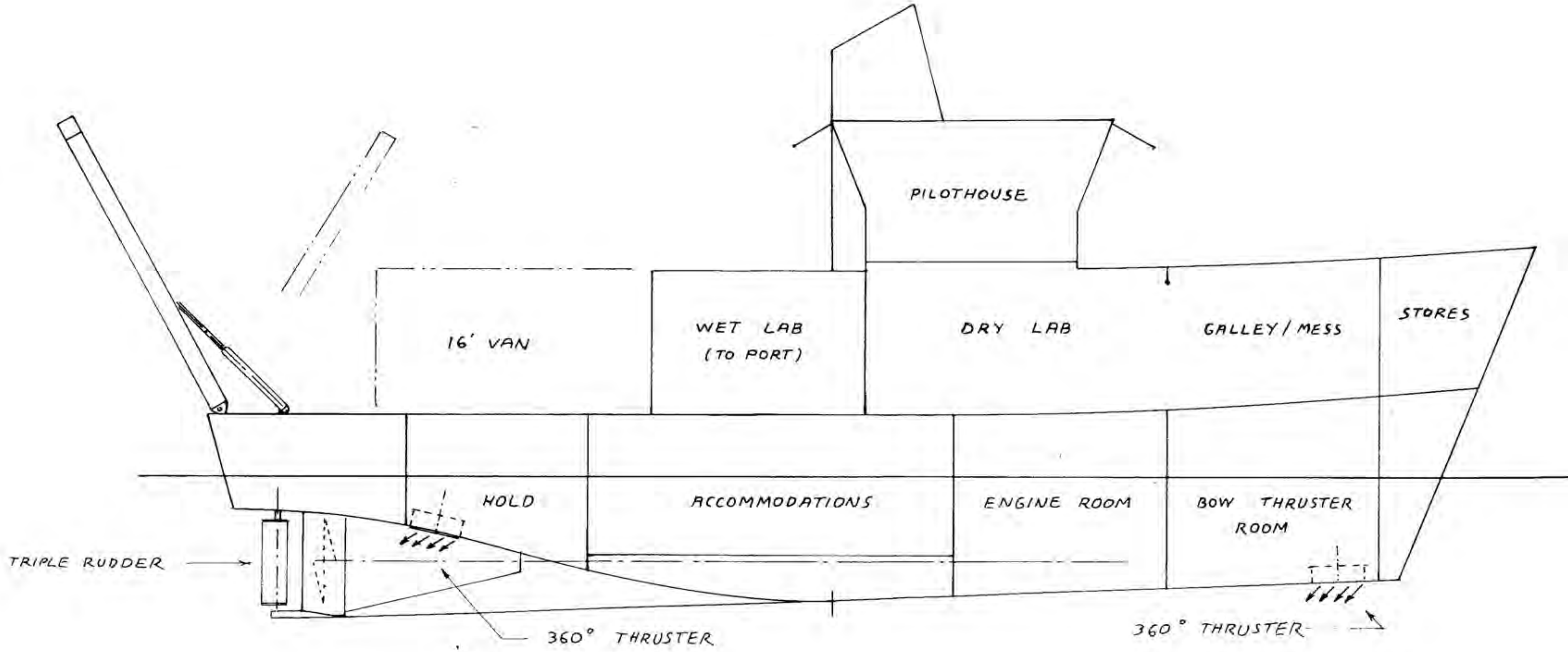






MEDIUM SPEED VESSEL CONCEPT

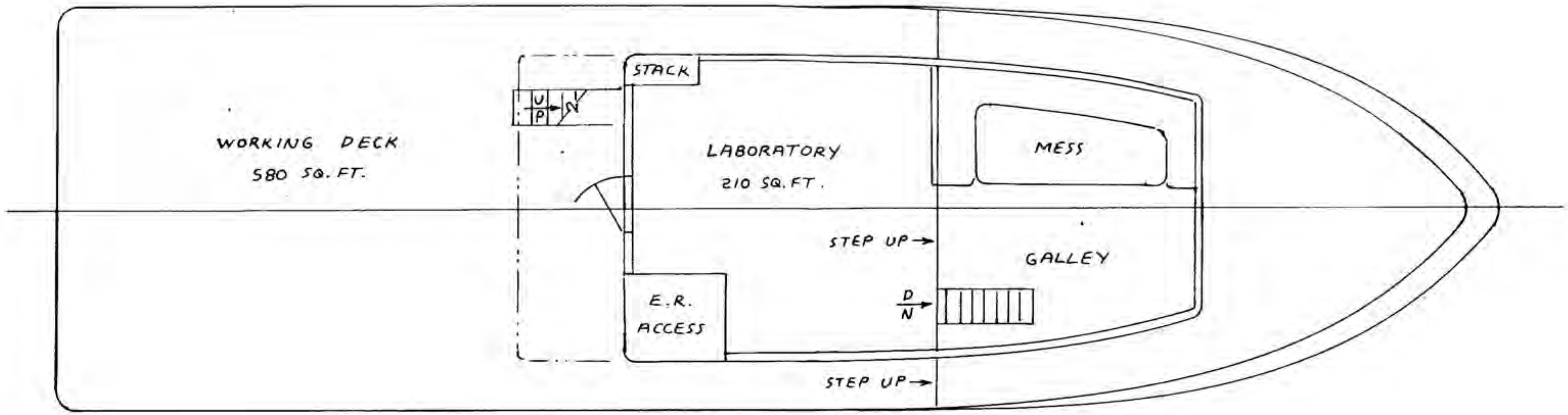
SCALE 1/8" = 1'-0" RWL 6-6-95

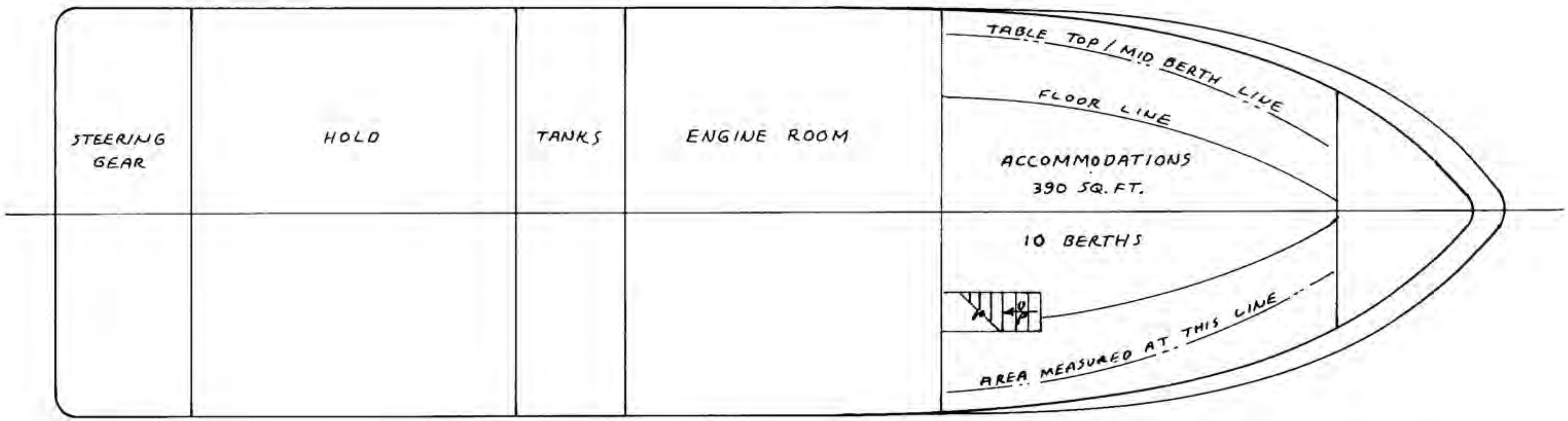


SLOW VESSEL CONCEPT

SCALE 1/8" = 1'-0"   RWL 6-5-95

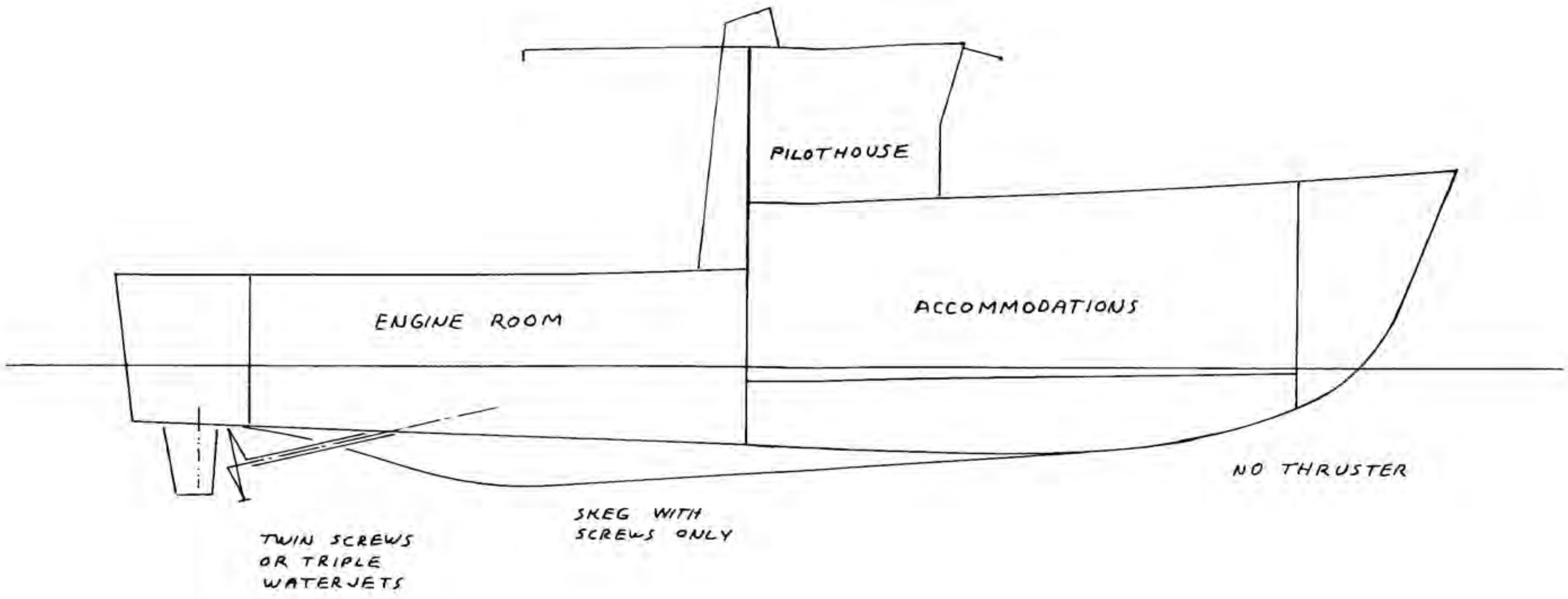
ROGER LONG
MARINE ARCHITECTURE, INC.

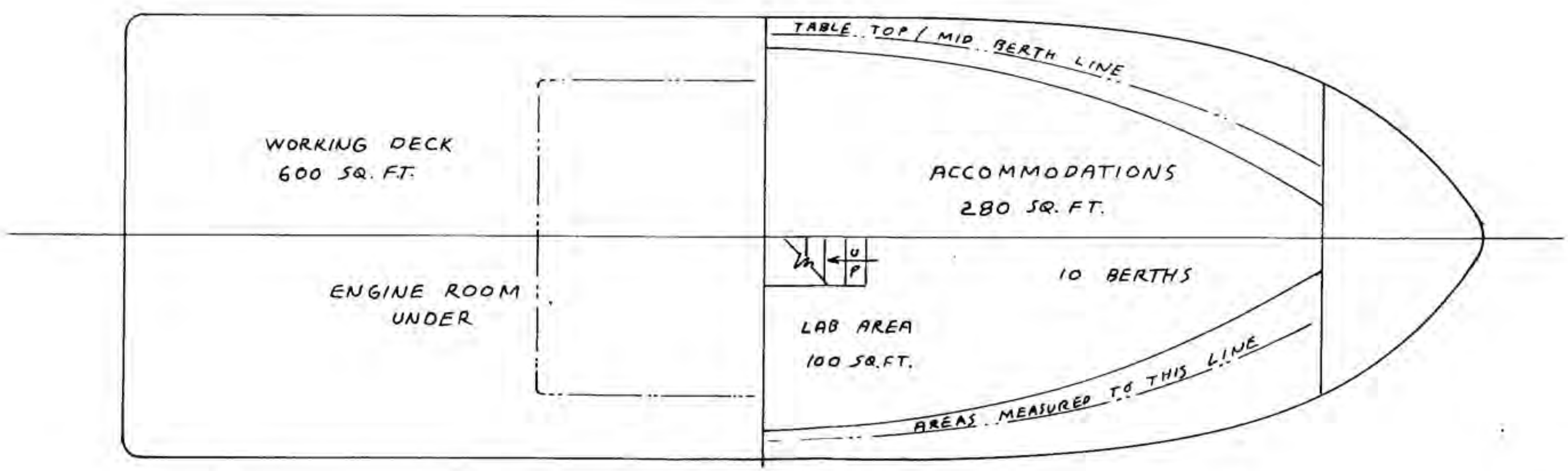




MEDIUM SPEED VESSEL CONCEPT

SCALE 1/8" = 1'-0"   RWL 6-6-95





FAST & JET VESSEL CONCEPTS

SCALE 1/8" = 1'-0"   RWL   6-6-95

Author’s Note:

It would nice if studies like this one could be timeless documents. This paper is dated nearly half a decade ago, however. A 55 foot vessel of the general configuration shown for the fast vessel concept is now in the final contracting stages at a cost 25% greater than this paper would indicate. I do not have current date to determine if this proportion would be the same for the slow and medium speed types.

For reasons that are inexplicable to me now, the cost of the "fast" and "jet" concepts is shown as being the same. Incorporation of jet drives in this type of vessel will add about 15% to the cost.

The text shows numerous artifacts from the OCR scanning process but they should not effect comprehension.

This paper should be read as a guide to a suggested methodology with some insights into vessel characteristics. It should not currently be relied on for initial cost estimates.

Monohull Research Vessel Motion and Comfort

Roger Long

The comfort of vessels is a complex subject because subjective human experience and reporting will determine a vessel's reputation more than technical analysis. A vessel that operates from an island location where there is an almost immediate transition to open ocean conditions will be considered less comfortable than the same vessel which makes a gradual transition through river, harbor, and coastal waters. A new vessel with capabilities that bring an institution more into the mainstream of research will become less comfortable as she attracts investigators who compare her with larger ones. The perception of motion can be effected by factors such as the arrangement of windows and the location of mess areas. People will focus most on motion while eating and their experience in this one part of the ship will heavily influence their overall impression.

Larger vessels are more comfortable than smaller ones of similar configuration for the simple reason that the waves become relatively smaller. There has been a lot of interest over the last decade in catamarans, SWATH, and other "magic bullet" solutions to the comfort and motion issue. Motion of these vessels can unquestionably be better than that of similarly sized monohulls. They are expensive craft to build however. The question which seldom gets asked is how their motions would compare with a low tech monohull of the same <u>cost</u>. The monohull could be significantly larger which wwould increase its comfort as well as its capacity.

The initial stability of a vessel is a measure of how far it will heel either under the influence of a gust of wind or moving a heavy weight around on deck. Basic to any discussion of seakeeping is the fact that, all else being equal, a vessel's roll period will correspond to its initial stability. The greater the stability, the faster the vessel will roll. A vessel with dangerously low stability will feel very comfortable, a counterintuitive fact which causes the deaths of several fishermen each year. Monohull design has traditionally focused on determining the minimal acceptable initial stability in order to achieve the slowest possible roll period. Deep hulls of modest beam are thus usually associated with comfort and the ability to work in heavier sea conditions.

Waterplane, the part of the hull intersected by the water's surface, is a primary determinant of motion. As the waves pass the hull, the buoyancy of the hull below the water remains the same. The change in volume at the waterline, as the ocean surface moves up and down, creates forces that move the hull. The more waterplane, the more motion excitation. Minimizing this area is the rational for the SWATH ship. Traditional ships have low waterplane areas relative to their mass and depth for the same reason.

Once an excitation has occurred and passed, the waterplane takes on a different role. The vessel will continue to move due to it's inertia and the waterplane now contributes to damping out that motion. If a single wave passes a low waterplane vessel, the hull will tend to make a small motion and then continue rolling and moving for some time after. The large waterplane vessel will tend to have a single, larger, response which stops quickly. Single waves are rare however and the response to the repeated periodic input of waves is the second primary factor in ship motion.

Safety and other design constraints make roll periods longer than 8 - 10 seconds impractical for mid size monohulls. If they are ballasted to a degree of stability that produces roll periods under six, the fast roll, combined with low damping from the waterplane, produces fast, deep, uncomfortable rolling. There is a fixed relationship between the length and period of waves and longer waves tend to be larger. Longer and larger waves are created by higher winds. The traditional hull will have a natural rolling period that tends to be the same as the period of waves developed by winds in the 20 to 30 knot range. The motion of the hull can carry over from each wave excitation so rhythmic rolling can develop and this will tend to happen in the conditions that will define the upper weather envelope for most oceanographic operations. Motions can become very large in these conditions and all sorts of devices such as bilge keels, and anti roll tanks have been employed to reduce the amplitude of rolling.

The development of the offshore supply vessel began to open designers' eyes in the 1970's to the possibilities of generous waterplane area monohulls (GWASH) with degrees of initial stability that would be unthinkable in traditional vessels. The rolling period of this type of vessel will be in the 4 to 6 second range which corresponds to the smaller waves generated in fair weather. The large waterplane damps motion quickly so it is harder for rhythmic rolling to develop. As the wind rises into the 20 to 30 knot range, wave periods will be unlikely to match the ships natural roll period. Vessels of this type tend to exhibit their rhythmic rolling behavior in small waves that do not produce large motions.

Anything which impedes the transverse flow of water around a hull will tend to reduce the amplitude, or angle, of rolling while leaving the period unaffected. Accelerations at any point removed from the rolling center are a function of both period and amplitude. This is the rational for installing bilge keels. The GWASH hull typically has hard chines which are similarly resistant to transverse flow and bilge keels are often installed as well. The large amount of damping due to hull shape, combined with that provided by the generous waterplane, keeps the amplitude of the rolling low enough to compensate for the shorter period. Deck edge accelerations remain tolerable.

The drawback to the GWASH hull form is that its large waterplane makes it more reactive to waves. This is most objectionable in confused and irregular sea states when many individual waves will be felt as a short and unpredictable motions. This type of hull will be at its best in regular and consistent seas where the high damping will minimize the addition of any rhythmic motion to that of the waves. The traditional hull will do better in the confused and irregular sea as it's immediate response will be less and the lack of consistency in wave period will minimize resonant responses. Waves often run as sets and, in the irregular sea, the traditional hull may encounter patches of waves that correspond to its roll period. These will set off episodes of deep rolling. The GWASH hull will also encounter waves that correspond to its roll period but they will tend to be smaller and the hull damping will restrict the reaction. In the confused and random sea, the motion of the traditional hull could be characterized as generally easy but occasionally extreme. The GWASH hull can be described as generally jerky but seldom, if ever, extreme.

The high stability and damping of the GWASH hull work to greatest advantage when the waves become large enough for the vessel to sit entirely on the face of a single wave. The physics of wave surface acceleration are such that "down" will always be perpendicular to the water's surface. Thus, a vessel which follows the motion of the wave, wave profiling, will seem to the observer to be rolling very little. The angle of the deck to the horizon will change greatly but an object hanging from an A-frame will tend to remain pointing at the same spot on the deck. The more traditional hull, by reacting slower to the changing slope of the wave, and then having a motion which may carry on beyond the wave slope, will have its "down" shift around more dramatically. This can make it harder to work with heavy suspended objects in large seas.

In theory, it is possible for a person in the interior of a vessel that is perfectly wave profiling to be unaware of any rolling motion at all if deprived of an outside reference. If this observer were to look out a window, the horizon would seem to tilt as the vessel remained level. Conversely, a vessel with so little stability that it did not respond to the wave might move up and down with out any roll motion at all. The observer of the horizon would see it remain parallel with the deck as the wave passed. "Down" however would move from side to side and an object hanging from an A-frame would swing. Seasickness is a response to lack of agreement between visual and inner ear cues. The comfort of these two ideal vessels would be perceived very differently depending upon whether the horizon was visible. No vessel will wave profile perfectly but the GWASH will come closer to this type of motion than the traditional vessel when the waves are of sufficient size.

Objects in space rotate around their centers of gravity and vessels attempt to do this as well. The motion is modified by the hydrodynamic forces on the hull so that the rolling center will appear to be between the center of gravity and the waterline. The traditional hull will typically have a center of gravity close to the waterline and thus, a fairly low rolling center. This type of hull will generally need higher freeboard to produce the reserve stability necessary to comply with stability requirements. The result is larger side to side motion at the level of the main deck as the vessel rolls. The center of gravity of the GWASH will be well above the waterline and can even be above the main deck. The rolling center will be higher reducing side to side movement at deck level. Standing and moving around are easier and objects placed on deck tend not to slide around. I should note that the exact location of roll center for purposes of rigorous analysis does not correspond to this simple explanation but the two vessel types will generally appear to behave as described.

Since accelerations due to vessel motion are a function of both distance and time, comfort will decrease as you move out from the vessel's center of gravity. Upper decks will be less comfortable than the main deck. The main deck of the GWASH vessel be more comfortable, at least from the oceanographic and equipment handling perspective, than the main deck on a traditional vessel. On the 01 deck levels, the motion advantage of the wider hull is reduced or eliminated. The importance of the equipment handling aspect of motion qualities is also insignificant on upper levels in most vessel arrangements. Above the 01 level, the motion of the GWASH will generally be more objectionable than in the traditional hull.

The high center of gravity of the GWASH has a further advantage. Deck loads are closer to the overall center of gravity so they raise it less. These vessels have initial stability that is considerably in excess of any regulatory or safety requirement and deck loads will degrade it only slightly. The result is a vessel that is a tremendous load carrier. They can be designed to carry deckloads well in excess of anything that would be necessary in ORV service.

Your opinion of which vessel type may depend on your tasks. If your primary job is to wrestle with awkward objects hanging from the A-frame, you will probably favor the motion of the wider and more heavily damped GWASH hull form. Although the motion may be more jerky and less predictable, it doesn't translate into large impulses and heel angles that send equipment sliding across the deck. If you spend most of your time inside; especially seated, you will probably prefer the smoother and more predictable motion of the traditional hull. Your preference may also be influenced by your past. In many years of listening to people comment about different boats, I've developed an impression that people new to the seagoing experience react more favorably to the highly damped hulls, at least when they are out of the galley/mess areas, than experienced sailors who have learned how to walk and work with the long rolls of traditional hulls.

A critical aspect of research vessel motion is the effect of rolling on side deployed gear such as CTD's. Loss of gear on long wires is usually the result of the vessel rolling down faster than the gear can sink causing slack in the wire. The dynamics of the slack being snapped out on the return roll will often break the wire. The highly damped GWASH hull form will be less likely than the traditional hull to experience the occasional large roll excursions that can exceed the natural wire stretch and terminal sink velocity of the instrument package.

GWASH hulls tend to have pitching periods that are very close to their roll period and this can have an adverse effect on comfort. If the periods are very close, it is possible for pitch and roll to become coupled. Pitch energy is then converted into roll. A corkscrew motion can also be produced that will challenge the most hardened stomachs. The effect of this will be most noticeable in the bow. The need to put labs and other mission critical functions in the middle of the vessel tends to push galley and mess areas forward. This is the least comfortable place in any vessel, especially one with close pitch and roll periods. Even in the absence of pitch/roll coupling, the observer deprived of horizon reference may interpret the pitch motion to be part of the roll if occurs at the same time. Since vertical pitch motions near the ends of the vessel can be very large, this may give the appearance of an extreme roll.

The GWASH vessel tends to have a great deal of waterplane aft. This moves the center of pitch aft as well so pitch motions are reduced at the stern which is an advantage for handling gear. They are correspondingly increased at the bow which, in combination with the typical galley/mess location, makes for poor interior habitability. Crew comfort has not been a significant design requirement in the supply vessel class that make up the bulk of GWASH craft so little attention has been paid to pitch reduction or pitch/roll coupling. Conversions of these vessels are well represented in the ORV fleet but their perceived level of motion comfort does not necessarily reflect what could be achieved in new designs based on this concept.

It is tempting to contemplate a compromise vessel but this approach will be more likely to lead to a craft with the worst features of each type. The resonant nature of reaction to waves require a design commitment to one side or the other of a middle ground. The choice is similar to that of car suspensions. You can have the firm, responsive suspension of the sports car which is less comfortable but better adapted to the job at hand or, you can have the soft, mushy motion of the American highway yacht with some sacrifice of the primary mission requirement.

Consider though a hypothetical middle ground vessel with a given mass of structure. The choice is to increase hull depth to produce a traditional hull type or to increase beam to produce a GWASH. A 15% increase in beam will translate directly into a 15% increase in deck space and interior accommodation. A 15% increase in hull depth however, will not be large enough to add an additional deck. It will only contribute to increased headroom or tankage, desirable characteristics but not ones that have a significant impact on mission capability. For a given amount of basic structure, which closely corresponds to cost, the GWASH will have more deck and accommodation space. It can also have shallower draft which is an advantage for vessels working in coastal waters.

The supply vessel conversions currently in the fleet appear to be doing a good job in their primary role of providing good working platforms for deployment of gear and avoiding loss of long wire instrument packages. The anecdotal reports on their motion comfort generally derive from interior habitability issues secondary to the research mission. If the primary function of the research vessel was the transport of passengers in interior spaces, the traditional hull might be a better choice. However, the current supply vessel conversions have not been able to utilize the proportions and features such as bow bulbs that can mitigate pitch. Their galley/mess locations are typically inherited from the original supply vessel with its short superstructure. It should be possible to develop new designs based on this model that are more comfortable in the interior spaces without sacrifice of other desirable motion characteristics. Even if no significant improvement could be gained, the qualities of the GWASH hull type as a working platform and the economics of space utilization make them a compelling starting point for new research vessel design.

Section XIV: Vessel Inventory

To see the latest inventory of Small Research Vessels, visit the following web page:

https://www.unols.org/document/unols-small-research-vessel-inventory