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CONCEPTUAL DESIGN of a SWATH OCEANOGRAPHIC RESEARCH SHIP

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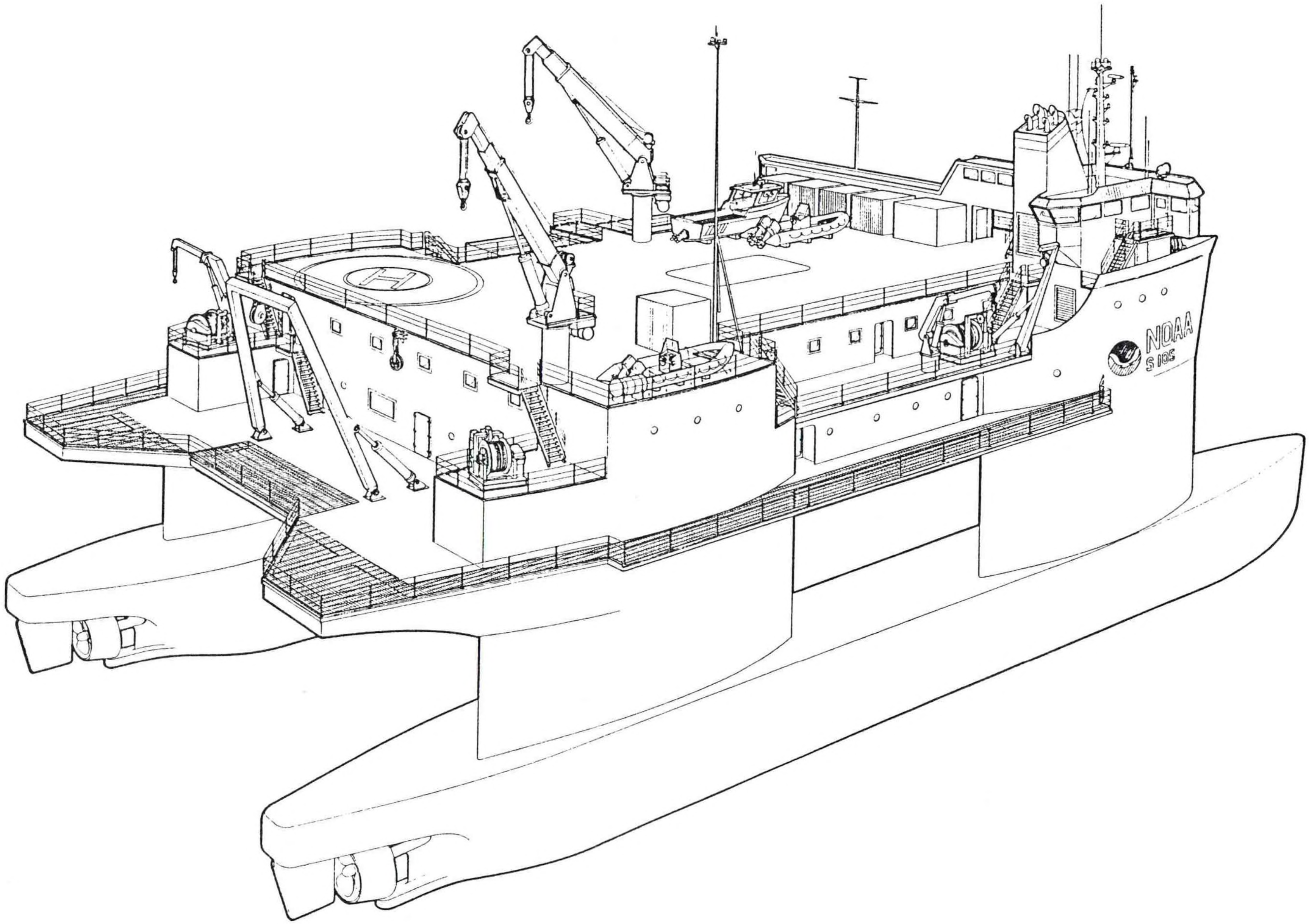

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CONCEPTUAL DESIGN OF A SWATH OCEANOGRAPHIC RESEARCH SHIP

1. INTRODUCTION

1.1 BACKGROUND

The SWATH (small waterplane area twin hull) ship design described in this report began its evolution with a study[1] done for the Institute for Geophysics of The University of Texas in 1984. A variation of the design[2] was done for the University-National Oceanographic Laboratory System (UNOLS) in April 1985. The basic design was modified and further developed in support of a proposal submitted to the Navy in February 1988 for construction of an oceanographic research ship designated AGOR 23[3].

The semisubmerged (variable draft) SWATH ship design summarized in this report used the baseline previously established as a departure point for tailoring a ship to NOAA requirements. The requirements were formulated by a working group as a part of the NOAA Fleet Assessment Study. An analysis[4] of SWATH options for fleet replacement was done to support the Fleet Assessment Study. The analysis grouped NOAA requirements into four categories and each category was characterized by a "point design". The High Endurance Oceanographic Research Ship was one of two classes that was included in the "POINT 3500" design category (the largest of the four). Part of the intent of the study described in this report is to provide a specific example of a NOAA ship class that falls within the POINT 3500 category.

1.2 SEMISUBMERGED SWATH SHIP TECHNOLOGY

A single draft for the full range of operating conditions is a common feature of typical SWATH ship designs. The first SWATH ship DUPLUS[5], built in 1969, and the U.S. Navy KAIMALINO[6,7], built in 1973, are constant draft. This characteristic is found in the SWATH ships built by Mitsui, most notably the KAIYO[8], as well as the Navy's SWATH T-AGOS[9] which is now under construction. The constant draft design for ships in this class (displacement of about 3,500 long tons) poses two significant drawbacks. One is that the full load draft must be at least 25 feet to satisfy seakeeping requirements. This draft is restrictive for access to many harbors that would be convenient for use by research and survey ships. The second is that submerged hull and column design considerations necessitate compromise of seakeeping in favor of propulsion performance.

The distinguishing feature of a semisubmerged SWATH ship is variable draft. Sufficient allowance for ballast transfer is made to enable the ship to vary its draft under all load conditions. The shallowest draft is well within usual harbor limits and gives the lower hulls a slight freeboard. The operator may elect to transit at shallow draft in low to moderate sea conditions in order to maintain cruise speed at minimum propulsion power. The semisubmerged SWATH design by BSM gives more flexibility to provide for deep draft conditions that strike a balance between operating requirements and seakeeping characteristics. Intermediate "storm" drafts can be selected that are a compromise between seakeeping, speed, and upper hull clearance needed to avoid slamming. A discussion of these and other tradeoffs in semisubmerged SWATH ship design for oceanographic applications is given in a paper by Gaul and McClure[10].

The semisubmerged SWATH technology gives rise to some notable contrasts with constant draft SWATH ships. For any propulsion power applied, the semisubmerged SWATH has a range of speed that depends on draft. Highest speeds are obtained at minimum (transit) draft. Because the lower hull freeboard is small at transit draft, seakeeping at service speed can be equal to or better than a monohull when operating in the presence of ocean waves. The ship is designed for maximum speed at transit draft so the lower hull form is more akin to a surface craft than a submarine. This allows use of a nearly rectangular cross section for the lower hulls. In view of reduced speeds at deeper drafts and the highly damped lower hull form, the ship need not be equipped with stabilizing fins. Since maximum speed is achieved with the columns (struts) out of the water, it is practical to use two columns, rather than one, on each lower hull. The four column configuration at deep drafts minimizes the variation of ship motion response with change in heading relative to surface wave direction. The width of the ship and lack of appendages on the lower hulls increases the utility of a large underside deck opening (moonpool) amidship.

The design discussed herein makes provision to float the ship on the lower hulls with a full allocation of deadweight on board. This is required to obtain a suitable draft for fully loaded access to shallow water harbors and to minimize propulsion requirements while transiting in mild to moderate weather conditions. The deeper draft modes of operation provide for transit in heavy weather and for minimum ship motion while on station or underway at lower speeds. The design is optimized for ship steadiness at zero and low speeds in heavy seas and at all ship headings relative to the waves.

2.

2. DESIGN REQUIREMENTS

2.1 GENERAL

2.1.1 Source

These functional design requirements initially were provided in April 1990 by a working group of the NOAA Fleet Assessment Study. The technical point of contact for interpretation and refinement of the requirements was Bruce Barber in the Office of NOAA Corps Operations.

2.1.2 Class

High endurance, multi-disciplinary oceanographic research ship.

2.1.3 Purposes

Hydrographic/tracer sections, buoy maintenance/handling, air-sea flux, moorings, continuous water and air sampling, sea floor processes, cross-disciplinary process studies, bathymetry, and remotely operated vehicles.

2.2 MISSION EQUIPMENT

2.2.1 Boom

A boom on the foc'sle to extend to the water forward of the bow wave with an instrument loading of approximately 500 pounds. Manned access to the end of the boom is required.

2.2.2 Cranes

A suite of modern cranes with constant tension capability including:

a) One large crane for heavy equipment up to 30,000 pounds located to support the fantail working area, to site vans and:
   - o articulated to work close to deck and water surface,

- o to handle overside loads up to 10,000 pounds, and
- o to have servo controls and motion compensation.

b) Two cranes, one on each quarter, capable of towing with line pull of up to 5,000 pounds at crane extension of 20 ft. for towed packages.

c) One crane or other equipment to service the bow working area (nominal 5,000 pounds capacity).

2.2.3 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 systems; local and remote controls.

Permanently installed general purpose winches include:

a) Two winches capable of handling 30,000 ft. of wire rope or electromechanical cables having diameters from 1/4" to 3/8".

b) A winch complex capable of handling 40,000 ft. of 9/16" trawling or coring wire and 30,000 ft. of 0.68" electromechanical cable (up to 10 KVA power transmissions and fiber optics). This could be two separate winches or one winch with two storage drums.

Additional special purpose winches may be installed temporarily at various locations along working decks with a footprint in accordance with tie-down locations. Winch sizes may range up to 40 tons (140 sq. ft.) and have power demands to 300 HP.

Portable shelters available to winch work areas for instrument adjustments and repairs. Winch control station(s) located for optimum operator visibility with reliable communication to laboratories and ship control stations.

A secondary winch control should be located on the bridge and in selected laboratories.

2.2.4 Overside Handling

Various frames and other handling gear to accommodate wire, cable and free launched arrays; matched to work with winch and crane locations but able to be relocated as necessary.

Stern A-frame to have minimum 20 ft. horizontal and 20 ft. vertical clearances; 15 ft. inboard and outboard reaches; safe working load up to 30 tons.

Midship J-frame with hydrowinch; located adjacent to wet lab.

Capability to handle, deploy and retrieve 30 m spar buoys.

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

2.2.5 Work Boats

At least one and preferably two 18-20 ft. semi-rigid boats located for ease of launching and recovery.

A scientific work boat, 25-30 ft. LOA, specially fitted out for supplemental operation at sea including sample collecting, instrumentation, and wide angle signal measurement; 12-hour endurance including both manned accommodations and automated operation; "clean" construction; can be carried in lieu of one of the optional vans cited above; to be equipped with own skids for easy tie down to deck.

2.2.6 Vans

Provision to carry at least four standardized 8 ft. by 20 ft. portable vans which may be laboratory, berthing, storage, or other specialized use; hookup provision for power, HVAC, fresh water, uncontaminated sea water, compressed air, drains, communications, data and shipboard monitoring systems; direct access to ship interior.

Provision to carry up to four additional portable non-standard vans (each up to 8 x 12 feet) on superstructure, foc'sle and working decks; supporting connections at selected locations.

Ship must be capable of loading and offloading vans using own cranes.

2.2.7 Routine Monitoring

Digital systems for routine environmental monitoring:

a) Water column: ocean skin temperature, surface temperature/salinity, chlorophyll, oxygen, mixed-layer depth, particulates, directional wave spectra, ADCP.
b) Bathymetric: multibeam, shallow sub-bottom profiling, gravity, magnetic.
c) Meteorological: UV radiation, global radiation, insolation, upper air soundings with rawinsonde, relative humidity, visibility, water vapor.

2.2.8 Satellite Monitoring

Carry transponding and receiving equipment including antenna to interrogate and receive satellite readouts of environmental remote sensing.

2.3 SHIP CAPABILITIES

2.3.1 Speed

15 knots trial; cruise speed of at least 13 knots sustainable through sea state 4 (SS-4). Speed control +/- 0.25 knot in 0-6 knot range; +/- 0.5 knot in 6-15 knots range.

2.3.2 Endurance

Sixty days to provide the capability needed to transit to the most remote area and work 3-4 weeks on station; 15,000 mile range needed at an economical speed.

2.3.3 Seakeeping

Capability to maintain science operations at speeds and in sea states as follows:

13 knots cruising through SS-4.
12 knots cruising through SS-5.
10 knots cruising through SS-6.
8 knots cruising through SS-7.

2.3.4 Station Keeping

Allow normal station and deck work in sea states through SS-5 and limited work through SS-7.

Maneuverability that would assure relative positioning at best heading in 35 knot wind and SS-5 with 2 knot current +/- 150 ft. maximum excursion from a point or trackline; ability to maintain +/- 5 degrees heading.

Maintain a precision trackline while towing at speeds as low as 0.5 knots with heading deviations no greater than 45 degrees from the prescribed trackline using GPS or bottom navigation as reference (see navigation and positioning). Speed control along track should be maintained +/- 0.25 knot (averaged over one minute intervals).

Trackline requirements should be met 95% of time considering range of specified sea states.

2.3.5 Dynamic Positioning

Cability in calm seas to maintain vessel in position to within one per cent of water depth greater than 2,000 m.

2.3.6 Towing

Capable of towing large scientific packages causing up to 10,000 pounds tension at 6 knots and 25,000 pounds at 2.5 knots in SS-5, 35 knot wind, and 3 knot current.

2.3.7 Ice Strengthening

ABS Ice Classification C; able to transit loose pack ice; not intended for ice breaking or close pack ice work;

protection against encounters with growlers and other glacial ice that is difficult to detect.

2.3.8 Navigation and Positioning

Global Positioning Systems (GPS) with appropriate interfaces to data systems and ship control processors in three dimensions.

Short baseline acoustic navigation system.

2.4 SHIP ARRANGEMENTS

2.4.1 Accommodations

30-35 scientific personnel in two-person staterooms; expandable to 40 through the use of vans. Science library-lounge and conference room shall be separate. Guidelines for total complement are given in the following table:

	Permanent	Temporary
Chief Engineer	1	-
3rd Assistant Engineer	1	-
Jr. Engineer (unlicensed)	1	-
Oiler	1	-
Wiper	-	1
Chief Boatswain	1	-
Able-Bodied Seaman	2	-
Ordinary Seaman	2	1
Survey Technician	4	-
Chief Steward	1	-
Chief Cook	1	-
2nd Cook	1	-
Messman	2	1
Subtotals - Wage Marine	18	3
Commanding Officer	1	
Commissioned Officer	5	-
Medical Officer	1	-
Scientists/Program Personnel	30	-
GS Electrical Technician	2	-
Subtotals - Tech. Staff	39	0
TOTAL COMPLEMENT	60	

2.4.2 Laboratories

Approximately 4,000 sq. ft. of laboratory space broken down into approximately 12 individual laboratories (see guidelines in table below) which could include the following activities: biological sample processing (flash freezing/washdown), trace chemistry (organic), trace chemistry (inorganic), biochemistry, radioisotope (low activity), radioisotope (high activity), wet lab, dry lab, electronic repair shop, air chemistry, photography, sediment processing, acoustic, meteorological, gravity, liquid nitrogen and liquid air processing facility, mechanical and electronic.

Two medium size general purpose wet labs to have large drains and associated strainers/cutters to accommodate sample residue.

Computer facility and associated user space.

An area for operating and controlling ROV's. This could be part of the computer facility.

A CTD prep room adjacent to midships J-frame connected by moving sidewalk through hinged door to ship interior. The CTD prep room must be capable of handling and storing 15 Gerard-type (200 liter) and 15, 20-30 liter water samplers. Multiple hose connectors in CTD prep room to enable water to be ported directly to other labs. A drain will be placed in the floor for draining large volumes of water. CTD prep room to have hose pumping system (inert inner walls) capable of delivering 50 liters/min of continuous and discrete depth samples down to 1,000 m.

Special environmental lab conditions: one working lab capable of being maintained at -2 to 25 +/- 1 degree for low temperature biological and chemical sample processing and flash freezing samples.

Labs should be located so that none serve as general passageways. Access between labs should be convenient. Labs, offices, and storage to be served by a man-rated elevator having clear inside dimensions of approximately 3 ft. by 4 ft. and, where appropriate, moving sidewalks. All labs should have structured inserts in bulkheads and decks for removal and addition of interior furnishing. Individual labs should be protected from cross-contamination through the ventilation system. 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. Fume hoods to be installed permanently in analytical labs. Main lab shall have provision for temporary installation of fume hoods. Cabinetry shall be high grade laboratory quality including flexibility through the use of unistruts and deck boltdowns.

Heating, ventilation, and air conditioning (HVAC) appropriate to laboratories, vans, and other science spaces being served: laboratories shall maintain temperature of 20-24 degrees C, 50% relative humidity, and 9-11 air changes per hour; filtered air to interior analytical and instrument labs; each lab area to have a separate electrical circuit with "clean" power continuous delivery capability of at least 40 volt amperes per square foot of lab deck area; labs to be furnished with 110 VAC and 220 VAC; total estimated laboratory power demand is 100 KVA.

A central facility to manufacture and store liquid nitrogen, dry ice and distilled and distilled-deionized water.

Sea water and "clean" sea water supplies to most laboratories, vans, and several key deck areas. Intakes should be from two areas: one on bow slightly below water line and the other midships on keel. Measurements that are required close to point of entry include: SST, salinity, chlorophyll, phaeophytin and particulates; flow rate of 50 liters/min required for these systems; compressed air supply to be clean and oil-free.

Modular vans connecting to a central walkway may be substituted for certain internal labs. These vans should be fabricated as part of the ships construction and contain full power, ducting and plumbing.

Guidelines for space allocation to laboratories is given in the following table:

Compartment Designation	Size (sq. ft.)	Space Option
Wet Laboratory	200	Ship
Dry Laboratory	150	Ship
Dry Laboratory	150	Ship/Van
Radioisotope Laboratory	150	Van
Clean Laboratory (Inorganic)	200	Van
Clean Laboratory (Organic)	200	Van
General Laboratory	250	Ship
Macrofauna Laboratory	300	Ship
Geology Laboratory	400	Ship
Climate Controlled Space(s)	300	Ship
Atmospheric Chemistry Laboratory	120	Ship
Photography Laboratory	120	Ship/Van
Computer Room	300	Ship
Bottom Topography Data Acquisition and Plotting Room	150	Ship
Doppler Current Data Acquisition and ROV Control Room	200	Ship
Gravity Room	50	Ship
Charting and Plotting Room	200	Ship/Van
Science and Electronics Shop	100	Ship/Van
Science Office	150	Ship
Meteorological Center	64	Ship
Total Space Requirement	3,754	

Notes:

a. Climate Control space needs ship refrigerant.

b. Atmospheric Chemistry Lab to be located near bridge.

c. The Meteorological Center is a permanent facility of the ship and would include atmospheric soundings feet with a balloon launch facility on the clear deck space on the fantail. All of hardware associated with the meteorological center would be part of the bridge or communications center.

d. Associated with all of the above would be a bow room and/or sea chest where the clean sea water intakes and some sensors are located as well as the acoustics equipment room(s).

2.4.3 Conference Room

Conference room with full communication with ship and deck operations; 32 person capacity.

2.4.4 Science Storage

Total of 16,000 cubic ft. of scientific storage accessible to labs by elevator (500 lb. load capable), moving sidewalks and/or weatherdeck hatch(es); half of storage to include suitable shelving, racks, and tie downs; remainder open hold; easily accessible storage in hold (4,000 cubic ft.) under, or in close proximity to, fantail area for moorings and weights (allowance for 60,000 pounds).

2.4.5 Deck Working Area

Total deck space 7,000 sq. ft. including spacious fantail area (3,000 sq. ft. minimum) with 2,000 sq. ft. clear area readily accessible to fantail with contiguous work area along 100 feet of one side with nominal width of 12 feet. Provide for deck loading up to 1,500 pounds per sq. ft. and an aggregate total of 100 tons for itinerant loading.

Allocate about 400 sq. ft. to accommodate an instrument tower and a support van.

Oversize holdowns (1 inch bolts) on 2-ft. centers. Highly flexible to accommodate large and heavy equipment. Dry working deck but not greater than 10-15 ft. above waterline.

All working decks accessible for power, water, air, data, voice and alarm communication ports.

2.4.6 Helicopter

A clear area to provide for helicopter hovering.

2.4.7 Remotely Opeated Vehicles

Hanger space for the storage and repair of ROVs. This is in addition to the control room and hull-mounted conformal arrays. Movable stern ramp or underside centerwell capable of opening to facilitate trawling and deployment/recovery of ROVs.

2.4.8 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(s) should be carefully designed to enhance the interaction of ship and science operations. For example, ship course, speed, attitude, and positioning often will be integrated with scientific operations requiring control to be exercised from a laboratory area.

2.5 SHIP SYSTEMS

2.5.1 Vibration Control

Vibration and noise to be minimized, especially by means of shock mounting engines and generators.

2.5.2 Acoustical Systems

Ship to be as acoustically quiet as practicable in the choice of all shipboard systems and their location and installation. Design target is minimum noise levels at 13 knots cruising in SS-5 at the following frequency ranges:

- o 3 kHz - 500 kHz echo sounding and acoustic navigation.
- o 75 kHz - 300 kHz Doppler Current profiling.

Ship to have 12 kHz and 3.5 kHz echo sounding systems with provision for additional systems.

Ship to have phased array, very wide multibeam precision echo sounding system.

Transducers appropriate to dynamic positioning system.

Transducer wells (20"), one located forward and two athwartships; large pressurized sea chest (4 ft. x 8 ft.) to be located at optimum acoustic location for at-sea installation and servicing of transducers and transponders.

Conformal arrays along hull to monitor and control ROVs.

2.5.3 Internal Communications

Internal communications system providing high quality voice and visual communications throughout all science spaces, working areas and other selected spaces (e.g., conference room, chief scientist stateroom).

Data transmission, monitoring and recording system available throughout science spaces (including vans and key working areas) networked through a central computing facility.

Closed circuit television monitoring and recording of all working areas and, where appropriate, ROV sensors.

Monitors for all ship control, environmental parameters, science and overside equipment performance to be available in all laboratories and other selected spaces (e.g., conference room, chief scientist stateroom) with data ports located at all winches and cranes.

2.5.4 External Communications

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

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

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

Antenna located to minimize EM contamination to portable and interior lab spaces.

3.

3. DESIGN SUMMARY

3.1 GENERAL APPROACH

The basic approach is to design a variable draft (semisubmerged) SWATH ship to meet the stated requirements (Section 2) and give the steadiest possible platform under all sea conditions. The ship is designed to float on the lower hulls with a full complement of deadweight on board. This is required to obtain a suitable draft for entry into shallow water harbors and to provide for minimizing propulsion requirements while transiting in mild to moderate weather conditions. The semisubmerged mode of operation will be used at sea for transiting in heavy weather and while conducting oceanographic research activities. Oceanographic operations typically are done dead in the water or at low speed. The design is optimized to minimize ship motions in this mode of operation.

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

3.2 LOAD CONDITIONS

Design deadweight loads for three operating conditions are given in Table 1. The transit condition is for a displacement of 3,500 long tons (LT) at 16.7 feet draft. Normal operations is for a displacement of 4,180 LT at 27 feet draft and special operations is for a displacement of 4,500 LT at 34 feet draft.

The total deadweight allowance is 980 LT which includes a service life margin of 113 LT. The fuel oil allowance is 640 tons. Depending on the proposed missions, the fuel allowance can be reduced and deck load or other allowances increased. Allowances for the weight of cranes, winches, frames, sonar transducers, laboratory equipment and other mission outfitting is included in the light ship weight of 2,510 LT.

Table 1. Deadweight loading summary.

	Weight (LT)	
Light Ship		2,510
Ship Deadweight:		
Fuel Oil	640	
Lube Oil	10	
Potable Water	30	
Miscellaneous Fluids	2	
Personnel and Effects	10	
Stores and Provisions	20	
Margin	113	
Subtotal - Ship Deadweight		825
Mission Deadweight:		
Boats	10	
Vans	25	
Stores and Spares	20	
Itinerant Loads	100	
Subtotal-Mission Deadweight		155
Light ship plus Deadweight		3,490
Transit Draft:		
Ballast for Operation	10	
Displacement		3,500
Normal Operations Draft:		
Ballast for Operation	690	
Displacement		4,180
Special Operations Draft:		
Ballast for Operation	1,010	
Displacement		4,500

3.3 STABILITY

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

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

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

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

3.4 SHIP MOTION RESPONSE

The dominant advantage that the semisubmerged SWATH ship offers is a significant reduction in ship motions provided in both the transit mode and, more importantly, during on-station research operations. This motion response reduction allows the semisubmerged SWATH ship to operate in much higher seas than can be tolerated with an equivalent monohull. At transit draft, the freeboard of the lower hulls is less than one foot. Wave crests wash over the lower hulls and increase resistance to heave. The radical decrease in waterplane area above the lower hull correspondingly reduces buoyant forces caused by wave action and ameliorates motion response. It should be noted that this is a key difference between a semisubmerged SWATH ship and a conventional catamaran vessel. Model tests of several designs have confirmed that the semisubmerged SWATH ship, even at transit draft, will have lower motion response than a monohull that is functionally equivalent. Figure 1 illustrates relative motion responses for a conventional monohull and a semisubmerged SWATH ship (at normal operations draft). In beam seas, roll of the monohull can be as much as ten times higher than that of the semisubmerged SWATH. Pitch response of the monohull typically is two to three times higher than the SWATH. Heave is about twice as much for the monohull in most sea conditions. Reduced ship motions alone prompt consideration of semisubmerged SWATH ships in place of monohulls for research and survey applications.

Response of any ship to the seaway is highly dependent on wave period or, more precisely, on encounter period which is a function of wave period, ship speed, and relative heading. At zero speed, encounter period equals wave period. When underway in head seas, the apparent period of encounter is shorter than the wave period, so ship motions are attenuated. In following seas, the encounter period is longer than the wave period, so motion amplitudes tend to be greater than at zero speed. However, at these long periods the accelerations are

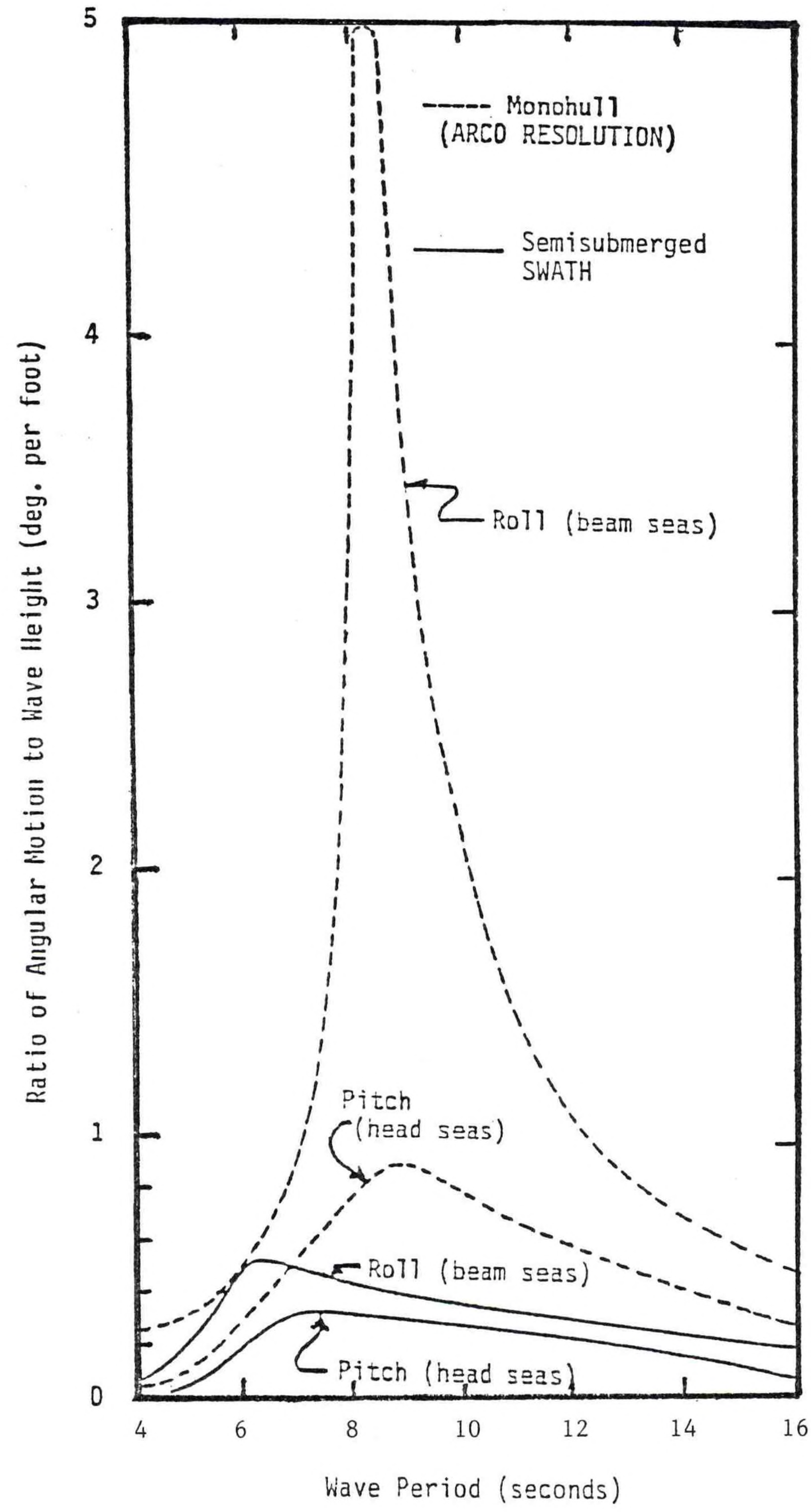

Figure 1. Typical ship motion response.

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very small. Deck motions rarely will exceed the acceleration threshold for seasickness discomfort (about 0.2 g).

The semisubmerged SWATH ship characteristics are such that motion response essentially is insensitive to wave direction. If the operation requires that the ship lie in the trough of the waves, this can be done as comfortably as lying head to the wind. Of greater importance is that motion impact on data acquisition will be nearly uniform for all headings contrary to long-standing experience with monohull ships.

3.5 SHIP PERFORMANCE

The semisubmerged SWATH configuration is sufficiently different from conventional (constant draft) SWATH hull forms that physical model tests are essential to supplement and verify propulsion power estimates obtained analytically. The Navy (DTRC/NAVSEA) has an analytical model for SWATH propulsion estimates which is highly developed and has been validated by tank tests of physical models for a variety of Navy designs. The model is configuration dependent so its use is not straight forward when applied to the BSM semisubmerged SWATH hull form. Furthermore, the analytical model is valid only when the lower hulls are fully submerged. None of the analytical models currently available can cope with the semisubmerged SWATH at transit draft. Therefore, BSM has conducted model testing programs on designs for several clients to build a data base for hull drag.

Relevant model tests performed for BSM designs are summarized in Table 2. All testing was done at Offshore Technology Corporation (now Arctec Offshore Corporation) in Escondido, California. The propulsion curves shown in Figure 2 are based on data acquired from these tests. These curves are

Table 2. BSM hull drag tests on physical models.

	ARCO[a] (1983)	WESGEO[b] (1986)	Penn[c] (1987)
Length, Overall (ft.)	243	238	225
Beam, Overall (ft.)	105	105	105
Draft, Transit (ft.)	15	16	17
Draft, Operations (ft.)	28	26	27
Displacement, Transit (LT)	3510	3450	3530
Displacement, Operations (LT)	4310	4100	4180
Speed Range for Tests (kts.)	6-18	5-18	6-17
Model Scale	1:30	1:30	1:20

a. ARCO Exploration Company; geophysical survey ship.
b. Western Geophysical Company; geophysical survey ship.
c. Pennsylvania Shipbuilding Company; oceanographic research ship.

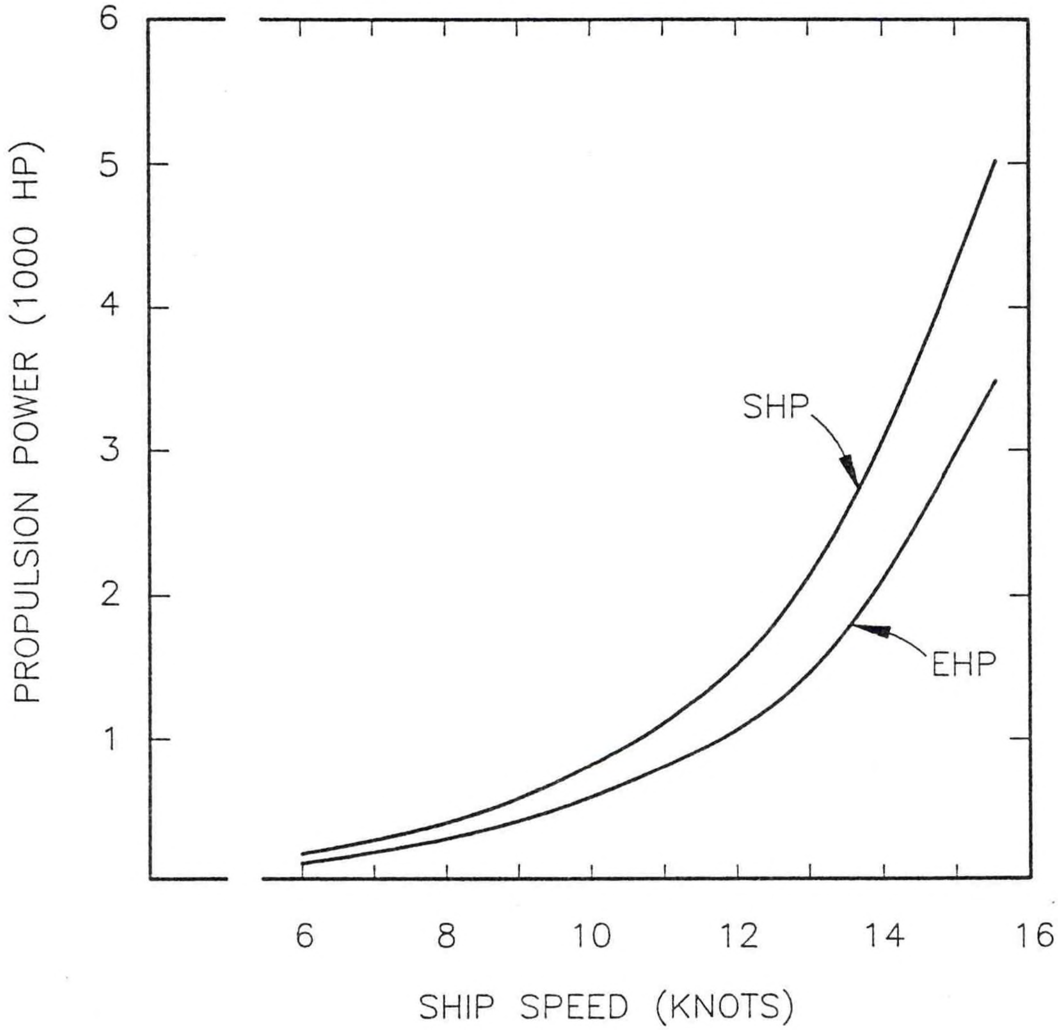


Figure 2. Transit speed in calm water.

for the transit draft condition in calm water with a clean hull. The conversion from EHP to SHP uses a propulsion coefficient (PC) that ranges from 0.62 at low speeds to 0.69 at higher speeds. This coefficient was derived from propeller/nozzle efficiencies that were calculated based on data developed from previous self-propulsion model tests of similar designs. Some SWATH ship designers have used coefficients as high as 0.77[11]. The range of values for PC used is considered reasonable (perhaps a bit conservative) for purposes of this conceptual design.

Performance estimates for the ship at normal operations draft have been made based on previous physical model tests and on analytical evaluation with the Navy program SWAD84[12]. The two sets of estimates are well correlated. The estimate for clean hull trial speed at normal operations draft is 11.2 knots.

3.6 MISSION PROFILES

Several iterations of "mission profiles" for various operating scenarios were developed as a basis for key performance parameters of the semisubmerged SWATH ship. These profiles were generated to evaluate speed, range, endurance, power, and fuel consumption. Selected mission profiles for the conceptual design of the SWATH Oceanographic Research Ship are summarized in Table 3. The "Normal Transit" at 14.3 knots provides a cruising range of 9,500 nautical miles with a 65 LT fuel reserve. The "Extended Transit" condition at a speed of 12 knots gives a range of 16,300 nautical miles with a 65 LT fuel reserve. Scenario number 1 allows eight days on station plus a transit range of 15,000 nautical miles at a speed of 12 knots. Calculations for this scenario allow for the equivalent of an average speed of four knots while on station in addition to an average hotel load of 300 KW. Scenario number 2 provides for a higher transit speed of 13 knots over a range of 11,500 nautical miles in addition to 21 days on station. Scenario number 3 provides for transit at 13 knots over a range of 10,000 nautical miles in addition to 28 days on station. All of these scenarios are considered reasonable for transit in average SS-4 sea conditions because of the allowance in the 20% power reduction used for speed estimates.

For purposes of calculation, stated in-service SHP has been converted to installed BHP by allowing for total mechanical and electrical systems losses of 15%. Total fuel consumption has been calculated based on operationally required BHP using an average fuel conversion rate of 0.36 pounds per horsepower-hour.

The transit cruise speed of 14.3 knots corresponds to 80% of rated propulsion power. Calculations of range at all speeds apply this 20% reduction to horsepower to account for power system degradation and fouling as well as average sea conditions. Maximum range calculations allow for a 10% fuel reserve.

Table 3. Mission performance profiles.

Parameter Description	Normal Transit	Extended Transit	Scenario No. 1	Scenario No. 2	Scenario No. 3
Mission Duration (Days)	28	57	60	58	60
Fuel Load (LT)	640	640	640	640	640
Transit Speed (kts.)	14.3	12	12	13	13
Transit Range (nm)	9,500	16,300	15,000	11,500	10,000
Transit Duration (days)	28	57	52	37	32
Station Duration (days)	---	---	8	21	28
Loitering Speed (kts.)	---	---	4	4	4
Fuel Consumption (LT)	575	575	560	570	530
Fuel Reserve (LT)	65	65	80	70	110

4.

4. SHIP CHARACTERISTICS

4.1 GENERAL DESCRIPTION

The SWATH Oceanographic Research Ship consists of a rectangular upper hull supported by two slender columns on each of two lower hulls. Table 4 is a list of principal particulars. The five pages following Table 4 are the general arrangement drawings that show an outboard profile, forward and aft end elevations, and the three deck plans. The entire structure is steel.

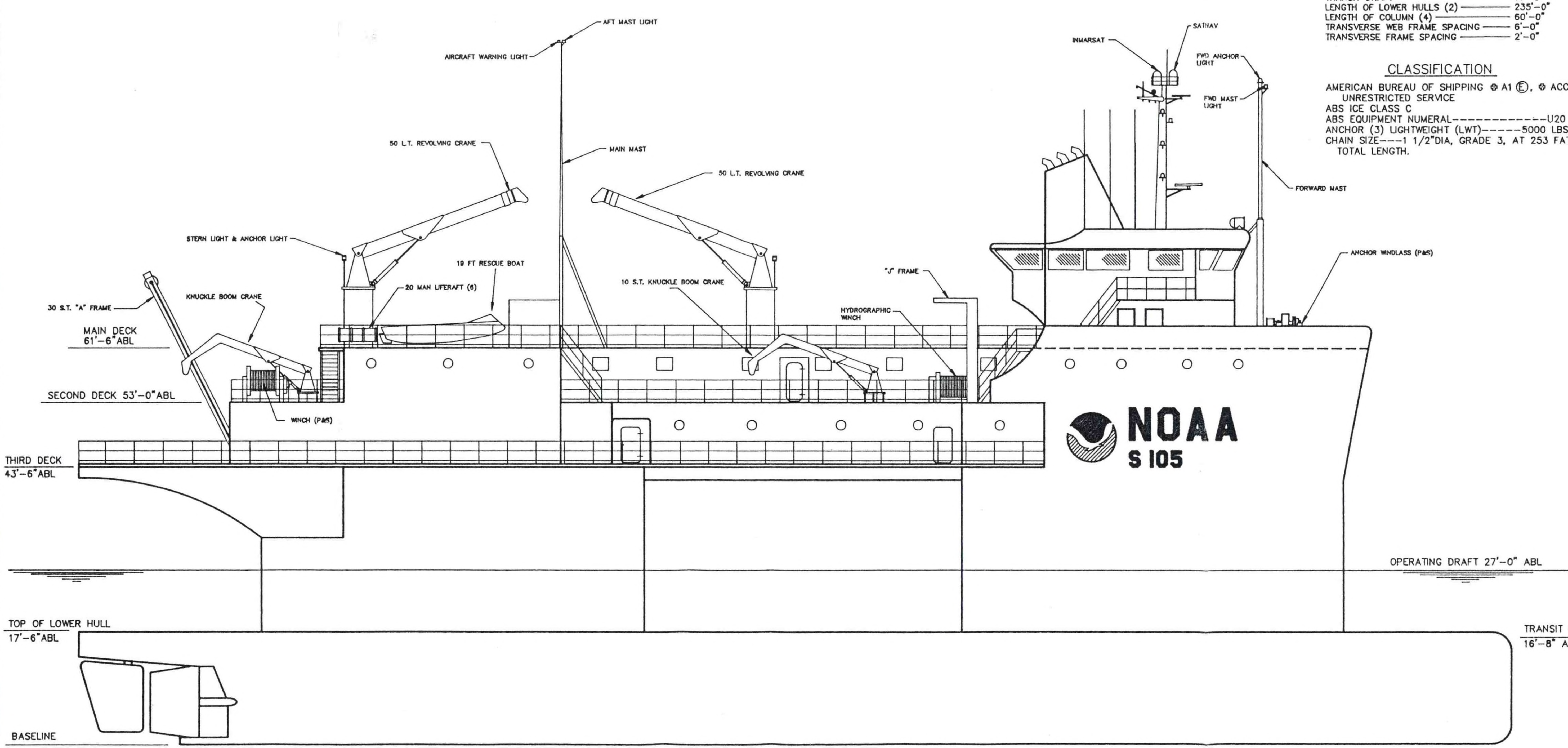
Four columns (struts), two port and two starboard, extend upward from the lower hulls to provide support for the upper hull. Each column is 60 feet in length, 9 feet 6 inches in width, and 23 feet 6 inches high. The columns are offset outboard on the lower hulls.

The ship has a maximum beam of 105 feet which allows passage through the Panama Canal. Each of the lower hulls has a width of 28 feet and a depth at midship of 17 feet 6 inches. The 28 feet width of each lower hull gives a clear space of 49 feet between the inboard sides. There are no appendages or cross bracing between the lower hulls.

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

Table 4. Principal particulars.

Ship	Length, Overall on Lower Hulls	235	feet
	Beam, Overall	105	feet
	Height, Keel to Main Deck at side	61.5	feet
	Draft, Transit, Full Load	16.7	feet
	Draft, Normal Operations	27	feet
	Draft, Special Operations	34	feet
Lower Hulls	Length	235	feet
	Beam	28	feet
	Depth, Midship	17.5	feet
	Spacing, Transverse Centerline	77	feet
Columns	Length, Overall	60	feet
	Beam, Overall	9.5	feet
	Height	23.5	feet
	Spacing, Transverse Centerline	90	feet
	Spacing, Longitudinal Centerline	110	feet
Upper Hull	Length, Overall	204	feet
	Length, Centerline at Third Deck	172	feet
	Beam, Midship at Second Deck	90	feet
	Beam, Maximum at Third Deck	103	feet
	Depth, to Main Deck	20.5	feet
Displacement	Light Ship	2600	LT
	Transit Draft (16.7 ft.)	3500	LT
	Normal Operations Draft (27 ft.)	4180	LT
	Special Operations Draft (34 ft.)	4500	LT
Power	Main Diesel Generators (5)	4670	KW
	In-Port/Emergency Generator	300	KW
	Propulsion Motors (4)	4200	HP
	Bow Thruster (1)	500	HP
Speed	Clean Hull Trial @16.7 ft. Draft	15.0	knots
	In-Service Transit @16.7 ft. Draft	14.3	knots
	Clean Hull Trial @27 ft. Draft	11.2	knots
Range	In-service at 14.3 Knots	9,500	n.m.
	Extended at 12 Knots	16,300	n.m.
Endurance	Stores and Supplies (Minimum)	60	days
Accommodations	Officers	7	
	Marine Crew	21	
	Research Staff	32	
	Total Complement	60	



PRINCIPAL PARTICULARS

LENGTH OVERALL	235'-0"
BEAM OVERALL	105'-00"
NORMAL OPERATING DISPL	4180 LT
NORMAL OPERATING DRAFT	27'-0"
TRANSIT DISPLACEMENT	3500 LT
TRANSIT DRAFT	16'-8"
LENGTH OF LOWER HULLS (2)	235'-0"
LENGTH OF COLUMN (4)	60'-0"
TRANSVERSE WEB FRAME SPACING	6'-0"
TRANSVERSE FRAME SPACING	2'-0"

CLASSIFICATION

AMERICAN BUREAU OF SHIPPING ✠ A1 Ⓔ, ✠ ACCU, ✠ AMS, UNRESTRICTED SERVICE
ABS ICE CLASS C
ABS EQUIPMENT NUMERAL--------------U20
ANCHOR (3) LIGHTWEIGHT (LWT)------5000 LBS EACH
CHAIN SIZE---1 1/2"DIA, GRADE 3, AT 253 FATHOMS TOTAL LENGTH.

NO.	DESCRIPTION	DATE	APPV'D.

ALTERATIONS

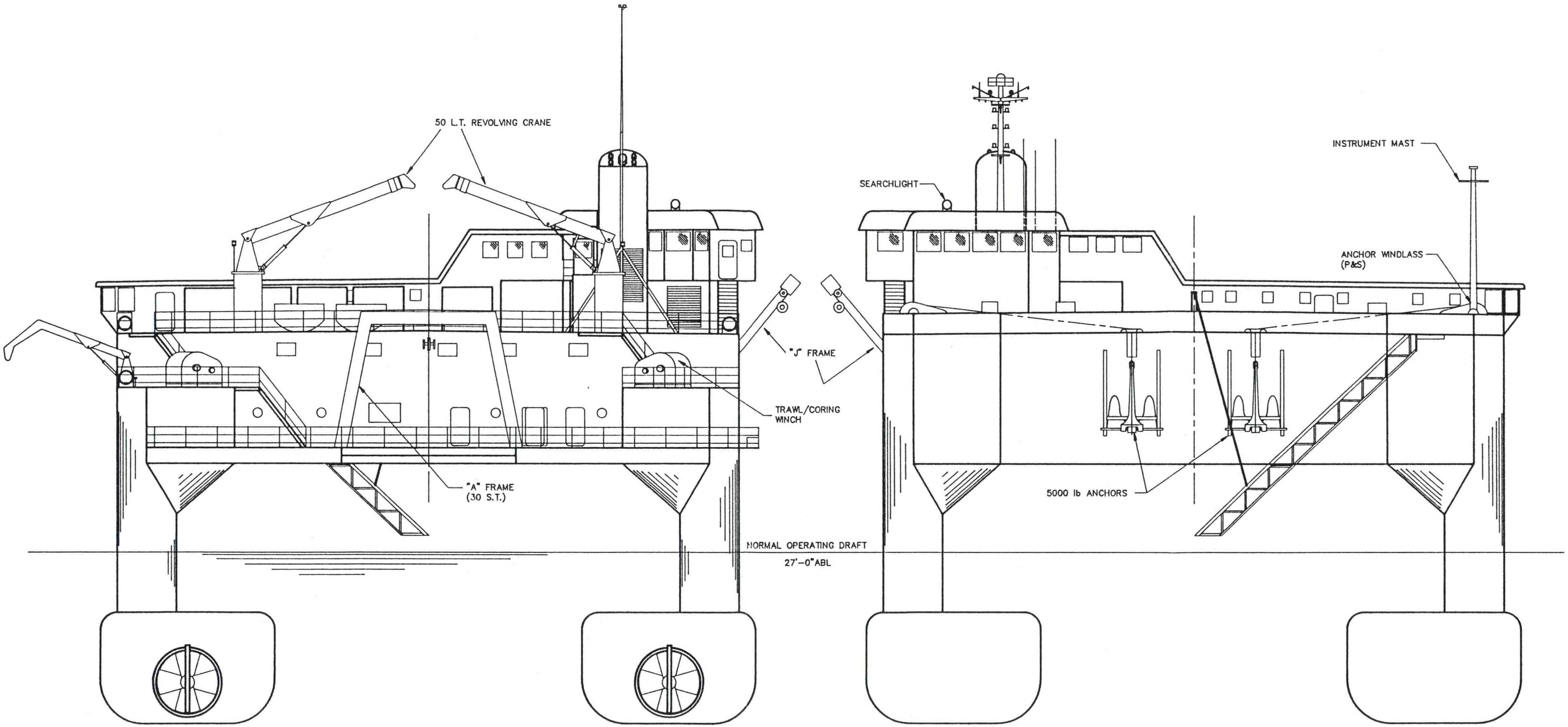
BSM JOINT VENTURE
14300 CORNERSTONE VILLAGE DRIVE, SUITE 317
HOUSTON TEXAS 77014

CLIENT
NOAA

TITLE
OCEANOGRAPHIC RESEARCH SHIP
GENERAL ARRANGEMENT
OUTBOARD PROFILE

DRWN.BY: PJA	DATE: 6/25/90	CHKD: H.Lloyd	DATE:
APPVD: HR	DATE: 7/9/90		SCALE: 1/8"=1'-0"

DWG. No. 2175-000-01 ALT.3



AFT ELEVATION

FWD ELEVATION

CLASSIFICATION

AMERICAN BUREAU OF SHIPPING ✠ A1 (E), ✠ ACCU,
✠ AMS, UNRESTRICTED SERVICE
ABS ICE CLASS C
ABS EQUIPMENT NUMERAL-------------U20
ANCHOR (3) LIGHTWEIGHT (LWT)-----5000 LBS EACH
CHAIN SIZE---1 1/2"DIA, GRADE 3, AT 253 FATHOMS
TOTAL LENGTH.

PRINCIPAL PARTICULARS

LENGTH OVERALL	235'-0"
BEAM OVERALL	105'-00"
NORMAL OPERATING DISPL	4180 LT
NORMAL OPERATING DRAFT	27'-0"
TRANSIT DISPLACEMENT	3500 LT
TRANSIT DRAFT	16'-8"
LENGTH OF LOWER HULLS (2)	235'-0"
LENGTH OF COLUMN (4)	60'-0"
TRANSVERSE WEB FRAME SPACING	6'-0"
TRANSVERSE FRAME SPACING	2'-0"

NO.	DESCRIPTION	DATE	APP'D.

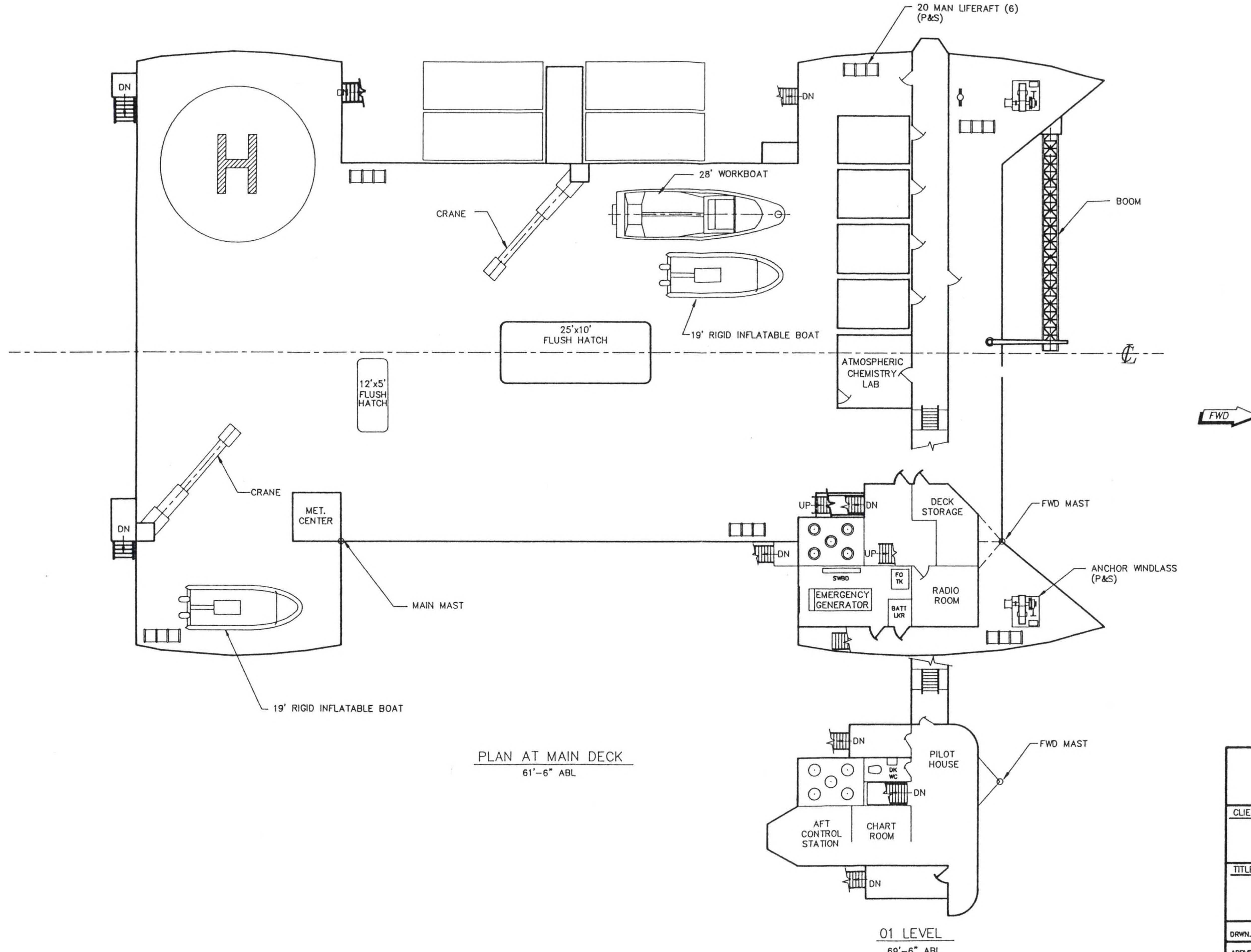
ALTERATIONS

BSM JOINT VENTURE
14300 CORNERSTONE VILLAGE DRIVE, SUITE 317
HOUSTON TEXAS 77014

CLIENT
NOAA

TITLE
OCEANOGRAPHIC RESEARCH SHIP
GENERAL ARRANGEMENT
FWD AND AFT ELEVATIONS

DRWN.BY: PJA DATE: 6/25/90 CHKD: H.Lloyd DATE:
APPVD: H. L. DATE: 7/9/90 SCALE: 1/8"=1'-0"
DWG. No. 2175-000-02 ALT. 3



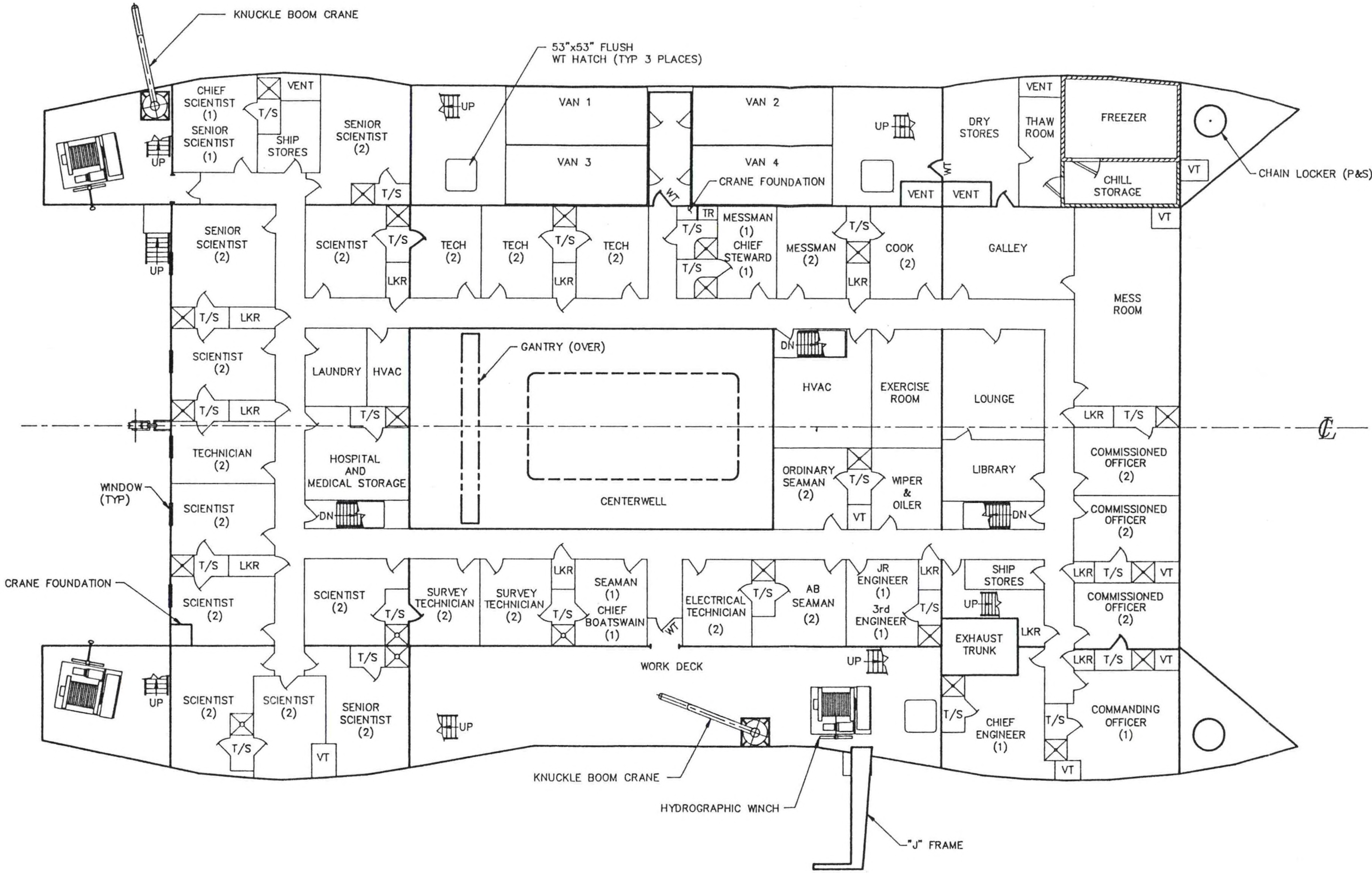
BSM JOINT VENTURE
14300 CORNERSTONE VILLAGE DRIVE, SUITE 317
HOUSTON TEXAS 77014

CLIENT
NOAA

TITLE
OCEANOGRAPHIC RESEARCH SHIP
GENERAL ARRANGEMENT
MAIN DECK AND 01 LEVEL

DRWN. BY: PJA	DATE: 6/27/90	CHKD: H.Lloyd	DATE:
APPVD: H.L.	DATE: 7/9/90		SCALE: 1/8"=1'-0"

DWG. No. 2175-000-04 ALT. 3



PLAN AT SECOND DECK
53'-0" ABL

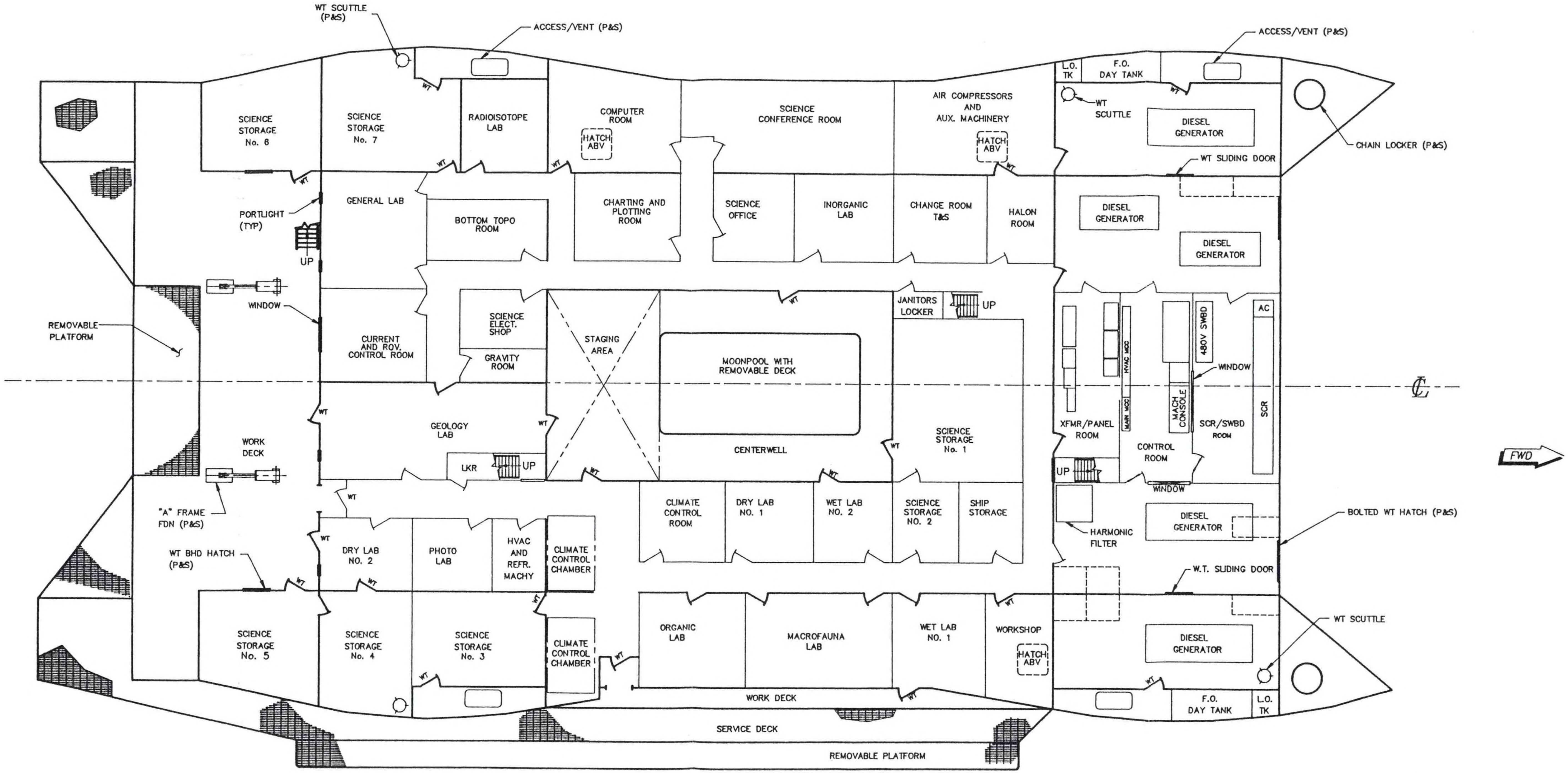
BSM JOINT VENTURE
14300 CORNERSTONE VILLAGE DRIVE, SUITE 317
HOUSTON TEXAS 77014

CLIENT
NOAA

TITLE
OCEANOGRAPHIC RESEARCH SHIP
GENERAL ARRANGEMENT
SECOND DECK

DRWN. BY: PJA	DATE: 6/26/90	CHKD: H.Lloyd	DATE:
APPVD: HL	DATE: 7/9/90		SCALE: 1/8"=1'-0"

DWG. No. 2175-000-05 ALT. 3



PLAN AT THIRD DECK

43'-6" ABL

BSM JOINT VENTURE 14300 CORNERSTONE VILLAGE DRIVE, SUITE 317 HOUSTON TEXAS 77014			
CLIENT NOAA			
TITLE OCEANOGRAPHIC RESEARCH SHIP GENERAL ARRANGEMENT THIRD DECK			
DRWN. BY: PJA	DATE: 6/12/90	CHKD: H.Lloyd	DATE: 6/21/90
APPVD: H. R.	DATE: 7/9/90		SCALE: 1/8"=1'-0"
DWG. No. 2175-000-06			ALT. 3

4.2 ARRANGEMENT

4.2.1 General

The upper hull has three continuous decks: main (weather), second and third, reckoning from the top down. The allocation of deck space in the upper hull is summarized in Table 5. In the middle of the upper hull is an open centerwell bounded top and bottom by the main and third decks, respectively. The centerwell at the third deck level is comprised of a moonpool (opening in the third deck) which is surrounded by work and staging areas. There is adjacent access to all laboratories, stern and starboard work areas, change room, storage rooms, and other mission spaces. The centerwell is serviced by a 10-ton capacity overhead traveling gantry crane. The centerwell overhead is formed by the main deck with a flush hatch access and affords an interior clear height of 17 feet. The five main diesel engine generator sets, the SCR/DC conversion system, main electrical switchboard, various auxiliary machinery, and transformers are located in the upper hulls. The lower hulls contain the propulsion systems, bow thruster, pumps, sea chests and fuel tanks.

4.2.2 Main Deck

Located on the main deck are two hydraulically powered 50-ton telescopic boom cranes with a 10,000 pound lift capacity at a radius of 55 feet. One is located on the starboard quarter to cover the fantail work area. The second is located amidship on the port side where it can cover the second deck space reserved for vans, the main deck space reserved for vans, the forward boat storage areas, the hatch over the centerwell and the helicopter landing area. The main pilot house is located at the 01 level on the starboard side and is connected by an enclosed passageway to a docking station on the port side. Access to the main deck forward is provided by an opening under

Table 5. Upper hull space allocation.

	Area (sq. ft.)	
Main Deck:		
Main Pilot House	1,400	
Passageway to Port Control Station	430	
Allocation for Vans (4 ea.)	420	
Mission Spaces	210	
Weather Deck	8,980	
Subtotal - First Deck		11,440
Second Deck:		
Accommodations	9,050	
Allocation for Vans (4 ea.)	680	
Miscellaneous	580	
Weather Deck	2,140	
Subtotal - Second Deck		12,450
Third Deck:		
Mission Spaces	8,290	
Centerwell	1,456	
Machinery and Miscellaneous	4,294	
Weather Deck	3,700	
Subtotal - Third Deck		17,740
Total - Upper Hull Deck Area		41,630

the passageway before it descends from the pilot house to the main deck. Space is allocated aft of the walkway for four 8x8x12 foot vans that have direct access to the accommodations area. The helicopter hovering area is located on the port side aft. Ship masts are forward and aft on the main deck. They are configured to accommodate antennas and instrumentation for research and survey applications. An instrument mast is located on the port bow forward of the enclosed passageway. A 300 KW in-port/emergency generator is located in the deck house at the main deck level.

4.2.3 Second Deck

The second deck contains quarters, lounge, library, recreational facilities, storage, galley and mess room. Weather deck platforms are provided aft on the port and starboard sides. A large winch complex is on the starboard platform. An articulated crane and a second general purpose oceanographic winch are positioned on the port side. This articulated crane, that serves the fantail area, has a capacity of three long tons at 20 feet. A second articulated crane is located on the starboard side that serves the starboard work areas and the main deck. Four 8x8x20 foot vans can be connected on the port side to the second deck accommodation spaces.

4.2.4 Third Deck

The third deck provides 3,750 square feet of weather deck work space that runs across the stern of the ship and continues around the starboard side. The maximum width of the starboard side work area is 12 feet and includes an outer section of grating four feet wide which will be folded down or removed and stored on the main deck when not in use. Direct access is provided from this deck to one of the two wet laboratories. The stern platform is serviced by a 30-ton capacity A-frame on centerline and a 50-ton telescopic boom crane on the main deck starboard. The work area on the starboard side is equipped with one hydrographic winch and a 12-ton J-frame. The area is serviced by the 50-ton telescopic boom crane as well as a 10-ton articulated crane mounted on the second deck. The aft and starboard work areas have water tight access to interior passageways adjacent to the laboratories. Scientific storage areas are arranged adjacent to the laboratories and work areas. The remaining (forward) part of the third deck contains main and auxiliary machinery for the ship.

4.2.5 Lower Hulls

One fixed pitch propeller per hull, fitted in a fixed propulsion nozzle, is driven by DC electric motors through a reduction gearbox. Ballast water tanks are in the lower hulls and columns. Fuel storage tanks are located in the lower hulls only. A pressurized sea chest for mission transducers is in the starboard hull. The bow thruster is in the port hull.

4.2.6 Accommodations

Complete living accommodations are provided for 60 persons. The complement allowed for in the arrangement is given in Table 6. The accommodations consist of 9 single and 22 double staterooms, all on the second deck. Table 7 gives the specific assignment of staterooms and the arrangement for access to toilet and shower. The arrangement allows for accommodation of a random mix of female and male staff in segregated facilities. In addition, up to four 8x8x20 foot accommodation vans can be mated on the exposed second deck. Appointments and construction are to commercial offshore marine standards. Separate mess and recreation rooms are provided. The mess room can accommodate up to 32 persons at one seating. Galley and storage spaces permit operations for a minimum of 60 days without replenishment.

Table 6. Complement used for arrangement of accommodations.

Officers		7
Marine Crew:		
Engineering	5	
Deck	6	
Survey Technician	4	
Service	6	
		21
Research Staff:		
Chief Scientist	1	
Sr. Scientists	7	
Scientists	14	
Technicians	8	
Electrical Technician	2	
		32
Total Complement		60

Table 7. Stateroom assignments.

	Stateroom	T&S
Commanding Officer	Single	Private
Commissioned Officer (5)	Double	Private
Medical Officer	Double	Private
Chief Engineer	Single	Private
3rd Assistant Engineer	Double	Private
Junior Engineer	Double	Private
Oiler	Double	Share
Wiper (temp.)	Double	Share
Chief Boatswain	Double	Share
Able Body Seaman (2)	Double	Share
Ordinary Seaman (2)	Double	Share
Ordinary Seaman (temp.)	Double	Share
Chief Steward	Double	Private
Chief Cook	Double	Share
2nd Cook	Double	Share
Messman (2)	Double	Share
Messman (temp.)	Double	Private
Survey Technician (4)	Double	Share
Elect. Technician (2)	Double	Share
Chief Scientist	Double	Private
Sr. Scientist (7)	Double	Private
Scientist (14)	Double	Share
Technician (8)	Double	Share

4.3 SHIP SYSTEMS

4.3.1 Power

A diesel electric power pool concept is incorporated in this design. Major rotating equipment is powered by electric motors supplied from a central plant consisting of multiple diesel electric generators. A separate 300 KW in-port/emergency diesel generator is installed and is connected to the main 480 volt AC bus.

Primary power is generated at 600 volts, 60 Hz, three phase by diesel generator sets situated in the upper hull on the third deck forward. All generated 600 volt AC power is then collected on a main AC bus and distributed as necessary. The bulk of this AC power is fed to an SCR (silicon controlled rectifier) system for conversion to 720 volts DC.

DC variable speed main propulsion motors and the bow thruster motor are powered by the DC system. AC power for other needs is extracted from the 600 volt AC bus and passed through transformers for conversion to ship service power at 480 volts. Two 100 KW 480 VAC MG sets, operated in parallel, will supply clean power for scientific laboratory service.

The multiple unit diesel generator plant will allow generation efficiency to be maintained at near optimum levels for all modes of operation. The space provided for the five diesel generator sets on the third deck forward is adequate to allow selection from several manufacturers. For the purposes of illustration and calculation in this conceptual design, three Caterpillar D3512 and two D3508 diesel generator sets were selected. The five units, three rated at 1080 KW and two rated at 715 KW (continuous), provide a total of about 4670 KW. All primary generators will be synchronized.

Main propulsion is provided by geared variable speed DC traction motors located in each lower hull. Each drive system is connected by reduction gears through shafting to a single four blade fixed pitch propeller mounted in a fixed nozzle. The nozzles provide increased thrust at low speeds for improved performance while towing. The propulsion shafting is carried through the hull by a conventional water lubricated Thordon SXL polymer type stern tube bearing system. The DC motor propulsion systems provide for continuously variable control from zero to maximum speed. A dual armature propulsion motor combination is provided for improved power factor. There is a separable auxiliary electrical power bus for the ship service transformers to isolate harmonic distortions.

4.3.2 Ventilation

Upper hull spaces are ventilated by air-handling units located in the upper hull. Air for ventilation and cooling for lower hull machinery is ducted down the strut (column) access ways. Exhaust air is discharged mechanically through ducting. Individual labs shall be protected from cross-contamination through the ventilation system.

4.3.3 Heating and Air Conditioning

Air conditioning is provided by a central chilled water plant and air handling units located in equipment rooms around the vessel with ducting to enclosed accommodations and laboratory work spaces. The A/C chiller units are located on the machinery flat at the top of the port side columns. Heating for these same areas is provided by electric resistance heating elements located in the duct work. Heating, ventilation, and air conditioning (HVAC) shall be appropriate to laboratories, vans, and other science spaces being served. Laboratories shall be maintained at a temperature of 20-24 degrees C, 50% relative humidity, and with 9-11 air changes per hour of filtered air to interior analytical and instrument labs.

4.3.4 Fresh Water

Two waste heat recovery type water makers, each rated at a minimum of 4,000 gallons per day, are provided. Production from each water maker will exceed the daily needs of the crew so that one water maker is available in reserve.

4.3.5 Sanitary

To reduce fresh water consumption, a reduced flush fresh water vacuum sewage collection system is provided. Sewage will either be discharged directly overboard or to a storage tank for treatment.

4.3.6 Ballast

A sea water ballast system is provided which includes dedicated ballast tanks in the lower hulls and columns, ballast pumps in both hulls, and controls in the pilot house control center. The control center contains tank level indicators as well as controls for adding or removing ballast. Four ballast pumps, with pumping capacities of 600 gallons per minute each, will provide for the ten foot draft excursion between transit and normal operations in less than 1.5 hours.

4.3.7 Emergency Systems

Six 20-man life rafts are provided and located on the main deck. Conventional fire fighting systems are provided. The main and auxiliary machinery spaces are fitted with Halon flooding systems. Fire mains and fire stations are in accordance with regulations. A smoke and fire detection system is provided throughout the ship (upper and lower hulls) with an alarm and indicator panel in the pilot house.

4.3.8 Hydraulic Systems

Each piece of hydraulically operated equipment such as cranes, A and J frames and anchor windlass shall be connected to a central hydraulic system. Steering is accomplished by a hydraulically powered tiller arm steering gear system which actuates a single conventional rudder at each nozzle exit. The steering system shall have its own self contained power unit.

4.4 SHIP CONTROL

4.4.1 General

The ship is equipped for remote operation, and monitoring of main propulsion machinery. Steering, ballast, and navigation controls are centered in the pilot house. An aft control station in the pilot house, a secondary station in the ROV control room, and a centerwell portable control unit are provided for use during maneuvering and retrieval/deployment operations. A secondary control station for docking also is provided on the port side forward.

4.4.2 Steering

Maneuvering and steering control for the ship is by means of a joystick. The control system commands the bow thruster, main propellers, and rudders to provide translational and rotational movement. The dynamic positioning system allows the operator to precisely maneuver the ship during deployments and retrievals, towing, and docking. Displays are included to provide thruster and propeller command information and to indicate the power availability of the thruster system. Master control of the system is located in the pilot house with secondary systems located at the aft control station, the port side docking station and the ROV control room. A plug in hand-held joystick controller also will be provided for use mainly in the centerwell. Control is assigned to the alternate stations during the various operations but can be overridden at any time by the master control console located in the pilot house.

The joystick unit provides lateral and fore-and-aft commands by displacement of the lever in those coordinates and, in addition, provides rotational commands when the lever is turned in one direction or the other. Outputs from the joystick are processed on the thruster allocation electronics, which proportionally allocates thrust to the thruster and propellers on the ship. At the point of power saturation, commands will be prioritized to optimize the power requirements for positioning the ship and to give the operator maximum control of the ship. All components and circuitry in the control system are latest state-of-the-art integrated circuits and solid-state devices. The computational units and allocation logic units are all mounted on circuit cards for ease of maintenance in the field.

4.4.3 Navigation

The ship navigation package shall consist of a 4-channel SATNAV global positioning system (GPS) deep ocean transponders and precise timekeeping capability, an automatic direction finder, a LORAN C with display and plotter, and a surface search radar. The GPS shall interface with the ship control processors and to the data systems.

4.4.4 Internal Communications

Internal communications system will provide high-quality voice and visual communications throughout all science spaces, working areas and other selected spaces (e.g., conference room and chief scientist stateroom).

A data transmission, monitoring and recording system available throughout science spaces (including vans and key working ares) shall be networked through a central computing facility. Closed-circuit television monitoring and recording of all working areas and, where appropriate, ROV sensors shall be installed. Monitors for all ship control, environmental parameters, science and overside equipment performance are to be available in all laboratories and other selected spaces with data ports located at all winches and cranes.

4.4.5 External Communications

Equipment will be installed to provide reliable voice channel continuous communications to shore stations (including home laboratories), other ships, and aircraft. This includes satellite, VHF and UHF. Other equipment includes facsimile and high-speed data communications (56K Baud) for links to shore labs and other ships on a continuous basis.

Antennas are located on the pilot house to minimize electromagnetic contamination to portable and interior lab spaces.

4.4.6 Satellite Monitoring

Transponding and receiving equipment, including antenna to interrogate and receive satellite readouts of environmental remote sensing, will be installed.

4.5 STRUCTURAL CONSIDERATIONS

The structural design is based on: global loads due to wave forces, gravity loads, and accelerations; local loads from hydrodynamics and hydrostatic pressure; loads from installed and movable equipment; and on operations. The design is governed by "Rules for Building and Classing Steel Vessels" by the American Bureau of Shipping and by basic principles of applied mechanics.

For structural considerations, the total ship consists of three main parts: upper hull, columns (four each), and lower hulls (two each). The upper hull is a simple box structure composed of plate decks, stiffeners and longitudinal and transverse bulkheads. The primary structural members are the transverse box girders formed by the main deck and hull bottom as flanges, and the transverse bulkheads (frames 13 and 47 forward, and 123 and 157 aft) as webs. These two girders connect the columns across the top and provide most of the transverse strength of the hull. Longitudinal strength is provided by similar box girders formed by the second deck and hull bottom as flanges and the outer shell and longitudinal bulkheads, 31 feet off center P & S, as webs. Longitudinal strength is much less critical than transverse strength in this type of vessel. Upper hull deck framing is run transversely and is continuous to augment the transverse strength of the decks.

The four columns are simple monocoque construction. Their strength is in the shell plating, supported by transverse bulkheads and flats. The columns are expanded into a haunch at the connection to the upper hull, resulting in direct connection of the column structure to the principal upper hull members. In addition, the inner column shell is changed from a curved plate to a flat plate over a distance of about six feet from the 27-foot level to the start of the haunch at 33 feet. This not only simplifies the haunch plate by keeping it flat between bulkheads 13 to 47 and 123 to 157, but also provides a small increase in column section modulus at this point to ease the transition.

Column framing is vertical which facilitates construction and provides strength in the most critical direction.

The two lower hulls are framed longitudinally for ease in construction. This complicates the connection of the columns to the lower hulls somewhat. However, this connection design is ample using material and local structure to achieve the required strength.

The columns are not aligned with the centerline of the lower hulls. This design feature is due to stability and roll motion response considerations. The structural design of the connection between columns and lower hulls takes account of the moments imposed by this asymmetrical arrangement.

Initial design of this structure was carried out by classical methods using American Bureau of Shipping rules as applicable. The design was analyzed in detail by finite element methods.

4.6 WEIGHT ESTIMATE

A detailed weight estimate was developed for the oceanographic research ship design by BSM that responded to the NAVSEA RFP[3] for AGOR 23. Light ship and deadweight margins conformed with NAVSEA guidelines and criteria. The weight estimate for the NOAA Oceanographic Research Ship was derived from that previous detailed weight estimate. Minor changes have been made to conform with differences in configuration, outfitting and loading. Table 8 summarizes the weight estimate in the SWBS (ship work breakdown structure) format used by NAVSEA.

Table 8. Summary of weight estimate.

SWBS Group	Description of Weight Group	Weights (LT)
100	Hull Structure	1,560
200	Propulsion Plant	107
300	Electric Plant	113
400	Command and Surveillance	16
500	Auxiliary Systems	354
600	Outfit and Furnishings	200
	LIGHT SHIP TOTAL WITHOUT MARGINS	2,350
	Design and Build Margins	160
	LIGHT SHIP TOTAL WITH MARGINS	2,510
	Deadweight without Margin	867
	Service Life Margin	113
	Ballast for Trim	10
	DISPLACEMENT, FULL LOAD, AT TRANSIT DRAFT	3,500
	Variable Draft Ballast	690
	DISPLACEMENT, FULL LOAD, AT OPEATIONS DRAFT	4,180

Of particular interest are weight allowances made for mission related equipment. Part of the equipment has been included in light ship and the remainder in deadweight. The weights allowed in the two divisions are given in Table 9.

Table 9. Mission equipment weight allowances.

SWBS Group	Equipment Description	Weight (LT)
100	Instrumentation Mast	3
400	Depth Sounding Systems	5
500	Winches	90
500	A & J Frames	15
500	Gantry Crane	5
500	Deck Cranes	35
500	Forward Boom	2
500	Air Compressors and Misc.	5
600	Laboratory Outfit	20
	Subtotal - Equipment in Light Ship	180
	Vans	25
	Boats	10
	Stores and Spares	20
	Itinerant Deck Loads	100
	Subtotal - Equipment in Deadweight	155
	TOTAL - Mission Equipment	335

5.

5. MISSION FEATURES

5.1 SPECIAL CHARACTERISTICS

The design of the SWATH Oceanographic Research Ship incorporates several noteworthy features, some of which are not found in monohulls. The objective throughout the design has been to adapt inherent attributes of the SWATH configuration to the requirements stated in Section 2 of this report. The resulting design meets or exceeds all of the requirements. In some minor instances, substitutions have been made to adapt the stated needs to the SWATH configuration. Since this is a conceptual design, explicit attention has not been given to detailed outfitting, e.g., internal communications, laboratory equipment, ship control substations, and the like. All such details as called out in Section 2 are able to be accommodated without major changes to the design described in this report.

5.1.1 Variable Draft/Elevation

The ship is designed to operate over a variable (selectable) range of drafts (and corresponding clearance between the upper hull and the sea surface). The shallow draft of less than 17 feet fully loaded allows access to most harbors with facilities appropriate to this class of oceanographic research ship. Ship motions in the seaway are minimum at the normal operations draft of 27 feet which typically would be used in exposed deep water locations for conducting technical activities. At the special operations draft of 34 feet, the level trim elevation of the stern and centerwell work decks is less than ten feet above still water. Adjustment of trim (by shifting ballast) can place the aft work deck awash. The penalty to provide these variable draft features is tankage for 690 LT of ballast in addition to ballast necessary for fuel compensation. This is equivalent to 30 feet in length of the lower hulls.

5.1.2 Omnidirectional Motion Response

The four-column design, coupled with lower hull geometry and overall weight distribution, gives ship motion response at deep drafts that essentially is independent of heading relative to surface wave direction. In beam seas, the opening between the columns affords more exposure under the moonpool than would be the case with a two-column design.

5.1.3 Harbor/Transit draft

The design has been developed and model tested to achieve superior propulsion and motion performance at the transit draft in light to moderate sea states, including Sea State 4. A major advantage of the variable draft SWATH configuration is the ability to transit at higher speeds in moderate sea states using less power than would be needed for an equivalent monohull. This is achievable because the incremental increase in resistance due to waves is significantly less than for a monohull. A key issue for evaluation of performance at transit draft is seakeeping of the semisubmerged SWATH compared to an equivalent monohull. At this shallow draft, the semisubmerged ship does not behave like a conventional catamaran because the lower hulls are ballasted to a freeboard of only about one foot. Therefore, waves wash over the lower hulls. When the water level rises above the top of the lower hull, the waterplane is reduced to the cross section of the columns which drastically reduces the buoyant forces. The water on the decks of the lower hulls also contributes to attenuation of motion response.

5.1.4 Load Handling

The deck service cranes are arranged such that a load in excess of 10,000 pounds can be transferred between the centerwell and over the stern or either side. This gives flexibility for loading supplies and equipment as well as for supporting oceanographic operations. The arrangement effectively interlinks the weather deck spaces aft, topside and on the starboard side. It also permits unassisted transfer of vans or equipment between the main deck and the second deck on the port side. A capability for load transfer up to ten tons is provided within the entire centerwell by a horizontal gantry crane mounted on the underside of the main deck.

5.1.5 Quiet Lower Hull

The starboard lower hull is designed as a "quiet" hull with sonar transducers located forward and away from ship service equipment. A single bow thruster is provided and is located in the port side ("noisy") lower hull. As much as possible, auxiliary machinery was positioned in the port side hull. Particular attention was given to the forward pump room in the starboard hull which only contains the pumps for oily water waste and bilge/ballast. The starboard fuel transfer pump is in the propulsion room (aft).

5.1.6 Pressurized Sea Chest

A pressurized sea chest for installation of acoustic transducers and other mission sensors is located about 80 feet aft in the starboard lower hull. Figure 3 shows the layout of the sea chest and entry lock. This arrangement will enable safe repair and changing of sensors while at sea.

5.1.7 Electrical Interference

In the layout of the wireways, major power cables are run at least one deck below sensitive instrumentation cables. Separate dedicated sonar cableways are installed in addition to those assigned to scientific equipment.

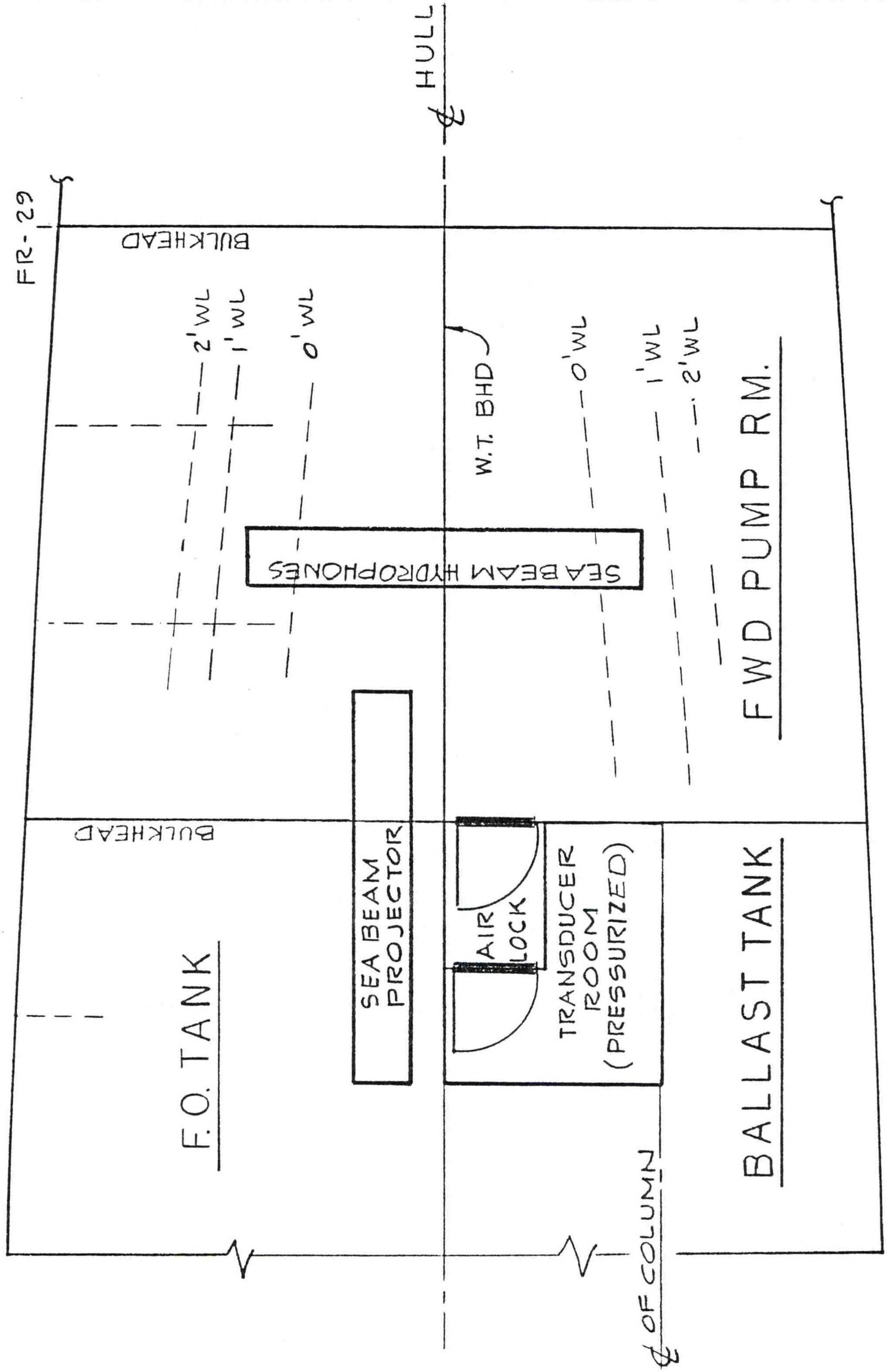


Figure 3. Arrangement of pressurized sea chest.

5.1.8 Ship Control

A portable "joystick" maneuvering control, integrated with the dynamic positioning system, is provided in the centerwell for operations using the moonpool. The portable joystick also can be used in the aft work area for operations over the stern. A secondary control station is provided in the ROV control room which has visibility of the stern work area. An aft control station in the main pilot house has visibility of the starboard side and the main deck aft including the helicopter hovering area. The deck forward of the control passageway and the lowerable boom are visible from the primary ship control station in the pilot house.

5.1.9 Tracking Capability

With its 77 foot transverse propeller separation, the semisubmerged SWATH ship has enormous turning capability for precise heading control in adverse conditions. The slim lower hulls and slender struts have high directional stability. The conventional rudder arrangement is designed to give maximum heading control at slow speed. Oscillatory forces exerted on the vertical columns by waves are much smaller than for a monohull and the center of force application is back from the bow so horizontal moments that cause trackline deviations are significantly reduced.

5.1.10 Clean Power

A "clean power" standby transformer, capable of being separately powered from the in-port generator, gives full flexibility for on board production of electrical power meeting scientific use requirements.

5.1.11 Data Management System

A distributed, computer controlled, vessel management system is provided with a total of four display/control/data logging stations with redundant work stations and high speed digital data highway capable of integration with the scientific mission computers. This computerized system will be programed for functions such as: automated trim, draft, stability control; extensive data logging with five call-up/printout stations; and machinery parameter trending and maintenance predictions.

5.1.12 ROV Capability

ROVs can be handled over the stern or through the moonpool. The centerwell will afford an excellent hanger space for storage and repair.

5.1.13 Work Boats

Provision is made for two 19 foot semi-rigid boats that are located on the main deck for ease of launching and recovery. The overside handling is done with the telescopic boom cranes. The boats also can be transferred to the centerwell for launch through the moonpool.

A 28 foot LOA work boat is provided. It is rigged for skid mounting and tie down on the port side of the main deck and will be handled by the telescoping boom crane in close proximity on the port side.

5.1.14 Instrument Mast

An instrument mast is provided on the port bow at the main deck level. The mast extends above the top of the control passageway and is otherwise clear of nearby obstructions.

5.1.15 Lowerable Boom

A boom is arranged athwartship with hinged connection at the main deck level on the interior side of the port bow. The boom is man-rated and one end can be lowered on centerline to the still water surface between the leading edges of the forward columns. The boom can be rigged such that the lift device on centerline can serve as a crane with 5,000 pounds capacity.

5.1.16 Removable Platforms

Removable platforms are provided on the stern and the starboard side as well as in the centerwell. The stern platform is in the gap outboard of the A-frame. The starboard platform extends the mission deck four feet outboard for almost 100 feet along the side. Both of these platforms are grating structures intended mainly for manned access and light loading. The platform over the moonpool is a segmented plate cover that can be used for moderate loading and to enclose the centerwell against spray and outside temperature extremes.

5.1.17 Stern Work Area

The stern work area is fitted with a sheave that enables fairleading the two aft winches through the A-frame. The A-frame can reach forward to place small loads on the main deck. Load handling on the stern deck and transfer to the main deck and the centerwell is by means of the telescopic boom crane on the starboard quarter. Four cranes are available (two on each side) to extend at least 20 feet outboard for towing purposes. Storage lockers afford 4,300 cubic feet on the stern (port and starboard) easily accessible for up to 30 tons of moorings, weights and miscellaneous heavy equipment.

5.1.18 Starboard Work Area

The starboard work area is equipped with a J-frame that can extend well outboard of the lower hull. The frame and hydrographic winch are mounted on the second deck. Normal access for work is on the third deck which is continuous with the stern deck. Long slender items, e.g., piston corers and spar buoys, can be handled by one or both of the cranes on the starboard side and can be supported over their entire length on the deck along the starboard side.

5.1.19 Helicopter Hovering Area

An oversize clear area for helicopter hovering is provided on the port quarter of the main deck. Space and arrangements are such that this can be upgraded to a landing area with facilities for refueling.

5.1.20 Vibration and Noise

The diesel engine generators will be shock mounted and the compartments engineered for suppression of acoustic noise and mechanical vibration. Use of shock mounted electrical propulsion motors in the lower hulls together with isolation of the main engines in the upper hull assures dramatic reduction of acoustic noise radiated underwater compared to a monohull. The SWATH configuration further allows preferential design so that one lower hull (starboard in this case) will be quieter than the other. It further should be noted that, contrary to monohulls, acoustic transducers mounted in the lower hull will not suffer bubble sweepdown when the ship is operating at normal deep draft.

5.2 SPACE ALLOCATION AND ARRANGEMENT

5.2.1 Functional Separation

The enclosed second deck is dedicated to accommodations and personnel support functions. These spaces are conveniently separated from scientific work functions and ship operation compartments which primarily are on the third deck.

5.2.2 Centerwell

The centerwell containing the moonpool is enclosed with clear headroom of more than 17 feet. A removable hatch in the main deck allows entry into the centerwell of objects up to 25 feet long. The hatch is positioned over the moonpool to allow free-fall access from the main deck to the water between the columns and lower hulls. A second smaller hatch is fitted over the staging area in the aft segment of the centerwell.

5.2.3 Mission Decks

A total of 3,750 square feet of weather exposed deck space for mission work is provided on the third deck in addition to 560 square feet for the two aft platforms and 1,100 square feet on the starboard side of the second deck. The subdivision of mission deck space is given in Table 10. The tabulation includes deck space within the centerwell (1,000 square feet exclusive of the removable cover for the moonpool). These areas are arranged to provide convenient access to labs and handling systems. The main deck provides about 8,900 square feet of weather deck that shares mission and operating functions. About three-fourths of this main deck space is unassigned and can be serviced by a combination of the A-frame and the cranes. A 10,000 pound load can be transferred between any part of the second and third mission work decks to the main deck, into the centerwell or over the port or starboard side at a distance of 40 feet outboard.

Table 10. Mission deck space allocation.

Deck	Description	Area (sq. ft.)
Main	Forward of control passageway	600
Main	Multiple use	8,300*
Second	Aft work deck	550
Second	Starboard work deck	1,100
Third	Aft work deck	1,650
Third	Aft service deck	600
Third	Aft removable platform	280
Third	Starboard work deck	190
Third	Starboard service deck	600
Third	Starboard removable platform	430
Third	Centerwell staging & work deck	1,000
Third	Moonpool removable platform	450
	Total Usable Deck Space*	13,500

* Allocates 6,050 square feet as usable of the 8,300 square feet of multiple use space on the main deck.

5.2.4 Mission Arrangement

All laboratories, except meterological compartments on the main deck, are located in the aft portion of the third deck and are adjacent to the centerwell, the aft work platform or the starboard side work area. The laboratories are arranged so that they do not serve as passageways. The Geology Laboratory has direct (watertight door) access to both the centerwell and aft work area. Mission storage spaces are located for convenient access to the laboratories and the aft work deck. The compartmentation and space assignments for mission functions are given in Table 11. The arrangement has enabled all of the mission compartment requirements to be met within the ship structure rather than having some functions assigned to vans as allowed in Subsection 2.4.2.

Table 11. Mission compartments.

Functional Designation	Required Area (ft^2)	Assigned Area (ft^2)	Deck Level
Atmospheric Chemistry Laboratory	120	120	1
Bottom Topographic Room	150	162	3
Charting and Plotting Room	200	208	3
Climate Controlled Spaces	300	310	3
Computer Room	300	300	3
Conference Room	--	414	3
Current and ROV Control Room	200	208	3
Dry Laboratory No. 1	150	156	3
Dry Laboratory No. 2	150	154	3
General laboratory	250	272	3
Geology Laboratory	400	416	3
Gravity Room	50	65	3
Inorganic Laboratory	200	208	3
Library	--	120	2
Macrofauna Laboratory	300	308	3
Meteorological Center	64	64	1
Organic Laboratory	200	224	3
Photography Laboratory	120	121	3
Pressurized Sea Chest	32	48	LH
Radioisotope Laboratory	150	182	3
Science Electronics Shop	100	104	3
Science Office	150	156	3
Science Storage No. 1	--	456	3
Science Storage No. 2	--	120	3
Science Storage No. 3	--	280	3
Science Storage No. 4	--	252	3
Science Storage No. 5	--	270	3
Science Storage No. 6	--	270	3
Science Storage No. 7	--	336	3
Wet Laboratory No. 1	200	196	3
Wet Laboratory No. 2	---	144	3

Summary:

Laboratories	3,922 sq. ft.	
Conference Room & Library	534 sq. ft.	
Science Office	156 sq. ft.	
Science Storage	1,984 sq. ft.	(16,864 cu. ft.)
Sea Chest	48 sq. ft.	

5.2.5 Laboratories

The aggregate total area of laboratories is about 3,900 square feet. This compares to a requirement of about 3,600 square feet given in Subsection 2.4.2. The labs are arranged for convenience to each other and to the three overboarding work areas (stern, starboard side and centerwell). None of the labs serve as general passageways. The laboratories are well isolated from ship machinery and operating functions. Some noteworthy features of the laboratory arrangement are given below.

(a) Wet Labs - One wet lab is adjacent to the J-frame with direct access to the weather deck. The other lab is interior with its own access to the centerwell.

(b) Climate Controlled Spaces - These are arranged in three compartments for flexibility of multipurpose use. The chambers are located for easy access to both the stern and starboard work areas.

(c) Geology Lab - The lab is arranged as a slender rectangle with direct access to both stern and centerwell.

(d) Current and ROV Control Room - This room is equipped with a secondary ship control station at a large window that gives visibility over the stern work area.

(e) The computer room is outfitted with a hatch above to give crane assisted access from the second deck for installation of equipment.

5.2.6 Mission Support Spaces

Except for the library, built-in mission support spaces are on the third deck integrated with the laboratories.

(a) Conference Room - This room is oversize and could be further subdivided.

(b) Library - The library is on the second deck adjacent to the lounge.

(c) Science Office - The office is located in immediate proximity to the conference room.

(d) Science Storage - There are seven storage compartments, two of which open onto the stern work deck. One of the storage areas is accessible from the centerwell. These three spaces account for half of the storage allocation. The total available storage volume is approximately 16,800 cubic feet based on a vertical dimension of 8.5 feet which is consistent with the second and third deck separation of 9.5 feet.

5.2.7 Vans

Space is assigned on the second deck port side to carry four standardized 8x8x20 feet portable vans which may be used for laboratories, berthing, storage, or other specialized use. Hookup provision is made for power, HVAC, fresh water, uncontaminated sea water, compressed air, drains, communications, and data monitoring systems. Direct access to the ship interior is provided via an enclosed passageway.

Space also is assigned to carry up to four additional portable non-standard vans (each up to 8x8x12 feet) on the main deck. Provision is made for each of these vans to have access into the control passageway.

The telescopic boom crane on the port side is capable of loading and offloading all vans.

6.

6. COST ESTIMATE

A design and construction price estimate for the semisubmerged SWATH Oceanographic Research Ship is given in Table 12. The estimate was prepared by BSM. The cost estimate is based on the following assumptions:

(1) Current year (1990) pricing.
(2) Construction in a U.S. Shipyard on the Gulf of Mexico.
(3) Initial order of three ships in the class.
(4) Construction period of 2-3 years for each ship.
(5) Construction cost is average for each of three ships.
(6) Non-recurring design, engineering and integrated logistic support costs are spread evenly over first three ships in the class.
(7) Commercial standards to meet requirements of the American Bureau of Shipping.
(8) U.S. flag that requires compliance with rules of USCG and other regulatory agencies.

The cost of mission equipment is <u>not</u> included in the estimate. Engineering and ILS estimates are based on recent bidding for Navy vessels (including T-AGOS 19 class and AGOR-23) so probably are conservative for NOAA acquisitions.

Table 12. Cost estimate.

SWBS Group	SWBS Category	Direct Labor Hours[2]	Direct Labor Cost[3]	Materials Cost[4]	Total Cost
100	Hull Structure	130,000	3.90	1.70	5.60
200	Propulsion Plant	12,000	0.36	0.89	1.25
300	Electric Plant	23,000	0.69	2.81	3.50
400	Command & Surveillance	4,000	0.12	1.38	1.50
500	Auxiliary Systems	39,000	1.17	4.43	5.60
600	Outfit & Furnishings	40,000	1.20	2.35	3.55
800	Engineering	4,000[5]	0.12[5]	1.28[5]	1.40[5]
900	Support Services	41,000	1.23	0.67	1.90
	Totals	300,000	8.79	15.51	24.30

Notes:

(1) All costs in millions of dollars.
(2) Labor hour estimates based on construction in a Gulf coast yard.
(3) Labor cost estimates based on average rate of $30/hour fully burdened (including profit).
(4) Most materials (including subcontracts) based on vendor quotes in 1990.
(5) These values are one-third of the estimated cost for the first ship which would be consistent with an initial order of three ships.

REFERENCES

REFERENCES

1. Blue Sea McClure, "Conceptual Design of Semisubmerged Oceanographic Research ship," Report to the Institute for Geophysics of the University of Texas, August 1984.

2. Blue Sea McClure, "Conceptual Design of SWATH Oceanographic Research Ship," BSM Report 8502-01 to the University-National Oceanographic Laboratory System, published by Woods Hole Oceanographic Institution, April 1985.

3. Naval Sea Systems Command, "AGOR-23 Oceanographic Research Ship," Request for Proposal No. N00024-87-R-2024, 27 May 1984.

4. Gaul, R. D., F. E. Shumaker and T. E. Short, SWATH Ship Analysis for NOAA New Ship Requirements," Report 700-2, BSM Joint Venture, Houston, Texas, May 22, 1990.

5. Van Sluijs, M. F., "Model and Full Scale Motions of a Twin-hull Vessel," Report No. 131S, Netherlands Ship Research Center TNO, 21 pp., August 1969.

6. Lang, T. G., J. D. Hightower and A. T. Strickland, "Design and Development of the 190-Ton Stable Semisubmerged Platform (SSP)," J. Engineering for Industry, Trans., ASME, pp. 1105-1111, November 1974.

7. Hightower, J. D. and R. L. Steiple, "Operational Experiences with the SWATH Ship SSP KAIMALINO," Paper 78-741, AIAA/SNAME Advanced Marine Vehicle Conf., San Diego, Calif., April 1978.

8. Saeki, M., and H. Nakamura, "Motion Characteristics of the KAIYO," Proceedings, OCEANS '86, Conference in Washington, D.C., 23-25 September 1986.

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

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

11. Semi-submerged Ship Corporation, "Conceptual Design of a 2500 Ton Oceanographic Research Ship," Report by Woods Hole Oceanographic Institution, February 1985.

12. Kennell, C. G., "User Manual for Computer Programs SWAD84 and SWAD84IN," NAVSEA Technical Note No. 051-55W-TN-0019, Naval Sea Systems Command, Washington, D.C., November 1984.