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SWATH SHIP DESIGNS FOR OCEANOGRAPHIC RESEARCH

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ABSTRACT

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

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

1. INTRODUCTION

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

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

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

The basic requirements for research ships are to be able to go to the desired locations, and to conduct the desired research operations, in a safe and economical manner. Existing ships come in different sizes to meet the needs of different research operations, but they all suffer from restrictions on transit speed and on research effectiveness caused by rough sea conditions. For example, 12 knots is commonly given as the cruising speed of larger research ships, although not often attained. A speed of 9-10 knots in many transits is normal, which is about a 20% reduction. Since transit is often 30-50% of the total voyage, this means a decrease of 6-10% in time available for research work. Heavier seas will cause a greater reduction, and on station they can cause delays in preparing, deploying and recovering equipment; they have also been the cause of loss or damage to equipment, and injury or death of personnel. Even in "normal" conditions at sea, ship motions have a degrading effect on human performance, ranging from total wipe-out by sea sickness to the less noticeable but more prevalent increase in fatigue. Since scientific organizations pay for each day at sea, whether they are getting data or not, the ratio of working time to total time is a measure of the value of the ship to their research. Reduced ship motions at sea provide a multiple payoff.

2. FOUR STRUT SWATH SHIPS

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

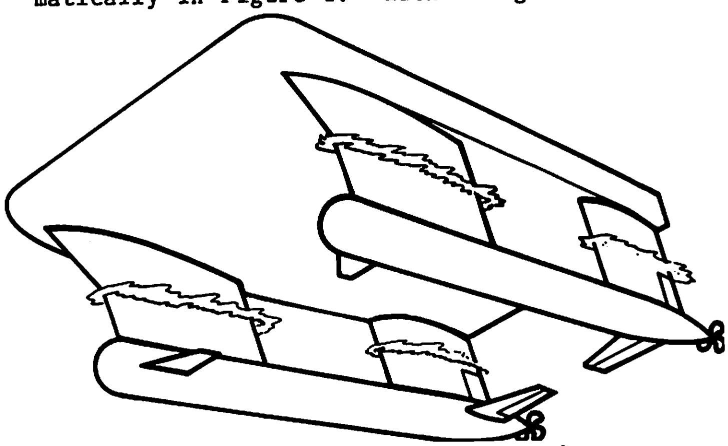

Figure 1. Schematic illustration of a four-strut SWATH.

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

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

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

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

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

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

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

3. 64-FOOT SWATH

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

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

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

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

TABLE I. SWATH RESEARCH VESSEL (RV) CHARACTERISTICS

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

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

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

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

△ THE SMALLER VALUE REFERS TO DAYTIME OPERATIONS.

4. 88-FOOT SWATH

This vessel is the SSP KAIMALINO [9,10,11], a 227-ton SWATH built in 1973 by the U.S.C.G Shipyard, Curtis Bay, Maryland for the Naval Ocean Systems Center (Figure 3). The KAIMALINO has operated in the rough seas off Hawaii since 1975 as a range support craft, and is capable of coastal operations for periods of up to two weeks duration. This relatively old SWATH design has

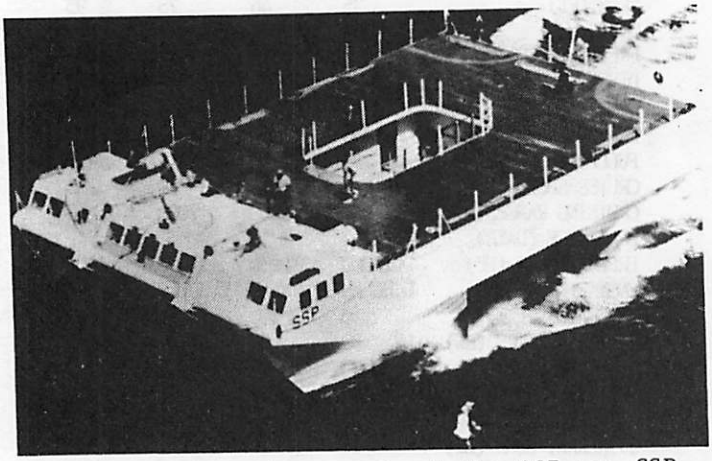

Figure 3. Navy photograph of the 227-ton SSP KAIMALINO operating in the waters off Hawaii.

performed exceptionally well, and has required only minor hydrodynamic and structural changes. However, changes made by a new design would greatly improve the SSP characteristics in Table I.

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

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

5. 150-FOOT SWATH

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

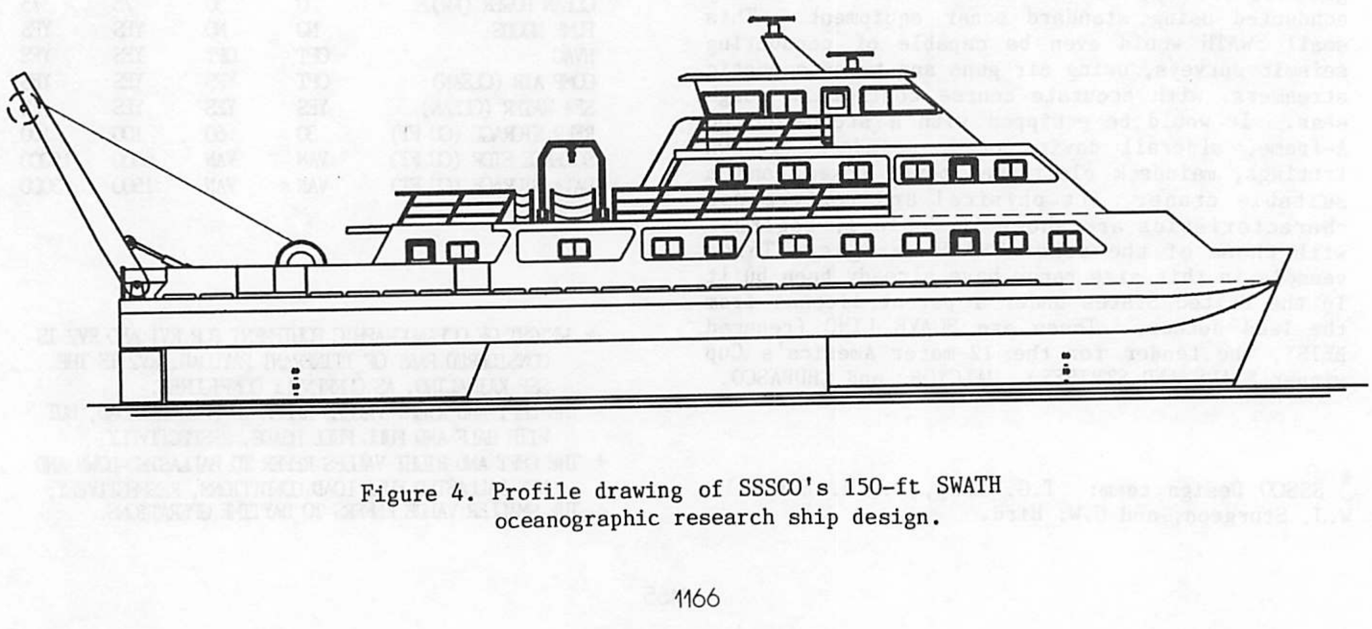

Figure 4. Profile drawing of SSSCO's 150-ft SWATH oceanographic research ship design.

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

6. 247-FOOT SWATH

This large SWATH [13] (Figure 5), was designed by SSSCO under contract from the Woods Hole Oceanographic Institution. It matches the university ships MELVILLE and KNORR in length, exceeds them in laboratory space and usable deck space, speed, low motions in rough seas, and in cruising range, but falls short in payload weight and endurance. This SWATH's range is 11,400 nm at 15 kts, or 16,880 nm at 12 kts, each with a 15%

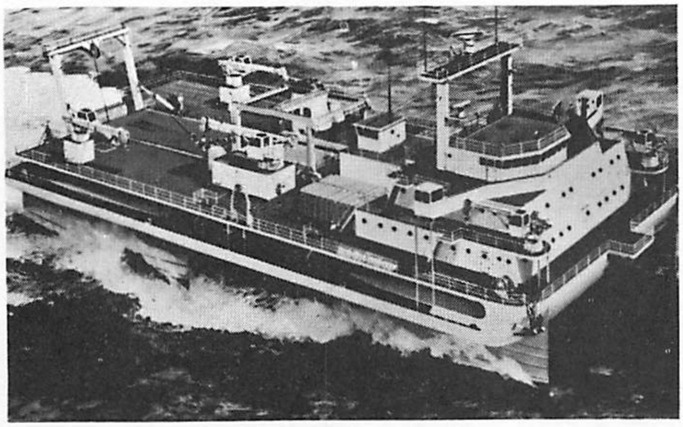

Figure 5. Artist's rendering of SSSCO's 247-ft oceanographic research vessel SWATH design.

fuel reserve. It carries 336 LT of oceanographic equipment, including a 100 LT itinerant payload, and has an endurance of 40 days. The large center well of this SWATH permits safe handling of large packages in sea conditions that would cancel operations of the MELVILLE and KNORR. In addition to the standard suite of winches, A-frames, davits and cranes, this SWATH has a large gantry crane mounted at the center well. This SWATH carries 35 scientists and 25 crew. Its large usable deck space of 13,800 sq ft provides space for all deck equipment and for the location of four vans for additional berthing, labs and storage.

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

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

7. SUMMARY

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

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

Efficiency and productivity is affected by a variety of factors. Cost of operations is significant to sponsors of research programs. Expeditions which are aborted, or which return with less results than planned because of ship limitations have a depressing effect on sponsors, particularly at times of new budget preparation. Loss of equipment because of difficulties in recovery in rough seas is not uncommon. Even when the seas do not present hazardous conditions for deck operations, their motions affect personnel with varying degrees of discomfort, ranging from increased fatigue to debilitating sea sickness. There is an associated cost in time, related to mistakes and slowness in accomplishing tasks that are normally easily done in calm conditions.

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

ACKNOWLEDGMENTS

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