

COASTAL SWATH SHIP DESIGN AND EXPERIENCE

Raymond G Allen

Richard S Holcomb

David Taylor Naval Ship Research and Development Center
Code 1110
Bethesda, Maryland 20084

Trials and experiments performed on existing Small Waterplane Area, Twin Hull (SWATH) ships have validated their operational superiority over monohulls in a number of offshore missions, particularly for ships of small displacement. SWATH ship technology has now matured to the point where a small SWATH ship can seriously be considered a competitor to small monohulls in a number of offshore tasks. This paper is a synopsis of recent work examining the potential of small SWATH ships in coastal and offshore patrol missions drawing on full scale operational trials data and early stage designs. Extensive operational trials on existing SWATH ships have been performed and have led to a number of postulated missions for small SWATH ships including mine countermeasures, oceanographic research, buoy-tending, search and rescue, and US coastal law enforcement. These mission applications have led to a number of early stage design studies to determine the characteristics of small SWATH ships configured for the various missions. A summary of small SWATH ship characteristics, based on three feasibility level designs and two concept level designs of SWATH ships done by the authors are presented herein. These ships were designed to meet current and planned United States Coast Guard (USCG) missions, and range from 125 LTON to 750 LTON in displacement. These data are presented as representative of small SWATH ships for those who might consider the SWATH concept for coastal and offshore duty. Opinions and conclusions presented in this paper are those of the authors and may not represent official US Navy (USN) or USCG thinking.

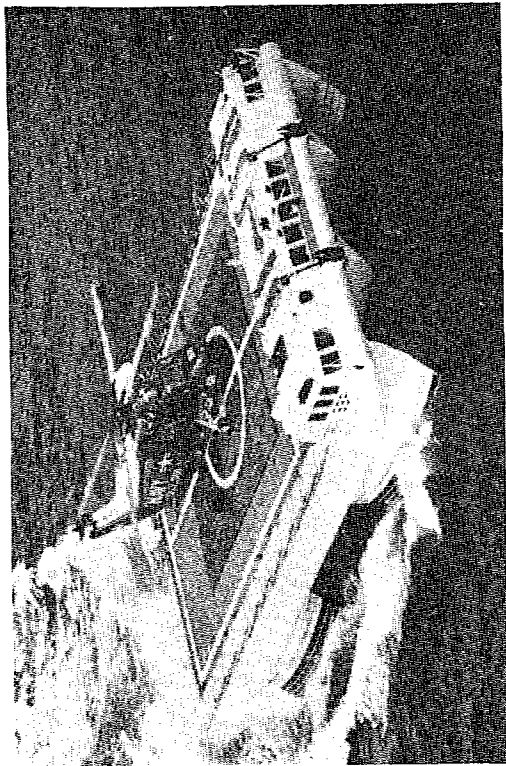
The basic theory underlying the SWATH concept is as follows: place most of the buoyant volume well below the sea surface and most of the useable volume well above the surface, and connect the two with the minimum reasonable volume. The result is a twin hull ship characterized by relatively large spacing between the underwater hulls and small waterplane area struts. These two factors provide the SWATH ship with some key advantages over conventional monohulls. Firstly, the amplitude of a ship's motion in a seaway is greatly affected by wave exciting forces which to the first order, is proportionate to its waterplane area. Therefore, a small waterplane area results in small ship motions. This superior seakeeping has been demonstrated time again in full scale trials, [1], model tests, and in numerous analytical studies, [2]. Secondly, due to their configuration, SWATH ships can be designed to have larger internal volumes and deck areas than monohulls of similar displacement, thereby enhancing the operational flexibility of the ship. This also has been demonstrated with full scale ships and early stage designs. The price paid for these attributes is a ship with greater weight sensitivity than most monohulls, resulting from the small waterplane area struts and the correspondingly low tons per inch of immersion (TPI) characteristics and usually a somewhat greater draft. In general, the SWATH concept has proven to be sensitive to a greater number of physical parameters than monohulls. These parameters have a substantial "feedback" effect in a SWATH ship design spiral. As a result, SWATH ship design is, as a whole, more complex than monohull design and the early stage concept definition is more critical.

As of 1983, the authors are aware of only five operational SWATH ships. In the United States there are the SSP KAIMALINO (SSP), [3], a US Navy work boat displacing 220 LTON, and the SUAVE LINO, [4], a 50 LTON privately owned fishing boat. The remaining three are in Japan: Mitsui Engineering and Shipbuilding has built the MESA 80 (now called SEA GULL), [5], a 402 passenger ferry, displacing approximately 350 LTON, and the KOTO-ZAKI, a hydrographic survey vessel, displacing 250 LTON. Mitsubishi Shipbuilding has built the OHTORI, a hydrographic survey vessel also displacing some 250 LTON. Currently, RMI of San Diego has designed and is in the process of constructing a vessel of about 60 LTON. Mitsui has recently begun construction of what is to be the largest SWATH ship in the world, a 2800 LTON oceanographic research vessel. Of principal interest in this paper are the SSP KAIMALINO, the MESA 80, and the SUAVE LINO. Data and photographs of these ships are presented in Figure 1.

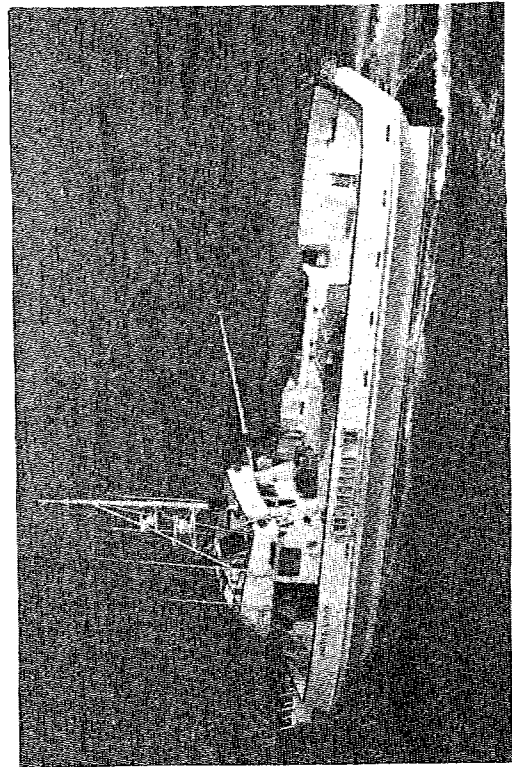
Comprehensive technical trials have been performed on the SSP, the SUAVE LINO and the MESA 80, all of which have validated the SWATH concept. Of particular interest to this paper though are the operational trials performed on the various craft. Since its launch in 1974, the SSP has seen numerous operational trials, including: remotely controlled submersible launch, recovery, tracking and support; helicopter launch and recovery trials with a LAMPS I helicopter; over-the-side or through-centerwell launch and recovery of test buoys, towed arrays, Zodiac boats, and other test equipment; tests for minehunting and acoustic sonar; acoustic trials; degaussing demonstrations; test range support operations; buoy-tending trials; salvage and towing operations; marine biological surveys; search and rescue; and side-by-side seakeeping trials with monohulls of larger displacements, [1]. These trials have been largely successful and have shown the SSP to be as operationally capable as much larger monohulls in a seaway, primarily as a result of the SSP's superior seakeeping. Numerous operational trials have also been performed on the SUAVE LINO, including: acoustic trials; bottom mapping; diver support; towing and being towed; and over-the-side launch and recovery of boats and test equipment. The SUAVE LINO has proven to be a very capable 50 LTON boat.

As a result of the demonstrated operational flexibility of the SWATH concept, a number of mission applications have been proposed, many of which have resulted in design studies to various degrees of detail. Among the proposed missions are: minehunting and neutralization; a range of USCG activities including buoy-tending, fishing and drug enforcement (using the SWATH ship as a small helicopter-capable patrol craft), and search and rescue; a USN vessel for acoustic testing; coastal hydrographic and bottom mapping survey vessels; and commercial activities including fishing, offshore supply, and a passenger ferry.

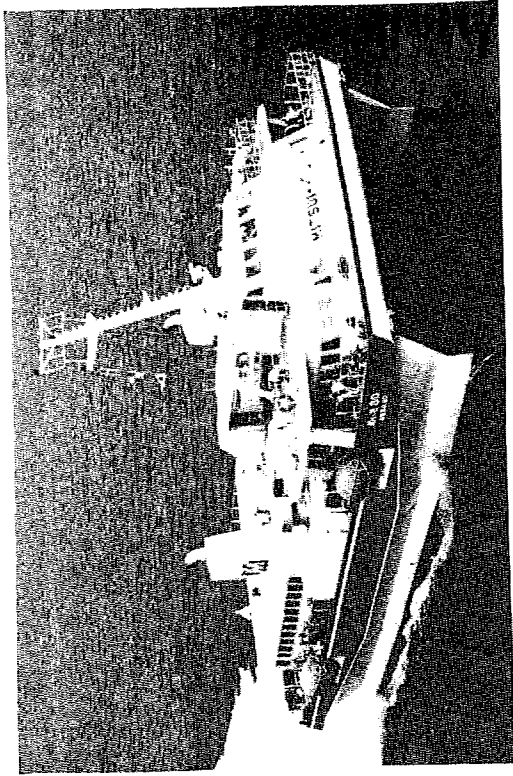
The potential of a SWATH ship in the minehunting/neutralization role was investigated, at a feasibility level, by the Naval Studies Board of the National Academy of Science, [6], in 1982. The study showed that a small SWATH ship was a viable alternative for both the minehunting and neutralization roles. Further, the study concluded that at this time the design and construction of an aluminum SWATH ship would entail few if



SSP KAIMALINO



SUAVE LINE



MESA 80

	MESA 80	KAIMALINO	SUAVE LINE
Full Load Disp (LTON)	345	220	52
Overall Length (ft)	109.5	87.8	62.9
LBP (ft)	106.0	77.0	54.1
Overall Beam (ft)	53	45	30
Maximum Draft (ft)	10.3	15.3	7.0
Clearance (ft)	8	4.9	2
Installed SHP (hp)	8100	4500	850
Drive System	Z Drive Dual Shaft	Z Drive, Chain	Z Drive Single Shaft
Maximum Speed (Kts)	27.1	18	18
Construction Material	All Aluminum	Steel Struts and Hulls, Aluminum Box	All Aluminum

any risks or unknowns. Based on trial work on the SUAVE LINO, the potential of the SWATH concept in the hydrographic survey role was investigated, at a feasibility level, by Messrs. Benen and Drummond, [7]. Seakeeping and stationkeeping being important factors, small SWATH ships show potential of being the ideal craft for that role.

Recently, the USCG has expressed great interest in the SWATH concept. After sponsoring numerous trials on both the SSP KAIMALINO and the SUAVE LINO, the USCG sponsored a number of design studies at both the feasibility and concept level. In 1981, the SWATH concept became a candidate for possible replacement of two classes of patrol craft - their 70 and 100 LTON Patrol Boats (WPB). The Marine Technology Branch, Research and Development Office sponsored a parametric feasibility study, [2], of four SWATH ships bracketing the size of the WPBs and a conceptual Medium Endurance Cutter (WMEC) similar to the 1000 LTON RELIANCE Class (SWATH ships displacing 125 LTON, 250 LTON, 750 LTON and 1250 LTON were investigated). In 1981, carrying the parametric study one step further, the USCG Naval Engineering Division sponsored a concept level study of a 170 LTON SWATH ship as a possible WPB. In 1982, the Naval Engineering Division sponsored a second concept level study for a new class of ship, a Patrol Cutter (WPC), which was intended to be the smallest size SWATH ship capable of carrying and operating a standard USCG helicopter. The result was a 450 LTON craft with a maximum cruise speed of 25 knots and a range of 4000 nmi at 12 knots. The remainder of this paper presents design data representative of small SWATH ships designed to meet USCG missions. Though the concepts are configured for USCG applications, the characteristics presented are also representative of baseline SWATH concepts configured for other missions, i.e., for those with lesser speed or range requirements, higher payload requirements, etc. Trade-offs should be performed to find the SWATH concept which best meets a given mission, but the data presented should provide good starting points for small SWATH ship designs.

The design criteria upon which the USCG studies are based are:

1. The resistance characteristics were optimized around 10-15 knots for cruise speeds, and 25-28 knots for maximum speeds;
2. Simple cylindrical lower hull forms (as opposed to contoured) were used, primarily for ease of construction;
3. Draft was minimized whenever possible;
4. Structural weight was reduced whenever possible;
5. Seakeeping was to be adequate;
6. A configuration with the rudder in the wake of the propeller was considered necessary to improve maneuvering;
7. All underwater portions of the configuration were to be within the envelope defined by the above water portion of the ship, to minimize underwater hazards and to ease docking and over-the-side work;
8. Deck wells were not considered necessary or desirable, especially on the helicopter-capable concepts.

The general approach used in designing each of the concepts was to use a configuration optimized for resistance and powering as a baseline, and then perform trade-offs on the various ship sub-systems and characteristics to find the configuration which best met the mission requirements (i.e., the concept which had satisfactory powering, satisfactory seakeeping, sufficient area, volume and payload capacity, a reasonable structural weight fraction and satisfactory hydrostatic characteristics). With the basic geometry and characteristics established, more precise weight, area and volume estimates were performed (using the Ship Work Breakdown System (SWBS) as an organizational basis), the seakeep-

ing properties were evaluated, the craft's range was estimated, and general arrangements of the craft were done. Depending on the level of the design, additional analyses were performed, such as intact and damaged stability, propulsion system trade-offs, and more detailed seakeeping evaluations. As with conventional monohulls, the structure (Group 1) and the propulsion system (Group 2) were the sub-systems with the greatest influence on the refinement of these concepts. For this reason, detailed estimates were made for the hull and propulsion weights in order to provide accurate ship characteristics.

Hull structural weight estimates were made, assuming an all-aluminum structure, by the use of a computer program which estimates the hull structure based only on local loads, with uniformly distributed normal pressure. Since hulls of smaller vessels are predominantly governed by local loadings, this seems to be the most efficient method to quickly converge on an acceptable estimate. After initial scantling selection is made, the hull is checked for transverse bending of the struts, hull, and cross-structure. If the bending stresses prove to be excessive, then the plating thicknesses in the strut/cross-structure intersection (the haunch area) are increased to reduce the stresses to an allowable level. The allowable stress in the haunch regions was assumed to be 10 ksi. This was to protect the aluminum structure against premature failure due to high cycle fatigue. More detailed Group 1 weight estimates were done for the 170 and 450 LTON concepts using independent methods to validate the structural weight algorithm, and showed good correlation.

A map of shaft power required for small SWATH ships is presented in Figure 2, from Reference 2. This power map is based on numerous analytic studies, the point designs presented herein, and existing SWATH ships. Though SWATH configurations can be "tuned" to meet specific speed requirements, the power estimates included in this figure are "middle of the road" estimates for given speeds and displacements. Please note that Figure 2 is a log-log plot.

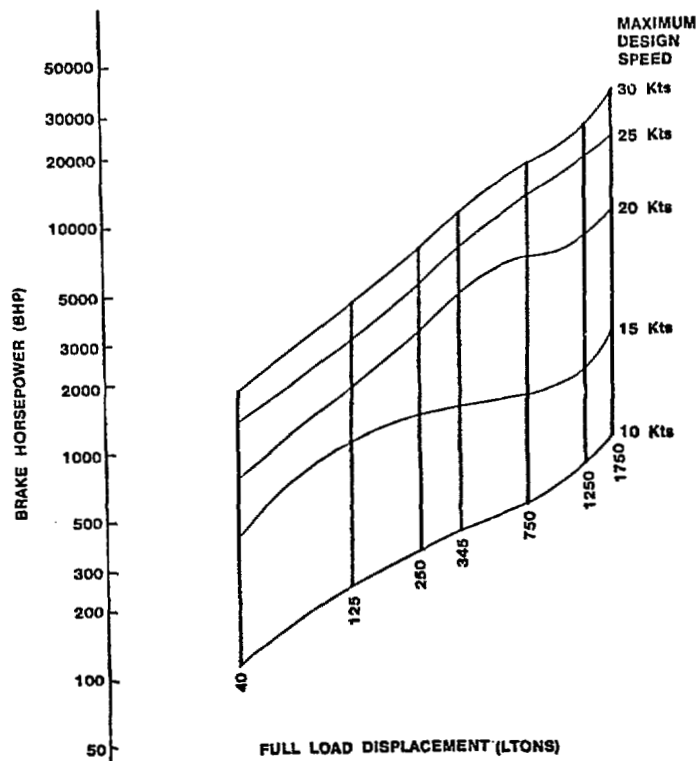


Figure 2 - Shaft Power Map for Small SWATH Ships

Diesel and gas turbine prime movers were considered for all concepts, however, given the speed requirements and the fuel economy consciousness of the day, gas turbines did not appear to be viable alternatives for small SWATH ships configured for the USCG missions. Despite the lighter system weight of a gas turbine installation, sufficient fuel to attain ranges comparable to diesel systems cannot be carried without increasing the size of the ship. The authors, therefore, do not recommend the use of gas turbines in small SWATH ships unless high speed is of the utmost importance. In all the cases presented, high speed diesels of either US or European manufacture were incorporated because of their substantially better specific fuel consumption, at both full and partial power. For most concepts, European diesels were the preferred choice because of their better weight/BHP characteristics when compared with US diesels. Engine location in each of the concepts was established on the main deck or on the sponson level. Drive systems were chosen to be mechanical Z-drives with bevel gear sets at both engine and lower hull levels, with single or twin vertical shafts in each strut. Such a drive system is quite similar to that installed in the MESA 80, [5]. Group 2 weight estimates were done at the component level where possible, or using existing weight estimation algorithms.

The other sub-system weights were estimated at the same level of detail as the Group 1 and 2 weights. Group 3 weights were based on actual components where possible (e.g., the generators and engines) and the distributed systems were derived from algorithms based primarily on enclosed ship volume. Groups 4 and 7 weights were determined at the component level based on specific USCG needs. Groups 5 and 6 weights were determined using algorithms primarily based on enclosed ship volume and secondarily on crew size. In all cases, margins were applied to each weight group reflecting the level of detail of each sub-system weight estimate, [8]. Care was taken to use conservative weight estimates, but not to compound the conservative estimates with conservative margins, thus stifling the concept.

A summary of the most important characteristics of the five concepts is presented in Table 1. The five concepts presented are balanced designs; the 125, 250 and 750 LTON designs all done to the feasibility level and the 170 and 450 LTON designs done to the concept level. Further, the authors believe that if one of these concepts were constructed, the final properties of the ship would be reasonably close to the estimates provided here. The authors have the most confidence in the weight estimates of the 170 and 450 LTON designs because of the greater detail with which they were done. The 170 and 450 LTON designs serve to validate, in part, the remaining concepts.

The authors believe that the data presented herein can serve as the basis for development, design and construction of SWATH ships for coastal and offshore missions. The authors encourage continued development of the SWATH concept in the commercial world as well as in the military world because they believe the concept offers new flexibility to ship design as well as new operational capabilities, most of which have yet to be exploited. But, researchers and early stage designers are seldom ship builders; the advantages of the SWATH concept cannot be conclusively demonstrated by paper studies, but must be proved with operational SWATH ships. It remains to the ship builders and operators to demonstrate the full potential of the SWATH concept.

ACKNOWLEDGEMENTS

The authors would like to acknowledge some of the many people who contributed to the detailed studies summarized in this paper. They would especially like to thank Mr. Peter Silvia of DTNSRDC for all the time he spent arranging the 170 and 450 LTON concepts, and for his detailed weight estimate of the 170 LTON concept. They would like to thank Mr. John Roper for his detailed structural arrangement and weight estimate of the 450 LTON concept. In addition, the authors would like to thank Mr. Tom Milton of the USCG Marine Technology Branch, Research and Development Office for his support of the SWATH concept and his management of the SWATH feasibility studies. Finally, the authors wish to express gratitude to CDR Pete Dickenson, LCDR Al Gracewski and LT Rich Formisano, all of the USCG Naval Engineering Division, for their support and management of the concept level design studies.

REFERENCES

1. Woolaver, D. A. and J. B. Peters, "Comparative Ship Performance Sea Trials for the US Coast Guard Cutters MELLON and CAPE CORWIN and the US Navy Small Waterplane Area Twin Hull Ship KAIMALINO," DTNSRDC Report 80/037, (Mar 1980).
2. Allen, R. G. and R. S. Holcomb, "The Application of Small SWATH Ships to Coastal and Offshore Patrol Missions," Paper 4 of the Royal Institute of Naval Architect's Second International Symposium on Small Fast Warships and Security Vessels, London (May 1982).
3. Hightower, J. D. and R. L. Seiple, "Operational Experiences with the SWATH Ship SSP KAIMALINO," presented at the AIAA/SNAME Advanced Marine Vehicle Conference, San Diego, paper 78-741, (Apr 1978).
4. Jones, M. P., "Test and Evaluation of the Ocean Systems Research 64' SWATH Demonstration Craft," Naval Sea Systems Command Detachment, Norfolk, VA, Report 6660-91 (Feb 1982).
5. Narita, H., T. Mabuchi, Y. Kunitake, H. Nakamura, and M. Matsushima, "Design and Full Scale Test Results of Semi-Submerged Catamaran (SSC) Vessels," Mitsui Engineering and Shipbuilding Co., Tokyo, Japan. Presented at first International Marine Systems Design Conference (IMSDC '82), London, England (22-24 Apr 1982).
6. Naval Studies Board, Commission on Physical Sciences, Mathematics, and Resources, "Report of the Mine Warfare Study Group, Volume VIII: The SWATH as an MCM Platform," National Academy Press, Washington D.C. (Sep 1982).
7. Benen, L. and S. E. Drummond, "The SWATH Survey Platform," presented at the 12th International Hydrographic Conference, Monaco (Apr 1982).
8. Koelbel, J. G., "Design Margin Management and Procedures for US Navy Small Craft," Combatant Craft Engineering, Naval Ship Engineering Center, Norfolk Division Report 23124-01-1 (Dec 1977).

TABLE 1 - SUMMARY OF CHARACTERISTICS OF SMALL SWATH CONCEPTS

	125 LTON WPB	170 LTON WPB	250 LTON WPC	450 LTON WPC	750 LTON WMEC
Length, OA (ft)	85.6	87	117.1	120.0	165.0
Beam, OA (ft)	40.3	42	53.5	54.0	68.2
Draft, Max (ft)	8.6	10.1	11.6	12.6	16.5
Length, BP (ft)	78.4	80	111.5	109.1	157.7
Strut Thickness (ft)	1.6	2	1.9	3.5	2.8
Waterplane Area (ft ²)	241.1	290	344.2	623.7	730.4
LCF (ft from strut nose)	39.3	37.1	47.9	54.5	82.6
Strut Volume ₃ (below WL, ft ³)	581	843	1330	1921	3926
Strut Setback (ft from hull nose)	1.6	1.2	0.5	5.5	0.7
Length, Lower Hull (ft)	77.6	76.1	103.0	109.1	145.7
Hull Diameter (ft)	6.2	7.2	7.8	9.5	11.1
LCB (ft from hull nose)	41.1	37.5	44.9	52.3	64.0
Lower Hull Volume (ft ³)	3714	5033	7588	12206	21782
Cross-Structure Volume (ft ³)	13810	21924	31890	69465	120410
GMT (ft)	11.6	2.6	12.5	6.3	8.1
GML (ft)	19.2	11.3	18.2	16.1	28.8
Group 100 (LTON)	43.9	48.6	77.4	139.5	253.4
200 (LTON) (Diesels)	19.4	29.4	30.8	56.3	86.3
300 (LTON)	5.2	6.0	6.4	16.9	28.9
400 (LTON)	1.9	2.1	4.4	8.5	9.4
500 (LTON)	14.9	18.2	31.1	61.0	89.2
600 (LTON)	9.9	13.0	27.5	41.2	60.4
700 (LTON)	0.1	0.9	2.4	4.5	2.4
Loads (LTON)	20.7	36.2	51.6	82.5	161.5
Lightship Margin (LTON)	10.4	19.7	20.3	45.8	60.3
Installed Propulsion Power (HP)	3006	4430	5350	9240	13060
Installed Electrical Power (kW)	115	180	145	370	1155
Max Speed (knots)	25	26	25	25.4	25
Range at Cruise Speed (nmi,kts)	1218,10	4000,11	2826,12	4200,12	3281,13
Manning	15	18	30	35	65