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AIAA'86

ANA-8612382
A New Small Waterplane Area Ship Concept

William C. O'Neill, Engineering Consultant

10-U16218

AIAA 8th Advanced Marine Systems Conference

September 22-24, 1986/San Diego, California

A NEW SMALL WATERPLANE AREA SHIP CONCEPT

by
William C. O'Neill
Engineering Consultant

ABSTRACT

This paper presents a new concept for a small waterplane ship which maintains the seakeeping advantages of the Small Waterplane Area Twin Hull (SWATH) ship concept while reducing the drag about 15%, doubling the control and low speed damping forces, producing steering forces without a conventional rudder, and reducing structural weight (by reducing the cross structure bending moment by a factor of 3). The configuration of the concept also offers excellent damage stability characteristics and is uniquely suitable for both hull-mounted and toned acoustic sensors.

This paper includes a discussion of the advantages and drawbacks of the concept compared to a conventional SWATH ship as well as calculations of key parameters to support the claims above.

BACKGROUND

During the summer of 1982, while I was still working at the David Taylor Naval Ship R&D Center (DTNSRDC), I was searching for ways of improving the low speed control and damping of SWATH ship motions, as well as continuing my search for an alternative method of steering a SWATH ship. Any method which significantly increased the drag, weight or complexity, or degraded the seakeeping performance was considered unacceptable. All solutions for improving the low speed control pointed to larger and more efficient (higher aspect ratio) appendages which increased the drag, weight and control power. Clearly, to accommodate this extra drag and weight the drag of the unappended SWATH must be reduced to stay within the guidelines stated above. But how?

The idea developed to take advantage of the square-cube relationship between the wetted area (a major source of drag) and the volume (displacement) by replacing the two lower hulls of a SWATH ship with a larger single central hull, while leaving the original SWATH struts which supply the waterplane area in place. The configuration, Figure 1, would allow full-span high aspect ratio foils to be placed between the central hull and the outer struts (which supply the same waterplane area in the same place as in a conventional SWATH*). These foils would be placed at an angle of about 20 degrees from the horizontal. By being at an angle, the lift generated by the foils has a significant horizontal component which can be used to supply the steering moment, thereby providing an alternative method of steering a small waterplane ship.

Before proceeding with this paper, I think it is appropriate to point to two alternative configurations shown in Lang's patent in which a single hull is used in a small waterplane ship.[1] These are shown in Figure 2.

As I develop the concept further in this paper, I will leave it to the reader to judge the degree of similarity and

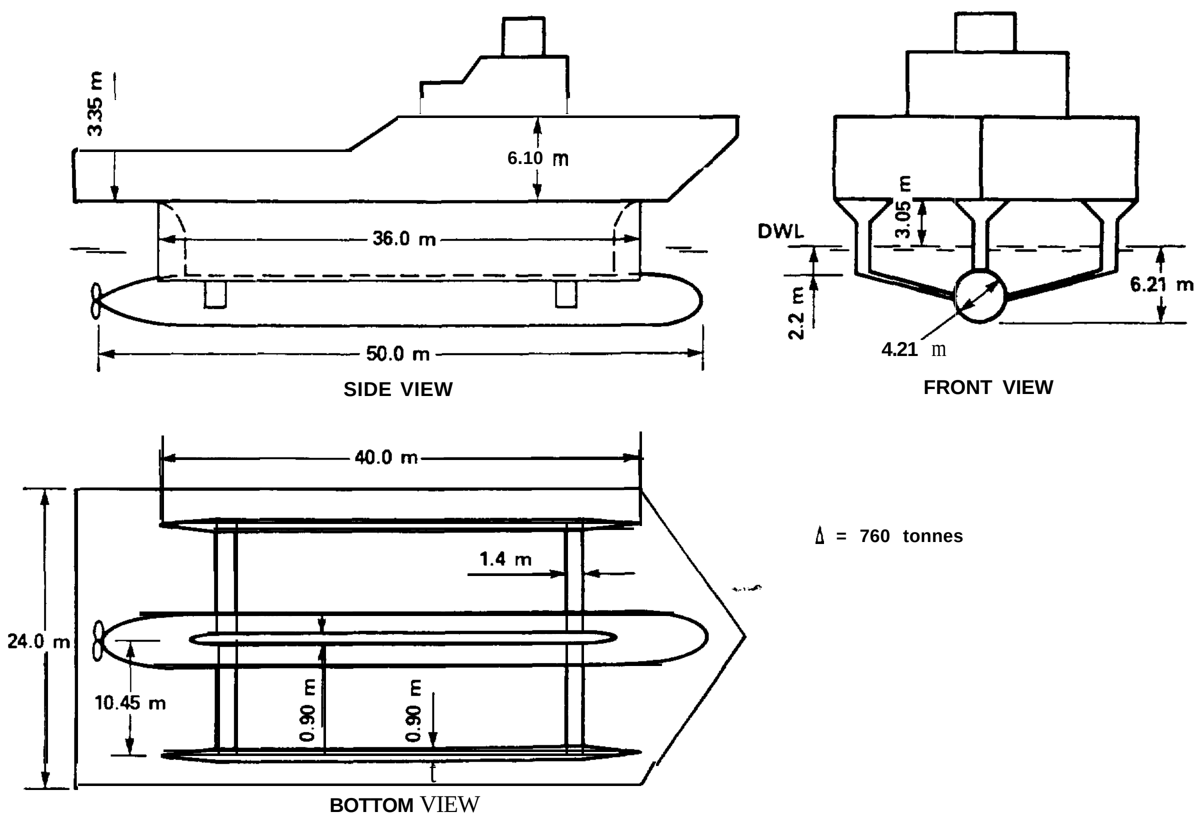
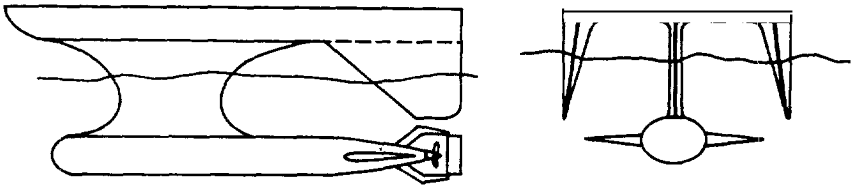
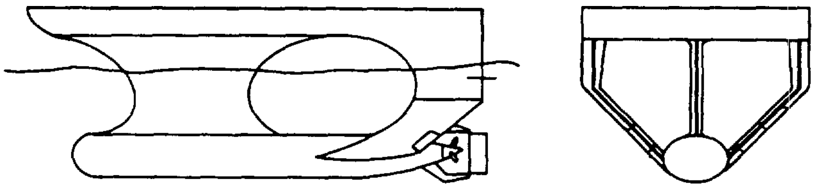


Figure 1 - The New Small-Waterplane-Area Ship Concept SWATS



VARIATION A



VARIATION B

Figure 2 - Two of the Alternative Configurations Shown in Lang’s Patent’

differences between this concept and those shown in Dr. Lang’s patent.

Having provided this background, let us proceed with a technical assessment of the concept in which its key features are discussed and quantified where appropriate.

*As shown in Figure 1, a thin strut is used to structurally support and supply access to the central hull. This strut results in additional waterplane area. However, by adjusting the beam, length and thickness of the outer struts one can obtain similar pitch, heave and roll stiffness as a conventional SWATH of the same displacement.

TECHNICAL ASSESSMENT

As a baseline with which to compare this concept, a conceptual design for a 765 tonne Coast Guard SWATH[2] was selected. To avoid confusion between this concept and a conventional SWATH the following terms will be used in the rest of this paper.

SWATS	- This concept. SWATS stands for Small-Waterplane-Area Triple-Strut
Lower Hull	- The submerged center hull
Center Strut	- Strut attached to the Lower Hull
Outer Struts	- Outboard struts which supply the waterplane area required for intact roll stability
Foils	- Control appendages which run between the Outer Struts and the Lower Hull

RESISTANCE

Typically, the two lower hulls of a SWATH provide about 80% of the total buoyant volume.[3] Since one of the premises of the SWATS concept is to retain essentially the same outer struts as for a comparable SWATH, it was assumed that the combination of the center hull and center strut provide 80% of the SWATS buoyant volume. If we neglect the contribution of the center strut as being very small, it follows that the center hull of the SWATS has twice the buoyancy of one SWATH lower hull. Assuming that the SWATS and SWATH lower hulls have the same length-to-diameter ratio, the SWATS lower hull will be about 26% longer than the SWATH hull. Consequently, for a given ship speed the Froude number of the SWATS will be about 12% lower than that for the SWATH. A lower Froude number at the maximum design speed frequently means lower wavemaking resistance. Because of the square-cube law, the wetted surface area of the SWATS lower hull per tonne of displacement will be about 26% lower than that for a SWATH. However, due to the additional wetted surface area of the center strut, a SWATS configuration has about the same total wetted surface area as a SWATH of the same displacement.

Since none of the Navy’s standard SWATH resistance-prediction computer programs could be quickly adapted to the SWATS configuration, a simplified method of calculating the drag was used. The drag of the lower hull was obtained from resistance curves previously generated for bodies of revolution of various sizes with 70% parallel mid-body. These curves had been developed for the Extended Performance Hydrofoil studies at DTNSRDC. The drag for these bodies was obtained by summing the wavemaking resistance predicted by Chapman’s program and the frictional resistance based on Schoenherr. Figure 3 is a plot of the ratio of drag to buoyancy at 20, 25, and 30 knots for hulls of different displacements and a length-to-diameter ratio of 12. This figure clearly shows the increase in efficiency with size. The drag of a basic lower hull for SWATS was calculated from the data in Figure 3. The remaining drags were calculated using the straightforward formulas shown in Table 1.

The drag and effective horsepower (EHP) for the 765 tonne Coast Guard design were also calculated using this simplified method and compared to the prediction from the Chapman SWATH drag program. As can be seen in Table 2

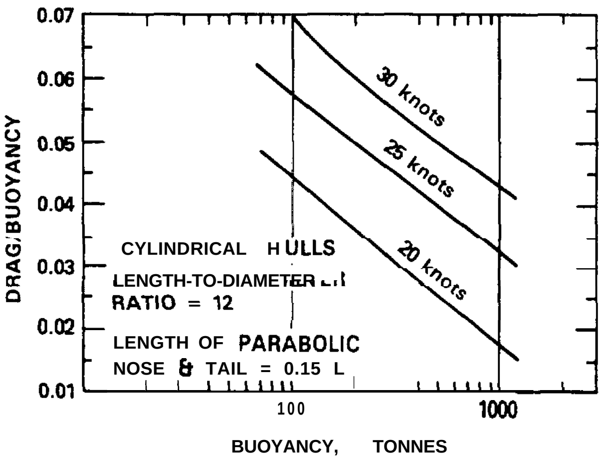


Figure 3 . Predicted Efect of Increased Size on the Ratio of Drag to Buoyancy for Submerged Cylinders

the two methods agree quite well, which gives credence to the drags calculated for the SWATS (shown in the last three columns on the right side of Table 1). The net result is that the estimated drag and EHP of the SWATS are 14% lower than the conventional SWATH at 20 kts., 10% lower at 25 kts., and 4% lower at 30 kts.

STRUCTURAL WEIGHT ESTIMATE

The structural weight of the SWATS was estimated using the same procedures used to estimate the structural weight of the 765 tonne Coast Guard design. The estimated weights of the major components are:

Lower Hull	38 tonnes
Center Strut	30 tonnes
Outer Struts	36 tonnes
Upper Hull or Box	I 15 tonnes
Deck House	60 tonnes
Total	279 tonnes

TABLE 1
SUMMARY OF DRAG ESTIMATE

Drag Component \ Config. / Speed	765 Tonne Coast Guard SWATH			750 Tonne SWATS		
	20 kt	25 kt	30 kt	20 kt	25 kt	30 kt
Lower Hull[a]	43,868	65,884	76,770	30,527	50,435	63,973
Hull Roughness[b]	4,682	7,316	10,535	3,676	5,743	8,271
Total Lower Hull Drag	(48,550)	(73,200)	(87,305)	(34,203)	(56,178)	(72,244)
Center Strut[c]	9,150	13,684	19,197	2,987	4,467	6,267
Spray Drag[d]	4,779	7,467	10,753	2,390	3,734	5,378
Total Center Strut Drag	(13,929)	(21,151)	(29,950)	(5,377)	(8,201)	(11,645)
Add'l. Residual Drag[e]	6,783	10,598	15,262	4,369	6,827	9,830
Total Unappended Drag	(69,262)	(104,949)	(132,517)	(43,949)	(71,206)	(93,719)
Foil Drag[f]	1,750	2,617	3,671	3,501	5,234	7,343
Rudder Drag[g]	1,175	1,757	2,465	N A	N A	N A
Outer Struts Friction	N A	N A	N A	9,986	14,936	20,953
Outer Struts Spray[h]	N A	N A	N A	4,779	7,467	10,752
Total Appendage Drag	(2,925)	(4,374)	(6,136)	(18,266)	(27,637)	(39,048)
TOTAL SHIP DRAG	72,187	109,324	138,653	62,215	98,843	132,767

NOTE: All drag values shown are in pounds.
[a] Lower Hull Drag = D/W x W
[b] Hull Roughness Drag = 0.0005 x Hull W.S. x q, where $q = 1/2\ \rho V^2$
[c] Strut Drag = [1 + 1.2 (t/c)] [C_F x Strut W.S. x q]
[d] Strut Spray Drag = 0.24 t^2 x q
[e] Additional Residual Drag = 0.0005 (L. Hull W.S. + Strut W.S.) x q
[f] Foil Drag = [1 + 1.2 (t/c)] [C_F x Foil W.S. x q]
[g] Rudder Drag = [1 + 1.2 (t/c)] [C_F x Rudder W.S. x q]
[h] O. Struts Spray Drag = 2 x (0.24) x t^2 x q

TABLE 2
COMPARISON OF ESTIMATED EFFECTIVE HORSEPOWER

Drag Component \ Config.	765 Tonne Coast Guard SWATH 20 kt	25 kt	30 kt	750 Tonne SWATS 20 kt	25 kt	30 kt
Estimated Total Ship EHP	4,433	8,393	12,774	3,821	7,588	12,231
EHP From Reference 2	4,384	8,338	12,010	N/A	N/A	N/A

This weight should be conservative (high) as it does not take into account the greatly reduced bending moments inherent in the SWATS. The structural weight estimate for the 765 tonnes SWATH Coast Guard design is 316 tonnes, or 37 tonnes higher than that of the SWATS. Both designs are assumed to be built of 5086 aluminum.

HULL STATIC BENDING MOMENT

To calculate the transverse static bending moment of a conventional SWATH and a SWATS, both were considered to be a beam. Figure 4 shows an estimate of the static loading for each. In both cases, the estimated total weight of the upper hull structure and its contents is 480 tonnes. The loadings shown result in a bending moment at the center of 1537 meter-tonnes (4960 ft-tonnes) for the SWATH and only -476 meter-tonnes (– 1536 ft-tons) for the SWATS. The estimated SWATS structural loading is less than one-third of that for a SWATH of equal displacement.

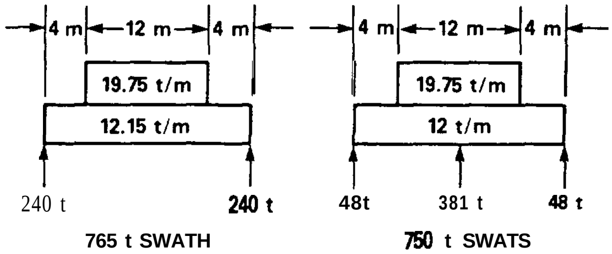


Figure 4 - Estimated Static Transverse Loading on the Upper Hull Structure of a SWATH and a Comparable SWATS

FOIL STRENGTH

When the SWATS concept was first shown to a structural engineer, his reaction to closing the box with the foils was very favorable. However, he did have reservations about the column loading on the foils, particularly since they may be simultaneously carrying high lift loads. To allay this concern the following analysis was made.

Bending. The maximum possible lift on the foil is equivalent to a lift coefficient of 1.2, which translates into a maximum foil loading of 147.5 kn/m^2 (3084 lbs/ft^2) at 30 kts. The foil for a 765 tonne SWATS was estimated to have a span of 7.1 m (23.3 ft), a chord of 1.4 m (4.59 ft) and a maximum thickness of 0.28 m (.92 ft). Under the maximum loading the foil would have a maximum bending moment of 1300 kn-m (11.52 million inch pounds) for a pinned-pinned beam and 867 kn-m (7.68 million inch pounds) for a fixed-fixed beam. Assuming the higher of these and a 2.54 cm (1 inch) thick skin at the highest stressed area, the resulting bending stress under the maximum possible load is 246 MPa (35700 psi). The resulting deflection at the center of the span is 4.47 cm (1.76 in.).

Column Load. The ratio of the length of the column to the radius of gyration of the foil is 75. The critical column load for this foil is 26,700 kn (6 million lbs.). Based on SWATH experience the maximum side load that would be experienced by this ship is 0.7 times its displacement.4 If this total load was passed through a single foil, the foil would have a column load of 5,246 kn (1.18 million lbs.). The extra moment created by this column load if the foil were at its maximum lift, and therefore at its maximum deflection, would be 234 kn-m (2.08 million in-lbs.). The new total moment would then be:

$$\frac{1300 \text{ kn-m}}{\left(1 - \frac{234}{1300}\right)} = 1585 \text{ kn-m (14 million inch pounds)}$$

If the maximum column and bending loads occurred simultaneously the resulting bending stress would be only 300 MPa (43500 psi). This is well below the yield stress of HY-100, the likely material for the foil.

CONTROL AND DAMPING FORCES

The control surfaces on the SWATS have approximately twice the area and a considerably higher aspect ratio than those of a conventional SWATH, and therefore are capable of generating more than twice the control forces.

Heave damping is that force which is 180 degrees out of phase with heave velocity. The heave force supplied by the foils resulting from heave velocity is:

$$(CL_\alpha)_F \frac{\dot{z}}{u} s\left(\frac{1}{2}\varrho u^2\right) = (CL_\alpha)_F \, s \, \dot{z}\left(\frac{1}{2}\varrho u\right)$$

where $(CL_\alpha)_F$ = lift curve slope of the foils

$\dot{z}$ = heave velocity

u = forward speed

s = area of the control surface

ϱ = mass density of water

In a two degree of freedom system, δ, the ratio of damping to critical damping, is obtained by dividing the force **due to heave** velocity by two times the square root of the product of heave stiffness times the mass. Using the physical values for a 765 tonne ship we get

$d = .0196\ u\ \frac{sec}{m}\left(.006\ u\ \frac{sec}{ft}\right)$ for the Coast Guard design and $d = .574\ u\ \frac{sec}{m}\left(.0175\ u\ \frac{sec}{ft}\right)$ on the SWATS.

In other words, the fins on the proposed concept supply three times the heave damping of those for a conventional SWATH.

TURNING

The actual turning moment which can be generated by the horizontal components of lift of the foils of a SWATS is between 50 and 70% of that generated by the large over-hanging rudders used in the SWATH Coast Guard design. There is, however, an extra source of side force when the foils generate lift. When the foils on the side of the hull are deflected to give upward lift, there is a low pressure field created on the upper side of the foil and a high pressure field on the lower side. The low pressure field extends quite far from the foil and acts over a considerable area on the upper part of the hull and the strut above it. On the other hand the high pressure field has only a limited area, the lower part of the hull, at most, to act on. The net result is a side force created by these pressure fields. The existence of the phenomenon has been well substantiated by model test at the David Taylor Naval Ship Research and Development Center. For the low aspect ratio foils used on conventional SWATHs, the magnitude of the force has been quantified and is equal to about one half the total lift on the foil. There is no data on higher aspect ratio foils as yet. but there appears to be little doubt that sufficient turning forces can be generated by the foils to eliminate the need for conventional rudders behind the propeller.

OTHER CONSIDERATIONS

Single Propeller. One feature of SWATS which raises questions is the single propeller. With a single propeller, docking and low speed maneuvering are difficult. To circumvent this problem and supply excellent low speed maneuvering control, it is proposed either:

- to place in the rear of each outer strut a small water jet with a steering and reversing bucket, or
- to place a thruster in the forward end of one strut and the rear of the opposite strut.

Draft. The SWATS would have a deeper draft than a conventional SWATH due to the larger lower hull. If this draft is excessive it can be reduced by using an elliptically shaped hull. For the currently assumed distribution of buoyant volume, a SWATS with an ellipitical hull having a horizontal axis 1.59 times its vertical axis would have the same draft as an equivalent displacement SWATH with circular lower hulls. Of course, the SWATH could use ellipitical cross-section hulls, in which case SWATS would have a greater draft.

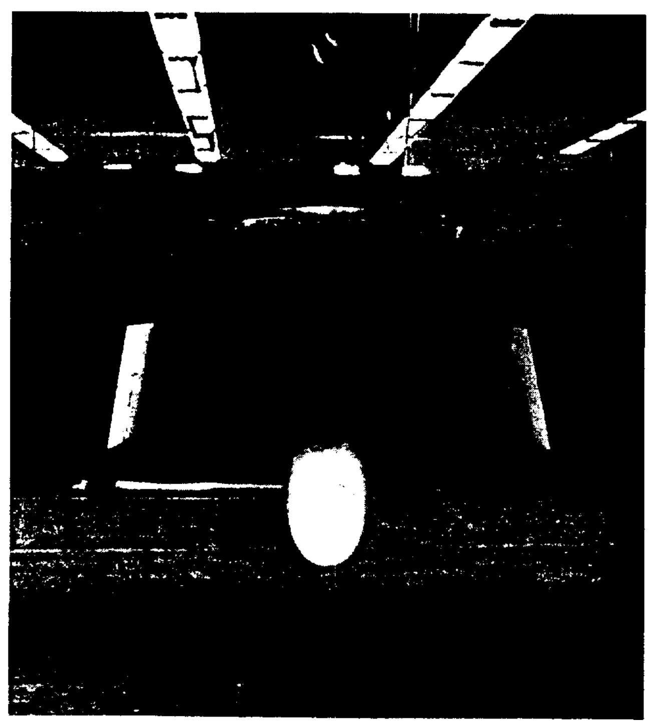
Survivability. It is reasonable to believe that the outer struts of the SWATS would act as side protection to the lower hull, which contains critical propulsion machinery. For this reason SWATS should be more survivable against missile hits than the equivalent monohull and should have comparable survivability to a SWATH (which has redundant propulsion systems because of its twin hulls).

Deck Length. The short main deck length of a SWATH ship, compared with a monohull of similar displacement, can present topside arrangement problems. Because the buoyant volume of a SWATS is concentrated in one hull rather than two, for the same length-to-diameter ratio the SWATS hull would be 26% longer than the hull of a SWATH ship of the same displacement. Consequently the strut will also tend to be longer than the strut on a SWATH ship. This makes possible a longer main deck, facilitating the topside arrangements.

Sensor Mounting. The larger diameter lower hull of a SWATS can accommodate a larger hull-mounted bow sonar than in a SWATH of the same displacement. This sensor would be well forward and free from the masking effects of an opposite hull.

VALIDATION OF RESISTANCE ESTIMATE

A resistance experiment was run at DTNSRDC in 1985 on an existing single hull small-waterplane-area ship model which had been modified by addling outer struts, to configure it as a SWATS. The dimensions of the model and the results of the tests are reported in reference 5. This model is shown in Figure 5. Although the configuration was not ideal, the center strut being too long and too thick, its geometry was sufficiently representative to give a good indication of the resistance characteristics of a SWATS.



Figure& . Bow View of the DTNSRDC 4328 Tonne SWATS Model

The model was a 1:25 scale of a 4328 tonne ship. It was tested unappended with and without the outer struts in place. The resistance of both cases is shown in Figure 6. For all of the experiments the model was held captive with respect to heave and trim. The diamonds are the resistance calculated by the simplified method previously described herein. As can be seen, the simplified method of calculation overestimates the

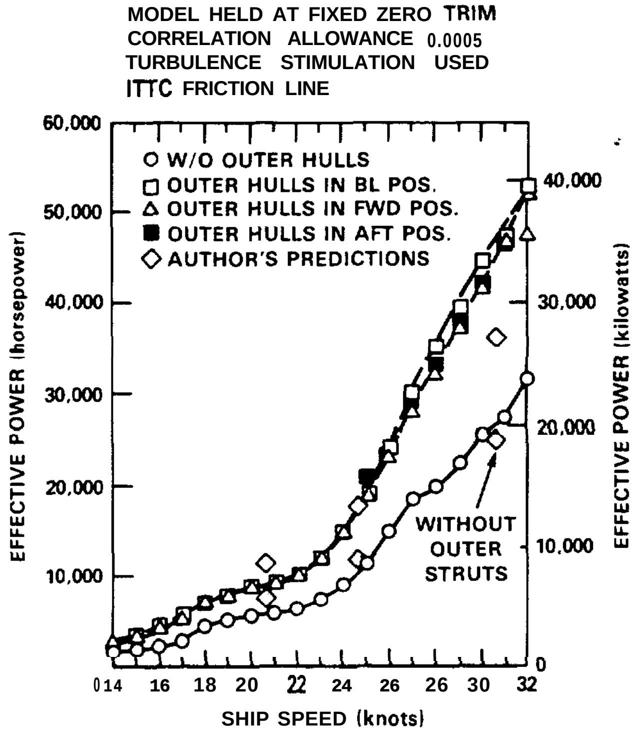


Figure 6 • Comparison of Measured and Predicted Effective Horsepower for the DTNSRDC 4328 Tonne SWATS Model

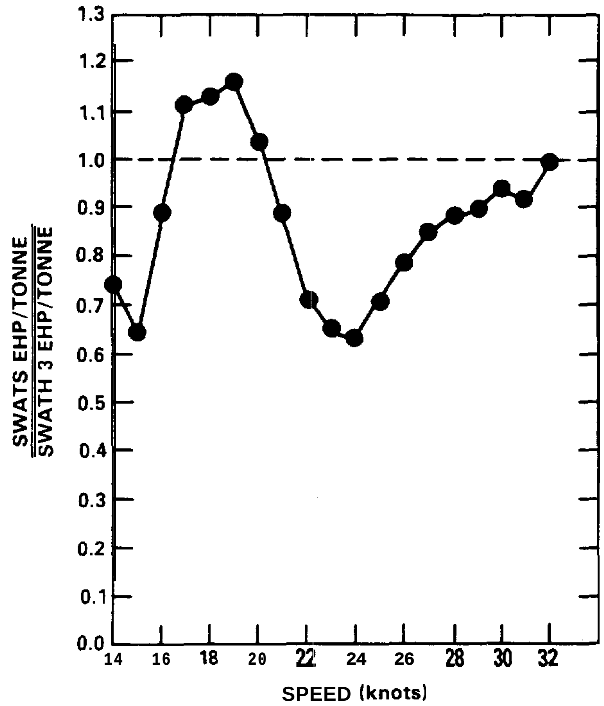


Figure 7 • Comparison of the Measured EHP per Tonne for the SWATS and SWATH 3 Models

EHP somewhat for the model without the outer struts but underestimates the drag of the outer struts, particularly at the higher speeds. The simplified method does not account for interference drag which, based on the model tests, is quite significant at higher speeds.

In order to get a more valid picture of the comparative resistance of the SWATS and a conventional SWATH, these model tests results were compared with previous model tests results of the unappended SWATH 3 model. In order to account for the 11% difference in displacement between SWATH 3 and the SWATS models, the Effective Horsepower (EHP) per tonne were compared. Figure 7 shows the ratio of EHP per tonne of the SWATS model and the EHP per tonne of the SWATH 3. As can be seen, except for speeds between 16.5 and 20 knots the EHP per tonne of the SWATS is considerably lower than that of the SWATH 3. It averages 13% lower between 14 and 32 knots and 19% lower between 20 and 30 knots. This lower resistance of the SWATS is impressive since the configuration of the model was far from optimum. Examples of what would be done for a more optimum design which would reduce its resistance are:

- contour the lower hull
- thin and possibly shorten the center strut
- reduce interference drag by moving the outer struts further aft, following some of the recommendations made by Narita.[6]

How much the above would reduce the resistance is a matter of conjecture, at this time, but it should be substantial.

SUMMARY

This paper has described a new configuration of a small waterplane ship in which the two lower hulls of a SWATH are replaced by a larger single central hull, and the original struts are left in place to supply the waterplane area for intact roll stability. This new configuration requires a small increase in draft and has a single propeller in lieu of two as a SWATH. The new concept appears to have many potential advantages which have been discussed in the paper. These advantages are summarized below:

- Lower Resistance
- Improved Control
- More Efficient Structural Design
- Longer Deck (Easier to Arrange)
- Accommodates Larger Sonars
- Higher Survivability Against Missile Hits
- Improved Damage Stability

In light of these potential advantages, it is hoped that development work on this concept will continue.

ACKNOWLEDGMENTS

The author wishes to thank Dennis Clark of DTNSRDC for his encouragement and sponsorship of the exploratory development work done to date on this concept. 1 would also like to thank Robert Lamb of DTNSRDC for applying his SWATH expertise in reviewing this paper.

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