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On the potential of SWATH ships for safe, efficient and fast transportation

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ABSTRACT

The way in which the building and design of SWATHs has developed over the last twenty years is discussed. The interaction between resistance minimisation and the design constraints relating to propulsive systems, fuel demand and structural weight is examined. In addition, consideration will be given to stability, both intact and damaged, to establish factors relating to safe operation.

INTRODUCTION TO SWATH TECHNOLOGY

With regard to seakeeping, it is recognised that deep submergence of buoyancy is desirable. The development of deep keeled boats and semi-submersibles has used of this property but it has to be recognised that the singleminded optimisation of a single design feature will probably have detrimental effects on performance elsewhere. SWATHs follow this indicator and offer remarkable seakeeping properties. The struts provide hydrostatic stability as well as helping to reduce the resistance. As a consequence of this stable ride in a seaway there is a lesser need to reduce speed in rough seas. The double benefit is that not only are the wave excitation forces reduced but the dependence of the natural periods on the waterplane area and the GMs allow designer control of the response curve.

In the early days of the development of the modern SWATH, there was a widespread expectation that SWATH like other advanced naval vehicle concepts would naturally fall into the category of fast ships. The developments to date have not fully borne out this anticipated trend. It is, of course, not realistic to consider any one aspect in isolation. Any vessel which is to satisfy high speed roles in the open ocean needs not only a high calm water speed but also the ability to maintain speed in a seaway and provide a good enough quality of ride for crew and passengers. With regard to high speed per se, SWATHs have the penalty of higher wetted surface area which contributes inevitably to penalties in the frictional resistance at lower speeds in particular. However, there is scope for managing the wavemaking resistance which stems from the interference between the different components of the SWATH geometry. It is when it comes to the behaviour in waves that the SWATH's excellent seakeeping and the remarkable evidence, from model and fullscale trials, for negative added resistance really start to bring the SWATH concept into consideration.

If, as is often stated, new concepts take of the order of 20 years to become accepted, SWATH is now close to its "limit" since it is appropriate to accept KAIMALINO (1973) as the first SWATH ship of significant size. Of the first 28 SWATHs built, the roles for which they were designed is quite large: ocean engineering, naval workboat / surveillance, fast ferry, hydrographic survey and oceanographic research, fishing, luxury cruise / yacht, and cruise liner. Further roles as combatants, minehunters, offshore patrol vessels, coast guard and drug enforcement vessels and ro-ro ferries are among other possible opportunities under consideration. This spread is both part of the solution and part of the problem in that SWATHs have not developed a clear well defined niche in the market but they have been shown to be versatile in a mix of roles.

"RESISTANCE" TO SWATH ACCEPTANCE

In spite of the demonstration of the seakeeping qualities of SWATH ships by the existing SWATHs, and by theoretical and test data, the the marine community is still not fully convinced of the utility of the concept.

A multi-hull geometry has a large surface area which in turn implies a high "steelweight" fraction and higher frictional drag. SWATHs also operate at higher Froude numbers for a given speed than monohull competitors. Early dreams of very high speeds were unfounded and even though there is a point at which lower wavemaking drag due to the slender waterplane does favour the SWATH, it is at a higher speed, and power level, than originally anticipated.

The twin hulls also lead to some duplication adding weight in terms of machinery, fuel and structure. It is also difficult in many designs to use space in the struts and haunch area efficiently and so a SWATH designed to carry a given payload will be larger than its monohull counterpart. To control construction costs, emphasis needs to be given light-weight structural design and material selection and simplified construction [1] and a high degree of care exercised at the design stage so that trade-offs in life cycle costs are properly identified and costed.

The waterplane area has its "down side" since it means large variable loads are impractical without sophisticated ballast systems which are themselves an expense in both money and payload. This introduces the need to consider the trim induced as fuel is used up and how best to use the deck space and box volume to ensure even loading. These problems can be overcome . A SWATH is a poor candidate for the transport of heavy cargoes but an excellent choice for low density cargoes and operations that require least motions.

Large beam and draught may exceed design constraints in some circumstances and render the SWATH impracticable where shallow water ports must be used or where the transit of canal locks is necessaary. There are also advantages. SWATHs do not have more deck area than monohulls of the same displacement but it is more useful, particularly for aircraft operations. High freeboard can be inconvenient in special circumstances with regard to accessing the sea surface but underwater operations are facilitated by having sufficient space around a centrally located moonpool for cranage and equipment handling. The deep draught and reduced motions improve sonar performance by reducing the bubble sweepdown and propeller aeration.

Geometric differences of the SWATH relative to the monohull and the "benefits" are summarised in [2].

FAST SWATHS

If the aim is to travel quickly then the sea surface is not the best place to try. The solution has been to try to move away from the free surface by using a combination of dynamic or static lift. SWATHs are among the least successful "advanced vehicles" at achieving this separation from the wave zone and consequently do not have a very high calm water speed. However, two thirds of the early SWATHs have a design Froude number greater than 0.5 and are in ship terms "fast". There is no discernible pattern of reduced payload fraction or transport efficiency as the Froude number increases. for these SWATHs.

It is important to consider the reasons for needing high speeds and the conditions under which they must be achieved. For ocean going vessels, the quality of ride in a seaway is of crucial importance to the acceptability of the craft by owners, crew and public. Even low vertical accelerations (0.2g) will produce sea sickness in seas dominated by 5 sec waves. The reliability of the service is critical to customer acceptance. This means keeping to schedule. It may not be the vessel with the highest calm water speed that provides transport with the minimum overall transit times. SWATHs, because of their ability to maintain speed in a rough sea, are good in this respect.

The design of any vessel is a synthesis of many aspects but to achieve higher speeds the crucial factor is being able to power a SWATH hull through the water at the desired speed with engines and fuel that can be housed within the vessel and still leave a useful payload. This implies that resistance, powering and machinery are the dominant factors in the context of the whole design. The design method used in this paper is the DESIN suite which has been describe in [3,4].

Resistance

Resistance test results show that above the strong peak at a Froude number (Fn) of 0.3 and the weaker peak near 0.5 there is a dip in the curves at Fn=0.65.[5]. Fig 1 shows how SWATH vessels have tended to the better values. At model scale the frictional and residual drag contributions are similar in magnitude. At full scale, this proportion is reduced but frictional drag is around 40% of the total. This factor alone is discouraging since the geometry of the SWATH necessarily implies a substantial increase in the wetted surface (around 60%). The various components of the SWATH geometry interact with each other to produce considerable interference in the wavemaking components and these can be greatly modified by judicious variations in shape. In an example [5], the wavemaking resistance coefficient was reduced by 70% at the design speed.

Parameters affecting Resistance at Higher Speeds

Demihull spacing At moderate speeds (Fn=0.35-0.44) favourable interference exists between the demihulls. This can lead to savings of around 40% in the optimum conditions but once the Fn goes above 0.5 the gain is lost.

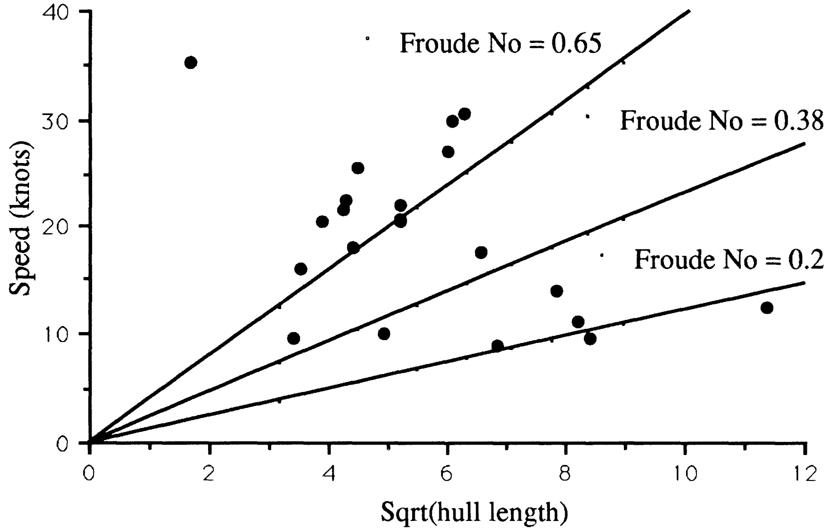

Fig 1: Froude Numbers for SWATH Ships

Hull / strut and strut / strut interference For tandem strut SWATHs, strut / strut interference is usually unfavourable at higher speeds. It does however become small if the two struts are more than a chord length apart and so locating the struts near the ends of the demihulls is beneficial since this also benefits the body / strut interference.

Draught Increasing draught increases the wetted surface area and more deeply submerges the hulls. Re wavemaking drag, the result is that the strut drag increases and the hulls drag decrease. In general, for tandem strut designs the reductions outweigh the increases at high speeds and increased draught helps above Fn=0.45. For single strut designs, increasing draught is a disadvantage in the higher speed range. A fuller investigation shows that these SWATHs are very thin and that if the slenderness ratio were decreased this would have the effect of increasing wavemaking resistance but the increase in draught would then have beneficial effects since the wetted surface area and hence the frictional resistance is reduced. Single strut SWATHs are likely to be relatively squat and deep draught if they are to operate at higher Froude numbers. For a given displacement, this Fn will correspond to less raw speed.

Strut length The short strut has the advantage for Fn > 0.5. The overhanging strut also has advantages suggesting care in designing the entrance and the run is necessary.

Strut number and shape A comparison [5] examined a range of non-optimised struts: namely single long, tandem, triple and contoured, and showed that, of this set, the triple strut design was slightly better at high speeds although very much worse at lower speeds. This tandem and single strut versions were similar at top speeds.

Fin contribution While most SWATH designers believe that fins are necessary to avoid trim instability at higher speeds, this is not always the case. From experimental investigations at Hyundai Maritime Research Institute, it was observed that well designed SWATHs never exhibit pitch instabilities at higher speeds.. Fins cause a drag penalty of 3 to 5% (depending on size) at even trim running condition in calm water. However, model self-propulsion tests showed that there was a considerable power saving from a SWATH model running at optimum trim (controlled by fins) as compared to that at even trim. This was confirmed during the full-scale sea trilas of Hyundai's 320 tonne SWATH in that the speed at optimum trim was 2 knots higher than that achieved for even trim. This optimum can be achieved by ballasting at the expense of displacement. In desgning high speed craft it is best to reduce the displacement for a given payload and engine power. In this regard, fins do not have a nett drag penalty but have a more or less positive effect on the powering. In addition the presence of fins enhance the seakeeping quality of SWATHs.

The presence of fins in the SWATH concept should be viewed as an advantage which is not shared by monohulls or catamarans even though the use of fins increases the construction cost and weight.

From PATRIA [6] it is seen that the use of a larger waterplane area and a tipped rudder give a speed benefit with a compromise in the seakeeping quality. In this regard, the use of sledge bow designs is worth serious consideration.

Hull shape. At high speeds, strut and strut / body interference reduce drag for the circular hulls. Hulls may be contoured to optimise resistance or to fit machinery. Comparing 3 styles of hull design; simple hull, high-speed "dogbone" and "cokebottle" designs [4] showed that while the cokebottle design perform well at slow speeds and have been adopted for the USN slow speed TAGOS 19, they are very poor as the speed increases. The dogbone designs are, in general, worse at slower speeds but produce small but significant savings at higher speeds.

Performance in Waves

Achieving high speeds in a seaway gives SWATHs one of their biggest advantages. Fig 2 compares resistance / displacement ratio from tank tests of three 1.5 m models: single strut SWATH3, a Destroyer DE-1006 (Cb=0.49) and Series 60 (Cb=0.7). In calm water, the SWATH has the greatest resistance at lower speeds but, at higher speeds, the Series 60 curve rises very steeply although the destroyer is still 8-10% lower. In waves, the situation is totally different. The monohulls have a much increased resistance and the power required by the SWATH at Fn=0.285 is around 60% less than that for the destroyer.

Tests with tandem strut SWATHs have shown negative added resistances [7,8]. In these cases the comparison would be even more dramatic over part of the speed range but it is the very low added resistance in waves at the higher speeds which gave fig 2. Trials with the 12m SWATH ALI have confirmed that the negative added resistance exists at sea (fig 3).

To investigate the interactions between the parts of the SWATH geometry, first and second order wave forces have been evaluated using a 3D panel source method [9]. Figure 4 compares the measured and computed added resistance coefficients. It is seen that when the motions of the model are small, the energy loss due to the radiated waves is low and sometimes negative over the speed range where the negative added restance occurs. The contribution from the diffraction waves wipes out the negative and leaves an overall positive value. The present theory is inadequate to predict this effect.

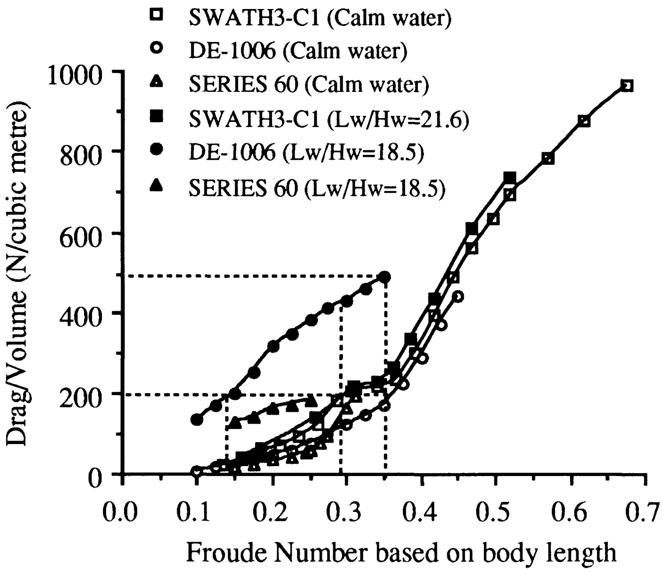

Fig 2: SWATH and Monohulls in Waves

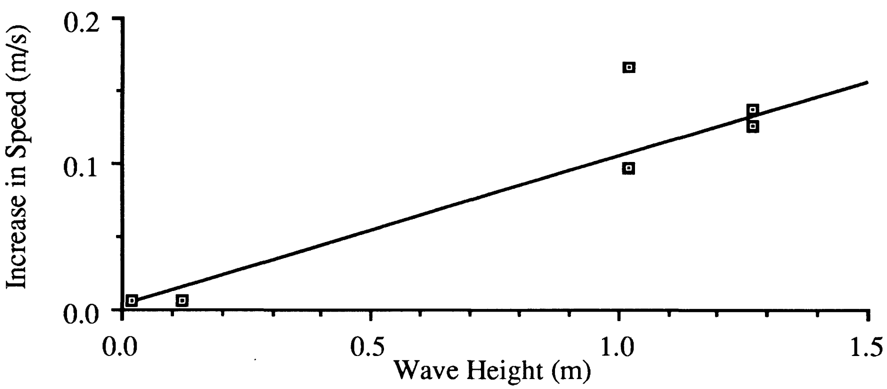

Fig 3: Augment in Speed for Fishing SWATH ALI at 1600rpm

<u>Powering</u>
A study into the design of 4 bladed propellers for a family of SWATHs from 1000t to 5000t for a range of moderate speeds [4] provides some guide as to what may be expected to happen at higher speeds.

<u>Quasi propulsive coefficient</u> The optimum QPC values are seen to range between 0.73 an 0.8 at the highest speed. These are high values and even though the curves for the higher displacement designs show some tendency to decline, they are encouraging for high speed performance.

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Optimum diameter The optimum propeller diameter increases with ship size even though its ratio to the hull diameter decreases in line with experience of several existing SWATHs which have ratios of the order of 0.83. For this family of SWATHs, the optimum propeller diameter ratio is proportional to the square root of the power speed ratio. This trend looks quite a good indication for the behaviour of faster vessels.

Machinery and Materials

The question is now whether it is possible to provide and fit the machinery with the required capacity into the vessel and still leave a useful payload.

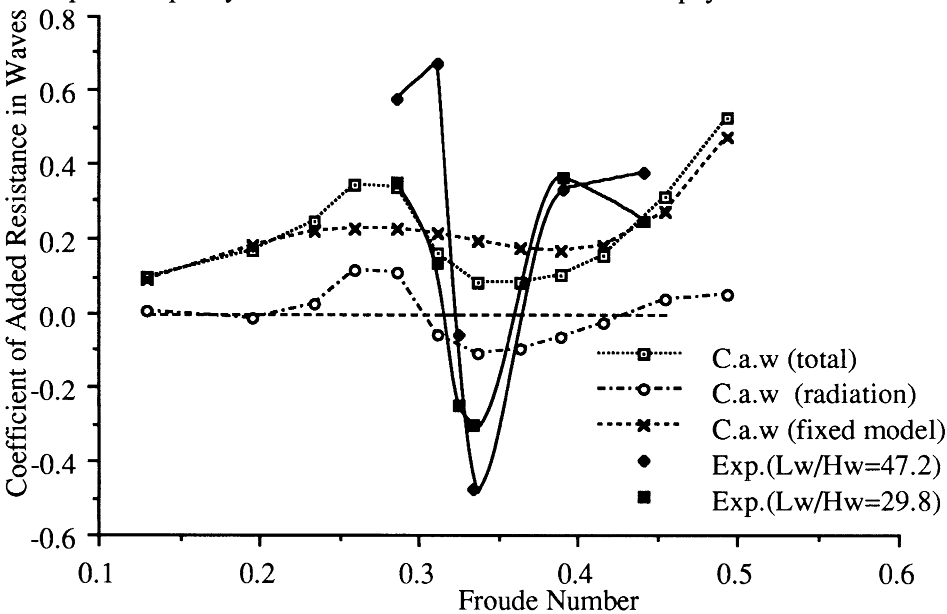

Fig 4: Added Resistance Coefficient of SWATH1-C5 for lw/Lb=1.5 (Head Sea)

Structural materials Since nothing affects the power / speed ratio more than displacement, the ideal choice in this context is a light weight material such as aluminium

Machinery The design of the propulsion system must be highly interactive because of the inter-relationship between hull form and required power and the awkwardness of the space available. The most powerful engine which can be fitted into a hull has been identified [4]. The smallest displacement for a given machinery fit is found when the hulls are elliptical (B/D=1.3).

With 15% appendage drag and 15% for design margins, it is not possible for any of the simple hulls to fit a propulsion scheme in the hulls to achieve a sustained speed of above 30 kts. Different hullforms may influence sustainable speeds as much by their capacity to fit machinery as by their drag and some dogbone designs may achieve higher speeds than simple hulls because they are more capacious even when they may be more resistful.

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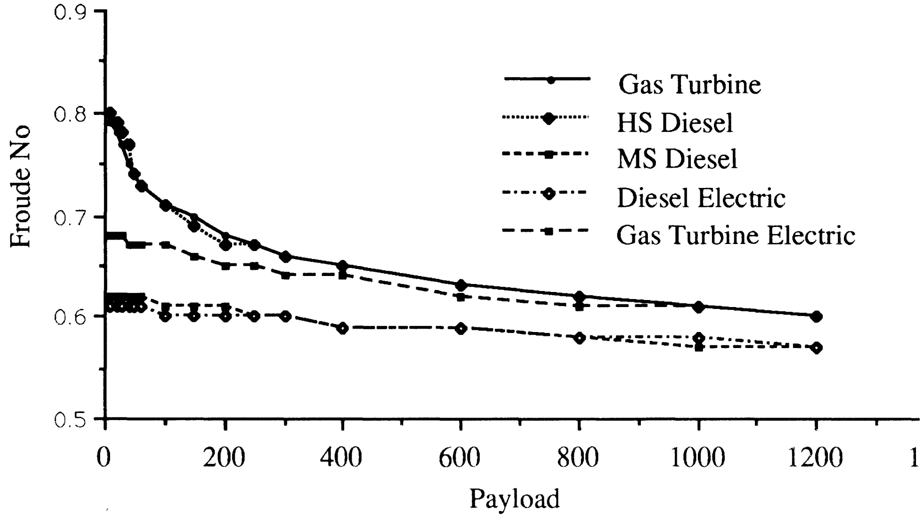

Fig 5: Probable Froude Number of 36kt Aluminium SWATHs against Payload

From an INITIAL SWATH design study with differing payloads for a speed of 36 kts with 500 nm range, fig 5 shows that smaller vessels would operate in a Fn-range from 0.6 to 0.8 but near to 0.6 for large ships (cf fig1).

Intact and Damaged Stability

SWATHs themselves have good stability characteristics and the designer has considerable choice over the longitudinal and transverse GMs since these and the waterplane area are dominant in the determination of natural periods.

According to [10], initial flooding leads to rapid changes in heel / trim but this is eased when the haunch area become submerged increasing the waterplane area. (This and the emergence of the submerged hulls cause very nonlinear stiffness characteristics and limit the dynamic roll to very moderate angles.) SWATH survivability is likely to be superior to that of an equivalent monohull. The maximum heel angle from a flooding of 25% of the hulls (with 95% permeability) was just over 20 degrees as shown in fig 6. This is an extreme case and, with the design intention being to keep the box structure watertight, one which should be very improbable and one which very few conventional ships would survive.

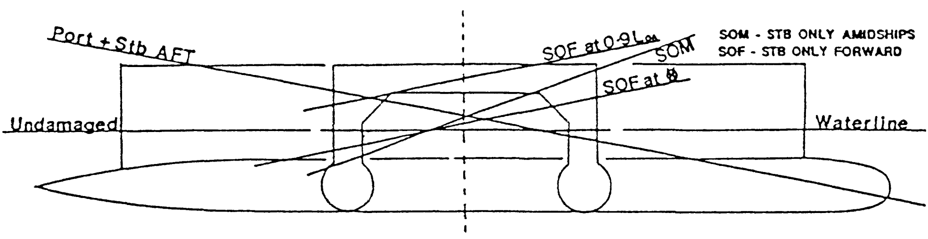

Fig 6: Illustration of damaged waterlines for 25% flooding

CONCLUSION

SWATHs have a potential for operating at high Froude numbers and in fact do so. They are not suited to achieving the highest of calm water speeds but for sustained speed in a seaway they are competitive for larger craft.

From both hydrodynamic and design viewpoints SWATHs with usable payload can achieve high speed operation. Although the hydrodynamic tools available are good, there are still unresolved areas relating to design.

The key to rapid growth is the willingness to be stringent in requiring high levels of seakeeping and not to compromise on comfort / operability for the sake of initial cost. It is essential that seakeeping be presented as part of a complete, balanced and realistic total package. Since a SWATH is more likely to be a contender when the expected environmental conditions are bad, roles which emphasise seakeeping and maintenance of speed in a seaway must be identified. In circumstances where high levels of seakeeping performance are essential for operability or comfort this should be an unequivocal part of the specification and then SWATHs may be the only contender.

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