SEAKEEPING INVESTIGATION OF WAVE PIERCING AND SWATH VESSELS USING A TIME DOMAIN STRIP THEORY

D. S. Holloway and M. R. Davis
Department of Civil and Mechanical Engineering,
University of Tasmania,
Hobart, Tasmania
Australia

ABSTRACT

A semi-SWATH vessel is proposed as a compromise between a conventional catamaran and a SWATH, with the aim of improving seakeeping without greatly sacrificing stability or resistance. A model has been designed and tested in head seas.

Because of the inherently non-linear seakeeping response of the type of hull proposed a time domain computational model is being developed. This is based on an adaptation of the strip theory of Salvesen et al. (1970), with sectional forces calculated using a panel method, allowing arbitrary shaped sections.

INTRODUCTION

Wave piercing catamarans commonly have peak responses in the frequency range that causes great discomfort to humans. Alternative configurations suitable for high speed passenger ferries include SWATH (small waterplane area twin hull) vessels but these generally have low stability, and must rely on ride control. The large surface area combined with the need for control surfaces gives these vessels a high frictional resistance, which makes them expensive to operate as high speed passenger ferries. A "semi-SWATH" vessel with reduced waterplane area is proposed as a compromise and its seakeeping performance is compared experimentally with an equivalent wave piercing vessel. In addition a time domain strip theory computer program is being developed for further evaluation and comparisons.

MODEL DESIGN

Design philosophy

It is generally agreed that susceptibility to sea-sickness is predominantly a function of acceleration amplitudes, but over a limited frequency range. Unfortunately this frequency range coincides with typical natural frequencies for passenger ferries in various modes of oscillation, thus improved seakeeping must rely on reduction of accelerations. The work of this paper focused on pitch and heave motions.

In regular waves at encounter frequencies significantly above resonance boat motion is negligible, while significantly below the resonant frequencies the boat tends to follow the waves and little can be done to influence the motion. Reduction of accelerations therefore must be achieved by lowering the natural frequencies (since acceleration varies with the square of frequency) and by having sufficient damping to reduce any peaks in the response spectrum at resonance.

Natural frequencies of oscillation are dependent mainly on mass (or moment of inertia for pitch motion) and hydrostatic stiffness, just as they are for the classical spring-mass problem. 'Mass' here is the total effective mass, which includes actual mass and the added mass effect due to the inertia of water surrounding the hull, and these two are of similar magnitude. The added mass is asymptotic to a constant value at high frequencies, and for slender hulls (i.e. beam and draught are both small compared to length) the natural frequencies of the boat in heave and pitch are effectively high frequencies as far as these sectional added masses are concerned. Thus for a hull of given displacement the natural frequency can only be significantly reduced by decreasing the hydrostatic stiffness, that is by reducing the waterplane area. This is the basis of the SWATH concept.

Damping is more difficult to predict. The model presented in this paper turned out to have rather low damping, and this has been attributed mainly to its vertical waterlines. A necessary condition for damping of the oscillations of a body in an essentially inviscid fluid is that waves are produced by its motions, and for sections whose mass is not concentrated near the surface (such as SWATH sections) this requires that for damping in heave motion the sides should be as far from vertical as possible. This feature could be included in future designs. This introduces a much more diverse set of geometrical design parameters, and for the present preliminary investigation reduction of the forcing function with a relatively simple vertical waterline semi-SWATH has been addressed. Further introduction of damping might be better achieved by addition of fins or bilge keels rather than the use of inclined waterplane sides.

Model configuration

In order to allow comparison with a more conventional design the 74m wave piercing catamaran built by Incat in Hobart, Tasmania was chosen as a benchmark. The semi-SWATH models have the same longitudinal distribution of buoyancy at the design loading, and the waterplane area retained the same non-dimensional shape. A reduction in waterplane area was achieved by scaling the waterline both longitudinally and transversely. The forward perpendicular was brought aft to move the centre of flotation closer to coincidence with the centre of buoyancy to reduce coupling between heave and pitch. Chines were added to be consistent with the Incat boat, and remaining design considerations were governed by fairing restrictions. Figures 1 and 2 show the configuration of the semi-SWATH model tested. The waterplane area in this case is 40% of that of the Incat hull.

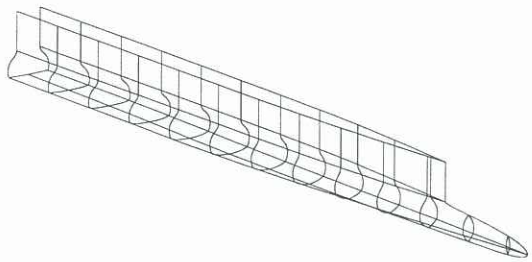

FIGURE 1: Three dimensional view of semi-SWATH model (overall length 2.5m)

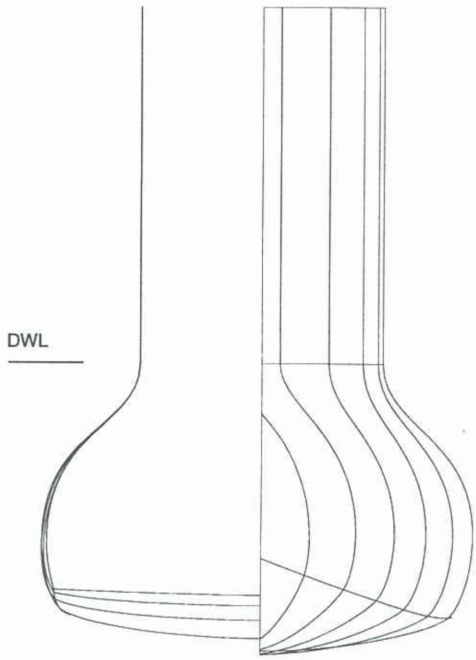

FIGURE 2: Body plan for semi-SWATH model

A second model with features intermediate between the first model and the Incat hull has been designed, with the object of better identifying any trends. At the time of writing no towing tank results were available for this intermediate model.

Test facilities

The model was tested at the towing tank at the Australian Maritime College in Launceston, Tasmania. This tank is 60m long, 3m wide and had a water depth of 1.5m.

TOWING TANK RESULTS

Towing tank test results for pitch and heave in head seas for the first model are given in figure 3. The model was tested at its design draught and at a deeper draught, and at various speeds that equate to up to about 35 knots at full scale.

As expected the semi-SWATH has a much lower natural frequency than a conventional hull, reducing peak accelerations, but resonance is sharper due to the reduced damping effect of the vertical waterline. The results for the deeper draught show a sharper resonance. This is evidence in favour of the explanation suggested above for the lower damping. Further research will focus on improving damping characteristics.

Other features to note include a coupling of pitch motion with heave, shown by the presence of two peaks in the pitch response. There is no such coupling evident in the heave spectrum, and this is simply due to the way that the values are non-dimensionalised. Pitch has been normalised with wave slope, which is small at such low frequencies. The pitch response is actually very small, and so coupling effects are very obvious, while also as a result it has little influence on heave.

The pitch results are not entirely conclusive. The resonant frequency for the predominantly pitch mode shape seems to be decreasing as boat speed increases. However only the lower Froude number results extend to frequencies below this peak, so the trend is unclear. Tank dimensions and apparatus limited the use of lower frequencies. Problems included finite depth effects because of the long wavelengths, and problems with timing and reflections due to the high wave speed. It is proposed to investigate the influence of finite depth effects numerically to determine how significant they are. In addition the general trends regarding the shift of resonance with speed can also be investigated numerically, as well as from further tests with the second model (which will have a larger waterplane area and hence a higher natural frequency).

STRIP THEORY

Development of a time domain theory

In developing a strip theory program there are at least two motivations for choosing to work in the time domain. First wave piercing and SWATH vessels are inherently non-linear in their response to waves and it is only in the time domain that non-linear behaviour can be introduced. Second it opens up possibilities for sea state monitoring in real time and for active ride control systems design on boats. While the theory proposed in this paper would not be suitable for calculations in real time with present computing power it could be used to calibrate a more empirical real time formu-

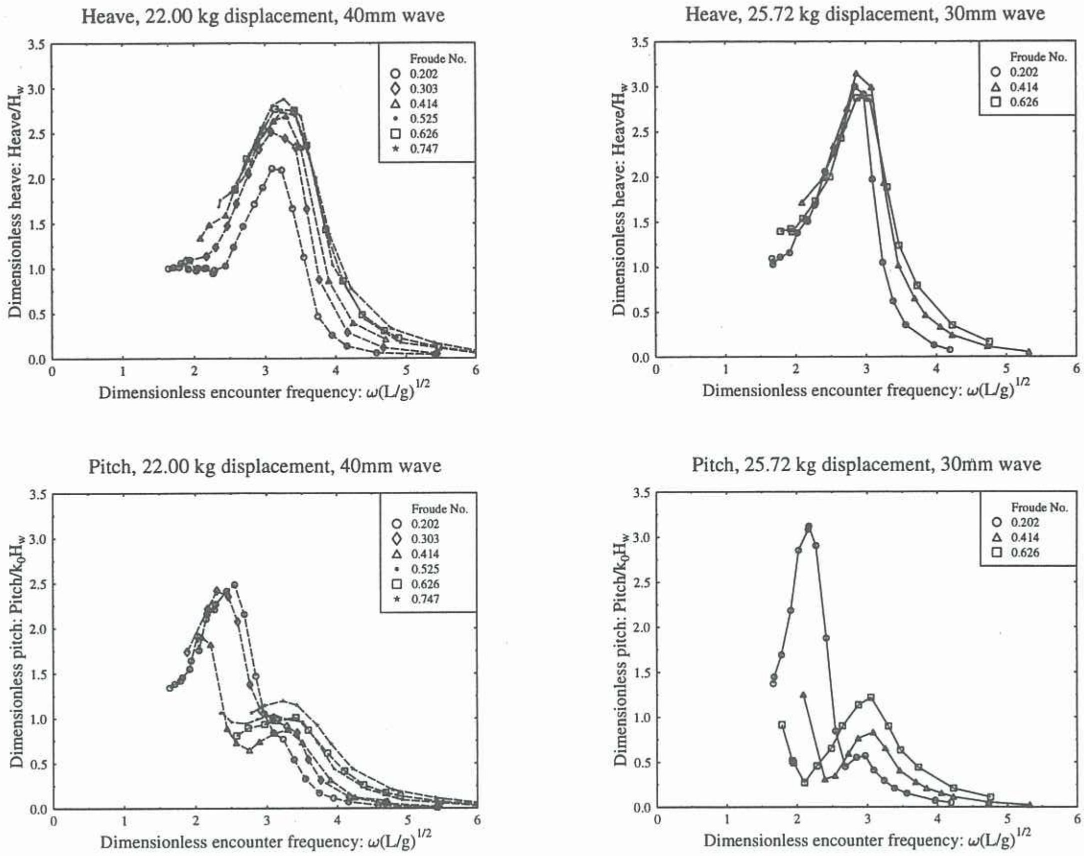

FIGURE 3: Pitch and heave response for semi-SWATH model

lation and thus have application in ride control design. Some useful non-linear aspects on the other hand are certainly capable of being handled by the proposed theory.

Non-linearities

The fully three dimensional non-linear viscous free surface flow problem is not feasible with present computing capabilities, so it is first necessary to identify the parameters that have greatest influence on the flow.

Non-linearities fall into four main categories:

- The slenderness assumption inherent in strip theory (which can not be avoided without attempting a fully three dimensional theory). This is of no particular concern since the type of hull proposed, being primarily for high speed passenger ferries, is typically very slender.
- The assumption of inviscid flow inherent in any potential flow method used to evaluate sectional force or coefficients.
- The free surface boundary conditions and hull surface pressure calculation, in particular the neglect of the velocity squared terms.
- the changing hull submergence.

Of these the one having the most dominant effect is the changing hull submergence. In particular for hulls such as SWATH's, wave piercing catamarans and bulbous bows a bow section may at one instant be completely submerged and at another completely out of the water.

It is this last non-linearity that this time domain theory seeks ultimately to address.

Features of the time domain theory

Initially coupled heave and pitch motions have been considered. The derivation of the equations of motion follows the theory of Salvesen et al. (1970) up to the point where periodicity is introduced. Unlike frequency domain strip theory the present theory is formulated in a fixed reference frame, offering many advantages over a moving reference frame. These include elimination of the transom and speed dependent terms present in frequency domain theories, elimination of the need to ignore the $\frac{\partial}{\partial x}$ terms in the free surface boundary conditions, and reduction of the time interval over which the convolution integral appearing in the solution for the flow fields needs to be evaluated. The latter in particular represents a major saving in computational time, which is of great benefit since time domain solutions are inherently slower than frequency domain solutions.

In a fixed reference frame the force and moment on the vessel are simply obtained by integrating the pressure over the wetted hull surface. This force is input into the differential equation of motion, which can be solved using various techniques. Of these techniques Taylor series methods appear to be most efficient when calculating the section forces in the manner proposed below since the derivatives can be evaluated with a negligible increase in program running time, although the programming required to evaluate the higher derivatives becomes complex. Methods such as predictor-corrector or Runge-Kutta would be substantially slower.

Also unlike conventional strip theory the flow potential is not decomposed into contributions from motions in the various degrees of freedom but a total potential is solved by combining the relevant boundary conditions. The total force then is evaluated from the linearised pressure $-\rho\frac{\partial\phi}{\partial t}$ and added mass and damping need not be considered. The resulting expression can in some circumstances be integrated once resulting in only a first order differential equation to solve.

The final formulation may look quite different from conventional strip theory, but it is nevertheless a strip theory in the sense that we still use the slenderness assumption to justify representing a complicated three dimensional problem as a set of simpler two dimensional problems.

Section forces

Calculation of the two dimensional sectional forces is by a boundary element or panel method, using the potential function for a *source of variable strength, starting from rest and following an arbitrary path* given by Wehausen and Laitone (1960)(eq 13.54). Because the proposed theory uses Green functions that automatically satisfy a linearised free surface boundary condition the need for source distributions on the free surface is eliminated, hence changing waterlines can be represented without any need for special treatment where the hull intersects the water surface.

Panel methods also allow calculations for arbitrarily shaped sections such as fully submerged sections, surface piercing sections, and sections that change shape with time; all with equal ease. Conformal mapping techniques (such as Lewis forms, which have often traditionally been used for strip theories because of the benefit in computational speed) were rejected because they do not have this ability, as well as being unable to represent truly transient solutions to free surface problems.

Frequency domain solutions for section coefficients assume that the radiated waves from an oscillating section extend infinitely in the lateral direction. This is not the case even in regular waves, especially near the bow, so some difference between the time domain and frequency domain solutions is anticipated.

VERIFICATION OF THEORY

Section forces

The boundary element program has undergone extensive testing, which has included comparison with various analytic solutions of Havelock (Wigley (1963)) and with steady state panel method solutions. The latter include the methods of Giesing and Smith (1967) and of Dawson (1977) for steady translating bodies, and the results of Doctors (1987) for floating bodies undergoing forced periodic oscillation.

Figure 4 shows a comparison of the present transient solution with the steady state solutions given by Doctors for a floating semi-circular cylinder in heave motion. Magnitude and phase for the periodic force were deduced from added mass and damping coefficients presented by Doctors. For the purpose of comparison the body displacement terms were disabled in the time domain solution to be consistent with the infinitesimal motion assumption in the periodic solution, thus the two from a theoretical standpoint should be identical. The solution is given for oscillation at the first irregular frequency reported by Doctors, where he found a lid was required on the section to eliminate spurious behaviour. No similar problems were encountered in the time domain solution, and a lid was unnecessary. The time domain solution uses 12 panels and approximately 30 time steps per period, while Doctors extrapolated to ∞ panels from results for 24, 48 and 96 panels. Doctors also used a more sophisticated *Galerkin* method. These differences are considered sufficient to account for the slight discrepancy between the two methods.

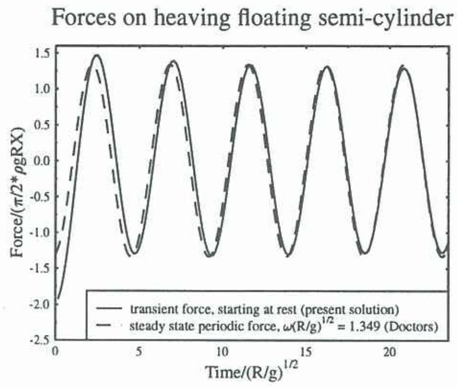

FIGURE 4: Time domain and steady state forces on floating semi-cylinder

Strip theory

At the time of writing incorporation of the section force calculations into a strip theory was not complete, however the authors are confident that this can be implemented without major problem. This can then be verified against the experimental data.

ACKNOWLEDGEMENTS

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REFERENCES

Dawson, C., 1977, "A practical computer method for solving ship-wave problems," in *Proc. Int. Conf. Numer. Ship Hydrodynamics*.

Doctors, L., 1987, "Application of the boundary-element method to bodies oscillating near a free surface," in *International Symposium on Computational Fluid Dynamics*.

Giesing, J. and Smith, A., 1967, "Potential flow about two-dimensional hydrofoils," *Journal of Fluid Mechanics*, Vol. 28, pp. 113–129.

Salvesen, N., Tuck, E. O., and Faltinsen, O., 1970, "Ship motions and sea loads," *Trans. Society of Naval Architects and Marine Engineers*, Vol. 78, pp. 250–287.

Wehausen, J. and Laitone, E., 1960, "Surface waves," *Encyclopedia of Physics: Fluid Dynamics III*, Vol. 9, pp. 445–814.

Wigley, C., ed., 1963, *The Collected Papers of Sir Thomas Havelock on Hydrodynamics*, Office of Naval Research.