Nonlinear Effects on the Squat of a Vessel with a Transom Stern

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Summary

Previous research on the subject of the inviscid linearized near-field solution for the flow past a marine vessel with a transom stern is enhanced in the present study by the inclusion of the major nonlinear effects. The theory is initially developed within the framework of classical thin-ship theory. Next, the hollow in the water behind the stern is represented by an extension to the usual centerplane source distribution employed to model the hull itself. Under the assumption of relatively long waves, the essential nonlinear influence of the hydrodynamics manifests itself through a change in the geometry of the submerged, or wetted, part of the hull. This is accounted for by means of a vertical straining process that is applied to the hull. Comparison of the theoretical results with a systematic series of twelve towing-tank models indicate that the simplest, traditional, theory is best.

1 Introduction

There is much interest among the Australian and international high-speed marine-vessel community in the effective prediction of the resistance characteristics of proposed vessels, with the aim of optimizing the hull shape and minimizing the requirements for the installed engine power.

To this end, previous work on the subject of prediction of resistance of marine vehicles, such as monohulls and catamarans, has shown that the *trends* in the curve of total resistance with respect to speed can be predicted with excellent accuracy, using the traditional Michell (1898) wave-resistance theory.

These principles were advanced in the research of Doctors and Day (1997). There, transom-stern effects were included in the theory by accounting for the hollow in the water behind the vessel in an approximate manner. The wave resistance was assumed to be simply that of the vessel plus its hollow in the water behind the transom. To this drag they added the so-called hydrostatic resistance, which represents the drag associated with the transom stern not being wetted.

This work was refined considerably by Doctors and Day (2000a), who computed the near-field solution to the flow using the classical thin-ship approximation. This idea clearly represented a major addition to the complexity of the solution which contrasts with the traditional far-field method.

Of course, this procedure requires iterating the position, or squat, of the hull until equilibrium has been achieved. The numerical predictions for the resistance and the squat were compared with measurements made on a series of twelve so-called Lego models, detailed by Doctors and Day (2000b).

In the latter paper, a more sophisticated approach was developed for modeling the transom-stern flow. The pressure distribution over the surface of the hollow in the water was computed and the hollow length was iterated until this pressure was minimized in a root-mean-square sense. In this way, the fact that the pressure should be zero was mimicked in the computer program.

2 Mathematical Formulation

Figure 1(a) illustrates the main geometric features representing a typical hull. The hollow that is developed in the water behind the transom stern is also depicted. A regular rectangular meshing (not shown in the figure), consisting of flat panels or "facets", is employed for the purpose of the numerical calculation of the pressure, or profile, resistance. This type of panel is algebraically simpler than the "pyramids" or "tents" which had been previously used by the authors for related ship-hydrodynamic analyses.

The use of flat facets implies a higher level of discontinuity on the hull surface. On the other hand, numerical convergence tests for wave resistance, based on the two types of panels, showed that a similar number of panels was required in either case; namely, 40 panels in the longitudinal direction and 10 panels in the vertical direction.

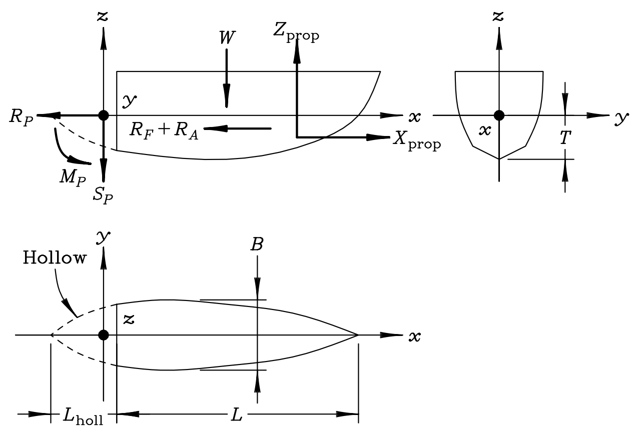

Figure 1: Definition of the Problem
(a) Geometry and Forces

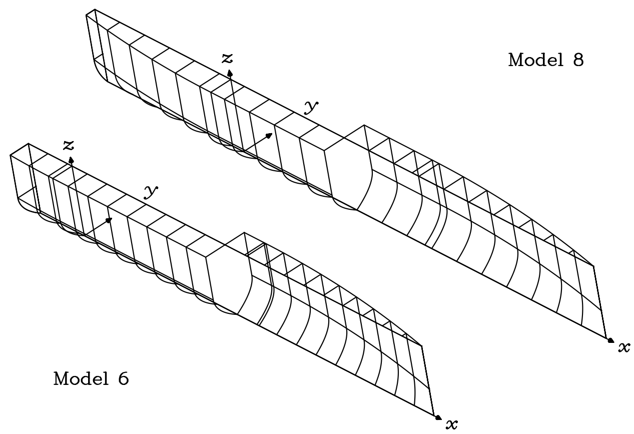

Figure 1: Definition of the Problem
(b) Lego Model 6 and Model 8

The starting point for the analysis is the potential due to a translating point source in infinitely deep water, obtained by Wehausen and Laitone (1960, p. 484, Equation (13.36)). The solution is traditionally represented as the combined effect of three contributions: an isolated source in an infinite domain, an image sink in the free surface, and a double integral over the wavenumber k and waveangle θ domain.

These three terms can be integrated analytically for a constant-strength source panel and a constant-slope field panel in the so-called Galerkin manner.

Furthermore, the wavenumber integration can also be effected analytically, provided one defines a series of wave functions, which are based on the exponential integral of a complex argument, as explained by Doctors and Beck (1987). The results were fully published by Doctors and Day (2000b).

Once the total gradient of the potential at the field panels has been computed, one can determine the pressure on the surface of the hull. The forces and moments on the vessel can then be found from this pressure distribution. Initially, the vessel will not be in equilibrium. Numerical experiments have shown that using the traditional *hydrostatic stiffness* coefficients worked well for iterating the sinkage and trim.

The five theories employed for this current work are:

1. The "Field" approach, which is based on the Michell integral together with a transom-stern hydrostatic drag correction. This method, of course, is too elementary to predict sinkage and trim.

2. The "Linear" near-field approach in which the actual pressure is computed, with the vessel fixed. Nevertheless, the sinkage and trim can still be computed, using the forces together with the stiffnesses of the vessel in sinkage and trim.

3. A partly nonlinear approach, denoted by "NL-1", in which the vessel attitude is properly iterated.

4. A more nonlinear approach, introduced here and denoted by "NL-2", in which the hull is also strained, or distorted, according to the formulas:

$$x' = x \,, \tag{1}$$
$$y' = y \,, \tag{2}$$
$$z' = z - \zeta \,. \tag{3}$$

   The primed coordinates indicate their new values and ζ is the local elevation of the free surface.

5. A further modification, denoted by "NL-3", in which the hull-surface pressure p is corrected so that the new pressure p' is zero on the (strained) free surface, as required by the physics of the problem:

$$p'(x, y, z) = p(x, y, z) - p(x, y, 0) \,. \tag{4}$$

3 Experiments and Numerical Results

The twelve so-called Lego towing-tank ship models were constructed from up to seven segments. The philosophy behind the models is the original Wigley (1934) simple ship. The bow and stern segments have parabolic waterplanes. The bow segments, stern segments, and the parallel middle-body segments all possess parabolic cross sections. Figure 1(b) shows pictorial views of two of the test models. Each model has a beam of 0.150 m and a draft of 0.0938 m. Model 6 has a length of 1.688 m and a prismatic coefficient of 0.8494. Model 8 has a length of 2.063 m and a prismatic coefficient of 0.8275.

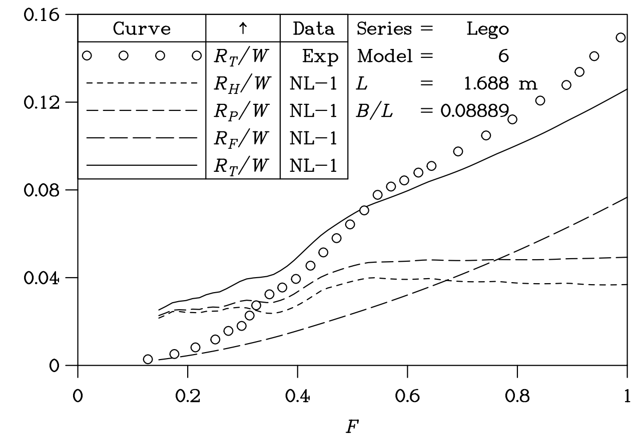

Figure 2: Resistance Components
(a) Lego Model 6

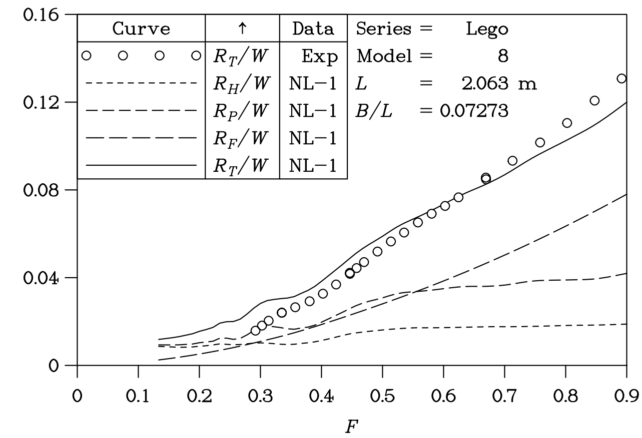

Figure 2: Resistance Components
(b) Lego Model 8

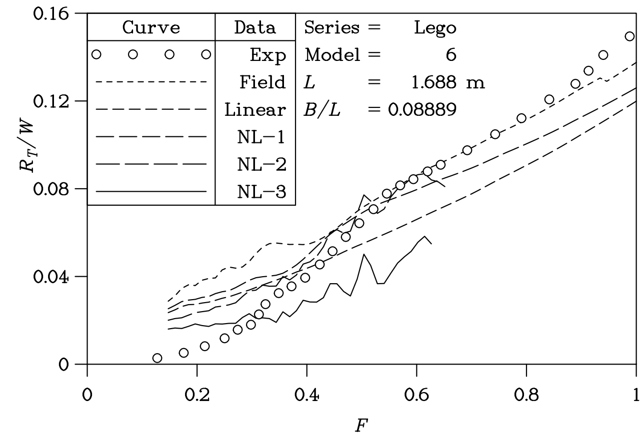

Figure 3: Total Resistance Predictions
(a) Lego Model 6

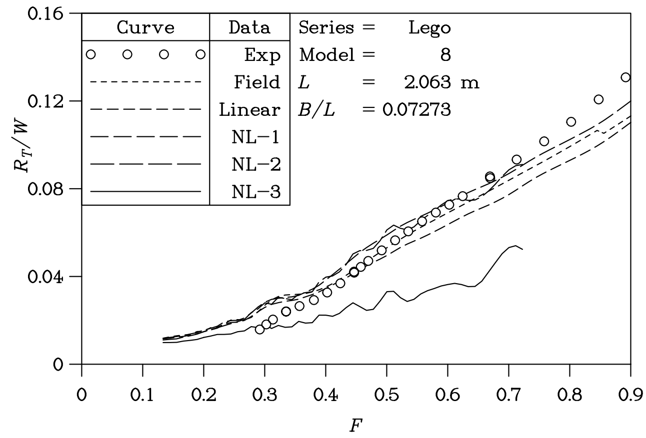

Figure 3: Total Resistance Predictions
(b) Lego Model 8

The theoretical specific-resistance components for two models are plotted in Figure 2. Here, R_H is the transom hydrostatic resistance, R_P is the pressure resistance, R_F is the frictional resistance according to the 1957 ITTC formula with a form factor of unity, and R_T is the total resistance. The other symbols are W the weight of the model, L its length, and B its beam. The abscissa is the Froude number $F = U/\sqrt{gL}$, in which U is the speed and g is the acceleration due to gravity. The chief discrepancy in the predictions occurs at low speeds, where the transom would in practice be partially wetted.

Figure 3 shows a comparison of the five abovementioned theories for the resistance of Model 6 and Model 8. It is remarkable that the field theory is indeed the best. Progressive nonlinear "improvements" appear to reduce the accuracy of the predictions. For the sake of authenticity, no smoothing has been applied to any of the curves. In some cases, the equilibrium iteration required by the nonlinear theories failed to converge. This outcome was a disappointment.

The sinkage (at the coordinate origin) and trim predictions appear in Figure 4 and Figure 5, respectively. In general, it can be stated that the (pure) linear approach is marginally superior to the simplest nonlinear theory NL-1, while the other nonlinear theories NL-2 and NL-3 are quite poor.

4 Conclusions

Future research should be directed toward a refinement of the analysis at low Froude numbers, where the transom stern is only partly wetted. This development should reduce the predicted drag and improve the correlation with experiments at these speeds.

5 Acknowledgments

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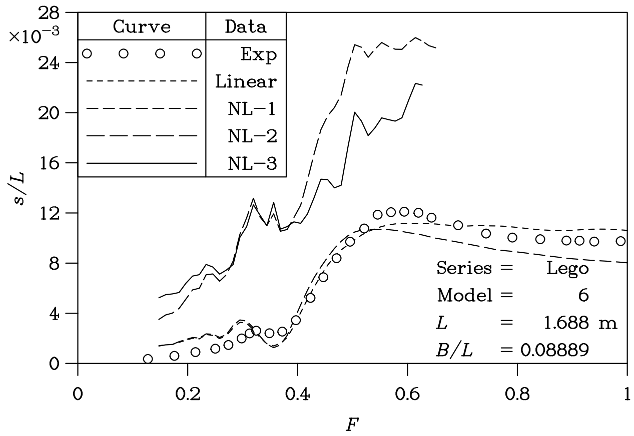

Figure 4: Sinkage Predictions
(a) Lego Model 6

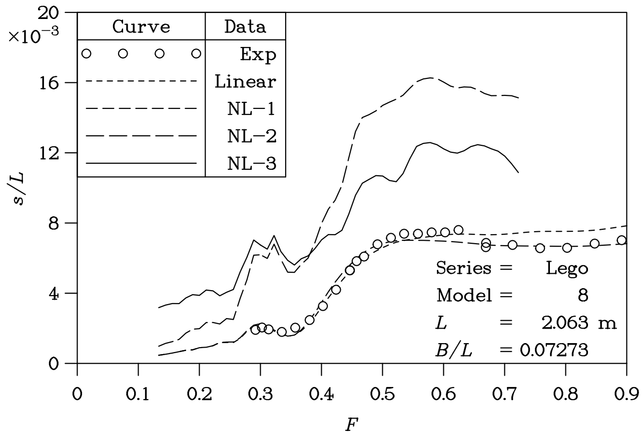

Figure 4: Sinkage Predictions
(b) Lego Model 8

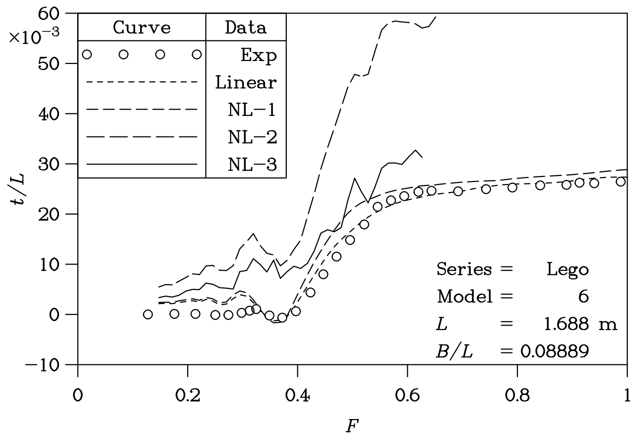

Figure 5: Trim Predictions
(a) Lego Model 6

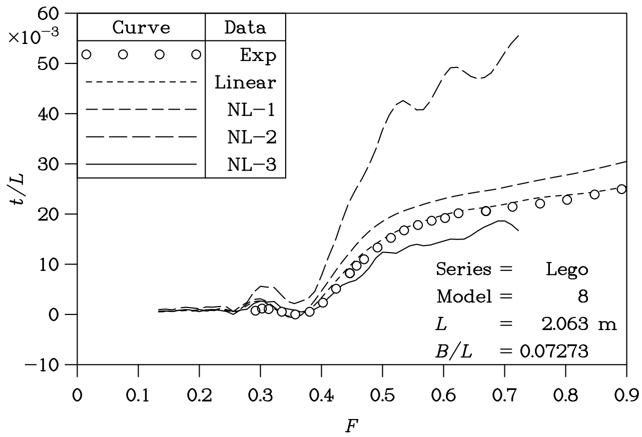

Figure 5: Trim Predictions
(b) Lego Model 8

DP0209656). They are also appreciative to The University of New South Wales and The Universities of Glasgow and Strathclyde for infrastructure support.

6 References

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Discussion Sheet

Abstract Title :	Nonlinear effects on the squat of a vessel with a transom stern		
(Or) Proceedings Paper No. :	09	***Page :***	033
First Author :	Doctors, L.J.		
Discusser :	Ronald W. Yeung		

Questions / Comments :

The suggested "nonlinear" correction of introducing the vertical variable z modified by the wave elevation ζ seems likely to bring inconsistency in. The transformation would change the free-surface boundary conditions and the Havelock source (Green's function) is not a solution of this modified boundary condition. It is a little difficult to justify this rationally.

Author's Reply :
(If Available)

Author did not respond.

Questions from the floor included; Paul Sclavounos, Ernest Tuck, Marshal Tulin & Greg Zilman.