Influence of the Transom-Hollow Length on Wave Resistance

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Summary

Previous experimental data for the wave profiles behind a series of transom-stern ship models has been re-analyzed in this paper. Convenient regression formulas for the unwetting of the stern and the length of the transom hollow are provided.

Predictions of wave resistance and, hence, total resistance can be improved by using this approach, together with the traditional thin-ship formulation for resistance. However, the accuracy of these predictions is improved further if one also considers that there must be a minimal effective hollow length based on the flow behind the well-known backward-facing step.

1 Introduction

The prediction of the wave resistance of a high-speed marine vessel can be done effectively by the use of linearized-free-surface potential-flow theory, based on the thin-ship approach of Michell (1898). Thus, Doctors and Day (1997) applied the theory to a catamaran model tested in a towing tank, using a pair of centerplane source distributions — one for each demihull. Furthermore, the resistance due to the assumed fully unwet transom was computed by considering the missing hydrostatic pressure.

The total drag was then estimated through a simple summation of the wave resistance, hydrostatic resistance, and frictional resistance. One can also apply a *frictional form factor* f_F to improve this estimate of the frictional or viscous resistance. The idealization of the flow is presented in Figure 1.

2 Experiments in Towing Tank

A set of five geosim transom-stern models was constructed. These models are wallsided. They possess a parabolic entrance, a parallel midship and a parallel run back to the transom. Each of the models was tested at five drafts. This permitted the investigation to cover the range of beam-to-draft ratios: $1 \leq B/T \leq 4$. This work has been described in detail by Doctors (2003) and Doctors and Beck (2005).

The two parts of Figure 2 give the dimensionless wave profiles ζ/L for the case of $B/T = 2$ for two different transom Froude numbers $F_T = U/\sqrt{gT}$. Complete flow separation typically occurs near these Froude numbers. Here, ζ is the wave elevation, L is the model length, T is the static draft at the stern of the vessel and U is the speed of the vessel. The curves for the five models collapse together well.

Also shown in Figure 2 are the parabolas which have been fitted to the experimental free surface. The intersection point of these parabolas with the undisturbed free surface provides the length of the transom hollow.

3 Regression Curves

Figure 3(a) shows the fraction of the transom that is dry η_{dry}. This is based on the transom draft at rest (the case shown here) or, alternatively, on the dynamic transom draft. A regression curve of the form:

$$\eta_{\mathrm{dry}} = C_1 F_T^{C_2} (B/T)^{C_3} R_{NT}^{C_4} \,, \qquad (1)$$

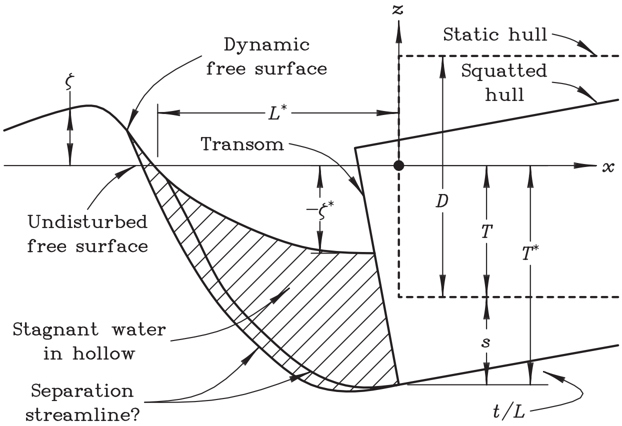

Figure 1: Definition of the Problem: Geometric Parameters

has also been fitted. Both the beam-to-draft ratio B/T and the Reynolds number $R_{NT} = \sqrt{gT^3/\nu}$ are included in the formulation.

A similar regression formula for the hollow length has been fitted in Figure 3(b). The curves have been truncated using horizontal lines; it is assumed that one desires the *effective length* for the calculation of resistance. This length includes the *dead-water region*.

4 Resistance Prediction

We now turn to the matter of the resistance of the vessel. Two examples, corresponding to two different values of the beam-to-draft ratio, are presented in Figure 4.

The graphs show the wave resistance R_W, the hydrostatic resistance R_H, and the frictional resistance R_F, plotted against the length Froude number $F = U/\sqrt{gL}$. The total predicted resistance R_T, being a simple sum of these components, is also shown. The experimental total resistance is plotted for comparison purposes. The resistance has been made dimensionless by the weight of the model W.

Good correlation between the theoretical resistance and the experimental resistance is demonstrated, even at low Froude numbers.

5 Transom-Unwetting Model

We finally turn to an explicit comparison of different models of the transom-stern flow.

This comparison appears in Figure 5 for two values of the beam-to-draft ratio. Five computational methods or physical approaches are shown. The first method (indicated by the key "Full") simply assumes that the transom is fully dry at all speeds; this is the approach of Doctors and Day (1997). The overestimation of resistance is very large at a low Froude number for these models.

The second method (indicated by the key "Fit,D") is based on the present work. In this case, the drop in the water level on the transom and the length of the hollow behind the transom are based on an analysis of the abovementioned experiments in which the dynamic draft is used to nondimensionalize the data. It is seen that this technique greatly improves the predictions in the low-speed range.

The third method (indicated by the key "Fit,S") is identical to the second method, except that in the analysis of the experiments the static draft is used to nondimensionalize the data. It is believed that this approach is somewhat more consistent, since the resistance calculations also ignore sinkage and trim. This surmise is borne out by the slightly improved agreement with the experimental results for the resistance.

The fourth method (indicated by the key "Fit,S,B") is an improvement to the third method, in that a minimal hollow length is also assumed. This minimum is that from an analysis of the flow behind a traditional backward-facing step. Thus, it was assumed that the hollow length could never be less than 6.680 times the transom draft. The fact that these predictions are even better suggests that there is a dead-water region extending beyond the visible hollow and that this plays a critical rôle in the creation of the wave resistance.

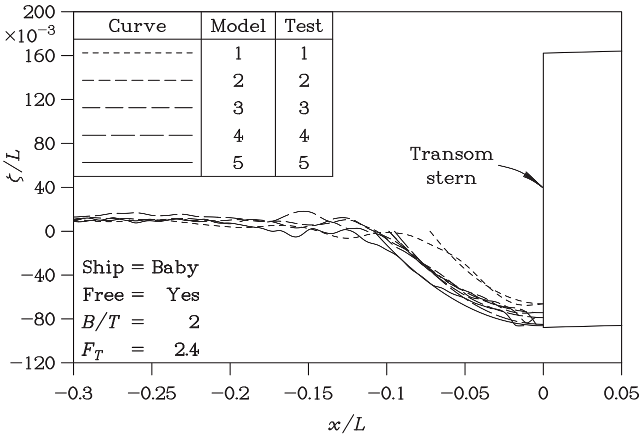

Figure 2: Parabolic Fit to Wave Profiles (a) $F_T = 2.4$

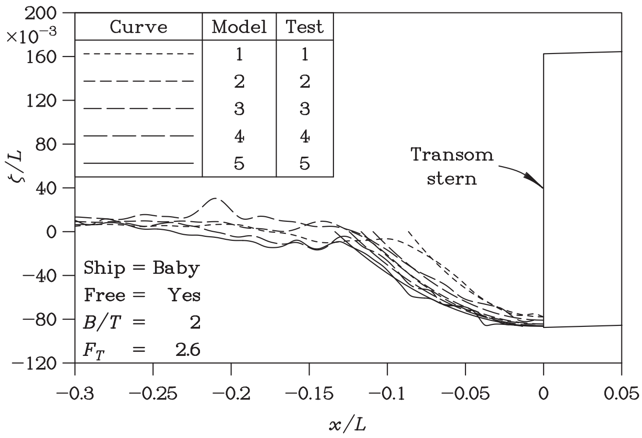

Figure 2: Parabolic Fit to Wave Profiles (b) $F_T = 2.6$

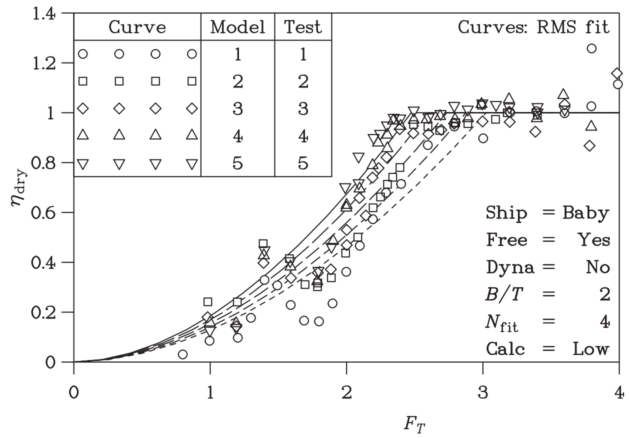

Figure 3: Analysis Based on Static Definition (a) Unwetting of Transom

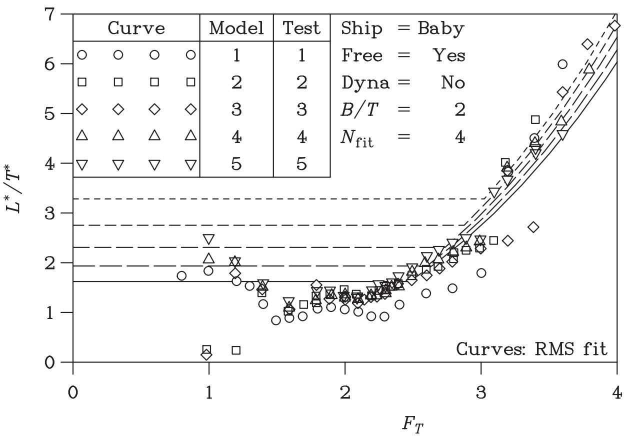

Figure 3: Analysis Based on Static Definition (b) Length of Hollow

Finally, the fifth method (also indicated by the key "Fit,S,B") is the same as the fourth method, except that a frictional form factor given by $f_F = 1.35$ has also been employed.

This choice seems to be reasonable in view of the sharp bilges that the models possess; it also provides excellent resistance predictions over the entire Froude-number range.

6 Conclusions

This research has demonstrated that this enhanced model for the water flow behind the transom leads to an accurate estimate of the transom hydrostatic drag. Additionally, a very good prediction of the wave resistance and the total resistance of such vessels is provided, even at very low speeds.

It is recommended that effort be invested in testing larger models in order to further study the relevance of the Reynolds number.

7 Acknowledgments

The tests were performed in the Towing Tank at the Australian Maritime College (AMC) by Mr Simon Robards, postgraduate student at UNSW, under the able supervision of Mr Gregor Macfarlane of the AMC.

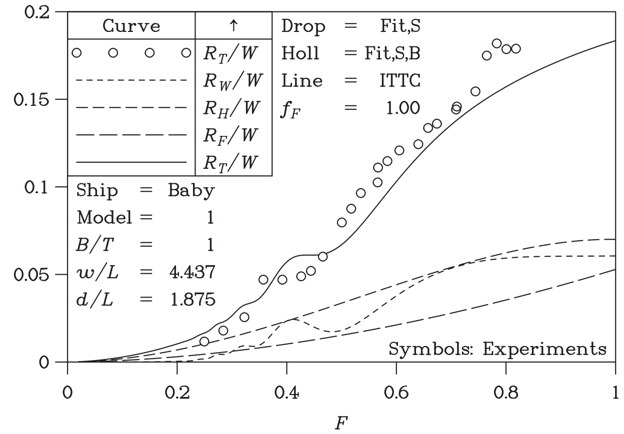

Figure 4: Components of Resistance
(a) $B/T = 1.000$

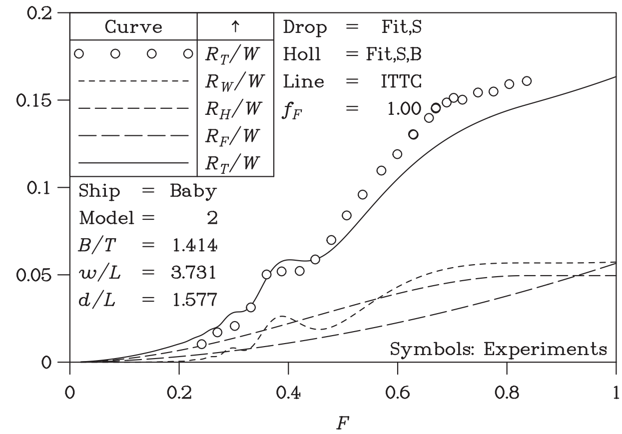

Figure 4: Components of Resistance
(b) $B/T = 1.414$

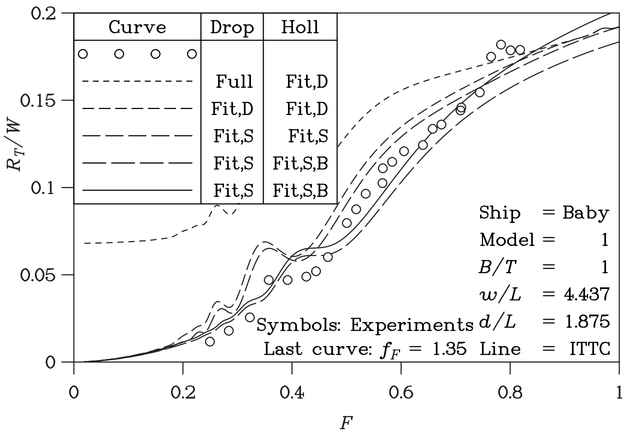

Figure 5: Transom-Stern Flow Model
(a) $B/T = 1.000$

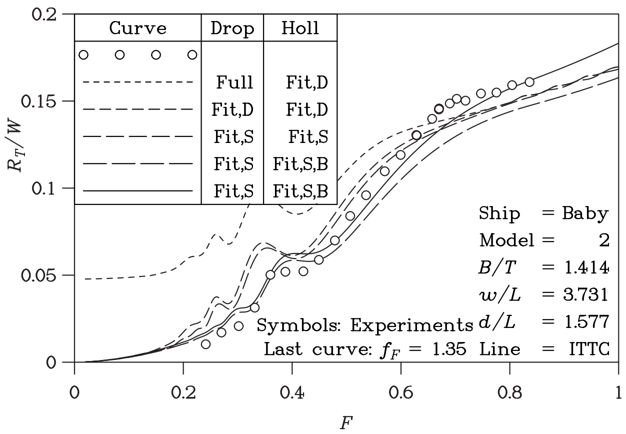

Figure 5: Transom-Stern Flow Model
(b) $B/T = 1.414$

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8 References

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‘Influence of the transom-hollow length on wave resistance’

Discusser - D.H. Peregrine:

With regard to Reynolds number: the separation from the base of the transom is likely to be affected by the boundary layer from the bottom of the vessel thus Re based on wetted length may be most relevant. Also whether or not this boundary layer is turbulent.

Reply:

Yes, these comments are absolutely correct. The ‘suction’ process that causes the water drop behind the transom stern is similar to the process that results ion the negative back pressure behind a blunt projectile, for example. The phenomenon seems to be depended on the development of the boundary layer ahead of the transom. It is intended to continue this research and to analyze the results based on the vessel-length Reynolds number, as suggested.