DRAG ON A SHIP AND MICHELL'S INTEGRAL

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Summary This year marks the 110th anniversary of Michell's [6] landmark paper on the wave resistance of thin ships. We show that when combined with the standard ITTC technique for estimation of the skin friction, Michell's method is still competitive with a modern CFD code for the total drag on a Wigley hull with $L/B = 8$, at a much reduced cost.

INTRODUCTION

After reviewing the performance of some 22 rival computer programs in 1979, Bai [1] was forced to conclude that *"... wave resistance predictions by first-order thin-ship* [i.e. Michell] *theory are rather consistent in comparison with experimental data and not worse than the envelope of predictions of seemingly more sophisticated methods ... "* Ten years later, one of us, Tuck [10] assessed that: *"The situation is not much better today"*. Nearly a further twenty years later, it seems that: *"The situation is not much better today."*.

In the present paper we compute the total drag on a ship in steady motion in water of infinite depth using Michell's integral for the wave resistance, and compare with experiments and a recent CFD study.

METHODOLOGY

We use the standard 1957 ITTC line [4] for the viscous skin friction. To this is added the wave resistance as given by thin-ship theory, first obtained by Michell [6]. We use the ITTC line here because it is well established and familiar, although our personal preference is for a more modern approach due to Grigson [3]. However, the two skin friction methods yield results in the present case that are relatively close to each other. In any case, the computer time needed for estimation of skin friction by such methods is essentially negligible relative to that for the wave resistance.

Our implementation of Michell's integral for the infinite-depth wave resistance is fully described in a local report [9] that is available online, based on an article [10] reviewing the 1898 Michell paper.. For further discussion of ship wave resistance, see Wehausen and Laitone [13]. Reports (e.g. [11]) describing wave resistance and ship wave elevation codes developed by us, including extensions to finite water depth, are also available online, as is a free computer program named `Michlet` [5] It should be noted that although the task is "just" that of a triple numerical integration, given the ship's offsets, some care needs to be taken with this integration task, the integrands being rapidly oscillating, and our implementation makes use of Filon's quadrature [2], [8] for this purpose. Careful testing has verified at least 4-figure accuracy over a wide range of Froude numbers. Results have also been obtained for finite water depth.

Even when the above-mentioned care is taken, demands on computer capabilities are very low. We have done most of our computing on a 3.2GHz PC, and at a single Froude number the total drag is computed in about 5ms. A complete smooth graph over a wide range of Froude numbers requires less than 2 seconds. By comparison, the CFD approach requires many hours, often on large supercomputers.

RESULTS

All results are for a fixed Wigley parabolic hull with model-scale length $L = 1.905$m, beam $B = 0.238$m, and draft $T = 0.095$m. The figure below shows the total drag coefficient $C_T = R_T/(0.5\rho U^2 S)$, where U is the ship speed and S is the (static) wetted area, as a function of the Froude number $Fr = U/\sqrt{gL}$.

Experimental points ("plus signs") are taken from Millward and Bevan [7]. Also shown ("crosses") are points computed by the CFD code CFD-SHIP-IOWA 4.00, as described by Sakamoto et al [12], for coarse grids at several speeds. At one particular speed ($Fr = 0.51$) we also show their CFD results for medium grids ("dot-cross") and fine grids ("open square"), plus an attempt by Sakamoto et al [12] to account for breaking waves ("filled square", identified as "CFD with Overset").

The curve in the graph represents our computations, using Michell's integral for the wave resistance, and the ITTC 1957 line for the skin-friction.

DISCUSSION

It should first be said that the agreement with the experiments is rather good, both for our Michell-based method and for the CFD technique. In order to better display the differences, we have chosen to display only values of the scaled total drag coefficient above 5.0. Hence in relative terms, the agreement is actually better than it appears from these graphs, and tends to be within about 10% at most Froude numbers. Given the many possibilities for error in both theory and experiment, this is quite a good achievement.

We do feel however, that the Michell method is doing a little better than the CFD method. In particular, the finer CFD grids were used only at the single Froude number 0.51 where the total drag is maximal. Both theories tend to do worst of all at this speed, Michell over-estimating the drag by about 10% and CFD (with the finest grid, both “squares") underestimating it by a similar amount. At other Froude numbers, the coarse CFD grid (“crosses") does significantly worse than Michell.

CONCLUSION

Prediction of the total resistance to steady motion of a ship as the sum of a skin friction estimated by the standard ITTC 1957 line and a wave resistance computed by Michell’s integral yields quite good results compared to model experiments. Furthermore it does so in a very small computer time. Better agreement might be desirable, but CFD seems incapable of providing this over a range of speeds within acceptable computer time.

References

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