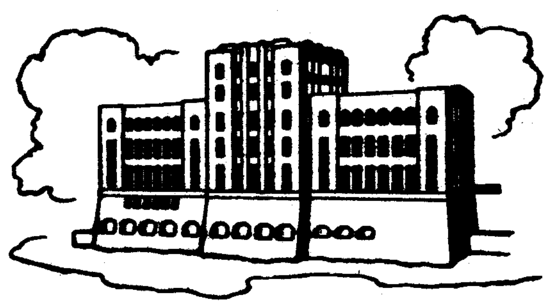
INVESTIGATION ON COMPONENTS OF SHIP RESISTANCE

FINAL REPORT

by

L. LANDWEBER

This research was carried out under the
Naval Ship Systems Command
General Hydromechanics Research Program
Subproject SR 023 01 01, administered by the
Naval Ship Research and Development Center
Contract N00014-68-0196-0005



IIHR Report No. 162

Iowa Institute of Hydraulic Research
The University of Iowa
Iowa City, Iowa

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ABSTRACT

The results of a decade of research on the separate measurements of the various components of resistance are summarized. Theoretical bases and the equipment and experimental procedures developed for determing the viscous, wave, and bilge vortex resistance, as well as some preliminary results on "blockage effect", are mentioned.

ACKNOWLEDGEMENT

The continuing support of this research by the Naval Ship Research and Development Center is gratefully acknowledged. This work has furnished thesis subjects to many graduate students, to whose talents and ingenuity many of the accomplishments under this contract are attributable. These include Jin Wu, Kenneth Key, Gabriel Echavez, Helmut Kobus, Jean-Claude Tatinclaux, Kent Tzou, David Moran, Chi-Ell Tsai, K. Gopalakrishnan and A. Swain. The indispensable assistance of Professor J. G. Glover in the design and execution of the data-gathering systems for the wake-survey and longitudinal-cut techniques must also be mentioned.

INVESTIGATIONS ON COMPONENTS OF SHIP RESISTANCE

Final Report

In the decade since October 1963, research on components of ship resistance was conducted at the Iowa Institute of Hydraulic Research under Contract N00014-68-0196-0005 of the General Hydromechanics Research Program, administered by the Naval Ship Research and Development Center. The accomplishments under this contract are summarized in the present report.

1. Viscous Resistance

Under a previous contract, a technique for measuring pressure and total-head distributions in a transverse section across a wake had been developed, the Betz-Tulin theory for the analysis of wake data had been verified and refined, and it had been demonstrated that the viscous drag was a sinuous function of the Froude number, contrary to the assumption of the Froude procedure for predicting ship resistance.

In the continuation of this work under the present contract, the instrumentation for conducting the wake survey was automated [1]. Instead of photographing a bank of manometer tubes and tediously reading the positions of a meniscus from a projected image, the automated system, employing a scanivalve, a pressure transducer and an IBM analog-digital computer, yielded the requred wake data in the course of the test. In theses by K. Key [2] and K. T. S. Tzou [3], and a paper by Tzou and Landweber [4], refinements of the Betz-Tulin viscous-drag formula were developed, and improvements in the measurements technique were reported. These include refinements of the calibration procedure and measurement of the water-surface profile above the wake to enable an important correction to be made for the contribution from the part of the wake near the free surface not explored by the pitot rake. Tzou [3,5] also investigated a basic assumption of the Betz-Tulin theory, that the wave resistance is unaltered when the actual wake is replaced by an irrotational flow, and it was shown that the error could be as large as 4 percent.

The important discovery that the viscous resistance coefficient varies in a sinuous way with Froude number has since been verified by other investigators. A correlation of this characteristic with the variation of shear stress on a Series-60 ship model was reported by Tzou [6], and the phenomenon was discussed by Landweber and Tzou in connection with a paper by Townsin [7]. A study of the effects of model size and prismatic coefficient on this characteristic curve of viscous resistance was reported by Tsai and Landweber [8], together with a suggestion for modifying the Froude procedure for predicting ship resistance from model tests, based on the observed trends. This suggestion was incorporated as a recommendation of the 13th IIIC, 1972. These results are presented more fully in Tsai's Ph. D. thesis [9] and have been submitted for publication in the Journal of Ship Research [10].

Additional measurements of the total and wave resistance of the aforementioned Series-60 models suggest that the wake-survey results for the viscous resistance are too small. Applying a theory of wake characteristics and Betz singularities in the wake by Landweber [11], based on the Reynolds equations and the assumption of irrotational flow outside the wake, a new and simpler expression for the viscous drag in terms of wake characteristics has been derived which yields the appreciably lower values required by the measurements. This has not yet been published; it has been presented only in progress reports to NSRDC.

2. Bilge-Vortex Resistance

Cross flow in the 3-dimensional boundary layer in the region of the bow, in conjunction with the tendency of the outer streamlines to pass around the turn of the bilge from the side to the bottom of a ship form, tends to generate a pair of longitudinal vortices which are convected downstream. These contribute to the drag as the analogous vortices on an airfoil of finite aspect ratio cause the so-called induced drag. This phenomenon was investigated by Echavez [12] and Tatinclaux [13], who developed the analytical basis and the experimental technique of determining the bilge-vortex resistance. This was then applied by Tatinclaux [14, 15, 16, 17], in a series of studies, to determine the effects of the radius of curvature of the bilge, the presence of bilge keels, and the influence of a bulbous bow on the phenomenon. With a well-rounded bilge, this effect was found to be small, but the strength of the vortices was appreciably increased bilge keels. In some cases, two vortices were generated at each bilge, and the generation and development of the vortices were found to be sensitive to the shape of the bow.

3. Wave Resistance

Under the present contract, Eggers' method of determining wave-making resistance from surface-profile measurements has been investigated. An experimental technique employing transverse-cut measurements was developed by Kobus [18] and applied to determine the wave resistance of a thin, vertical strut for which the Michell theory for wave resistance was considered to be valid [19,20]. It was concluded that the wave resistance, determined by Eggers' theory for a transverse cut, was unreliable because of the large effect of the wake. This work was continued by Landweber and Tzou [21], who investigated analytically the optimum downstream locations for transverse cuts. In view of Kobus's work, however, the transverse-cut technique appears to be suitable only for wide towing tanks in which the wake width is small relative to that of the tank. An analytical study by Tatinclaux [22,23,24,25], analyzed the effect of the vorticity in the wake on wave making and suggested a procedure for correcting the analysis of transverse-cut data to take this effect into account.

An alternative method, also proposed by Eggers, employed data from a longitudinal cut. The analysis used to calculate the wave resistance from these data required that the cut be terminated before the first wave reflected from a wall was encountered. With this restriction, the length of usable surface-profile record depended on the width of the tank. For narrow tanks, the limited data resulted in ill-conditioned equations and, consequently, unreliable results for the wave resistance. An alternative method which accepts data from reflected waves, includes the effects of the tank walls in the analysis, and improves the conditioning of the equations by employing a preliminary Fourier-type analysis was then developed and reported by Moran and Landweber [26, 27]. This procedure was subsequently refined by Tsai and Landweber [9,10] by determining optimum transverse locations of longitudinal cuts and analyzing several simultaneous cuts by the method of least squares.

4. Blockage Effect

The problem of correcting model data for the effect of tank walls is a perennial one for which many empirical procedures have been proposed and are being used, but a rational solution has not yet been obtained. An attempt to derive such a solution was initiated in the last year of the subject contract, and is being continued under its successor. In the first stage of this problem, wall corrections were computed for the axisymmetric flow about bodies of revolution in a circular tube [28,29]. This work was intended to establish a norm against which blockage effects for channels of rectangular section can be compared. Results for velocity increments due to channel boundaries for tanks of rectangular section of various width-depth ratios, and ship forms of various prismatic coefficients have already been calculated and correlated against an equivalent "hydraulic radius," which collapses all the results to a single curve. Preliminary results of this work were presented by Landweber to the 13th ITTC [30].

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