The University of New South Wales
School of Mechanical and Manufacturing Engineering

THE HYDRODYNAMICS OF HIGH-SPEED TRANSOM-STERN VESSELS

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In the design of all marine craft the prediction of a vessel's resistance characteristics is a major consideration. The accurate prediction of resistance is particularly important in the design of modern high-speed vessels where the primary contractual obligation placed upon the builder is the vessel's achievable speed. Investigation was made of the methods of Doctors and Day, whereby the traditional Michell wave-resistance theory, published in 1898, is improved on through a better understanding of the hydrodynamics of transom sterns and the application of statistically determined form factors.

One of the difficulties with the Michell theory is how to account for the hollow that forms behind a transom stern, a feature prevalent in high-speed vessels. A common approach in the numerical prediction of wave resistance for transom-stern vessels is to discretize the hollow as a geometrically-smooth addition to the vessel. Therefore, of great importance in accurate prediction of wave resistance is the hydrodynamics of, and in particular, the length and depth of the hollow formed behind the transom stern. Accordingly, a systematic series of transom-stern models were tank tested at various drafts and speeds in order to determine experimentally the length and depth of the hollow as a function of vessel speed, draft and beam.

From the experimental data, algorithms for the determination of the length and depth of the transom hollow, have been developed and utilised in the discretization of the transom hollow for prediction of resistance using the Michell wave-resistance theory. Application of the developed hollow algorithms produced significant improvements in correlation of the experimental and theoretical predictions of total resistance, particularly in the lower Froude range.

In addition to the transom-hollow investigation, form factors were obtained using least-squares regression of existing experimental data. The form factors were based on the major geometric parameters of the models used. In the research presented here, the method was applied to a large range of published resistance data for high-speed displacement vessels. Considerable improvement in correlation, between theoretical and experimental predictions of total resistance, was obtained by incorporating the calculated form-factors into the total resistance formulation.

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Abstract

Australia is currently a world leader in the design and construction of high-speed vessels. In today's society, time is a precious commodity, driving the need for shorter voyage times, faster freight delivery times, and quicker deployment of troops in times of war. Indeed, the primary contractual obligation placed upon the builder of high-speed vessels is the vessel's achievable speed upon completion. Therefore, paramount in the design of these vessels is the accurate prediction of the vessel's resistance characteristics. Prediction of these characteristics early in the design stage can be critical in installing the correct powering required to achieve the contract speed.

There are several methods by which a design company may estimate the total resistance of their hullform; computation using linear theory or non-linear theory, statistical extrapolation from existing model data of models possessing similar form and, finally, ship-model experiments. Traditionally, though expensive and time consuming, ship-model tank testing has provided the most accurate method for predicting the resistance of the designed hullform. Due to the expense of experimental testing, and the relative inaccuracy of the simplified linear theory, extensive time and resources have been invested in developing fully non-linear computer codes for prediction of resistance. Currently, the execution time of these non-linear codes is far too long, especially for design companies competing in a global market. The work presented here therefore covers research undertaken to improve the accuracy of predictions of resistance for high-speed displacement transom-stern vessels using linear theory.

A common characteristic of high-speed vessels is that of a transom stern, a feature which provides additional complexity to hydrodynamic analysis. A transom stern, due to its truncated form, introduces a hollow into the wake aft of the vessel. It is commonly observed that the transom hollow deepens and lengthens as the vessel's speed increases until the transom itself is fully ventilated or "running dry". A common approach in the numerical prediction of wave-resistance for transom-stern vessels is to discretize the hollow as a geometrically-smooth addition to the vessel. Therefore, of great importance in accurate prediction of wave-resistance is the hydrodynamics of, and in particular the length and depth of the hollow formed behind, the transom stern. However, little is known of the relationship between speed and hollow dimensions, nor of the effect of other potential influences such as vessel geometry.

To improve the correlation between theoretical predictions and experimental results, an investigation of the hydrodynamics of transom sterns was therefore undertaken. A systematic series of transom-stern models was tank tested at various drafts and speeds in order to determine experimentally the length and depth of the transom hollow as a function of vessel speed, draft and beam. The results of these experiments are presented in the form of hollow profiles measured on the centreline of the models. Analysis of these results has provided insight into the driving forces influencing the length and depth of the hollow formation. The results of this experimental investigation were also utilised to create algorithms for the prediction of the length and depth of the transom hollow. The developed algorithms were then incorporated for the discretization of the transom hollow in prediction of resistance using the Michell wave-resistance theory. Results indicated that significant reductions in RMS error in the correlation between theory and experiment could be achieved through utilisation of the hollow-prediction algoriths.

The research presented also encompasses an expansion of the work by Doctors and Day (1997) into form factors, whereby the traditional Michell wave-resistance theory, published in 1898, is improved upon through the application of correction factors determined from statistical analysis of published experimental data. The form factors are formulated using the major geometric parameters of the models used in a least-squares regression analysis. The method was applied to a large range of published resistance data for high-speed displacement vessels possessing transom sterns. The hullform characteristics, geometric parameters, testing procedures and experimental results of the thirteen model series utilised in the regression analysis are presented in detail. Considerable improvement in correlation between theory and experiment was achieved by incorporating the calculated form factors into the total resistance formulation.

Form factors were also formulated specific to each of the individual model series used in the overall regression analysis. Although limited in their range of applicability, the series-specific form factors provide vastly improved correlation between theory and experiment and, hence, improved resistance prediction for vessels of form similar to the particular model series.

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Nomenclature

Roman Variables

A_T	Transverse projected superstructure cross-sectional area
B_{WL}	Waterline beam of a vessel
C_A	Correlation allowance
C_B	Block coefficient
C_F	Frictional resistance coefficient
C_M	Midship-section area coefficient
C_P	Prismatic coefficient
C_R	Residuary resistance coefficient
C_T	Total resistance coefficient
C_V	Volumetric coefficient
C_{VP}	Vertical prismatic coefficient
C_X	Maximum-section area coefficient
D_H	Hollow depth
f_F	Frictional resistance form factor
F_{n_B}	Beam Froude number
F_{n_L}	Length Froude number

F_{n_T}	Draft Froude number
$F_{n_{PR}}$	Froude number based on the diameter of the wave-probe
f_W	Wave resistance form factor
g	Acceleration due to gravity
gf	Grams-force
L_H	Hollow length
L_{WL}	Waterline length of a vessel
P_B	Brake power
P_E	Effective power
R_A	Correlation resistance
R_{AA}	Aerodynamic resistance
R_F	Frictional resistance
R_H	Hydrostatic resistance
R_{n_L}	Reynolds number based on length
R_{n_T}	Reynolds number based on draft
R_T	Total resistance
R_W	Wave resistance
S	Wetted surface area of a vessel's hull
T	Draft of a vessel
T_H	Hydrodynamic draft at transom
U	Carriage speed
V	Vessel speed
V_R	Apparent or relative wind speed

V_T	True wind speed
W	Vessel weight

Greek Variables

α	Angle of true wind direction relative to vessel
δz	Heave
Δ	Vessel displacement
ζ	Measured water elevation
η	Coefficient of overall propulsive efficiency
ν	Kinematic viscosity
ξ	Wave amplitude
ρ	Water density
ρ_{air}	Air density

Symbols

©	Copyright
Ø	Diameter
$\bigtriangledown$	Displaced volume
⊗	Midships
®	Registered trademark

Abbreviations

3-D	Three dimensional
AC	Alternating current

AMC	Australian Maritime College
AP	Aft Perpendicular
BL	Baseline
CAD	Computer-aided drafting
CFD	Computational Fluid Dynamics
CL	Centreline
DWL	Design waterline
fwd	Forward
FP	Forward Perpendicular
i.e.	That is
ITTC	International Towing Tank Committee
LDV	Laser doppler velocimetry
LVDT	Linear variable displacement transducer
NURBS	Non-uniform rational B-splines
PC	Personal Computer
RMS	Root-mean-square
SHC	Ship Hydrodynamics Centre
SI	Système Internationale des Unités (International System of Units)
VMS	Virtual Memory System

Glossary of Terms

Aft: Behind or negative longitudinally; nautical term meaning opposite of forward.

Baseline: The origin for vertical measurements in relation to a vessel, typically taken at the lowest part of the hull.

Beam: The breadth of vessel measured either at the waterline or between extremities of the moulded hull.

Bow: The foremost part of a vessel's hull.

Catamaran: A vessel possessing two hulls joined by a bridging structure.

Draft: The vertical distance from the waterline to the lowest point of the hull.

Geosim: Geometrically similar models, possessing hull shapes of exactly the same form but of differing scale (term coined by Prof. Telfer).

Greenwater: Water taken onboard due to large bow waves or from breaking waves in heavy seas.

Midships: The longitudinal midpoint on the waterline length of a vessel.

Rooster Tail: The name given to the point of closure of the flow around the hollow behind a transom-stern, due to the associated uplifting spray pattern.

Static: Used to describe the draft or waterline associated with the vessel when stationary.