Assignment -1

RESISTANCE TESTS OF A SYSTEMATIC SERIES OF PLANING HULL FORMS

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ABSTRACT
This paper discusses the results of five planing boats with varying length-beam ratios. The tests were carried out at the David Taylor Model Basin, Maryland. Each model tested had varying loads at different LCG locations. The results were tabulated and presented as graphs of resistance-weight ratio versus Froude number. Furthermore, using a systematic series, the test results were corrected for boat weights of 10,000 lb. and 100,000 lb. Moreover, simplified prediction method was devised, using the obtained results, to determine the resistance of high-speed boats with planing hull-forms –given a gross weight from 1000 to 100,000 lb. Lastly, this prediction model was revisited and a mathematical regression equation was formulated to fit the data points, using Statistica 12.5; with the help of MATLAB this mathematical model was automated.

INTRODUCTION
The need for this experiment arose from the lack of data available for planing boats, at the time. The one and only test available was the EMB Series 50, which had a few shortcomings –the boundary flow of the models, during the tests was not fully turbulent. Thus, for some of the total resistance data points the value was less than those of the frictional resistance –indicating that the wave making resistance was negative.
Consequently, this led to the development of five models of different length-beam ratio were built and each of them was tested for resistance at varying loads and LCG locations. This new series was termed TMB Series 62.

NOMENCLATURE

A_P	Projected planning bottom area, excluding area of external spray strips.	l_{Cp}	Distance of center of pressure forward of transom
B_P	Beam or breadth over chine, excluding external spray strips.	R	Total resistance, lb.
B_{PA}	mean breadth over chines, A_P/L_P	S	Wetted surface area -weeded surface area underway including area of sides which is wetted at low speeds and wetted bottom area of external spray strips; however, area wetted by spray is excluded.
B_{PT}	Breadth over chines, excluding external spray strips.	u	Speed, fps
B_{PX}	Maximum breadth over chines, excluding external spray strips.	V	Speed, knots
BL	Baseline	W	Displacement at rest weight of
b	Breadth over spray strips at longitudinal location of center of gravity.	w	Density of water (weight per unit volume)
CL	Centerline	λ	Linear ratio, ship to model
CG	Center of gravity	a	Angle of attack of after portion of planning bottom, deg
C_{Lb}	Lift coefficient, $W/(\frac{1}{2}\rho u^2 b^2)$	β	Dead rise angle of planning bottom in degrees
$F\nabla$	Froude number based on volume, $\upsilon/(g\nabla^{1/3})^{1/2}$	υ	Kinematic viscosity, sq-ft/sec
g	Acceleration due to gravity	ρ	Mass density of water. Slugs/cu-ft
L_P	Projected chine length	∇	Displacement at rest, volume of
LCG	Longitudinal center of gravity location		

ABBREVIATIONS
EMB Experimental Model Basin
TMB The Model Basin
LCG Longitudinal Center-of-Gravity
CG Center of Gravity

KEYWORDS

Planing Boats, Resistance, High-Speed, Regression

THEORY: DEVELOPMENT OF THE PARENT MODEL

Major changes in Series 62 include:

1. The deadrise angle at the transom of 12.5°.
2. Constant deadrise angle to prevent twisting of the high-speed planing area.
3. Narrow stern, with transom width equal to about 65% of the maximum chine width.
4. Convex bow section.

The tests showed that this new design had less resistance than any of the conventional stepless planing boat designs tested previously at TMB, and thus was satisfactorily selected to be the parent form for the systematic series.

THEORY: PLAN AND SCOPE OF SERIES

Three of the most important parameters affecting the performance of planing hulls are:

1. Ratio of length to beam: Defined as the ratio of the projected chine length, L_P, to the maximum breadth over the chines, B_{PX}, in this paper.
2. Relationship of hull size and gross weight: Defined as $A_P/\nabla^{2/3}$, in this paper.
3. Location of LCG: Where LCG is defined as the distance from the centroid area, A_P, expressed as a percentage of length, L_P.

Five models: Models 4665, 4666, 4667-1, 4668, and 4669, were tested to explore the influence of length-beam ratio. The ratios tested were L_P/B_{PX} = 2.00, 3.06, 4.09, 5.50, and 7.00, respectively [Appendix A].

EXPERIMENT SETUP

The model with a length-beam ratio of 3.06 has proportions like that of a smaller size pleasure craft, propelled by either an outboard motor attached to the transom or by in-board motor with the engine in the extreme stern. Since the CG for such a vessel is far aft, narrow width provides insufficient buoyancy. Thus, the transom widths were arbitrarily widened for the two models with the lowest length-beam ratios. For Models 4665 and 4666 the angle of afterbody chine line in plan view is the same as that for the parent model (5°). Models 4667-1. 4668, 4669 were each 8ft long. Models 4665 and 4666 were 4ft and 6ft long, respectively. For each model, spray strips were the only appendages fitted. The ratio between spray-strip width and hull width was kept constant for all models in the series.

The $\boldsymbol{A_P/\nabla^{2/3}}$ values tested were: 5.5, 7.0, and 8.5. The speed range was: $\boldsymbol{F_\nabla}$ = 0.2-6.0. The LCG locations were: 0%, 4%, 8%, and 12% L_P aft of the CG. All possible combinations were tested, amassing a total of 80 tests.

MODEL CONSTRUCTION AND TEST PROCEDURE

The parent model was made of fiberglass and plastic for it to be light enough for future testing. The remaining models were constructed out of wood. On each of the models, scales were marked along the keel, along one chine, and on one side of the transom for reading the solid-water wetted lengths on the bottom and the dimensions of the side area which was wetted at low speeds. The models were tested at Carriage 3 of TMB. The basin is 20ft wide 2968ft long, with a depth of 16ft –for the first 1800ft– and 10ft for the reaming 1168ft.

Note: the change in depth had negligible effects on the results.

Models 4666 (6ft) and 4669 (8ft) were large enough to give accurate results without the need for external turbulence simulation. Model 4665, the 4ft model, had 0.035 in trip wires fitted at the stem. The resistance recorded was the horizontal component of the towing force. Heave, and pitch were recorded at each test speed. The intersections of the solid water with keel and chine and, at low speeds, the boundaries (at chine and transom) of the side wetted area were also recorded.

RESULTS

The resistance data of the series have been expanded to boat weights of 10,000 lb. and 100,000 lb. The heavier weight is representative of military planing craft, and the lighter weight is of a medium-sized motor yacht. The resistance data for a boat weight of 100,000 lb. are presented by Fig 1-7 in Appendix B. Graphs for ***R/W versus*** $\boldsymbol{F_\nabla}$ for 10,000 lb. boat are presented in Fig 8-12. Fig 1. Compares values of resistance and angle of attack for the five models of the series. Note: Model with the highest length-beam value has low drag for $\boldsymbol{F_\nabla}$ = 3.0-5.0. This is contrary to what would be true: short wide hull would have less drag at high speed due to its higher aspect ratio. Thus, this anomaly is attributed to the lower aerodynamic drag of the narrow hulls. Its is observed that at speeds below $\boldsymbol{F_\nabla}$ = 1.5 the hull forms of this series have slightly more drag than other designs. Between $\boldsymbol{F_\nabla}$ =

2.0-2.5 the hull forms have less drag than most of the other designs, and finally, at for $F_\nabla > 3.0$ the hull forms of the series have less drag than any other designs tested so far.
The following are the observations from Figs 3-7 and Figs 8-12:

1. Length-beam ratio of 2 is extremely low because the extreme *hump* in the drag curve;
2. At LCG location at the centroid of the projected chine area (0% L_P aft of CG) is too far forward because the drag is constantly high throughout the speed range;
3. At $A_P/\nabla^{2/3} = 5.5$, the LCG location is at 12% L_P aft of the CG and produces significant hump in both drag and trim curves. Thus, concluding that the LCG location is too far aft;
4. Lastly, the tests concluded that an LCG location between 4% and 8% L_P aft of the centroid will give good performance.

The conditions that produced porpoising are of interest for high-speed boats, a prediction model was created to predict this occurrence in the models. Accordingly, the speeds for inception of porpoising were determined for the various conditions of loading and LCG location by towing each model and then gradually increasing the speed. For this test, Models 4665 and 4666 were tested since these exhibited the most porpoising instability. The experimental values of conditions corresponding to the inception of porpoising collapsed into a single curve of the form: $C_{LB}/(l_{cp}/b)$ *versus* F_∇. The plot is given in Appendix C.

SIMPLIFIED PREDICTION METHOD

From the works at TMB it can be shown that at high speeds the resistance of a planing hull of a given weight can be presented as a function of only three variables: deadrise angle, aspect ratio, and lift coefficient. For Series 62, the deadrise angle is fixed at 12.5°. Since, the resistance data for varying loads collapsed onto a single curve, the resistance can be represented by only two variables: lift coefficient, C_{LB}, and LCG location. Thus, nine plots, for l_{CP}/b = 0.8, 1.0, 1.2, 1.4, 1.6, 2.0, 2.4, 2.8, and 3.2 at 8% L_P aft of CG, were plotted for varying C_{LB} on a R/W *vs.* W plot; for gross weight range of 1000lb – 100,000lb.
This predictive method was summarized in a series of plots listed in Appendix D.

CONCLUSION & DISCUSSION

In order to test the accuracy of the predictive model, let us assume the following values:

Gross Weight = 15,000lb

l_{cp} = 15.3ft

b = 10.9ft

Following the procedure described in Appendix D, we get the following plot:

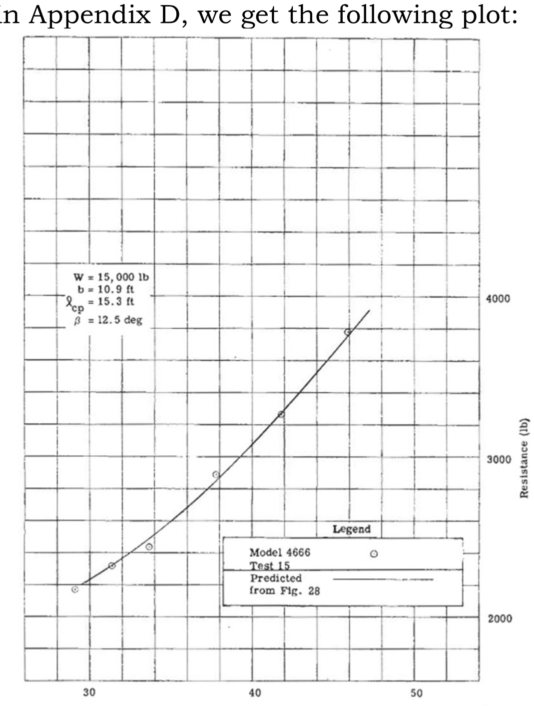

FIG. A: COMPARISON OF HIGH-SPEED BOAT RESISTANCE FROM EXPERIMENT

Observations: the curve shown represents the predicted values of resistance against the given velocity and the dotted points represent the actual test data from Test 15 of Model 4666, corrected for 15,000lb. From the close agreement, it is concluded that the proposed predictive model will give accurate predictions of the high-speed resistance of planing boats for a wide range of size and proportions.

FORMULATION OF A PREDICTIVE EQUATION THROUGH REGRESSION ANALYSIS

An attempt was made at Florida Tech to further generalize the predictive model presented in this paper, using a simple mathematical equation and regression analysis. Furthermore, in order to automate the process of resistance calculation using the devised general equation, a MATLAB code was written. The approach taken to formulate the generalized equation and the results are discussed below.

METHODOLOGY

Since, the experimental data was not readily available to the author, an approach of digitizing the given plots, from Appendix D, was taken. For this, WebPlotDigitizer was used. Plot for each set of l_{CP}/b ratio was digitized by hand, equaling almost 6,000 data points in total for nine plots.

Once the data was obtained, two different set of regression software were used to determine the most accurate non-linear regression approach. For this, the data points of l_{CP}/b = 0.8 were used, as benchmark.

First software used was Microsoft Excel, with its built in *Solver* applet. This method used the *Generalized Reduced Gradient* Non-Linear Optimization approach for convergence.

The second software used was TIBCO Statistica v12.5. Statistica used the *Rosenbrock & Quasi-Newton* Non-Linear Optimization approach for convergence.

In both cases, the R/W value was the dependent variable, whereas Weight (W), lift coefficient (C_{LB}) and length-beam ratio (l_{cp}/b) were the independent variables.

After various trials, the following two equations were found to give the most accurate prediction, across the board:

$$v1 = a0 + (a1 \times v2^{a2}) + \frac{a3 \times v3^{a4}}{a5 \times v4^{a6}} - (1)$$

$$v1 = a0 + \frac{(a1 \times v2^{a2}) + (a3 \times v3^{a4})}{a5 \times v4^{a6}} - (2)$$

Where: $v1$ = R/W

$v2$ = Weight (lb.)

$v3$ = C_{LB}

$v4$ = l_{CP}/b

From the initial trials with l_{CP}/b = 0.8 data sets, it was concluded that Equation (2) gave much more convergent results than Equation (1) –by comparing the R^2 values. Hence, Equation (2) was used for the final analysis. Given as:

$$\frac{R}{W} = a0 + \frac{(a1 * W^{a2}) + (a3 * (CLB)^{a4})}{a5 * (\frac{LCP}{B})^{a6}}$$

Thus, for the rest of the analysis, Equation (2) was analyzed with using the Rosenbrock & Quasi-Newton Non-Linear Optimization in TIBCO Statistica v12.5. All the nine plots were analyzed to find their respective coefficients: a0, a1, a2, a3, a4, a5, and a6. This data is included in the submission.

Once the coefficients were found, Equation (2) was coded into MATLAB to obtain program that calculates the resistance of high-speed planing boats for a gross weight of 1000lb-1000,000lb for a given length-beam ratio.

The accuracy of the obtained equation is compared to the findings and conclusion from the referenced paper.

OBSERVED VALUES VERSUS PREDICTED VALUES

The plot below compares the observed values from the reference paper (used as an example to prove the accuracy of their *Simplified Prediction Method*) to that predicted by the generalized equation:

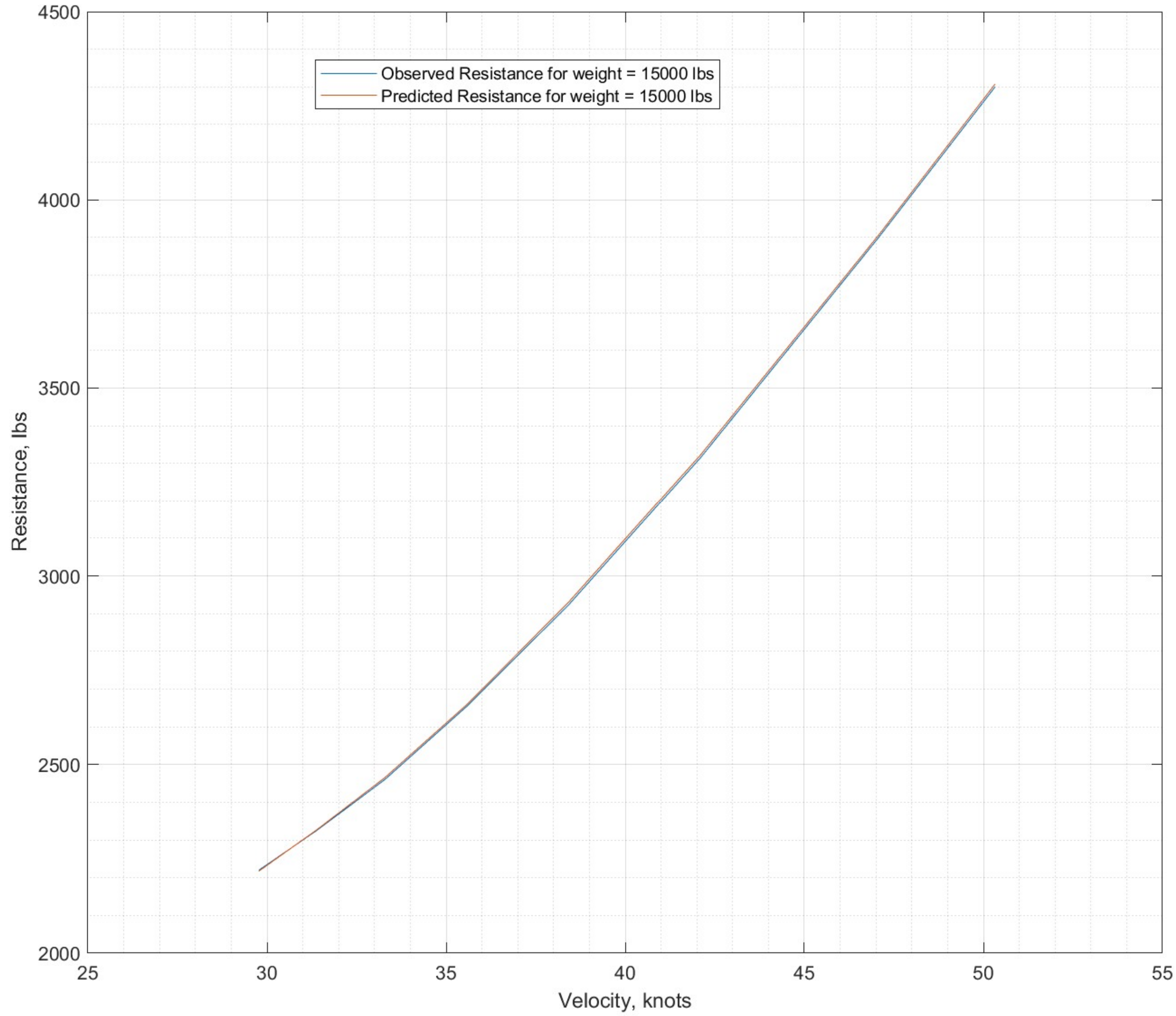

Fig B. *Simplified Prediction Method* vs. Generalized Equation

Input: Weight = 15,000lb
L_{cp} = 15.3 ft
b = 10.9 ft

Thus, because of the transitive relationship, it is concluded that the devised equation:

$$\frac{R}{W} = a0 + \frac{(a1 * W^{a2}) + (a3 * (CLB)^{a4})}{a5 * (\frac{LCP}{B})^{a6}}$$

Will give accurate resistance values for high-speed boats for a specified weight range of 1000lb-100,000lb.