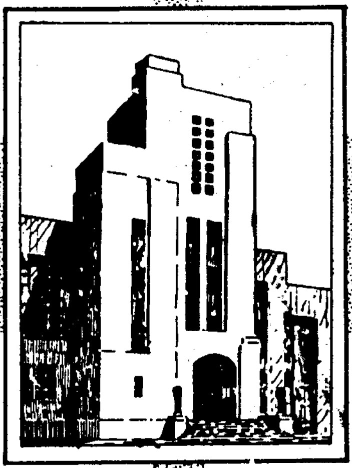

NAVY DEPARTMENT
DAVID TAYLOR MODEL BASIN

TESTS OF A PLANING BOAT MODEL WITH PARTIAL HYDROFOIL SUPPORT

by

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NOTATION

B.L.	Baseline
C_D	Drag Coefficient, $\frac{D}{\frac{1}{2}\rho S v^2}$
C_L	Lift Coefficient, $\frac{L}{\frac{1}{2}\rho S v^2}$
D	Drag of foil, lb
L	Lift of foil, lb
S	Projected area of foil, ft^2
V	Speed, knots
v	Speed
α	Angle of attack, of foil, deg
α_o	Angle of attack of foil relative to the baseline of the hull, deg
A	Projected bottom area bounded by chines, and transom, in plan view
EHP	Effective Horsepower
$F_{n\nabla}$	Froude number based on volume, in any consistent units $v/\sqrt{g\nabla^{1/3}}$
g	Acceleration due to gravity
L	Overall length of the area, A, measured parallel to baseline
R	Total Resistance
R_m	Total model resistance, lb
SW/FW	Density ratio, salt water to fresh water
V_m	Model speed, knots
Δ	Displacement at rest, weight of
Δ_m	Displacement of model at rest, lb

Δ_s	Displacement of full-scale boat at rest, lb
τ	Trim angle of hull with respect to attitude as drawn, deg
τ_o	Trim at rest, deg
∇	Displacement at rest, volume of

ABSTRACT

A model of a planing boat was equipped with two horizontal submerged hydrofoils which were designed to carry part of the weight of the craft. Smooth-water resistance tests were made with the foils at various fore-and-aft positions and various angles of attack to determine the optimum arrangement. Tests were also made of the foils alone. It was found that an appreciable scale effect on foil performance existed at Reynolds numbers below about 5×10^5.

The data from the tests of the hull with foils, when corrected for scale effect on foil performance, indicated that the resistance of a planing boat can be decreased when such foils are added by as much as 27½ percent. The best result was attained with the foils located at 28 percent of the hull length aft of the bow, and with the foil chord line at an angle of -3.5 deg with respect to the hull baseline.

INTRODUCTION

High-speed small craft continue to be used for a variety of military purposes. Possible means of improving the performance of such craft are accordingly of interest.

The application of hydrofoils to small craft has been extensively investigated in recent years. It has been found, however, that a boat which is entirely supported by hydrofoils is relatively expensive and complex, both to develop and to build.

A possible alternative way of improving the performance of high-speed small craft would be to utilize a planing hull together with hydrofoils which support only part of the weight of the craft. By this approach it can be presumed that the craft's resistance would be reduced in two ways. First, part of the weight would be supported by hydrofoils operating at a higher lift-drag ratio than the hull alone. Second, the hydrofoil lift could be applied in such a way as to improve the trim angle of the hull.

From a practical point of view this arrangement has a number of points in its favor. For one thing it could be adapted to existing hulls having conventional shafting systems. Also, it can be expected that the hull would provide sufficient stability, so that there would be no necessity for a complicated and expensive electric or mechanical incidence control system.

Tests to determine the smooth-water resistance and EHP of such a design were undertaken by the Model Basin, and the results are presented in this report.

THE MODEL TESTED

An existing hull model was used for the present investigation. This was Model 4377, which is a 1/8-scale model of a 52-ft aircraft rescue boat. It was necessary to select a relatively small model so that the hull and foil combination would fit in the test bay of the most suitable facility - Carriage 3 in the High-Speed Basin. Previous tests of the hull model are reported in Reference 1.*

The arrangement of the hull and hydrofoils is shown in Figure 1 It can be seen that it is possible to adjust the fore-and-aft position, the vertical position, and the angle of attack of the foils.

The foils were designed so that the full-scale working stress in smooth water would be approximately 15,000 pounds per square inch. The NACA 16-509 foil section was utilized. The very flat curve of pressure distribution on the low pressure side of this foil makes it particularly well suited as a hydrofoil, because relatively high speeds can be attained before cavitation inception. A cavitation check indicated that the craft considered here could attain a full-scale speed of about 45 knots, in smooth water, before the inception of cavitation on the foils.

TEST OF HYDROFOIL ALONE

It has been pointed out in Reference 2 that at low Reynolds numbers there is an appreciable change with Reynolds number in the lift and drag coefficients of hydrofoils. Hence, it was necessary to determine quantitatively the effect of Reynolds number on the hydrodynamic performance of the present hydrofoil.

The lift and drag of one of the hydrofoils was measure on Carriage 3 by means of the setup shown in Figure 2. The drag of the foils was measured by the carriage resistance dynamometer, and the lift was measured as the reduction in the tension on a strain gage dynamometer.

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*References are listed on page 6

The foil lift and drag were measured for a range of speeds and angles of attack. The air drag of the towing gear was subtracted from the measured drag data.

Coefficients of lift and drag as determined from these tests are plotted in Figures 3 and 4. It is apparent that the lift and drag coefficients are very much dependent upon speed (or Reynolds number.) The lift coefficients increase with increasing speed, while the drag coefficients decrease with speed. Reynolds numbers for the test speed range (using mean chord length as the characteristic length) are as follows:

V Knots	Reynolds Number
5	1.156×10^5
10	2.313×10^5
15	3.470×10^5
20	4.626×10^5
25	5.782×10^5

In Figure 5, lift coefficient is plotted against angle of attack. References 3 and 4 were used to obtain the predicted lift curve in this figure. It is apparent that the angle of zero lift decreases with increasing speed. Also, the slope of the lift coefficient curve varies slightly with speed.

Figure 6 shows a plot of lift coefficient against drag coefficient. Predicted curves for the model foil at 25 knots and the full-scale foil at 40 knots (assuming no cavitation,) as calculated from the information in References 3 and 4, are included. (It is apparent that as the Reynolds number increases the experimental values approach the predicted full-scale values.)

Figure 7, a plot of lift-drag ratio against lift coefficient, presents the data from Figure 6 in a different form.

From these tests it is apparent that there is a very large effect of Reynolds number on the performance of a model hydrofoil. It appears that a model foil should operate at a Reynolds number above about 5×10^5 in order to approximate the performance of the full-scale foil.

TESTS OF HULL WITH AND WITHOUT FOILS

The hull was tested without foils at values of $A/\nabla^{2/3}$ of 5, 6, and 7, and with foils at values of $A/\nabla^{2/3}$ of 5 and 6. The C.G. of all test conditions was located at 6 percent L aft of the centroid of the area A. It was not possible to test the hull with foils at an $A/\nabla^{2/3}$ of 7 because of the weight of the foil assembly.

A value of $A/\nabla^{2/3}$ of 6 corresponds to a full-scale displacement of 51,338 pounds. Reference 5 reports the empty weight of the full-scale boat as 47,266 pounds. Therefore, the loaded weight of the full-scale craft would be close to the displacement corresponding to an $A/\nabla^{2/3}$ of 6.

The model was towed in the shaft line, which is shown in Reference 1. Resistance, wetted lengths, and trim angle were measured for model speeds up to 20 knots. The resistance data presented include the air drag of the model above the water. The air drag of the towing gear, however, has been subtracted. Wetted lengths of the hull were measured forward of the transom to the intersection of solid water with the keel and chine.

Photographs of the hull model without foils, running at a displacement corresponding to $A/\nabla^{2/3} = 6$, are presented in Figure 8. Curves of trim and predicted full-scale EHP are given in Figure 10. The model without foils was stable at all speeds at the three displacements tested.

The model with foils was tested up to the speed at which it "took off." This was the speed at which the bow rose to an appreciable height above the water and only the aft-most part of the bottom touched the water surface. The trim of the model greatly increased at this point. Disturbing forces were applied to the model at speeds below the point where it "took off," and the model appeared to be very stable and well damped in all motions except yaw. In yaw, the model exhibited a tendency to oscillate back and forth. This can be accounted for by the fact that the model was not fitted with rudders or shaft struts and accordingly there was not enough lateral area aft to compensate for the lateral area of the foil struts forward. Figure 9 shows the model running with foils at a displacement corresponding to $A/\nabla^{2/3} = 6$.

Figures 11 and 12 show the trim and predicted full-scale EHP curves for the craft with foils at $A/\nabla^{2/3}$ equal to 6. For the tests shown in Figure 11 the fore-and-aft location of the foils was varied while angle of attack of the foils with respect to the hull was kept constant. In Figure 12 the angle of attack of the foils with respect to the hull was varied while the fore-and-aft location was kept constant.

Figure 13 shows predicted full-scale EHP curves for the craft with foils at $A/\nabla^{2/3}$ equal to 6, with the lift-drag ratio of the foils corrected for the Reynolds number effect. Figure 7 shows this Reynolds number effect on the lift-drag ratio. The lift of the foils was corrected by counter-balancing the model at the foil assembly by the amount of lift that the foils were lacking at that speed. The drag was corrected by subtracting the difference between the experimental and the predicted drag of the foils from the craft drag measured in the tests. The running trim of the craft for these tests is also plotted in Figure 13.

Figure 14 shows predicted full-scale EHP curves for the craft with foils at a displacement corresponding to $A/\nabla^{2/3} = 5$. The fore-and-aft location of the foils was varied in this test while the angle of attack with respect to the hull was held constant. These data were not corrected for Reynolds number effect on foil performance.

All EHP calculations were made in accordance with Reference 6. In calculating the EHP with foils, the Reynolds number of the hull was used in calculating the frictional drag coefficients of model and full-scale craft. The fact that the Reynolds numbers of the foils were lower and hence the slope of the drag coefficient curve was steeper was not taken into account in calculating the EHP. The values of predicted EHP will therefore be slightly high.

COMPARATIVE DATA

The curve of R/Δ for the craft with the foils at their optimum location and angle of attack for an $A/\nabla^{2/3}$ equal to 6 is shown in Figure 15. The test is the same as that shown in Figure 13 ($\alpha_0 = -3.5^{\circ}$) with the L/D corrected. The R/Δ curve for the craft without foils is also shown in this figure. The R/Δ curves have been corrected to a displacement of 100,000 pounds as is done on DTMB Planing Boat Design Data Sheets (see Reference 7.) The percentage reduction in resistance is also plotted on this figure. The maximum reduction in resistance is 27½ percent.

CONCLUSIONS

1. Some preliminary model tests indicate that partial support of a planing boat with hydrofoils is not only practical but can be highly advantageous in reducing overall still-water resistance.

2. In still water, the partially supported craft is perfectly stable up to the speed where the hull "takes off."

3. When disturbed by an external force the model appeared to be perfectly stable and well damped in pitch and roll. However, there was a tendency of the model to oscillate back and forth in yaw. This can be attributed to the lack of lateral area aft on the model as tested.

RECOMMENDATIONS

1. Preliminary results indicate that it might be highly advantageous to make further investigations into partially supported craft. The dynamic stability of these craft should be the primary subject investigated.

2. Investigate the possibilities of using surface-piercing foils instead of submerged foils.

3. A large amount of lateral area aft is necessary in the partially supported craft. This may be accomplished by utilizing a high-deadrise stern or by providing sufficient skeg area aft.

REFERENCES

1. Curry, J.H., "Model Test Results and Predicted EHP for Bureau of Ships Design 52-Foot Aircraft Rescue Boat from Tests of Model 4377," David Taylor Model Basin Report 769 (June 1951).

2. Waldin, K.L., el al., "A Theoretical and Experimental Investigation of the Lift and Drag Characteristics of Hydrofoils at Subcritical and Supercritical Speeds," National Advisory Committee for Aeronautics Report 1232 (1955).

3. Gibbs and Cox, Inc., "Hydrofoil Handbook, Volume II, Hydrodynamic Characteristics of Components," Bath Iron Works Corp. (1954).

4. Stack, J., "Tests of Airfoils Designed to Delay the Compressibility Burble," National Advisory Committee for Aeronautics Report 763 (1943).

5. Meyer, E.R., CDR, USN, "Results of Standardization, Tactical, and Rough Water Trials on Five Aircraft Rescue Boats," David Taylor Model Basin Report 1108 (April 1957).

6. Gertler, M., "The Prediction of Effective Horsepower of Ships by Methods in Use at the David Taylor Model Basin," David Taylor Model Basin Report 576 (December 1947).

7. Clement, E.P., "Analyzing the Stepless Planing Boat," David Taylor Model Basin Report 1093 (November 1957).

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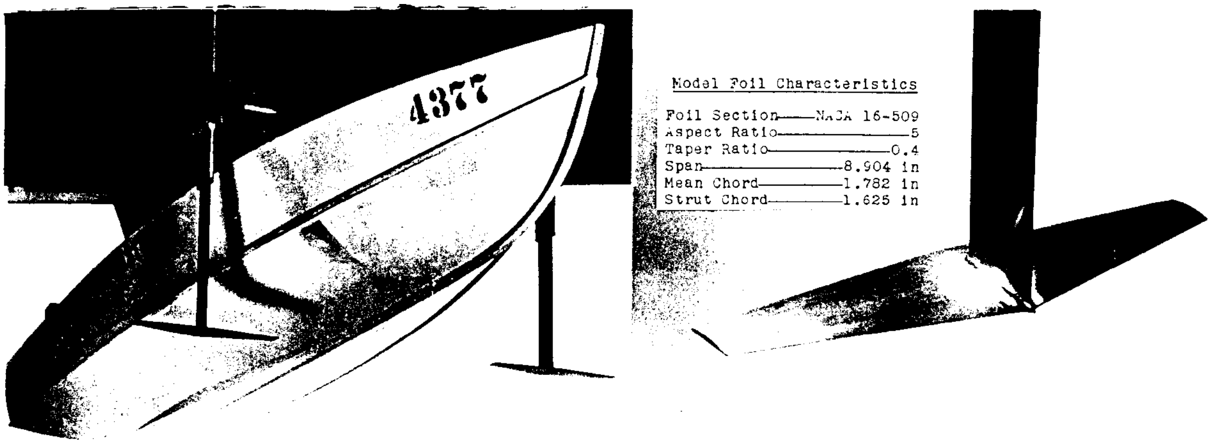


Model Foil Characteristics

Foil Section	NACA 16-509
Aspect Ratio	5
Taper Ratio	0.4
Span	8.904 in
Mean Chord	1.782 in
Strut Chord	1.625 in

Underside of Model

Model Foil

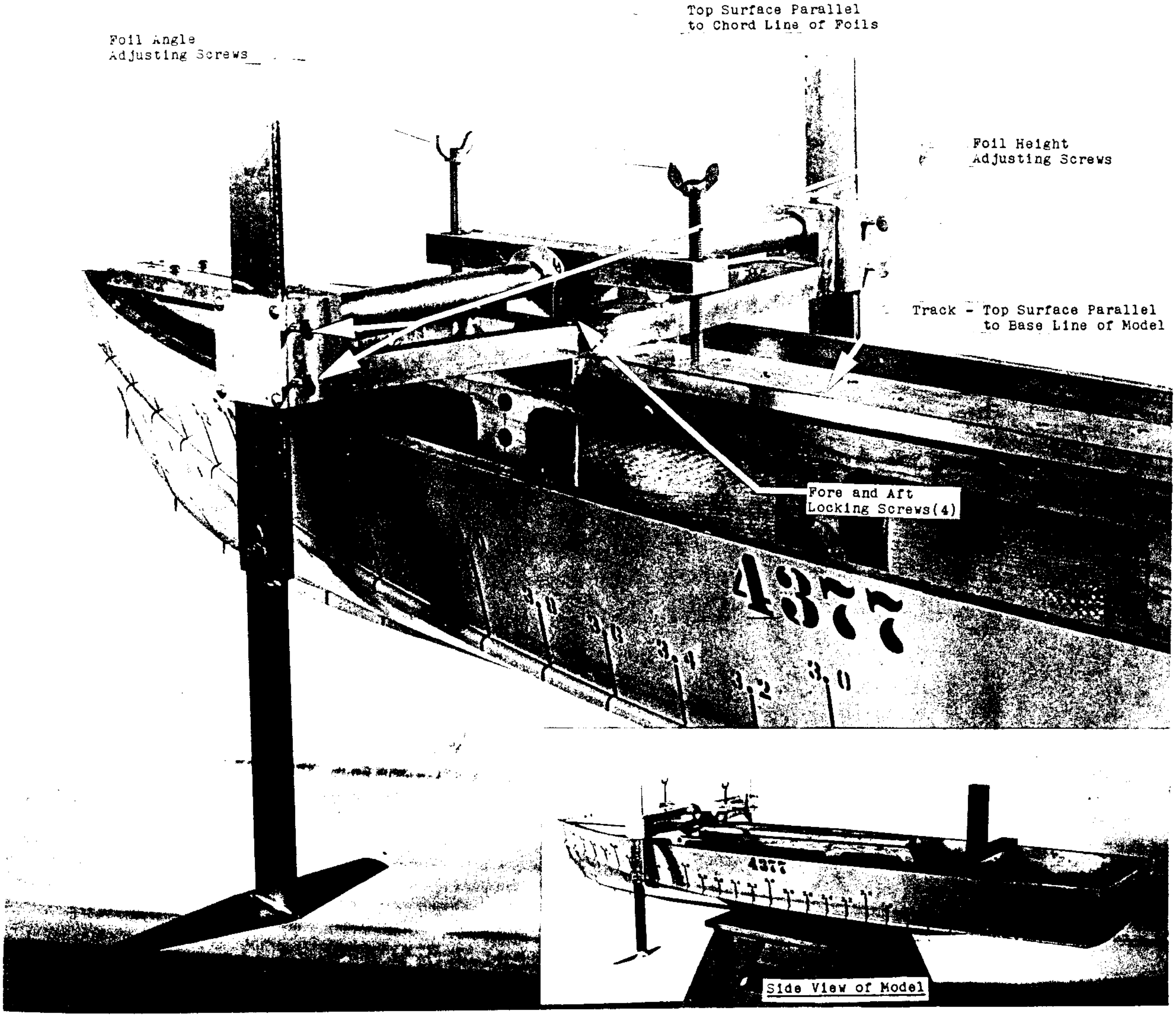


Figure 1 - Photographs of Model

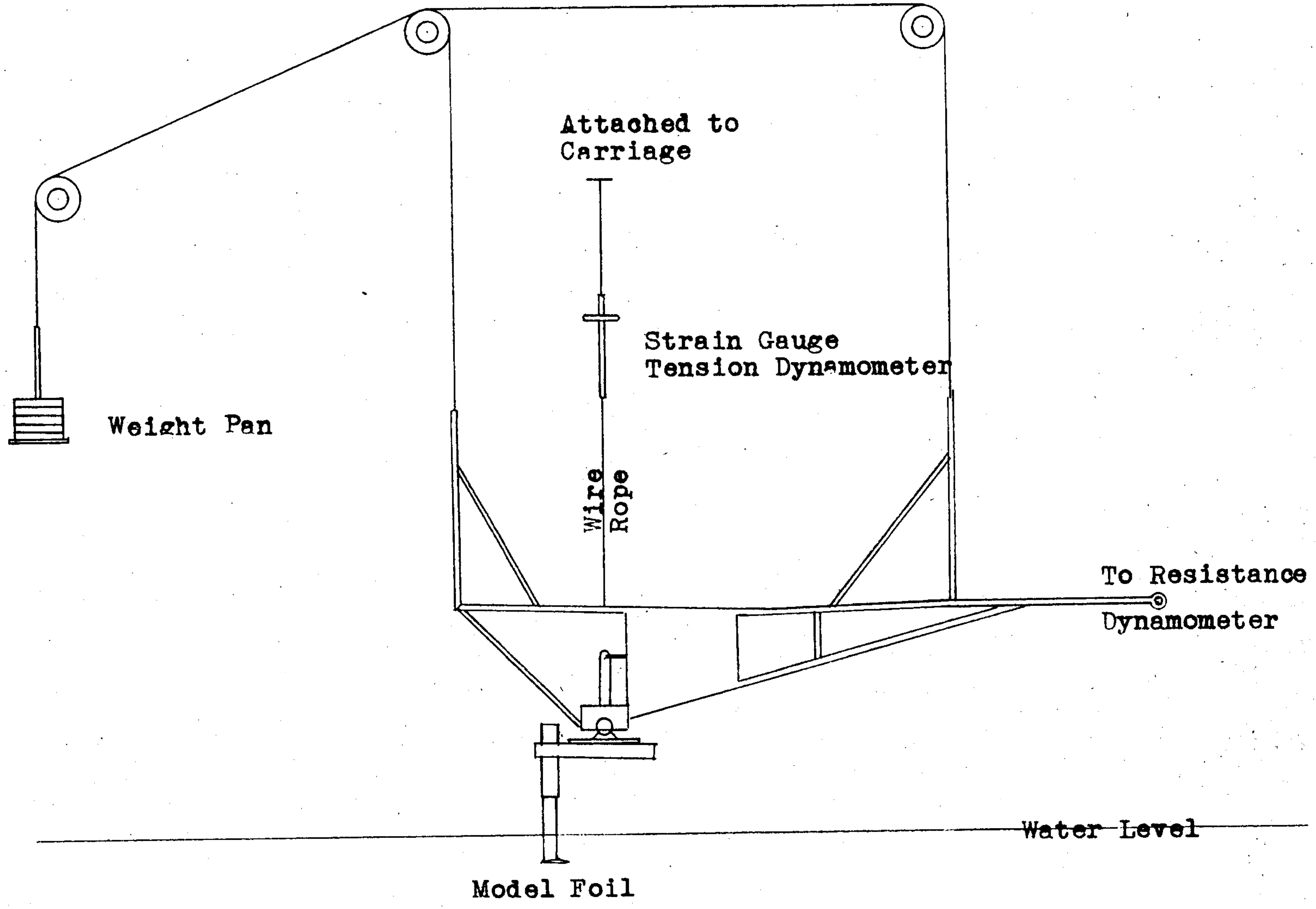


Figure 2 - Setup of Model Foil and Towing Gear

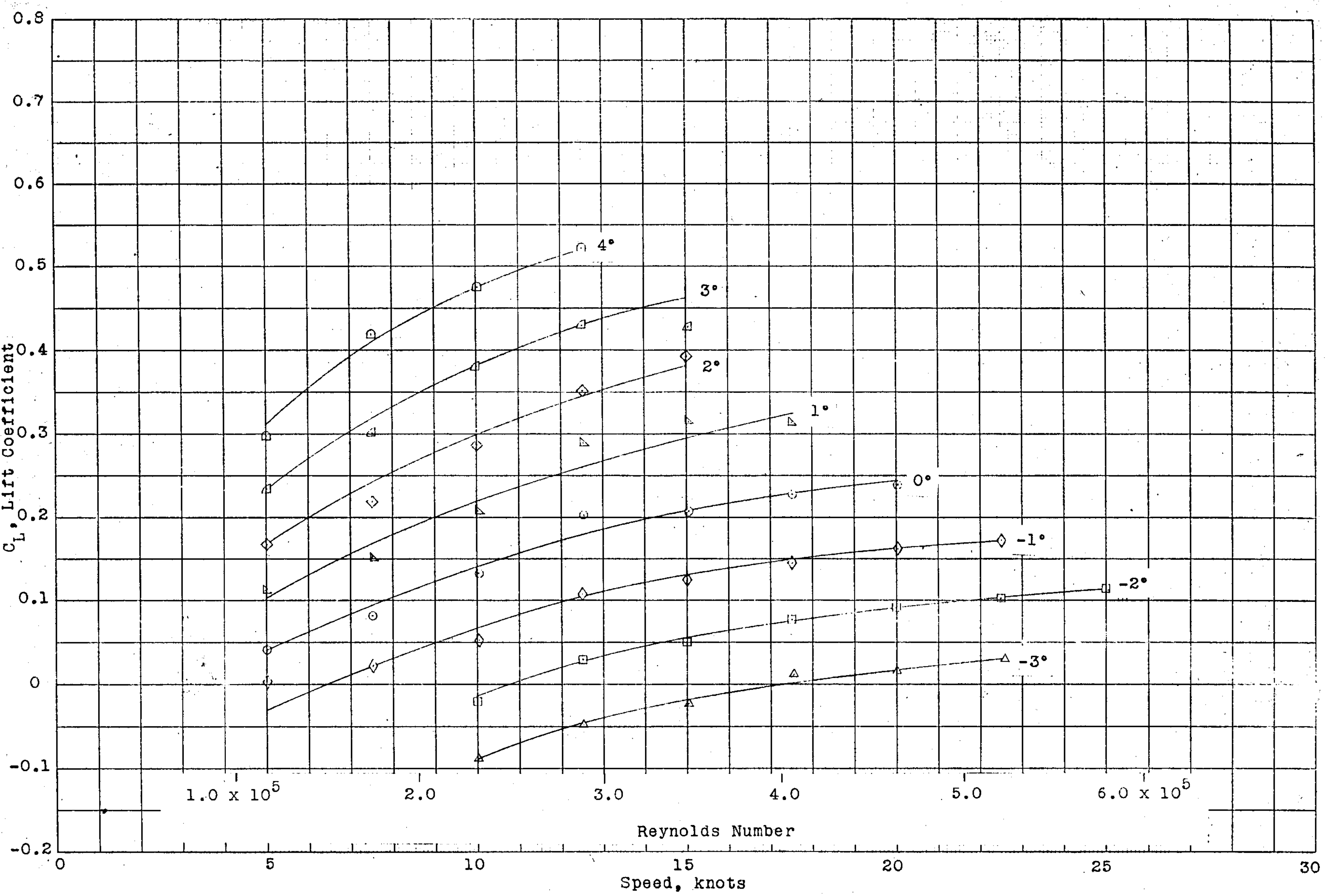


Figure 3 - Lift Coefficient vs. Speed, $1\frac{1}{2}$ Chords Submergence(3.82 in.)

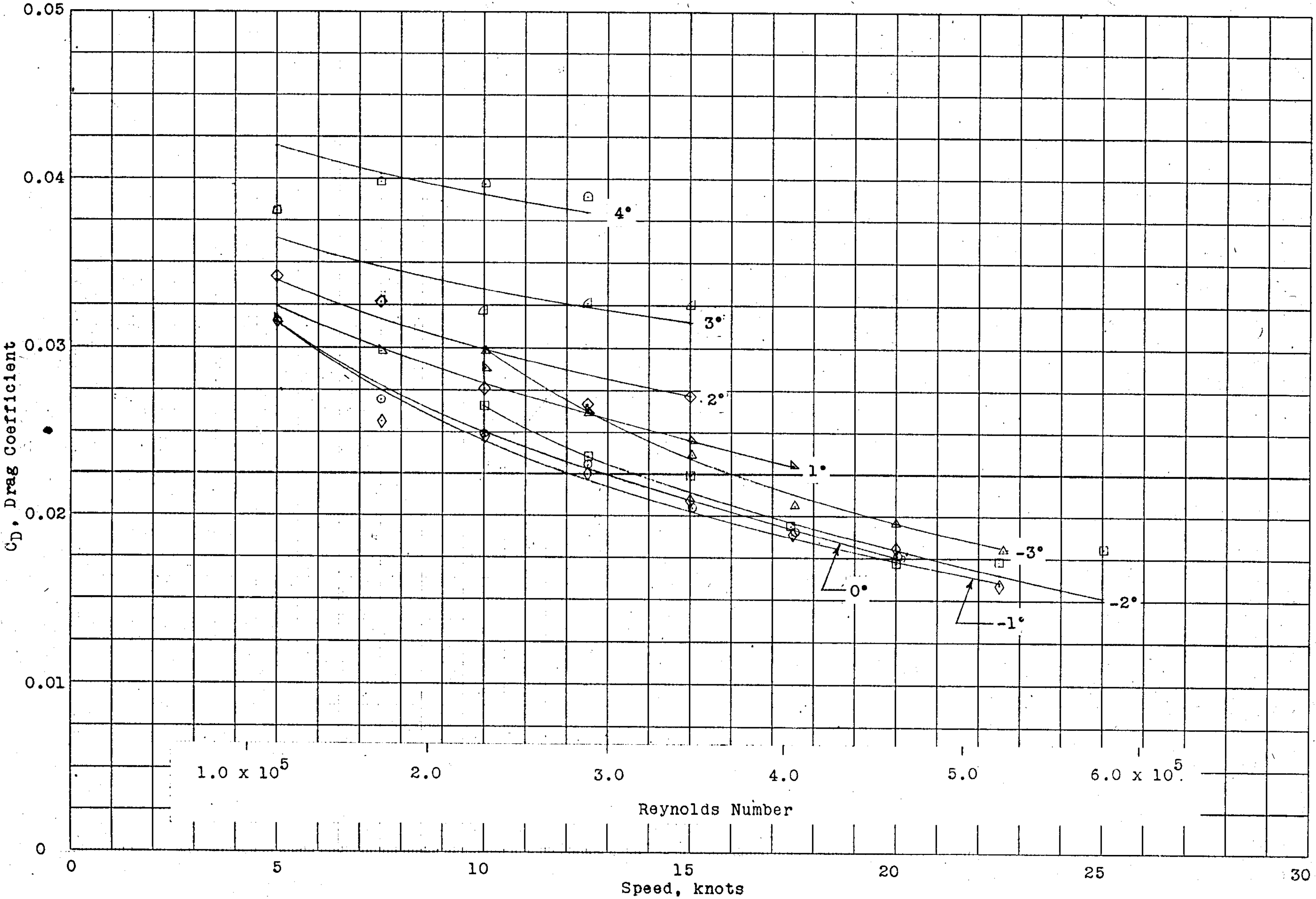


Figure 4 - Drag Coefficient vs. Speed, 1¼ Chords Submergence(3.82 in.)

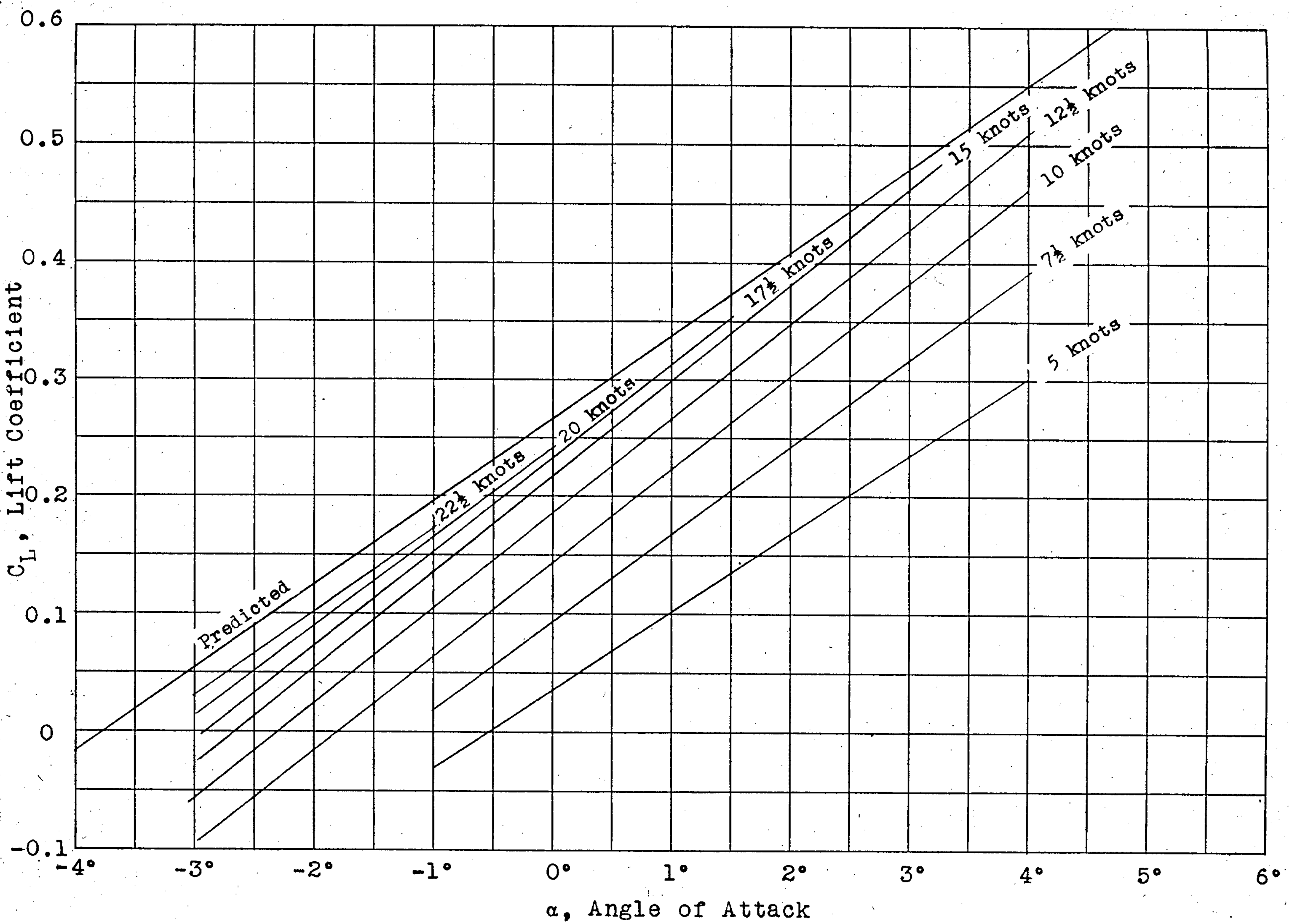


Figure 5 - Lift Coefficient vs. Angle of Attack, 1½ Chords Submergence(3.82 in.)

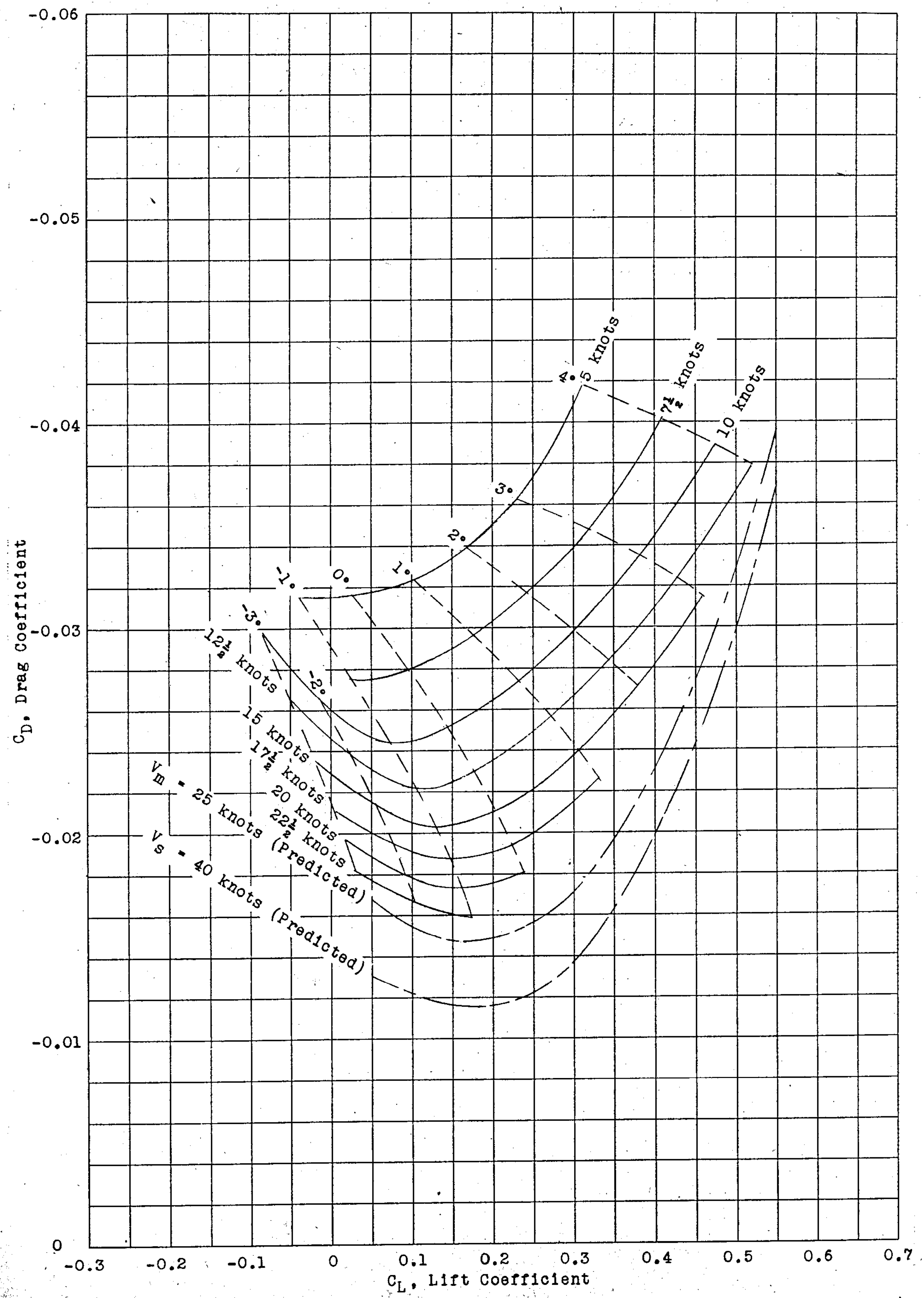


Figure 6 - Drag Coefficient vs. Lift Coefficient, 1½ Chords Submergence(3.82 in.)

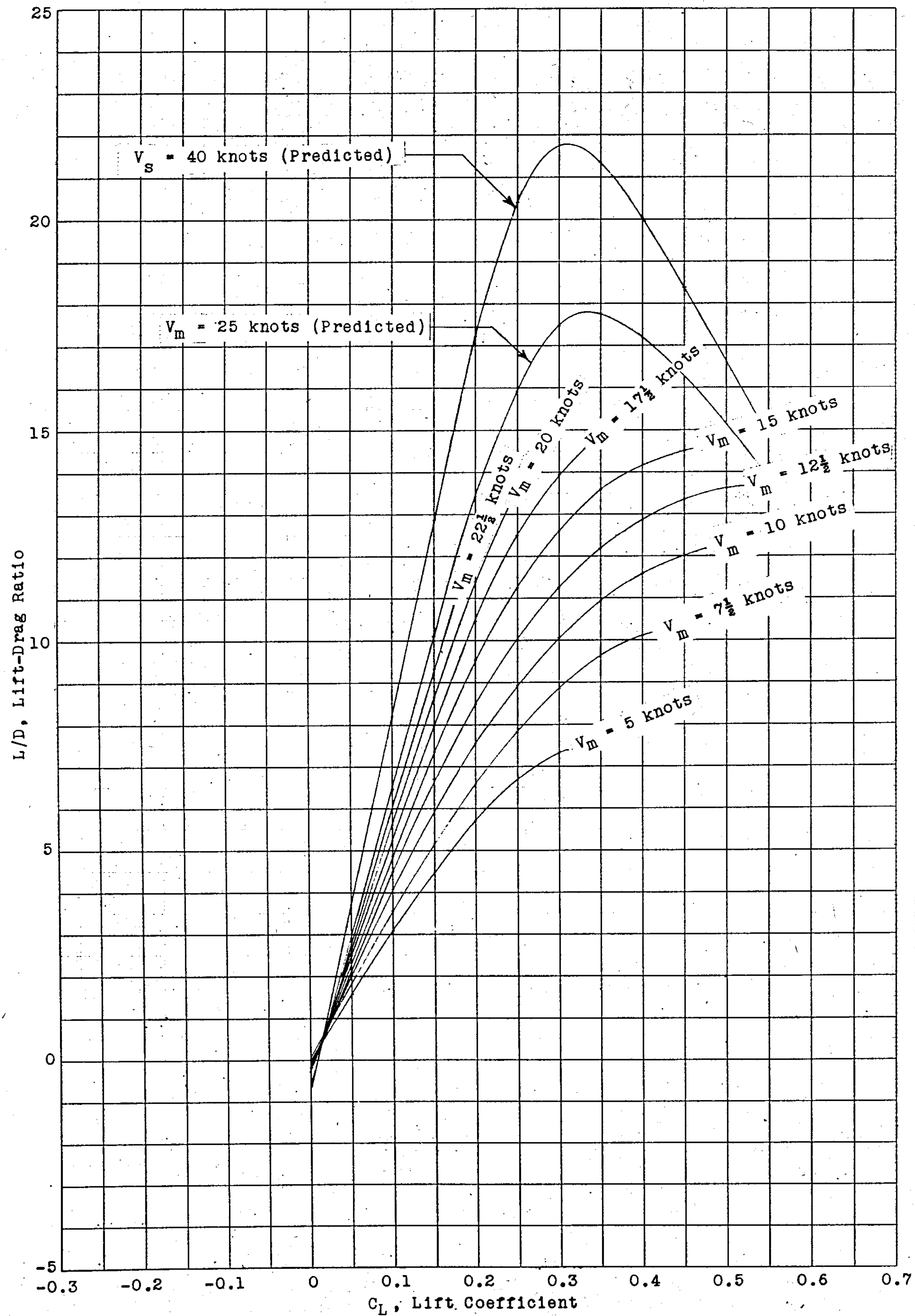
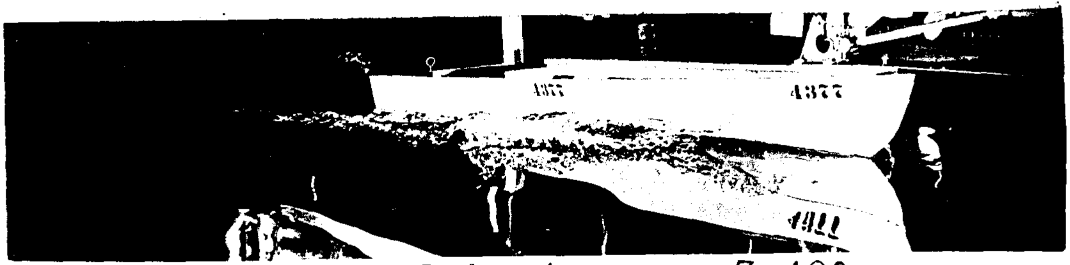
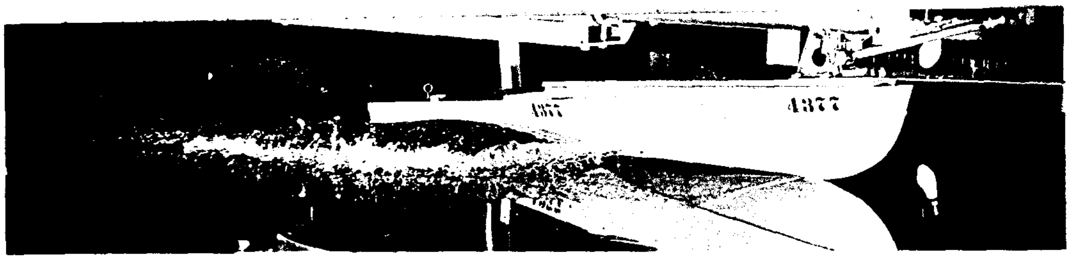


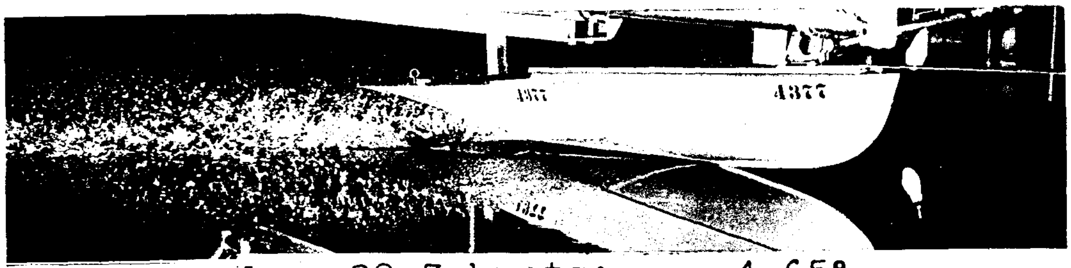
Figure 7 - Lift - Drag Ratio vs. Lift Coefficient, 1½ Chords Submergence (3.82 in.)



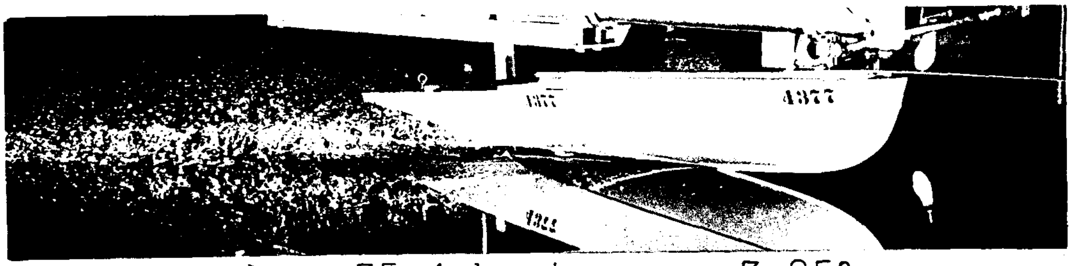
V_s = 14.1 knots; τ = 3.40°



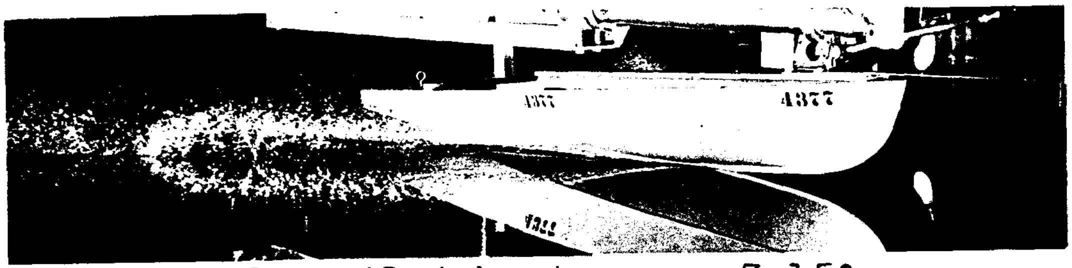
V_s = 21.2 knots; τ = 4.35°



V_s = 28.3 knots; τ = 4.65°

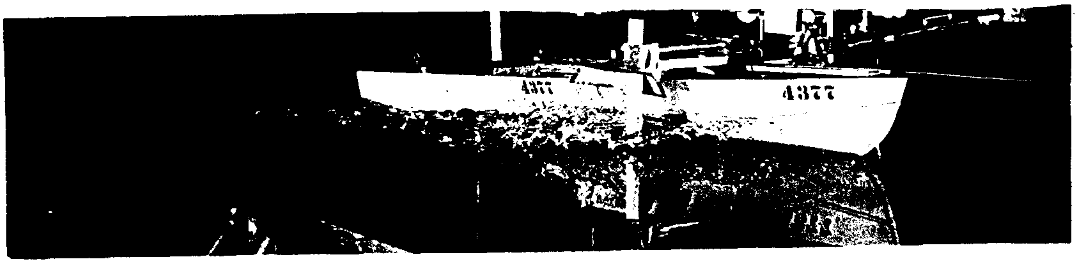


V_s = 35.4 knots; τ = 3.85°

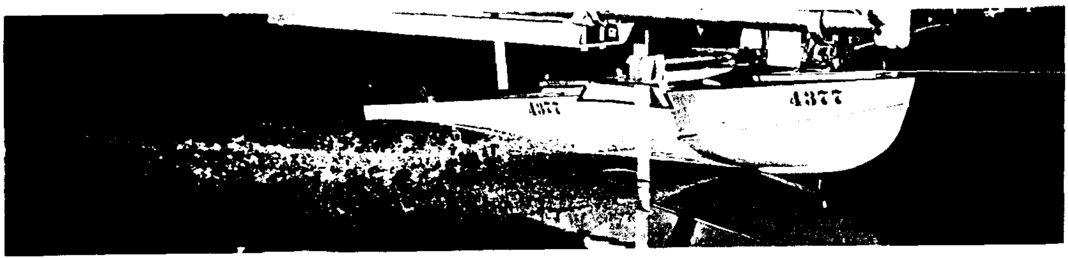


V_s = 42.4 knots; τ = 3.15°

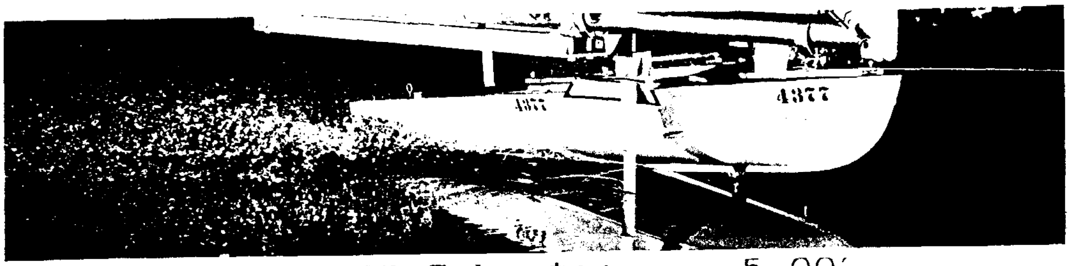
Figure 8 - Photographs of Model without Foils; $A/\nabla^{2/3}$ = 6; τ_0 = -0.18°.



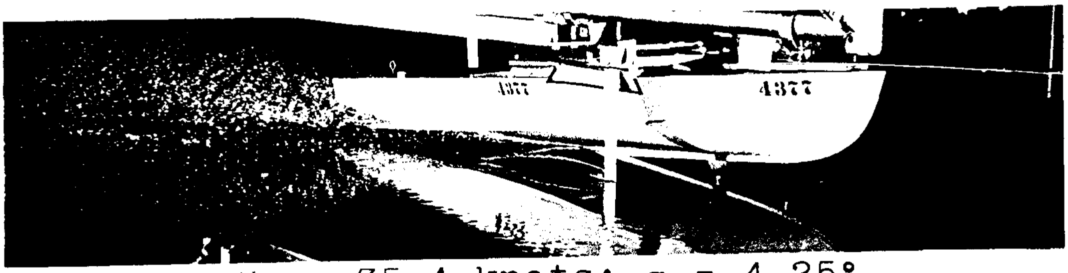
$V_S = 14.1$ knots



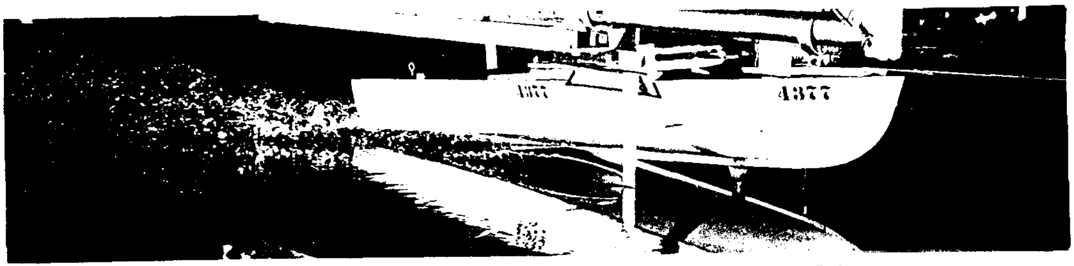
$V_S = 21.2$ knots



$V_S = 28.3$ knots; $\tau = 5.00'$



$V_S = 35.4$ knots; $\tau = 4.25^\circ$



$V_S = 42.4$ knots; $\tau = 3.40^\circ$

Figure 9 - Photographs of Model with Foils 24" fwd C.G., $\alpha_0 = -3.0^\circ$ $A/\nabla^{2/3} = 6$; $\tau_0 = -0.18^\circ$.

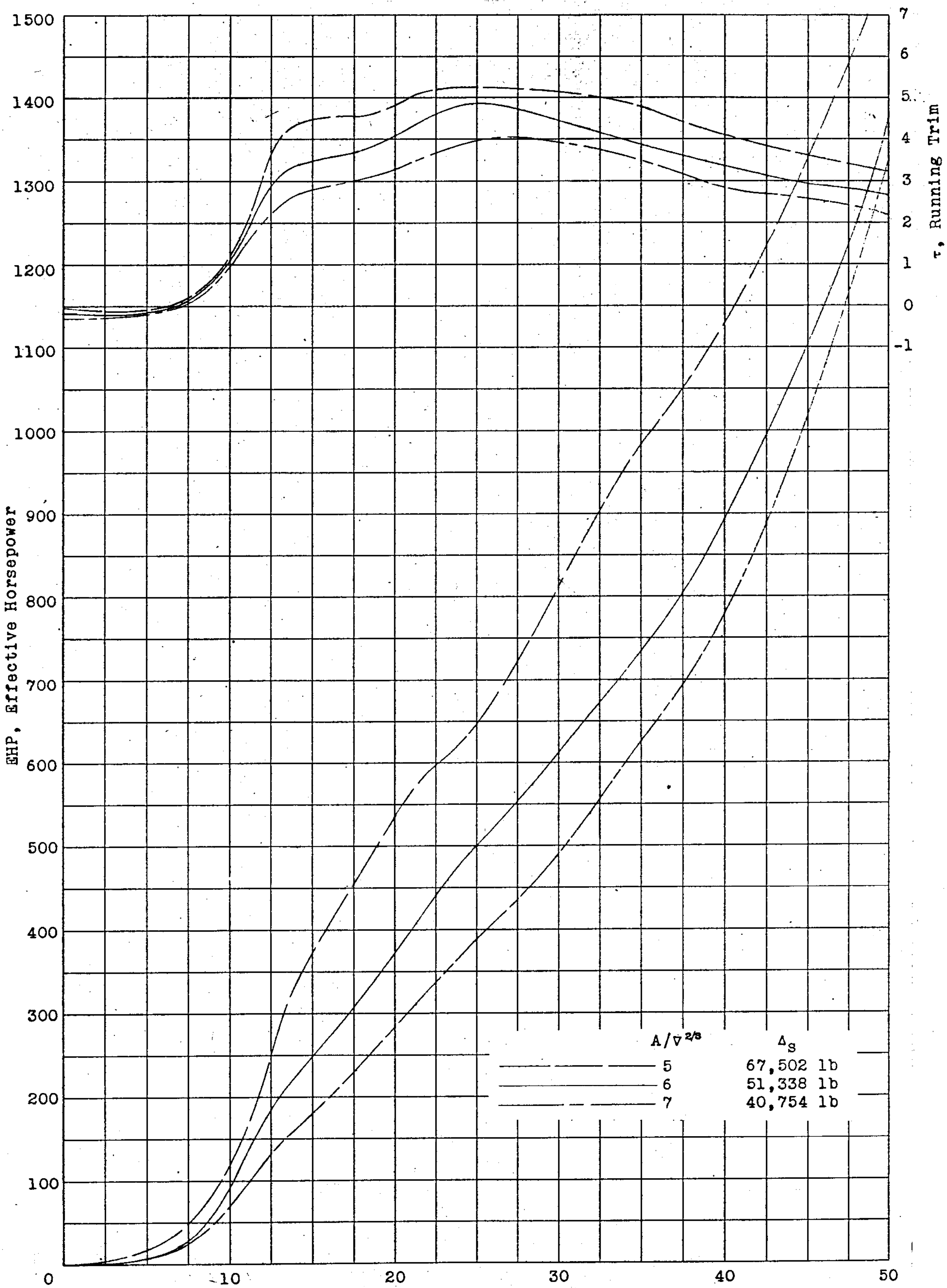


Figure 10 - Predicted EHP (using 1947 ATTC Model-Ship Correlation Line with Zero Roughness Allowance) and Running Trim from tests of Model 4377 without Foils; $A/\nabla^{2/3}$ = 5,6, and 7.

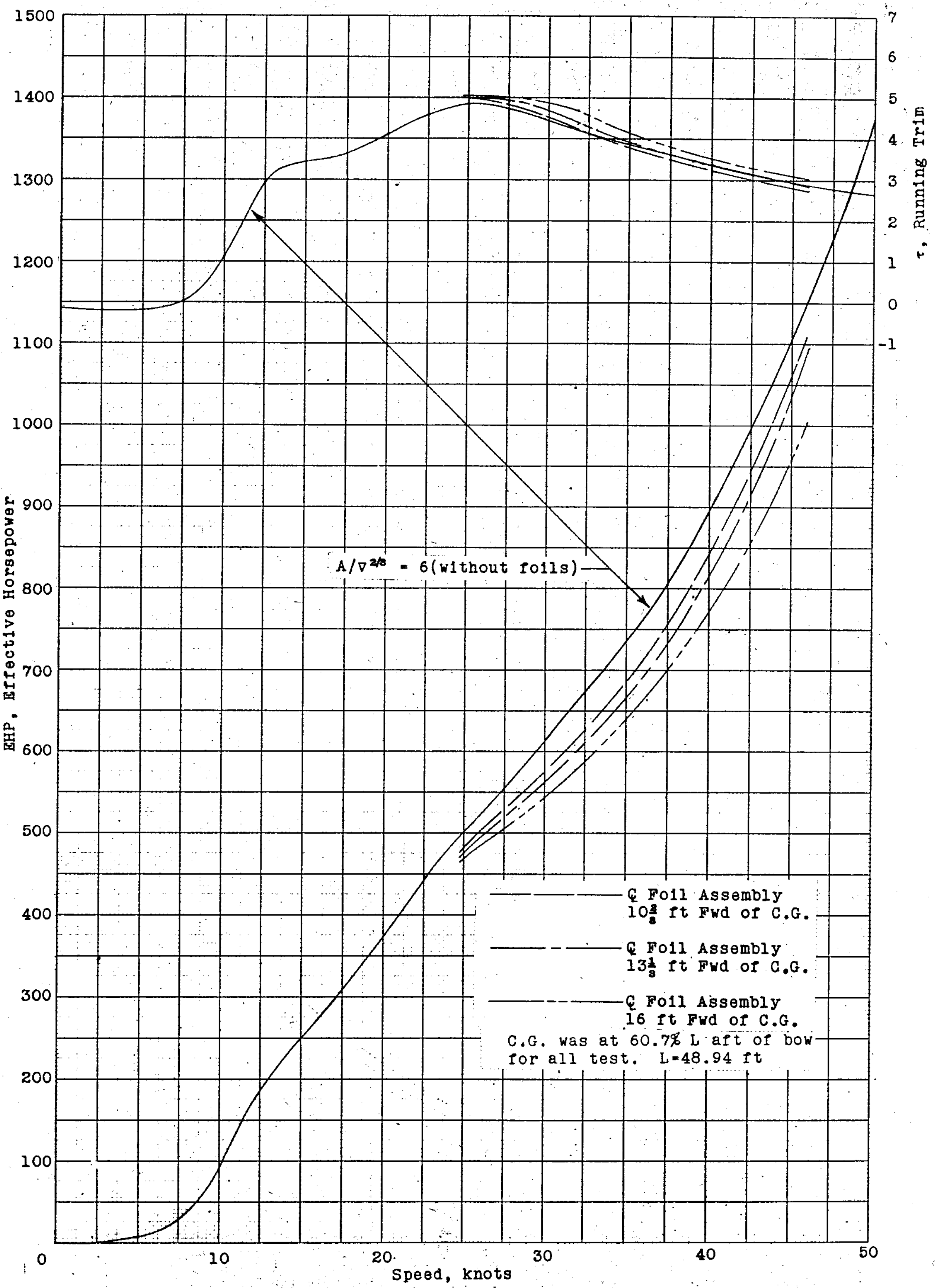


Figure 11 - Predicted EHP (using 1947 ATTC Model-Ship Correlation Line with Zero Roughness Allowance) and Running Trim from tests of Model 4377 with Foils; $\alpha_\circ = -3.5°$; $A/\nabla^{2/3} = 6$.

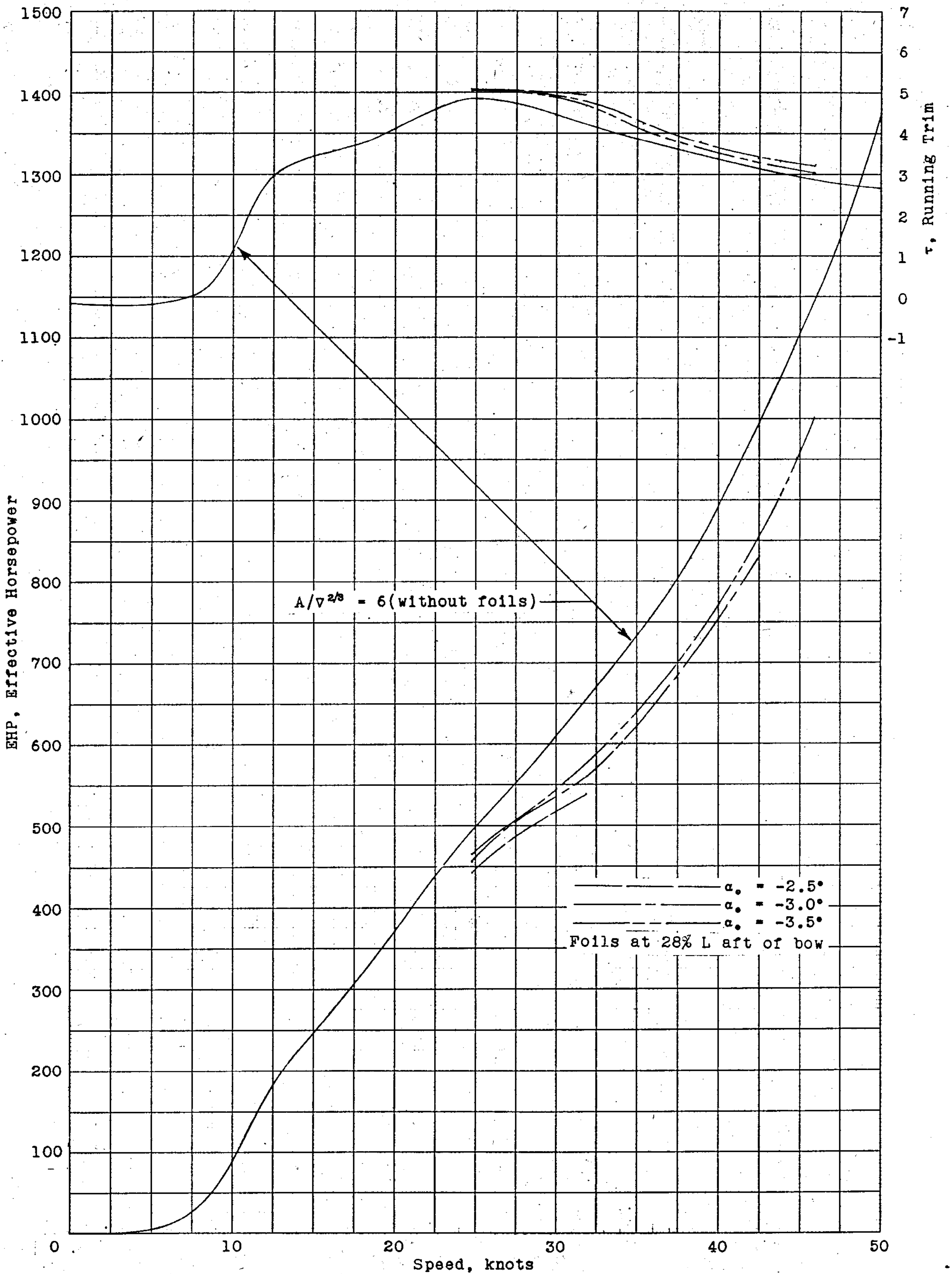


Figure 12 - Predicted EHP (using 1947 ATTC Model-Ship Correlation Line with Zero Roughness Allowance) and Running Trim from tests of Model 4377 with Foils 16 ft Fwd of C.G.; $A/\nabla^{2/3} = 6$.

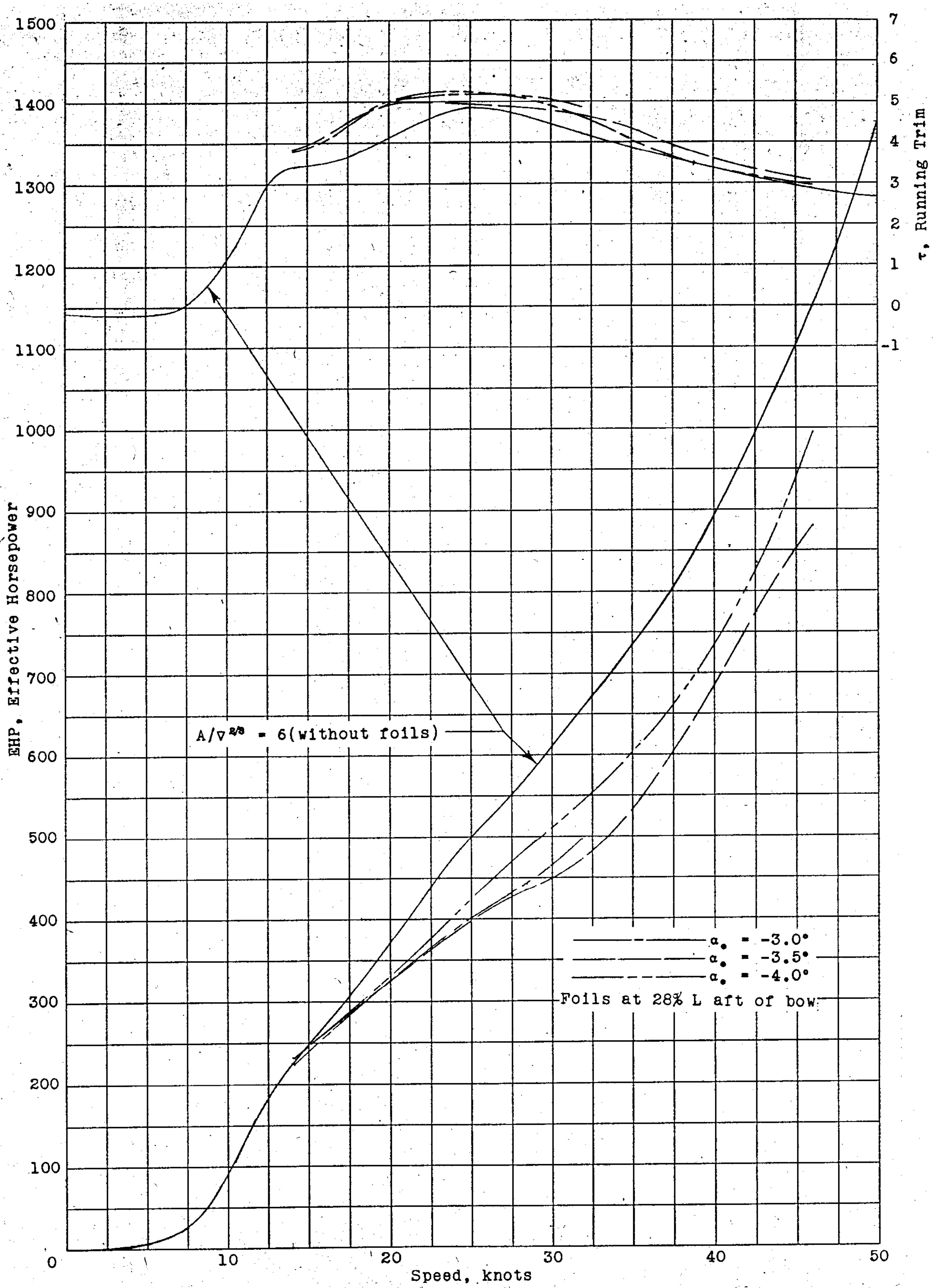


Figure 13 - Predicted EHP (using 1947 ATTC Model-Ship Correlation Line with Zero Roughness Allowance) and Running Trim from tests of Model 4377 with Foils 16 ft Fwd of C.G.; $A/\nabla^{2/3} = 6$; L/D of Foils corrected for Reynolds Number Effect.

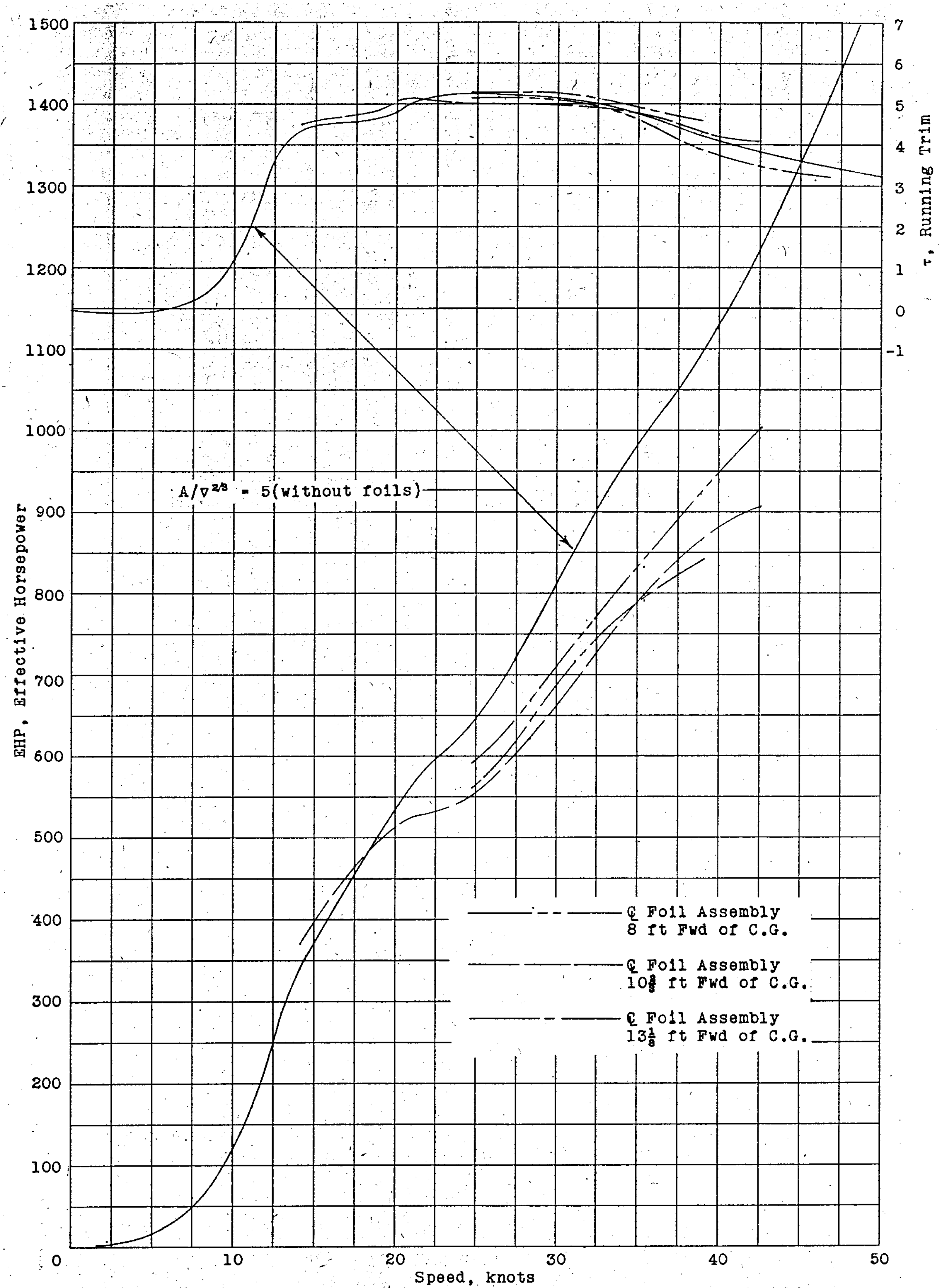


Figure 14 - Predicted EHP (using 1947 ATTC Model-Ship Correlation Line with Zero Roughness Allowance) and Running Trim from tests of Model 4377 with Foils; $\alpha_o = -2.30°$; $A/\nabla^{2/3} = 5$.

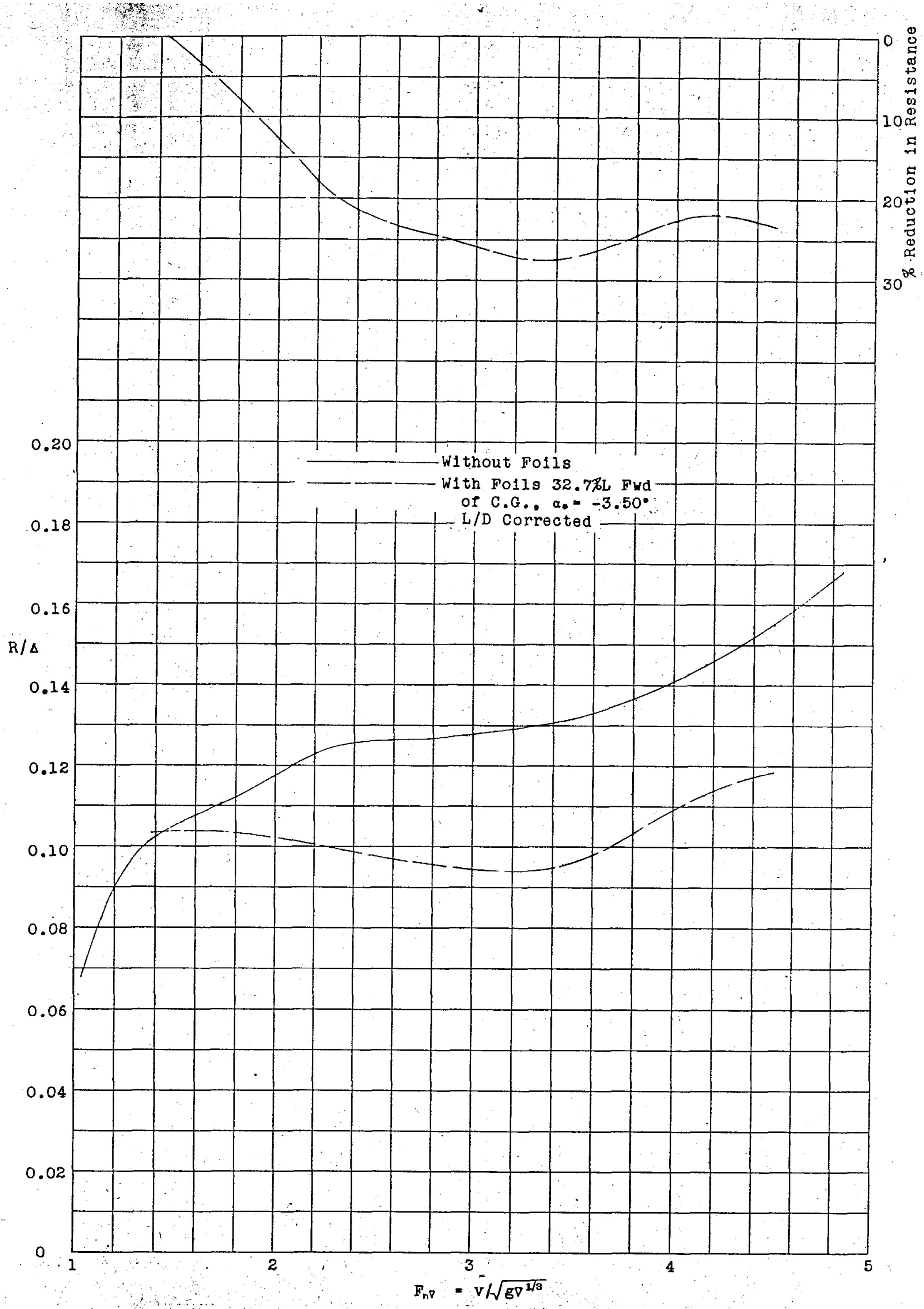


Figure 15 - Resistance of Craft, with and without Foils, in Dimensionless Form. $\Delta/\nabla^{2/3} = 6$. Resistance Corrected to 100,000 lb Displacement Using 1947 ATTC Model-Ship Correlation Line with Zero Roughness Allowance.