DAVID TAYLOR MODEL BASIN
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GENERAL RESISTANCE TEST OF A STEPLESS PLANING HULL WITH APPLICATION TO A HYDROFOIL CONFIGURATION

by

Lawrence Benen

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HYDROMECHANICS LABORATORY
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SS 600-000
Task 1707

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

NOTATION

A_p	Projected planing bottom area, excluding area of external spray strips, in feet^2
B_p	Beam or breadth over chines, excluding external spray strips, in feet
B_{PA}	Mean breadth over chines, A_p/L_p
B_{PX}	Maximum breadth over chines, excluding external spray strips, in feet
b	Mean breadth over chines, $b = B_{PA} = A_p/L_p$, in feet
C_d	Draft coefficient d/b
C_f	Friction coefficient
CG	Center of gravity
C_{La}	Lift coefficient of aft foil $L_a/\frac{1}{2}\rho S_a V^2$
C_{Lf}	Lift coefficient of forward foil $L_f/\frac{1}{2}\rho S_f V^2$
C_{lm}	Mean wetted length coefficient l_m/b
C_M	Trimming moment coefficient M/wb^4
C_R	Resistance coefficient R/wb^3
C_S	Wetted surface coefficient S/b^2
C_V	Speed coefficient $V/\sqrt{gb}$
C_Δ	Load coefficient Δ/wb^3
D	Drag in pounds
D_a	Drag of aft foil in pounds
D_f	Drag of forward foil in pounds
d	Draft, feet
g	Acceleration due to gravity, 32.174 feet per second^2
H	Depth of foil below water surface in feet

L	Hydrofoil lift in pounds
L_a	Lift on aft foil in pounds
LCG	Longitudinal center of gravity (see Figure 1)
$(L/D)_a$	Lift-drag ratio of aft foil
$(L/D)_f$	Lift-drag ratio of forward foil
L_f	Lift on forward foil in pounds
L_p	Projected chine length of model in feet
l_m	Mean wetted length in feet
M	Trimming moment of the hull about LCG in pound feet
M_{cg}	Moment about CG of boat in pound feet
q	Dynamic pressure, $\rho V^2/2$ in pounds per foot^2
R	Hull resistance in pounds
Re	Reynolds Number, Vl/ν
S	Area of wetted surface in square feet (This is the actual wetted surface of the bottom area including spray strips; however, the area wetted by spray is not included.)
S_a	Projected area of aft foil in feet^2
S_f	Projected area of forward foil in feet^2
T	Propeller thrust in pounds
V	Speed of boat in feet/second
V_o	Takeoff velocity in feet/second
w	Density of water in pound/feet^3
X_a	Distance along X-axis from CG to lift force on aft foil in feet
X_f	Distance along X-axis from CG to lift force on forward foil in feet
X,Y,Z	Coordinate axis system fixed in the boat
Z_a	Distance along Z-axis from CG to drag force on aft foil in feet
Z_f	Distance along Z-axis from CG to drag force on forward foil in feet

Z_T Distance along Z-axis from CG to thrust axis in feet

α_a Total angle of attack of aft foil with respect to the horizontal in degrees

α_f Total angle of attack of forward foil with respect to the horizontal in degrees

α_o Angle of foil incidence in degrees

β Angle of change in foil incidence (trim control forward foil) in degrees

Δ Load on hull in pounds

Δ_o Displacement at rest in pounds

ν Kinematic viscosity of water in feet^2/second

ρ Density of water in slugs per feet^3

τ Trim angle of hull (angle between water surface and the reference line of hull) in degrees

ABSTRACT

General resistance tests of TMB Model 4667 were conducted in the Langley Field facility of the David Taylor Model Basin to determine the performance characteristics of one of a series of hulls which might be adaptable for use with hydrofoils. Resistance, trimming moment, and wetted length were measured for several load, trim, and speed conditions. All data are presented in nondimensional form for use in comparing hull forms and calculating take-off performance.

ADMINISTRATIVE INFORMATION

This study was authorized as part of the Hydrofoil Accelerated Program by Bureau of Ships letter S-F013 02 01, Serial 420-228 of 30 August 1960. The scope of the program was delineated in Bureau of Ships letter 3900, Serial 341B-125 of 13 August 1963. Funding was under SS 600-000, Task 1707.

INTRODUCTION

With the recent development of hydrofoil craft as a means of commercial and military transport, theoretical and experimental effort has been concentrated on the hydrofoil. Such concentration of effort is proper inasmuch as the hydrofoils make this craft different from a planing or displacement boat. This difference must be exploited in order to realize possible advantages, such as increase in speed or improvement of behavior in rough water, which can be obtained by the use of hydrofoils.

Along with the development of hydrofoil systems, however, the design of the hull is also of importance. Experience with hull designs for other types of boats has provided the basis for most of the hydrofoil hull designs. The designers of various hydrofoil craft have pursued policies of independent development that have given rise to striking differences in the hull lines. Although it is quite possible that there is little difference in the performance of good examples of the various types of hulls, direct comparisons are not possible at present because of the scarcity of published test results. Moreover, much of the data have been obtained at only a few loads and trims. Little data are directly applicable to hydrofoil use, where the trim change during takeoff may be large and the load on the hull varies from full load to zero.

In order to provide data on hydrofoil hulls which might be used in performance calculations for preliminary designs, the Bureau of Ships initiated a program under which a number of hulls at representative unloading conditions were to be tested at a range of speeds and trims. The object of this program was to obtain data and to develop a method of presenting the results in the form of nondimensional lift, drag, and trimming moment coefficients for use in comparing hull forms and calculating takeoff performance. The end result is to establish criteria on which the design of efficient and optimized hulls can be based.

The High Speed Phenomena Division of the David Taylor Model Basin tested three hull models: Models 4667, 4335-2, and 4776. Model 4667 is a stepless planing hull; Models 4335-2 and 4776 are stepped planing hulls. This report presents the results of the tests of Model 4667 in nondimensional form together with a sample calculation for a takeoff performance computation.

DESCRIPTION OF MODEL

Figure 1 presents the line and form characteristics of the 8-foot model designated as Model 4667. Previous data[1] have indicated that this hull has less resistance than most stepless planing hull designs tested to date; accordingly Model 4667 was chosen as representative of an efficient planing hull used as a hydrofoil craft. The ratio of length to average beam (L_p/b) is 5. The model has a constant deadrise of 12 1/2 deg which continues from the transom to 40 percent of the length. The deadrise increases from this point to 36 deg at 90 percent length. The model was made of laminated mahogany, painted with gray enamel, and rubbed to a smooth finish. Scales were marked on keel, chine, and transom to facilitate the reading of wetted lengths.

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[1]References are listed on page 39.

APPARATUS AND PROCEDURE

Langley Tank 1, in which the model was tested, is described in Reference 2. The towing gear used during the tests is shown in Figure 2. It consists primarily of a drag dynamometer incorporating a load cell to measure drag and a counterbalancing arrangement which includes two lift load cells to measure the tension in the tapes which support the towing gate and the model. By counterbalancing the model to zero displacement and then removing weight from the balance pan equal to the desired load, a range of model displacements may be obtained. Likewise, for a given displacement, the lift of a hydrofoil may be simulated by adding weights to the balance pan. The readings of the load cells were recorded on strip charts.

The model was fixed in trim at the towing point. The trim was set at zero when the baseline was parallel to the undisturbed water surface. The hydrodynamic trimming moments were calculated from the distribution of the load as determined from changes in tensions in the supporting tapes. The trimming moments are referred to the LCG. Positive moments tend to raise the bow.

Wetted lengths were read visually and from underwater and over-water photographs. Wetted areas were computed from these data.

The draft of the model was determined by use of a sonic surface-wave transducer. The transducer, as shown in Figure 2, was attached to the towing gate, ahead of the model. The draft was set at zero with the keel at the transom just touching the water. The output from the transducer was recorded on an oscillograph recorder.

In a general fixed-trim test, data are obtained for a number of constant loads, speeds, and trims through a range which is considered practicable. This procedure is similar to that used for tests of seaplane hulls.[3] Resistance, wetted length, draft, and trimming moment are measured. A wide range of trim angles is investigated so that, in general, the trim angle for minimum resistance and for zero trimming moment can be established. The unloading curves which set the boundaries for the range of speed and load conditions used in these tests are shown in Figure 3.

RESULTS AND DISCUSSION

Various methods were considered for the presentation of data. The primary consideration in selecting a method is that it should lend itself to computation of the hydrofoil craft takeoff resistance and should be suitable for comparing the resistance characteristics of different hull designs for various sizes of boats.

The takeoff of a hydrofoil boat is similar to that of a seaplane in that an auxiliary lifting device unloads the hull as the speed increases. Consequently coefficients were chosen which had been found satisfactory for presenting results of force tests of seaplane hulls. These coefficients are usually based upon the maximum beam; however the mean beam B_{PA}, indicated in Figure 1, is probably a more familiar dimension in working with boats and is therefore used. For simplicity, the symbol b is henceforth substituted for B_{PA}. The nondimensional coefficients are defined as follows:

C_Δ	load coefficient (Δ/wb^3)
C_R	resistance coefficient (R/wb^3)
C_V	speed coefficient ($V/\sqrt{gb}$)
C_M	trimming-moment coefficient (M/wb^4)
C_{lm}	mean wetted length coefficient (l_m/b)
C_S	wetted-surface coefficient (S/b^2)
C_d	draft coefficient (d/b)

Any consistent system of units may be used.

The basic data are presented in coefficient form in Table 1. The resistance coefficients include the air drag of the model, but the air tare of the towing gear has been deducted. Crossplots at specific speed coefficients have been prepared from plots of the basic data against speed coefficient. These crossplots are presented in Figure 4 where resistance coefficient is plotted against trim with load coefficient as a parameter (solid lines). Selection of speed coefficient included in Figure 4 was such that, in the vicinity of the hump resistance, the speed coefficients are closely spaced. Curves of constant trimming moment coefficient (dashed lines) are included so that the resistance coefficient and the trimming moment coefficient required to maintain the trim may be readily determined for any given load coefficient and trim. The resistance corresponding to zero trimming moment coefficient (free to trim) or any other assumed trimming moment coefficient may be obtained with equal facility.

The static data are presented in Figure 5; trimming moment coefficient and draft coefficient are plotted against trim with load coefficient as the parameter. The trimming moment coefficients may be used to compute the trim at rest for other positions of the center of gravity than that used in these tests.

The wetted area coefficients C_S plotted against trim with load coefficient as the parameter are presented in Figure 6. The mean wetted length coefficients C_{lm} versus trim with load coefficient as the parameter are presented in Figure 7. The curves for C_{lm} are used for the calculation of Reynolds number. C_{lm} and C_S are used to make friction corrections that are required in calculation of the total resistance of the full size craft.

USE OF DATA

To illustrate the use of the hull data for determining the resistance in preliminary design studies, a sample calculation will be made for a hypothetical hydrofoil boat having a gross load Δ_o of 100,000 lb and a cruising speed of 50 knots when foilborne. The hydrofoil characteristics will be assumed, and results of tests of Model 4667 will be used to determine the contribution of the hull to the total resistance.

HULL DIMENSIONS

In order to determine the factor for scaling the model to the full-size craft, it will be assumed that Δ_o of 100,000 corresponds to a gross load coefficient C_Δ of 0.6, which is the design gross load coefficient for the hull without hydrofoils. The model gross load then becomes

$$wb^3 \times C_\Delta = 63.2(1.6)^3 \times 0.6 = 155.3 \text{ lb}$$

The linear ratio is given by

$$\lambda = \left(\frac{\text{ship } \Delta_o}{\text{model } \Delta_o} \times \frac{\text{density of water in which model was tested}}{\text{density of sea water}} \right)^{1/3}$$

$$= \left(\frac{100{,}000}{155.3} \times \frac{1.964}{1.9905} \right)^{1/3}$$

$$\lambda = 8.597$$

The full-size dimensions of the hull are

length - λL_p (model) = 8.597 × 8.00 = 68.78 ft

mean beam - λB_{PA} (model) = 8.597 × 1.600 = 13.76 ft

LCG - λ LCG (model) = 8.597 × 3.47 = 29.83 ft distance forward of Station 10 where L_p, B_p, and LCG are obtained from Figure 1.

The following numerical relationships can be established, knowing the mean beam of the hull

$$C_\Delta = \frac{\Delta}{64.04 \times (13.76)^3} = \frac{\Delta}{166{,}800}$$

$$C_R = \frac{R}{166{,}800}$$

$$C_V = \frac{V}{\sqrt{32.174 \times 13.76}} = \frac{V}{21.04}$$

$$C_M = \frac{M}{64.04 \times (13.76)^4} = \frac{M}{2{,}296{,}000}$$

HYDROFOIL CONFIGURATION

The foil configuration (Figure 8) is a Canard system, consisting of a submerged small control foil ahead of the LCG and a submerged large main foil just aft of the LCG. At cruising speed, the forward foil carries 25 percent of the gross load (25,000 lb) and the main foil carries 75 percent (75,000 lb). The spacing between the foils is 38 ft.

The selection of a Canard system is not an arbitrary choice but one that, at the outset, appears to be adaptable to a stepless planing hull. At high speed coefficients, an acceptable hull lift-drag ratio is obtained only with large negative (bow down) hull trimming moments. To overcome this negative moment, the Canard system produces an opposite moment by virtue of a positive lift force on the control surface. If a more conventional hydrofoil system with the control foil behind the CG were used, the moment opposing the negative hull moment would be produced by a negative lift by the control foil.

For simplicity, the main and the bow foils are considered to have the same geometry. No mention is made of form characteristics such as aspect ratio, span of the foil, spray interference effect, etc., as they are not considered essential to the scope of this report. The foil as designed is considered satisfactory for the problem at hand, i.e., to illustrate the takeoff computations. The assumed curves for the lift and drag coefficients are presented in Figure 9 and apply to both foils. These curves are for complete foil assemblies, including strut, pod, and foil. To further simplify the illustration, the lift and drag coefficients are considered to be independent of speed.

If the foil loading is taken at 1100 lb/ft^2, the areas of the bow and the main foils become 22.7 and 68.2 ft^2, respectively. At a cruise speed of 50 knots, the lift coefficient is determined from

$$C_L = L/1/2\rho\ SV^2$$

and

$$C_L = 0.1550$$

for both foils. From Figure 9, the corresponding angle of attack α_0 while in the cruising condition is 1.7 deg and the lift-drag ratio L/D of the foil system is 8.1.

Assuming the boat trim to be zero and the thrust axis coincident with the drag vector, the relative locations of the foils and the LCG must be such that the sum of the pitching moments due to the lift of the foils is zero. Since the distance between foils is 38 ft, the distance of the main foil behind the LCG is found to be 9.5 ft and the forward foil is 28.5 ft forward of the LCG.

COMPUTATION OF TAKEOFF RESISTANCE

At any given speed, the following conditions must be satisfied:

a. The sum of the lift forces must equal the gross load

$$\Delta + L_f + L_a = \Delta_o \qquad [1]$$

b. The sum of the moments must equal zero

$$\Sigma M_{CG} = TZ_T + M + L_f X_f - L_a X_a - D_f Z_f - D_a Z_a = 0 \qquad [2]$$

Equation [2] is the static moment equation for the Canard configuration shown in Figure 8. The moments are taken about the LCG and the assumption is made that the trim angles will be small and that the thrust vector is parallel to the X-axis.

In order to determine the resistance coefficient C_R, the load coefficient C_Δ must be known for each speed. The load Δ and, consequently, C_Δ depend upon the bow and main foil lift, which, in turn, depends upon the angle of attack of the foils, hence on the trim τ of the hull. Because the angle of incidence of the bow foil will vary throughout the speed range, the following method has been devised to make possible a good first approximation for the bow foil angle of attack. Using the numerical relationships previously established, at a $C_V = 2.0$

$$V = 2.0 \times 21.04 = 42.08 \text{ fps}$$

Entering the curves of Figure 4g, it can be seen that the trim for the hull at this speed must be a compromise between drag and moment. The minimum values of C_R occur between approximately 2.3 and 4.4 deg, whereas C_M equal to zero corresponds to a trim variation from 1.4 to 3.4 deg for the values of C_Δ expected at this C_V. Choosing the hull trim τ equal to 2.5 deg, the angle of attack of the rear foil is

$$\tau + \alpha_o = \alpha_a$$

$$2.5 + 1.7 = 4.2 \text{ deg}$$

The dynamic pressure

$$q = 1/2 \, \rho \, V^2 = 1/2(1.9905)\ (42.08)^2 = 1762$$

The lift coefficient and the lift drag ratio of the rear foil from Figure 9 are

$$C_{La} = 0.26$$

$$(L/D)_a = 9.2$$

and the lift and drag are

$$L_a = q\ S_a\ C_{La} = 1762 \times 68.2 \times 0.26 = 31{,}240 \text{ lb}$$

$$D_a = \frac{31{,}240}{9.2} = 3396 \text{ lb}$$

Assuming that $Z_a = Z_f = Z_T = 8$ ft and putting this value and the thrust $T = 16{,}000$ lb obtained from the assumed thrust curve (Figure 10) into the moment Equation [2]

$$M_{CG} = 16{,}000 \times 8 + 2{,}296{,}000\ C_M + 28.5\ L_f - 31{,}240 \times 9.5$$

$$- 8\ D_f - 3396 \times 8 = 0$$

which reduces to

$$28.5\ L_f - 8\ D_f = 195{,}948 - 2{,}296{,}000\ C_M$$

The moment due to the drag of the front foil is evidently small compared to that due to its lift. Therefore the assumption of a value of 10 for its lift-drag ratio is reasonable. This substitution will further simplify the moment equation by eliminating D_f. With some rearranging, the equation becomes

$$L_f = 7{,}074 - 82{,}888\ C_M$$

The total load is sustained by the sum of the hull lift and foil lift; therefore, referring to Equation [1]

$$100{,}000 = L_f + 31{,}240 + 166{,}800\ C_\Delta$$

Eliminating L_f from this and the preceding equation

$$C_M = 2.012\ C_\Delta - 0.7442$$

A few trial values of C_Δ with some interpolation in Figure 4g are required to determine that

$$C_\Delta = 0.345$$

and

$$C_M = -0.050$$

and

$$C_R = 0.042$$

and the hull resistance

$$R = 0.042 \times 166,800 = 7,006 \text{ lb}$$

The lift required of the front foil is

$$L_f = 100,000 - 31,240 - 166,800 \times 0.345 = 11,214 \text{ lb}$$

The lift coefficient of the front foil is

$$C_{Lf} = \frac{11,214}{1762 \times 22.7} = 0.2804$$

which, by referring to Figure 9, can be obtained with $\alpha_f = 4.7$ deg. The control angle

$$\beta = \alpha_f - \tau - \alpha_o =$$

$$4.7 - 2.5 - 1.7 =$$

$$\beta = 0.5 \text{ deg}$$

From Figure 9

$$(L/D) = 9.2$$

$$D_f = \frac{11,214}{9.2} = 1,219 \text{ lb}$$

The error introduced into the moment equation by the assumption of an L/D of 10 (whereas the actual L/D is 9.2) is 784 ft lb. This error is small. The practicable accuracy is mainly dependent upon the precision of taking values from the plots. It should be possible to interpolate C_M to $\pm$ .005.

The resulting variation in moment would therefore be

$$(2,296,000)\ .005 = 11,480 \text{ ft lb}$$

This moment corresponds to a shift in the LCG for the full-size craft of approximately 0.11 ft, or a change in the angle of attack of the control foil of approximately 0.2 deg.

A complete takeoff computation sheet is shown as Table 2. The columns are headed with the values of C_V covering the speed range to foil-borne operation. Results of the takeoff computation are presented in Figure 10. The curves show the variation of thrust, hull resistance, hull trim, and change of foil incidence with speed coefficient.

FRICTION CORRECTION

An accurate preliminary analysis of the data for the 100,000-lb craft requires that the drag data should be corrected for the difference between the frictional resistance coeffficients of the model and the full-scale craft. The following equations are used to determine this friction correction:

$$Re = \frac{C_V \sqrt{gb}\ C_{1m}\ b}{\nu} \qquad [3]$$

$$C_{R\ corr} = C_R + 1/2(C_V)^2\ C_S \left[-C_{f\ (model)} + C_{f\ (full\ size)}\right] \qquad [4]$$

Equation [3] has been derived from the standard form of Reynolds number so that the coefficients from Figure 7 for the desired speed coefficient and trim may be substituted directly. Equation [4] has been derived so that C_R and C_S from Figures 4 and 6, respectively, can be substituted with the friction coefficients corresponding to the model and full-size Reynolds numbers obtained from Equation [3] to obtain the corrected resistance coefficient.

The correction for hull friction drag is computed in the following manner. Referring to Figure 7b, for a C_V of 2, enter the curves at τ of 2.5 deg. At a C_Δ of 0.345, C_{1m} is found to be 3.47. Substituting this value and the model mean beam into Equation [3], for the model:

$$Re = \frac{2.0 \times 1.600 \times 3.47 \sqrt{32.174 \times 1.600}}{1.028 \times 10^{-5}}$$

$$Re = 7.750 \times 10^{6}$$

$$C_f = 3.059 \times 10^{-3}$$

for the full-size craft and salt water at 59F:

$$Re = \frac{2.0 \times 13.76 \times 3.47 \sqrt{32.174 \times 13.76}}{1.282 \times 10^{-5}}$$

$$Re = 1.567 \times 10^{8}$$

$$C_f = 1.947 \times 10^{-3}$$

Using Equation [4] and C_S from Figure 6

$$C_{R\,corr} = 0.042 + 1/2(2.0)^2 \times 3.90 \left[(-3.059 + 1.947)\, 10^{-3}\right]$$

$$C_{R\,corr} = 0.0333$$

$$R_{corr} = 166,800 \times 0.0333 = 5,554 \text{ lb}$$

It can be seen from this result that at a $C_V = 2.0$, the correction for friction drag is 21 percent of the total hull drag and should definitely be taken into consideration when making a detailed design analysis of the hull.

Total correct drag = 5,554 + 1,219 + 3,396 = 10,169

CONCLUDING REMARKS

This report is the first of a series under the Bureau of Ships Accelerated Hydrofoil Program which deals with methods of testing and presentation of data specifically for the application of the hull to a hydrofoil configuration. Hulls of different design have been and will be tested and the data presented in a similar manner.

After the completion of this phase of the program, a correlation of the data and characteristics of the various hull designs can be made. An outcome of the correlation should be design criteria utilizing the best characteristics of those tested.

The results of the test program for Model 4667 indicate that because of the high negative trimming moments (bow down), a Canard foil system with controlled incidence on the forward foil is a practical configuration. If a conventional or tandem foil system is used, a controlled negative angle of incidence with negative lift would have to be used for the aft foil to oppose the high lift on the aft portion of the hull planing surface.

In order to avoid the high negative trimming moments found in the tests of Model 4667, it would seem that a good hydrofoil hull might possibly have a step or the hull should have narrow sections aft with the CG located forward. A combination of these might be preferable.

It is noted here, however, that the tests made and those to be made are indicative only of trends in the design of hydrofoil hulls and should not be considered applicable for specific design purposes. For a specific design, it would be necessary to test the model in combination with a foil system.

David Taylor Model Basin Small Craft Data Sheet

Hard chine boat, $L_P/B_{PX} = 4.09$

TMB Model No. 4667

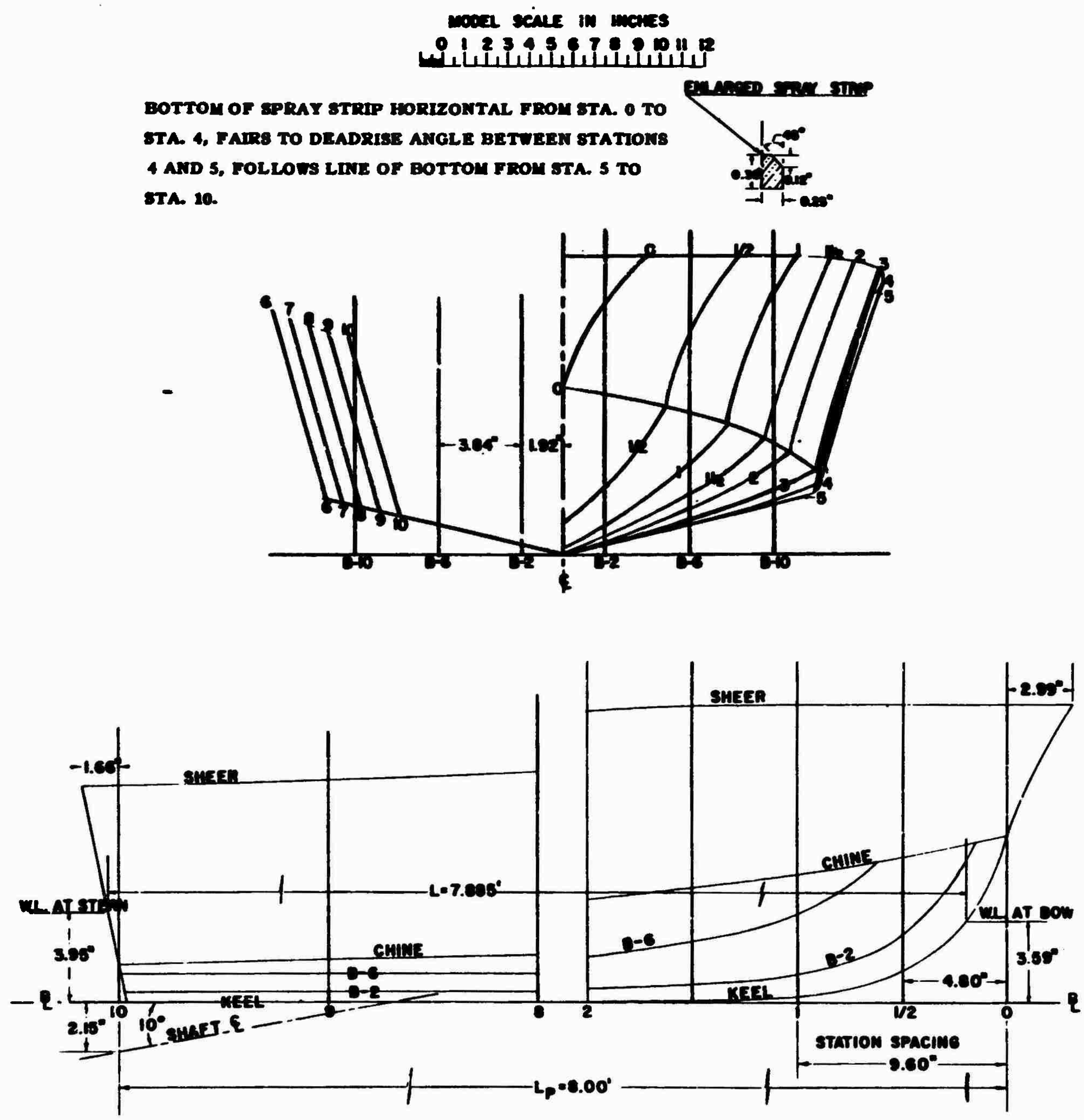


Figure 1 - Design Data Sheet

MODEL PARTICULARS, TEST CONDITIONS, AND RESULTS

Boat Research Model for Hydrofoil Hull Series
Model Number 4667
Appendages Spray Strips
Laboratory DATMOBAS
Basin Langley Tank 1

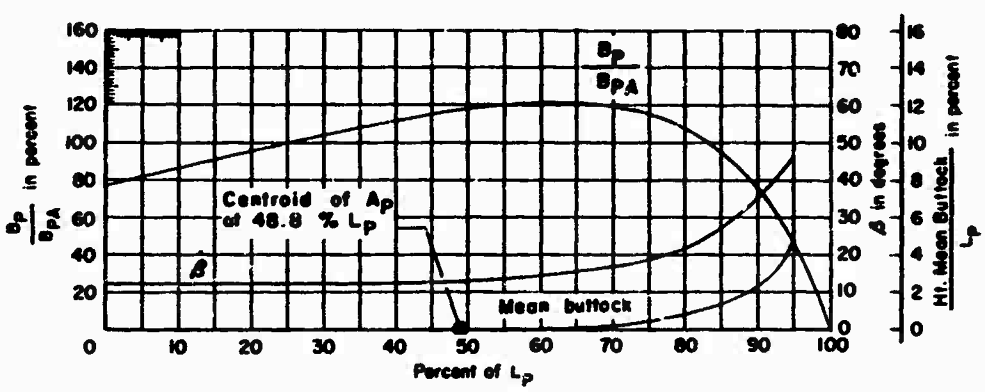
Basin Size 2920' X 24' X 12'
Model Length 8.00 ft
Water Temperature 72°F
Specific Weight 63.2 lb/ft^3
Model Material Wood
Model Finish Paint
Turbulence Stimul. None

Planing Bottom Dimensions and Coefficients	
L_p	8.00 ft
B_{PX}	1.955 ft
B_{PA}	1.600 ft
A_p	12.80 ft^2
$A_p/\nabla^{2/3}$	7.00
$L_p/\nabla^{1/3}$	5.917
L_p/B_{PA}	5.000

LWL Dimensions and Coefficients	
L	
B_X	
H	
L/B_X	
$L/\nabla^{1/3}$	
C_B	
C_P	
C_W	

LCG location 3.42 ft forward of station 10
(LCG location 6 percent L_p aft of centroid of A_p)

FORM CHARACTERISTICS



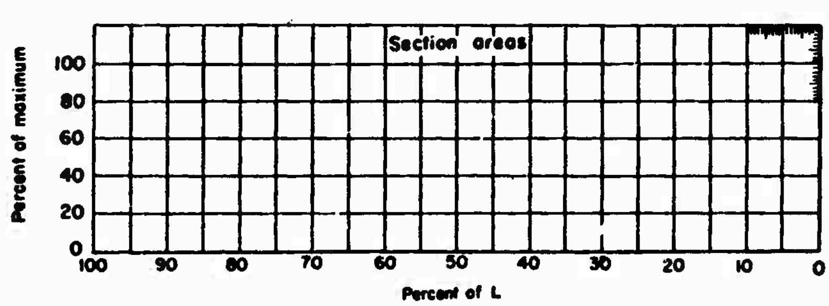


Figure 1 - Continued

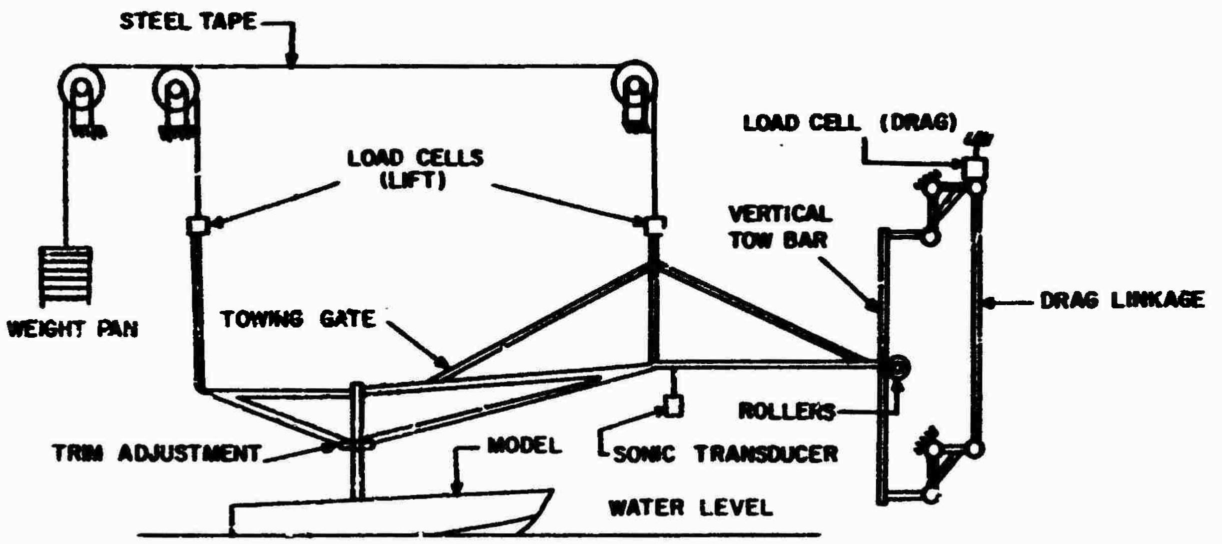


Figure 2 - Small Boat Towing Gear

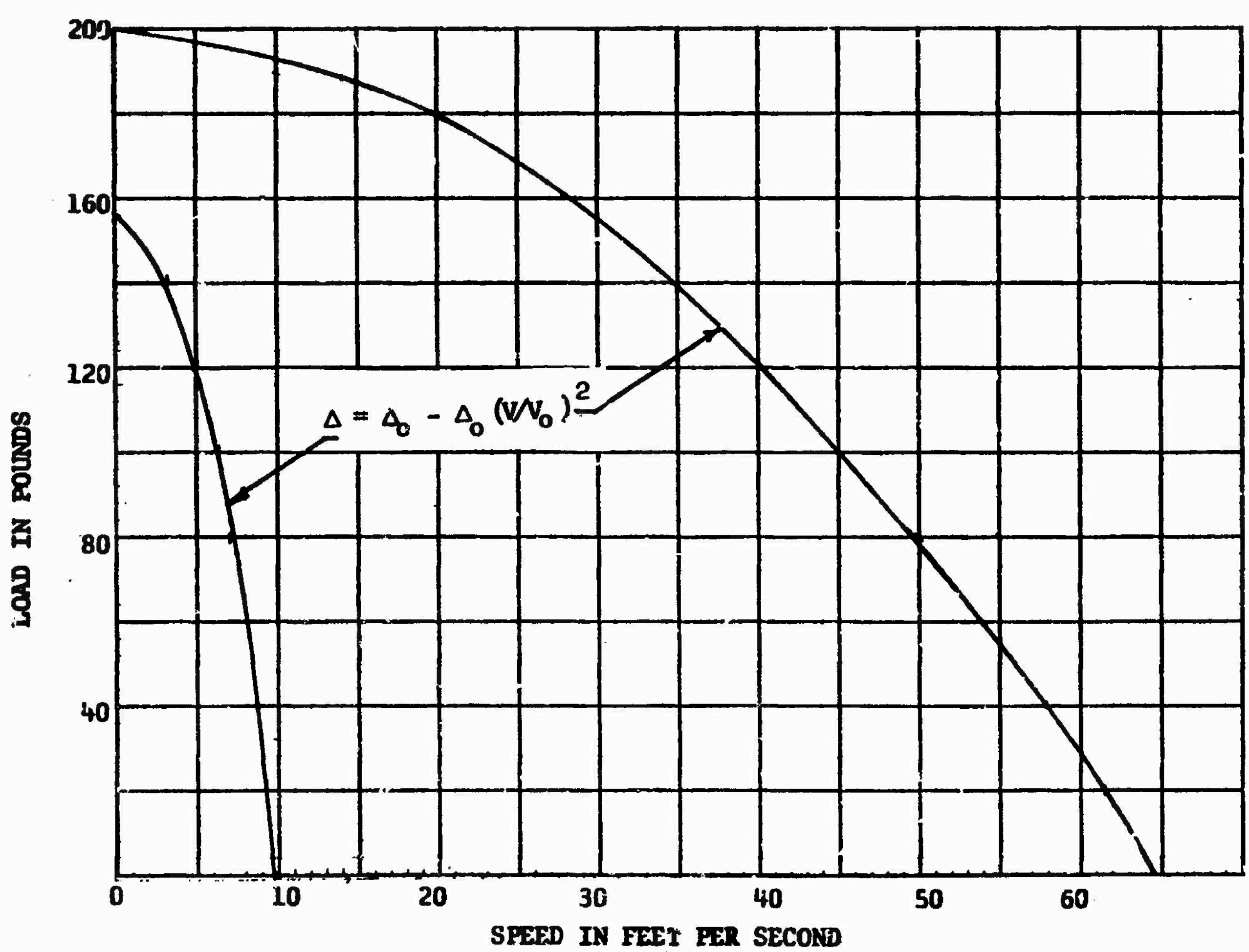
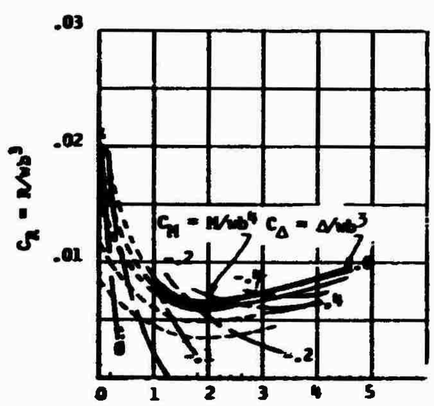
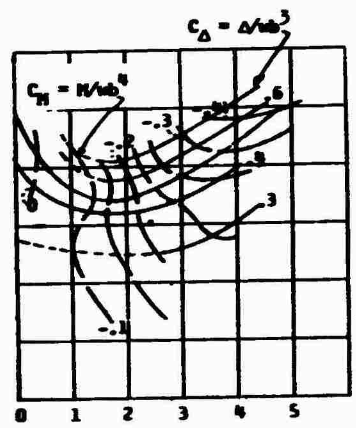


Figure 3 - Unloading Boundaries

Figure 4 - Variation of Resistance and Pitching Moment Coefficients with Trim and Load Coefficients





TRIM IN DEGREES

Figure 4a - C_V = 0.5

Figure 4b - C_V = 0.75

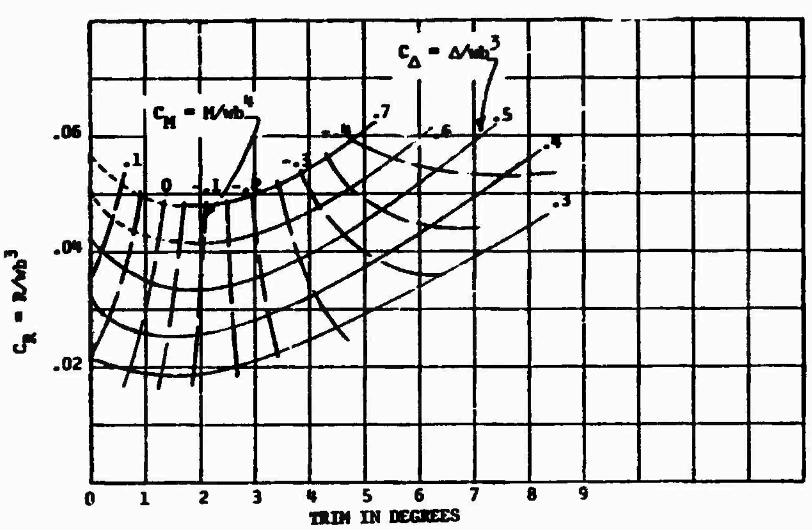


Figure 4c - C_V = 1.0

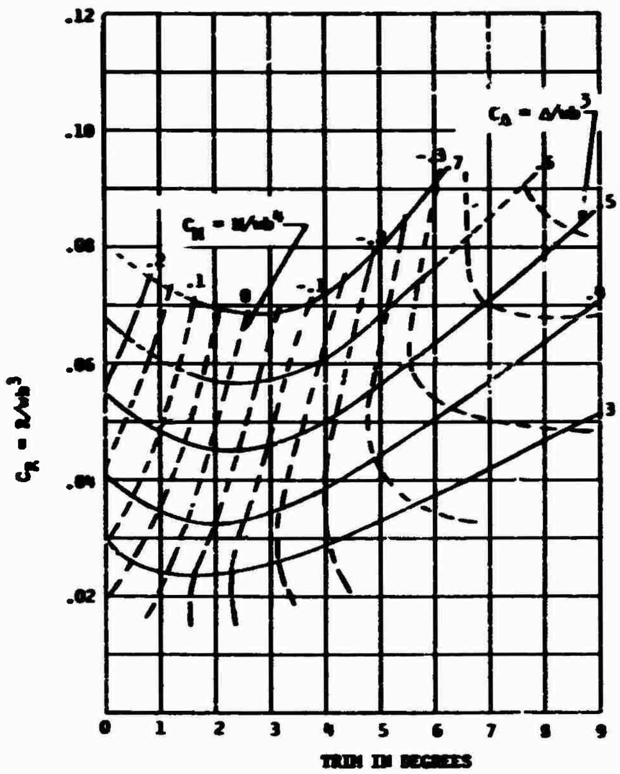


Figure 4d - $C_V = 1.25$

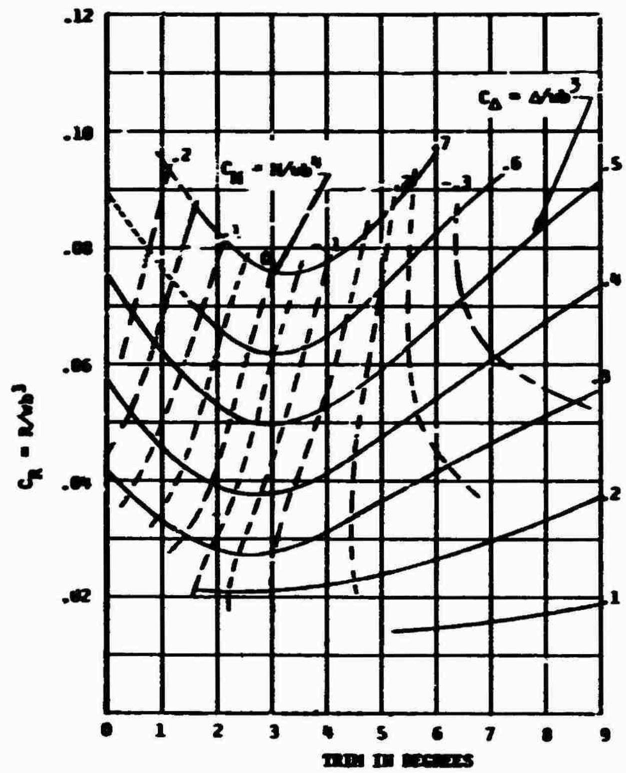


Figure 4e - $C_V = 1.5$

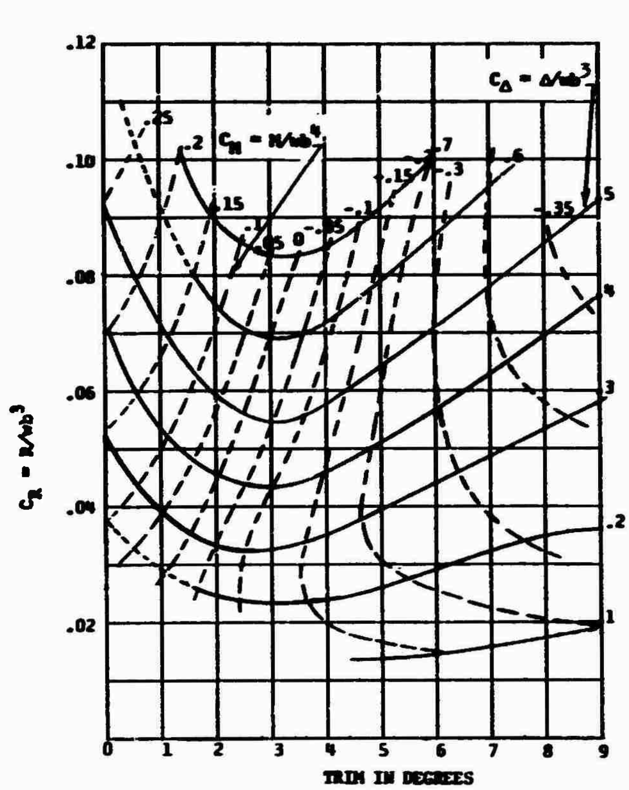


Figure 4f - $C_V = 1.75$

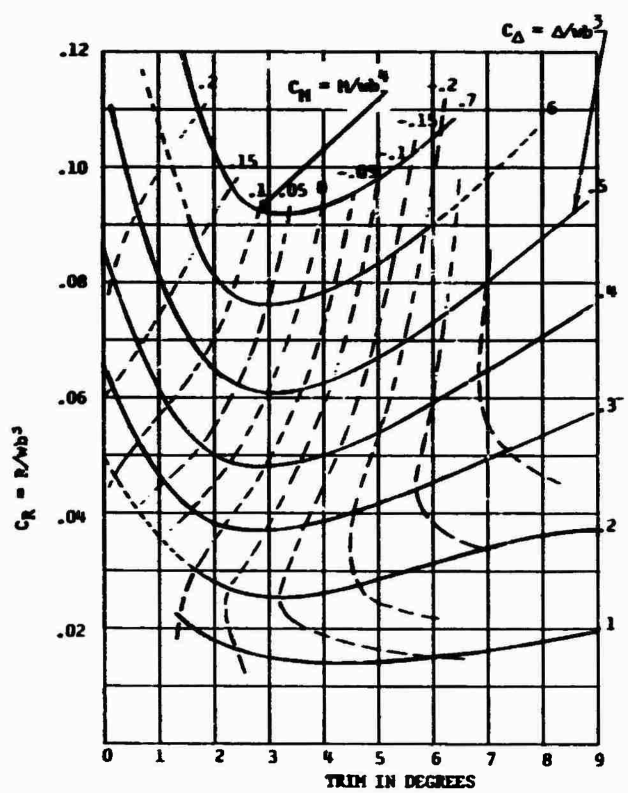


Figure 4g - $C_V = 2.0$

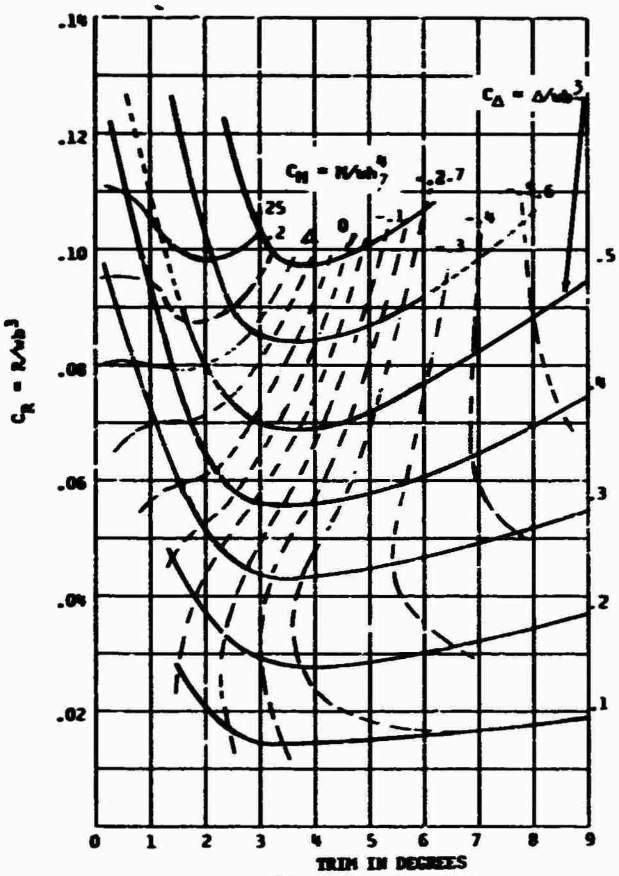


Figure 4h - C_V = 2.5

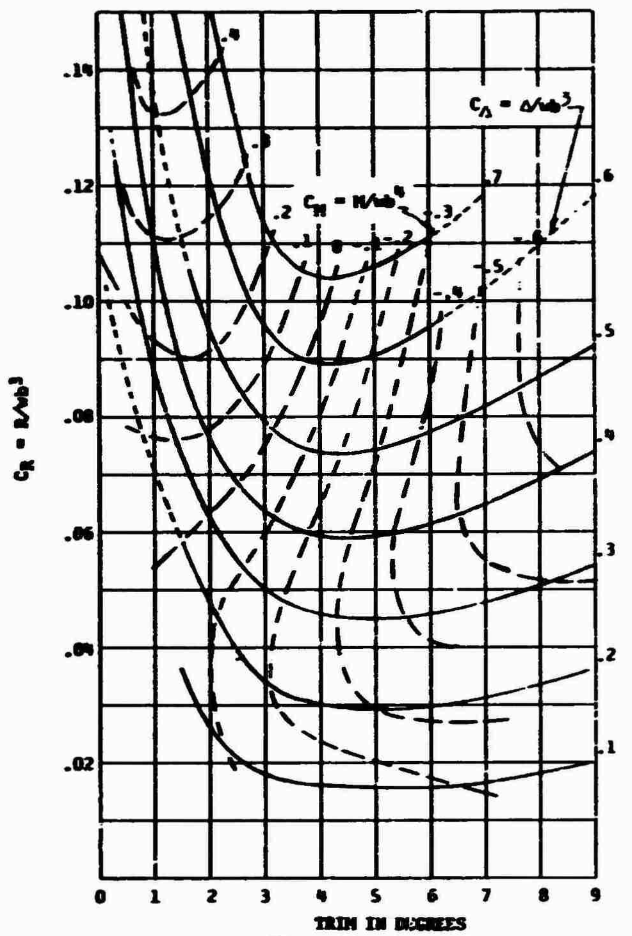


Figure 4i - C_V = 3.0

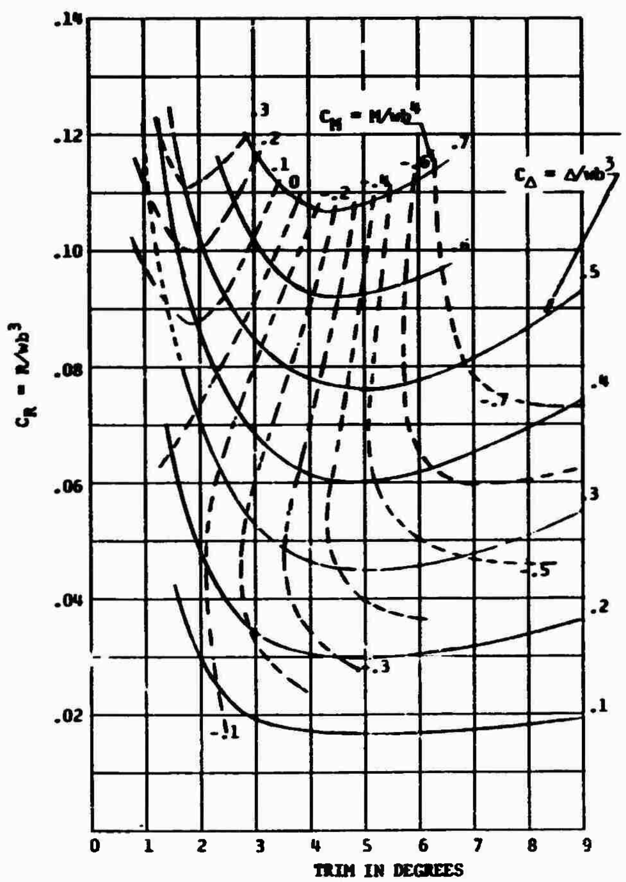


Figure 4j - C_V = 3.5

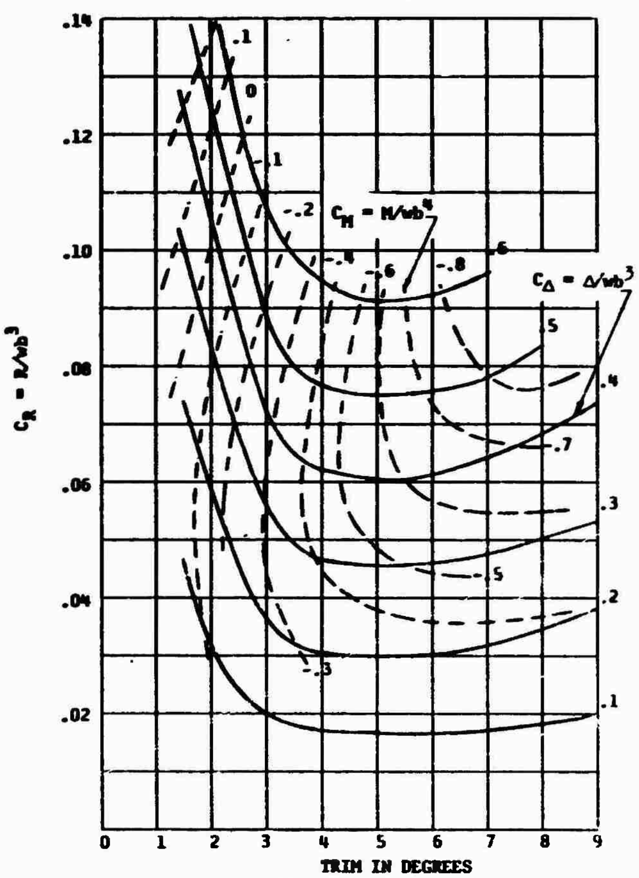


Figure 4k - C_V = 4.0

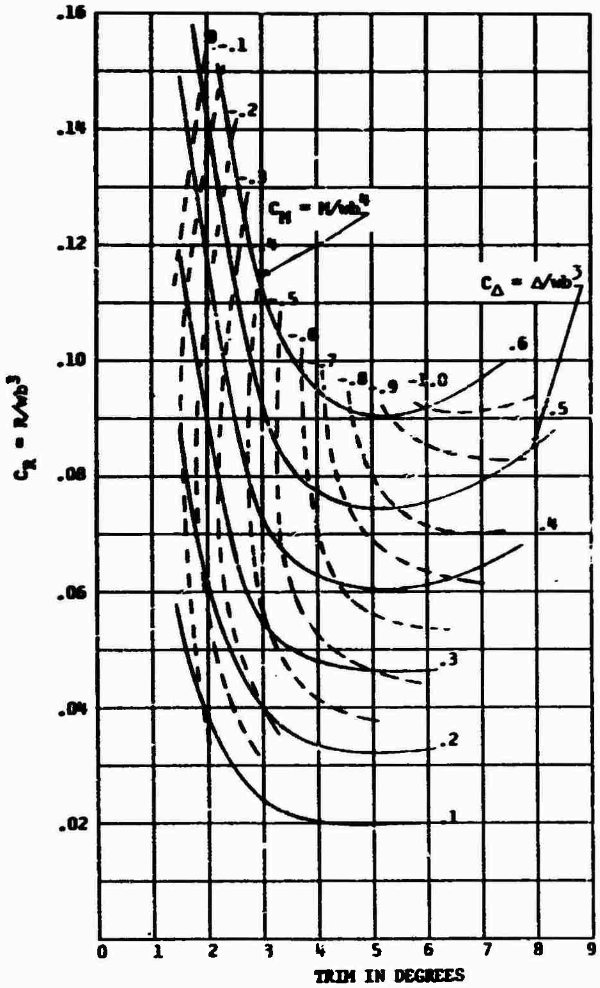


Figure 4l - C_V = 5.0

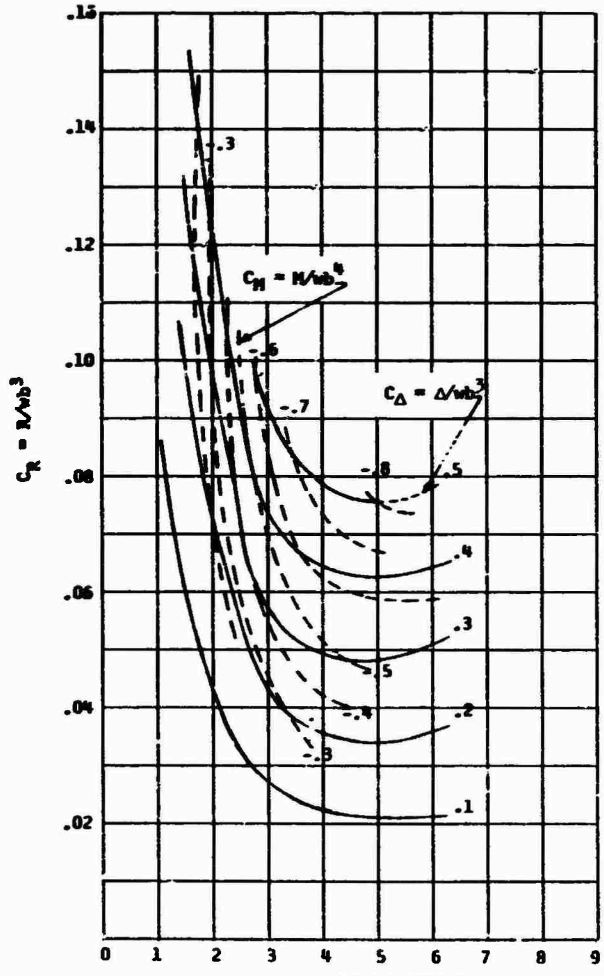


Figure 4m - C_V = 6.0

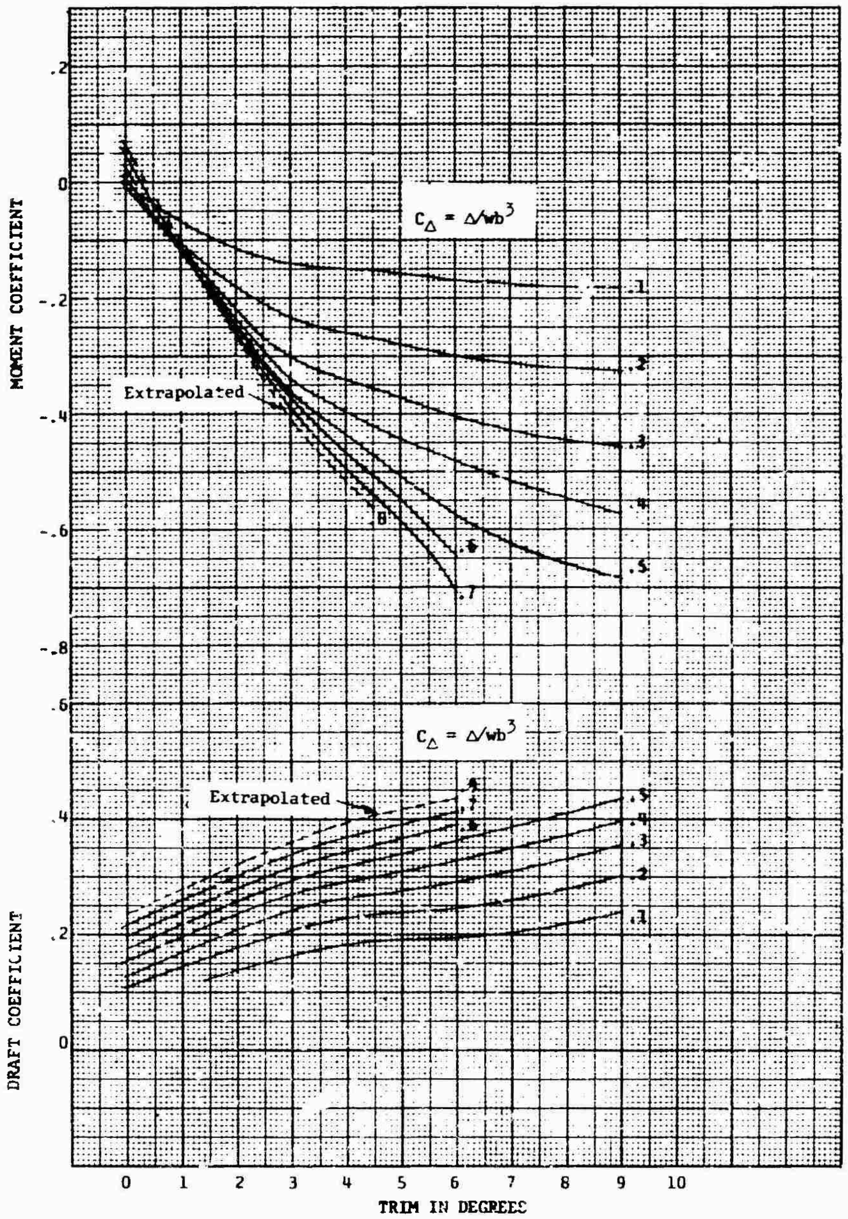


Figure 5 - Model 4667 Static Properties

Figure 6 - Variation of Wetted Surface Coefficient with Trim and Load Coefficient

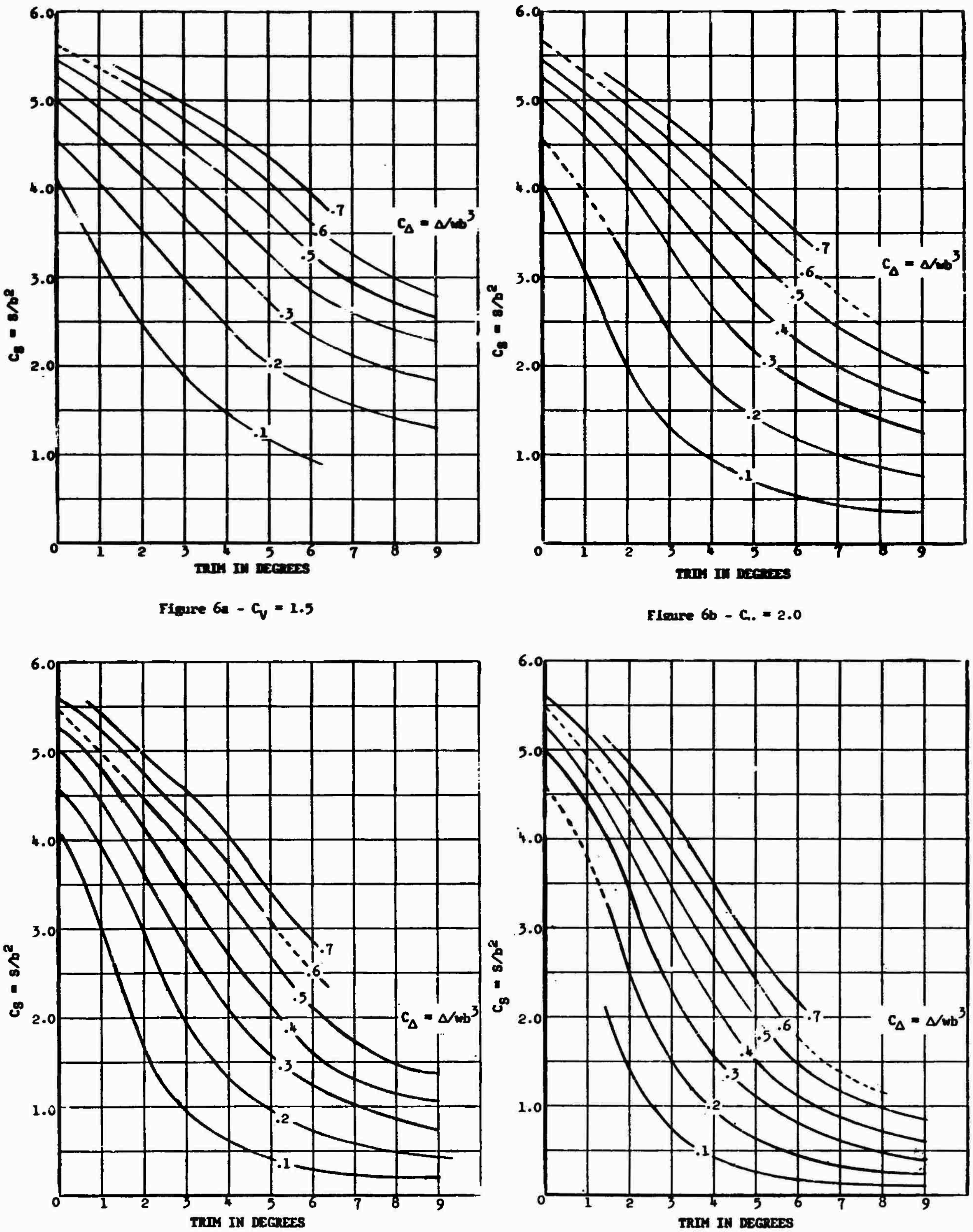


Figure 6a - C_V = 1.5

Figure 6b - $C_.$ = 2.0

Figure 6c - C_V = 2.5

Figure 6d - C_V = 3.0

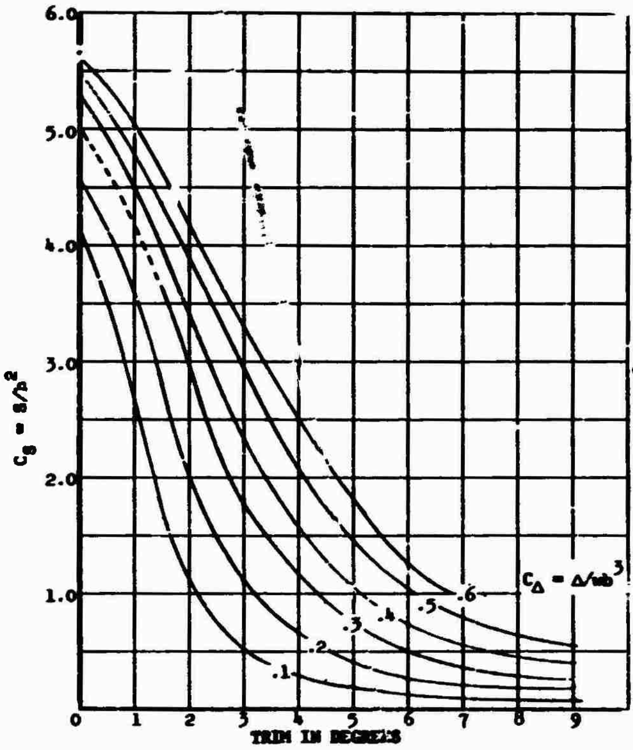


Figure 6e - C_V - 3.5

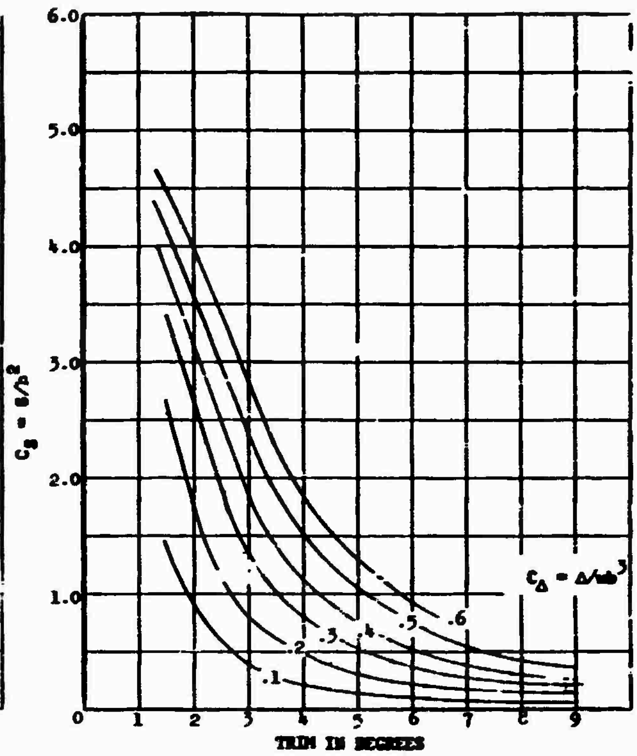


Figure 6f - C_V = 4.0

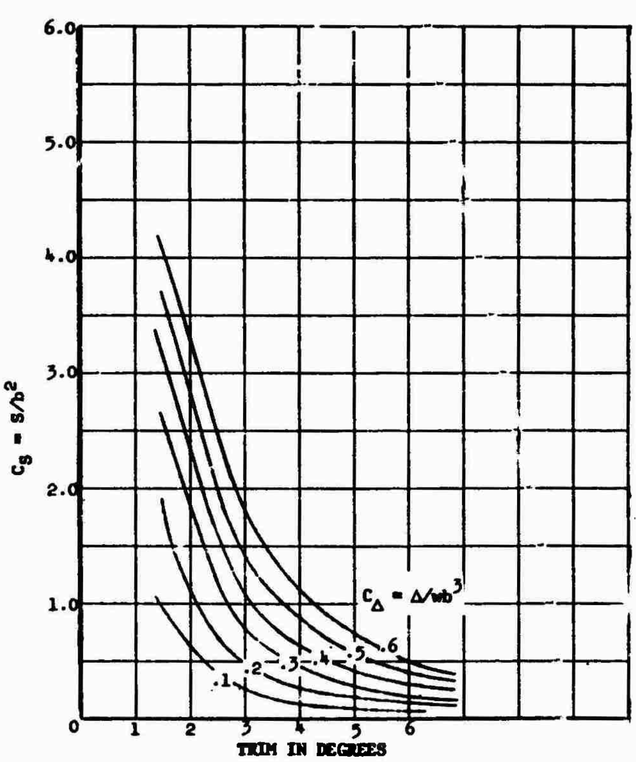


Figure 6g - C_V - 5.0

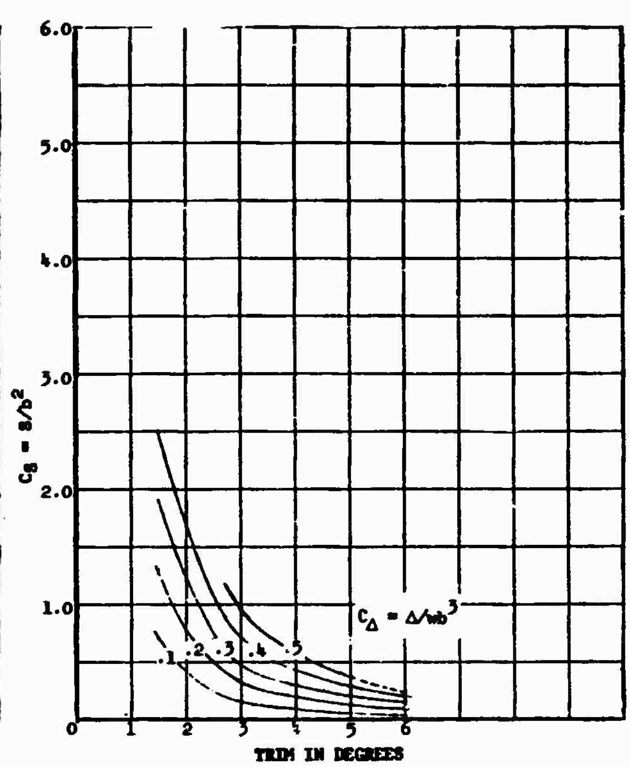


Figure 6h - C_V = 6.0

Figure 7 - Variation of Mean Wetted Length Coefficient with Trim and Load Coefficients

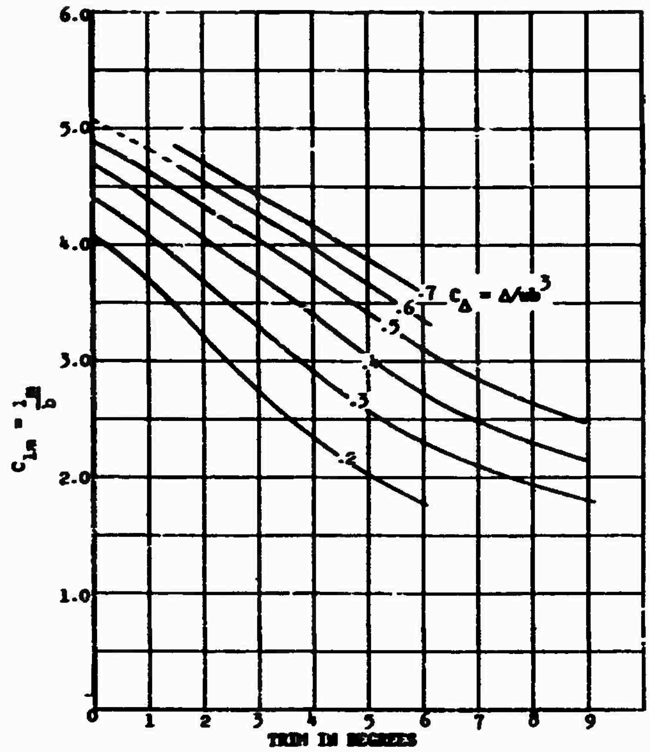


Figure 7a - C_V = 1.5

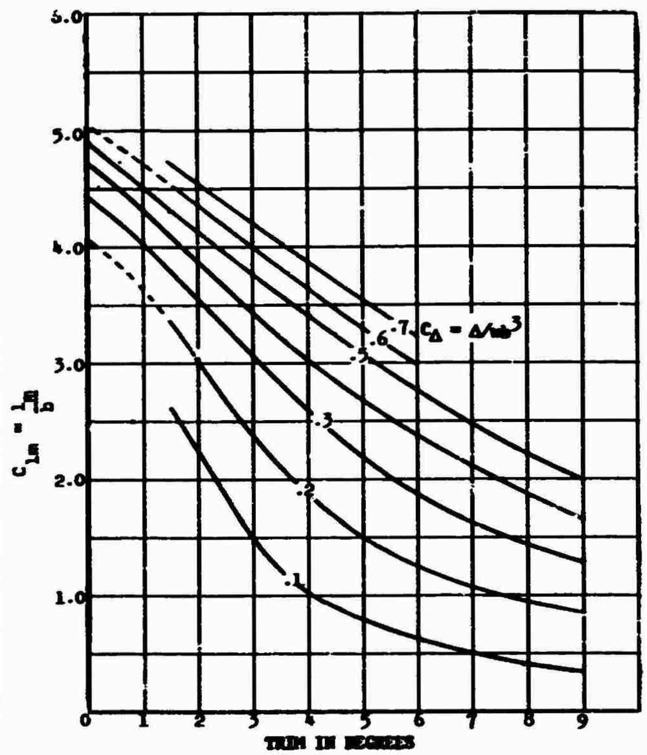


Figure 7b - C_V = 2.0

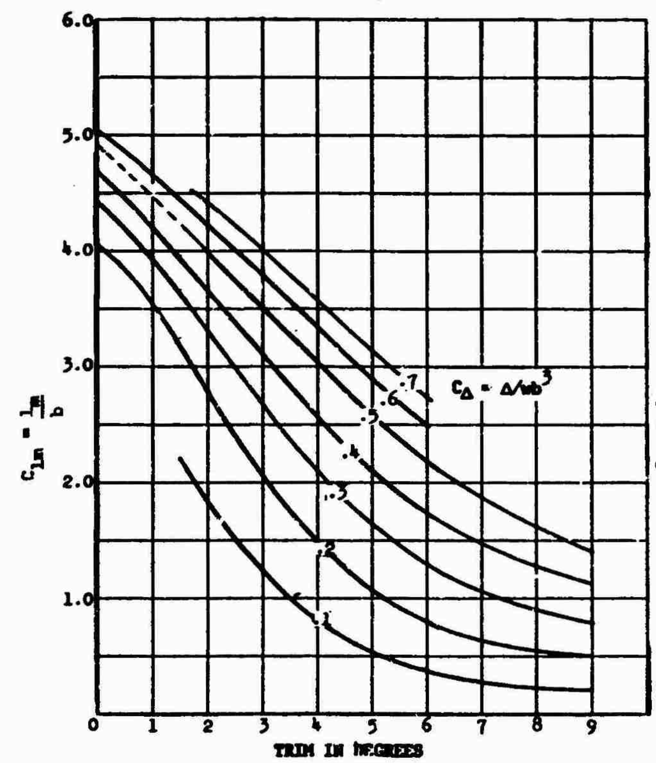


Figure 7c - C_V = 2.5

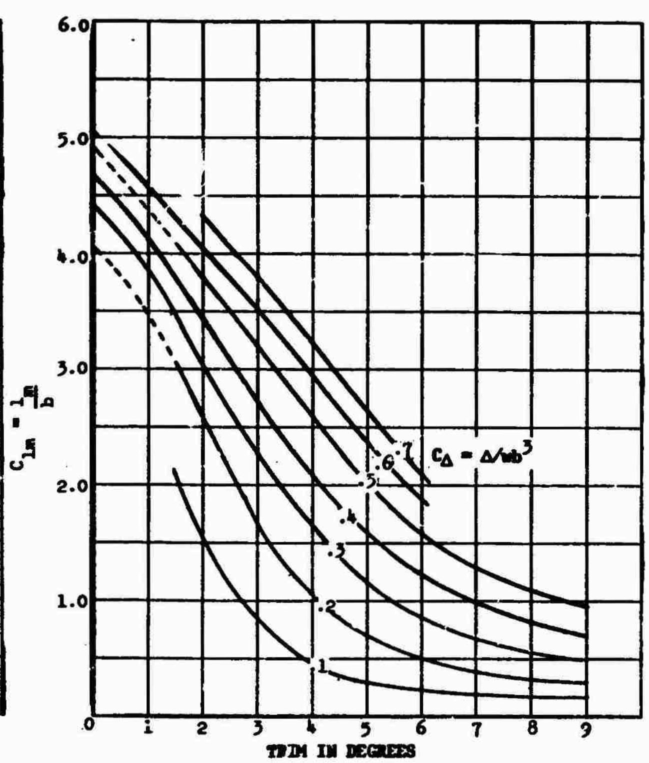


Figure 7d - C_V = 3.0

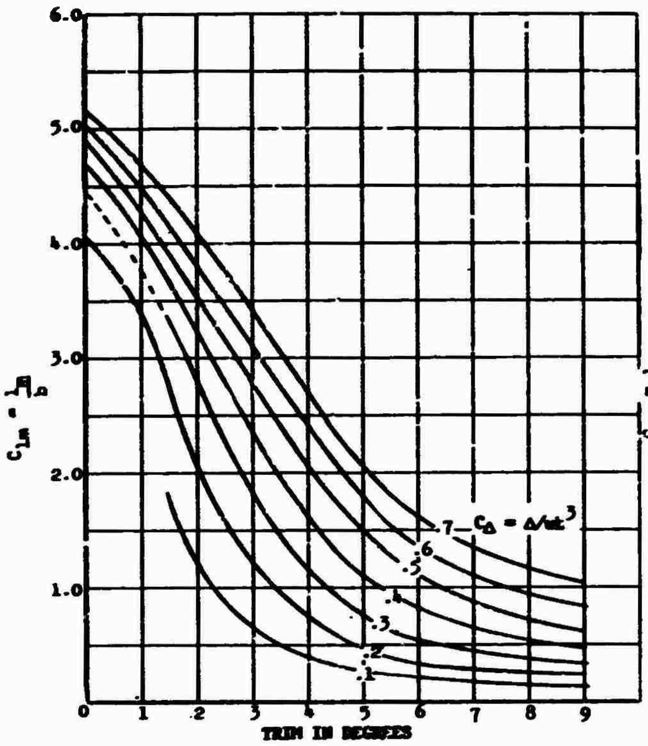


Figure 7e - C_V = 3.5

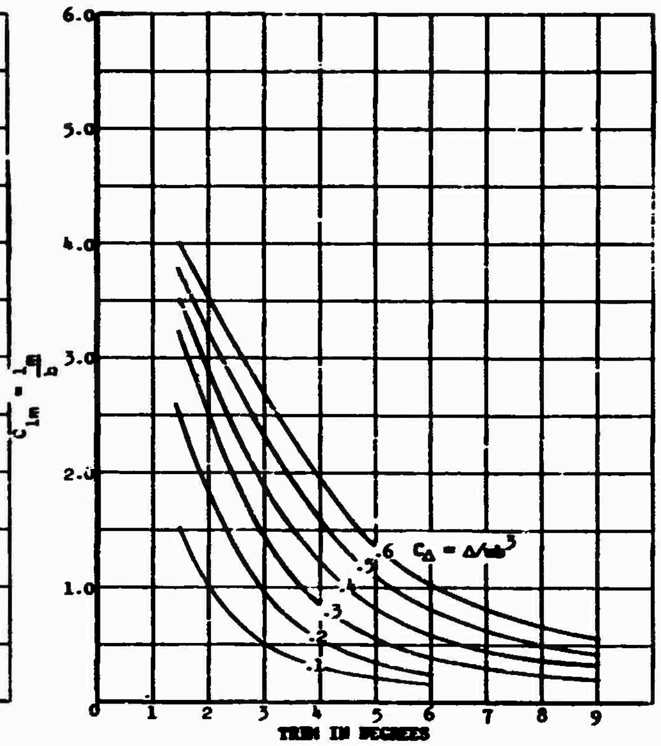


Figure 7f - C_V = 4.0

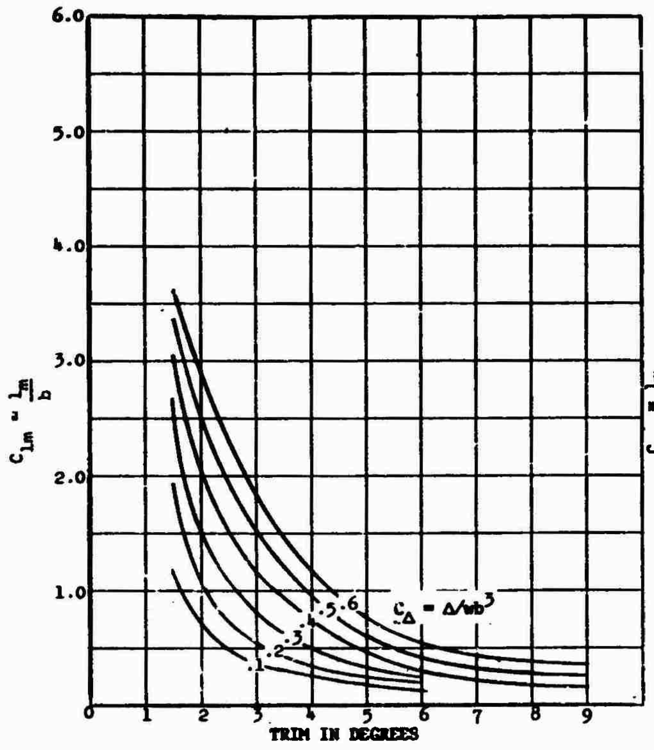


Figure 7g - C_V = 5.0

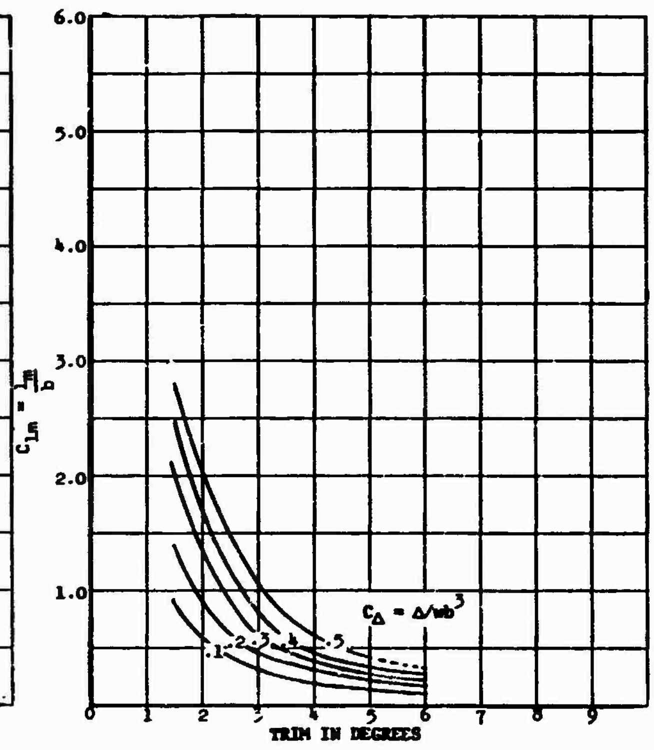


Figure 7h - C_V = 6.0

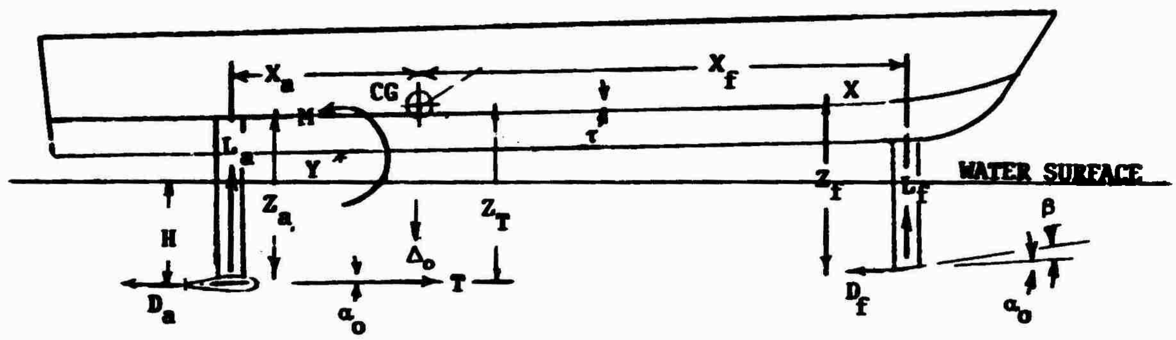


Figure 8 - Geometry and Forces of a Canard Configuration during Takeoff

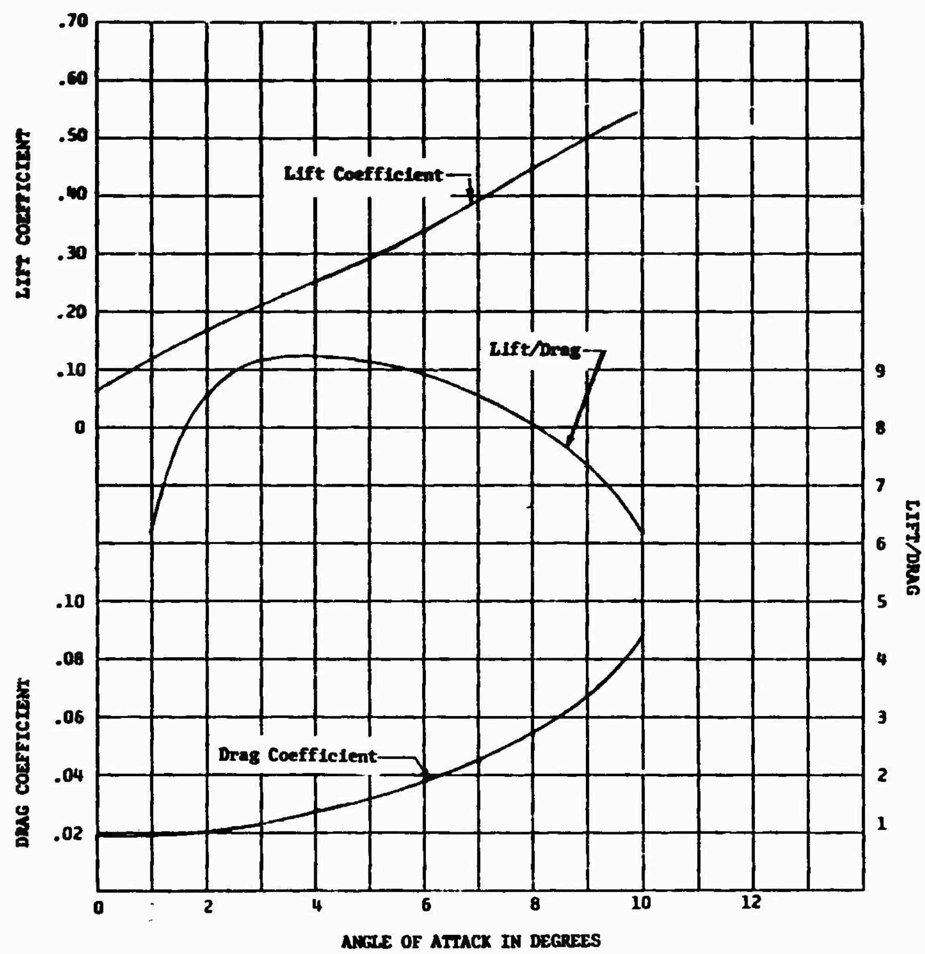


Figure 9 - Lift and Drag Coefficients for Foil Assemblies

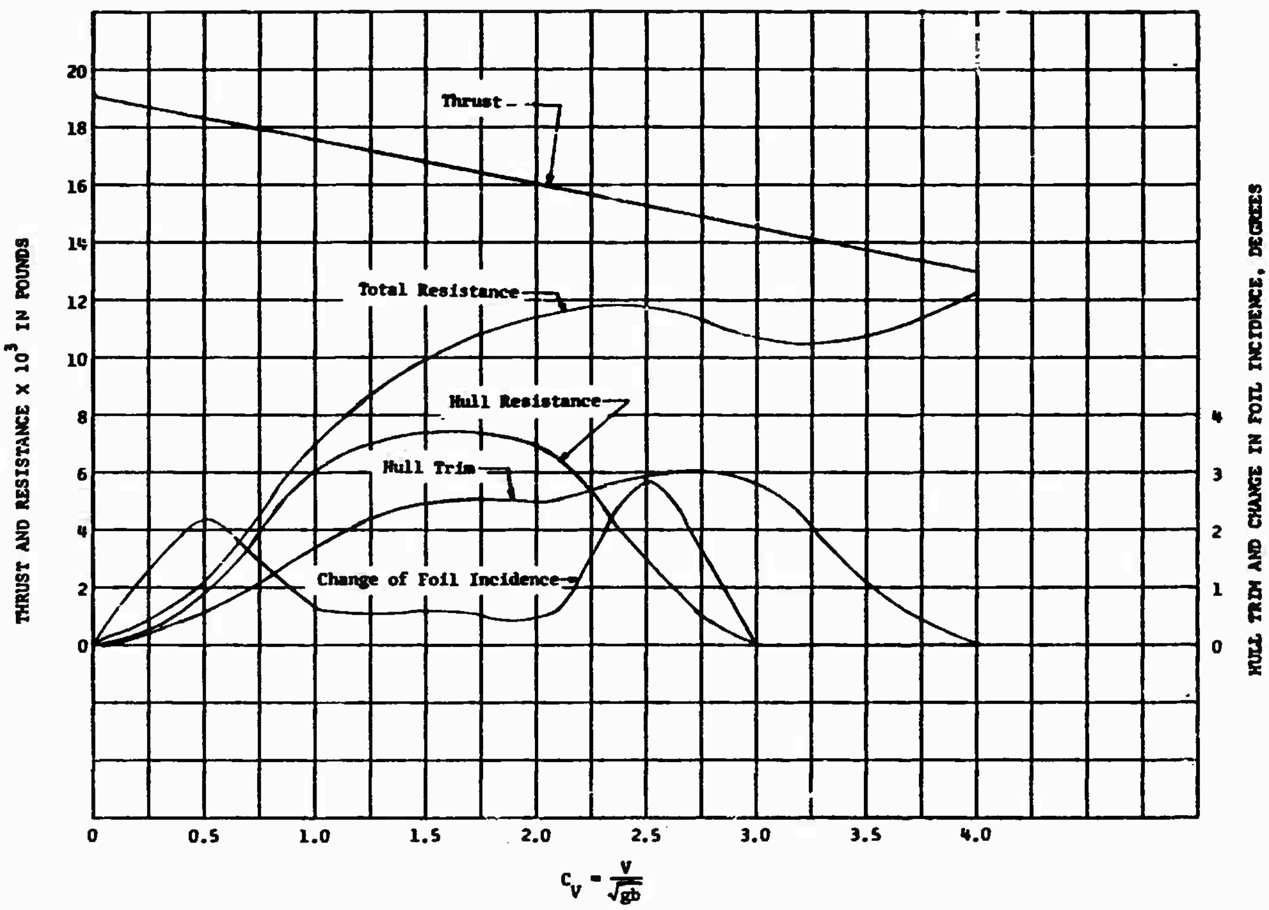


Figure 10 - Variation of Thrust, Hull Resistance, Total Resistance, Hull Trim, and Change of Foil Incidence with Speed Coefficient

TABLE 1

Test Data for Model 4667

Trim, τ deg	C_Δ	C_V	C_R	C_M	C_S	C_{lm}	C_d
0	0.232	1.19	0.0208	0.063	4.69	4.11	-0.008
0	.232	1.64	.0367	.114	4.69	4.11	-.010
0	.232	1.99	.0575	.137	4.69	4.04	-.018
0	.232	2.39	.0733	.155	4.69	4.04	-.010
0	.232	2.78	.1007	.206	4.69	4.04	-.016
0	.232	3.31	.1393	.282	4.69	4.04	-.016
0	.232	3.87	.1783	.355	4.69	4.04	-.021
0	.309	1.12	.0259	.076	5.00	4.50	.018
0	.309	1.60	.0479	.157	5.00	4.50	.016
0	.309	1.99	.0675	.173	5.00	4.44	.010
0	.309	2.41	.0953	.219	5.00	4.44	.005
0	.309	2.87	.1355	.297	5.00	4.44	.005
0	.309	3.38	.1857	.406	5.00	4.44	.008
0	.386	.89	.0200	.037	5.24	4.69	.031
0	.386	1.15	.0363	.123	5.24	4.69	.042
0	.386	1.61	.0598	.194	5.24	4.69	.039
0	.386	1.99	.0853	.219	5.24	4.69	.021
0	.386	2.42	.1212	.268	5.24	4.69	.016
0	.386	2.78	.1664	.349	5.24	4.69	.034
0	.386	3.37	.2582	.495	5.24	4.69	.039
0	.463	.56	.0058	.008	5.40	4.12	.036
0	.463	.86	.0208	.030	5.40	4.12	.050
0	.463	1.13	.0455	.154	5.40	4.84	.068
0	.463	1.59	.0722	.233	5.40	4.84	.060
0	.463	2.02	.1061	.244	5.40	4.84	.047
0	.463	2.39	.1474	.285	5.40	4.84	.042
0	.463	2.84	.2185	.359	5.40	4.84	.060
0	.541	.56	.0089	.007	5.40	4.25	.060
0	.541	.84	.0247	.032	5.40	--	.070
0	.541	1.11	.0517	.167	5.40	4.91	.068
0	.541	1.53	.0845	.259	5.40	4.91	.078
0	.541	1.95	.1258	.264	5.40	4.91	.070
0	.541	2.37	.1748	.282	5.40	4.91	.070
1.5	.077	1.97	.0181	-.050	2.13	2.25	.022
1.5	.077	2.41	.0228	-.055	1.92	2.00	.031
1.5	.077	2.71	.0278	-.049	1.74	1.83	.032
1.5	.077	3.33	.0347	-.049	1.37	1.56	.041
1.5	.077	3.87	.0386	-.051	1.12	1.25	.052
1.5	.077	4.52	.0440	-.056	.86	1.03	.057
1.5	.077	5.45	.0498	-.044	.63	.88	.065
1.5	.077	6.22	.0544	-.049	.50	.78	.069
1.5	.077	6.99	.0590	-.042	.42	.72	.073
1.5	.077	7.52	.0629	-.042	.38	.66	.077
1.5	.077	8.38	.0676	-.037	.28	.59	.078
1.5	.154	1.60	.0201	-.060	3.41	3.20	-.003
1.5	.154	1.99	.0274	-.050	3.28	3.13	.012
1.5	.154	2.48	.0378	-.040	3.09	2.94	.023
1.5	.154	2.78	.0455	-.029	2.91	2.81	.026
1.5	.154	3.35	.0540	-.029	2.50	2.50	.036
1.5	.154	3.91	.0618	-.047	2.11	2.13	.047
1.5	.154	4.63	.0702	-.074	1.60	1.75	.062
1.5	.154	5.40	.0780	-.094	1.20	1.38	.073
1.5	.154	6.18	.0849	-.108	.94	1.08	.078
1.5	.154	6.93	.0922	-.108	.75	.94	.086
1.5	.154	7.66	.0984	-.095	.64	.89	.094
1.5	.154	8.35	.1042	-.096	.63	.82	.096

Table 1 - Continued

Trim, τ deg	C_Δ	C_V	C_R	C_M	C_S	C_{lm}	C_d
1.5	0.232	1.15	0.0164	-0.058	3.99	3.29	-0.016
1.5	.232	1.52	.0239	-.032	4.00	3.63	0
1.5	.232	1.99	.0340	-.016	3.91	3.50	.016
1.5	.232	2.30	.0448	-.005	3.77	3.38	.026
1.5	.232	2.78	.0579	.016	3.60	3.31	.032
1.5	.232	3.35	.0699	.012	3.27	3.11	.043
1.5	.232	3.91	.0818	.014	2.85	2.81	.055
1.5	.232	4.56	.0934	-.028	2.39	2.38	.073
1.5	.232	5.47	.1034	-.076	1.78	1.86	.088
1.5	.232	6.33	.1127	-.116	1.33	1.50	.099
1.5	.232	6.96	.1189	-.144	1.09	1.31	.104
1.5	.232	7.66	.1262	-.156	.91	1.06	.117
1.5	.309	1.15	.0232	-.037	4.40	3.88	-.021
1.5	.309	1.59	.0316	0	4.43	3.94	0
1.5	.309	1.99	.0417	.015	4.32	3.78	.012
1.5	.309	2.45	.0533	.050	4.20	3.71	.023
1.5	.309	2.83	.0670	.079	4.07	3.63	.033
1.5	.309	3.27	.0822	.095	3.87	3.48	.047
1.5	.309	3.91	.1000	.100	3.46	3.25	.052
1.5	.309	4.63	.1162	.041	2.94	2.91	.068
1.5	.309	5.47	.1289	-.018	2.33	2.34	.091
1.5	.309	6.25	.1366	-.106	1.82	1.94	.104
1.5	.309	6.96	.1440	-.159	1.49	1.63	.115
1.5	.386	.84	.0193	-.112	4.07	3.69	-.020
1.5	.386	1.15	.0289	-.013	4.69	4.19	-.020
1.5	.386	1.54	.0405	.043	4.65	4.13	-.003
1.5	.386	1.99	.0521	.070	4.54	4.00	.016
1.5	.386	2.46	.0645	.115	4.42	3.93	.026
1.5	.386	2.74	.0791	.163	4.34	3.84	.034
1.5	.386	3.37	.0984	.192	4.08	3.70	.050
1.5	.386	3.87	.1185	.194	3.85	3.48	.060
1.5	.386	4.63	.1374	.154	3.37	3.23	.077
1.5	.386	5.47	.1548	.057	2.78	2.78	.099
1.5	.386	6.33	.1633	.048	2.17	2.25	.117
1.5	.386	6.96	.1737	-.119	1.80	1.94	.125
1.5	.463	.58	.0077	-.169	4.42	3.91	-.004
1.5	.463	.86	.0224	-.106	4.32	3.81	-.013
1.5	.463	1.11	.0351	-.001	5.16	4.44	-.018
1.5	.463	1.54	.0502	.078	4.85	4.31	-.003
1.5	.463	1.99	.0652	.116	4.73	4.21	.016
1.5	.463	2.32	.0776	.170	4.65	4.14	.026
1.5	.463	2.78	.0934	.241	4.54	4.03	.036
1.5	.463	3.31	.1115	.301	4.36	3.86	.050
1.5	.463	3.87	.1312	.315	4.11	3.71	.064
1.5	.463	4.55	.1552	.282	3.78	3.44	.083
1.5	.463	5.47	.1768	.168	3.21	3.08	.104
1.5	.541	.28	.0010	-.185	4.50	3.98	-.008
1.5	.541	.56	.0077	-.173	4.69	4.03	-.009
1.5	.541	.86	.0243	.044	4.38	3.88	-.018
1.5	.541	1.15	.0452	.036	5.40	4.63	-.026
1.5	.541	1.60	.0652	.123	5.10	4.49	-.008
1.5	.541	1.99	.0791	.161	4.99	4.39	.008
1.5	.541	2.32	.0961	.244	4.86	4.25	.018
1.5	.541	2.78	.1139	.361	4.71	4.21	.034
1.5	.541	3.31	.1305	.424	4.54	4.00	.050
1.5	.541	3.87	.1455	.436	4.34	3.86	.068
1.5	.541	4.63	.1714	.419	4.03	3.63	.088
1.5	.541	5.41	.1953	.317	3.61	3.31	.109

Table 1 - Continued

Trim, τ deg	C_Δ	C_V	C_R	C_M	C_S	C_{lm}	C_d
1.5	0.618	0.28	0.0011	-0.193	4.54	4.06	-0.005
1.5	.618	.56	.0085	-.182	4.69	4.13	-.008
1.5	.618	.86	.0282	-.120	--	--	-.026
1.5	.618	1.15	.0552	.056	5.40	4.69	-.036
1.5	.618	1.57	.0760	.149	5.26	4.63	-.021
1.5	.618	1.99	.0965	.196	5.16	4.46	0
1.5	.618	2.38	.1208	.290	5.04	4.45	.010
1.5	.618	2.78	.1420	.182	4.13	4.38	.123
1.5	.618	3.33	.1583	.545	4.77	4.19	.042
1.5	.618	3.94	.1698	.585	4.60	4.00	.062
1.5	.695	.28	.0019	-.210	4.69	4.16	-.005
1.5	.695	.56	.0089	-.199	4.77	4.19	-.016
1.5	.695	.86	.0309	-.141	--	--	-.016
1.5	.695	1.15	.0641	.053	5.40	4.81	-.026
1.5	.695	1.59	.0911	.165	5.36	4.75	-.016
1.5	.695	1.99	.1150	.202	5.32	4.69	0
1.5	.695	2.32	.1440	.311	5.24	4.56	.013
1.5	.695	2.84	.1795	.494	5.16	4.56	.031
1.5	.695	3.31	.1980	.638	5.00	4.43	.047
1.5	.772	.28	.0010	-.215	4.85	4.25	.010
1.5	.772	.57	.0096	-.203	4.85	4.28	.003
1.5	.772	.86	.0336	-.142	--	--	-.008
1.5	.772	1.15	.0714	.066	5.40	4.88	-.013
1.5	.772	1.54	.1034	.196	5.40	4.81	-.005
1.5	.772	1.99	.1316	.245	5.40	4.78	.008
1.5	.772	2.32	.1710	.347	5.40	4.75	.021
3.0	.077	1.97	.0112	.106	.89	1.13	.055
3.0	.077	2.32	.0108	.121	.80	.88	.072
3.0	.077	2.80	.0131	.133	.56	.62	.083
3.0	.077	3.51	.0154	.131	.37	.45	.099
3.0	.077	4.25	.0170	.102	.27	.38	.108
3.0	.077	4.87	.0181	.102	.20	.33	.113
3.0	.077	5.56	.0197	.107	.16	.29	.119
3.0	.077	6.76	.0212	.085	.12	.25	.121
3.0	.077	6.96	.0239	.067	.10	.22	.125
3.0	.077	7.65	.0255	.059	.09	.21	.127
3.0	.077	8.35	.0290	.053	.08	.19	.129
3.0	.154	1.57	.0181	.148	2.39	2.33	.021
3.0	.154	1.95	.0220	.147	2.03	2.03	.042
3.0	.154	2.38	.0235	.159	1.66	1.71	.068
3.0	.154	2.78	.0251	.172	1.25	1.36	.087
3.0	.154	3.54	.0278	.215	.77	.88	.116
3.0	.154	4.18	.0285	.227	.53	.62	.133
3.0	.154	4.83	.0320	.235	.40	.47	.140
3.0	.154	5.56	.0351	.228	.30	.41	.145
3.0	.154	6.26	.0367	.204	.25	.38	.149
3.0	.154	6.96	.0390	.205	.20	.34	.152
3.0	.154	7.65	.0413	.188	.17	.31	.156
3.0	.154	8.35	.0452	.189	.15	.29	.157
3.0	.232	1.12	.0201	.155	3.52	3.25	-.005
3.0	.232	1.52	.0243	-.148	3.13	2.91	.016
3.0	.232	1.96	.0297	-.139	2.70	2.60	.036
3.0	.232	2.34	.0332	.147	2.35	2.32	.057
3.0	.232	2.81	.0378	.174	1.92	1.94	.080
3.0	.232	3.45	.0405	.237	1.35	1.44	.112
3.0	.232	4.15	.0421	.304	.86	.98	.141
3.0	.232	4.83	.0425	.336	.59	.68	.155

Table 1 - Continued

Trim, τ deg	C_Δ	C_V	C_R	C_M	C_S	C_{lm}	C_d
3.0	0.232	5.57	0.0460	0.344	0.45	0.51	0.165
3.0	.232	6.26	.0483	.348	.35	.45	.171
3.0	.232	6.96	.0540	.338	.29	.41	.174
3.0	.232	7.72	.0568	.355	.25	.38	.177
3.0	.309	.87	.0224	-.220	3.83	3.50	-.006
3.0	.309	1.12	.0305	-.152	4.07	3.66	-.009
3.0	.309	1.56	.0378	-.152	3.76	3.41	.014
3.0	.309	1.96	.0463	.111	3.38	3.13	.026
3.0	.309	2.37	.0518	.099	2.98	2.83	.053
3.0	.309	2.80	.0590	.101	2.56	2.47	.073
3.0	.309	3.41	.0668	.222	1.92	1.96	.111
3.0	.309	4.17	.0691	.325	1.21	1.38	.146
3.0	.309	4.85	.0695	.399	.85	.95	.167
3.0	.309	5.56	.0710	.435	.61	.70	.181
3.0	.309	6.26	.0722	.425	.48	.55	.189
3.0	.309	6.96	.0784	.440	.40	.47	.194
3.0	.386	.87	.0224	.244	4.08	3.63	-.018
3.0	.386	1.12	.0305	.147	4.30	3.88	-.016
3.0	.386	1.56	.0378	.126	4.14	3.73	.005
3.0	.386	1.96	.0463	.082	3.83	3.50	.026
3.0	.386	2.37	.0518	.076	3.52	3.22	.047
3.0	.386	2.80	.0590	.072	3.07	2.88	.067
3.0	.386	3.41	.0668	.164	2.42	2.36	.099
3.0	.386	4.17	.0691	.318	1.56	1.66	.144
3.0	.386	4.85	.0695	.428	1.11	1.21	.169
3.0	.386	5.56	.0710	.488	.80	.91	.188
3.0	.386	6.26	.0722	.548	.63	.72	.199
3.0	.386	6.96	.0784	.544	.49	.56	.206
3.0	.463	.53	.0070	.338	4.09	3.73	-.013
3.0	.463	.86	.0251	.265	4.22	3.81	-.023
3.0	.463	1.12	.0375	.130	4.42	4.06	-.021
3.0	.463	1.51	.0455	.094	4.38	3.94	.004
3.0	.463	1.95	.0548	.053	4.17	3.75	.018
3.0	.463	2.35	.0620	.010	3.91	3.54	.043
3.0	.463	2.77	.0700	.012	3.52	3.23	.064
3.0	.463	3.45	.0780	.101	2.75	2.64	.104
3.0	.463	4.18	.0826	.263	1.96	2.00	.142
3.0	.463	4.81	.0840	.408	1.45	1.48	.159
3.0	.463	5.56	.0854	.522	1.03	1.13	.194
3.0	.463	6.26	.0854	.616	.80	.91	.207
3.0	.541	.28	.0019	.292	4.29	3.79	-.002
3.0	.541	.55	.0085	.350	4.32	3.87	-.008
3.0	.541	.87	.0289	.266	4.39	3.87	-.016
3.0	.541	1.13	.0460	.111	4.54	4.22	-.023
3.0	.541	1.57	.0560	.064	4.61	4.08	.004
3.0	.541	1.99	.0668	.007	4.43	3.94	.026
3.0	.541	2.39	.0738	.052	4.22	3.77	.045
3.0	.541	2.81	.0819	.070	3.91	3.50	.068
3.0	.541	3.45	.0922	-.015	3.21	2.99	.107
3.0	.541	4.15	.0962	-.185	2.36	2.35	.146
3.0	.541	4.84	.0984	-.129	1.72	1.77	.179
3.0	.541	5.56	.0992	-.522	1.25	1.34	.203
3.0	.618	.31	.0031	-.390	4.36	3.88	-.003
3.0	.618	.59	.0108	-.362	4.42	3.97	-.009
3.0	.618	.88	.0309	-.283	4.50	4.00	-.019
3.0	.618	1.12	.0544	-.099	4.61	4.36	-.031
3.0	.618	1.57	.0668	-.028	4.81	4.22	0

Table 1 - Continued

Trim, τ deg	C_Δ	C_V	C_R	C_M	C_S	C_{lm}	C_d
3.0	0.618	1.98	0.0780	0.048	4.65	4.09	0.020
3.0	.618	2.39	.0864	.139	4.42	3.95	.042
3.0	.618	2.79	.0946	.167	4.22	3.78	.065
3.0	.618	3.45	.1042	.096	3.54	3.25	.105
3.0	.618	4.18	.1115	.010	2.66	2.59	.148
3.0	.618	4.86	.1146	.343	2.02	2.08	.183
3.0	.695	.28	.0027	.401	4.46	3.98	-.002
3.0	.695	.59	.0116	.370	4.50	4.04	-.009
3.0	.695	.88	.0359	.275	4.56	3.99	-.022
3.0	.695	1.12	.0633	.086	4.85	4.48	-.031
3.0	.695	1.53	.0776	.011	4.97	4.38	-.005
3.0	.695	1.96	.0907	.053	4.82	4.23	.011
3.0	.695	2.41	.1015	--	4.61	4.08	.040
3.0	.695	2.78	.1081	--	4.38	3.91	.062
3.0	.695	3.48	.1173	--	3.75	3.50	.107
3.0	.772	.28	.0019	.152	4.54	4.03	-.005
3.0	.772	.56	.0096	.369	4.55	4.13	-.013
3.0	.772	.84	.0328	.288	4.61	4.06	-.029
3.0	.772	1.12	.0706	.064	5.08	4.59	-.039
3.0	.772	1.49	.0880	.065	5.06	4.53	-.015
3.0	.772	1.98	.1042	.152	4.90	4.34	.018
4.5	.077	1.99	.0104	-.121	.63	.72	.086
4.5	.077	2.38	.0112	-.134	.35	.41	.109
4.5	.077	2.78	.0120	-.132	.28	.34	.112
4.5	.077	3.30	.0127	-.130	.21	.29	.117
4.5	.077	3.91	.0139	-.128	.15	.25	.127
4.5	.077	4.56	.0150	-.118	.09	.20	.130
4.5	.077	5.42	.0174	-.107	.06	.19	.135
4.5	.077	6.26	.0189	-.089	.05	.16	.140
4.5	.077	6.96	.0212	-.070	.04	.12	.143
4.5	.077	7.66	.0228	-.046	.03	.11	.148
4.5	.077	8.35	.0250	-.027	.02	.09	.152
4.5	.154	1.60	.0189	-.157	1.64	1.81	.042
4.5	.154	1.95	.0204	-.172	1.27	1.48	.073
4.5	.154	2.32	.0212	-.196	.94	1.04	.104
4.5	.154	2.78	.0224	-.230	.67	.75	.131
4.5	.154	3.36	.0235	-.252	.41	.46	.150
4.5	.154	3.98	.0247	-.250	.27	.34	.163
4.5	.154	4.64	.0243	-.256	.19	.29	.170
4.5	.154	5.41	.0266	-.253	.14	.25	.176
4.5	.154	6.26	.0313	-.226	.11	.22	.181
4.5	.154	6.79	.0336	-.220	.09	.20	.185
4.5	.154	7.66	.0343	-.195	.07	.19	.190
4.5	.154	8.35	.0374	-.176	.06	.16	.193
4.5	.232	1.16	.0235	-.214	2.78	2.66	0
4.5	.232	1.54	.0266	-.184	2.39	2.34	.031
4.5	.232	1.94	.0301	-.188	1.92	2.01	.050
4.5	.232	2.32	.0324	-.217	1.49	1.61	.094
4.5	.232	2.78	.0332	-.272	1.13	1.22	.122
4.5	.232	3.36	.0324	-.340	.77	.79	.156
4.5	.232	3.87	.0336	-.363	.48	.56	.180
4.5	.232	4.55	.0355	-.379	.31	.36	.195
4.5	.232	5.42	.0382	-.374	.23	.31	.202
4.5	.232	6.26	.0397	-.372	.17	.27	.209
4.5	.232	6.96	.0425	-.368	.14	.25	.214
4.5	.232	7.66	.0459	-.323	.11	.22	.216

Table 1 - Continued

Trim, τ deg	C_Δ	C_V	C_R	C_M	C_ε	C_{lm}	C_d
4.5	0.309	1.16	0.0316	-0.221	3.28	3.03	0.005
4.5	.309	1.54	.0370	-.205	2.90	2.76	.026
4.5	.309	1.93	.0401	-.183	2.49	2.47	.057
4.5	.309	2.31	.0440	-.221	2.03	2.03	.083
4.5	.309	2.78	.0467	-.267	1.56	1.66	.125
4.5	.309	3.27	.0486	-.364	1.09	1.13	.159
4.5	.309	3.87	.0475	-.442	.73	.78	.190
4.5	.309	4.55	.0471	-.485	.47	.52	.214
4.5	.309	5.42	.0490	-.503	.31	.36	.229
4.5	.309	6.26	.0517	-.484	.24	.31	.237
4.5	.309	6.96	.0529	-.490	.19	.28	.241
4.5	.386	.87	.0276	-.316	3.75	3.38	-.016
4.5	.386	1.12	.0370	-.240	3.75	3.38	-.008
4.5	.386	1.55	.0448	-.199	3.44	3.18	.018
4.5	.386	1.99	.0506	-.165	2.97	2.84	.050
4.5	.386	2.38	.0540	-.191	2.44	2.41	.083
4.5	.386	2.78	.0575	-.250	1.99	1.97	.117
4.5	.386	3.33	.0583	-.366	1.41	1.47	.159
4.5	.386	3.91	.0582	-.484	.95	1.03	.195
4.5	.386	4.64	.0587	-.568	.61	.70	.225
4.5	.386	5.40	.0587	-.621	.41	.47	.242
4.5	.386	6.22	.0618	-.624	.30	.34	.250
4.5	.386	6.96	.0637	-.621	.25	.31	.254
4.5	.463	.53	.0085	-.440	3.52	3.25	-.008
4.5	.463	.88	.0316	-.329	4.27	3.66	-.010
4.5	.463	1.13	.0452	-.229	4.22	3.66	-.009
4.5	.463	1.59	.0536	-.185	3.73	3.34	.021
4.5	.463	1.99	.0602	-.129	3.36	3.13	.046
4.5	.463	2.39	.0644	-.146	2.90	2.75	.073
4.5	.463	2.78	.0679	-.201	2.42	2.38	.109
4.5	.463	3.36	.0706	-.339	1.74	1.81	.156
4.5	.463	3.91	.0702	-.494	1.25	1.38	.198
4.5	.463	4.57	.0690	-.627	.85	.88	.227
4.5	.463	5.37	.0690	-.720	.56	.59	.251
4.5	.463	6.26	.0714	-.748	.39	.44	.263
4.5	.541	.56	.0096	-.462	3.97	3.56	-.005
4.5	.541	.89	.0355	-.353	4.38	3.81	-.009
4.5	.541	1.16	.0544	-.223	4.38	3.88	-.005
4.5	.541	1.57	.0629	-.172	4.09	3.63	.016
4.5	.541	1.99	.0706	-.098	3.74	3.44	.042
4.5	.541	2.38	.0753	-.099	3.32	3.00	.070
4.5	.541	2.82	.0795	-.149	2.82	2.66	.102
4.5	.541	3.31	.0822	-.291	2.11	2.09	.146
4.5	.541	3.87	.0830	-.468	1.52	1.53	.190
4.5	.541	4.64	.0811	-.652	1.02	1.09	.232
4.5	.541	5.42	.0811	-.802	.66	.72	.260
4.5	.541	6.22	.0818	-.874	.45	.50	.276
4.5	.618	.54	.0108	-.485	4.14	3.72	0
4.5	.618	.86	.0324	-.403	4.38	3.91	-.009
4.5	.618	1.16	.0614	-.216	4.54	4.06	-.010
4.5	.618	1.54	.0726	-.153	4.34	3.88	.016
4.5	.618	1.99	.0811	-.076	3.99	3.59	.042
4.5	.618	2.37	.0857	-.038	3.60	3.28	.068
4.5	.618	2.78	.0903	-.074	3.09	2.88	.099
4.5	.618	3.36	.0938	-.243	2.42	2.31	.138
4.5	.618	3.91	.0953	-.446	1.80	1.81	.190
4.5	.618	4.64	.0934	-.693	1.17	1.25	.242
4.5	.618	5.36	.0934	-.861	.78	.84	.271

Table 1 - Continued

Trim, τ deg	C_Δ	C_V	C_R	C_M	C_S	C_{lm}	C_d
4.5	0.695	0.28	0.0038	-0.538	4.14	3.69	-.005
4.5	.695	.58	.0135	-.513	4.38	3.88	-.010
4.5	.695	.86	.0355	-.402	4.69	4.16	-.010
4.5	.695	1.16	.0710	-.223	4.73	4.19	-.008
4.5	.695	1.59	.0822	-.131	4.57	4.00	.010
4.5	.695	1.94	.0899	-.042	4.22	3.78	.026
4.5	.695	2.41	.0973	-.032	3.83	3.56	.060
4.5	.695	2.78	.1027	-.007	3.44	3.13	.073
4.5	.695	3.38	.1054	-.181	2.66	2.47	.141
4.5	.772	.23	.0035	-.576	4.38	3.86	-.003
4.5	.772	.28	.0038	-.572	4.38	3.86	-.003
4.5	.772	.56	.0127	-.546	4.54	3.96	-.005
4.5	.772	.86	.0316	-.470	4.69	3.93	-.010
4.5	.772	1.11	.0768	-.220	4.85	4.30	-.010
4.5	.772	1.60	.0930	-.084	4.69	4.13	0
4.5	.772	1.99	.1042	-.020	4.34	3.98	.023
6.0	.077	1.54	.0112	-.124	.72	.82	.078
6.0	.077	1.99	.0116	-.130	.37	.42	.115
6.0	.077	2.37	.0112	-.122	.24	.28	.130
6.0	.077	2.78	.0123	-.126	.18	.24	.130
6.0	.077	3.48	.0131	-.125	.11	.19	.142
6.0	.077	4.18	.0150	-.116	.08	.16	.148
6.0	.077	4.87	.0162	-.111	.05	.12	.151
6.0	.077	5.57	.0174	-.084	.04	.12	.154
6.0	.077	6.33	.0197	-.073	.03	.09	.156
6.0	.077	6.96	.0220	-.056	.02	.08	.157
6.0	.077	8.28	.0247	-.003	.02	.06	.159
6.0	.154	1.13	.0201	-.180	1.80	1.81	.021
6.0	.154	1.59	.0228	-.176	1.41	1.44	.065
6.0	.154	1.99	.0235	-.200	.94	.94	.117
6.0	.154	2.27	.0235	-.238	.58	.66	.146
6.0	.154	2.74	.0235	-.259	.37	.42	.172
6.0	.154	3.44	.0239	-.268	.23	.27	.186
5.0	.154	4.18	.0247	-.261	.15	.22	.194
6.0	.154	4.87	.0270	-.251	.11	.19	.200
6.0	.154	5.57	.0282	-.242	.08	.17	.204
6.0	.154	6.26	.0305	-.221	.06	.14	.208
6.0	.154	7.66	.0343	-.188	.03	.10	.211
6.0	.154	8.35	.0367	-.159	.02	.09	.211
6.0	.232	.85	.0251	-.272	2.50	2.38	-.005
6.0	.232	1.13	.0289	-.242	2.27	2.25	.016
6.0	.232	1.53	.0328	-.223	1.96	1.94	.052
6.0	.232	1.95	.0343	-.244	1.49	1.56	.104
6.0	.232	2.39	.0355	-.303	.94	1.13	.156
6.0	.232	2.78	.0359	-.343	.67	.75	.183
6.0	.232	3.48	.0347	-.385	.39	.38	.214
6.0	.232	4.18	.0351	-.404	.24	.28	.227
6.0	.232	4.84	.0367	-.398	.17	.23	.234
6.0	.232	5.47	.0397	-.390	.13	.20	.238
6.0	.232	6.17	.0428	-.364	.11	.19	.242
6.0	.232	6.85	.0452	-.362	.08	.16	.246
6.0	.232	7.52	.0463	-.352	.06	.14	.247
6.0	.309	.87	.0320	--	--	2.69	-.009
6.0	.309	1.08	.0374	-.281	2.82	2.63	.003
6.0	.309	1.69	.0452	-.243	2.27	2.19	.055
6.0	.309	1.96	.0471	-.258	1.92	1.94	.083
6.0	.309	2.25	.0479	-.297	1.56	1.63	.255

Table 1 - Continued

Trim. τ deg	C_Δ	C_V	C_R	C_M	C_S	C_{lm}	C_d
6.0	0.309	2.37	0.0479	-0.318	1.47	1.50	0.138
6.0	.309	2.76	.0475	-.389	1.02	1.09	.180
6.0	.309	3.06	.0471	-.437	.77	.84	.202
6.0	.309	3.48	.0463	-.486	.55	.62	.227
6.0	.309	4.12	.0471	-.524	.33	.38	.245
6.0	.309	4.80	.0475	-.537	.24	.28	.255
6.0	.309	5.61	.0502	-.512	.17	.24	.260
6.0	.309	6.22	.0517	-.516	.13	.20	.265
6.0	.309	6.96	.0540	-.488	.11	.19	.267
6.0	.309	7.60	.0552	--	--	.17	.270
6.0	.385	.56	.0116	-.458	2.82	2.69	-.026
6.0	.386	.88	.0374	-.374	3.21	2.98	-.008
6.0	.386	1.18	.0482	-.305	3.13	2.91	0
6.0	.386	1.58	.0536	-.256	2.77	2.61	.036
6.0	.386	1.99	.0571	-.251	2.35	2.25	.078
6.0	.386	2.39	.0587	-.321	1.72	1.75	.128
6.0	.386	2.78	.0598	-.419	1.25	1.34	.169
6.0	.386	3.48	.0598	-.559	.72	.78	.229
6.0	.386	3.86	.0598	-.606	.55	.62	.250
6.0	.386	4.63	.0594	-.653	.35	.40	.268
6.0	.386	5.41	.0606	-.655	.21	.27	.279
6.0	.386	6.18	.0625	-.652	.18	.24	.284
6.0	.386	6.96	.0648	-.648	.13	.20	.289
6.0	.463	.60	.0127	-.506	3.21	2.97	-.010
6.0	.463	.88	.0413	-.414	3.44	3.19	-.016
6.0	.463	1.15	.0571	-.315	3.36	3.13	-.005
6.0	.463	1.55	.0641	-.268	3.07	2.88	.029
6.0	.463	2.00	.0679	-.237	2.61	2.56	.068
6.0	.463	2.41	.0710	-.299	2.11	2.06	.120
6.0	.463	2.78	.0726	-.404	1.64	1.69	.162
6.0	.463	3.34	.0718	-.553	1.06	1.16	.221
6.0	.463	3.87	.0714	-.670	.74	.78	.255
6.0	.463	4.52	.0695	-.765	.51	.50	.281
6.0	.463	5.47	.0718	-.796	.27	.28	.300
6.0	.463	6.18	.0733	-.794	.20	.25	.305
6.0	.541	.28	.0027	-.606	3.28	3.06	0
6.0	.541	.60	.0143	-.580	3.40	3.13	-.026
6.0	.541	.86	.0386	-.480	3.75	3.38	-.008
6.0	.541	1.18	.0660	-.342	3.75	3.38	.001
6.0	.541	1.59	.0745	-.281	3.44	3.13	.031
6.0	.541	2.07	.0803	-.237	2.97	2.78	.083
6.0	.541	2.38	.0814	-.300	2.42	2.38	.115
6.0	.541	2.78	.0841	-.400	1.92	1.91	.164
6.0	.541	3.34	.0849	-.583	1.29	1.38	.227
6.0	.541	3.94	.0826	-.744	.86	.95	.271
6.0	.541	4.73	.0822	-.881	.48	.56	.302
6.0	.541	5.57	.0830	-.934	.32	.38	.320
6.0	.618	.28	.0031	-.654	3.60	3.25	--
6.0	.618	.56	.0154	-.619	3.60	3.25	--
6.0	.618	.85	.0374	-.524	3.91	3.54	--
6.0	.618	1.17	.0756	-.338	4.07	3.65	--
6.0	.618	1.56	.0865	-.277	3.75	3.31	.026
6.0	.618	1.99	.0915	-.198	3.30	3.06	.065
6.0	.618	2.32	.0946	-.229	2.74	2.69	.094
6.0	.618	2.78	.0965	-.377	2.21	2.16	.159
6.0	.618	3.33	.0984	-.558	1.50	1.59	.224
6.0	.618	3.90	.0961	-.763	1.03	1.13	.271
6.0	.618	4.73	.0946	-.958	.63	.69	.318

Table 1 - Continued

Trim, τ deg	C_Δ	C_V	C_R	C_M	C_S	C_{lm}	C_d
6.0	0.618	5.57	0.0949	-1.048	0.39	0.44	0.340
6.0	.695	.28	.0038	-.699	3.75	3.38	.001
6.0	.695	.56	.0193	-.648	3.83	3.44	-.003
6.0	.695	.84	.0386	-.561	4.14	3.69	-.005
6.0	.695	1.11	.0845	-.356	4.22	3.75	-.005
6.0	.695	1.53	.0973	-.260	3.91	3.50	.021
6.0	.695	1.95	.1038	-.166	3.52	3.25	.052
6.0	.695	2.37	.1065	-.190	2.99	2.81	.094
6.0	.695	2.78	.1081	-.300	2.50	2.38	.141
6.0	.695	3.34	.1112	-.535	1.76	1.78	.208
6.0	.695	3.90	.1081	-.764	1.68	1.28	.260
6.0	.772	.28	.0046	-.730	3.91	3.50	.005
6.0	.772	.56	.0193	-.693	3.99	3.56	.003
6.0	.772	.84	.0459	-.569	4.38	3.88	0
6.0	.772	1.11	.0930	-.348	4.46	3.94	0
6.0	.772	1.53	.1085	-.231	4.14	3.69	.021
6.0	.772	1.95	.1169	-.125	3.79	3.44	.050
9.0	.077	1.60	.0143	-.140	.44	.50	.120
9.0	.077	1.99	.0147	-.147	.24	.26	.151
9.0	.077	2.35	.0147	-.147	.17	.19	.162
9.0	.077	2.78	.0154	-.144	.12	.15	.162
9.0	.077	3.36	.0162	-.137	.08	.12	.168
9.0	.077	3.91	.0158	-.130	.06	.10	.174
9.0	.154	1.54	.0278	-.218	1.02	1.08	.094
9.0	.154	1.99	.0282	-.257	.57	.62	.167
9.0	.154	2.39	.0278	-.281	.31	.40	.208
9.0	.154	2.78	.0282	-.281	.22	.25	.220
9.0	.154	3.36	.0282	-.282	.15	.17	.224
9.0	.154	3.91	.0289	-.281	.12	.15	.234
9.0	.232	1.16	.0386	-.254	1.84	1.84	.018
9.0	.232	1.55	.0428	-.248	1.41	1.47	.031
9.0	.232	2.01	.0432	-.303	.90	.97	.172
9.0	.232	2.32	.0432	-.350	.60	.62	.211
9.0	.232	2.78	.0425	-.380	.36	.44	.247
9.0	.232	3.34	.0425	-.406	.22	.25	.263
9.0	.232	3.87	.0432	-.379	.16	.19	.268
9.0	.309	1.15	.0529	-.316	2.21	2.16	.021
9.0	.309	1.58	.0575	-.318	1.83	1.84	.073
9.0	.309	1.99	.0583	-.352	1.31	1.38	.146
9.0	.309	2.32	.0579	-.443	.86	.94	.208
9.0	.309	2.74	.0556	-.510	.55	.61	.255
9.0	.309	3.31	.0560	-.556	.34	.41	.292
9.0	.309	3.87	.0556	-.566	.23	.25	.305
9.0	.309	4.80	.0590	-.561	.14	.17	.315
9.0	.386	.88	.0444	-.452	2.58	2.47	-.007
9.0	.386	1.11	.0664	-.353	2.50	2.41	.003
9.0	.386	1.54	.0722	-.336	2.19	2.16	.055
9.0	.386	1.99	.0733	-.381	1.64	1.69	.130
9.0	.386	2.36	.0722	-.475	1.19	1.26	.203
9.0	.386	2.78	.0718	-.588	.74	.81	.260
9.0	.386	3.35	.0714	-.664	.45	.51	.307
9.0	.386	3.98	.0714	-.705	.27	.32	.328
9.0	.386	4.73	.0733	-.698	.17	.21	.343
9.0	.463	.56	.0185	-.608	2.66	2.53	-.010

Table 1 - Continued

Trim, τ deg	C_Δ	C_V	C_R	C_M	C_S	C_{lm}	C_d
9.0	0.463	0.84	0.0490	-0.520	2.82	2.66	-0.013
9.0	.463	1.11	.0787	-.417	2.78	2.63	-.003
9.0	.463	1.53	.0845	-.355	2.42	2.34	.042
9.0	.463	1.94	.0880	-.386	1.91	1.91	.112
9.0	.463	2.36	.0884	-.507	1.33	1.41	.198
9.0	.463	2.78	.0876	-.630	.94	1.00	.258
9.0	.463	3.34	.0857	-.758	.56	.62	.315
9.0	.463	3.89	.0845	-.820	.36	.41	.341
9.0	.463	4.73	.0872	-.850	.22	.25	.362
9.0	.463	5.56	.0892	-.848	.16	.19	.372
9.0	.541	.28	.0038	-.755	2.74	2.56	-.003
9.0	.541	.56	.0193	-.676	2.82	2.63	-.010
9.0	.541	.84	.0475	-.590	3.13	2.84	-.016
9.0	.541	1.11	.0895	-.455	3.09	2.81	-.008
9.0	.541	1.53	.0961	-.384	2.66	2.53	.034
9.0	.541	1.94	.1004	-.393	2.19	2.16	.099
9.0	.541	2.36	.1023	-.566	1.56	1.68	.190
9.0	.541	2.78	.1011	-.665	1.16	1.28	.250
9.0	.541	3.34	.1011	-.815	.74	.81	.312
9.0	.541	3.89	.0992	--	.47	.53	.354
9.0	.541	4.73	.0996	--	.27	.32	.383
9.0	.541	5.56	.1027	--	.17	.25	.396

TABLE 2

Calculated Take-off Data

C_V	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0
Velocity	10.52	21.04	31.56	42.08	52.60	63.12	73.64	84.16
Trim	0.60	1.70	2.50	2.50	3.00	2.90	1.10	0
α_a	2.30	3.40	4.20	4.20	4.70	4.60	2.80	1.70
C'_{La}	0.180	0.230	0.260	0.260	0.280	0.277	0.204	0.156
$(L/D)_a$	8.50	9.20	9.20	9.20	9.20	9.20	9.10	8.10
q	110	441	991	1,762	2,753	3,964	5,396	7,050
L_a	1,350	6,918	17,572	31,240	52,571	75,000	75,000	75,000
D_a	159	752	1,910	3,396	5,714	8,152	8,242	9,259
C_Δ	0.592	0.547	0.464	0.345	0.127			
C_M	-0.066	-0.061	-0.0476	-0.050	-0.136		FOILBORNE	
C_R	0.012	0.0375	0.045	0.042	0.018			
R	1,986	6,206	7,448	7,006	2,979	0	0	0
M	-150,117	-138,744	-108,266	-114,800	-309,332			
L_f	680	2,491	5,630	11,214	26,411	25,000	25,000	25,000
C_{Lf}	0.272	0.249	0.250	0.280	0.422	0.277	0.204	0.156
$(L/D)_f$	9.2	9.2	9.2	9.2	8.3	9.2	9.1	8.1
α_f	4.5	4.0	4.0	4.7	7.6	4.6	2.8	1.7
D_f	74	270	612	1,219	3,182	2,717	2,743	3,086
$D_f + D_a$	233	1,022	2,522	4,615	8,896	10,869	10,985	12,345
$R + D_f + D_a$	2,219	7,228	9,970	11,621	11,875	10,869	10,985	12,345
T	18,100	17,700	16,800	16,000	15,300	14,500	13,800	13,000
H	8.0	8.0	8.0	8.0	8.0	2.0	2.0	2.0
β	2.2	0.6	0.6	0.5	2.9	0	0	0

NOTE: Where the hull is foilborne, the air drag of the hull has not been added.

REFERENCES

1. Clement, E. P., "Development and Model Tests of an Efficient Planing Hull Design," David Taylor Model Basin Report 1314 (Apr 1959).

2. Olson, R. E. and Brownell, W. F., "Facilities and Research Capabilities, High Speed Phenomena Division, David Taylor Model Basin, Langley Field, Va.," David Taylor Model Basin Report 1809 (Apr 1964).

3. Parkinson, J. B. et al., "Aerodynamic and Hydrodynamic Tests of a Family of Models of Flying-Boat Hulls Derived from a Streamline Body, NACA Model 84 Series," National Advisory Committee for Aeronautics Report 766 (1943).

ERRATA SHEET

for

David Taylor Model Basin Report 2006, July 1965

Report 2006 – General Resistance Test of a Stepless Planing Hull with Application to a Hydrofoil Configuration:

The values of C_M and C_d are erroneous and the data required to compute correct values are not available.