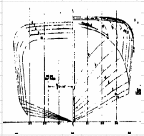
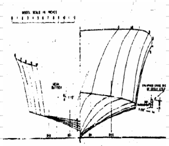
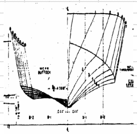
Eugene P. Clement Models

EUGENE P.CLEMENT

Model	Lpx	Lwl	Bpx	Dep	$\beta\chi$	$\beta\tau\chi$	Centroid	Lcg aft of Centroid	Lcg from Transom	Lcg/Lp	Centerline angle	Ap	Twisted angle	Lpx/Bpx	Ap/Vol	Lpx/Ap	Lpx/Vol	Cv	Vcg/Lpx	Shaft Angle	Lce Transom
3626	7,649 ft	7,504 ft	1,791 ft	129,600 Lb	17,55	7,00	49,00	-6,00	3,289 ft	0,430	-1,90	11,415 ft^2	10,55	4,27	7,003	5,126	6,061	0,352	-------------	8,30	0,000 ft
	2,331 m	2,287 m	0,546 m	58,787 kg					1,003 m			1,0605 m^2									0,0000 m
3720	8,200 ft	8,015 ft	1,786 ft	139,600 Lb	21,50	3,00	46,90	-6,00	3,354 ft	0,409	-1,70	11,993 ft^2	18,50	4,59	7,002	5,607	6,338	0,382	-------------	---------	0,000 ft
	2,499 m	2,443 m	0,545 m	63,323 kg					1,022 m			1,1142 m^2									0,0000 m
3722	8,488 ft	8,064 ft	1,791 ft	148,000 Lb	17,55	7,00	48,40	-6,00	3,599 ft	0,424	-0,50	12,466 ft^2	10,55	4,74	7,000	5,779	6,434	0,402	-------------	11,00	0,000 ft
	2,587 m	2,458 m	0,546 m	67,133 kg					1,097 m			1,1581 m^2									0,0000 m
	8,488 ft	8,064 ft	1,791 ft	121,100 Lb	17,55	7,00	48,40	-6,00	3,599 ft	0,424	-0,50	12,466 ft^2	10,55	4,74	8,002	5,779	6,879	0,329	-------------	11,00	0,000 ft
	2,587 m	2,458 m	0,546 m	54,931 kg					1,097 m			1,1581 m^2									0,0000 m







LİTERATURE = Analyzing the Stepless Planing Boat -DTMB 1956

Comparative tests for four boat series

Analyzing the Stepless Planing Boat - ISP

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REPORTS

NAVY DEPARTMENT
THE DAVID W. TAYLOR MODEL BASIN
WASHINGTON 7, D.C.

ANALYZING THE STEPLESS PLANING BOAT

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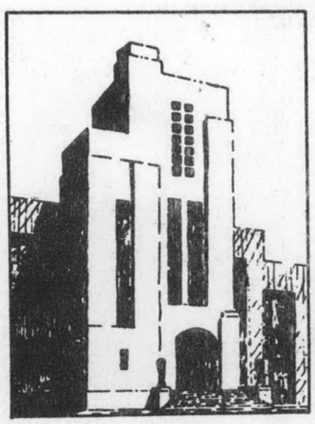

RESEARCH AND DEVELOPMENT REPORT

NOVEMBER 1956 Report 1093

ANALYZING THE STEPLESS PLANING BOAT

By

Eugene P. Clement

NOVEMBER 1956

Report 1093
NS 715-102

NOTATION

A	Projected area bounded by chines and transom, in plan view
B	Breadth over chines at any point
B_A	Mean breadth over chines, A/L
B_T	Breadth over chines at transom
B_X	Maximum breadth over chines
℔	Baseline
bhp	Engine brake horsepower
℄	Centerline
CG	Center of gravity
C_{H_F}	Draft coefficient at rest, forward; equals draft at 100% L (Measured from tangent to mean buttock at stern) multiplied by A/∇
C_{H_A}	Draft coefficient at rest, aft; equals draft at 0% L (measured from tangent to mean buttock at stern) multiplied by A/∇
ehp	Effective horsepower
$F_{n\nabla}$	Froude number based on volume, $v/\sqrt{g\nabla^{1/3}}$
g	Acceleration due to gravity
L	Overall length of the area A, measured parallel to baseline
LCG	Longitudinal center of gravity location
R	Total resistance, lb
S	Wetted surface, area of (includes side wetted area at low speeds)
SW/FW	Density ratio, salt water to fresh water

NOTATION (continued)

v	Speed
V	Speed, knots
w	Density of water (weight per unit volume)
WL_C	Intersection of chine with solid water, forward of 0%L, ft
WL_K	Wetted length of keel, forward of 0%L, ft
WL_{SP}	Intersection of chine with spray, forward of 0%L, ft
λ	Linear ratio, ship to model
α	Angle with horizontal of mean buttock at stern, degrees
β	Deadrise angle of hull bottom, degrees
Δ	Displacement at rest, weight of
τ	Trim angle of hull with respect to attitude as drawn
∇	Displacement at rest, volume of

Subscripts:

M, m	Model
S, s	Ship
o	Value at rest

ANALYZING THE STEPLESS PLANING BOAT*

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INTRODUCTION

During recent years the David Taylor Model Basin has towed a number of models of planing craft in smooth water to determine resistance, trim angle, wetted lengths and wetted surface. In most cases each of these models was considered to represent a particular full-scale boat, and the data obtained were presented in dimensional form for specific boat dimensions and displacements. Each model, however, can represent a boat of any size. Therefore, when a new design is to be developed, all models of previous designs can be considered to represent boats of the size of the new design, and the data on their performance can be used for guidance. In order to do this easily the designer needs to have the information on the previous designs in suitable form. The purpose of this report is mainly to indicate appropriate methods of presenting and utilizing the accumulated information on hull forms and model test results for planing boats to guide the design of future boats.

In this report the important planing hull parameters are defined and a convenient method of combining them in a hull-form characteristics sheet is shown. A plan for presenting model test results in a dimensionless form suitable for comparison and analysis is next given. The hull-form characteristics and model test results are at present being incorporated in a Taylor Model Basin design data sheet, an example of which is given. The effects on performance of variations in some of the primary parameters are then illustrated and discussed. Also, methods are proposed for improving the usefulness of future model tests for purposes of comparison and analysis. Finally, a step by step design method is proposed, and data are presented which it is believed will assist the designer in making design decisions quickly and with assurance of correctness.

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* This report combines, with some alterations, two papers presented by the author to the Chesapeake Section of the SNAME: "The Analysis of Stepless Planing Hulls" on 3 May 1951 and "Hull Form of Stepless Planing Boats" on 12 January 1955.

HULL FORM AND HULL LOADING PARAMETERS

The primary parameters affecting the performance of planing hulls, in the approximate order of their importance, are as follows:

(a) Ratio of length to beam. This important ratio is defined here as the ratio of the length L, of the hull bottom, to the mean breadth B_A, of the chines (see Notation pg ii). The chief reason for defining the length of a planing hull in this way is so that only one value of the length dimension will be assigned to each set of lines. If the length dimension is defined as the length of the load waterline, then a given set of lines could conceivably have various lengths assigned to it at different times, depending upon the particular displacement and center of gravity location of each instance.

(b) Size-displacement, or area, coefficient. The relationship between hull size and gross weight can be expressed in convenient dimensionless form by the ratio $A/\nabla^{2/3}$, where A is the projected area bounded by the chines and transom, in plan view, and ∇ is the volume of water displaced at rest. Since this coefficient is dimensionless it yields the same value for geometrically similar boats of different size but of corresponding loading. It also yields the same value for two boats which have different length-beam ratios but the same area, A, and the same displacement. If two designs having different ratios of length to beam are compared on the basis of equal values of $A/\nabla^{2/3}$ the comparison will be a valid one; for, to a good first approximation (assuming the same depth of hull and similar construction) the two designs will then have equal hull area, equal hull volume, and equal hull structural weight.

It does not appear possible to make as plausible a case for any of the other coefficients which have been used to characterize the size-displacement relationship of planing boats. The well known displacement-length ratio, $\Delta/(L/100)^3$, and the load coefficient, $\Delta/wB_X{}^3$, are the ones most commonly employed. The unsatisfactory result of using $\Delta/(L/100)^3$ as the size-displacement criterion may best be illustrated by an example. Suppose that two sets of lines, A & B, are under consideration for a boat of given displacement, and that design A has a higher ratio of length to beam than design B. Comparison of these two designs on the basis of equal $\Delta/(L/100)^3$ will then result in comparing the two boats at the same length and displacement. Compared in this manner, however, design B has more beam, more hull area, and (assuming the same depth of hull, and similar construction) more hull volume and more hull structural weight than design A. These differences will clearly preclude a valid comparison. A similar confusion would result if the two designs were compared on the basis of equal Δ/wB_x^3.

(c) Longitudinal CG location. It is considered appropriate to define longitudinal CG location as the distance of the CG from the centroid of the area, A, expressed as a percentage of the length L.

(d) Deadrise. Deadrise angle of the hull bottom generally varies from a large angle near the bow to an angle of a few degrees at the transom. The variation of this important angle throughout the length of the boat can be indicated by approximating each section of the body plan by a straight line (see Figure 1) and then plotting a curve of deadrise variation versus boat length. Examples of this curve, for three different designs, are shown in Figure 2. The variation of deadrise angle with boat length generally gives very nearly a straight line for the after half of the hull length.

(e) Longitudinal curvature. The longitudinal curvature of the hull bottom is shown by the shape of the buttock lines. For purposes of comparison and analysis it is desirable to define an average, or mean, buttock. This can be conveniently done by intersecting the straight line approximations to the body plan sections by a buttock plane spaced at $B_A/4$ from the centerline plane, as shown in Figure 1. Examples of the mean buttock curves obtained by this method are shown in dimensionless form in Figure 3a. The mean buttock lines shown in Figure 3a reflect the general practice to have straight buttock lines in the after portion of planing hull bottoms. Buttock lines are generally straight for at least the after 30 per cent of the hull length. It is difficult to make further comparisons of the buttock lines as they appear in Figure 3a, since their attitudes, and their heights from the horizontal axis, reflect the arbitrary attitudes and heights above the baseline at which the corresponding lines were originally drawn. Comparison and analysis can be facilitated, therefore, by shifting each mean buttock curve so that its after end is tangent to the horizontal axis of the graph. The mean buttock lines of Figure 3a, after being shifted in this manner, are shown in Figure 3b. In the presentation of model test results in this report the angle of attack, or running trim of a hull is defined as the angle which the tangent to the mean buttock at the stern makes with the horizontal. This angle is designated α.

(f) Plan view of chine. The significant features which are determined by the shape of the chine line in plan view are the length/beam ratio of the boat and the fore-and-aft distribution of breadth and of bottom area. Length/beam ratio has already been adequately defined as the ratio L/B_A. Therefore, it is desirable to reduce the plan view of the chine line to a form which is independent of length/beam ratio, in order to compare relative fore-and-aft distribution of bottom area. This is accomplished by plotting the ratio of local chine breadth to B_A, against hull length, as shown in Figure 4. Each of the chine lines in Figure 4 encloses the same area, although the ratios L/B_A of the hulls from which they were derived are all different. Several dimensionless ratios indicative of the relative fore-and-aft distribution of breadth are apparent in Figure 4. First, the location of the point of maximum chine breadth, as a percentage of hull length from the transom, is apparent. Also, the ratios of maximum breadth and of transom breadth to the mean breadth (B_A) can be read directly from the scale of the ordinate. An important criterion of the fore-and-aft distribution of the plan-view bottom area (area, A) is the location of the centroid of this area. This dimension is given in Figure 4, for the different designs.

(g) Type of section. Planing boat sections generally fall into one of the following four categories:

1. Concave - An example of this type of section is shown in Figure 1.
2. Convex - The use of developable surfaces will generally result in this type of section.
3. Convex at keel and concave at chine - This type is exemplified by the British Vosper PT boat of World War II.
4. Concave at keel and convex at chine

All of the foregoing parameters of hull form and hull loading are incorporated in the Taylor Model Basin's design data sheet for planing boats, an example of which is shown in Figure 5. Also included in Figure 5 are draft coefficients at bow and stern for each of the model test conditions. Drafts at rest were measured up from the straight line which is tangent to the mean buttock at the stern. The draft readings were then converted to dimensionless coefficient form on the is to compare the resistances of planing hulls by plotting the ratio of resistance to displacement against speed-length ratio ($V/\sqrt{L}$). This method often gives an incorrect comparison, as shown by the following example. Suppose that a 100,000 lb., 40 knot boat is required. In Figure 6 the resistance curves for two models having different values of length-displacement constant ($L/\nabla^{1/3}$) are plotted in the usual manner*. Figure 6 gives the impression that a boat based on Model 2727 would have higher resistance than a boat based on Model 2742. Such is not the case, however, because the use of $V/\sqrt{L}$ as abscissa does not bring the actual full scale speeds into correspondence. That is, since the models have different values of length-displacement constant ($L/\nabla^{1/3}$), a given value of $V/\sqrt{L}$ does not correspond to the same full scale speed for both designs. For Model 2727, expanded to 100,000 lbs. displacement, 40 knots corresponds to a value of $V/\sqrt{L} = 3.93$, while for Model 2742, expanded to 100,000 lbs. displacement, 40 knots corresponds to a value of $V/\sqrt{L} = 4.95$. Therefore, plotting R/Δ against $V/\sqrt{L}$ amounts, in this case, to comparing the resistances of the two designs at entirely different speeds. What is required is a plot of R/Δ versus a coefficient which will bring the full scale speeds into alignment. The speed coefficient $F_{n\nabla}$ is correct for the purpose because it is derived from the significant quantities of the design problem, i.e.: speed and displacement. In Figure 7, the data from Figure 6 have been replotted on an abscissa of $F_{n\nabla}$. Here, the resistance curves are shown in their correct relationship, and the order of superiority is the reverse of that shown in Figure 6. The value of $F_{n\nabla} = 3.5$ corresponds to 40 knots for both designs at 100,000 lbs displacement. More generally, a particular value of $F_{n\nabla}$ corresponds to the same full scale speed for both designs, for the same displacement.

A resistance comparison made by plotting R/Δ versus $V/\sqrt{L}$ will be incorrect unless the length-displacement constant ($L/\nabla^{1/3}$) is identical for both hulls, and an identity of $L/\nabla^{1/3}$ will generally not be the case. Confusion and error will also result from using the speed coefficient $v/\sqrt{gB_x}$ (which is sometimes used for planing boat analysis) to compare hulls of different proportions, except when the ratio $B_x/\nabla^{1/3}$ (or Δ/wB_x^3) is the same for both boats.

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* These values are taken from the original data for Reference 1. The data for Model 2727 are from the test at normal displacement and 2^o initial trim by stern. The data for Model 2742 are from the test at normal displacement and 0^o initial trim. No correction for the difference in the frictional resistance coefficients of model and full size boat has been made, since that seemed unnecessary for the purpose of this illustration.

basis of the following reasoning:

Draft is proportional to $\frac{\nabla}{A}$

Then, draft = (draft coefficient) x $\frac{\nabla}{A}$.

Therefore, draft coefficient (C_H) = draft x $\frac{A}{\Delta}$.

The draft coefficient defined in this way is independent of differences in absolute size and of differences in length/beam ratio. Also, by measuring the draft from the tangent to the mean buttock, this draft coefficient is made relatively independent of differences in deadrise angle. Accordingly, the draft coefficients for a new design can be approximately determined when draft coefficients are available from a previous similar design. The two designs should be similar in respect to $A/\nabla^{2/3}$, CG location, and longitudinal curvature. Differences in type of section and in plan form of chine should cause only slight changes in the relative values of the draft coefficients.

PERFORMANCE CHARACTERISTICS

A performance characteristics sheet, which presents model test results for planing hulls in a dimensionless form suitable for comparison and analysis, is included in the design data sheet shown in Figure 5. Also included in the design data sheet are the hull lines and other pertinent dimensions and coefficients. It is the intention of the Taylor Model Basin to prepare such a design data sheet for each planing hull model tested in the future, and also for a selected number of those models previously tested.

Since displacement is a fundamental design quantity it is desirable to compare hull forms on the basis of equal displacement. This is facilitated in the performance characteristics sheet shown in Figure 5 by relating each of the variables, speed, resistance and wetted surface, to displacement, by means of the dimensionless ratios $v/\sqrt{g\nabla^{1/3}}$, R/Δ and $S/\nabla^{2/3}$, respectively.

Relating resistance to displacement as indicated here is the usual practice in this country in dealing with planing boats. Unfortunately however, it is not general practice to relate planing boat speed to displacement. The general practice

Wetted surface and trim angle are included in the performance sheet because they are proportional, respectively, to the frictional and wavemaking resistance of planing hulls. At a given speed the frictional resistance is almost directly proportional to the wetted surface, so that for constant displacement, which is the basis of the present method of comparison, the frictional resistance of two different designs are proportional to their respective values of the dimensionless quantity, $S/\nabla^{2/3}$.

In the planing condition, the wavemaking resistance of a prismatic planing surface equals the product of the displacement and the tangent of the angle of attack of the bottom (equals $\Delta \tan \alpha$). The planing area of the conventional planing boat generally closely resembles a prismatic planing surface, and the angle α of the present paper is defined in such a way as to represent approximately the effective angle of attack of the planing area. Therefore, the wavemaking resistances of two designs which are being compared on the basis of equal displacement are in nearly the same ratio as their respective values of $\tan \alpha$.

EFFECTS ON PERFORMANCE OF CHANGES IN AREA COEFFICIENTS, LENGTH-BEAM RATIO AND LCG LOCATION

An aggregate of data suitable for analyzing the effects of area coefficient and length-beam ratio on the resistance of stepless planing boats is available from the tests of EMB Series 50 (Reference 1). The original data, for 0° initial trim only, was used for the present analysis. The procedures used for varying the model loading and proportions in this series, and for presenting the resistance data in Reference 1 are the same as those used by Taylor for his standard series of ship forms. The form in which the data are available will be found disappointing by anyone who attempts to use them for determining the effects of the significant planing hull parameters on resistance, and a new approach, therefore, seems desirable.

When each of the tests of EMB Series 50 is represented by an x on a grid of $A/\nabla^{2/3}$ vs L/B_A, the result is as shown in Figure 8. It can be seen that the tests fall into groups corresponding to substantially constant values of L/B_A. Three resistance curves from group D are plotted in Figure 9 to show the effect of area coefficient on resistance for a constant value of L/B_A (which is about 4.25 in this case). The resistance curve corresponding to an area coefficient of 8.2 can be seen to be superior to the resistance curve corresponding to either the higher or the lower value of area coefficient.

Resistance curves for all the 0^{o} initial trim tests of EMB Series 50 were compared by groups of equal L/B_A, and for each value of L/B_A it was possible to distinguish an optimum resistance curve corresponding to a particular value of area coefficient. In Figure 8, the area coefficient for optimum resistance for each of the values of length-beam ratio is indicated by a circle around the appropriate x. It can be seen that the variation of optimum area coefficient with length-beam ratio can be represented with reasonable accuracy by a single straight line.

Resistance curves for the three tests of Figure 8 indicated by $\bar{x}$ are plotted in Figure 10. This shows the effect of length-beam ratio on resistance for a constant value of $A/\nabla^{2/3}$ (about 8.6). It can be seen that the high speed resistance decreases markedly with decrease of length-beam ratio, but that this is accompanied by some increase in low speed resistance. Or, looked at in a different fashion, Figure 10 shows that a relatively long slender hull gives lower resistance at speeds below $F_{n\nabla} = 2.3$, while a relatively short wide hull gives lower resistance at speeds above $F_{n\nabla} = 2.3$.

Additional data showing the effects of a change in area coefficient on the performance of a planing hull are shown in Figure 11. These data were obtained from tests of the same model at two different displacements but approximately the same LCG location. The resistance data from both tests were corrected to 100,000 lb displacement (a convenient average value for boats of the PT and AVR types) and are plotted in Figure 11 in the form of R/Δ versus $F_{n\nabla}$. Compared in this manner the resistance curves indicate the relative resistance of two boats of the same hull form, same displacement, and same center of gravity location, but of different hull area. It can be seen that the smaller boat with area coefficient $(A/\nabla^{2/3})$ equal to 4.93, has a high resistance hump. This is evidently caused mainly by wavemaking resistance since it corresponds to a similar hump in the trim angle curve. At the hump speed the lower wetted surface of the smaller boat apparently is of relatively little effect in reducing resistance. At high speed the frictional effect predominates, since the frictional resistance is approximately proportional to the wetted surface times the square of the speed. Therefore, at high speed, because of her smaller wetted area, the small boat has the lower net resistance, in spite of the fact that the trim angle curves indicate that she has the higher wavemaking resistance.

The resistance curve for the small boat indicates that an area coefficient of 4.93 is too low for most practical purposes. One reason is that it would be difficult to provide adequate propeller thrust for such a high resistance hump; also, resistance at cruising speed would be high; and, finally, the high trim angle would aggravate pounding in waves.

The effects on the performance of a planing boat of a change in LCG location are shown in Figure 12. These data were obtained from tests of a model at two different LCG locations, and the same displacement. As would be expected, moving the CG aft increases the trim angle of the boat and decreases the wetted area. At low speeds, where the wavemaking resistance predominates, the CG forward condition produces the least resistance because of the smaller trim angle. At high speeds, where the frictional resistance predominates, the CG aft condition produces the least resistance because of the smaller wetted area.

STANDARD MODEL TEST CONDITIONS

It was shown in the previous section that changes in the area coefficient and in LCG location have large effects on the performance of planing boats. Therefore, in order to show the effects of other variables on performance, it is desirable in any comparison to hold these two constant. Comparison would evidently be greatly facilitated if future tests of planing boat models included one or more tests at "standard" conditions of $A/\nabla^{2/3}$ and LCG location. Future designs could then be readily compared without interpolation, without the necessity of searching for test conditions that happened to be similar, and without having significant performance differences unnecessarily obscured by even small differences in area coefficient and center of gravity location. The standard test conditions should, of course, be selected from consideration of the practical and desirable region of planing boat design.

Figure 13 shows the values of $A/\nabla^{2/3}$ and LCG location (with respect to the centroid of the area, A) corresponding to the model test conditions for a number of boats. The after limit in the practical range of center of gravity location is the point at which longitudinal instability (porpoising) occurs. The test condition for which one of the models porpoised is indicated by a tail on the corresponding symbol. Additional points of instability, from other model tests, are also shown, in order to define more accurately the after limit of the practical range of center of gravity location. Each of these points is indicated by a diamond with a tail.

The standard test conditions decided upon for tests of planing boat models at the Taylor Model Basin are $A/\nabla^{2/3} = 7$, and LCG location at 6 per cent L aft of the centroid of A. Where additional conditions are desired it is planned to select them from among the conditions indicated by the solid circles of Figure 13.

EFFECTS ON PERFORMANCE OF CHANGES IN TWIST AND DEADRISE ANGLE

The effect of warp, or twist of the planing area, on the performance of planing hulls is indicated by a comparison of the World War II Elco and Higgins PT designs. Figure 2 shows that the deadrise of the Elco design increases from 7 degrees at the transom to 18 degrees at midlength, giving a twist of the planing area of 11 degrees. The deadrise of the Higgins design increases from 2 degrees at the transom to 21 degrees at midlength, giving a twist of 19 degrees, or roughly twice as much as the Elco design. The mean planing deadrises for the two designs (average of deadrise at mid-length and transom) are practically the same ($12\frac{1}{2}$ degrees for the Elco and $11\frac{1}{2}$ degrees for the Higgins design). Figures 3b and 4 indicate that the two designs are fairly similar with respect to mean buttock curvature and shape of chine in plan view. Performance of the two designs, from model tests, are compared in Figure 14. The resistance of the Higgins design is appreciably higher than the resistance of the Elco design, and the difference is considered to be chiefly attributable to the larger twist in the planing bottom of the Higgins design.

Data are not available to show how a planing boat with a low average deadrise angle compares in performance, throughout the speed range, with a boat having a high average deadrise angle. The range of deadrise angles covered by the tests of EMB Series 50 was small, and deadrise angle was not varied systematically. However, the effects of change in deadrise angle on performance at high speeds can be shown by means of data obtained from tests of prismatic planing surfaces. Figure 15 shows the performance predicted from such data for a 100,000 lb boat, of typical dimensions, for deadrise angles of 0, 10, and 20 degrees. These performance curves were calculated from the data of Reference 2. It can be seen that an increase in deadrise angle from 0 degrees to 20 degrees increases the wetted surface about 25 per cent, increases the trim angle 1 degree, and increases the value of R/Δ at high speeds by about 0.040. For a prismatic planing bottom the amount of the increase in R/Δ caused by increased wavemaking resistance is the same as the value of the increase in the tangent of the trim angle. For the range of angles of interest here an increase in trim angle of 1 degree corresponds to an increase in the tangent of approximately 0.018. Evidently then, of the increase in R/Δ of 0.040, approximately 45 per cent (0.018) can be attributed to increased wavemaking resistance and the remaining 55 per cent to increased frictional resistance.

In spite of the fact that a flat planing surface has less resistance than one with deadrise, in practice a deadrise angle at the transom of at least 10° is desirable in order to give a boat good directional stability, and in order that it will have the desirable characteristic of banking inboard on turns.

Model data are not readily available to show the effects on resistance of longitudinal curvature, plan form of chine, and type of section. It is expected that this situation will be improved in the future, however, as models are tested at standard conditions and comparison and analysis are thereby facilitated.

DESIGN PROCEDURE

The coefficients and parameters presented in this report have been introduced with the intent that they should be useful for design purposes. Accordingly, in this section, a design procedure utilizing these coefficients and parameters will be outlined. This report does not attempt to present a complete design procedure. It would be necessary to include a considerable amount of additional information to accomplish that. Among the information needed would be data on weights, engine particulars and propeller characteristics, all reduced to conveniently usable form.

Tentatively, then, it is considered that an effective design procedure would be to proceed somewhat as follows. First the designer should obtain sufficiently complete specifications as to payload, endurance, speed, equipment, and crew to be carried, so that a preliminary estimate of gross weight, and a preliminary arrangement plan can be made. Ratio of length to beam (L/B_A) can then be selected.

In this connection, Figure 10 shows that a low ratio of L/B_A is an attractive prospect with respect to high speed resistance. Experience indicates, however, that a low length-beam ratio can be utilized only for sheltered water boats, and that for seaworthiness a relatively high value is necessary. Thus, for stepless run-abouts the length-beam ratio is about 3.6, while for the motor torpedo boats of World War II the ratio is about 5.6. A logical design procedure, then, is to select the length-beam ratio of a new design from the proportions of previous successful boats of the same type. Figure 16 has been prepared for this purpose. Having selected a value of L/B_A, Figure 8 can now be used to determine a good value for the area coefficient, $A/\nabla^{2/3}$. From the indicated value of $A/\nabla^{2/3}$, and the preliminary gross weight, the hull area A, can be calculated as follows:

$$\nabla = \frac{\Delta}{w}\text{; then, since } w = 64\text{lb/ft}^3 \text{ for sea water,}$$

$$\nabla^{2/3} = \left(\frac{\Delta}{64}\right)^{2/3} = \frac{\Delta^{2/3}}{16}$$

$$\text{Then} \quad A = \left(\frac{A}{\nabla^{2/3}}\right) \times \frac{\Delta^{2/3}}{16}$$

This value should be compared with the required hull area as indicated by the preliminary arrangement plan.

Several considerations are involved in the decision as to the choice (or compromise) between the hull area indicated by the preliminary arrangement plan and the hull area indicated by the area coefficient, $A/\nabla^{2/3}$. If the arrangement-plan area is very much less than the area indicated by Figure 8, then the arrangement plan area will give a heavily loaded hull, and conversely, if the arrangement-plan area is very much greater than the area indicated by Figure 8, then the arrangement plan area will give a lightly loaded hull. It should be pointed out that the "optimum" line of Figure 8, from the nature of the development is of limited significance. Only one type of hull lines and one LCG location are represented in this graph. Furthermore, Figures 9 and 11 show that the optimum value of area coefficient (value for minimum average resistance) is a function of top speed as well as L/B_A, and that a relatively low speed boat would have a low average resistance with a high value of area coefficient (light loading), while a high speed boat would have low average resistance with a more economical arrangement plan and a low value of area coefficient (heavy loading). Accordingly it would be desirable to recheck the hull size selected, after the lines have been completed, by making a model test to show the effects on performance of increasing or decreasing the hull size. The procedure would be to test a model over a wide range of displacements, calculate the resistance for the full-size design displacement from each of the tests, and compare the results in a graph of R/Δ versus $F_{n\nabla}$. The scale ratio between model and full size boat will be different for each model displacement, and can readily be calculated as follows:

$$\lambda = \sqrt[3]{\frac{\Delta_s}{\Delta_m \times SW/FW}}$$

For an accurate analysis the data should be corrected for the difference between the frictional resistance coefficients of model and of full-size boat. The method of making this correction for planing hulls is given in Reference 3. Figure 17 shows the results of a model test calculated and plotted in the proposed manner. The model tested was a planing hull of normal form, and the tests were originally made to determine the resistance of a given size of hull for three different full-size displacements. For the present purpose, however, the three tests are considered to represent tests of a particular set of lines at three different scale ratios, each test corresponding to the same full size displacement (100,000 lb). Considered in this fashion, the following interpretation may be put upon the data shown in Figure 17: A 100,000 lb boat built to the lines tested and having a length, L = 58.0', and a mean beam, B_A = 11.4', will have the resistance given by curve A. If L = 63.1, and B_A = 12.4' the resistance will be that given by curve B; and if L = 70.6', and B_A = 13.9', the resistance will be that given by curve C. It is clear from this figure that if the anticipated top speed of the boat under consideration corresponds to a value of $F_{n\nabla}$ of 3.5 or less, then the best boat of the three represented is that corresponding to curve C. If the top speed of the boat corresponds to a value of $F_{n\nabla}$ of 4.0 or greater, then a reduction in top speed resistance would result from selecting boat dimensions corresponding to curves A or B, instead of those corresponding to curve C; the curves also show, however, that this selection would be accompanied by substantial resistance penalties in the low and cruising speed ranges.

After selecting a value of $A/\nabla^{2/3}$ (tentative, or otherwise), the next step in the envisioned design procedure is for the designer to select suitable non-dimensional curves defining the chine line in plan view, the deadrise variation, and the longitudinal curvature of the mean buttock. These curves are shown, for the particular boats, in each of the Taylor Model Basin's design data sheets. It is anticipated that when a number of these sheets have been made available the designer will be able to select the form characteristic curves for a new design with the confidence of obtaining superior performance.

The form characteristics presented in the design data sheets have all been derived with a view to the reverse process, i.e. with the idea that the designer should be able to construct the complete hull lines for a new design from the form characteristics selected.

When the values of L/B_A and A have been obtained the values of L and B_A can be calculated as follows:

Since $B_A = \frac{A}{L}$, then $L^2 = A \times L/B_A$. From this L can be calculated, and then, readily B_A (equals A/L).

The form characteristic curves of the design data sheets are given in terms of L and B_A, so that when the values of these two dimensions have been determined, and the form characteristic curves for the new design have been selected, the new body plan, and subsequently the complete lines can be constructed. A description of the method of constructing one section will indicate the essential features of the process. The process of constructing a section at 70 per cent of L forward of the stern is indicated in Figure 18. The centerline is drawn and then a horizontal line representing that waterline plane which is tangent to the mean buttock at the stern. This plane is the primary horizontal reference plane in the proposed design process. A vertical line indicating the buttock plane at $B_A/4$ outboard of the centerline is then drawn, and a baseline is drawn at any convenient location. Then, from the selected mean buttock curve the height at 70 per cent L is read (in per cent of L); this number is multiplied by L and the resulting dimension is plotted on the line representing the mean buttock plane, measuring up from the horizontal reference plane. A straight line is then drawn through the point thus obtained at the deadrise angle for 70 per cent L, as indicated by the selected curve of deadrise variation. From the selected curve of the chine in plan view the dimensionless ratio B/B_A for the 70 per cent point can be determined, and multiplying this by B_A and dividing by 2 gives the half breadth of the chine at 70 per cent L. This dimension is then indicated on the drawing. The type of section selected is then sketched in, using the lines previously established for guidance. The other sections of the body plan are developed in similar fashion and the lines faired in all three views in the conventional manner. It is believed that by following such a design procedure it will be possible to incorporate the desirable features of previous superior hull forms in a new design.

The waterline at which the boat will float can be approximated by means of the draft coefficient data presented in the design data sheets. The draft forward, for example, can be estimated by determining the draft coefficient forward for a previous similar design at values of $A/\nabla^{2/3}$ and LCG location corresponding to those for the new design. Multiplying the draft coefficient value by ∇/A gives an approximation to the draft at 100 per cent L as measured up from the horizontal reference plane. The draft at the stern is determined in similar fashion.

ANALYSIS OF FULL SCALE DATA

Resistance data from model tests are useful for determining the relative efficiencies of different designs and also for estimating the ehp requirements of new designs. The information which the designer ultimately needs, however, is the required engine brake horsepower, bhp. Some data are available on the weights, speeds and brake horsepowers of actual full size boats. These data can be reduced as follows to a dimensionless form similar to that in which resistance data are presented:

$$\text{bhp} \cdot \frac{550}{\Delta \cdot V} = \frac{R \cdot v}{550} \cdot \frac{\text{bhp}}{\text{ehp}} \cdot \frac{550}{\Delta \cdot v} = \frac{R}{\Delta} \cdot \frac{\text{bhp}}{\text{ehp}}$$

Brake horsepower, weight and speed data for various types of racing boats are given in Reference 4. The data from this reference on small vee-bottom motor boats are plotted in dimensionless form in Figure 19. This figure can be used to make rough estimates of the bhp requirements of new designs. It can be readily seen that since differences in propellers, in hull form, and in hull loading are not considered here, the answers obtained will only be very approximate.

Suppose that it is desired to estimate the bhp required to propel a 5,000 lb boat at a speed of 25 knots. Then from Figure 20 the corresponding value of F_{n_∇} is 3.6. Entering Figure 19 with this value we obtain a value of $\frac{R}{\Delta} \cdot \frac{\text{bhp}}{\text{ehp}}$ of 0.265. We then obtain bhp as follows:

$$bhp = \frac{R}{\Delta} \cdot \frac{bhp}{ehp} \cdot \frac{\Delta \cdot v}{550}$$

$$bhp = 0.265 \cdot \frac{5000 \cdot 25 \cdot 1.689}{550} = 102$$

In Reference 5 a large quantity of data on pre-war American and foreign motor torpedo boats were compiled. These data are plotted in Figure 21 in the form of $\frac{R}{\Delta} \cdot \frac{bhp}{ehp}$ versus $F_{n\nabla}$. The data on German boats have been omitted, because of the bad scatter. Data on stepped boats, and on unconventional forms, have also been omitted. A line has been drawn through the intermediate region of the remaining points. This line is considered to be of some value as a criterion of good performance, and for roughly estimating the bhp requirements of a projected design.

If the published information on the performance of full scale boats also included the center of gravity locations and values of the average breadths and average dead rises in the planing condition, the total information would be extremely valuable. The resistance of the boat in the planing condition could then be calculated from available planing surface data, and from this and the engine bhp data, values of propulsive coefficient could be obtained. Such data are particularly necessary and desirable because it has not been possible heretofore in this country to self-propel models of high-powered planing craft and make torque and thrust measurements.

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2. Savitsky, Daniel, and Neidinger, Joseph W., "Wetted Area and Center of Pressure of Planing Surfaces at Very Low Speed Coefficients", Stevens Institute of Technology, Experimental Towing Tank, Report No. 493, (July 1954), Sherman M. Fairchild Publication Fund Paper No. FF-11, Institute of the Aeronautical Sciences, New York.

3. Murray, Allan B., "The Hydrodynamics of Planing Hulls", Transactions of The Society of Naval Architects and Marine Engineers, Vol. 58 (1950), pp 658-692.

4. Nicolson, Daniel, "High Speed Motor Craft", North-East Coast Institute of Engineers and Shipbuilders, Transactions, Vol. LIV (1937-1938).

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3. Phillips-Birt, Douglas, "Motor Yacht and Boat Design", Distributed in U. S. A. by John de Graff, Inc. (1953).

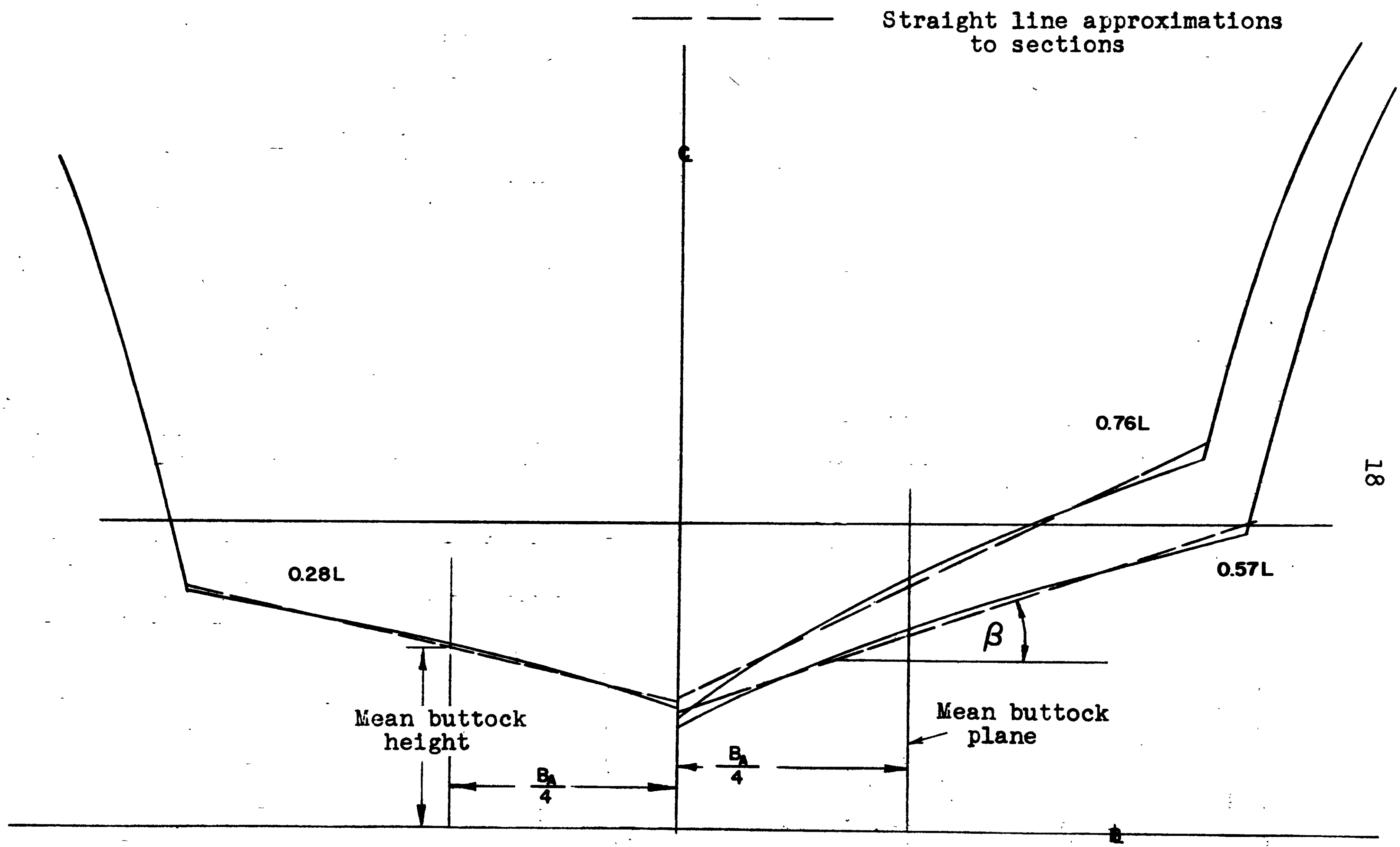


Figure 1 - Typical Planing Boat Body Plan with Straight Line Approximations to Sections.

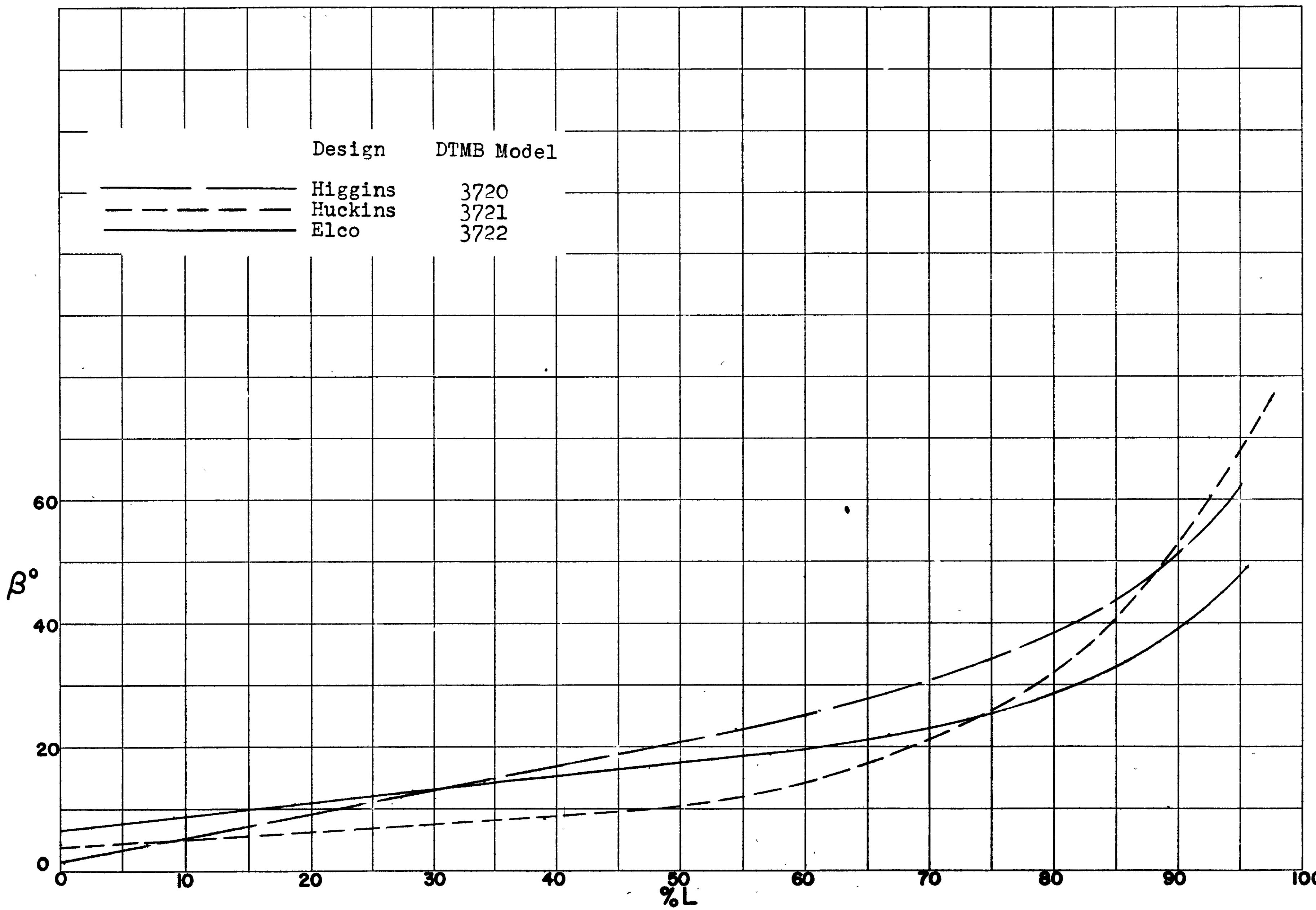


Figure 2. Curves of Deadrise Angle vs Boat Length for Three PT Boats of World War II

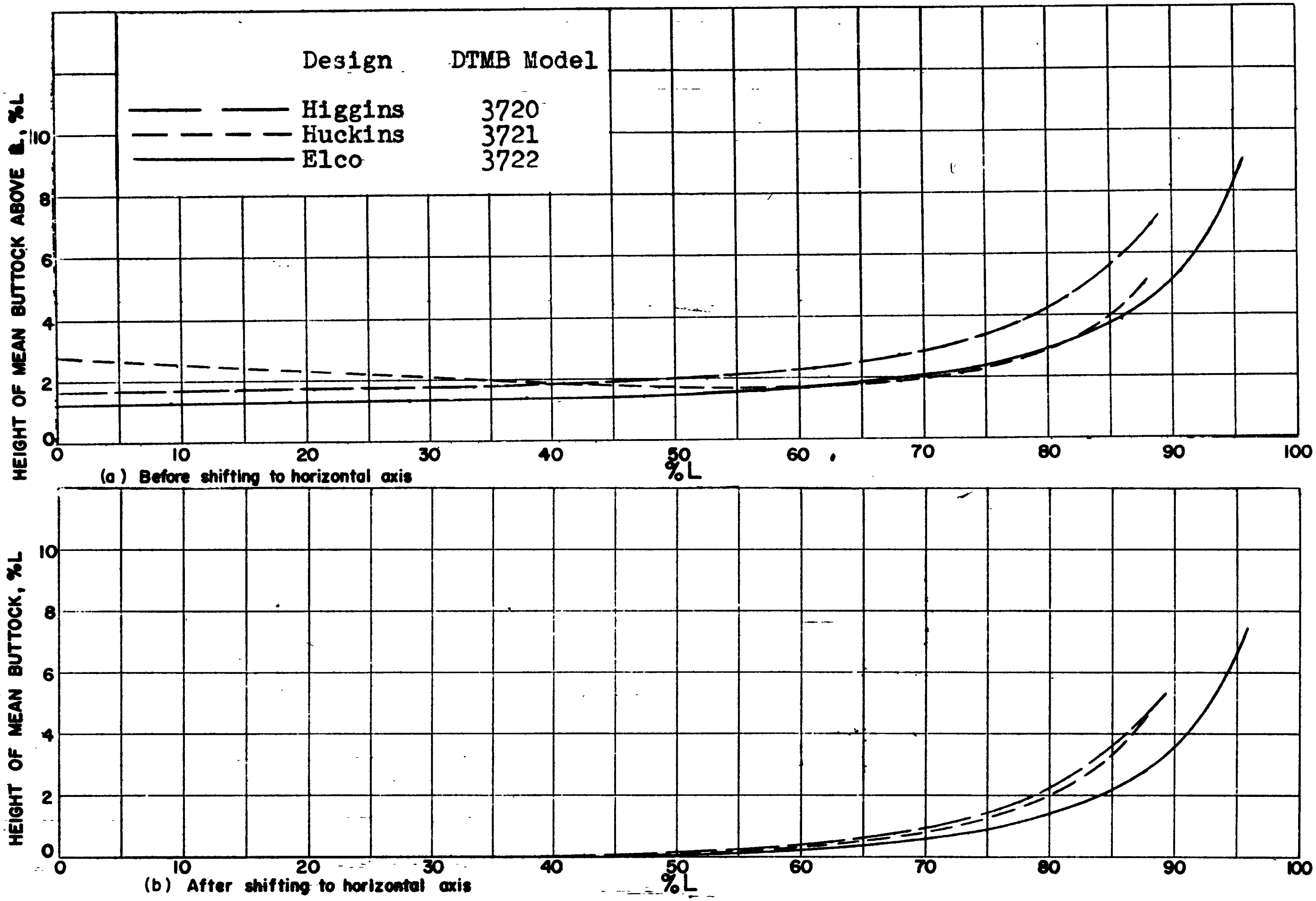
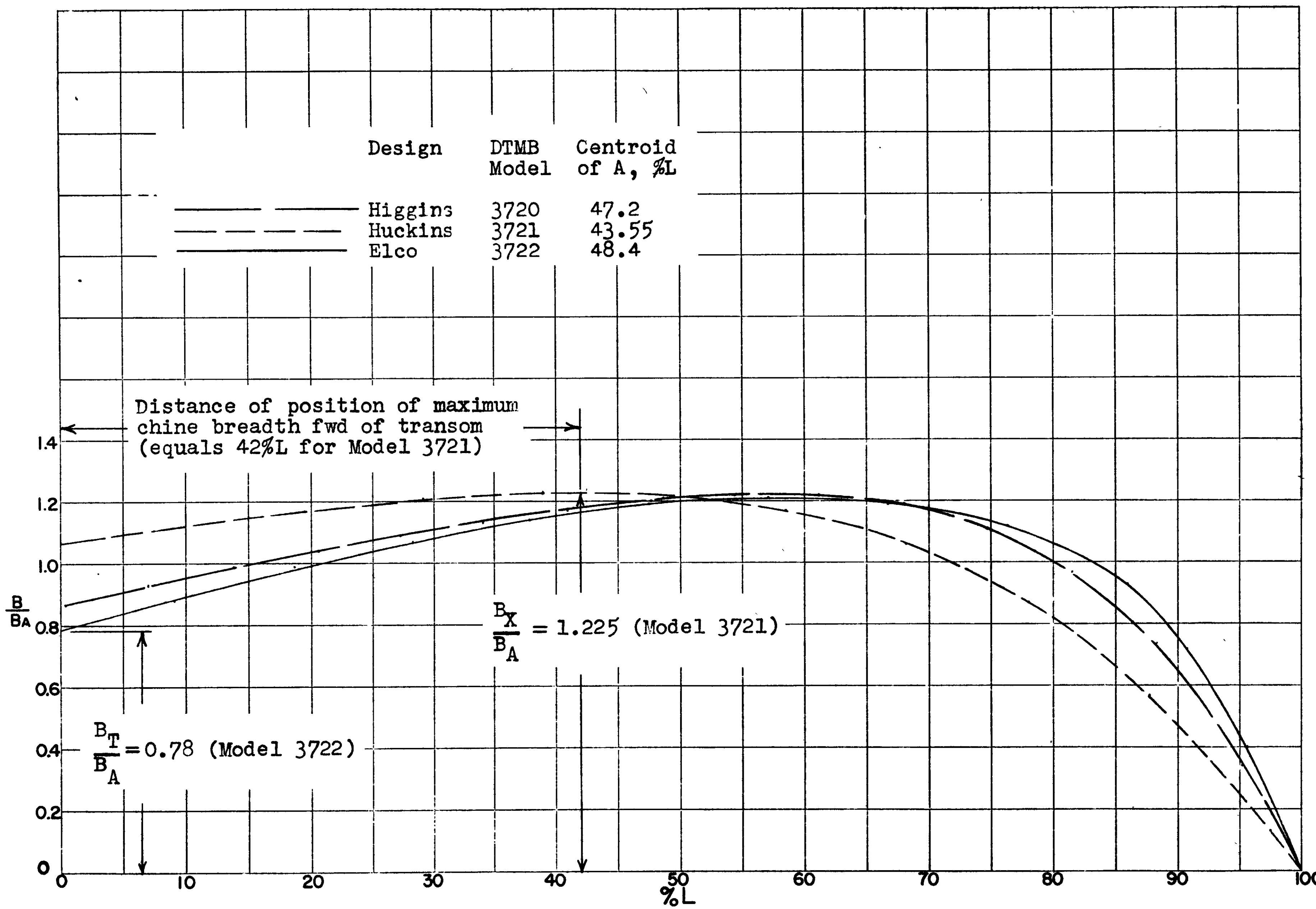


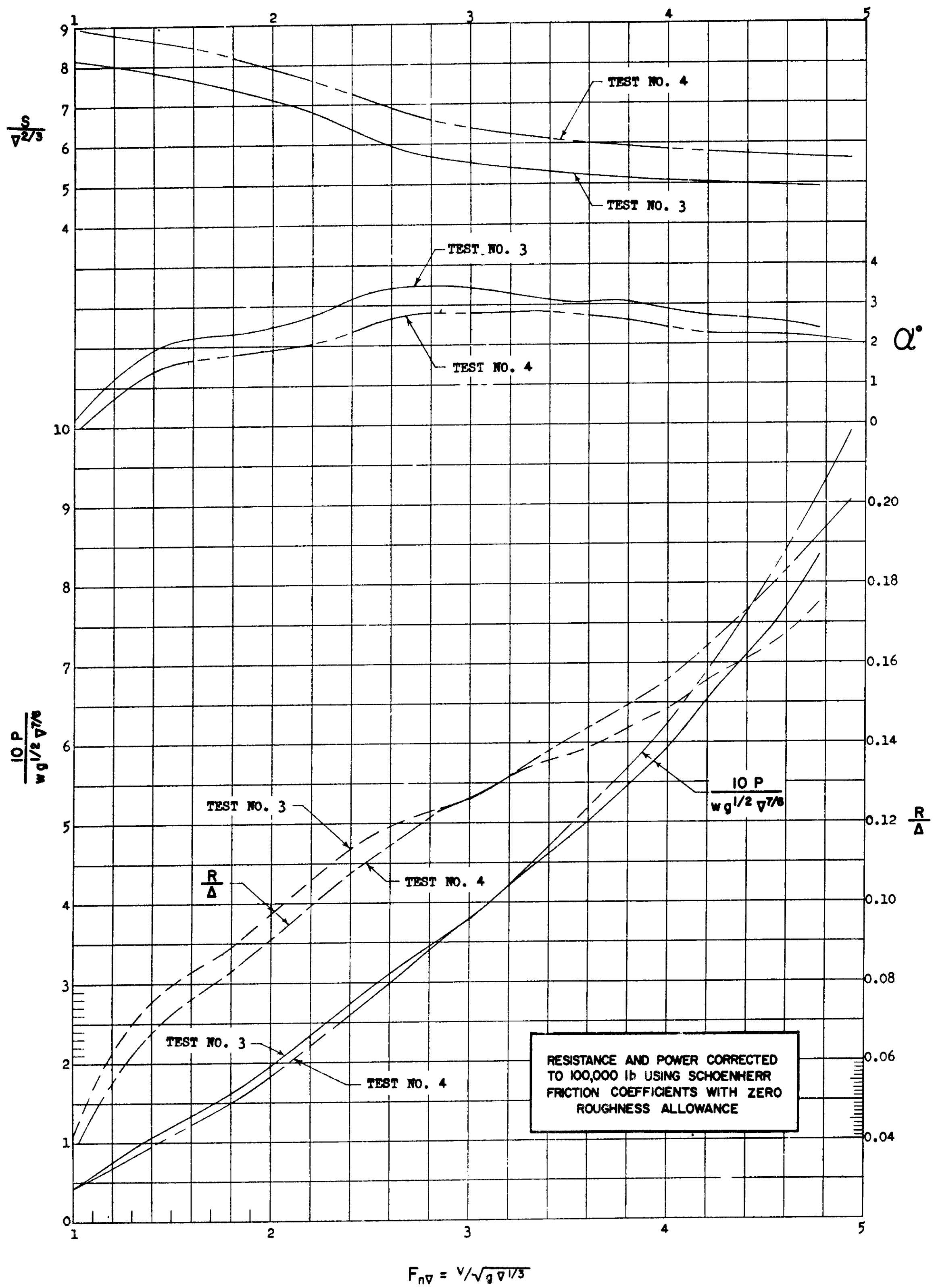
Figure 3 - Mean Buttock Curves for Three PT Boats of World War II.



Design
DTMB Model
Centroid of A, %L
Higgins 3720 47.2
Huckins 3721 43.55
Elco 3722 48.4
Distance of position of maximum chine breadth fwd of transom (equals 42%L for Model 3721)
$\frac{B_X}{B_A}$ = 1.225 (Model 3721)
$\frac{B_T}{B_A}$ = 0.78 (Model 3722)
$\frac{B}{B_A}$
%L
0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
10
20
30
40
50
60
70
80
90
100

DTMB MODEL 3722

IV PERFORMANCE CHARACTERISTICS



PLANING BOAT DESIGN DATA SHEET
DAVID W. TAYLOR MODEL BASIN

JUNE 1955

DTMB MODEL 3722 | 1/9 SCALE | 80 FT. ELCO PT BOAT

REMARKS:

Relatively high $\frac{L}{B_A}$ ratio and narrow transom give low resistance characteristics at Fn_∇ < 3. Average resistance characteristics at Fn_∇ > 3.

MODEL DATA

BASIN HIGH SPEED BASIN
BASIN SIZE 2968'x21'x(10'and 16')
DATE OF TEST 8 FEB 55
WATER TEMP. 61°F
APPENDAGES SPRAY STRIPS
TURBULENCE STIM. NONE
MODEL MATERIAL WOOD
MODEL FINISH PAINT

TEST NO. 3

V_M	R_M	WL_K	WL_C	WL_{SP}
3.89	6.97	8.22	7.50	8.18
4.87	11.12	8.10	6.95	7.84
5.85	13.46	8.00	6.48	7.53
6.81	15.10	7.95	6.19	7.30
7.77	16.89	7.86	5.91	7.08
8.72	18.83	7.75	5.58	6.60
9.67	20.49	7.53	5.15	5.82
10.69	21.69	7.39	4.82	5.40
11.67	22.76	7.22	4.60	5.72
12.60	24.24	7.19	4.38	4.95
13.60	25.43	7.12	4.20	4.80
14.59	26.84	7.10	4.02	4.67
15.57	28.38	7.10	3.89	4.53
16.53	30.39	7.13	3.73	4.42
17.52	32.10	7.16	3.65	4.40
18.51	34.40	7.20	3.53	4.30

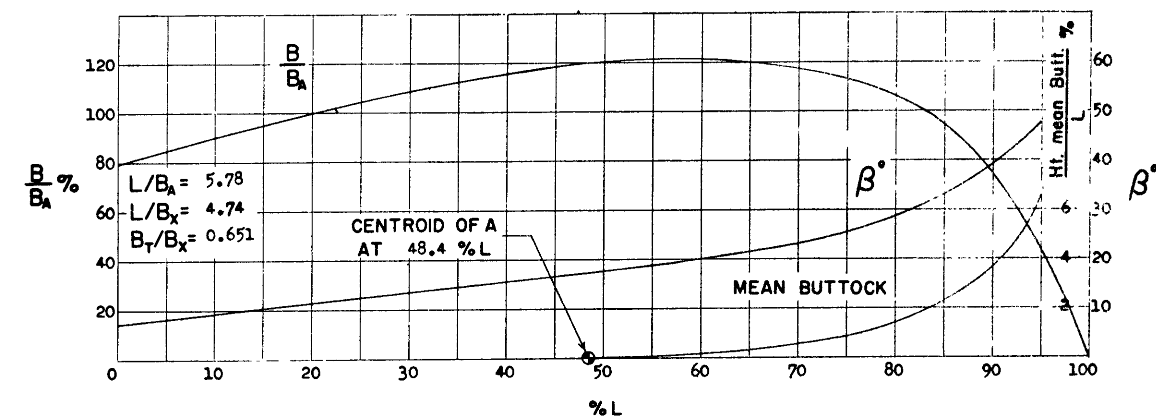
TEST NO. 4

V_M	R_M	WL_K	WL_C	WL_{SP}
3.88	5.58	8.20	7.20	8.02
4.82	8.49	8.09	6.72	7.80
5.82	10.55	8.00	6.22	7.45
6.79	12.08	7.92	5.98	7.22
7.75	13.78	7.90	5.70	7.04
8.72	15.49	7.80	5.41	6.64
9.68	17.02	7.63	5.02	6.00
10.70	18.61	7.50		5.40
11.67	19.75	7.40	4.42	5.10
12.59	21.25	7.35	4.22	4.90
13.60	22.73	7.29	4.02	4.70
14.60	24.32	7.24	3.83	4.60
15.60	26.22	7.27	3.72	4.40
16.56	28.28	7.28	3.60	4.40
17.49	30.45	7.30	3.48	4.30
18.51	33.02	7.30		4.35

I TEST CONDITIONS

TEST NO.	Δ_M lb	Δ_S lb	$\frac{A}{\nabla^{2/3}}$	$\frac{L}{\nabla^{1/3}}$	MAXIMUM STABLE $F_{n\nabla}$	τ_0	α_0	DRAFT COEFF FWD.	DRAFT COEFF AFT.	CG AFT OF CENTROID OF A	LCG %L
1	128.7	94,500	7.79	6.70	--------	1.60° x BOW	- 1.30°	1.795	0.762	2.1%L	46.3
2	142.9	105,000	7.25	6.47	--------	0.90° x BOW	- 0.60°	1.380	0.994	5.1%L	43.3
3	148.0	110,960	7.00	6.36	--------	0.65° x BOW	- 0.35°	1.444	1.171	6.0%L	42.4
4	121.1	90,790	8.00	6.80	--------	0.75° x BOW	- 0.45°	1.409	0.982	6.0%L	42.4

II FORM CHARACTERISTICS



III LINES

MODEL

A = 12.466 sq ft
L = 8.488 ft
B_A = 1.469 ft

FULL SIZE

A = 1009.8 sq ft
L = 76.39 ft
B_A = 13.22 ft

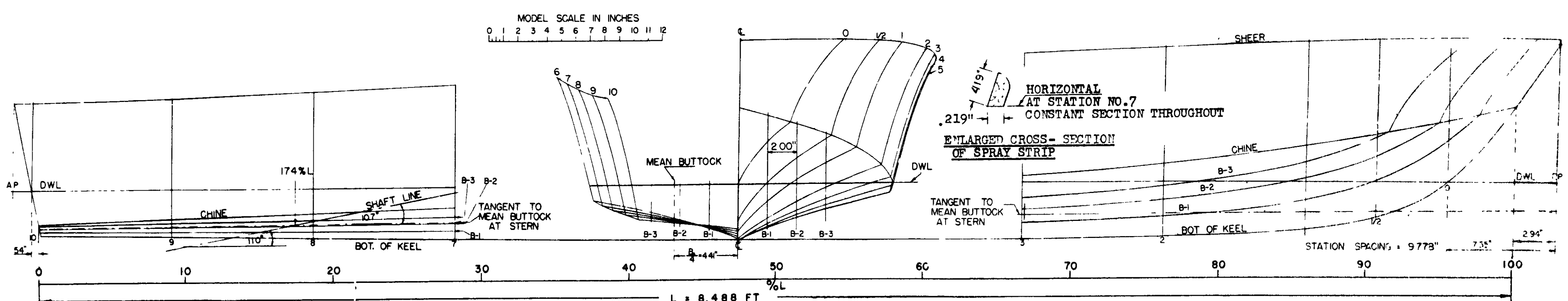


Figure 5 - Typical Design Data Sheet.

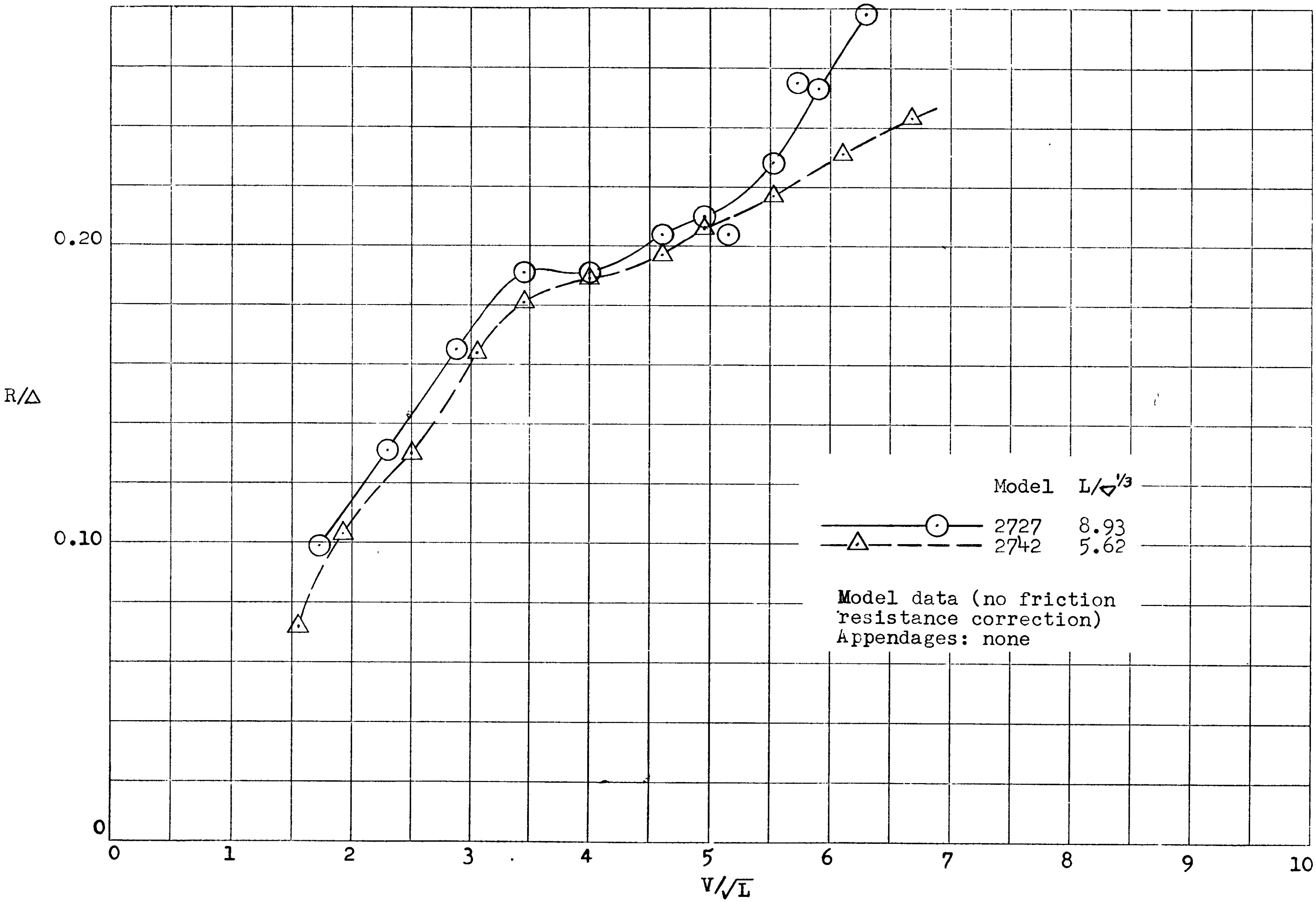


Figure 6 - Resistances of Two Models from EMB Series 50, Compared by the Method in General Use.

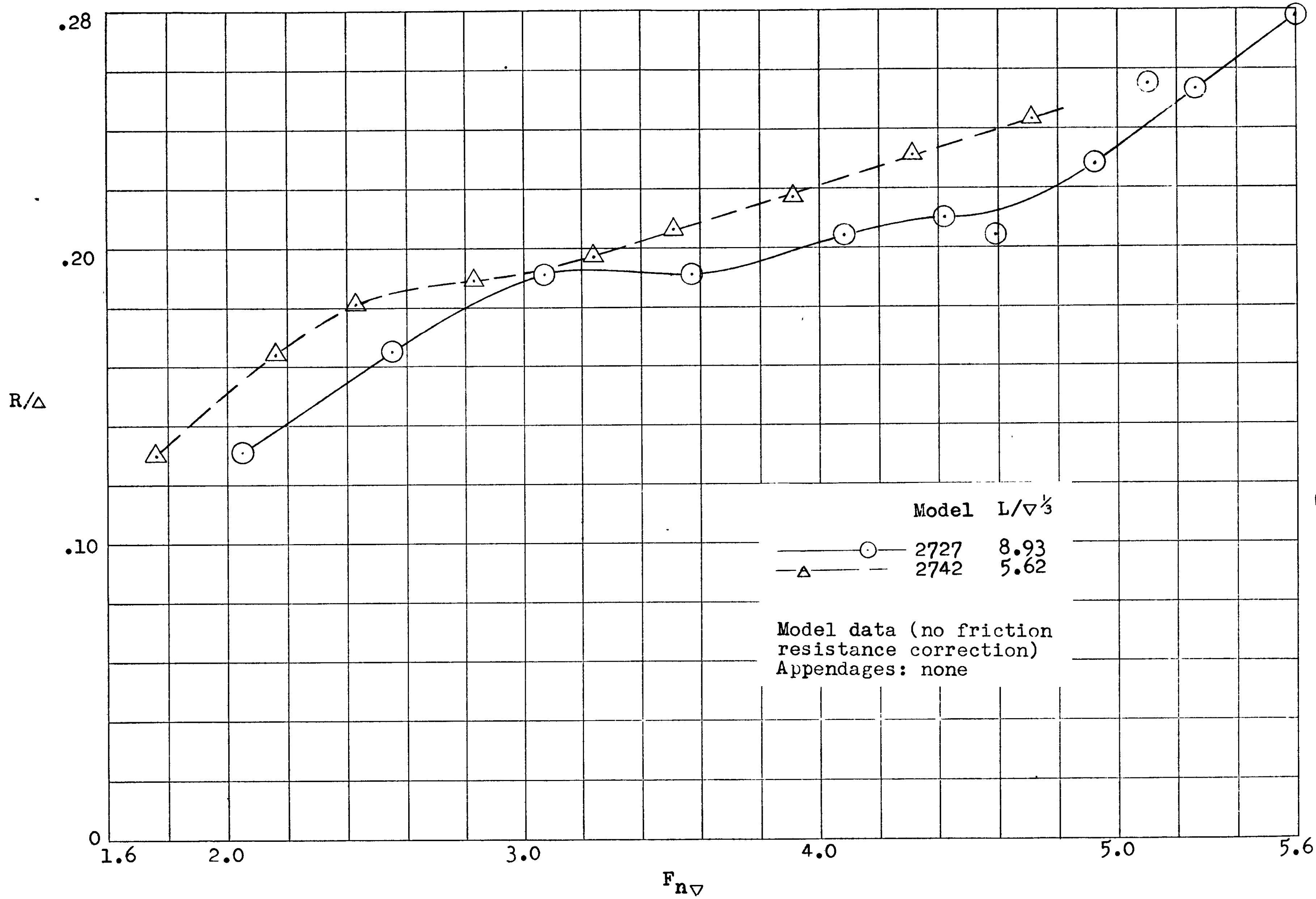


Figure 7 - Resistances of Two Models from EMB Series 50, Compared by a Correct Method.

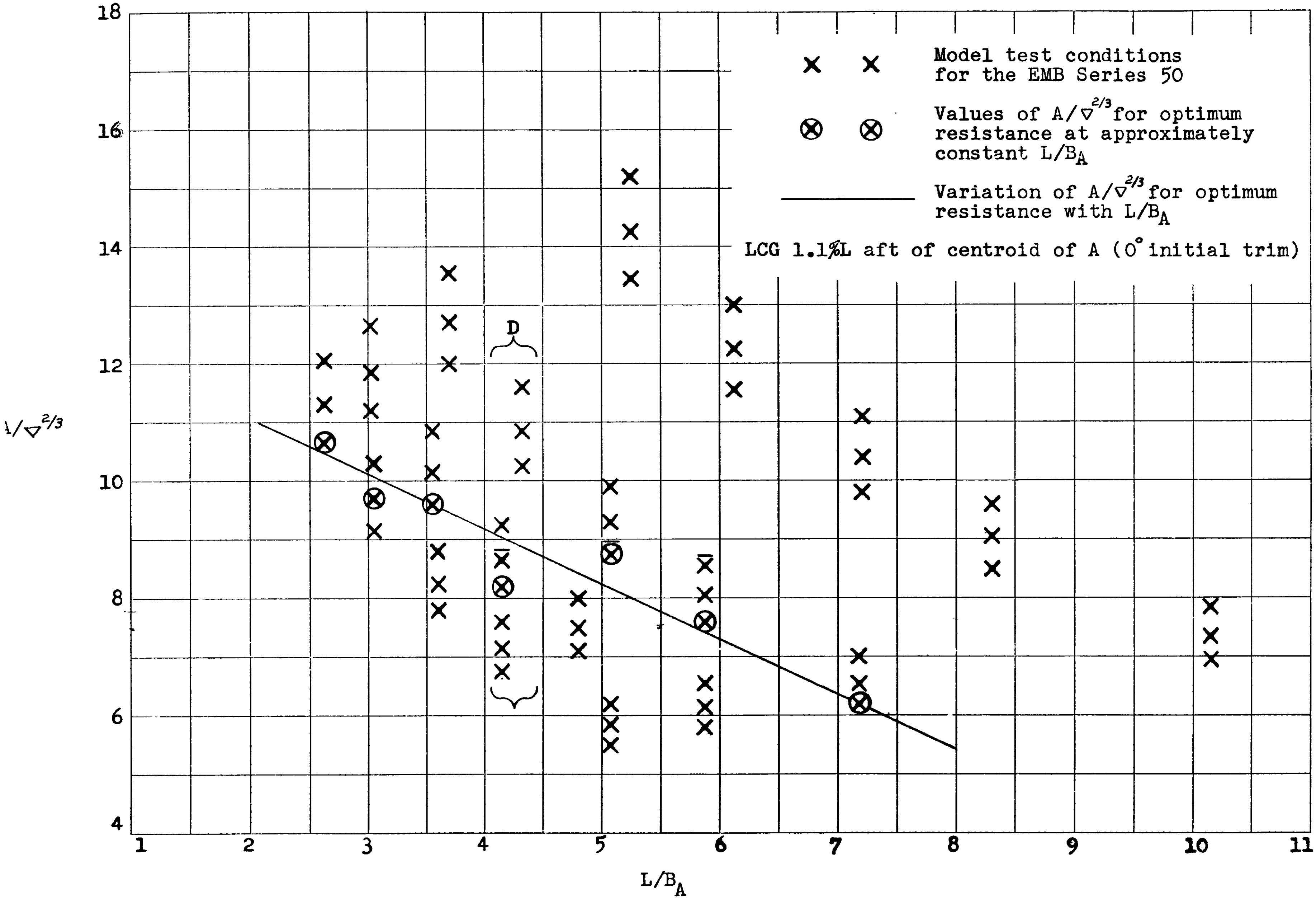


Figure 8 - Variation of Area Coefficient for Optimum Resistance with Length/Beam Ratio, from the Data of the EMB Series 50

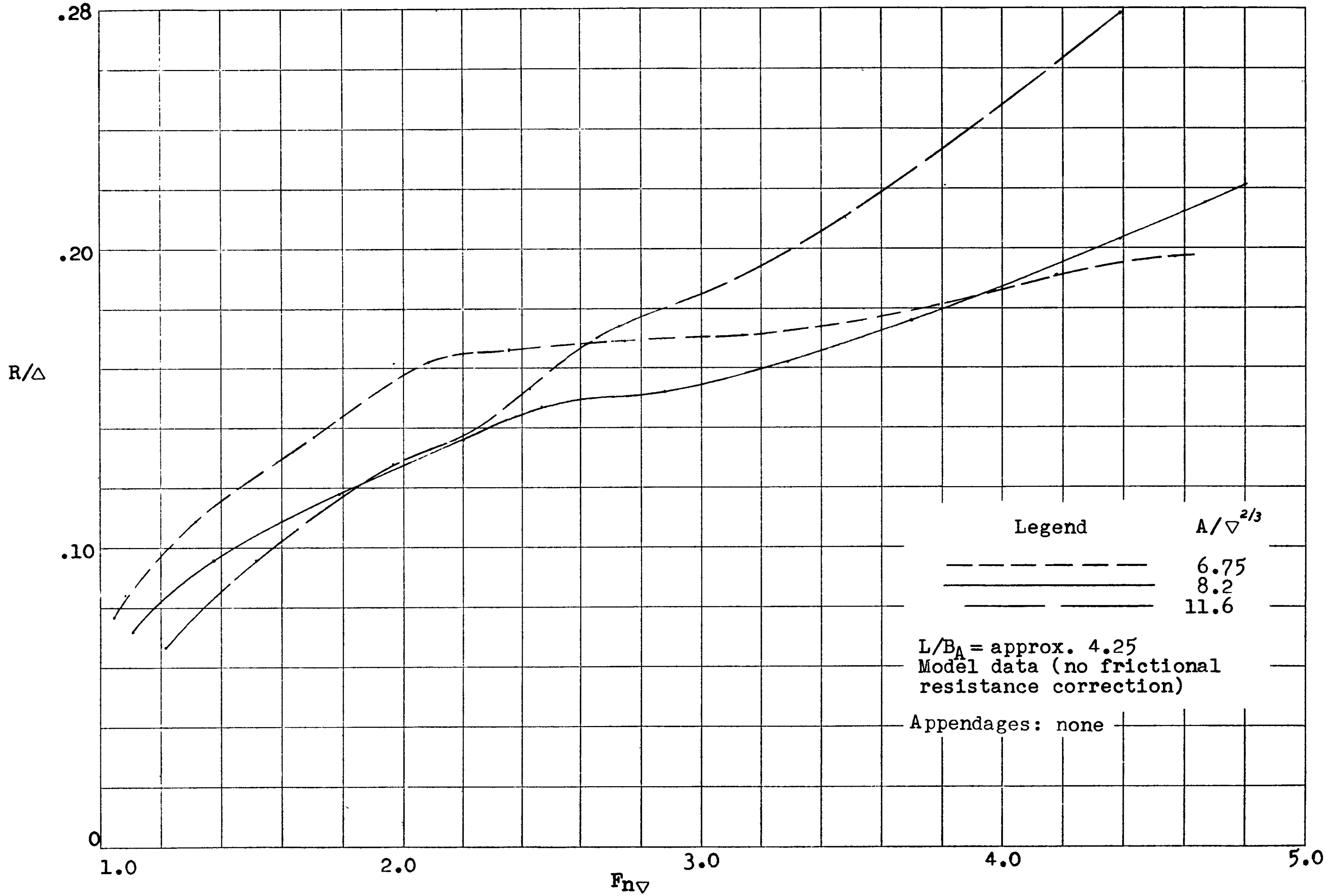


Figure 9 - Effect of Area Coefficient on Resistance, with Constant Length/Beam Ratio.

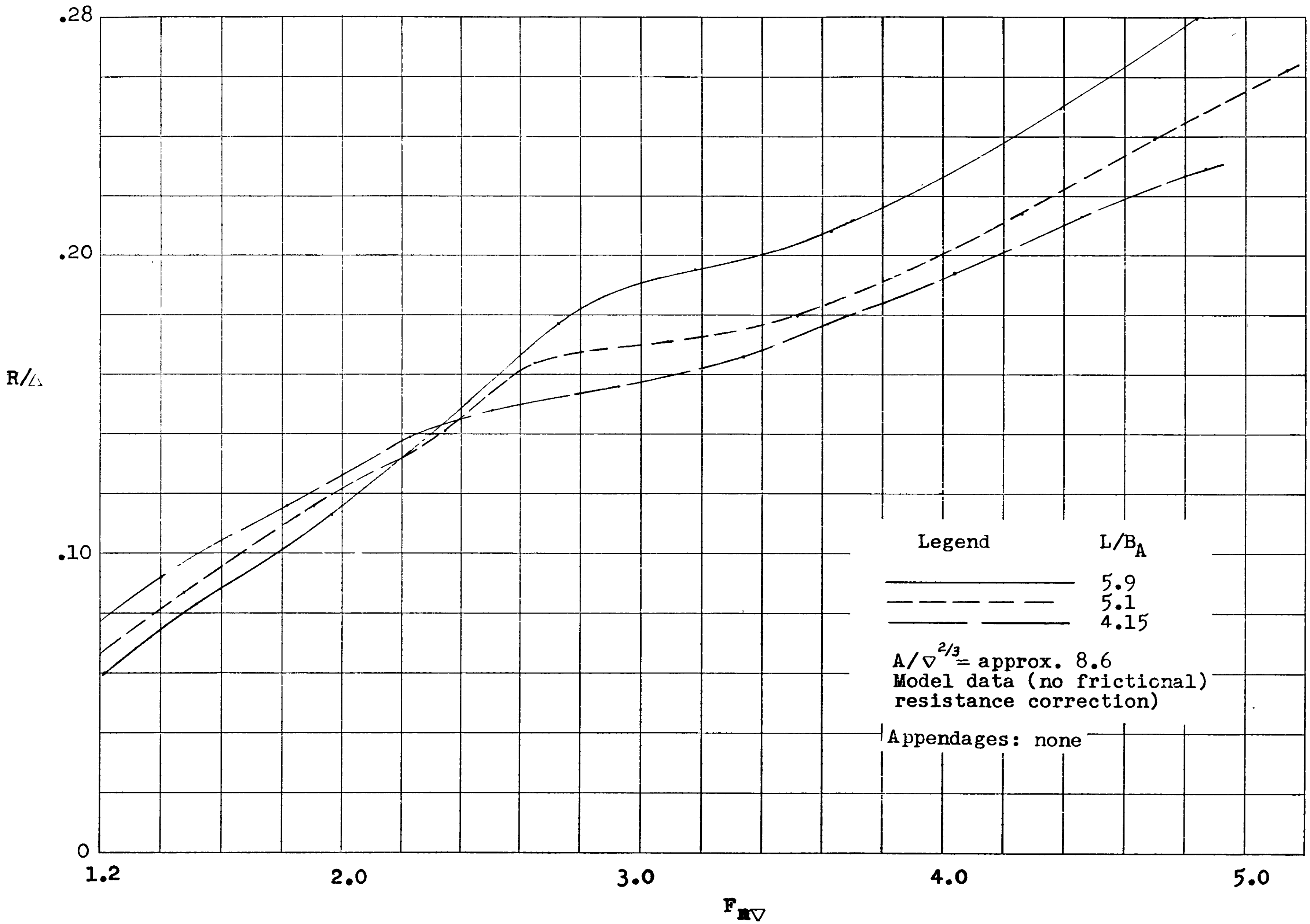


Figure 10 - Effect of Length/Beam Ratio on Resistance, with Constant Area Coefficient.

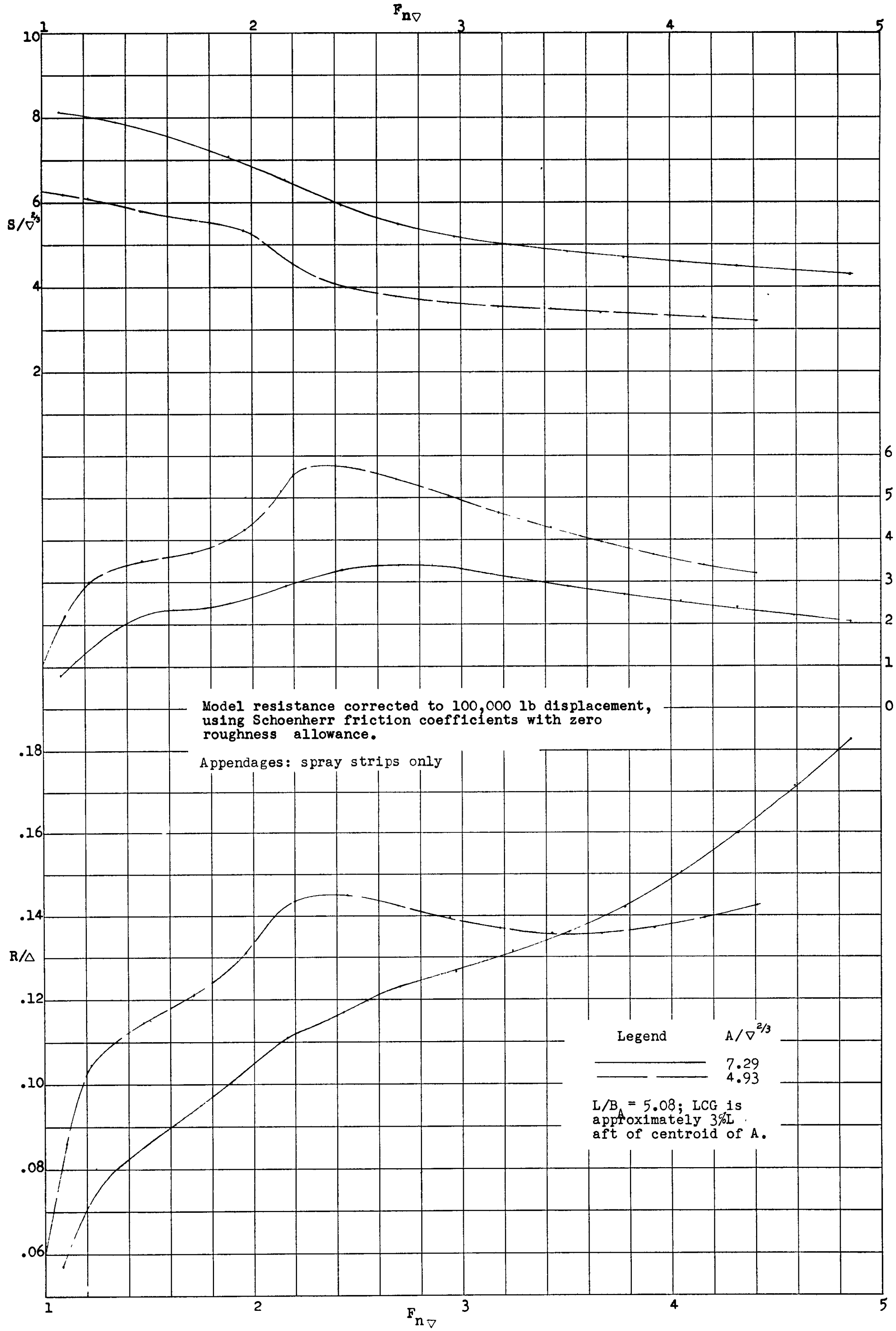


Figure 11 - Effects on the Performance of a Typical Planing Boat Hull Form, of a Variation in Area Coefficient.

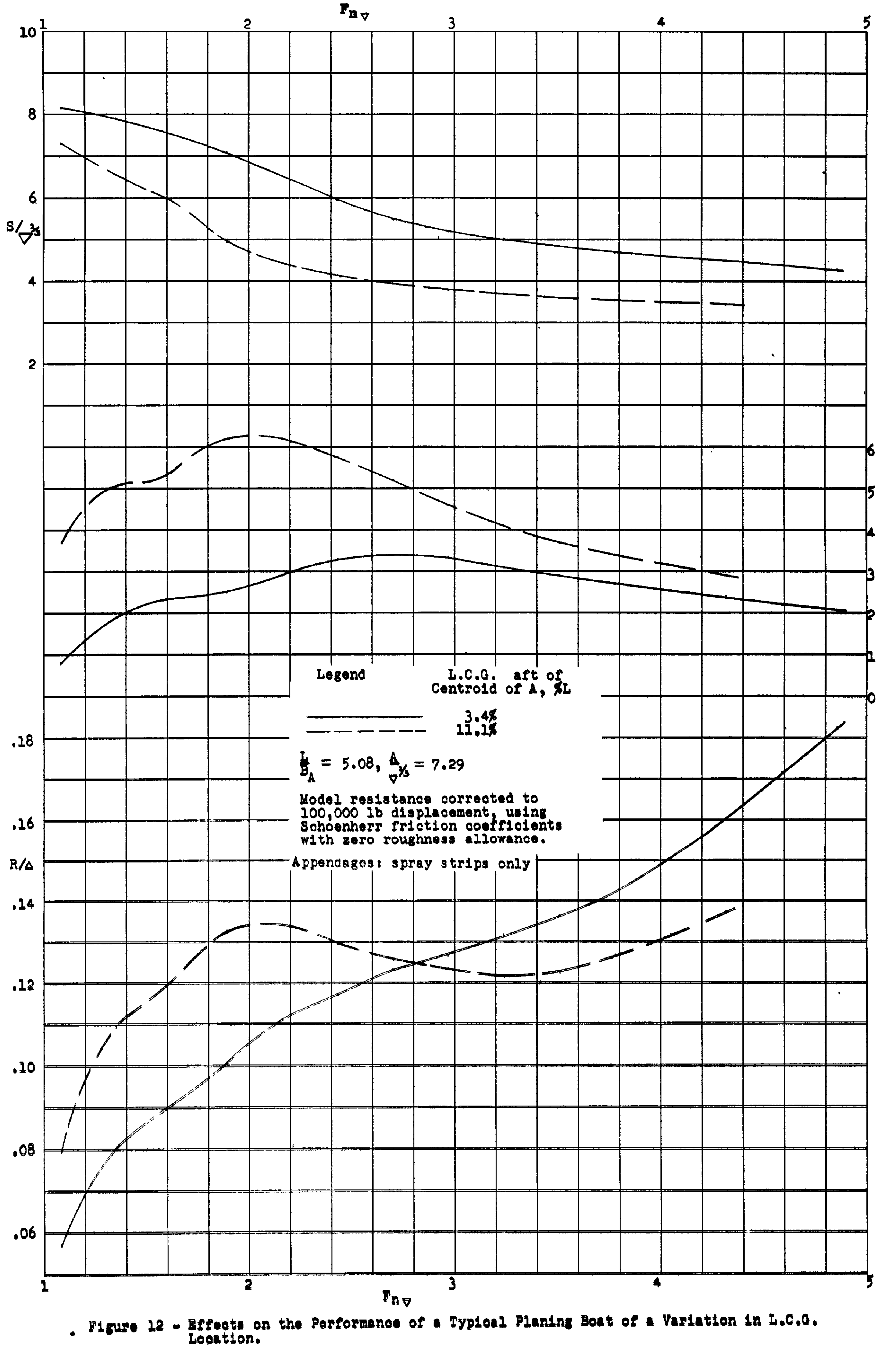


Figure 12 - Effects on the Performance of a Typical Planing Boat of a Variation in L.C.G. Location.

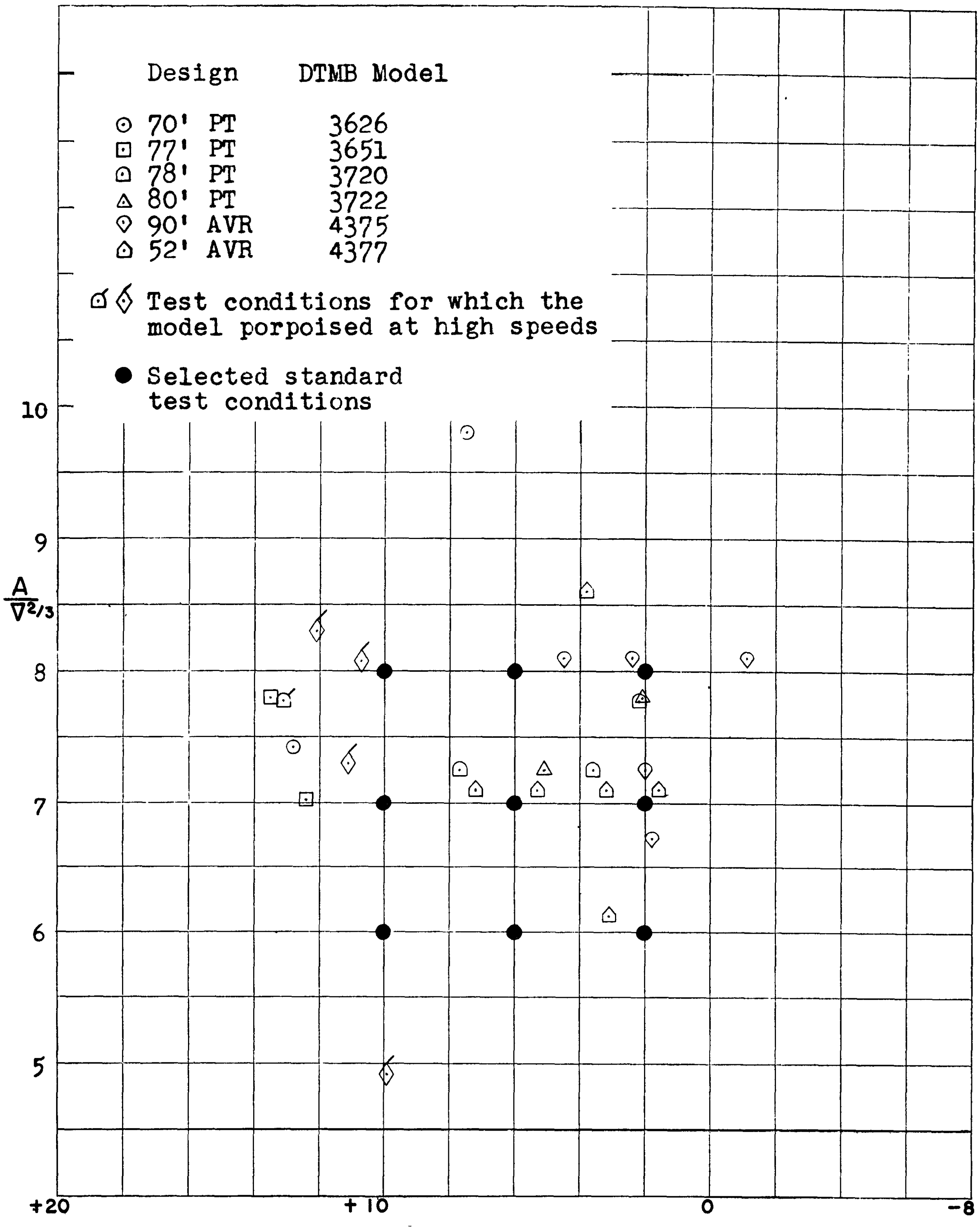


Figure 13 - Area Coefficients & LCG Locations Corresponding to Model Tests of Typical PT & Aircraft Rescue Boats.

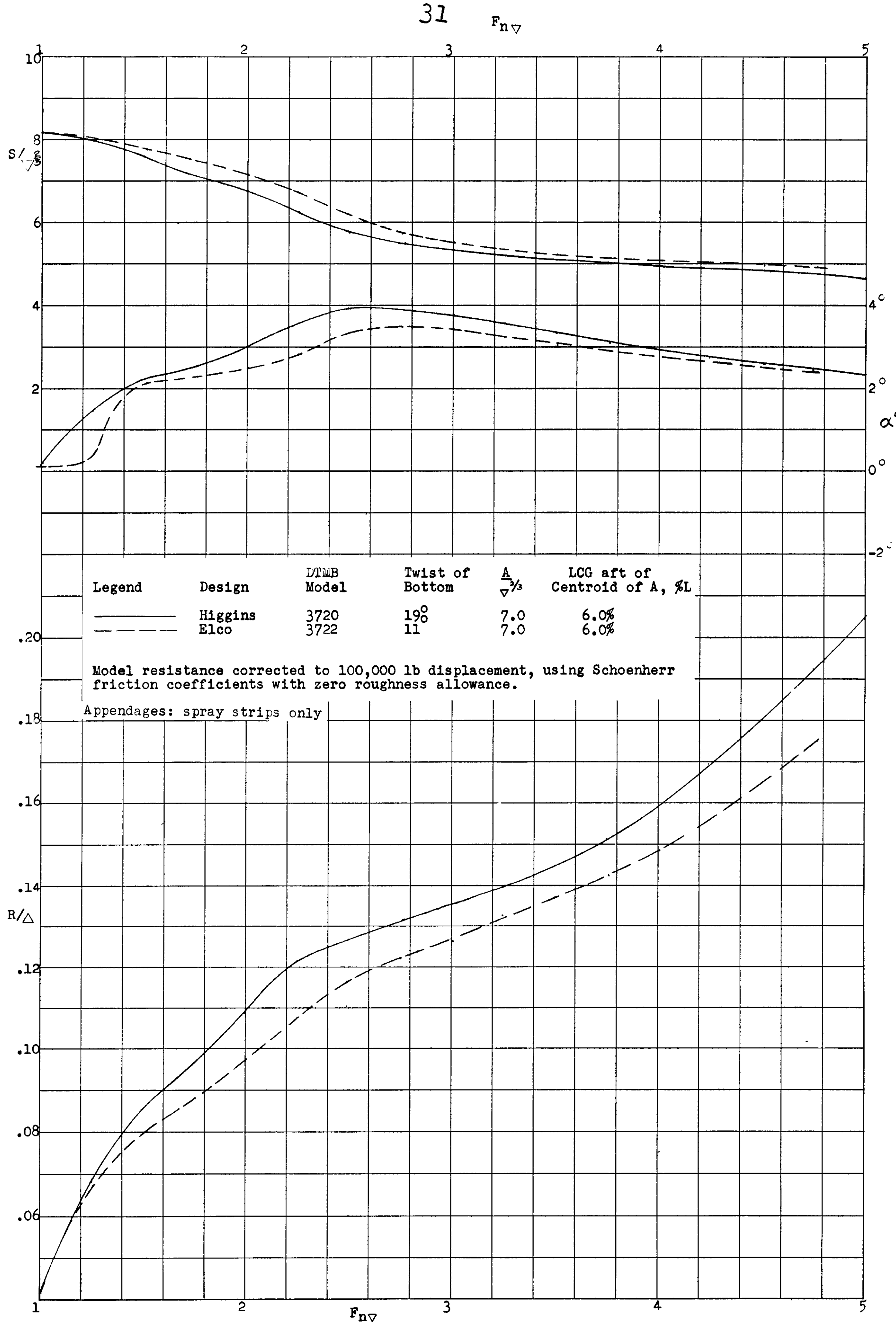


Figure 14 - Effects on Planing Boat Performance of Different Amounts of Twist in the Hull Bottom.

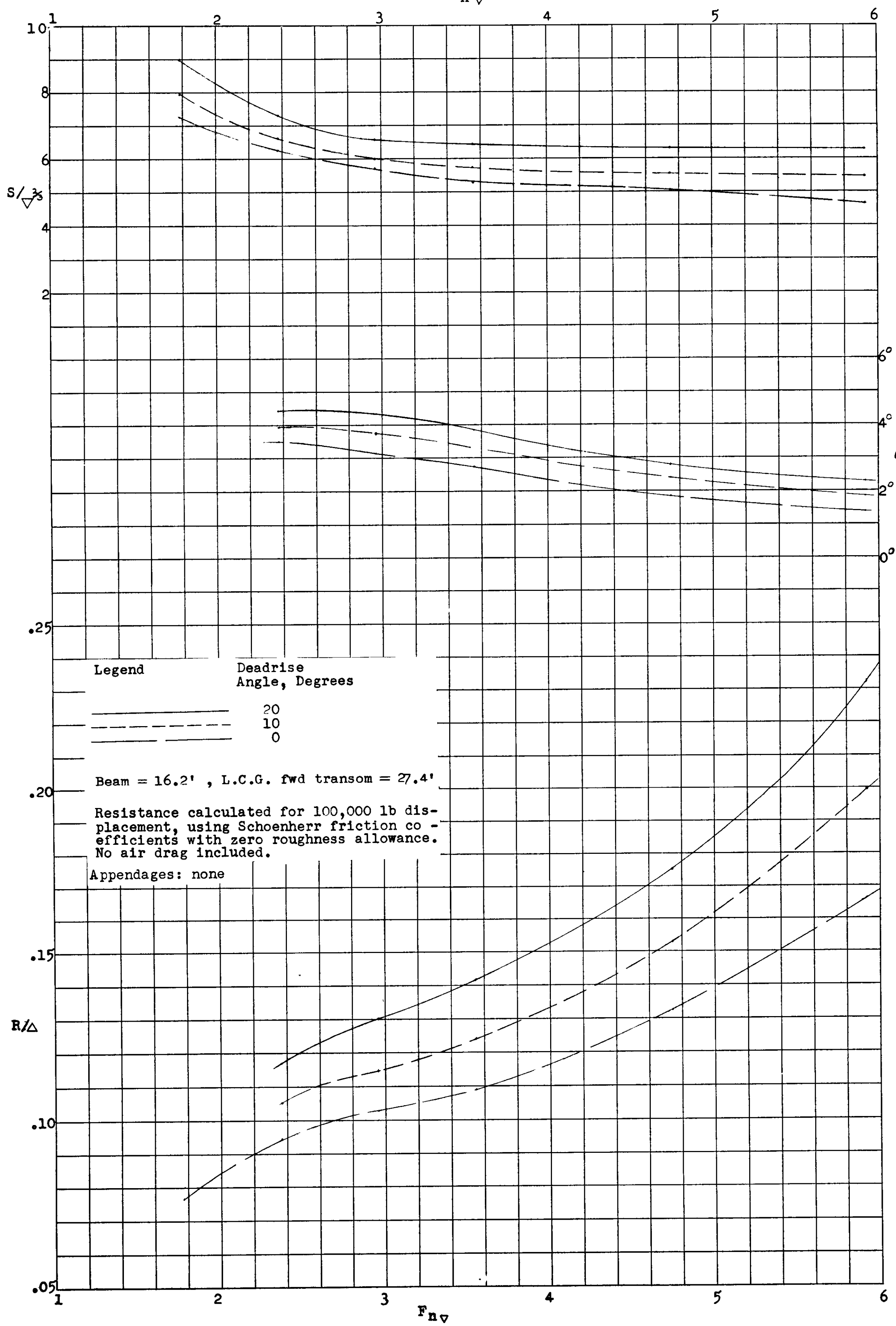


Figure 15 - Effects on Planing Performance of Variation in the Deadrise Angle of the Hull Bottom, from Planing Surface Data.

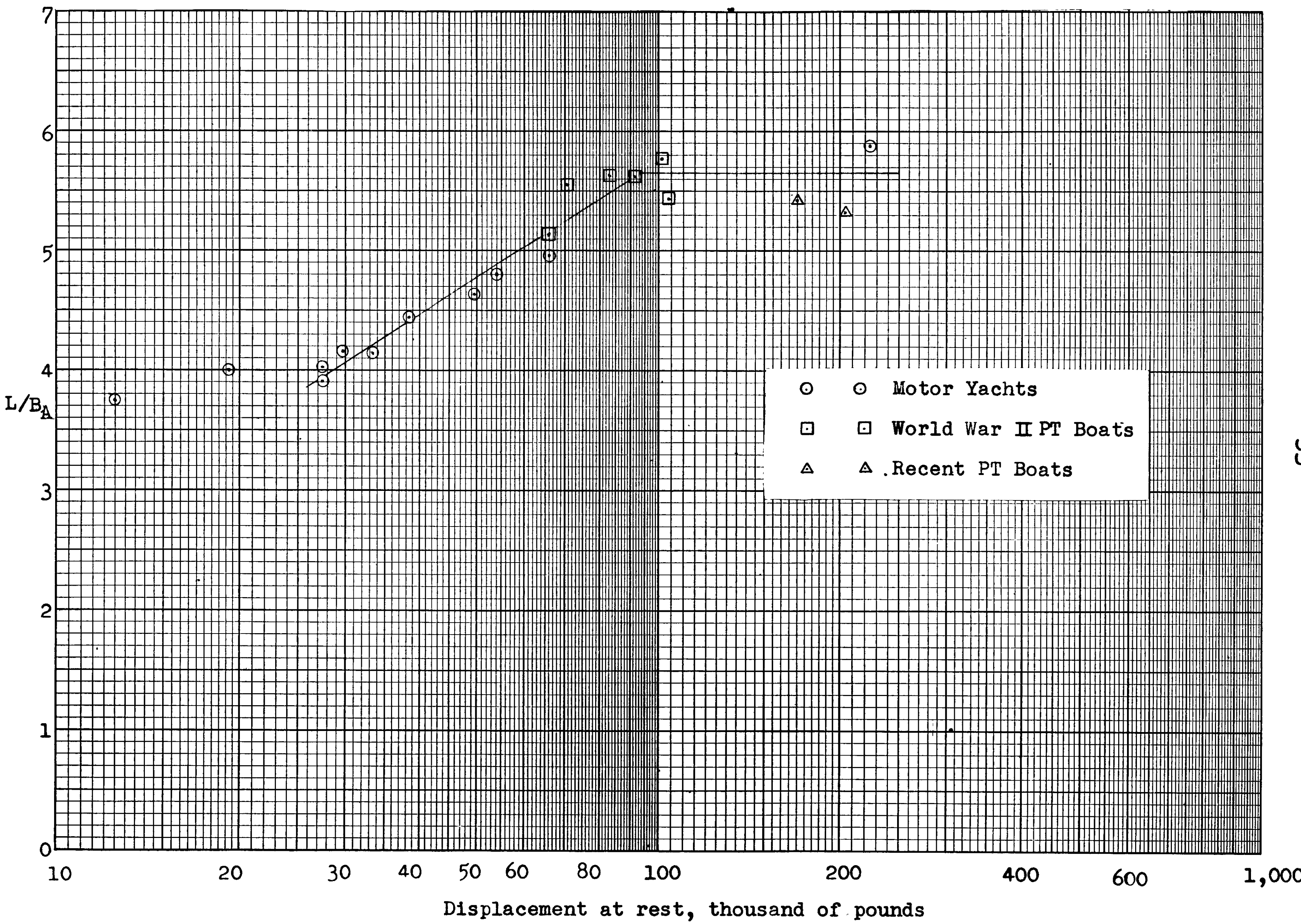


Figure 16 - Variation of Length / Beam Ratio with Displacement.

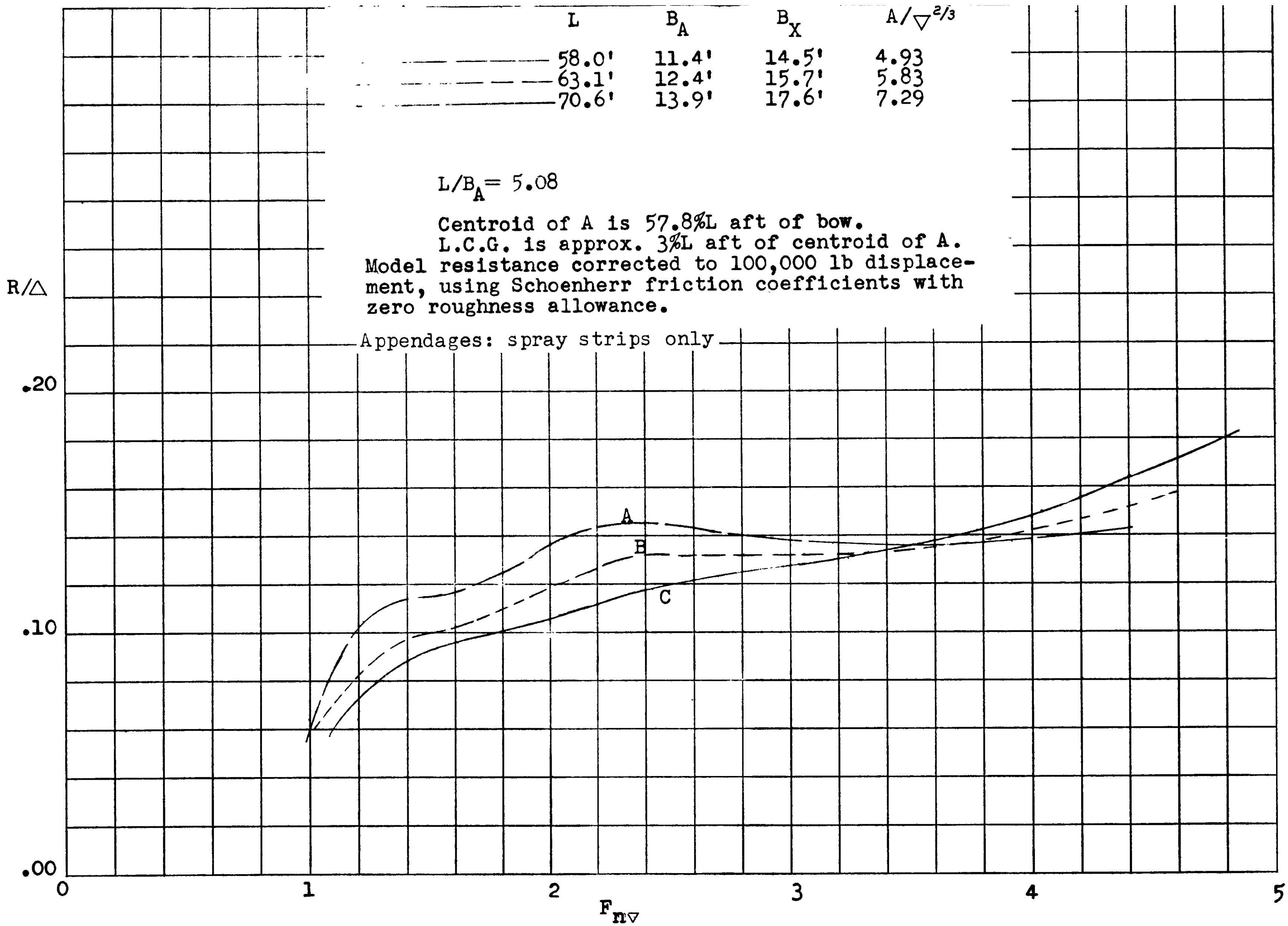


Figure 17- Effect of Size of Hull on Resistance for Constant Displacement (100,000 lb)..

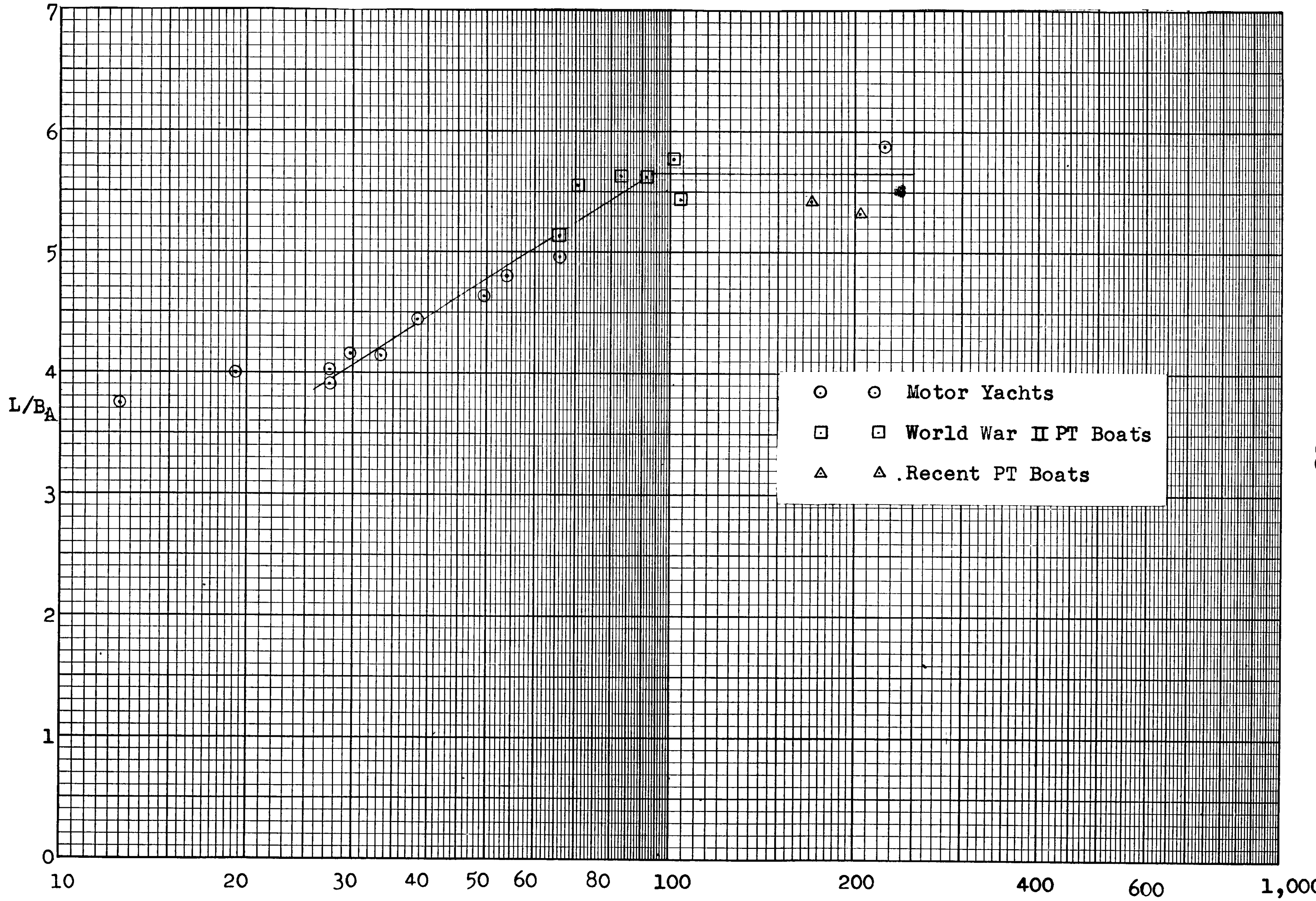


Figure 16 - Variation of Length / Beam Ratio with Displacement.

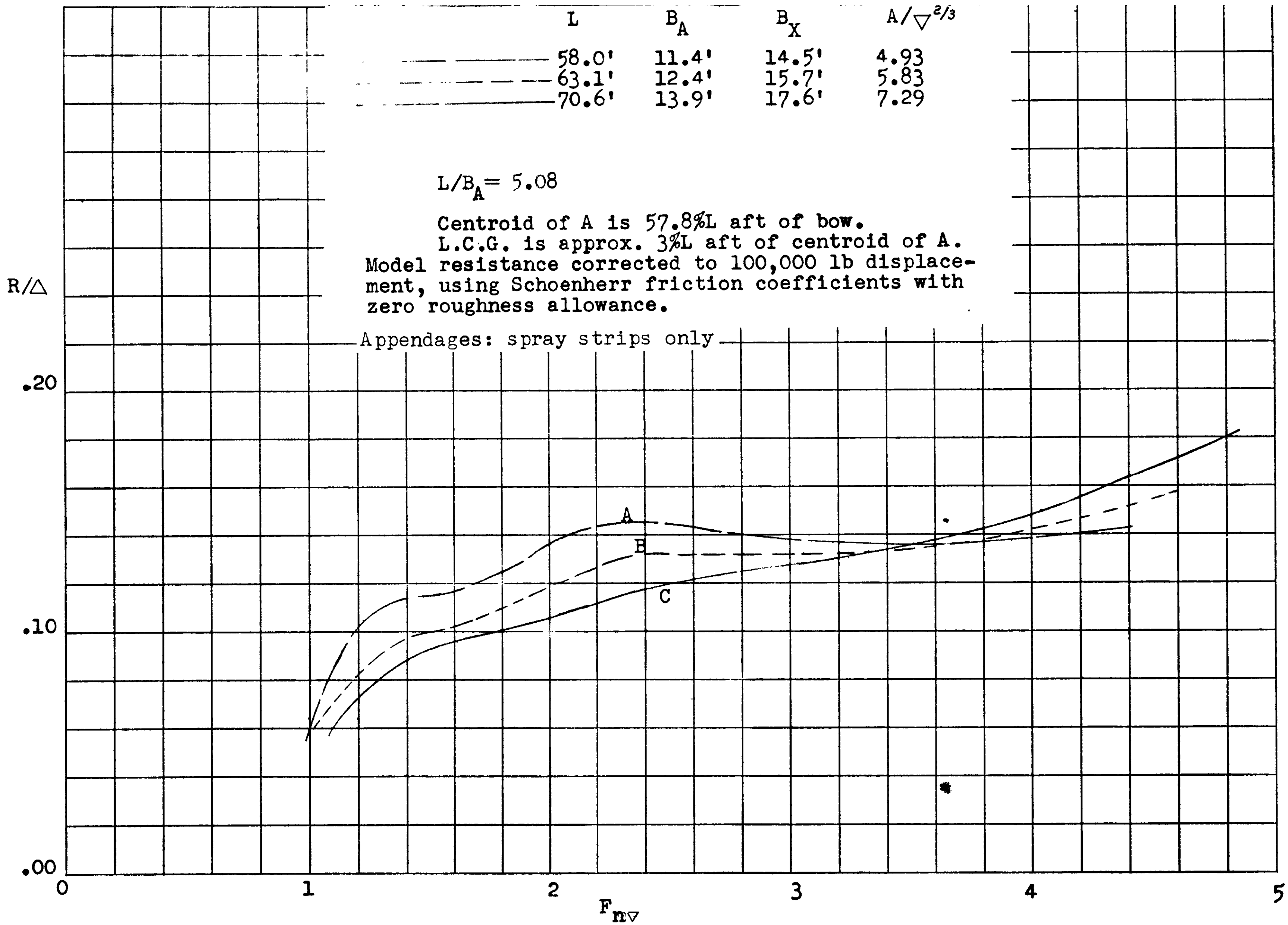


Figure 17– Effect of Size of Hull on Resistance for Constant Displacement (100,000 lb)..

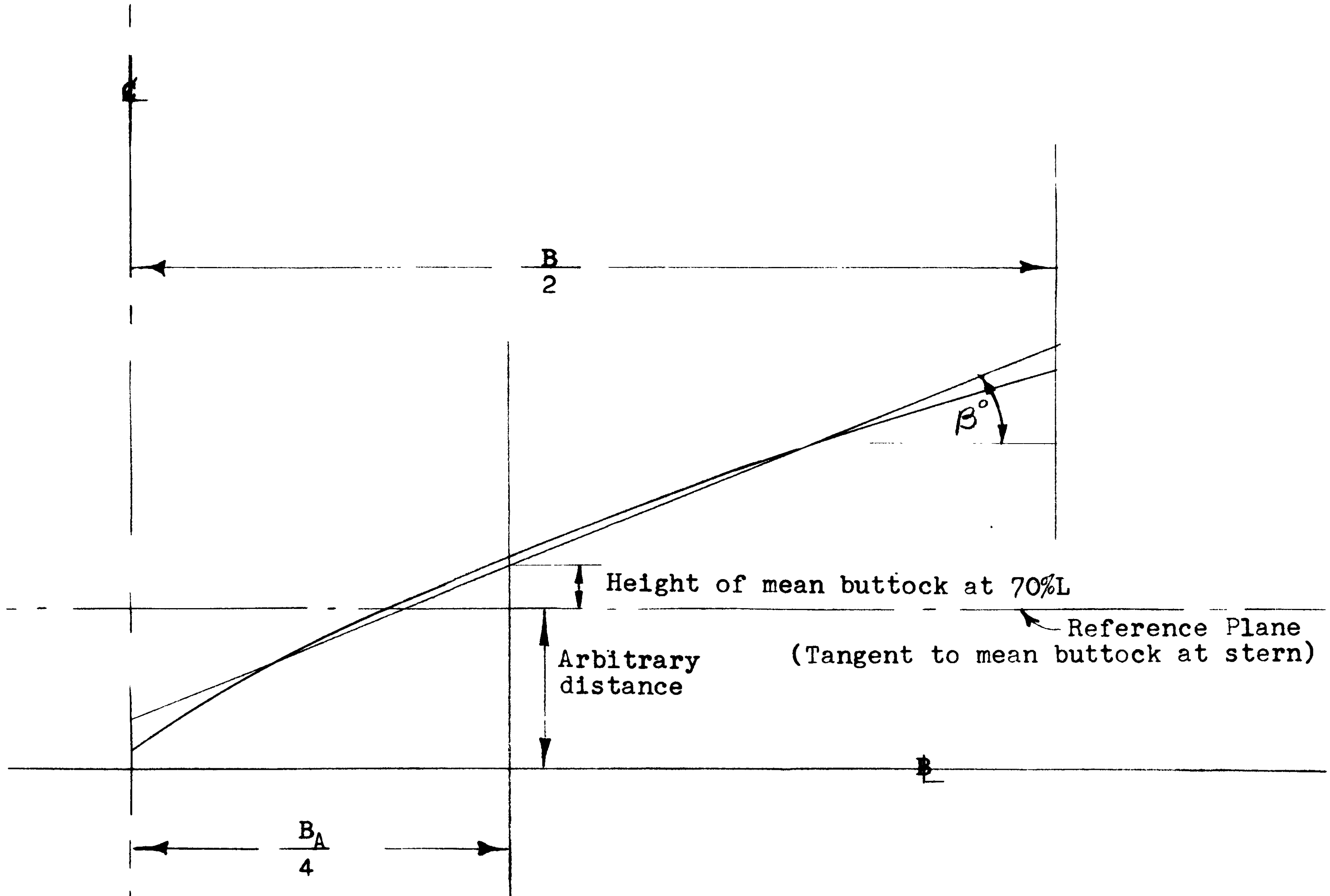


Figure 18 - Constructing a Body Plan Section at 70%L.

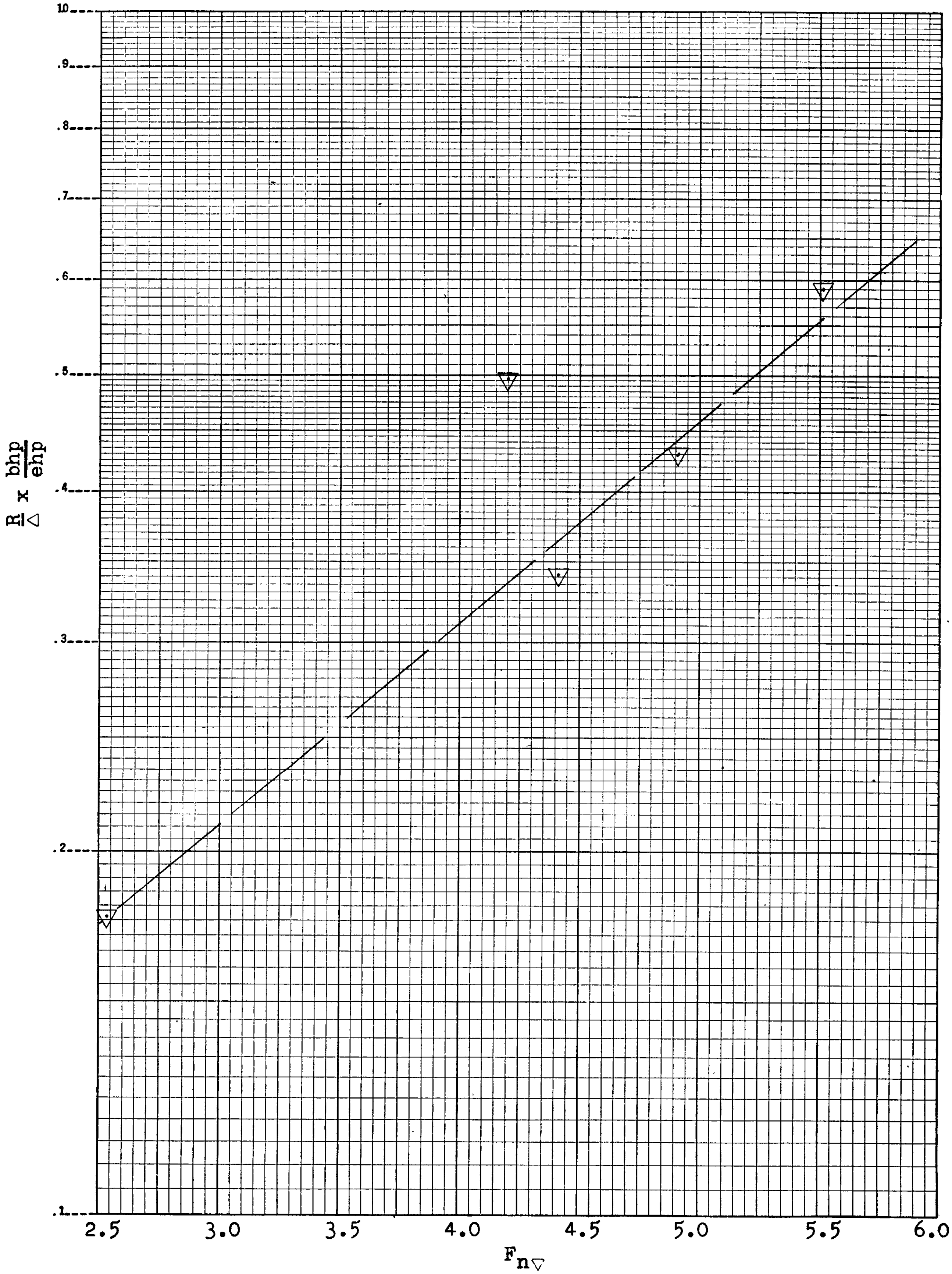


Figure 19 - Brake Horsepower Requirements of Vee-Bottom Racing Motor Boats, from the Data of Reference (4).

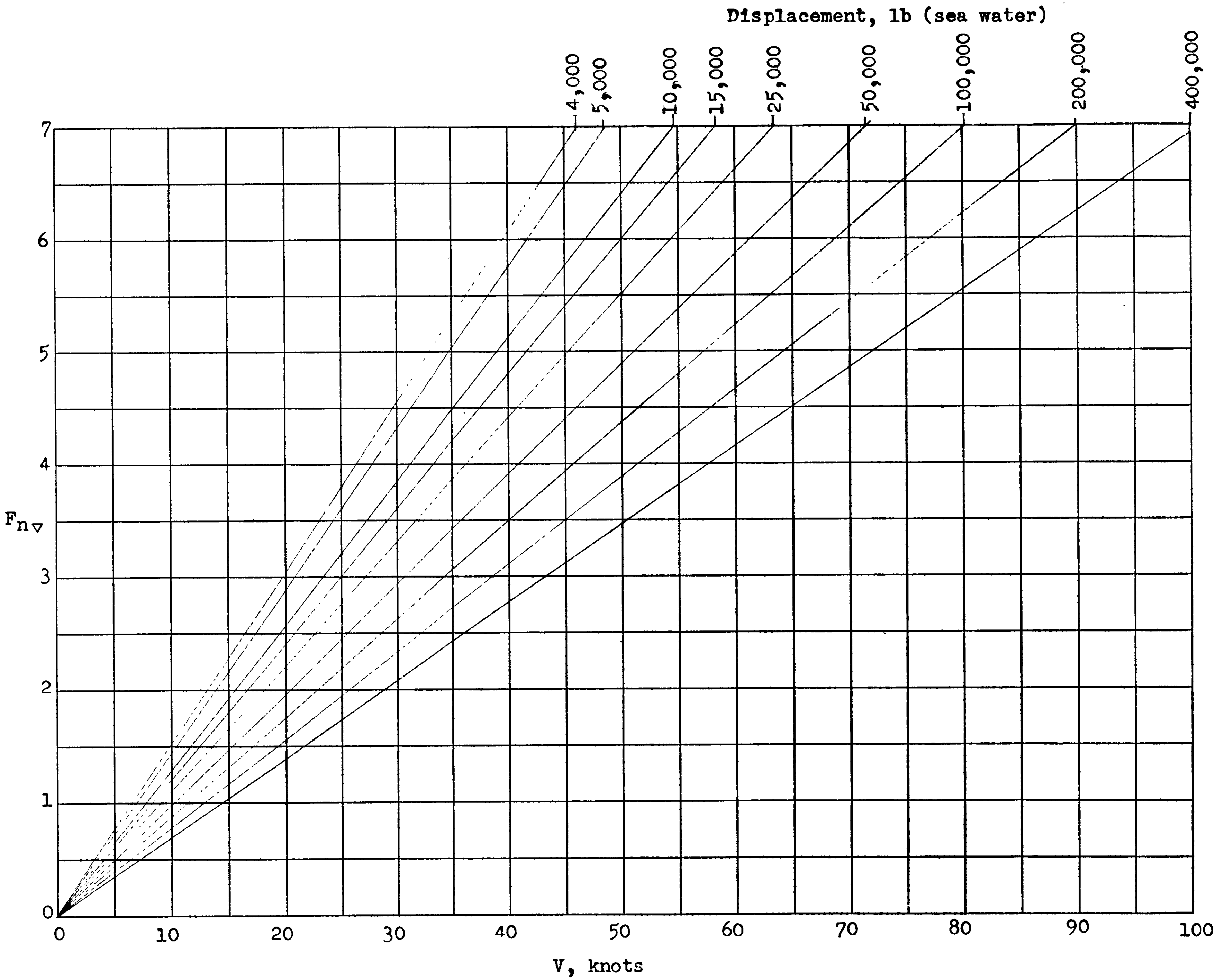


Figure [illegible] - Variation of $F_{n\nabla}$ with Speed and Displacement

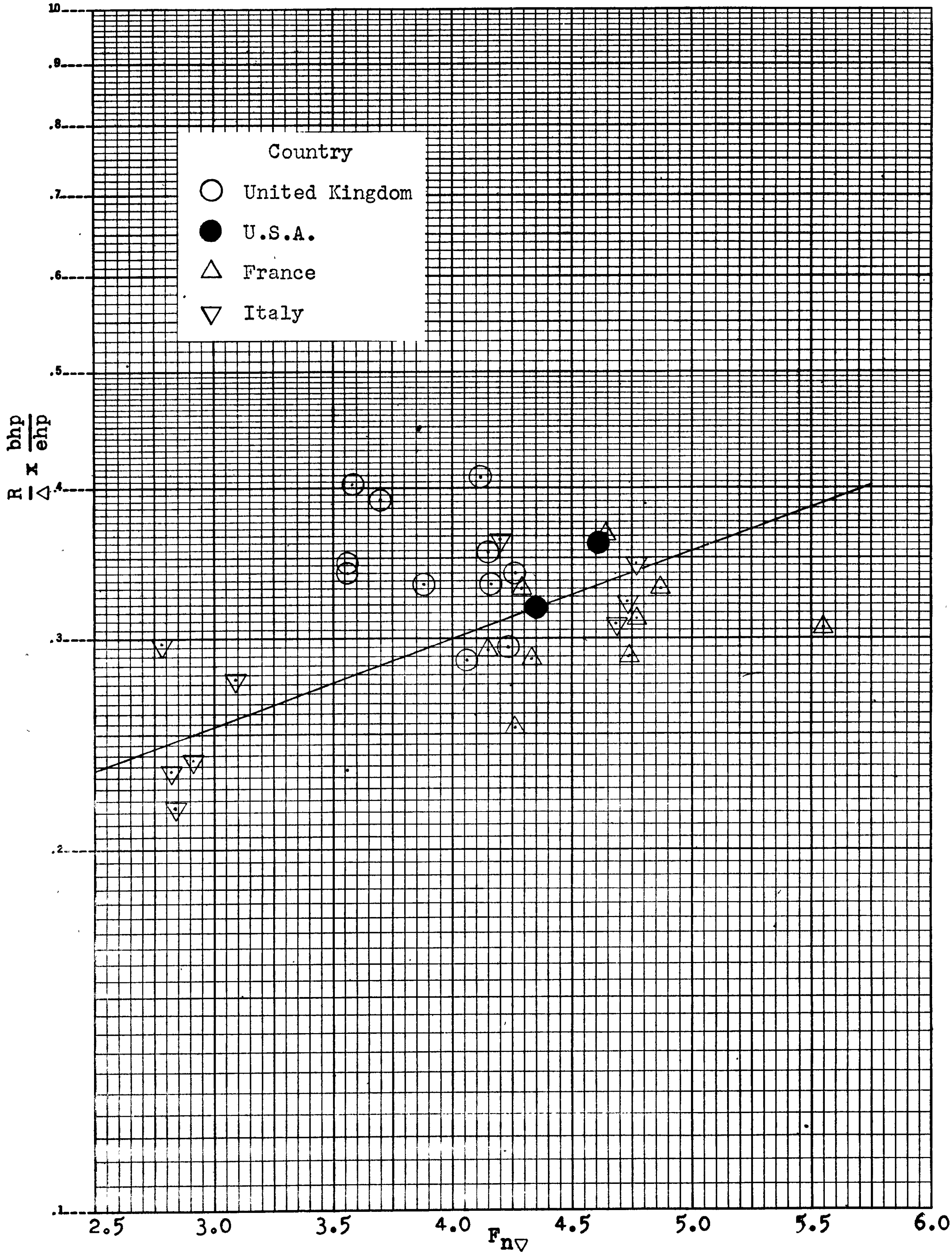


Figure 21 - Coefficients of Brake Horsepower and Speed for Various Motor Torpedo Boats, from the Data of Reference (5).

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3 CJS

David W. Taylor Model Basin. Rept. 1093.
ANALYZING THE STEPLESS PLANING BOAT, by Eugene P. Clement. Nov. 1956. iii, 40 p. incl. figs., refs. (Research and development report) UNCLASSIFIED

This report gives methods of presenting and using information on the hull forms and model performance of planing boats to guide the design of future boats. The effects on performance of variations in some of the primary planing boat parameters are illustrated and discussed. A design method is proposed, and data are presented to assist in making correct design decisions.

1. Hydroplane boats - Characteristics
2. Hydroplane boats - Performance - Model test
3. Ship models - Performance
I. Clement, Eugene P.
II. NS 715-102

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NAVY DEPARTMENT

THE DAVID W. TAYLOR MODEL BASIN

WASHINGTON 7, D.C.

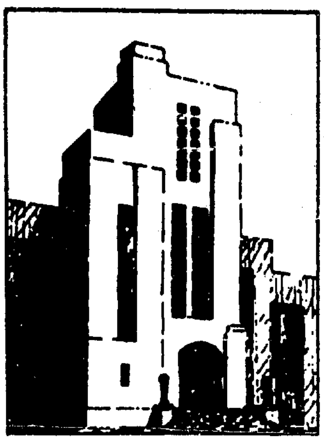
COMPARATIVE RESISTANCE DATA FOR FOUR PLANING BOAT DESIGNS

By

Eugene P. Clement

and

Peter M. Kimon



RESEARCH AND DEVELOPMENT REPORT

JANUARY 1957

Report No. 1113

COMPARATIVE RESISTANCE DATA FOR FOUR PLANING BOAT DESIGNS

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NOTATION

Symbols

A	Projected area bounded by chines and transom, in plan view
B	Breadth over chines at any point
B_A	Mean breadth over chines, A/L
B_T	Breadth over chines at transom
B_X	Maximum breadth over chines
bhp	Engine brake horsepower
C_{HA}	Draft coefficient, aft; equals draft at 0%L (measured from tangent to mean buttock at stern) multiplied by A/∇
C_{HF}	Draft coefficient, forward; equals draft at 100%L (measured from tangent to mean buttock at stern) multiplied by A/∇
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
LCG	Longitudinal center of gravity location
P	Effective power, ft-lb/sec
R	Total resistance
R_m	Total model resistance, lb
S	Wetted surface, area of
SW/FW	Density ratio, salt water to fresh water

v	Speed
V	Speed, knots
w	Density of water (weight per unit volume)
WL_C	Intersection of chine with solid water, forward of 0%L, ft
WL_K	Wetted length of keel, forward of 0%L, ft
WL_{SP}	Intersection of chine with spray, forward of 0%L, ft
α	Angle with horizontal of tangent to mean buttock at stern, deg
β	Deadrise angle of hull bottom, deg
Δ	Displacement at rest, weight of
τ	Trim angle of hull with respect to attitude as drawn, deg
∇	Displacement at rest, volume of

Subscripts

M,m	Model
S,s	Ship
o	Value at rest

ABSTRACT

Four existing models of planing craft were retested at the Taylor Model Basin's "standard condition" for planing boat models. The test results for each model are presented in a design data sheet. The data are compared to show the effects of differences in hull form. These comparisons are independent of differences in hull loading, in LCG location, or in size of boat. Auxiliary graphs are included to assist in making estimates of speed and power for new designs.

INTRODUCTION

The Taylor Model Basin has accumulated a number of models of planing boats which were tested for smooth water performance in previous years. In general each of these models was built to represent a particular boat and the test results in each case were presented in dimensional form for a boat of specific size. In general the hull forms and the test conditions were unrelated. Data of this kind are not well suited for answering one of the chief questions that arises in design work, - the question as to the relative merit of different hull forms. When planing boat data of the kind referred to above are compared, even in dimensionless form, differences in performance due to differences in hull form are usually confused or obscured by two factors:

(a) By differences in hull loading and LCG location.

(b) By differences in size of boat to which the model resistance is corrected.

Fortunately these kinds of differences can be eliminated by adopting the practice of testing each model at a standard condition of hull loading and LCG location, and correcting the resistance data from each model to the same full size displacement. This has now been done for four of the models of planing boats which were on hand at the Model Basin, and the results are given in the present report.

STANDARD TEST CONDITIONS

Definition of hull loading

The definitions of hull loading and of LCG location for the planing boat need to be selected with some care in order to be significant and useful. Hull loading is defined here as the ratio $\Delta/\nabla^{2/3}$, as proposed in Reference 1*. The suitability of this coefficient can probably best be shown by analogy of the planing boat to the airplane. At high speed a planing boat's chief support is not from buoyancy, but from that type of lift which supports an airplane, i.e., dynamic lift. Accordingly, the important factors affecting the design and performance of the planing hull are not those involving the waterline at rest or the shape of the underwater hull at rest, as in the case of the displacement-type hull; instead, the important factors are those influencing the performance of the planing bottom in providing effective dynamic lift. And, as the projected wing area is of fundamental importance in the case of the airplane, so is the projected bottom area of fundamental importance in the case of the planing boat. It may be pointed out as an objection that when a boat is planing at high speed in smooth water a large proportion of the bottom area is unwetted, and therefore is making no contribution to the dynamic lift. In the more important and critical condition of operation in rough water, however, the entire bottom area contributes periodically to the dynamic lift. Therefore in rough water, and especially in a following sea, the magnitude and disposition of this area assume very great importance.

Now in the case of the airplane a significant relationship involving the wing area is the "wing loading", which is the ratio of the gross weight to the projected wing area. A somewhat similar relationship is significant for the planing boat. However, it is not appropriate to use the identical ratio in this case. The reason for this can probably best be shown by means of an example. Assume that we have a boat 30 feet long with a projected bottom area, A, of 180 ft^2 and a gross weight of 8000 lb, and also a geometrically similar boat 60 feet long and of corresponding weight. The ratio $\frac{\Delta}{A}$, or "bottom loading", for the 30-ft boat is then $\frac{8000}{180} = 44.5$ lb/ft^2. Since the linear dimensions of the large boat are twice those of the small boat, the bottom area of the large boat equals $(2)^2$ times the bottom area of the small boat, and the gross weight of the large boat equals $(2)^3$ times the gross weight of the small boat. The "bottom loading" for the 60-ft boat is then:

$$\frac{\Delta}{A} = \frac{8000 \cdot (2)^3}{180 \cdot (2)^2} = 2 \cdot 44.5 = 89.0 \ lb/ft^2$$

Evidently then, "bottom loading" in lb/ft^2 is a function of absolute size and is therefore unsuitable as a criterion of the

* References are listed on page 8.

relationship between gross weight and bottom area for different sizes of boats. In the example just considered a suitable coefficient would have yielded identical values, since the boats were geometrically similar. If the relationship is changed from Δ/A to $\Delta^{2/3}/A$, the ratio will no longer be affected by absolute size and a useful criterion of loading will have been attained. In the present example $\Delta^{2/3}/A = 2.22$ for both boats. If the ratio is further altered from $\Delta^{2/3}/A$ to $\nabla^{2/3}/A$, a dimensionless ratio is attained which has some physical significance and which is not affected by differences in water density (as between a full size boat in salt water and the corresponding model in fresh water). Inverting this we obtain the area coefficient, $A/\nabla^{2/3}$, as proposed in Reference 1. The value of this area coefficient is 7.2 for both of the boats in the present example. This ratio has a useful physical interpretation; it indicates the ratio of the projected bottom area of the boat to the area of one side of a cube whose volume equals the volume of water displaced at rest.

Definition of LCG location

Analogy to aircraft practice is also useful in arriving at a satisfactory method of defining LCG location. The problem involved is indicated by Figure 1 which shows plan views of the bottoms of two planing boat designs. Design I has a narrow transom, with the centroid of the projected bottom area and the position of maximum breadth relatively far forward. Design II has a wide transom, with the centroid of the projected bottom area and the position of maximum breadth relatively far aft. It seems evident that it would not be correct to consider that these two designs have corresponding center of gravity locations simply if the LCG's of the two designs are located at the same percentage points on the centerline lengths. This would be somewhat the same as if an aerodynamicist were to treat his longitudinal C.G. location in terms of the centerline chord of the wing, without regard to the amount of sweepback of the wing. The aerodynamicist, of course, does not do this; instead he treats the LCG location in terms of the mean aerodynamic chord of the entire wing. A similar effect is achieved for planing boats by DTMB's practice of treating the longitudinal center of gravity in terms of the distance from the centroid of the area, A.

In order to arrive at representative average values of $A/\nabla^{2/3}$ and LCG location, the weights, hull areas and LCG locations for a number of planing boat designs were evaluated in Reference 1. From this evaluation, the standard condition selected for tests of planing boat designs at the Model Basin corresponds to $A/\nabla^{2/3} = 7$, and the LCG located at 6%L aft of the centroid of the area A.

Four models were retested at this standard condition and the results are given in this report in Figures 2 through 5. In addition, Model 3592-1 (Figure 2) was tested at $A/\nabla^{2/3} = 7$, with the LCG at 10%L aft of the centroid of A, and Model 3722 (Figure 5) was tested at $A/\nabla^{2/3} = 8$, with the LCG at 6%L aft of the centroid of A.

DESIGN DATA SHEETS

The test results for each model are presented in a design data sheet, as proposed in Reference 1. The dimensionless speed coefficient used is Froude's number based on volume of water displaced at rest, referred to as $F_{n\nabla}$. The effect of using this speed coefficient is the same as that of using Ⓚ. By using $F_{n\nabla}$, however, an unnecessary constant, $\sqrt{4\pi}$, is avoided ($F_{n\nabla} = v/\sqrt{g\nabla^{1/3}}$, whereas Ⓚ $= \sqrt{4\pi} \cdot v/\sqrt{g\nabla^{1/3}}$).

Curves of the dimensionless power coefficient, $\frac{10\,P}{wg^{1/2}\nabla^{7/6}}$ are included in the performance characteristics section of each design data sheet. The advantages of using this power coefficient, and also the speed coefficient $F_{n\nabla}$, are clearly explained in Reference 2.

The main reason for the form in which the performance characteristics are presented is so that the designer can pick the most efficient hull form with the least effort. The curves of R/Δ as they appear in the design data sheets can be compared directly to show the relative merit of different hull forms, throughout the speed range. The same picture of relative merit will be shown by a comparison of the curves of power coefficient. The latter curves are also included for another purpose, however, as will appear later. The curves of α and of $S/\nabla^{2/3}$, for the different designs, can also be compared directly to show how the angle of attack and the wetted areas of different designs compare.

ESTIMATING THE SPEED OF A NEW DESIGN

Auxiliary graphs, Figures 6, 7 and 8 are included to assist in applying the information in the design data sheets to specific design problems. Assume for example that it is desired to estimate the speed of a 50,000 lb boat having an engine horsepower of 1200 bhp; the hull form and loading to be similar to that for Model 3626, which is shown in Figure 3. Since the design data sheet gives resistance and ehp data without appendages it is first necessary to estimate the value of the ratio of ehp without appendages to bhp with appendages. For the present example the value of this ratio would be about 0.5. Then, ehp (without appendages) = 0.5 · bhp (with appendages) = 600. Then from Figure 6, the value of the power coefficient, $10\ P/wg^{1/2}\nabla^{7/6}$ is 3.84. Now the curve of power coefficient in each of the design data sheets was necessarily calculated for a specific full scale displacement. As indicated the displacement assumed was 100,000 lb. Therefore Figure 7 has been prepared to assist in converting between power coefficients at 100,000 lb displacement and power coefficients at other values of displacement. The procedure for the present example is to ehter the horizontal scale of Figure 7 with the value of displacement (50,000 lb); then, from this point extend a vertical line to the power coefficient value of 3.84 in the family of curved lines. From this point extend a horizontal line to the scale at the left side of the graph and here read off the value of power coefficient for 100,000 lb displacement (3.80 in this case).

The family of curved lines in Figure 7 indicates constant values of the power coefficient for displacements ranging from 20,000 to 160,000 lb. The horizontal lines, together with the scale at the left of the graph, indicate corresponding constant values of the power coefficient for 100,000 lb displacement. The fact that the value of this dimensionless power coefficient varies with displacement (i.e., with size of boat), is caused, of course, by the fact that the larger of two similar boats will have a higher value of Reynolds' number than the smaller boat when the two are operating at corresponding speeds; therefore the frictional resistance coefficients, and hence also the values of power coefficient, will be lower for the large boat than for the small boat. In the present example the magnitude of the correction for difference in size is very small; the value of the power coefficient is only about 1% less for 100,000 lb displacement than for 50,000 lb displacement. At higher speeds, and with greater differences in displacement, the magnitude of the correction can become appreciable. Figure 7 shows for example that when the value of power coefficient for 20,000 lb displacement equals 8.2, the corresponding value for 100,000 lb displacement is 7.74, which is 5.6% less.

The next step in estimating the speed for the 50,000 lb, 1200 bhp boat is to enter the power coefficient curve in Figure 3 with the value of 3.8. The corresponding value of $F_{n\nabla}$ is found to be 3.04. Entering Figure 8 with this value, at a displacement of 50,000 lb, we obtain an estimated speed of 31 knots.

ESTIMATING THE POWER FOR A NEW DESIGN

The information in the design data sheets can also be used for the reverse process, i.e., to estimate the ehp required for a given speed and gross weight. Either the curve of R/Δ or the curve of power coefficient can be used for this calculation. The procedure is essentially the reverse of the procedure just indicated.

COMPARISON OF RESISTANCES

The curves of R/Δ (or of $10\ P/wg^{1/2}\nabla^{7/6}$) in Figures 2, 3, 4 and 5 can be compared directly to show the relative resistances (or power requirements) of the different designs. The resistances are compared in Figure 9. This comparison is on the basis of equal size (i.e., equal area, A, and equal gross weight), equal speed, and corresponding center of gravity location. The remaining differences in resistance are caused by differences in hull form.

As discussed in Reference 1, the superiority of Model 3722 over Model 3720 can be attributed to the much smaller amount of twist in the hull bottom of Model 3722. It is evident from Figure 9 that Models 3626 and 3722 are the two designs which are of the most interest: Model 3626 because it has the least resistance at high speeds, and Model 3722 because it has the lowest average resistance throughout the speed range. The chief difference between the hull forms of Models 3626 and 3722 is that the length/beam ratio of Model 3626 is appreciably lower than that of Model 3722. It was shown in Reference 1 that length/beam ratio has an appreciable influence on resistance; also it was pointed out that the choice of the length/beam ratio for a new design depends to a large extent on the size of the boat and on the type of service intended. For these reasons it is desirable to compare the performance of different hull forms on the basis of equal length/beam ratio. This suggests a graph like Figure 10, in which R/Δ is plotted against length/beam ratio for several different values of the speed coefficient. The data from the four designs reported on here are plotted in this graph. A useful advantage can now be derived from the fact that except for the difference in length/beam ratios, and some difference in the extreme bow portions, Models 3626 and 3722 are very similar. The bow portions are dry in smooth water at all but very low speeds and therefore have no effect on the smooth water resistance for the speeds of significance. Evidently then, lines connecting the data points for Models 3626 and 3722 in Figure 10 will indicate the trend of the effect of length/beam ratio on resistance for the different speeds. Lines of this sort are drawn in the figure. However, instead of depending entirely on the data from only two models, additional data (not included here) from other pairs of models which were similar except for differences in length/beam ratio, were used to guide the slopes to which the lines should be drawn. Accordingly it was possible to extend the lines of Figure 10 over a greater range of length/beam ratio, and to have more confidence in their significance, than if they depended only on the limited data shown.

The lines of Figure 10 illustrate the fact that for speeds below $F_{n\nabla} = 2.5$, planing boat resistance decreases with increasing length/beam ratio. At higher speeds (up to $F_{n\nabla}$ equals about 4.2) the resistance increases with increasing length/beam ratio.

By means of Figure 10 it is now possible to make resistance comparisons which are not affected by differences in length/beam ratio. When resistance data are available for a new design they can be plotted on Figure 10. Then at each speed the vertical distance from the data point for the new design to the line in the graph, will show the difference between the resistance of the new design and a hull of the form represented by Models 3626 and 3722, but having the same length/beam ratio as the new design. Or, alternatively, the resistance curve for the new design can be compared with a curve constructed from Figure 10 using the length/beam ratio of the new design. By eliminating the effect of length/beam ratio in this way it will be possible to see the effects on resistance of the other hull form parameters.

REFERENCES

1. Clement, Eugene P., "Analyzing the Stepless Planing Boat", DTMB Report 1093, November 1956.

2. Nordstrom, H. F., "Some Tests with Models of Small Vessels", Publication No. 19 of the Swedish State Shipbuilding Experimental Tank, 1951.

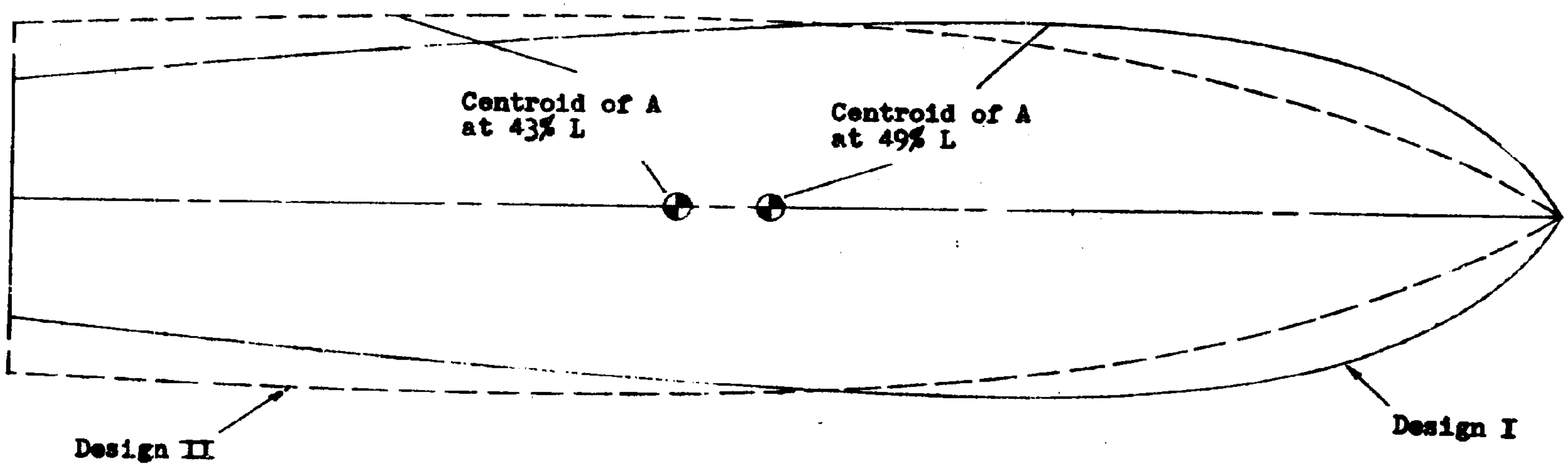
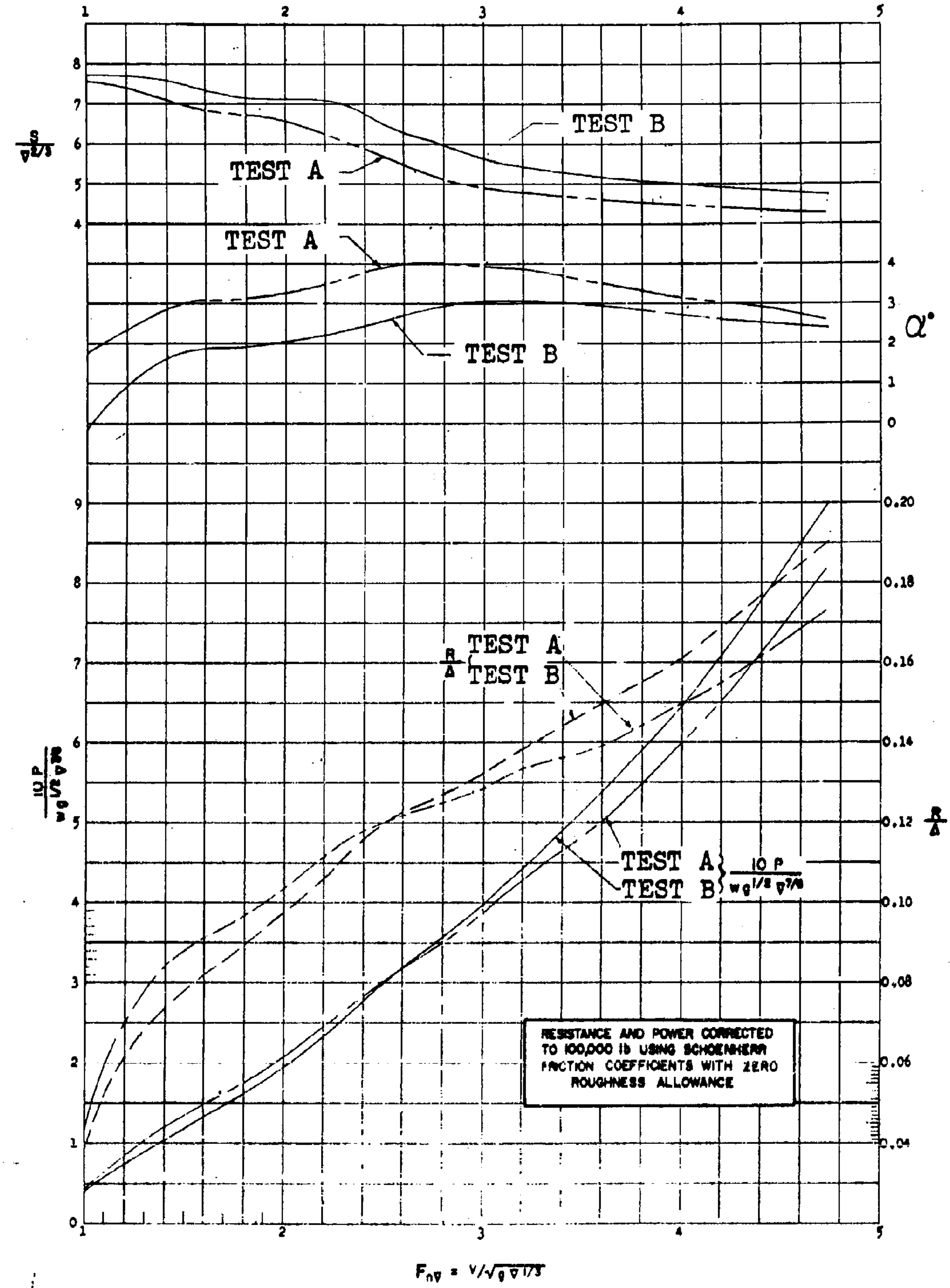
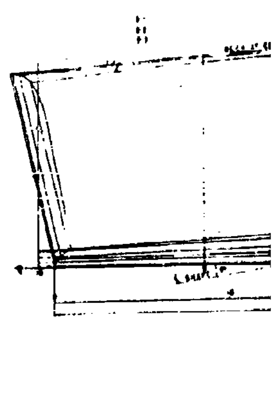


Figure 1 - The Chine Lines in Plan View of Two Planing Boat Designs.

IV PERFORMANCE CHARACTERISTICS



TE	
V_M	R_M
3.91	7.82
4.91	13.43
5.87	16.17
6.86	17.79
7.82	19.64
8.85	21.68
9.86	23.29
10.86	24.31
11.84	25.43
12.82	26.89
13.84	27.94
14.84	29.45
15.72	31.01
16.74	32.80
17.76	34.87
18.72	36.96



PLANING BOAT DESIGN DATA SHEET
DAVID W. TAYLOR MODEL BASIN

JUNE 1955

2

DTMB MODEL 3592-1 1/9 SCALE

MODEL DATA

BASIN HIGH SPEED BASIN
BASIN SIZE 2968'x21'x(10'and 16')
DATE OF TEST 23 FEB 55
WATER TEMP. 68°F
APPENDAGES SPRAY STRIPS
TURBULENCE STIM. NONE
MODEL MATERIAL WOOD
MODEL FINISH PAINT

TEST A

V_M	R_M	WL_K	WL_C	WL_{SP}
3.91	7.82	8.42	4.92	
4.91	13.43	8.25	6.42	6.73
5.87	16.17	8.08	6.08	6.58
6.86	17.79	7.92	5.88	6.58
7.82	19.64	7.75	5.62	6.54
8.85	21.68	7.50	5.29	6.33
9.86	23.29	7.32	4.93	6.10
10.86	24.31	6.96	4.62	5.83
11.84	25.43	6.75	4.42	5.71
12.82	26.89	6.67	4.17	5.46
13.84	27.94	6.58	4.00	5.38
14.84	29.45	6.58	3.83	5.25
15.72	31.01	6.57		
16.74	32.80	6.54	3.54	5.12
17.76	34.87	6.58	3.42	5.08
18.72	36.96	6.58	3.25	5.08

TEST B

V_M	R_M	WL_K	WL_C	WL_{SP}
3.98	7.30	8.46	7.33	7.75
4.97	12.23	8.42	6.96	7.42
5.93	14.76	8.35	6.62	7.25
6.93	16.73	8.28	6.42	7.13
7.90	18.91	8.25	6.17	7.04
8.90	21.37	8.08	5.83	6.88
9.88	23.57	7.92	5.71	6.67
10.90	25.15	7.67	5.33	6.46
11.87	26.53	7.50	5.00	6.29
12.81	28.28	7.35	4.75	6.13
13.85	30.11	7.25	4.58	6.04
14.82	31.79	7.08	4.33	5.92
15.82	33.59	7.08	4.17	5.83
16.76	35.78	7.08	4.04	5.75
17.74	38.14	7.08	3.87	5.75
18.75	40.55	7.04	3.71	5.68

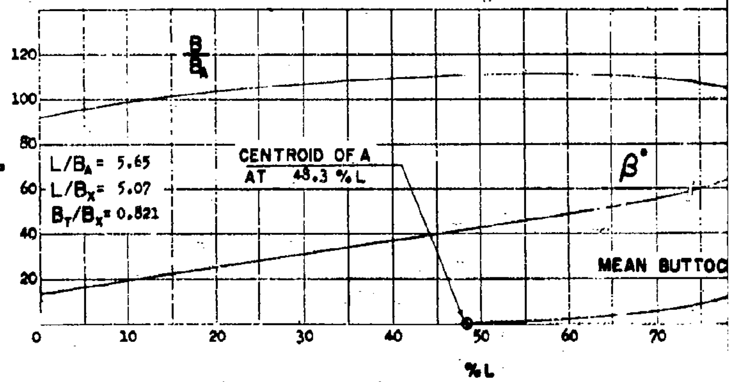
REMARKS:

Relatively high $\frac{L}{B_A}$ ratio and excessive twist (indicated by rate of cha[nge of] angle β) give poor resistance characteristics at $F_{n\nabla} > 2.8$. Relative[ly] sections associated with narrow stern give low resistance at $F_{n\nabla} < 2.$[…] average resistance at $2.3 < F_{n\nabla} < 2.8$

I TEST CONDITIONS

TEST	Δ_M lb	Δ_S lb	$\frac{A}{\nabla^{2/3}}$	$\frac{L}{\nabla^{1/3}}$	MAXIMUM STABLE $F_{n\nabla}$	τ_0	α_0	DRAFT COEFF. FWD.	AFT.
A	167.5	125,575	7.00	6.29	--------	1.10° x BOW	+ 0.30°	1.062	1.292
B	167.5	125,575	7.00	6.29	--------	2.10° x BOW	- 0.70°	1.527	0.990

II FORM CHARACTERISTICS



III LINES

MODEL	FULL SIZE
A = 13.536 sq. ft.	A = 1096.4 sq. ft.
L = 8.742 ft.	L = 78.68 ft.
B_A = 1.548 ft.	B_A = 13.93 ft.

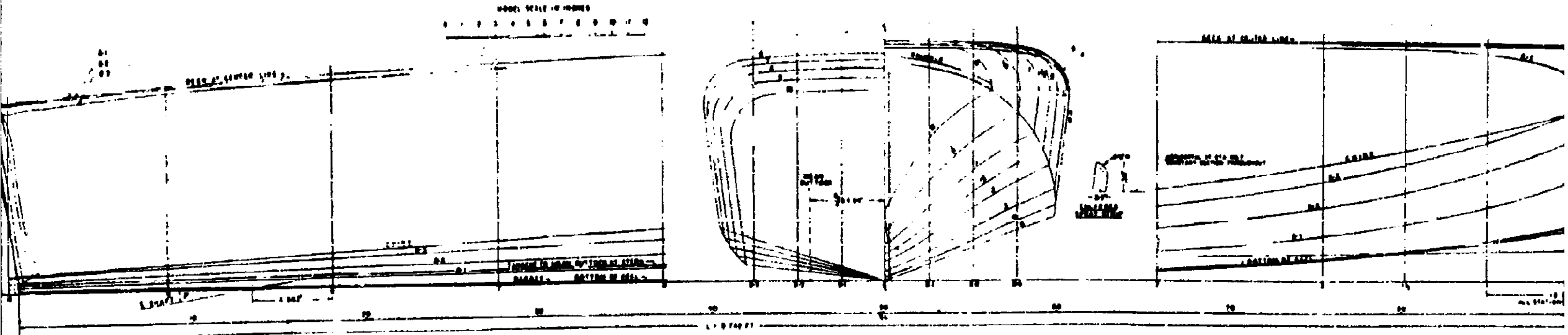


Figure 2 - Design Data Sheet for Model 3[…]

PLANING BOAT DESIGN DATA SHEET
DAVID W. TAYLOR MODEL BASIN

JUNE 1955

DTMB MODEL 3592-1 | 1/9 SCALE | 80 FT. PT 8

3

...EL DATA

...PEED BASIN
...968'x21'x(10' and 16')
...ST 23 FEB 55
... 68°F
SPRAY STRIPS
STIM. NONE
...RIAL WOOD
...H PAINT

TEST B

V_M	R_M	WL_K	WL_C	WL_{SP}
3.98	7.30	8.46	7.33	7.75
4.97	12.23	8.42	6.96	7.42
5.93	14.76	8.35	6.62	7.25
6.93	16.73	8.28	6.42	7.13
7.90	18.91	8.25	6.17	7.04
8.90	21.37	8.08	5.83	6.88
9.88	23.57	7.92	5.71	6.67
10.90	25.15	7.67	5.33	6.46
11.87	26.53	7.50	5.00	6.29
12.81	28.28	7.35	4.75	6.13
13.85	30.11	7.25	4.58	6.04
14.82	31.79	7.08	4.33	5.92
15.82	33.59	7.08	4.17	5.83
16.76	35.78	7.08	4.04	5.75
17.74	38.14	7.08	3.87	5.75
18.75	40.55	7.04	3.71	5.68

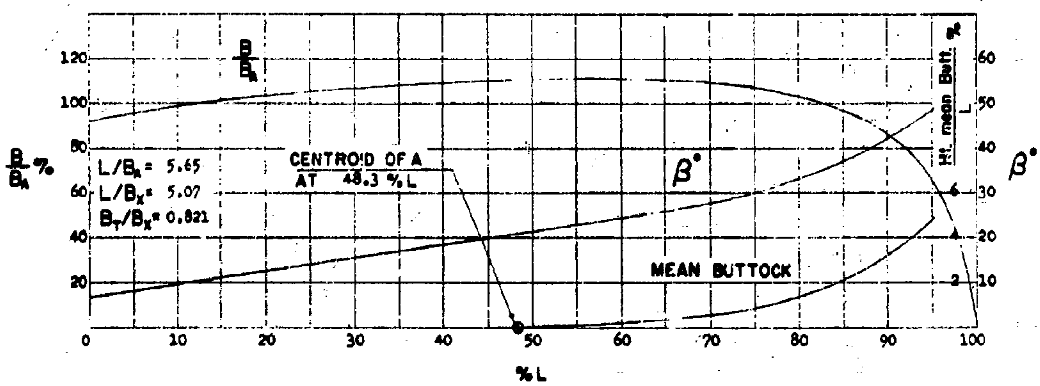
REMARKS:

Relatively high $\frac{L}{B_A}$ ratio and excessive twist (indicated by rate of change of angle β) give poor resistance characteristics at $F_{n\nabla} > 2.8$. Relatively straight sections associated with narrow stern give low resistance at $F_{n\nabla} < 2.3$ and average resistance at $2.3 < F_{n\nabla} < 2.8$

I TEST CONDITIONS

TEST	Δ_M lb	Δ_S lb	$\frac{A}{\nabla^{2/3}}$	$\frac{L}{\nabla^{1/3}}$	MAXIMUM STABLE $F_{n\nabla}$	τ_o	α_o	DRAFT COEFF. FWD.	DRAFT COEFF. AFT.	CG AFT OF CENTROID OF A	LCG % L
A	167.5	125,575	7.00	6.29	--------	1.10° x BOW	+ 0.30°	1.062	1.292	10.0%L	38.3
B	167.5	125,575	7.00	6.29	--------	2.10° x BOW	- 0.70°	1.527	0.990	6.0%L	42.3

II FORM CHARACTERISTICS



III LINES

MODEL	FULL SIZE
A = 13.536 sq. ft.	A = 1096.4 sq. ft.
L = 8.742 ft.	L = 78.68 ft.
B_A = 1.548 ft.	B_A = 13.93 ft.

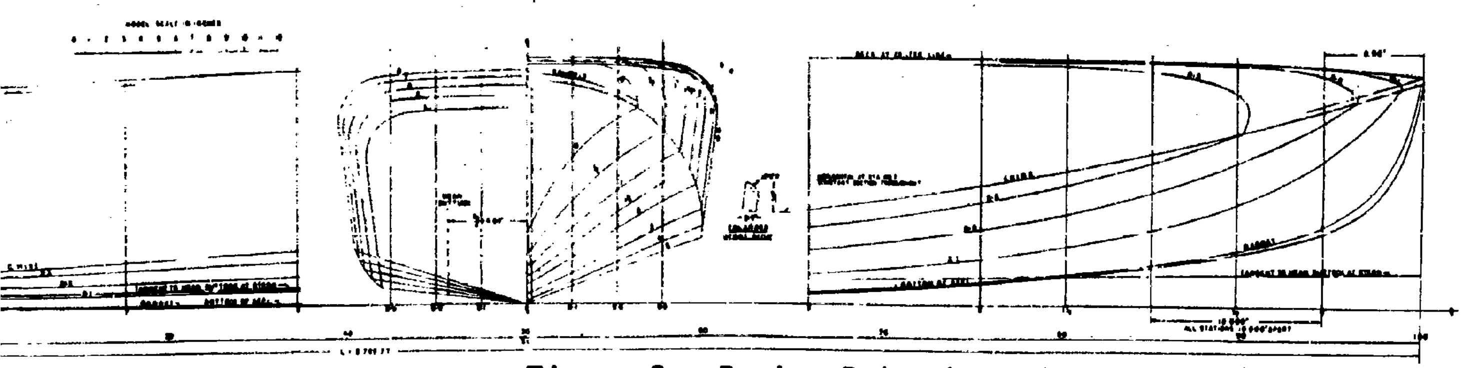
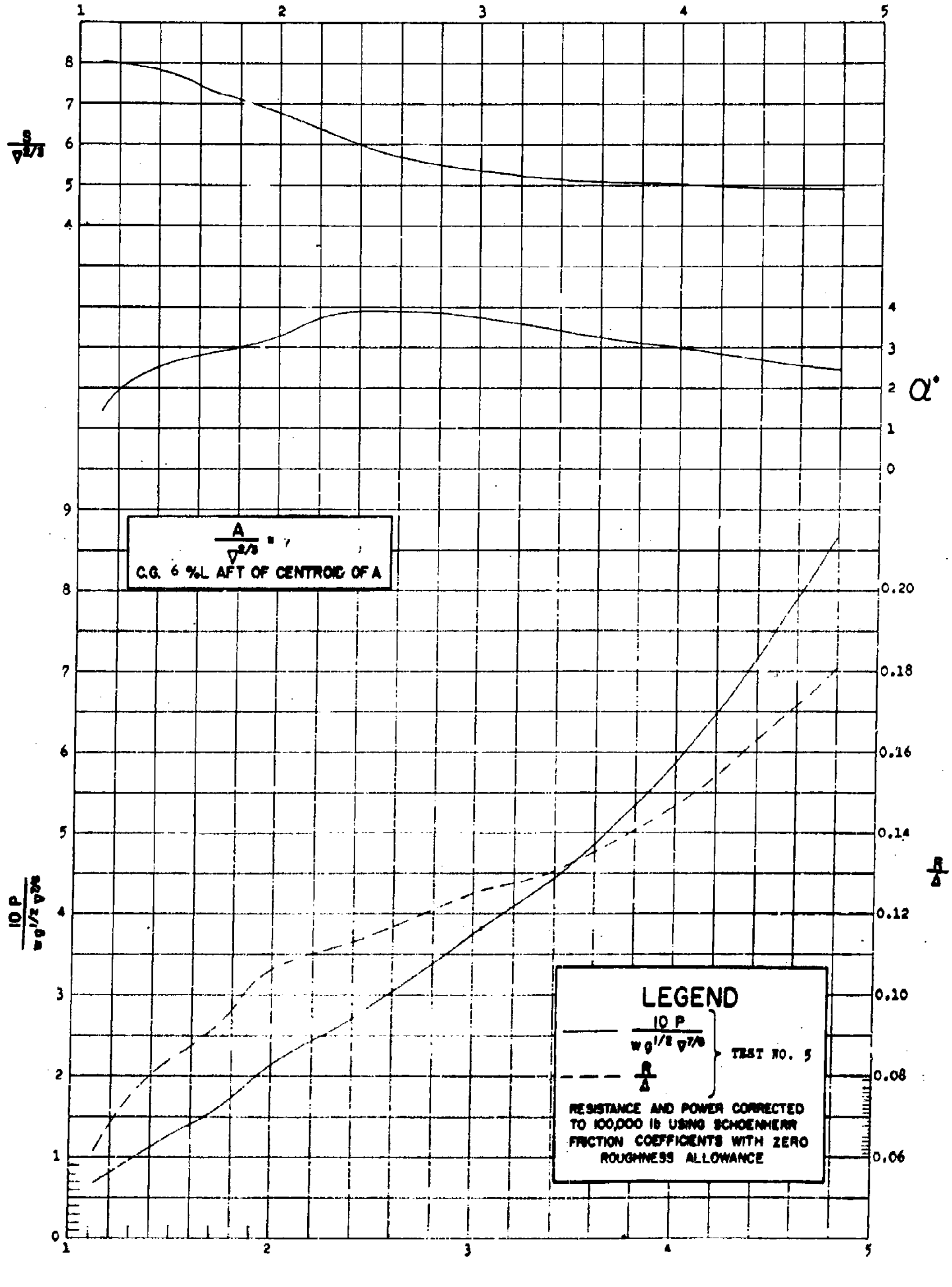


Figure 2 - Design Data Sheet for Model 3592-1

IV PERFORMANCE CHARACTERISTICS



PLANING BOAT DESIGN DATA SHEET
DAVID W. TAYLOR MODEL BASIN

JUNE 1955

DTMB MODEL 3626 $\frac{1}{8.5}$ SCALE 70

2

MODEL DATA

BASIN HIGH SPEED BASIN
BASIN SIZE 2968'x21'x(10'and 16')
DATE OF TEST 6 OCT 54
WATER TEMP 73°F
APPENDAGES SPRAY STRIPS
TURBULENCE STIM. NONE
MODEL MATERIAL WOOD
MODEL FINISH PAINT
TEST NO. 5

V_M	R_M	WL_K	WL_C	WL_{SP}
4.26	8.82	7.50	6.90	7.60
5.34	11.68	7.45	6.20	7.25
6.40	13.33	7.40	5.70	6.80
7.48	14.98	7.30	5.20	6.20
8.54	16.67	7.10	4.80	5.50
9.60	17.58	6.90	4.40	5.10
10.70	18.79	6.70	4.10	4.80
11.76	19.92	6.65	3.90	4.60
12.82	20.88	6.60	3.70	4.40
13.95	22.39	6.60	3.55	4.35
15.06	24.14	6.65	3.40	4.25
16.08	26.04	6.65	3.25	4.20
17.16	28.30	6.70	3.20	4.25
18.22	30.64	6.75	3.05	4.25

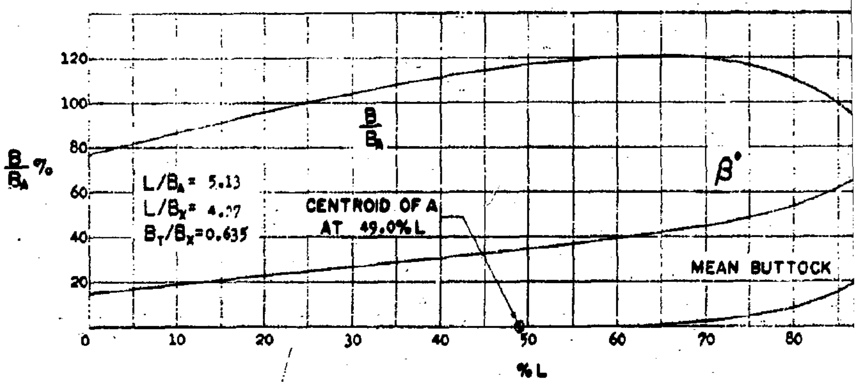
REMARKS:

Average $\frac{L}{B_A}$ ratio and narrow transom give low resistance characteristics at $2.3 < Fn_\nabla < 3.5$ and average resistance characteristics at $Fn_\nabla > 3.5$. Relatively straight buttocks forward give only average resistance characteristics at $Fn_\nabla < 2.3$.

I TEST CONDITIONS

TEST NO.	Δ_M lb	Δ_S lb	$\frac{A}{\nabla^{2/3}}$	$\frac{L}{\nabla^{1/3}}$	MAXIMUM STABLE $F_{n\nabla}$	τ_o	α_o	DRAFT COEFF. FWD.	DRAFT COEFF. AFT.	CG AFT OF CENTROID OF A
2	98.0	61,900	8.44	6.58	------	2.25° x STERN	+ 1.55°			
3	78.9	49,000	9.75	7.07	------	1.78° x STERN	+ 1.08°			
4	120.8	75,000	7.34	6.13	------	2.68° x STERN	+ 1.98°			
5	129.6	81,850	7.00	5.99	------	0.75° x STERN	+ 0.05°	1.133	1.170	6.0 %L

II FORM CHARACTERISTICS



III LINES

MODEL

A = 11.415 sq. ft.
L = 7.649 ft.
B_A = 1.492 ft.

FULL SIZE

A = 824.73 sq. ft
L = 65.02 ft.
B_A = 12.68 ft.

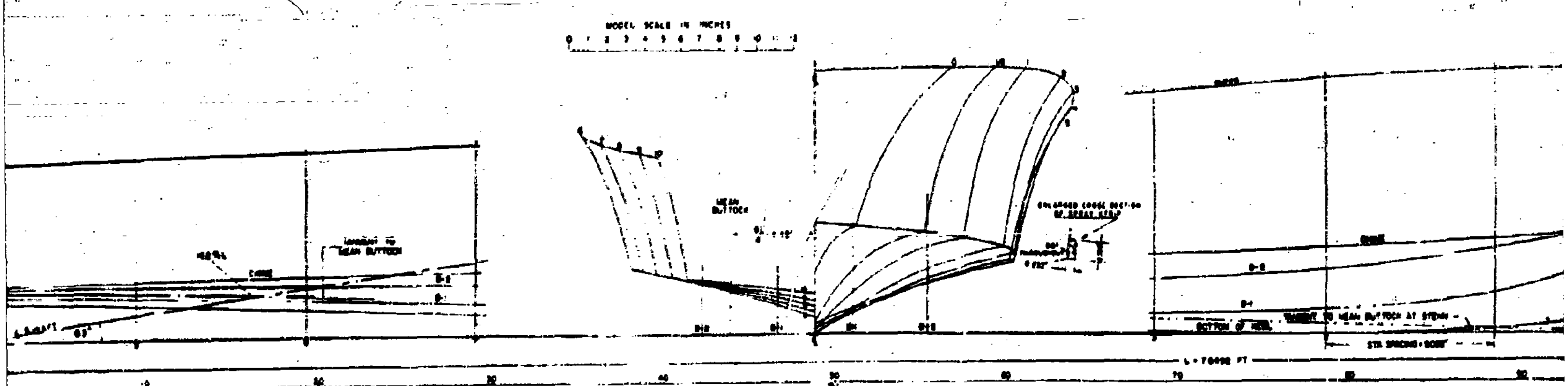


Figure 3 - Design Data Sheet for Model 3

PLANING BOAT DESIGN DATA SHEET
DAVID W. TAYLOR MODEL BASIN

JUNE 1955

DTMB MODEL 3626 $\frac{1}{8.5}$ SCALE 70 FT. ELCO PT BOAT

3

MODEL DATA

BASIN HIGH SPEED BASIN

BASIN SIZE 2968'x21'x(10' and 16')

DATE OF TEST 6 OCT 54

WATER TEMP. 73°F

APPENDAGES SPRAY STRIPS

TURBULENCE STIM. NONE

MODEL MATERIAL WOOD

MODEL FINISH PAINT

TEST NO. 5

V_M	R_M	WL_K	WL_C	WL_{sp}
4.26	8.82	7.50	6.90	7.60
5.34	11.68	7.45	6.20	7.25
6.40	13.33	7.40	5.70	6.80
7.48	14.98	7.30	5.20	6.20
8.54	16.67	7.10	4.80	5.50
9.60	17.58	6.90	4.40	5.10
10.70	18.79	6.70	4.10	4.80
11.76	19.92	6.65	3.90	4.60
12.82	20.88	6.60	3.70	4.40
13.95	22.39	6.60	3.55	4.35
15.06	24.14	6.65	3.40	4.25
16.08	26.04	6.65	3.25	4.20
17.16	28.30	6.70	3.20	4.25
18.22	30.64	6.75	3.05	4.25

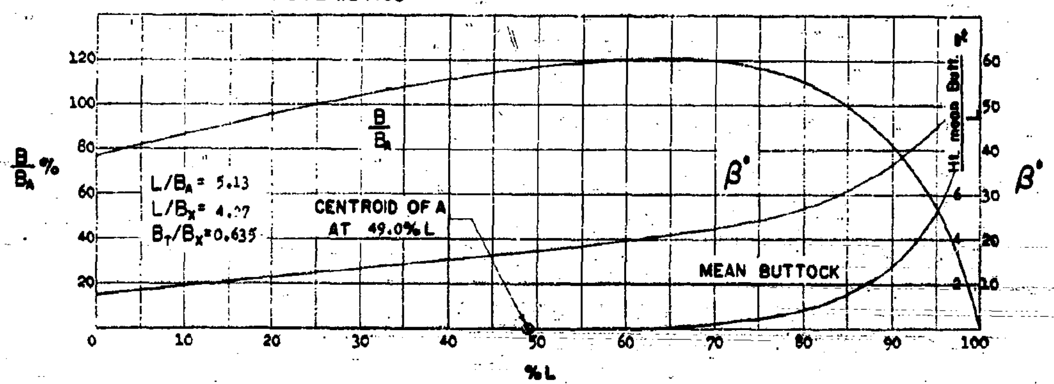
REMARKS:

Average $\frac{L}{B_A}$ ratio and narrow transom give low resistance characteristics at 2.3 $< Fn_\nabla <$ 3.5 and average resistance characteristics at $Fn_\nabla >$ 3.5. Relatively straight buttocks forward give only average resistance characteristics at $Fn_\nabla <$ 2.3.

I TEST CONDITIONS

TEST NO.	Δ_M lb	Δ_S lb	$\frac{A}{\nabla^{2/3}}$	$\frac{L}{\nabla^{1/3}}$	MAXIMUM STABLE $F_{n\nabla}$	τ_o	α_o	DRAFT COEFF. FWD.	DRAFT COEFF. AFT.	CG AFT OF CENTROID OF A	LCG % L
2	98.0	61,900	8.44	6.58	------	2.25° x STERN	+ 1.55°				
3	78.9	49,000	9.75	7.07	------	1.78° x STERN	+ 1.08°				
4	120.8	75,000	7.34	6.13	------	2.68° x STERN	+ 1.98°				
5	129.6	81,850	7.00	5.99	------	0.75° x STERN	+ 0.05°	1.133	1.170	6.0 %L	43.0

II FORM CHARACTERISTICS



III LINES

MODEL	FULL SIZE
A = 11.415 sq. ft.	A = 824.73 sq. ft
L = 7.649 ft.	L = 65.02 ft.
B_A = 1.492 ft.	B_A = 12.68 ft.

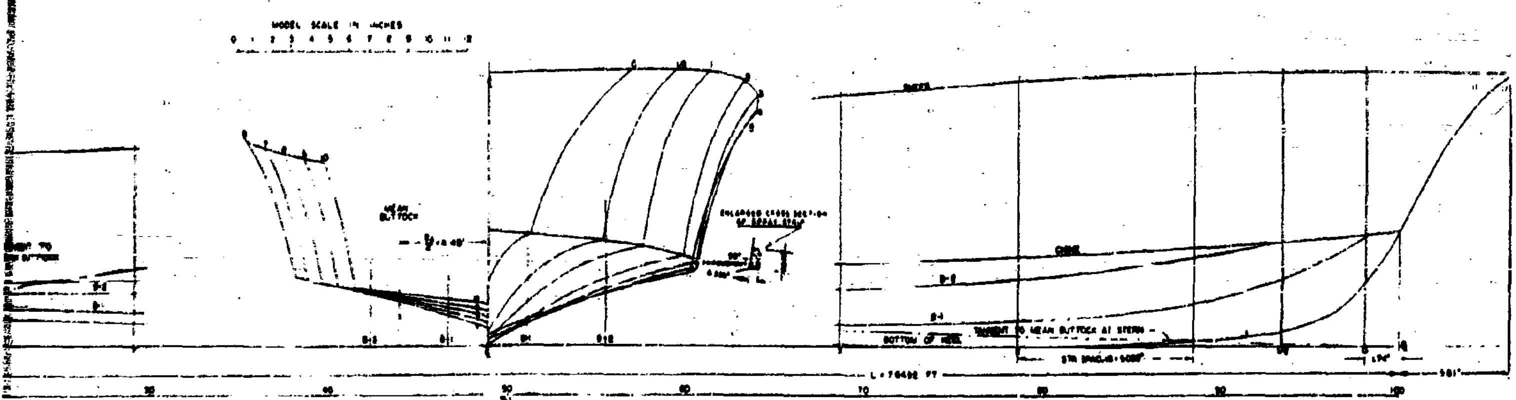
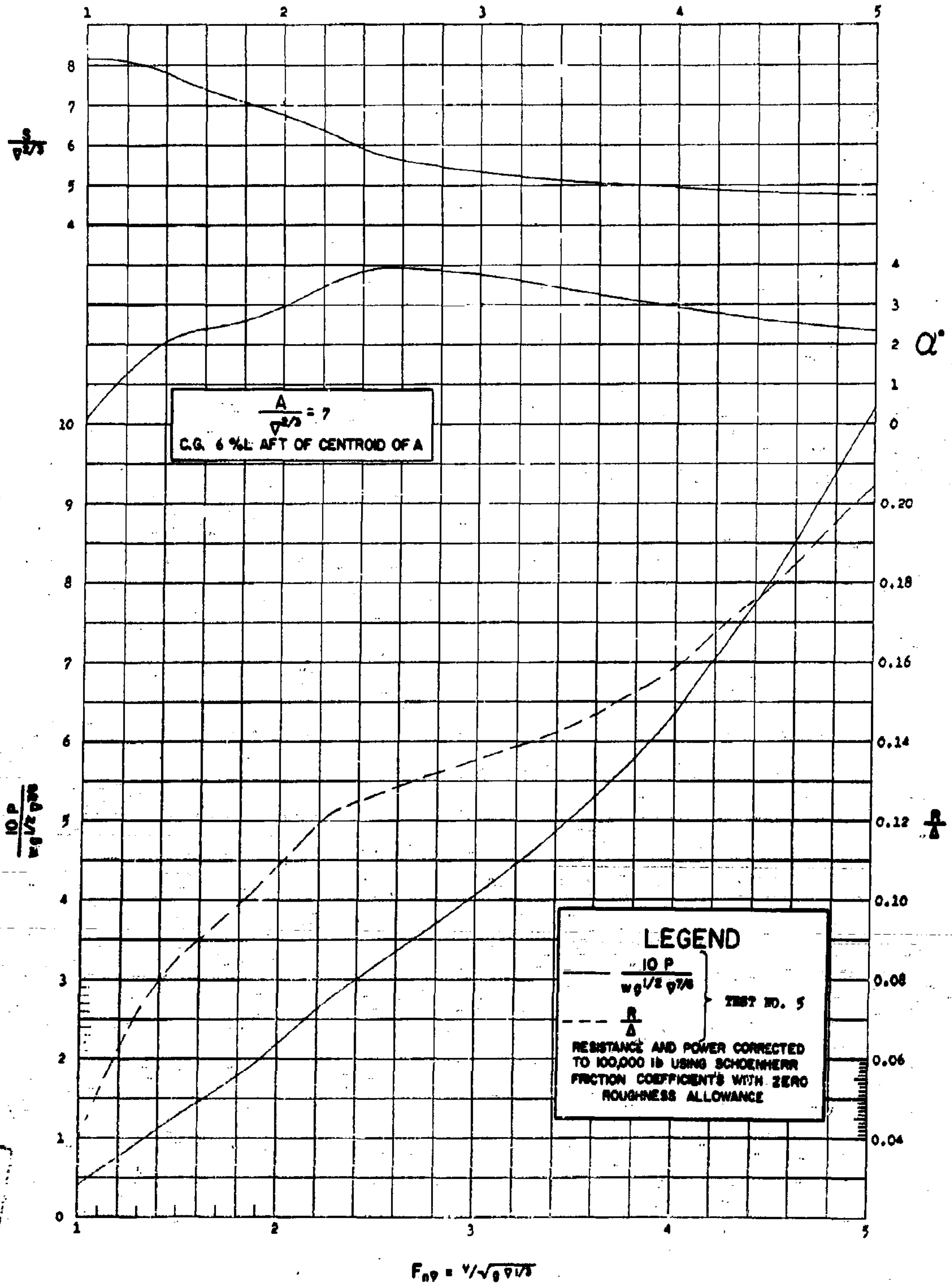
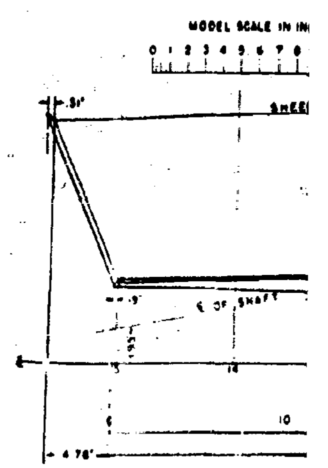


Figure 3 - Design Data Sheet for Model 3626

IV PERFORMANCE CHARACTERISTICS





1

PLANING BOAT DESIGN DATA SHEET
DAVID W. TAYLOR MODEL BASIN

JUNE 1955

DTMB MODEL 3720 1/9 SCALE 79 FT. HIG

REMARKS:

Relatively high $\frac{L}{B_A}$ ratio, excessive twist (indicated by rate of change of β) and pronounced concave sections give average resistance characteristics at $Fn_{\nabla} < 2$ and poor resistance characteristics at $Fn_{\nabla} > 2$.

I TEST CONDITIONS

TEST NO.	Δ_M lb	Δ_S lb	$\frac{A}{\nabla^{2/3}}$	$\frac{L}{\nabla^{1/3}}$	MAXIMUM STABLE $F_{n\nabla}$	τ_o	α_o	DRAFT COEFF. FWD.	DRAFT COEFF. AFT.	CG AFT OF CENTROID OF A
1	121.3	89,120	7.78	6.61	--------	0.58° x STERN	+1.12°			13.1%
2	121.3	89,120	7.78	6.61	--------	1.79° x BOW	-1.25°			2.3%
3	134.5	98,830	7.26	6.39	--------	1.57° x BOW	-1.03°			3.7%L
4	134.5	98,830	7.26	6.39	--------	0.87° x BOW	-0.33°			7.7%L
5	139.6	104,660	7.00	6.27	--------	1.05° x BOW	-0.51°	1.557	1.123	6.0%L

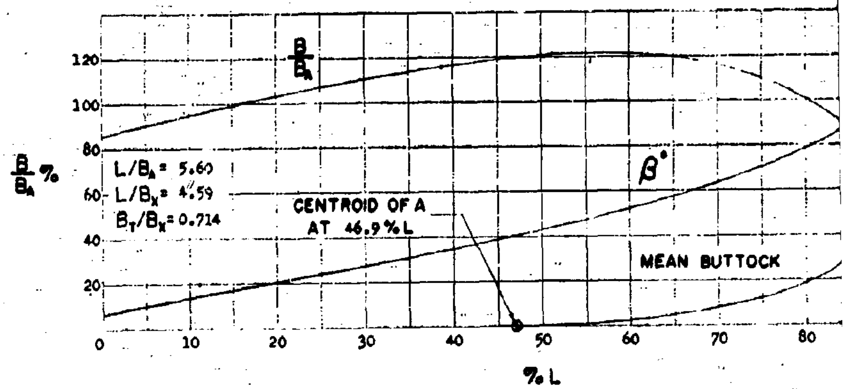
MODEL DATA

BASIN HIGH SPEED BASIN
BASIN SIZE 2968'x21'x(10'and 16')
DATE OF TEST 7 DEC 54
WATER TEMP. 63°F
APPENDAGES KEEL & SPRAY STRIPS
TURBULENCE STIM. NONE
MODEL MATERIAL WOOD
MODEL FINISH PAINT
TEST NO. 5

V_M	R_M	WL_K	WL_C	WL_{SP}
3.84	6.37	7.82	6.60	7.40
4.80	10.63	7.72	6.20	7.10
5.74	13.37	7.60	5.77	6.80
6.73	15.35	7.50	5.45	6.60
7.68	17.46	7.40	5.13	6.25
8.64	19.53	7.20	4.73	5.60
9.58	20.56	7.00	4.40	5.15
10.62	21.67	6.80	4.15	4.85
11.53	22.68	6.75	3.95	4.55
12.50	23.78	6.70	3.77	4.40
13.46	24.93	6.70	3.60	4.35
14.41	26.48	6.70	3.40	4.35
15.42	28.18	6.70	3.30	4.35
16.30	30.18	6.70	3.15	4.35
17.28	32.27	6.75	3.00	4.40
18.26	34.76	6.80	3.00	4.45
19.20	37.08	6.80	2.80	4.55

2

II FORM CHARACTERISTICS



III LINES

MODEL

A = 11.993 sq ft
L = 8.200 ft
B_A = 1.463 ft

FULL SIZE

A = 971.4 sq ft
L = 7.38 ft
B_A = 13.17 ft

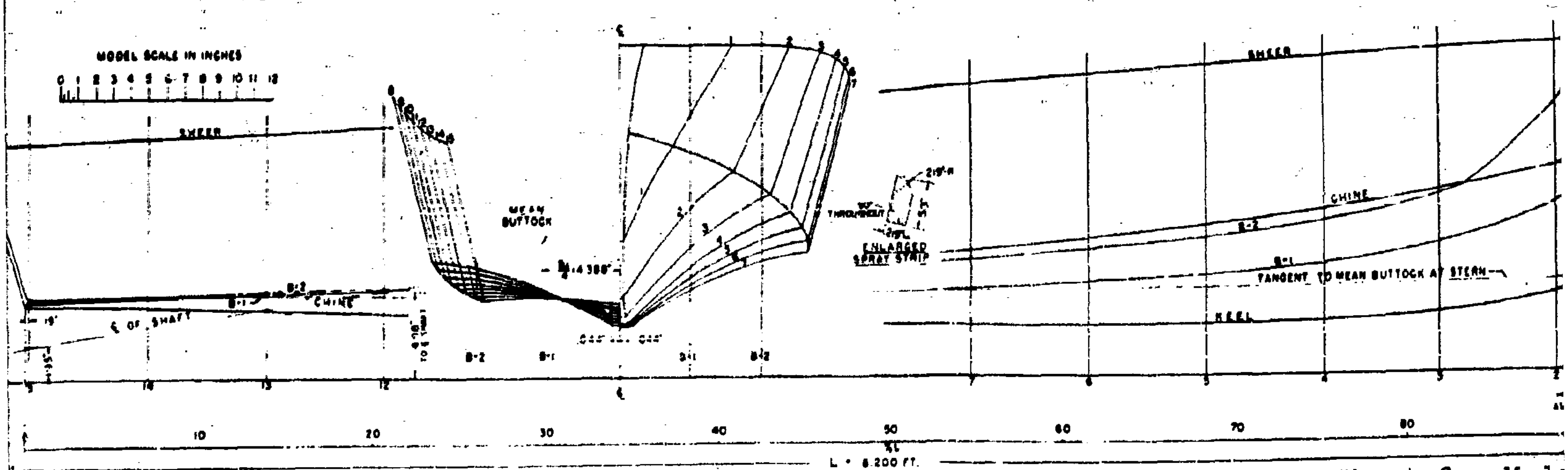


Figure 4 - Design Data Sheet for Mode

PLANING BOAT DESIGN DATA SHEET
DAVID W. TAYLOR MODEL BASIN

JUNE 1955

DTMB MODEL 3720 | 1/9 SCALE | 79 FT. HIGGINS PT BOAT

3

REMARKS

Relatively high $\frac{L}{B_A}$ ratio, excessive twist (indicated by rate of change of angle β) and pronounced concave sections give average resistance characteristics at $Fn_\nabla < 2$ and poor resistance characteristics at $Fn_\nabla > 2$.

MODEL DATA

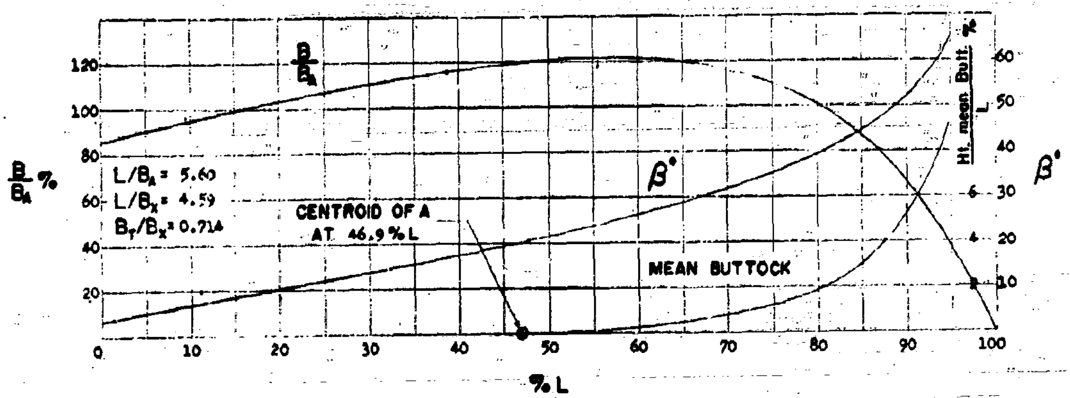
N HIGH SPEED BASIN
N SIZE 2968'x21'x(10'and 16')
: OF TEST 7 DEC 54
ER TEMP. 63°F
NDAGES KEEL & SPRAY STRIPS
BULENCE STIM. NONE
EL MATERIAL WOOD
EL FINISH PAINT
NO. 5

R_M	WL_K	WL_C	WL_{SP}
6.37	7.82	6.60	7.40
10.63	7.72	6.20	7.10
13.37	7.60	5.77	6.80
15.35	7.50	5.45	6.60
17.46	7.40	5.13	6.25
19.53	7.20	4.73	5.60
20.56	7.00	4.40	5.15
21.67	6.80	4.15	4.85
22.68	6.75	3.95	4.55
23.78	6.70	3.77	4.40
24.93	6.70	3.60	4.35
26.48	6.70	3.40	4.35
28.18	6.70	3.30	4.35
30.18	6.70	3.15	4.35
32.27	6.75	3.00	4.40
34.76	6.80	3.00	4.45
37.08	6.80	2.80	4.55

I TEST CONDITIONS

TEST NO.	Δ_M lb	Δ_S lb	$\frac{A}{\nabla^{2/3}}$	$\frac{L}{\nabla^{1/3}}$	MAXIMUM STABLE Fn_∇	$\tau_\circ$	$\alpha_\circ$	DRAFT COEFF. FWD.	DRAFT COEFF. AFT.	C.G. AFT OF CENTROID OF A	LCG % L
1	121.3	89,120	7.78	6.61	--------	0.58°x STERN	+1.12°			13.1%L	33.8
2	121.3	89,120	7.78	6.61	--------	1.79°x BOW	-1.25°			2.3%L	44.6
3	134.5	98,830	7.26	6.39	--------	1.57°x BOW	-1.03°			3.7%L	43.2
4	134.5	98,830	7.26	6.39	--------	0.87°x BOW	-0.33°			7.7%L	39.2
5	139.6	104,660	7.00	6.27	--------	1.05°x BOW	-0.51°	1.557	1.123	-6.0%L	40.9

II FORM CHARACTERISTICS



III LINES

MODEL

A = 11.993 sq ft
L = 8.200 ft
B_A = 1.463 ft

FULL SIZE

A = 971.4 sq ft
L = 73.8 ft
B_A = 13.17 ft

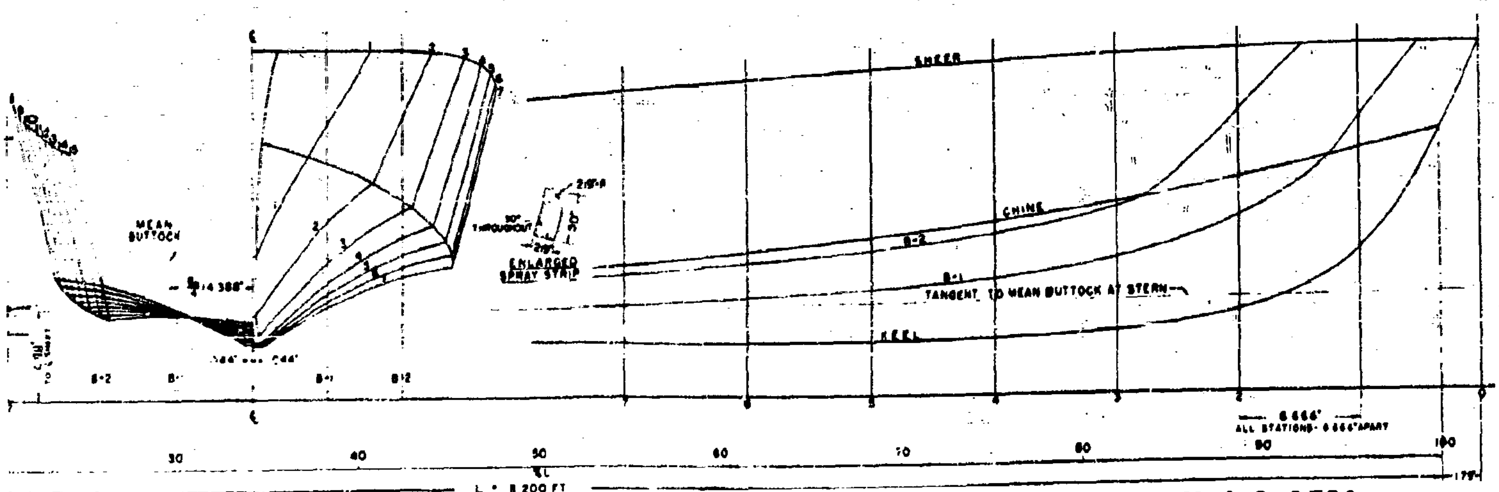
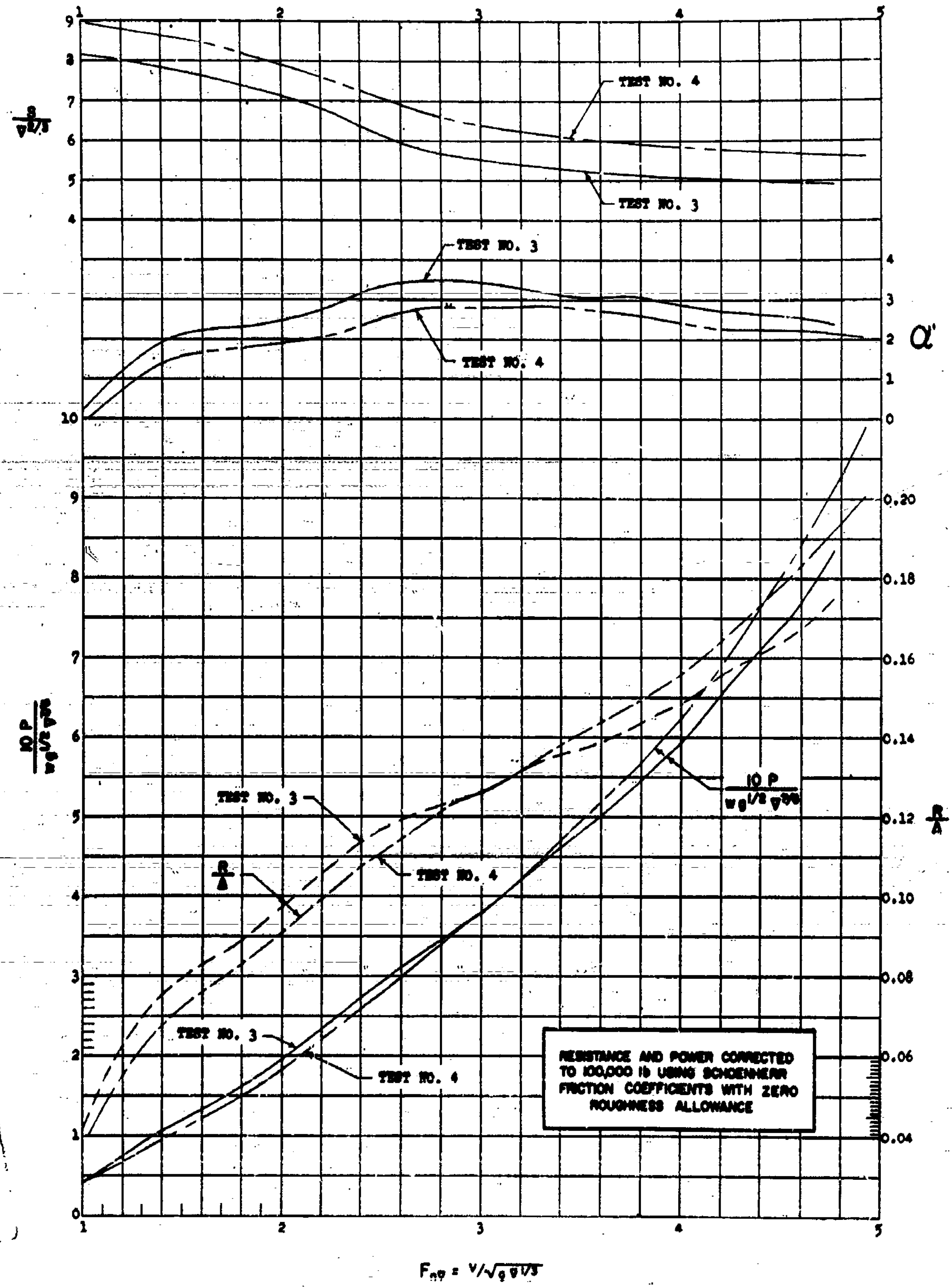


Figure 4 - Design Data Sheet for Model 3720

IV PERFORMANCE CHARACTERISTICS



2

PLANING BOAT DESIGN DATA SHEET
DAVID W. TAYLOR MODEL BASIN

JUNE 1955

DTMB MODEL 3722 | 1/9 SCALE

REMARKS:

Relatively high $\frac{L}{B_A}$ ratio and narrow transom give low resistance chara[cteristics] at $Fn_{\nabla} < 3$. Average resistance characteristics at $Fn_{\nabla} > 3$.

MODEL DATA

BASIN HIGH SPEED BASIN
BASIN SIZE 2968'x21'x(10'and 16')
DATE OF TEST 8 FEB 55
WATER TEMP 61°F
APPENDAGES SPRAY STRIPS
TURBULENCE STIM NONE
MODEL MATERIAL WOOD
MODEL FINISH PAINT

TEST NO. 3

V_M	R_M	WL_K	WL_C	WL_{SP}
3.89	6.97	8.22	7.50	8.18
4.87	11.12	8.10	6.95	7.84
5.85	13.46	8.00	6.48	7.53
6.81	15.10	7.95	6.19	7.30
7.77	16.89	7.86	5.91	7.08
8.72	18.83	7.75	5.58	6.60
9.67	20.49	7.53	5.15	5.82
10.69	21.69	7.39	4.82	5.40
11.67	22.76	7.22	4.60	5.72
12.60	24.24	7.19	4.38	4.95
13.60	25.43	7.12	4.20	4.80
14.59	26.84	7.10	4.02	4.67
15.57	28.38	7.10	3.89	4.53
16.53	30.39	7.13	3.73	4.42
17.52	32.10	7.16	3.65	4.40
18.51	34.40	7.20	3.53	4.30

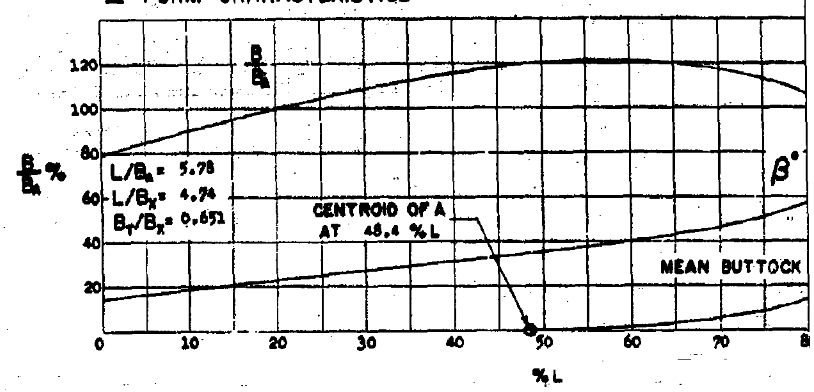
TEST NO. 4

V_M	R_M	WL_K	WL_C	WL_{SP}
3.88	5.58	8.20	7.20	8.02
4.82	8.49	8.09	6.72	7.80
5.82	10.55	8.00	6.22	7.45
6.79	12.08	7.92	5.98	7.22
7.75	13.78	7.90	5.70	7.04
8.72	15.49	7.80	5.41	6.64
9.68	17.02	7.63	5.02	6.00
10.70	18.61	7.50		5.40
11.67	19.75	7.40	4.42	5.10
12.59	21.25	7.35	4.22	4.90
13.60	22.73	7.29	4.02	4.70
14.60	24.32	7.24	3.83	4.60
15.60	26.22	7.27	3.72	4.40
16.56	28.28	7.28	3.60	4.40
17.49	30.45	7.30	3.48	4.30
18.51	33.02	7.30		4.35

I TEST CONDITIONS

TEST NO.	Δ_M lb	Δ_S lb	$\frac{A}{\nabla^{2/3}}$	$\frac{L}{\nabla^{1/3}}$	MAXIMUM STABLE $F_{n\nabla}$	τ_o	α_o	DRAFT COEFF. FWD.	DRAFT COEFF. AFT.
1	128.7	94,500	7.79	6.70	--------	1.60° x BOW	-1.30°	1.795	0.762
2	142.9	105,000	7.25	6.47	--------	0.90° x BOW	-0.60°	1.380	0.994
3	148.0	110,960	7.00	6.36	--------	0.65° x BOW	-0.35°	1.444	1.171
4	121.1	90,790	[illegible]	6.80	--------	0.79° x BOW	-0.45°	1.409	0.982

II FORM CHARACTERISTICS



III LINES

MODEL	FULL SIZE
A = 12.466 sq ft	A = 1009.8 sq ft
L = 8.488 ft	L = 76.39 ft
B_A = 1.469 ft	B_A = 13.22 ft

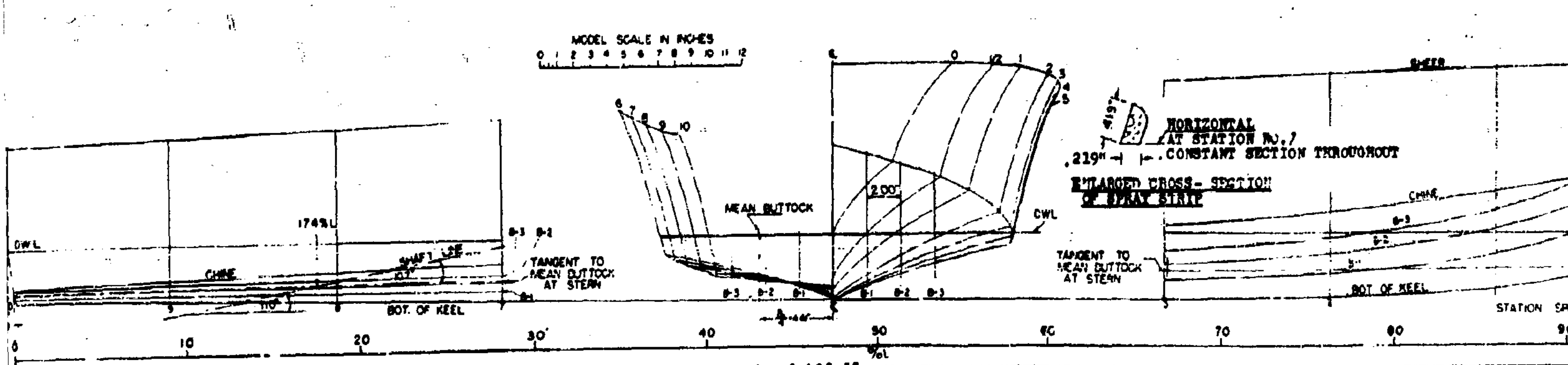


Figure 5 - Design Data Sheet for Model

PLANING BOAT DESIGN DATA SHEET
DAVID W. TAYLOR MODEL BASIN

JUNE 1955

DTMB MODEL 3722   1/9 SCALE   80 FT. ELCO PT BOAT

3

DATA

ASIN

21'x(10'and 16')

EB 55

STRIPS

NONE

WOOD

PAINT

TEST NO. 4				
V_M	R_M	WL_K	WL_C?	WL_{SP}?
3.88	5.58	8.20	7.20	8.02
4.82	8.49	8.09	6.72	7.80
5.82	10.55	8.00	6.22	7.45
6.79	12.08	7.92	5.96	7.22
7.75	13.78	7.90	5.70	7.04
8.72	15.49	7.80	5.41	6.64
9.68	17.02	7.63	5.02	6.00
0.70	18.61	7.50		5.40
1.67	19.75	7.40	4.42	5.10
2.59	21.25	7.35	4.22	4.90
3.60	22.73	7.29	4.02	4.70
4.60	24.32	7.24	3.83	4.60
5.60	26.22	7.27	3.72	4.40
6.56	28.28	7.28	3.60	4.40
.49	30.45	7.30	3.48	4.30
8.51	33.02	7.30		4.35

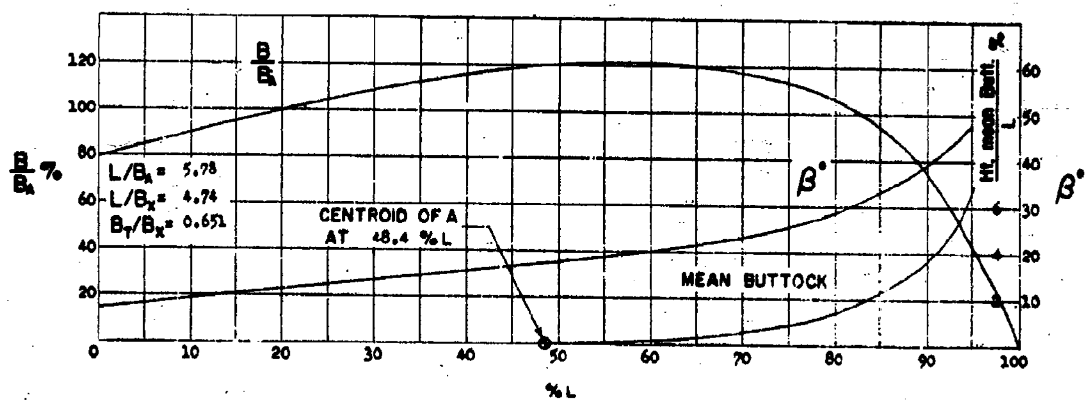
REMARKS:

Relatively high $\frac{L}{B_A}$ ratio and narrow transom give low resistance characteristics at $Fn_\nabla < 3$. Average resistance characteristics at $Fn_\nabla > 3$.

I TEST CONDITIONS

TEST NO.	Δ_M lb	Δ_S lb	$\frac{A}{\nabla^{2/3}}$	$\frac{L}{\nabla^{1/3}}$	MAXIMUM STABLE $F_{n\nabla}$	τ_o	α_o	DRAFT COEFF. FWD.	DRAFT COEFF. AFT.	CG AFT OF CENTROID OF A	LCG %L
1	128.7	94,500	7.79	6.70	--------	1.60° x BOW	-1.30°	1.795	0.762	2.1%L	46.3
2	142.9	105,000	7.25	6.47	--------	0.90° x BOW	-0.60°	1.380	0.994	5.1%L	43.3
3	148.0	110,960	7.00	6.36	--------	0.65° x BOW	-0.35°	1.444	1.171	6.0%L	42.4
4	121.1	90,790	8.00	6.80	--------	0.75° x BOW	-0.45°	1.409	0.982	6.0%L	42.4

II FORM CHARACTERISTICS



III LINES

MODEL	FULL SIZE
A = 12.466 sq ft	A = 1009.8 sq ft
L = 8.488 ft	L = 76.39 ft
B_A = 1.469 ft	B_A = 13.22 ft

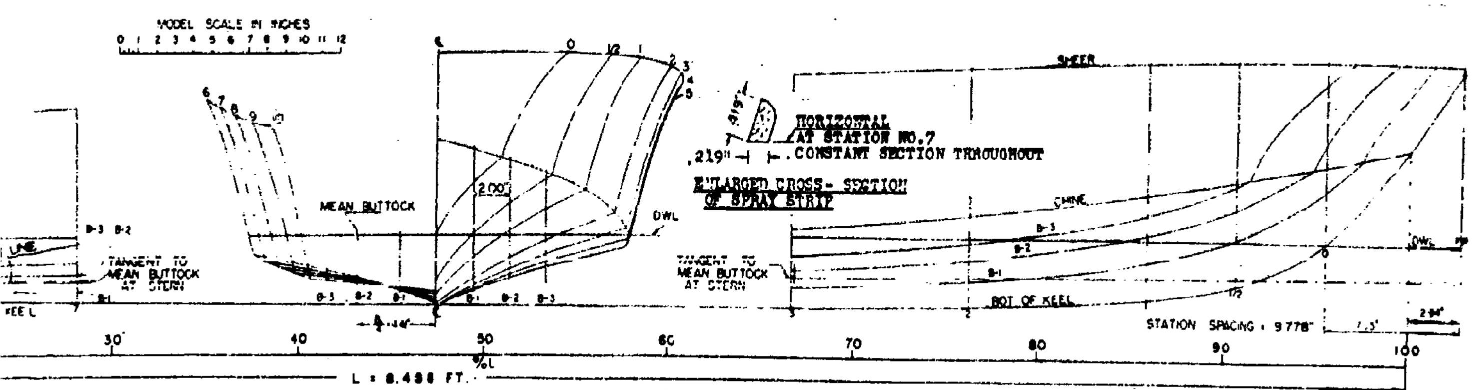


Figure 5 - Design Data Sheet for Model 3722

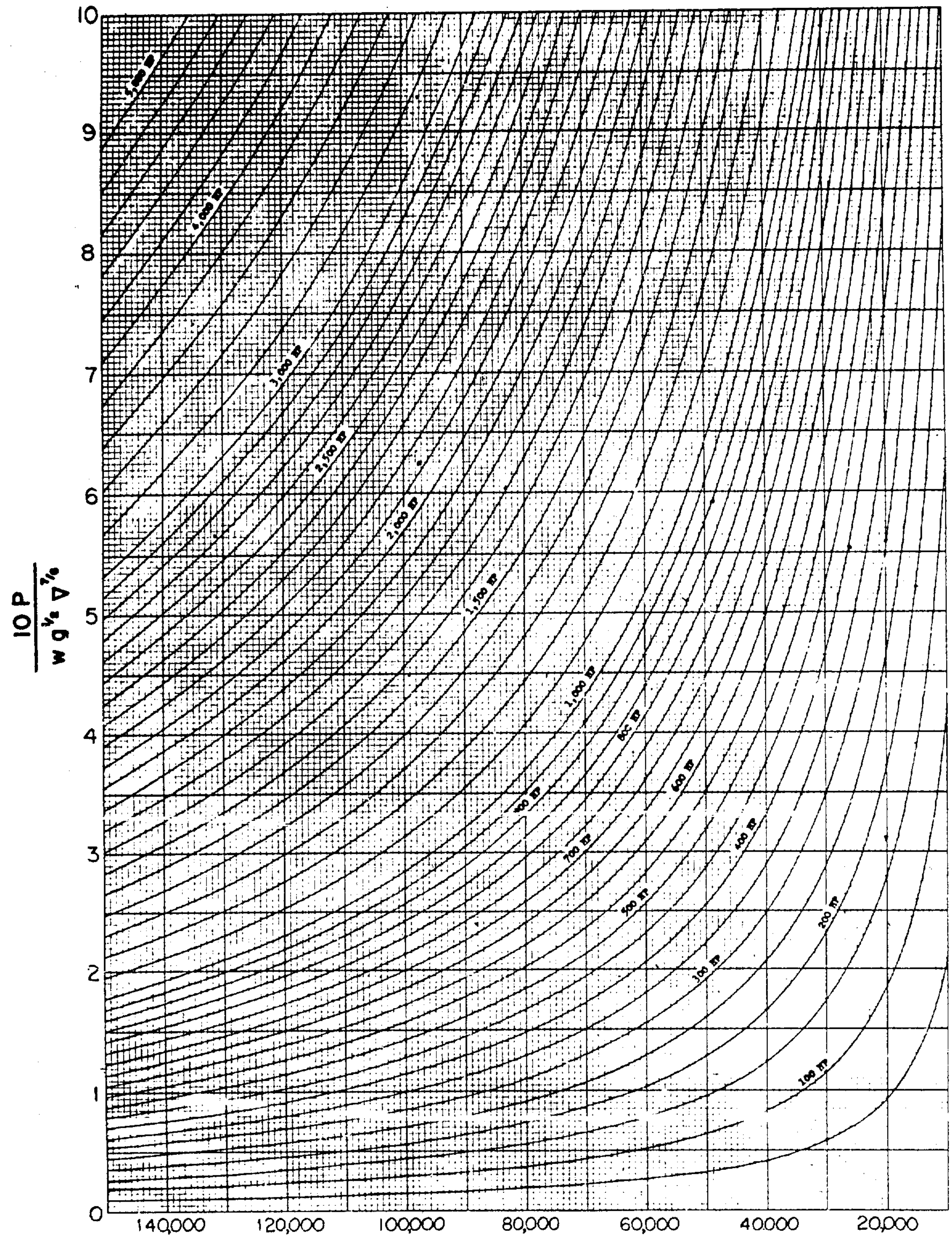


Figure 6 - Variation of Power Coefficient with Displacement and Effective Horsepower.

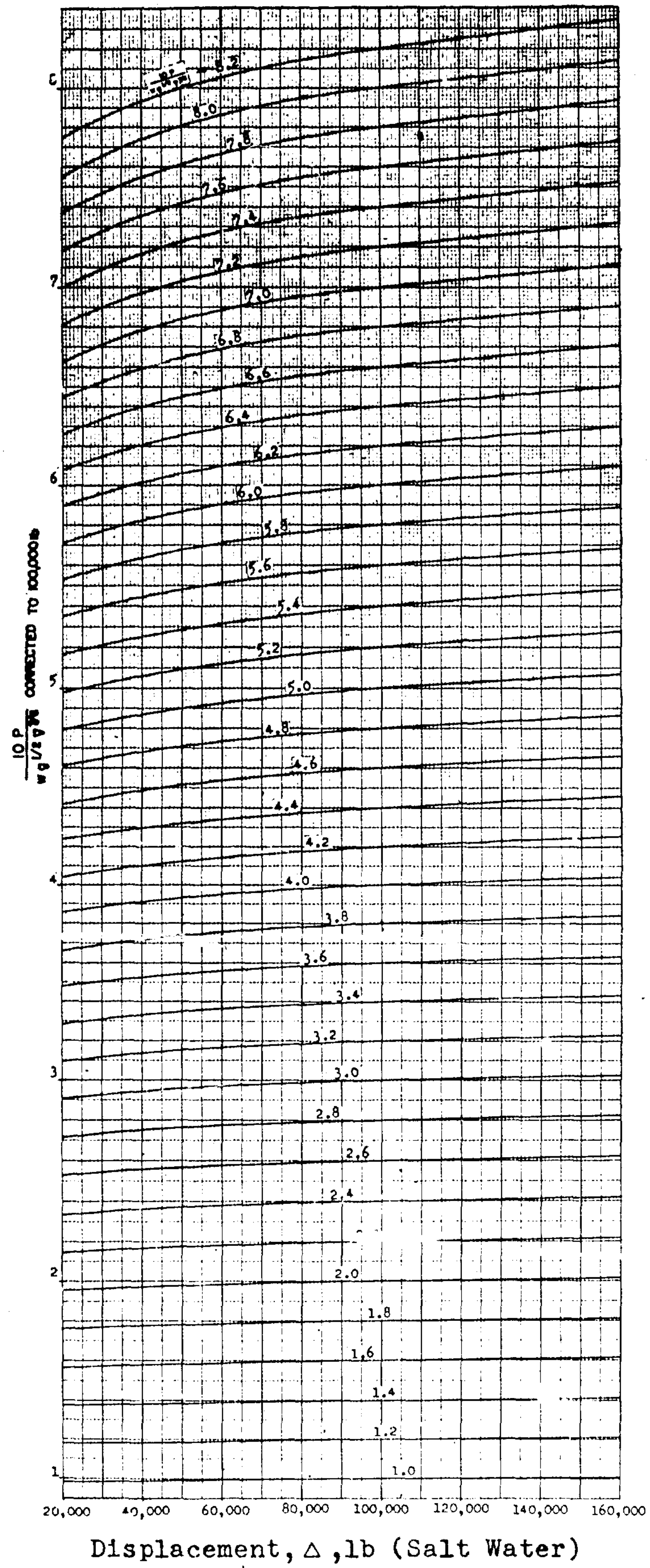


Figure 7 - Chart for Converting Power Coefficients at 100,000 Pounds Displacement to Other Values of Displacement.

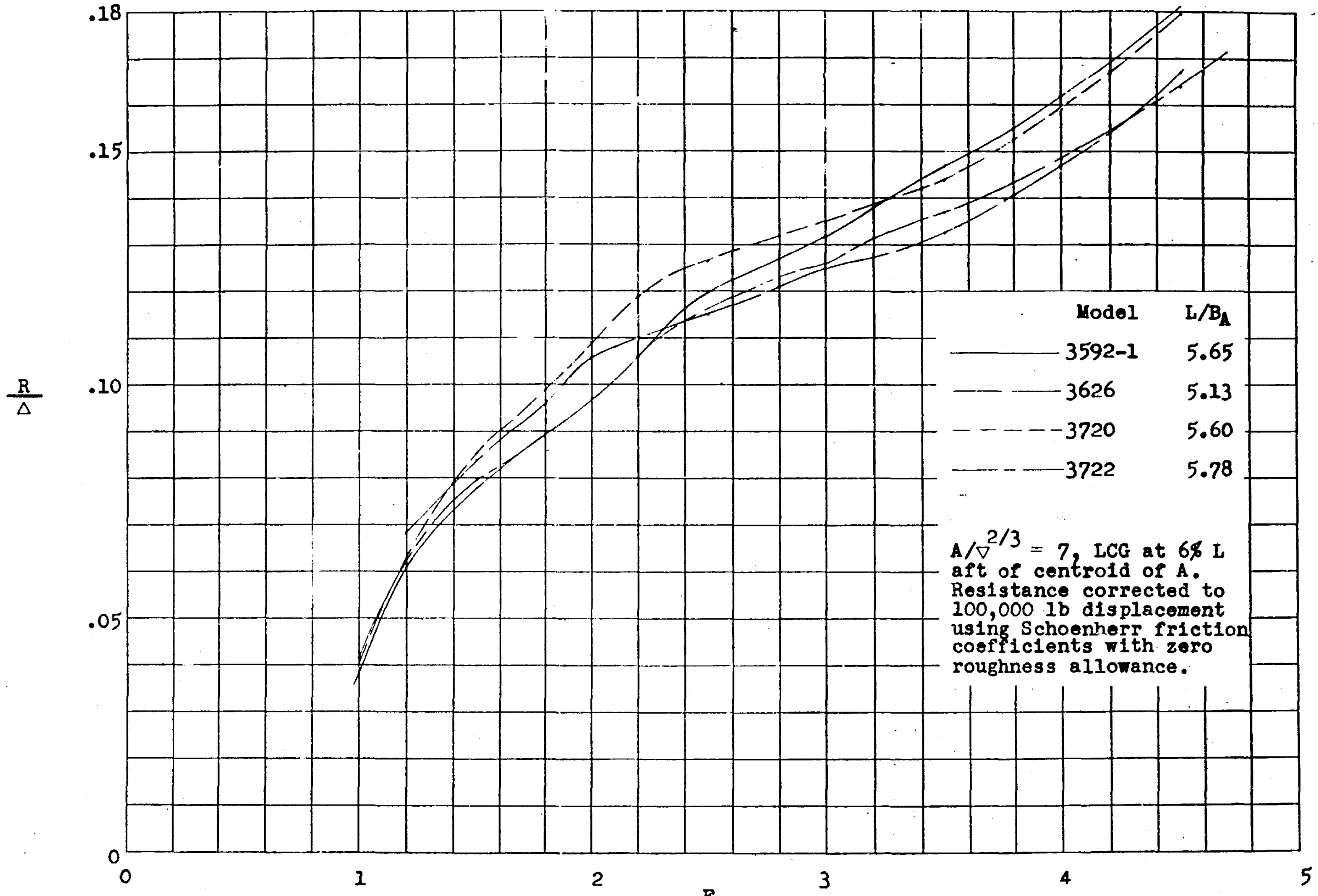


Figure 9 - A Comparison of the Resistance of Four Planing Boat Designs.

ANALYZING THE STEPLESS PLANING BOAT

by

EUGENE P. CLEMENT

Introduction

During recent years the David Taylor Model Basin has towed a number of models of planing craft in smooth water to determine resistance, trim angle, wetted lengths and wetted surface. In most cases each of these models was considered to represent a particular full-scale boat, and the data obtained were presented in dimensional form for specific boat dimensions and displacements. Each model, however, can represent a boat of any size. Therefore, when a new design is to be developed, all models of previous designs can be considered to represent boats of the size of the new design, and the data on their performance can be used for guidance. In order to do this easily the designer needs to have the information on the previous designs in suitable form. The purpose of this report is mainly to indicate appropriate methods of presenting and utilizing the accumulated information on hull forms and model test results for planing boats to guide the design of future boats.

In this report the important planing hull parameters are defined and a convenient method of combining them in a hullform characteristics sheet is shown. A plan for presenting model test results in a dimensionless form suitable for comparison and analysis is next given. The hull-form characteristics and model test results are at present being incorporated in a Taylor Model Basin design data sheet, an example of which is given. The effects on performance of variations in some of the primary parameters are then illustrated and discussed. Also, methods are proposed for improving the usefulness of future model tests for purposes of comparison and analysis. Finally, a step by step design method is proposed, and data are presented which it is believed will assist the designer in making design decisions quickly and with assurance of correctness.

Hull Form and Hull Loading Parameters

The primary parameters affecting the performance of planing hulls, in the approximate order of their importance, are as follows:

a. Ratio of length to beam. This important ratio is defined here as the ratio of the length L, of the hull bottom, to the mean breadth B_A, of the chines (see Notation, p. 253). The chief reason for defining the length of a planing hull in this way is so that only one value of the length dimension will be assigned to each set of lines. If the length dimension is defined as the length of the load waterline, then a given set of lines could conceivably have various lengths assigned to it at different times, depending upon the particular displacement and center of gravity location of each instance.

b. Size-displacement, or area, coefficient. The relationship between hull size and gross weight can be expressed in convenient dimensionless form by the ratio $A/\nabla^{2/3}$, where A is the projected area bounded by the chines and transom, in plan view, and ∇ is the volume of water displaced at rest. Since this coefficient is dimensionless it yields the same value for geometrically similar boats of different size but of corresponding loading. It also yields the same value for two boats which have different length-beam ratios but the same area, A, and the same displacement. If two designs having different ratios of length to beam are compared on the basis of equal values of $A/\nabla^{2/3}$ the comparison will be a valid one; for, to a good first approximation (assuming the same depth of hull and similar construction) the two designs will then have equal hull area, equal hull volume, and equal hull structural weight.

It does not appear possible to make as plausible a case for any of the other coefficients which have been used to characterize the size-displacement relationship of planing boats. The well known displacement-length ratio, $\Delta/(L/100)^3$, and the load coefficient, $\Delta/wB_x{}^3$, are the ones most commonly employed. The unsatisfactory result of using $\Delta/(L/100)^3$ as the size-displacement criterion may best be illustrated by an example. Suppose that two sets of lines, A and B, are under consideration for a boat of given displacement, and that design A has a higher ratio of length to beam than design B. Comparison of these two designs on the basis of equal $\Delta/(L/100)^3$ will then result in comparing the two boats at the same length and displacement. Compared in this manner, however, design B has more beam, more hull area, and (assuming the same depth of hull and similar construction) more hull volume and more hull structural weight than design A. These differences will clearly preclude a valid comparison. A similar confusion would result if the two designs were compared on the basis of equal $\Delta/wB_x{}^3$.

c. Longitudinal CG location. It is considered appropriate to define longitudinal CG location as the distance of the CG from the centroid of the area, A, expressed as a percentage of the length L.

d. Deadrise. Deadrise angle of the hull bottom generally varies from a large angle near the bow to an angle of a few degrees at the transom. The

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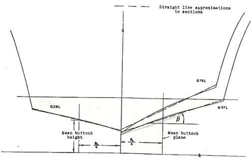


Fig. 1. *Typical Planing Boat Body Plan with Straight Line Approximations to Sections*

variation of this important angle throughout the length of the boat can be indicated by approximating each section of the body plan by a straight line (see Fig. 1) and then plotting a curve of deadrise variation versus boat length. Examples of this curve, for three different designs, are shown in Fig. 2. The variation of deadrise angle with boat length generally gives very nearly a straight line for the after half of the hull length.

e. Longitudinal curvature. The longitudinal curvature of the hull bottom is shown by the shape of the buttock lines. For purposes of comparison and analysis it is desirable to define an average, or mean, buttock. This can be conveniently done by intersecting the straight line approximations to the body plan sections by a buttock plane spaced at $B_A/4$ from the centerline plane, as shown in Fig. 1. Examples of the mean buttock curves obtained by this method are shown in dimensionless form in Fig. 3a. The mean buttock lines shown in Fig. 3a reflect the general practice to have straight buttock lines in the after portion of planing hull bottoms. Buttock lines are generally straight for at least the

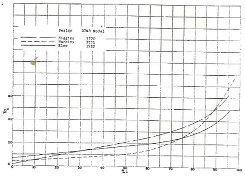


Fig. 2. *Curves of Deadrise Angle vs Boat Length for Three PT Boats of World War II*

after 30 per cent. of the hull length. It is difficult to make further comparisons of the buttock lines as they appear in Fig. 3a, since their attitudes, and their heights from the horizontal axis, reflect the arbitrary attitudes and heights above the baseline at which the corresponding lines were originally drawn. Comparison and analysis can be facilitated, therefore, by shifting each mean buttock curve so that its after end is tangent to the horizontal axis of the graph. The mean buttock lines of Fig. 3a, after being shifted in this manner, are shown in Fig. 3b. In the presentation of model test results in this report the angle of attack, or running trim of a hull is defined as the angle which the tangent to the mean buttock at the stern makes with the horizontal. This angle is designated α.

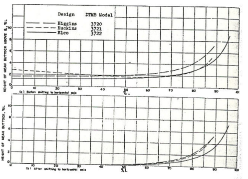


Fig. 3. *Mean Buttock Curves for Three PT Boats of World War II*

f. Plan view of chine. The significant features which are determined by the shape of the chine line in plan view are the length/beam ratio of the boat and the fore-and-aft distribution of breadth and of bottom area. Length/beam ratio has already been adequately defined as the ratio L/B_A. Therefore, it is desirable to reduce the plan view of the chine line to a form which is independent of length/beam ratio, in order to compare relative fore-and-aft distribution of bottom area. This is accomplished by plotting the ratio of local chine breadth to B_A, against hull length, as shown in Fig. 4. Each of the chine lines in Fig. 4 encloses the same area, although the ratios L/B_A of the hulls from which they were derived are all different. Several dimensionless ratios indicative of the relative fore-and-aft distribution of breadth are apparent in Fig. 4. First, the location of the point of maximum chine breadth, as a percentage of hull length from the transom, is apparent. Also, the ratios of maximum breadth and of transom breadth to the mean breadth (B_A) can be read directly from the scale of the ordinate. An important criterion of the fore-and-aft distribution of the plan-view bottom area (area A) is the loca-

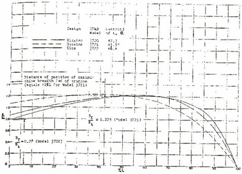


Fig. 4. *Chine Offsets in Plan View, for Three PT Boats of World War II*

tion of the centroid of this area. This dimension is given in Fig. 4, for the different designs.

g. *Type of section.* Planing boat sections generally fall into one of the following four categories:

1. *Concave.* An example of this type of section is shown in Fig. 1.
2. *Convex.* The use of developable surfaces will generally result in this type of section.
3. *Convex at keel and concave at chine.* This type is exemplified by the British Vosper PT boat of World War II.
4. *Concave at keel and convex at chine.*

All of the foregoing parameters of hull form and hull loading are incorporated in the Taylor Model Basin's design data sheet for planing boats, an example of which is shown in Fig. 5. Also included in Fig. 5 are draft coefficients at bow and stern for each of the model test conditions. Drafts at rest were measured up from the straight line which is tangent to the mean buttock at the stern. The draft readings were then converted to dimensionless coefficient form on the basis of the following reasoning:

Draft is proportional to $\frac{\nabla}{A}$.

Then, draft $=$ (draft coefficient) . $\frac{\nabla}{A}$.

Therefore, draft coefficient (C_H) $=$ draft . $\frac{A}{\nabla}$.

The draft coefficient defined in this way is independent of differences in absolute size and of differences in length/beam ratio. Also, by measuring the draft from the tangent to the mean buttock, this draft coefficient is made relatively independent of differences in deadrise angle. Accordingly, the draft coefficients for a new design can be approximately determined when draft coefficients are available from a previous similar design. The two designs should be similar in respect to $A/\nabla^{2/3}$, CG location, and longitudinal curvature. Differences in type of section and in plan form of chine should cause only slight changes in the relative values of the draft coefficients.

Performance Characteristics

A performance characteristics sheet, which presents model test results for planing hulls in a dimensionless form suitable for comparison and analysis, is included in the design data sheet shown in Fig. 5. Also included in the design data sheet are the hull lines and other pertinent dimensions and coefficients. It is the intention of the Taylor Model Basin to prepare such a design data sheet for each planing hull model tested in the future, and also for a selected number of those models previously tested.

Since displacement is a fundamental design quantity it is desirable to compare hull forms on the basis of equal displacement. This is facilitated in the performance characteristics sheet shown in Fig. 5 by relating each of the variables, speed, resistance and wetted surface, to displacement, by means of the dimensionless ratios $v/\sqrt{g}\nabla^{1/6}$, R/Δ and $S/\nabla^{2/3}$, respectively.

Relating resistance to displacement as indicated here is the usual practice in this country in dealing with planing boats. Unfortunately, however, it is not general practice to relate planing boat speed to displacement. The general practice is to compare the resistances of planing hulls by plotting the ratio of resistance to displacement against speed-length ratio ($V/\sqrt{L}$). This method often gives an incorrect comparison, as shown by the following example. Suppose that a 100,000 lb., 40 knot boat is required. In Fig. 6 the resistance curves for two models having different values of length-displacement constant ($L/\nabla^{1/3}$) are plotted in the usual manner.[1]) Fig. 6 gives the impression that a boat based on Model 2727 would have higher resistance than a boat based on Model 2742. Such is not the case, however, because the use of $V/\sqrt{L}$ as abscissa does not bring the actual full scale speeds into correspondence. That is, since the models have different values of length-displacement constant ($L/\nabla^{1/3}$), a given value of $V/\sqrt{L}$ does not correspond to the same full scale speed for both designs. For Model 2727, expanded to 100,000 lbs. displacement, 40 knots corresponds to a value of $V/\sqrt{L} = 3.93$, while for Model 2742, expanded to 100,000 lbs.

[1]) These values are taken from the original data for Reference 1. The data for Model 2727 are from the test at normal displacement and 2° initial trim by stern. The data for Model 2742 are from the test at normal displacement and 0° initial trim. No correction for the difference in the frictional resistance coefficients of model and full size boat has been made, since that seemed unnecessary for the purpose of this illustration.

PLANING BOAT DESIGN DATA SHEET
DAVID W. TAYLOR MODEL BASIN

JUNE 1955

DTMB MODEL 3722 — 1/9 SCALE — 80 FT. ELCO PT BOAT

$B_T = 7°$
$B_X = 18°$
$\tau = 11°$

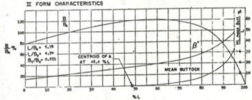
REMARKS.

Relatively high $\frac{L}{B_A}$ ratio and narrow transom give low resistance characteristics at $Fn_{\nabla} < 3$. Average resistance characteristics at $Fn_{\nabla} > 3$.

I TEST CONDITIONS

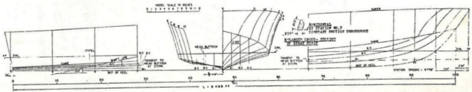
TEST NO.	Δ_M lb	Δ_S lb	$\frac{A}{\nabla^{2/3}}$	$\frac{L}{\nabla^{1/3}}$	MAXIMUM STABLE $F_{n\nabla}$	τ_0	α_0	DRAFT COEFF. FWD.	DRAFT COEFF. AFT.	CG AFT OF CENTROID OF A	LCG %L
1	128.7	94,500	7.79	6.70	--------	1.60° x BOW	-1.30°	1.795	0.762	2.1%L	46.3
2	142.9	105,000	7.25	6.47	--------	0.90° x BOW	-0.60°	1.380	0.994	5.1%L	43.3
3	148.0	110,960	7.00	6.36	--------	0.65° x BOW	-0.35°	1.444	1.171	6.0%L	42.4
4	121.1	90,790	8.00	6.80	--------	0.75° x BOW	-0.45°	1.409	0.982	6.0%L	42.4

II FORM CHARACTERISTICS



III LINES

MODEL	FULL SIZE
A = 12.466 sq ft	A = 1009.8 sq ft
L = 8.488 ft	L = 76.39 ft
B_A = 1.469 ft	B_A = 13.22 ft



MODEL DATA

BASIN HIGH SPEED BASIN
BASIN SIZE 2968'x21'x(10' and 16')
DATE OF TEST 8 FEB 55
WATER TEMP 61°F
APPENDAGES SPRAY STRIPS
TURBULENCE STIM. NONE
MODEL MATERIAL WOOD
MODEL FINISH PAINT

TEST NO. 3

V_M	R_M	WL_K	WL_C	WL_{SP}
3.89	6.97	8.22	7.50	8.18
4.87	11.12	8.10	6.95	7.84
5.85	13.46	8.00	6.48	7.53
6.81	15.10	7.95	6.19	7.30
7.77	16.89	7.86	5.91	7.08
8.72	18.83	7.75	5.58	6.60
9.67	20.49	7.53	5.15	5.82
10.69	21.69	7.39	4.82	5.40
11.67	22.76	7.22	4.60	5.72
12.60	24.24	7.19	4.38	4.95
13.60	25.43	7.12	4.20	4.80
14.59	26.84	7.10	4.02	4.67
15.57	28.38	7.10	3.89	4.53
16.53	30.39	7.13	3.73	4.42
17.52	32.10	7.16	3.65	4.40
18.51	34.40	7.20	3.53	4.30

TEST NO. 4

V_M	R_M	WL_K	WL_C	WL_{SP}
3.88	5.58	8.20	7.20	8.02
4.82	8.49	8.09	6.72	7.80
5.82	10.55	8.00	6.22	7.45
6.79	12.08	7.92	5.98	7.22
7.75	13.78	7.90	5.70	7.04
8.72	15.49	7.80	5.41	6.64
9.68	17.02	7.63	5.02	6.00
10.70	18.61	7.50		5.40
11.67	19.75	7.40	4.42	5.10
12.59	21.25	7.35	4.22	4.90
13.60	22.73	7.29	4.02	4.70
14.60	24.32	7.24	3.83	4.60
15.60	26.22	7.27	3.72	4.40
16.56	28.28	7.28	3.60	4.40
17.49	30.45	7.30	3.48	4.30
18.51	33.02	7.30		4.35

DTMB MODEL 3722

IV PERFORMANCE CHARACTERISTICS

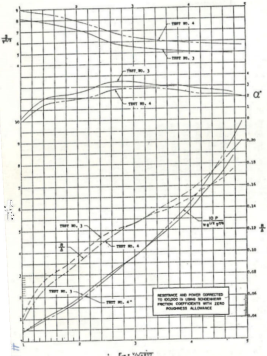


Fig. 5. *Typical Design Data Sheet*

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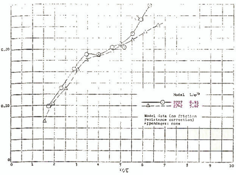

Fig. 6. *Resistances of Two Models from EMB Series 50, Compared by the Method in General Use*

displacement, 40 knots corresponds to a value of $V/\sqrt{L} = 4.95$. Therefore, plotting R/Δ against $V/\sqrt{L}$ amounts, in this case, to comparing the resistances of the two designs at entirely different speeds. What is required is a plot of R/Δ versus a coefficient which will bring the full scale speeds into alignment. The speed coefficient $F_{n\nabla}$ is correct for the purpose because it is derived from the significant quantities of the design problem, i.e.: speed and displacement. In Fig. 7, the data from Fig. 6 have been replotted on an abscissa of $F_{n\nabla}$. Here, the resistance curves are shown in their correct relationship, and the order of superiority is the reverse of that shown in Fig. 6. The value of $F_{n\nabla} = 3.5$ corresponds to 40 knots for both designs at 100,000 lbs. displacement. More generally, a particular value of $F_{n\nabla}$ corresponds to the same full scale speed for both designs, for the same displacement.

A resistance comparison made by plotting R/Δ versus $V/\sqrt{L}$ will be incorrect unless the length-displacement constant $(L/\nabla^{1/3})$ is identical for both

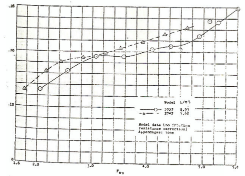

Fig. 7. *Resistances of Two Models from EMB Series 50, Compared by a Correct Method*

hulls, and an identity of $L/\nabla^{1/3}$ will generally not be the case. Confusion and error will also result from using the speed coefficient $v/\sqrt{gB_x}$ (which is sometimes used for planing boat analysis) to compare hulls of different proportions, except when the ratio $B_x/\nabla^{1/3}$ (or Δ/wB_x^3) is the same for both boats.

Wetted surface and trim angle are included in the performance sheet because they are proportional, respectively, to the frictional and wavemaking resistance of planing hulls. At a given speed the frictional resistance is almost directly proportional to the wetted surface, so that for constant displacement, which is the basis of the present method of comparison, the frictional resistance of two different designs are proportional to their respective values of the dimensionless quantity, $S/\nabla^{2/3}$.

In the planing condition, the wavemaking resistance of a prismatic planing surface equals the product of the displacement and the tangent of the angle of attack of the bottom (equals $\Delta \tan \alpha$). The planing area of the conventional planing boat generally closely resembles a prismatic planing surface, and the angle α of the present paper is defined in such a way as to represent approximately the effective angle of attack of the planing area. Therefore, the wavemaking resistances of two designs which are being compared on the basis of equal displacement are in nearly the same ratio as their respective values of tan α.

Effects on Performance of Changes in Area Coefficients, Length-beam Ratio and LCG Location

An aggregate of data suitable for analyzing the effects of area coefficient and length-beam ratio on the resistance of stepless planing boats is available from the tests of EMB Series 50 (Reference 1). The original data, for 0° initial trim only, was used for the present analysis. The procedures used for varying the model loading and proportions in this series, and for presenting the resistance data in Reference 1 are the same as those used by Taylor for his standard series of ship forms. The form in which the data are available will be found disappointing by anyone who attempts to use them for determining the effects of the significant planing hull parameters on resistance, and a new approach, therefore, seems desirable.

When each of the tests of EMB Series 50 is represented by an x on a grid of $A/\nabla^{2/3}$ *vs* L/B_A, the result is as shown in Fig. 8. It can be seen that the tests fall into groups corresponding to substantially constant values of L/B_A. Three resistance curves from group D are plotted in Fig. 9 to show the effect of area coefficient on resistance for a constant value of L/B_A (which is about 4.25 in this case). The resistance curve corresponding to an

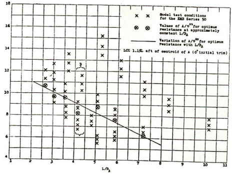

Fig. 8. *Variation of Area Coefficient for Optimum Resistance with Length/Beam Ratio, from the Data of the EMB Series 50*

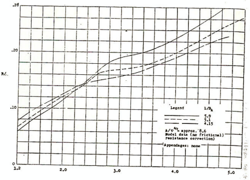

Fig. 10. *Effect of Length/Beam Ratio on Resistance, with Constant Area Coefficient*

area coefficient of 8.2 can be seen to be superior to the resistance curve corresponding to either the higher or the lower value of area coefficient.

Resistance curves for all the 0° initial trim tests of EMB Series 50 were compared by groups of equal L/B_A, and for each value of L/B_A it was possible to distinguish an optimum resistance curve corresponding to a particular value of area coefficient. In Fig. 8, the area coefficient for optimum resistance for each of the values of length-beam ratio is indicated by a circle around the appropriate *x*. It can be seen that the variation of optimum area coefficient with length-beam ratio can be represented with reasonable accuracy by a single straight line.

Resistance curves for the three tests of Fig. 8 indicated by $\bar{x}$ are plotted in Fig. 10. This shows the effect of length-beam ratio on resistance for a constant value of $A/\nabla^{2/3}$ (about 8.6). It can be seen that the high speed resistance decreases markedly with decrease of length-beam ratio, but that this is accompanied by some increase in low speed resistance. Or, looked at in a different fashion, Fig. 10 shows that a relatively long slender hull gives lower resistance at speeds below $F_{n\nabla} = 2.3$, while a relatively short wide hull gives lower resistance at speeds above $F_{n\nabla} = 2.3$.

Additional data showing the effects of a change in area coefficient on the performance of a planing hull are shown in Fig. 11. These data were obtained from tests of the same model at two different displacements but approximately the

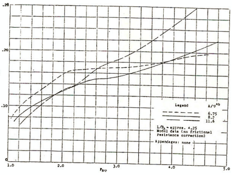

Fig. 9. *Effect of Area Coefficient on Resistance, with Constant Length/Beam Ratio*

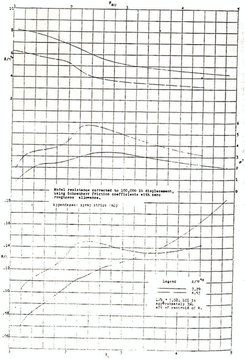

Fig. 11. *Effects on the Performance of a Typical Planing Boat Hull Form, of a Variation in Area Coefficient*

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same *LCG* location. The resistance data from both tests were corrected to 100,000 lb. displacement (a convenient average value for boats of the *PT* and *AVR* types) and are plotted in Fig. 11 in the form of R/Δ versus $F_{n\nabla}$. Compared in this manner the resistance curves indicate the relative resistance of two boats of the same hull form, same displacement, and same center of gravity location, but of different hull area. It can be seen that the smaller boat with area coefficient ($A/\nabla^{2/3}$) equal to 4.93, has a high resistance hump. This is evidently caused mainly by wavemaking resistance since it corresponds to a similar hump in the trim angle curve. At the hump speed the lower wetted surface of the smaller boat apparently is of relatively little effect in reducing resistance. At high speed the frictional effect predominates, since the frictional resistance is approximately proportional to the wetted surface times the square of the speed. Therefore, at high speed, because of her smaller wetted area, the small boat has the lower net resistance, in spite of the fact that the trim angle curves indicate that she has the higher wavemaking resistance.

The resistance curve for the small boat indicates that an area coefficient of 4.93 is too low for most practical purposes. One reason is that it would be difficult to provide adequate propeller thrust for such a high resistance hump; also, resistance at cruising speed would be high; and, finally, the high trim angle would aggravate pounding in waves.

The effects on the performance of a planing boat of a change in *LCG* location are shown in Fig. 12. These data were obtained from tests of a model at two different *LCG* locations, and the same displacement. As would be expected, moving the *CG* aft increases the trim angle of the boat and decreases the wetted area. At low speeds, where the wavemaking resistance predominates, the *CG* forward condition produces the least resistance because of the smaller trim angle. At high speeds, where the frictional resistance predominates, the *CG* aft condition produces the least resistance because of the smaller wetted area.

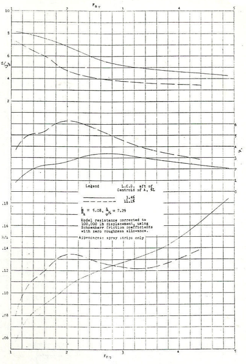

Fig. 12. *Effects on the Performance of a Typical Planing Boat of a Variation in L.C.G. Location*

Standard Model Test Conditions

It was shown in the previous section that changes in the area coefficient and in *LCG* location have large effects on the performance of planing boats. Therefore, in order to show the effects of other variables on performance, it is desirable in any comparison to hold these two constant. Comparison would evidently be greatly facilitated if future tests of planing boat models included one or more tests at "standard" conditions of $A/\nabla^{2/3}$ and *LCG* location. Future designs could then be readily compared without interpolation, without the necessity of searching for test conditions that happened to be similar, and without having significant performance differences unnecessarily obscured by even small differences in area coefficient and center of gravity location. The standard test conditions should, of course, be selected from consideration of the practical and desirable region of planing boat design.

Fig. 13 shows the values of $A/\nabla^{2/3}$ and *LCG* location (with respect to the centroid of the area, *A*) corresponding to the model test conditions for a number of boats. The after limit in the practical range of center of gravity location is the point at which longitudinal instability (porpoising) occurs. The test condition for which one of the models porpoised is indicated by a tail on the corresponding symbol. Additional points of instability, from other model tests, are also shown, in order to define more accurately the after limit of the practical range of center of gravity location. Each of these points is indicated by a diamond with a tail.

The standard test conditions decided upon for tests of planing boat models at the Taylor Model Basin are $A/\nabla^{2/3} = 7$, and *LCG* location at 6 per cent. *L* aft of the centroid of *A*. Where additional conditions are desired it is planned to select them from among the conditions indicated by the solid circles of Fig. 13.

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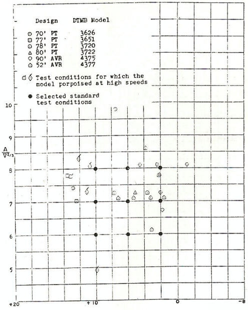

LCG aft of centroid of A, % L

Fig. 13. *Area Coefficients and LCG Locations Corresponding to Model Tests of Typical PT and Aircraft Rescue Boats*

Effects on Performance of Changes in Twist and Deadrise Angle

The effect of warp, or twist of the planing area, on the performance of planing hulls is indicated by a comparison of the World War II Elco and Higgins *PT* designs. Fig. 2 shows that the deadrise of the Elco design increases from 7 degrees at the transom to 18 degrees at midlength, giving a twist of the planing area of 11 degrees. The deadrise of the Higgins design increases from 2 degrees at the transom to 21 degrees at midlength, giving a twist of 19 degrees, or roughly twice as much as the Elco design. The mean planing deadrises for the two designs (average of deadrise at mid-length and transom) are practically the same (12½ degrees for the Elco and 11½ degrees for the Higgins design). Figs. 3b and 4 indicate that the two designs are fairly similar with respect to mean buttock curvature and shape of chine in plan view. Performance of the two designs, from model tests, are compared in Fig. 14. The resistance of the Higgins design is appreciably higher than the resistance of the Elco design, and the difference is considered to be chiefly attributable to the larger twist in the planing bottom of the Higgins design.

Data are not available to show how a planing boat with a low average deadrise angle compares in performance, throughout the speed range, with a boat having a high average deadrise angle. The range of deadrise angles covered by the tests of EMB Series 50 was small, and deadrise angle was not varied systematically. However, the effects of change in deadrise angle on performance at high speeds can be shown by means of data obtained from tests of prismatic planing surfaces. Fig. 15 shows the performance predicted from such data for a 100,000 lb. boat, of typical dimensions, for deadrise angles of 0, 10 and 20 degrees. These performance curves were calculated from the data of Reference 2. It can be seen that an increase in deadrise angle from 0 degrees to 20 degrees increases the wetted surface about 25 per cent., increases the trim angle 1 degree, and increases the value of $R/\triangle$ at high speeds by about 0.040. For a prismatic planing bottom the amount of the increase in $R/\triangle$ caused by increased wavemaking resistance is the same as the value of the increase in the tangent of the trim angle. For the range of angles of interest here an increase in trim angle of 1 degree corresponds to an increase in the tangent of approximately 0.018. Evidently then, of the increase in $R/\triangle$ of 0.040, approximately 45 per cent. (0.018) can be attributed to increased wavemaking resistance and

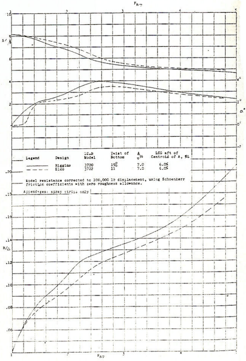

Fig. 14. *Effects on Planing Boat Performance of Different Amounts of Twist in the Hull Bottom*

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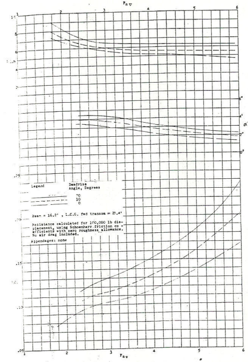


Fig. 15. *Effects on Planing Performance of Variation in the Deadrise Angle of the Hull Bottom, from Planing Surface Data*

the remaining 55 per cent. to increased frictional resistance.

In spite of the fact that a flat planing surface has less resistance than one with deadrise, in practice a deadrise angle at the transom of at least 10° is desirable in order to give a boat good directional stability, and in order that it will have the desirable characteristic of banking inboard on turns.

Model data are not readily available to show the effects on resistance of longitudinal curvature, plan form of chine, and type of section. It is expected that this situation will be improved in the future, however, as models are tested at standard conditions and comparison and analysis are thereby facilitated.

Design Procedure

The coefficients and parameters presented in this report have been introduced with the intent that they should be useful for design purposes. Accordingly, in this section, a design procedure utilizing these coefficients and parameters will be outlined. This report does not attempt to present a complete design procedure. It would be necessary to include a considerable amount of additional information to accomplish that. Among the information needed would be data on weights, engine particulars and propeller characteristics, all reduced to conveniently usable form.

Tentatively, then, it is considered that an effective design procedure would be to proceed somewhat as follows. First the designer should obtain sufficiently complete specifications as to payload, endurance, speed, equipment and crew to be carried, so that a preliminary estimate of gross weight, and a preliminary arrangement plan can be made. Ratio of length to beam (L/B_A) can then be selected.

In this connection, Fig. 10 shows that a low ratio of L/B_A is an attractive prospect with respect to high speed resistance. Experience indicates, however, that a low length-beam ratio can be utilized only for sheltered water boats, and that for seaworthiness a relatively high value is necessary. Thus, for stepless run-abouts the length-beam ratio is about 3.6, while for the motor torpedo boats of World War II the ratio is about 5.6. A logical design procedure, then, is to select the length-beam ratio of a new design from the proportions of previous successful boats of the same type. Fig. 16 has been prepared for this purpose. Having selected a value of L/B_A, Fig. 8 can now be used to determine a good value for the area coefficient, $A/\nabla^{2/3}$. From the indicated value of $A/\nabla^{2/3}$, and the preliminary gross weight, the hull area A, can be calculated as follows:

$$\nabla = \frac{\Delta}{w}\text{; then, since } w = 64 \text{ lb/ft}^3 \text{ for sea water,}$$

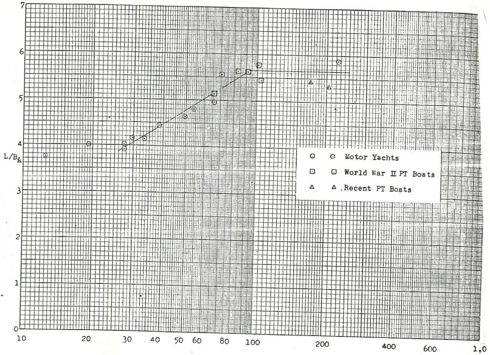
$$\nabla^{2/3} = \left(\frac{\Delta}{64}\right)^{2/3} = \frac{\Delta^{2/3}}{16}$$

Then:

$$A = \left(\frac{A}{\nabla^{2/3}}\right) \cdot \frac{\Delta^{2/3}}{16}$$

This value should be compared with the required hull area as indicated by the preliminary arrangement plan.

Several considerations are involved in the decision as to the choice (or compromise) between the hull area indicated by the preliminary arrangement plan and the hull area indicated by the area coefficient, $A/\nabla^{2/3}$. If the arrangement plan area is very much less than the area indicated by Fig. 8, then the arrangement plan area will give a heavily loaded hull, and conversely, if the arrangement plan area is very much greater than the area indicated by Fig. 8, then the arrangement plan area will give a lightly loaded hull. It should be pointed out that the "optimum" line of Fig. 8, from the nature of the development is of limited significance. Only one type of hull lines and one *LCG* location are represented in this graph. Furthermore, Figs. 9 and 11 show that the optimum value of area coefficient (value for minimum average resistance) is a function of top speed as well as L/B_A, and that a relatively low speed boat would have a low average



Displacement at rest, thousand of pounds

Fig. 16. *Variation of Length/Beam Ratio with Displacement*

resistance with a high value of area coefficient (light loading), while a high speed boat would have low average resistance with a more economical arrangement plan and a low value of area coefficient (heavy loading). Accordingly it would be desirable to recheck the hull size selected, after the lines have been completed, by making a model test to show the effects on performance of increasing or decreasing the hull size. The procedure would be to test a model over a wide range of displacements, calculate the resistance for the full-size design displacement from each of the tests, and compare the results in a graph of $R/\triangle$ versus $F_{n\nabla}$. The scale ratio between model and full size boat will be different for each model displacement, and can readily be calculated as follows:

$$\lambda = \sqrt[3]{\frac{\triangle_s}{\triangle_m \cdot SW/FW}}$$

For an accurate analysis the data should be corrected for the difference between the frictional resistance coefficients of model and of full-size boat. The method of making this correction for planing hulls is given in Reference 3. Fig. 17 shows the results of a model test calculated and plotted in the proposed manner. The model tested was a planing hull of normal form, and the tests were originall made to determine the resistance of a given size o hull for three different full-size displacements. Fo the present purpose, however, the three tests ar considered to represent tests of a particular set o lines at three different scale ratios, each test corresponding to the same full size displacement (100,00 lb). Considered in this fashion, the following inter-

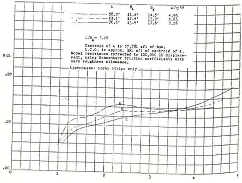


Fig. 17. *Effect of Size of Hull on Resistance for Constant Displacement (100,000 lb)*

#0018

pretation may be put upon the data shown in Fig. 17: *A* 100,000 lb boat built to the lines tested and having a length $L = 58.0'$ and a mean beam $B_A = 11.4'$, will have the resistance given by curve *A*. If $L = 63.1'$, and $B_A = 12.4'$ the resistance will be that given by curve *B*; and if $L = 70.6'$ and $B_A = 13.9'$, the resistance will be that given by curve *C*. It is clear from this figure that if the anticipated top speed of the boat under consideration corresponds to a value of $F_{n\nabla}$ of 3.5 or less, then the best boat of the three represented is that corresponding to curve *C*. If the top speed of the boat corresponds to a value of $F_{n\nabla}$ of 4.0 or greater, then a reduction in top speed resistance would result from selecting boat dimensions corresponding to curves *A* or *B*, instead of those corresponding to curve *C*; the curves also show, however, that this selection would be accompanied by substantial resistance penalties in the low and cruising speed ranges.

After selecting a value of $A/\nabla^{2/3}$ (tentative, or otherwise), the next step in the envisioned design procedure is for the designer to select suitable non-dimensional curves defining the chine line in plan view, the deadrise variation, and the longitudinal curvature of the mean buttock. These curves are shown, for the particular boats, in each of the Taylor Model Basin's design data sheets. It is anticipated that when a number of these sheets have been made available the designer will be able to select the form characteristic curves for a new design with the confidence of obtaining superior performance.

The form characteristics presented in the design data sheets have all been derived with a view to the reverse process, i.e. with the idea that the designer should be able to use the form characteristics selected to construct the hull lines for a new design. Some guidance from a previous design as to section shape will also be needed.

When the values of L/B_A and *A* have been obtained the values of *L* and B_A can be calculated as follows:

Since $B_A = \dfrac{A}{L}$ then $L^2 = A \,.\, L/B_A$. From this *L* can be calculated, and then, readily B_A (equals A/L).

The form characteristic curves of the design data sheets are given in terms of *L* and B_A, so that when the values of these two dimensions have been determined, and the form characteristic curves for the new design have been selected, the new body plan, and subsequently the complete lines can be constructed. A description of the method of constructing one section will indicate the essential features of the process. The process of constructing a section at 70 per cent. of *L* forward of the stern is indicated in Fig. 18. The centerline is drawn and

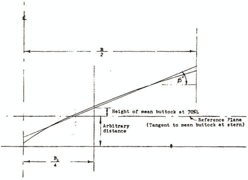


Fig. 18. *Constructing a Body Plan Section at 70 % L*

then a horizontal line representing that waterline plane which is tangent to the mean buttock at the stern. This plane is the primary horizontal reference plane in the proposed design process. A vertical line indicating the buttock plane at $B_A/4$ outboard of the centerline is then drawn, and a baseline is drawn at any convenient location. Then, from the selected mean buttock curve the height at 70 per cent. *L* is read (in per cent. of *L*); this number is multiplied by *L* and the resulting dimension is plotted on the line representing the mean buttock plane, measuring up from the horizontal reference plane. A straight line is then drawn through the point thus obtained at the deadrise angle for 70 per cent *L*, as indicated by the selected curve of deadrise variation. From the selected curve of the chine in plan view the dimensionless ratio B/B_A for the 70 per cent. point can be determined, and multiplying this by B_A and dividing by 2 gives the half breadth of the chine at 70 per cent. *L*. This dimension is then indicated on the drawing. The type of section selected is then sketched in, using the lines previously established for guidance. The other sections of the body plan are developed in similar fashion and the lines faired in all three views in the conventional manner. It is believed that by following such a design procedure it will be possible to incorporate the desirable features of previous superior hull forms in a new design.

The waterline at which the boat will float can be approximated by means of the draft coefficient data presented in the design data sheets. The draft forward, for example, can be estimated by determining the draft coefficient forward for a previous similar design at values of $A/\nabla^{2/3}$ and *LCG* location corresponding to those for the new design. Multiplying the draft coefficient value by ∇/A gives an approximation to the draft at 100 per cent. *L* as measured up from the horizontal reference plane. The draft at the stern is determined in similar fashion.

#0019

Analysis of Full Scale Data

Resistance data from model tests are useful for determining the relative efficiencies of different designs and also for estimating the ehp requirements of new designs. The information which the designer ultimately needs, however, is the required engine brake horsepower, bhp. Some data are available on the weights, speeds and brake horsepowers of actual full size boats. These data can be reduced as follows to a dimensionless form similar to that in which resistance data are presented:

$$\text{bhp} \cdot \frac{550}{\Delta \cdot V} = \frac{R\ v}{550} \cdot \frac{\text{bhp}}{\text{ehp}} \cdot \frac{550}{\Delta \cdot v} = \frac{R}{\Delta} \cdot \frac{\text{bhp}}{\text{ehp}}$$

Brake horsepower, weight and speed data for various types of racing boats are given in Reference 4. The data from this reference on small vee-bottom motor boats are plotted in dimensionless form in Fig. 19. This figure can be used to make rough estimates of the bhp requirements of new designs. It can be readily seen that since differences in propellers, in hull form, and in hull loading are not considered here, the answers obtained will only be very approximate.

Suppose that it is desired to estimate the bhp required to propel a 5,000 lb boat at a speed of

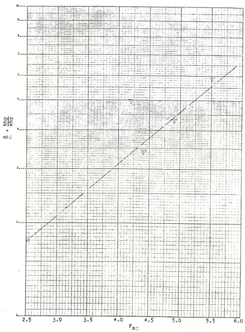


Fig. 19. *Brake Horsepower Requirements of Vee-Bottom Racing Motor Boats, from the Data of Reference (4)*

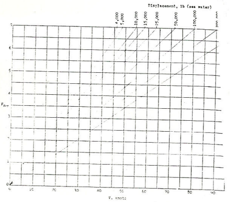


Fig. 20. *Variation of $F_{n\nabla}$ with Speed and Displacement*

25 knots. Then from Fig. 20 the correspondi value of $F_{n\nabla} = 3.6$. Entering Fig. 19 with t value we obtain a value of $\frac{R}{\Delta} \cdot \frac{\text{bhp}}{\text{ehp}}$ of 0.265. V then obtain bhp as follows:

$$\text{bhp} = \frac{R}{\Delta} \cdot \frac{\text{bhp}}{\text{ehp}} \cdot \frac{\Delta \cdot v}{550}$$

$$\text{bhp} = 0.265 \cdot \frac{5000 \cdot 25 \cdot 1.689}{550} = 102$$

In Reference 5 a large quantity of data on pre war American and foreign motor torpedo boat were compiled. These data are plotted in Fig. 21 ir the form of $\frac{R}{\Delta} \cdot \frac{\text{bhp}}{\text{ehp}}$ versus $F_{n\nabla}$. The data on German boats have been omitted, because of the bad scatter. Data on stepped boats, and on unconventional forms, have also been omitted. A line has been drawn through the intermediate region of the remaining points. This line is considered to be of some value as a criterion of good performance, and for roughly estimating the bhp requirements of a projected design.

If the published information on the performance of full scale boats also included the center of gravity locations and values of the average breadths and average deadrises in the planing condition, the total information would be extremely valuable. The resistance of the boat in the planing condition could then be calculated from available planing surface data, and from this and the engine bhp data, values of propulsive coefficient could be obtained. Such data are particularly necessary and desirable because it has not been possible heretofore in this country to self-propel models of high-powered planing craft and make torque and thrust measurements.

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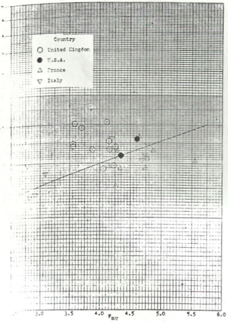

Fig. 21. *Coefficients of Brake Horsepower and Speed for Various Motor Torpedo Boats, from the Data of Reference (5)*

Notation

A = Projected area bounded by chines and transom, in plan view

B = Breadth over chines at any point

$B_{[illegible]}$ = Mean breadth over chines, A/L

B_T = Breadth over chines at transom

B_X = Maximum breadth over chines

BL = Baseline

bhp = Engine brake horsepower

CL = Centerline

CG = Center of gravity

$C_{[illegible]}$ = Draft coefficient at rest, forward; equals draft at 100 % L (Measured from tangent to mean buttock at stern) multiplied by A/∇

$C_{[illegible]}$ = Draft coefficient at rest, aft; equals draft at 0 % L (measured from tangent to mean buttock at stern) multiplied by A/∇

ehp = Effective horsepower

[illegible] = Froude number based on volume, $v/\sqrt{g\nabla^{1/3}}$

g = Acceleration due to gravity

L = Overall length of the area A, measured parallel to baseline

LCG = Longitudinal center of gravity location

P = Effective power, ft-lb/sec

R = Total resistance, lb

S = Wetted surface, area of (includes area of sides wetted at low speeds)

SW/FW = Density ratio, salt water to fresh water

v = Speed

V = Speed, knots

w = Density of water (weight per unit volume)

WL_C = Intersection of chine with solid water, forward of 0 % L, ft

WL_K = Wetted length of keel, forward of 0 % L, ft

WL_{SP} = Intersection of chine with spray, forward of 0 % L, ft

λ = Linear ratio, ship to model

α = Angle with horizontal of tangent to mean buttock at stern, deg.

β = Deadrise angle of hull bottom, deg.

Δ = Displacement at rest, weight of

τ = Trim angle of hull with respect to attitude as drawn, deg.

∇ = Displacement at rest, volume of

Subscripts

M, m = Model

S, s = Ship

o = Value at rest

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