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NAVY DEPARTMENT

THE DAVID W. TAYLOR MODEL BASIN

WASHINGTON 7, D.C.

ANALYZING THE STEPLESS PLANING BOAT

By

Eugene P. Clement

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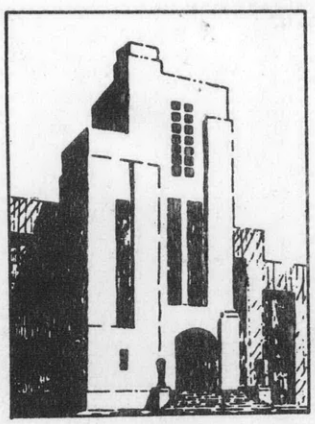

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Report 1093

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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
℄ (B)	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

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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, Δ/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° 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.

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° 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 $\overline{x}$ 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 (12½ degrees for the Elco and 11½ 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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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).

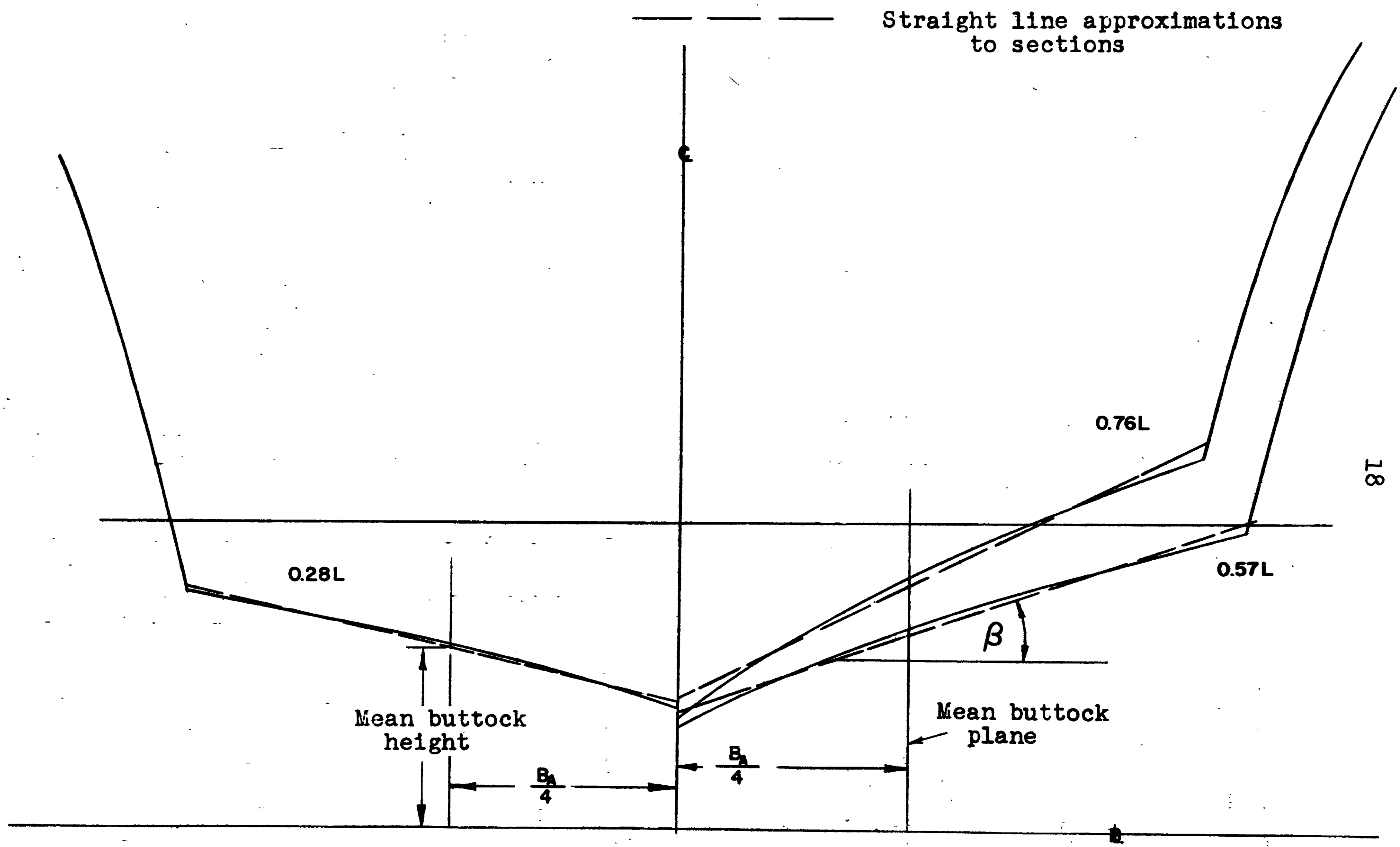


Figure 1 - Typical Planing Boat Body Plan with Straight Line Approximations to Sections.

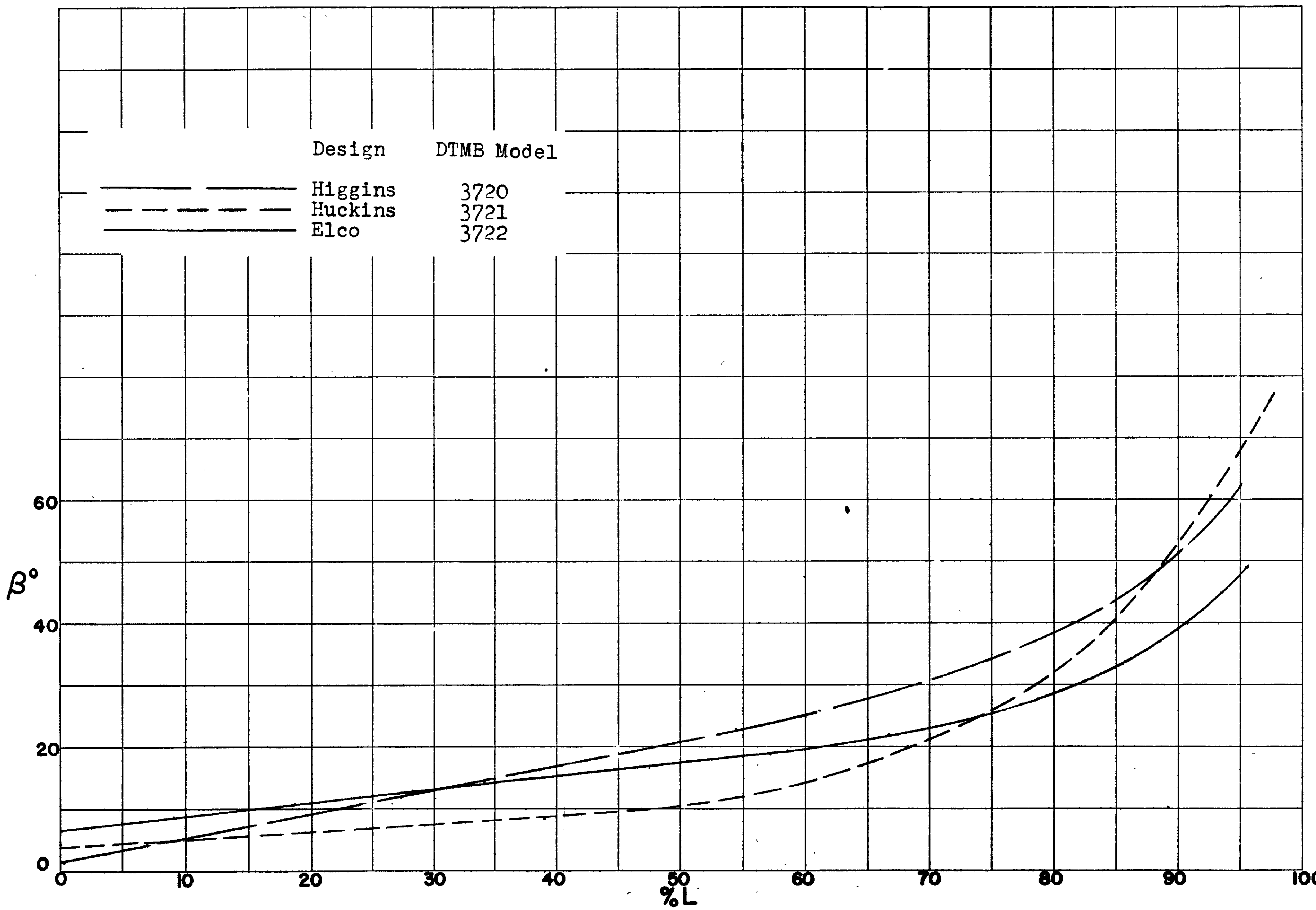


Figure 2 - Curves of Deadrise Angle vs Boat Length for Three PT Boats of World War II

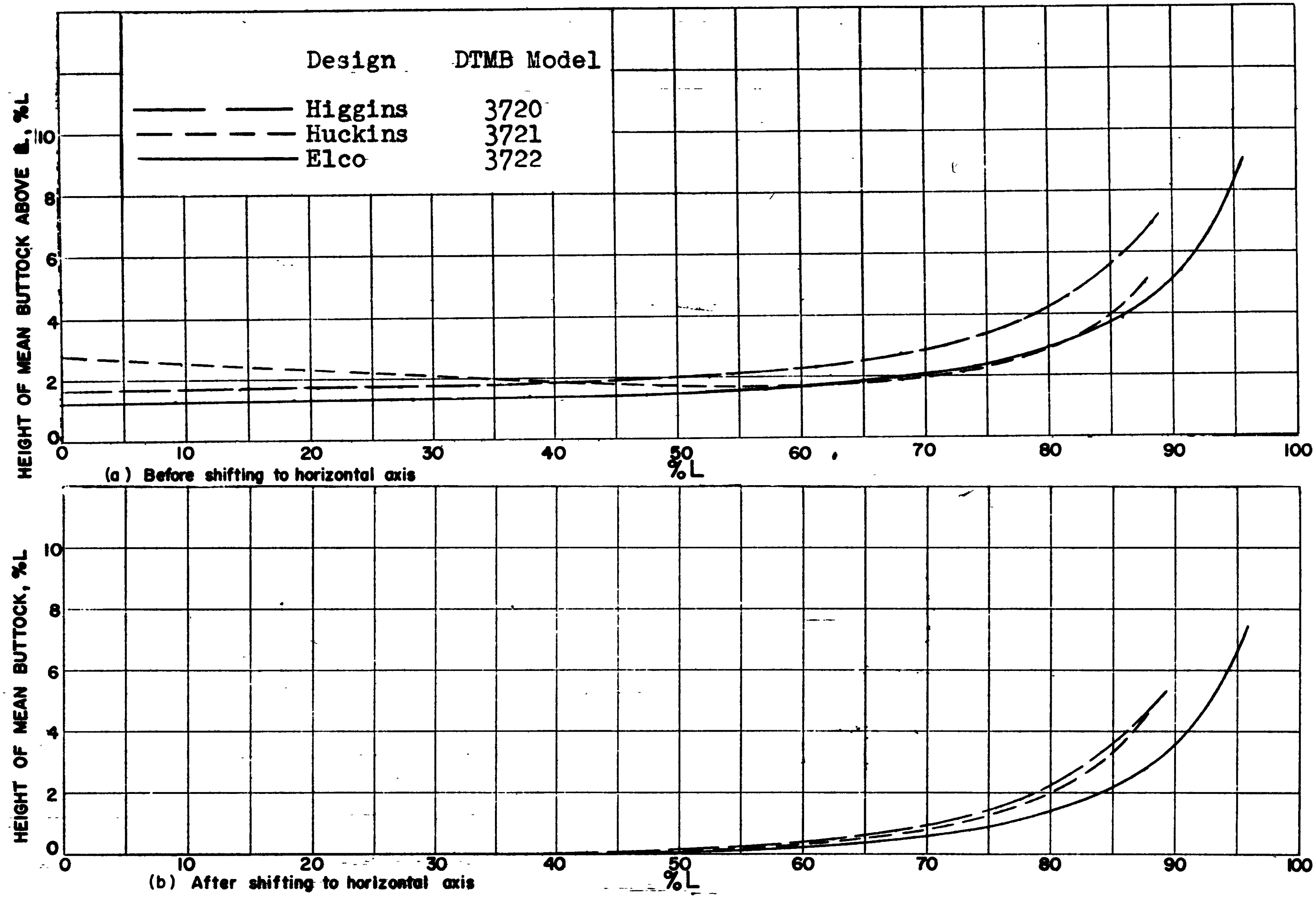
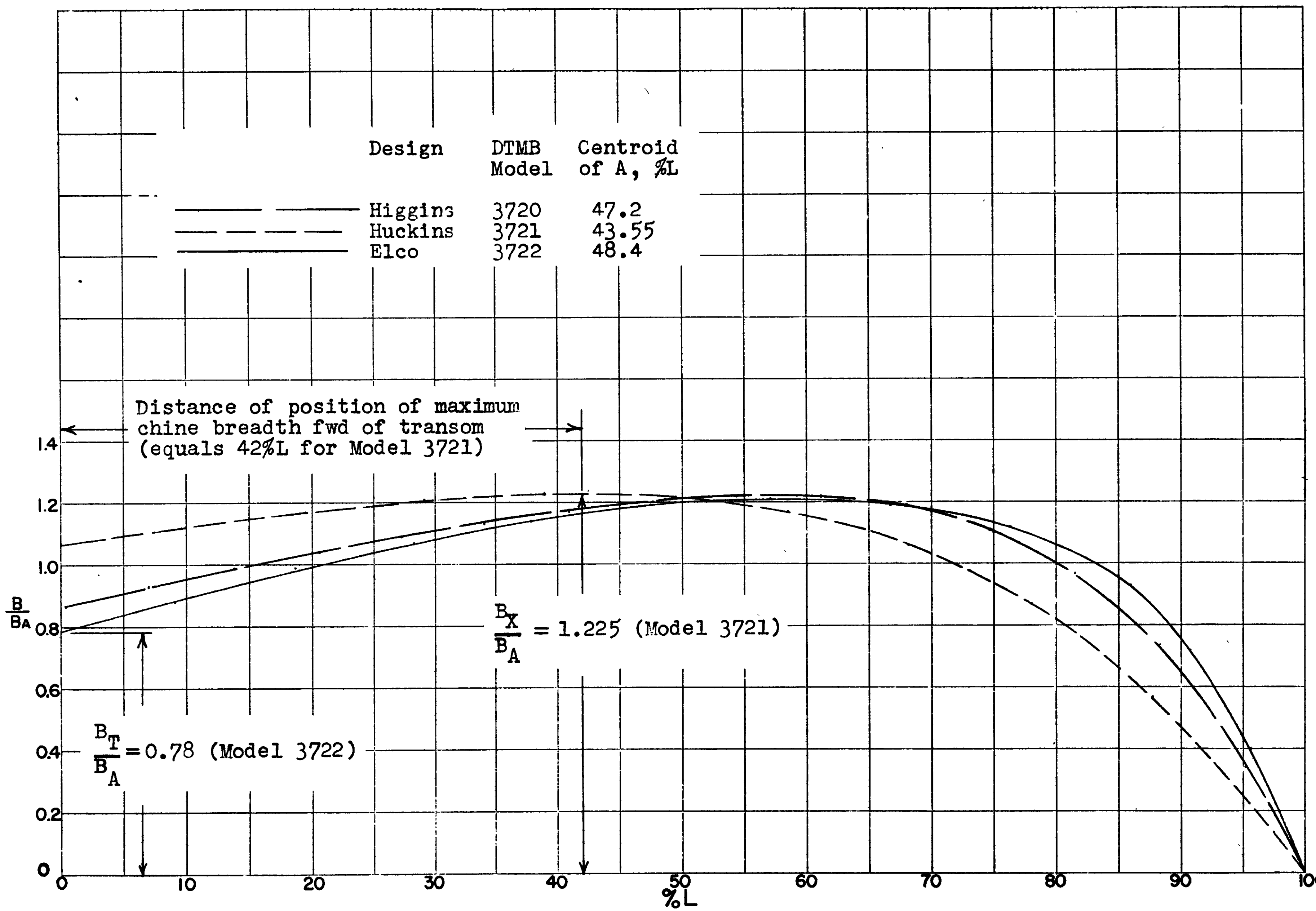
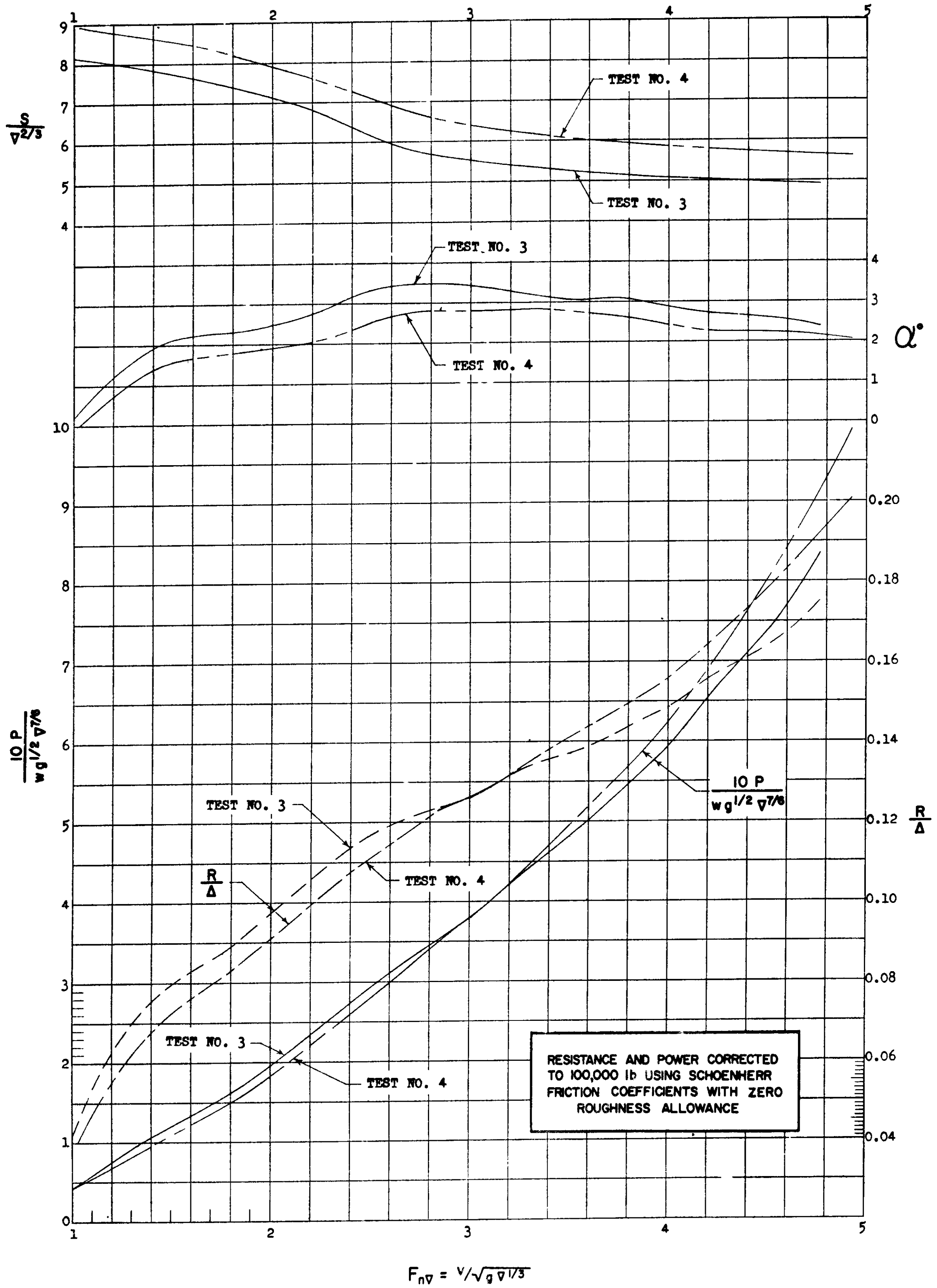


Figure 3 - Mean Buttock Curves for Three PT Boats of World War II.


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

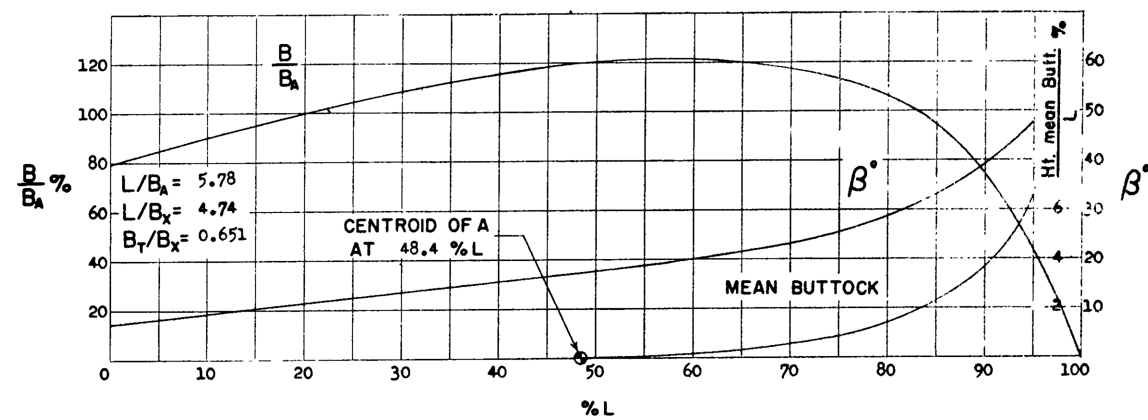
TEST NO. 4

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_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

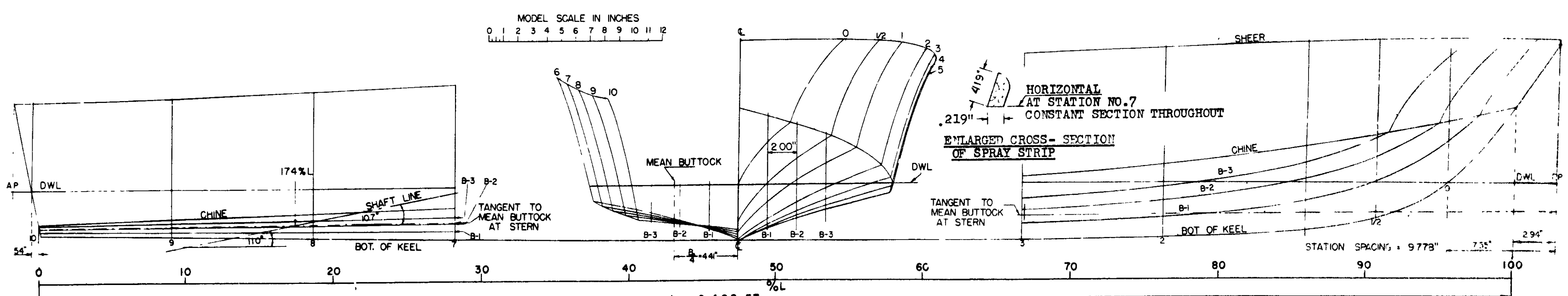


Figure 5 - Typical Design Data Sheet.

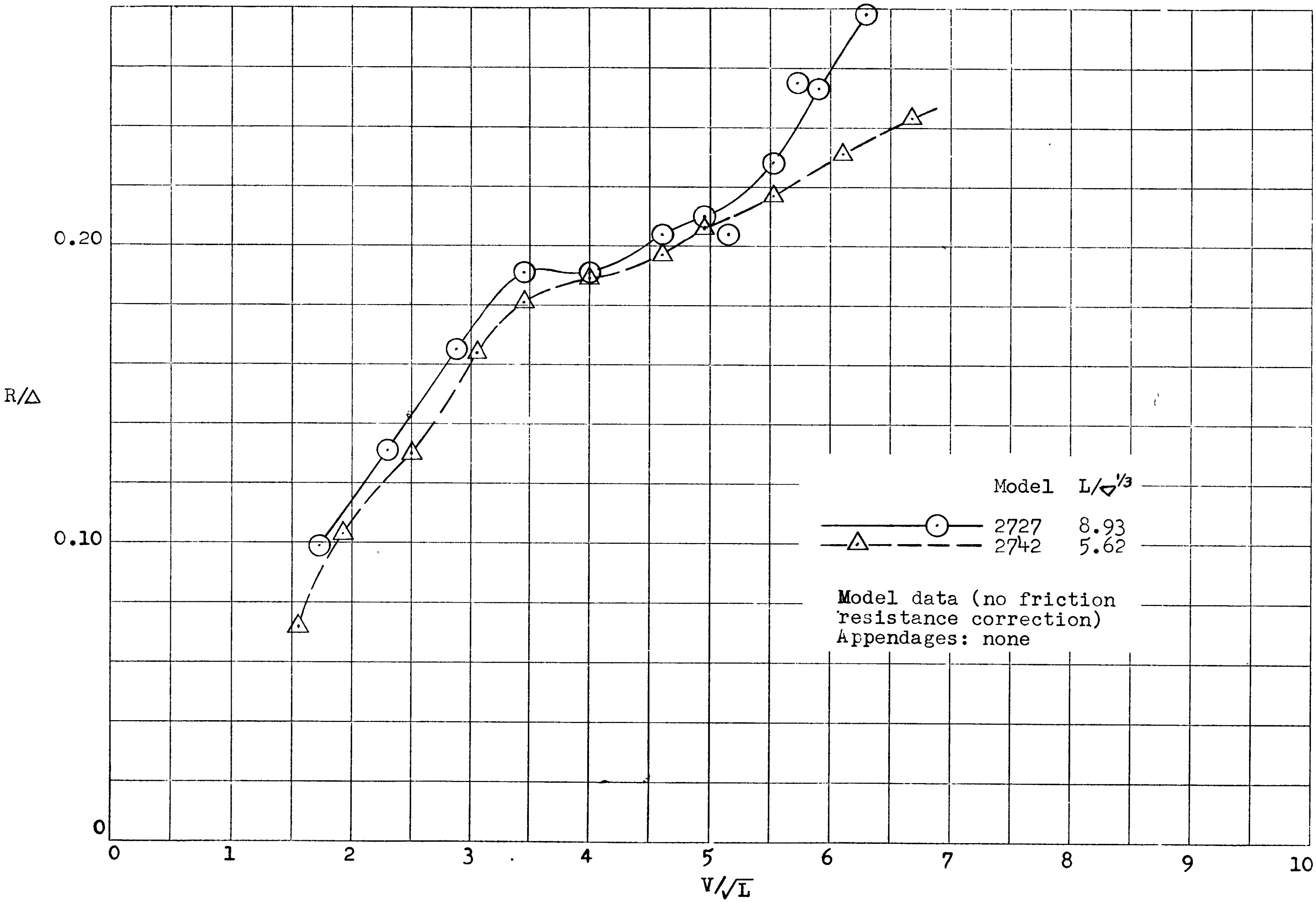


Figure 6 - Resistances of Two Models from EMB Series 50, Compared by the Method in General Use.

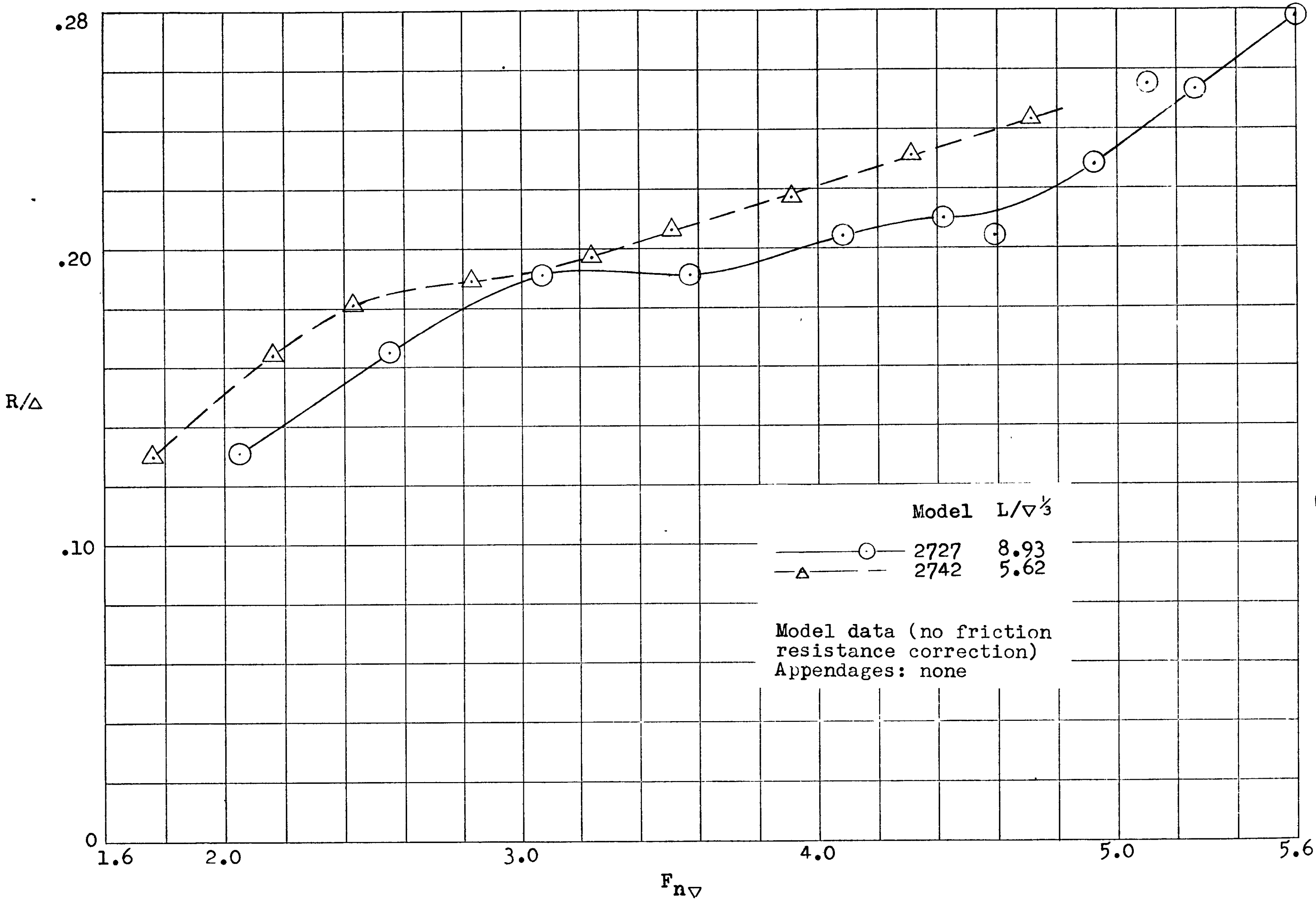


Figure 7 - Resistances of Two Models from EMB Series 50, Compared by a Correct Method.

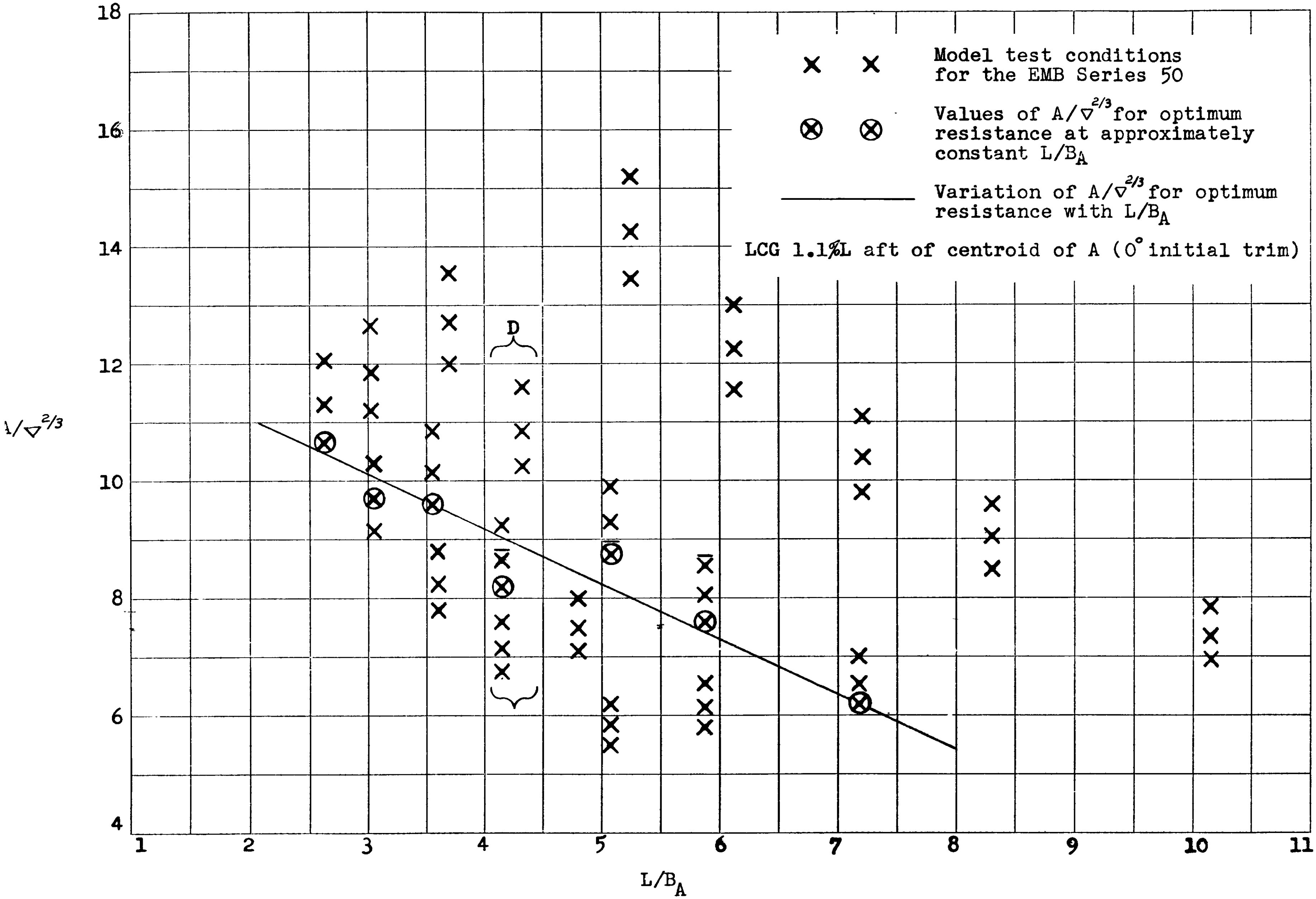


Figure 8 - Variation of Area Coefficient for Optimum Resistance with Length/Beam Ratio, from the Data of the EMB Series 50

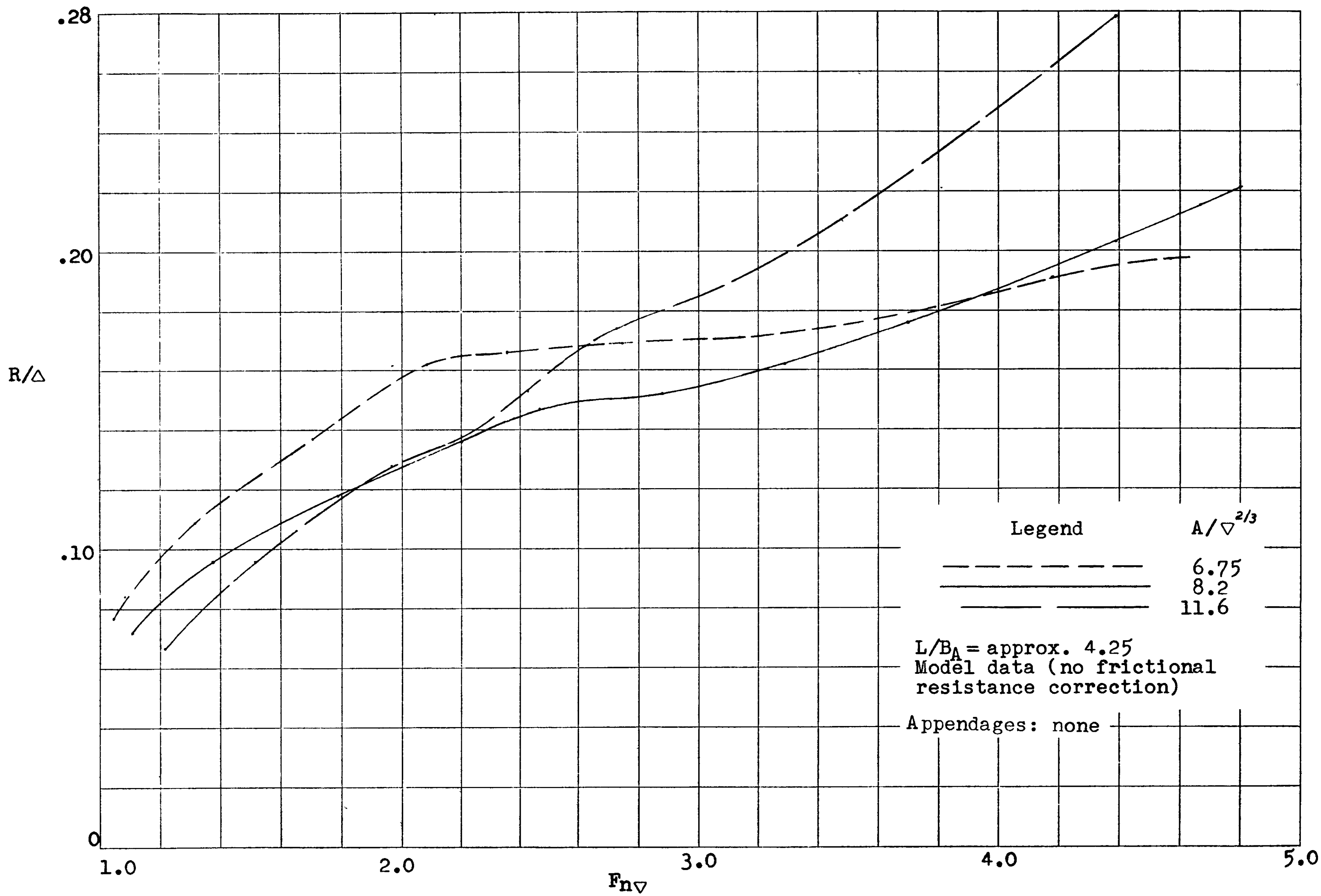


Figure 9 - Effect of Area Coefficient on Resistance, with Constant Length/Beam Ratio.

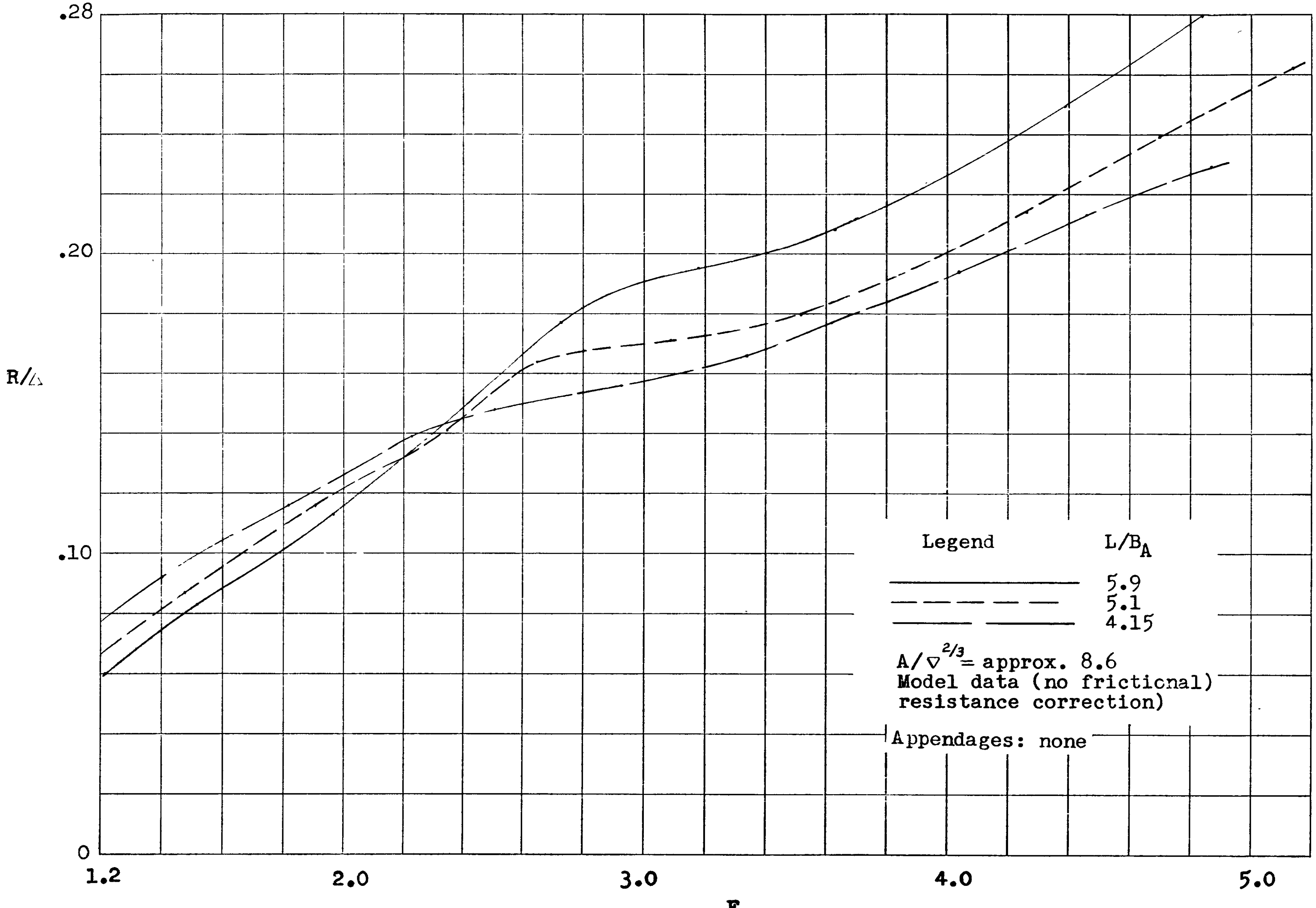


Figure 10 - Effect of Length/Beam Ratio on Resistance, with Constant Area Coefficient.

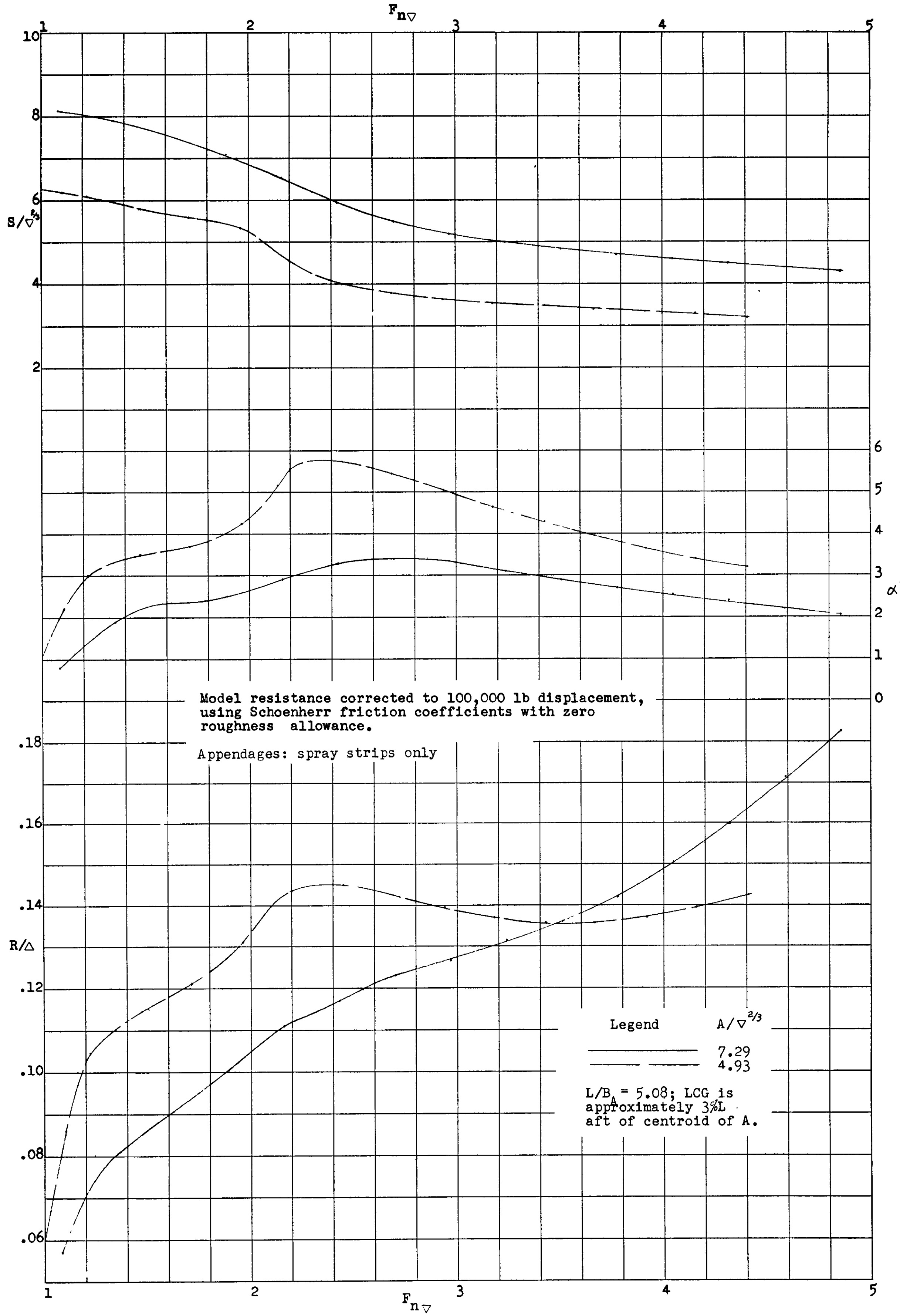


Figure 11 - Effects on the Performance of a Typical Planing Boat Hull Form, of a Variation in Area Coefficient.

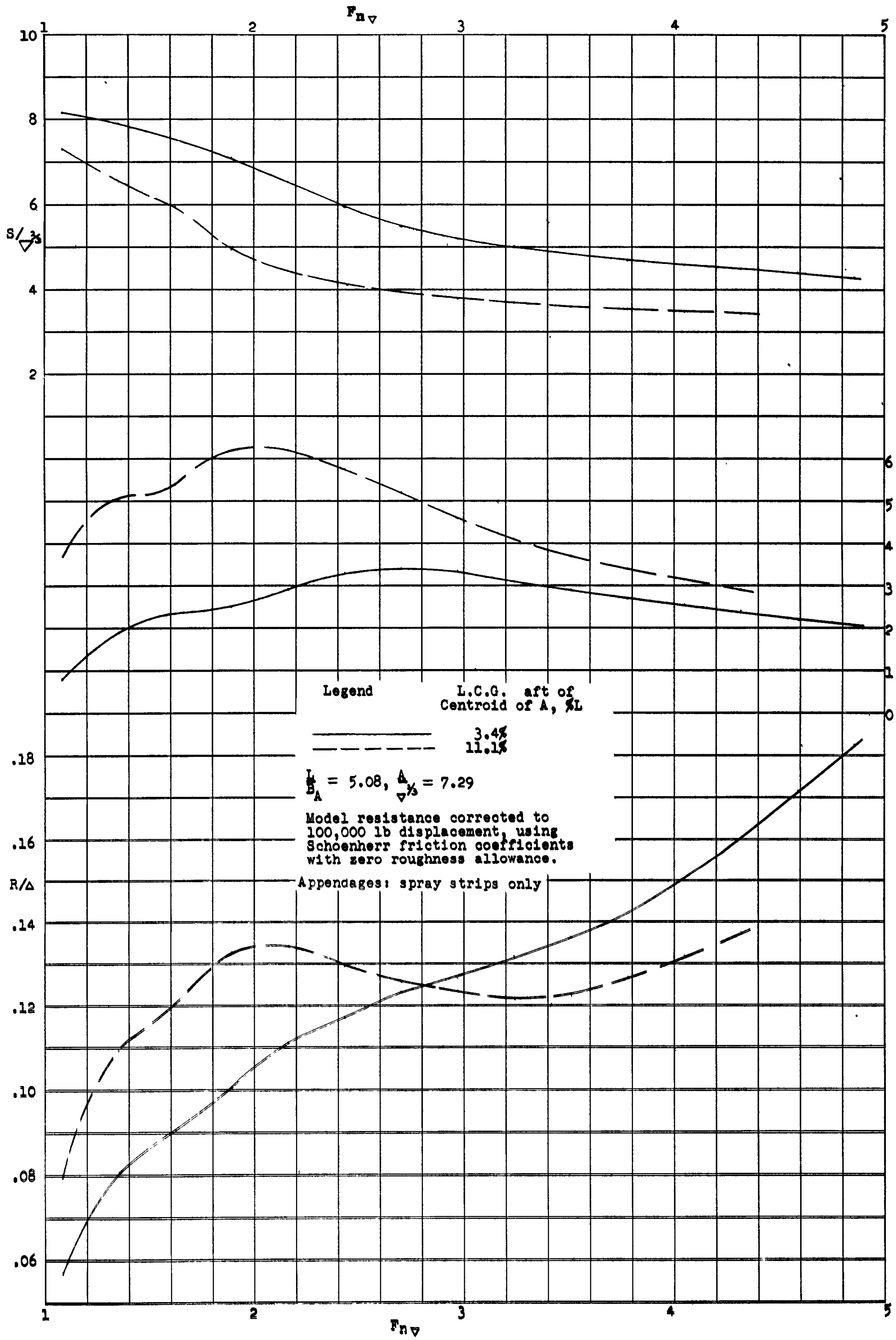


Figure 12 - Effects on the Performance of a Typical Planing Boat of a Variation in L.C.G. Location.

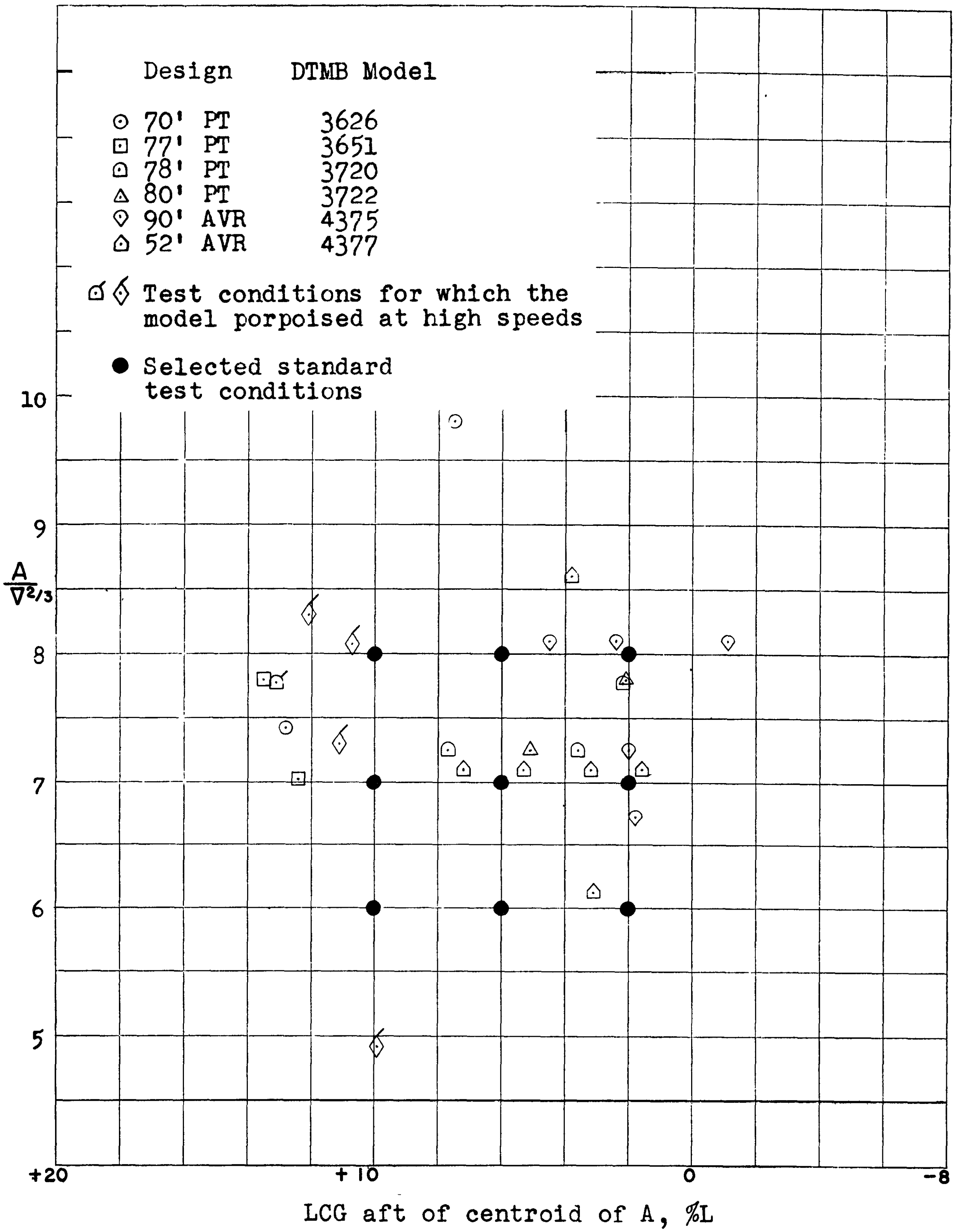


Figure 13 - Area Coefficients & LCG Locations Corresponding to Model Tests of Typical PT & Aircraft Rescue Boats.

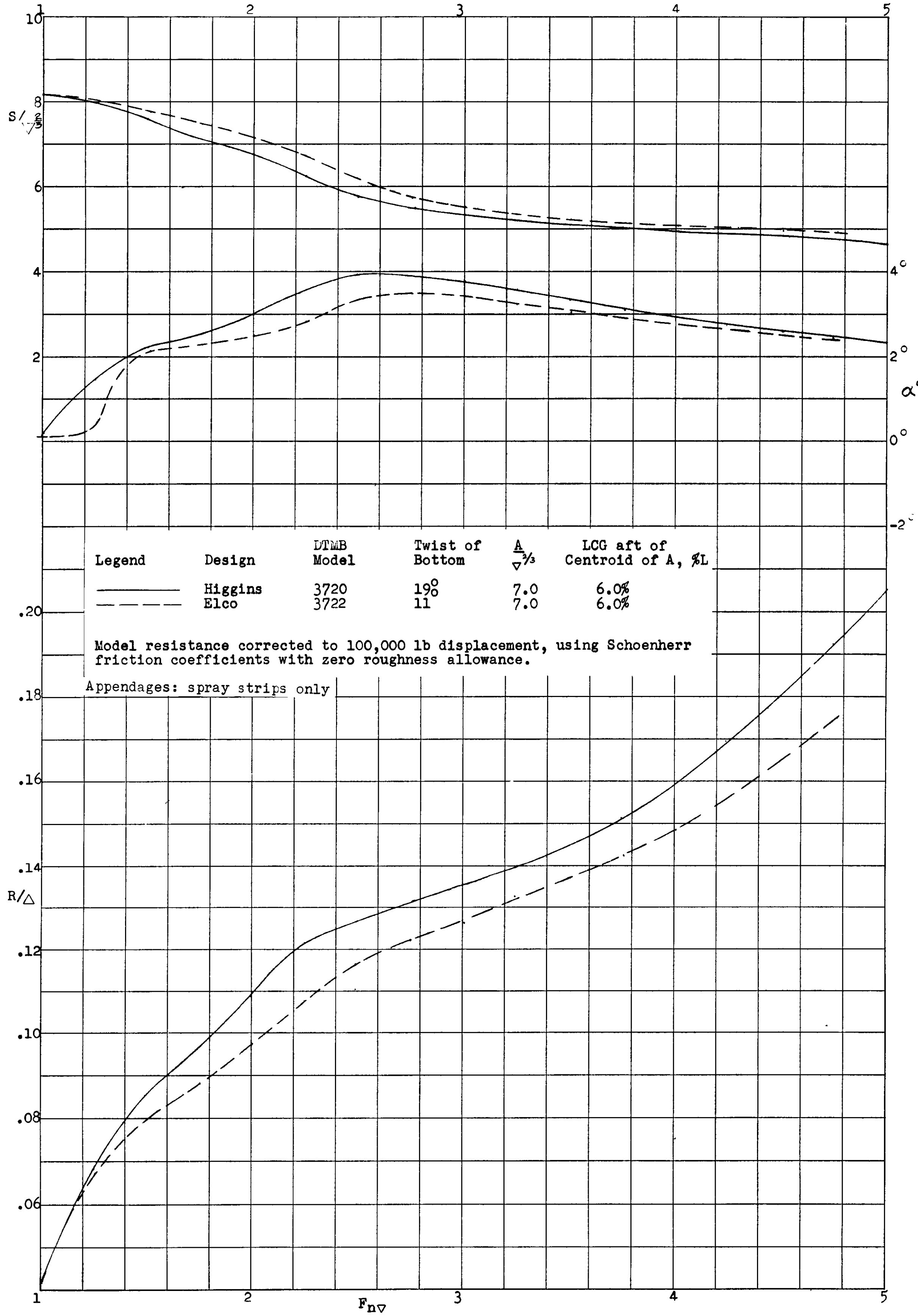


Figure 14 - Effects on Planing Boat Performance of Different Amounts of Twist in the Hull Bottom.

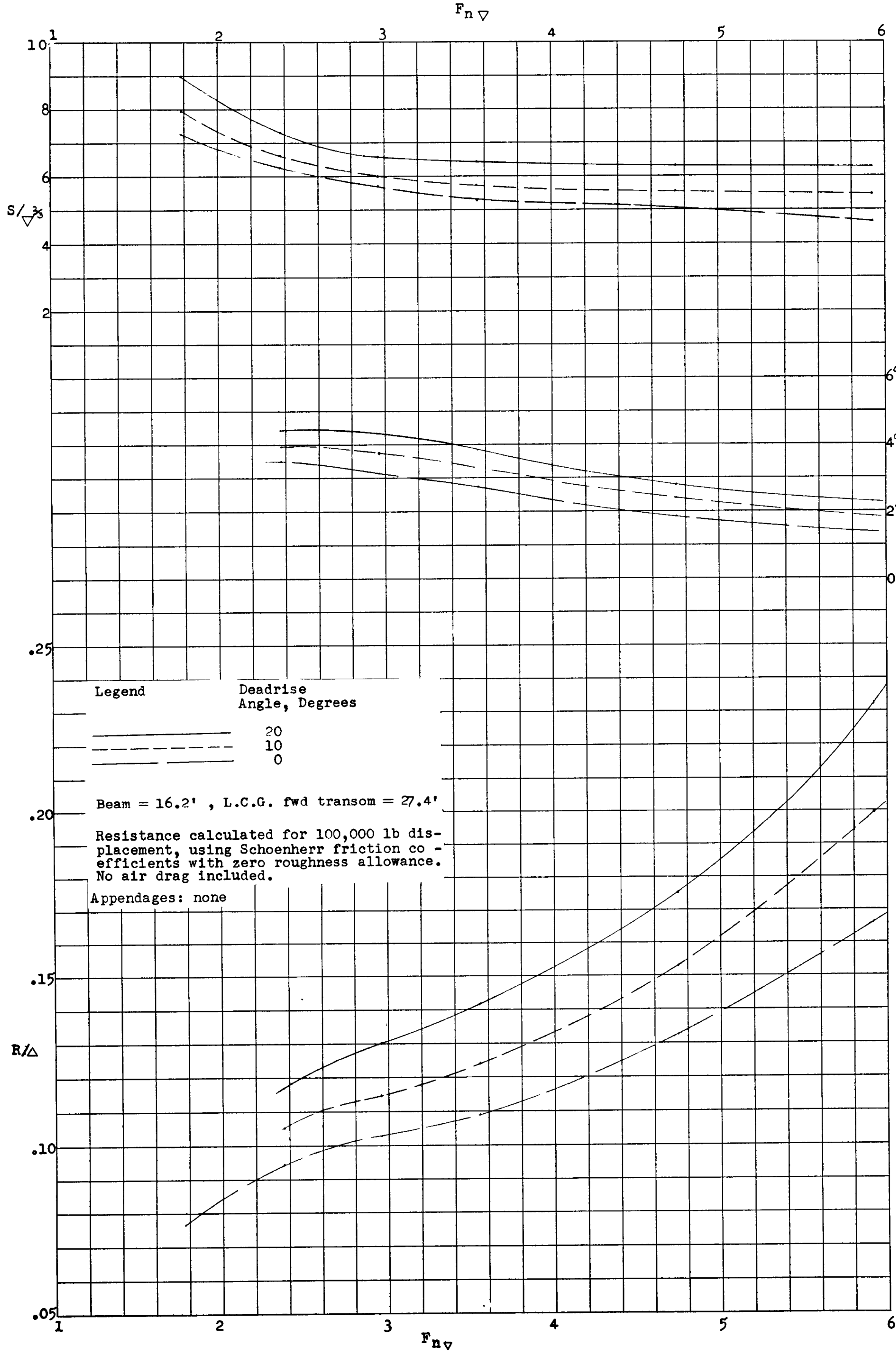


Figure 15 - Effects on Planing Performance of Variation in the Deadrise Angle of the Hull Bottom, from Planing Surface Data.

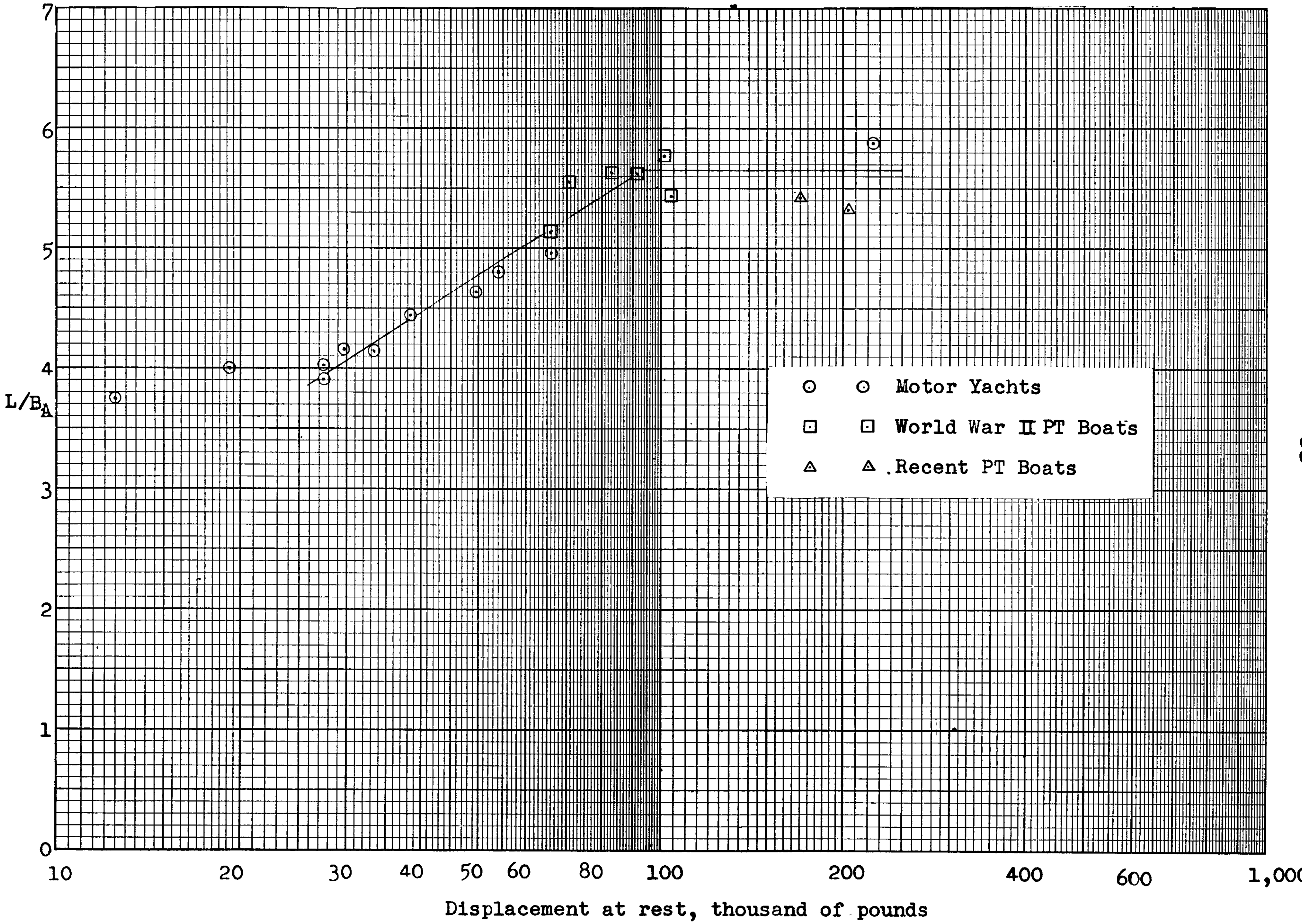


Figure 16 - Variation of Length / Beam Ratio with Displacement.

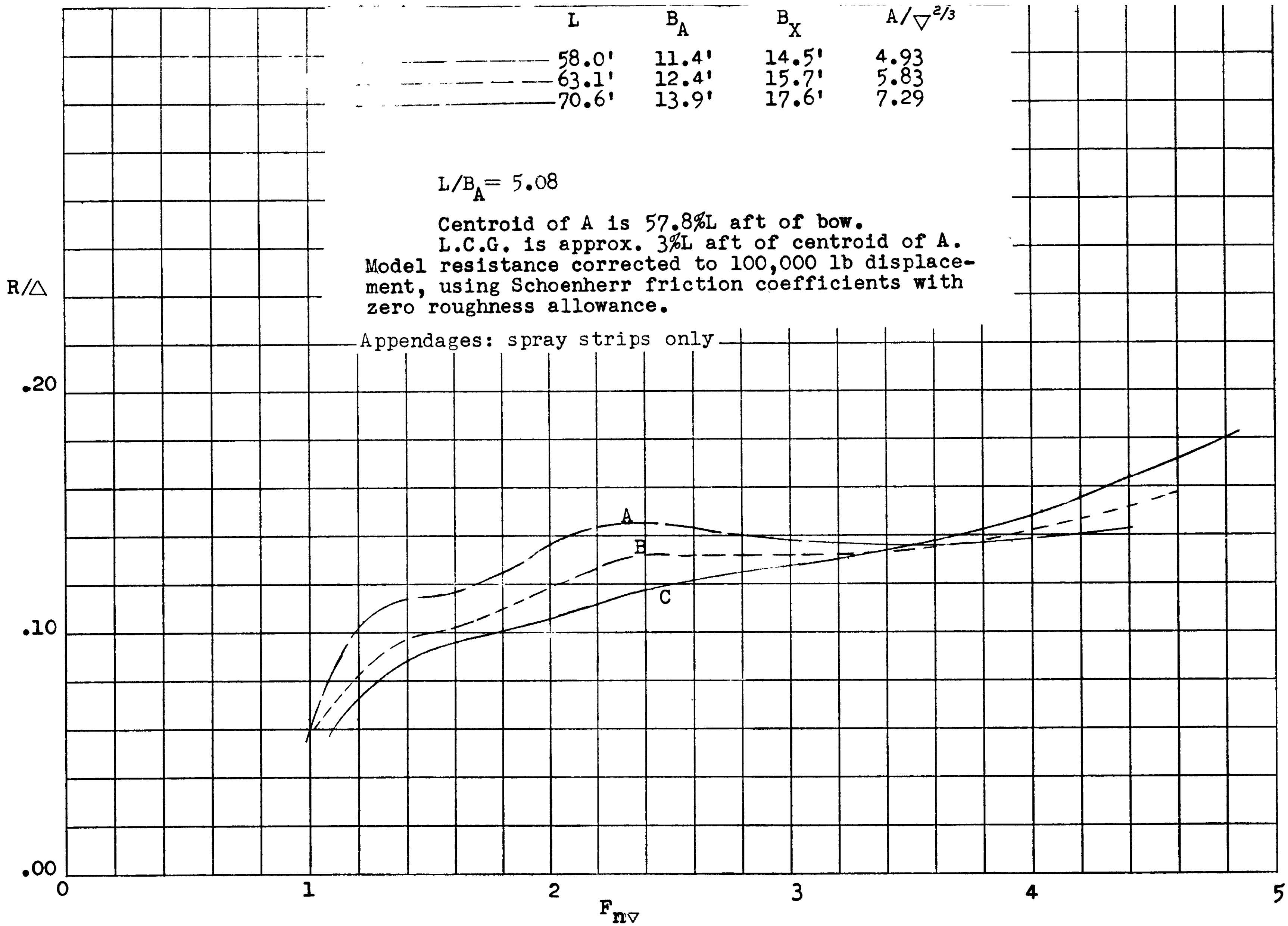
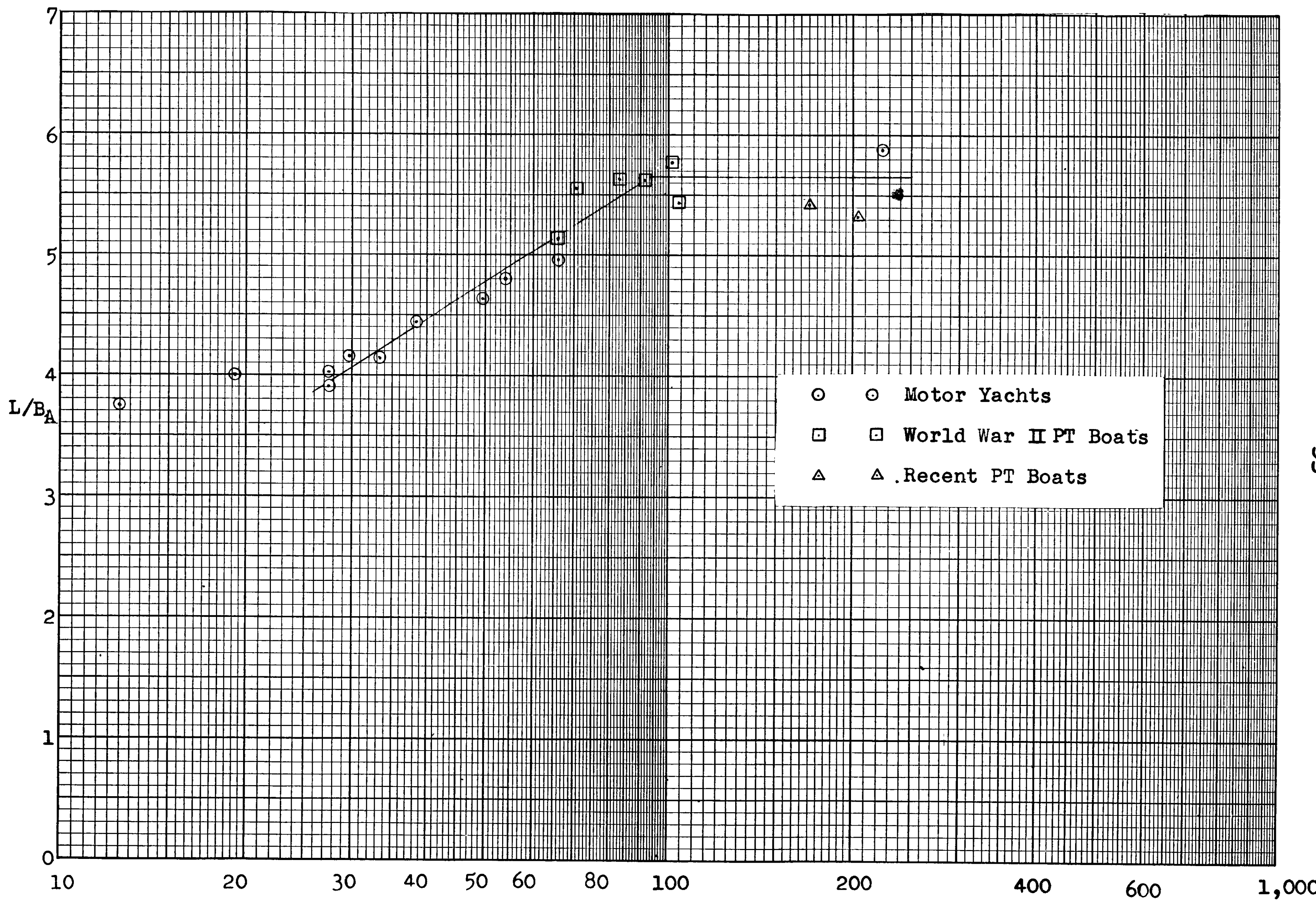


Figure 17- Effect of Size of Hull on Resistance for Constant Displacement (100,000 lb)..



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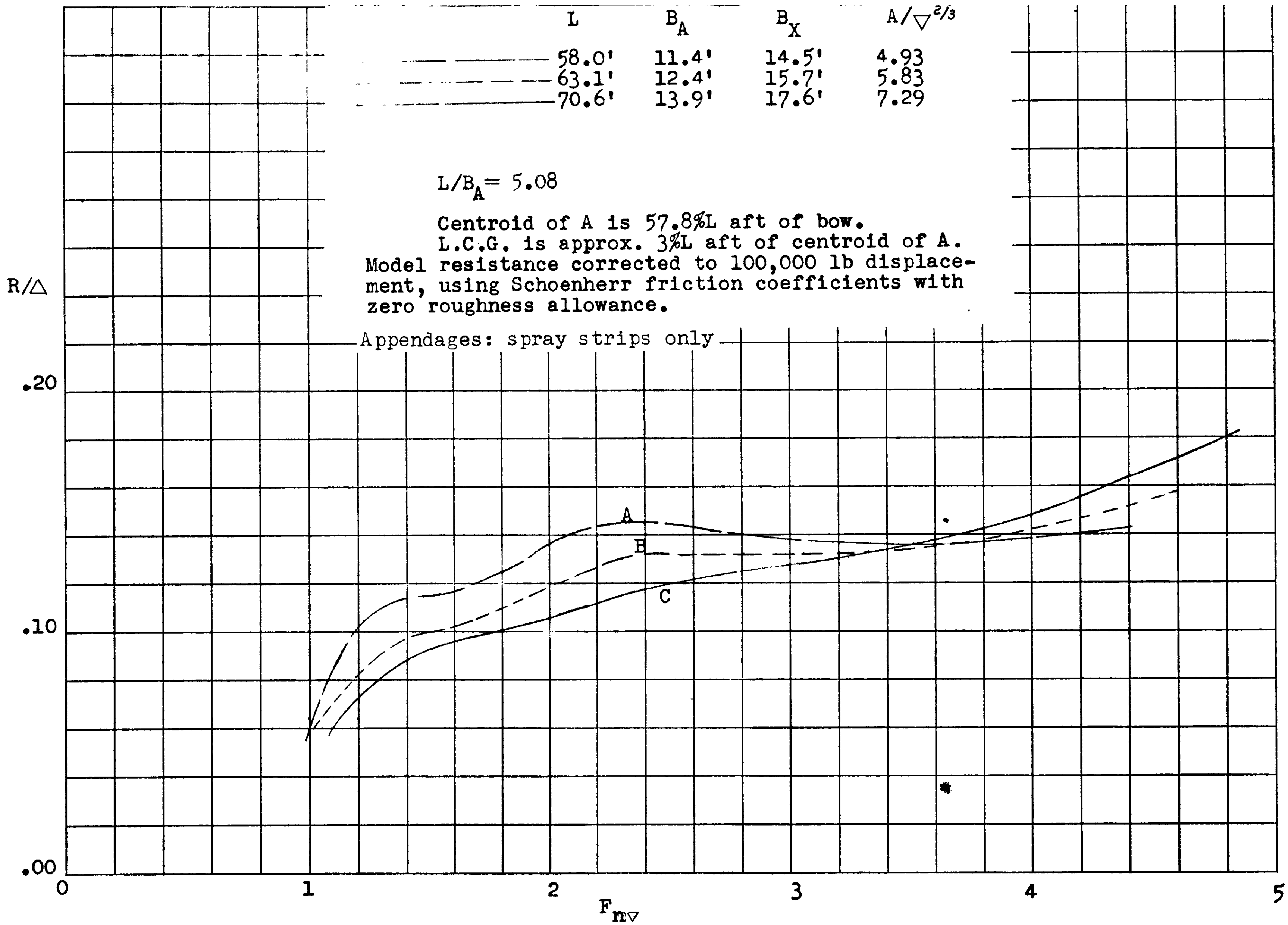

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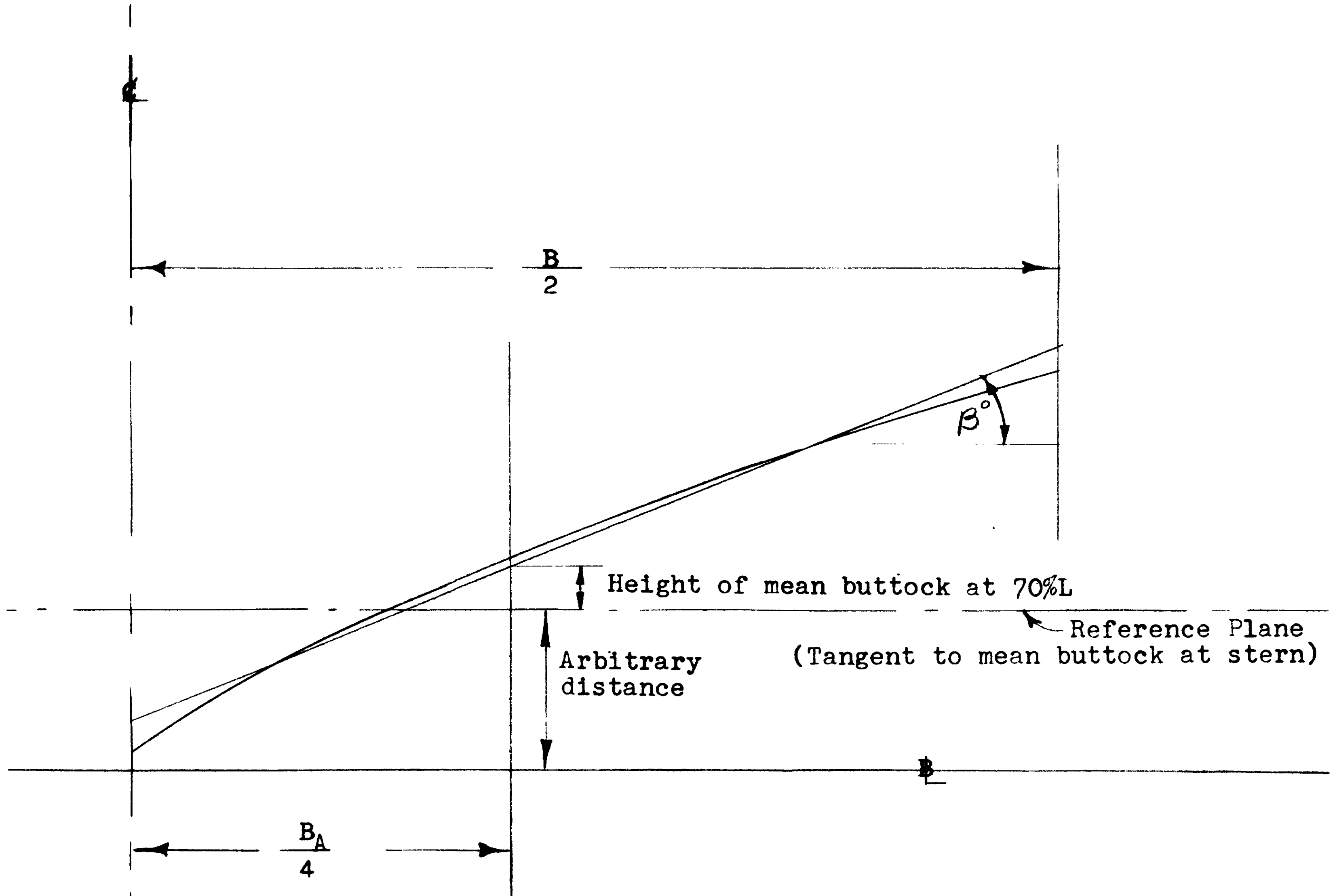

Figure 18 - Constructing a Body Plan Section at 70%L.

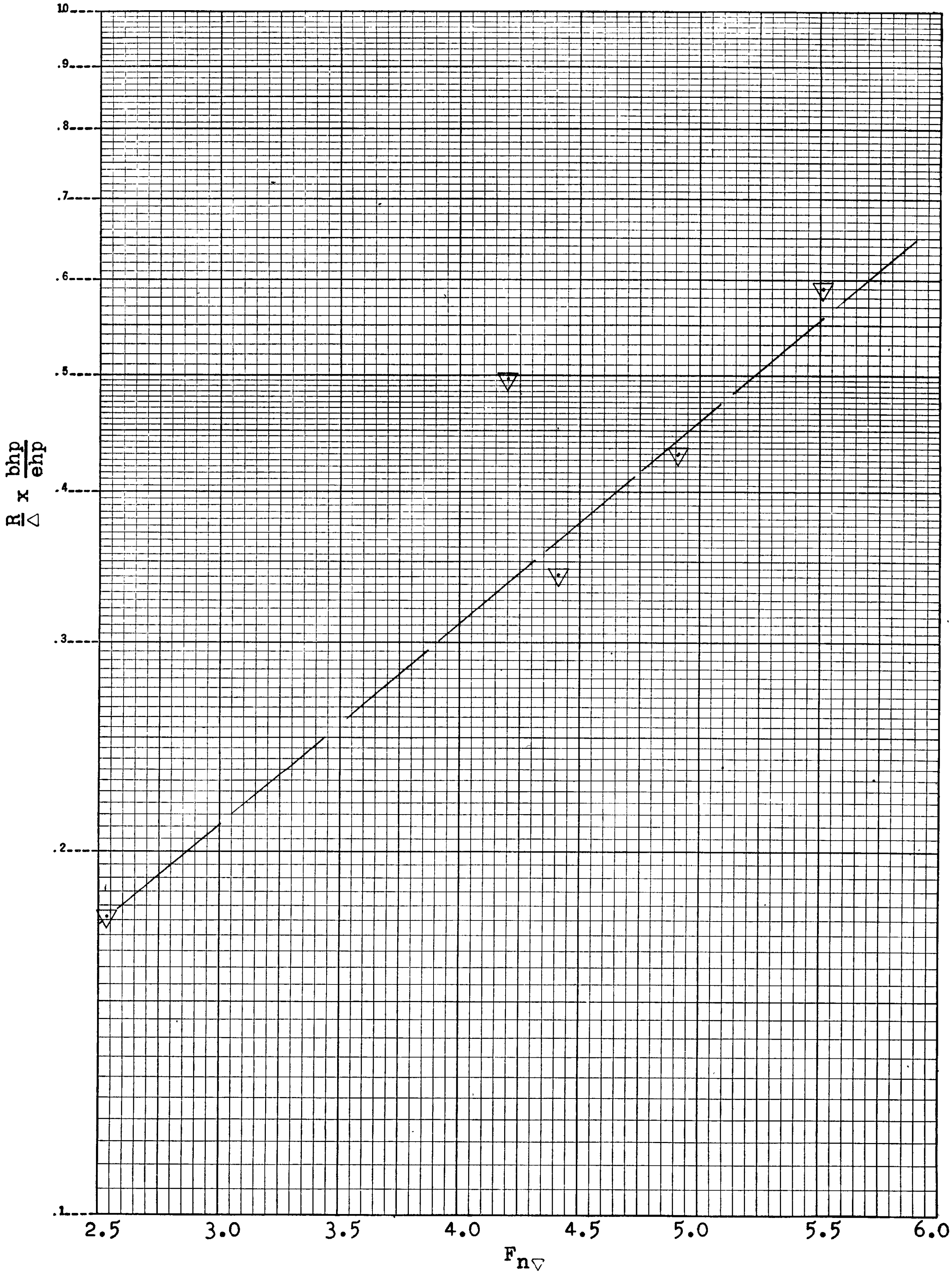

Figure 19 - Brake Horsepower Requirements of Vee-Bottom Racing Motor Boats, from the Data of Reference (4).

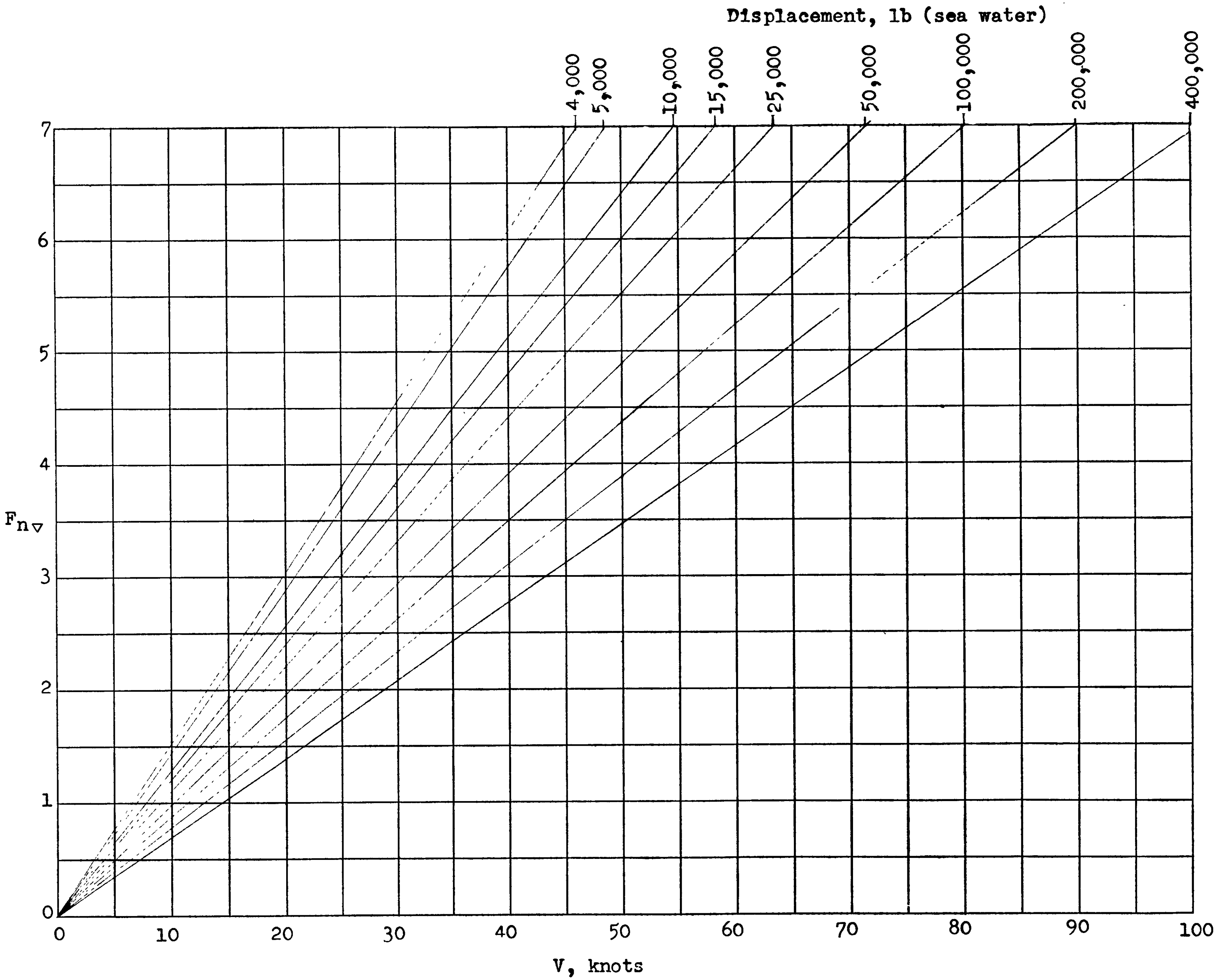

Figure [illegible] - Variation of $F_{n\nabla}$ with Speed and Displacement

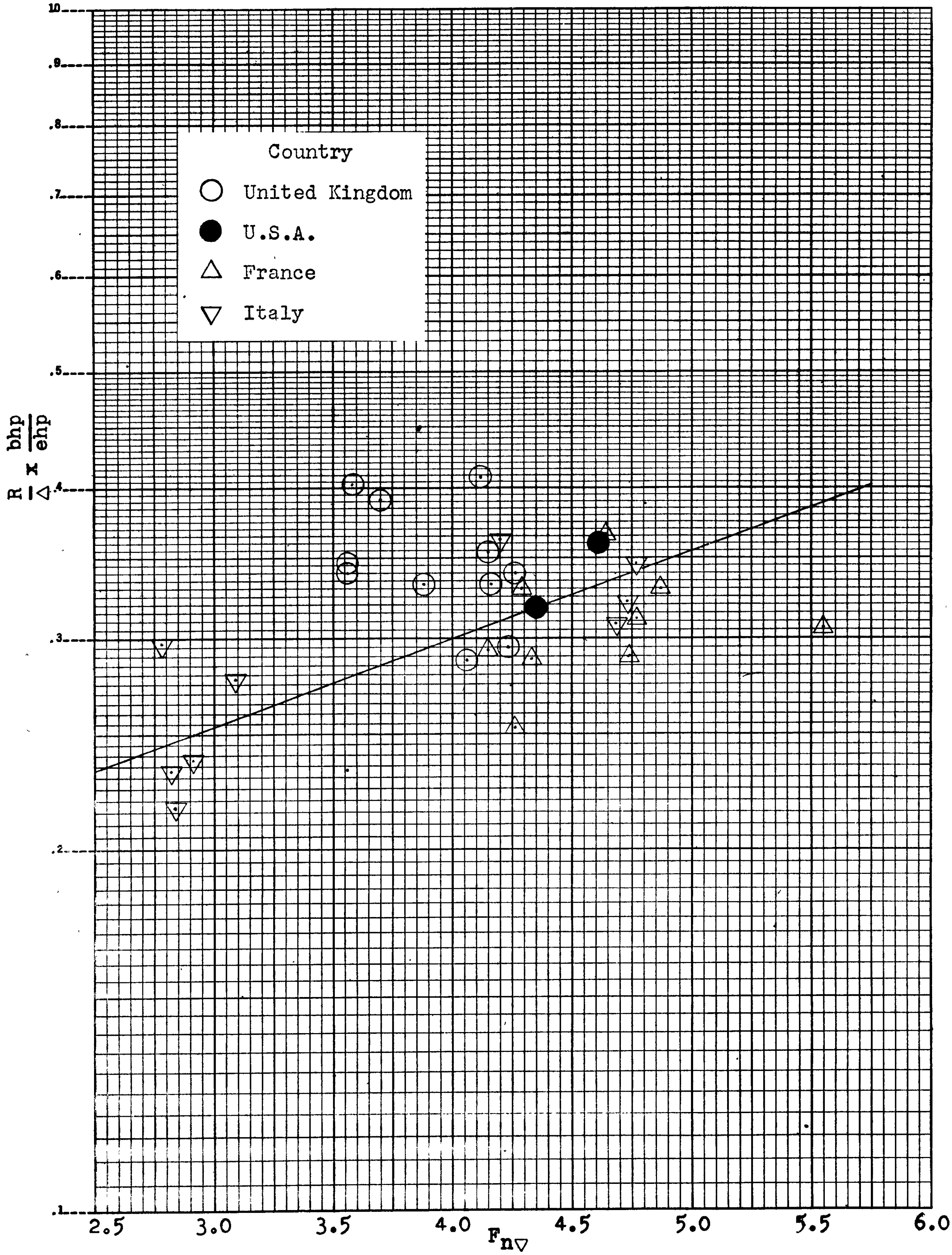

Figure 21 - Coefficients of Brake Horsepower and Speed for Various Motor Torpedo Boats, from the Data of Reference (5).

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2. Hydroplane boats - Performance - Model test
3. Ship models - Performance
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