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THE RESISTANCE OF THREE SERIES OF FLYING-BOAT HULLS AS AFFECTED BY LENGTH-BEAM RATIO

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WASHINGTON

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THE RESISTANCE OF THREE SERIES OF FLYING-BOAT HULLS AS AFFECTED BY LENGTH-BEAM RATIO

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SUMMARY

Data obtained from several independent length-beam-ratio investigations were correlated in order to determine the general effect of length-beam ratio on the resistance characteristics of three series of flying-boat hulls. The study involved length-beam ratios ranging from 5.07 to 10.5 for a large range of loading conditions. Analyses were made at the best-trim hump, the free-to-trim hump, and a high-speed condition near get-away.

Comparisons were made by use of coefficients based on beam, length-beam product, and length^2-beam product. An optimum length-beam ratio was found beyond which no further reduction in hydrodynamic resistance occurred. This optimum varied with the hull lines of the series.

INTRODUCTION

The trend in the design of flying boats has been toward higher length-beam ratios. It is inferred from experience with flying boats that an improvement in hydrodynamic characteristics is obtained with increasing length-beam ratio; otherwise, the heavier loadings now used at the higher length-beam ratios would not have been acceptable. Investigations of the degree and extent of improvement of the hydrodynamic characteristics with higher length-beam ratios than conventional length-beam ratios would therefore be advantageous.

Data for the investigations were obtained from model tests conducted at the Deutsche Versuchsanstalt für Luftfahrt (DVL), the Langley Laboratory of the NACA, and Stevens Institute of Technology (references 1 to 4). The data were analyzed and compared to determine trends for each series. The over-all effect of length-beam ratio on the resistance characteristics of flying-boat hulls was then determined from the trends.

MODELS

The Series

Inasmuch as the three series involve a total of 11 models representing variations of three basic designs, data pertinent to a comparison of the series are presented in table I.

DVL series.- The basic model of the DVL series was evolved by Sottorf (reference 1). The models of this series (table I) were developed from the basic form by starting at the step and increasing the spacing of the stations of the forebody and afterbody along the tangent to the keels at the step in proportion to the length (fig. 1). In this manner the values of beam, angle of dead rise, angles of forebody and afterbody keels, and depth of step remain constant. The three DVL models had length-beam ratios of 6.04, 7.50, and 9.19; Langley tank model 184 (reference 2), which is a continuation of the DVL series, had a length-beam ratio of 10.5.

NACA series.- The basic form of the NACA series was similar to NACA model 84-AF (reference 5) except for a greater depth of step to conform with current practice in obtaining good landing stability. The series was evolved by maintaining constant products of length and beam and by making corresponding transverse sections of the bottom surfaces geometrically similar (fig.2). Constant values were also maintained for angle of dead rise, angles of forebody and afterbody keels, height of hull, and depth of step in inches. The three NACA models had length-beam ratios of 5.23, 6.53, and 7.84 (table I).

Stevens Institute series.- The hull of the XPB2M-1 flying boat was used as the basis of the Stevens Institute series. The models were developed in the same manner as the DVL models; that is, by expanding the station spacing along a tangent to the forebody and afterbody keels at the step (fig. 3). Four models having length-beam ratios of 5.07, 6.19, 7.32, and 8.45 were used in the investigation (table I).

Variations in Hull Form

A comparison of the plan forms of the bottom surfaces of the three series for a selected length-beam ratio and beam is made in figure 4. This figure facilitates a comparison of the differences in forebody-afterbody length ratios and in the hull lines themselves.

As seen in figure 4, the NACA series has the largest ratio of forebody length to afterbody length; whereas little difference exists in the forebody-afterbody length ratios of the other two series. The lines of the afterbodies of the DVL series and the Stevens Institute series are fuller than the lines of the afterbody of the NACA series, especially near the sternpost.

A tail extension may contribute to decreasing the trimming moment at low speeds. The DVL models had no tail extension inasmuch as they were designed as seaplane floats rather than as flying-boat hulls. The NACA series and the Stevens Institute series, both models of flying-boat hulls, had tail extensions.

The DVL float had no chine flare on the afterbody whereas the NACA series had chine flare over the entire length of the afterbody. The Stevens Institute series had chine flare near the sternpost accompanied by a small "breaker" step just forward of the sternpost. All three series had approximately the same amount of chine flare on the forebody.

The included angle between the forebody and afterbody keels was 7.0° for the DVL and the Stevens Institute series and was 6.8° for the NACA series. This difference in included angle is considered negligible.

The depth of step (percent beam) was the same for the DVL and the Stevens Institute series but was greater for the NACA series.

Each of the three series of models was tested about a center of moments that was thought to be reasonable. These centers of moments are not in the same location with respect to the step but they are close enough to preclude any differences in the trends of the series.

RESULTS

Standard coefficients.- The results of the tests were reduced to the usual coefficients based on Froude's law to make them independent of size. In these coefficients, the beam was chosen as the characteristic dimension. The nondimensional coefficients are defined as follows:

C_Δ load coefficient (Δ/wb^3)

C_V speed coefficient $(V/\sqrt{gb})$

C_M trimming-moment coefficient (M/wb^4)

Δ/R load-resistance ratio

where

Δ load on water, pounds

w specific weight of water, pounds per cubic foot (63.4 for these tests; usually taken as 64 for sea water)

b beam, feet

R resistance, pounds

V speed, feet per second

g acceleration of gravity (32.2 ft/sec^2)

M trimming moment, pound-feet

Any consistent system of units may be used. The moment data are referred to the centers of moments shown in figures 1 to 3. Tail-heavy moments are considered positive. Trim is the angle between the base line of the model and the horizontal.

Special coefficients.- The beam of the hull is usually considered as the characteristic dimension in the coefficients based on Froude's law. In reference 3, however, Bell discusses length-beam product as being fundamental in eliminating size; in reference 6, Parkinson considers length^2-beam as being a fundamental quantity controlling forebody spray.

In an effort to determine the comparative effects based on the foregoing considerations, nondimensional coefficients having characteristic dimensions of the square root of length-beam product and cube root of length^2-beam product have been used in this report in addition to the standard coefficients used. These "special" coefficients are not proposed as substitutes for the standard ones but are used merely to facilitate this analysis.

These special coefficients are defined as follows:

Load coefficients:

$$C_{\Delta_1} = \frac{\Delta}{w(Lb)^{3/2}}$$

$$C_{\Delta_2} = \frac{\Delta}{wL^2b}$$

Speed coefficients:

$$C_{V_1} = \frac{V}{\sqrt{g}\,\sqrt[4]{Lb}}$$

$$C_{V_2} = \frac{V}{\sqrt{g}\,\sqrt[6]{L^2b}}$$

Trimming-moment coefficients:

$$C_{M_1} = \frac{M}{w(Lb)^2}$$

$$C_{M_2} = \frac{M}{w(L^2b)^{4/3}}$$

where L is length from stem to sternpost measured in feet.

In comparing hulls of different length-beam ratios by means of the standard coefficients, the beam is constant and hence the hull of the model with the highest length-beam ratio is obviously much larger than the hull of the model with the lowest length-beam ratio. If coefficients based on length-beam product are used, comparable hull sizes (reference 3) are maintained as the length-beam ratio is changed. If coefficients based on length^2-beam product are used, models with high length-beam ratios have smaller length-beam products than models with lower length-beam ratios but the spray characteristics are more nearly comparable (reference 6).

The special coefficients therefore are employed to make the resistance characteristics of models having various length-beam ratios comparable when the size and spray are comparable.

Figure 5 illustrates the relation between the standard and special coefficients.

Table of results.- Comparisons of the series were made at the best-trim hump, the free-to-trim hump, and a high-speed condition; the results are summarized in table II. No results are given in this table at best-trim hump or the high-speed condition for the Stevens Institute series because data were unavailable.

No data are presented for speed coefficient C_V at the free-to-trim hump because of very indefinite resistance humps in references 1 to 4.

DISCUSSION

Best-trim hump.- Best-trim hump is only of academic interest because, with the length-beam ratios used at present, it is seldom attained. The control moments involved are often unavailable and the best trim is usually below the lower trim limit of stability. A comparison of the three series at the best-trim hump is given, however, because with high length-beam ratios the stability characteristics may be such that best-trim hump may be attained in practice. If the best-trim hump is attainable, analyses of the

DVL series (figs. 6(b), 7(b), and 8(b)) indicate definite advantages in going to higher length-beam ratios than are used in present design practice. For the DVL series, at all coefficient bases considered, the load-resistance ratio Δ/R increases with increasing length-beam ratio and attains an optimum at a length-beam ratio of approximately 9.

An analysis of the NACA series (figs. 6(a), 7(a), and 8(a)) does not indicate so clear a conclusion as the analysis of the DVL series. On the basis of constant beam loading, load-resistance ratio increased with increasing length-beam ratio as far as the tests extended. With constant length-beam product, an optimum length-beam ratio of about 6.5 is shown. When the NACA series of hulls is loaded in proportion to length^2-beam product, the resistance increases slightly as the length-beam ratio is increased.

The speed at which the hump occurs increases with increasing length-beam ratio. If small changes in thrust with speed are assumed, a higher hump speed may be favorable in that at higher speeds more load is supported by the wing; hence, less load is on the water.

Although, in general, the load-resistance ratio increases with increasing length-beam ratio, the best trim decreases with an accompanying rise in trimming moment.

For either the DVL or the NACA series, loading proportional to length^2-beam product decreases the effect of length-beam ratio on resistance and trim. This trend leads to the conclusion that, as length-beam ratio is increased for a given gross load, a smaller hull (smaller length-beam product) could be used with no increase in hydrodynamic resistance.

Free-to-trim hump.- At the free-to-trim hump, for the three coefficient bases considered, Δ/R increases with length-beam ratio to an optimum length-beam ratio of about 9 for the DVL series (figs. 9 to 11). The NACA series has an optimum length-beam ratio of about 7 if compared on a basis of constant beam and an optimum of about 6 if compared on a basis of constant length-beam product. Comparison of the NACA series on the basis of constant length^2-beam product results in a reversal of trend; that is, Δ/R decreases with increasing length-beam ratio. No optimum was attained for the Stevens Institute series on any basis but the indication is that one might have been found if the series had been extended to higher length-beam ratios.

Except for the comparison made at constant length^2-beam product, the trim at the hump for the three series of models decreases with increasing length-beam ratio. The comparison at constant length^2-beam product indicates a slight increase in trim with length-beam ratio for the NACA and DVL series and a slightly varying trim with length-beam ratio for the Stevens Institute series. Perhaps the least slope occurs somewhere between the constant length-beam product and the constant length^2-beam product.

Loadings proportional to length^2-beam decrease the effect of length-beam ratio on the free-to-trim-hump resistance and trim.

High-speed characteristics.- From take-off consideration, it was desirable to ascertain the effects of length-beam ratio at a high-planing-speed condition. The condition chosen was one in which the angle between the forebody keel and the water was 7° and the speed coefficient C_V based on beam was 6.0 at a length-beam ratio of 6.04. Inasmuch as a difference in size is implied when changing from one basis of comparison to another, a difference must also occur in the speed. The relation between speed coefficients based on beam, length-beam product, and length^2-beam product for this condition is shown in figure 5.

Up to a length-beam ratio of 7.5 (see figs. 12 and 13) the Δ/R trends of the DVL and the NACA series are similar. Small differences may be attributed to the fairing of the curves inasmuch as the number of test points were few. An optimum Δ/R value for the DVL series occurs at about 9 regardless of the basis used for comparison.

At high planing speeds, length-beam ratio has the least effect on load-resistance ratio when the hulls are loaded in proportion to the length-beam product.

CONCLUSIONS

A comparison of data obtained from three series of flying-boat hulls investigated at the Deutsche Versuchsanstalt für Luftfahrt (DVL), the Langley Laboratory of the NACA, and Stevens Institute of Technology and incorporating length-beam ratios ranging from 5.07 to 10.5 indicate the following conclusions:

1. An optimum length-beam ratio was found beyond which no further reduction in resistance occurred. The optimum ratio depended upon the hull lines of any given model series.

2. The least change in the resistance characteristics with length-beam ratio occurred when:

(a) Best-trim hump was considered on the basis of constant length^2-beam product.

(b) Free-to-trim hump was considered either on the basis of constant length-beam product or constant length^2-beam product.

(c) A high-speed condition was considered on the basis of constant length-beam product.

3. The small change in hydrodynamic characteristics with length-beam ratio, when compared on the basis of constant length^2-beam product, seemed to indicate that at high length-beam ratios smaller hulls could be used without sacrificing resistance characteristics.

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TABLE I

DIMENSIONS OF MODELS

Geometric dimensions	DVL series (references 1 and 2)				NACA series (reference 3)			Stevens Institute series (reference 4)			
	1a	8	7	Langley tank model 184	144	145	146	339-22	339-1	339-23	339-46
Over-all length, in.	71.33	88.58	108.53	124.12	114.85	128.41	140.67	-----	-----	-----	-----
Length to sternpost, in.	71.33	88.58	108.53	124.12	83.33	93.17	102.06	27.37	33.45	39.53	45.61
Length of forebody, in.	39.36	48.87	59.92	68.48	50.10	56.02	61.36	15.22	18.60	21.98	25.36
Length of afterbody, in.	31.97	39.71	48.61	55.64	33.23	37.15	40.70	12.15	14.85	17.55	20.25
Maximum beam, in.	11.81	11.81	11.81	11.81	15.92	14.24	13.00	5.40	5.40	5.40	5.40
Length-beam ratio	6.04	7.50	9.19	10.5	5.23	6.53	7.84	5.07	6.19	7.32	8.45
Forebody-afterbody length ratio	1.231	1.231	1.231	1.231	1.507	1.507	1.507	1.253	1.253	1.253	1.253
Angle of dead rise excluding chine flare, deg	20	20	20	20	20	20	20	20	20	20	20
Angle of afterbody keel, deg	5.0	5.0	5.0	5.0	5.5	5.5	5.5	7.0	7.0	7.0	7.0
Angle of forebody keel, deg	2.0	2.0	2.0	2.0	1.3	1.3	1.3	0	0	0	0
Depth of step, percent beam	5.0	5.0	5.0	5.0	6.28	7.02	7.70	5.0	5.0	5.0	5.0
c.g., forward of step, in.	5.4	5.4	5.4	5.4	7.2	7.2	7.2	1.89	1.89	1.89	1.89
c.g., height above keel at step, in.	16.56	16.56	16.56	16.56	17.94	17.94	17.94	4.86	4.86	4.86	4.86
Chine flare, forebody	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Chine flare, afterbody	No	No	No	No	Yes	Yes	Yes	←Near sternpost only→			

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TABLE II

SUMMARY OF COMPARISONS OF THE SERIES

Series	Bases (constant)	Best-trim hump					Free-to-trim hump			High speed	
		Fig.	Trim (deg)	Speed coefficient	Δ/R	Trimming-moment coefficient	Fig.	Trim (deg)	Δ/R	Fig.	Δ/R
DVL	Beam	6(b)	Decreases with increase in L/b.	Increases with increasing L/b. No maximum value attained.	Increases with increasing L/b to optimum value of about 9.5.	Increases with increasing L/b. (Moment accelerates with increasing L/b.)	9(a)	Decreases with increase in L/b	Increases with increasing L/b to optimum value of about 9.5.	12(a)	Increases with increasing L/b at heavy loads to optimum of about 9.25. Little change with L/b at light loads.
	Length-beam product	7(b)	Decreases with increase in L/b. Slopes of curves less than those at constant beam.	Increases with increasing L/b to extrapolated maximum value at L/b of about 9.5. Slopes of curves less than those at constant beam.	Increases with increasing L/b to optimum value of about 9.0. Slopes of curves less than those at constant beam.	Increases with increasing L/b. (Moment proportional to L/b.)	10(a)	Very slight decrease with increasing L/b. Minimum attained at L/b of about 9.5.	Slight increase with increasing L/b. Optimum value at L/b about 9.0.	12(b)	Increases with increasing L/b at all loads to optimum of about 9.25.
	Length²-beam product	8(b)	Decreases with increase in L/b to a minimum L/b of 8.5. Least change of trim with L/b.	Increases with increasing L/b to extrapolated maximum value at L/b of about 10.5. Slopes of curves less than those at constant length-beam product.	Very slight increase with increasing L/b to optimum value at a L/b of about 8.5, after which it drops off rapidly.	Increases with increasing L/b. (Moment decelerates with increasing L/b.)	11(a)	Slight increase with increasing L/b.	Negligible change with increasing L/b. Falls off after L/b of about 9.5.	12(c)	Increases with increasing L/b at all loads to optimum of about 9.25.
NACA	Beam	6(a)	Decreases with increase in L/b.	Increases with increasing L/b. No maximum value attained.	Steady increase with L/b. Appears to approach an optimum but no optimum value attained.	Increase with increasing L/b. (Small acceleration in moment with increasing L/b.)	9(b)	Decreases with increase in L/b.	Increases with increasing L/b to optimum value at L/b of about 7.5.	13(a)	Small decrease with increasing L/b for all loads.
	Length-beam product	7(a)	Decreases with increase in L/b. Slopes of curves less than those at constant beam.	Increases with increasing L/b. Slopes of curves less than those at constant beam.	Increases with L/b to optimum value at L/b of approximately 6.5.	Increases with increasing L/b. (Slight deceleration in moment with increasing L/b.)	10(b)	No change to a L/b of 6.5; slight decrease with increasing L/b thereafter.	No change with L/b to a value of 7.0, after which it decreases.	13(b)	Small increase with increasing L/b at the heavier load. No change at the lighter load.
	Length²-beam product	8(a)	Decreases with increase in L/b ratio. Least change of trim with L/b.	Increases with increasing L/b. Slopes of curves less than those at constant length-beam product.	Slight decrease with increasing L/b.	Increases with increasing L/b. (Moment decelerates with increasing L/b.)	11(b)	Slight increase with increasing L/b to maximum at L/b of 7.0.	Decreases with increasing L/b.	13(c)	Small increase with increasing L/b at all loads.
Stevens Institute	Beam		No data.	No data.	No data.	No data.	9(c)	Sharp decrease with increasing L/b.	Increases with increasing L/b. No optimum value attained.		No data.
	Length-beam product		No data.	No data.	No data.	No data.	10(c)	Slight increase with L/b to L/b of 6.0; marked decrease thereafter.	Small increase with increasing L/b. No optimum value attained.		No data.
	Length²-beam product		No data.	No data.	No data.	No data.	11(c)	Increases with increasing L/b to L/b of 6.0; decreases thereafter.	Very slight increase with increasing L/b. No optimum value attained.		No data.

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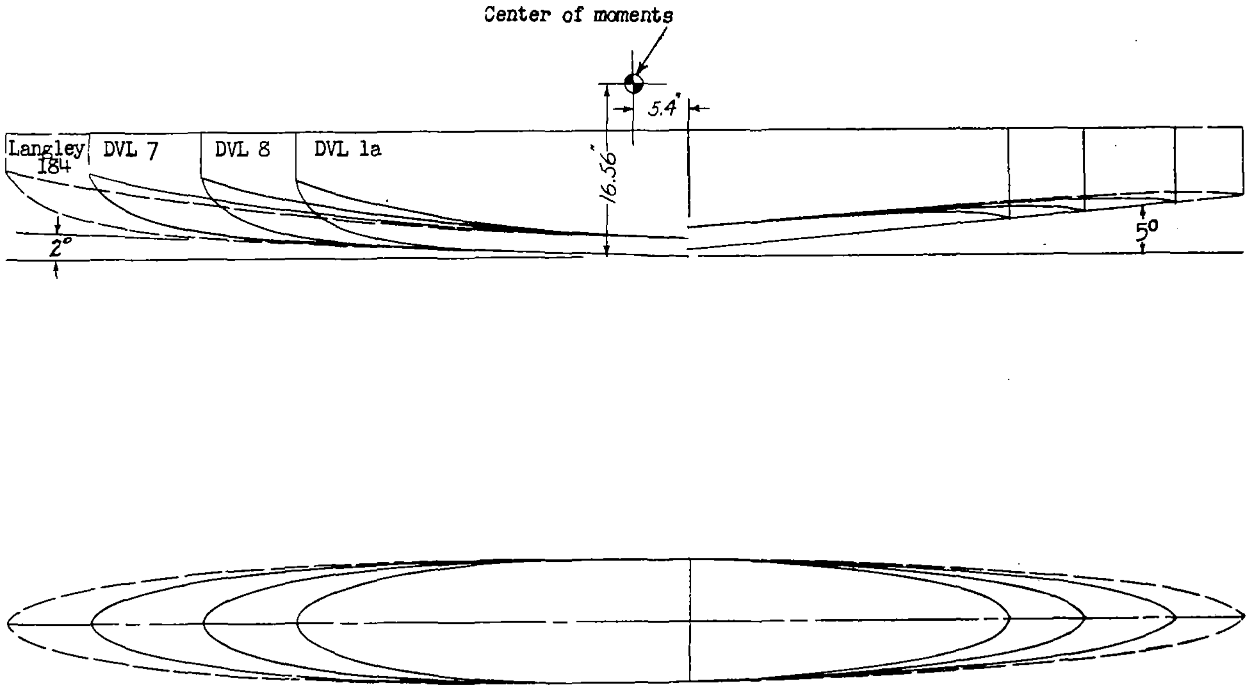

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Figure 1.- Profile and plan views of the DVL series including Langley tank model 184.

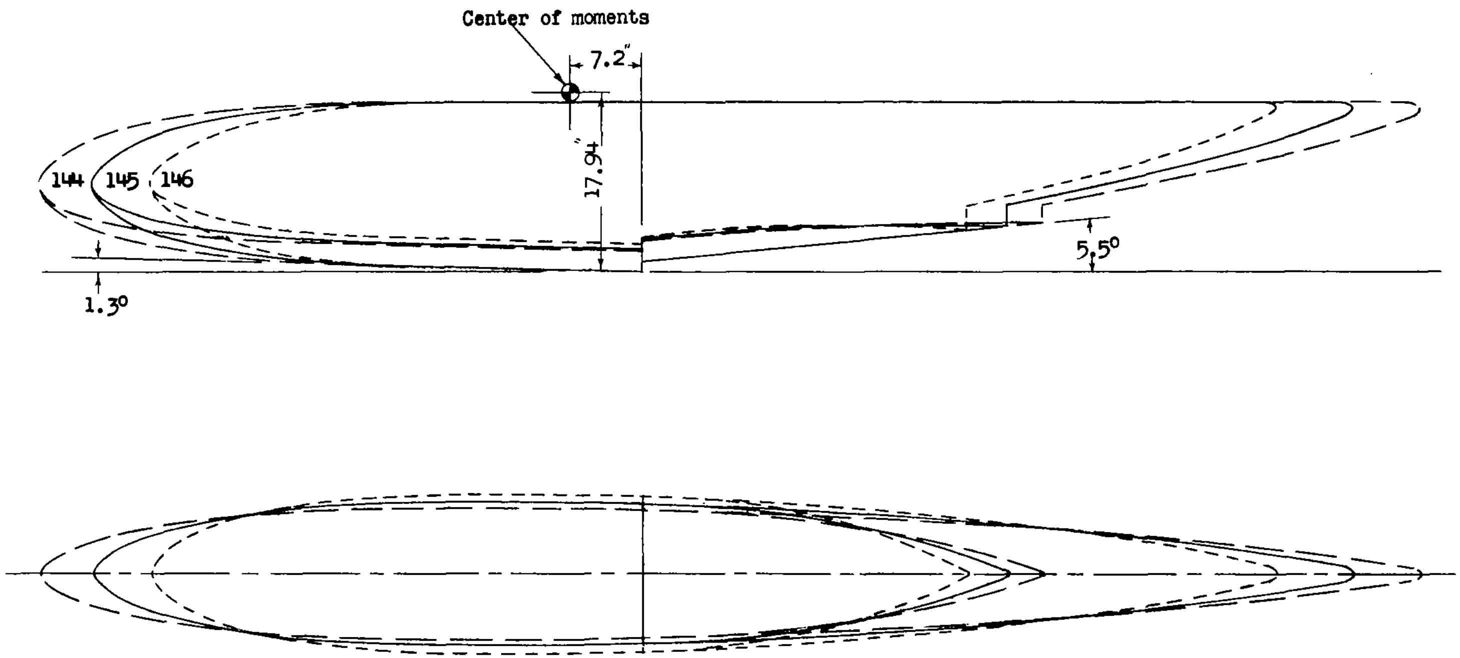

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Figure 2.- Profile and plan views of the NACA series.

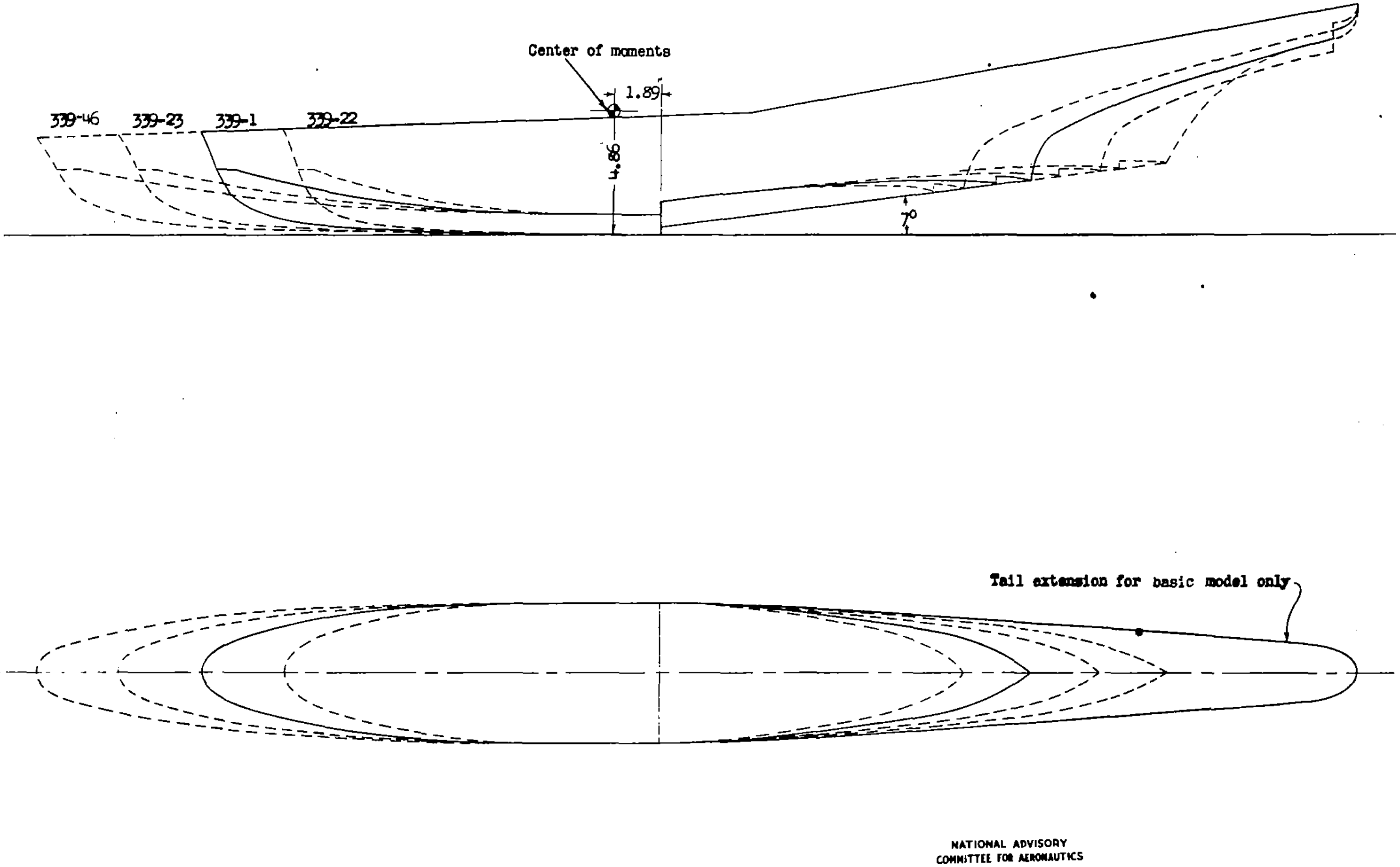

Figure 3.- Profile and plan views of the Stevens Institute series.

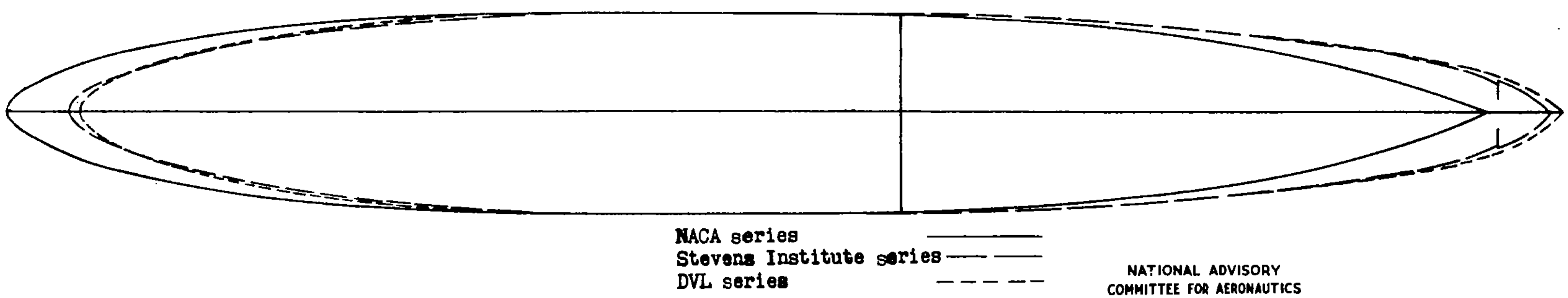

Figure 4.- Plan views of the three series of models at an arbitrary length-beam ratio of 7.5 and a constant maximum beam. (Tail extensions omitted.)

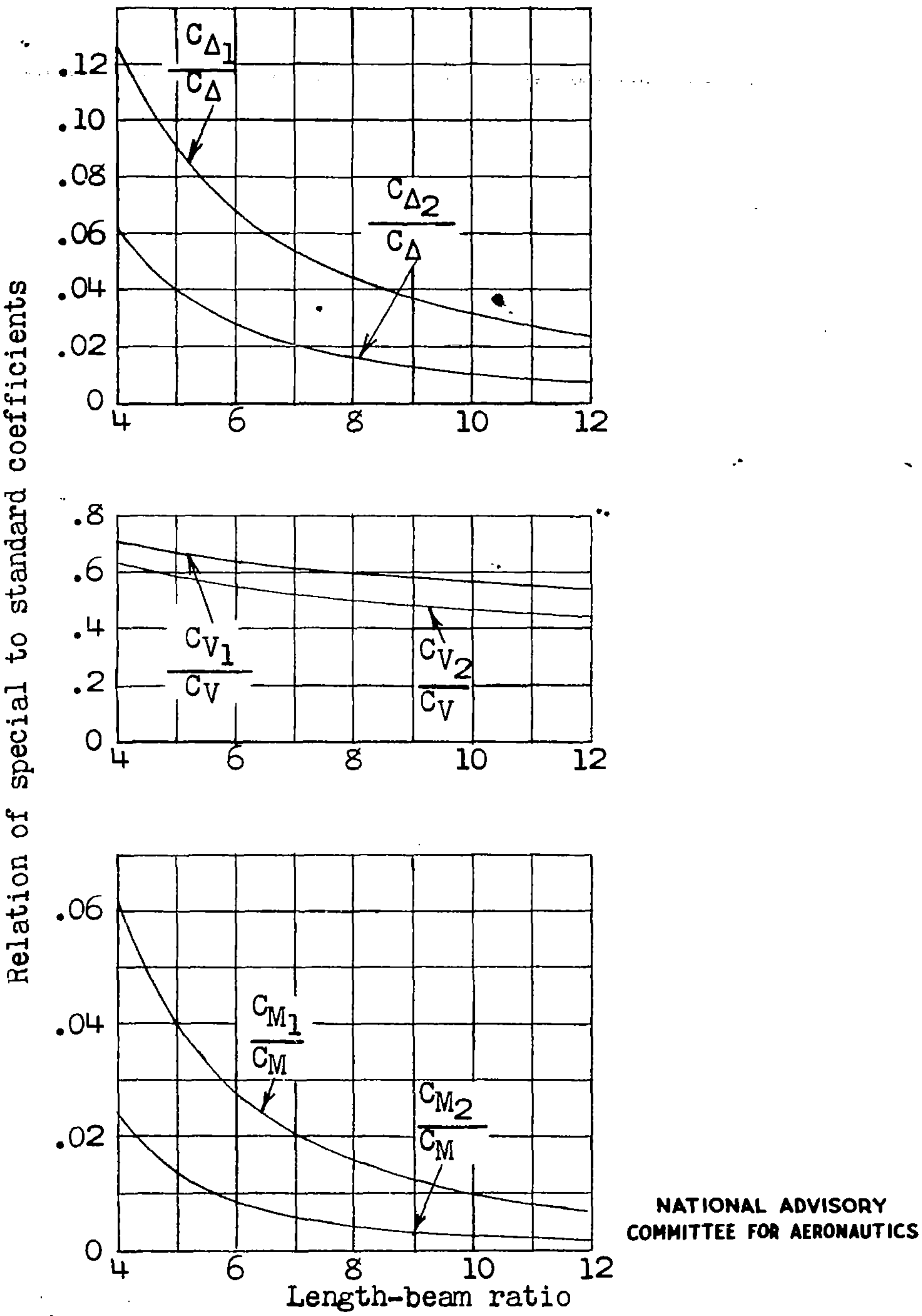

Figure 5.- Variation of relation between special and standard coefficients with length-beam ratio.

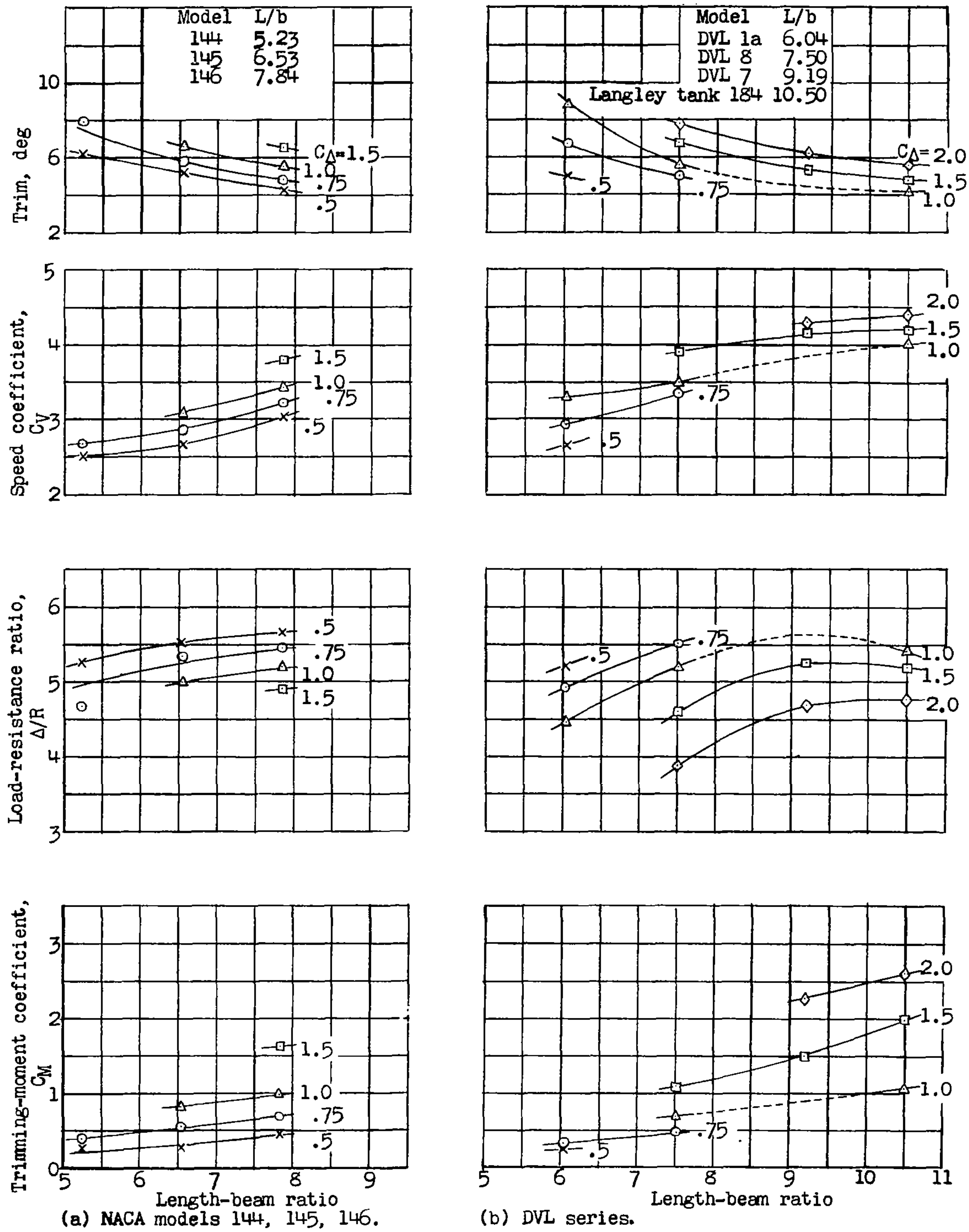

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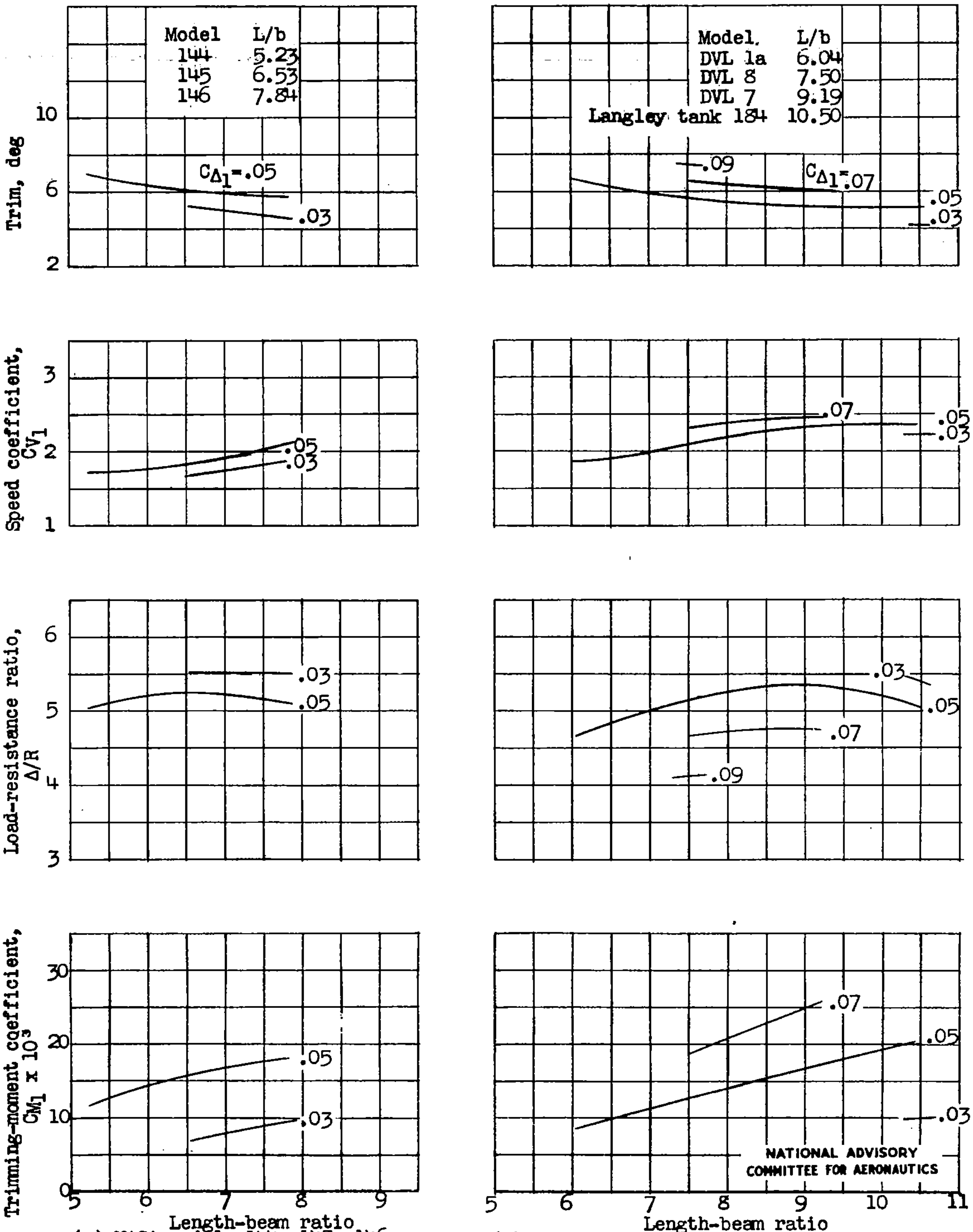
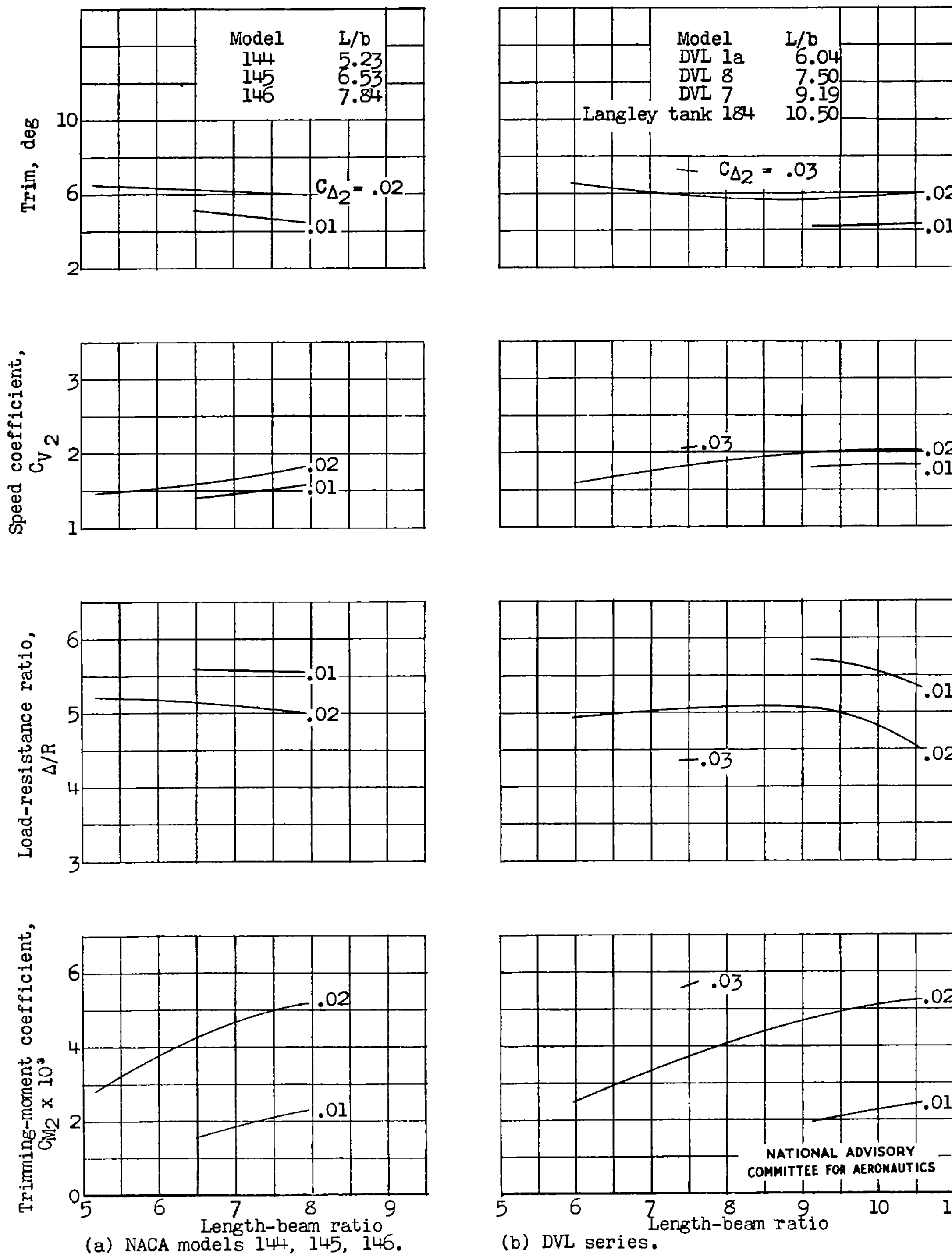
Figure 6.- Best-trim hump characteristics for two series of models about their respective center-of-gravity positions. Constant beam.



(a) NACA models 144, 145, 146.

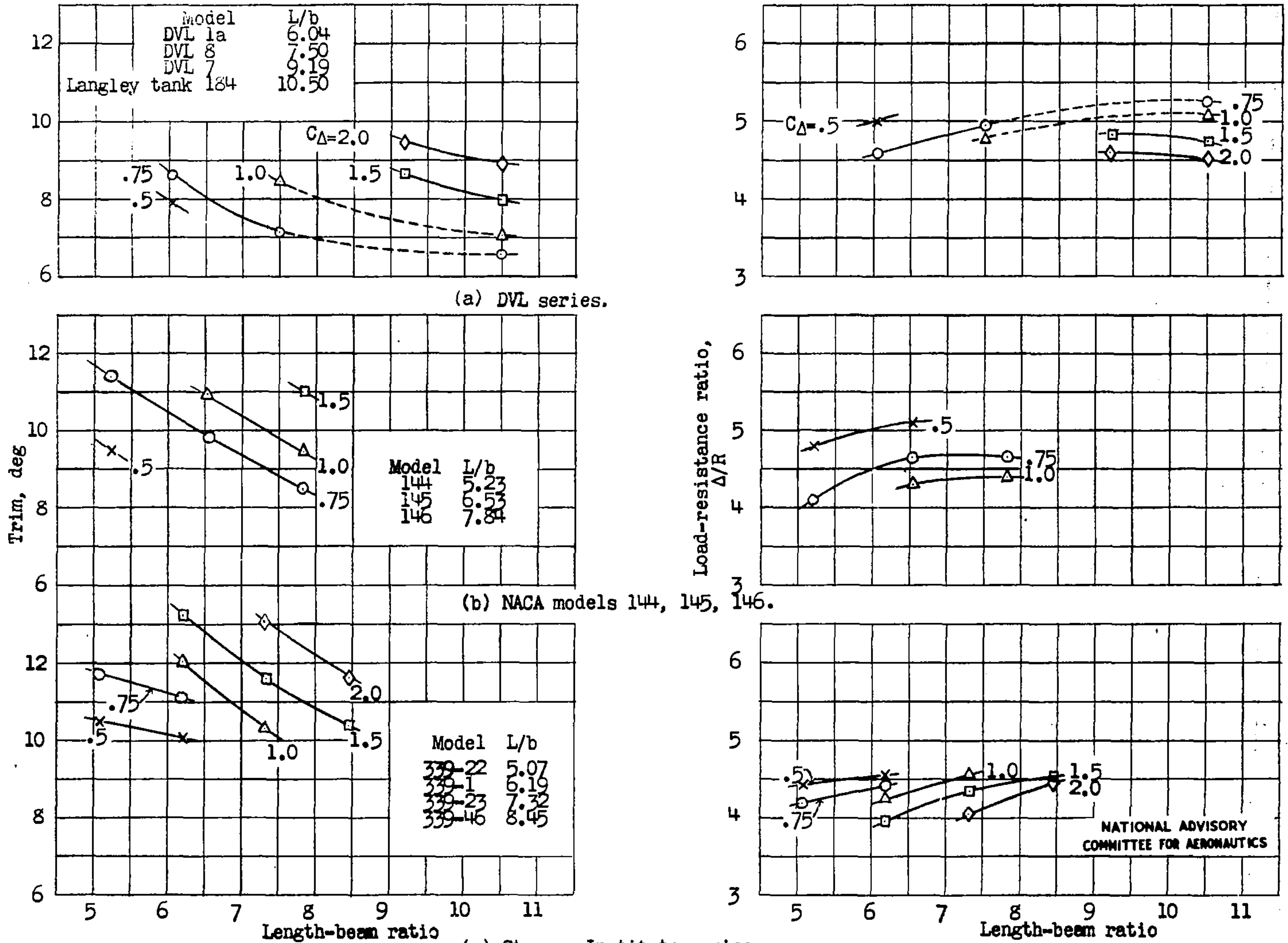
(b) DVL series.

Figure 7.- Best-trim hump characteristics for two series of models about their respective center-of-gravity positions. Constant length-beam product.



(a) NACA models 144, 145, 146. (b) DVL series.

Figure 8.- Best-trim hump characteristics for two series of models about their respective center-of-gravity positions. Constant length^2-beam product.



(a) DVL series.

(b) NACA models 144, 145, 146.

(c) Stevens Institute series.

Figure 9.- Free-to-trim characteristics at the hump for three different series of models about their respective center-of-gravity positions. Constant beam.

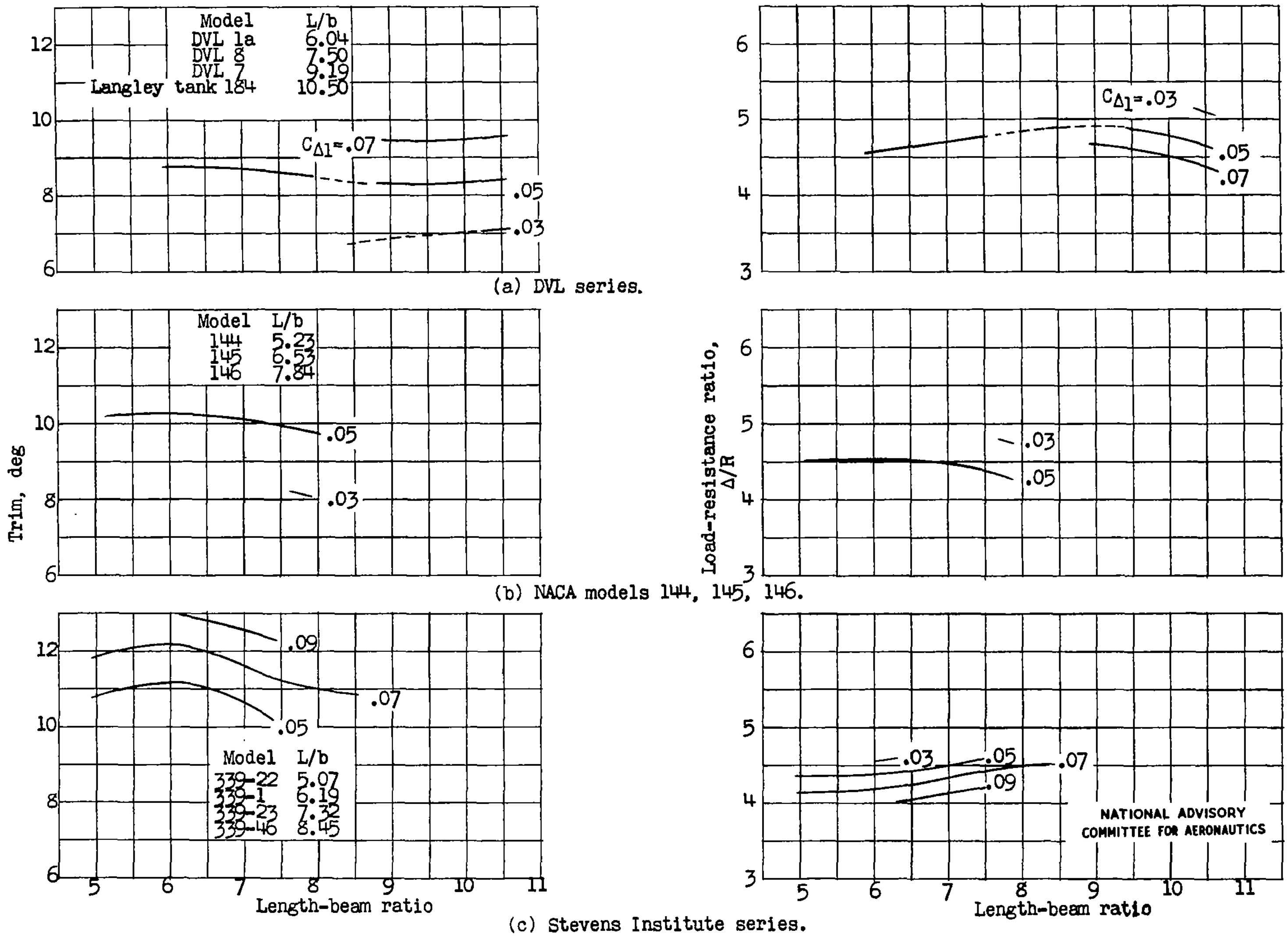
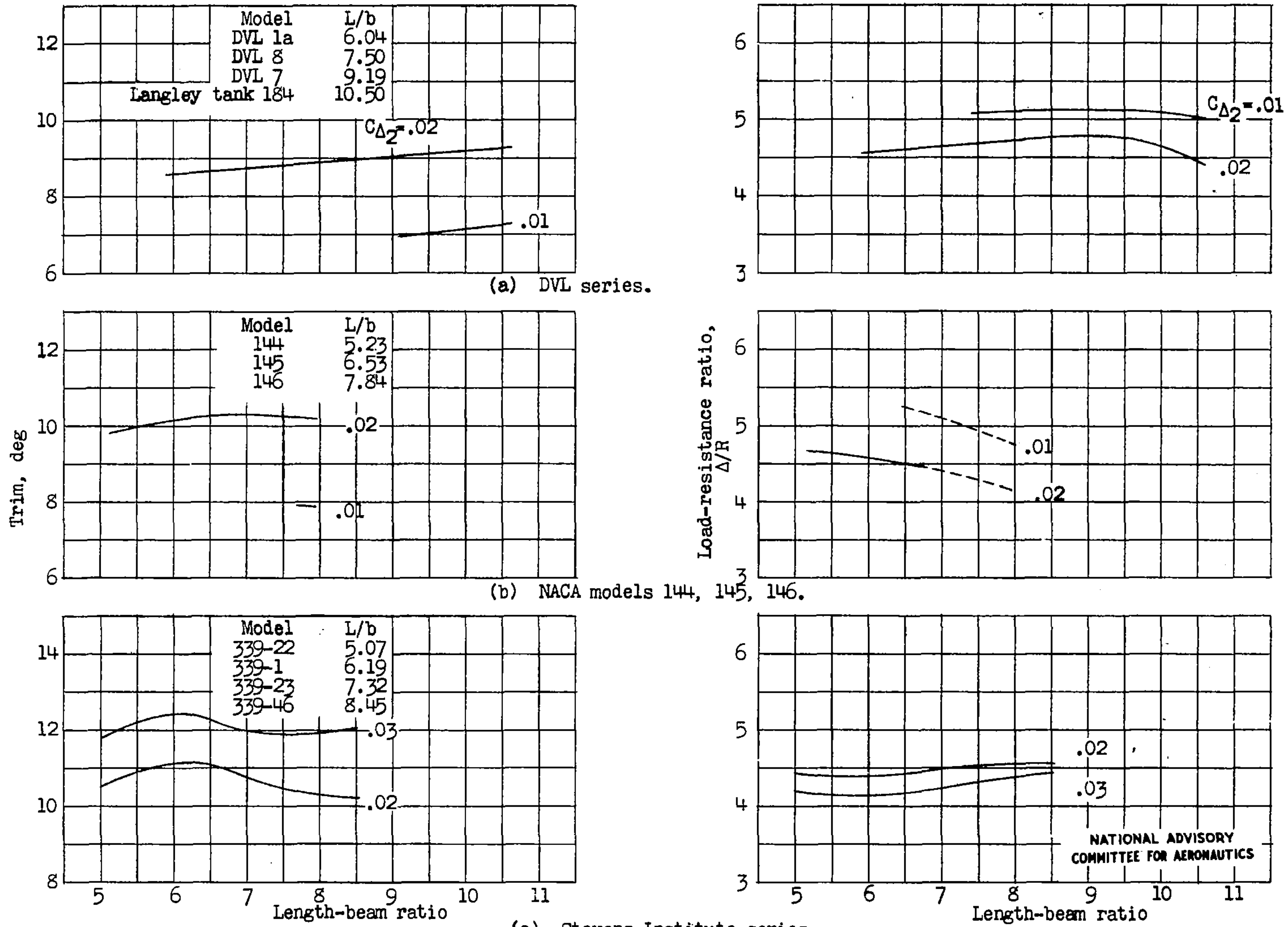


Figure 10 .- Free-to-trim characteristics at the hump for three different series of models about their respective center-of-gravity positions. Constant length-beam product.

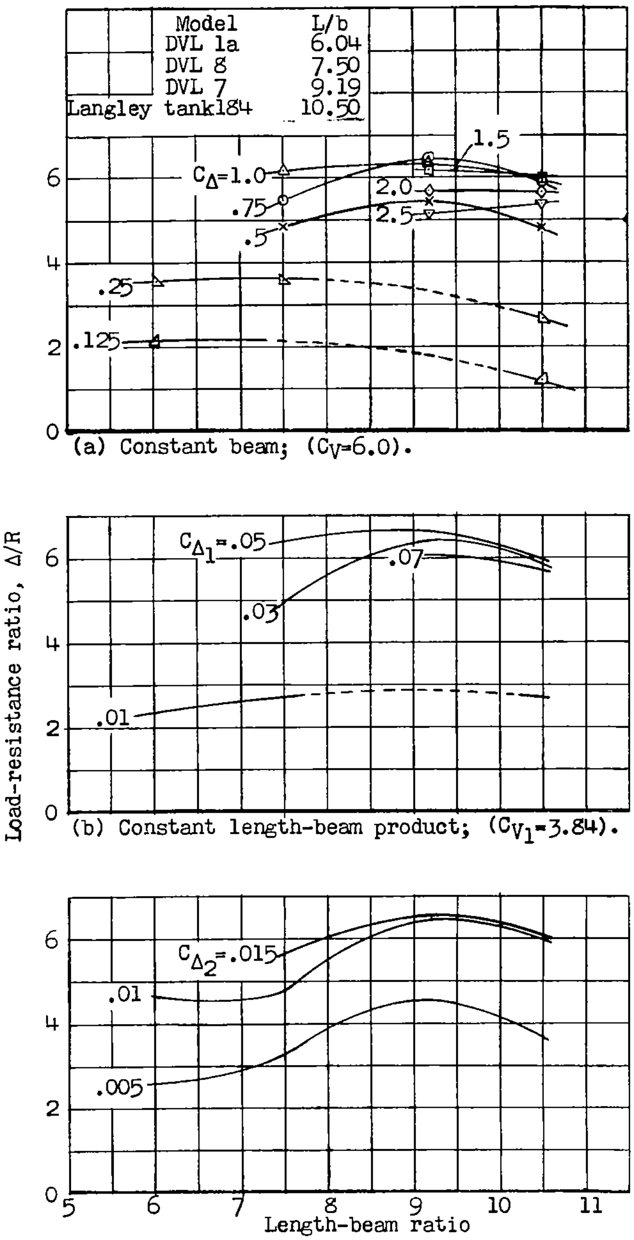


(a) DVL series.

(b) NACA models 144, 145, 146.

(c) Stevens Institute series.

Figure 11 .- Free-to-trim characteristics at the hump for three different series of models about their respective center-of-gravity positions. Constant length^2-beam product.

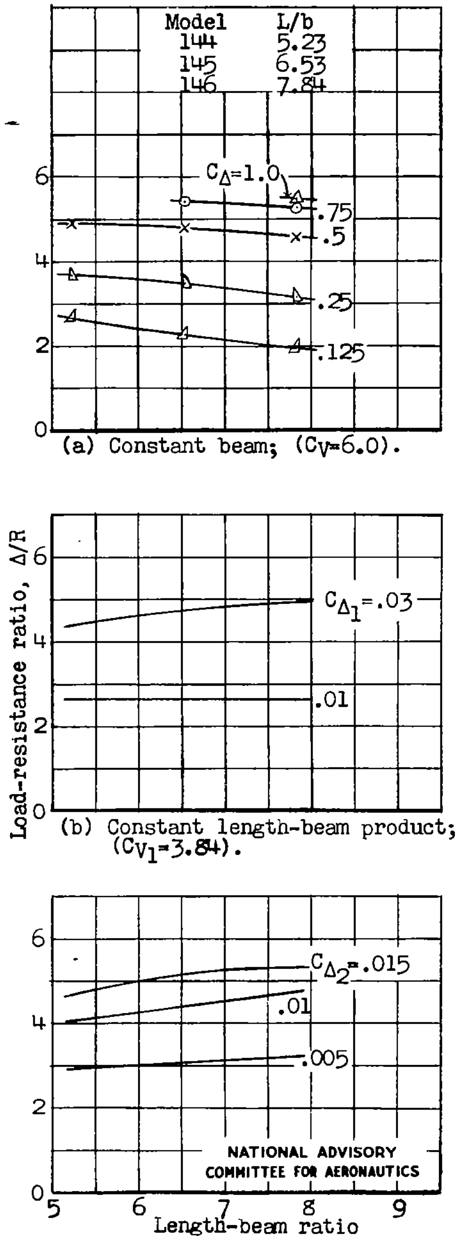


(a) Constant beam; (C_V=6.0).

(b) Constant length-beam product; (C_{V_1}=3.84).

(c) Constant length^2-beam product; (C_{V_2}=3.27).

Figure 12.- High-speed characteristics of models of DVL series about their respective center-of-gravity positions. C_V=6.0 at length-beam ratio of 6.04; angle between forebody keel and horizontal, 7°.



(a) Constant beam; (C_V=6.0).

(b) Constant length-beam product; (C_{V_1}=3.84).

(c) Constant length^2-beam product; (C_{V_2}=3.27).

Figure 13.- High-speed characteristics of models of NACA series about tneir respective center-of-gravity positions. C_V=6.0 at length-beam ratio of 6.04; angle between forebody keel and horizontal, 7°.