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RESISTANCE TESTS OF A $\frac{1}{16}$-SIZE MODEL OF THE HUGHES-KAISER FLYING BOAT, NACA MODEL 183

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NACA

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

MEMORANDUM REPORT

for the

Department of Commerce

RESISTANCE TESTS OF A $\frac{1}{16}$-SIZE MODEL OF THE HUGHES-KAISER FLYING BOAT, NACA MODEL 183

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SUMMARY

Resistance tests of a $\frac{1}{16}$-size model of the hull of the Hughes-Kaiser cargo airplane were made in NACA tank no. 1. The results of these tests were required for estimates of the take-off performance and the maximum gross load for take-off. The most recent changes in the form of the hull were incorporated in the model.

At hump speeds, with the model free to trim, the trim and resistance were high, which resulted in a load-resistance ratio of approximately 4.0 for a gross load coefficient of 0.75. The addition of chine flare at the stern post caused an increase in positive trimming moments and reduced the trim just beyond hump speed. The addition of breaker strips on the tail extension caused a further reduction in positive trimming moment, the final load-resistance ratio at the hump, free to trim, being approximately 4.8 for a gross load coefficient of 0.75.

The results of fixed-trim tests are presented as working charts. Take-off computations using these data, together with estimated aerodynamic lift and drag curves for the flying boat, indicate that the maximum gross load for take-off with 16.6-foot four-blade propellers is 375,000 pounds full-size, and with 18.5-foot four-blade propellers is 400,000 pounds full size.

At a gross load corresponding to 400,000 pounds full-size, a take-off is possible in 69 seconds over a distance of 5600 feet. Correcting for scale effect on the frictional resistance reduces the hump resistance

8 percent. By trimming at the lower trim limit of stability at hump speeds, the hump resistance is reduced 14 percent. Trim for minimum water resistance cannot be used at hump speeds because of excessive positive hydordynamic trimming moments and because lower-limit porpoising would be encountered.

INTRODUCTION

Tank tests of a $\frac{1}{16}$-size model of the hull of the Hughes-Kaiser cargo airplane were made to determine the hydrodynamic resistance and trimming moments over a range of trims, loads, and speeds that might be encountered during take-off. These results were required for estimates of the take-off performance and the maximum gross weight for take-off.

An attempt was made to determine the resistance characteristics of this design by towing the $\frac{1}{16}$-size dynamic model (NACA model 158-1) used for stability tests. The accuracy of these results, however, was impaired by warping of the model. Earlier resistance tests of a $\frac{1}{40}$-size model of the hull alone were not considered adequate for purpose of estimating hydrodynamic performance inasmuch as the tests were not complete. In addition, modifications to the hull lines had been made since the construction of the dynamic model and the $\frac{1}{40}$-size hull model. Tests of a new model, incorporating all the latest changes in form, were therefore considered advisable. This hull, designated NACA model 183, was designed and built by the Hughes Aircraft Company.

These tests were made as a part of an extensive investigation requested by the Secretary of Commerce on September 28, 1942, and were made in NACA tank no. 1 during January and February 1944.

DESCRIPTION OF MODEL

The lines of the hull, designated NACA model 183, are shown in figure 1, and photographs are shown in figure 2. Full-size and model dimensions are given in table 1, together with comparable data for the dynamic model 158-1.

The principal differences between model 183 and the dynamic model 158-1 are:

(a) The forebody chines of model 183 faded out at station 6.25 while the chines of model 158-1 were carried to the forward perpendicular.

(b) The main step of model 183 was approximately 0.75 inch (1 foot full size) farther aft than that of model 158-1.

(c) The chine flare on the afterbody was horizontal for model 183; whereas it was turned down for model 158-1.

(d) The cross sections of the tip of the tail extension of model 183 were circular while those of model 158-1 were approximately elliptical, figure 3. The height of the deck at the tip of the tail extension was less for model 183 than for model 158-1.

(e) The diameter of the basic circle of the tail extension of model 183 was 18 inches while that of model 158-1 was 16.5 inches.

Two modifications of model 183, figure 4, were also tested:

(a) Model 183A - The chine flare at the stern post was increased.

(b) Model 183A-1 - Breaker strips were added to the tail extension of model 183A.

APPARATUS AND PROCEDURE

The tests were made in NACA tank no. 1 using the towing equipment and test procedure described in reference 1. The water in the tank was at the 12-foot level during these tests.

General free-to-trim tests were made to speeds just beyond the hump. A thrust moment of 80 inch-pounds, corresponding to an approximate thrust of 20 pounds (80,000 pounds full size), was applied to the model during these tests.

Tests were made over a range of fixed trims that included trim for minimum water resistance. Enough data were obtained to allow for change in trimming moment with possible changes in the position of the center of gravity or in the position of the main step.

Wetted-length measurements were taken at the keel and chines of both the forebody and afterbody. From these data average wetted lengths were determined for use in making corrections for scale effect on the frictional resistance.

The center of gravity for these tests was 14.84 inches above the keel at the step and 4.94 inches forward of the step. The trim was referred to the base line, and moments tending to increase the trim were considered positive.

The aerodynamic drag of the model is included in the final resistance, but the windage tare of the towing gear has been deducted. In order to estimate that part of the resistance contributed by the aerodynamic drag of the model, it was towed just clear of the water and the aerodynamic drag was measured for several trims.

The draft and trimming moment at rest were measured over a wide range of trims and loads that included those obtained when a concentrated load was located at the bow.

The results of the tests were reduced to the usual nondimensional coefficients based on Froude's law to make them independent of size. The maximum beam of forebody chine was used as the characteristic dimension. These coefficients are defined as follows:

C_Δ load coefficient $\left(\frac{\Delta}{wb^3}\right)$

C_R resistance coefficient $\left(\frac{R}{wb^3}\right)$

C_V speed coefficient $\left(\frac{V}{\sqrt{gb}}\right)$

C_M trimming-moment coefficient $\left(\frac{M}{wb^4}\right)$

$C_{W.L.}$ wetted-length coefficient $\left(\frac{W.L.}{b}\right)$

C_d draft coefficient $\left(\frac{d}{b}\right)$

where

Δ load on water, pounds

w specific weight of water, pounds per cubic foot (63.5 for these tests, usually taken as 64 for sea water)

b maximum beam of forebody chine, feet

R resistance, pounds

V speed, feet per second

g acceleration of gravity, 32.2 feet per second^2

M trimming moment, pound-feet

W.L. average wetted length, $\frac{\text{wetted-length keel + wetted-length chine}}{2}$, feet

d draft at main step, feet

RESULTS AND DISCUSSION

Free-to-Trim Tests

The results of the free-to-trim tests of model 183 are presented in figure 5(a) for load coefficients from 0.4 to 0.75. The trim did not decrease just beyond hump speed, which resulted in high resistances and unfavorable load-resistance ratios. The spray from under the afterbody did not break clear of the model, and suction forces (sticking) apparently developed which tended to produce the high trims. As the speed was increased, the trim decreased sharply and the tail extension came clear of the water. If the trim was decreased by application of a bow-down moment at speeds where the sticking occurred, the model generally tended to run at a lower trim when this moment was removed.

Tests of the dynamic model indicated that the trim control was adequate for overcoming any forces due to sticking of the afterbody and tail extension. The circular sections of the tail cone of model 183 were not the same as those of model 158-1, and the flow of water over the circular sections may have contributed to the sticking. The chine flare at the stern post of model 183 was probably less effective in decreasing the trim than the similar flare on model 158-1.

Increasing the chine flare at the stern post, model 183A, reduced the speed range over which the sticking occurred (fig. 5(b)). The addition of breaker strips on the tail extension, model 183A-1, further reduced the sticking (fig. 5(c)). The load-resistance ratio at the hump for a gross load coefficient of 0.75 was 4.8 for model 183A-1 as compared with 4.0 for model 183. These modifications were included in the test program as possible solutions in the event that flow over the tail extension caused sticking at hump speeds.

Fixed-Trim Tests

The results of the fixed-trim tests of model 183 are presented as working charts in figure 6. The use of these charts is described in reference 2. The forebody and afterbody wetted lengths are plotted as nondimensional coefficients in figure 7 for speed coefficients from 1.8 to 4.0.

The discontinuities in the resistance data at low speeds are associated with ventilation at the main step. Large negative aerodynamic pitching moments would be required to operate at the low trims at which these discontinuities occur.

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The discontinuities at high speeds represent the trims at which the model would no longer run on the forebody, and the load was carried on the afterbody alone. The transition from planing on the forebody and afterbody surfaces to planing on the afterbody alone is accompanied by an increase in negative hydrodynamic trimming moment. At a trim of 12° the tests were not made at speed coefficients greater than 5.0 because the negative trimming moments exceeded the capacity of the moment springs.

The sticking of the tail extension noted in the free-to-trim tests also appears to a lesser extent in the fixed-trim cross plots (fig. 6). At a speed coefficient of 3.75 a sharp reversal in the curves of constant moment coefficient was noted. For a given moment coefficient and load coefficient, the model may assume two different trims corresponding to those found in the free-to-trim tests.

Curves of resistance coefficient and trimming-moment coefficient at the trim for minimum water resistance for model 183 are plotted in figure 8. The load-resistance ratio at hump speeds varied from 4.95 for a load coefficient of 0.75 to 5.70 for a load coefficient of 0.40. Large negative trimming moments would be required to operate at trim for minimum water resistance at hump speeds.

Model 183A was tested at several high trims to show the effect of added chine flare at the stern post on the fixed-trim resistance and trimming moments; these results are given in figure 9. At a given trim, no appreciable change in the hydrodynamic resistance was caused by the addition of the chine flare, but increased bow-down moments were noted. This change in hydrodynamic moment would reduce the trim and, therefore, the resistance.

Model 183A-1 was tested at a trim of 10° for speed coefficients from 3.4 to 4.0. A further increase in bow-down moment was noted, but these data were insufficient for inclusion in this report.

The static properties of model 183 are given in figure 10 and the aerodynamic resistance of the hull alone is given in figure 11.

TAKE-OFF CALCULATIONS

Results of tests of a $\frac{1}{40}$-size model (unpublished) indicated that the excess thrust available for acceleration over the hump was small. Both the resistance and thrust at hump speeds limit the take-off performance. Thrust curves for three full-size propellers are reproduced in figure 12. A comparison of these propellers is made in the following table:

Thrust curve	Propeller diameter (ft)	Number of blades	Gear ratio	Activity factor	RPM	Computed by
[a]I	16.6	4	0.381	80	2700	HAC
II	18.5	3	.425	-----	2700	HAC
[a]III	18.5	4	.425	118.5	2700	NACA

[a]Computed from data given in reference

At hump speed, approximately 70 feet per second, the 16.6-foot-diameter propellers developed 69,500 pounds thrust which is 13 percent lower than that developed by the 18.5-foot-diameter four-blade propellers.

Take-off computations were made for values of the gross load from 350,000 pounds to 425,000 pounds. The flying boat was assumed to be free to trim to speeds beyond the hump and at trim for minimum water resistance at planing speeds. Just before take-off speed, 110 percent of stalling speed, a pull-up was made in order to simulate more closely full-size take-off. For the take-off computations, the aerodynamic lift and drag curves, without power and corrected for ground effect, were supplied by the Hughes Aircraft Company and are reproduced in figure 13. The total resistance and aerodynamic drag for each of the four loads are plotted in figure 14, together with thrust curves I and III. With thrust curve I, a take-off at loads much greater than 375,000 pounds is not possible. With thrust curve III, a take-off at loads much greater than 400,000 pounds is not possible. A 14-percent increase in thrust at the hump results in a 7-percent increase in the maximum gross load for take-off.

Take-off times and distances for three loads were computed using thrust curve III and the total resistance curves shown in figure 14. A typical take-off integration by the graphical method described in reference 4 is shown in figure 15 for a gross load of 400,000 pounds. In this case a time of 69 seconds over a distance of 5600 feet is found necessary for take-off. The take-off time and distance and the excess thrust at the hump are plotted against load in figures 16 and 17. For a gross load of 416,000 pounds, the total resistance at the hump is equal to the available thrust.

In the preceding computations, the full-size water resistance was computed using Froude's law and no correction of the frictional resistance was made for scale effect. To determine the effect of such a correction on the total resistance at hump speed, a computation was made for a gross load of 400,000 pounds using the method described in reference 5. Computations by this method do not include the effect of differences in the roughness of the planing surfaces of the model and the full-size flying boat. In figure 18 these results are compared with the uncorrected results using thrust curve I. A reduction in the hump resistance of 8 percent was obtained by making the correction, and a take-off would just be possible with the 16.6-foot four-blade propellers.

A comparison of the total resistance at hump speed was made assuming the airplane running free to trim, at trim for minimum resistance, and at the estimated lower trim limit of stability for a gross load of 400,000 pounds. These results are plotted in figure 19, together with the hydrodynamic trimming moments, which indicate the magnitude of the negative aerodynamic pitching moment required to trim the airplane. Assuming adequate elevator control to be available, the airplane cannot be trimmed to trims for minimum water resistance without encountering lower-limit porpoising until a speed of 90 feet per second is attained.

A 14-percent decrease in resistance is obtained if the flying boat is operated at the lower trim limit of stability at the hump. In actual operation it is probable that at speeds just beyond the hump the trim will be between the lower trim limit of stability and the free-to-trim curve.

A comparison of the total resistance at hump speeds using the following results is shown in figure 20:

(a) Tests of the $\frac{1}{16}$-full-size model of the hull alone - model 183.

(b) Tests of the $\frac{1}{40}$-full-size model of the hull alone - model 155A.

(c) Tests of the $\frac{1}{16}$-full-size dynamic model - model 158-1.

The aerodynamic lift and drag curves of figure 13 and the free-to-trim resistance with applied thrust moment were used for computations (a) and (b). The predictions of the hump resistance, as determined from the three sets of data, are in fair agreement.

Aerodynamic data were not available for take-off computations that included the effect of propeller slipstream on the aerodynamic lift, drag, and pitching moments. The propeller slipstream would increase the aerodynamic lift which would therefore decrease the load on the water and the water resistances. The propeller slipstream would increase the aerodynamic drag which would reduce the advantage gained by the decrease in load on the water. The use of aerodynamic data that include the effect of power would, in all probability, result in a net reduction in the hump resistance, but the prediction of take-off performance would be less conservative. The use of power-off aerodynamic data in take-off calculations for smaller flying boats has been satisfactory, however, and, until further correlation between model and full-size take-off performance is available, it is believed that the more conservative results obtained from computations using power-off data should be used.

CONCLUSIONS

1. The tail extension of model 183 did not break clear of the water at hump speeds when tested free to trim. This resulted in high trims, and the load-resistance ratio at hump speeds was approximately 4.0 for a gross load coefficient of 0.75.

2. Increasing the chine flare at the stern post, model 183A, caused a reduction in the positive trimming moments and caused the tail extension to break clear of the water at lower speeds than was found for model 183.

3. The addition of breaker strips on the tail extension of model 183A, model 183A-1, caused a further reduction in positive trimming moments. The load-resistance ratio at hump speeds, when free to trim, was approximately 4.8 for a gross load coefficient of 0.75.

4. At trim for minimum water resistance for model 183, the load-resistance ratio at hump speeds was approximately 4.95 for a gross load coefficient of 0.75. Large negative aerodynamic pitching moments would be required to operate at trim for minimum water resistance at hump speeds.

5. With the 16.6-foot four-blade propellers, a take-off could not be made at a gross load much greater than 375,000 pounds full size. With the 18.5-foot four-blade propellers, a take-off could not be made at a gross load much greater than 400,000 pounds full size. A take-off time of 69 seconds over a distance of 5600 feet was found necessary for a take-off at 400,000 pounds full size. A 14-percent increase in thrust at the hump results in a 7-percent increase in the maximum gross load for take-off.

6. A correction for scale effect on the frictional resistance for a gross load of 400,000 pounds full size, decreased the hump resistance approximately 8 percent.

7. It would not be possible to use trim for minimum water resistance at hump speeds during a take-off because of excessive hydrodynamic moments and because lower-limit porpoising would be encountered.

8. A take-off made following the lower trim limit of stability results in a 14-percent reduction in hump resistance when compared with a take-off free to trim.

9. The predictions of hump resistance using data obtained from tests of a $\frac{1}{40}$-size model of the hull alone, tests of a $\frac{1}{16}$-size model of the hull alone, and tests of a $\frac{1}{16}$-size dynamic model of the flying boat are in fair agreement.

Langley Memorial Aeronautical Laboratory
National Advisory Committee for Aeronautics
Langley Field, Va., June 2, 1944

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2. Dawson, John R.: A General Tank Test of a Model of the Hull of the P3M-1 Flying Boat Including a Special Working Chart for the Determination of Hull Performance. NACA TN No. 681, 1938.

3. Desmond, Gerold L., and Freitag, Robert F.: Working Charts for the Computation of Propeller Thrust throughout the Take-Off Range. NACA ARR No. 3G26, 1943.

4. Olson, R. E. and Allison, J. M.: The Calculated Effect of Various Hydrodynamic and Aerodynamic Factors on the Take-Off of a Large Flying Boat. NACA TR No. 702, 1940.

5. Parkinson, J. B.: Tank Tests to Show the Effect of Rivet Heads on the Water Performance of a Seaplane Float. NACA TN No. 657, 1938.

TABLE I

Hull Dimensions

	Full Size	Model 183	Model 158-1
Maximum beam, at chines . .	22.0 ft	16.5 in.	16.5 in.
Length of forebody (bow to step)	80.8 ft	60.6 in.	59.88 in.
Length of afterbody (step to stern post) . .	51.0 ft	37.28 in.	38.0 in.
Length of tail extension .	87.0 ft	65.21 in.	66.12 in.
Length, over all	21.75 ft	163.09 in.	164.0 in.
Depth of step at keel . . .	2.0 ft	1.5 in.	1.5 in.
Depth of step, mean	2.0 ft	1.5 in.	1.5 in.
Angle of deadrise at step, excluding chine flare	20 deg	20 deg	20 deg
Angle of deadrise at step, including chine flare	18 deg	18 deg	18 deg
Angle of forebody keel . .	2 deg	2 deg	2 deg
Angle of afterbody keel . .	5 deg	5 deg	5 deg
Angle between keel lines at step	7 deg	7 deg	7 deg
Normal gross load . . .	400,000 lb	97.5 lb	97.5 lb
Center of gravity forward of step	6.59 ft	4.94 in.	5.76 in.
Center of gravity above keel at step . . .	19.8 ft	14.84 in.	14.84 in.

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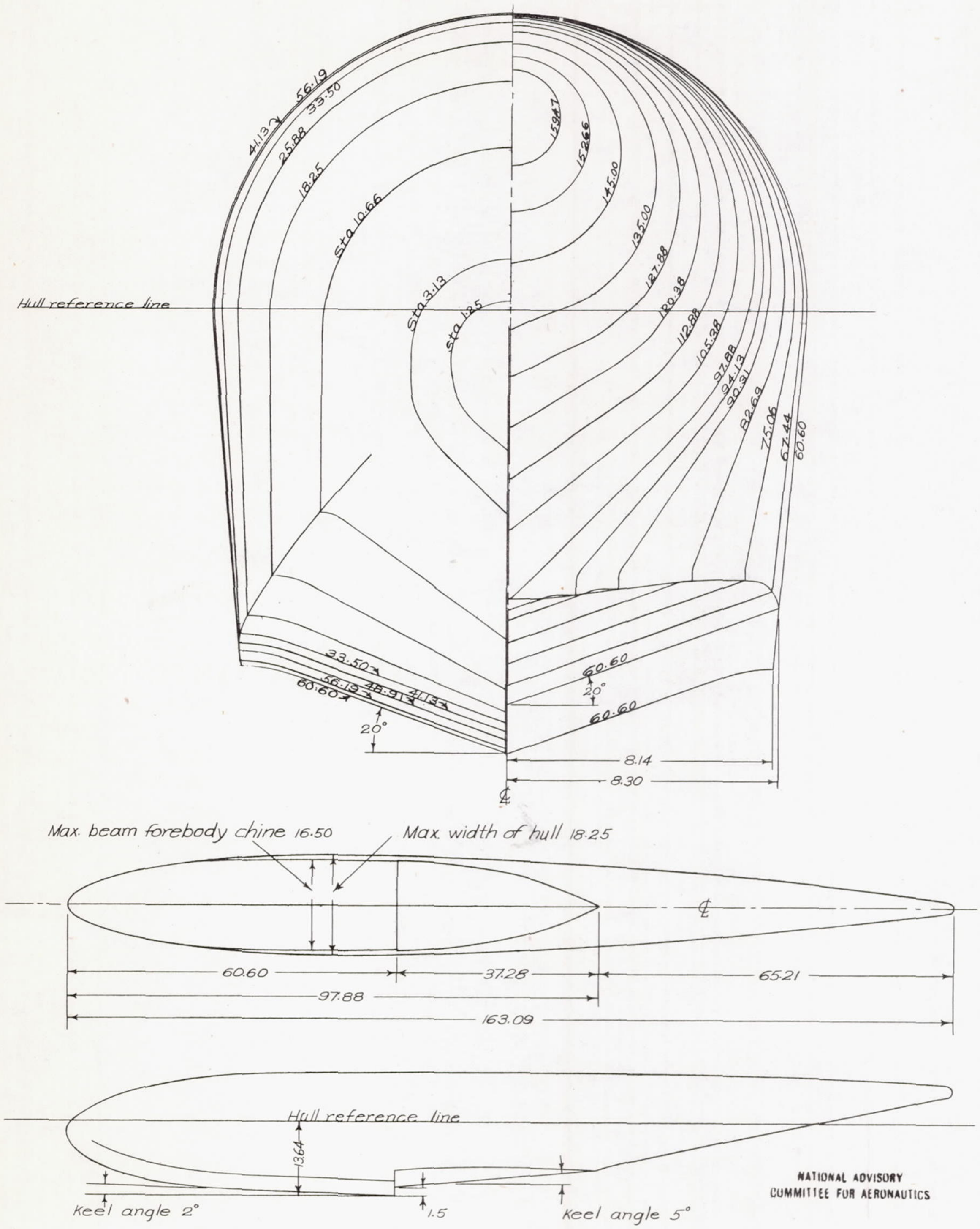

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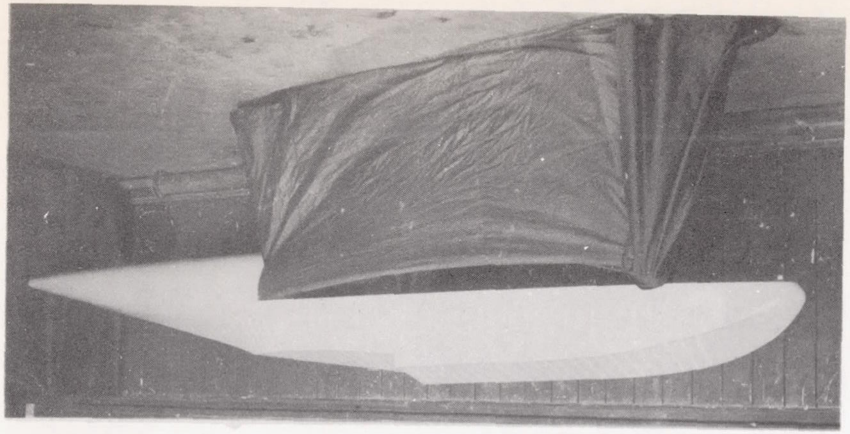
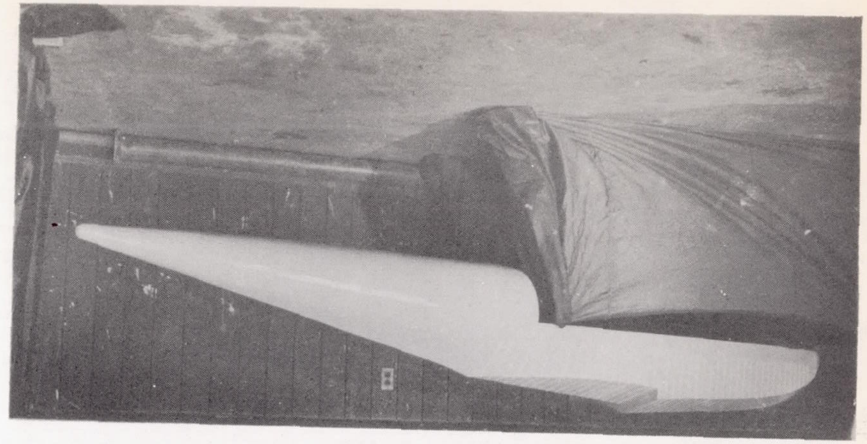
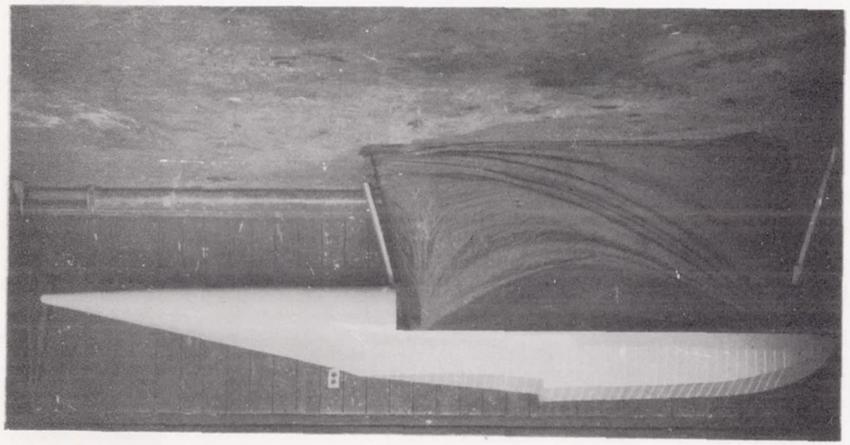
Figure 1.- Model 183, lines of hull.



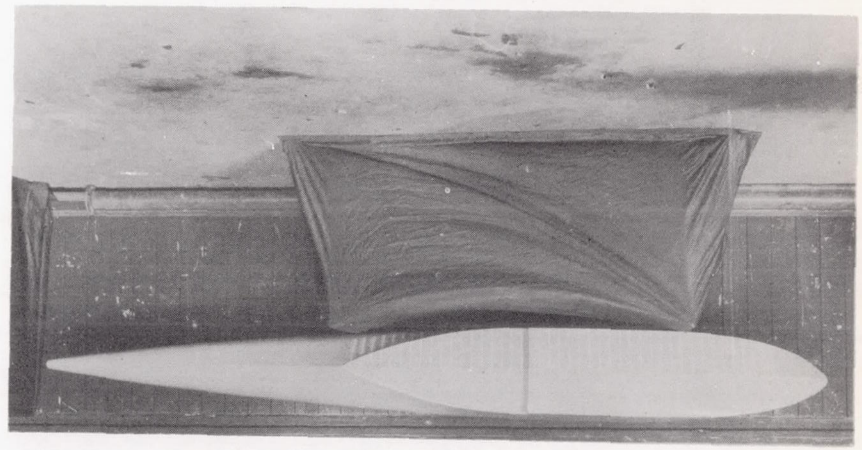
Three-fourths bow.



Three-fourths stern.



Side



Plan

Figure 2.- Model 183. Photographs of hull.

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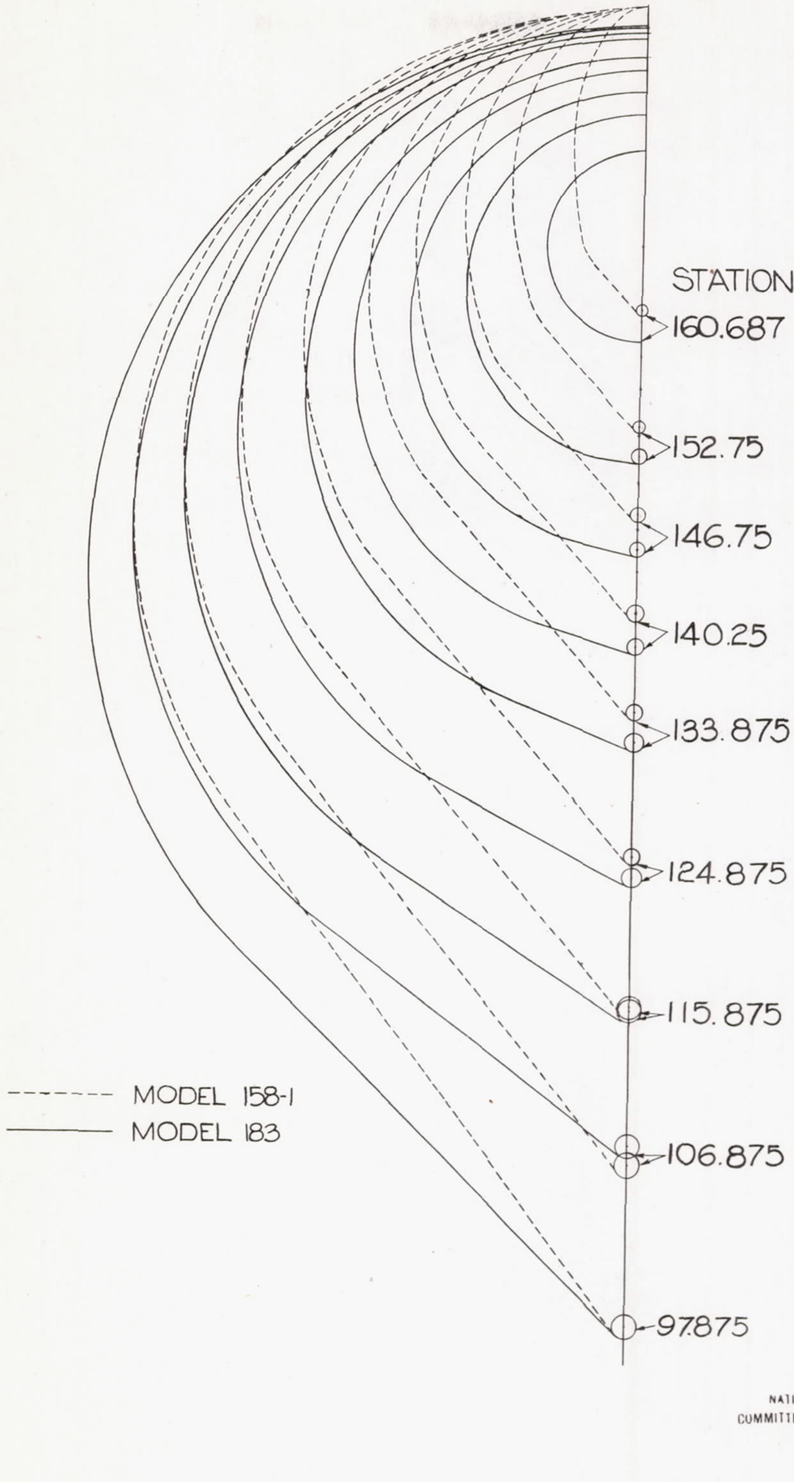

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FIGURE 3.- MODELS 183 AND 158-1. COMPARISON OF BODY PLANS OF THE TAIL EXTENSION.

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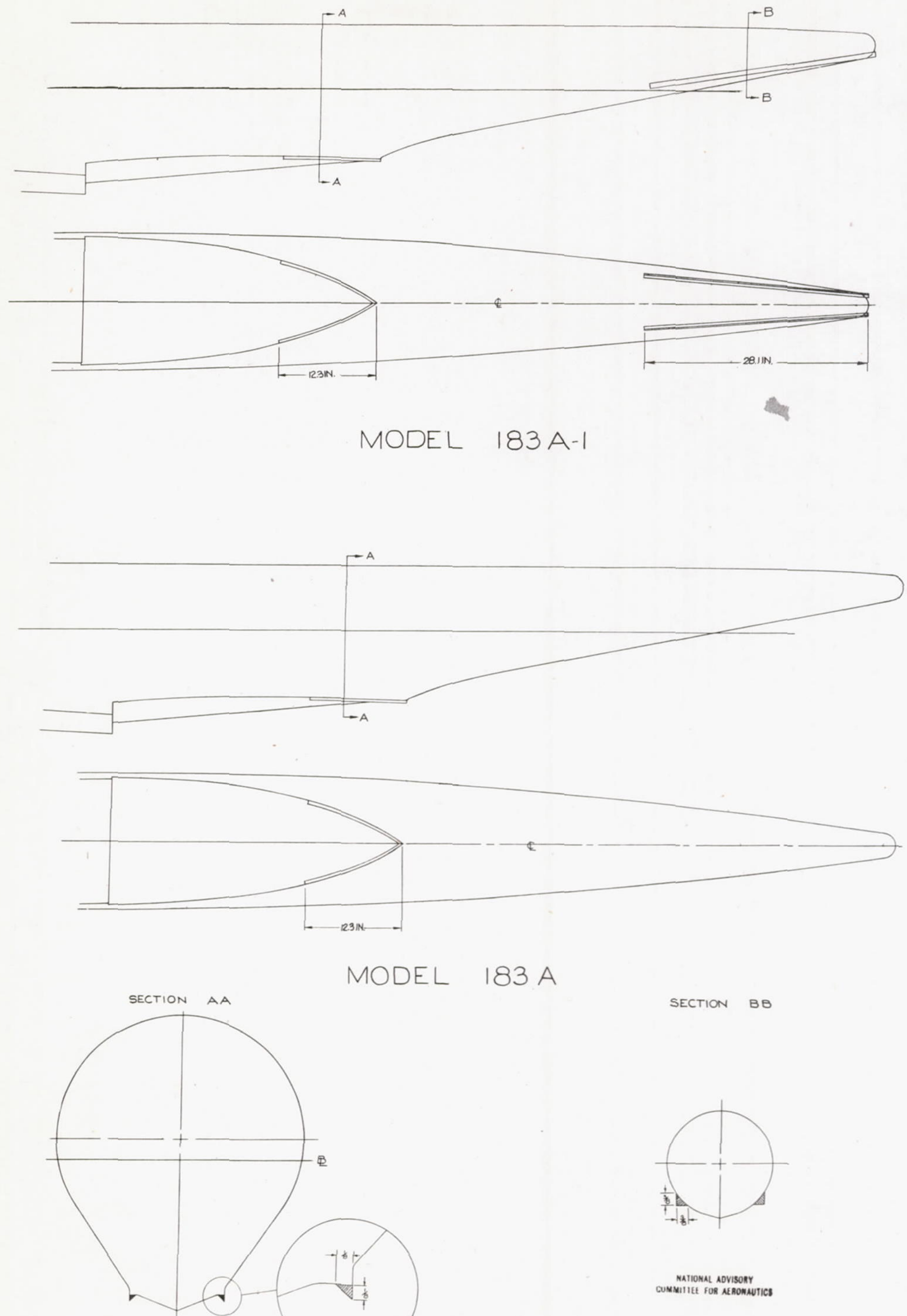
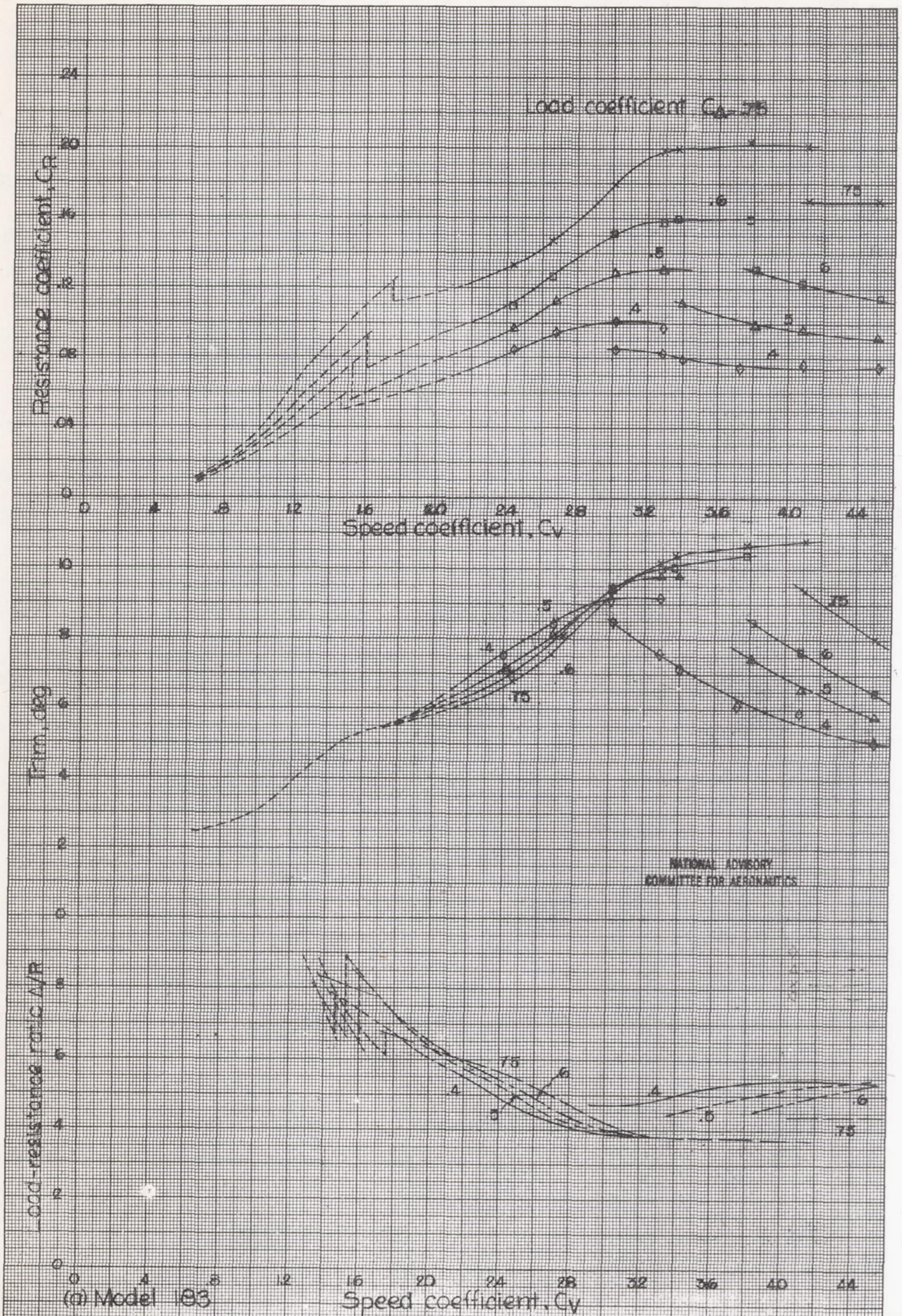
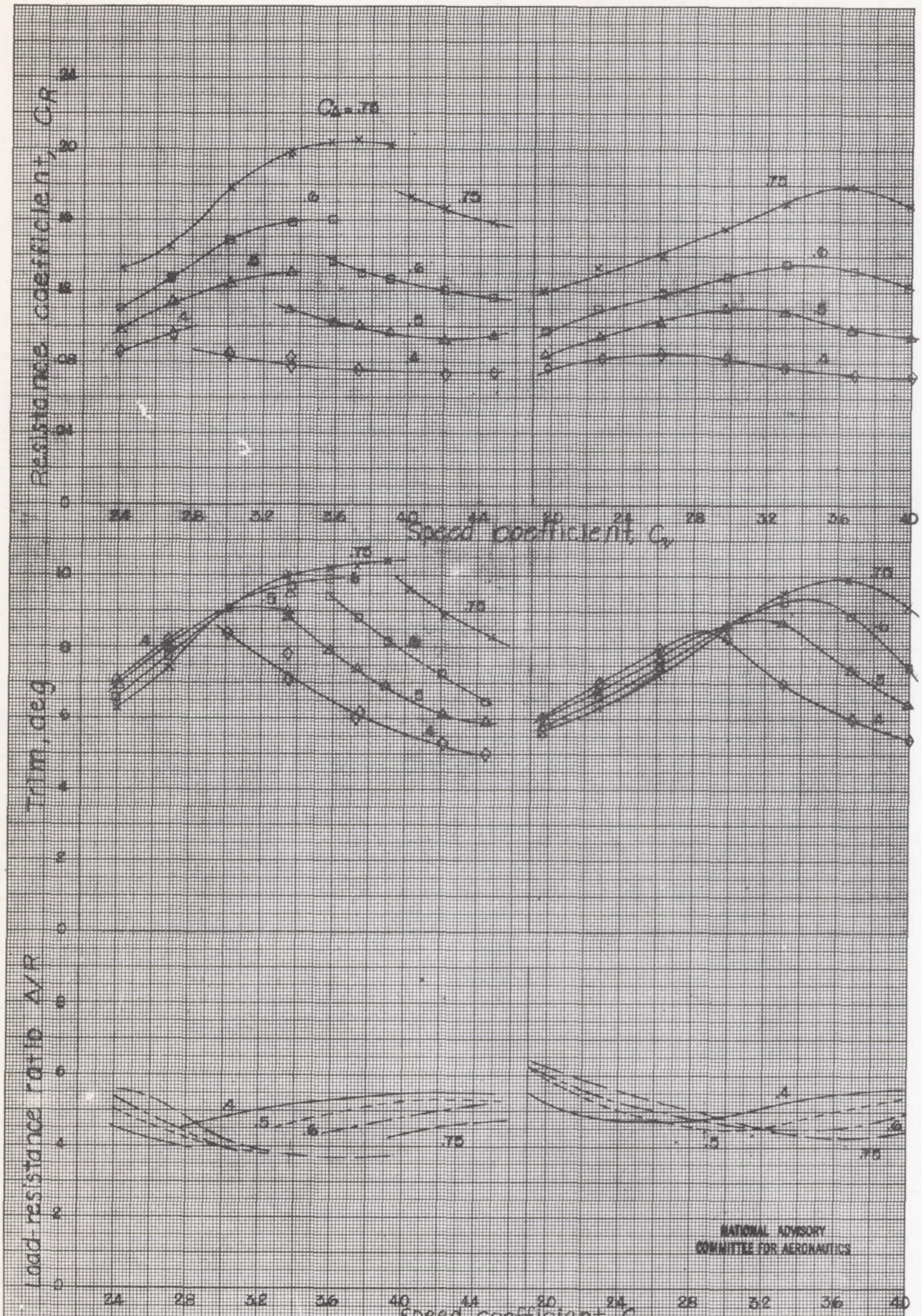


FIGURE 4.- MODELS 183 A AND 183 A-1. GENERAL ARRANGEMENT OF AFTERBODY AND TAIL EXTENSION.



(a) Model 183.

Figure 5.- Variation of resistance and trim with speed. Free-to-trim with 80 inch-pounds thrust moment applied.



(b) Model 183A

(c) Model 183A-1

Figure 5- Concluded.

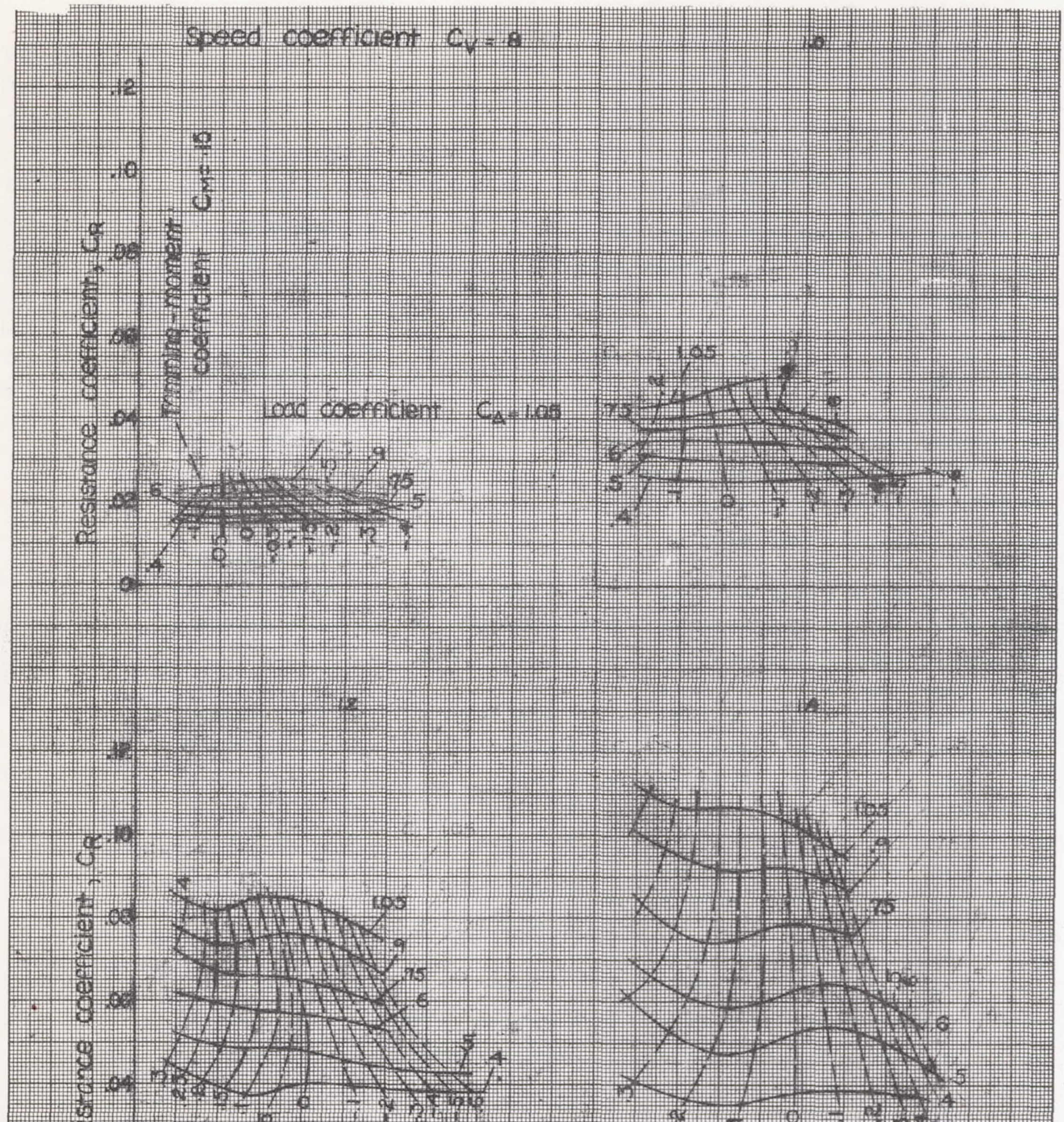
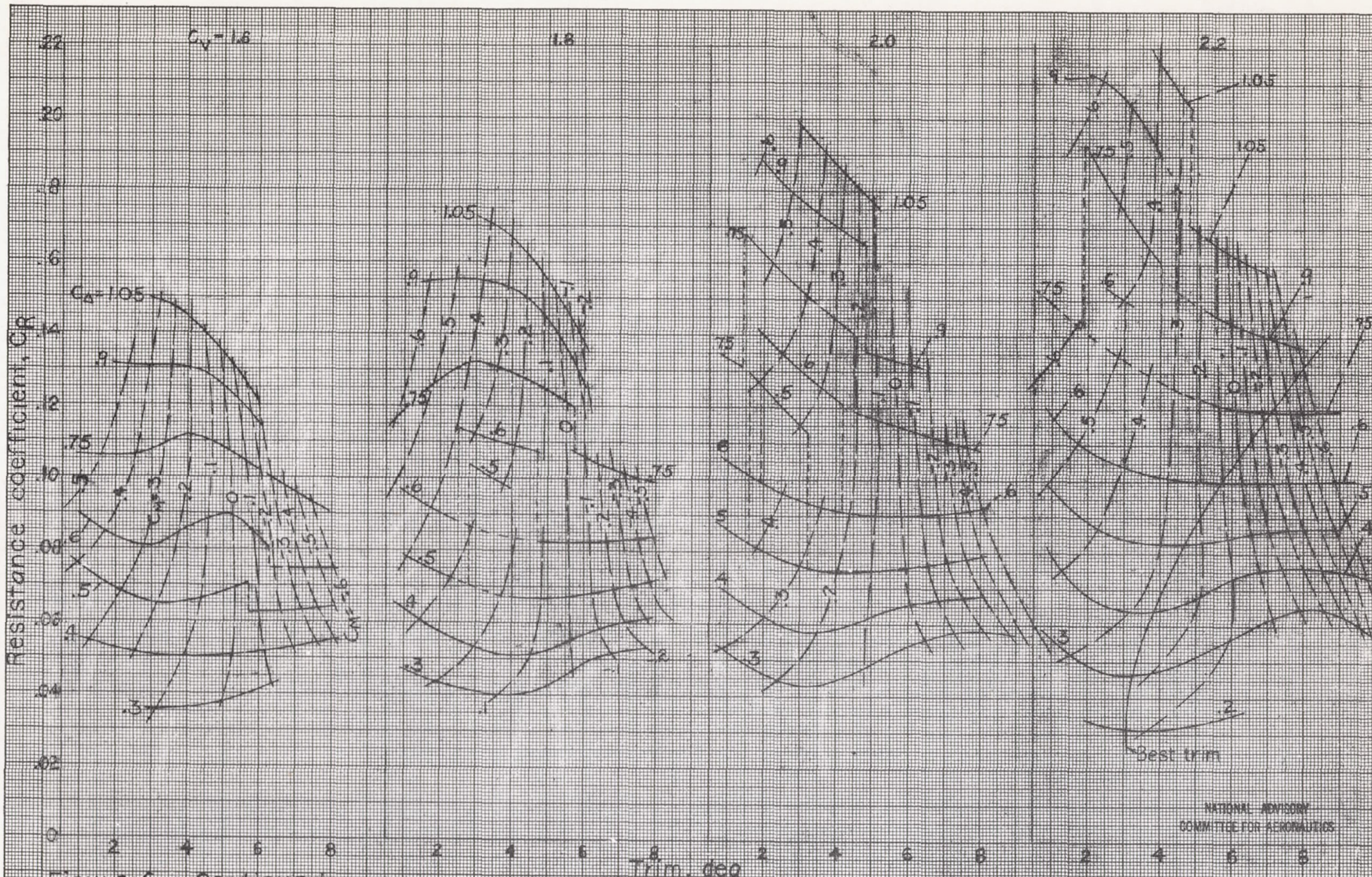


Figure 6.- Model 183 Resistance and trimming-moment. Fixed trim.



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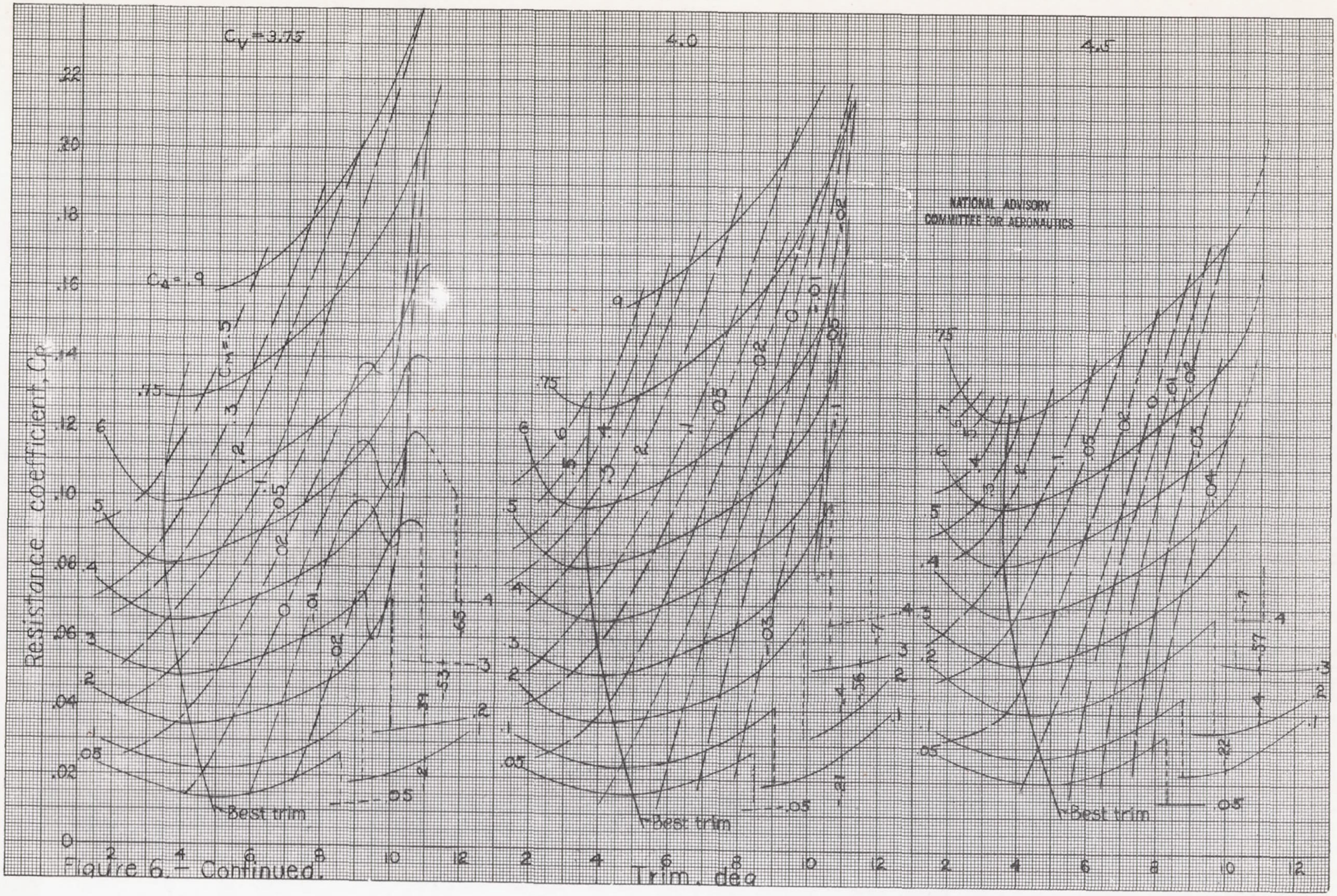

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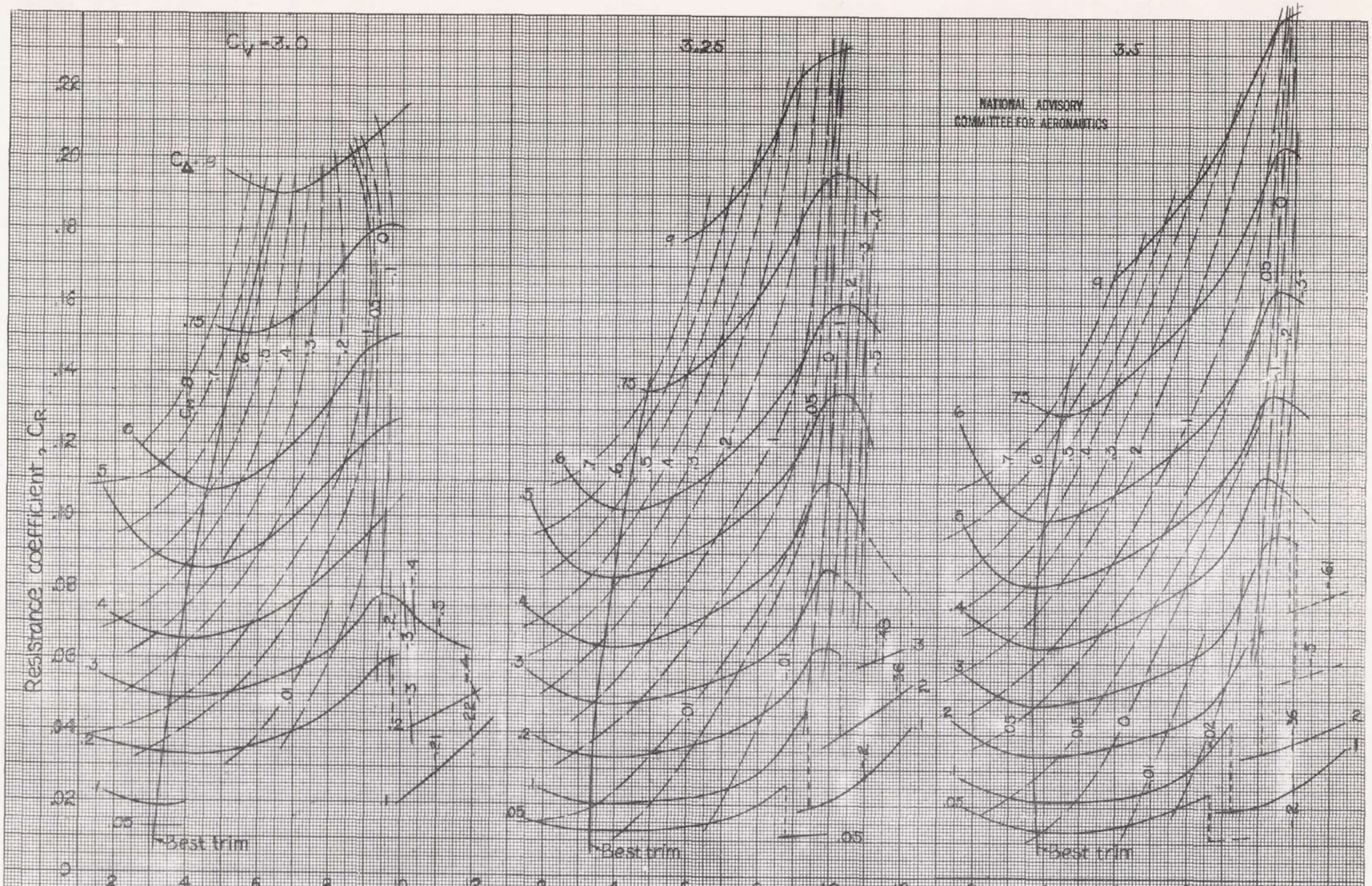

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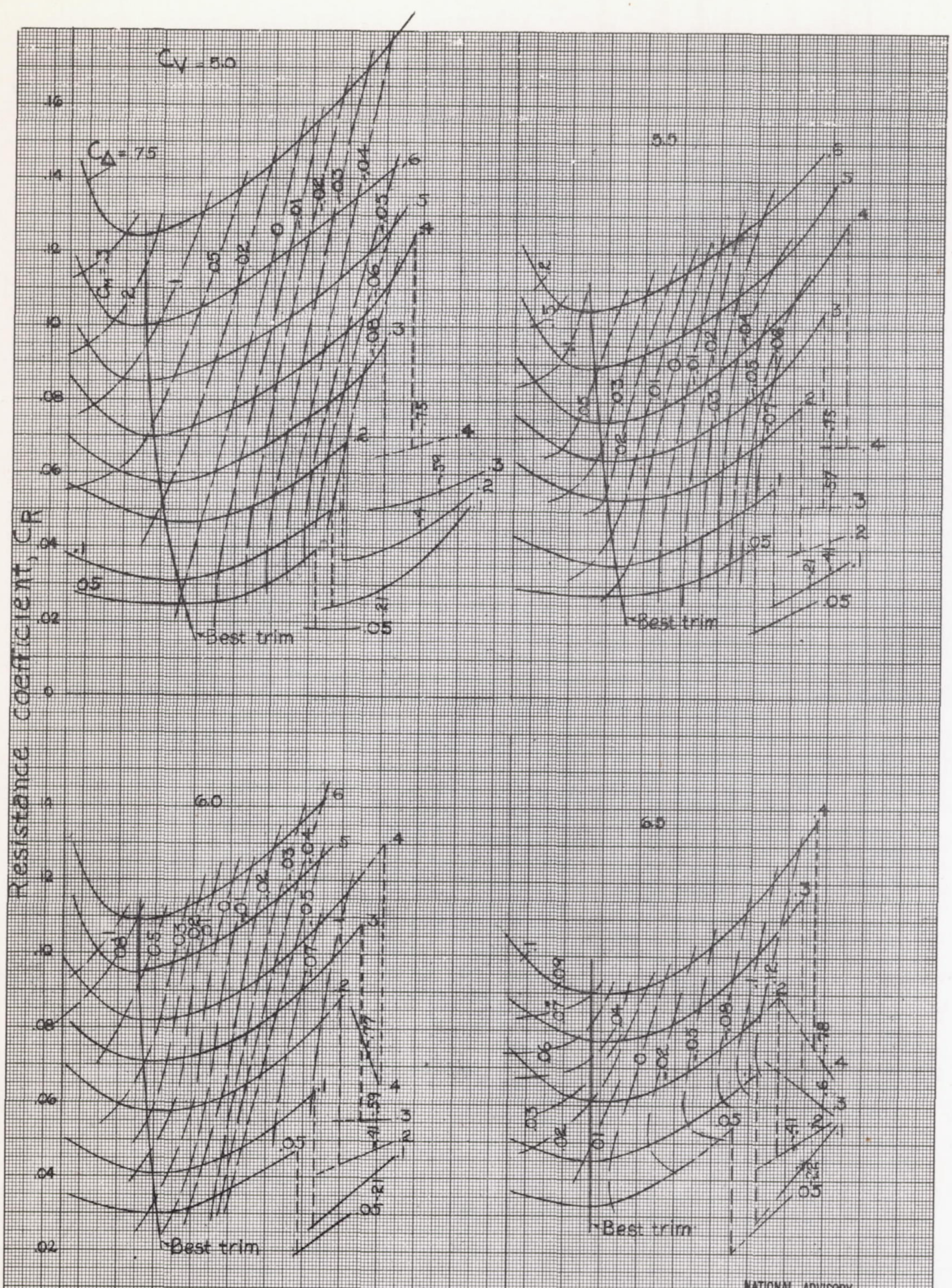

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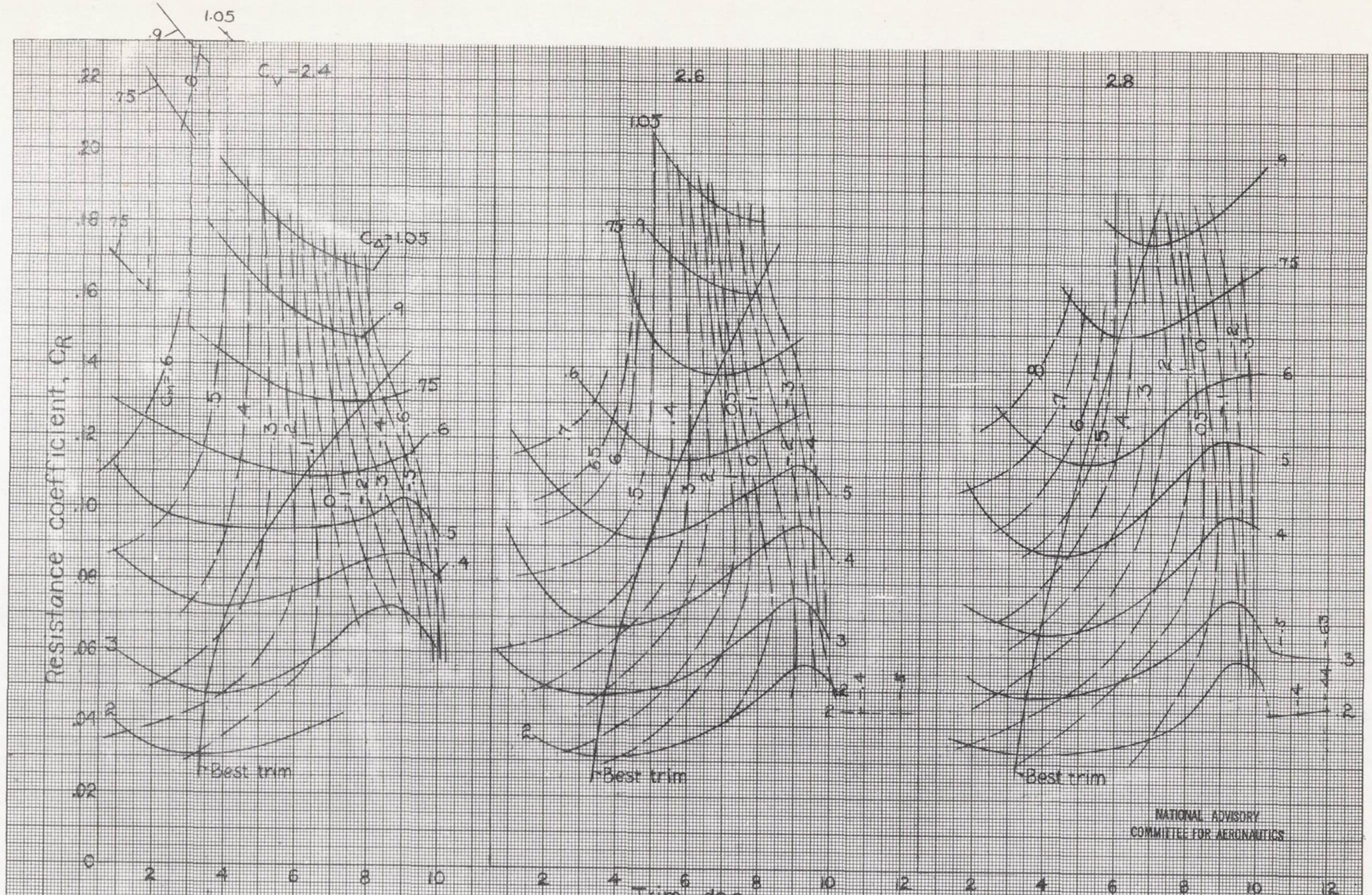

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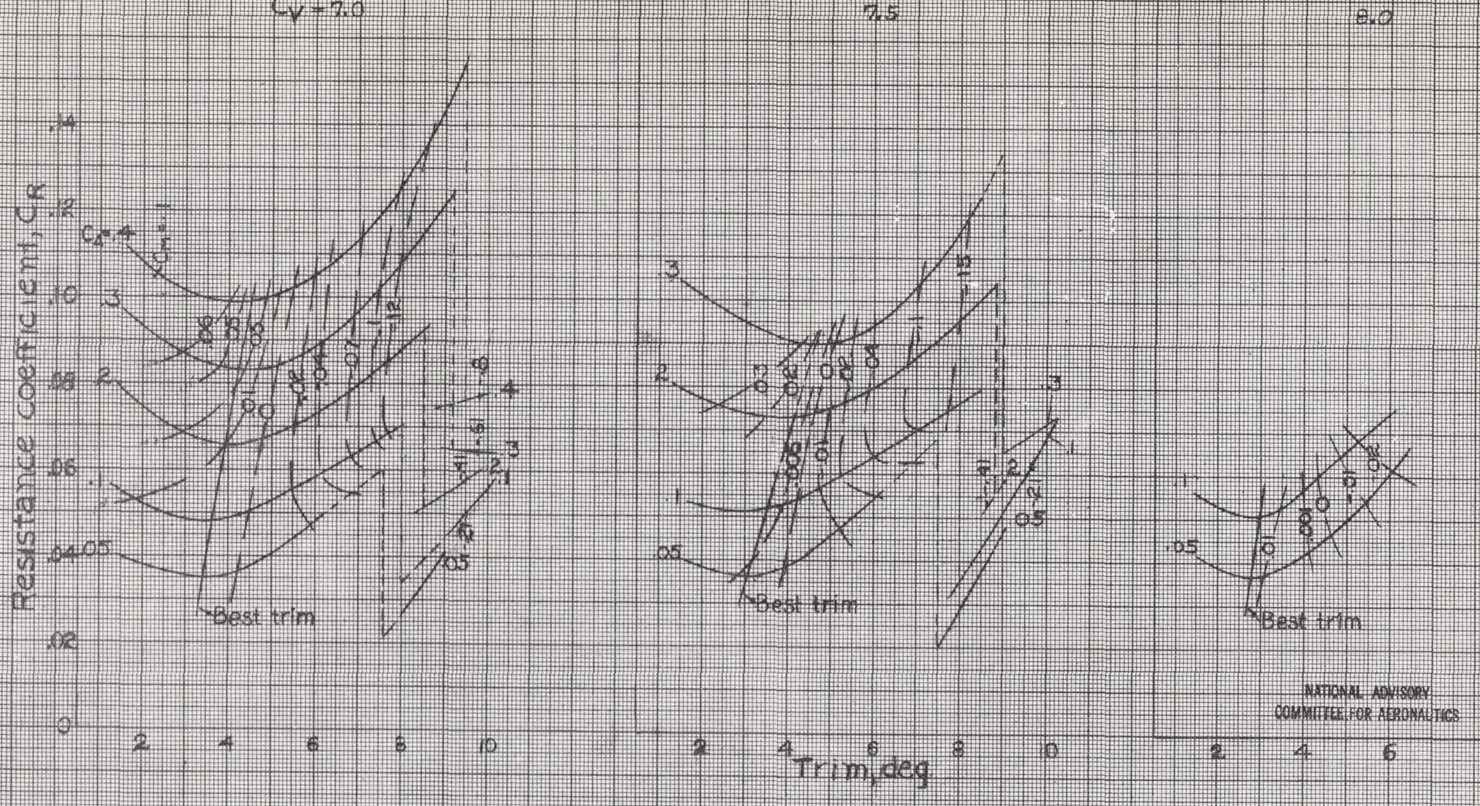

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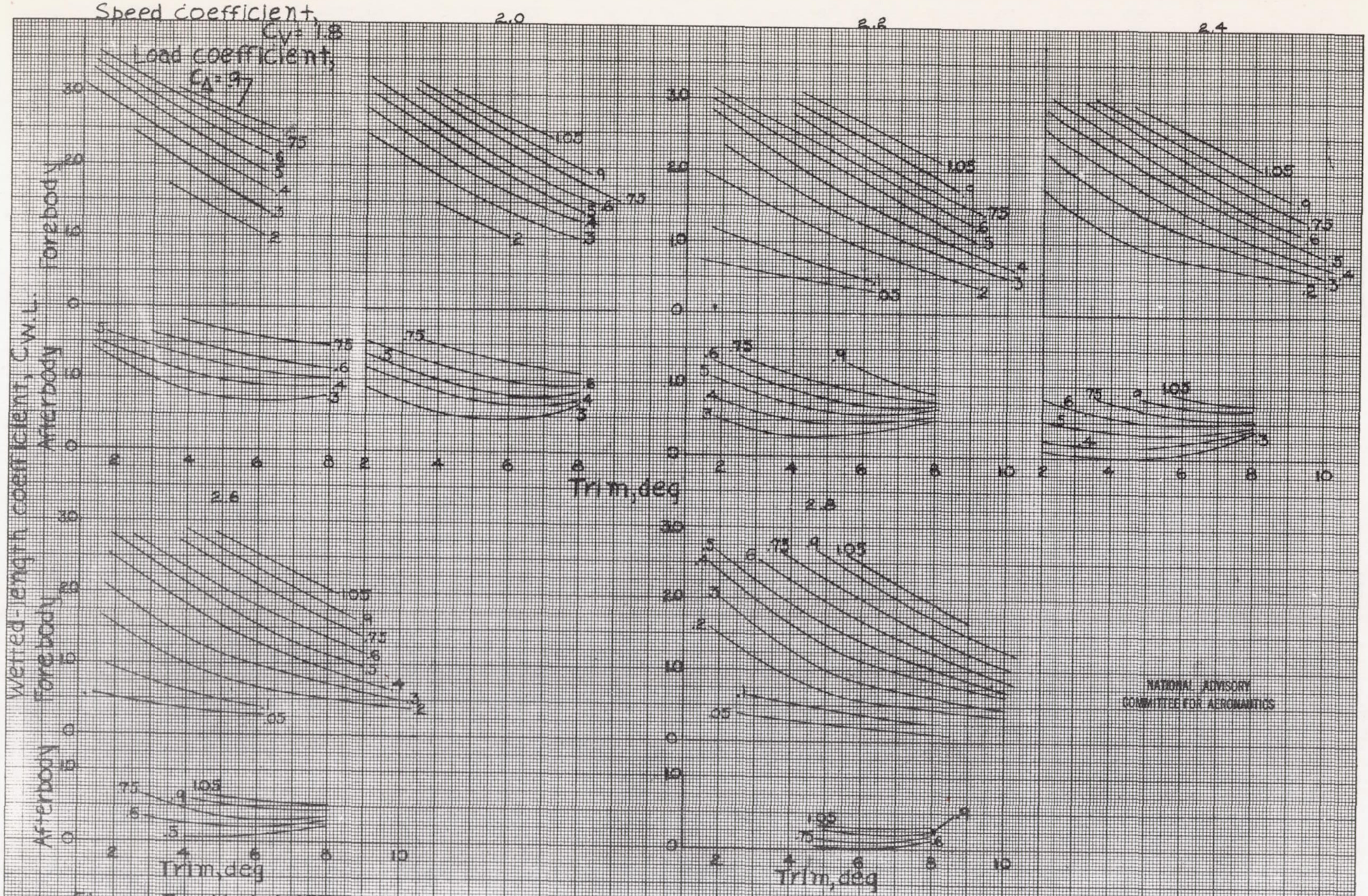
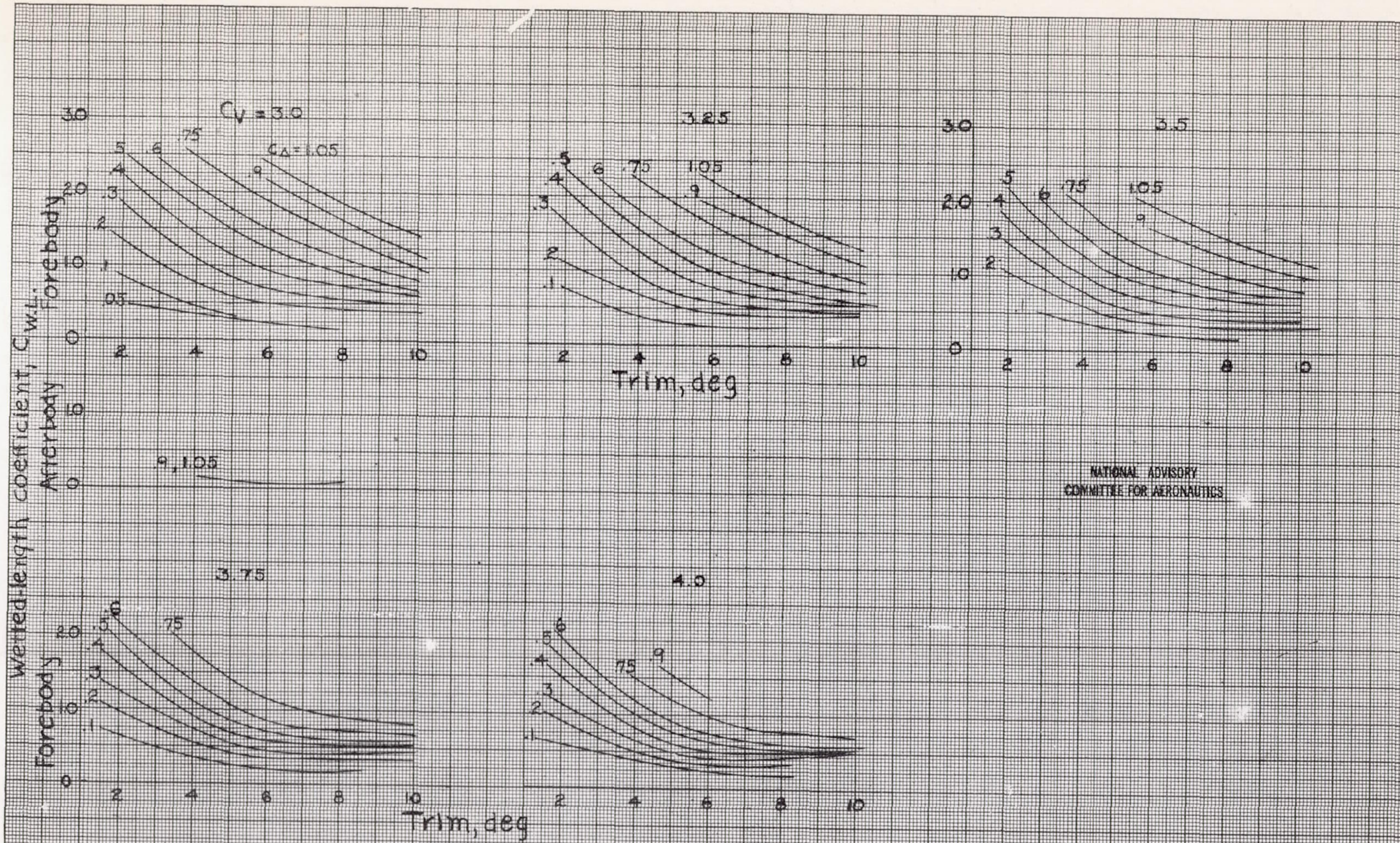


Figure 7.- Model 183. Wetted-length measurements. Fixed trim.



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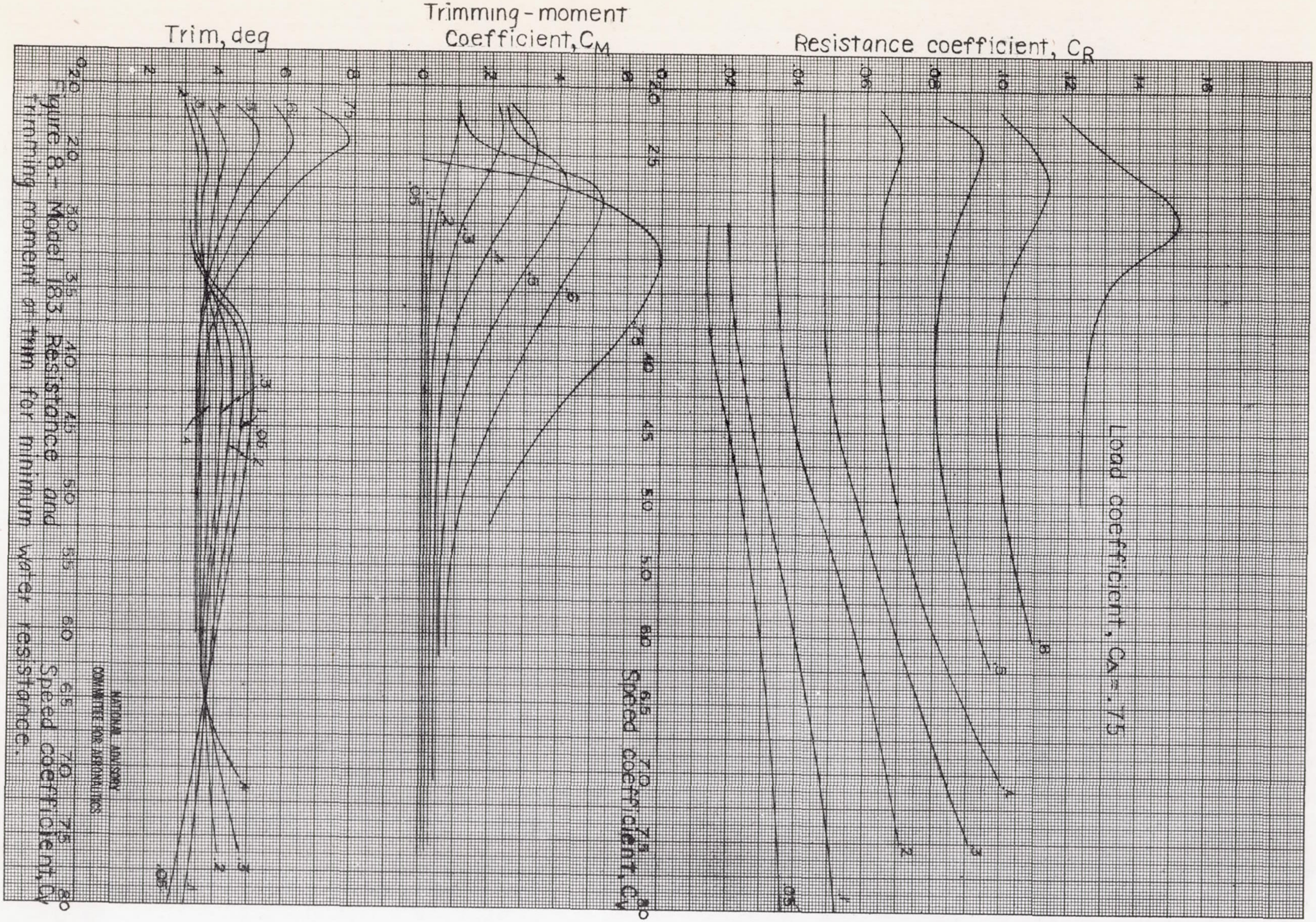

Figure 8.- Model 183. Resistance and trimming moment at trim for minimum water resistance.

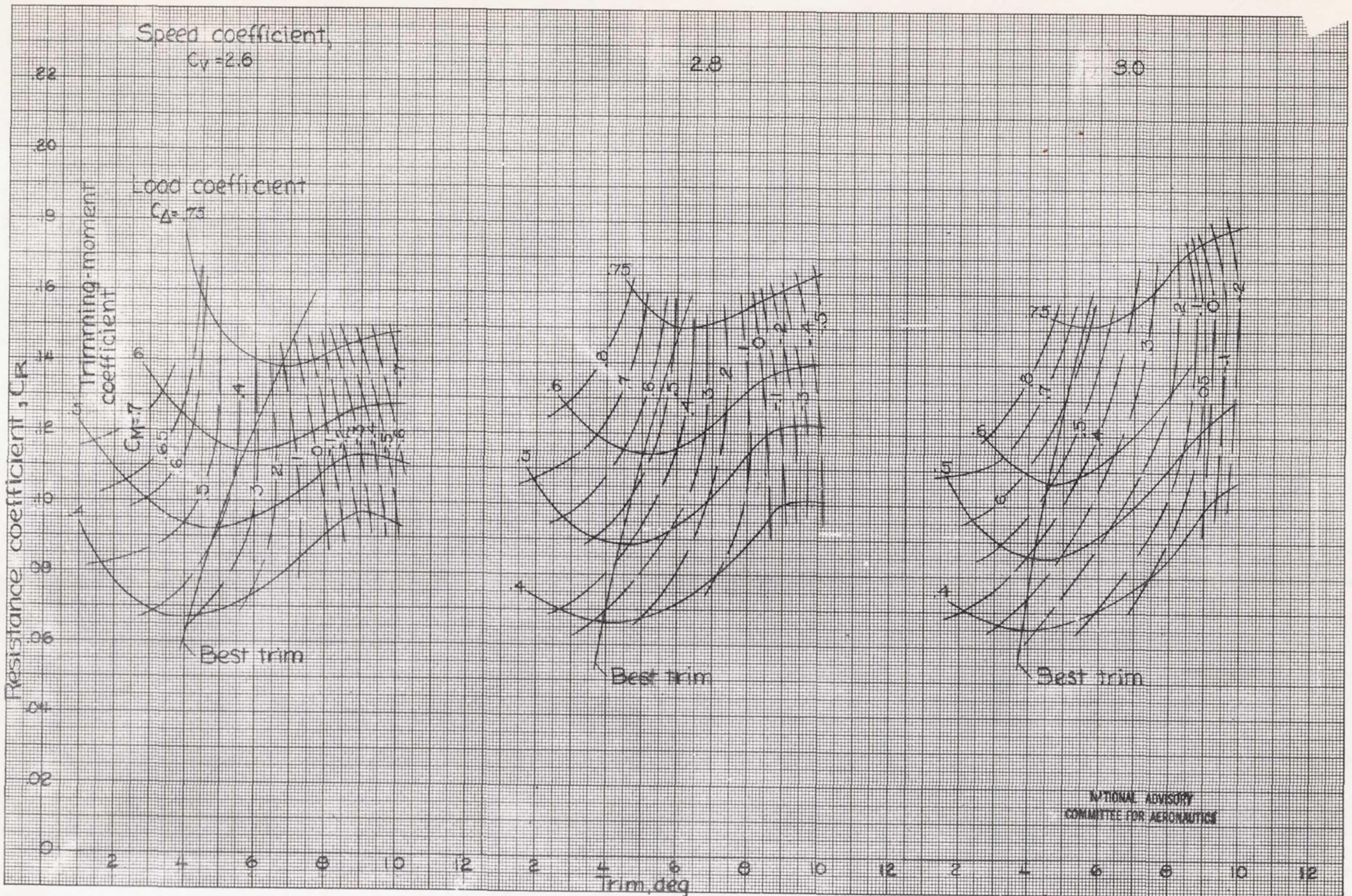

Figure 9.- Model 183A Resistance and trimming-moment. Fixed trim.

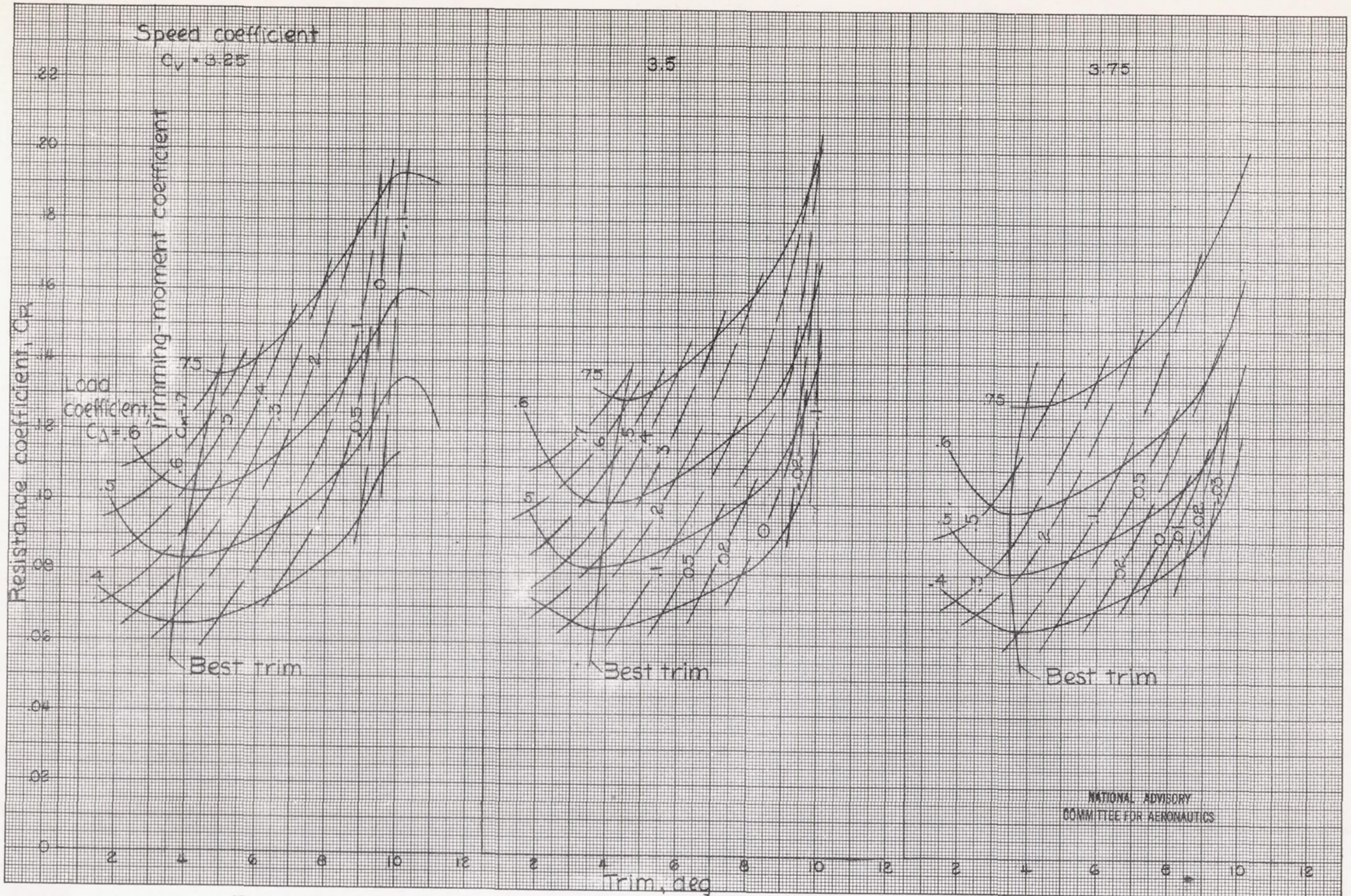

Figure 9.- Concluded

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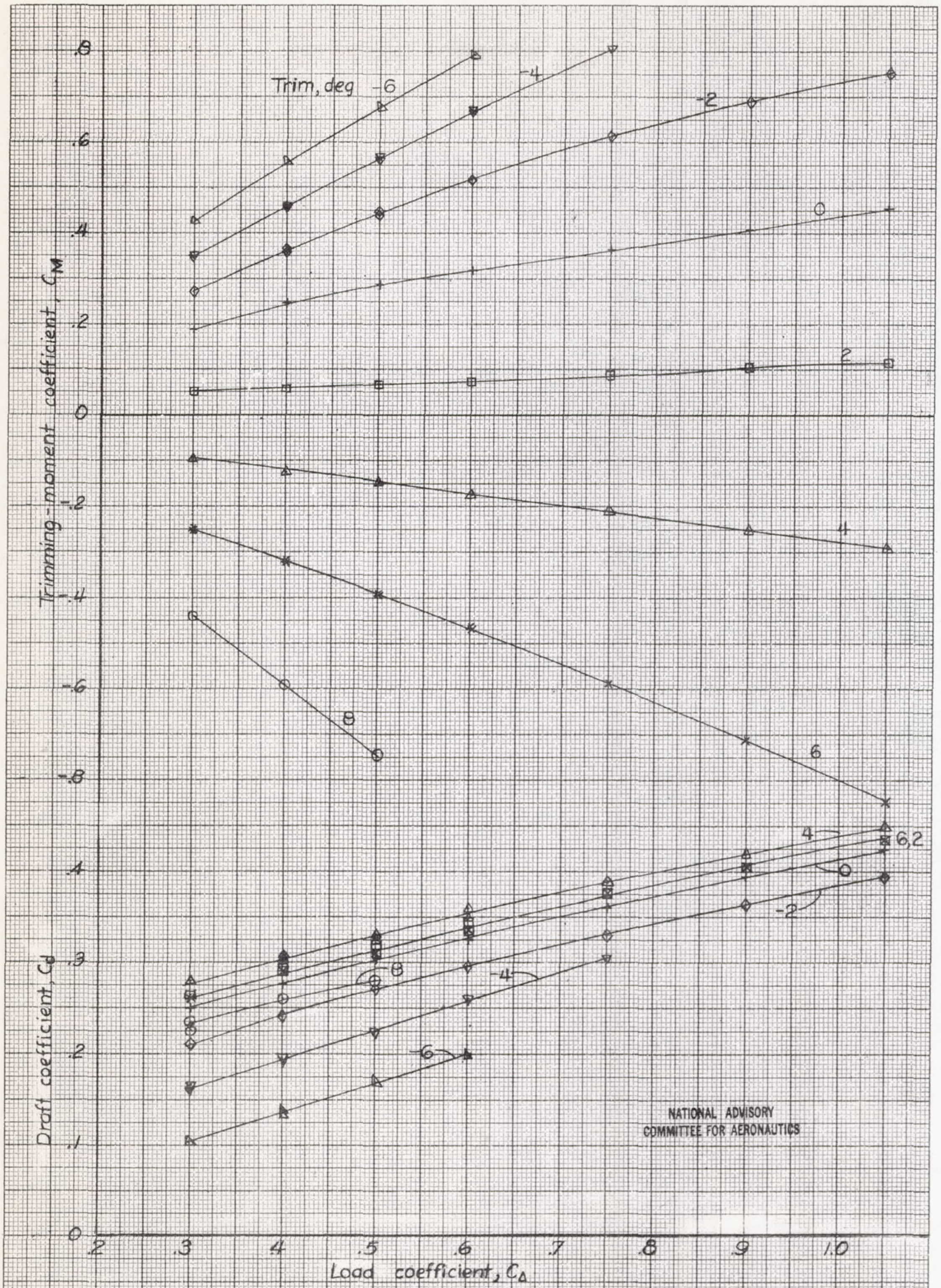

Figure 10.- Model 183. Static properties.

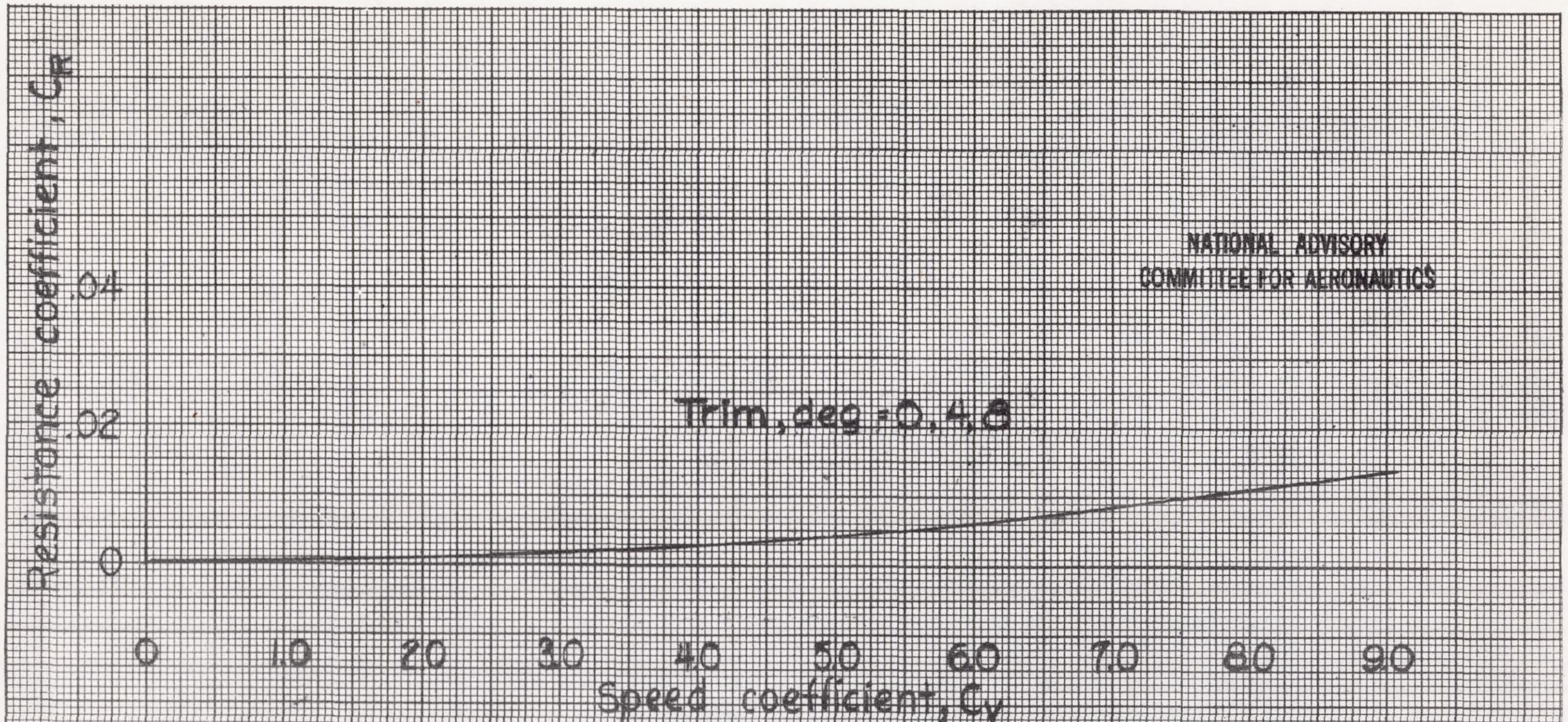

Figure 11.– Model 183. Aerodynamic resistance measured with the main step just clear of the water.

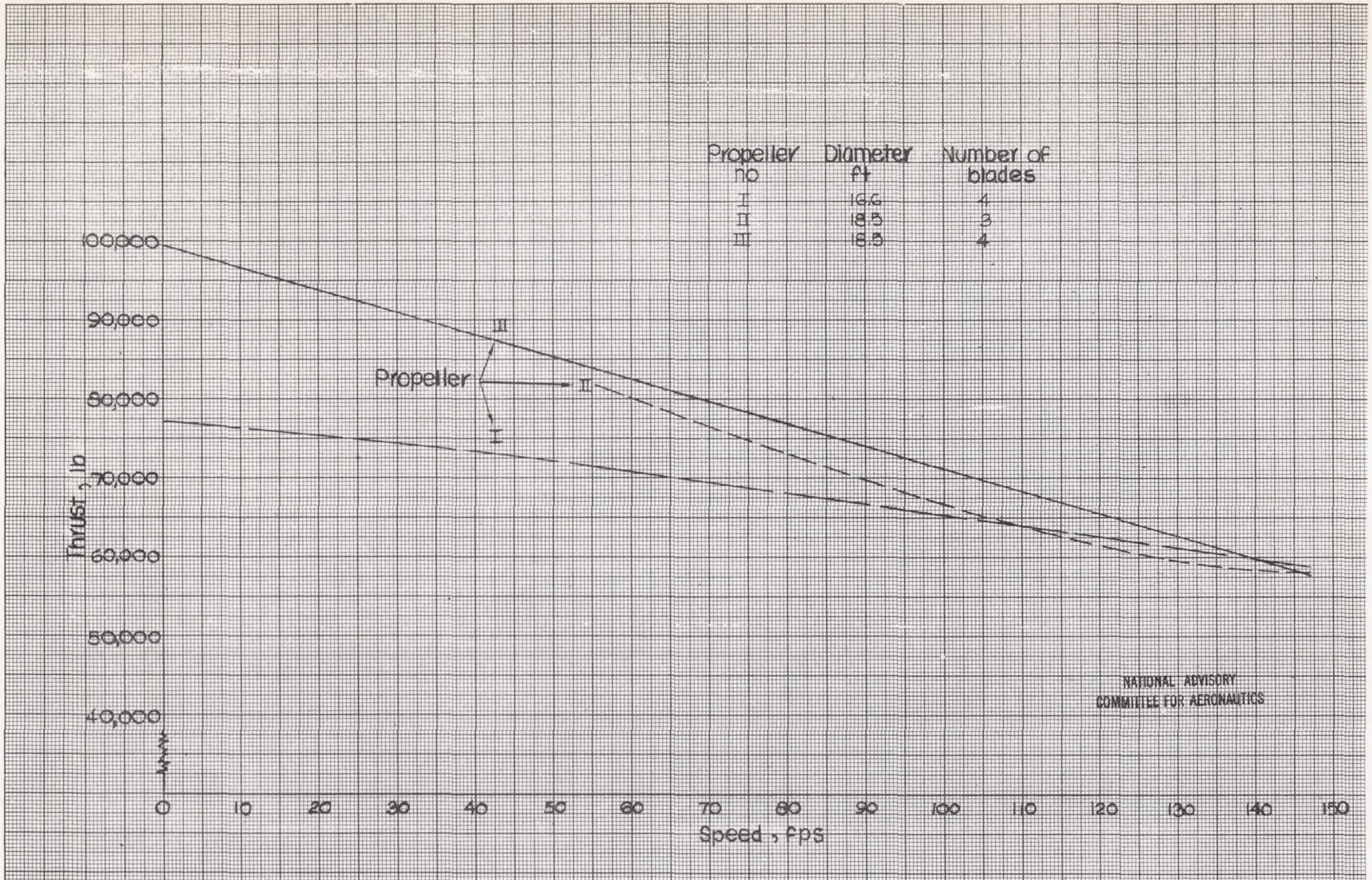

Figure 12.- Variation of thrust with speed for three propellers.

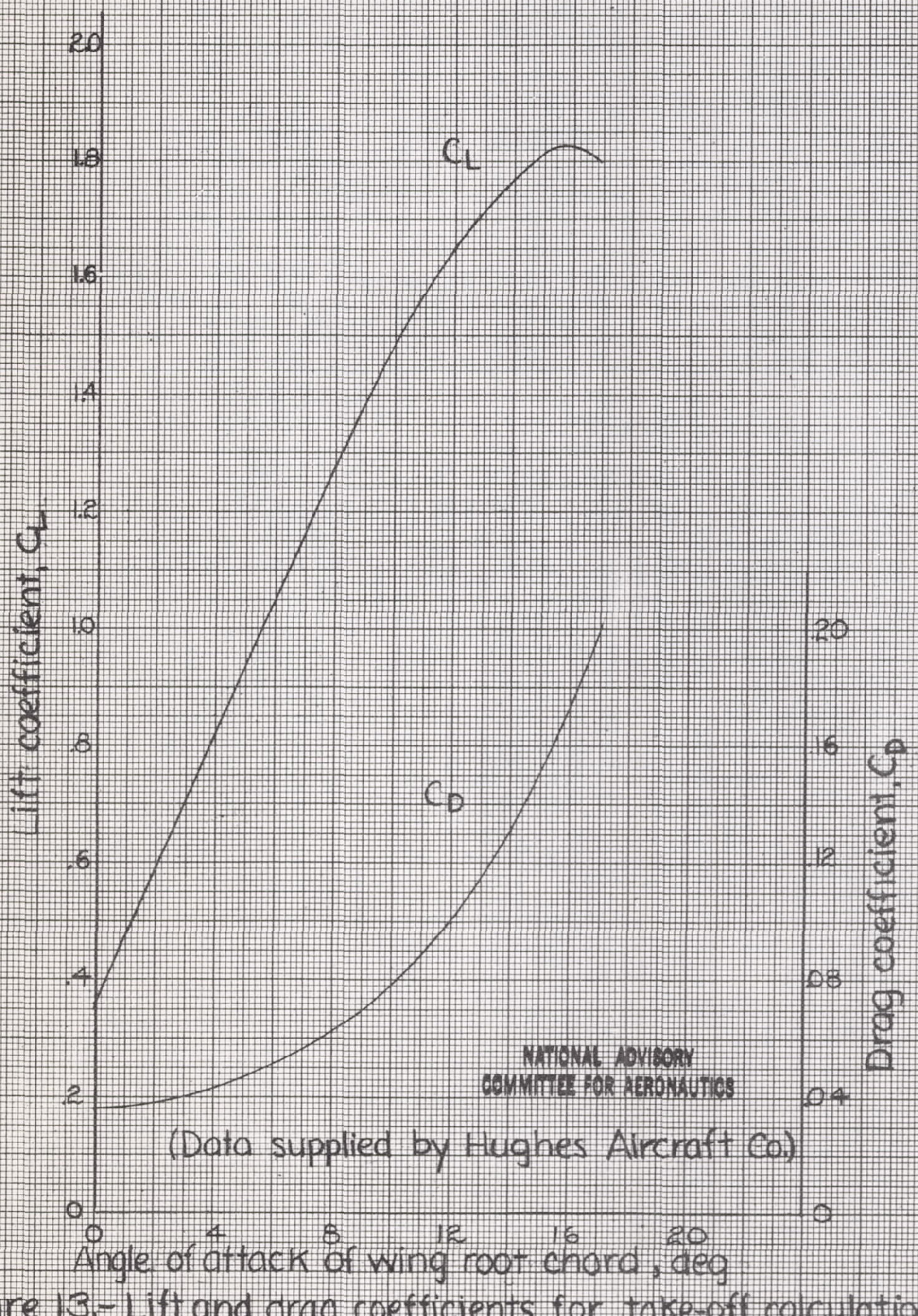

Figure 13.- Lift and drag coefficients for take-off calculations. Power-off, corrected for ground effect. δ_f,20° i_w,5°

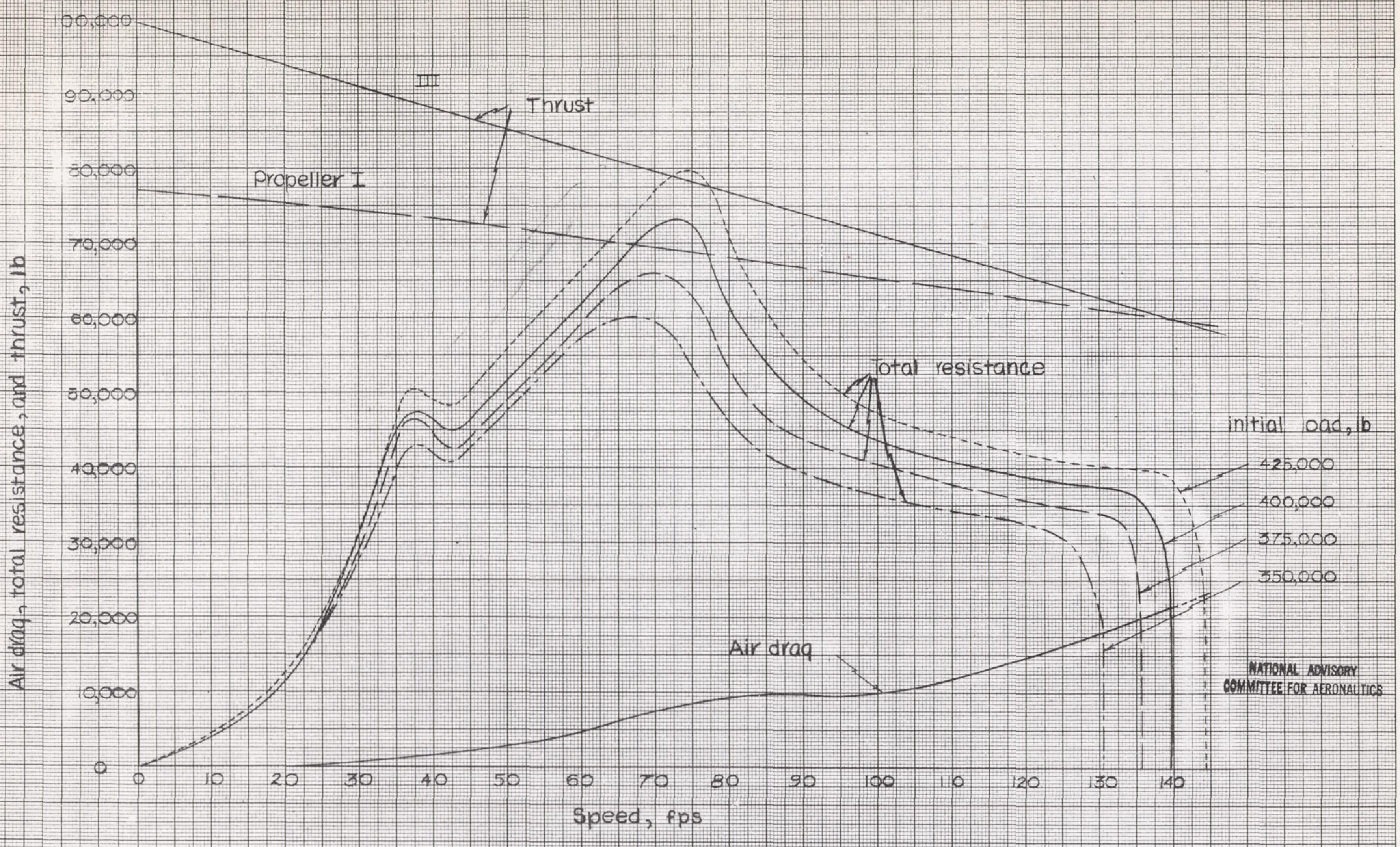

Figure 14.– Take-off performance for four values of gross load.

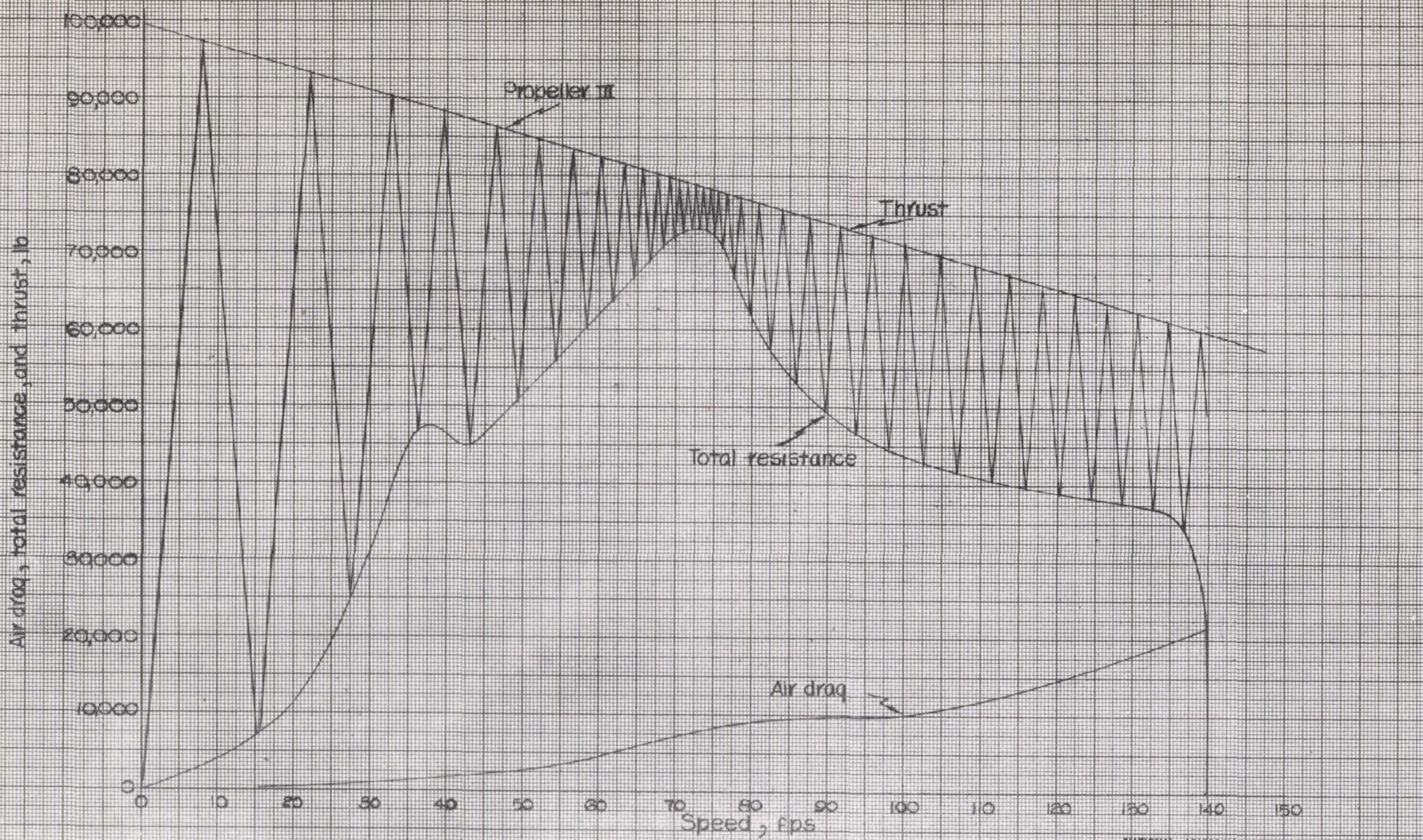

Figure 15.- Model 183. Typical integration for take-off time and distance. Gross load, 400,000 lb; take-off time 69 seconds, take-off distance 5,600 feet.

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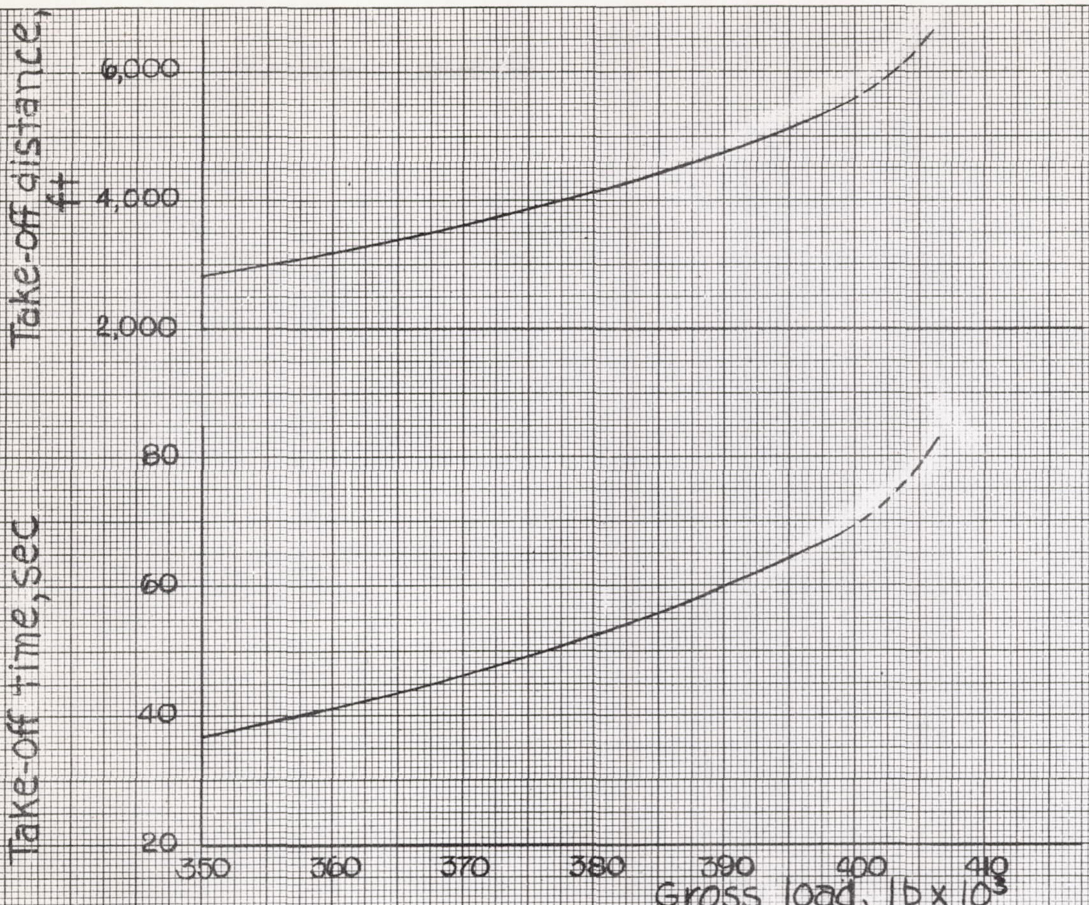

Figure 16.- Model 183. Variation of take-off time and distance with gross load.

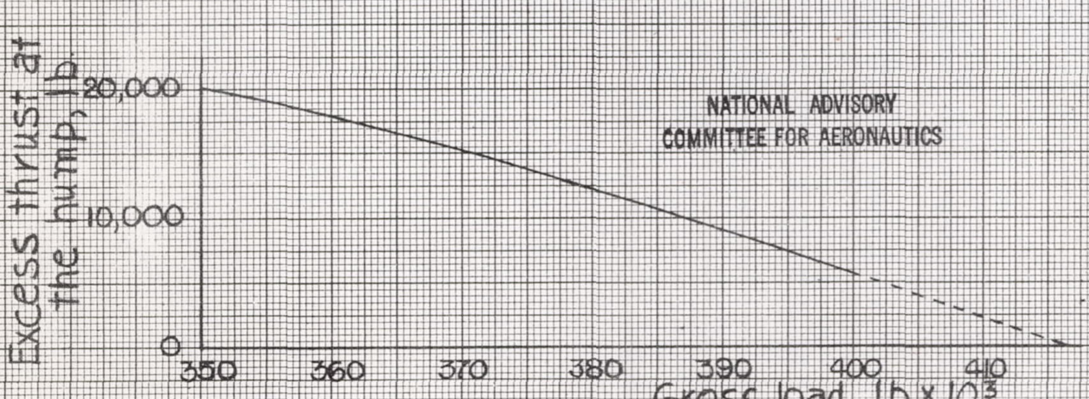

Figure 17.- Model 183. Variation of excess thrust at hump speeds with gross load.

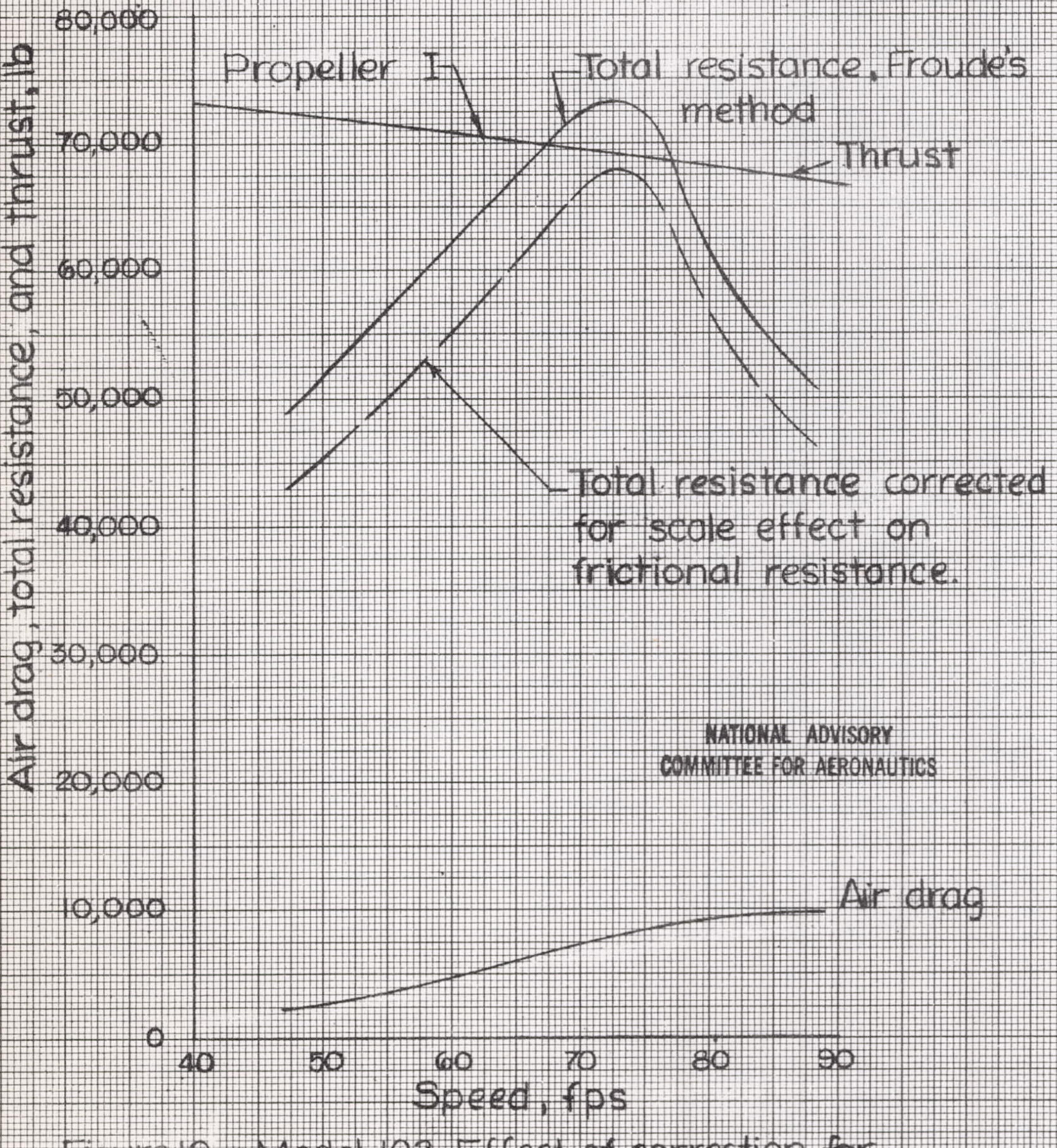

Figure 18.- Model 183. Effect of correction for scale effect on total resistance at hump speed.

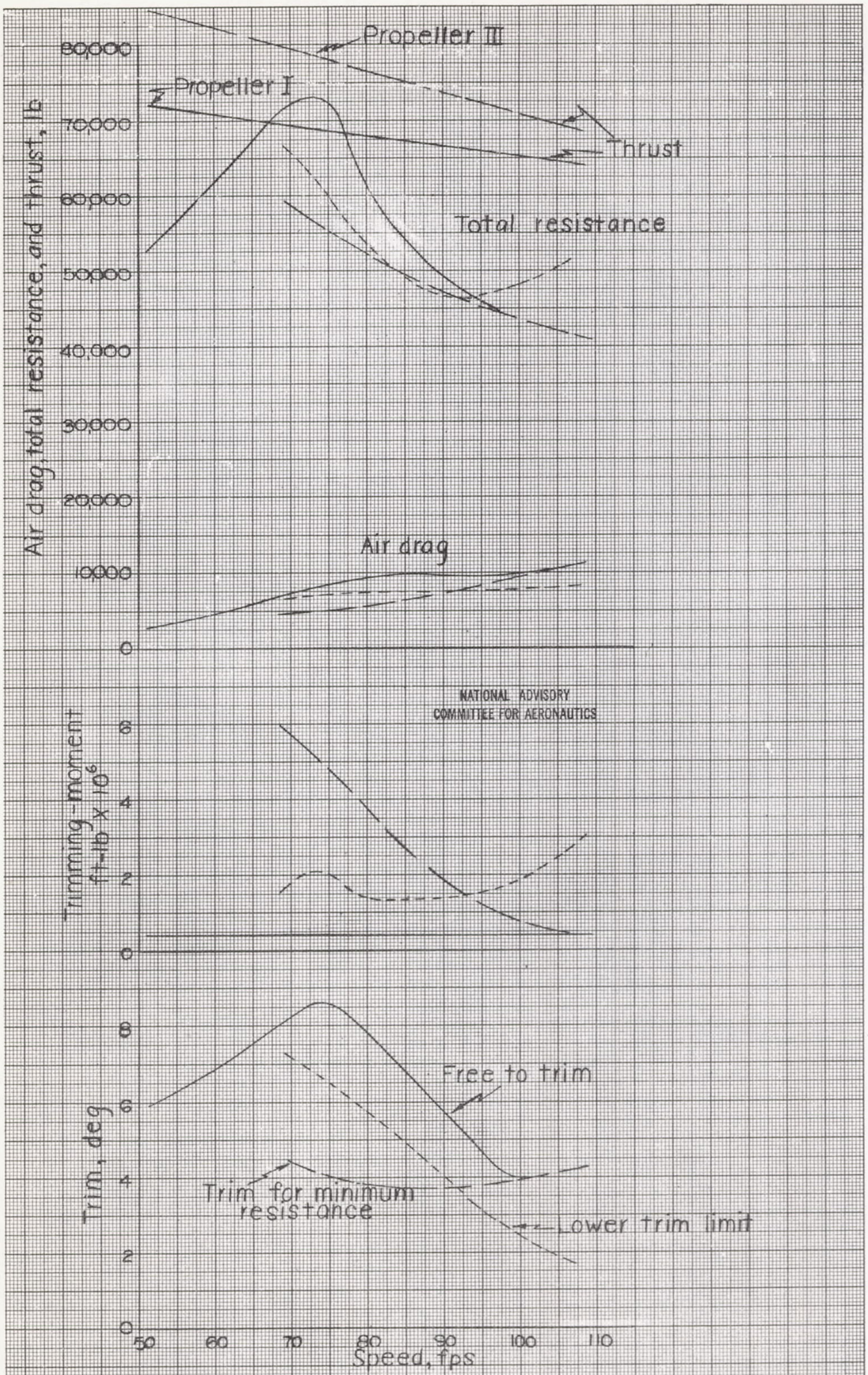

Figure 19.- Model 183. Total resistance, free to trim, trim for minimum resistance, and lower trim limit.

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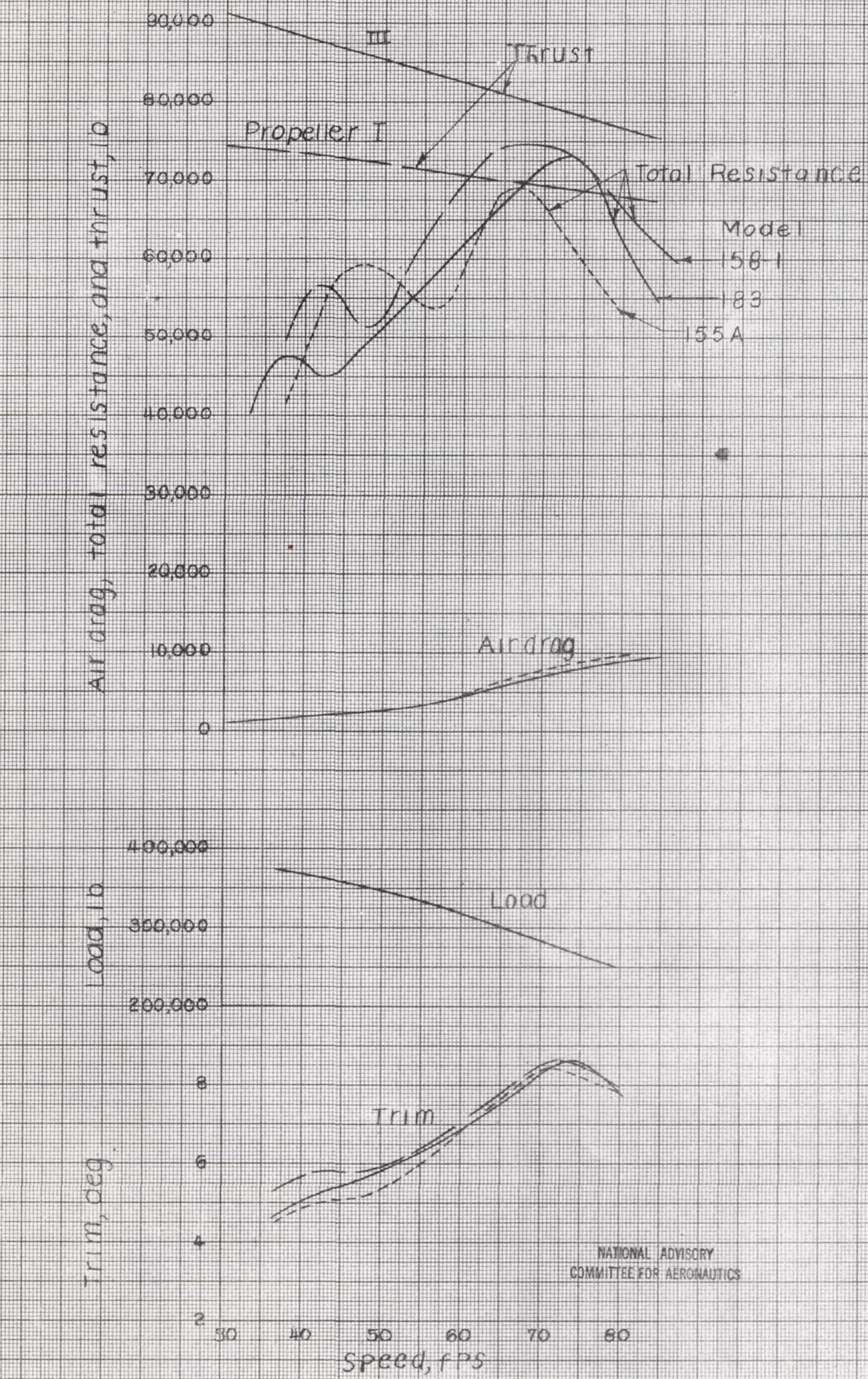

Figure 20.- Comparison of take-off performance at hump speeds three models of the Hughes-Kaiser flying boat.