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No. 545

TANK TESTS OF A MODEL OF A FLYING-BOAT HULL HAVING A LONGITUDINALLY CONCAVE PLANING BOTTOM

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SUMMARY

The N.A.C.A. model 11-B, which has a longitudinally concave planing bottom forward of the step, was tested in the N.A.C.A. tank over a wide range of loadings. The results of the tests are presented as curves of resistance and trimming moment plotted against speed for various trim angles and as curves of resistance coefficient at best trim angle, best trim angle, and trimming-moment coefficient at best trim angle plotted against speed coefficient. The characteristics of the form at the optimum trim are compared with those of N.A.C.A. model 11-C, which has the same form with the exception of a planing bottom longitudinally straight near the step. Photographs of the models being towed in the tank are included for a comparison of the spray patterns.

At the best angles of trim in each case, model 11-B has lower resistance at high speeds, a higher maximum positive trimming moment near the hump speed, and a more favorable spray pattern than that of model 11-C.

INTRODUCTION

The portion of a flying-boat hull or seaplane float forward of the step supports a large part of the total load during take-off and receives the major portion of the impact in alighting. Its proper form is a compromise resulting from considerations of water resistance, drag in flight, and shock-absorbing qualities. The most common solution is fundamentally a V-bottom planing surface having a straight or slightly convex profile near the step.

As a part of a comprehensive study of planing phenomena, Sottorf (reference 1) investigated two planing surfaces that were transversely flat but longitudinally concave. The surfaces were tested at various angles of trim for a load coefficient C_Δ of 0.65 and a speed coefficient C_V of 3.55. The ratios of longitudinal radius to beam were 38.3 and 20, and the load-resistance ratios at the best angle of trim were found to be 10 and 16 percent higher, respectively, than that of a plane surface. The trimming moment about the trailing edge and the height of the spray were reduced.

Tank tests of N.A.C.A. model 11-A demonstrated the superiority of a straight profile for the planing bottom of a flying boat over the convex profile of N.A.C.A. model 11 in regard to water resistance (reference 2). Tests of a model of the U.S. Navy PH-1 flying boat (reference 3) showed that a small downward drop or "hook" at the step caused the resistance of this hull to be slightly lower. A logical extension of these tests is the investigation of a model in which a generally concave profile of the planing bottom would be compared with a straight profile. Accordingly, a concave planing bottom was introduced into N.A.C.A. model 11-C and the resulting form was tested in the N.A.C.A. tank as model 11-B.

DESCRIPTION OF MODEL

Figure 1 shows the form of model 11-B and that of 11-C, to which its performance is later compared. Model 11-C was designed to be generally similar to N.A.C.A. model 11-A (reference 2), the essential differences being in the form of the forebody ahead of the flat planing bottom and the introduction of a small transverse flat at the keel.

Forward of station 3, models 11-B and 11-C are identical. Aft of station 3, the lines in the profile of model 11-B become concave, their curvature decreasing slightly toward the step. At the step, these lines are 1 inch below their corresponding positions on model 11-C and are tangent to a line at an angle of 4-1/2° with the model base line. The afterbody is identical with that of model 11-C but is dropped bodily as indicated in figure 1 to maintain the same depth of step in both cases. Thus, comparative tests of the two forms show the effects of planing bottom curvature alone.

The offsets for model 11-B are given in table I. The model was constructed of mahogany, close tolerances being maintained with the offsets given in the table. Several coats of gray enamel were applied to the surface which was carefully sanded and rubbed between successive coats.

APPARATUS AND PROCEDURE

The N.A.C.A. tank in which the tests were made is described in reference 3. The model suspension and the method of applying the resistance force to the dynamometer are described and shown diagrammatically in reference 4. The device used for measuring the trimming moment differs from that previously described in that the model is held at the trim angle desired by a very stiff calibrated spring. A moment imposed on the model rotates it slightly within the tolerance allowed on angle of trim ($\pm 0.1^{\circ}$). The resulting deflection of the spring is measured by a dial gage and the trimming moment in pound-feet is obtained from a calibration curve.

The tests were made by the "general" method (customarily referred to in the past as the "complete" method) whereby the performance of a given form is investigated over a wide range of possible loadings. The resistance, draft, and trimming moment are measured for all speeds, loads, and angles of trim that might be of interest.

The test schedule for model 11-B was shortened to obtain data only in the neighborhood of the hump speed, usually a critical point in the take-off, and at planing speeds between speed coefficients of 4.5 to 7.0. The loads applied correspond to load coefficients at rest of from approximately 0.28 to 0.60. Only trim angles near the optimum were included. Photographs were taken at intervals for the purpose of studying the spray.

RESULTS AND DISCUSSION

Test Data

The resistance and trimming moment obtained from the towing tests of model 11-B are plotted against speed in figures 2 to 7 for various constant angles of trim. The trim angle τ is the inclination of the model base line to the horizontal. The resistance is the water resistance plus the air drag of the above-water portion of the hull, the air drag of the towing gear being deducted. The reference point for the trimming moments is the center of moments shown on figure 1. Following the usual aerodynamic convention, tail-heavy moments are considered positive.

Best-Angle Curves

Comparisons with other models at the same angle of trim are likely to be misleading because the manner of introducing the curvature has changed the effective trim angle of the planing bottom. The effect of trim angle, however, may be eliminated by comparisons at the optimum angle of trim τ_o for any load and speed. In order to effect this, cross plots of resistance and moment were prepared from figures 2 to 7 at various speeds. From these cross plots the minimum resistance, the angle at which it occurs, and the trimming moment existing at that angle were found for the various loads. The values thus obtained were then converted to nondimensional coefficients, based on Froude's law of model similitude. These coefficients are defined as follows:

Speed coefficient, $C_V = \frac{V}{\sqrt{gb}}$

Load coefficient, $C_\Delta = \frac{\Delta}{wb^3}$

Resistance coefficient, $C_R = \frac{R}{wb^3}$

Trimming-moment coefficient, $C_M = \frac{M}{wb^4}$

where V is speed, f.p.s.

Δ, load, lb.

R, resistance, lb.

M, trimming moment, lb.-ft.

b, beam of hull, ft.

g, acceleration of gravity, 32.2 ft. per sec.^{2}

w, specific weight of water, lb. per cu.ft.

(w for water in the tank at the time of the test = 63.5 lb. per cu.ft.)

Any consistent units may, of course, be employed in place of those given.

The resistance coefficients C_R at best trim angle, the best trim angle τ_o, and the trimming-moment coefficient C_M at the best trim angle are plotted against speed coefficient C_V in figures 8, 9, and 10, respectively. These figures represent the characteristics of the hull under the conditions for the most favorable take-off.

Comparison with Model 11-C

The characteristics of model 11-B given in figures 8, 9, and 10 may be compared with the corresponding characteristics of model 11-C by cross plots against load coefficient at several representative values of speed coefficient. These cross plots are shown in figures 11 and 12.

Resistance.- In figure 11 the load-resistance ratios, Δ/R, or C_Δ/C_R, of the two forms are compared. At the hump speed, usually a critical point in the take-off, the difference in form appears to have little or no effect, but at $C_V = 3.2$ the Δ/R of model 11-B is appreciably higher, indicating that after the maximum has been reached, the resistance of 11-B falls off more sharply than that of 11-C. At $C_V = 4.5$ the differences are again small but at the higher planing speeds there is a definite gain in Δ/R, as shown in the curves at $C_V = 6.5$, the increase being from 10 to 15 percent.

Tests of model 11-C with various angles of afterbody keel show that a similar reduction in high-speed resistance may be obtained by the use of a larger angle of afterbody keel, presumably because of a decrease in the frictional resistance that is caused by the afterbody being wetted by water from the step. The decreased resistance of model 11-B might then be attributed to the increase in the clearance of the afterbody given by its down-curved forebody rather than to an improvement in the form of the planing bottom, since at these speeds the curvature of that part of the forebody actually in the water is small.

Best angle.- As indicated in figure 12, the best trim of model 11-B is from 2° to 2.5° lower than that of 11-C for all speeds and loads. Whether this reduction is desirable depends on the angle of wing setting and on the resulting unloading of the hull in a specific application. The lower best trim angle indicates that the "effective" angle of the planing bottom has been increased by the manner in which the curvature has been added.

Moments.- Figure 12 shows that, although the best trim angle has been reduced, the maximum positive and high-speed negative values of C_M have been increased over those for the straight forebody. The curves at $C_V = 3.0$ show, however, that the positive humps in the moment curves drop off more sharply after the maximum value has been reached. The relative magnitudes and the signs of the trimming-moment coefficients depend, of course, on the center of moments to which they are referred but the relative vertical positions of the curves will remain the same.

Spray pattern.- The height and volume of spray thrown from the forebody of model 11-B are, in general, less than those from model 11-C. The reduction parallels Sottorf's observations of a concave planing plate and extends that found in going from a convex to a straight planing bottom on a hull (reference 2). Typical photographs taken during the tests of 11-B and 11-C are shown in figure 13. Because of the different geometry of the forms referred to the trim base line, the patterns are contrasted with each hull near its optimum trim rather than at the same trim. The upper four pictures show the spray near the hump speed for a very heavy loading ($C_\Delta = 0.55$). Model 11-B appears to run considerably cleaner. The two lower views contrast the hulls under conditions near the get-away speed. Here, the plan form of the spray from 11-B appears to spread over a wider area although no great difference in height was noted. In neither case would tail surfaces in the usual positions be seriously wetted.

Longitudinal Stability

In order to obtain information concerning longitudinal stability while in motion, tests were made with the model free to trim both at constant speed and in accelerated motion. In these tests the model was pivoted at the center of moments shown in figure 1 and the wing lift was applied by the hydrovane device described in reference 3. The model was assumed to represent the hull of a flying boat and was tested under the following loading conditions:

		Full size	Model
Full load	Gross load, lb.	15,000	90.2
	Get-away speed, f.p.s.	100.0	42.8
Light load	Gross load, lb.	11,000	66.2
	Get-away speed, f.p.s.	85.5	36.5
	Linear-scale ratio	5.5	

During runs at constant speed, the model showed a tendency to "porpoise" at speeds slightly above the hump. This instability usually limits the range over which free-to-trim tests are conducted on hulls of conventional form. As it is not very marked during accelerated motion, it is not considered to be dangerous.

During accelerated runs simulating take-offs and landings for both loading conditions, no instability appeared that could not be controlled by slight damping in rise and pitch. Although dynamic conditions were not truly represented to scale, it is inferred from the behavior of conventional models under similar conditions that the concave profile of model 11-B does not induce undesirable oscillations in smooth water.

The use of greater curvature of the bottom, however, should be approached with caution. Sottorf (reference 1) observed an increase in longitudinal instability, particularly in disturbed water, with the increase in curvature of planing surfaces. In addition, the Bureau of Aeronautics, Navy Department, has stated that an excessive local "hook" in the region of the step (greater than one half of 1 percent of the beam) is likely to result in uncontrollable bounces in take-off and landing. From this experience with sharp hooks, it is believed that a greater general concavity than that found on model 11-B would result in objectionable performance in rough seas.

CONCLUDING REMARKS

The longitudinally concave planing bottom of model 11-B had the following effects on the performance at best trim angles as compared with model 11-C whose planing bottom is longitudinally straight:

1. The Δ/R ratios at the hump speed and at the lower planing speeds were changed by only small amounts.

2. The Δ/R ratios at high planing speeds were increased somewhat.

3. The best angles of trim were reduced, in general, approximately 2°.

4. The maximum positive moments and the negative moments at high speeds were increased.

5. The height and volume of spray were reduced.

The comparisons made would undoubtedly have shown greater differences had the concavity of model 11-B been more pronounced. There are, however, practical limits to the degree of curvature that might be employed in an actual hull. Sottorf found that the instability of planing surfaces increased with the curvature. In addition, sharper curvature, particularly if it accelerated toward the step, would increase the separation of the air flow where the forebody and afterbody join, thus tending to increase the drag in flight.

Tank tests of planing surfaces having V cross sections in addition to longitudinal concavity are planned by the Committee to ascertain whether the effects found by Sottorf on surfaces having flat cross sections would extend to the V sections used in practice on seaplanes. The results of these tests will possibly indicate a more favorable method of utilizing the properties of this type of planing bottom than that used in model 11-B.

Langley Memorial Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., April 8, 1935.

REFERENCES

1. Sottorf, W.: Experiments with Planing Surfaces. T.M. No. 739, N.A.C.A., 1934.

2. Parkinson, John B.: A Complete Tank Test of a Model of a Flying-Boat Hull - N.A.C.A. Model No. 11-A. T.N. No. 470, N.A.C.A., 1933.

3. Truscott, Starr: The N.A.C.A. Tank - A High-Speed Towing Basin for Testing Models of Seaplane Floats. T.R. No. 470, N.A.C.A., 1933.

4. Shoemaker, James M.: Tank Tests of Flat and V-Bottom Planing Surfaces. T.N. No. 509, N.A.C.A., 1934.

TABLE I

Offsets for N.A.C.A. Model No. 11-B Flying-Boat Hull (Inches)

Station	Distance from F.P.	Distance from base line									Half breadths							
		Keel	B1 [1]1.50	B2 3.00	B3 4.50	B4 6.00	B5 7.50	Main chine	Cove	Upper chine	Main chine	Cove	Upper chine	WL1 [2]12.50	WL2 11.00	WL3 9.50	WL4 8.00	WL5 6.50
F.P.	0.0	4.00						4.00			0.15							
1/2	2.4	9.17	5.90					5.29			2.07						0.52	1.16
1	4.8	10.85	8.20	6.64				6.34			3.53					0.73	1.64	3.22
1½	7.2	11.87	9.72	8.12	7.24			7.18			4.67				0.64	1.67	3.15	
2	9.6	12.52	10.76	9.27	8.27			7.87			5.59			0.16	1.30	2.74	5.13	
3	14.4	13.21	12.01	10.83	9.83	9.13		8.89			6.90			.93	2.76	5.10		
4	19.2	13.47	<——>	11.80	10.93	10.19	9.68	9.64			7.71							
5	24.0	13.64	<——>	12.30	11.60	10.93	10.34	10.12			8.17							
6	28.8	13.81	<--Elements of stations ——> Straight lines from here aft					10.36			8.40							
7	33.6	14.02						10.57			8.48							
8	38.4	14.30						10.85			8.50							
9	43.2	14.63						11.18			8.50							
10.F.	48.0	15.00						11.55			8.50							
10.A.	48.0	14.44						10.98			8.50							
11	52.8	13.97						10.51			8.50							
12	57.6	13.51						10.22	9.29	9.16	8.10	8.10	8.40					
13	62.4	13.04						10.22	8.63	8.15	6.97	6.97	8.11					
14	67.2	12.58						10.54	8.27	7.23	5.07	5.07	7.58					
15	72.0	12.11						11.10	8.17	6.44	2.59	2.59	6.77					
S.P.	76.0	11.74 8.24						11.72	8.22		.20	.20						
16	76.8	8.04								5.71			5.78					
17	81.6	6.91								5.06			4.61					
18	86.4	5.77								4.46			3.31					
19	91.2	4.64								3.91			1.90					
20	96.0	3.50								3.39			.40					

[1] Distance from center line (plane of symmetry) to buttock (section of hull surface made by a vertical plane parallel to plane of symmetry)

[2] Distance from base line to water line (section of hull surface made by a horizontal plane parallel to base line)

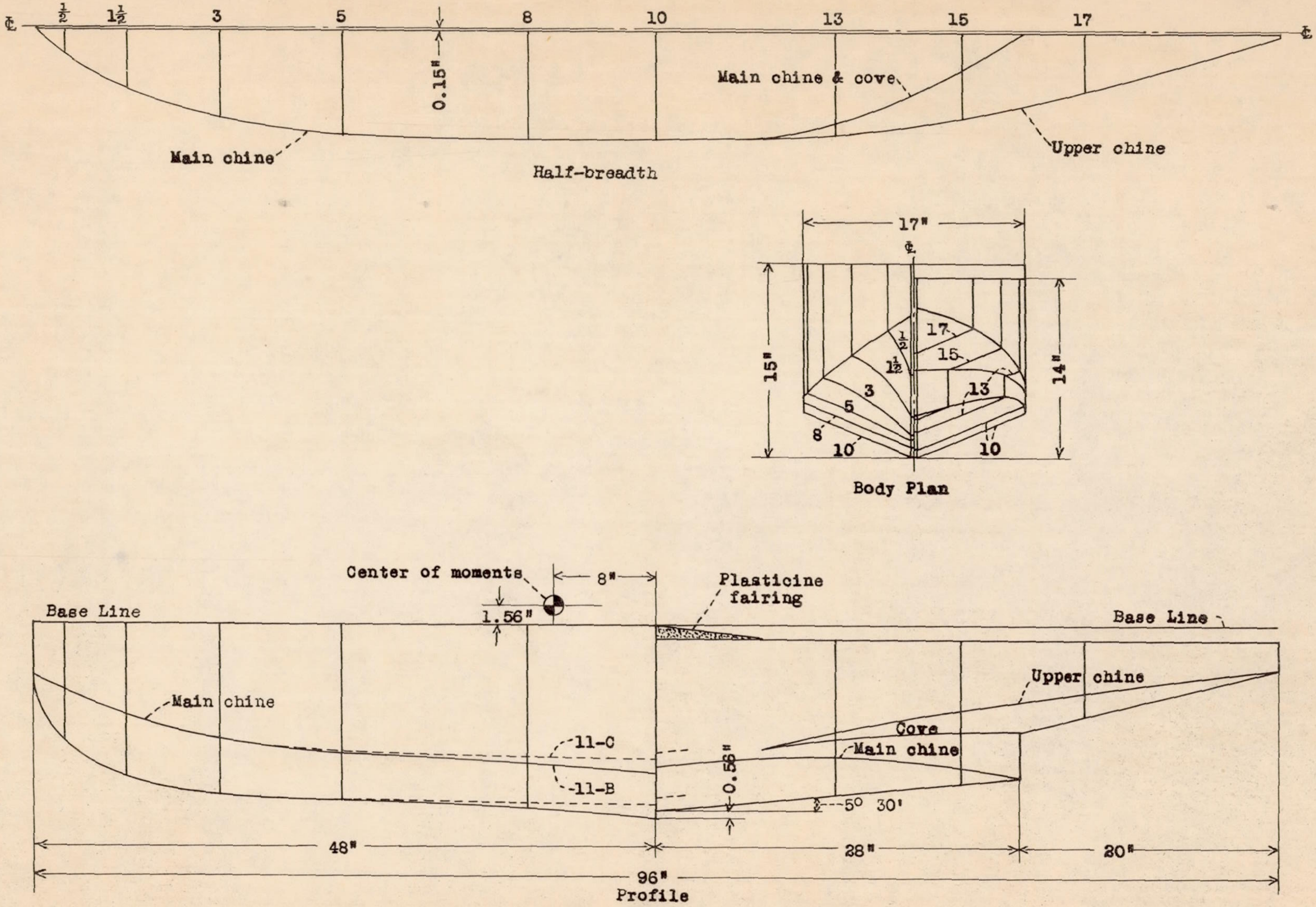


Figure 1.- Lines of N.A.C.A. Model 11-B

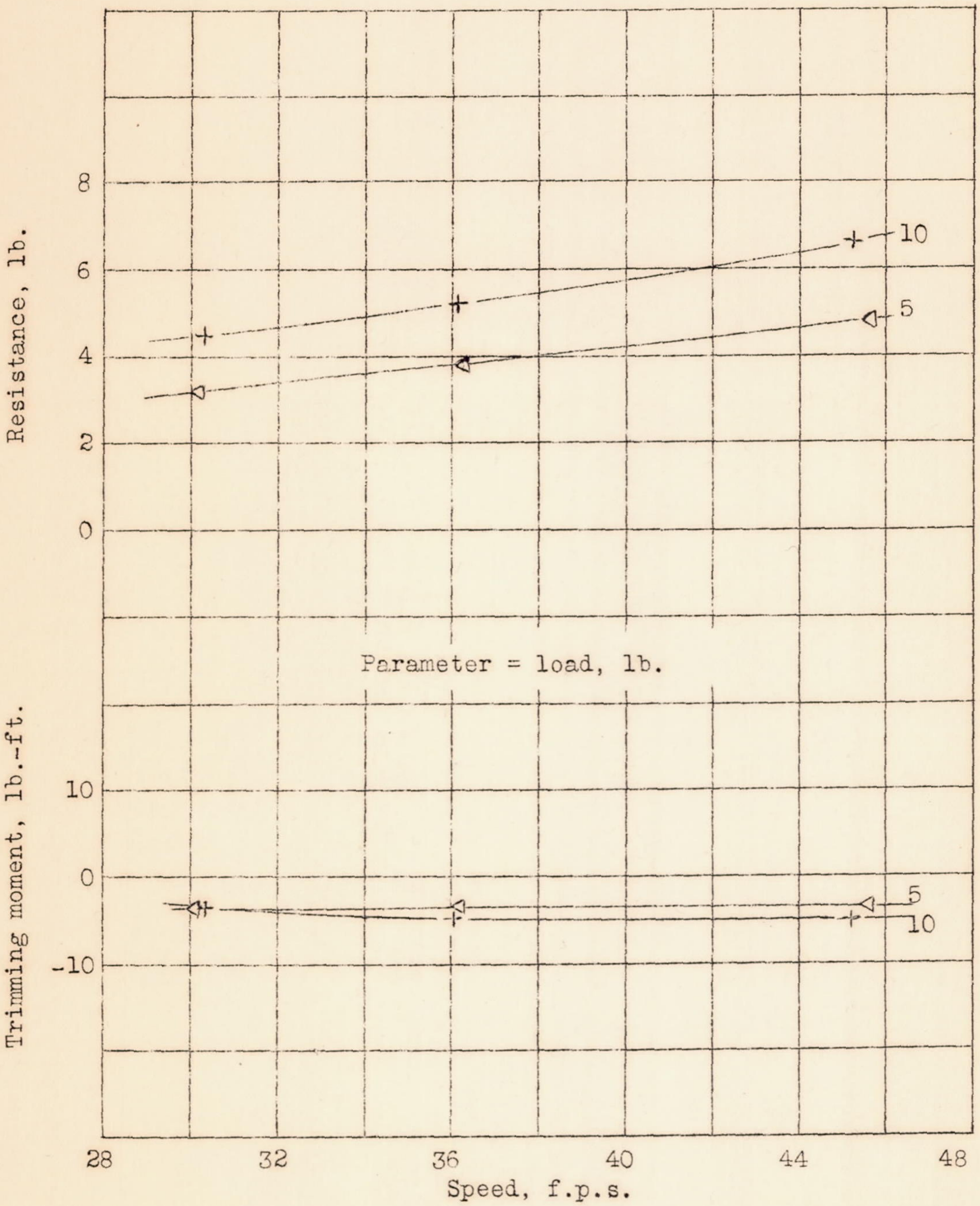


Figure 2.- Resistance and trimming moment. Trim angle, $\tau = 0^{\circ}$

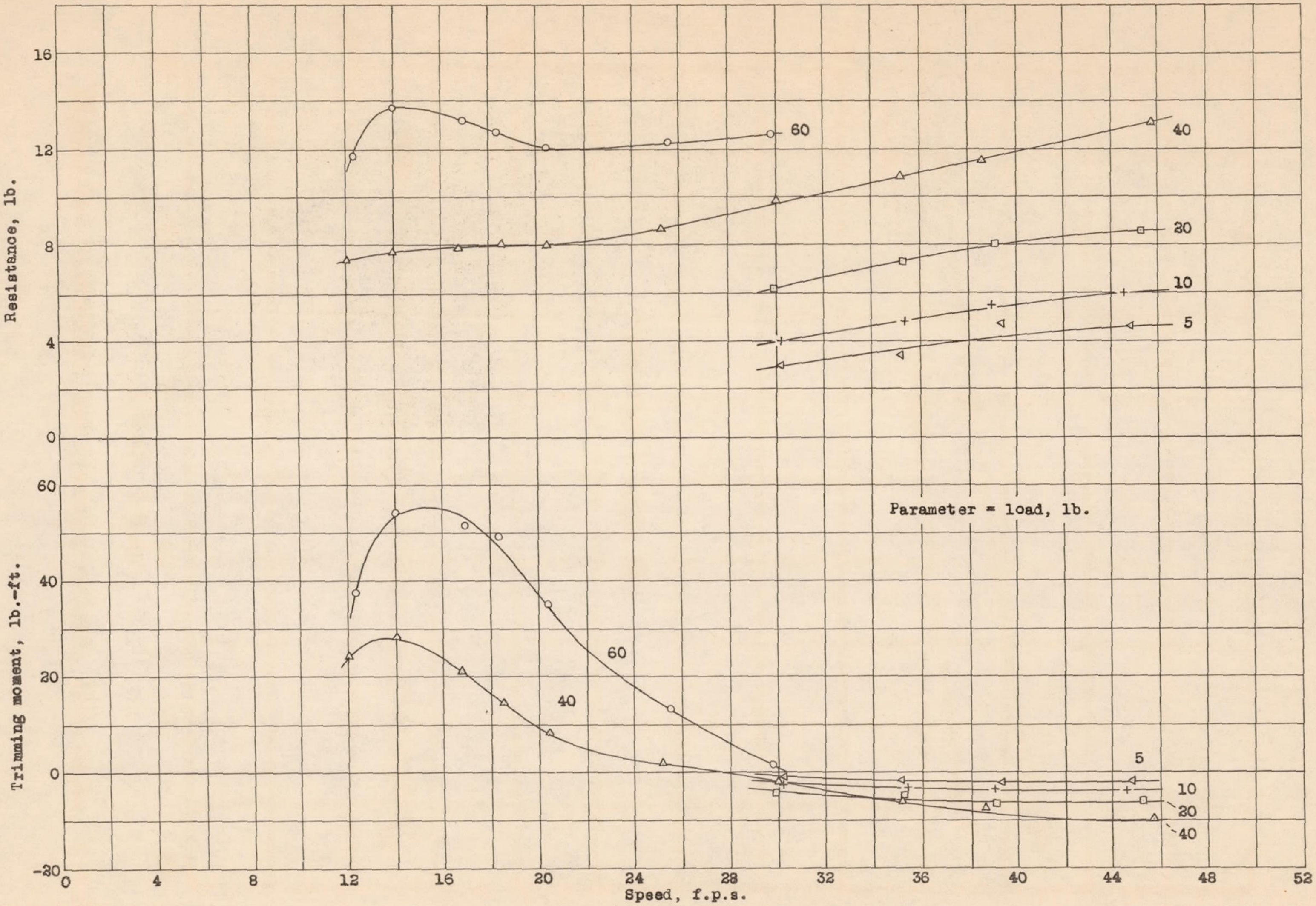


Figure 3.- Resistance and trimming moment, $\tau = 1^{\circ}$

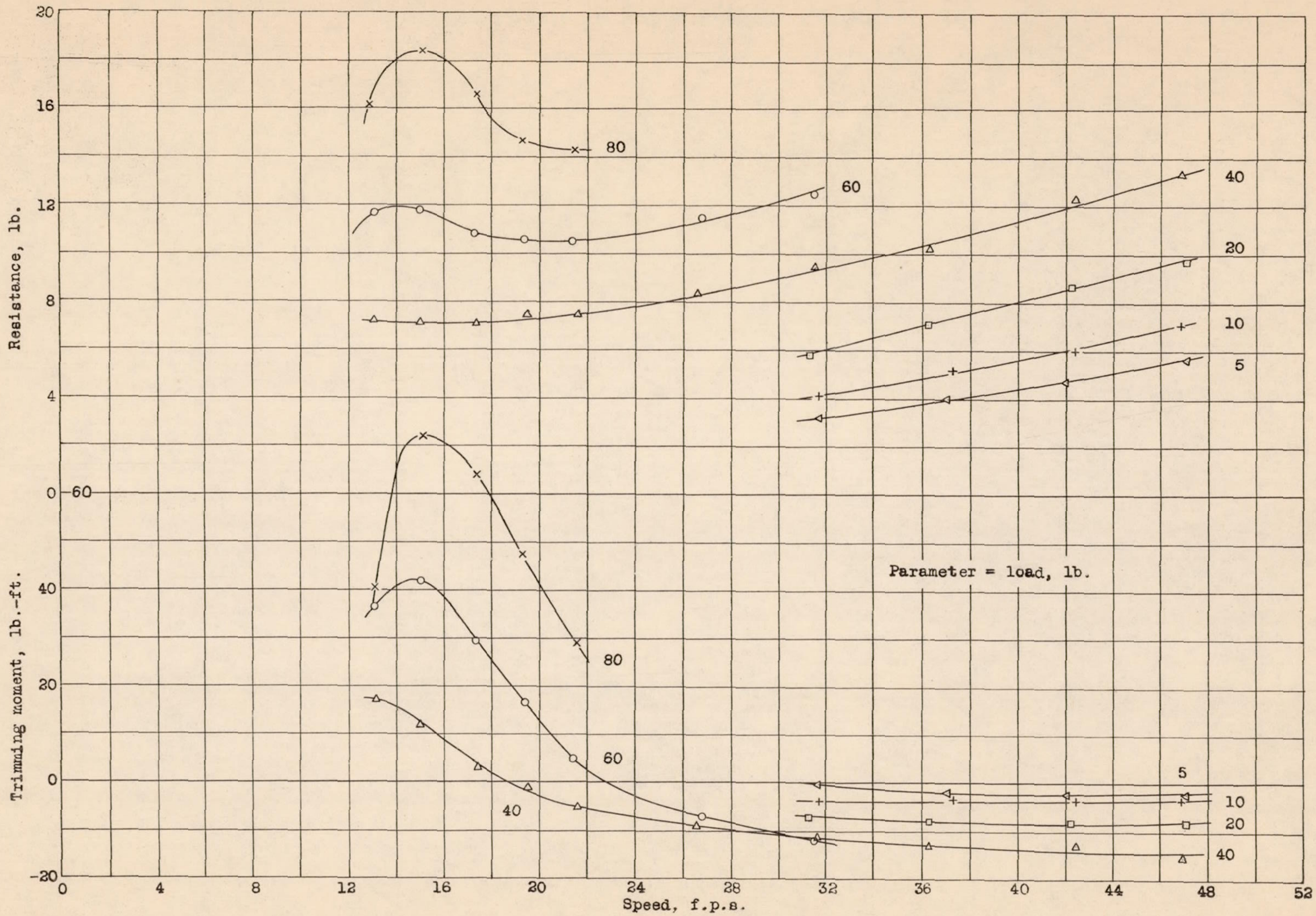


Figure 4.- Resistance and trimming moment, $\tau = 3^\circ$

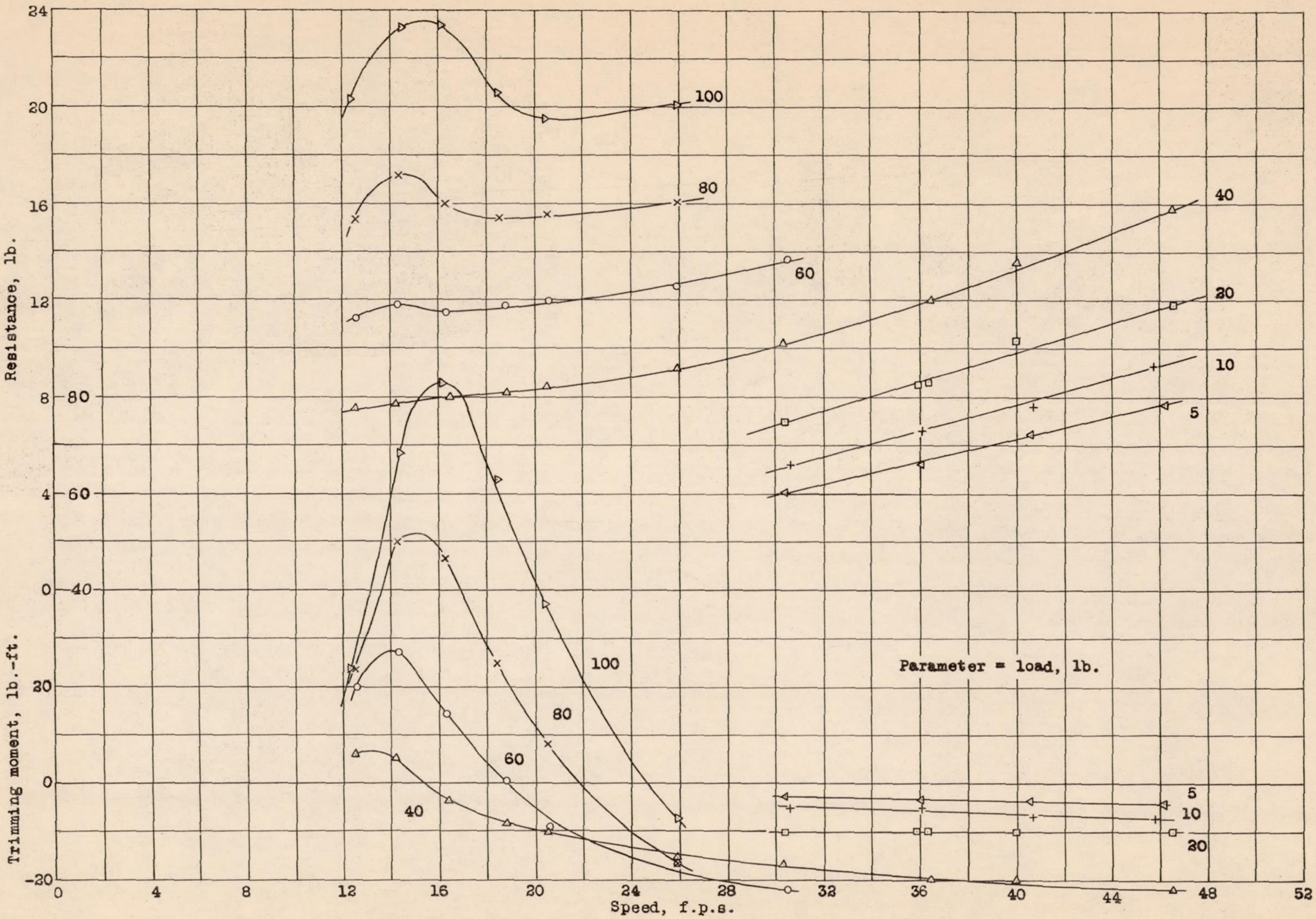


Figure 5.- Resistance and trimming moment, $\tau = 5^{\circ}$

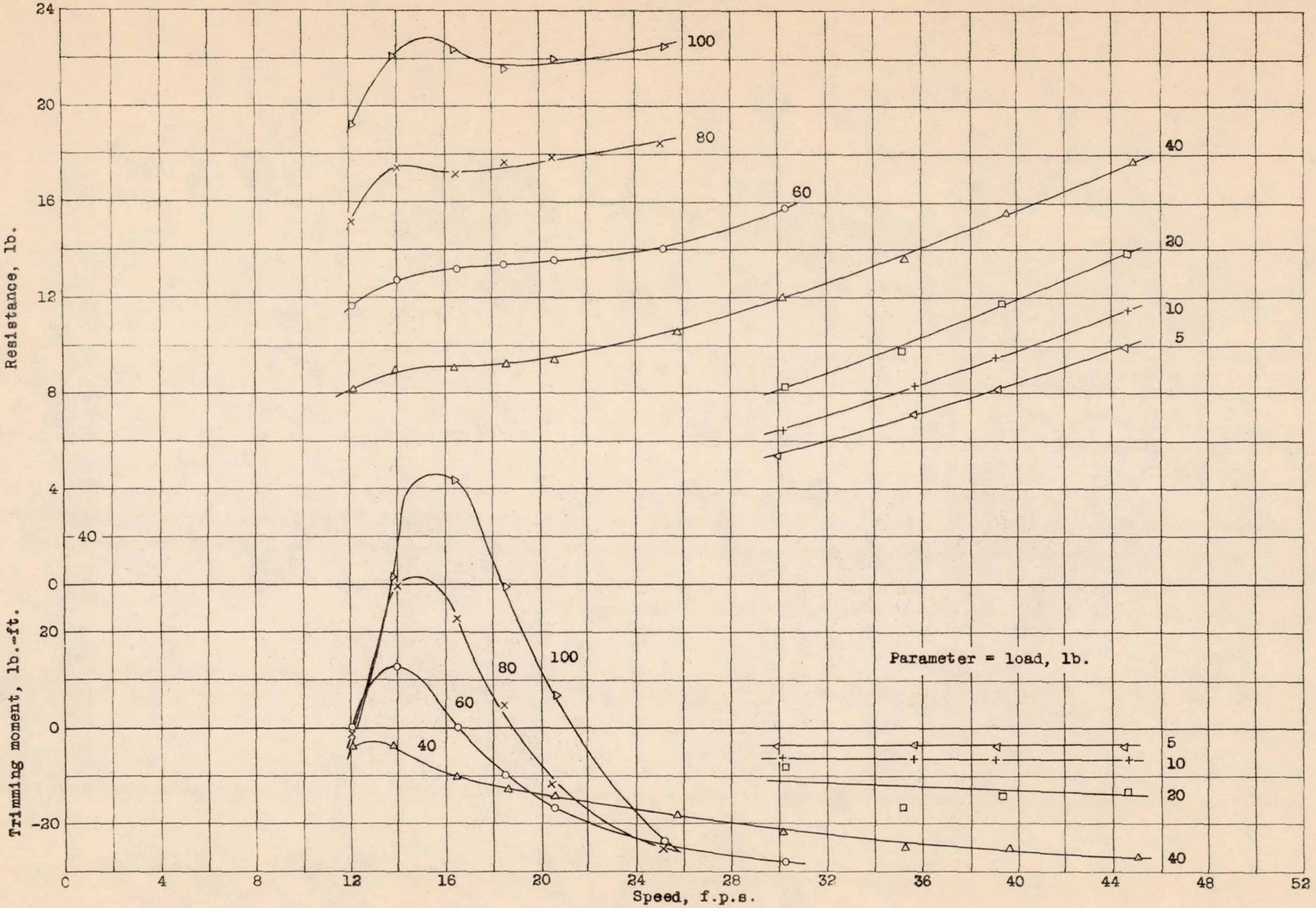


Figure 6.- Resistance and trimming moment, $\tau = 7^\circ$

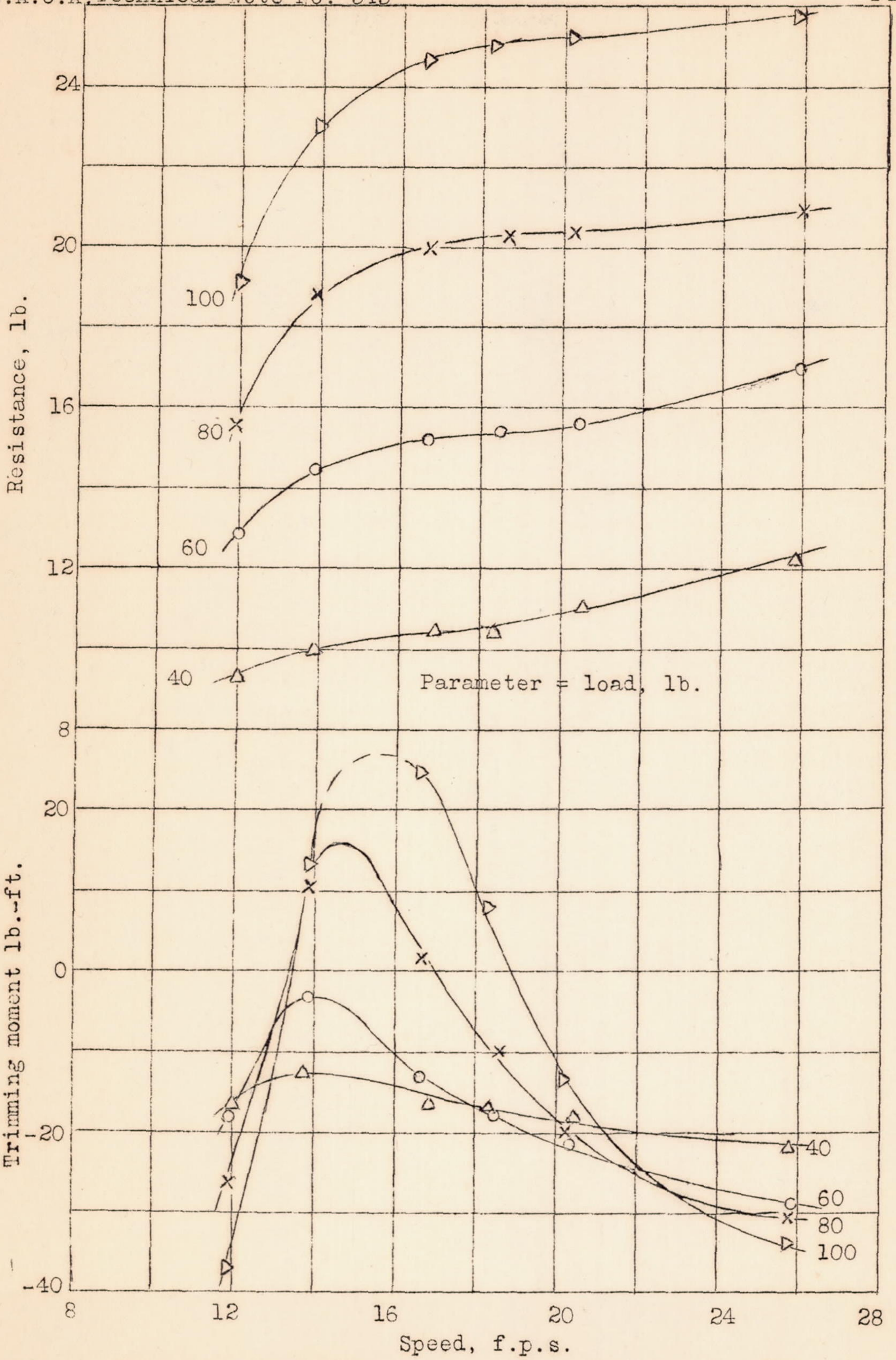


Figure 7.- Resistance and trimming moment, $\tau = 9^0$

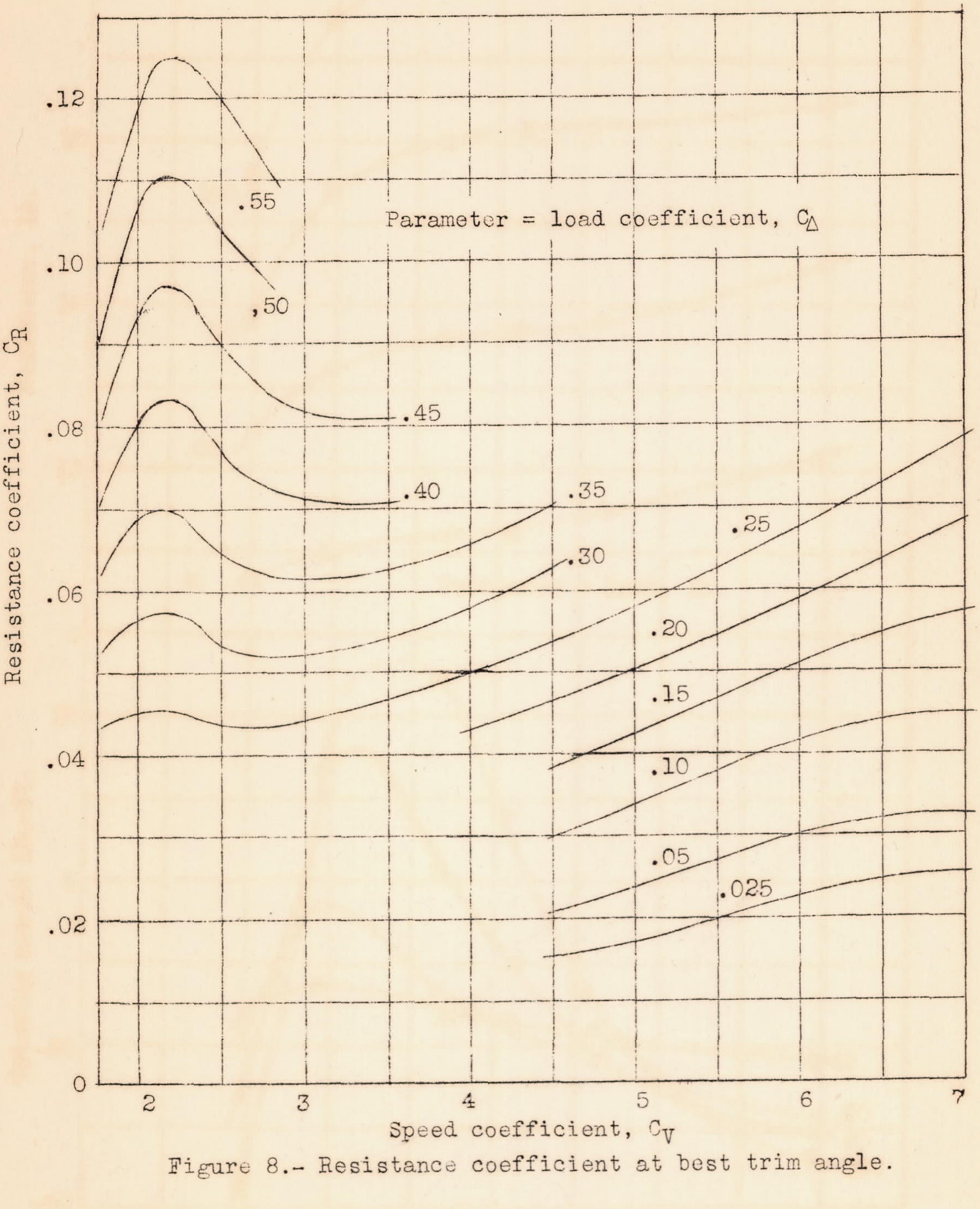


Figure 8.- Resistance coefficient at best trim angle.

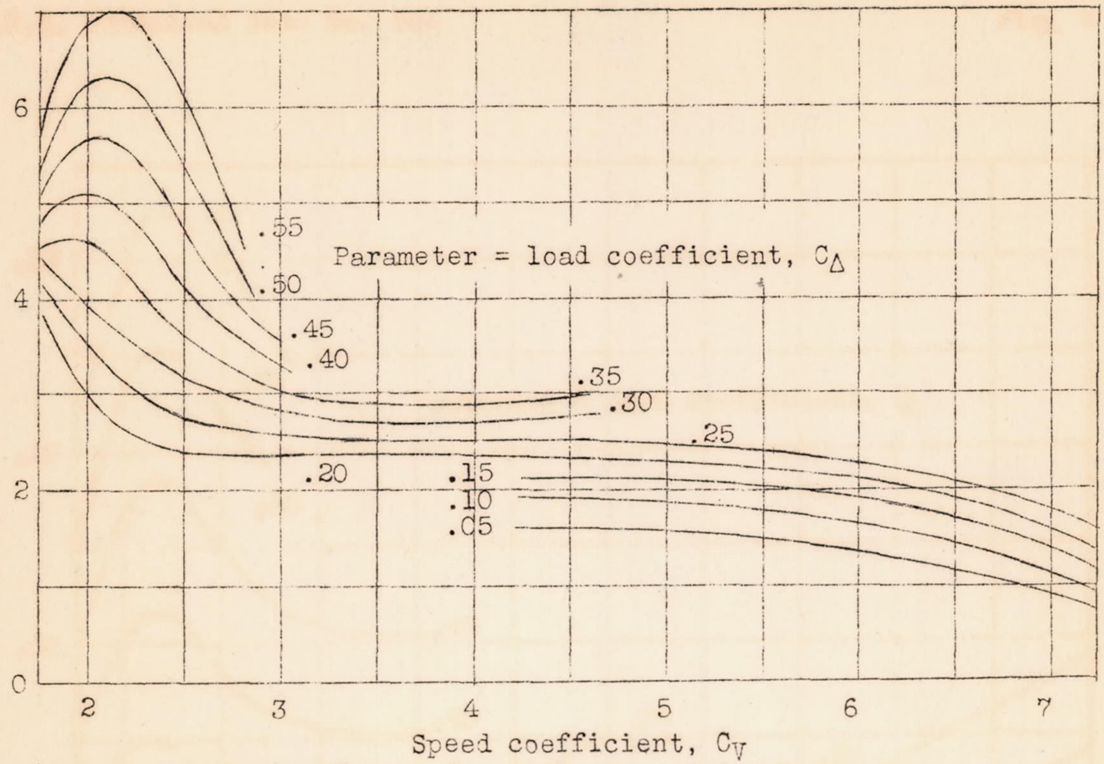


Figure 9.- Angle of trim for minimum resistance

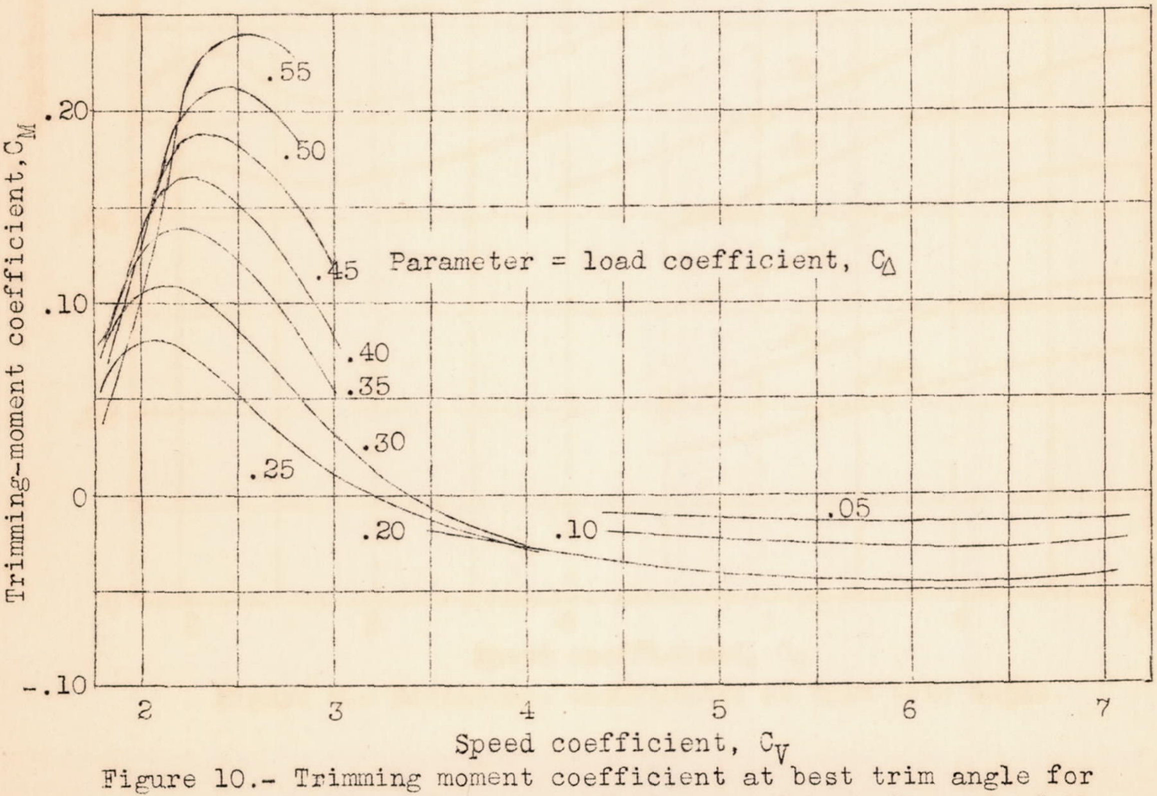


Figure 10.- Trimming moment coefficient at best trim angle for center of moments 47.06 percent beam forward of the step and 97.41 percent beam above the keel at the step.

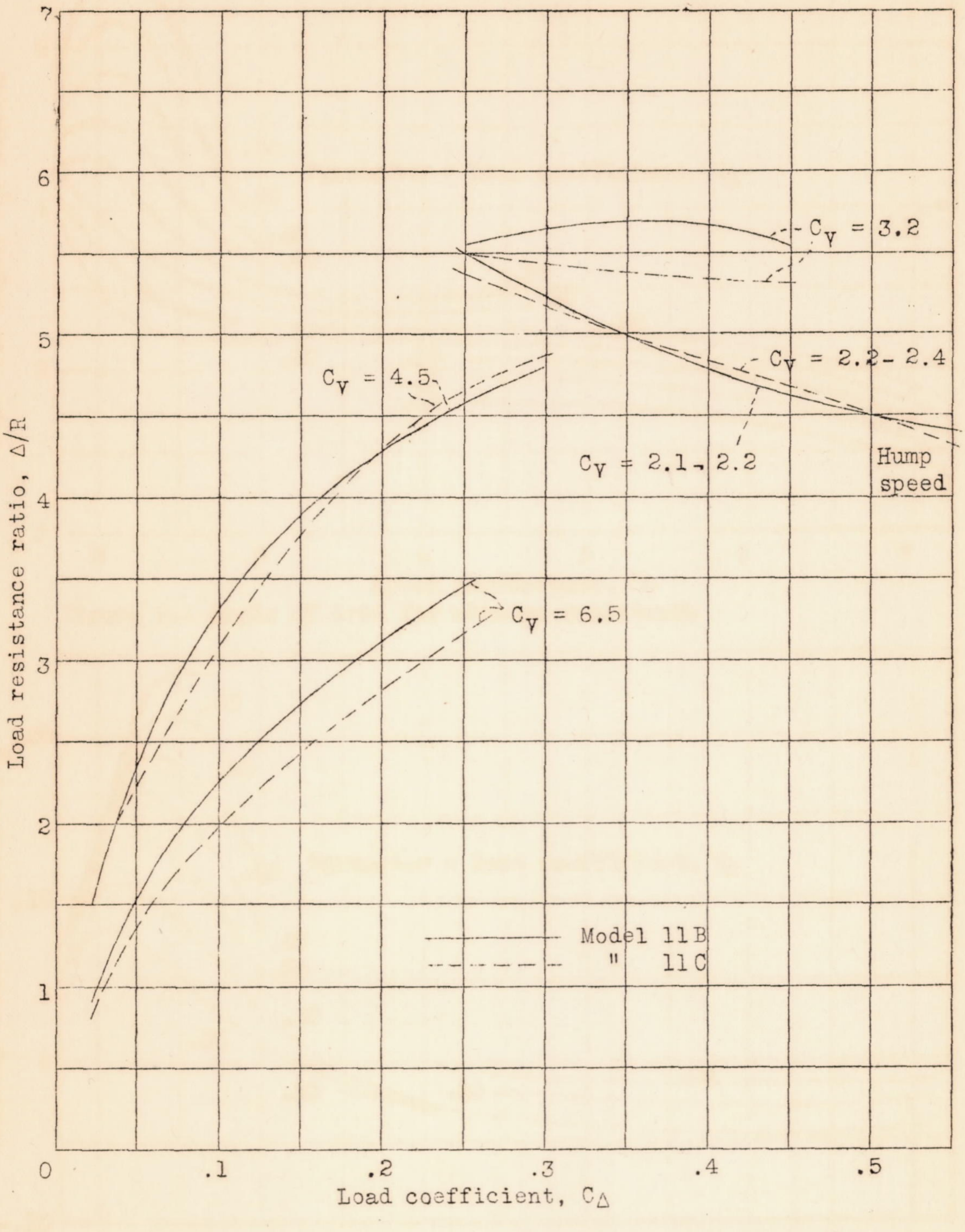


Figure 11.- Effect of concave planing bottom on Δ/R at best trim angle.

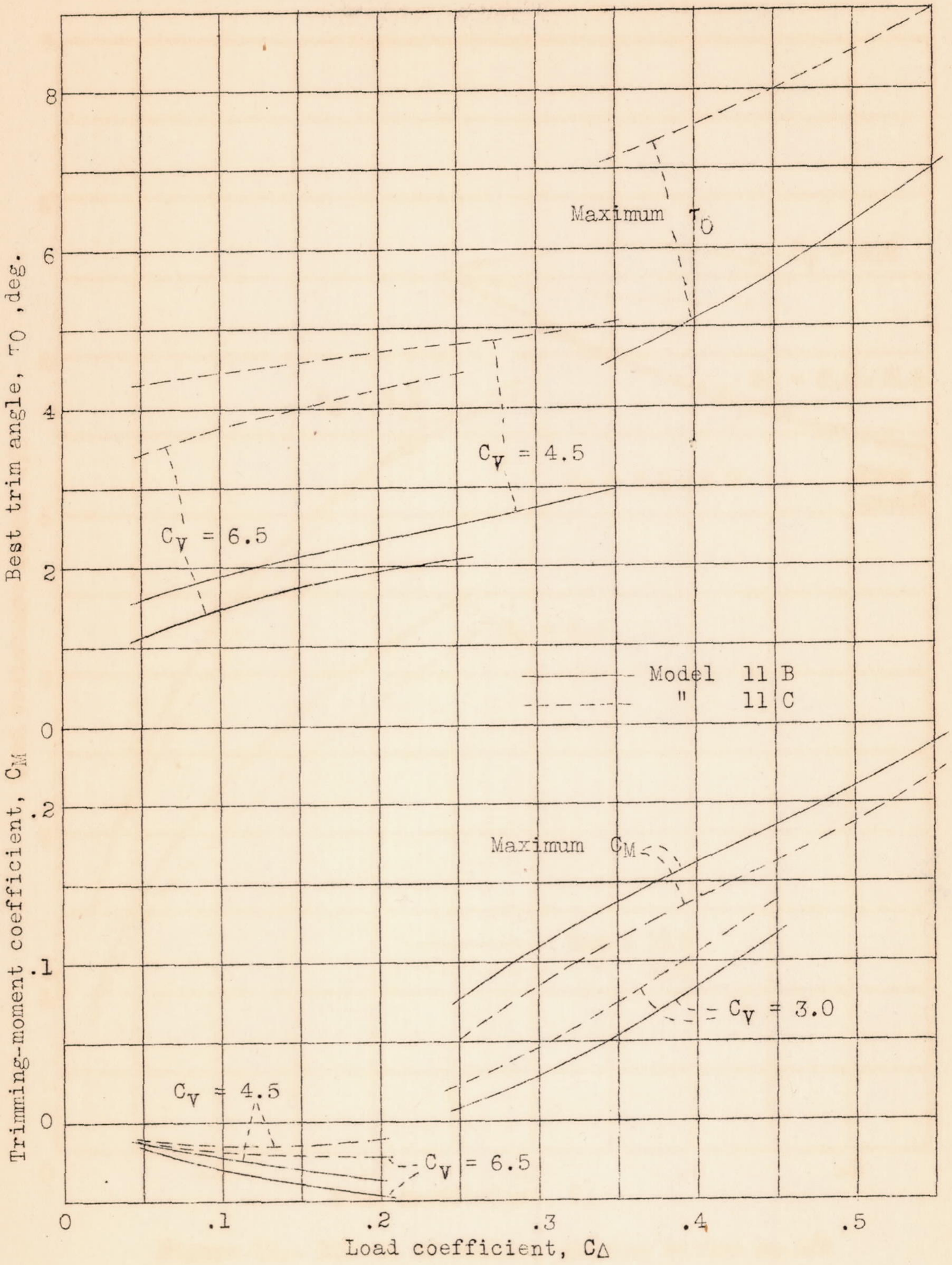
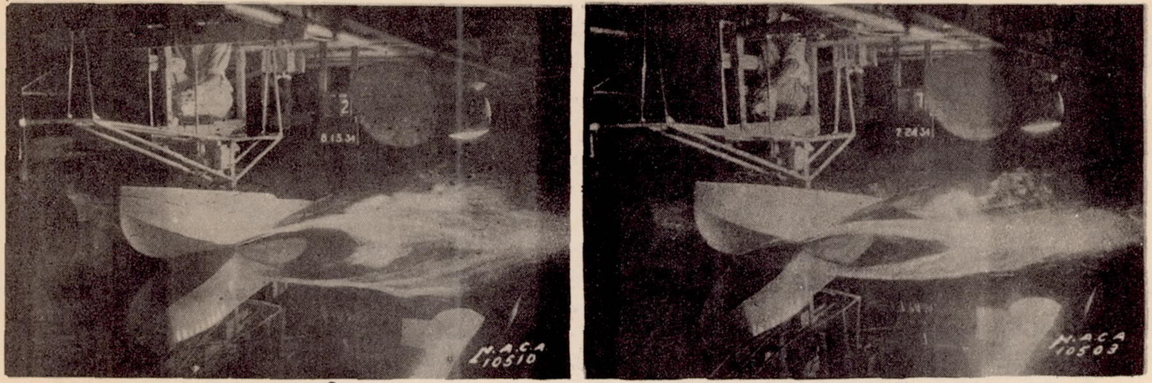


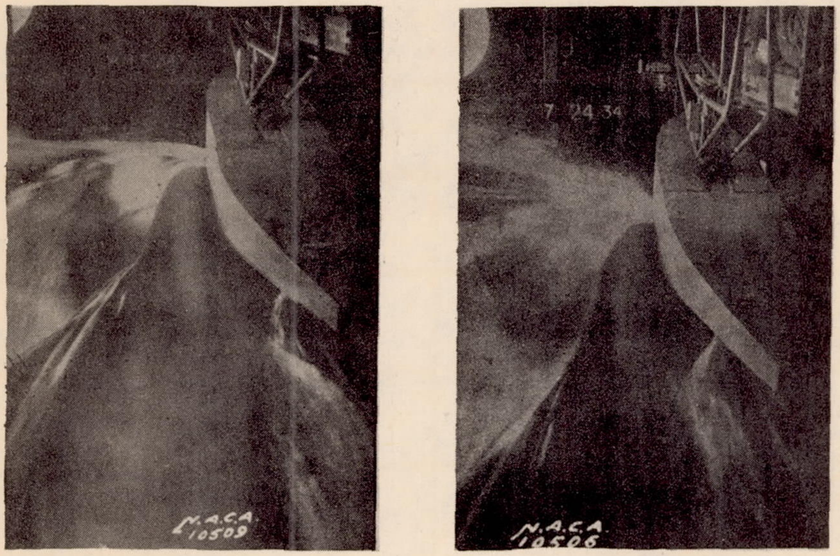
Figure 12.- Effect of concave planing bottom on best trim angle and trimming moment coefficient at best trim angle.

Model 11-B Model 11-C



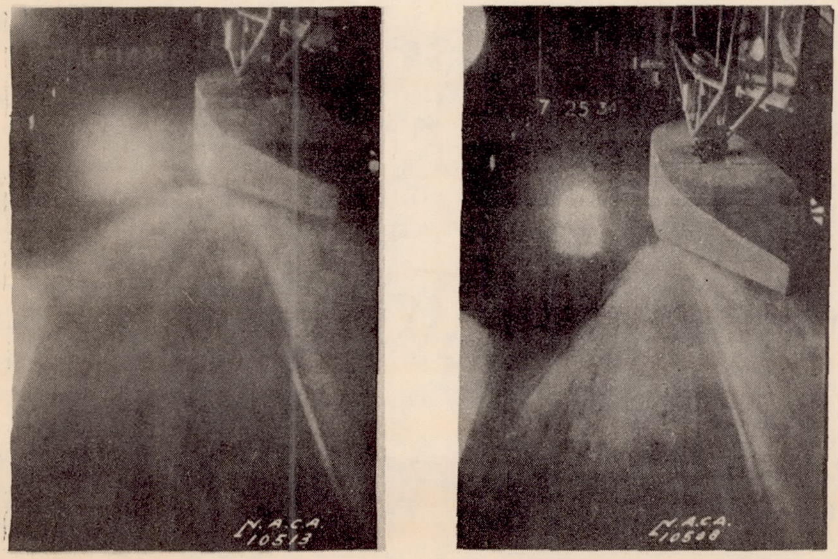
16.4 f.p.s., $\tau = 7^{\circ}$, Δ = 100 lb. 15.3 f.p.s., $\tau = 9^{\circ}$, Δ = 100 lb.

20.6 f.p.s., $\tau = 7^{\circ}$, Δ = 100 lb.



18.9 f.p.s., $\tau = 9^{\circ}$, Δ = 100 lb.

45.2 f.p.s., $\tau = 0^{\circ}$, Δ = 10 lb.



45.0 f.p.s., $\tau = 2^{\circ}$, Δ = 10 lb.

Figure 13.- Effect of concave planing bottom on spray pattern