TECHNICAL NOTES

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

No. 590

HYDRODYNAMIC TESTS IN THE N.A.C.A. TANK OF A MODEL OF THE HULL OF THE SHORT CALCUTTA FLYING BOAT

By Kenneth E. Ward
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Washington
January 1937

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SUMMARY

The hydrodynamic characteristics of a model of the hull of the Short Calcutta (N.A.C.A. Model 47) are presented in nondimensional form. This model represents one of a series of hulls of successful foreign and domestic flying boats the characteristics of which are being obtained under similar test conditions in the N.A.C.A. tank.

The take-off distance and time for a flying boat having the hull of the Calcutta are compared at two values of the gross load with the corresponding distances and times for the same flying boat having hulls of two representative American types, the Sikorsky S-40 and the N.A.C.A. 11-A. This comparison indicates that for hulls of the widely different forms compared, the differences in take-off time and distance are negligible.

INTRODUCTION

The N.A.C.A. is testing a series of models representing the hulls of various successful foreign and domestic flying boats. The chief purpose of these tests, as pointed out in reference 1, is to obtain directly comparable hydrodynamic characteristics of the hulls. The knowledge thus obtained should result in a concentration of future development on the forms showing the greatest promise. While it is realized that hulls of the different types used by the designers in different countries require different technique in handling while on the water, comparative data as to the hydrodynamic characteristics should be of considerable value to all designers.

The present tests were made of a model of a hull representing that of the Short Calcutta, a successful British flying boat, the lines of which were kindly supplied by Short Bros., Ltd. The hull of the Calcutta has a transverse second step, a forebody of approximately half the length to the second step, and an extended beam at the chines. The gross load and take-off speed, as stated by the designers, are 21,700 pounds and 51-1/2 knots, respectively.

DESCRIPTION OF MODEL

The model as tested in the N.A.C.A. tank (N.A.C.A. Model 47) was constructed to a scale of 17:119.90, or approximately 1/7, and was of laminated mahogany, painted and rubbed, with a tolerance on the offsets of ±0.02 inch. The model was constructed with fair deck and sides, following the design of the actual Calcutta hull, for the purpose of obtaining the aerodynamic characteristics from wind-tunnel tests in another investigation. The principal lines are shown in figure 1 and the offsets are given in table I. Figure 2 shows the model as tested in the tank.

The proportions of the Calcutta hull are typical of British practice at the time the Calcutta was designed in that it has a relatively short forebody and long afterbody, as compared with contemporary American practice, with the center of gravity well forward and near the main step. The bow is rather full and the hull has a flare at the chine with an extended beam over the portion near the main step. The maximum beam is ahead of the main step and the relatively narrow afterbody ends with a small transverse second step having a pronounced hook.

The principal geometric characteristics of the hull are as follows:

	Model	Full size
Length:		
Over-all (O.A.), in.	102.95	726
Forebody, in.	38.75	273-1/4
To second step, in.	76.08	536-1/2
Maximum beam, in.	17.00	119.90
Dead rise at step (tangent, keel arc to chine), deg.	21.1	21.1

	Model	Full size
Gross load, lb.	61.4	21,700
Get-away speed, f.p.s.	32.8	87
Center of gravity above keel at step, in.	21.27	150
Center of gravity forward of step, in.	2.09	14-3/4
Angle of keel forward of step to base line, deg.	-.3	-.3
Angle of keel aft of step to base line, deg.	8.3	8.3
Depth of step, in.	.56	3.90
Linear ratio of model to full size	17:119.90 or 1:7.053	

Forebody:	
Percent of O.A. length	37.6
Percent of length to second step	51.0
Beam:	
Percent of O.A. length	16.5
Percent of length to second step	22.3
Percent of forebody length	43.9
Center of gravity above keel at step:	
Percent of O.A. length	20.7
Percent of length to second step	28.0
Percent of forebody length	54.9
Center of gravity forward of step:	
Percent of O.A. length	2.0
Percent of length to second step	2.8
Percent of forebody length	5.4
Depth of step, percent of beam	3.25

APPARATUS AND PROCEDURE

A description of the N.A.C.A. tank, the equipment, and the method of testing is given in reference 2. The towing gear has been modified from that described in the reference and the gear as now used is described in reference 3.

Test data were obtained by the general method (see reference 2) in which the independent variables were load, speed, and trim, and the dependent variables were resistance, trimming moment, and draft. Tests were also made with the model free to trim about the design center of gravity. Two methods were used for these free-to-trim tests: the specific or hydrofoil method, during which the load on the water was automatically adjusted to the speed by means of a hydrofoil running in the water; and the general method, during which the load was made an independent variable. This latter method of obtaining the free-to-trim characteristics is more comprehensive than the hydrofoil method as it provides data from which the characteristics (for a given center of moments) may be obtained for various gross loads and unloading conditions.

RESULTS AND DISCUSSION

Experimental results.- The experimental results are presented in the form of nondimensional coefficients defined as follows:

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

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

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

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

Draft-beam ratio . . . . $\frac{d}{b}$

where

V is the speed.

R, resistance (including the air resistance of the model)

Δ, load on the water

M, trimming moment (bow-up moments considered positive)

b, maximum beam

d, draft (distance from keel at step to free-water surface)

w, specific weight of water (63.5 lb./cu.ft. for these tests)

g, acceleration of gravity

The units must, of course, be consistent. In order to express the experimental results in convenient units of the load coefficient, it is necessary to use counterweights of predetermined weight based on the density of the water at the time of the test and on the beam of the model. The other coefficients are readily obtained by the application of factors to the recorded data.

The precision of the data as presented is believed to be within the following limits:

Load coefficient	0.002 -.001
Resistance coefficient	±.001
Trimming-moment coefficient	±.005
Speed coefficient	±.02
Trim	$\pm .1^{\circ}$
Draft-beam ratio (under way)	±.01
Draft-beam ratio (at rest)	±.005

The trimming-moment coefficient and the draft-beam ratio of the model at rest are shown in figure 3. The data of this figure permit the trim and draft of the hull while at rest to be obtained for various loads and various positions of the center of gravity.

The results of tests of the model free to trim (fig. 4) are particularly useful for determining the hydrodynamic resistance of the hull at low speeds where the aerodynamic control may be insufficient to maintain the hull at the best trim. Figure 4 also gives the trim assumed by the hull for this condition. The results are shown for a wide range of loads for use in obtaining the free-to-trim characteristics of the hull for various initial loads and unloading conditions and for one position of the center of gravity. The long-dash line on the resistance curves indicates the variation of resistance with speed for the hull with the design-load coefficient of 0.34 and get-away speed coefficient of 4.85 while operating at a constant value of the lift coefficient.

The resistance and trimming-moment coefficients for the hull at several fixed trims are shown in figures 5 to 10. These curves show the usual variation of resistance and moment with speed for the several trims and are useful for obtaining the resistance and moment at a trim other than best trim.

Derived results.- The resistance and trimming-moment coefficients corresponding to the best trim are shown in figure 11, and the best trim is shown in figure 12. The curves are derived in the usual manner; that is, the resistance is plotted against trim at suitable intervals of the speed for the loads used. The hydrodynamic characteristics are then obtained at the trim that gives the least resistance. These curves are useful for estimating the performance of the flying boat during take-off. The long-dash line superimposed on the resistance curves (fig. 11) represents the resistance at best trim during the assumed take-off shown and is later compared (fig. 16) with the corresponding curve of figure 4. The resistance curves, together with the best-trim curves, provide the necessary test data for the take-off problem. The large moments and high trims below the hump speed, shown in the figures, indicate that for this hull the free-to-trim characteristics should be used up to a speed coefficient of approximately 2.0. Such a procedure will be on the conservative side. At higher speeds the aerodynamic control is probably sufficient to maintain the best trim.

The curves of figure 11, when compared with similar curves for other models, show that in general the hump resistance is considerably higher and the high-speed resistance is lower for a hull of the Calcutta type than for hulls of conventional American types. The curves of figure 13, which give the load-resistance ratio at several representative values of the speed coefficient, may also be used to compare the relative merits of various hull forms.

Figures 14 and 15 show the variation of resistance with load for the model free to trim and at best trim, respectively. These curves are more convenient for obtaining the resistance corresponding to a particular load at a given speed than the corresponding curves of figures 4 and 11.

Figure 16 compares directly the resistance and trim during the assumed take-off (shown in figs. 4 and 11) for the model running at best trim and running free to trim. The comparison indicates the considerable decrease in resistance, particularly above the hump speed, resulting from holding the hull at the best trim. Below the hump speed, the moments required to maintain the hull at the best trim are excessive, as may be noted in figure 11, and the hull will necessarily trim much lower with a small increase in the resistance.

Figure 16 also shows the results obtained from the specific test of the model free to trim. The test points are superimposed on the curves of the resistance coefficient and trim derived from the results of the general test (fig. 4) and show a very satisfactory agreement. In the high-speed range, the results of the general test are believed to be more reliable than those of the specific test, principally because the load on the water is more closely controlled. Practically, however, the free-to-trim characteristics in this region are of little importance as it is probable that ample aerodynamic control is available to maintain any desired trim.

The resistance curves for this model take an unusual form at light loads and moderately high speeds. In figure 11 it will be seen that the resistance for the lighter load ($C_\Delta = 0.025$) is greater than that for the heavier load ($C_\Delta = 0.05$) for a small range of speeds. This peculiarity has been noted for another model of generally similar design. (See reference 4.) The higher resistance for the lighter load is probably caused by an increase in the wetted area due to the jet from the main step striking the afterbody; whereas for the heavier load, the afterbody runs clear or nearly clear. This characteristic may be noted for the fixed-trim tests at trims of 7° and 9°. (See figs. 7 and 8.)

The best trim for the model (see fig. 12) is unusually high over the entire speed range, probably as a result of the large effective angle of the afterbody keel. At moderate speeds the curves for best trim cross and the model trims slightly higher for lighter loads. At high speeds the trim for light loads decreases rapidly with increase in speed.

The draft-beam ratio corresponding to the best trim is shown in figure 17. Although these data have little practical use at present because the water surface around the hull is quite different from the free-water surface, still some indication is given of the position occupied by the hull in the water. Knowledge of this position may be useful in connection with stabilizing-float problems.

Spray photographs.- The photographs showing the spray and wave formations produced by the model (fig. 18) indicate that the hull is particularly clean-running at all speeds above the hump. Furthermore, observations during the tests indicated that the spray is not excessive at the hump speed and below. Figures 18 (a) to (c) represent the heavily loaded hull at speeds just beyond the hump speed, where the water-borne load is largely supported by hydrodynamic reaction. Figure 18 (a) shows the high roach which follows the hull but is well clear of the tail surfaces and which is rapidly reduced as the speed is increased. Figures 18 (d) to (f) represent the lightly loaded hull near the hump speed and at moderate speeds in the early planing condition.

Figures 18 (g) to (i) represent the hull near the take-off speed for different gross loads. A comparison of figure 18 (g) with figures 18 (h) and 18 (i) shows, for one load, the clean-running condition at the lower speed, which becomes less clean with higher speeds as the jet from the forebody strikes the afterbody and envelops it with spray. This evidence of increased wetted surface may be associated with the rapid increases in resistance and the overlapping of the resistance curves for light loads at certain speeds as previously noted.

TAKE-OFF COMPARISONS

Any true comparison of the relative merits of hull forms must consider the purpose for which the hull is designed, the conditions under which it must operate, and the technique with which it is to be handled while on the water. Useful information is obtained, however, by comparing the take-off distance and time for hypothetical seaplanes in which hulls for a particular class are used. On this basis, the gross load, wing characteristics, hull weight, and power available are assumed to be the same, respectively, for the various seaplanes under consideration.

The performance of a hypothetical seaplane having the hull of the Calcutta (N.A.C.A. Model 47) is compared with the performance of two similar seaplanes having hulls of the N.A.C.A. Model 26 (reference 5) and of the N.A.C.A. Model 11-A (reference 6) at two values of the gross load. The two hulls used for comparison represent hulls of conventional American types and the performance comparisons give some indication of the relative merits of the three hulls.

The first comparison is made on the basis of a gross load of 20,000 pounds, which represents a load coefficient near that of the actual Calcutta flying boat. The second comparison is for a gross load of 35,000 pounds, which represents a load coefficient nearer that of American practice. The dimensions of the hulls are based on the length-beam product of the Calcutta flying boat (446 square feet based on the length to the second step) so as to base the comparison on hulls of approximately equal weights. The design data assumed for the two loading conditions are as follows:

Gross load, lb.	20,000	35,000
Wing loading, lb./sq.ft. . . .	12	18.5
Power loading, lb./hp. . . .	14	14

A hypothetical elliptically loaded wing of aspect ratio 10 (including the assumed ground effect), which has characteristics as shown in figure 19, is assumed.

The curves of the total resistance, air resistance, and net propeller thrust for the three seaplanes are shown in figures 20 and 21. The take-off distances and times were computed from the usual relations between net accelerating force, speed, and mass. All three seaplanes were assumed to be taken off at a speed 10 percent above the stalling speed by means of a slight pull-up. The values of the wing setting chosen were assumed to be the maximum values permissible from considerations of the air drag at cruising speed for the hypothetical seaplanes.

The take-off performance and pertinent data of the seaplanes for the two assumed initial loads are as follows:

	20,000-lb. load			35,000-lb. load		
Model	47	26	11-A	47	26	11-A
Beam, ft.	9.99	9.85	9.99	9.99	9.85	9.99
Gross-load coefficient.	0.314	0.327	0.314	0.549	0.572	0.549
Wing setting, deg. . .	7-1/2	10	10	7-1/2	10	10
Take-off time, sec. . .	28	27	28	47	43	43
Take-off distance, ft.	1,370	1,410	1,440	2,710	2,740	2,740

This comparison indicates that the Calcutta hull has a slight advantage over the other two hulls with regard to the take-off distance of the seaplane for both light and heavy loads but that the differences in both distance and time are practically negligible.

Langley Memorial Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., December 19, 1936.

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TABLE I

Offsets for N.A.C.A. Model 47 (Short Bros. Calcutta) Flying-Boat Hull (Inches)

Station	Distance from F.P.	A	B	D	E	Radius G	Radius H	Radius J	K	L	Radius M	N	O	Chine half-breadth	Chine above base line	Keel above base line	Buttock dist. from ℄ [1] 1.70 B1	3.40 B2	5.10 B3	6.81 B4
F.P.	0.00	10.96												2,41 radius	10.39	10.39				
OA	.85	12.16	1.93		11.01	See buttocks	0.99		0.00		0.23	0.58	0.38	1.93	9.81	6.29	11.64 9.50 12.46	Deck		
OB	1.99	12.52	2.94		11.07		1.36		1.05		.33	.68	.33	2.94	9.10	4.75	7.54			
1	3.55	12.95	3.81		11.15	2.41	1.65		1.70	8.24	.49	.76	.21	3.89	8.24	3.52	5.76	7.81		
2	5.81	13.42	4.59		11.27	2.40	2.10		2.26	7.27	.67	.82	.10	4.88	7.24	2.44	4.19	6.03		
3	8.79	13.88	5.13		11.42	2.46			2.67	6.41	.78	.84	.04	5.87	6.22	1.60	2.99	4.52	5.78	
4	12.20	14.15	5.52		11.60	2.55			2.96	5.73	.85			6.74	5.38	1.06	2.22	3.51	4.61	
5	15.60	14.33	5.72		11.78	2.55			3.17	5.24	.85			7.38	4.81	.77	1.78	2.90	3.86	4.62
6	19.00	14.51	5.85		11.96	2.55			3.32	4.88	.85			7.87	4.42	.64	1.56	2.55	3.41	3.97
7	22.40	14.69	5.92		12.14	2.55			3.37	4.62	.85			8.21	4.17	.61	1.45	2.35	3.16	3.80
8	25.81	14.87	5.95		12.31	2.55			3.40	4.46	.85			8.42	4.03	.62	1.43	2.28	3.05	3.66
9	29.21	15.04	5.96		12.49	2.55			3.40	4.40	.85			8.50	3.94	.65	1.45	2.28	3.02	3.61
9A	31.62	15.17	5.93		12.48	2.57			3.37	4.41	.85			8.49	3.92	.68	1.47	2.30	3.04	3.60
11	35.63	15.38	5.88		12.73	2.65			3.23	4.54	.85			8.31	3.86	.72	1.50	2.33	3.05	3.60
12, F.	38.75	15.54	5.82		12.77	2.77			3.04	4.76	.85			8.13	3.82	.74	1.53	2.37	3.07	3.59
12, A.	38.75	15.54	5.82		12.77	2.77			3.04	4.76	.85			8.02	4.76	1.30	2.14	3.03	3.82	4.45
13	41.48	15.69	5.75		12.78	2.91			2.84	5.03	.85			7.66	5.05	1.66	2.52	3.43	4.21	4.83
13A	43.82	15.80	5.67		12.76	3.03			2.64	5.31	.85			7.29	5.32	2.01	2.88	3.81	4.60	5.20
15	48.22	16.04	5.52		12.72	3.32			2.20	5.88	.85			6.53	5.87	2.73	3.63	4.58	5.37	
16	51.90	16.23	5.37	9.19	12.66	3.57		4.18	1.80	6.38	.85			5.87	6.31	3.37	4.30	5.27	6.05	
17	55.59	16.42	5.20	9.93	12.58	3.85		4.57	1.35	6,85	.85			5.24	6.72	4.04	4.98	5.94	6.68	
18	59.14	16.61	5.02	10.63	12.51	4.01	4.15	4.91	.98	7.27	.85			4.67	7.08	4.68	5.62	6.55		
19	62.68	16.83	4.82	11.26	12.51	4.11	4.45	5.21	.64	7.65	.85			4.17	7.41	5.30	6.21	7.10		
20	66.23	17.04	4.60	11.79	12.56	4.12	4.72	5.33	.37		.85			3.74	7.70	5.84	6.73	7.56		
21	69.63	17.27	4.37	12.29	12.71	4.03	4.93	5.35	.17		.85			3.37	7.92	6.28	7.15			
22	73.03	17.51	4.13	12.78	12.94	3.85	5.05	5.29	.04		.85			3.21	8.15	6.63	7.48			
23A, F.	76.08	17.74	3.89	13.20	13.25	3.60	5.07	5.18	.00		.85			3.22	8.25	6.75				

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

TABLE I (Continued)

Offsets for N.A.C.A. Model 47 (Short Bros. Calcutta) Flying-Boat Hull (Inches)

Station	Distance from F.P.	A	B	D	E	Radius G	Radius H	Radius J	K	L	Radius M	N	O	Chine half-breadth	Chine above base line	Keel above base line	Buttock dist. from ℄ 1.70 B1	3.40 B2	5.10 B3	6.81 B4
23A, A.	76.08	17.74	3.89	13.20	13.25	3.60	5.07	5.18	.00		0.85			3.19	8.31	6.82	See			
23B	76.84		3.83	13.31				5.14			.94					7.38	table			
23C	77.69		3.76	13.44				5.10			1.04					7.86	below			
24	79.40	18.00	3.62	13.68		3.27		5.01			1.26					8.61	9.34			
25	82.85	18.29	3.32	14.24		2.96		4.79			3.11					9.81	10.58			
26	86.31	18.63	3.01	14.84		2.63		4.52								10.95	11.66			
26A	89.27	18.88	2.72	15.40		2.34		4.23								11.91	12.65			
28	93.17	19.26	2.28	16.26		1.92		3.72								13.26				
28A	95.51	19.51	1.99	16.85		1.66		3.33								14.19				
30	98.27	19.79	1.57	17.65		1.28		2.72								15.51				
31	99.97	19.94	1.24	18.22		1.00		2.20								16.51				
32	101.25	19.98	.92	18.69		.73		1.66								17.41				
A.P.	102.95	19.37	.00	19.37		.00		.00								19.37				

Additional Buttock Heights for Second Step and Fairing

Station	Buttock distance from ℄ 0.43	0.85	1.28	1.70	2.13	2.34	2.55	2.77	2.98
23A, F.	6.86	7.09	7.34	7.57	7.79	7.89	7.99	8.08	8.16
23A, A.	6.94	7.18	7.42	7.66	7.88	7.98	8.07	8.16	8.24
23B	7.49	7.71	7.95	8.21	8.47	8.59	9.00	9.71	10.36
23C	7.96	8.14	8.37	8.64	8.98	9.28	9.70	10.20	10.66

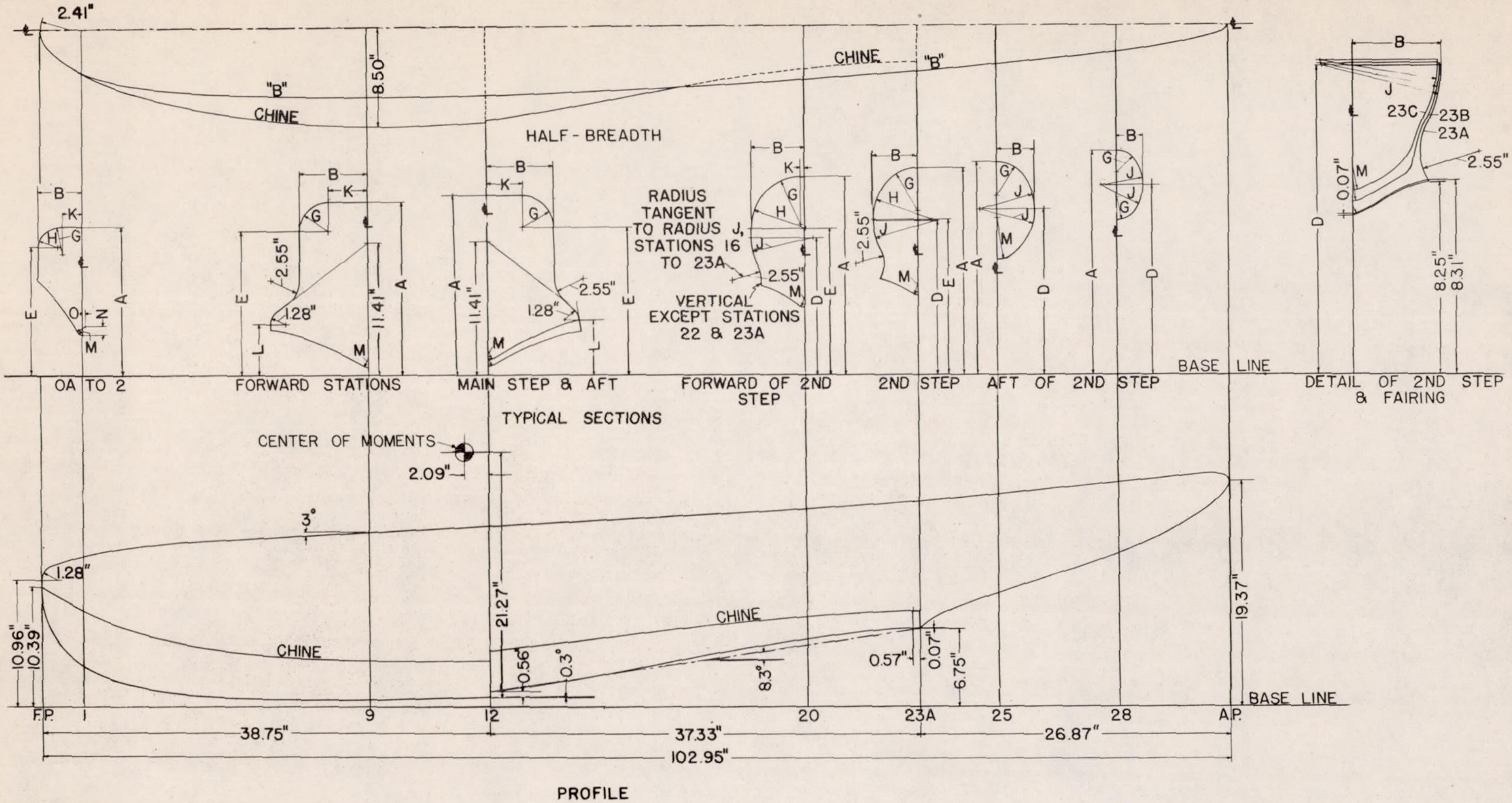


Figure 1. Lines of N.A.C.A. model 47 (Short Bros. Calcutta)

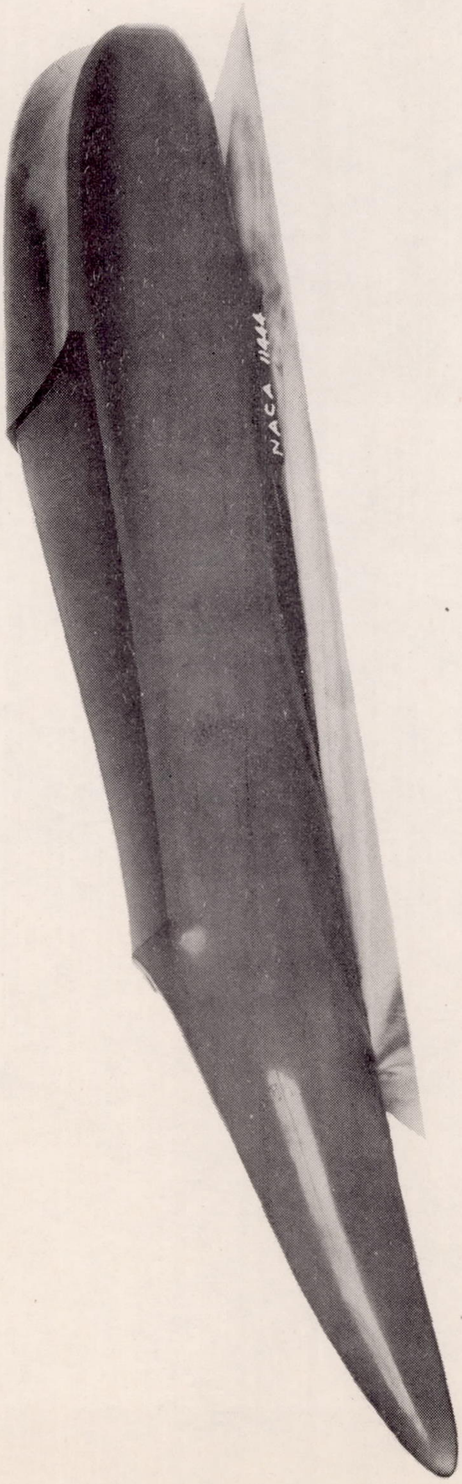


Figure 2.- N.A.C.A. model 47 as tested in the tank

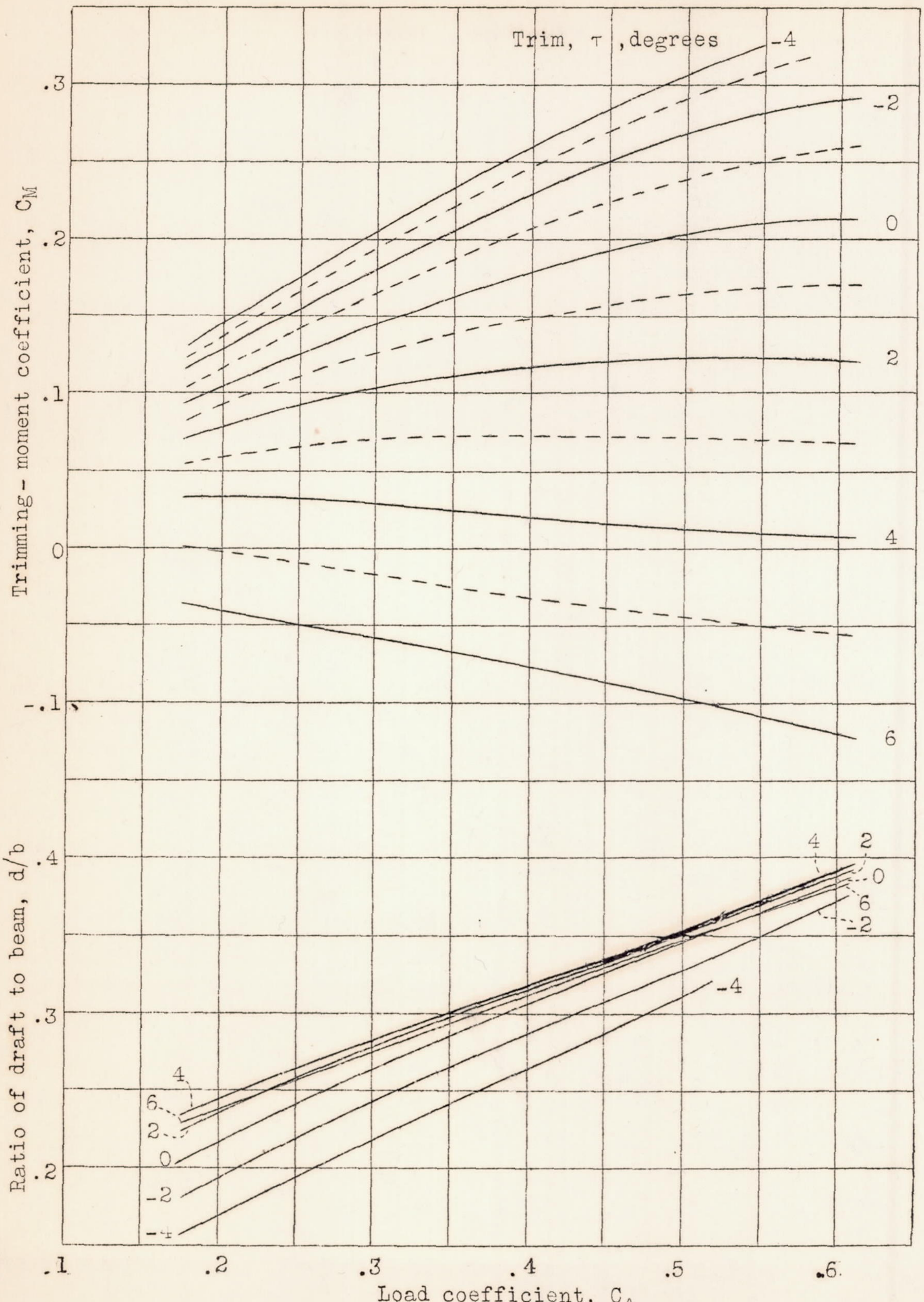


Figure 3.- Trimmimg- moment coefficient and draft- beam ratio, at rest. N.A.C.A. model 47

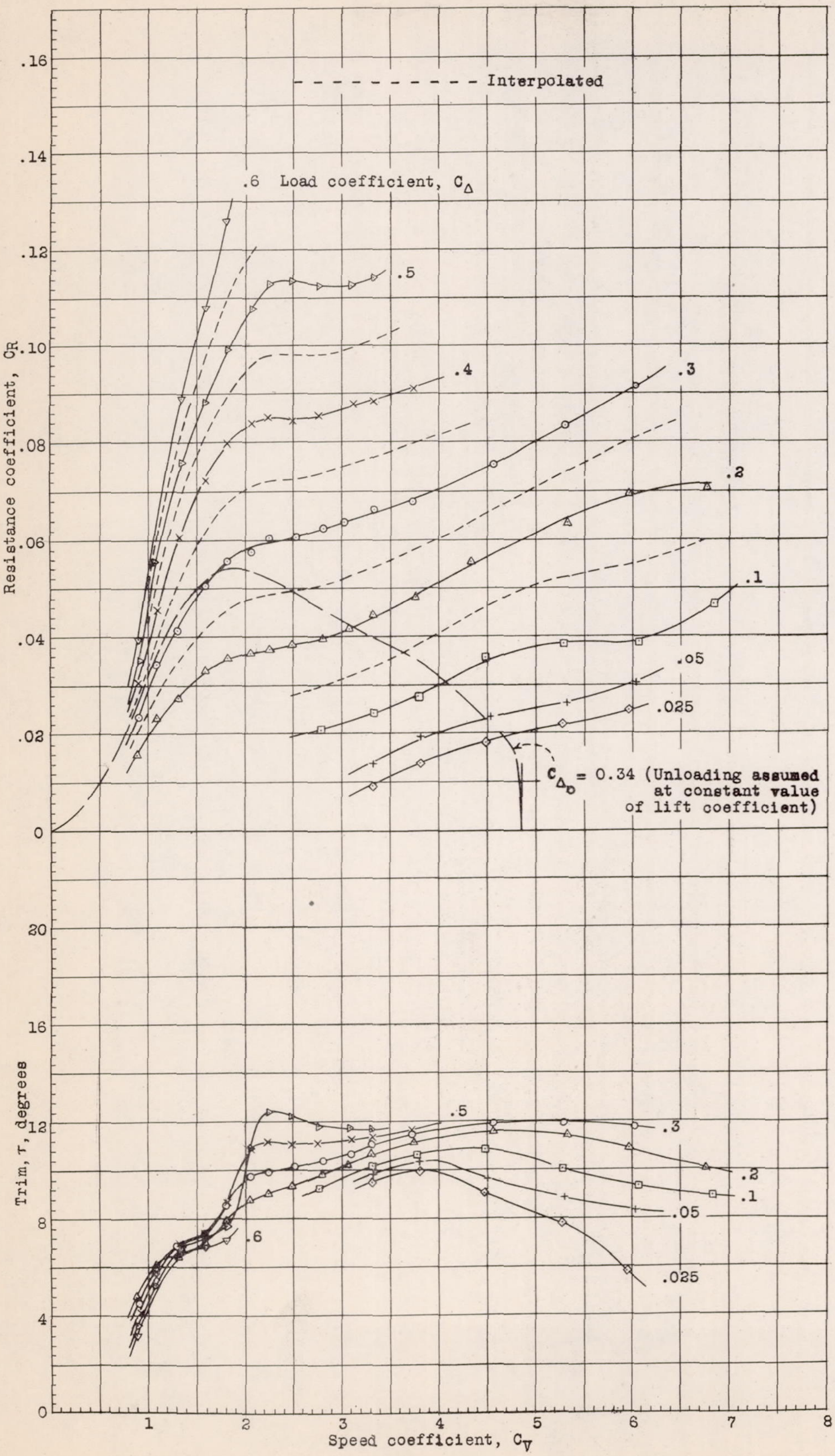


Figure 4. Resistance coefficient and trim, free to trim. N.A.C.A. model 47

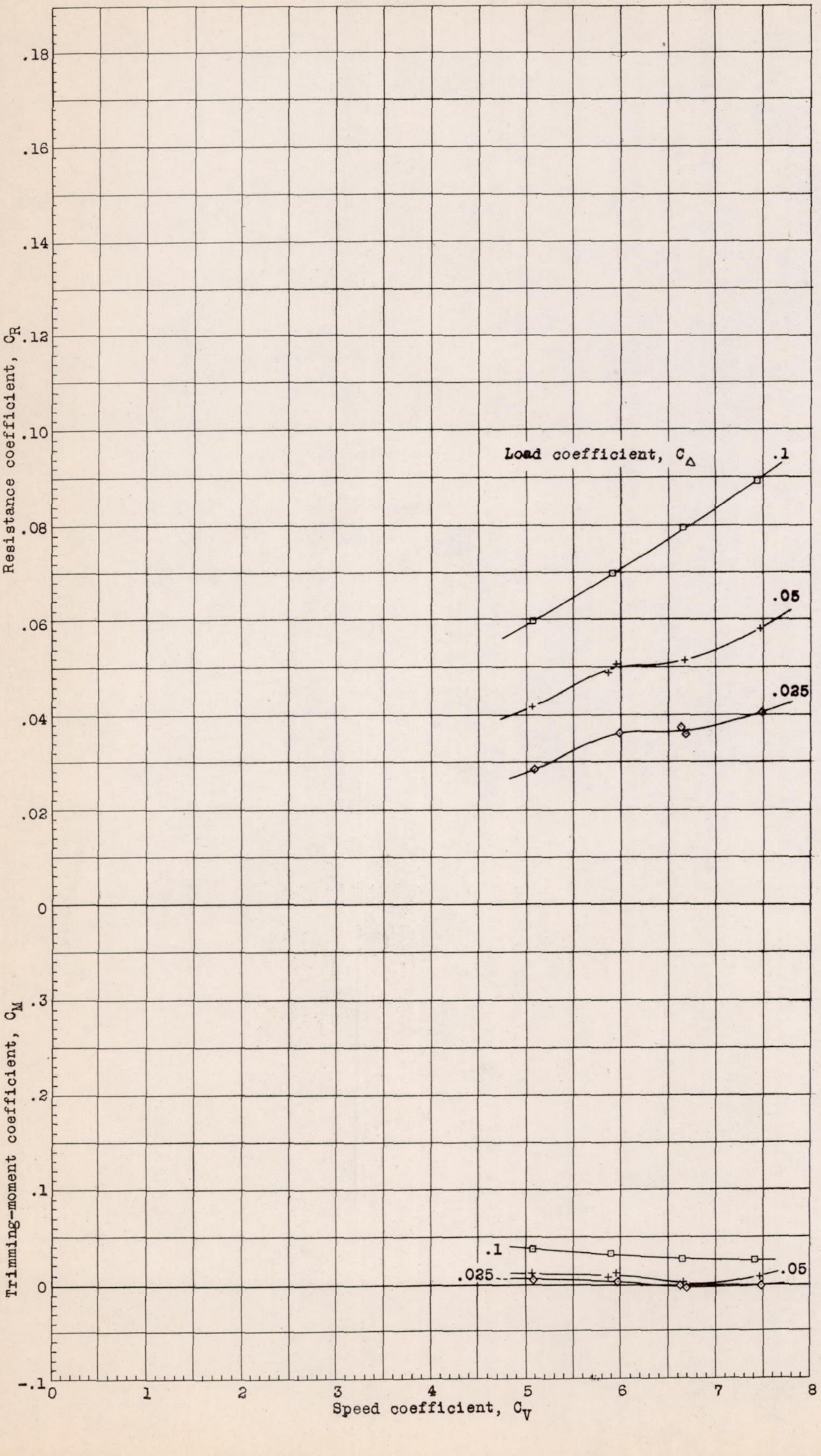


Figure 5. Resistance and trimming-moment coefficients, $\tau = 3^\circ$. N.A.C.A. model 47

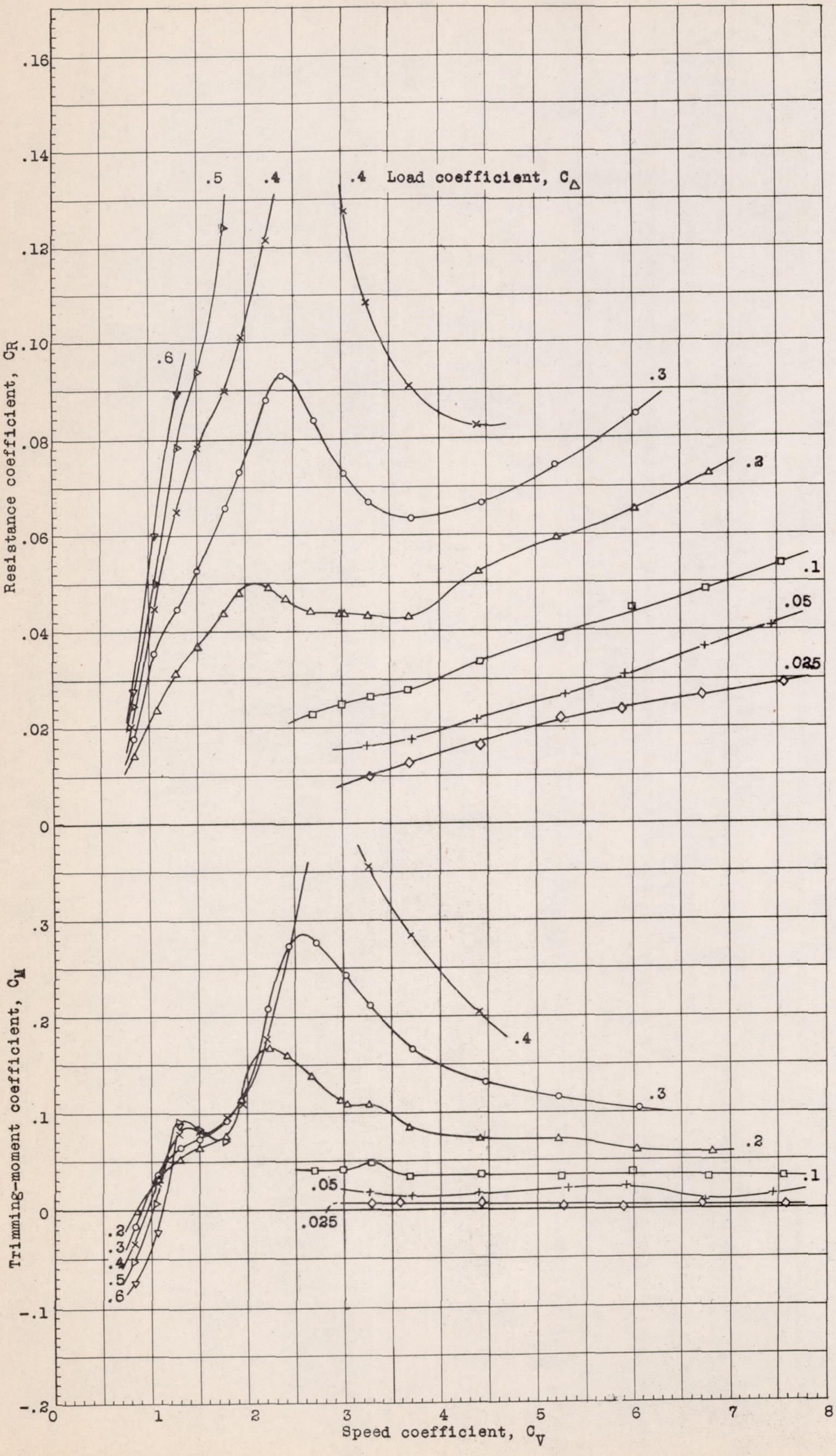


Figure 6. Resistance and trimming-moment coefficients, $\tau = 5^{\circ}$. N.A.C.A. model 47

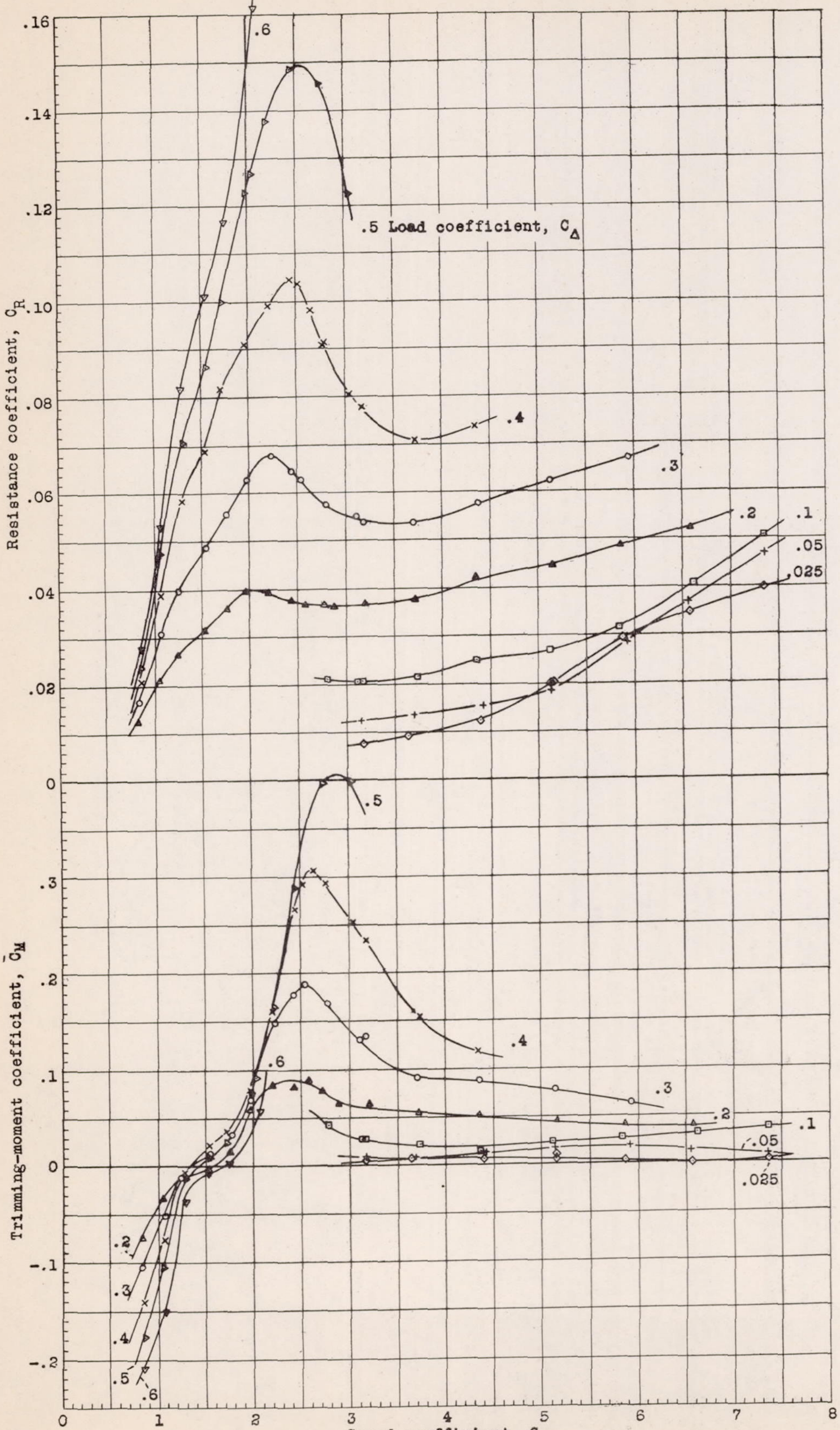


Figure 7. Resistance and trimming-moment coefficients, $\tau = 7^{\circ}$. N.A.C.A. model 47

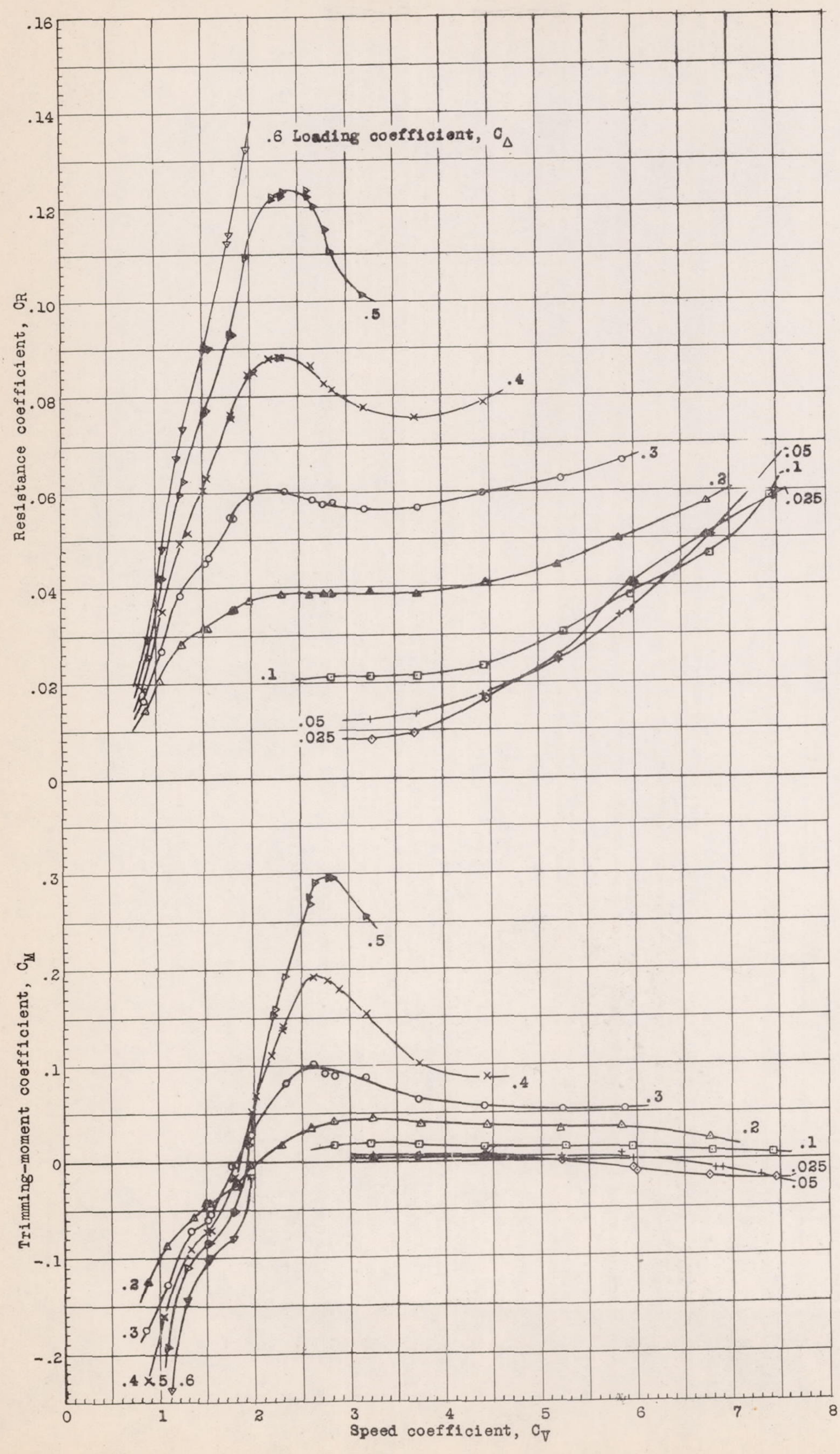


Figure 8. Resistance and trimming-moment coefficients. N.A.C.A. model 47. $\tau = 9^\circ$

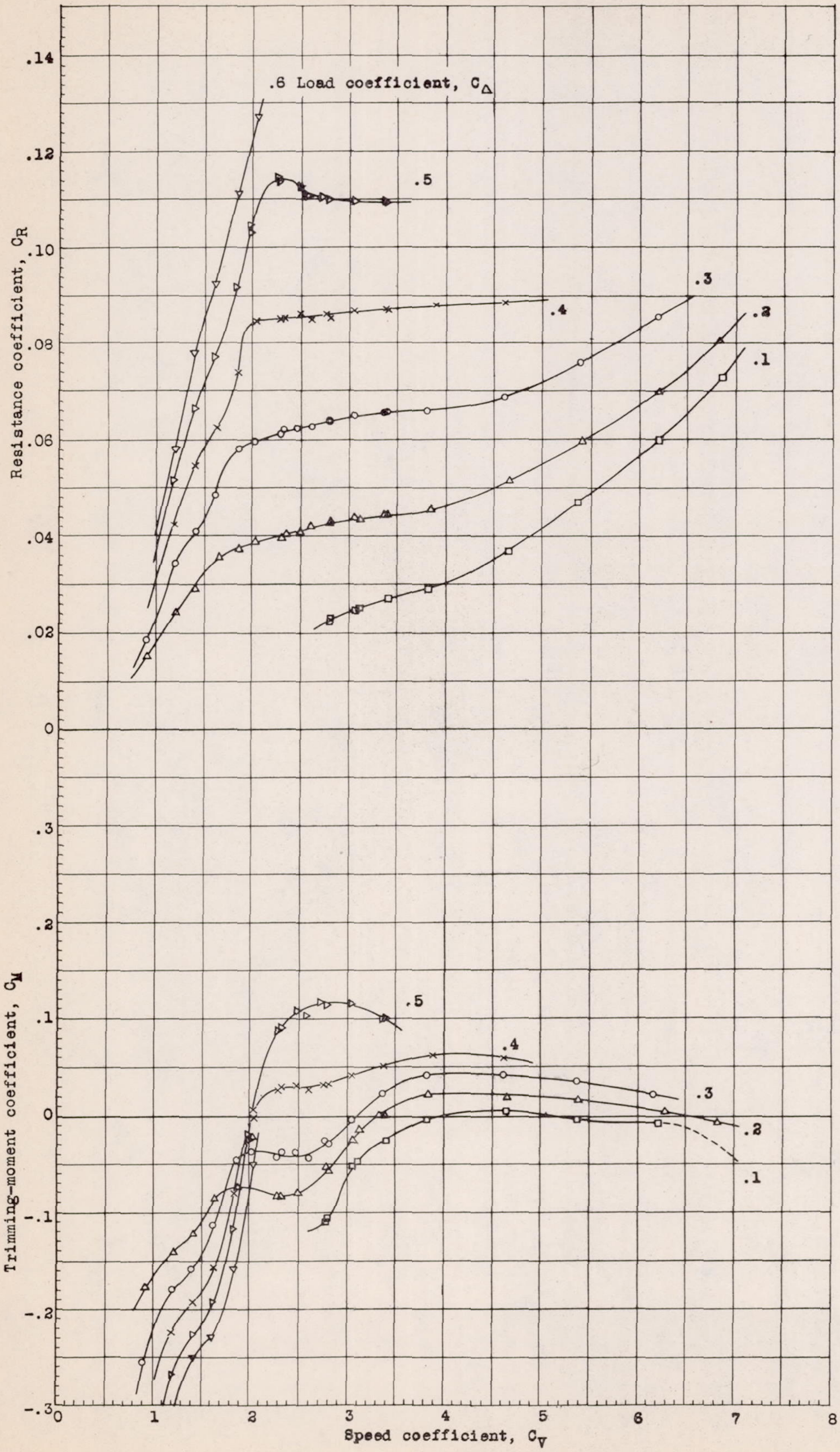


Figure 9. Resistance and trimming-moment coefficients, $\tau = 11^\circ$. N.A.C.A. model 47

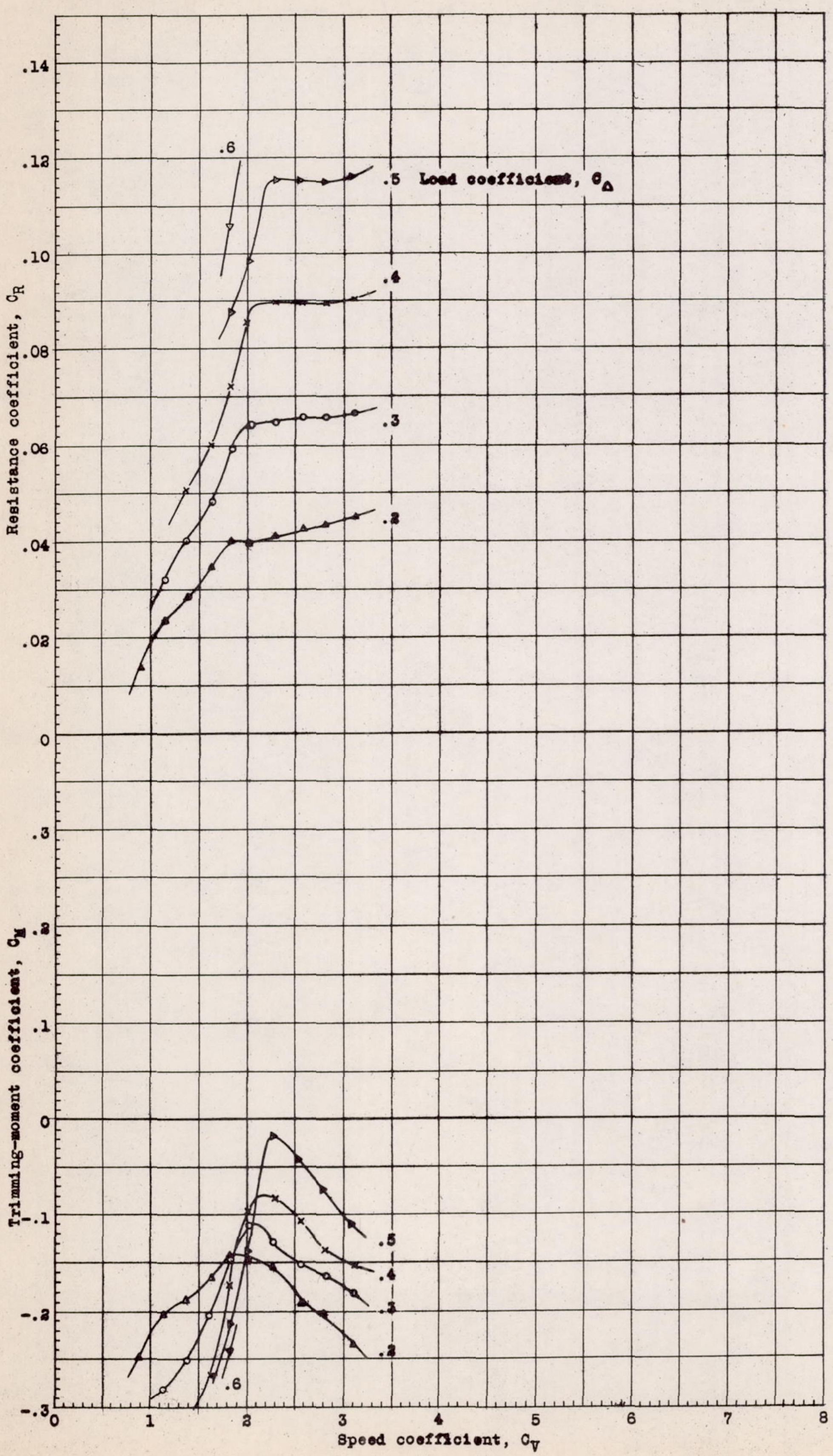


Figure 10. Resistance and trimming-moment coefficients. N.A.C.A. model 47. $\tau = 13^\circ$

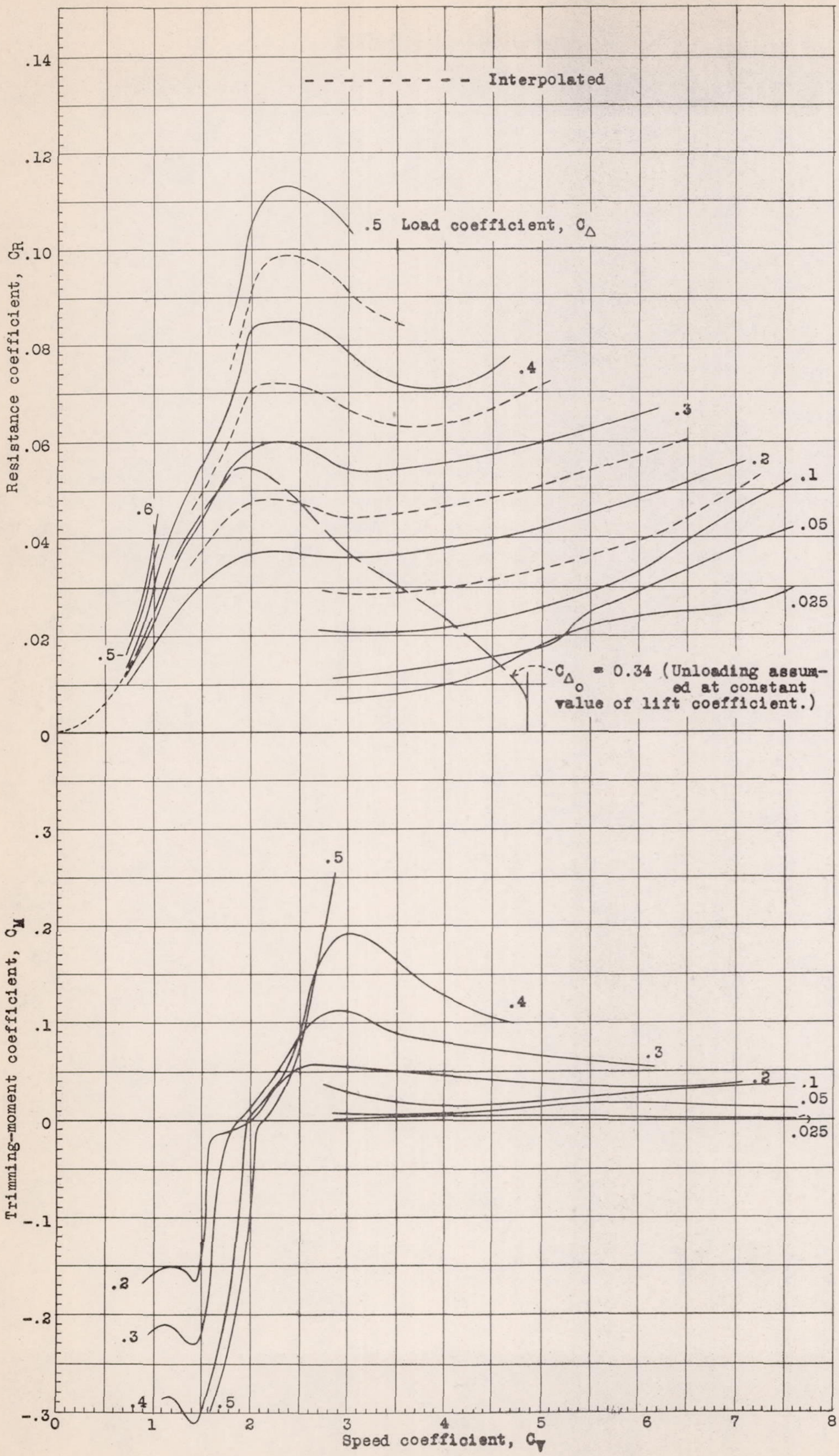


Figure 11. Resistance and trimming-moment coefficients at best trim. N.A.C.A. model 47

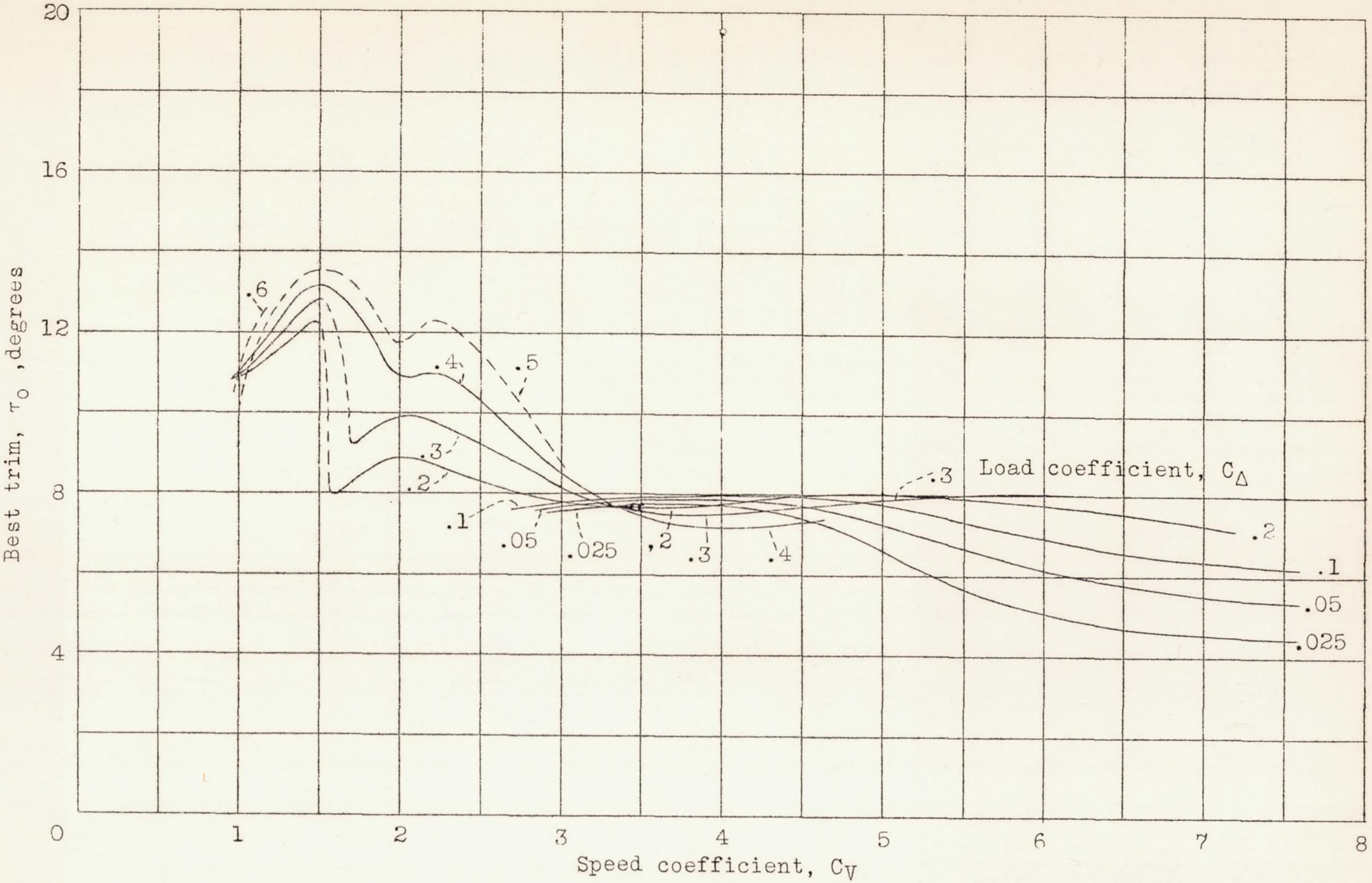


Figure 12.- Best trim (trim for minimum resistance). N.A.C.A. model 47

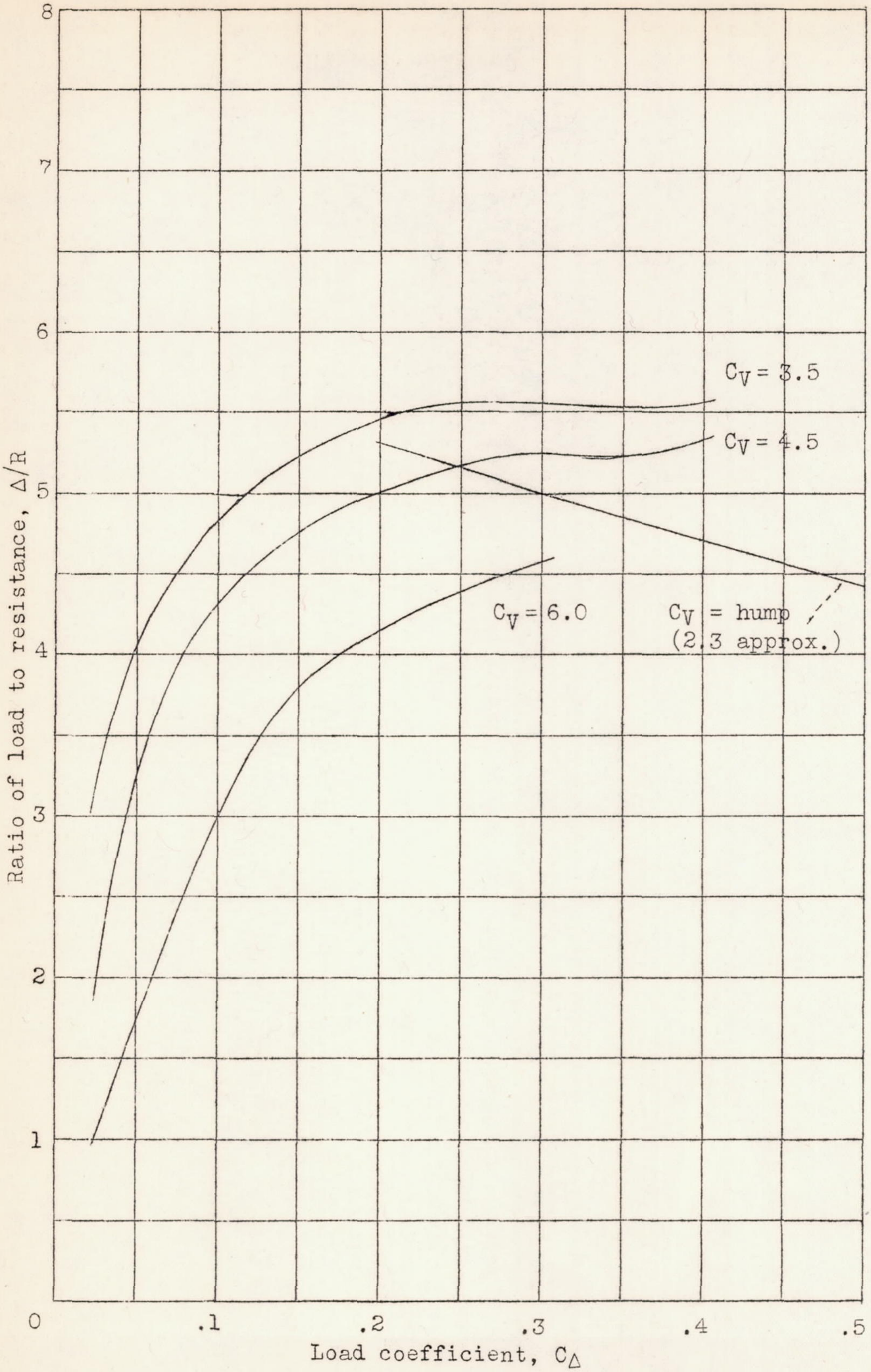


Figure 13.- Load-resistance ratio at best trim. N.A.C.A. model 47.

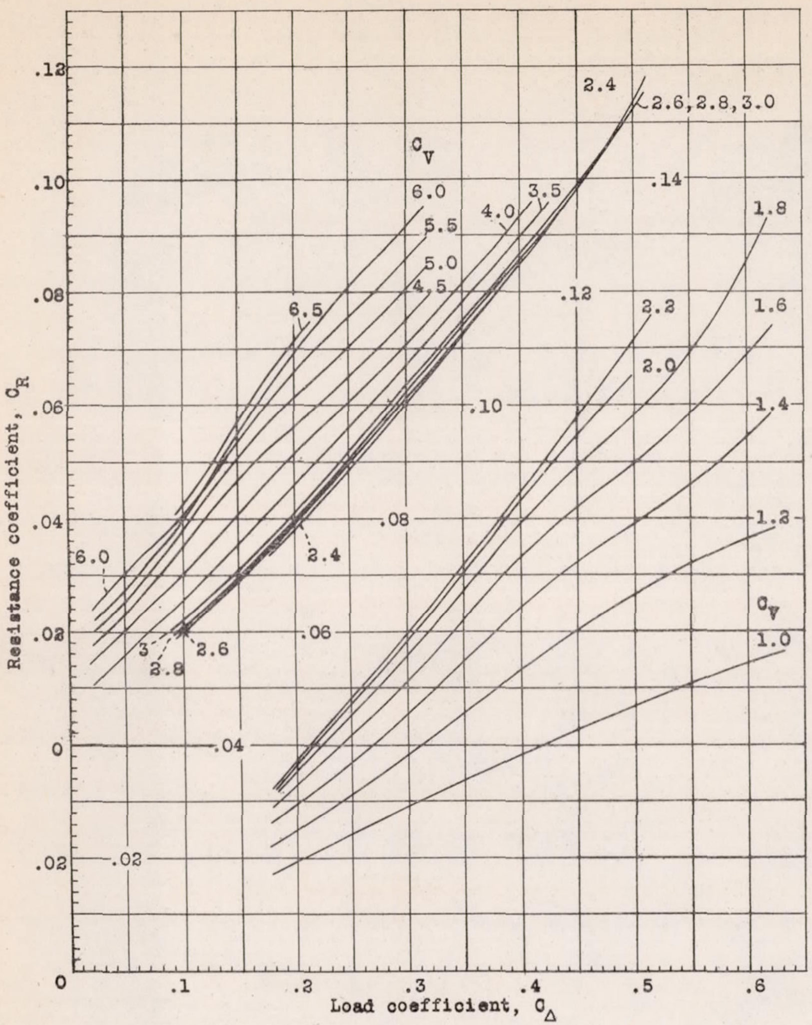


Figure 14.- Variation of resistance with load, free to trim. N.A.C.A. model 47.

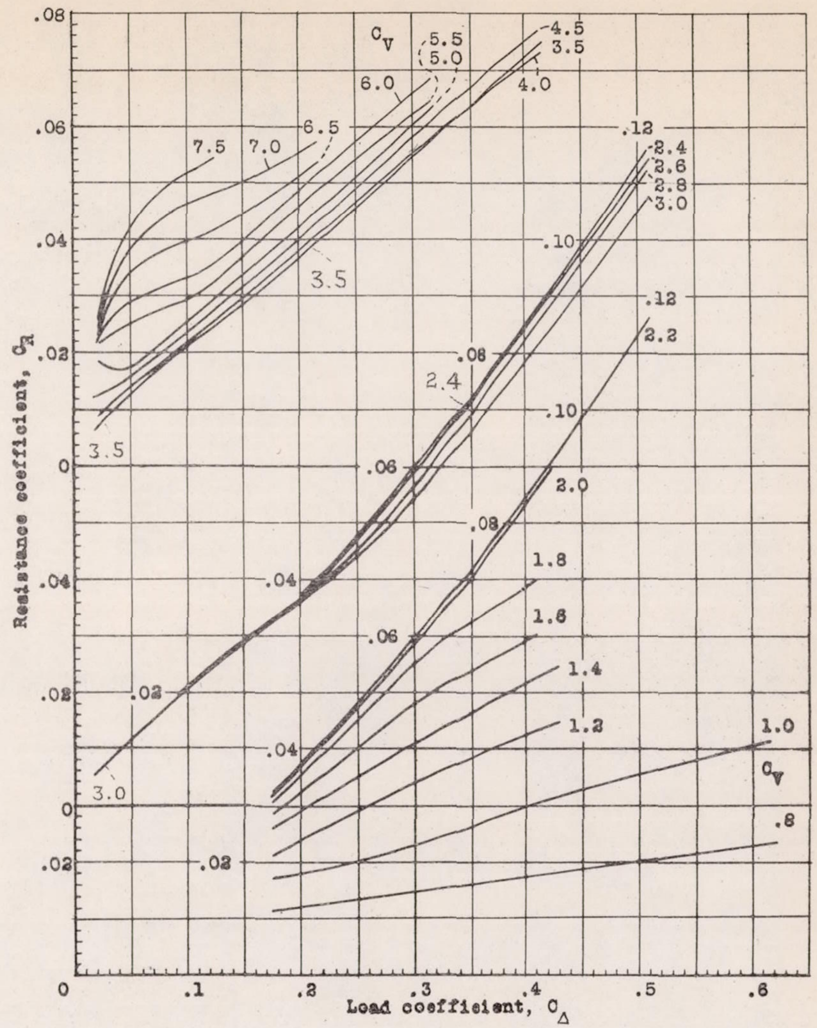


Figure 15.- Variation of resistance with load at best trim. N.A.C.A. model 47.

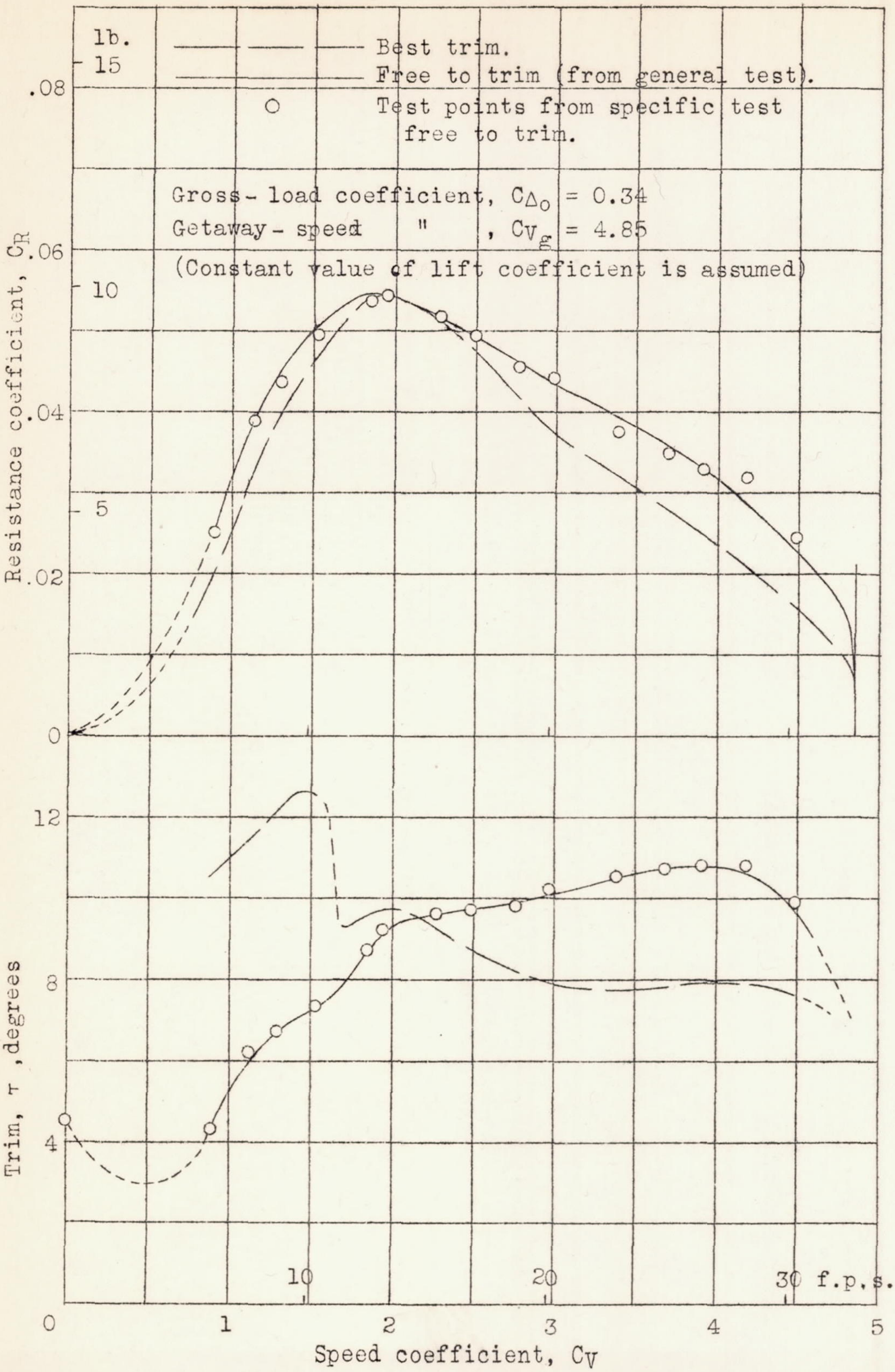


Figure 16.- Comparison of resistance and trim during take-off for model at best trim and free to trim. N.A.C.A. model 47.

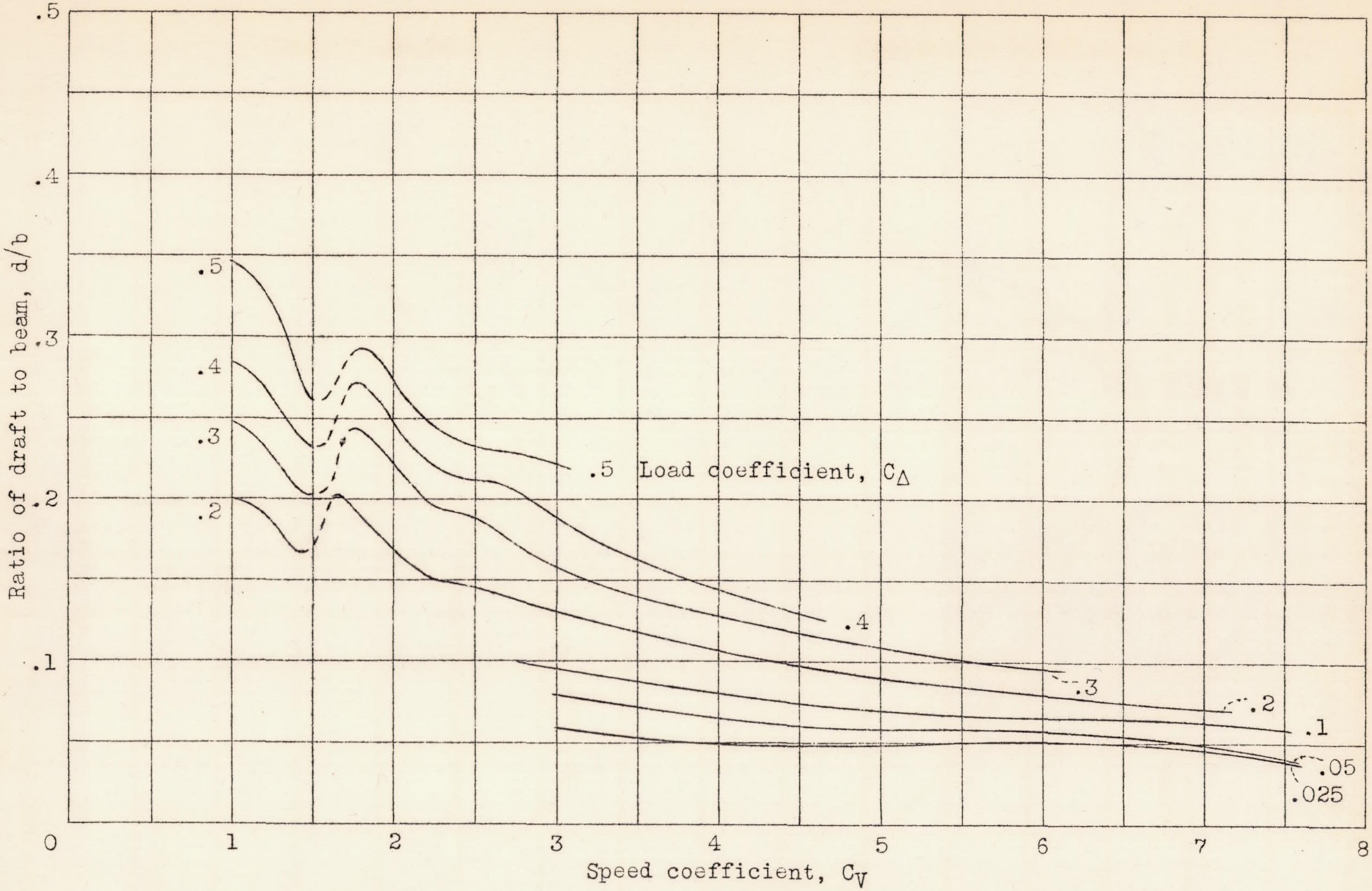
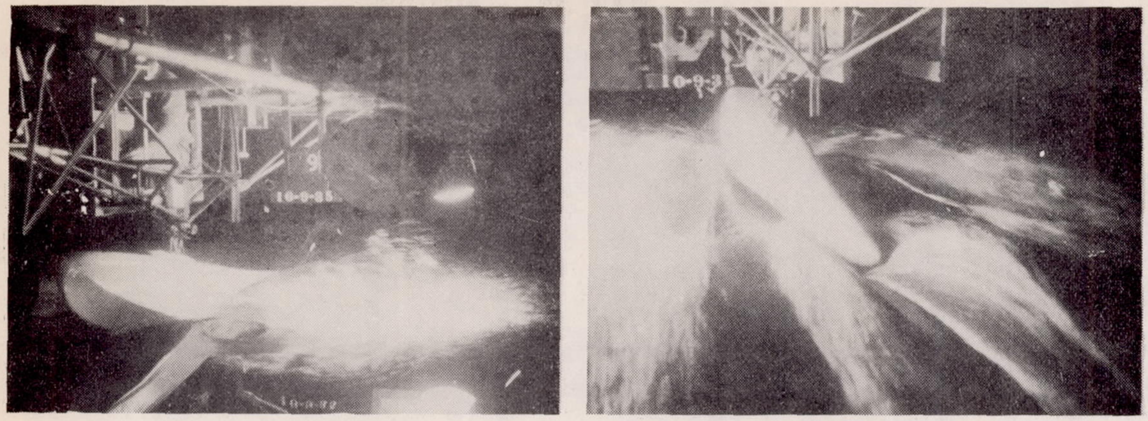
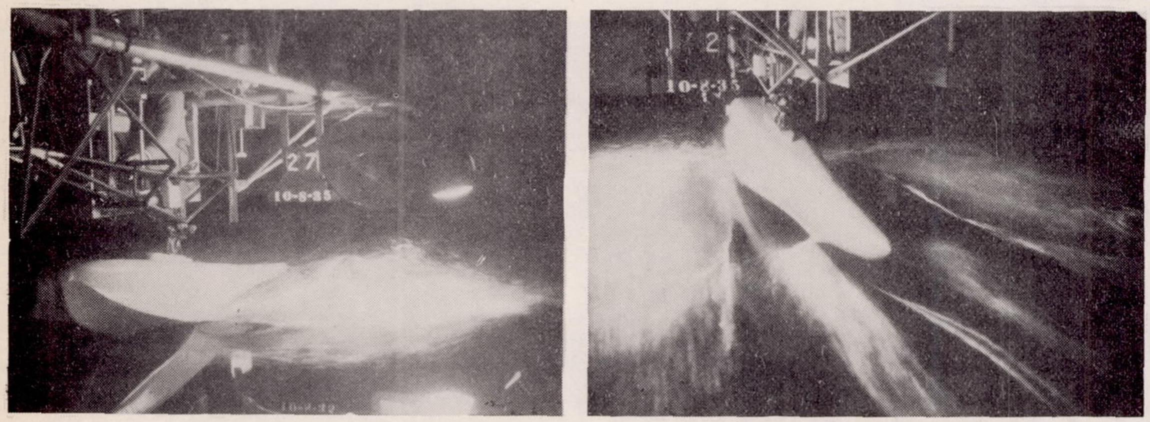


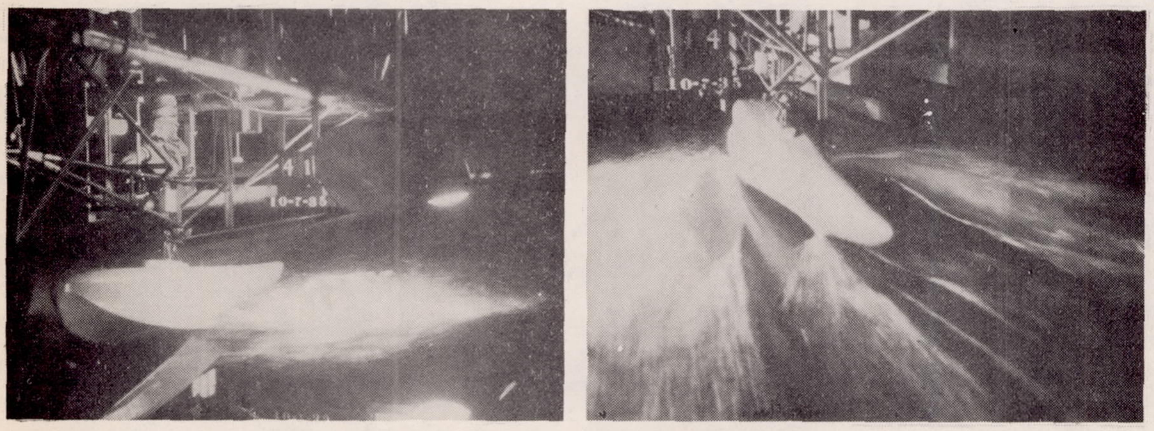
Figure 17.- Draft- beam ratio at best trim. N.A.C.A. model 47



(a) $C_\Delta = 0.5$; $C_V = 2.29$; $\tau = 13^\circ$

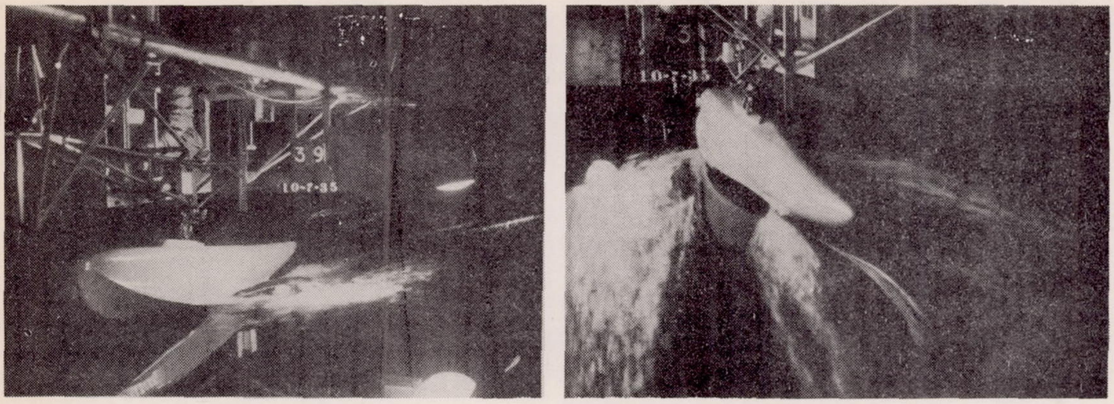


(b) $C_\Delta = 0.5$; $C_V = 2.73$; $\tau = 11^\circ$

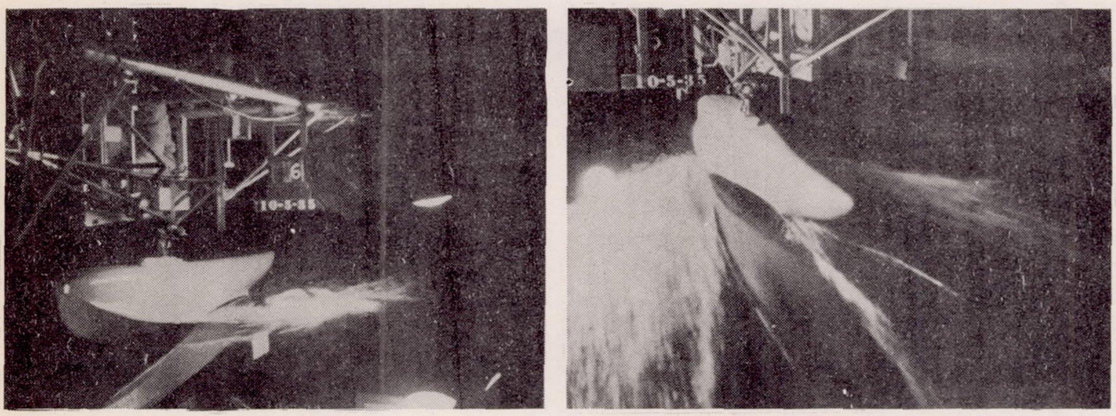


(c) $C_\Delta = 0.4$; $C_V = 3.84$; $\tau = 9^\circ$

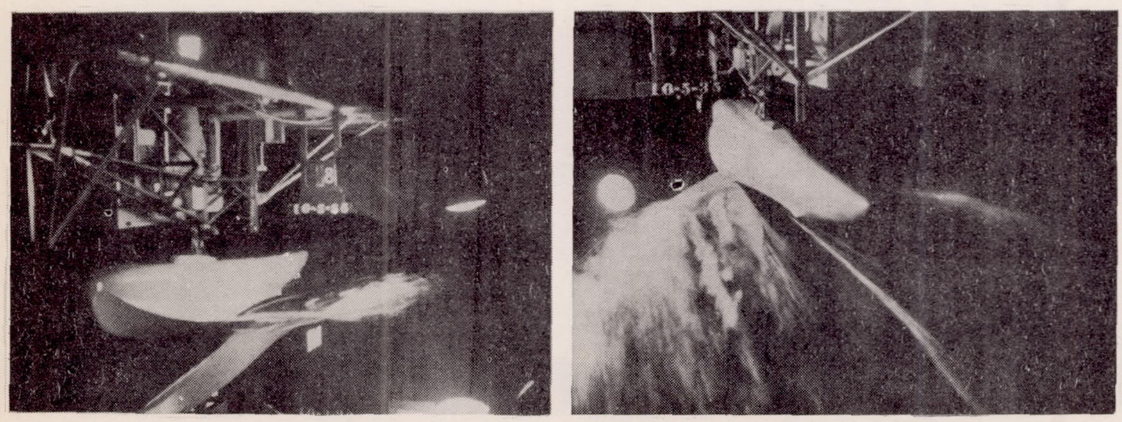
Figure 18. Spray photographs. N.A.C.A. model 47.
(Continued on following pages).



(d) $C_\Delta = 0.2$; $C_V = 1.95$; $\tau = 9^\circ$

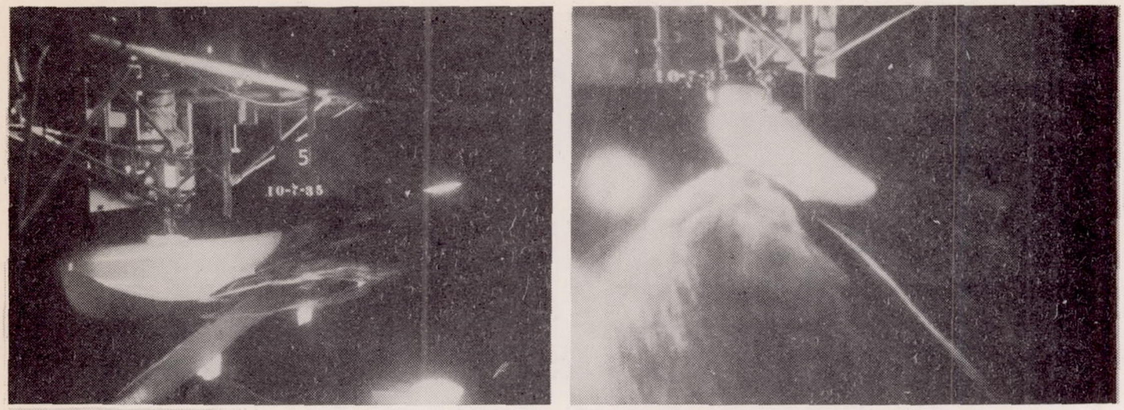


(e) $C_\Delta = 0.2$; $C_V = 2.58$; $\tau = 7^\circ$

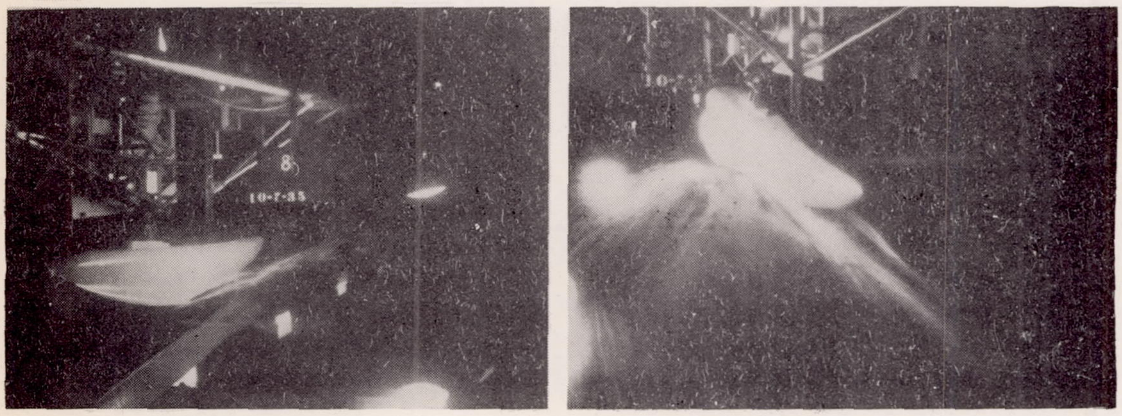


(f) $C_\Delta = 0.1$; $C_V = 3.13$; $\tau = 7^\circ$

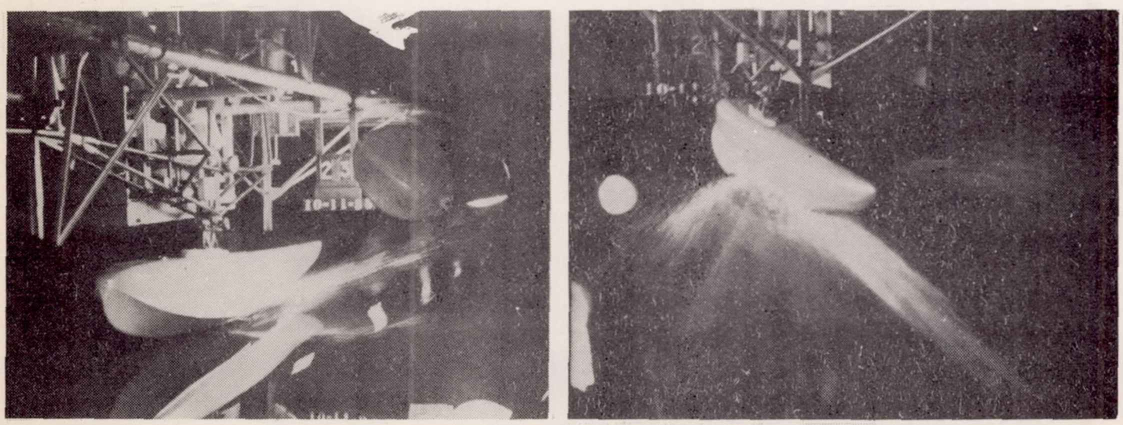
Continuation of figure 18



(g) $C_\Delta = 0.025$; $C_V = 3.17$; $\tau = 7^\circ$



(h) $C_\Delta = 0.025$; $C_V = 4.40$; $\tau = 7^\circ$



(i) $C_\Delta = 0.025$; $C_V = 5.95$; $\tau = 5.8^\circ$

Continuation of figure 18

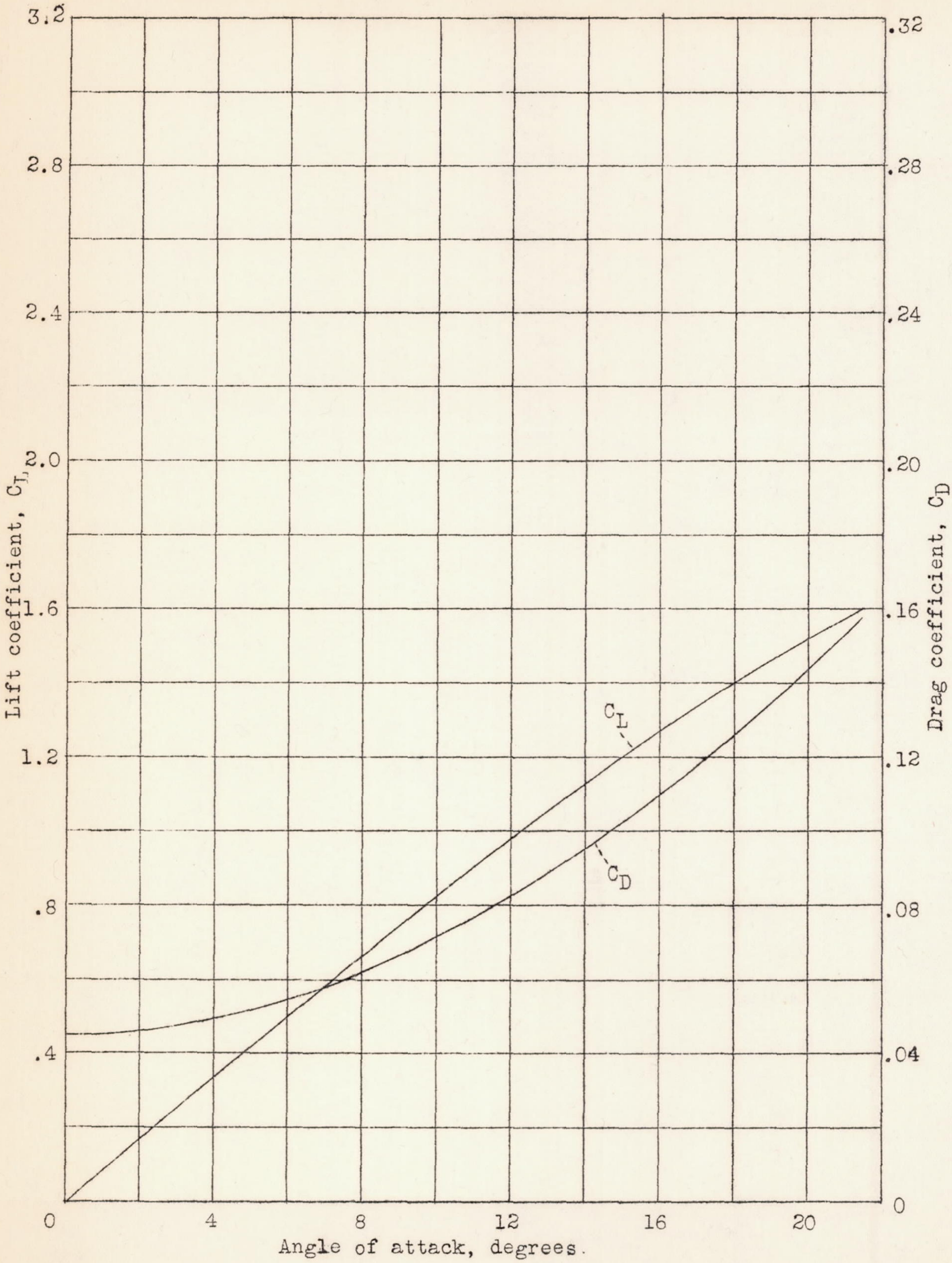


Figure 19.- Lift and drag coefficients for assumed wing.

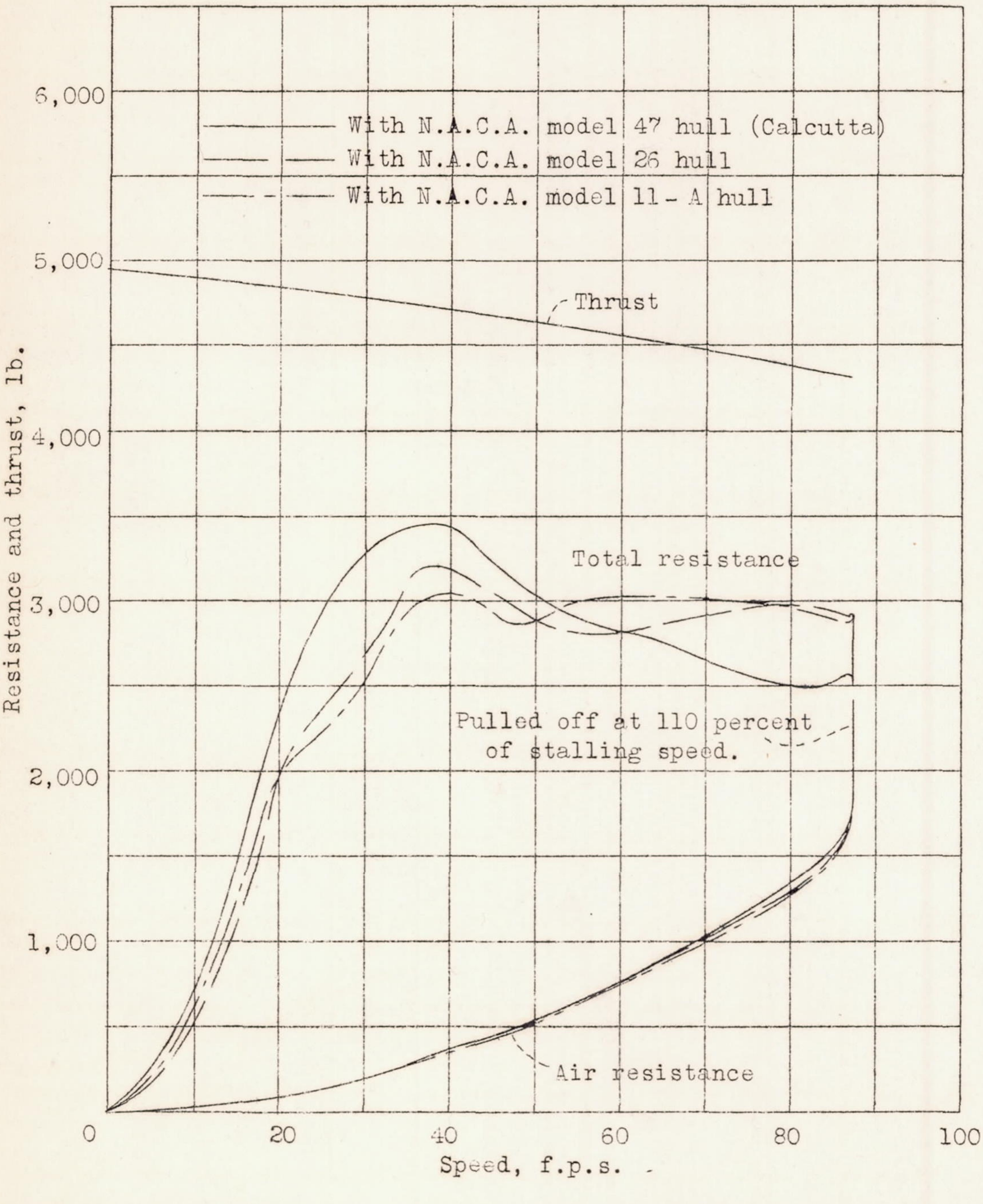


Figure 20.- Resistance and thrust for take-off with 20,000 lb. load.

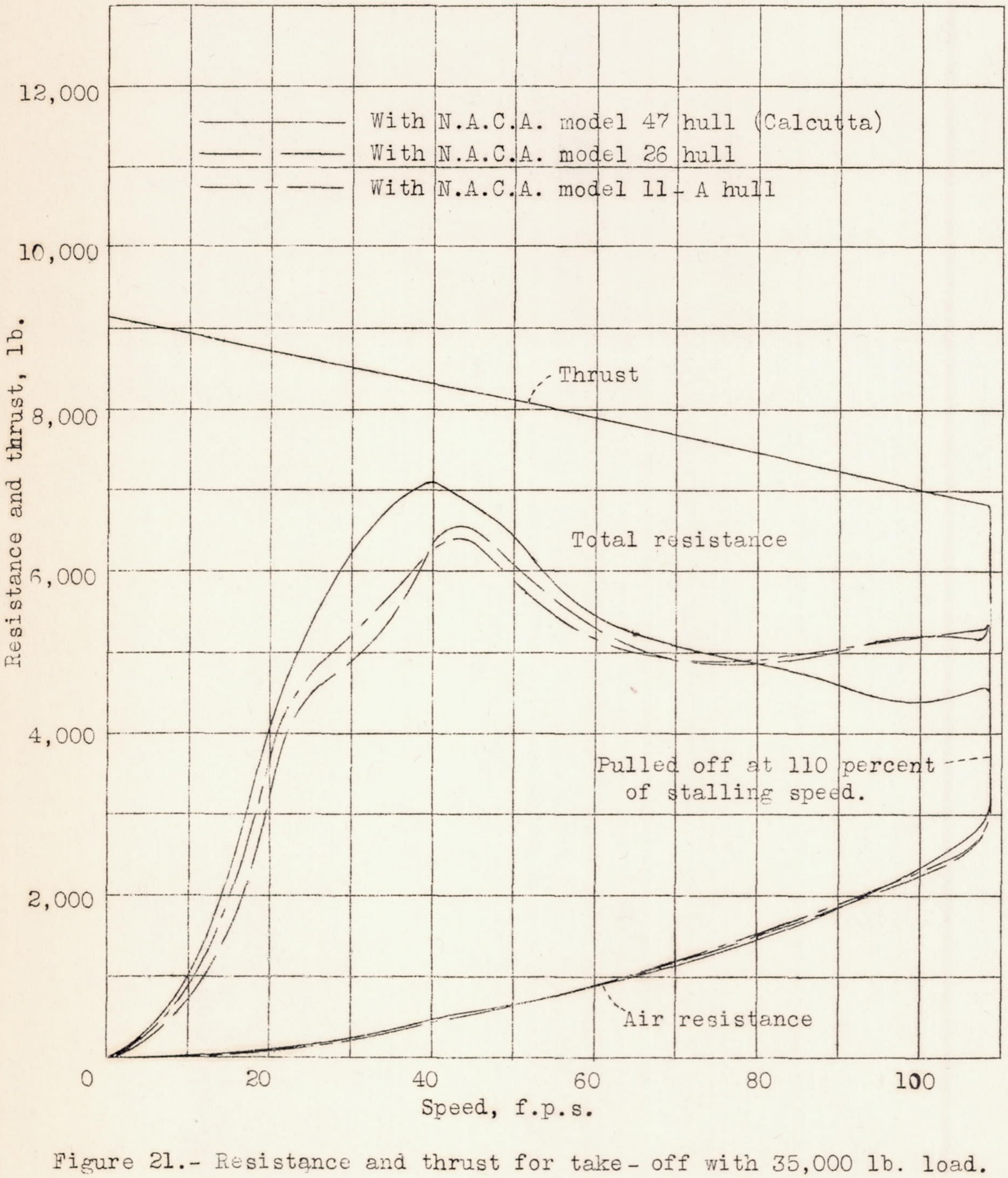


Figure 21.- Resistance and thrust for take-off with 35,000 lb. load.