TECHNICAL NOTES

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

No. 525

THE AERODYNAMIC DRAG OF FLYING-BOAT HULL MODELS AS MEASURED IN THE N.A.C.A. 20-FOOT WIND TUNNEL - I

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SUMMARY

Measurements of aerodynamic drag have been made in the 20-foot wind tunnel on a representative group of 11 flying-boat hull models. The models were originally constructed for the N.A.C.A. tank and the results of tank tests on 9 of them have already been published.

Four of the models were modified to investigate the effect of variations in over-all height, contour of deck, depth of step, angle of afterbody keel, and the addition of spray strips and windshields.

The results of these tests, which cover a pitch-angle range from -5° to 10°, are presented in a form suitable for use in performance calculations and for design purposes.

INTRODUCTION

The scarcity of aerodynamic drag data on flying-boat hulls has been brought to the attention of the N.A.C.A. through repeated requests for such data. At the present time practically all of the data on the aerodynamic characteristics of flying-boat hull models that have been published are to be found in reference 1. The tests reported therein were made on models of which the greatest number are at present obsolete and of which the dimensions were less than one half those of the models in the present tests.

The present tests were greatly facilitated by using the models that had been constructed for hydrodynamic research in the N.A.C.A. tank. These models formed a representative group of recent hull lines and were of such size as to permit a Reynolds Number (based on hull length) of about 7,500,000 to be obtained.

The main purpose of this investigation is to make available to the designer useful information with regard to the aerodynamic drag of various types of flying-boat hull models. The present report is the first in a series covering an investigation in this field. Through close cooperation between the hydrodynamics and aerodynamics divisions it is hoped that results leading to improvements in hull design may be obtained.

As the air characteristics of a flying-boat hull will be most useful to the designer when supplemented by tank data, a list of the N.A.C.A. publications in which the water characteristics of all the hulls in the present study that have thus far been tank-tested is given below.

Model no.	Publication
11-A	T.N. 470
16	T.N. 471
18	T.N. 482
14	T.N. 491
35	T.N. 504
22-A	T.N. 504
26	T.N. 512
1	T.R. 470
1	T.R. 503

APPARATUS AND METHODS

Models.- The body lines and dimensions of the models investigated in this report are given in figures 1 and 2 and 4 to 12, and in table I, the identifying numbers being the same as those used in the reports of the tank tests. The models were made of mahogany; the surfaces were smooth and painted.

Seven of the models were built with flat plywood-covered decks. This construction was considerably less costly than one with a normal superstructure and facilitated testing in the tank but, unfortunately for the present tests, these models bore little aerodynamic resemblance to normal hulls with nicely rounded deck corners.

The possibility was considered of fitting rounded decks on 3 of the flat-decked models and from tests on these 3 predicting what the effect of the rounding would be on the other 4. The drag of a hull will vary somewhat with the curvature of the rounded deck but it was thought that most of the benefit of a fully rounded deck could be obtained by merely giving the corners a generous radius of curvature. A detachable rounded-deck layer having a corner radius and thickness equal to one quarter of the beam at each station was therefore made for models 11-A, 26, and 35. In figures 2, 8, and 9 the rounded-deck layer is shown by broken lines. The solid lines in all of the figures except figure 20(a) indicate the lines of the original models.

Other structural modifications made to models 35 and 11-A consisted of cutting them down to the minimum height possible without cutting through the chines and then rebuilding them with a number of detachable flat layers, each $1\frac{1}{2}$ inches in thickness. This construction enabled the determination of the variation of hull drag with hull height. One of the flat layers is shown by broken lines in figures 2 and 9. The amount that the original models were cut down is not indicated in the drawings.

As received, the decks of all the flat-decked models were covered with 5/16-inch plywood and rounded at the corners to about 1/4-inch radius. The discrepancy between the heights indicated in the figures and in table I is accounted for by the thickness of this plywood layer, not shown in the figures, with which all of the flat-decked models were tested.

The flat-decked model 11-A was made in two main parts, the forebody and afterbody, separable at the main step. Variations in depth of step were obtained by shifting the forebody up or down relative to the afterbody, and variations in angle of afterbody keel were obtained by inserting wedges between the two sections. In both cases the deck was built up to avoid irregularities.

Model 35 was further modified to permit the determination of the effect of both the ordinary and undercut types of windshield. These modifications (shown in fig. 20(a)) were made by cutting down the foredeck and building up the windshields with plasticine.

Apparatus.- The tests were made in the 20-foot tunnel described in reference 2. The models were mounted in an inverted position on a strut as shown in figure 3 and the changes in angle of pitch were obtained by rotating the model about a horizontal bar to which the vertical strut was attached.

All of the supporting structure except a short portion of the supporting strut was totally enclosed by fairing and the system was electrified to detect any fouling of the fairing with the active supports.

Methods.- The models were tested through a pitch-angle range from -5° to 10° at intervals of $2\frac{1}{2}^\circ$, measured from the straight part of the deck center line. Drag readings were taken at seven or more air speeds ranging from 45 miles per hour to somewhat more than 100 miles per hour and were plotted against dynamic pressure q for each angle of pitch. The values of gross drag at a dynamic pressure corresponding to a velocity of 100 miles per hour in standard air were taken from these plots and, after making tare and horizontal-buoyancy corrections, the net drags thus obtained were converted to coefficient form and plotted against the angle of pitch.

The tare drag was determined at each angle of pitch by supporting the model on the balance with an alternate set of struts and making drag tests with and without the normal supporting strut. The tare drag thus obtained amounted to about 22 percent of the average minimum drag of the models.

A horizontal-buoyancy correction was necessary since in the portion of the tunnel jet where the models were tested there exists a static-pressure gradient in the direction parallel to the air flow. The correction was found to be about 8 percent of the minimum drag of each hull model.

The drag coefficient given in all the figures of this report, $C_D = \text{drag}/qA$, is based on the maximum cross-sectional area of the model. A coefficient based on the two-thirds power of the volume might have been equally suitable and for this reason table I gives, in addition to the major dimensions, the volume of each hull model and its minimum drag coefficient $C_{D_{V^{2/3}}}$ based on $(\text{volume})^{2/3}$.

PRECISION

The balance system was calibrated during the period when these tests were being made and it was found to be accurate to 0.05 pound in the range of drag values encountered in the hull-model tests.

The plots of gross drag against q showed few points removed more than 0.10 pound from the mean line and, after considering the possibility of other minor errors peculiar to wind-tunnel testing, it is believed that in the range of minimum drag the tests are accurate to ±0.15 pound, or about ±5 percent. This percentage accuracy may also be assumed as holding for the higher angles of pitch.

RESULTS AND DISCUSSION

The results of the present tests are presented in figures 13 to 23 and in table I. Figure 13 shows the drag curves for all the models with rounded decks and figure 14 shows the curves for three flat-decked models. The drag curve of model 44, one of the NC class, is notable because of its low value of minimum drag and because of the angle at which the minimum occurs. It must be remembered, however, that flying boats using the form of model 44 require either a hull extension, or booms, to carry the tail surfaces, the drag of which must be added to the drag of the hull for a true comparison with the drag of other hulls.

Models 11-A and 26, which have the most favorable drag characteristics of any of the hulls tested, have vertical sides. Model 35 also has vertical sides but, like model 22-A, it has a pointed step that seems to have a higher drag than the usual transverse step.

Effect of height.- The relation between drag coefficient and over-all height of hull is shown in figures 15 and 16. These results were obtained by adding flat-deck layers to the models and testing with and without the rounded-deck layer. The curves in figures 15 and 16 indicate, as one would expect, that the drag coefficient decreases with increase in the height of hull. It is to be noted that, although the coefficient decreases with height, the drag actually increases.

Effect of rounded deck.- Figures 17, 18, and 19 indicate the benefit derived from a rounded deck. The differences between the drag coefficients of the three hull models with and without rounded decks are exaggerated by the disproportion between the height of the three models with and without the rounded deck. With the data in figures 15 and 16 it is possible to estimate a height correction that will put the curves on a comparable basis. Such a method was used to produce the dotted curves in figures 18 and 19, which give the drag of flat-decked hull models having the same cross-sectional areas as the models with rounded deck in these figures. No correction was necessary for model 35 (fig. 17) as the cross-sectional areas for the two conditions were nearly the same.

If the minimum drag of hull model 26 with the flat deck and with the additional rounded-deck layer is calculated, it is found that, although the cross-sectional area has been increased 33 percent by the rounded-deck layer, the minimum drag has actually been reduced by about 12 percent. When the hulls are of the same over-all height the reduction is from 20 to 25 percent.

Effect of windshields.- The additional drag caused by two common types of windshields is shown in figure 20. Although hull model 35 was the only one tested with a windshield, the results of the tests on it may be used to estimate the additional windshield drag coefficient for the other hull models. The high drag of the undercut windshield is noteworthy.

Effect of spray strips, depth of step, and angle of afterbody keel.- The effect of adding spray strips to model 40 is shown in figure 21. The spray strips, which were about 2 percent of the beam in width, increased the minimum drag of the model by about 8 percent; at 10° angle of pitch the increase in drag was about 15 percent. For other hull models the effect of the strips will probably vary somewhat with the chine lines.

Tests were made on model 11-A with three depths of step: 1 inch, 1/2 inch, and no step. The results of these tests are shown in figure 22. A calculation based on these data shows that the increase in drag caused by the step when expressed as a coefficient based on the area of the step gives a value which does not vary greatly and which averages about 0.21. Earlier in this report it was mentioned that pointed steps appear to have a higher drag than transverse steps. This characteristic is probably due to the fact that pointed steps are deeper than transverse steps and are rounded to the center line so sharply that separation of the air occurs.

Figure 23 shows that up to an angle of about 6° the effect of the angle of afterbody keel (measured as indicated in fig. 2) on drag is practically negligible but increases quite rapidly for larger angles. These results also were obtained from hull model 11-A.

Take-off.- The resistance of a hull model as measured in the N.A.C.A. tank includes the air drag of that portion rising above the water surface so that in making take-off calculations the data in this report need be used only indirectly in a manner described in various tank publications; e.g., reference 3.

General discussion.- A comparison between the drag coefficients of flying-boat hulls and the drag coefficient of an airship hull should be of some interest. The drag coefficient of an airship hull at approximately the same Reynolds Number as the hull models tested here was calculated from airship data obtained in the 20-foot tunnel (reference 4) and found to be about 0.052; whereas in figure 15 the minimum drag coefficient of model 26, the "cleanest" model, is found to be 0.092. It therefore appears that it would be possible, disregarding all practical considerations, to reduce the drag of model 26 by about 43 percent.

The requirements of good water performance demand, of course, a variation from ideal aerodynamic form. Although such irregularities as chines and steps appear at this time to be essential features of hull form, it may be possible through judicious design development to reduce their ill effects without impairing the water characteristics. The results of these tests indicate that large improvements in the design of many hulls would, indeed, be possible.

Since the beginning of their use the design of flying-boat hulls has been dominated by their water performance rather than by their aerodynamic qualities. The increasing tendency toward high-speed flying boats having low power loadings and using controllable propellers will undoubtedly shift the focus of attention in the aerodynamic direction and it is not beyond the realm of possibility to expect radical innovations in the way of retractable steps and controllable fairings for steps and chines.

The data for a representative group of flying-boat hull models presented in this report should be useful in design and for performance calculations. It is planned to make further tests on additional models that have been or will be tested in the N.A.C.A. tank thus including a greater number and variety of hull forms. Research of a more fundamental nature to determine the extent to which the drag of a hull is influenced by modifications of chines, steps, and body contours is also contemplated.

Langley Memorial Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., March 25, 1935.

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1. Diehl, Walter S.: Tests on Airplane Fuselages, Floats, and Hulls. T.R. No. 236, N.A.C.A., 1926.

2. Weick, Fred E., and Wood, Donald H.: The Twenty-Foot Propeller Research Tunnel of the National Advisory Committee for Aeronautics. T.R. No. 300, N.A.C.A., 1928.

3. Dawson, John R.: A Complete Tank Test of the Hull of the Sikorsky S-40 Flying Boat - American Clipper Class. T.N. No. 512, N.A.C.A., 1934.

4. Freeman, Hugh B.: Force Measurements on a 1/40-Scale Model of the U.S. Airship "Akron". T.R. No. 432, N.A.C.A., 1932.

TABLE I

BASIC DIMENSIONS AND MINIMUM AERODYNAMIC DRAG CHARACTERISTICS OF HULL MODELS

Hull No.	Dimensions					Coefficients		Pitch angle
	Length	Height	Beam	Area A	Volume V	C_D (min.)	$C_{D_{V^{2/3}}}$ (min.)	
	In.	In.	In.	Sq.ft.	Cu.ft.			Deg.
1	96.6	13.8	16.7	1.14	5.50	0.130	0.0475	0
11-A	96.0	17.5	17.0	1.80	9.76	.098	.0387	0
11-A[1]	96.0	16.3	17.0	1.70	7.86	.130	.0560	-1
14[1]	96.0	14.3	19.0	1.66	8.30	.140	.0567	-1
16	100.0	13.3	15.9	1.02	4.80	.116	.0416	0
18	117.5	13.8	16.8	1.22	7.10	.124	.0409	1
22-A[1]	98.8	12.3	17.0	1.36	6.36	.158	.0627	-2½
26	99.4	17.5	17.9	1.90	10.56	.092	.0365	1
26[1]	99.4	13.3	17.9	1.43	7.80	.140	.0509	0
35	80.0	13.8	13.0	1.13	5.20	.103	.0388	-3
35[1]	80.0	13.5	13.0	1.14	5.43	.130	.0480	-3
36[1]	100.0	12.8	14.0	1.13	6.42	.146	.0477	0
40[1]	100.0	14.3	13.0	1.19	6.63	.119	.0402	-1
40[1,2]	100.0	14.3	13.0	1.19	6.63	.128	.0432	-1
44	76.1	13.0	17.0	1.12	5.02	.094	.0360	-6

[1] Indicates models with flat decks; the others have rounded decks.

[2] With spray strips.

$$C_D = \frac{D}{qA} \qquad C_{D_V}{}^{2/3} = \frac{D}{qV^{2/3}}$$

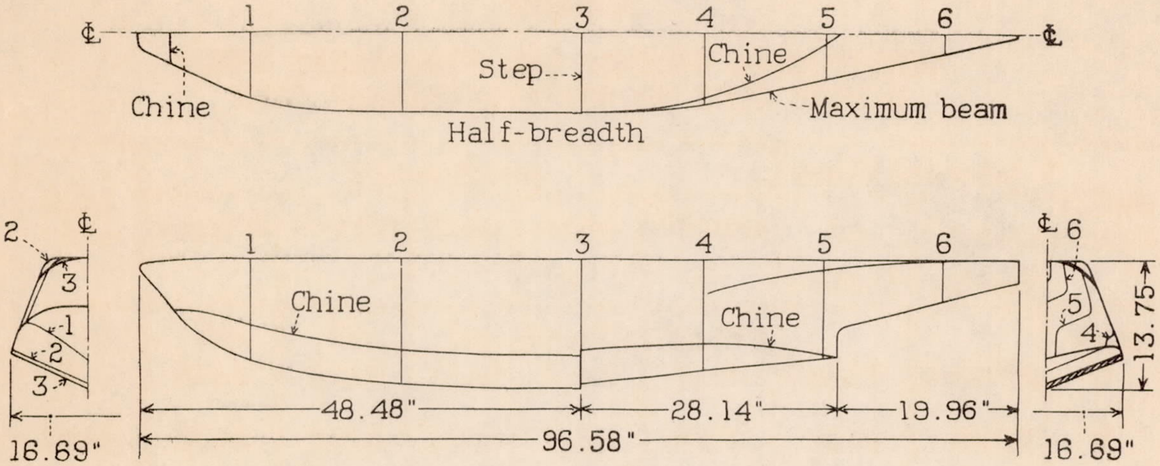


Figure 1.- Lines of N.A.C.A. Model 1.

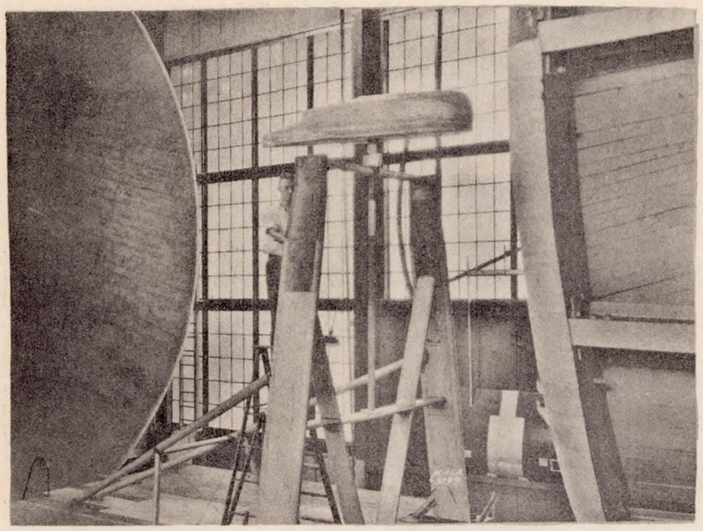


Figure 3.- Model 11-A in testing position.

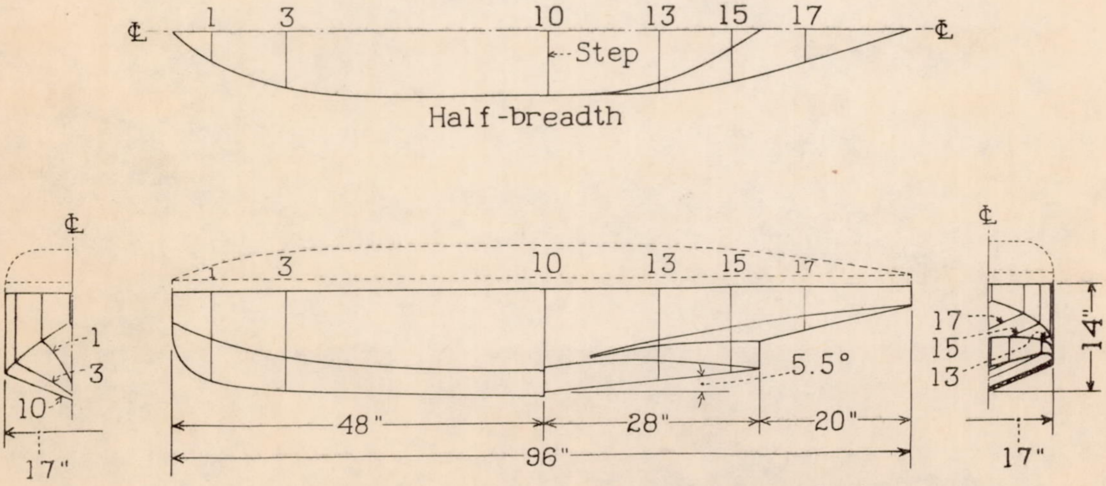


Figure 2.- Lines of N.A.C.A. Model 11-A.

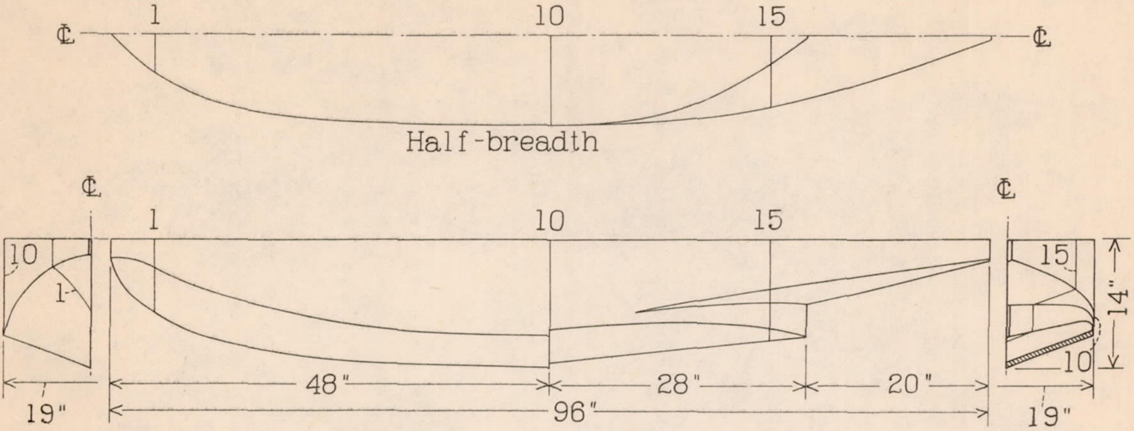


Figure 4.- Lines of N.A.C.A. Model 14.

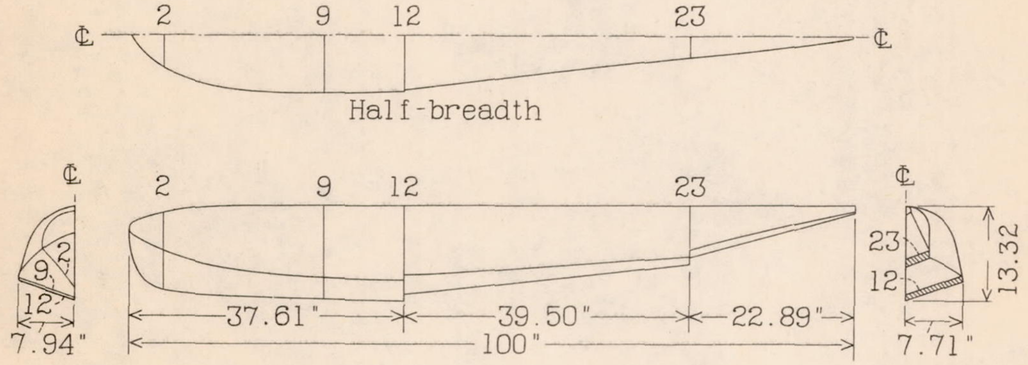


Figure 5.- Lines of N.A.C.A. Model 16.

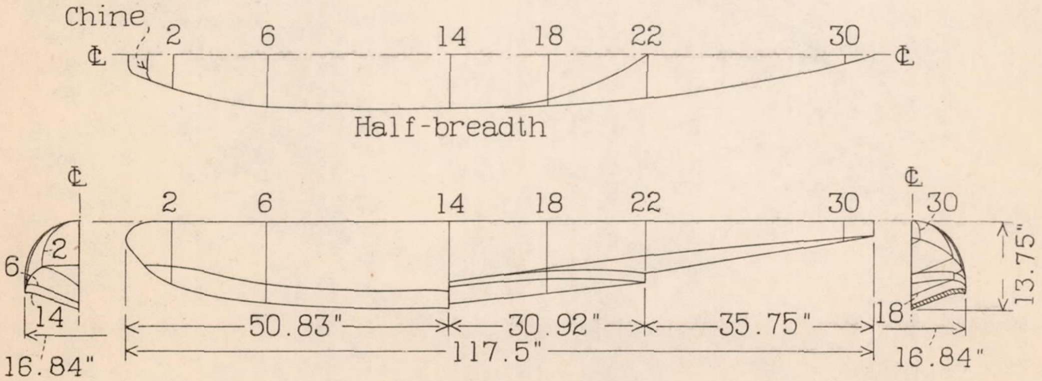


Figure 6.- Lines of N.A.C.A. Model 18.

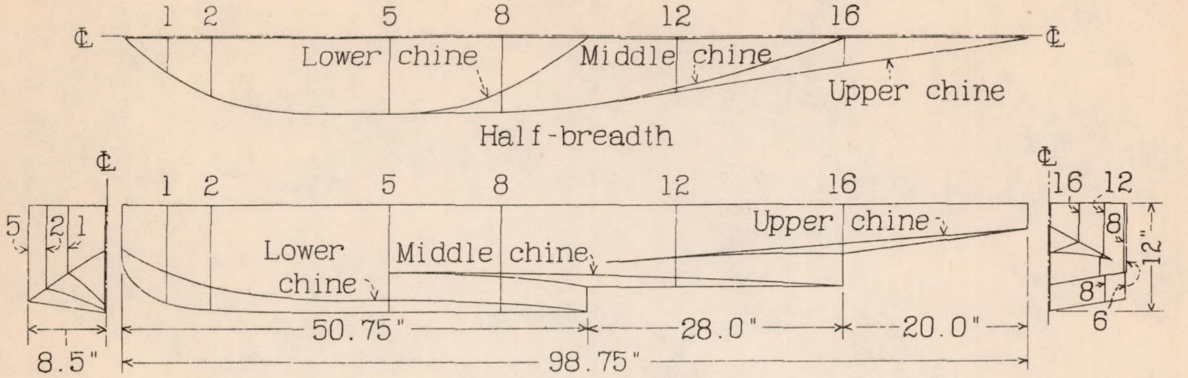


Figure 7.- Lines of N.A.C.A. Model 22-A

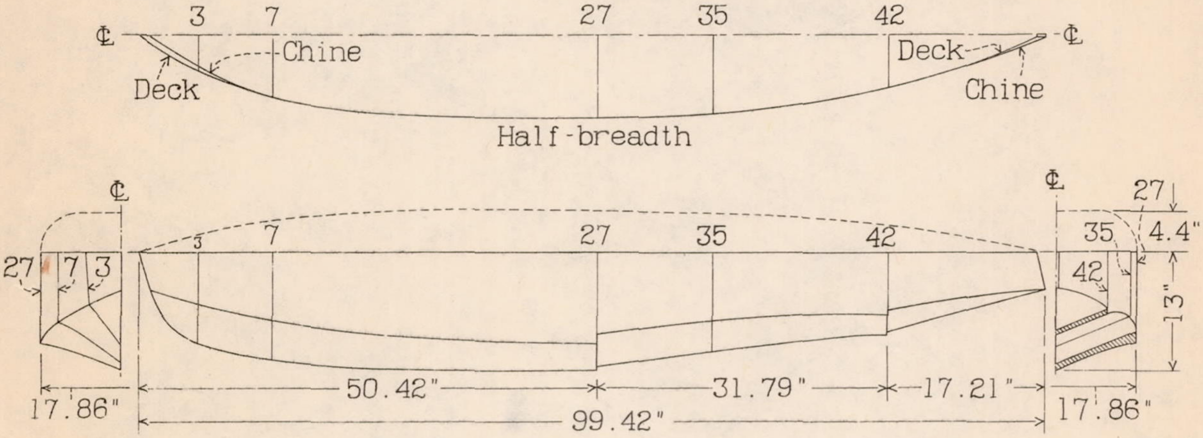


Figure 8.- Lines of N.A.C.A. Model 26.

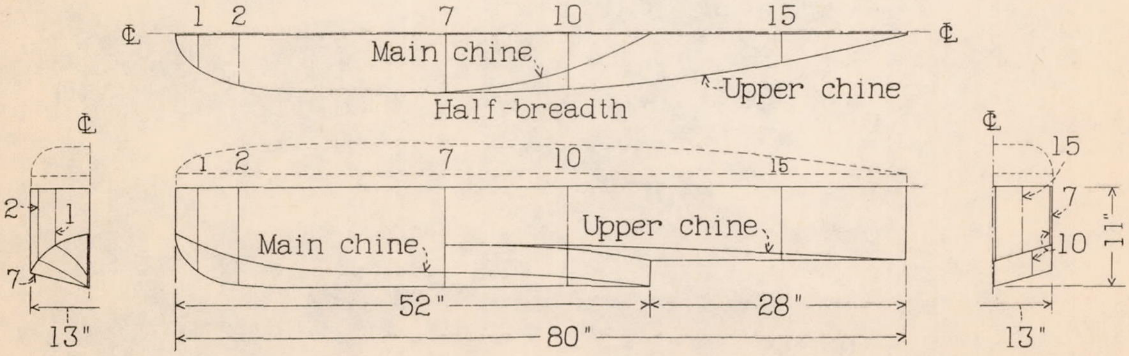


Figure 9.- Lines of N.A.C.A. Model 35.

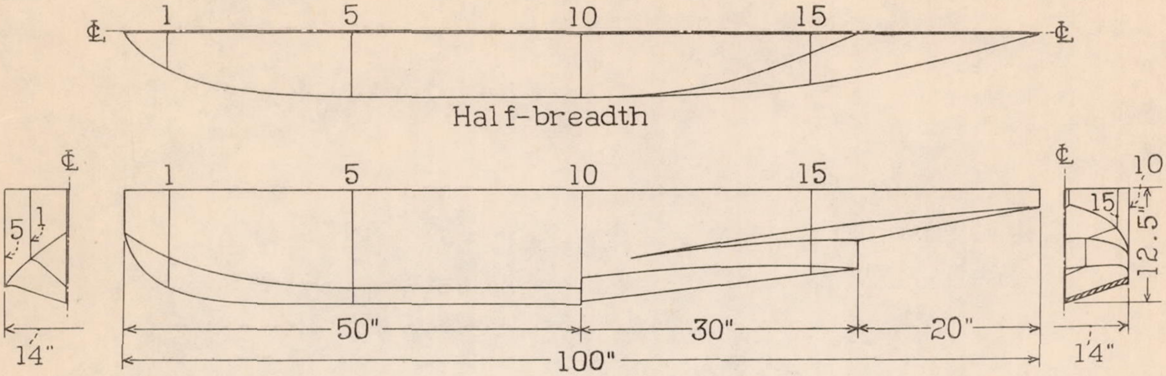


Figure 10.- Lines of N.A.C.A. Model 36.

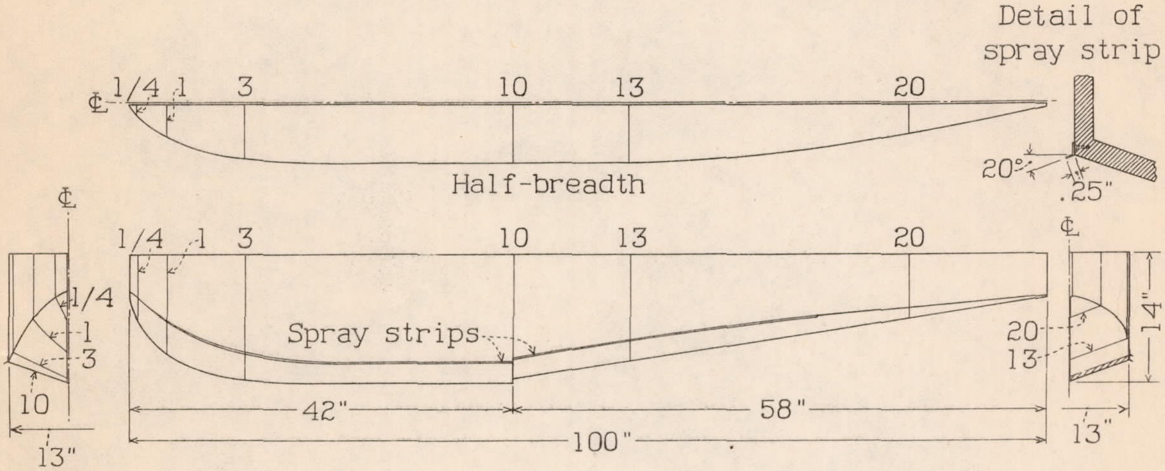


Figure 11.- Lines of N.A.C.A. Model 40.

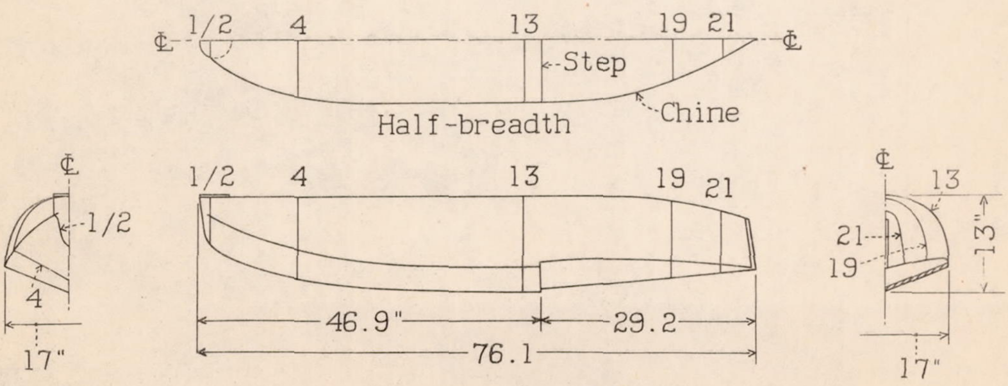


Figure 12.- Lines of N.A.C.A. Model 44.

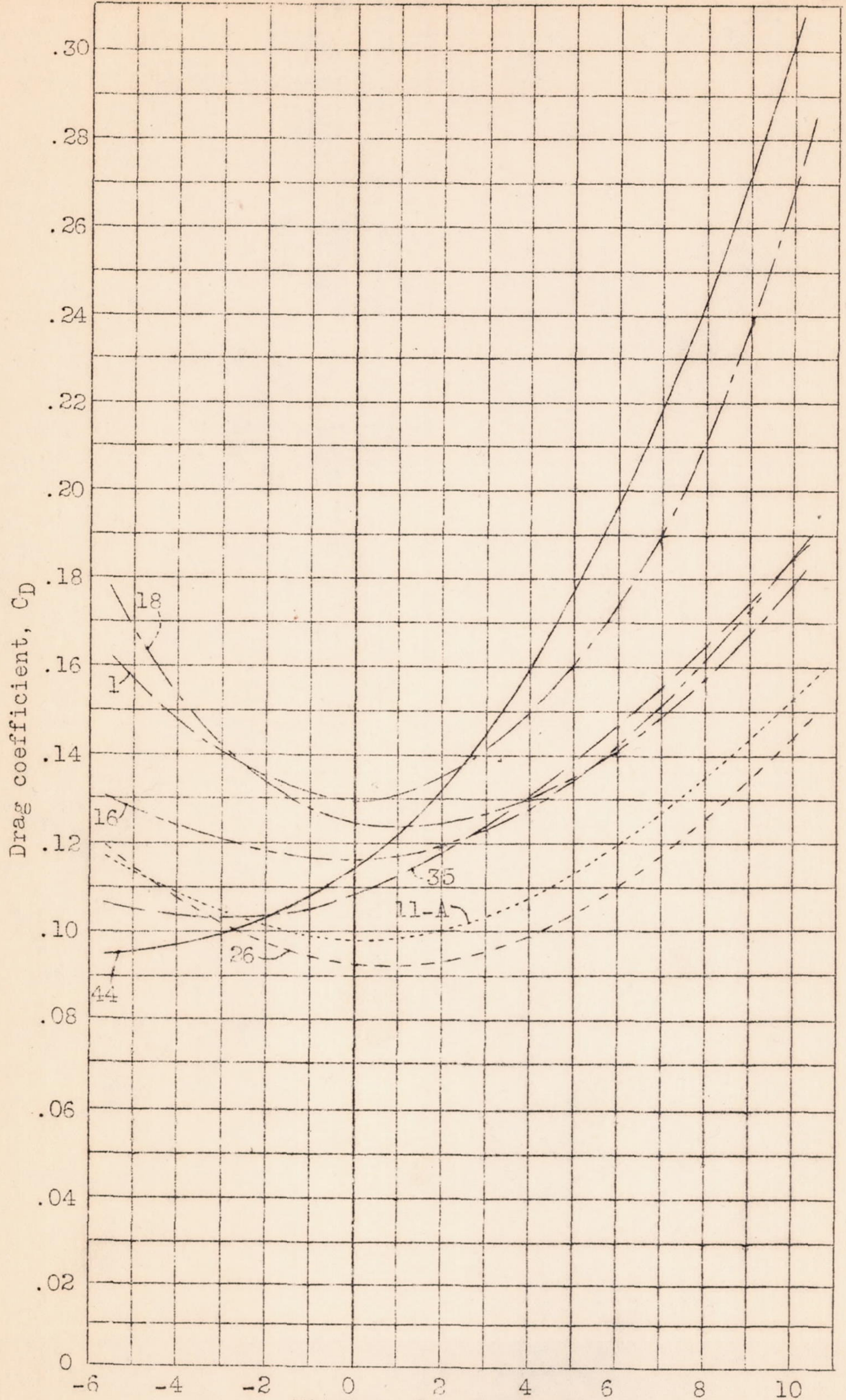


Figure 13.-The drag coefficients of hulls with rounded decks.

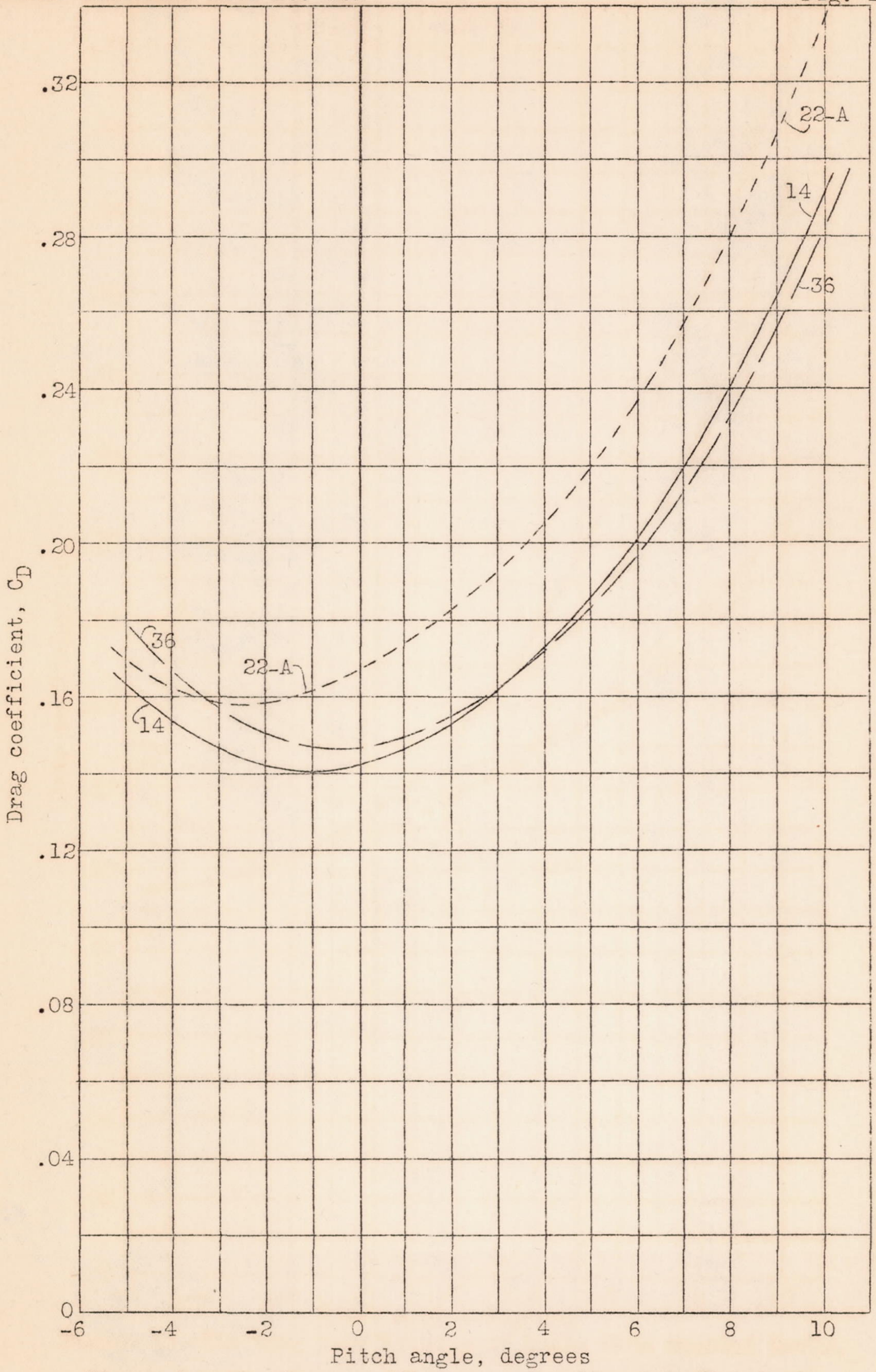


Figure 14.-The drag coefficients of hulls with flat decks.

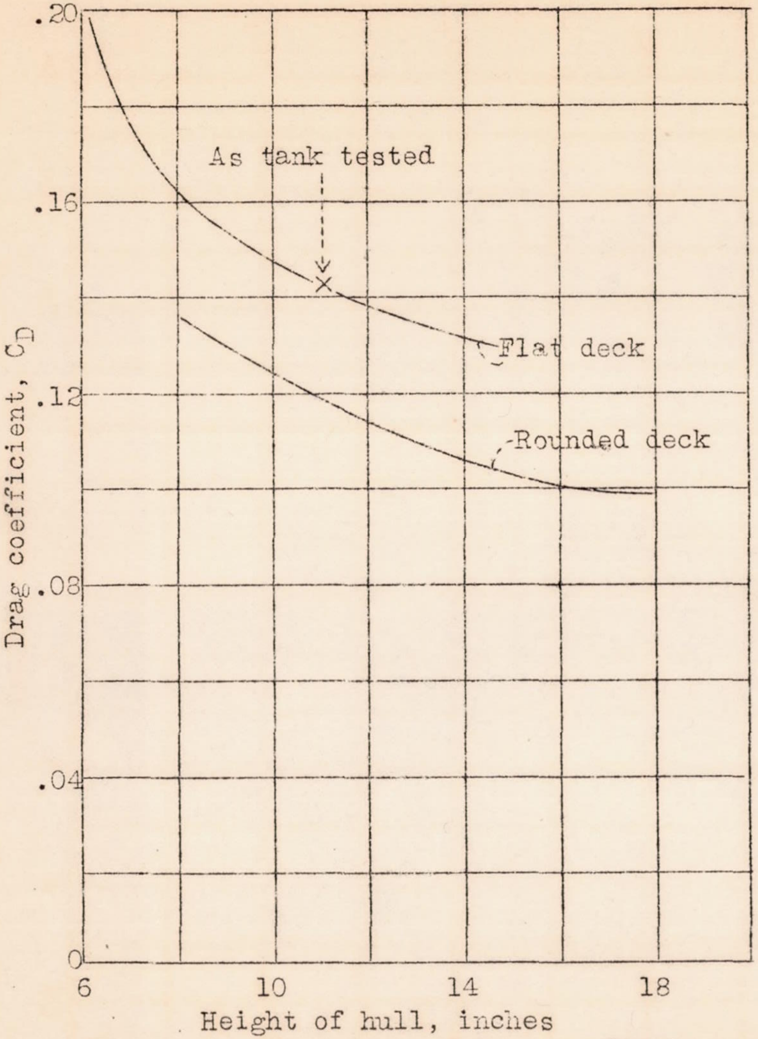


Figure 15.-Variation of drag coefficient with height for hull model 35; pitch angle -2 1/2°.

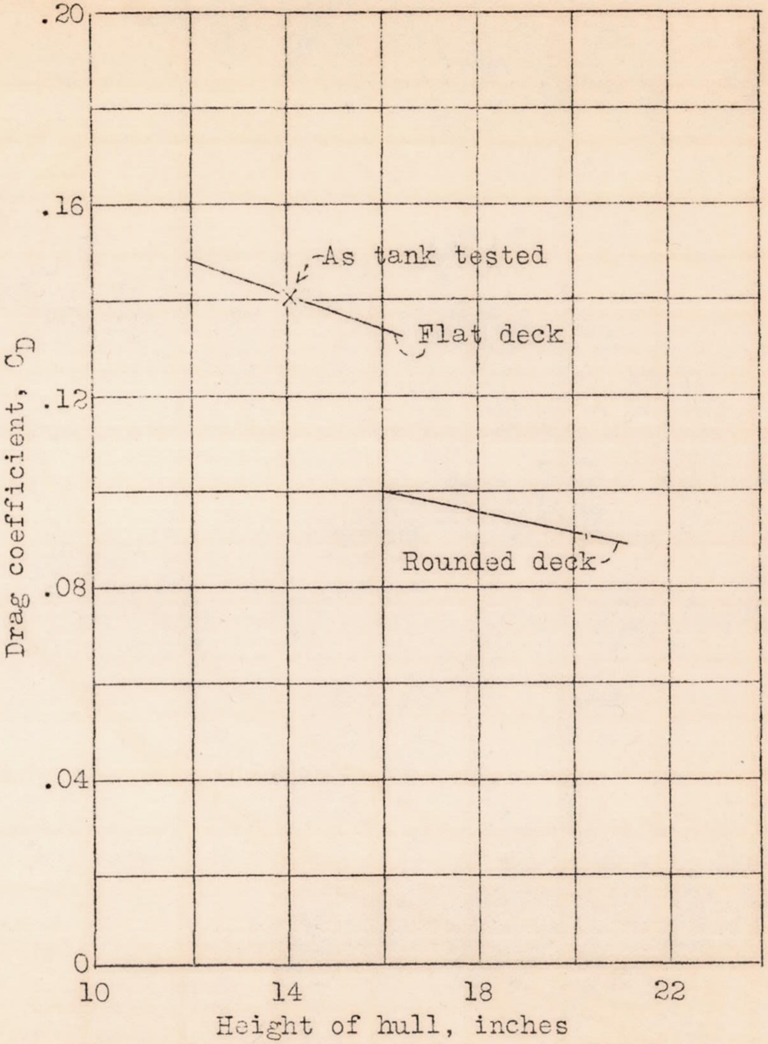


Figure 16.-Variation of drag coefficient with height for hull model 11-A; pitch angle 0°.

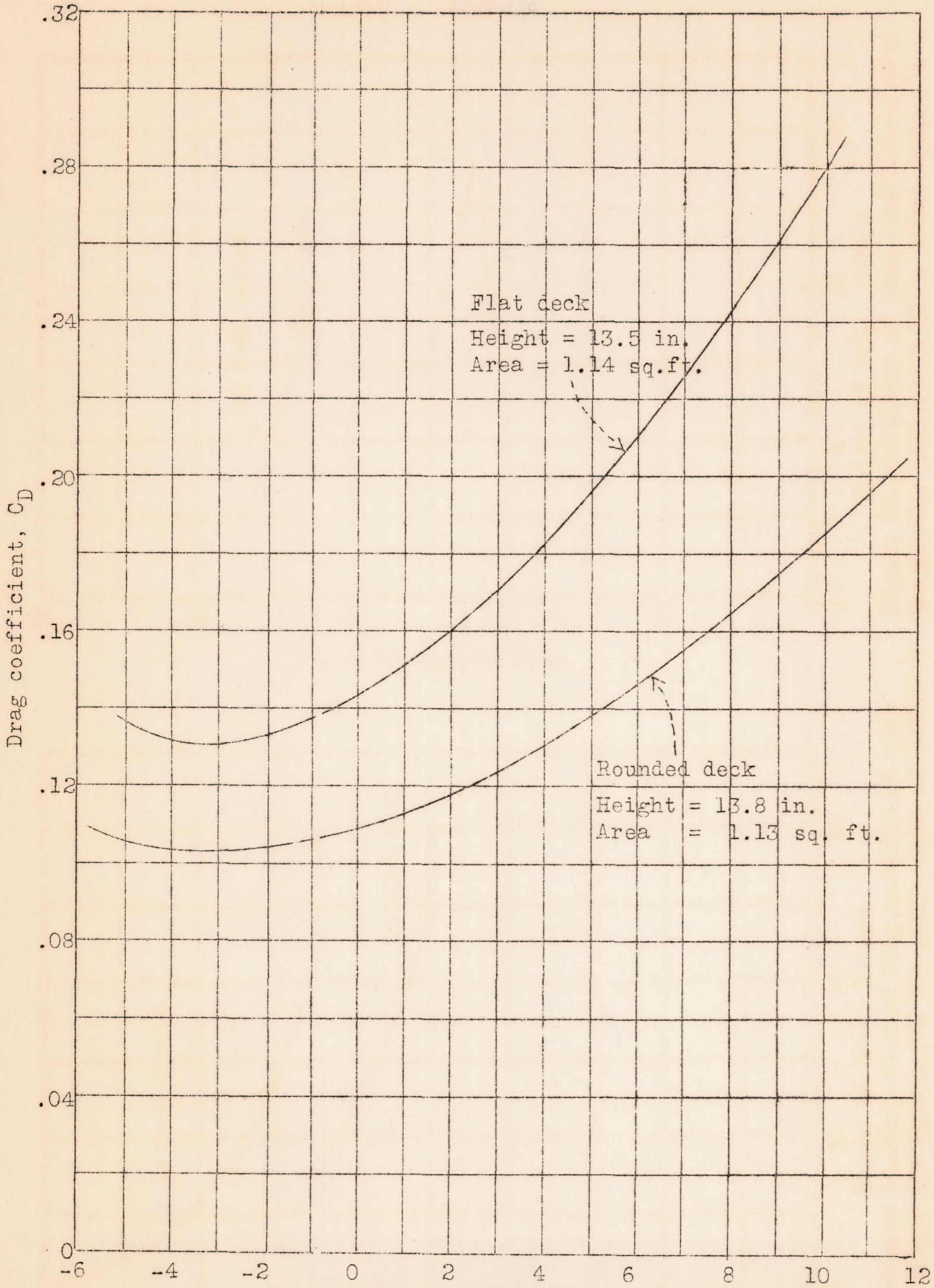


Figure 17.-The variation of drag coefficient of model 35 with flat and rounded decks.

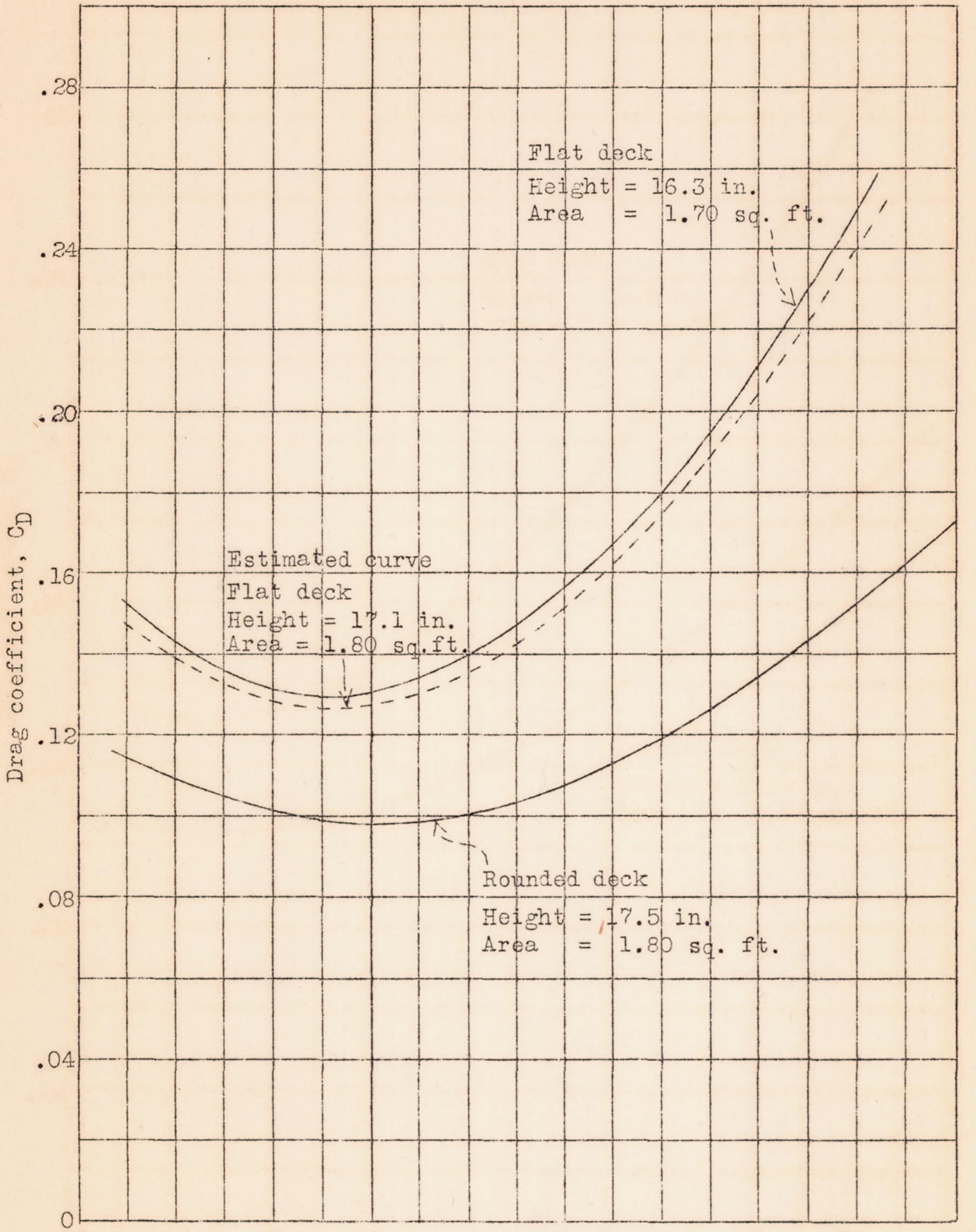


Figure 18.-The variation of drag coefficient of model 11-A with flat and rounded decks.

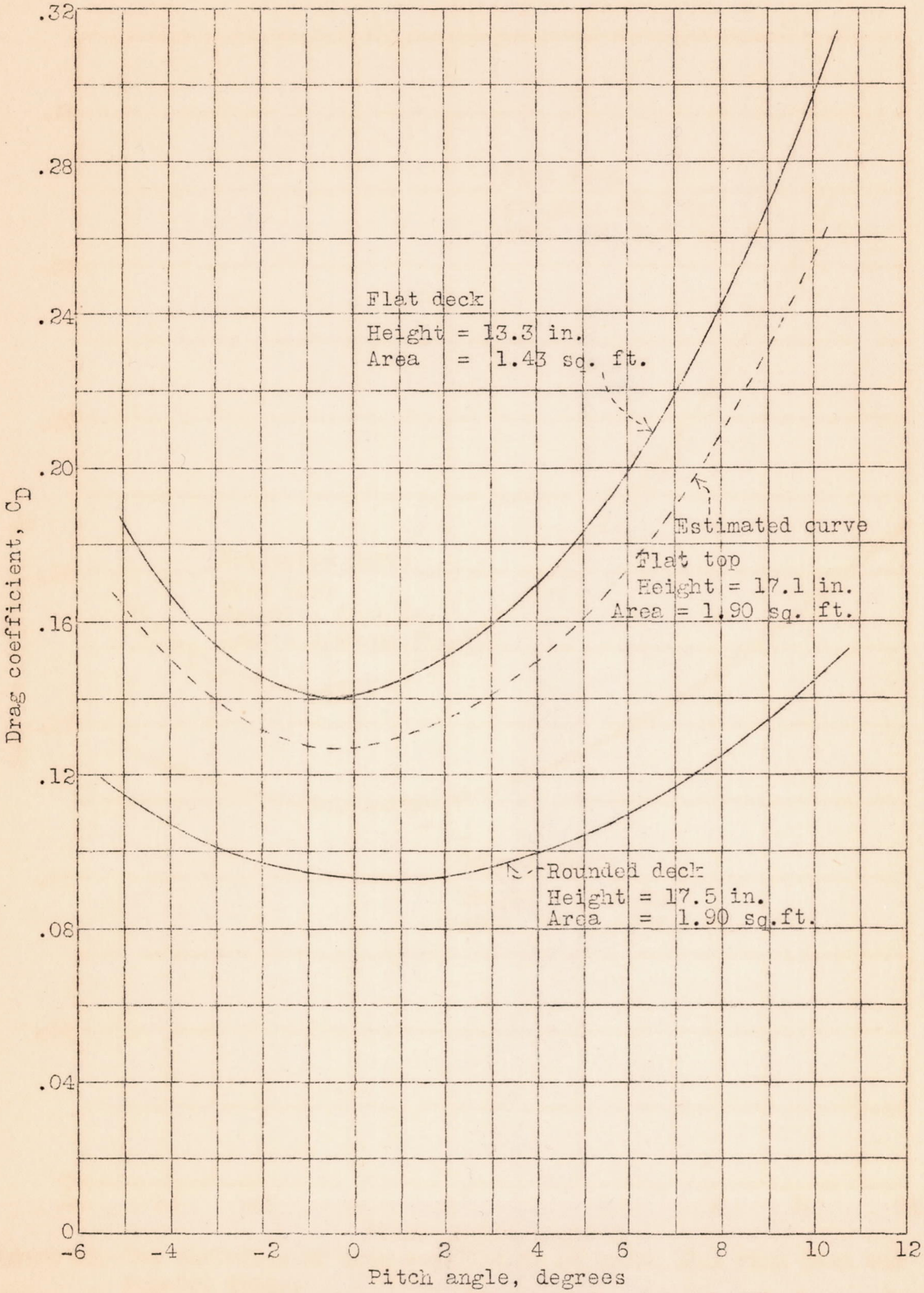
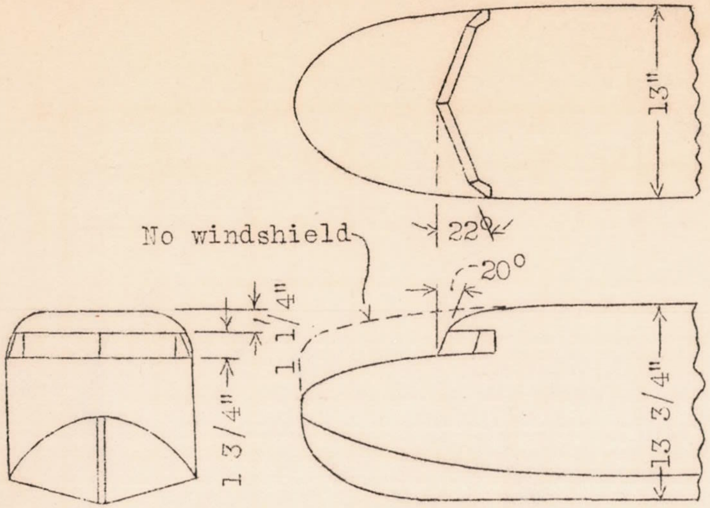
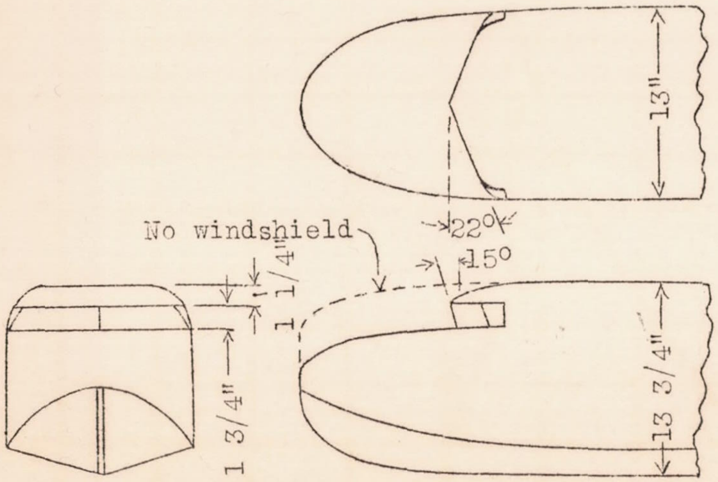


Figure 19.-The variation of drag coefficient of model 26 with flat and rounded decks.



Hull No. 35, ordinary windshield



Hull No. 35, undercut windshield

Figure 20a.-Model 35 with two types of windshields.

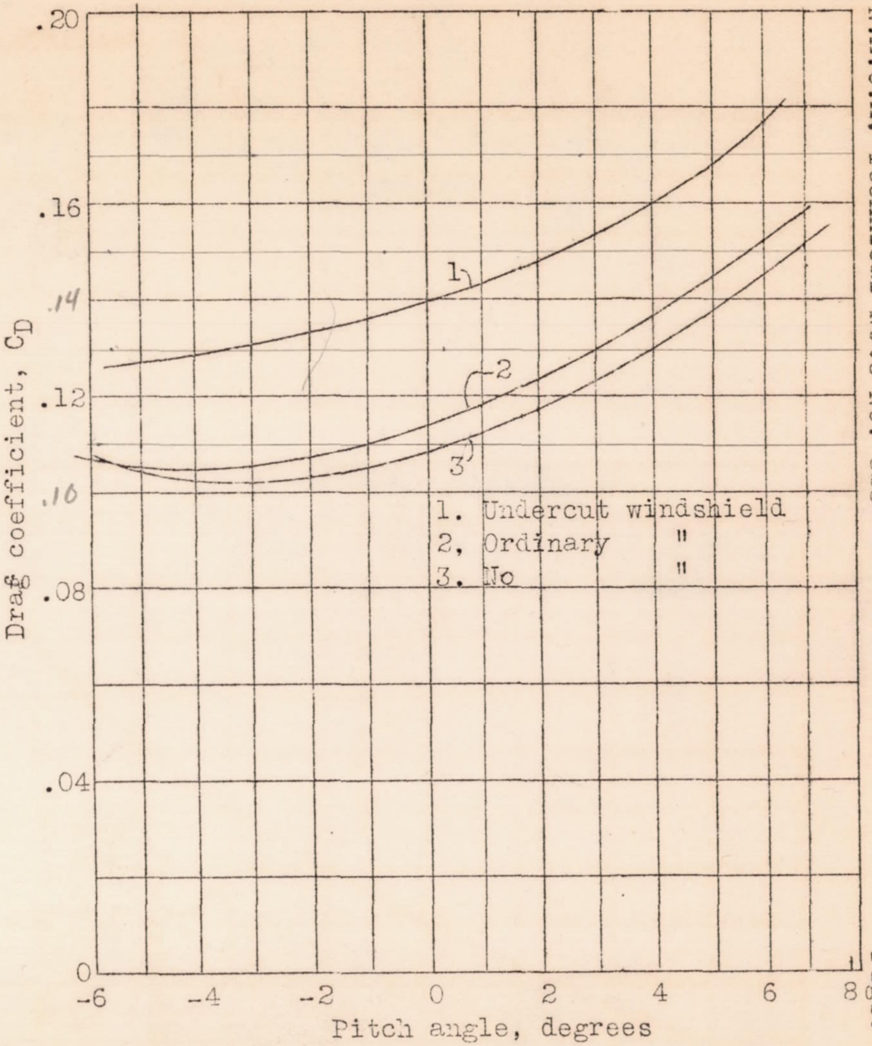


Figure 20b.-The variation of the drag coefficient of model 35 with two types of windshields.

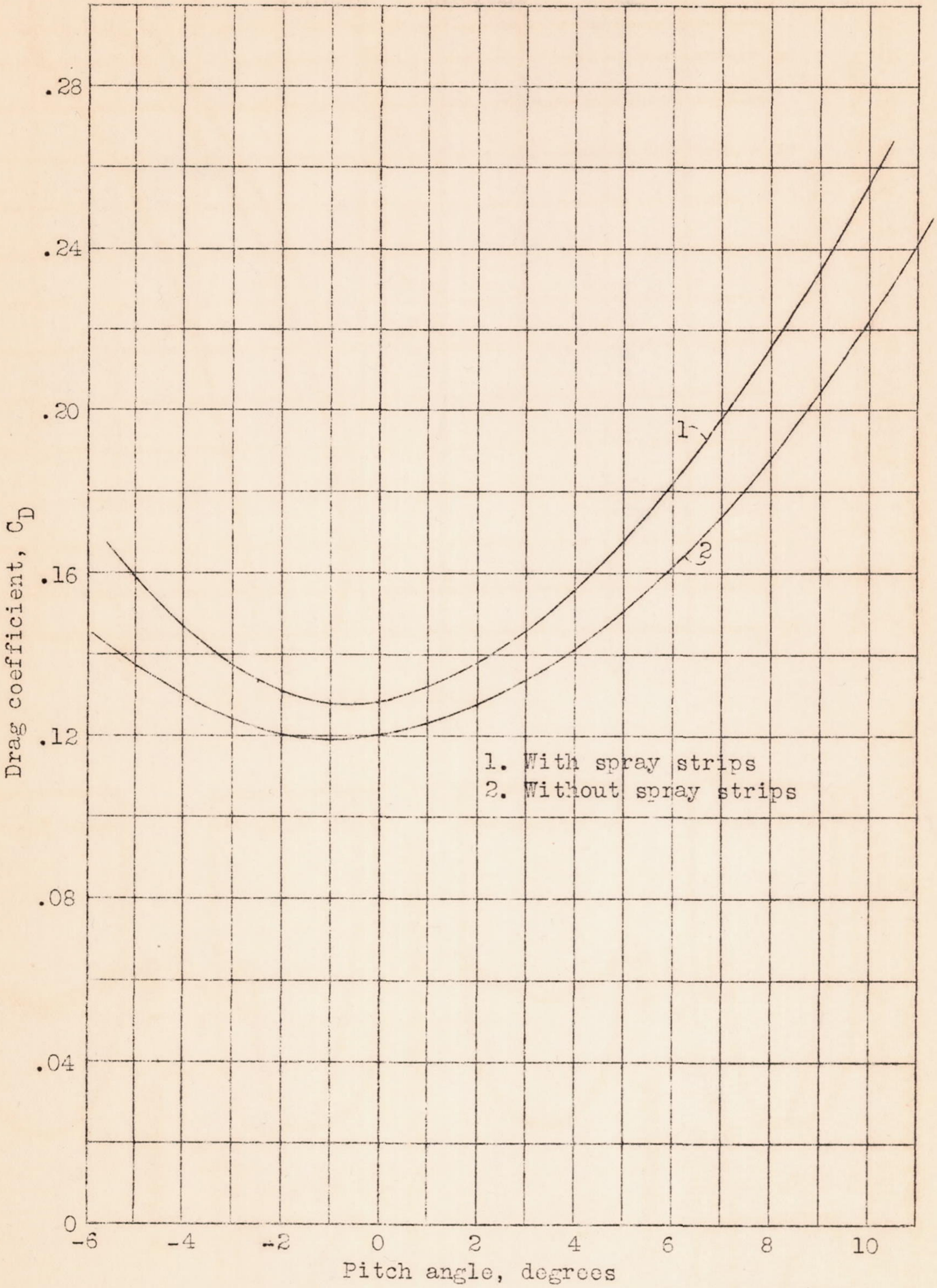


Figure 21.-The variation of the drag coefficient of model 40 with the addition of spray strips.

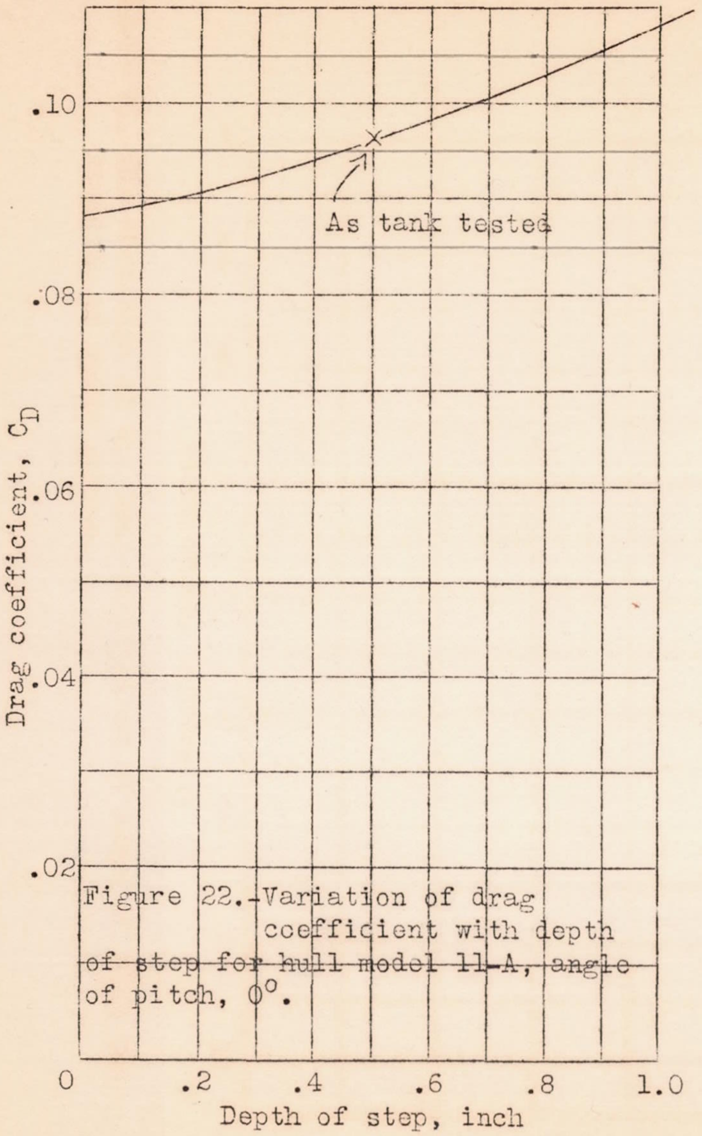


Figure 22.-Variation of drag coefficient with depth of step for hull model 11-A, angle of pitch, 0°.

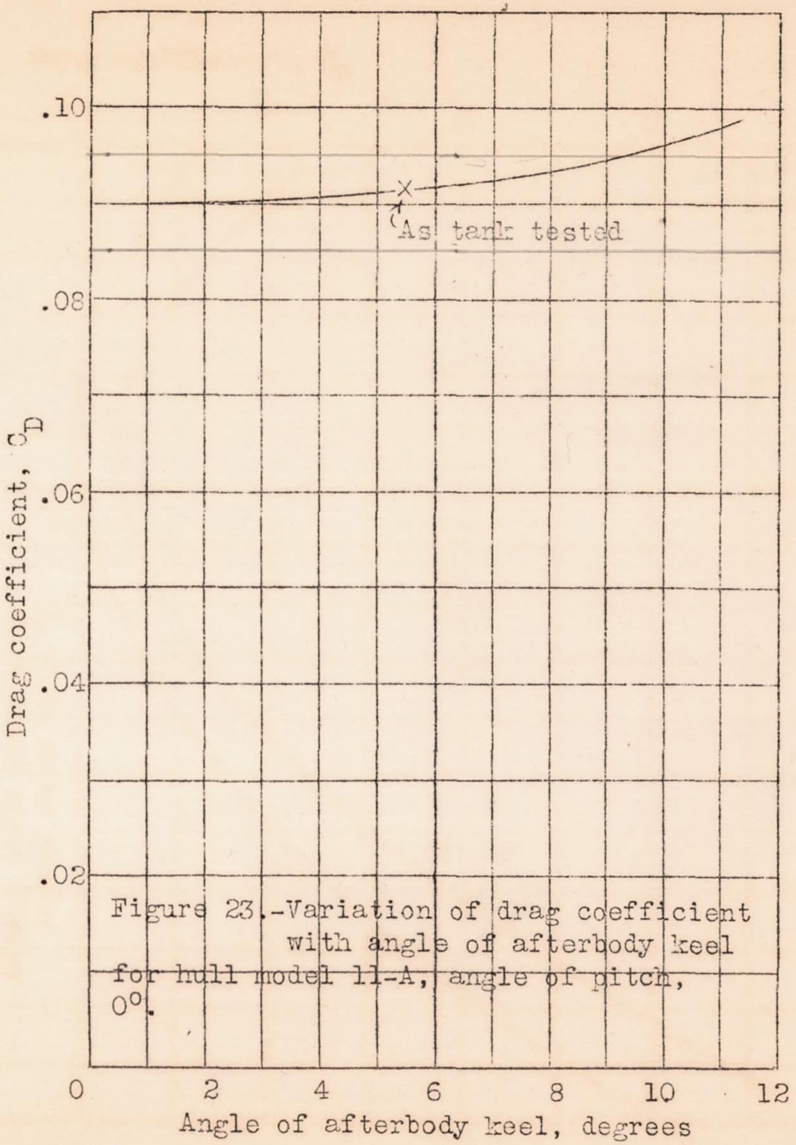


Figure 23.-Variation of drag coefficient with angle of afterbody keel for hull model 11-A, angle of pitch, 0°.