RESTRICTED

NACA

CASE FILE
COPY

RESEARCH MEMORANDUM

AERODYNAMIC CHARACTERISTICS OF FLYING-BOAT HULLS

HAVING LENGTH-BEAM RATIOS OF 20 AND 30

By

John M. Riebe

Langley Aeronautical Laboratory
Langley Field, Va.

NATIONAL ADVISORY COMMITTEE
FOR AERONAUTICS

WASHINGTON

November 10, 1948

RESTRICTED

RESTRICTED

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

RESEARCH MEMORANDUM

AERODYNAMIC CHARACTERISTICS OF FLYING-BOAT HULLS

HAVING LENGTH-BEAM RATIOS OF 20 AND 30

By John M. Riebe

SUMMARY

An investigation of a series of hulls of length-beam ratios from 6 to 15 previously reported in NACA TN No. 1305 has been extended to length-beam ratios 20 and 30. The hulls of the entire series were designed to have approximately the same hydrodynamic performance with respect to spray and resistance characteristics regardless of length-beam ratio.

The results of the investigation indicated that, although an increase in length-beam ratio from 6 to 15 resulted in a substantial decrease in drag coefficient, only a small decrease was obtained in going from 15 to 30. The hulls of length-beam ratios 20 and 30 had slightly more longitudinal stability and slightly less directional stability than the lower length-beam-ratio hulls.

INTRODUCTION

Because of the requirements for increased range and increased speed in flying boats, the Langley Laboratory of the National Advisory Committee for Aeronautics is making an investigation to reduce the drag of flying-boat hulls without severely penalizing the aerodynamic stability or hydrodynamic performance. Reference 1 which presented test results of hulls with length-beam ratios of 6, 9, 12, and 15 with interference of a 21-percent-thick wing indicated a 29-percent minimum-drag-coefficient reduction for the over-all length-beam-ratio increase without any large change in aerodynamic stability; test results of the same hulls without wing interference are presented in reference 2. The trend of decreasing minimum drag coefficients with increasing length-beam ratios indicated that further drag reductions might be obtained at still higher length-beam ratios. The present investigation is an extension of tests on the hull series to length-beam ratios of 20 and 30. As in reference 1, most of the data included the effects of wing interference determined by subtraction of wing-alone data from wing-plus-hull data. However, as in reference 2, results are given that present hull drag coefficients without wing interference.

COEFFICIENTS AND SYMBOLS

The results of the tests are presented as standard NACA coefficients of forces and moments. Rolling-moment, yawing-moment, and pitching-moment coefficients are given about the locations (wing 30-percent-chord point) shown in figure 1. Except where noted, the wing area, mean aerodynamic chord, and span used in determining the coefficients and Reynolds numbers are those of a hypothetical flying boat (reference 1).

The hull coefficients with wing interference were derived by subtraction of wing-alone data from wing-plus-hull data. The wing-alone data were determined by including in the tests that part of the wing which is normally enclosed in the hull. The hull coefficients with wing interference, therefore, include the wing interference resulting from the interaction of the velocity fields of the wing and hull and also the negative wing interference caused by shielding from the air stream that part of the wing enclosed within the hull. The data are referred to the stability axes, which are a system of axes having the origin at the center of moments shown in figure 1 and in which the Z-axis is in the plane of symmetry and perpendicular to the relative wind, the X-axis is in the plane of symmetry and perpendicular to the Z-axis, and the Y-axis is perpendicular to the plane of symmetry. The positive directions of the stability axes are shown in figure 2.

The coefficients and symbols are defined as follows:

C_L lift coefficient (Lift/qS)

C_D drag coefficient (Drag/qS)

C_Y lateral-force coefficient (Y/qS)

C_l rolling-moment coefficient (L/qSb)

C_m pitching-moment coefficient $(M/qS\bar{c})$

C_n yawing-moment coefficient (N/qSb)

Lift = $-Z$

Drag = $-X$ when $\psi = 0$

X   force along X-axis, pounds

Y   force along Y-axis, pounds

Z   force along Z-axis, pounds

L   rolling moment, foot-pounds

M   pitching moment, foot-pounds

N   yawing moment, foot-pounds

q   free-stream dynamic pressure, pounds per square foot $\left(\rho V^2/2\right)$

S   wing area of a $\frac{1}{10}$-scale model of a hypothetical flying boat
                (18.264 sq ft)

$\bar{c}$ wing mean aerodynamic chord (M.A.C.) of a $\frac{1}{10}$-scale model
                of a hypothetical flying boat (1.377 ft)

b   wing span of a $\frac{1}{10}$-scale model of a hypothetical flying boat
                (13.971 ft)

V   air velocity, feet per second

ρ mass density of air, slugs per cubic foot

α angle of attack of hull base line, degrees

ψ angle of yaw, degrees

R   Reynolds number, based on wing mean aerodynamic chord of a
                $\frac{1}{10}$-scale model of a hypothetical flying boat

L/b   length-beam ratio, where L is distance from forward per-
                pendicular (F.P.) to sternpost and b is maximum beam
                (fig. 1)

$C_{D_{min}}$ minimum drag coefficient

$C_{D_{A_{min}}}$ minimum drag coefficient based on maximum cross-sectional
                area A of hull (Drag/qA)

$C_{D_{v_{min}}}$ minimum drag coefficient based on volume v of hull
                $\left(\text{Drag}/qv^{2/3}\right)$

$C_{D_{W_{min}}}$ minimum drag coefficient based on surface area W of hull
                (Drag/qW)

$$C_{m_\alpha} = \frac{\partial C_m}{\partial \alpha}$$

$$C_{n_\psi} = \frac{\partial C_n}{\partial \psi}$$

$$C_{Y_\psi} = \frac{\partial C_Y}{\partial \psi}$$

MODEL AND APPARATUS

The hulls were designed by the Langley Hydrodynamics Division. Hull models 239 (L/b = 20) and 240 (L/b = 30) which are extensions of the series previously reported in reference 1 were constructed by the David Taylor Model Basin. Dimensions of the complete length-beam-ratio series are given in figure 1 and the offsets for hulls 239 and 240 are given in tables I and II; offsets for the other hulls are given in reference 1. The hulls were derived from a hypothetical flying boat essentially similar to the Boeing XPBB-1 (fig. 3 and reference 1). All hulls of this L/b series had the same value of L^2b to provide similar hydrodynamic perform- ance with respect to spray and resistance characteristics. Tank tests on model 239 indicate that it will have spray and resistance characteristics similar to that of the lower length-beam ratios; the hydrodynamic stability will, however, be less.

The volumes, surface areas, maximum cross-sectional areas, and side areas for the series of hulls are compared in table III.

For the hull tests with wing interference the models were attached to the support wing of reference 1 which was mounted in the tunnel as shown in figure 4; the support wing was not a scale model of the hypo- thetical wing (fig. 3). The wing was located the same distance from the step on all models, was set at an angle of incidence of 4° to the base line, had a 20-inch chord, and was of the NACA 4321 airfoil section.

The tunnel test section was lengthened by using plywood fillets in the corners (fig. 4) to accommodate the long forebodies of hulls 239 and 240. At the same time, the longitudinal static pressure gradient was considerably reduced.

TESTS

Test Conditions

The tests were made in the Langley 300 MPH 7- by 10-foot tunnel at dynamic pressures of approximately 25, 100, and 140 pounds per square foot, corresponding to airspeeds of approximately 100, 200, and 240 miles per hour. Reynolds numbers for these airspeeds, based on the mean aero- dynamic chord of the hypothetical flying boat, were approximately 1.3×10^6, 2.5×10^6, and 2.9×10^6, respectively. Corresponding Mach numbers were 0.13, 0.26, and 0.31.

Corrections

Blocking corrections have been applied to the hull-alone, wing, and wing-plus-hull data. The hull drag has been corrected for longitudinal buoyancy effects caused by a small tunnel static pressure gradient. Angles of attack have been corrected for structural deflections caused by aero-dynamic forces. For the hull-alone tests the effect of the support strut has been subtracted from the data.

Test Procedure

The aerodynamic characteristics of the hulls with interference of the support wing were determined by testing the wing-alone and the wing-and-hull combinations under identical conditions.

For the hull-alone tests the effects of the support strut were determined by using an image system to determine the tare values which were subtracted from the data.

Tests were made at three Reynolds numbers. Because of structural limitations of the support wing, it was necessary to limit the hull data with wing interference at the higher Reynolds numbers to the angle-of-attack range shown.

To minimize possible errors resulting from transition shift on the wing, the wing transition was fixed at the leading edge by means of roughness strips of carborundum particles of approximately 0.008-inch diameter. The particles were applied for a length of 8 percent airfoil chord measured along the airfoil contour from the leading edge on both upper and lower surfaces.

Hull transition for all tests was fixed by a strip of 0.008-inch-diameter carborundum particles $\frac{1}{2}$ inch wide located approximately 5 per-cent of the hull length aft of the bow. Hull-with-wing-interference tests were made with the support setup shown in figure 4; hull-alone tests were made with the setup shown in figure 5.

As stated previously, the extreme length of the 20 and 30 length-beam-ratio hulls necessitated extension of the tunnel test section. Because the alteration resulted in a much smaller longitudinal static pressure gradient than that of reference 1 and, consequently, smaller buoyancy corrections, several check tests were made on the 6-to-15 length-beam-ratio hulls.

RESULTS AND DISCUSSION

The effects of changes in length-beam ratio from 6 to 30 on the variation in aerodynamic characteristics of flying-boat hulls including wing interference with angle of attack are presented in figure 6. The variation of the aerodynamic characteristics in yaw of hulls 239 and 240 ($L/b = 20$ and 30, respectively) are given in figure 7. Aerodynamic characteristics in pitch of hulls with length-beam ratios 15, 20, and 30 without wing interference are given in figure 8. The effects of length-beam ratio on minimum drag coefficient and on the stability parameters C_{m_α}, C_{n_ψ}, and C_{Y_ψ}, as determined from the present investigation, are summarized in figure 9; wherever no check tests were made on the 6-to-15 length-beam-ratio hulls, the curves were obtained from references 1 and 2.

Extending length-beam ratio from 15 to 20 with or without wing interference, figures 6, 8, and 9 produced only a small reduction in minimum drag coefficient (about 0.0003); very little change occurred when length-beam ratio was extended from 20 to 30.

Comparison of the length-beam-ratio 6-to-15 data of figures 6 and 9 with that of reference 1 shows good agreement; there was about a 29-percent minimum-drag-coefficient reduction with no large change in aerodynamic stability when length-beam ratio was changed from 6 to 15. The good agreement between the data of reference 1, which required a buoyancy correction of about 20-percent hull minimum drag, and that of the present report, which required only a small correction, indicates that the buoyancy corrections of reference 1 were of correct magnitude. As in reference 1, Reynolds number had little effect on drag coefficient. Minimum drag coefficient for the hulls with wing interference occurred near 2° angle of attack and near 0° without wing interference. The positive shift in angle of attack for minimum drag with wing interference resulted from support-wing camber and incidence.

The drag coefficients with wing interference were lower than the hull-alone drag coefficients by an amount dependent upon the drag of the support wing submerged within the hulls and the interference effect caused by interaction of the velocity fields of the hull and wing. In general, the interference effects caused by velocity fields increase the drag coefficient; however, the increase has been found to be small compared to the decrease caused by submerging the wing, reference 3.

The results of the present investigation show little or no gain in flying-boat aerodynamic performance in the low and middle subsonic region by using hull length-beam ratios higher than about 18. However, other factors such as a weight reduction with length-beam ratio, reference 4, may still have some effect provided the hydrodynamic stability is not

too adversely affected. That further large drag reduction with length-beam ratio cannot be expected is also shown from hull skin drag considerations. Figure 9 includes an estimate of the turbulent skin friction, reference 5, of the various length-beam-ratio hulls converted into drag coefficient based on the hypothetical wing area. Comparison with hull-alone drag coefficient shows that a large part of low-length-beam-ratio hull drag coefficient was pressure drag. Extending length-beam ratios to higher values reduced the pressure drag because of the better aerodynamic shape resulting from the narrower hulls. However, at the same time, there was an increase in hull skin-friction drag because of skin-area increase, table III. Therefore, because the major part of high-length-beam-ratio hull drag is skin drag and because of the rapid rise in skin area, an increase in minimum drag coefficients can probably be expected for length-beam ratios above 30.

Minimum drag coefficients based on cross-sectional area $C_{D_{A_{min}}}$, volume $C_{D_{V_{min}}}$, and surface area $C_{D_{W_{min}}}$ are plotted in figure 10 against length-beam ratio. The data indicate that for unit volume, a hull length-beam ratio of approximately 15 has the least drag.

Extending the length-beam ratio to 20 and 30 resulted in a very slight increase in longitudinal stability as determined by C_{m_α} and a slight decrease in directional stability, both of which followed the trends as set up by length-beam ratios 6 to 15. For convenience the stability parameters for each value of L/b are presented in table IV. The values given in the table for the 6-to-15 length-beam-ratio hulls were determined from the check tests wherever they were made; otherwise, the values were obtained from references 1 and 2.

Included in table IV for convenient comparison with other hulls and fuselages are the parameters K_f, $\partial C_{n_f}'/\partial\psi'$, and $\partial C_n/\partial\beta$, as given in references 6, 7, and 8, respectively. The parameter K_f is a fuselage moment factor in the form of $\partial C_m/\partial\alpha$, based on hull beam and length where α is in radians. The yawing-moment coefficient C_{n_f}' in $\partial C_{n_f}'/\partial\psi$ is based on volume and is given about a reference axis 0.3 of the hull length from the nose. The parameter $\partial C_n/\partial\beta$ is based on hull side area and length for which the yawing-moment is also given about a reference axis 0.3 of the hull length from the nose, and β is given in radians.

CONCLUSIONS

The results of an investigation in the Langley 300 MPH 7- by 10-foot tunnel made in order to extend a previous investigation of hulls with length-beam ratios ranging from 6 to 15 to ratios of 20 and 30 indicate the following conclusions:

1. With or without wing interference, extending the length-beam ratio from 15 to 20 produced only a small reduction in minimum drag coefficient; very little change occurred when length-beam ratio was extended from 20 to 30.

2. The hulls of length-beam ratios 20 and 30 had slightly more longitudinal stability and slightly less directional stability than the lower length-beam-ratio hulls.

Langley Aeronautical Laboratory
     National Advisory Committee for Aeronautics
          Langley Field, Va.

REFERENCES

1. Yates, Campbell C., and Riebe, John M.: Effect of Length-Beam Ratio
      on the Aerodynamic Characteristics of Flying-Boat Hulls. NACA
      TN No. 1305, 1947.

2. Lowry, John G., and Riebe, John M.: Effect of Length-Beam Ratio on
      Aerodynamic Characteristics of Flying-Boat Hulls without Wing
      Interference. NACA TN No. 1686, 1948.

3. Jacobs, Eastman N., and Ward, Kenneth E.: Interference of Wing and
      Fuselage from Tests of 209 Combinations in the N.A.C.A. Variable-
      Density Tunnel. NACA Rep. No. 540, 1935.

4. Benscoter, Stanley U.: Estimate of Hull-Weight Change with Varying
      Length-Beam Ratio for Flying Boats. NACA RM No. L7F24, 1947.

5. Prandtl, L.: Recent Results of Turbulence Research. NACA TM No. 720,
      1933.

6. Gilruth, R. R., and White, M. D.: Analysis and Prediction of Longi-
      tudinal Stability of Airplanes. NACA Rep. No. 711, 1941.

7. Pass, H. R.: Analysis of Wind-Tunnel Data on Directional Stability
      and Control. NACA TN No. 775, 1940.

8. Imlay, Frederick H.: The Estimation of the Rate of Change of Yawing
      Moment with Sideslip. NACA TN No. 636, 1938.

TABLE I

OFFSETS FOR LANGLEY TANK MODEL 239 (L/b = 20)

All dimensions are in inches

Station	Distance to forward perpendicular	Keel above BL	Chine above BL	Half-beam at chine	Radius and half maximum beam	Height of hull at CL	Line of centers above BL	Angle of chine flare (deg)	Forebody bottom, heights above BL, (in.)								
									Buttock 0.29	Buttock 0.59	Buttock 0.88	Buttock 1.18	Buttock 1.47	Buttock 1.76	Buttock 2.06	Buttock 2.35	Buttock 2.64
F.P.	0	10.30	10.30	0	0	11.00	11.00										
1/2	2.78	5.49	7.14	1.35	1.35	14.29	12.94	10	6.07	6.67	7.05	7.15					
1	5.55	3.76	5.49	1.80	1.80	15.72	13.92	10	4.21	4.66	5.12	5.41	5.53	5.50			
2	11.09	1.83	3.45	2.27	2.27	17.36	15.09	10	2.16	2.49	2.83	3.11	3.33	3.46	3.48		
3	16.64	.80	2.23	2.54	2.54	18.41	15.87	10	1.04	1.29	1.54	1.79	2.00	2.15	2.24	2.25	
4	22.19	.27	1.50	2.71	2.71	19.12	16.41	10	.46	.65	.85	1.04	1.22	1.37	1.48	1.53	1.51
5	27.73	.04	1.08	2.81	2.81	19.60	16.79	10	.19	.34	.49	.63	.78	.91	1.02	1.09	1.10
6	33.28	0	.87	2.87	2.87	19.88	17.01	5	.11	.24	.35	.46	.56	.69	.78	.86	.89
7	38.83	0	.82	2.89	2.89	19.99	17.10	0	.11	.21	.32	.43	.54	.64	.72	.78	.82
8	44.37	0	.82	2.89	2.89	20.00	17.11	0	.11	.21	.32	.43	.54	.64	.72	.78	.82
9	49.92	0	.82	2.89	2.89	20.00	17.11	0	.11	.21	.32	.43	.54	.64	.72	.78	.82
10	55.46	0	.82	2.89	2.89	20.00	17.11	0	.11	.21	.32	.43	.54	.64	.72	.78	.82
11	61.01	0	.82	2.89	2.89	20.00	17.11	0	.11	.21	.32	.43	.54	.64	.72	.78	.82
12F	66.61	0	.82	2.89	2.89	20.00	17.11	0	.11	.21	.32	.43	.54	.64	.72	.78	.82
12A	66.61	1.16	2.21	2.89	2.89	20.00	17.11										
13	72.10	1.68	2.72	2.85	2.87	20.00	17.13										
14	77.65	2.20	3.19	2.73	2.82	20.00	17.18										
15	83.20	2.73	3.66	2.56	2.73	20.00	17.27										
16	88.74	3.25	4.10	2.35	2.60	20.00	17.40										
17	94.29	3.78	4.53	2.05	2.42	20.00	17.58										
18	99.84	4.30	4.91	1.69	2.23	20.00	17.77										
19	105.38	4.82	5.26	1.21	1.97	20.00	18.03										
20	110.93	5.35	5.59	.62	1.67	20.00	18.33										
SP	115.73	5.80	5.80	0	1.38	20.00	18.62										
21	116.48	6.66			1.33	20.00	18.67										
22	122.03	12.36			.98	20.00	19.02										
23	127.58	16.43			.58	20.00	19.42										
AP	132.22	18.90			.23	20.00	19.77										

Radius and half maximum beam

Straight line

Angle of chine flare

Buttock

Line of centers

Hull height at CL

Straight line

Keel above BL

Chine above BL

Half-beam at chine

Forebody   Afterbody   Tail extension

NACA

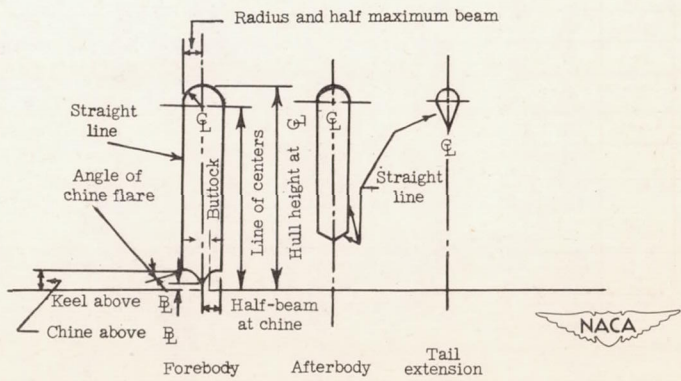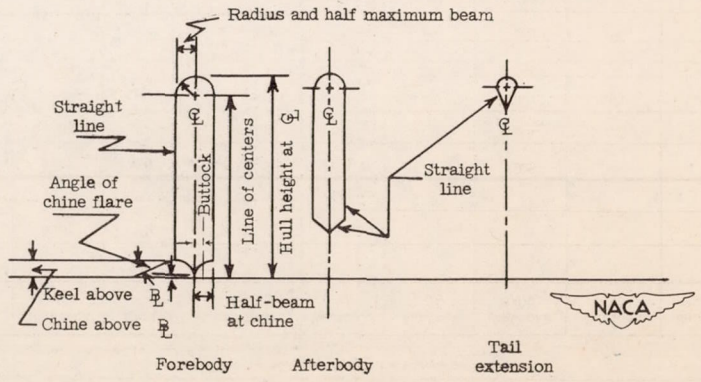## TABLE II

OFFSETS FOR LANGLEY TANK MODEL 240 (L/b = 30)

[All dimensions are in inches]

Station	Distance to forward perpendicular	Keel above BL	Chine above BL	Half-beam at chine	Radius and half maximum beam	Height of hull at CL	Line of centers above BL	Angle of chine flare (deg)	Forebody bottom, heights above BL, (in.)								
									Buttock 0.22	Buttock 0.45	Buttock 0.65	Buttock 0.90	Buttock 1.12	Buttock 1.34	Buttock 1.57	Buttock 1.79	Buttock 2.02
F.P.	0	10.30	10.30	0	0	11.00	11.00										
1/2	3.18	5.49	6.75	1.03	1.03	14.29	13.26	10	5.93	6.39	6.68	6.76					
1	6.35	3.76	5.08	1.37	1.37	15.72	14.35	10	4.10	4.45	4.80	5.02	5.11	5.09			
2	12.70	1.83	3.07	1.73	1.73	17.36	15.63	10	2.09	2.34	2.59	2.81	2.97	3.07	3.09		
3	19.04	.80	1.89	1.94	1.94	18.41	16.47	10	.98	1.18	1.36	1.56	1.72	1.83	1.90	1.91	
4	25.39	.27	1.21	2.07	2.07	19.12	17.05	10	.41	.56	.71	.86	1.00	1.11	1.19	1.23	1.22
5	31.74	.04	.83	2.15	2.15	19.60	17.45	10	.15	.27	.38	.49	.60	.70	.78	.84	.85
6	38.09	0	.68	2.19	2.19	19.88	17.69	5	.09	.18	.26	.35	.44	.53	.60	.65	.68
7	44.43	0	.63	2.21	2.21	19.99	17.78	0	.08	.16	.25	.33	.41	.49	.55	.60	.63
8	50.78	0	.63	2.21	2.21	20.00	17.79	0	.08	.16	.25	.33	.41	.49	.55	.60	.63
9	57.13	0	.63	2.21	2.21	20.00	17.79	0	.08	.16	.25	.33	.41	.49	.55	.60	.63
10	63.48	0	.63	2.21	2.21	20.00	17.79	0	.08	.16	.25	.33	.41	.49	.55	.60	.63
11	69.82	0	.63	2.21	2.21	20.00	17.79	0	.08	.16	.25	.33	.41	.49	.55	.60	.63
12F	76.23	0	.63	2.21	2.21	20.00	17.79	0	.08	.16	.25	.33	.41	.49	.55	.60	.63
12A	76.23	1.16	1.96	2.21	2.21	20.00	17.79										
13	82.52	1.75	2.54	2.17	2.19	20.00	17.81										
14	88.87	2.35	3.11	2.08	2.14	20.00	17.86										
15	95.21	2.95	3.66	1.95	2.05	20.00	17.95										
16	101.56	3.55	4.20	1.79	1.92	20.00	18.08										
17	107.91	4.15	4.72	1.56	1.75	20.00	18.25										
18	114.26	4.75	5.22	1.29	1.52	20.00	18.48										
19	120.66	5.35	5.68	.92	1.27	20.00	18.73										
20	126.95	5.95	6.12	.48	.98	20.00	19.02										
SP	132.45	6.47	6.47	0	.71	20.00	19.29										
21	133.30	8.05			.66	20.00	19.34										
22	139.65	17.90			.20	20.00	19.80										
AP	141.84	19.66			.17	20.00	19.83										

Radius and half maximum beam — Straight line — Angle of chine flare — Buttock — Line of centers — Hull height at CL — Straight line — Keel above BL — Chine above BL — Half-beam at chine — Forebody — Afterbody — Tail extension — NACA

TABLE III

VOLUMES AND AREAS OF FAMILY OF LENGTH-BEAM-RATIO HULLS

Langley tank model	Length beam	Volume (cu in.)	Surface area (sq in.)	Maximum cross-sectional area (sq in.)	Side area (sq in.)
213	6	14,831	4540	226	1639
203	9	12,916	4581	182	1752
214	12	11,528	4654	150	1870
224	15	10,653	4760	130	1985
239	20	9,705	4993	109	2127
240	30	8,367	5328	85	2340

NACA
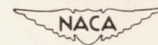
TABLE IV

MINIMUM DRAG COEFFICIENTS AND STABILITY PARAMETERS WITH WING INTERFERENCE

FOR LANGLEY TANK MODELS OF THE LENGTH-BEAM-RATIO INVESTIGATION

Model	L/b	$C_{D_{min}}$		C_{m_α}		K_f		C_{Y_ψ}		C_{n_ψ}		$\partial c_n/\partial\beta$		$\partial c_{n_f}'/\partial\psi$	
			(1)		(1)		(1)	α = 2	α = 6	α = 2	α = 6	α = 2	α = 6	α = 2	α = 6
213	6	0.0072	0.0093	0.0057	0.0061	0.77	0.82	0.0048	0.0048	0.0009	0.0008	-0.099	-0.081	0.021	0.017
203	9	.0062	.0079	.0045	.0049	.99	1.07	.0051	.0050	.0012	.0010	-.100	-.088	.027	.023
214	12	.0056	.0072	.0037	.0040	1.14	1.23	.0051	.0051	.0013	.0012	-.100	-.115	.034	.040
224	15	.0053	.0068	.0033	.0031	1.32	1.24	.0051	.0051	.0014	.0013	-.101	-.126	.041	.052
239	20	.0050	.0066	.0030	.0024	1.68	1.46	.0055		.0015		-.078		.040	
240	30	.0049	.0066	.0024	.0017	2.16	1.62	.0065		.0017		-.073		.051	

[1]Hull without wing interference.
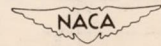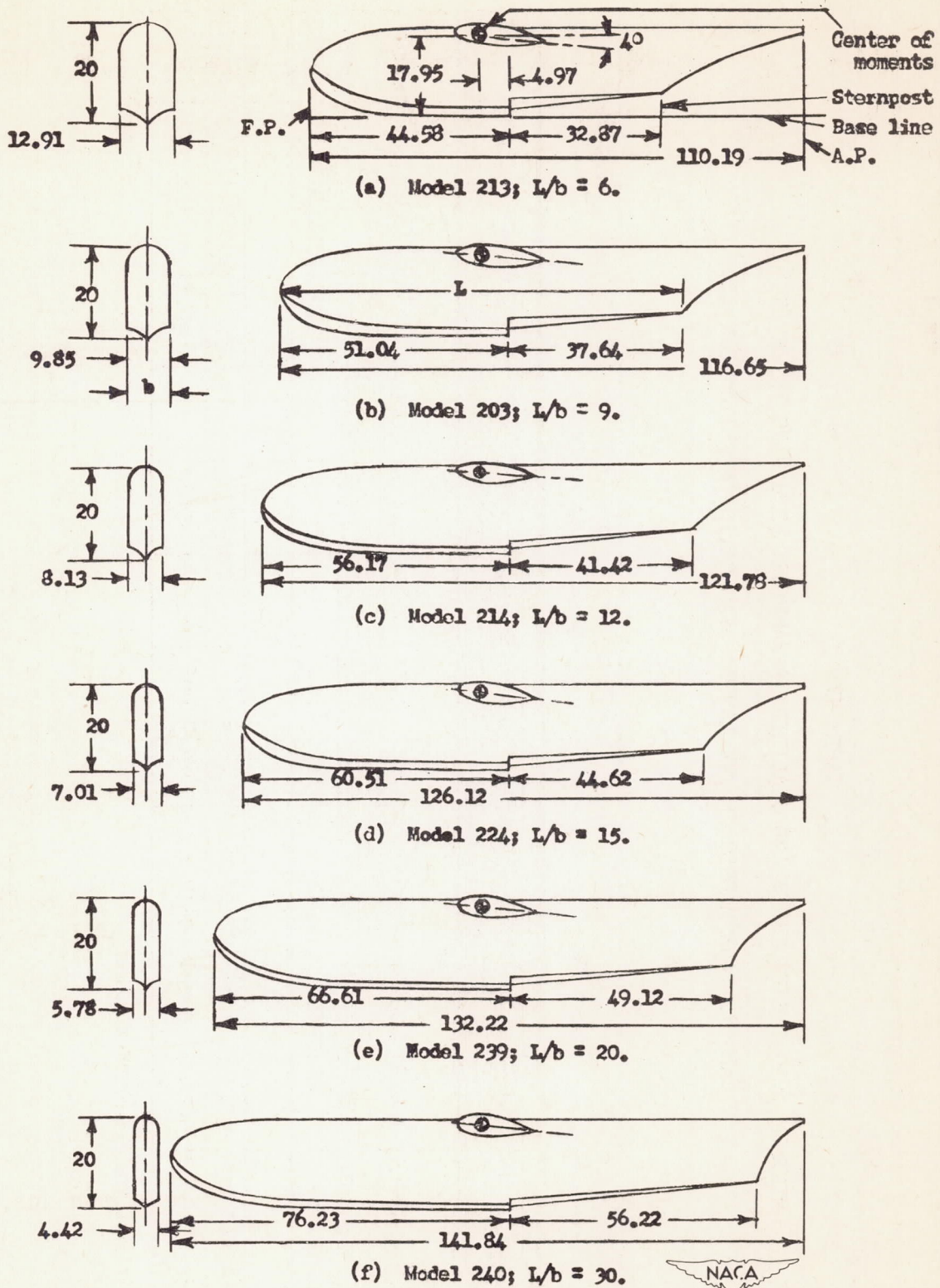
Figure 1.- Hulls of the Langley 300 MPH 7- by 10-foot-tunnel length-beam-ratio investigation. (All dimensions are in inches.)
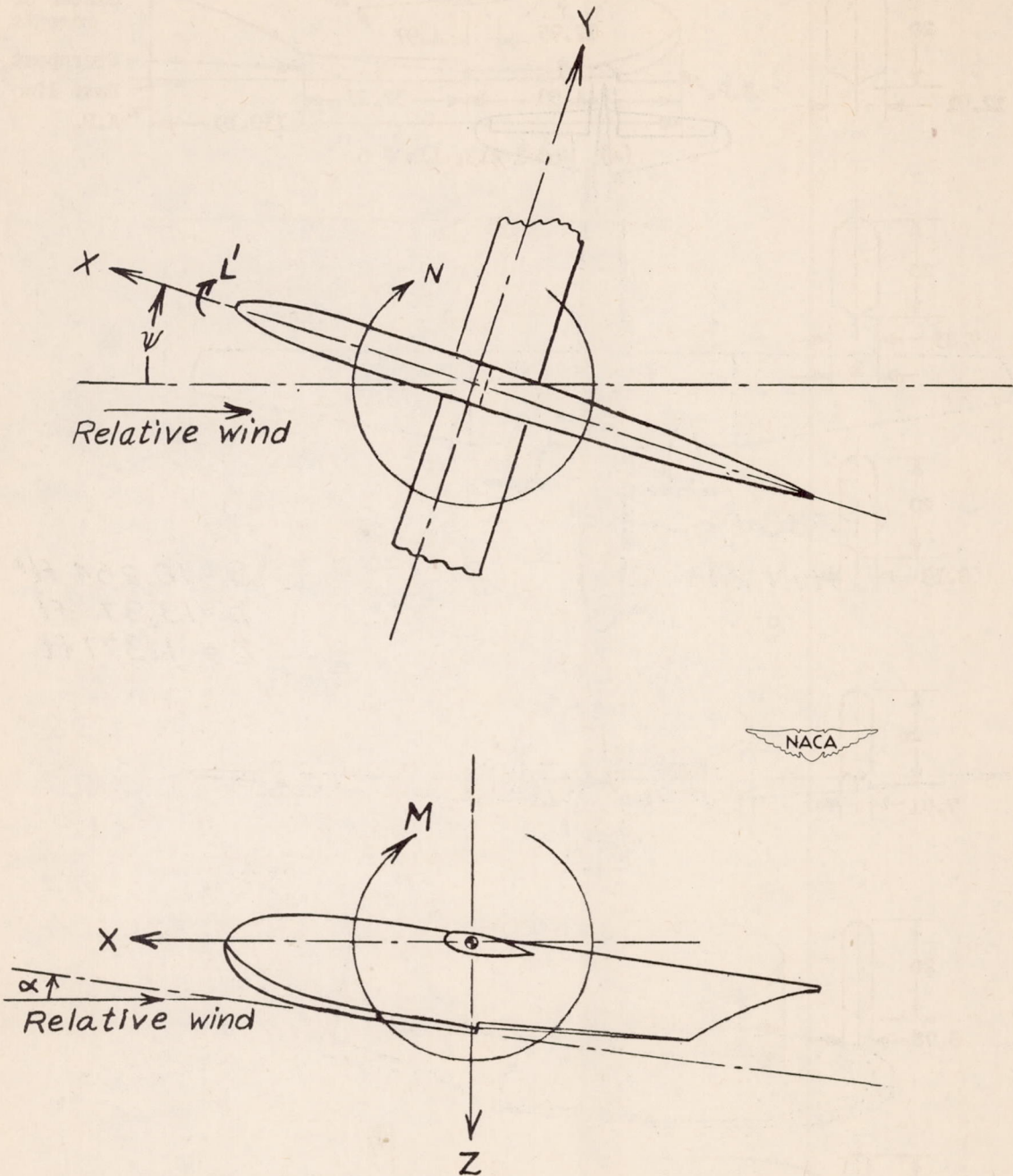
Figure 2.- System of stability axes. Positive directions of forces, moments, and angles are indicated by arrows.

XPBB-1

Hull 203
$h/b = 9$

$S = 18.264\ ft^2$
$b = 13.97\ ft$
$\bar{c} = 1.377\ ft$

NACA
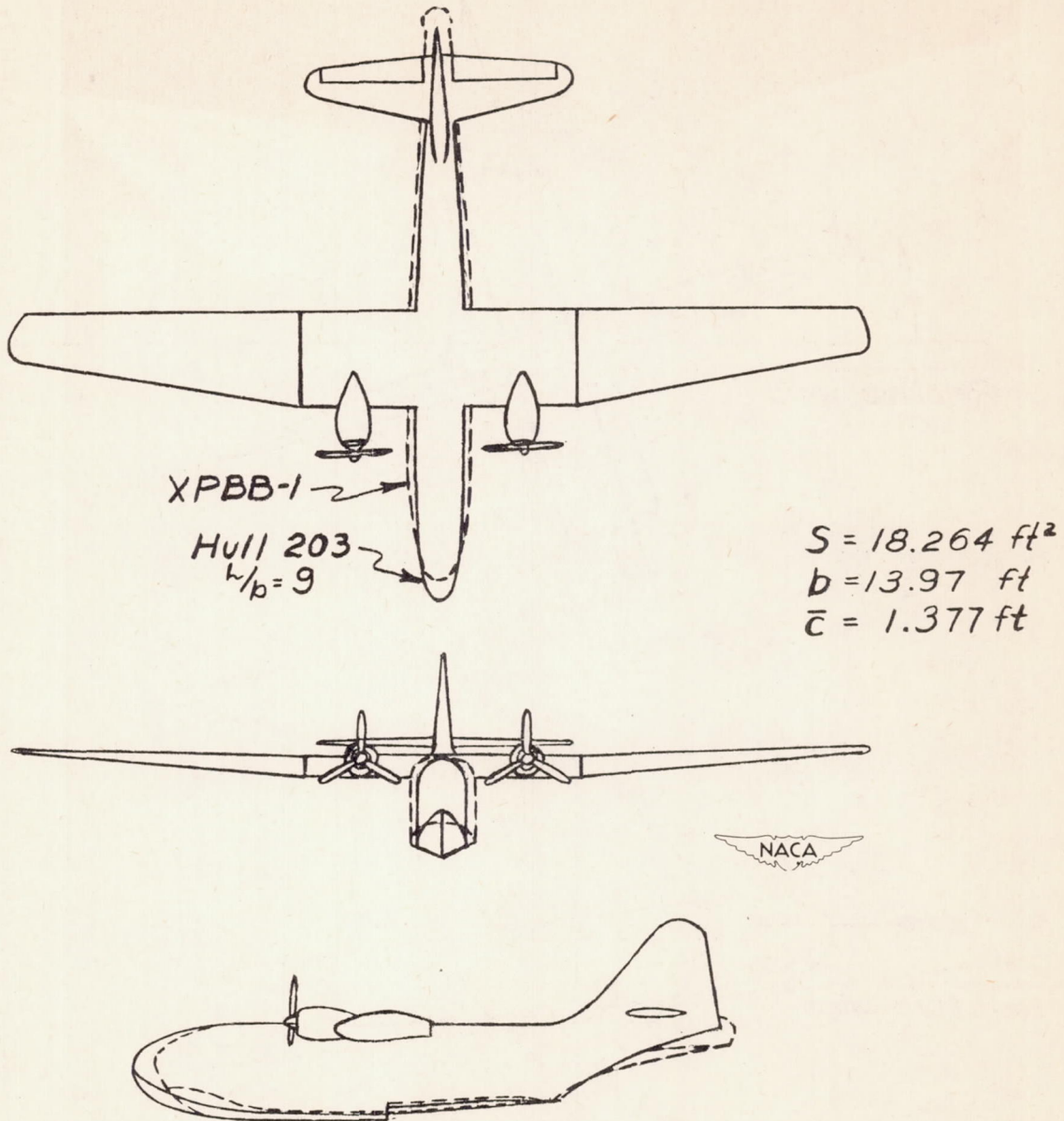
Figure 3.- Comparison of $\frac{1}{10}$-scale models of the XPBB-1 flying boat and
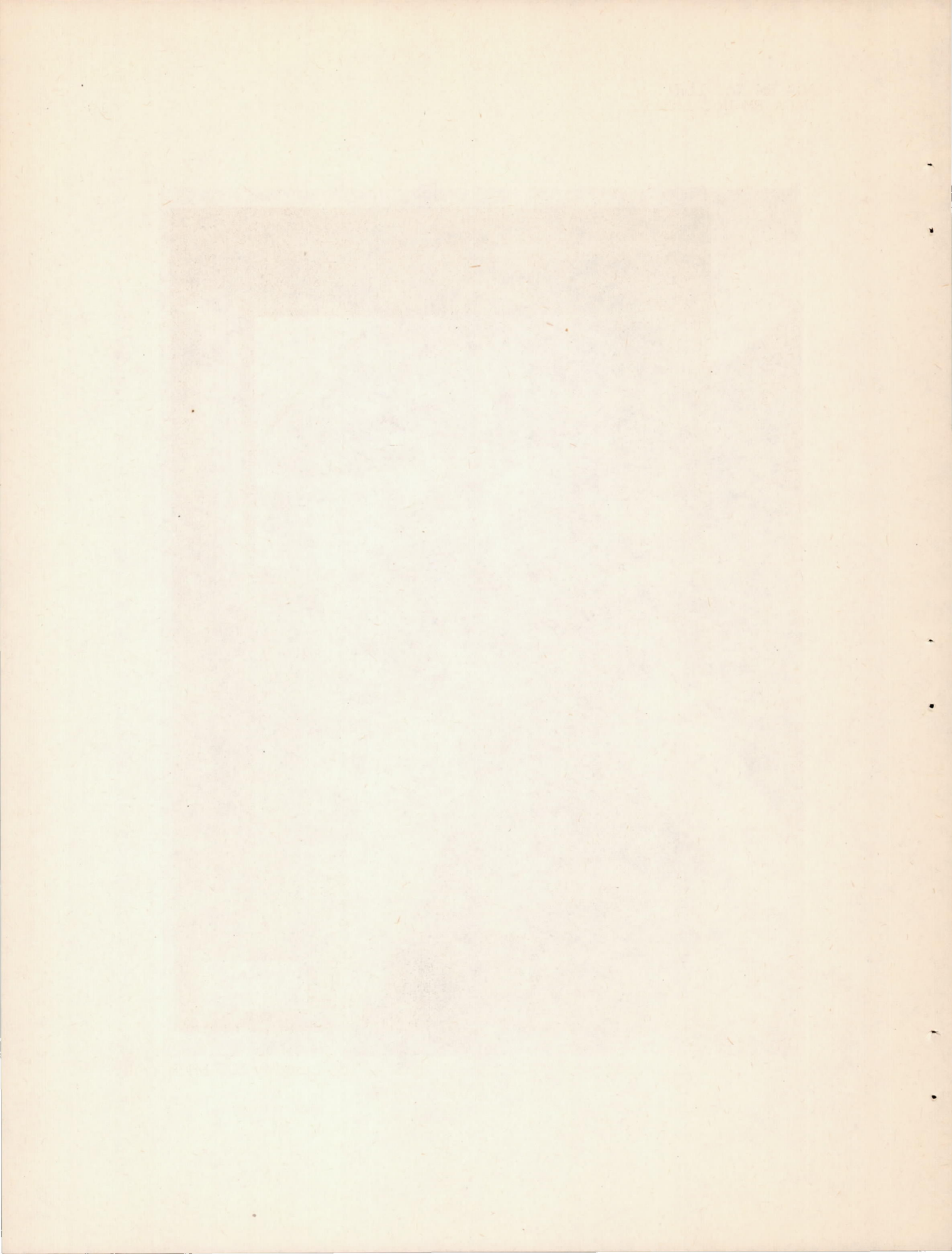hypothetical flying boat incorporating hull 203.
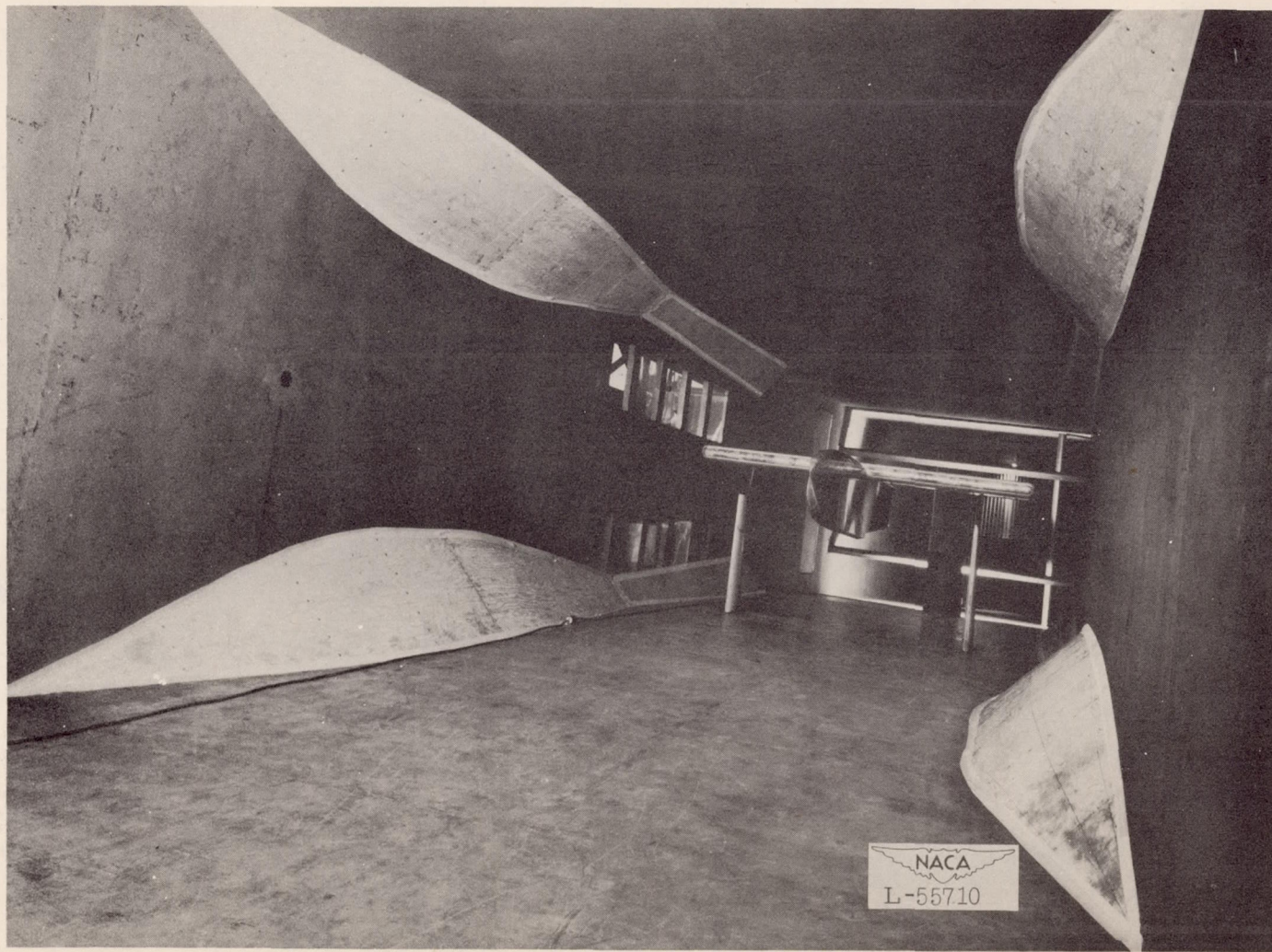
Figure 4.- Langley tank model 240 mounted in altered test section of the Langley 300 MPH 7- by 10-foot tunnel.
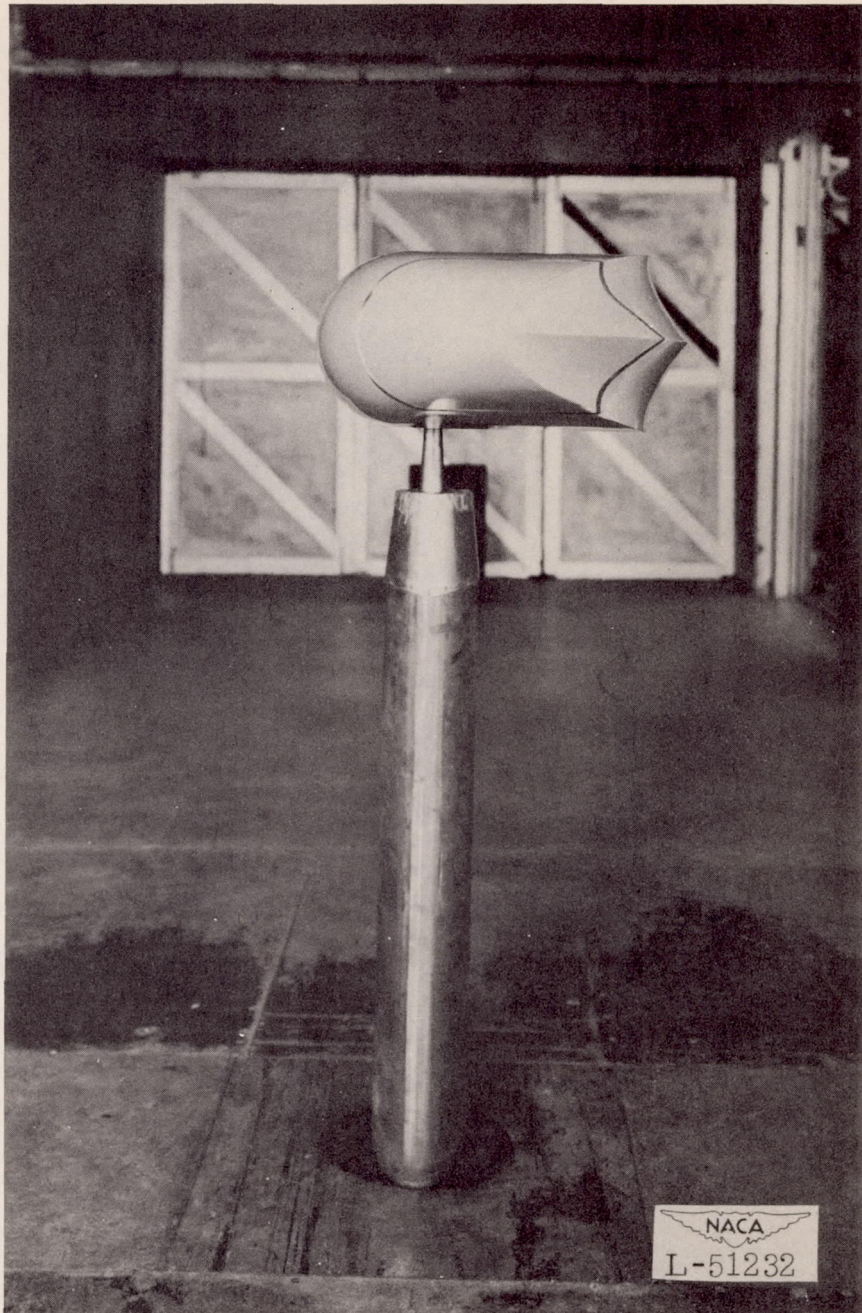
Figure 5.- Hull mounted on single support strut in the Langley 300 MPH 7- by 10-foot tunnel.
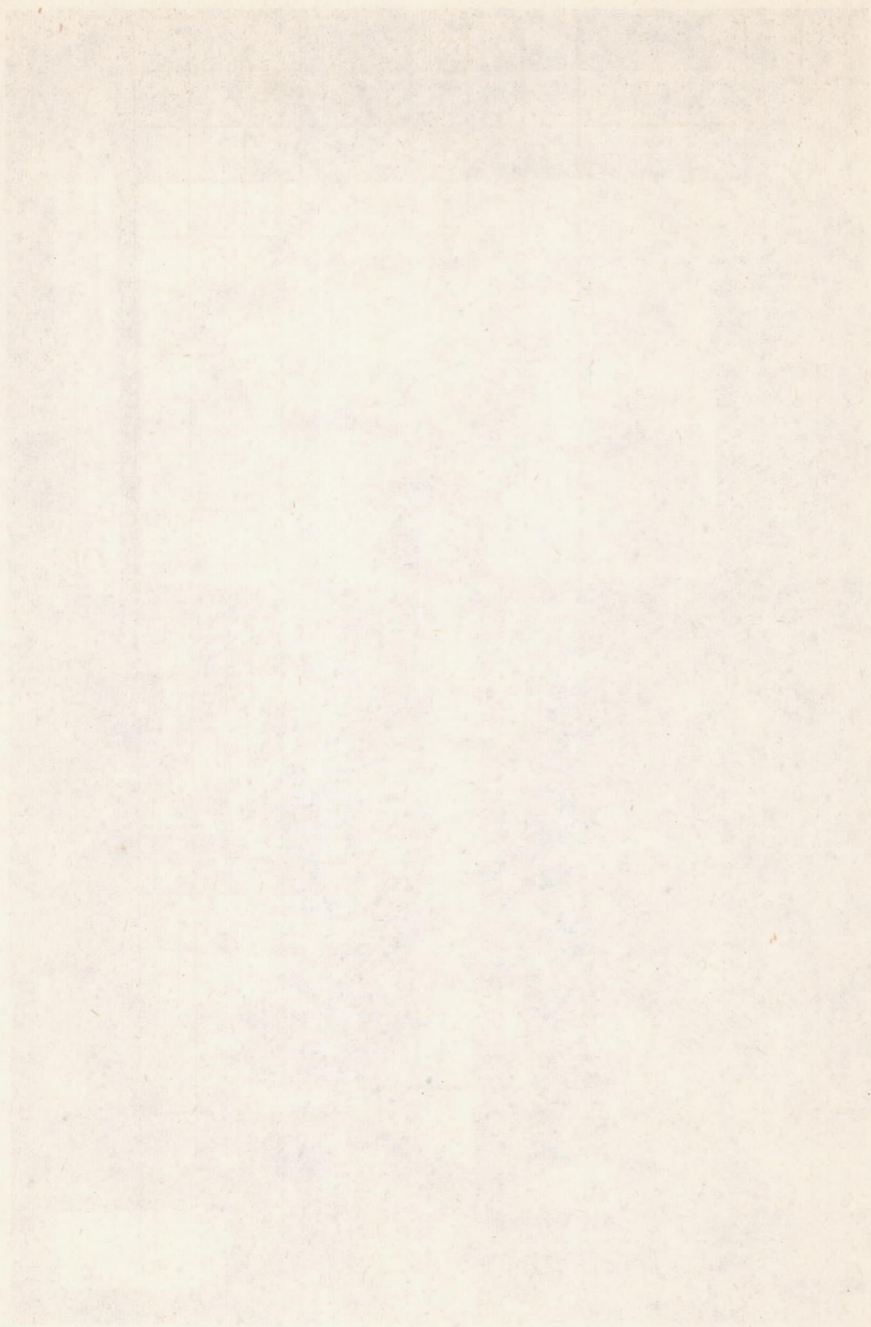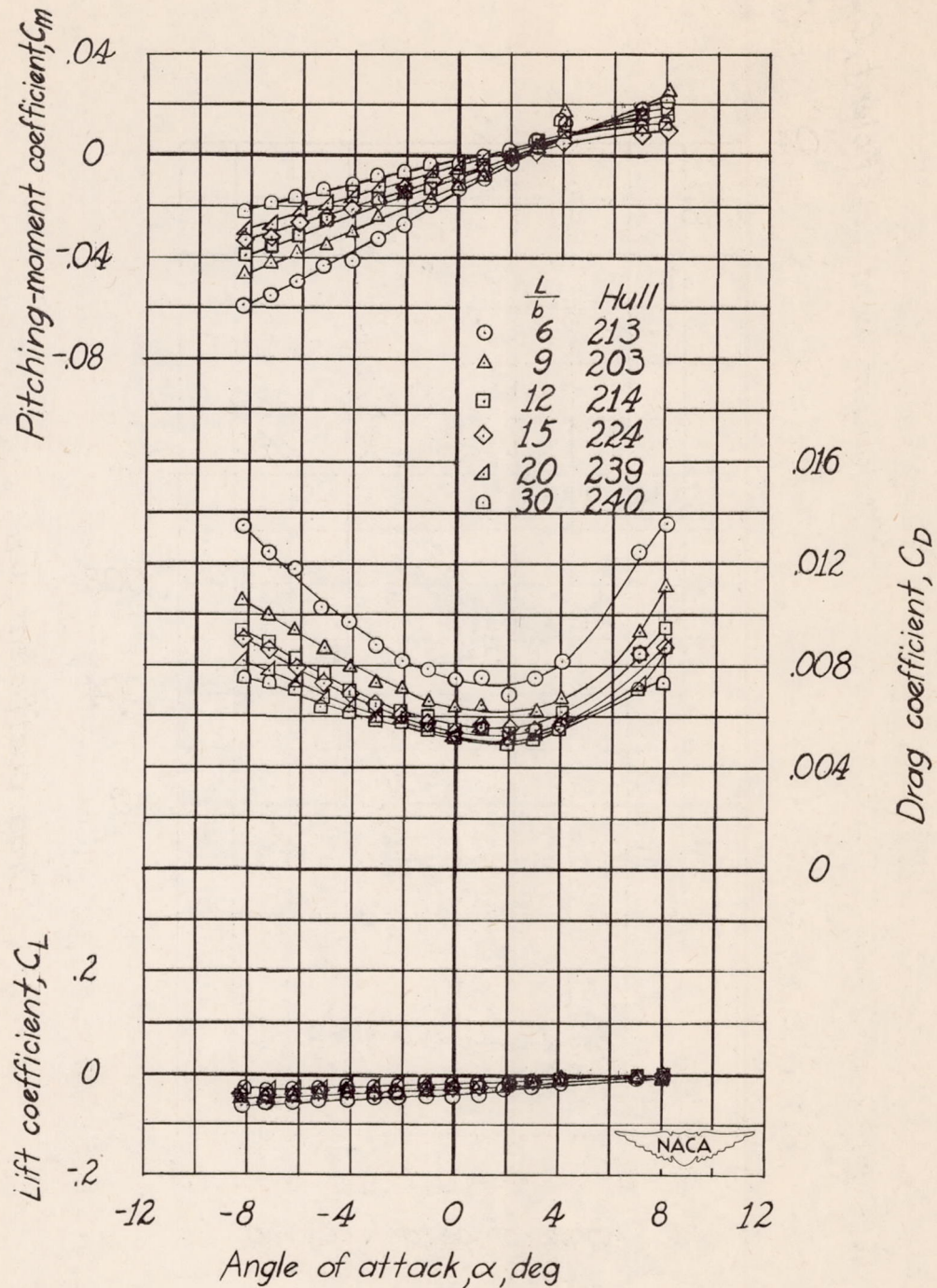
(a) $R \approx 2.5 \times 10^6$.

Figure 6.- Aerodynamic characteristics in pitch of flying-boat hulls with wing
interference of length-beam ratios ranging from 6 to 30.
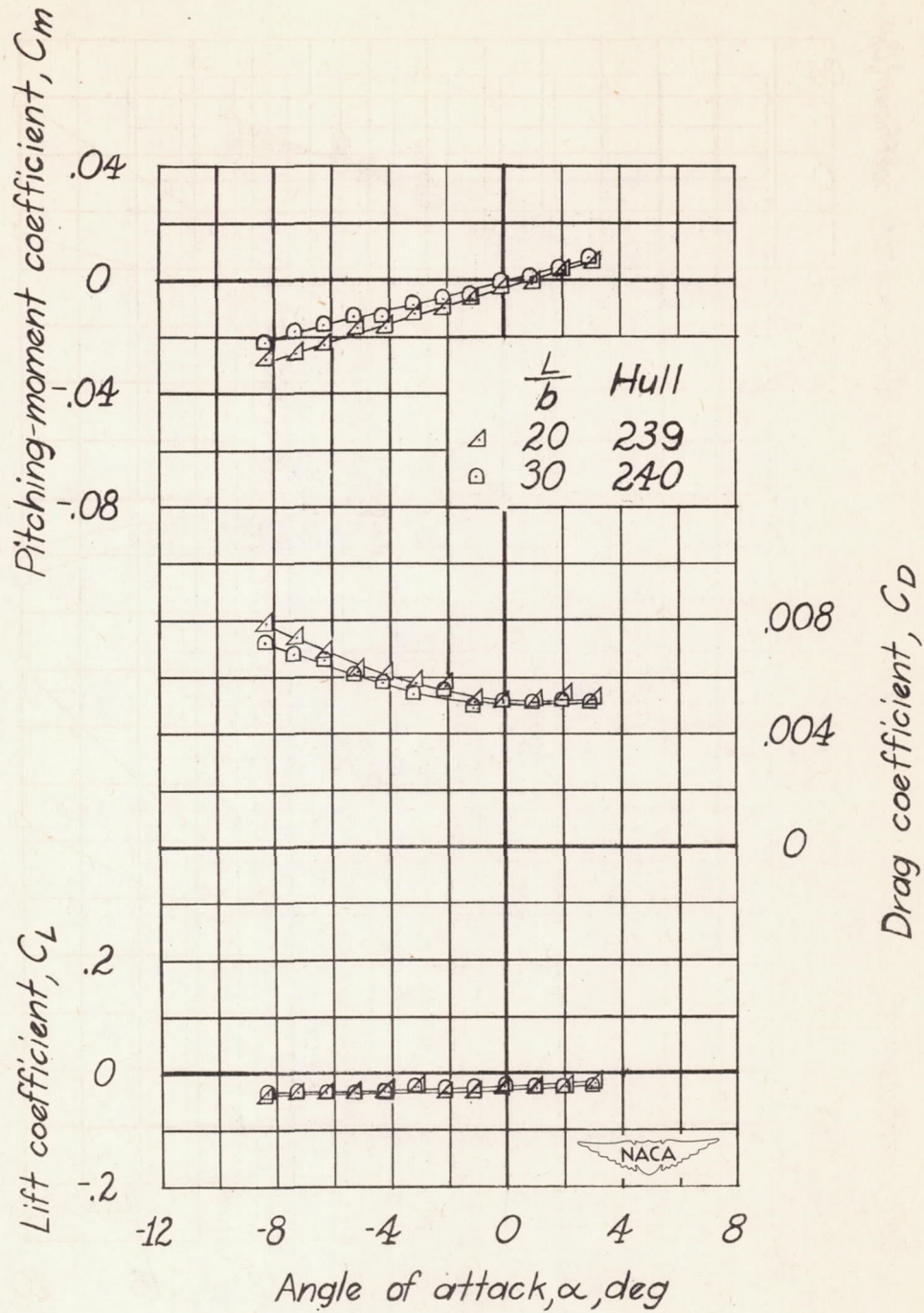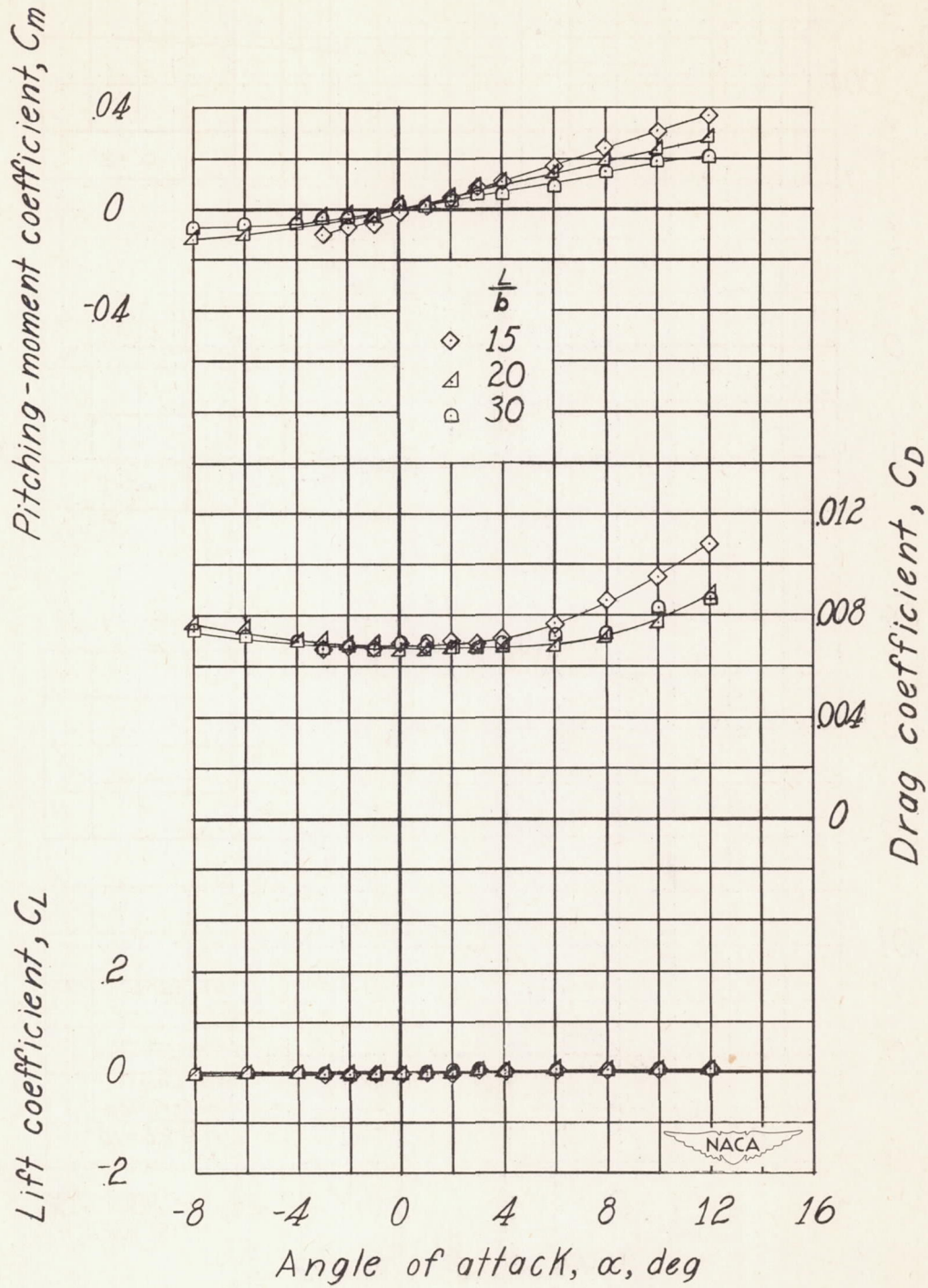
(b) R $\approx 2.9 \times 10^6$.

Figure 6.- Concluded.
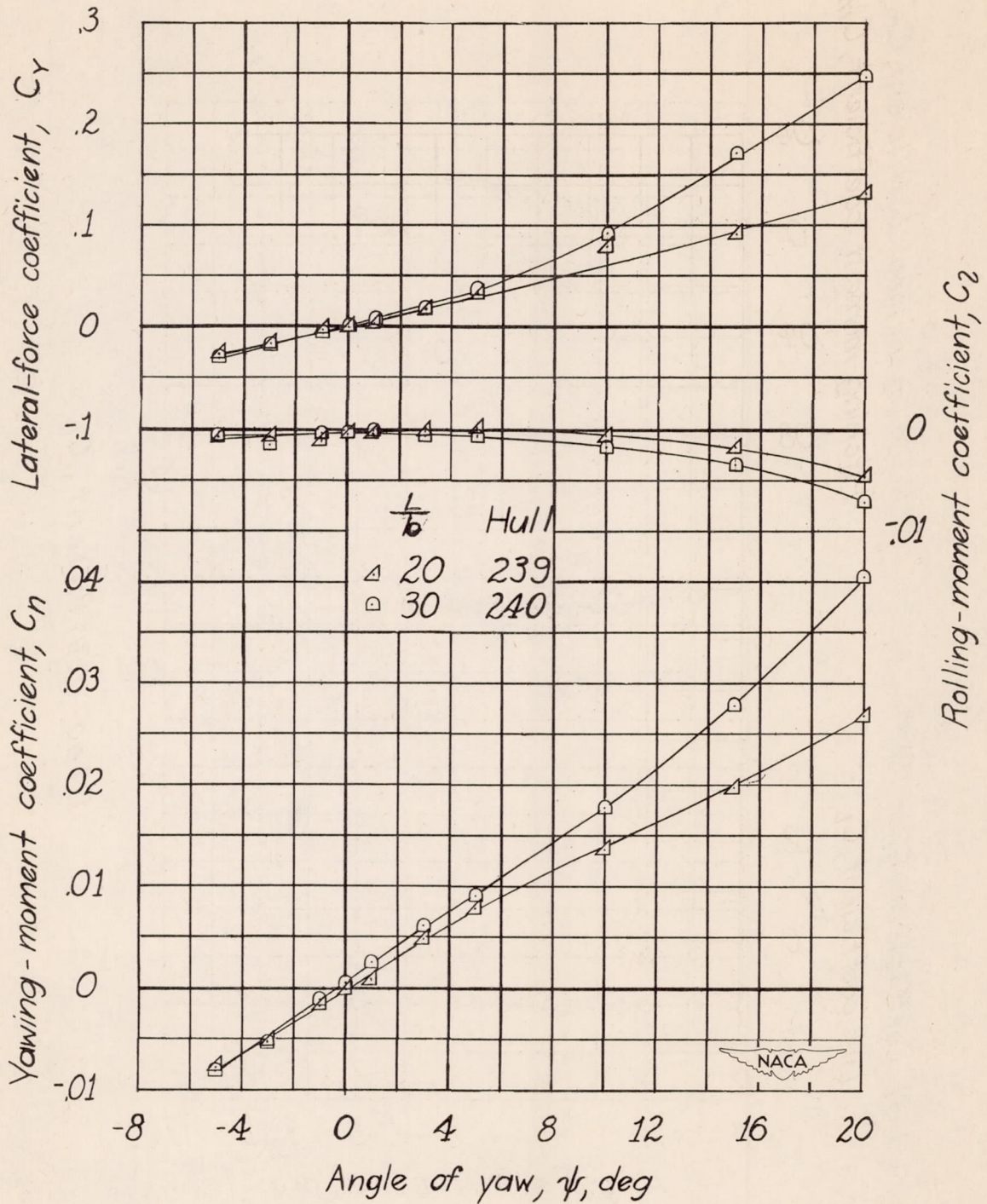
Figure 7.- Aerodynamic characteristics in yaw of flying-boat hulls with wing interference of length-beam ratios 20 and 30. $\alpha = 2^{o}$; R $\approx$ 1.3 $\times$ 10^{6}.

Figure 8.- Aerodynamic characteristics in pitch of flying-boat hulls without
wing interference of length-beam ratios 15, 20, and 30. $\alpha = 2^{\circ}$;
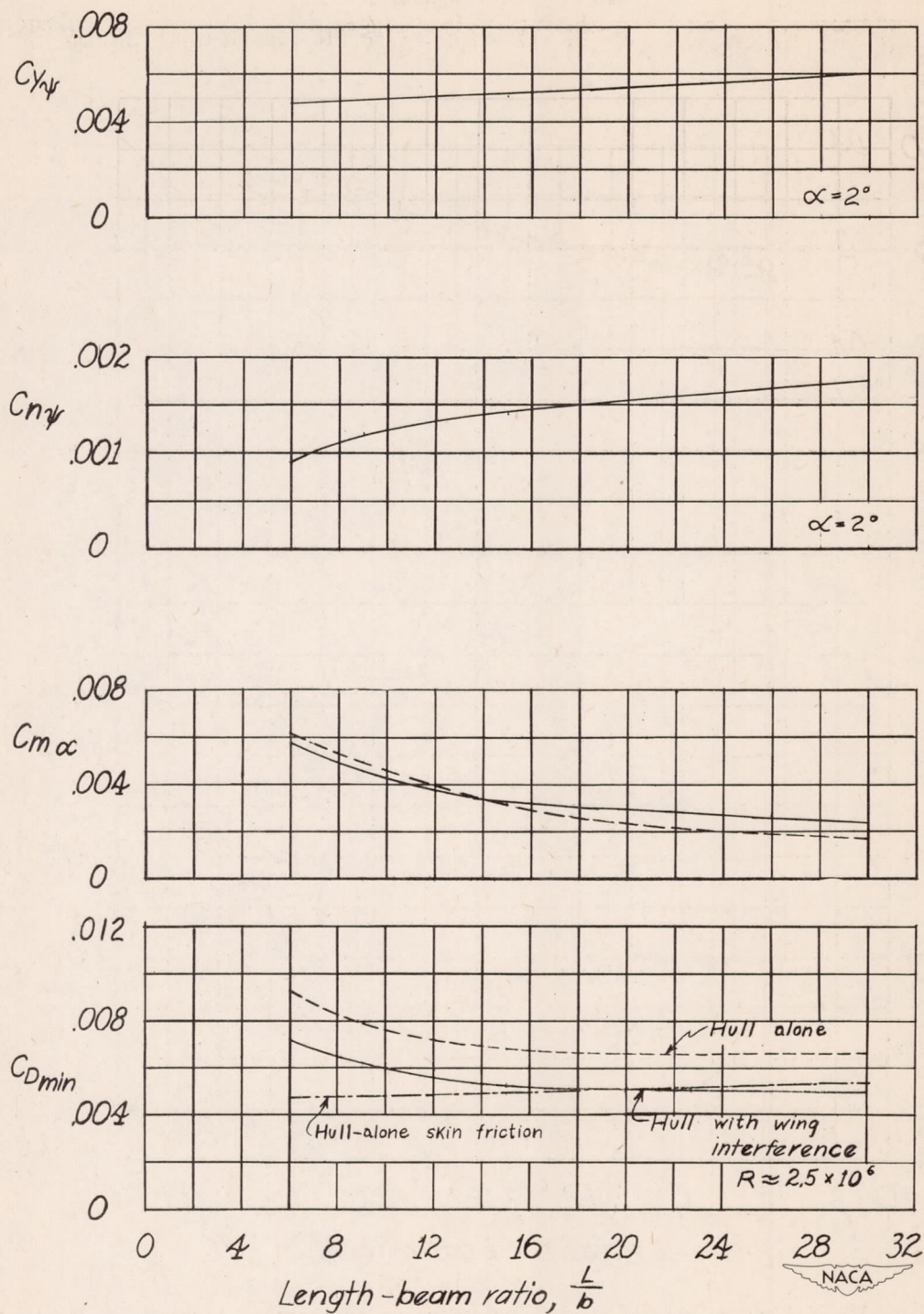R ≈ 2.9 × 10^6.

Figure 9.- Effect of hull length-beam ratio on $C_{D_{min}}$ and the parameters C_{m_α}, C_{n_ψ}, and C_{Y_ψ}.
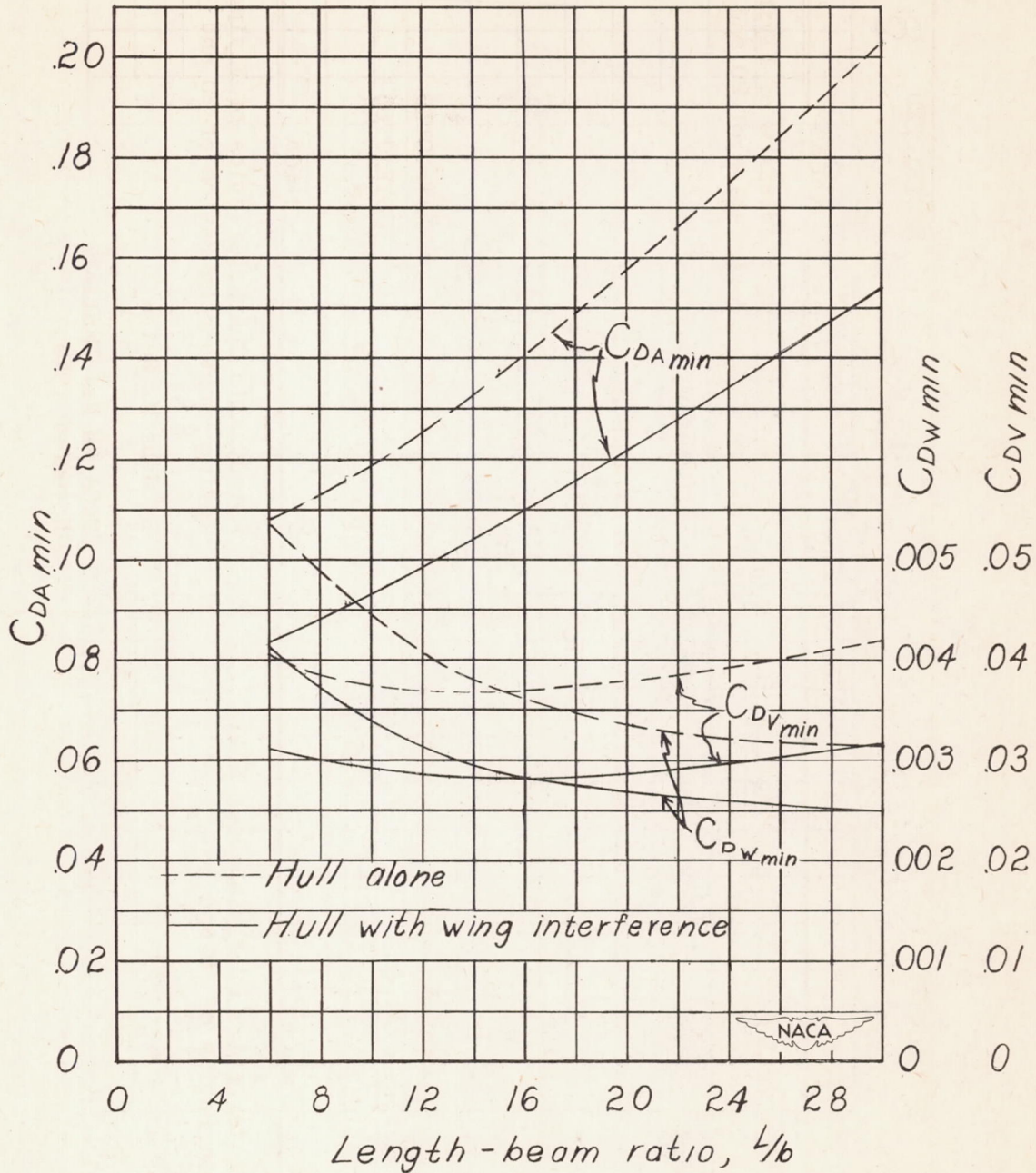
Figure 10.- Effect of hull length-beam ratio on minimum drag coefficients $C_{DA_{min}}$, $C_{DV_{min}}$, $C_{DW_{min}}$. $R \approx 2.5 \times 10^6$.