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RESEARCH MEMORANDUM

for the

Bureau of Aeronautics, Navy Department

AERODYNAMIC CHARACTERISTICS OF A FLYING-BOAT HULL HAVING A LENGTH-BEAM RATIO OF 15

TED No. NACA 2206

By

John M. Riebe and Rodger L. Naeseth

Langley Memorial Aeronautical Laboratory
Langley Field, Va.

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RESEARCH MEMORANDUM

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AERODYNAMIC CHARACTERISTICS OF A FLYING-BOAT HULL HAVING A LENGTH-BEAM RATIO OF 15

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SUMMARY

An investigation was made in the Langley 300 MPH 7- by 10-foot tunnel to determine the aerodynamic characteristics of a flying-boat hull of a length-beam ratio of 15 in the presence of a wing. The investigation was an extension of previous tests made on hulls of length-beam ratios of 6, 9, and 12; these hulls were designed to have approximately the same hydrodynamic performance with respect to spray and resistance characteristics.

Comparison with the previous investigation at lower length-beam ratios indicated a reduction in minimum drag coefficient of 0.0006 (10 percent) with fixed transition when the length-beam ratio was extended from 12 to 15. As with the hulls of lower length-beam ratio, the drag reduction with a length-beam ratio of 15 occurred throughout the range of angle of attack tested and the angle of attack for minimum drag was in the range from 2° to 3°. Increasing the length-beam ratio from 12 to 15 reduced the hull longitudinal instability by an amount corresponding to an aerodynamic-center shift of about $\frac{1}{2}$ percent of the mean aerodynamic chord of the hypothetical flying boat. At an angle of attack of 2°, the value of the variation of yawing-moment coefficient with angle of yaw for a length-beam ratio of 15 was 0.00144, which was 0.00007 larger than the value for a length-beam ratio of 12.

INTRODUCTION

In view of the requirements for increased range and increased speed in flying-boat designs, the Bureau of Aeronautics, Navy Department,

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has requested an investigation of the aerodynamic characteristics of flying-boat hulls as affected by hull dimensions and hull shape.

One phase of this investigation, the effect of length-beam ratio on a series of hulls designed to have no appreciable change in hydrodynamic performance with respect to spray and resistance characteristics, has been presented in reference 1. The results of the investigation have shown that substantial drag reductions can be attained by extending length-beam ratios up to the highest value tested, namely, 12, and has indicated that further drag reductions might be obtained at still higher length-beam ratios.

The present investigation, made in the Langley 300 MPH 7- by 10-foot tunnel, is an extension of the models of the series of reference 1 to a length-beam ratio of 15 (Langley tank model 224). As in the investigation of reference 1, the drag and stability parameters include the effects of wing interference. Throughout the present paper the term "hull aerodynamic characteristics" is used to indicate hull aerodynamic characteristics with 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 location (wing 30-percent-chord point) shown in figure 1. Except where noted, the wing area, the mean aerodynamic chord, and the span of a hypothetical flying boat derived from the XPBB-1 flying boat (fig. 2) are used in determining the coefficients and Reynolds numbers. The data are referred to the stability axes, which are a system of axes having their 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 3.

The coefficients and symbols are defined as follows:

C_L lift coefficient $\left(\frac{\text{Lift}}{qS}\right)$

C_D drag coefficient $\left(\frac{\text{Drag}}{qS}\right)$

C_Y lateral-force coefficient $\left(\frac{Y}{qS}\right)$

C_l	rolling-moment coefficient $\left(\frac{L}{qbS}\right)$
C_m	pitching-moment coefficient $\left(\frac{M}{qcS}\right)$
C_n	yawing-moment coefficient $\left(\frac{N}{qbS}\right)$
Lift	$-Z$
Drag	$-X$ when $\psi = 0$
X, Y, Z	forces along X, Y, and Z stability axes, respectively, pounds
L	rolling moment, about X axis, foot-pounds
M	pitching moment, about Y axis, foot-pounds
N	yawing moment, about Z axis, foot-pounds
q	free-stream dynamic pressure, pounds per square foot $\left(\frac{\rho V^2}{2}\right)$
S	wing area of a $\frac{1}{10}$-scale model of a hypothetical flying boat (18.264 sq ft) (fig. 2)
c	wing mean aerodynamic chord of a $\frac{1}{10}$-scale model of a hypothetical flying boat (1.377 ft) (fig. 2)
b	wing span of a $\frac{1}{10}$-scale model of a hypothetical flying boat (13.971 ft) (fig. 2)
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
L/B	length-beam ratio where L is distance from forward perpendicular (F.P.) to sternpost and B is the maximum beam (fig. 1)
R	Reynolds number, based on wing mean aerodynamic chord of a $\frac{1}{10}$-scale model of a hypothetical flying boat

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

$C_{D_{V_{min}}}$ minimum drag coefficient based on $(volume)^{2/3}$ of hull $\left(\frac{Drag}{q(volume)^{2/3}}\right)$

$C_{D_{W_{min}}}$ minimum drag coefficient based on surface area, W, of hull $\left(\frac{Drag}{qW}\right)$

C_{m_α} rate of change of pitching-moment coefficient with angle of attack of hull base line $\left(\frac{\partial C_m}{\partial \alpha}\right)$

C_{n_ψ} rate of change of yawing-moment coefficient with angle of yaw $\left(\frac{\partial C_n}{\partial \psi}\right)$

C_{Y_ψ} rate of change of lateral-force coefficient with angle of yaw $\left(\frac{\partial C_Y}{\partial \psi}\right)$

Subscript:

min minimum

MODEL AND APPARATUS

The hull used in the present tests was designed by the Langley Hydrodynamics Division. Dimensions of the hull are given in figure 1 and in table I. Hull model 224 is an extension of the series previously reported in reference 1. The present hull model (224) and the hulls of reference 1 were derived from a hypothetical flying boat essentially similar to the Boeing XPBB-1 when incorporating Langley tank model 203 (fig. 2). The geometry of these hulls was varied in a manner to allow no appreciable change in hydrodynamic performance with respect to spray and resistance characteristics (references 2 and 3).

The volume, the surface area, and the maximum cross-sectional area of the hull were 10,653 cubic inches, 4760 square inches, and 130.2 square inches, respectively. The side area was 1985 square inches.

The hull was constructed of laminated mahogany and was finished with pigmented varnish. A photograph of the model is given in figure 4.

The hull was attached to a wing which was mounted in the tunnel horizontally, as shown in figure 5. The wing, which was the same wing used in the investigation of reference 1, was set at an angle of incidence of 4° on the model, had a 20-inch chord, and was of the NACA 4321 section.

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 165 pounds per square foot, which correspond to airspeeds of about 100, 200, and 268 miles per hour, respectively. Reynolds numbers for these airspeeds, based on the mean aerodynamic chord of the hypothetical flying boat, were approximately 1.20, 2.26, and 2.97×10^{6}, respectively. Corresponding Mach numbers were 0.13, 0.27, and 0.34, respectively.

Corrections

Blocking corrections have been applied to the wing and the wing-hull data. The hull drag has been corrected for horizontal buoyancy effects caused by a tunnel static-pressure gradient. Angles of attack have been corrected for structural deflections caused by aerodynamic forces.

Test Procedure

All the tests were made with the wing mounting setup as shown in figure 5. The aerodynamic characteristics of the hulls with interference of the mounting wing were determined by testing the wing alone and the wing and hull combination of the wing and hull under identical conditions. The hull aerodynamic coefficients were thus determined by subtraction of coefficients of the wing alone from coefficients of the wing and hull combined.

In order 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 of the airfoil chord measured along the airfoil contour from the leading edge on both upper and lower surfaces.

Hull transition for all the tests was fixed by a strip of 0.008-inch-diameter carborundum particles $\frac{1}{2}$-inch wide and located approximately 5 percent of the hull length aft of the bow.

RESULTS AND DISCUSSION

The variation of the aerodynamic characteristics of hull model 224 with angle of attack is presented in figure 6; the variation with angle of yaw is given in figure 7.

In order to compare the aerodynamic characteristics of hull model 224 ($L/B = 15$) with the aerodynamic characteristics of the models having lower values of L/B, the minimum drag coefficients and stability parameters C_{m_α}, C_{n_ψ}, and C_{Y_ψ} are plotted together with data from reference 1 in figure 8. The data show a 10-percent reduction ($\Delta C_{D_{min}} = 0.0006$) in minimum drag coefficient when the value of L/B is extended from 12 to 15.

Comparison of figure 6 with data of reference 1 indicates that the reduction in drag resulting from extension of the length-beam ratio to 15 generally occurred throughout the range of angle of attack tested. With the hull of a length-beam ratio of 15, as with the hulls of lower values of L/B, the angle of attack for minimum drag occurred in the range of 2° to 3°. Because of structural limitations of the mounting wing, the data obtained at the higher Reynolds numbers were necessarily limited to the angle-of-attack range shown.

Estimates indicate that the skin friction of the hulls increases only slightly with increasing values of L/B. The reduction in hull drag is therefore caused primarily by a reduction in pressure drag. The analysis indicates that the lowest minimum drag coefficient for this series of hulls will probably occur at a length-beam ratio of about 18.

The increase of length-beam ratio to 15 decreased the hull longitudinal instability but caused an increase in directional instability. The decrease in longitudinal instability corresponds to an aerodynamic-center shift of about $\frac{1}{2}$ percent of the mean aerodynamic chord of the hypothetical flying boat. Estimates made in reference 1 have indicated that the geometry of the hulls probably accounted for most of the variation of C_{m_α} with L/B; therefore, wing interference had a negligible effect. At an angle of attack for minimum drag, that is, 2°, the directional instability measured by C_{n_ψ} for a value of L/B of 15 was 0.00144, which was 0.00007 larger than the

directional instability for a value of L/B of 12. Increasing the angle of attack to 6° had the same effect on C_{n_ψ} as in reference 1, that is, the value of C_{n_ψ} was decreased 0.00017. The parameter C_{Y_ψ} was affected only slightly by an increase in the length-beam ratio. As in reference 1, angle of attack had a negligible effect on C_{Y_ψ}.

For convenience, minimum drag coefficients and stability parameters are presented in table II. In order to compare the results of the present tests with investigations made of other hulls and fuselages, the parameters K_f, $dC_{n_f}'/d\psi$, and $dC_n/d\beta$, as given in references 4, 5, and 6, respectively, are included in this table. The parameter K_f is a fuselage moment factor, in the form of $dC_m/d\alpha$, based on hull beam and length, where α is in radians. The yawing-moment coefficient C_{n_f}' in the parameter $dC_{n_f}'/d\psi$ 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, where the yawing moment is also given about a reference axis 0.3 of the hull length from the nose and β, the angle of sideslip, is given in radians. Instability, as given by the parameter $\partial C_n/\partial\beta$, agreed closely with the hull values given in reference 6.

Values of $\partial C_{n_f}'/\partial\psi$ for the hull with a value of L/B of 15 are higher than representative values given in reference 5. This increase can be attributed to the reduced volume at the higher length-beam ratio as well as to the generally destabilizing effect of increasing length-beam ratio.

CONCLUSIONS

Tests were made in the Langley 300 MPH 7- by 10-foot tunnel to determine the aerodynamic characteristics of a flying-boat hull of length-beam ratio 15 in the presence of a wing. Comparison of the results of these tests with results of tests made on hulls of lower length-beam ratios of 6, 9, and 12 designed to have approximately the same spray and resistance characteristics indicated the following conclusions:

1. With transition fixed, the minimum drag coefficient of the hull of a length-beam ratio of 15 was 0.0006 (10 percent) less than that of the hull of a length-beam ratio of 12.

2. As with the hulls of lower length-beam ratio, the angle of attack for minimum drag for the hull of a length-beam ratio of 15 occurred in the range of 2° to 3°.

3. Increasing the length-beam ratio from 12 to 15 decreased the hull longitudinal instability by an amount corresponding to an aerodynamic-center shift of about $\frac{1}{2}$ percent of the mean aerodynamic chord of the hypothetical flying boat.

4. At an angle of attack of 2°, the value of the variation of yawing-moment coefficient with angle of yaw for a length-beam ratio of 15 was 0.00144, which was 0.00007 larger than the value for a length-beam ratio of 12.

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TABLE I

OFFSETS FOR LANGLEY TANK MODEL 224 ($\frac{L}{B}$ = 15)

[All dimensions are in inches]

[redacted]

Station	Distance to F.P.	Keel above B	Chine above B	Half beam at chine	Radius and half maximum beam	Height of hull at ℄	Line of centers above B	Angle of chine flare	Forebody bottom, heights above B								
									Butt 0.36 in.	Butt 0.71 in.	Butt 1.07 in.	Butt 1.42 in.	Butt 1.78 in.	Butt 2.13 in.	Butt 2.49 in.	Butt 2.85 in.	Butt 3.20 in.
F.P.	0	10.30	10.30	0	0	11.00	11.00										
½	2.52	5.49	7.49	1.64	1.64	14.29	12.65	10°	6.19	6.91	7.38	7.50					
1	5.04	3.76	5.86	2.18	2.18	15.72	13.54	10°	4.30	4.86	5.42	5.75	5.90	5.87			
2	10.08	1.83	3.79	2.75	2.75	17.36	14.61	10°	2.24	2.63	3.04	3.38	3.64	3.80	3.83		
3	15.12	.80	2.54	3.07	3.07	18.41	15.34	10°	1.09	1.40	1.70	2.00	2.26	2.44	2.54	2.57	
4	20.15	.27	1.76	3.28	3.28	19.12	15.84	10°	.50	.73	.97	1.20	1.42	1.60	1.74	1.80	1.77
5	25.19	.04	1.30	3.41	3.41	19.60	16.19	10°	.22	.40	.58	.75	.94	1.09	1.22	1.31	1.33
6	30.23	0	1.07	3.48	3.48	19.88	16.40	5°	.14	.28	.42	.56	.70	.84	.95	1.04	1.08
7	35.27	0	1.00	3.50	3.50	19.99	16.49	0°	.13	.26	.39	.52	.65	.78	.88	.95	1.00
8	40.31	0	1.00	3.505	3.505	20.00	16.49	0°	.13	.26	.39	.52	.65	.78	.88	.95	1.00
9	45.34	0	1.00	3.505	3.505	20.00	16.49	0°	.13	.26	.39	.52	.65	.78	.88	.95	1.00
10	50.38	0	1.00	3.505	3.505	20.00	16.49	0°	.13	.26	.39	.52	.65	.78	.88	.95	1.00
11	55.42	0	1.00	3.505	3.505	20.00	16.49	0°	.13	.26	.39	.52	.65	.78	.88	.95	1.00
12F	60.51	0	1.00	3.505	3.505	20.00	16.49	0°	.13	.26	.39	.52	.65	.78	.88	.95	1.00
12A	60.51	1.16	2.43	3.505	3.505	20.00	16.49										
13	65.50	1.63	2.89	3.45	3.48	20.00	16.52										
14	70.54	2.11	3.31	3.31	3.44	20.00	16.56										
15	75.58	2.58	3.71	3.10	3.35	20.00	16.65										
16	80.61	3.06	4.10	2.85	3.23	20.00	16.77										
17	85.65	3.54	4.44	2.48	3.07	20.00	16.93										
18	90.69	4.01	4.75	2.04	2.84	20.00	17.16										
19	95.73	4.49	5.02	1.46	2.58	20.00	17.42										
20	100.77	4.97	5.24	.75	2.29	20.00	17.71										
SP	105.13	5.38	5.38	0	2.00	20.00	18.00										
21	105.80	6.19			1.96	20.00	18.04										
22	110.84	11.17			1.59	20.00	18.41										
23	115.88	14.63			1.19	20.00	18.81										
24	120.92	17.09			.75	20.00	19.25										
25	125.96	18.84			.29	20.00	19.71										
A.P.	126.12	18.90			.28	20.00	19.72										

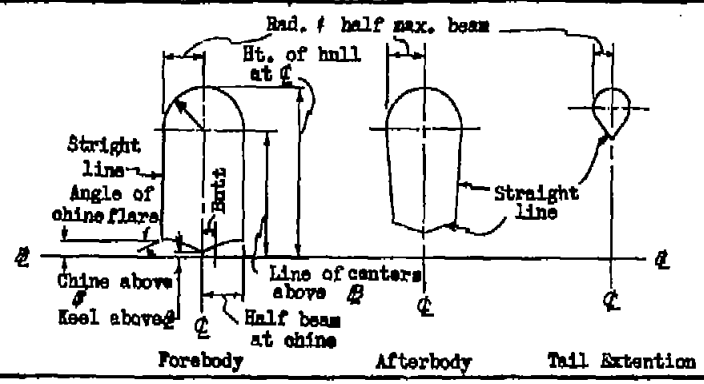

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TABLE II

MINIMUM DRAG COEFFICIENTS (TRANSITION FIXED) AND STABILITY PARAMETERS FOR LANGLEY TANK MODEL 224 (L/B = 15)

$C_{D_{min}} = 0.0053$

$C_{D_{A_{min}}} = 0.1073$

$C_{D_{V_{min}}} = 0.0288$

$C_{D_{\psi_{min}}} = 0.00293$

$\frac{\partial C_m}{\partial \alpha} = 0.0039$

$K_f = 1.561$

$\left(\frac{\partial C_n}{\partial \psi}\right)_{\alpha=2} = 0.0014$

$\left(\frac{\partial C_n}{\partial \psi}\right)_{\alpha=6} = 0.0028$

$\left(\frac{\partial C_{n_f}'}{\partial \psi}\right)_{\alpha=2} = 0.0413$

$\left(\frac{\partial C_{n_f}'}{\partial \psi}\right)_{\alpha=6} = 0.0517$

$\left(\frac{\partial C_n}{\partial \beta}\right)_{\alpha=2} = -0.1008$

$\left(\frac{\partial C_n}{\partial \beta}\right)_{\alpha=6} = -0.1260$

$\left(\frac{\partial C_Y}{\partial \psi}\right)_{\alpha=2} = 0.0051$

$\left(\frac{\partial C_Y}{\partial \psi}\right)_{\alpha=6} = 0.0051$

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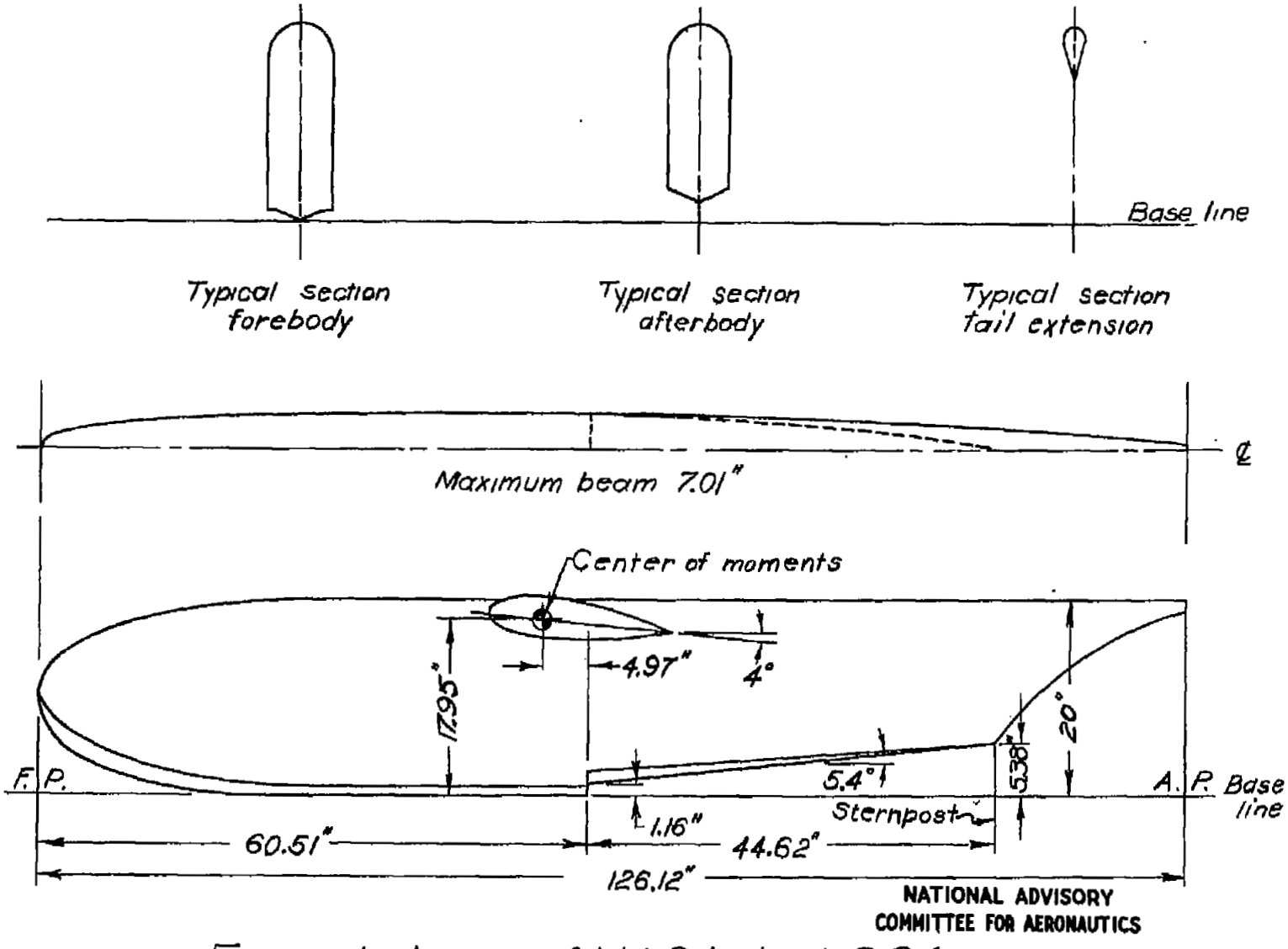

Figure 1. -Lines of N.A.C.A. hull 224.

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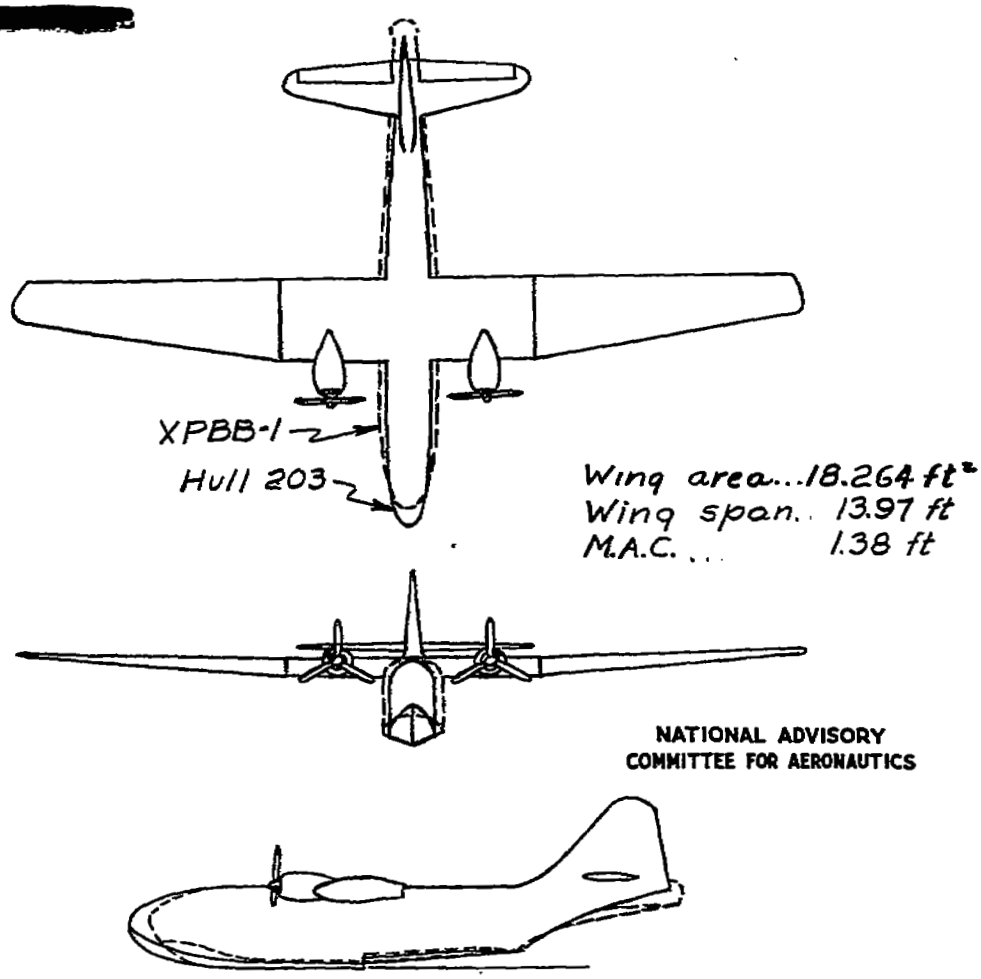

Figure 2.- Comparison of $\frac{1}{10}$-scale models of the XPBB-1 and hypothetical flying boat incorporating hull 203 ($\frac{L}{B}$ = 9).

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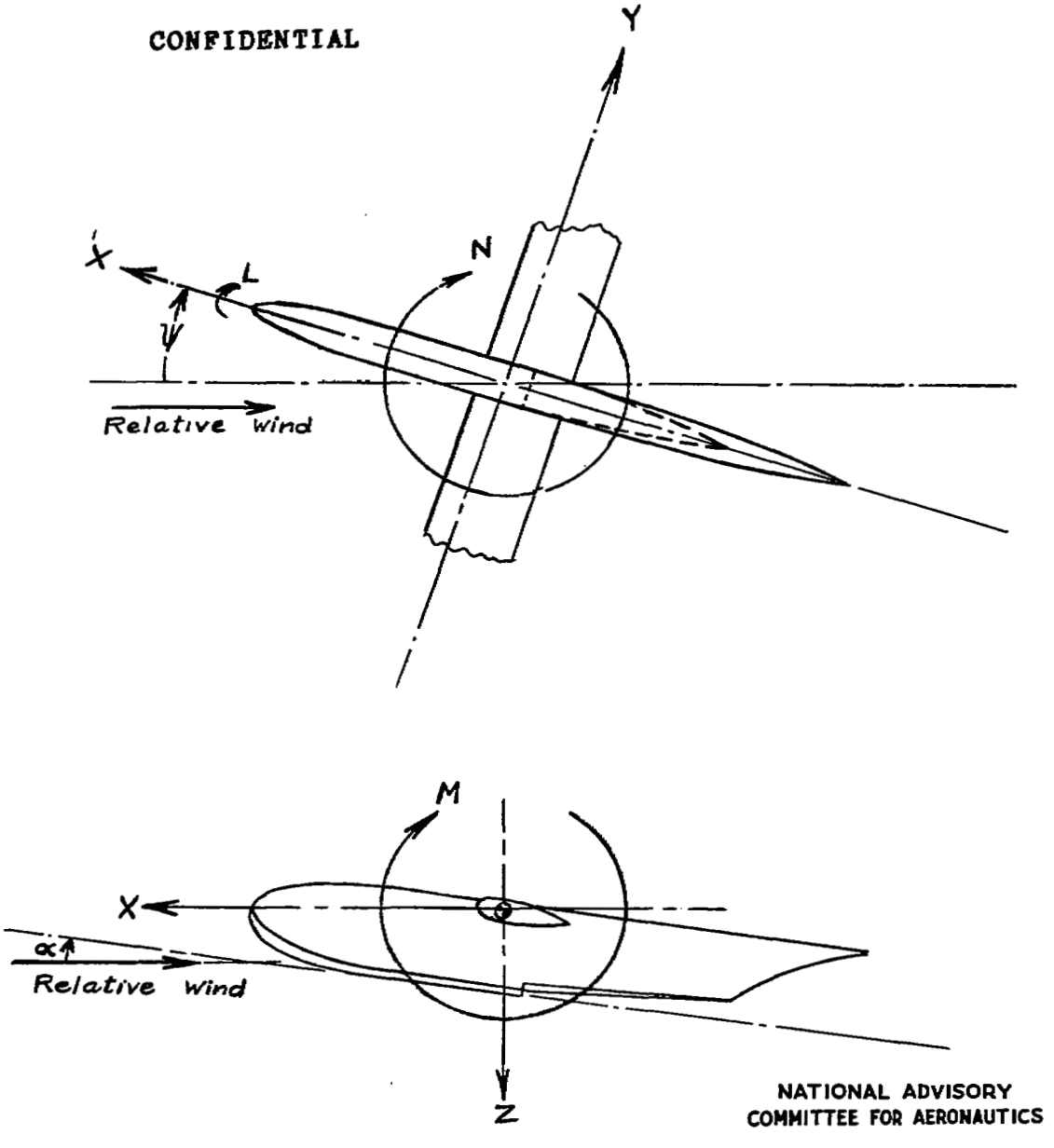

Figure 3.- System of stability axes. Positive values of forces, moments, and angles are indicated by arrows.

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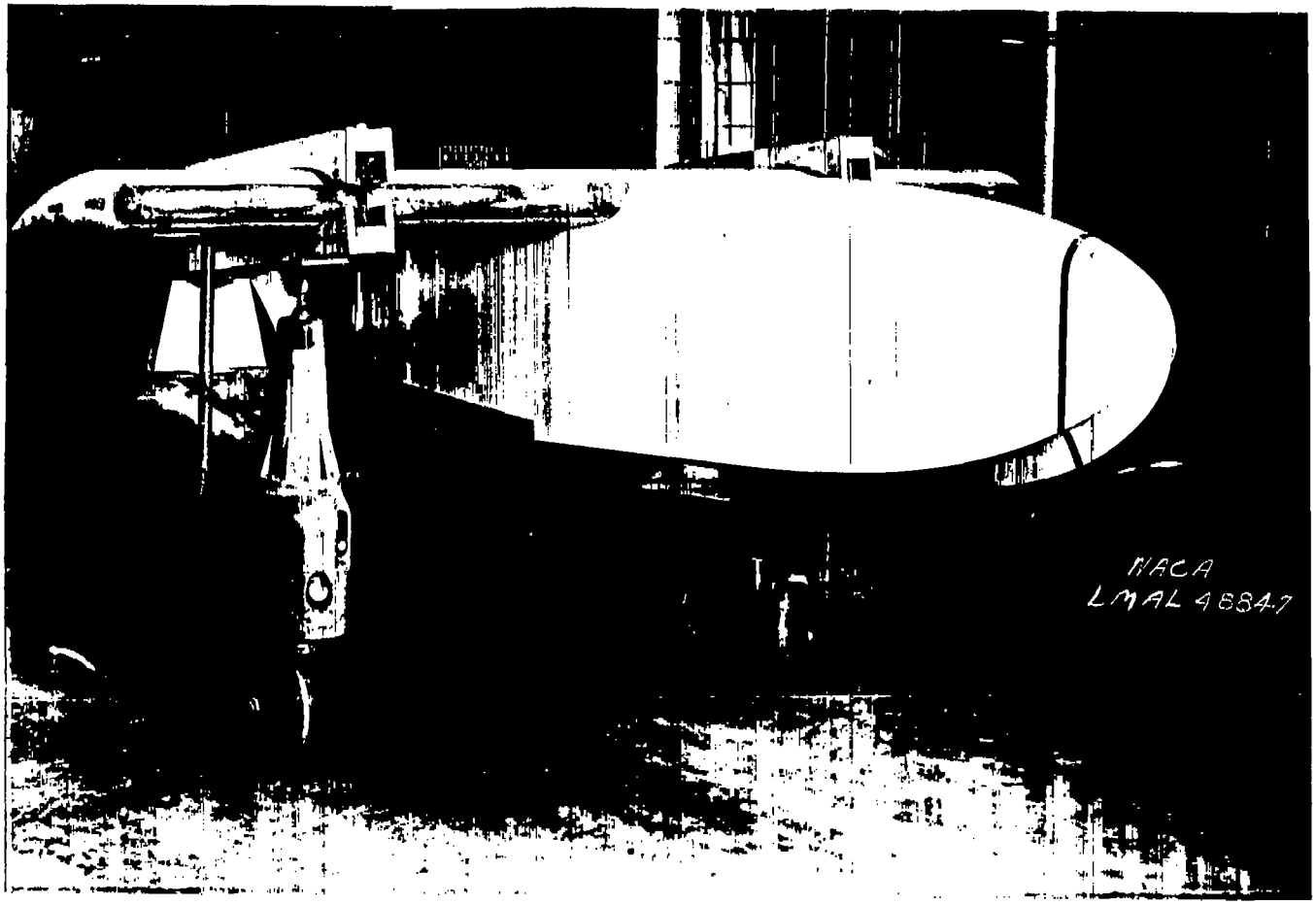

Figure 4.- Hull model 224 ($\frac{L}{B}$ = 15) of the length-beam-ratio investigation made in the Langley 300 MPH 7- by 10-foot tunnel.

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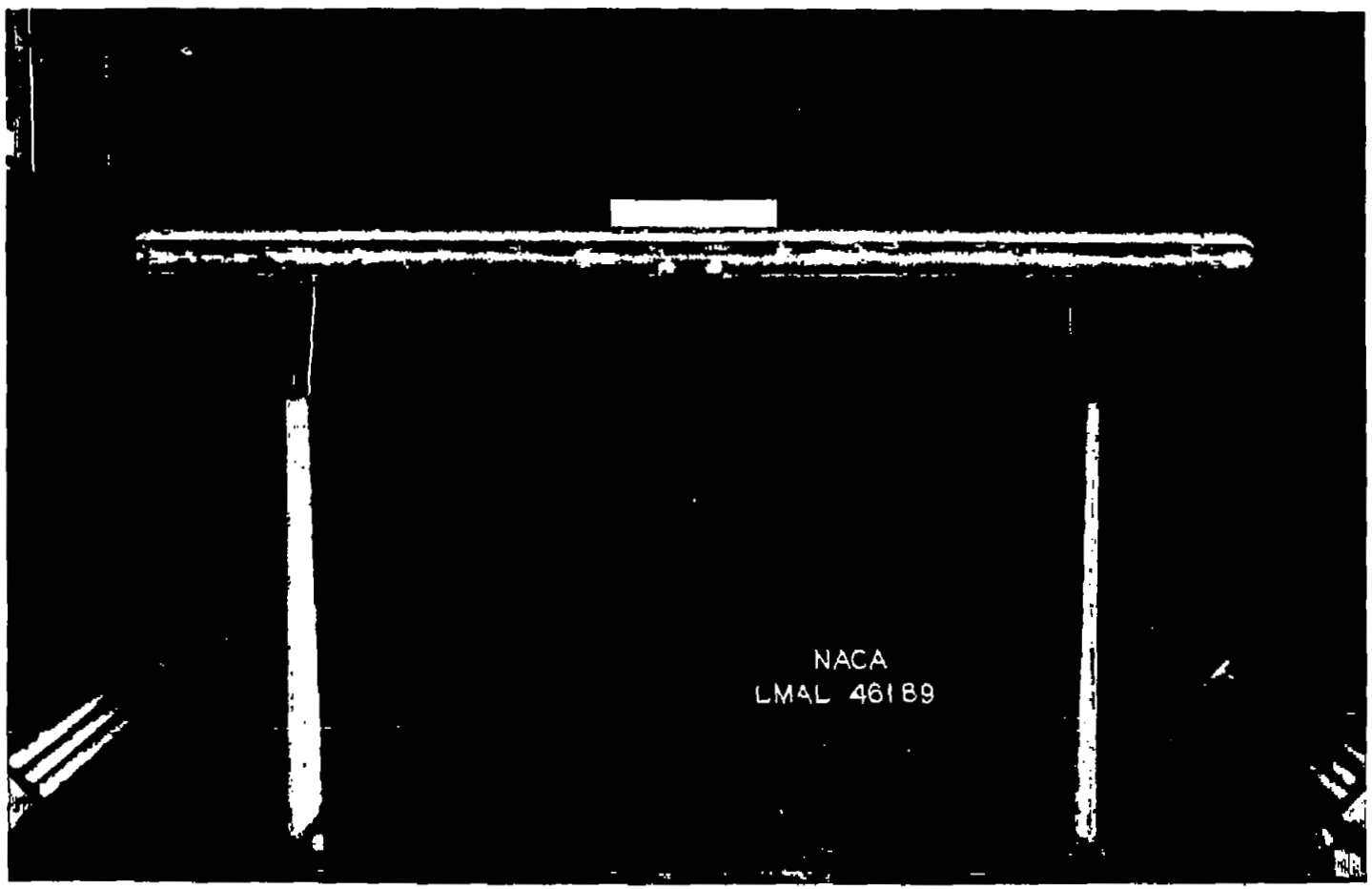

Figure 5.- Mounting of the wing alone of the hull investigation in the Langley 300 MPH 7- by 10-foot tunnel.

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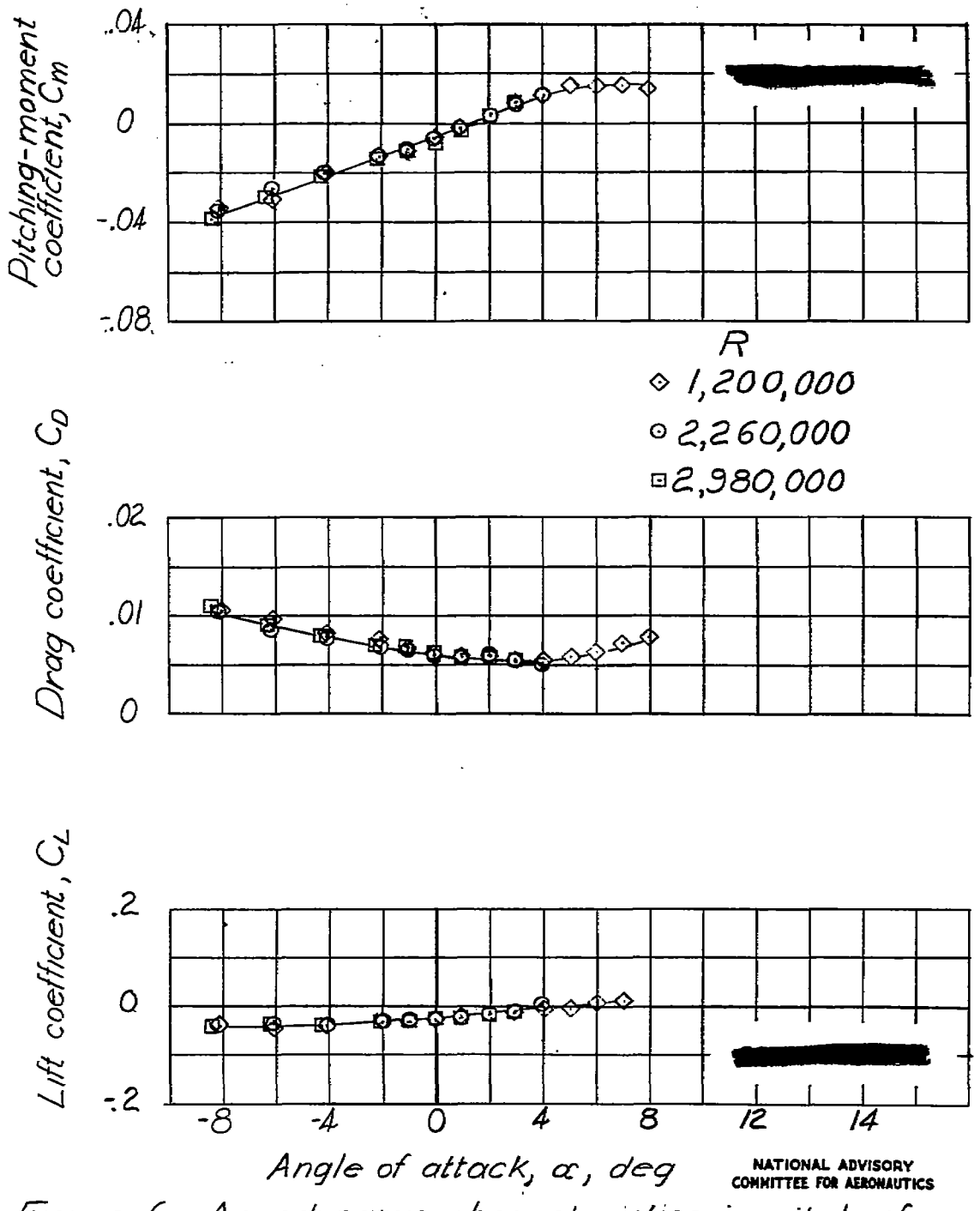

Figure 6.- Aerodynamic characteristics in pitch of a $\frac{1}{10}$-scale hull of a hypothetical flying boat, NACA hull model 224 ($\frac{L}{B}$ =15).

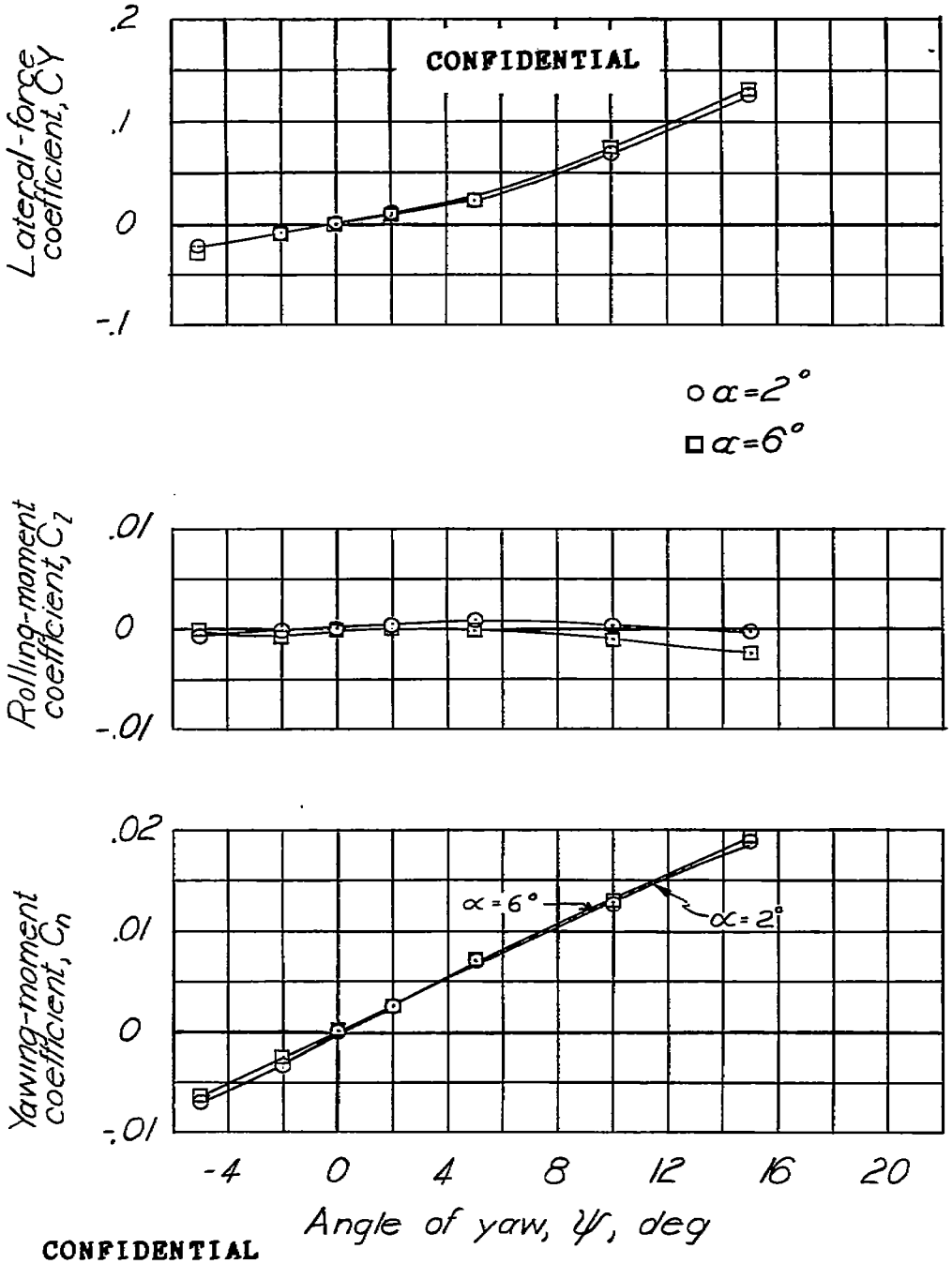

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Figure 7.-Aerodynamic characteristics in yaw of a $\frac{1}{10}$-scale hull of a hypothetical flying boat, NACA hull model 224 ($\frac{L}{B}$=15); $R = 1.2 \times 10^6$.

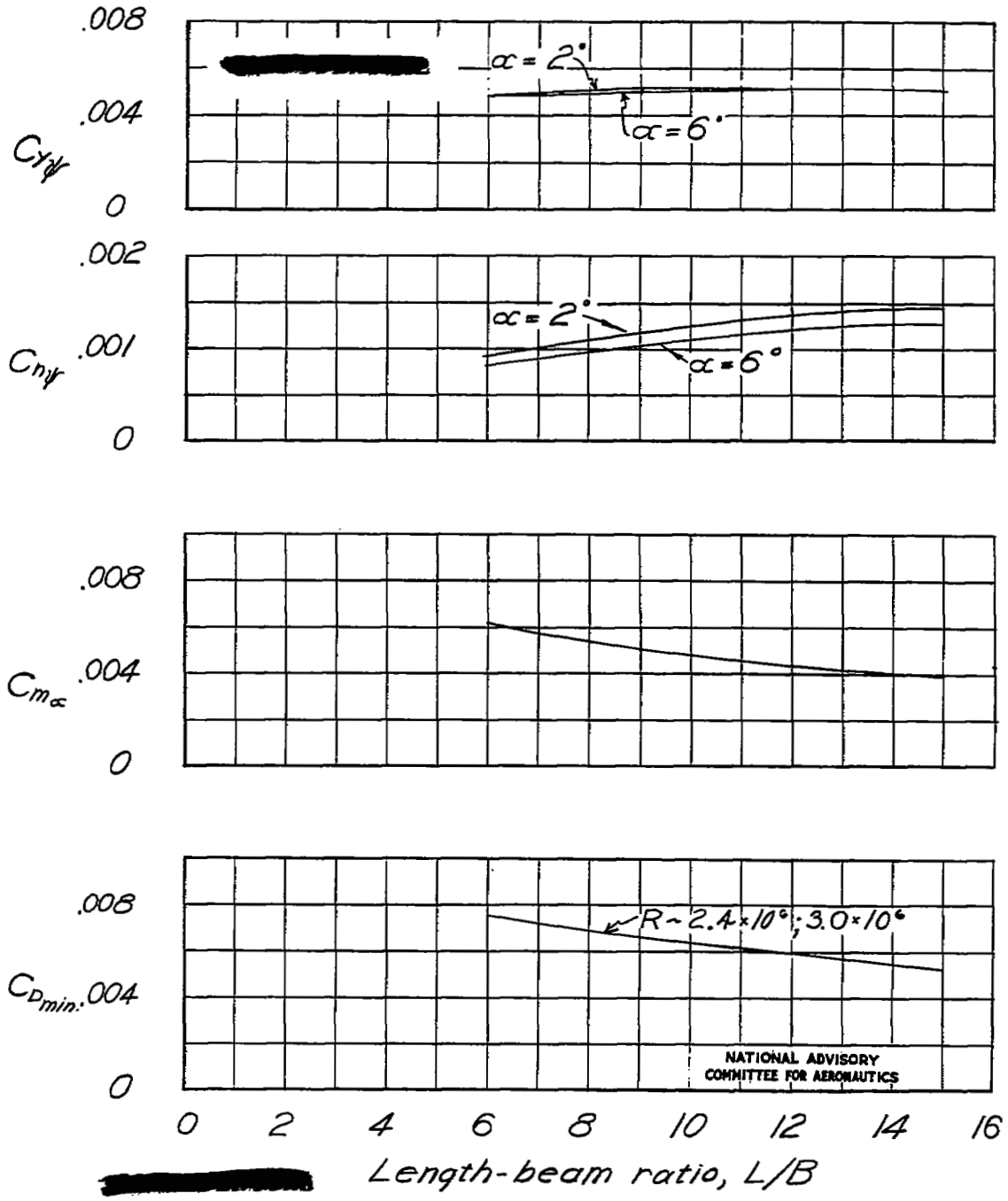

Figure 8.- Effect of length-beam ratio on $C_{D_{min}}$ and on the parameters C_{m_α}, C_{n_ψ}, C_{Y_ψ} for the $\frac{1}{10}$-scale hulls of a hypothetical flying boat.

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