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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

REPORT No. 278

LIFT, DRAG, AND ELEVATOR HINGE MOMENTS OF HANDLEY-PAGE CONTROL SURFACES

By R. H. SMITH

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AERONAUTICAL SYMBOLS

1. FUNDAMENTAL AND DERIVED UNITS

	Symbol	Metric		English	
		Unit	Symbol	Unit	Symbol
Length	l	meter	m	foot (or mile)	ft. (or mi.)
Time	t	second	sec	second (or hour)	sec. (or hr.)
Force	F	weight of one kilogram	kg	weight of one pound	lb.
Power	P	kg/m/sec		horsepower	HP.
Speed		km/hr		mi./hr	M. P. H.
		m/sec		ft./sec	f. p. s.

2. GENERAL SYMBOLS, ETC.

W, Weight, $=mg$

g, Standard acceleration of gravity $=9.80665$ m/sec.$^2=32.1740$ ft./sec.^{2}

m, Mass, $=\frac{W}{g}$

ρ, Density (mass per unit volume).

Standard density of dry air, 0.12497 (kg-m^{-4} sec.^{2}) at 15° C and 760 mm $=0.002378$ (lb.-ft.$^{-4}$ sec.^{2}).

Specific weight of "standard" air, 1.2255 kg/m$^3=0.07651$ lb./ft.^{3}

mk^2, Moment of inertia (indicate axis of the radius of gyration, k, by proper subscript).

S, Area.

S_w, Wing area, etc.

G, Gap.

b, Span.

c, Chord length.

b/c, Aspect ratio.

f, Distance from $c.\ g.$ to elevator hinge.

μ, Coefficient of viscosity.

3. AERODYNAMICAL SYMBOLS

V, True air speed.

q, Dynamic (or impact) pressure $=\frac{1}{2}\rho V^2$

L, Lift, absolute coefficient $C_L=\frac{L}{qS}$

D, Drag, absolute coefficient $C_D=\frac{D}{qS}$

C, Cross-wind force, absolute coefficient $C_C=\frac{C}{qS}$

R, Resultant force. (Note that these coefficients are twice as large as the old coefficients L_C, D_C.)

i_w Angle of setting of wings (relative to thrust line).

i_t, Angle of stabilizer setting with reference to thrust line.

γ, Dihedral angle.

$\rho\frac{Vl}{\mu}$, Reynolds Number, where l is a linear dimension.

e. g., for a model airfoil 3 in. chord, 100 mi./hr. normal pressure, 0° C: 255,000 and at 15° C., 230,000;

or for a model of 10 cm chord 40 m/sec, corresponding numbers are 299,000 and 270,000.

C_p, Center of pressure coefficient (ratio of distance of $C.\ P.$ from leading edge to chord length).

β, Angle of stabilizer setting with reference to lower wing, $=(i_t-i_w)$.

α, Angle of attack.

ϵ, Angle of downwash.

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Aerodynamical Laboratory, Bureau of Construction and Repair, U. S. Navy

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INTRODUCTION

This report combines the wind-tunnel results of tests on four control surface models made in the two wind tunnels of the Navy aerodynamic laboratory, Washington Navy Yard, during the years 1922 and 1924, and submitted for publication to the National Advisory Committee for Aeronautics May 7, 1927. The purpose of the tests was to compare, first, the lifts and the aerodynamic efficiencies of the control surfaces from which their relative effectiveness as tail-planes could be determined; then the elevator hinge moments upon which their relative ease of operation depended. The lift and drag forces on the control surface models were obtained for various stabilizer angles and elevator settings in the 8 by 8 foot tunnel by the writer in 1922; the corresponding hinge moments were found in the 4 by 4 foot tunnel by Mr. R. M. Bear in 1924.

DESCRIPTION OF MODELS

For all four models the over-all dimensions are 6 by 18 inches and the basic profile a twin cambered section of easy form known as the Martin M–1. One is provided with a plain flap elevator, three with Handley-Page balanced elevators. The sizes of the elevators and the manner of hinging them, the main dimensions of the members, and the offsets of the cambered surfaces are given in the diagram and tables of Figure 2, which also defines the stabilizer angle of attack and elevator pitch. Figure 3 is a photograph of Model No. 4 mounted for the determination of the elevator hinge moments. The models were made of dry pine and varnished.

METHOD OF TEST

The lift and drag forces were measured on the six-component balance to which the models were attached by means of the standard 5-inch model holder, whose two thin streamlined prongs engaged the models at mid span. For zero degrees stabilizer angle and for each 5° increase to +20° the elevator was set at a succession of angles to the stabilizer, ranging from −20° to +20° by 5° increments for Models 1, 3, and 4 and from −25° to +25° by the same increments for Model 2. These limits to the elevator pitch were chosen to exceed the angles at which air leakage between the elevator and stabilizer begins. For Models 2, 3, and 4 the respective angles of incipient leak are 19°−6′, 13°−29′, and 10°−40′. Measurements were not made at negative stabilizer angles because they are inferable from symmetry.

The elevator hinge moments were measured in pound-inches on the 4 by 4 foot tunnel cross-arm balance, according to the usual procedure of finding the pitching moments on an aerofoil. The angles of stabilizer and elevator pitch corresponded in the tests on Models 1, 2, and 3, to those used in the lift and drag tests on these models, except for the inclusion of the symmetrical angles for negative stabilizer. In testing Model 4 the elevator angle range was again ±20°, but the moment measurements, at zero stabilizer angle, showed an overbalance control condition, and in order to shorten a test of no apparent practical value the usual additional stabilizer angles were limited to ±10° and ±20°.

RESULTS OF TESTS

The net lift and drag forces on the models and the derived coefficients are given without correction for model symmetry, Vl/μ or wall effect in Tables I to VII; the absolute coefficients are plotted in Figures 4 to 11. The engineering coefficients are tabulated but not plotted.

Elevator hinge moments are given in Table VIII corrected for model asymmetry by taking the mean of the moments for symmetrical stabilizer angles and elevator settings and subtracting or adding to all these mean moments the moment at zero angle of stabilizer and elevator setting. Figures 16 to 19, inclusive, give various direct and derived plots of the moments thus corrected.

LIFT COEFFICIENT

The following mathematical analysis of the lift coefficient plots, given in Figures 3 to 6, as well as that of the drag coefficient plots in the next section, was made by Doctor Zahm.

Each lift diagram presents a family of lines that are nearly straight for small values of the stabilizer angle α, and of the elevator setting δ. The equation for the rectilinear parts of each diagram may be written

$$C_L = m\alpha + n\delta \qquad (1)$$

in which m and n are fairly constant, and have the respective values $m = \delta C_L/\delta\alpha$ and $n = \delta C_L/\delta\delta$.

Of these partial derivatives the first expresses the slope of the line; the second its vertical shift per degree turn of elevator, so that the intercept on the vertical axis is $n\delta$.

To find the relation of α and δ, differentiate (1), C_L constant, giving $n/m = \delta\alpha/\delta\delta = C/E$ where C and E are the distances from the trailing edge, respectively, to the pivot and to the leading edge, as shown in Figures 1 and 2. Writing $n = m\ C/E = mr$ the original equation becomes

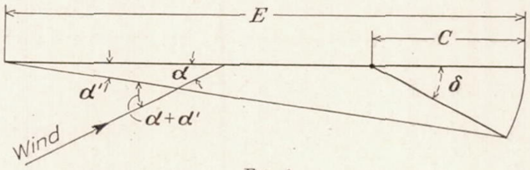

FIG. 1

$$C_L = \left.\begin{matrix} m\alpha + m\ r\ \delta \\ m\ (\alpha + \alpha') \end{matrix}\right\} \qquad (2)$$

in which $r = C/E$, varies with shifting of the elevator pivot, and $\alpha' = r\delta$, is the virtual increase of incidence contributed to α by the increase δ of the elevator setting.

On scaling the diagrams it is found that m has practically the same value for all; n is constant for each diagram, but declines successively from the first to the last with the shortening

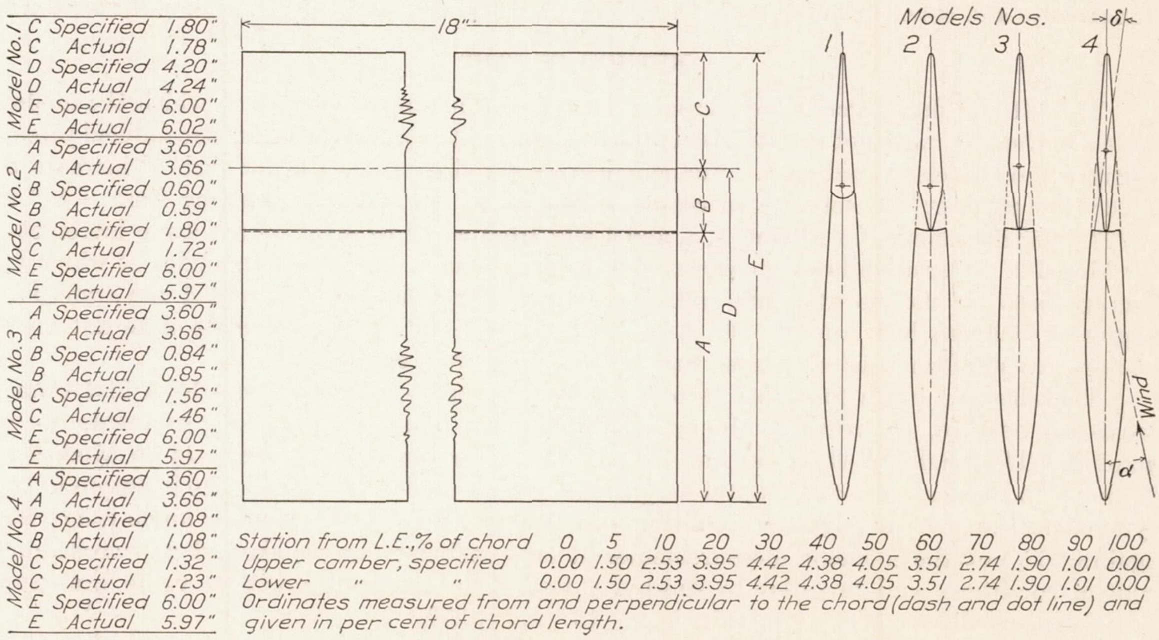

FIG. 2.—Dimensions of models used in tests on Handley-Page control surfaces

of C. Owing to the constancy of $m = \delta C_L/\delta\alpha$, for all the diagrams, it follows that the increment of lift per unit change of the effective incidence $\alpha + \alpha'$, whether this change results from pitching the whole model or from pitching only the elevator, is the same for all four models. Its mean value for angles ranging from 0 to ±10, as detailed in Table IX, is for the models in the order 1, 2, 3, 4.

$$m = \delta C_L/\delta\alpha = -.0517 \quad .0472 \quad .0480 \quad .0514$$

The increment α' due to the elevator setting δ, is, of course, proportional to the linear displacement of the trailing edge, as shown in Figure 1, by which also one may derive the geometrical ratio already assumed $\delta\alpha/\delta\delta = C/E$.

It is noticeable that $\delta\alpha'/\delta\delta$ here derived is positive, but that $\delta\alpha/\delta\delta$ derived from (1) is negative. In taking this derivative C_L was assumed constant, which means that as the elevator setting δ is given a positive increment $+\delta\alpha$, the model angle α must be given a negative increment $-\delta\alpha$, to preserve the constancy of the lift. The absolute value of the two derivatives is of course the same.

The maximum value of the lift coefficient, as should be expected, and as seen in all the diagrams, occurs at progressively lower angles of the stabilizer as the elevator is given increased setting angles. The greatest maximum, 1.15 is found for the fairest model with the stabilizer at about 13° angle of attack and the elevator at 20° setting. If the aspect ratio were increased twofold or more, the lift coefficient would be considerably increased, and would indicate a serviceable high-lift wing. Still higher values could be found with larger elevator settings, without prohibitive lift/drag ratios.

The effect of leakage of air between the elevator and stabilizer at large elevator settings is clearly manifest in Figures 4, 5, and 6. For the balanced elevator the lift drops sharply at settings beyond the leakage angle, while for the plain elevator the lift continues to rise with the setting up to angles known to be far beyond the ones here used, possibly extending beyond 60°.

Some of the lift relations of immediate practical interest may be summarized.

1. For elevator setting angles that cause no leakage between the stabilizer and elevator, all models exert the same lift at equal angles of the stabilizer and equal linear displacement of the trailing edge of the elevator.

2. The lift of each balanced control increases continuously with the elevator setting until leakage occurs, and for larger settings declines sharply, while the lift of the plain-elevator control continues to increase for still higher settings.

3. For all the particular controls here tested the lift coefficient is well expressed by the formula

$$C_L = 0.050 \quad (\alpha + r\delta)$$

in which α and δ are respectively the stabilizer angle of attack and the elevator setting, in degrees, and r is the ratio of the distances from the elevator's rear edge respectively to the pivot and to the stabilizer's leading edge. The statement applies for α ranging from 0° to ±10°.

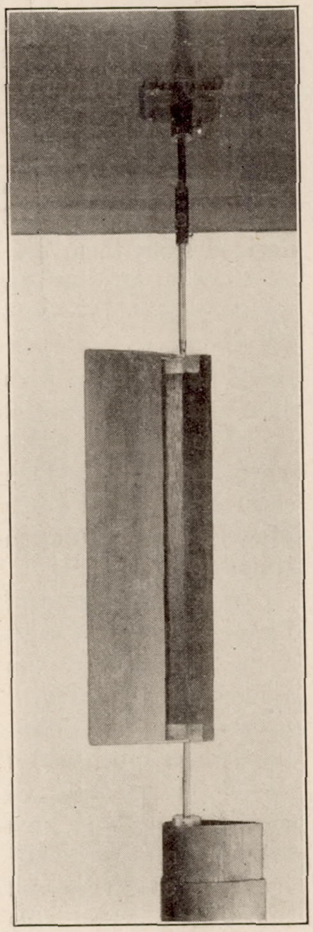

FIG. 3.—Model No. 4, mounted in 4 by 4 inch tunnel for measuring elevator hinge moments on Handley-Page control surface

DRAG COEFFICIENTS

The drag coefficients are plotted in Figures 8 to 11. For the smaller values of α and δ the graphs on each diagram form a family of upturned parabolas symmetrically grouped to right and left of the axis $\alpha = 0$. Rotating each actual plot 180° about the axis $\alpha = 0$ gives an extension to each graph which completes it for negative incidence.

The equation of each family has approximately the form

$$C_D = p(\alpha - a\delta)^2 + b\delta^2 + c \qquad (3)$$

in which $a\delta$ and $b\delta^2 + c$ are the coordinates of the vertex; p, a, b, and c being constants that can be found by scaling from the diagrams. The vertices of the parabolas are approximately on the locus—itself a parabola—whose parametric equations are $\alpha = a\delta$, $C_D = b\delta^2 + c$. The locus is a parabola because the drag is a quadratic function of the effective incidence $\alpha + \alpha'$, which is a linear function of the elevator setting δ. As the drag is of minor importance in the present study, the determination of the constants is omitted.

The leak effect, though manifest, is not so marked as for the lift.

LIFT/DRAG

The efficiency diagrams, Figures 12 to 15, call for little comment. The largest lift/drag for zero elevator setting is found with Model 1 as 10.5, at just under 5° angle of attack. For 5° to 10° elevator setting the maximum ratio is well above 12. For the other models the maximum is somewhat, though not greatly, less. The diagram for negative stabilizer angle of attack obviously can be derived by rotating the present one 180° about the axes $\alpha = 0, L/D = 0$.

HINGE MOMENTS

The elevator hinge moments of the four models, tabulated in Table VIII, are plotted against elevator setting, δ, in Figure 16 and against stabilizer angle, α, in Figure 17. Four diagrams derived from them are plotted in Figure 18. The values of α for the elevator and stabilizer angles of no-lift were read from Figures 4, 5, and 6. The no-lift curves of Figure 18 were obtained by plotting the moments of the dashed no-lift curves of Figure 17 against δ. The α vs. δ curves for complete elevator balance or for zero moment, of Figure 18, were plotted from data read from the curves of Figure 16. Figure 19 contains curves plotted from lift and hinge moment data and their ratios, for the controls with stabilizer angle, $\alpha = 0°$.

The moment curves of Figures 16, 17, and 18 show that the elevator of Model 2 is the only one of the Handley-Page types which is always underbalanced within the limits of the test. The elevator of Model 4 is completely overbalanced for the usual elevator setting range, and that of Model 3 exhibits uncertain conditions at settings of δ between −10° and −20° for stabilizer angles above 10°.

For a general comparison of the ease with which each elevator controls, the curves of Figure 18, for $L = 0$ and $\alpha = 0$, are useful, as each curve is typical of the family to which it belongs. A comparison of the moment versus δ curves for $\alpha = 0$, of Figure 18, shows the elevator hinge moments for Handley-Page Model 2 to vary from two-thirds to one-half as much as for the conventional plain flap type. Also the hinge moments for Model 3 are seen to average about one-fifth as much as for the conventional type.

The relative lift values and the L/M ratios, where L = lift and M = hinge moment, may be seen, for $\alpha = 0°$, in Figure 19. Although Model 3 shows a very much greater L/M ratio than Model 2, and for small elevator settings and stabilizer angles a superiority to the latter as a balanced control surface, the unstable conditions at higher elevator settings and stabilizer angles are objectionable.

Aerodynamical Laboratory,
Bureau of Construction and Repair,
Navy Yard, Washington, D. C. *May 7, 1927.*

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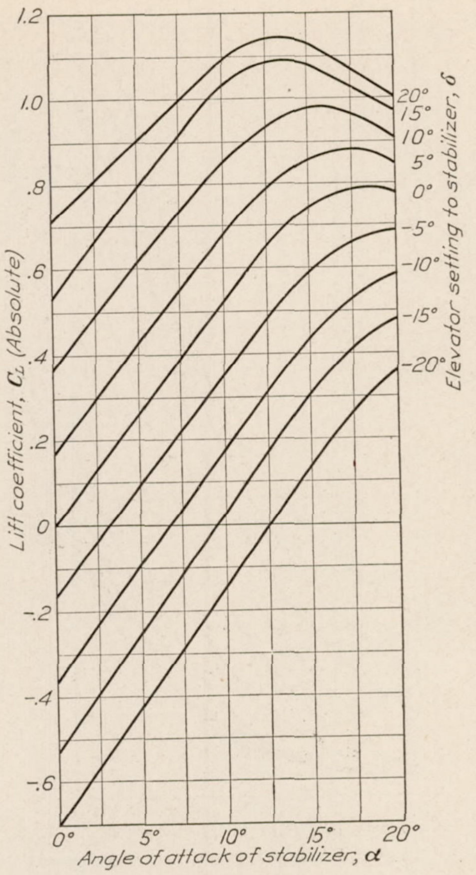

Fig. 4.—Lift coefficients for Model No. 1. Air speed, 40 M. P. H.

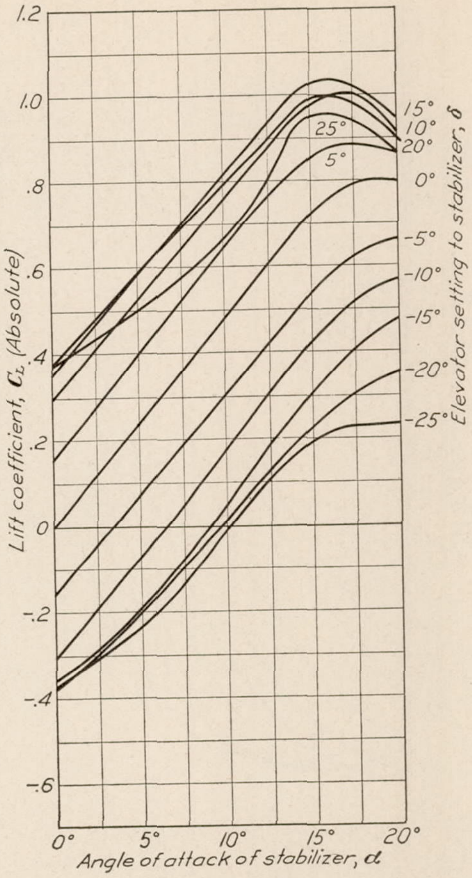

Fig. 5.—Lift coefficients for Model No. 2. Air speed, 40 M. P. H.

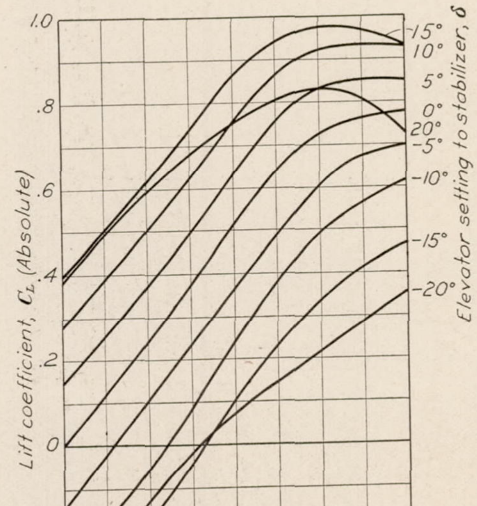

Fig. 6.—Lift coefficients for Model No. 3. Air speed, 40 M. P. H.

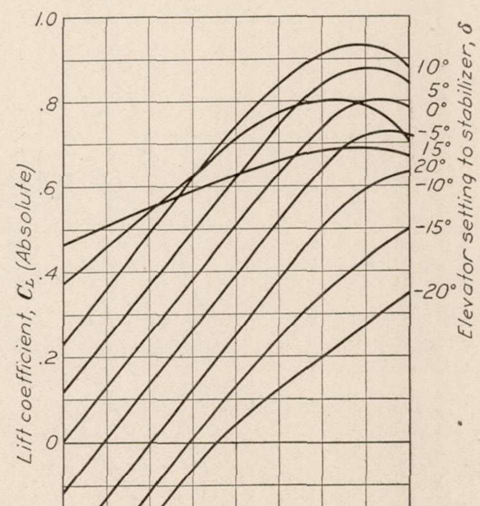

Fig. 7.—Lift coefficients for Model No. 4. Air speed, 40 M. P. H.

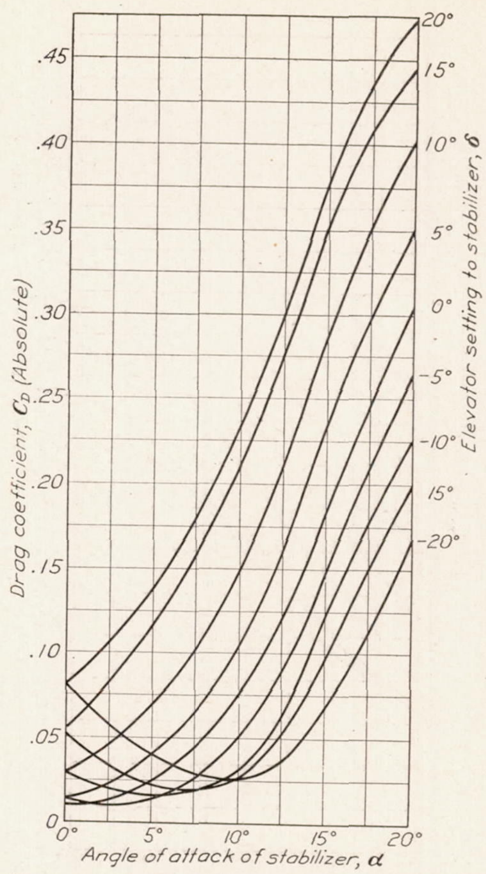

FIG. 8.—Drag coefficients for Model No. 1. Air speed, 40 M. P. H.

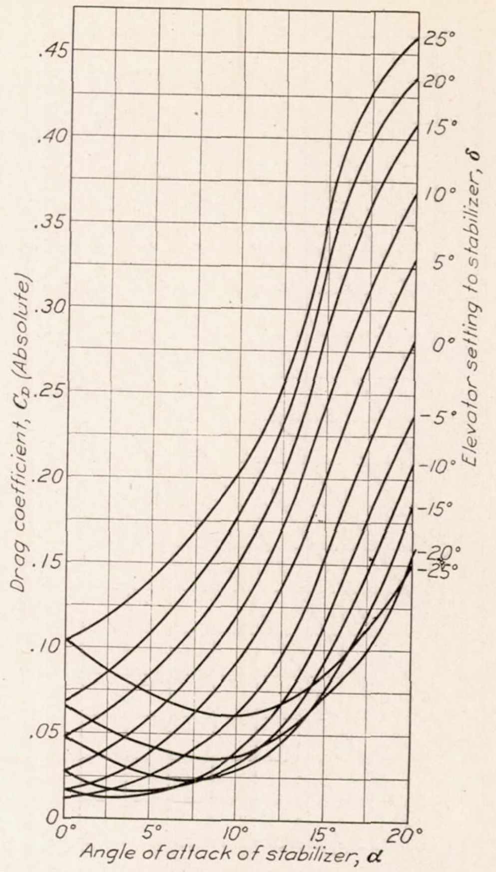

FIG. 9.—Drag coefficients for Model No. 2. Air speed, 40 M. P. H.

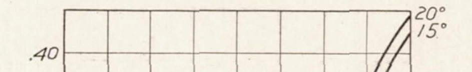

FIG. 10.—Drag coefficients for Model No. 3. Air speed, 40 M. P. H.

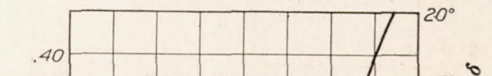

FIG. 11.—Drag coefficients for Model No. 4. Air speed, 40 M. P. H.

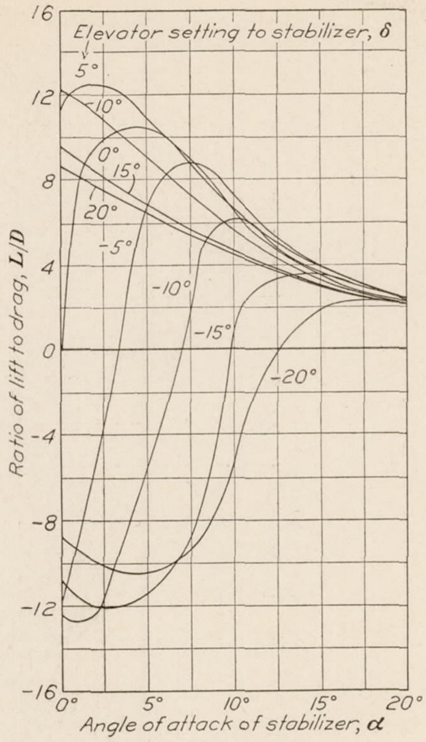

FIG. 12.—Ratio of lift to drag for Model No. 1. Air speed, 40 M. P. H.

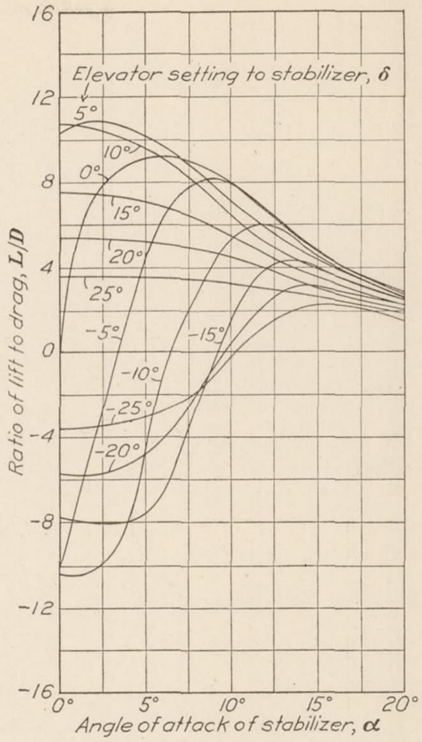

FIG. 13.—Ratio of lift to drag for Model No. 2. Air speed, 40 M. P. H.

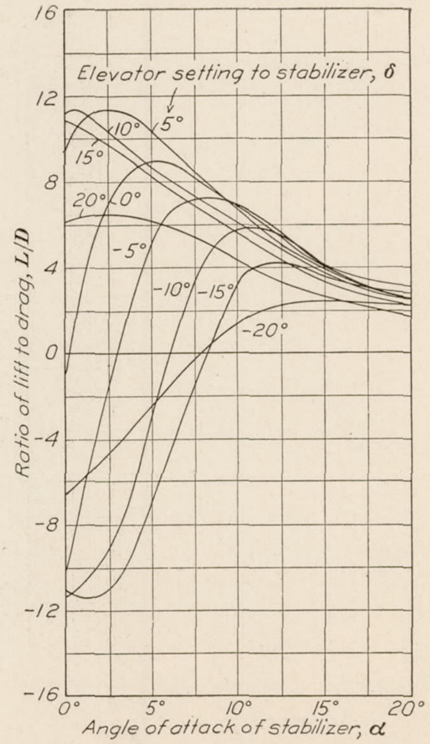

FIG. 14.—Ratio of lift to drag for Model No. 3. Air speed, 40 M. P. H.

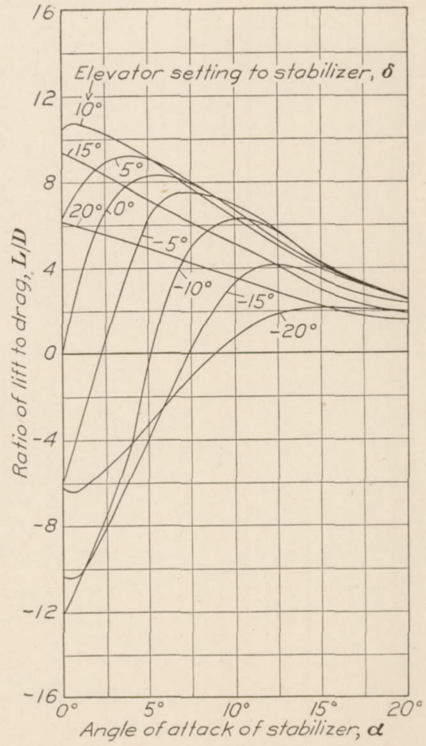

FIG. 15.—Ratio of lift to drag for Model No. 4. Air speed, 40 M. P. H.

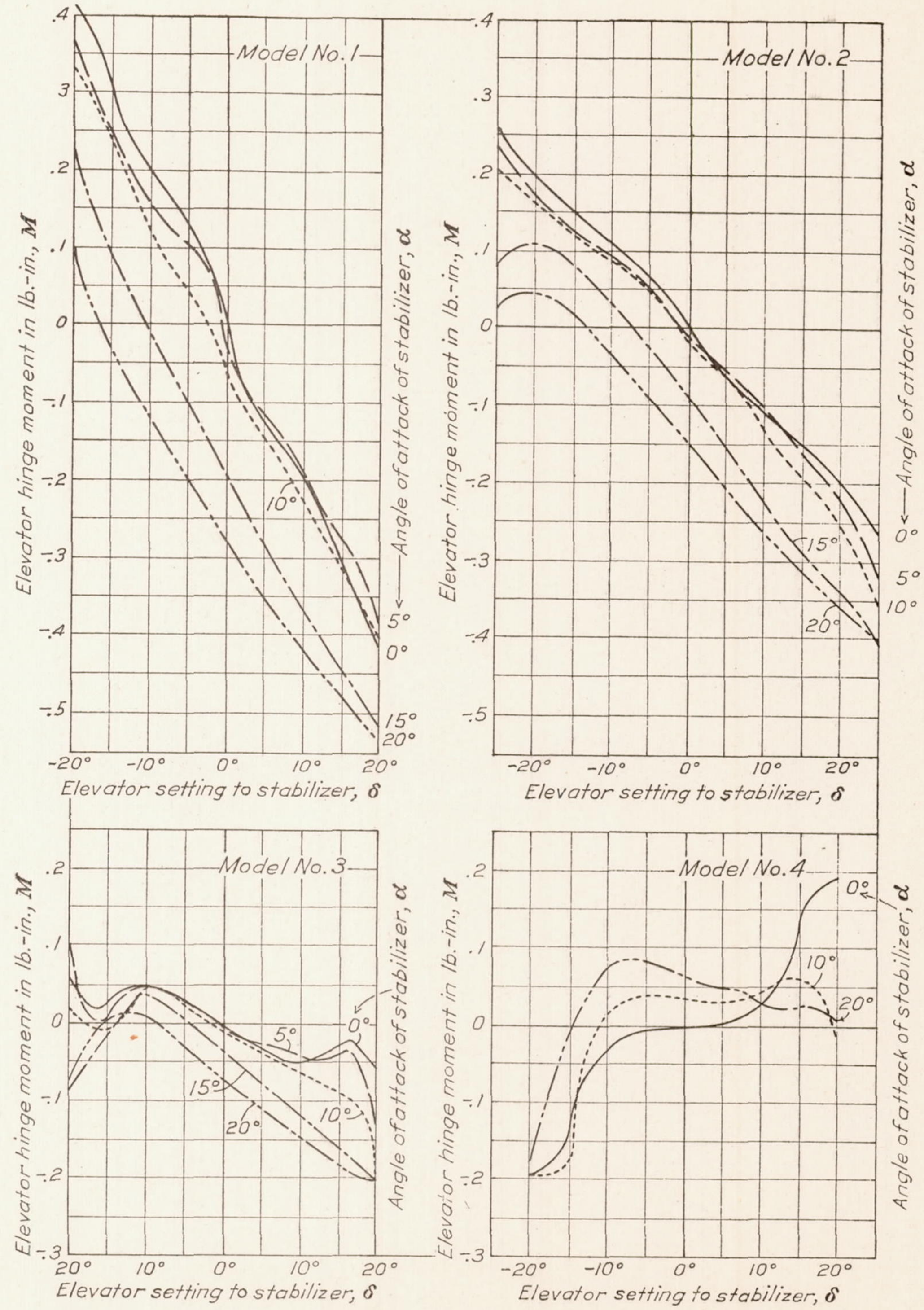

FIG. 16.—Elevator hinge moments, M vs. δ at different αf or Models Nos. 1, 2, 3, and 4

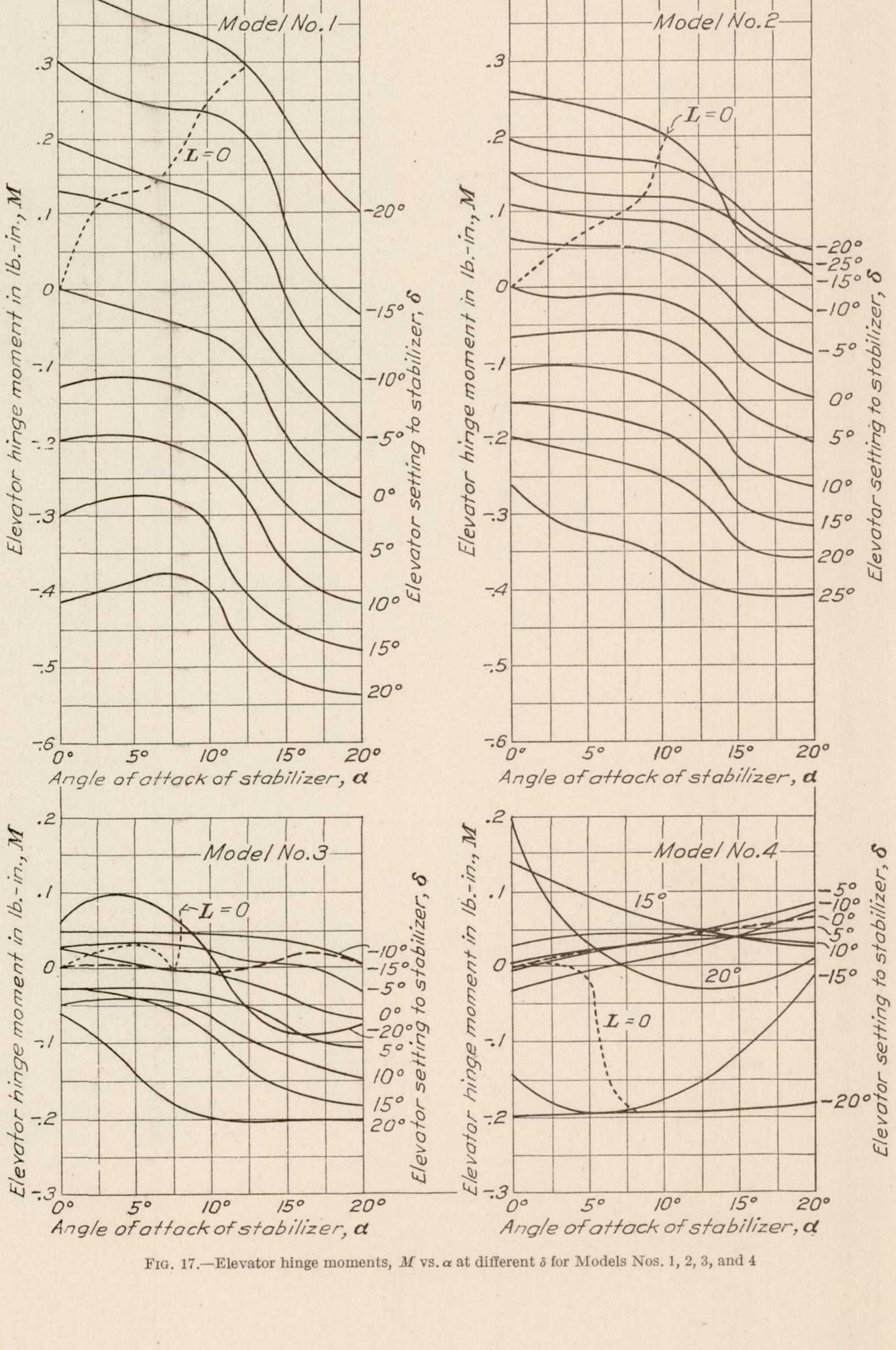

FIG. 17.—Elevator hinge moments, M vs. α at different δ for Models Nos. 1, 2, 3, and 4

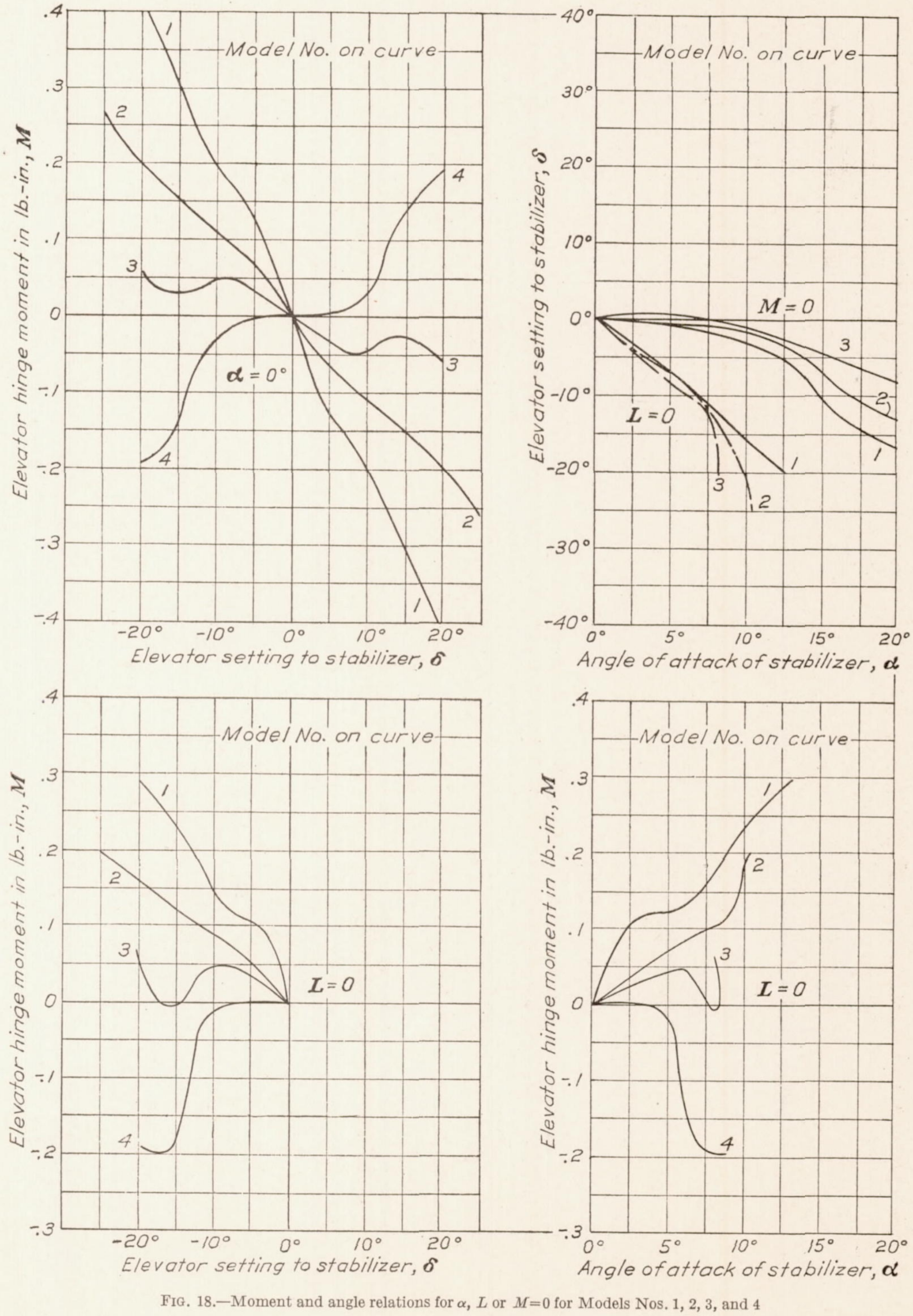

FIG. 18.—Moment and angle relations for α, L or $M=0$ for Models Nos. 1, 2, 3, and 4

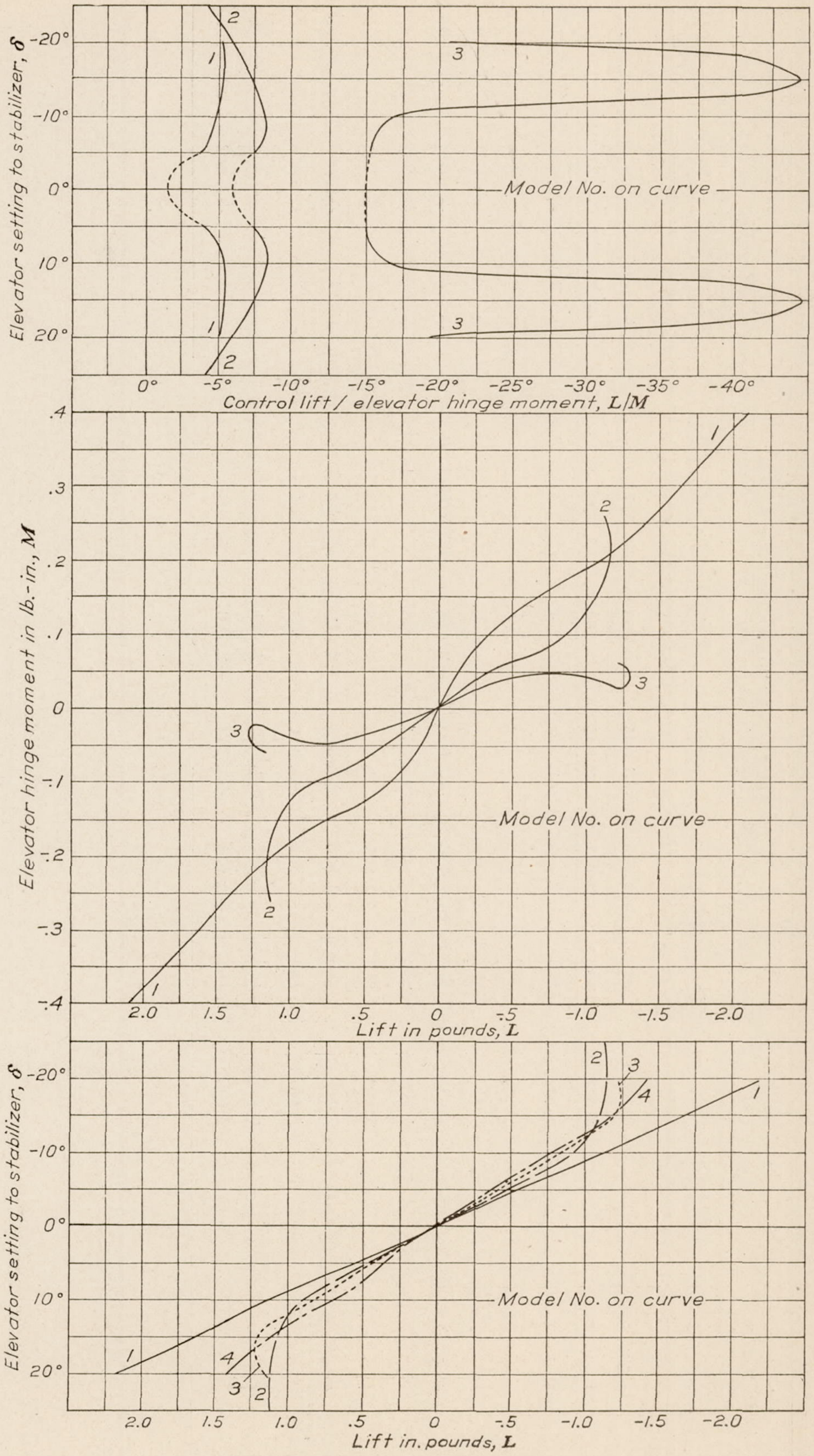

FIG. 19.—Lift and moment data for $\alpha=0$ at 40 M. P. H.

TABLE I

Lift of Handley-Page stabilizer and elevator (pounds)

(Air speed, 40 M. P. H.)

Angle of attack of stabilizer α (degrees)	Elevator setting to stabilizer (degrees) $=\delta$										
	+25	+20	+15	+10	+5	0	−5	−10	−15	−20	−25
Model No. 1:											
0	----------	+2.182	+1.639	+1.124	+0.505	−0.009	−0.511	−1.124	−1.644	−2.174	----------
+ 5	----------	2.734	2.434	1.880	1.307	+.809	+.299	−.274	−.776	1.294	----------
10	----------	3.368	3.198	2.621	2.086	1.598	1.090	+.564	+.095	−.457	----------
15	----------	3.467	3.314	3.012	2.638	2.286	1.822	1.387	.972	+.437	----------
+20	----------	+3.045	+2.970	+2.795	+2.579	+2.374	+2.114	+1.802	+1.470	+1.104	----------
Model No. 2:											
0	+1.131	+1.149	+1.080	+.916	+.473	+.001	−.481	−.921	−1.077	−1.157	−1.131
+ 5	1.529	1.811	1.794	1.602	1.231	.721	+.204	−.231	−.556	−.610	.685
10	2.018	2.419	2.491	2.333	1.971	1.473	.926	+.534	+.135	+.054	−.025
15	2.922	3.049	3.142	2.975	2.609	2.199	1.649	1.288	.920	.675	+.608
20	+2.646	+2.736	+2.877	+2.798	+2.645	+2.448	+2.029	+1.717	+1.451	+1.083	+.710
Model No. 3:											
0	----------	+1.159	+1.200	+.831	+.434	−.003	−.443	−.829	−1.200	−1.221	----------
+ 5	----------	1.798	1.865	1.536	1.142	+.755	+.325	−.159	−.519	−.376	----------
10	----------	2.293	2.619	2.291	1.918	1.563	1.112	+.740	+.369	+.238	----------
15	----------	2.534	2.964	2.804	2.530	2.211	1.839	1.495	.991	.677	----------
20	----------	+2.198	+2.835	+2.825	+2.588	+2.352	+2.125	+1.862	+1.410	+1.069	----------
Model No. 4:											
0	----------	+1.407	+1.139	+.702	+.351	+.003	−.354	−.783	−1.165	−1.418	----------
+ 5	----------	1.672	1.641	1.498	1.135	.778	+.426	.000	−.356	−.538	----------
10	----------	1.907	2.183	2.269	1.893	1.551	1.212	+.771	+.398	+.133	----------
15	----------	2.097	2.468	2.793	2.565	2.275	1.968	1.548	1.066	.580	----------
+20	----------	+2.043	+2.154	+2.678	+2.548	+2.390	+2.190	+1.901	+1.514	+1.062	----------

TABLE II

Drag of Handley-Page stabilizer and elevator (pounds)

(Air speed, 40 M. P. H.)

Angle of attack of stabilizer α (degrees)	Elevator setting to stabilizer (degrees) $=\delta$										
	+25	+20	+15	+10	+5	0	−5	−10	−15	−20	−25
Model No. 1:											
0	----------	0. 254	0. 170	0. 092	0. 045	0. 028	0. 044	0. 090	0. 160	0. 247	----------
+ 5	----------	. 426	. 356	. 210	. 123	. 077	. 045	. 052	. 068	. 124	----------
10	----------	. 720	. 646	. 462	. 325	. 227	. 155	. 090	. 084	. 082	----------
15	----------	1. 173	1. 096	. 892	. 737	. 567	. 463	. 378	. 298	. 217	----------
+20	----------	1. 458	1. 373	1. 237	1. 078	. 940	. 819	. 699	. 624	. 520	----------
Model No. 2:											
0	0. 314	. 209	. 144	. 085	. 046	. 037	. 048	. 089	. 140	. 201	0. 317
+ 5	. 438	. 338	. 252	. 185	. 120	. 079	. 046	. 051	. 072	. 126	. 222
10	. 618	. 546	. 457	. 371	. 279	. 183	. 117	. 097	. 084	. 113	. 183
15	1. 091	. 994	. 880	. 752	. 615	. 478	. 352	. 287	. 233	. 225	. 263
+20	1. 398	1. 330	1. 241	1. 118	1. 003	. 855	. 723	. 636	. 559	. 483	. 458
Model No. 3:											
0	----------	. 189	. 110	. 074	. 046	. 039	. 044	. 073	. 109	. 189	----------
+ 5	----------	. 292	. 229	. 178	. 109	. 084	. 061	. 060	. 075	. 162	----------
10	----------	. 532	. 467	. 371	. 286	. 229	. 158	. 128	. 103	. 159	----------
15	----------	. 948	. 888	. 758	. 654	. 565	. 460	. 371	. 288	. 287	----------
+20	----------	1. 287	1. 257	1. 126	1. 009	. 910	. 811	. 599	. 501	. 484	----------
Model No. 4:											
0	----------	. 228	. 121	. 068	. 056	. 044	. 059	. 065	. 114	. 228	----------
+ 5	----------	. 345	. 229	. 164	. 126	. 093	. 069	. 054	. 085	. 165	----------
10	----------	. 531	. 426	. 357	. 285	. 230	. 174	. 121	. 119	. 169	----------
15	----------	. 966	. 850	. 732	. 630	. 570	. 477	. 383	. 304	. 287	----------
+20	----------	1. 371	1. 169	1. 100	1. 013	. 930	. 848	. 743	. 657	. 572	----------

TABLE III

Absolute lift coefficient, C_L, for Handley-Page stabilizer and elevator

(Air speed, 40 M. P. H.)

Angle of attack of stabilizer α (degrees)	Elevator setting to stabilizer (degrees) $=\delta$										
	+25	+20	+15	+10	+5	0	−5	−10	−15	−20	−25
Model No. 1:											
0	----------	+0. 7100	+0. 5333	+0. 3657	+0. 1643	−0. 0029	−0. 1663	−0. 3657	−0. 5350	−0. 7074	----------
+ 5	----------	. 8896	. 7920	. 6118	. 4253	+. 2632	+. 0973	−. 0892	−. 2525	. 4211	----------
10	----------	1. 0959	1. 0406	. 8529	. 6788	. 5200	. 3547	+. 1835	+. 0309	−. 1487	----------
15	----------	1. 1282	1. 0784	. 9801	. 8584	. 7439	. 5929	. 4513	. 3163	+. 1422	----------
+20	----------	+. 9908	+. 9664	+. 9095	+. 8392	+. 7725	+. 6879	+. 5864	+. 4783	+. 3592	----------
Model No. 2:											
0	+0. 3711	+. 3770	+. 3544	+. 3006	+. 1552	+. 0003	−. 1578	−. 3022	−. 3534	−. 3796	−0. 3711
+ 5	. 5017	. 5942	. 5886	. 5256	. 4039	. 2366	+. 0669	−. 0758	−. 1824	−. 2002	. 2248
10	. 6621	. 7937	. 8173	. 7655	. 6467	. 4833	. 3038	+. 1752	+. 0443	+. 0177	−. 0082
15	. 9588	1. 0004	1. 0310	. 9762	. 8561	. 7215	. 5411	. 4226	. 3019	. 2215	+. 1995
+20	+. 8682	+. 8977	+. 9440	+. 9181	+. 8679	+. 8032	+. 6658	+. 5634	+. 4761	+. 3554	+. 2330
Model No. 3:											
0	----------	+. 3803	+. 3937	+. 2727	+. 1424	−. 0010	−. 1454	−. 2720	−. 3937	−. 4006	----------
+ 5	----------	. 5900	. 6119	. 5040	. 3747	+. 2477	+. 1066	−. 0522	−. 1703	−. 1234	----------
10	----------	. 7524	. 8593	. 7517	. 6293	. 5129	. 3649	+. 2428	+. 1211	+. 0781	----------
15	----------	. 8315	. 9725	. 9200	. 8301	. 7255	. 6034	. 4905	. 3252	. 2221	----------
+20	----------	+. 7212	+. 9302	+. 9269	+. 8492	+. 7717	+. 6973	+. 6110	+. 4626	+. 3508	----------
Model No. 4:											
0	----------	+. 4617	+. 3737	+. 2303	+. 1152	+. 0010	−. 1162	−. 2569	−. 3823	−. 4653	----------
+ 5	----------	. 5486	. 5384	. 4915	. 3724	. 2553	+. 1398	. 0000	−. 1168	−. 1765	----------
10	----------	. 6257	. 7163	. 7445	. 6211	. 5089	. 3977	+. 2530	+. 1306	+. 0436	----------
15	----------	. 6881	. 8098	. 9164	. 8416	. 7465	. 6457	. 5079	. 3498	. 1903	----------
+20	----------	+. 6703	+. 7068	+. 8787	+. 8360	+. 7842	+. 7186	+. 6238	+. 4968	+. 3485	----------

TABLE IV

Absolute drag coefficient, C_D, for Handley-Page stabilizer and elevator

(Air speed, 40 M. P. H.)

Angle of attack of stabilizer α (degrees)	Elevator setting to stabilizer (degrees) $=\delta$										
	+25	+20	+15	+10	+5	0	−5	−10	−15	−20	−25
Model No. 1:											
0		0. 0827	0. 0553	0. 0299	0. 0146	0. 0091	0. 0143	0. 0293	0. 0521	0. 0804	
+5		. 1386	. 1158	. 0683	. 0400	. 0251	. 0146	. 0169	. 0221	. 0403	
10		. 2343	. 2102	. 1503	. 1058	. 0739	. 0504	. 0293	. 0273	. 0267	
15		. 3817	. 3566	. 2903	. 2398	. 1845	. 1507	. 1230	. 0970	. 0706	
+20		. 4744	. 4468	. 4025	. 3508	. 3059	. 2665	. 2275	. 2030	. 1692	
Model No. 2:											
0	0. 1030	. 0686	. 0472	. 0279	. 0151	. 0121	. 0157	. 0292	. 0459	. 0660	0. 1040
+5	. 1437	. 1109	. 0827	. 0607	. 0394	. 0259	. 0151	. 0167	. 0236	. 0413	. 0728
10	. 2028	. 1791	. 1500	. 1217	. 0915	. 0600	. 0384	. 0318	. 0276	. 0371	. 0600
15	. 3580	. 3261	. 2887	. 2467	. 2018	. 1568	. 1155	. 0942	. 0765	. 0738	. 0863
+20	. 4587	. 4364	. 4072	. 3668	. 3291	. 2805	. 2372	. 2087	. 1834	. 1585	. 1503
Model No. 3:											
0		. 0620	. 0361	. 0243	. 0151	. 0128	. 0144	. 0240	. 0358	. 0620	
+5		. 0958	. 0751	. 0584	. 0358	. 0276	. 0200	. 0197	. 0246	. 0532	
10		. 1746	. 1532	. 1217	. 0938	. 0751	. 0518	. 0420	. 0338	. 0522	
15		. 3111	. 2914	. 2487	. 2146	. 1854	. 1509	. 1217	. 0945	. 0942	
+20		. 4223	. 4124	. 3695	. 3311	. 2986	. 2661	. 1965	. 1644	. 1588	
Model No. 4:											
0		. 0748	. 0397	. 0223	. 0184	. 0144	. 0194	. 0213	. 0374	. 0748	
+5		. 1132	. 0751	. 0538	. 0413	. 0305	. 0226	. 0177	. 0279	. 0541	
10		. 1742	. 1398	. 1171	. 0935	. 0755	. 0571	. 0397	. 0390	. 0555	
15		. 3170	. 2789	. 2402	. 2067	. 1870	. 1565	. 1257	. 0997	. 0942	
+20		. 4499	. 3836	. 3609	. 3324	. 3052	. 2782	. 2438	. 2156	. 1877	

TABLE V

Lift/drag for Handley-Page stabilizer and elevator

(Air speed, 40 M. P. H.)

Angle of attack of stabilizer α (degrees)	Elevator setting to stabilizer (degrees) $=\delta$										
	+25	+20	+15	+10	+5	0	−5	−10	−15	−20	−25
Model No. 1:											
0	------	+8.60	+9.64	+12.22	+11.22	−0.32	−11.61	−12.50	−10.27	−8.81	------
+ 5	------	6.42	6.84	8.96	10.63	+10.51	+6.65	−5.27	−11.41	10.43	------
10	------	4.68	4.95	5.68	6.42	7.04	7.04	+6.27	+1.13	−5.58	------
15	------	2.96	3.02	3.38	3.58	4.03	3.94	3.67	3.26	+2.02	------
+20	------	+2.09	+2.16	+2.26	+2.39	+2.53	+2.58	+2.58	+2.36	+2.12	------
Model No. 2:											
0	+3.61	+5.50	+7.50	+10.78	+10.28	+.03	−10.02	−10.35	−7.70	−5.76	−3.57
+ 5	3.49	5.36	7.12	8.66	10.25	9.13	+4.44	−4.53	−7.72	−4.84	3.09
10	3.27	4.43	5.46	6.30	7.07	8.06	7.91	+5.51	+1.61	+.48	−.14
15	2.68	3.07	3.57	3.96	4.24	4.60	4.69	4.49	3.95	3.00	+2.31
+20	+1.89	+2.06	+2.32	+2.50	+2.64	+2.86	+2.81	+2.70	+2.60	+2.24	+1.55
Model No. 3:											
0	------	+6.14	+10.91	+11.23	+9.44	−.77	−10.06	−11.35	−11.00	−6.46	------
+ 5	------	6.16	8.14	8.64	10.48	+8.99	+5.33	−2.65	−6.92	−2.32	------
10	------	4.32	5.61	6.18	6.71	6.83	7.04	+5.78	+3.58	+1.50	------
15	------	2.67	3.34	3.70	3.87	3.92	4.00	4.03	3.44	2.36	------
+20	------	+1.71	+2.26	+2.51	+2.56	+2.59	+2.62	+3.11	+2.81	+2.21	------
Model No. 4:											
0	------	+6.18	+9.42	+10.32	+6.28	+.07	−6.00	−12.05	−10.22	−6.22	------
+ 5	------	4.85	7.17	9.14	9.01	8.37	+6.18	0.00	−4.19	−3.26	------
10	------	3.59	5.13	6.36	6.64	6.75	6.97	+6.37	+3.34	+.79	------
15	------	2.17	2.90	3.82	4.07	4.00	4.13	4.04	3.51	2.02	------
+20	------	+1.49	+1.84	+2.43	+2.51	+2.57	+2.58	+2.56	+2.31	+1.86	------

TABLE VI

Lift coefficient, K_y, for Handley-Page stabilizer and elevator ($Lb./ft.^3/mi.^2/hr.^2$)

(Air speed 40 M. P. H.)

α*	Elevator setting to stabilizer (degrees) = δ										
	+25	+20	+15	+10	+5	0	−5	−10	−15	−20	−25
Model No. 1:											
0	------	+0.001818	+0.001365	+0.000936	+0.000421	−0.000007	−0.000426	−0.000936	−0.001370	−0.001811	------
+ 5	------	.002277	.002028	.001566	.001089	+.000674	+.000249	−.000228	−.000646	.001078	------
10	------	.002806	.002664	.002183	.001738	.001331	.000908	+.000470	+.000079	−.000381	------
15	------	.002888	.002761	.002509	.002198	.001904	.001518	.001155	.000810	+.000364	------
+20	------	+.002536	+.002474	+.002328	+.002148	+.001978	+.001761	+.001501	+.001224	+.000920	------
Model No. 2:											
)	+0.000950	+.000965	+.000907	+.000770	+.000397	+.000001	−.000404	−.000774	−.000905	−.000972	−0.000950
+ 5	.001284	.001521	.001507	.001346	.001034	.000606	+.000171	−.000194	−.000467	−.000513	.000575
10	.001695	.002032	.002092	.001960	.001656	.001237	.000778	+.000449	+.000113	+.000045	−.000021
15	.002455	.002561	.002639	.002499	.002192	.001847	.001385	.001082	.000773	.000567	+.000511
+20	+.002223	+.002298	+.002418	+.002350	+.002222	+.002056	+.001704	+.001442	+.001219	+.000910	+.000596
Model No. 3:											
0	------	+.000974	+.001008	+.000698	+.000365	−.000003	−.000372	−.000696	−.001008	−.001026	------
+ 5	------	.001510	.001566	.001290	.000959	+.000634	+.000273	−.000134	−.000436	−.000316	------
10	------	.001926	.002200	.001924	.001611	.001313	.000934	+.000622	+.000310	+.000200	------
15	------	.002129	.002490	.002355	.002125	.001857	.001545	.001256	.000833	.000569	------
+20	------	+.001846	+.002381	+.002373	+.002174	+.001976	+.001785	+.001564	+.001184	+.000898	------
Model No. 4:											
0	------	+.001182	+.000957	+.000590	+.000295	+.000003	−.000297	−.000658	−.000979	−.001191	------
+ 5	------	.001404	.001378	.001258	.000953	.000654	+.000358	.000000	−.000299	−.000452	------
10	------	.001602	.001834	.001906	.001590	.001303	.001018	.000648	+.000334	+.000112	------
15	------	.001762	.002073	.002346	.002154	.001911	.001653	.001300	.000895	.000487	------
+20	------	+.001716	+.001809	+.002249	+.002140	+.002008	+.001840	+.001597	+.001272	+.000892	------

*α = angle of attack of stabilizer (degrees).

TABLE VII

Drag coefficient, K_x, for Handley-Page stabilizer and elevator (lb./ft.^{2}/mi.^{2}/hr.^{2})

(Air speed, 40 M. P. H.)

α*	Elevator setting to stabilizer (degrees) = δ										
	+25	+20	+15	+10	+5	0	−5	−10	−15	−20	−25
Model No. 1:											
0	------	0.0002117	0.0001416	0.0000765	0.0000374	0.0000233	0.0000366	0.0000750	0.0001334	0.0002058	------
+ 5	------	.0003548	.0002964	.0001748	.0001024	.0000643	.0000374	.0000433	.0000566	.0001032	------
10	------	.0005998	.0005381	.0003848	.0002708	.0001892	.0001290	.0000750	.0000699	.0000684	------
15	------	.0009772	.0009129	.0007431	.0006139	.0004723	.0003858	.0003149	.0002483	.0001807	------
+20	------	.0012145	.0011438	.0010304	.0008980	.0007831	.0006822	.0005824	.0005197	.0004332	------
Model No. 2:											
0	0.0002637	.0001756	.0001208	.0000714	.0000387	.0000310	.0000402	.0000748	.0001175	.0001690	0.0002662
+ 5	.0003679	.0002839	.0002117	.0001554	.0001009	.0000663	.0000387	.0000428	.0000604	.0001057	.0001864
10	.0005192	.0004585	.0003840	.0003116	.0002342	.0001536	.0000983	.0000814	.0000707	.0000950	.0001536
15	.0009165	.0008348	.0007391	.0006316	.0005166	.0004014	.0002957	.0002412	.0001958	.0001889	.0002209
+20	.0011743	.0011172	.0010424	.0009390	.0008425	.0007181	.0006072	.0005343	.0004695	.0004058	.0003848
Model No. 3:											
0	------	.0001587	.0000924	.0000622	.0000387	.0000328	.0000369	.0000614	.0000916	.0001587	------
+ 5	------	.0002452	.0001923	.0001495	.0000916	.0000707	.0000512	.0000504	.0000630	.0001362	------
10	------	.0004470	.0003922	.0003116	.0002401	.0001923	.0001326	.0001075	.0000865	.0001336	------
15	------	.0007964	.0007460	.0006367	.0005494	.0004746	.0003863	.0003116	.0002419	.0002412	------
+20	------	.0010811	.0010557	.0009459	.0008476	.0007644	.0006812	.0005030	.0004208	.0004065	------
Model No. 4:											
0	------	.0001915	.0001016	.0000571	.0000471	.0000369	.0000497	.0000545	.0000957	.0001915	------
+ 5	------	.0002898	.0001923	.0001377	.0001057	.0000781	.0000579	.0000453	.0000714	.0001385	------
10	------	.0004460	.0003579	.0002998	.0002394	.0001933	.0001462	.0001016	.0000998	.0001421	------
15	------	.0008115	.0007140	.0006149	.0005292	.0004787	.0004006	.0003218	.0002552	.0002412	------
+20	------	.0011517	.0009820	.0009239	.0008509	.0007813	.0007122	.0006241	.0005519	.0004805	------

*α = angle of attack of stabilizer (degrees).

TABLE VIII

Elevator hinge moments for Handley-Page control surfaces (lb. in.)

(Air speed, 40 M. P. H.)

Angle of attack of stabilizer α^i (degrees)	Elevator setting to stabilizer (degrees) $=\delta$										
	25°	20°	15°	10°	5°	0°	−5°	−10°	−15°	−20°	−25°
Model No. 1:											
0		−0.412	−0.301	−0.199	−0.129	0.000	+0.129	0.199	0.301	+0.412	
5		−.384	−.272	−.195	−.116	−.029	+.106	.159	.251	+.367	
10		−.398	−.310	−.225	−.143	−.059	+.044	.126	.235	+.333	
15		−.514	−.444	−.367	−.284	−.193	−.100	−.007	+.092	+.231	
20		−.537	−.478	−.418	−.350	−.278	−.199	−.118	−.033	+.102	
Model No. 2:											
0	−0.260	−.199	−.151	−.109	−.064	.000	+.064	.109	.151	.199	+0.260
5	−.324	−.220	−.161	−.105	−.057	−.011	+.055	.093	.123	.173	+.240
10	−.355	−.251	−.191	−.129	−.063	−.017	+.044	.088	.120	.163	+.205
15	−.407	−.339	−.288	−.223	−.154	−.088	−.025	+.035	.081	.108	+.079
20	−.407	−.358	−.317	−.263	−.204	−.146	−.089	−.034	+.019	.046	+.025
Model No. 3:											
0		−.059	−.027	−.050	−.029	.000	.029	.050	.027	+.059	
5		−.137	−.039	−.039	−.023	+.004	.034	.049	+.009	+.099	
10		−.196	−.087	−.061	−.035	−.006	+.024	+.046	−.006	+.022	
15		−.201	−.160	−.117	−.075	−.034	+.006	.039	+.015	−.087	
20		−.201	−.181	−.144	−.107	−.069	−.029	+.011	+.007	−.073	
Model No. 4:											
0		+.196	.142	.030	+.003	.000	−.003	−.030	−.142	−.196	
5											
10		−.019	+.062	.045	.033	.038	.039	+.016	−.176	−.190	
15											
20		+.010	.028	.031	.052	.067	.087	+.075	−.012	−.181	

TABLE IX

Slope, m, of C_L curves for elevator settings between +10° and −10° for Handley-Page stabilizer and elevator

$\Delta\alpha=5°$ in each case. Air speed, 40 M. P H.

Elevator setting to stabilizer δ (degrees)	Model No. 1		Model No. 2		Model No. 3		Model No. 4	
	ΔC_L	Slope $m=\frac{\Delta C_L}{\Delta\alpha}$	ΔC_L	Slope $m=\frac{\Delta C_L}{\Delta\alpha}$	ΔC_L	Slope $m=\frac{\Delta C_L}{\Delta\alpha}$	ΔC_L	Slope $m=\frac{\Delta C_L}{\Delta\alpha}$
+10	0.246	0.0492	0.232	0.0464	0.227	0.0454	0.260	0.0520
+5	.255	.0510	.248	.0496	.230	.0460	.255	.0510
0	.260	.0520	.241	.0482	.245	.0490	.258	.0516
−5	.259	.0518	.228	.0456	.258	.0516	.256	.0512
−10	.273	.0546	.232	.0464			.256	.0512
Average slope		.0517		.0472		.0480		.0514

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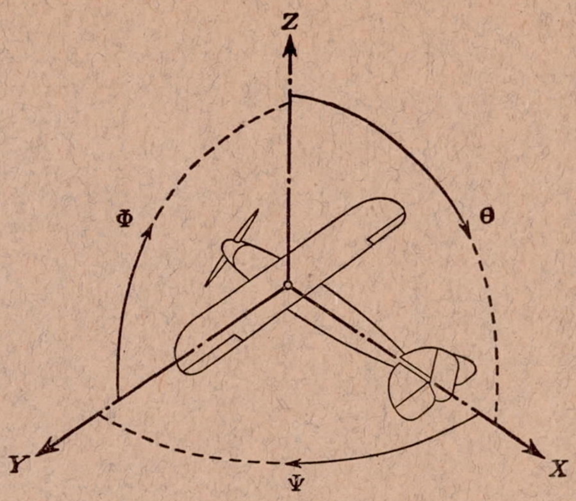

Positive directions of axes and angles (forces and moments) are shown by arrows

Axis		Force (parallel to axis) symbol	Moment about axis			Angle		Velocities	
Designation	Symbol		Designation	Symbol	Positive direction	Designation	Symbol	Linear (component along axis)	Angular
Longitudinal	X	X	rolling	L	$Y \longrightarrow Z$	roll	Φ	u	p
Lateral	Y	Y	pitching	M	$Z \longrightarrow X$	pitch	Θ	v	q
Normal	Z	Z	yawing	N	$X \longrightarrow Y$	yaw	Ψ	w	r

Absolute coefficients of moment

$$C_L=\frac{L}{qbS}\quad C_M=\frac{M}{qcS}\quad C_N=\frac{N}{qfS}$$

Angle of set of control surface (relative to neutral position), δ. (Indicate surface by proper subscript.)

4. PROPELLER SYMBOLS

D, Diameter.
p_e, Effective pitch
p_g, Mean geometric pitch.
p_s, Standard pitch.
p_v, Zero thrust.
p_a, Zero torque.
p/D, Pitch ratio.
V', Inflow velocity.
V_s, Slip stream velocity.

T, Thrust.
Q, Torque.
P, Power.
(If "coefficients" are introduced all units used must be consistent.)
η, Efficiency $= T\,V/P$.
n, Revolutions per sec., r. p. s.
N, Revolutions per minute., R. P. M.
Φ, Effective helix angle $=\tan^{-1}\left(\frac{V}{2\pi rn}\right)$

5. NUMERICAL RELATIONS

1 HP = 76.04 kg/m/sec. = 550 lb./ft./sec.
1 kg/m/sec. = 0.01315 HP.
1 mi./hr. = 0.44704 m/sec.
1 m/sec. = 2.23693 mi./hr.

1 lb. = 0.4535924277 kg.
1 kg = 2.2046224 lb.
1 mi. = 1609.35 m = 5280 ft.
1 m = 3.2808333 ft.