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RESEARCH MEMORANDUM

HINGE-MOMENT MEASUREMENTS OF A WING WITH LEADING-EDGE AND TRAILING-EDGE FLAPS AT A MACH NUMBER OF 1.93

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HINGE-MOMENT MEASUREMENTS OF A WING WITH LEADING-EDGE AND TRAILING-EDGE FLAPS AT A MACH NUMBER OF 1.93

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SUMMARY

Hinge-moment measurements were obtained from a semispan wing with both leading-edge and trailing-edge flaps in the Langley 9-inch supersonic tunnel. The wing had a straight taper of taper ratio equal to 0.59, an aspect ratio of 3.14, and constant-chord flaps (18.9 percent at the root). All tests were carried out at a Mach number of 1.93 and a Reynolds number of 1.31×10^6 based on mean chord of model.

Leading-edge-flap test results show that the rates of change of hinge-moment coefficient C_h with angle of attack α are almost identical with values of the rate of change of hinge-moment coefficient with flap deflection δ and are in excellent agreement with theoretical calculations. The slopes of both tend to increase at the higher values of the total angle of the flap plus the angle of attack as the theoretical calculations predict.

For the trailing-edge flap, the test results indicate that $dC_h/d\alpha$ and $dC_h/d\delta$ are essentially the same for the small range of both flap angles and angles of attack that were tested. The test values of both $dC_h/d\alpha$ and $dC_h/d\delta$ were somewhat lower than the values obtained by theoretical calculations, as might be expected, primarily because of separation near the trailing edge.

It is indicated from the results that, at least for the test Mach number of 1.93, a linkage system with a fixed ratio between the leading-edge and the trailing-edge flap might be used to reduce to approximately zero the resultant force required to deflect the flaps.

INTRODUCTION

One of the problems in the design of supersonic aircraft and missiles is a means for overcoming the large stick or servocontrol forces resulting from control-surface deflection. A wing or stabilizer, which has both leading-edge and trailing-edge flaps connected by a linkage such that the hinge moment of one helps to counteract that of the other, has been suggested. In an effort to investigate the feasibility of such a linkage, hinge-moment measurements from a wing with leading-edge and trailing-edge flaps have been made at a Mach number of 1.93.

SYMBOLS

α	wing angle of attack
δ	flap-deflection angle with respect to the wing (positive when in the direction that will increase the wing lift coefficient, up deflection for leading-edge flap and down deflection for trailing-edge flap)
Λ	angle of sweepback
λ	wing taper ratio $\left(c_t/c_r\right)$
ρ	free-stream density
θ	flap semiangle (measured in streamwise direction)
μ	absolute viscosity
A	aspect ratio (b^2/S)
b	span of model
$\bar{c}$	mean geometric chord of wing
c_f	chord of flap (perpendicular to hinge line)
c_r	wing chord at root
c_t	wing chord at tip
C_h	hinge-moment coefficient $\left(\dfrac{H}{q(c_f)^2\frac{b}{2}}\right)$
H	hinge moment of flap about its hinge line (of opposite sign than δ when acting as a restoring moment)
M	stream Mach number

p	stream static pressure
q	dynamic pressure $(0.7pM^2)$
R	Reynolds number $(\rho V\bar{c})/\mu$
S	total area of full-span model
t	thickness of wing
V	free-stream velocity

Subscripts:

LE	leading edge
TE	trailing edge

APPARATUS AND TEST METHODS

All tests were conducted in the Langley 9-inch supersonic tunnel at a Mach number of 1.93 and a Reynolds number of 1.31×10^6 (based on mean geometric chord of the wing). The tunnel is of the closed-return type, and the Mach number is varied by interchanging nozzle blocks which form test sections approximately 9 inches square. The air is sufficiently dried before each test for the effects of condensation in the supersonic nozzle to be negligible.

The semispan model tested was of all-steel construction with both leading-edge and trailing-edge full-span flaps of wedge section (fig. 1). The geometric characteristics of the model are presented in the following table:

Wing semispan, $b/2$, inches	6.00
Wing root chord, c_r, inches	4.81
Wing-tip chord, c_t, inches	2.84
Flap chord, c_f, inches	0.91
Wing area, S, square inches	45.90
Flap area, S_f, square inches	5.52
Wing aspect ratio, A	3.14
Taper ratio, λ	0.59
Wing thickness, t, inches	0.30
Angle of sweepback, Λ, degrees	9.33
Flap semiangle, θ, degrees	9.16

Each flap was coupled to the wing through strain-gage beams, with $\frac{1}{64}$-inch clearance between the flap and the wing.

The deflection of one flap was set at a value in the range -5° to 5°, with the other flap set at approximately zero, with the tunnel not running. Then, with the tunnel running, hinge-moment measurements were made through a range of wing angles of attack from -3° to 10°. Because of strain-gage trouble with one of the flaps, the tests were conducted with the leading-edge flap at a given angle; the whole model was then rotated 180°, and the leading-edge flap became the trailing-edge flap. Neither flap remained at a constant deflection because of changing loads on the flap as the angle of attack was varied. However, all angles were measured from photographs of the tip taken simultaneously with the hinge-moment measurements. Both angles of attack and flap angles were referenced to the center line of the tunnel. The flap angles were practically the same as if the angles were measured normal to the hinge line of the flap since there was only 9.33° sweep of the hinge lines.

The semispan model was mounted on a boundary-layer scoop-off plate so that the part of the model near the root was free of tunnel-wall boundary-layer effects. One of the characteristics of semispan testing is that the data include the interference effects of a mirror image of the wing being tested (due to reflections of disturbances back on the wing); thus the data presented correspond to those for a full-span wing where the control surfaces operate as flaps and not as ailerons.

PRECISION OF RESULTS

It was found from a survey along the air stream at three vertical positions that, for a Mach number of 1.62, the installation of the boundary-layer scoop-off plate alone caused a maximum change in static pressure of 0.8 percent in the region to be occupied by the model. It is believed that this change in static pressure was even less at a Mach number of 1.93. The maximum streamwise variation in static pressure for a Mach number of 1.93 with no boundary-layer plate installed is ±1.5 percent over the region occupied by the model.

It is believed that the strain gages permitted accurate measurements of the hinge moments to within $C_h = \pm 0.003$. This figure is based on observations of how well the zero readings checked before and after each test and the linearity and the lack of hysteresis of the calibration curves.

The angles of attack of the wing and the flap angles were measured from photographs taken normal to the tip while the tunnel was running. It is believed that these angles are accurate to within ±0.25° with respect to the tunnel center line. This value is based on the consistency with which it was possible to recheck angle measurements taken from the photographs of the model. In figure 2 it can be seen that for $\alpha = 0^{\circ}$, zero hinge moment for the leading-edge flap occurs at $\delta = 1.1^{\circ}$ and, similarly in figure 3, that for $\delta = 0^{\circ}$, zero hinge moment occurs at $\alpha = 1.1^{\circ}$. Because of the manner of testing, that is, rotating the model 180° when taking trailing-edge-flap data as compared with the position when taking leading-edge-flap data, ±0.4° can be ascribed to model asymmetry. This may be seen by comparing (in figs. 2 and 3) the zero hinge-moment values of the leading-edge and trailing-edge flaps with each other. The remaining part of the displacement of the curves is believed to be a combination of two other possible sources of error: (1) stream angle, and (2) misplacement of the reference axis.

DISCUSSION

The data obtained from these tests are presented in table I. It was necessary to modify the test points, for more convenient analysis of the data, in the following manner: curves of the measured values of C_h against the measured values of α were plotted; and, at selected constant values of α, the corresponding hinge-moment coefficients were read. The values of flap deflection at the selected angles of attack were read from plots of the measured flap-deflection angles against the measured angles of attack, where smooth curves were faired through the points. (The accuracy was believed to be ±0.25° and also it was recognized that other than a smooth variation of deflection under load with angle of attack seemed highly improbable.) Curves were then plotted of the variation of hinge-moment coefficient with flap deflection for constant values of angle of attack (fig. 2). The variation in hinge-moment coefficient with angle of attack for constant values of flap deflection (fig. 3) was obtained by cross-plotting.

For the leading-edge flap, for which the results can be expected to be independent of trailing-edge-flap position and for which there was no discernible interrelation for the small range of angles tested, the experimental value of both $dC_h/d\delta$ and $dC_h/d\alpha$ was the same in the low-angle region at a value of 0.030. At the higher flap-deflection angles and angles of attack there was a tendency for the slope to increase. An interesting point is that, for the 9.16° half-wedge angle of the flap and a stream Mach number of 1.93, the leading-edge shock would detach (theoretically) at a total angle (flap-deflection angle plus angle of attack) of about 12.6°. No abrupt break in the curves was noticed at this point. The theoretical values of $dC_h/d\delta$ and $dC_h/d\alpha$ for the leading-edge flap are the same, and this value of 0.031 in the low-angle range with a gradual increase to about 0.035 in the range from about 6° to 12° compares favorably with the test results. These theoretical values were obtained by use of the inviscid shock and expansion theory over the two-dimensional region of the flap (outside the Mach cones arising from the leading edge of the tip and of the root) and by use of the linear theory for the region within these Mach cones.

The effect of the leading-edge-flap position on the trailing-edge-flap results was expected to be small, and for the random variations of leading-edge-flap angles between -2.5° and 2.5°, there was no discernible interrelation. The trailing-edge experimental values obtained were $dC_h/d\delta$ of -0.010 with no appreciable variation with α and $dC_h/d\alpha$ of -0.0095 for various δ values. In spite of any effect of the leading-edge flap, there was very little scatter of the test points. The theoretical value of $dC_h/d\delta$ for the trailing-edge flap was computed by the method outlined in reference 1 and, for $\alpha = 0^\circ$, was -0.015. The theoretical value of $dC_h/d\alpha$ of -0.011 at $\delta = 0^\circ$ was computed by assuming that the ratio of the thickness effect in the two-dimensional case and the three-dimensional case (computed from the linearized theory) were the same. The test results are seen to be somewhat lower than these theoretical values, as might be expected, primarily because of separation near the trailing edge.

If a wing or stabilizer with both leading-edge and trailing-edge flaps were so designed that the hinge moment of one flap helped counteract that of the other, then for the design to be feasible the difference between $dC_h/d\alpha$ and $dC_h/d\delta$ must be small. The results for the configuration as tested indicated that this difference was not large, the ratio of hinge moments for equal deflection of the two flaps varying only from about 2.65 to 3.35 throughout the test range of angle of attack, as shown in figure 4. In order to reduce to zero the resultant force required to deflect the flaps, it can be shown that the ratio of flap deflections (which is equal to the mechanical advantage of any suitable linkage) would vary accordingly from about $\sqrt{2.65}$ to $\sqrt{3.35}$, or from 1.63 to 1.83. An analysis of the forces involved in the linkage will show the relation between the linkage ratio for zero resultant force and the hinge-moment ratio for equal flap angles, namely that the former ratio is the square root of the latter. The smallness of the variation of the required linkage ratio suggests that a constant ratio of about 1.73 would reduce the resultant force required to deflect the flaps to a value close to zero. The constancy of this ratio for higher angles might be in some doubt owing to the fact that the effect on the trailing-edge flap of larger leading-edge-flap deflections was not determined; however, since the leading-edge flap will deflect only 1/1.73 of the trailing-edge-flap deflection and the test results include leading-edge-flap deflections of -2.5° to 2.5°, the results should be applicable to a range of trailing-edge-flap deflections from about -4.3° to 4.3°. The ratio between hinge moments may also be a function of Mach number so that a linkage of fixed ratio might hold hinge-moment values close to zero for only a limited range of Mach number.

CONCLUDING REMARKS

The experimental results as obtained for the leading-edge flap were in excellent agreement with theoretical calculations. For the trailing-edge flap, the measured hinge-moment values were somewhat lower than the theoretical calculations, as might be expected, primarily because of separation near the trailing edge. The small differences in $dC_h/d\delta$ and $dC_h/d\alpha$ for each flap suggest that a linkage between the two flaps, which would reduce the resulting hinge-moment value close to zero, would be feasible for the test Mach number. However, the ratio between hinge moments may also be a function of Mach number so that a linkage of fixed ratio might hold hinge-moment values close to zero for only a limited range of Mach number.

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National Advisory Committee for Aeronautics
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REFERENCE

1. Tucker, Warren A., and Nelson, Robert L.: Theoretical Characteristics in Supersonic Flow of Constant-Chord Partial-Span Control Surfaces on Rectangular Wings Having Finite Thickness. NACA TN No. 1708, 1948.

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TABLE I.- EXPERIMENTAL RESULTS SHOWING MODIFICATION TO TEST POINTS

C_h (Measured)	α (Measured)	δ (Measured)	α (Selected)	C_h (At selected α)	δ (At selected α)	C_h (Measured)	α (Measured)	δ (Measured)	α (Selected)	C_h (At selected α)	δ (At selected α)	C_h (Measured)	α (Measured)	δ (Measured)	α (Selected)	C_h (At selected α)	δ (At selected α)	C_h (Measured)	α (Measured)	δ (Measured)	α (Selected)	C_h (At selected α)	δ (At selected α)	C_h (Measured)	α (Measured)	δ (Measured)	α (Selected)	C_h (At selected α)	δ (At selected α)
Leading-edge flap																													
-0.1272	-2.24	-0.40	-3	-0.148	-0.40	-0.0682	-2.87	2.14	-3	-0.072	2.15	0.0340	-3.15	5.60	-3	0.039	5.50	-0.267	-3.27	-4.55	-3	-0.259	-4.60	-0.3305	-3.09	-6.52	-3	-0.325	-6.42
-.0673	-.23	-.46	-1	-.085	-.29	-.0058	-1.32	2.24	-1	.006	2.22	.0936	-1.00	5.85	-1	.096	5.50	-.202	-1.03	-4.31	-1	-.196	-4.40	-.2533	-1.32	-5.92	-1	-.243	-5.92
-.0328	.11	-.05	0	-.046	-.21	.0324	-.23	2.28	0	.040	2.27	.1293	0	5.62	0	.125	5.48	-.171	-.17	-4.53	0	-.163	-4.28	-.2192	-.28	-6.08	0	-.208	-5.70
-.004	1.03	.23	1	-.006	-.14	.0611	.75	2.47	1	.069	2.30	.1609	1.32	5.05	1	.156	5.48	-.140	.69	-4.16	1	-.132	-4.20	-.1865	.52	-5.62	1	-.170	-5.50
.0596	3.15	.06	3	.052	0	.1208	2.87	2.45	3	.126	2.38	.2306	3.09	5.30	3	.222	5.50	-.075	2.75	-4.01	3	-.066	-4.02	-.1190	2.58	-4.99	3	-.105	-5.05
.1252	5.28	.17	5	.110	.17	.1945	5.16	2.56	5	.190	2.42	.3120	5.34	5.26	5	.297	5.58	-.008	5.11	-4.54	5	-.002	-3.88	-.0515	4.96	-4.76	5	-.045	-4.70
.1667	6.83	.36	6.5	.152	.27	.2488	6.83	2.43	6.5	.239	2.49	.3882	6.60	5.87	6.5	.370	5.72	.047	6.37	-3.68	6.5	.050	-3.77	-.0030	6.43	-4.53	6.5	0	-4.47
.2109	8.51	.52	8	.198	.38	.3030	8.51	2.39	8	.288	2.52	.4552	8.34	6.14	8	.434	5.95	.105	8.02	-3.60	8	.102	-3.62	.0565	7.91	-4.14	8	.047	-4.25
.2618	9.85	.46	10	.264	.52	.3952	10.20	3.16	10	.370	2.60	.5113	10.14	6.66	10	.505	6.40	.167	9.85	-3.48	10	.172	-3.48	.1126	10.20	-4.64	10	.113	-4.30
Trailing-edge flap																													
.0342	-2.52	-.46	-3	.037	-.66	.0153	-3.09	1.37	-3	.016	1.55	-.0259	-2.98	4.99	-3	-.027	4.77	.0707	-3.15	-4.03	-3	.070	-3.90	.0828	-3.67	-4.89	-3	.078	-4.77
.0158	-.52	-.91	-1	.020	-.70	.0014	-.96	1.41	-1	.002	1.54	-.0401	-1.43	4.81	-1	-.044	4.85	.0533	-1.03	-4.25	-1	.052	-3.90	.0641	-1.38	-4.76	-1	.063	-4.77
.0074	.34	-1.03	0	.011	-.72	-.0102	-.12	1.55	0	-.010	1.53	-.0507	-.46	4.53	0	-.053	4.88	.0446	-.29	-3.74	0	.044	-3.90	.0574	-.34	-4.77	0	.055	-4.77
-.0010	1.09	-.40	1	.001	-.75	-.0198	1.00	1.46	1	-.019	1.53	-.0612	1.00	4.53	1	-.062	4.93	.0379	.81	-3.85	1	.036	-3.90	.0494	.74	-4.75	1	.045	-4.78
-.0180	2.98	-.80	3	-.020	-.80	-.0368	2.89	1.47	3	-.036	1.52	-.0785	2.64	4.89	3	-.080	5.02	.0191	2.64	-3.61	3	.019	-3.90	.0321	2.46	-4.58	3	.028	-4.80
-.0369	4.90	-.75	5	-.039	-.84	-.0555	5.20	1.56	5	-.053	1.51	-.0989	4.70	5.38	5	-.098	5.08	-.0007	5.16	-4.07	5	.002	-3.96	.0087	4.88	-4.99	5	.012	-4.87
-.0489	6.49	-.40	6.5	-.049	-.87	-.0685	6.58	1.73	6.5	-.067	1.50	-.1105	6.37	5.23	6.5	-.112	5.06	-.0131	6.61	-4.32	6.5	-.012	-4.02	-.0023	6.83	-5.23	6.5	-.002	-4.92
-.0600	8.22	-.77	8	-.059	-.90	-.0797	7.82	1.68	8	-.081	1.49	-.1197	7.47	5.12	8	-.124	4.98	-.0258	7.70	-3.80	8	-.026	-4.10	-.0150	8.28	-5.36	8	-.013	-4.99
-.0721	10.31	-1.03	10	-.071	-.96	-.0934	10.25	1.34	10	-.092	1.48	-.1333	9.50	4.98	10	-.137	4.95	-.0395	10.00	-4.00	10	-.040	-4.25	-.0297	9.85	-4.74	10	-.030	-5.11

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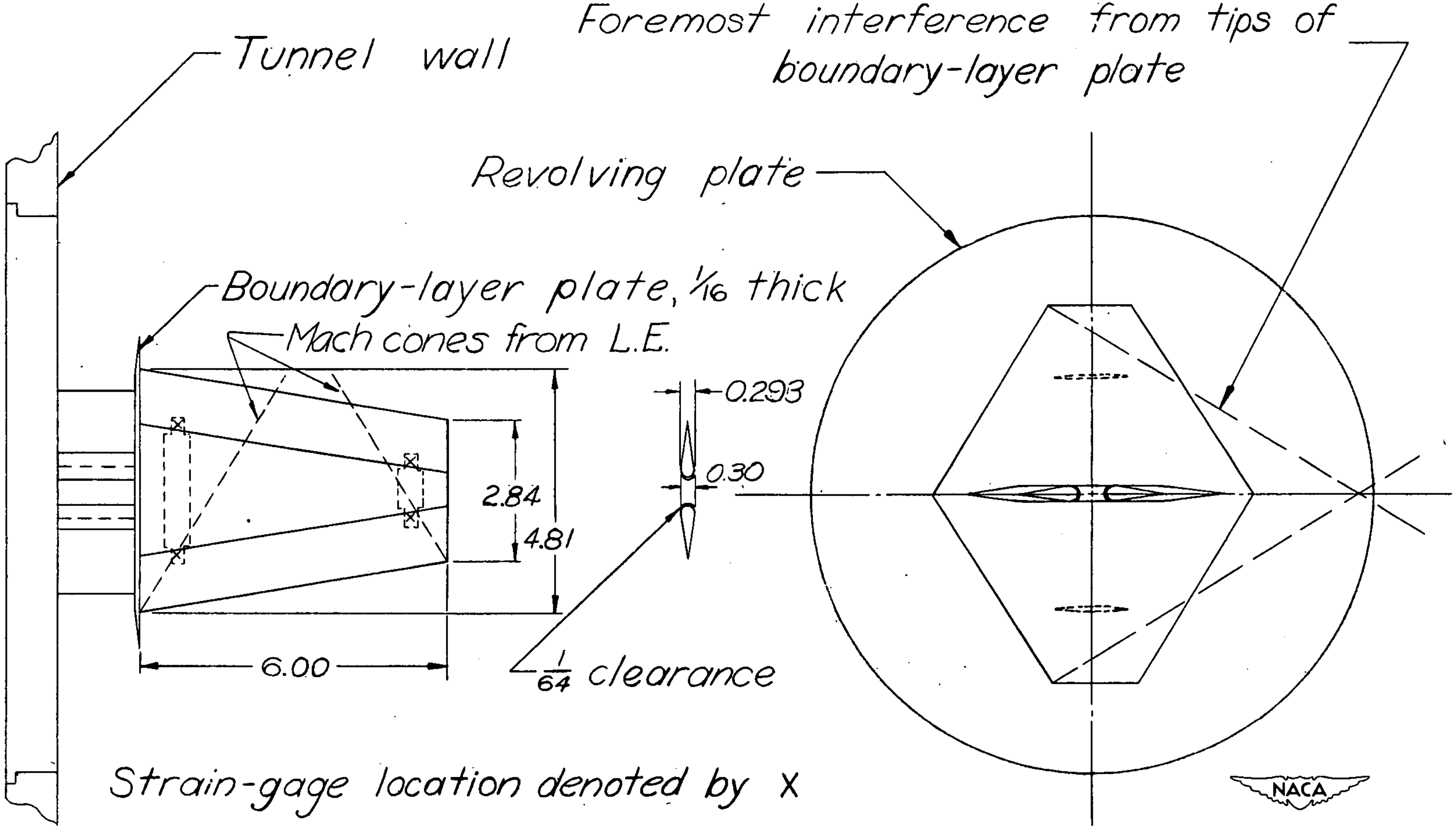

(a) Top view.

(b) Side view.

Figure 1.- Hinge-moment-model installation. (All dimensions are in inches.)

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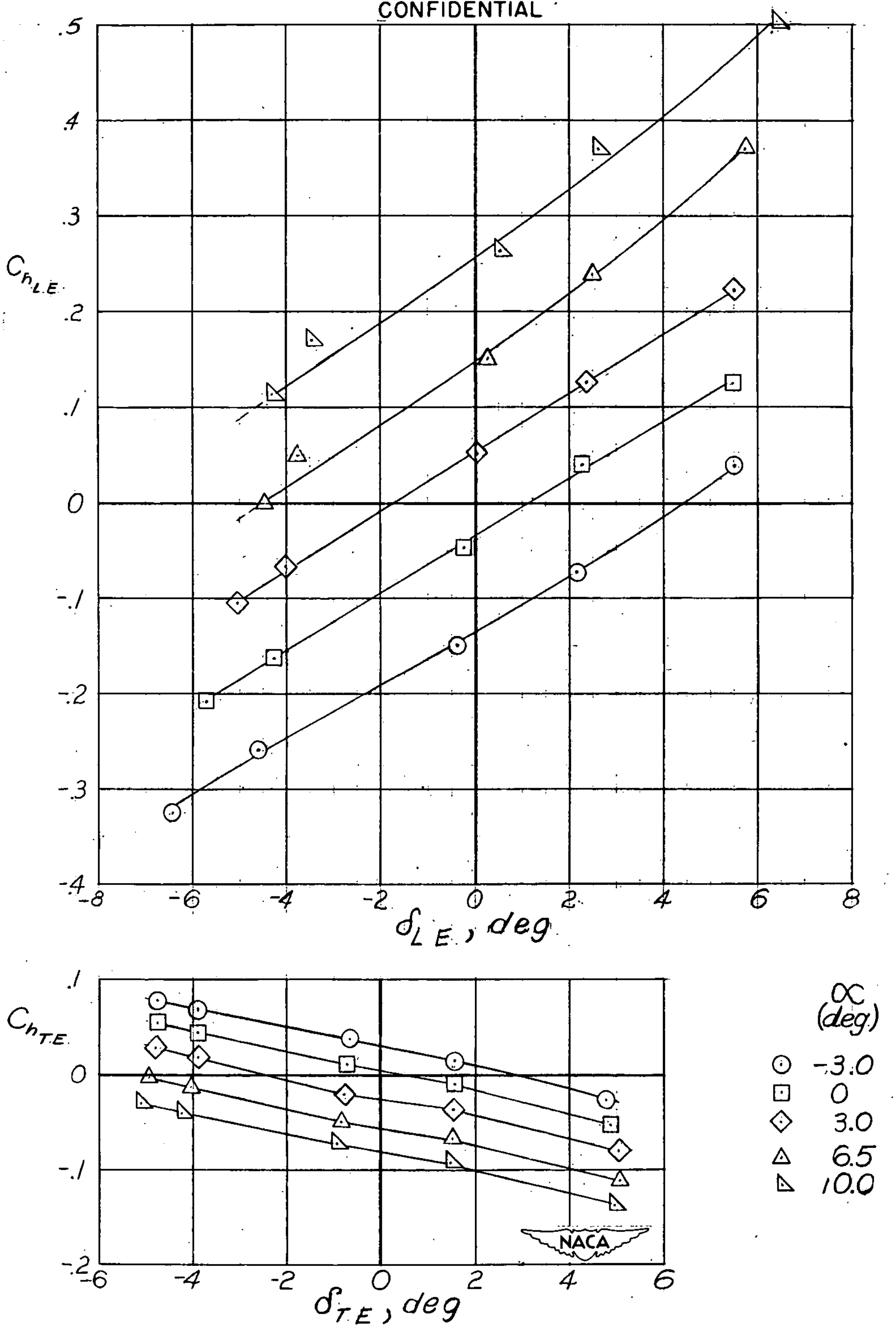

Figure 2.- Leading-edge-flap and trailing-edge-flap hinge-moment coefficients against flap angle for constant values of angle of attack.

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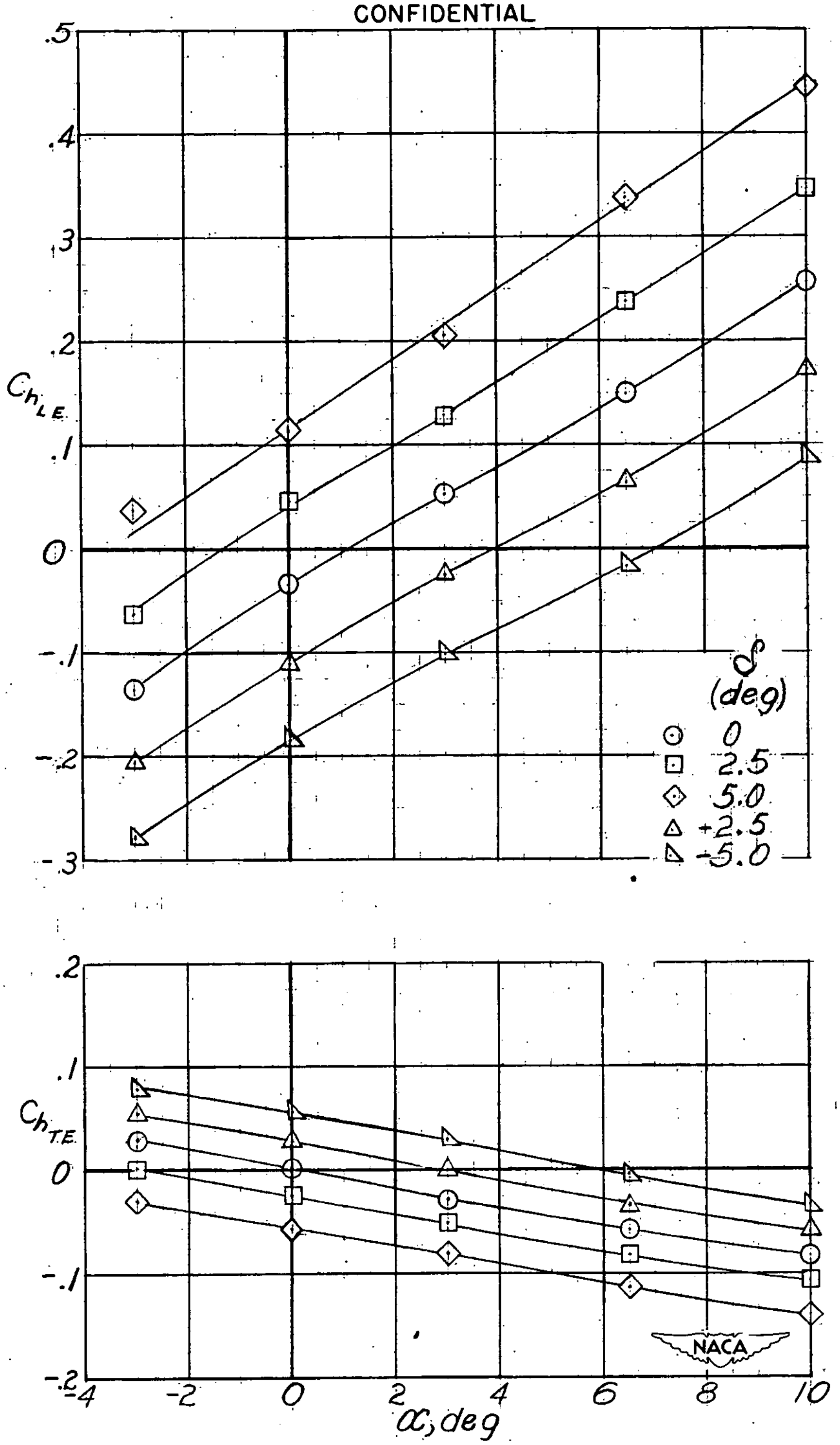

Figure 3.- Leading-edge-flap and trailing-edge-flap hinge-moment coefficients against angle of attack for constant values of flap-deflection angle. (Cross plot of fig. 2.)

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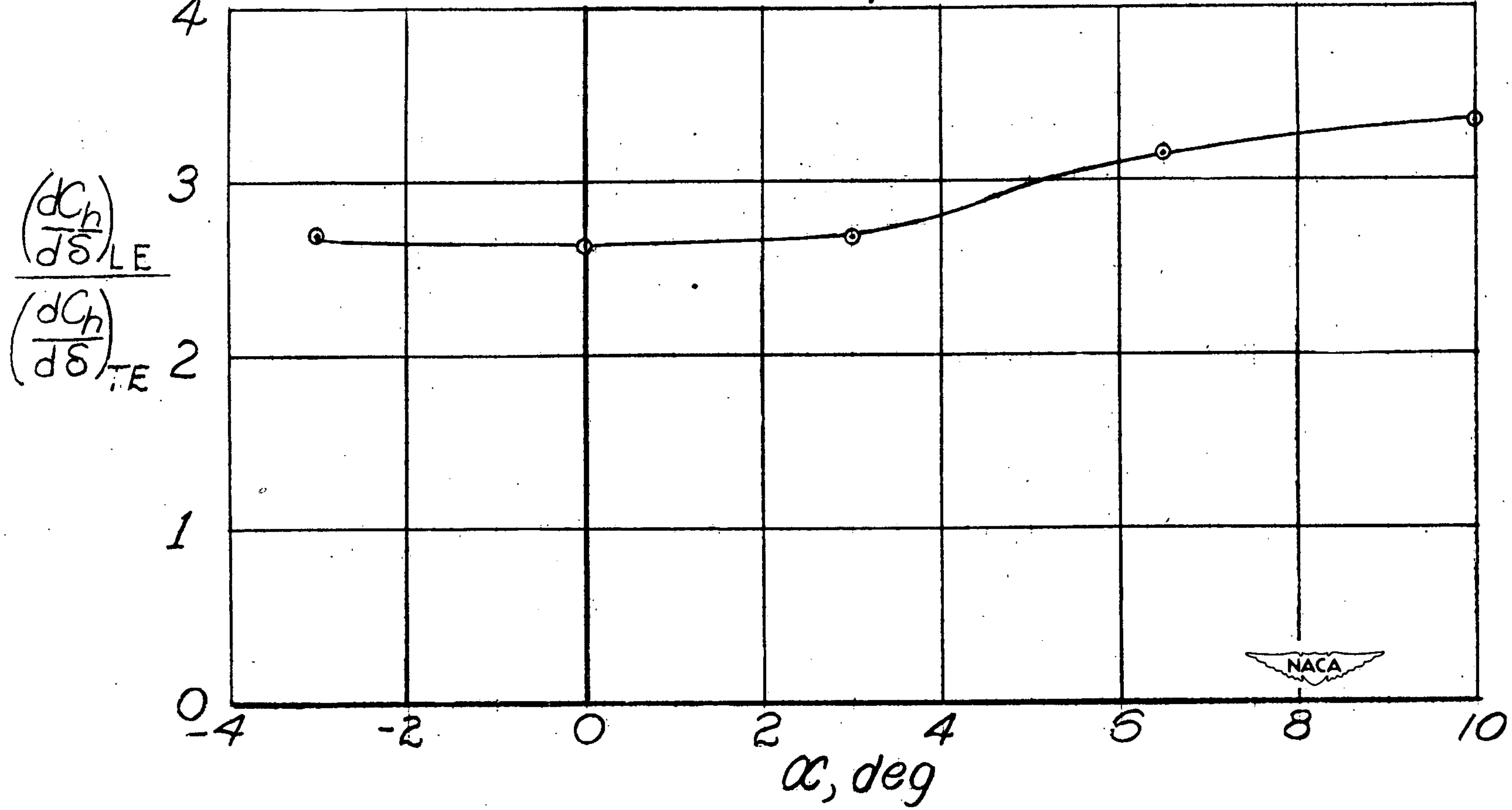

Figure 4.- Ratio of the leading-edge-flap hinge-moment coefficient to the trailing-edge-flap hinge-moment coefficient for equal flap-deflection angles as a function of angle of attack. (Average slopes from fig. 2 used.)

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