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RESEARCH MEMORANDUM

INVESTIGATION OF A THIN WING OF ASPECT RATIO 4 IN THE AMES 12-FOOT PRESSURE WIND TUNNEL. III - THE EFFECTIVENESS OF A CONSTANT-CHORD AILERON

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

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RESEARCH MEMORANDUM

INVESTIGATION OF A THIN WING OF ASPECT RATIO 4 IN THE AMES 12-FOOT PRESSURE WIND TUNNEL. III – THE EFFECTIVENESS OF A CONSTANT-CHORD AILERON

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SUMMARY

A wind-tunnel investigation was made at Mach numbers from 0.27 to 0.94 with a constant Reynolds number of 2,370,000 of a semispan model of a thin, unswept wing of aspect ratio 4 and taper ratio 0.5 equipped with a constant-chord aileron extending inboard from the wing tip a distance of 39.12 percent of the wing semispan. The wing had a modified diamond profile with a thickness ratio of 0.042.

Compressibility effects on the aileron effectiveness were small at Mach numbers up to 0.85. At Mach numbers above 0.85, the aileron effectiveness became erratic even at angles of attack well below the stall. At a Mach number of 0.94 a reversal in aileron effectiveness was observed at an aileron deflection of 2° and an angle of attack of only 5°. Similar reversals were noted at angles of attack near the stall for Mach numbers of 0.27 and 0.50. At angles of attack up to 4°, the total rolling-moment coefficient due to equal up- and down-aileron deflections varied smoothly with aileron deflection at all Mach numbers up to 0.94. At low speeds, some degree of rolling effectiveness was retained by the up-aileron even for angles of attack above the stall.

The data have been applied to the prediction of low-speed lateral-control characteristics of a hypothetical airplane equipped with the wing-aileron combination tested. The maximum value of the helix angle generated by the wing tip was predicted to be adequate at the flight condition investigated.

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INTRODUCTION

As part of a general study of supersonic airplane configurations, tests have been made of a thin, straight wing of aspect ratio 4 in the Ames 12-foot pressure wind tunnel. Tests of the plain wing have been reported in reference 1, and the effects of leading-edge and trailing-edge flaps on the low-speed characteristics have been reported in reference 2. The tests reported herein were made to determine the effectiveness of a constant-chord aileron on this wing at Mach numbers up to 0.94, and were conducted at a constant Reynolds number of 2,370,000.

COEFFICIENTS AND SYMBOLS

The following coefficients are used in this report:

C_L lift coefficient $\left(\frac{\text{lift}}{qS/2}\right)$

C_l rolling-moment coefficient $\left(\frac{\text{rolling moment}}{qSb}\right)$

C_{l_p} damping-moment coefficient in roll; the rate of change of rolling-moment coefficient C_l with wing-tip helix angle $pb/2V$

C_{l_u} measured rolling-moment coefficient of the semispan model

The following symbols are used in this report:

a speed of sound, feet per second

a_o section lift-curve slope, per degree

b twice the span of the semispan wing, feet

c local wing chord, feet

c' wing mean aerodynamic chord, chord through centroid of the wing semispan plan-form area $\left(\frac{\int_0^{b/2} c^2\,dy}{\int_0^{b/2} c\,dy}\right)$, feet

M Mach number $\left(\frac{V}{a}\right)$

p angular velocity in roll, radians per second

q dynamic pressure $(\frac{1}{2}\rho V^2)$, pounds per square foot

R Reynolds number $\left(\frac{\rho V c'}{\mu}\right)$

S twice the area of the semispan wing, square feet

V airspeed, feet per second

y distance from the plane of symmetry to any spanwise station, feet

α angle of attack of wing-chord plane, degrees

α_u angle of attack of the wing-chord plane in the wind tunnel, uncorrected for tunnel-wall interference, degrees

δ_a aileron deflection, measured in a plane perpendicular to the aileron hinge axis, positive downward, degrees

μ viscosity of air, slugs per foot-second

ρ mass density of air, slugs per cubic foot

MODEL AND APPARATUS

The tests were conducted in the Ames 12-foot pressure wind tunnel which is a closed-throat, variable-density wind tunnel with a low turbulence level closely approximating that of free air.

The semispan wing with a plain aileron used for this investigation was the same as that used in the tests of reference 1. The ridges of the basic diamond profile had been rounded so that the thickness-chord ratio was 0.042. The semispan model represented a wing of aspect ratio 4 and taper ratio 0.50. The span of the constant-chord aileron was 39.12 percent of the wing semispan and extended to the wing tip. The aileron had an area of 7.8 percent of the wing area and the ratio of aileron chord to local wing chord varied from 0.216 at the aileron root to 0.300 at the aileron tip. The unsealed gap between the aileron and the wing was 0.015 inch. Dimensions of the wing are given in figure 1. The semispan model was mounted vertically in the tunnel as shown in figure 2. The aileron was attached to the wing by hinges and rigidly held in position by steel angle plates. Angular distortion of the aileron under aerodynamic loads was negligible.

CORRECTIONS TO DATA

The data have been corrected for tunnel-wall interference, constriction due to the tunnel walls, and model-support tare forces. The corrections to the data for tunnel-wall interference, determined by the method of reference 3, are:

$$\alpha = \alpha_u + 0.363\ C_L$$

$$C_l = 0.905\ C_{l_u}$$

For these calculations, span loading due to aileron deflection was obtained from the charts of reference 4.

Corrections to the data for constriction effects of the tunnel walls, evaluated by the method of reference 5, are given in the following table:

Corrected Mach number	Uncorrected Mach number	q, corrected / q, uncorrected
0.94	0.931	1.041
.92	.915	1.031
.90	.897	1.028
.87	.868	1.021
.85	.848	1.017
.80	.799	1.012
.50	.500	1.005
.27	.270	1.000

The turntable on which the model was mounted was connected directly to the force-measuring apparatus, hence the measured rolling moments included a tare rolling moment as a result of the asymmetry of the pressure distribution on the turntable due to lift on the wing. In the reduction of the data, the rolling moment due to aileron deflection was calculated by subtracting the measured rolling moment with aileron neutral from the measured rolling moment with aileron deflected for each angle of attack and Mach number.

This procedure eliminates the turntable rolling moment due to angle of attack of the plain wing, but neglects the change in turntable rolling moment due to aileron deflection. The effect of aileron deflection on the turntable rolling moments would tend to reduce the measured rolling moments. Therefore, the aileron effectiveness presented herein is believed to be slightly conservative.

TESTS

Lift and rolling-moment data have been obtained for a range of angles of attack at a constant Reynolds number of 2,730,000 and Mach numbers from 0.27 to 0.94. For each angle of attack and Mach number, tests were made at seven aileron deflections from 0° to 18°. At low speeds, the angle-of-attack range was from −15° to 15°, but at Mach numbers above 0.80 this range was limited by tunnel power and model strength.

RESULTS AND DISCUSSION

Lift and rolling-moment characteristics of the wing as a function of angle of attack are presented in figure 3 for aileron deflections of 0°, 2°, 4°, 6°, 10°, 14°, and 18° at Mach numbers of 0.27, 0.50, 0.80, 0.85, 0.87, 0.90, 0.92, and 0.94. Since the wing profile was symmetrical, the data presented in figure 3 for positive aileron deflections can be used to indicate the effect of negative aileron deflections by simply reversing the algebraic signs of the coordinate axes.

Figures 3(a) and 3(b) indicate that, at Mach numbers up to 0.50, the aileron is effective in producing rolling moments up to the largest aileron deflection tested, 18°, and that the rolling effectiveness reaches a maximum at an angle of attack of approximately 6°. The aileron deflected downward (i.e., data for positive angles of attack) is seen to lose effectiveness rapidly at angles of attack greater than 6°, but the aileron deflected upward (i.e., data for negative angles of attack) is seen to remain effective at angles of attack above the stall.

At a Mach number of 0.80 (fig. 3(c)), the rolling moment due to positive aileron deflection is seen to increase rapidly with increasing angle of attack up to an angle of attack of 8°. Examination of the lift curve, given in the same figure, indicates an increase in lift-curve slope for the same combinations of aileron angle and angle of attack. This same characteristic is indicated at the higher Mach numbers up to 0.94 (figs. 3(d), 3(e), 3(f), 3(g), and 3(h)), but the angle of attack at which the maximum rolling moment was attained decreased to 4° as the Mach number increased to 0.87. The angle of attack for maximum rolling moment was little affected by further increase in Mach number. After reaching a maximum, the rolling moment decreases rapidly with further increase in the angle of attack. At a Mach number of 0.94 and an angle of attack of 5°, a reversal in the aileron effectiveness occurred for small aileron deflections. Similar reversals are noted for Mach numbers of 0.27 and 0.50 at angles of attack near the stall.

The effect of Mach number on the aileron effectiveness is summarized in figure 4 for angles of attack of approximately 0°, 2°, and 4°. For these curves, the data obtained with a positive aileron deflection and a negative angle of attack are represented as negative aileron deflections at a positive angle of attack. At an angle of attack of 0°, the effects of compressibility on the rolling moment due to aileron deflection were moderate throughout the test range of Mach numbers. At an angle of attack of 4°, the compressibility effects on the measured rolling moments were large and erratic at Mach numbers above 0.80. To determine the effect of compressibility on the aileron effectiveness of a typical installation, the experimental data of figure 3 have been plotted in figure 5 as total rolling moment due to equal up- and down-aileron deflections as a function of total aileron deflection for an angle of attack of 4°. The data of this figure indicate that, despite the erratic behavior of the rolling moment due to individual aileron deflection at high Mach numbers, application of the ailerons with equal up- and down-deflections results in a smooth and uniform variation of rolling moment with total aileron deflection up to a Mach number of 0.94.

Free-flight data for a similar wing-aileron combination (but with the wing thickness 0.046 chord) at Mach numbers from 0.60 to 1.92 have been reported in reference 6. Values of $pb/2V$ in steady rolls are presented in this reference as a function of Mach number for a rocket-fired model with a fixed aileron deflection of 4.6°. The data of reference 6 indicate very large and abrupt losses in rolling velocity in the Mach number range from 0.92 to 0.97. Whether this abrupt loss in rolling velocity was caused by an increase in the damping-moment coefficient due to rolling or to an abrupt decrease in the rolling moment due to aileron deflection is difficult to ascertain. In view of the data of reference 6, it is recommended that no attempt be made to extrapolate the aileron-effectiveness data of figure 3 to any Mach number above the reported value of 0.94.

The data of figure 3 have been applied to the prediction of the low-speed rolling performance of a hypothetical airplane flying at sea level. The calculations are based on the method of reference 7, assuming zero sideslip of the airplane and no torsional deflection of the wing. Values of the damping-moment coefficient due to rolling C_{l_p} were obtained from reference 8 using values of wing-section lift-curve slope a_o interpolated from the data of reference 9.

The calculated variation of the wing-tip helix angle with total aileron deflection (sum of equal up-and down-deflections) is presented in figure 6 for an airplane with a wing loading of 60 pounds per square foot. Values are presented for flight Mach numbers of 0.27 and 0.50. The variation of $pb/2V$ with aileron deflection is smooth and uniform and the maximum value of $pb/2V$ is larger than specified by reference 10.

CONCLUSIONS

By the results of tests of a semispan model representing a thin wing of aspect ratio 4 and taper ratio 0.50 with a constant-chord aileron of 39.12 percent of the wing semispan in the Ames 12-foot pressure wind tunnel at Mach numbers up to 0.94, the following conclusions are indicated:

1. The ailerons were successful in producing rolling moments up to the highest test Mach number 0.94, at lift coefficients up to 0.5. At Mach numbers of 0.85 and above, the rolling moments produced by small aileron deflections were small and erratic at lift coefficients greater than 0.5. At a Mach number of 0.94, a reversal in aileron effectiveness was observed at an angle of attack of only 5°. Similar reversals were noted at angles of attack near the stall for Mach numbers of 0.27 and 0.50.

2. At low speeds, the ailerons were predicted to be capable of producing a wing-tip helix angle greater than 0.10 radians. With the aileron deflected upward, some degree of rolling effectiveness was retained at angles of attack above the stall.

3. Despite the erratic behavior of the rolling moments due to individual aileron deflections at Mach numbers above 0.85, the rolling moments calculated for equal up- and down-aileron deflections varied smoothly and uniformly with total aileron deflection at angles of attack up to 4° and Mach numbers up to 0.94. The effect of compressibility on the rate of change of wing-tip helix angle with aileron

deflection will be confined primarily to its effect on the damping moment due to rolling and its effect on wing twist for flight at Mach numbers up to 0.94 and angles of attack up to 4°.

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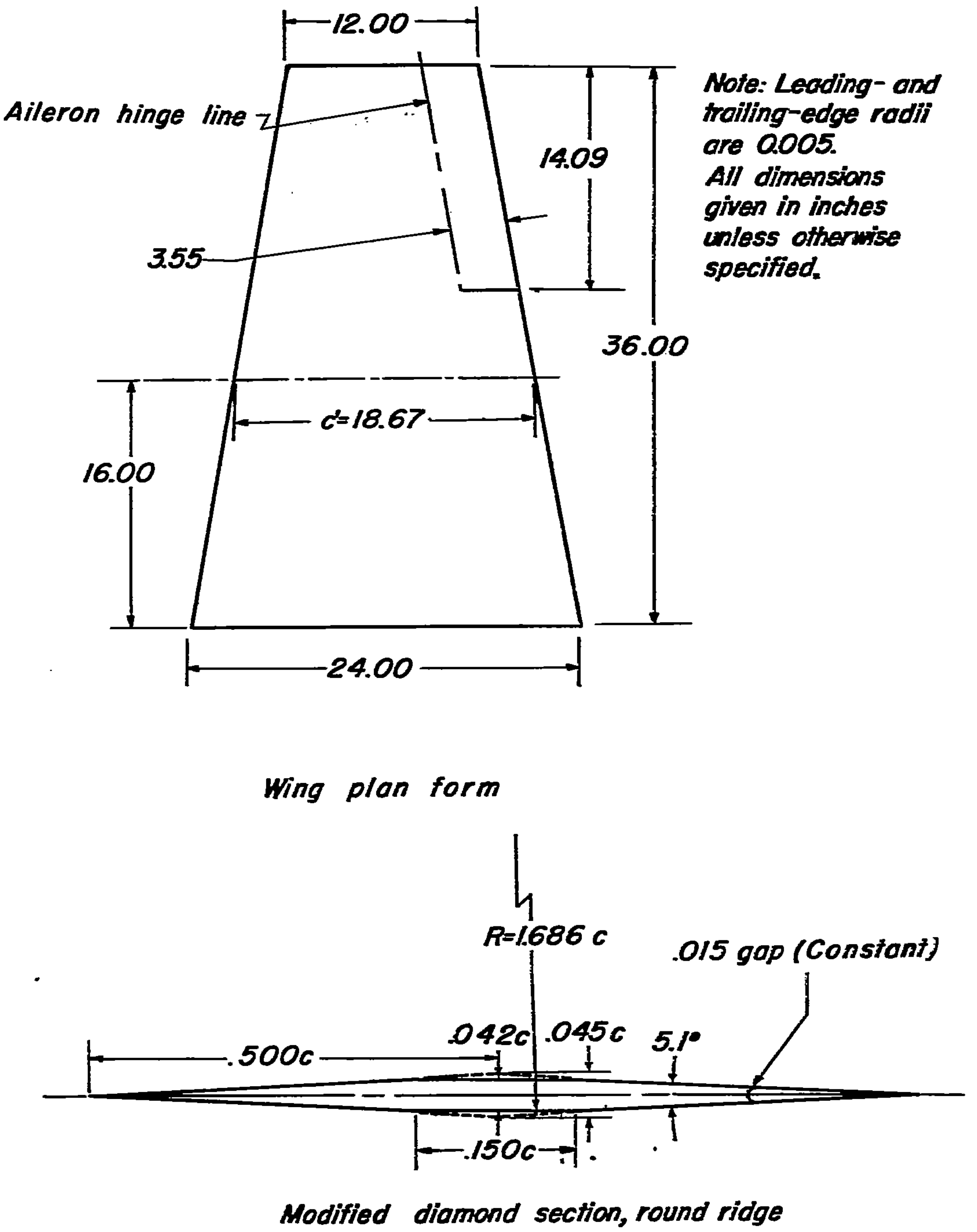

Figure 1.- Semispan model of a wing of aspect ratio 4 tested in the Ames 12-foot pressure wind tunnel.

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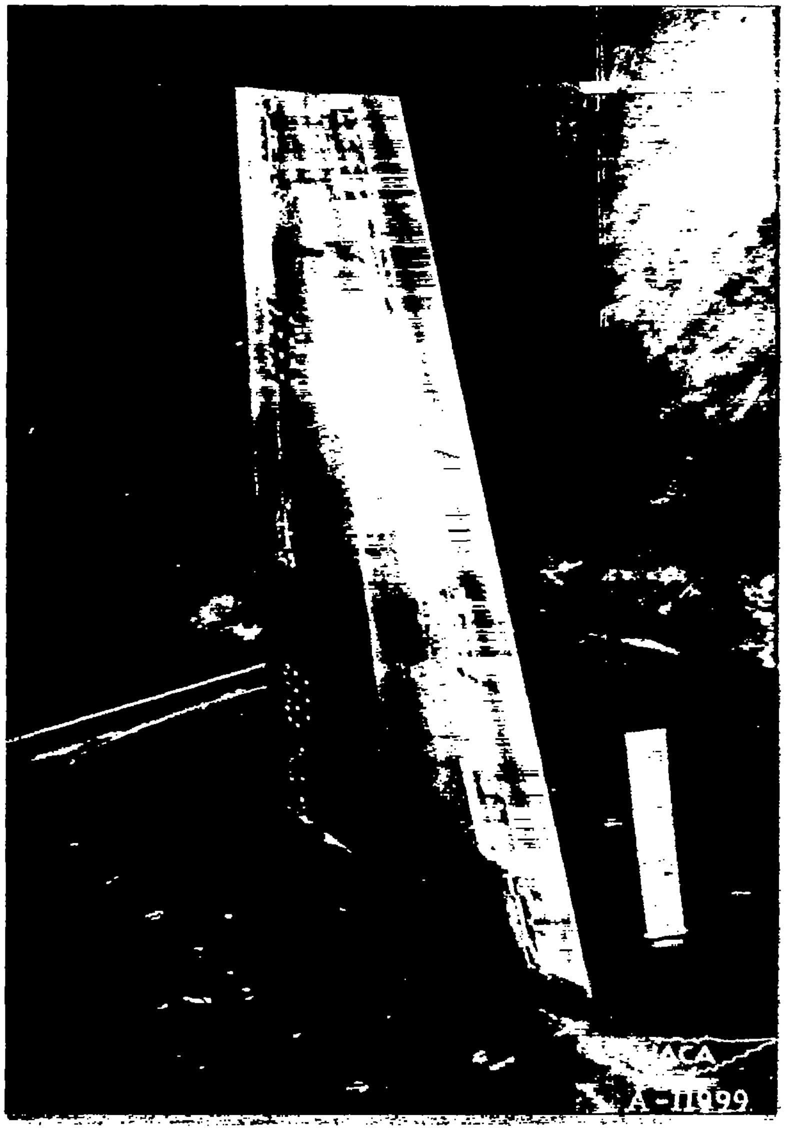

Figure 2.– Semispan model of a wing of aspect ratio 4 tested in the Ames 12-foot pressure wind tunnel.

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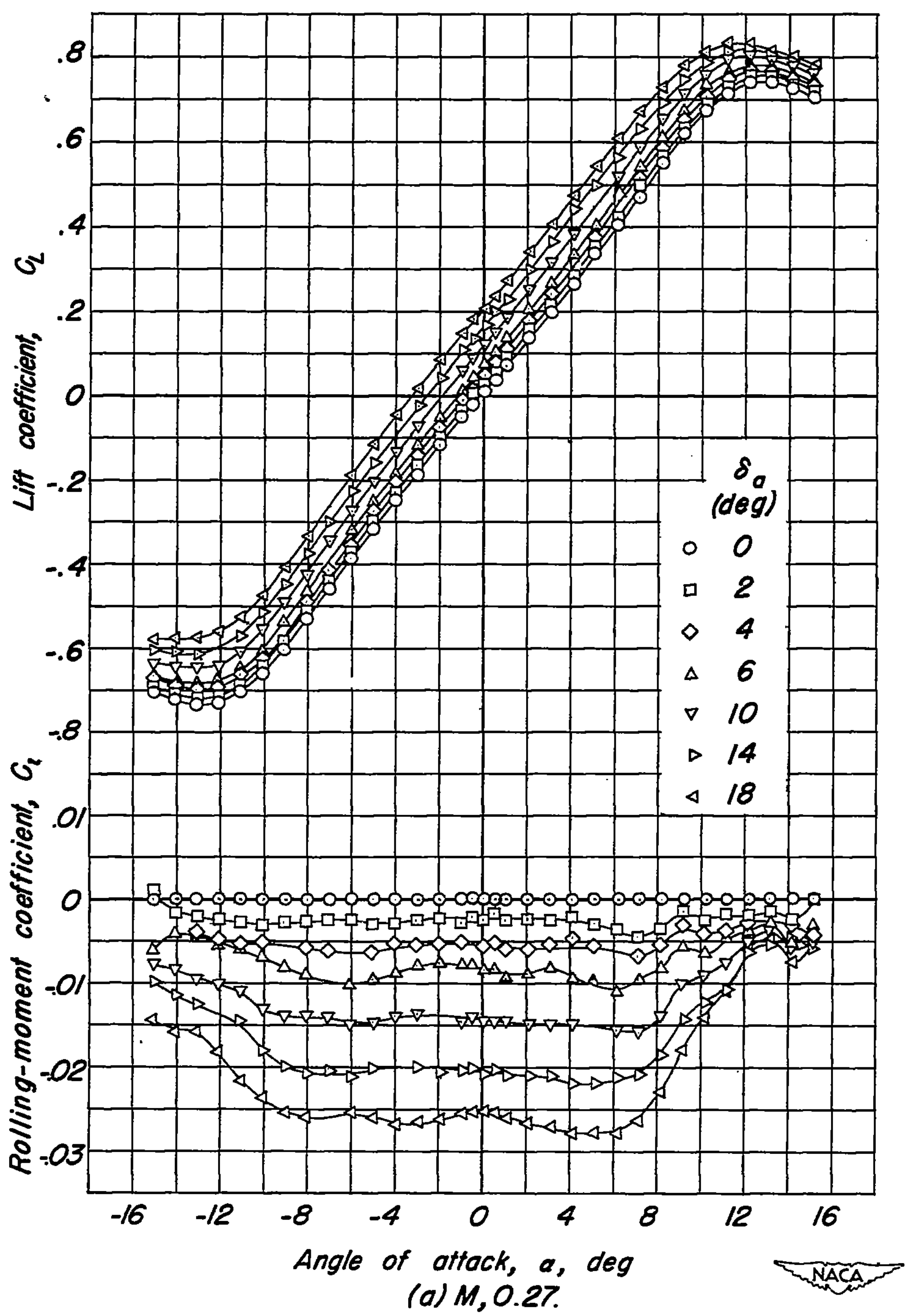
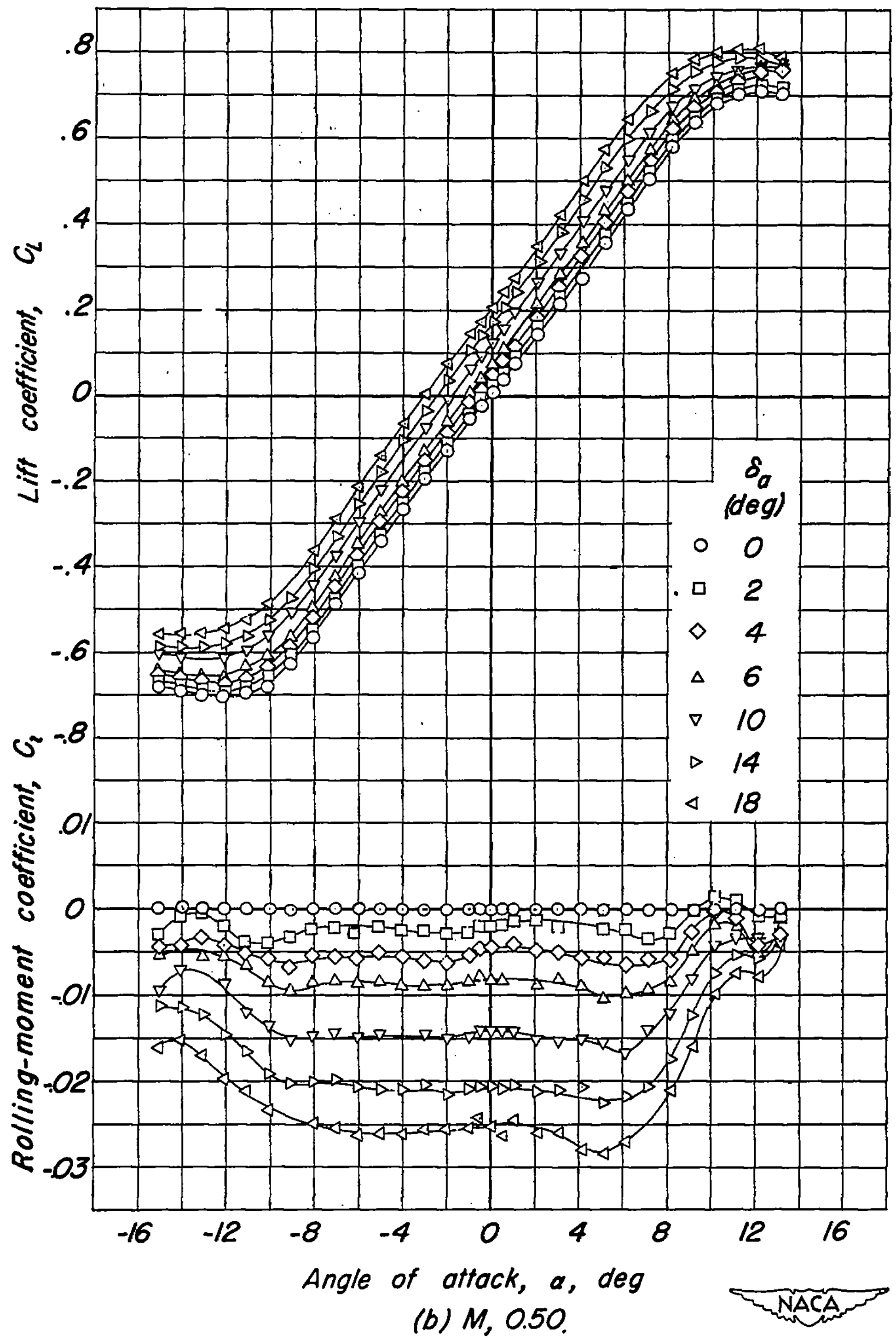


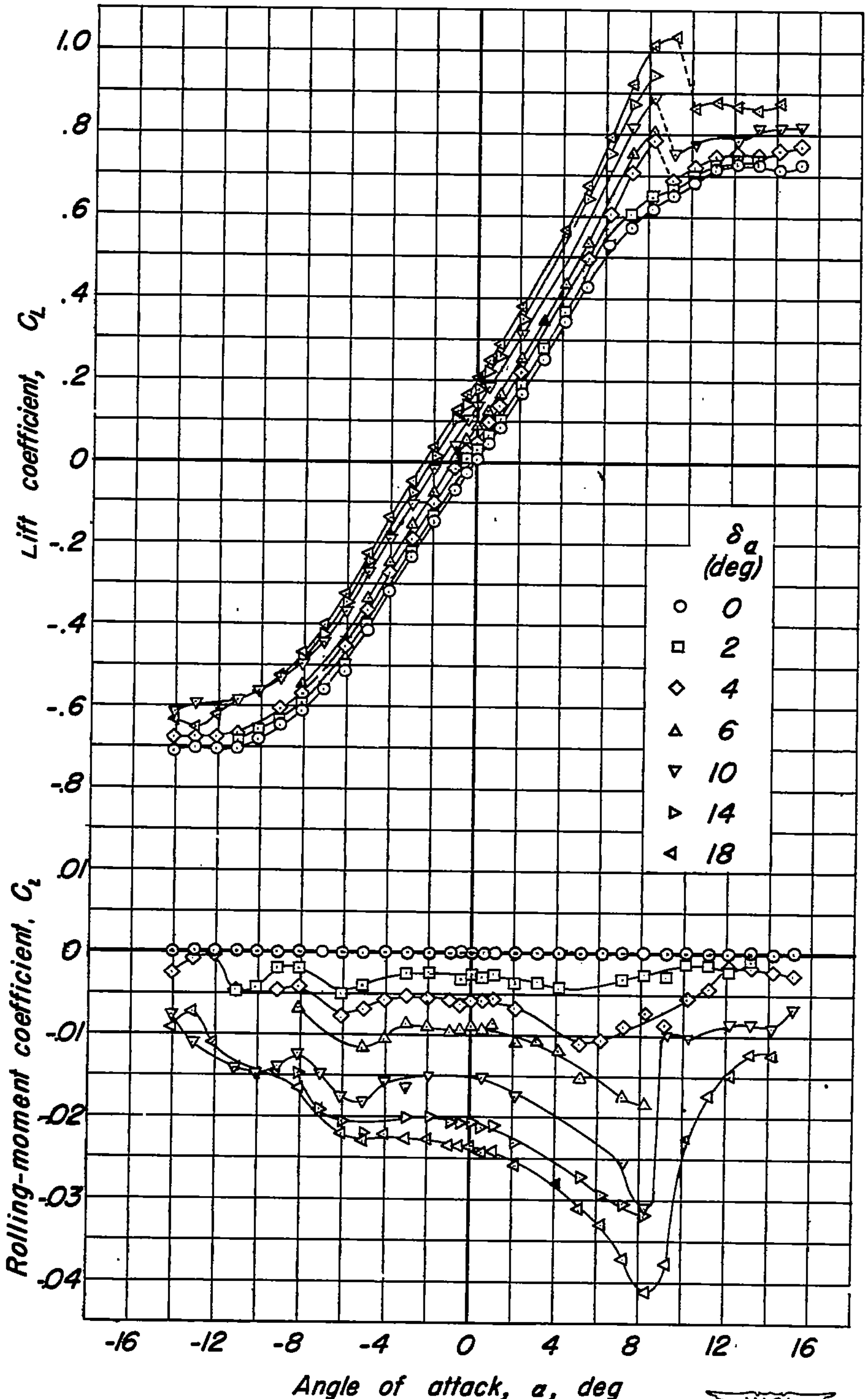
(a) M, 0.27.

Figure 3.— The effect of deflection of a constant-chord aileron on the lift and rolling-moment characteristics of the wing. R, 2,730,000.



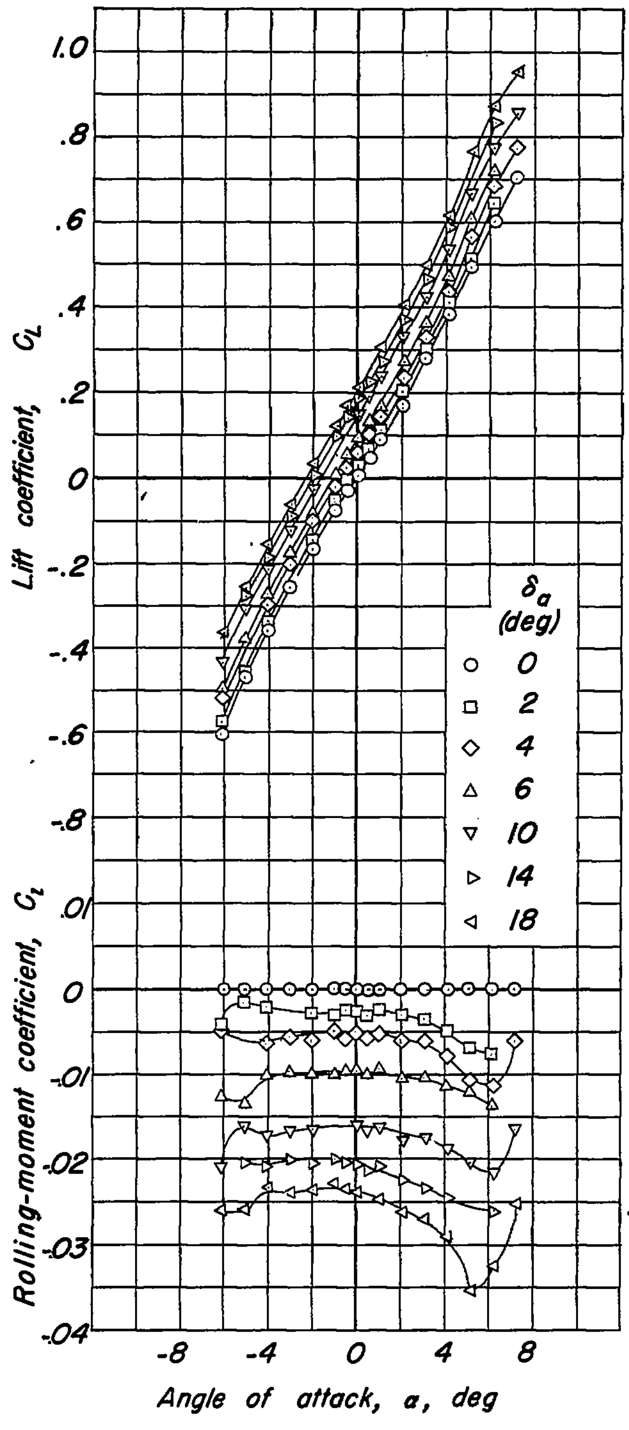
(b) M, 0.50.

Figure 3.–continued.



(c) M, 0.80.

Figure 3.—continued.



(d) M, 0.85.

Figure 3.— continued.

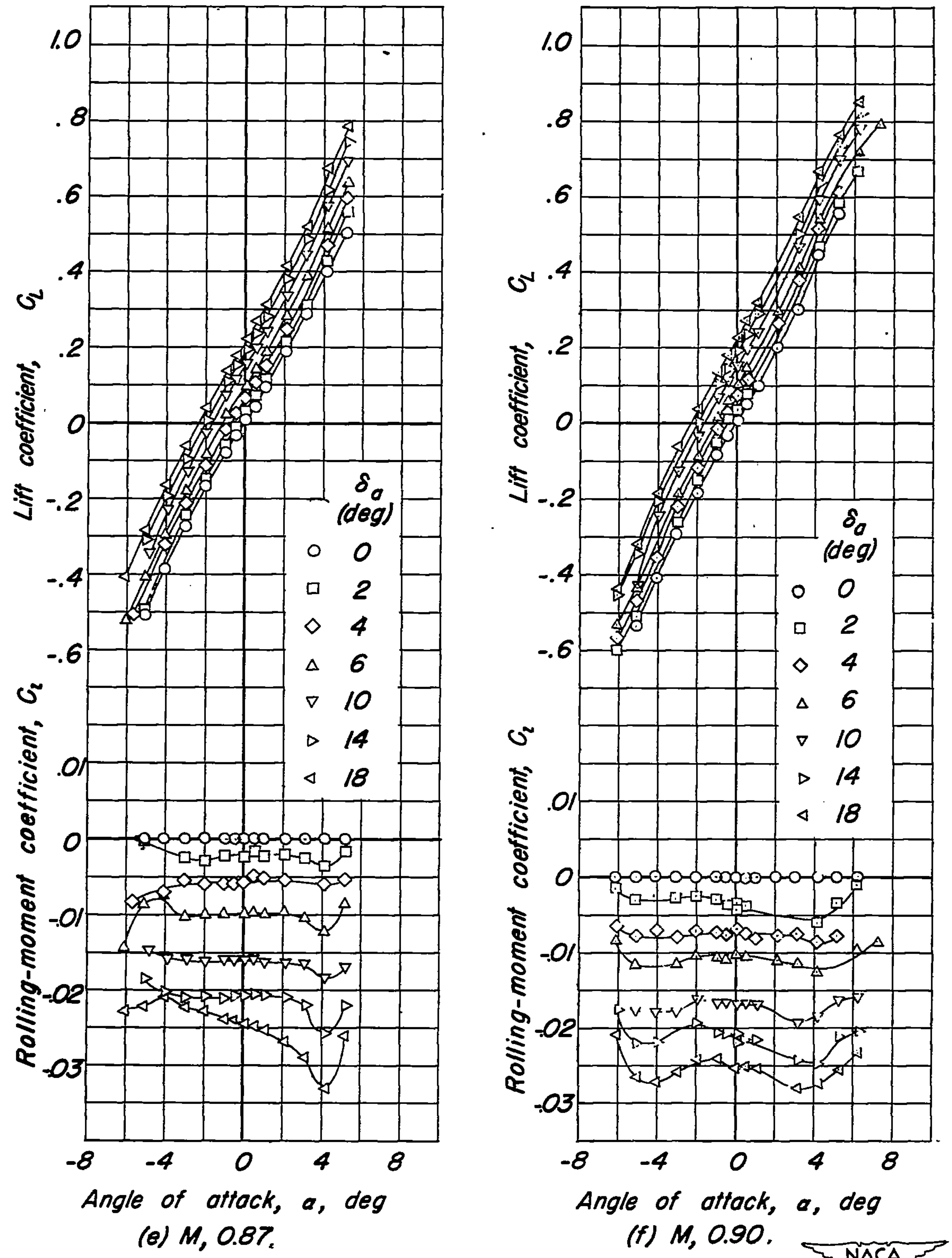
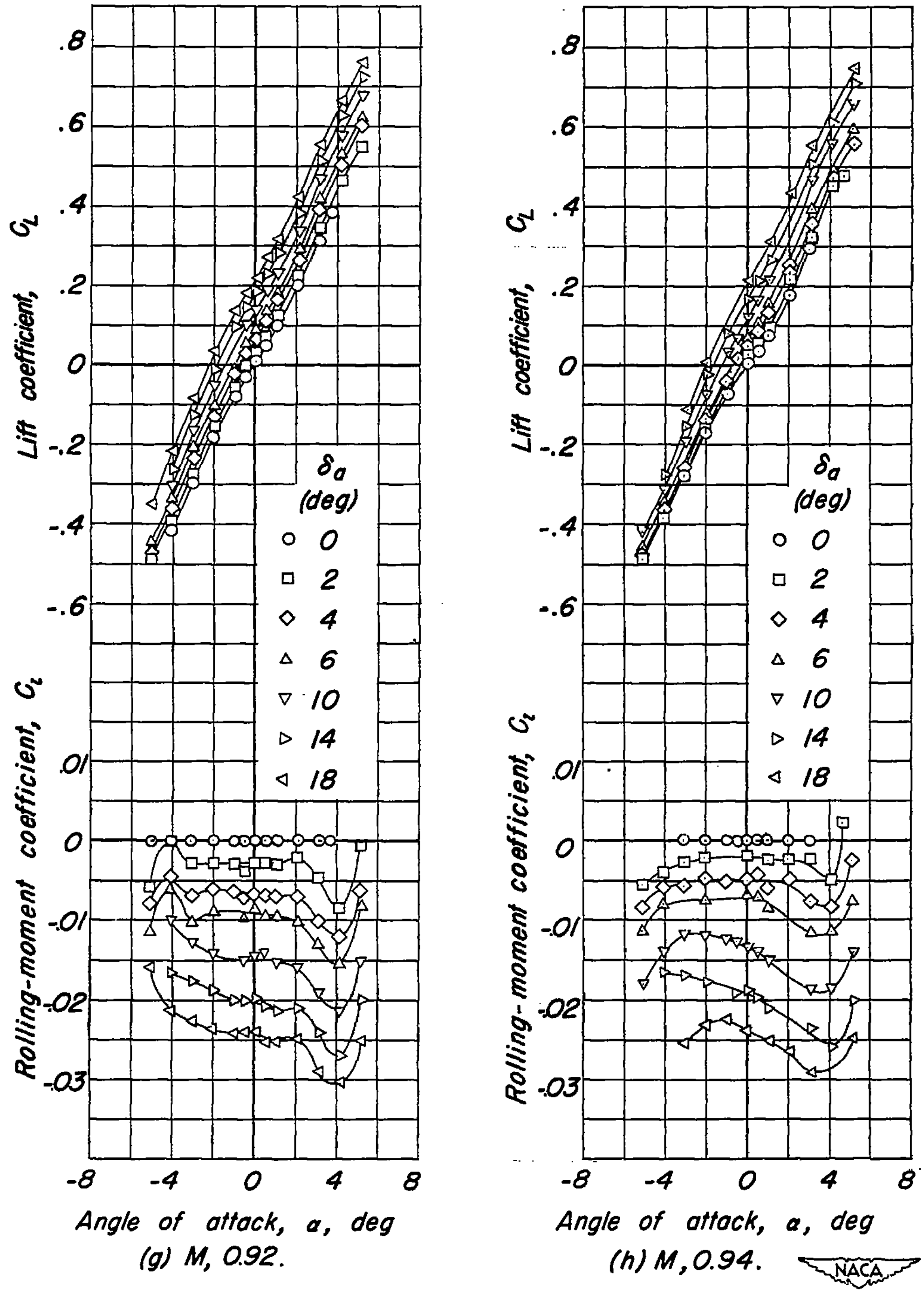


Figure 3.—continued.



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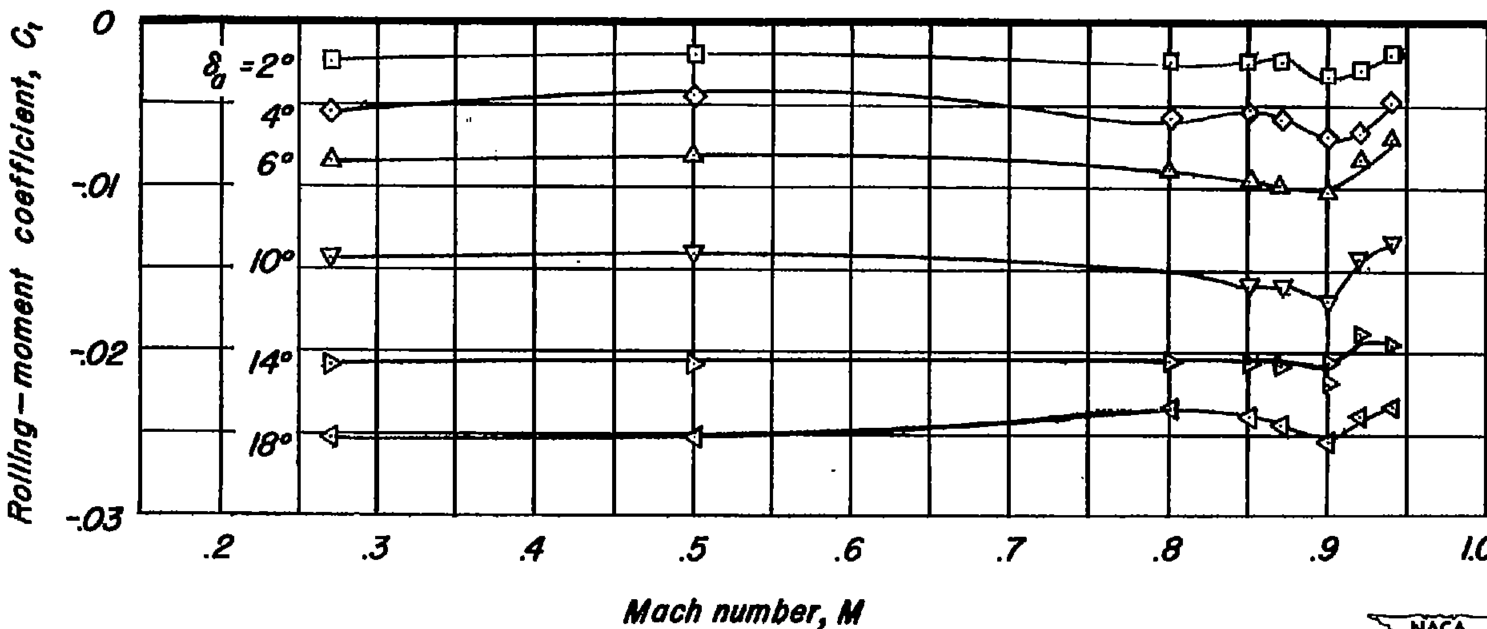
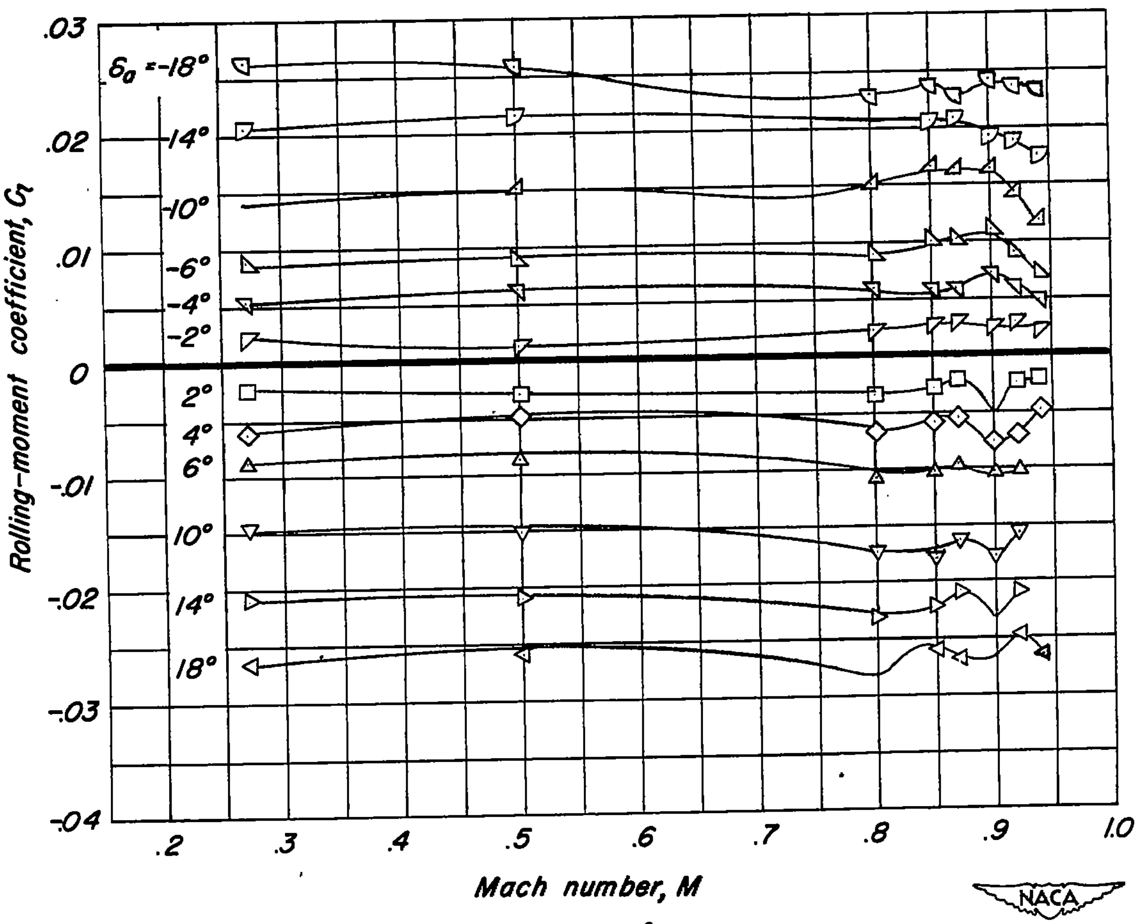


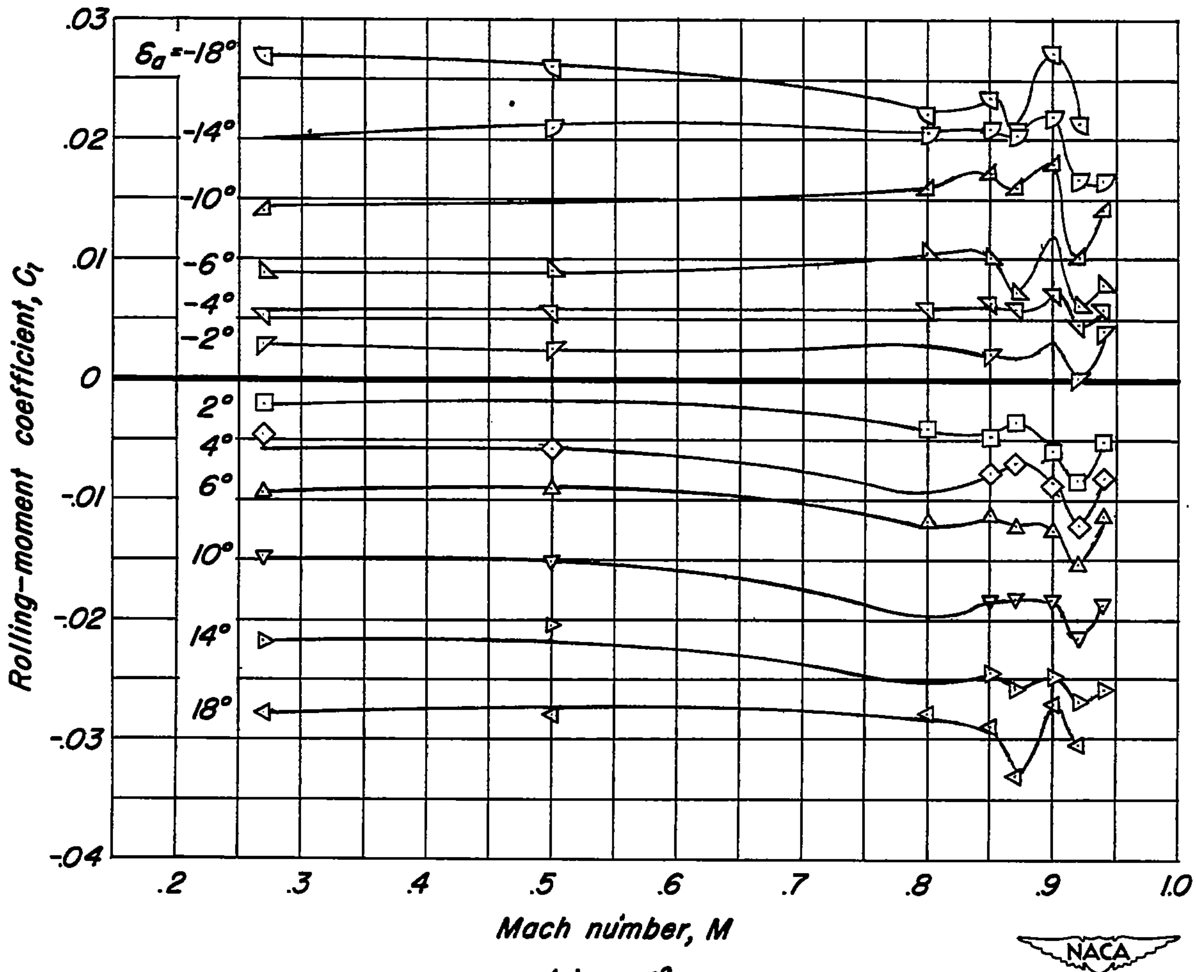
(a) $\alpha \approx 0°$.

Figure 4.– The variation of rolling-moment coefficient with Mach number. R = 2,730,000.



(b) $\alpha = 2°$.

Figure 4.- continued.



(c) α=4°

Figure 4.-concluded.

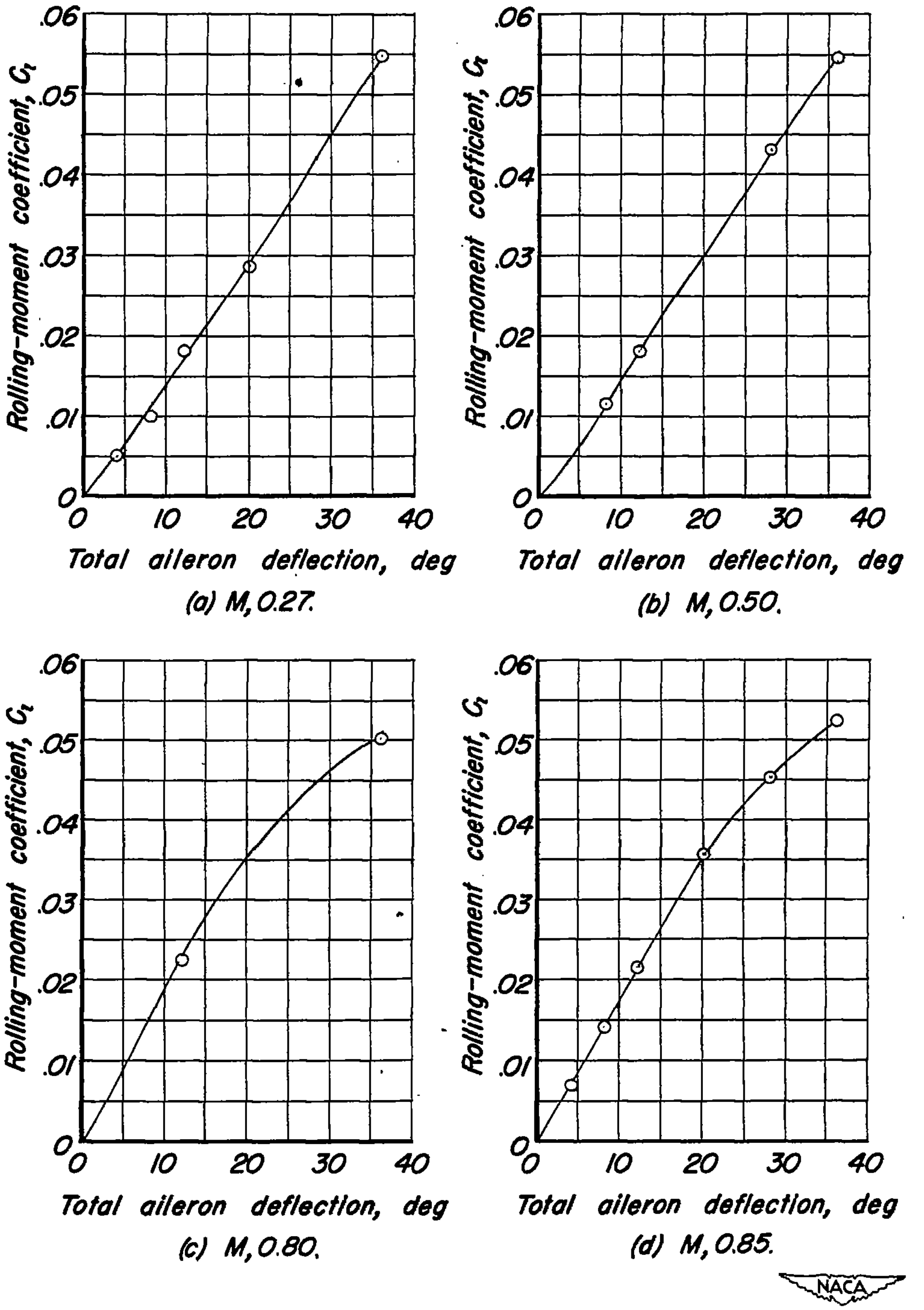


Figure 5.– The effect of total aileron deflection on the rolling-moment coefficient at various Mach numbers. Equal up-and down-aileron deflections; $\alpha = 4°$.

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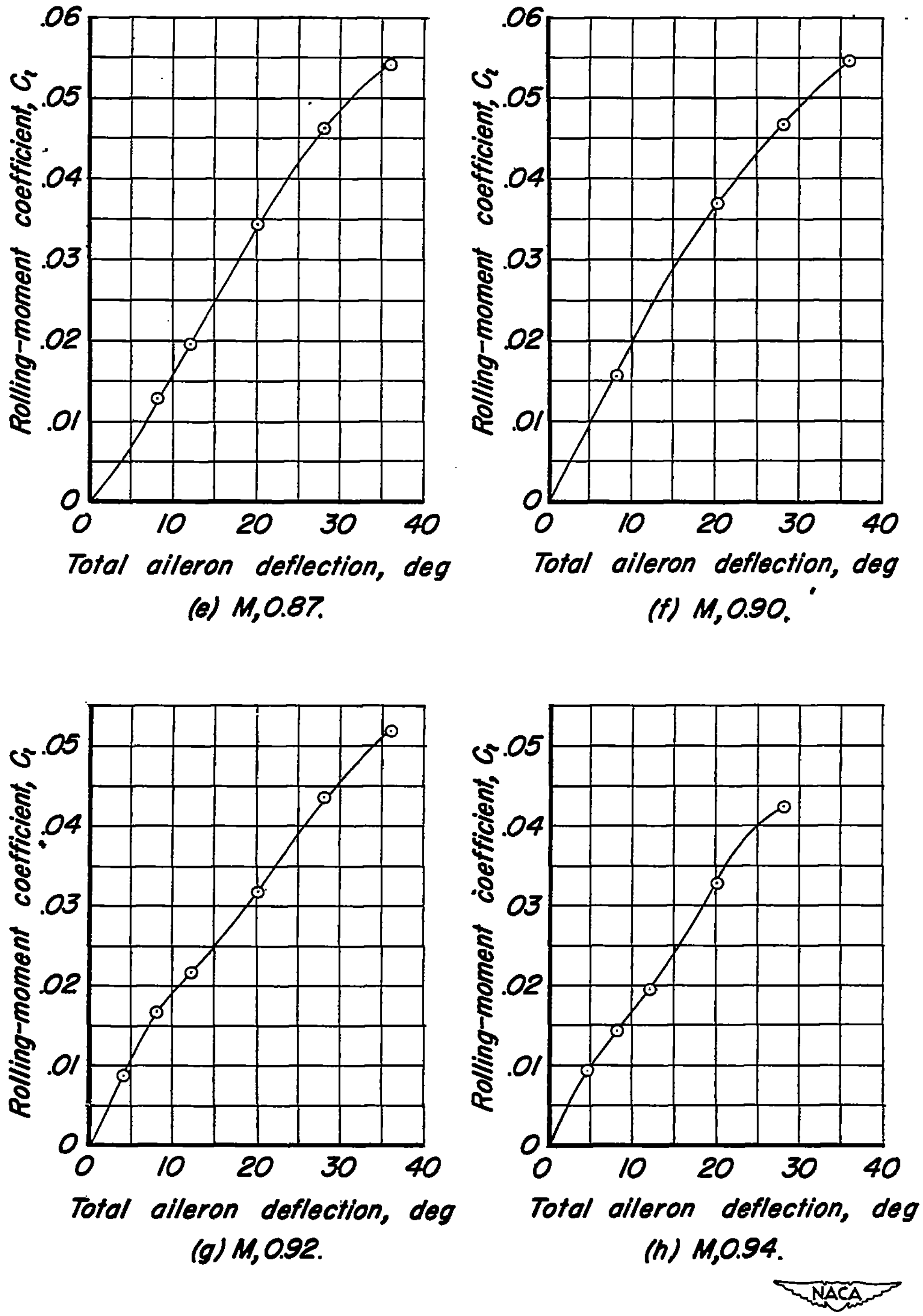

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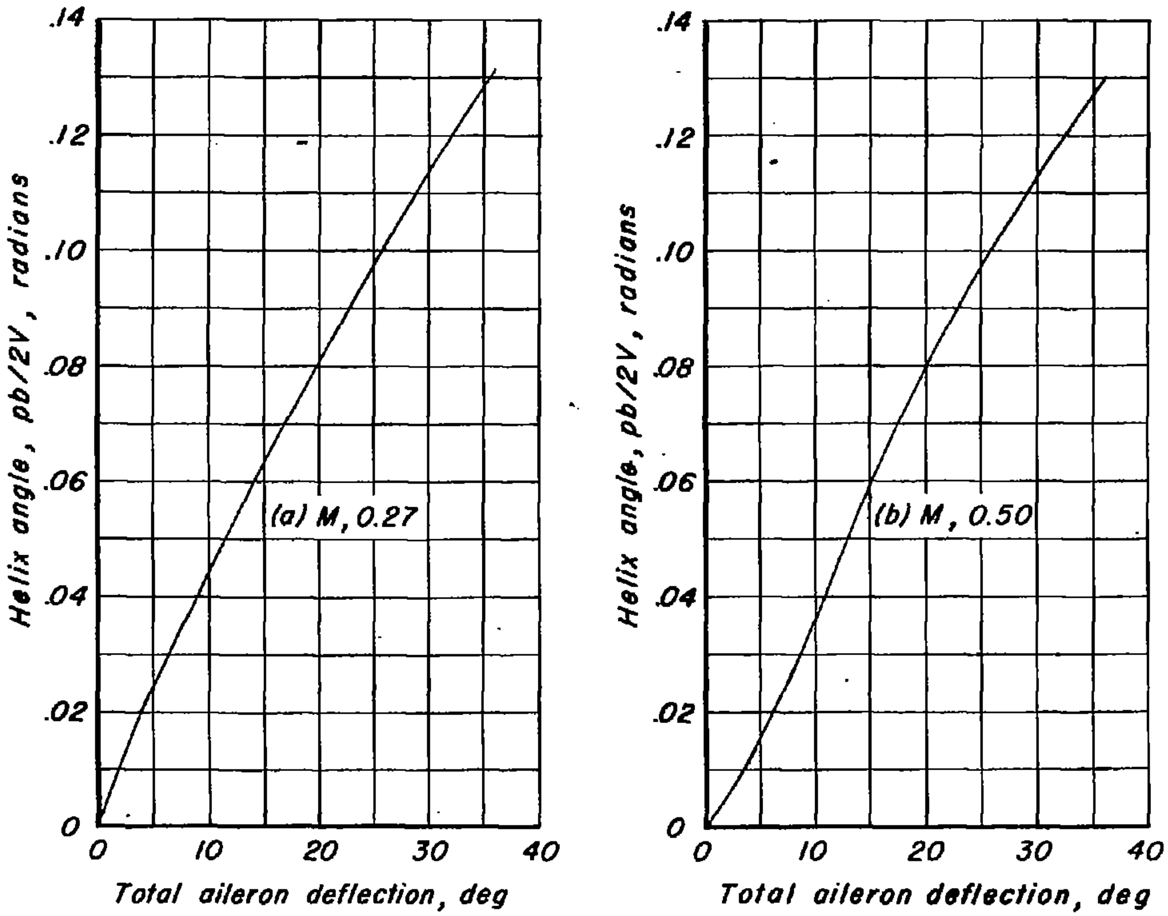

Figure 6.- The variation of wing-tip helix angle with total aileron deflection for flight at sea level. Wing loading, 60 pounds per square foot; equal up-and down-aileron deflection; assumed rigid wing and zero sideslip.