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RESEARCH MEMORANDUM

INVESTIGATION OF A THIN WING OF ASPECT RATIO 4 IN THE AMES 12-FOOT PRESSURE WIND TUNNEL. IV - THE EFFECT OF A CONSTANT-CHORD LEADING-EDGE FLAP AT HIGH SUBSONIC SPEEDS

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS
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INVESTIGATION OF A THIN WING OF ASPECT RATIO 4 IN THE AMES 12-FOOT PRESSURE WIND TUNNEL. IV - THE EFFECT OF A CONSTANT-CHORD LEADING-EDGE FLAP AT HIGH SUBSONIC SPEEDS

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SUMMARY

Wind-tunnel tests have been made of a semispan model of a thin sharp-edged unswept wing of aspect ratio 4 and taper ratio 0.5 equipped with a full-span, constant-chord, leading-edge flap. The effectiveness of the leading-edge flap in improving the lift-drag ratio of the wing was investigated at Mach numbers from 0.20 to 0.94 at a constant Reynolds number of 2,000,000.

Deflection of the leading-edge flap resulted in an increase in maximum lift-drag ratio at Mach numbers below 0.94. At a Mach number of 0.65 this increase was 46 percent of the maximum lift-drag ratio of the plain wing. The magnitude of the gain decreased with further increase in Mach number, and at a Mach number of 0.94 deflection of the leading-edge flap resulted in a decrease in maximum lift-drag ratio. The leading-edge flap also increased the lift coefficient for maximum lift-drag ratio. At a Mach number of 0.8, the maximum lift-drag ratio of the wing with the flap undeflected occurred at a lift coefficient of 0.21. With the leading-edge flap deflected, this same value of lift-drag ratio could be obtained at a lift coefficient of 0.55.

The flap is thus effective in improving the take-off and climbing performance of a heavily loaded supersonic aircraft. Application of the data to the prediction of the wing lift-drag ratio of an airplane with a wing loading of 120 pounds per square foot in level flight at a Mach number of 0.85 and an altitude of 30,000 feet indicated an increase in lift-drag ratio from 12.3 to 17.1 due to 4° deflection of the leading-edge flap.

Deflection of the leading-edge flap increased the maximum lift and also the angle of attack for maximum lift. Between Mach numbers of 0.70 and 0.80 the type of stall on the wing changed from a gentle stall with little loss of lift at the lower Mach numbers to an abrupt stall with a substantial loss of lift at Mach numbers of 0.80 and above. At this same Mach number, 0.80, the effectiveness of the leading-edge flap in improving the maximum lift increased abruptly.

INTRODUCTION

When the lifting surfaces of a supersonic aircraft are not swept behind the Mach cone, extremely thin wing sections with sharp leading edges are considered necessary to minimize the wave resistance. At subsonic speeds such sharp-edged wings have large profile drag as a result of flow separation at the leading edge at very low angles of attack. These poor section characteristics combined with the large induced drag resulting from the low aspect ratio necessitated by the small wing thickness ratio severely penalize the performance at subsonic speeds of such supersonic aircraft.

The present series of tests was made to investigate the effectiveness of a leading-edge flap in improving the lift-drag ratio and the maximum lift characteristics over a large range of subsonic speeds of a low-aspect-ratio sharp-edged wing suitable for supersonic aircraft. The aerodynamic characteristics of the plain wing have been reported in reference 1 and the effects of leading-edge and trailing-edge flaps at low speeds have been reported in reference 2. The aerodynamic characteristics of the wing with the leading-edge flap deflected are presented herein for a range of Mach numbers from 0.20 to 0.94 at a constant Reynolds number of 2,000,000.

COEFFICIENTS AND SYMBOLS

The following coefficients are used in this report:

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

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

C_m pitching-moment coefficient about quarter-chord point of the wing mean aerodynamic chord $\left(\frac{\text{pitching moment}}{qSc'}\right)$

The following symbols are used in this report:

a speed of sound, feet per second

b twice wing semispan, feet

c local chord, feet

c' wing mean aerodynamic chord, chord through centroid of 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 $\left(\frac{V}{a}\right)$

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

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

S area of the semispan wing, square feet

V airspeed, feet per second

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

α angle of attack of wing-chord plane, degrees

δ_n leading-edge flap deflection, positive downward, degrees

μ viscosity of air, slugs per foot-second

ρ mass density of air, slugs per cubic foot

MODELS 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 full-span, constant-chord, leading-edge flap was the same as that used in the tests reported in reference 2. The ridge of the basic diamond profile had been rounded so that the thickness ratio was 0.042. The semispan model represented a wing of aspect ratio 4, and taper ratio 0.50. The area of the leading-edge flap was 15 percent of the total wing area. The unsealed gap between the flap 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 flap was attached to the wing by hinges and rigidly held in position by steel plates. Angular distortion of the flap 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 method of reference 3 was used in correcting the data for tunnel-wall interference. The following corrections were added:

$$\Delta\alpha = 0.363\ C_L$$

$$\Delta C_D = 0.0056\ C_L^2$$

$$\Delta C_m = 0$$

Corrections to the data for constriction effects of the tunnel walls have been evaluated by the method of reference 4. The magnitude of these corrections as applied to Mach number and dynamic pressure (measured with the tunnel empty) is illustrated by the following table:

Corrected Mach Number	Uncorrected Mach Number	$\frac{q_{corrected}}{q_{uncorrected}}$
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
.70	.700	1.008
.50	.500	1.005
.20	.200	1.000

Tare corrections due to the air forces exerted on the exposed area of the turntable were obtained from force measurements made with the model removed from the tunnel. Possible interference effects between the model and the turntable were not evaluated but they are believed to be small. The magnitude of the measured tare drag coefficient was 0.0063.

TESTS

Lift, drag, and pitching-moment data were obtained for a Mach number range of 0.20 to 0.94 at a constant Reynolds number of 2,000,000. The angle-of-attack range at low speeds was from -6° to $+19^{\circ}$; whereas at the higher Mach numbers this range was limited by model strength and tunnel power. At low speeds, flap deflections of 0°, 2°, 4°, 6°, 10°, and 20° were tested; whereas at the higher Mach numbers the deflection was limited to a maximum of 6°.

RESULTS AND DISCUSSION

The effects of deflection of the leading-edge flap on the aerodynamic characteristics of the wing are presented in figures 3 to 6 for a range of Mach numbers from 0.20 to 0.94.

Lift Characteristics

The lift characteristics of the wing as a function of angle of attack are presented in figure 3. Deflection of the leading-edge flap had little effect on the lift-curve slope for flap deflections up to 10°. An increase in lift-curve slope resulted from 20° deflection of the flap. The angle of attack for zero lift was little affected by deflections of the flap up to 10° but was increased to 1° for deflection of the flap to 20°.

For the range of Mach numbers at which it was possible to obtain data at maximum lift (Mach numbers less than 0.87), deflection of the leading-edge flap increased the maximum lift of the wing and also increased the angle of attack for maximum lift. Between Mach numbers of 0.70 and 0.80 the type of stall on the wing changed from a gentle stall with little loss of lift at the lower Mach numbers to an abrupt stall with a substantial loss of lift at Mach numbers of 0.80 and above. The effect of deflection of the leading-edge flap on the maximum lift coefficient underwent a sudden change at this same Mach number. At a Mach number of 0.70, a flap deflection of 10° resulted in an increase in maximum lift coefficient of only 11 percent, while at a Mach number of 0.80 the same flap deflection produced a 25-percent increase in the maximum lift coefficient. This same flap deflection increased the angle of attack for maximum lift less than 1° at a Mach number of 0.70 compared to an increase of 4° at a Mach number of 0.80.

Drag Characteristics

The effects of deflection of the leading-edge flap on the drag characteristics of the wing are presented in figure 4. At Mach numbers below 0.70, the minimum drag was not affected by deflection of the flap to 2°; whereas it was increased approximately 45 percent by deflection of the flap to 6°, 100 percent by deflection of the flap to 10°, and 250 percent by deflection of the flap to 20°. At the higher Mach numbers, the increase in minimum drag was greater, the minimum drag increasing approximately 25 percent by deflection of the flap to 2° at a Mach number of 0.94. At all Mach numbers at which tests were made, the rate of rise of drag with lift decreased with increasing deflection of the leading-edge flap.

Pitching-Moment Characteristics

Tests of the plain wing, reported in reference 1, revealed a marked rearward movement of the aerodynamic center at angles of attack well below that for maximum lift. Tests made at low Mach numbers with the leading-edge flap deflected 20° (reference 2) indicated a beneficial effect of this leading-edge flap deflection in delaying the rearward movement of the aerodynamic center to very near maximum lift. The pitching-moment data presented in figure 5 indicate that flap deflections less than 20° had considerably less effect in increasing the lift coefficient at which the aerodynamic center moves rearward. At a Mach number of 0.20, deflection of the leading-edge flap 20° delayed the start of the rearward movement of the aerodynamic center to a lift coefficient which was 94 percent of the maximum lift coefficient. With zero flap deflection, this rearward movement commenced at about 54 percent of the maximum lift coefficient; whereas 10° of flap deflection delayed the rearward movement to 74 percent of maximum lift coefficient.

The pitching-moment coefficient corresponding to zero lift became increasingly negative as the leading-edge flap was deflected. For all flap deflections for which data were obtained, increasing the Mach number increased the magnitude of this negative pitching-moment coefficient.

Lift-Drag Ratio

The lift-drag ratio as a function of the lift coefficient is presented in figure 6 for various values of leading-edge flap deflection. The maximum values of lift-drag ratio are presented in figure 7 as a function of the Mach number. Deflection of the leading-edge flap resulted in an increase in maximum lift-drag ratio for all test Mach numbers below 0.94. At a Mach number of 0.94, deflection of the flap resulted in a loss in lift-drag ratio for lift coefficients less than 0.58. At all test Mach numbers, deflection of the flap increased the lift coefficient for maximum lift-drag ratio.

After reaching a maximum at a Mach number of 0.65, the effectiveness of the flap in improving the maximum lift-drag ratio decreased with further increase in Mach number. The leading-edge flap deflection for maximum lift-drag ratio decreased as Mach number increased, with a very rapid decrease at Mach numbers above 0.80.

Figure 8 presents the variation of wing lift-drag ratio with Mach number for the wing lift coefficients corresponding to level flight at an altitude of 30,000 feet for airplane wing loadings of 80, 100, and 120 pounds per square foot. The values of flap deflection presented in figure 8 are the values corresponding to the largest attainable lift-drag ratio at each Mach number for the wing lift coefficient necessary for level flight. For the three wing loadings for which calculations were made, the leading-edge flap was capable of producing a considerable increment in the lift-drag ratio at all Mach numbers up to 0.94. The maximum lift-drag ratio with the leading-edge flap deflected was from 30 to 40 percent higher than the maximum lift-drag ratio with the flap neutral. For the wing loadings and altitudes used in the computations, maximum lift-drag ratio for the wing with the flap deflected occurred at 0.05 lower Mach number than for the plain wing, and the optimum leading-edge flap deflection varied linearly with Mach number and had values of approximately 20° at a Mach number of 0.50 and 0° at a Mach number of 0.94.

SUMMARY OF RESULTS

Results of the tests of a semispan model of a thin, straight wing of aspect ratio 4 and taper ratio 0.5 with a full-span, constant-chord, leading-edge flap at Mach numbers from 0.20 to 0.94 may be summarized as follows:

1. Deflection of the leading-edge flap resulted in an increase in the maximum lift-drag ratio at all test Mach numbers below 0.94. At a Mach number of 0.65 this increase was 46 percent of the maximum lift-drag ratio of the plain wing. Increasing the Mach number above 0.65 resulted in a decrease in the gain in maximum lift-drag ratio. At a Mach number of 0.94, deflection of the flap resulted in a decrease in the maximum lift-drag ratio.

2. Deflection of the leading-edge flap resulted in an increase in the lift coefficient for maximum lift-drag ratio for all Mach numbers up to 0.94.

3. The flap deflection required for maximum lift-drag ratio decreased as Mach number increased, the rate of decrease becoming very rapid for Mach numbers above 0.80.

4. Deflection of the leading-edge flap increased the maximum lift of the wing and also increased the angle of attack for maximum lift. These effects of flap deflection increased abruptly at a Mach number of 0.80, which is the same Mach number at which the type of stall on the wing changes from a gentle stall with little loss of lift at lower Mach numbers to an abrupt stall at Mach numbers of 0.80 and above.

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REFERENCES

1. Johnson, Ben H., Jr.: Investigation of a Thin Wing of Aspect Ratio 4 in the Ames 12-Foot Pressure Wind Tunnel. I - Characteristics of a Plain Wing. NACA RM No. A8D07, 1948.

2. Johnson, Ben H., Jr., and Bandettini, Angelo: Investigation of a Thin Wing of Aspect Ratio 4 in the Ames 12-Foot Pressure Wind Tunnel. II - The Effect of Constant-Chord Leading- and Trailing-Edge Flaps on the Low Speed Characteristics of the Wing. NACA RM No. A8F15, 1948.

3. Sivells, James, and Deters, Owen J.: Jet-Boundary and Plan-Form Corrections for Partial-Span Models with Reflection Plane, End Plate, or No End Plate, in a Closed Circular Wind Tunnel. NACA TN No. 1077, 1946.

4. Herriot, John G.: Blockage Corrections for Three-Dimensional-Flow Closed-Throat Wind Tunnels, with Consideration of the Effect of Compressibility. NACA RM No. A7B28, 1947.

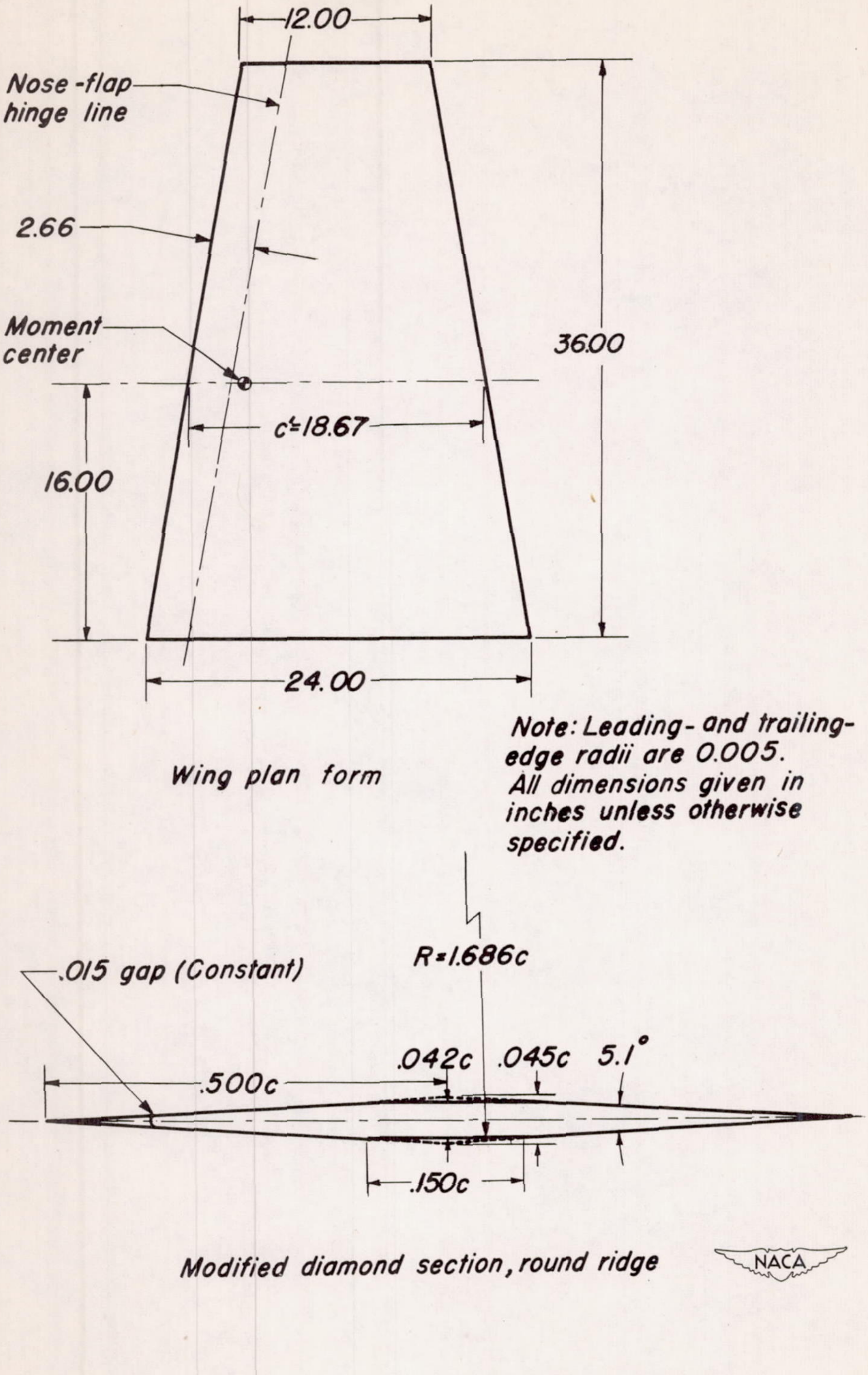


Figure 1.- Semispan model of a wing of aspect ratio 4, tested in the Ames 12-foot pressure wind tunnel.

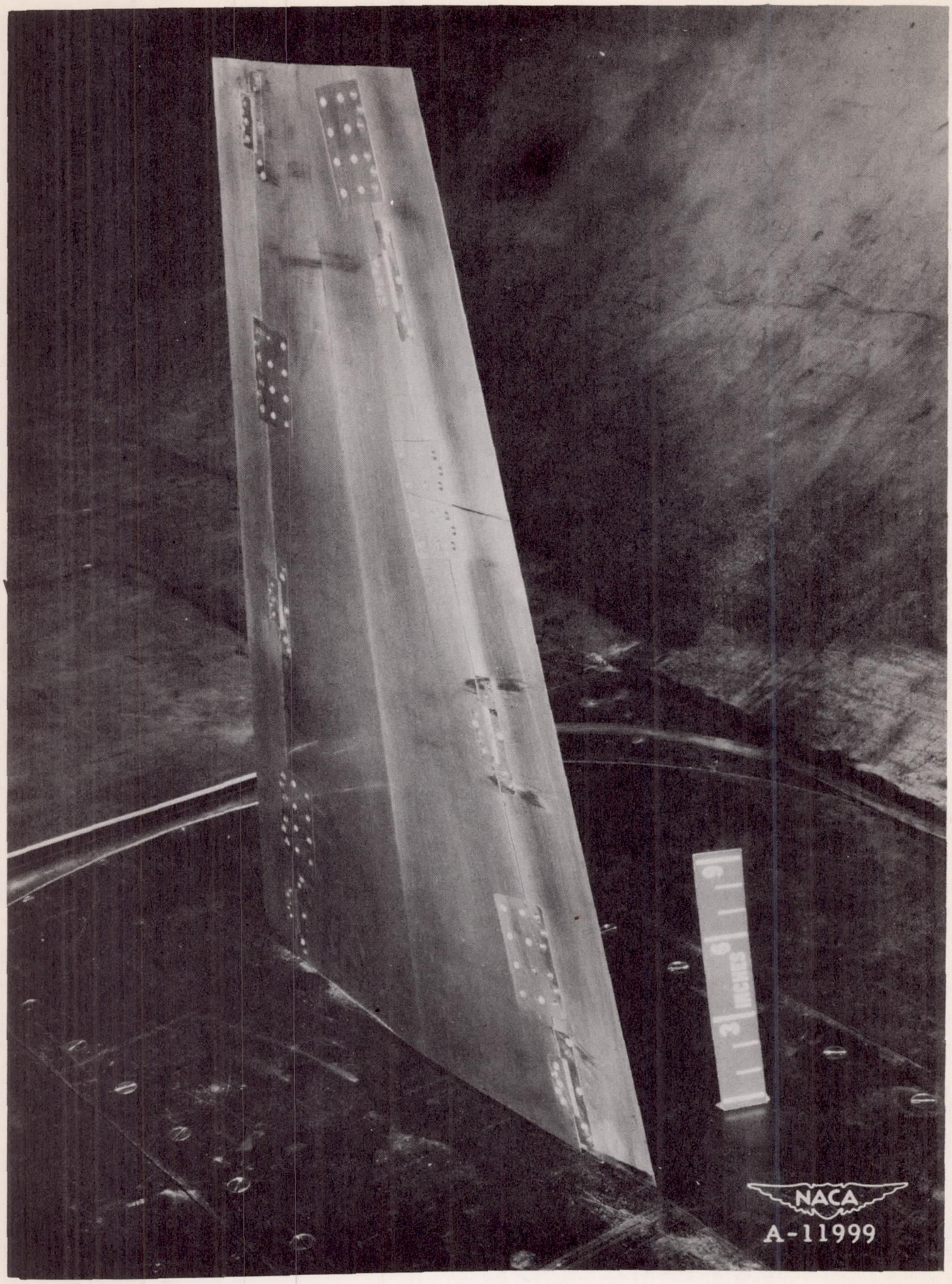
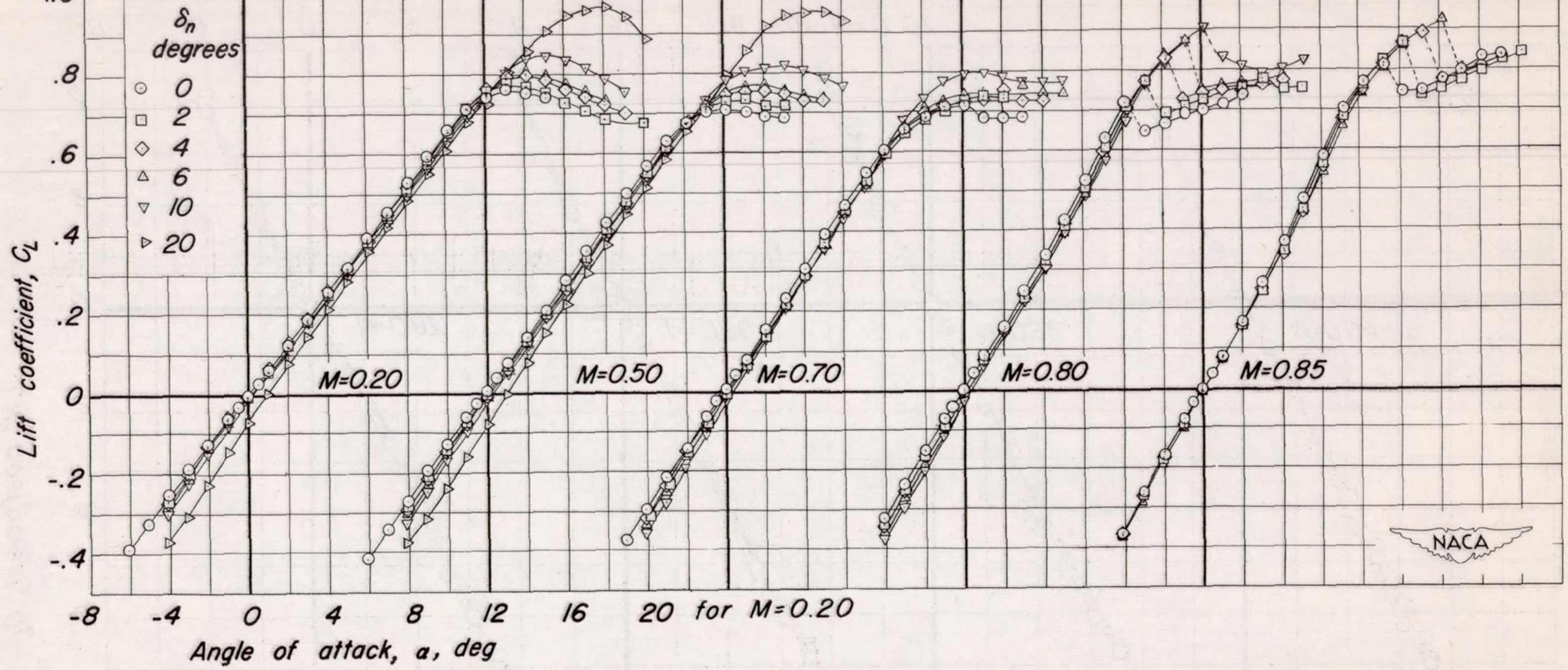


Figure 2.- Semispan model of a wing of aspect ratio 4, mounted in the Ames 12-foot pressure wind tunnel.



(a) M = 0.20, 0.50, 0.70, 0.80, and 0.85.

Figure 3.- The effect of deflection of the leading-edge flap on the lift characteristics of the wing.

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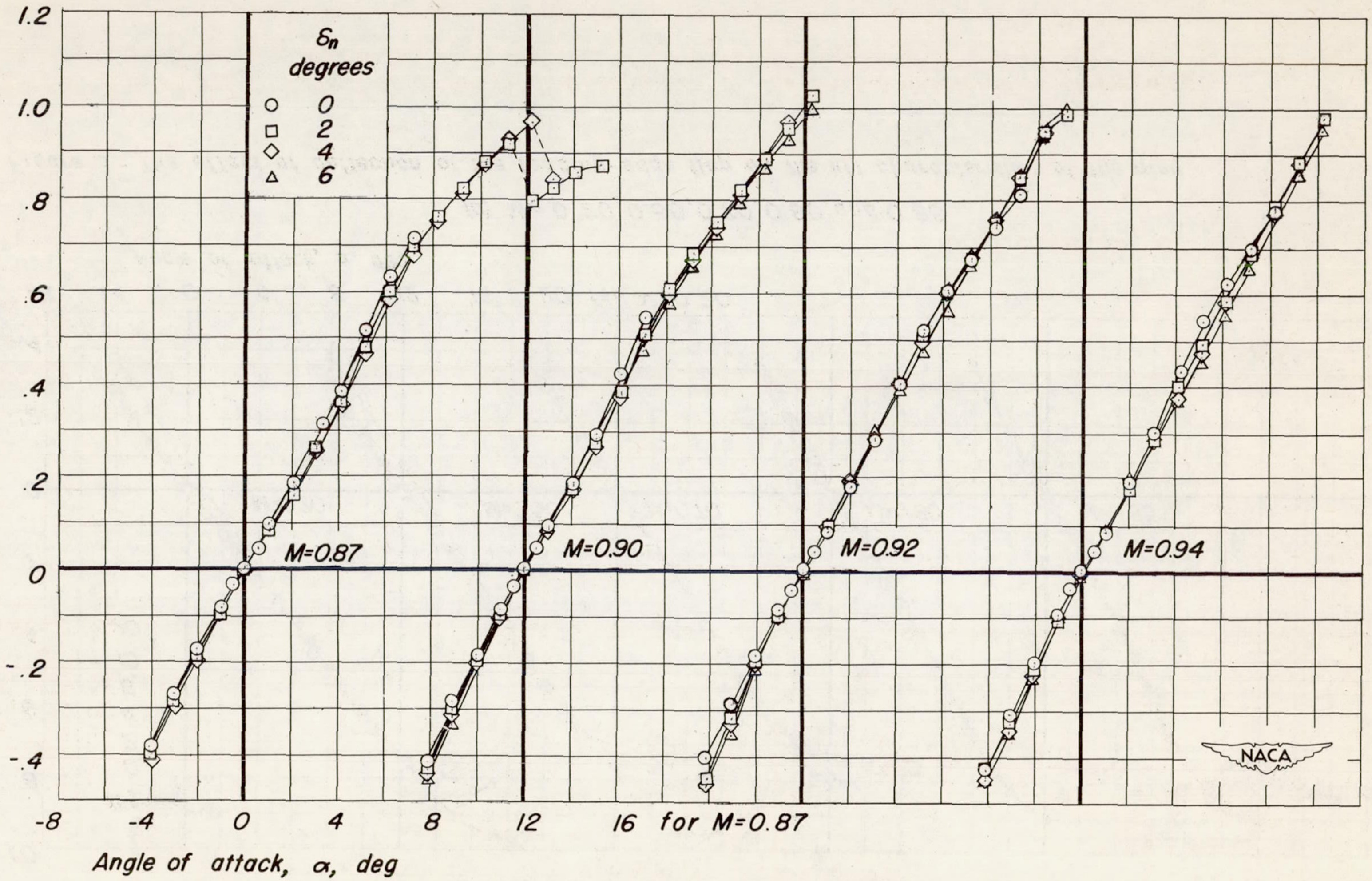

(b) M = 0.90, 0.92, and 0.94.

Figure 3.- Concluded.

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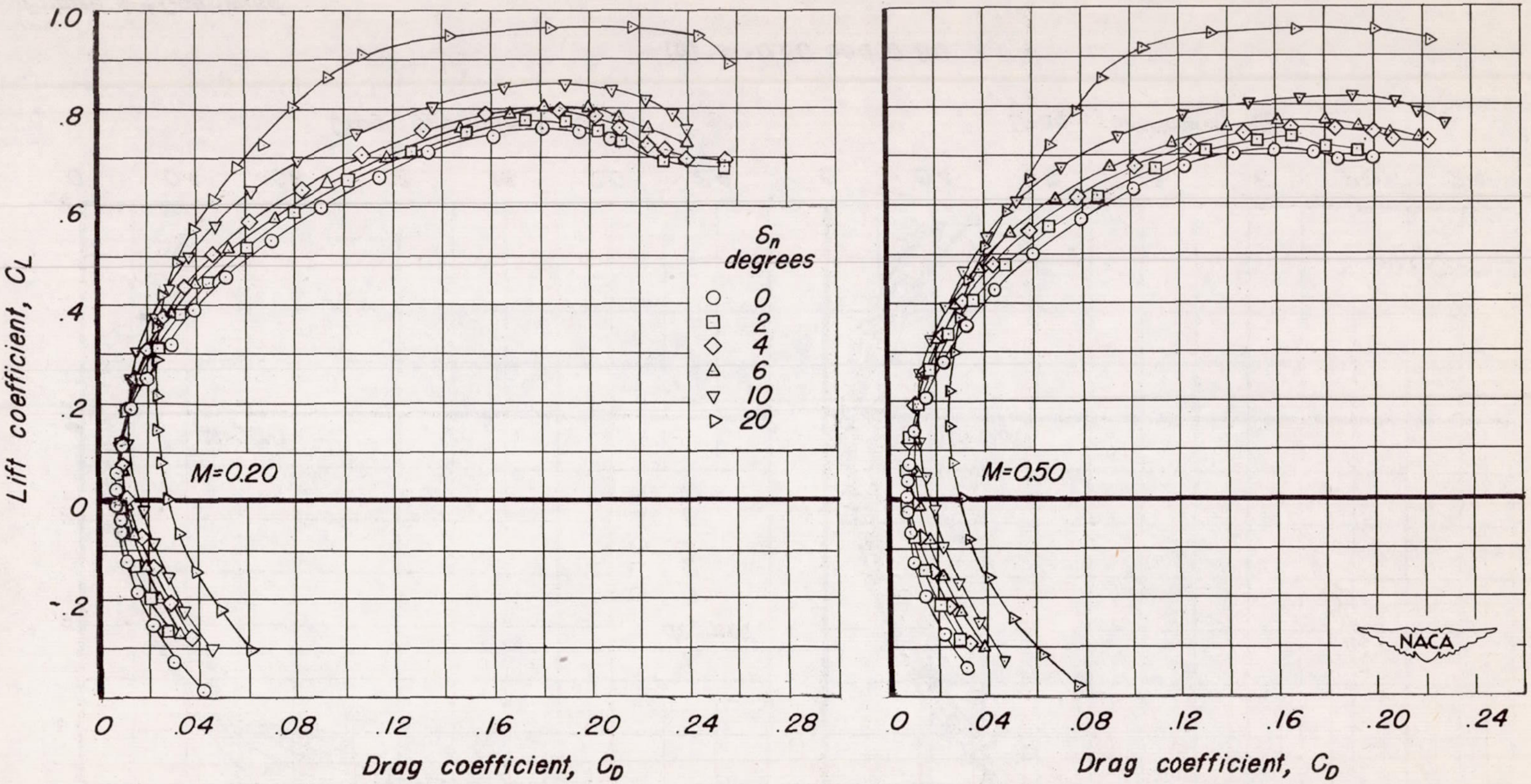

(a) M = 0.20 and 0.50.

Figure 4.- The effect of deflection of the leading-edge flap on the drag characteristics of the wing.

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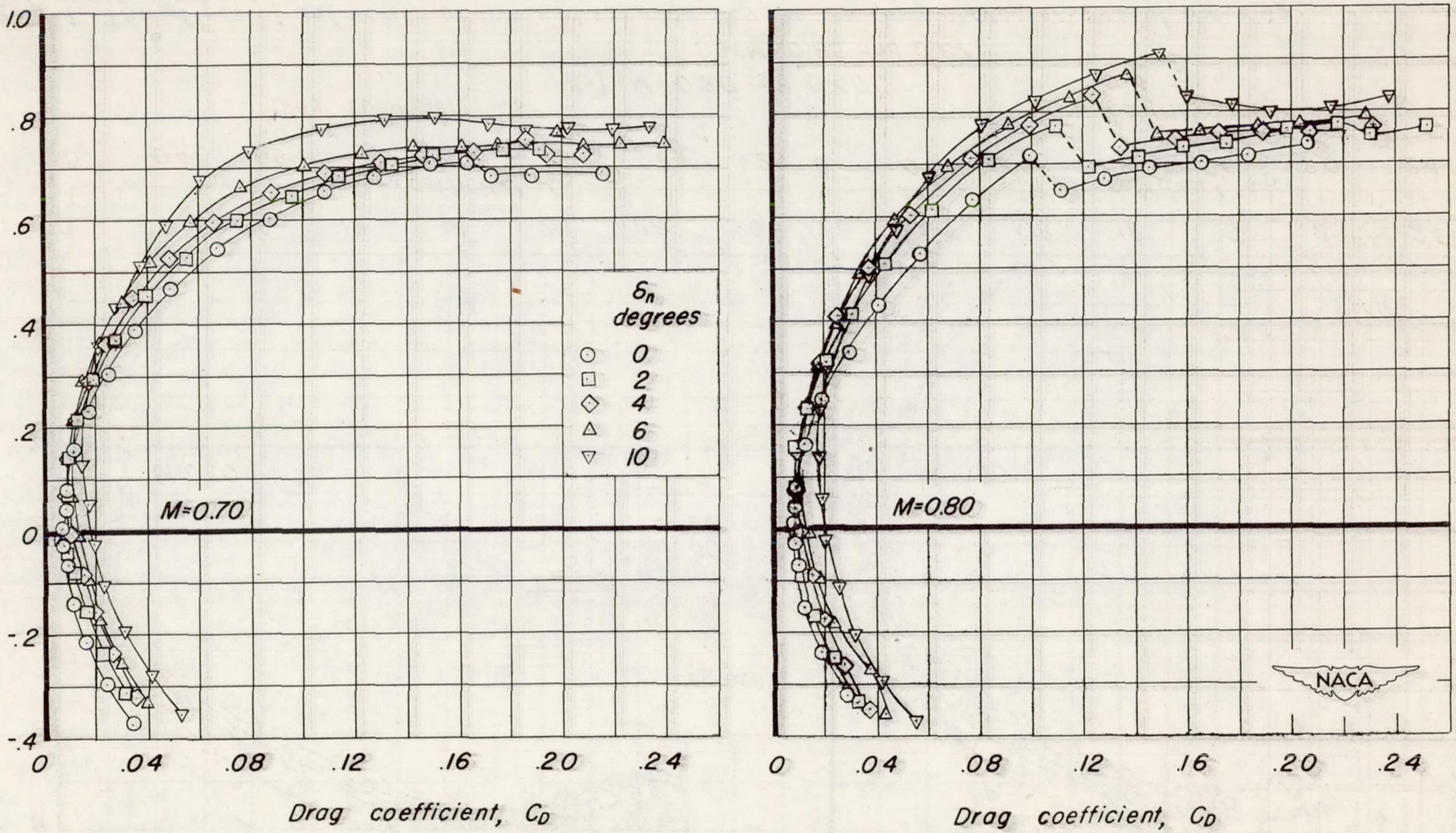

(b) M=0.70 and 0.80.

Figure 4.- Continued.

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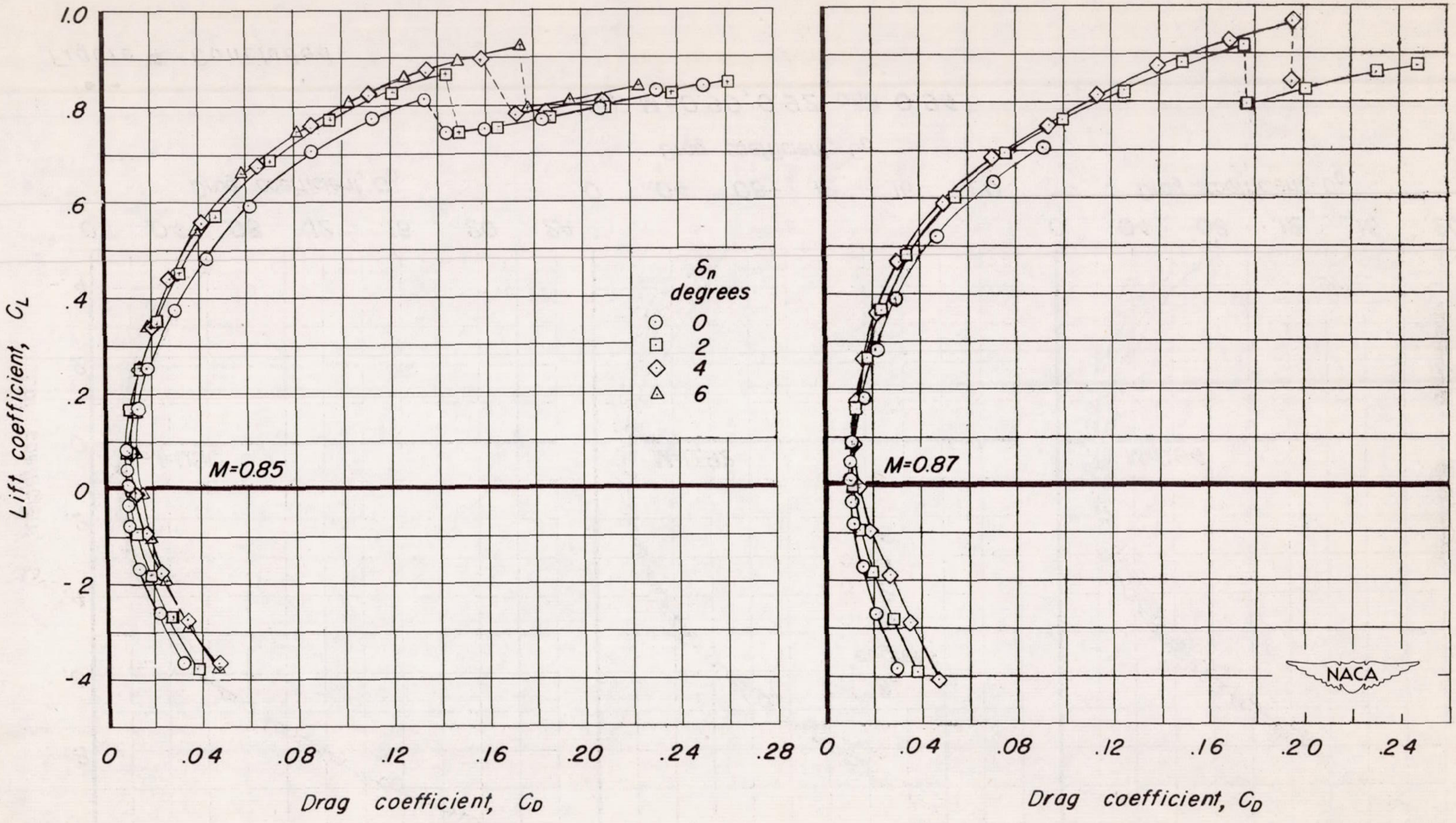

(c) M = 0.85 and 0.87.

Figure 4.- Continued.

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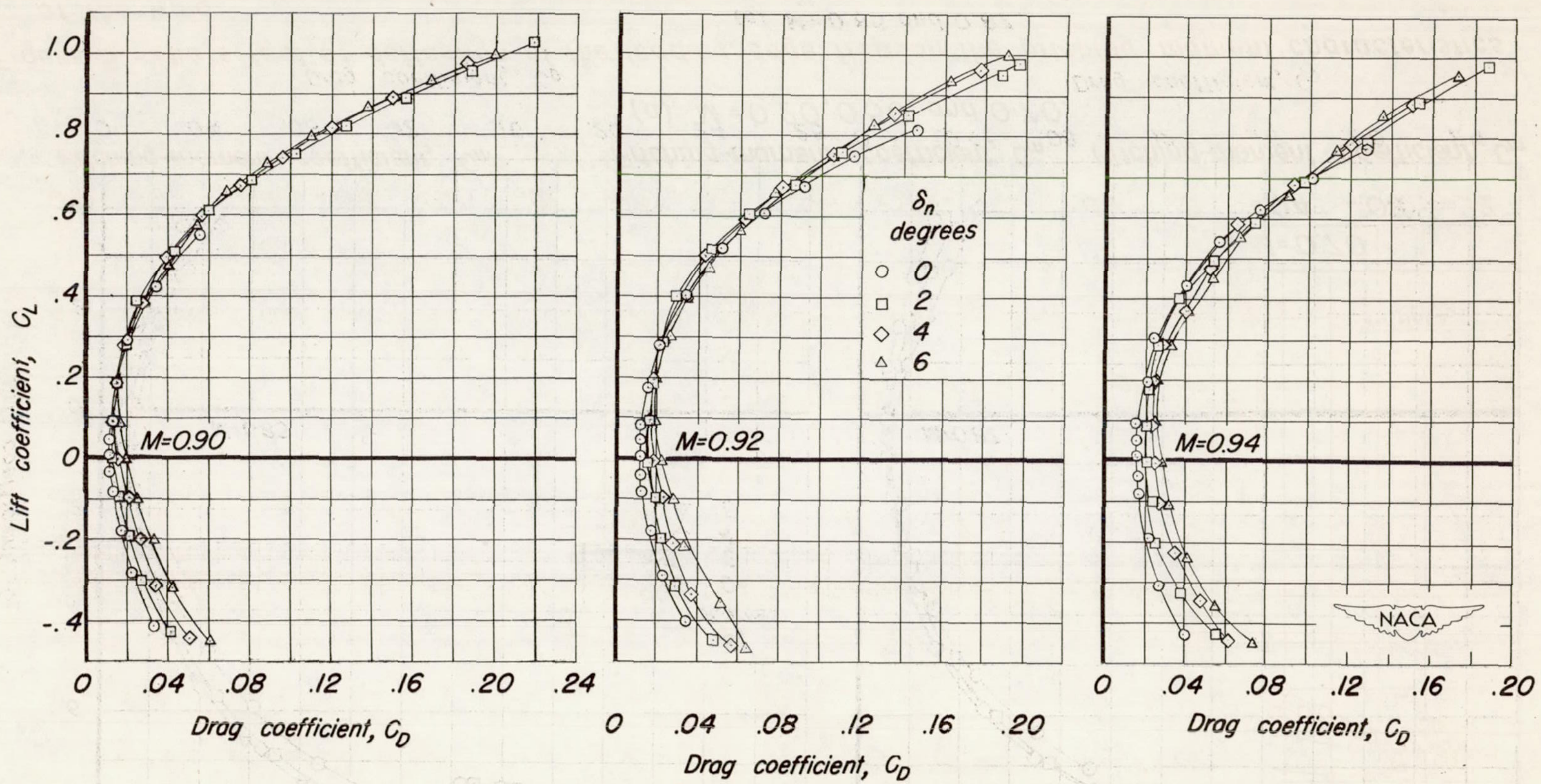

(d) M=0.90, 0.92, and 0.94.

Figure 4.- Concluded.

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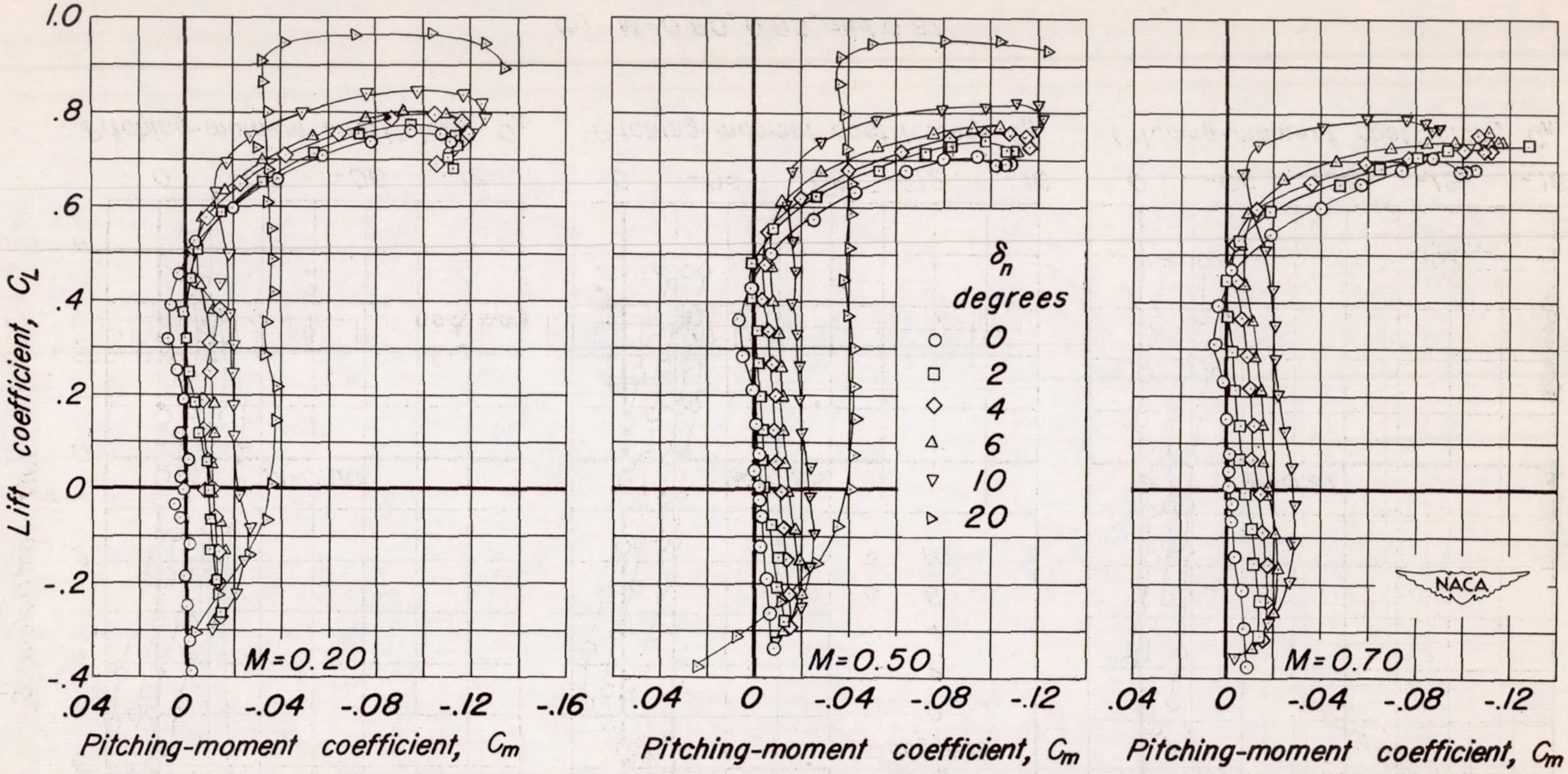

(a) M = 0.20, 0.50, and 0.70.

Figure 5.- The effect of deflection of the leading-edge flap on the pitching-moment characteristics of the wing.

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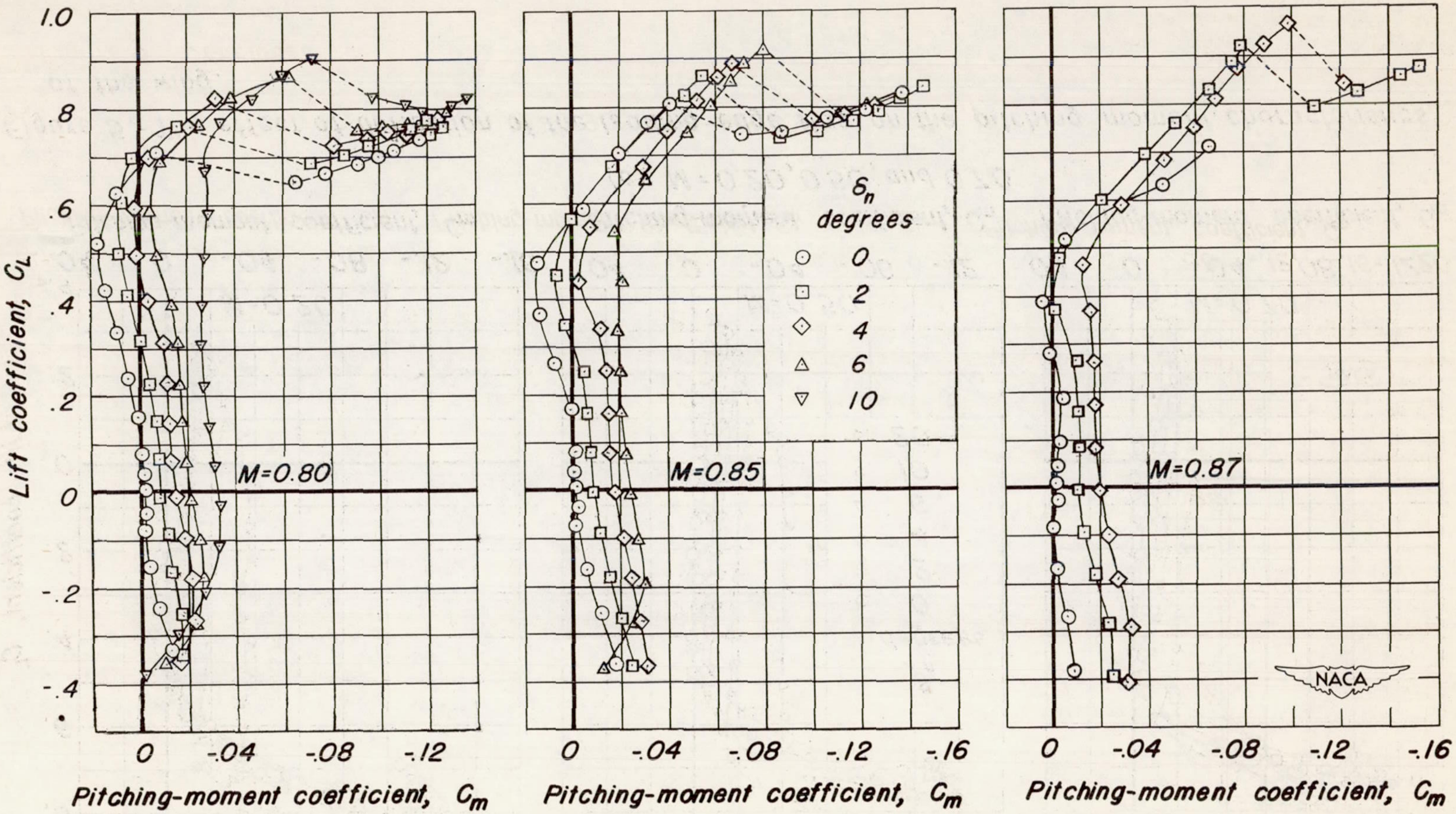

(b) M=0.80, 0.85, and 0.87.

Figure 5.- Continued.

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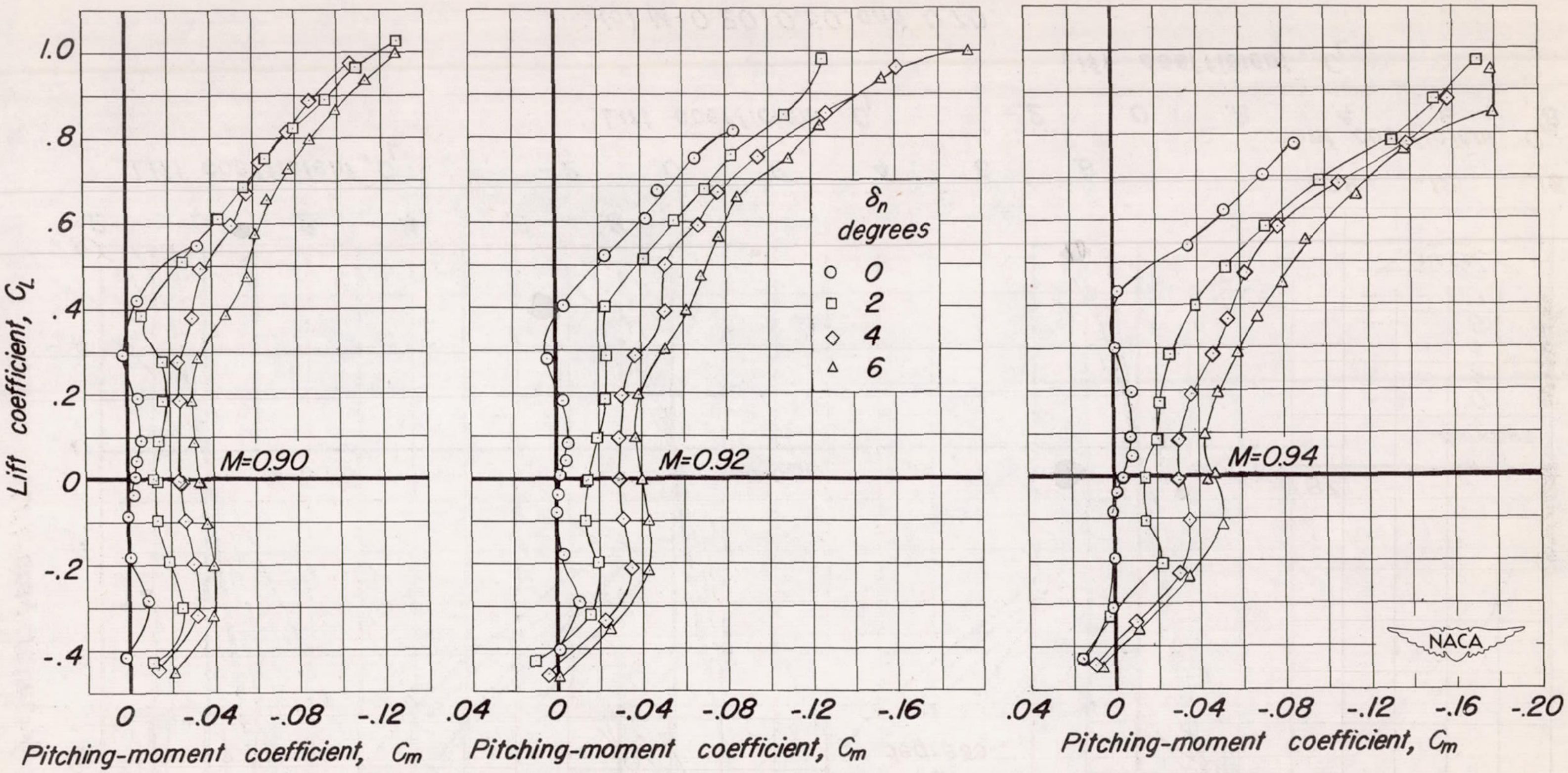

(c) M=0.90, 0.92, and 0.94.

Figure 5.- Concluded.

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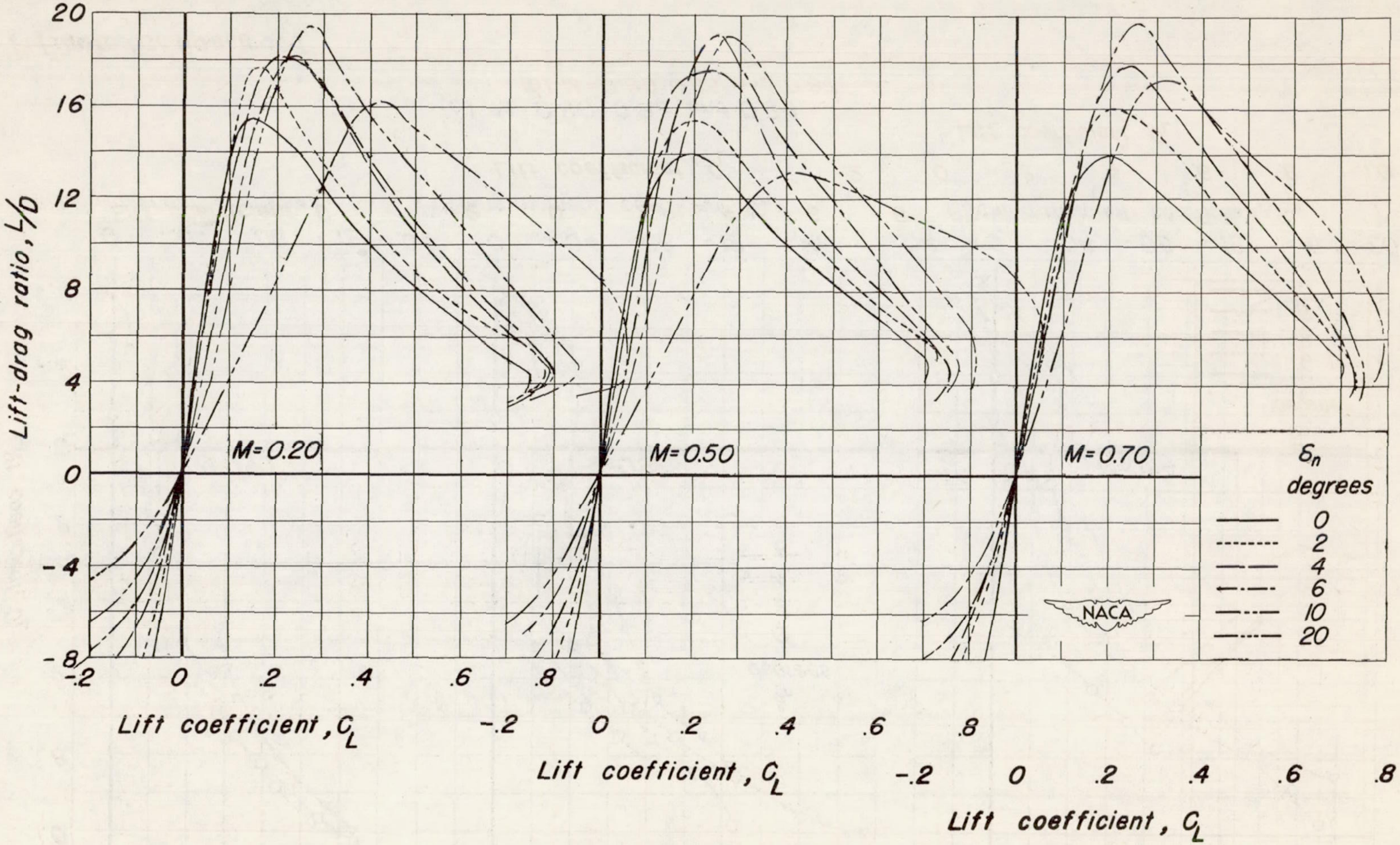

(a) M=0.20, 0.50, and 0.70.

Figure 6.- The effect of deflection of the leading-edge flap on the lift-drag ratio of the wing.

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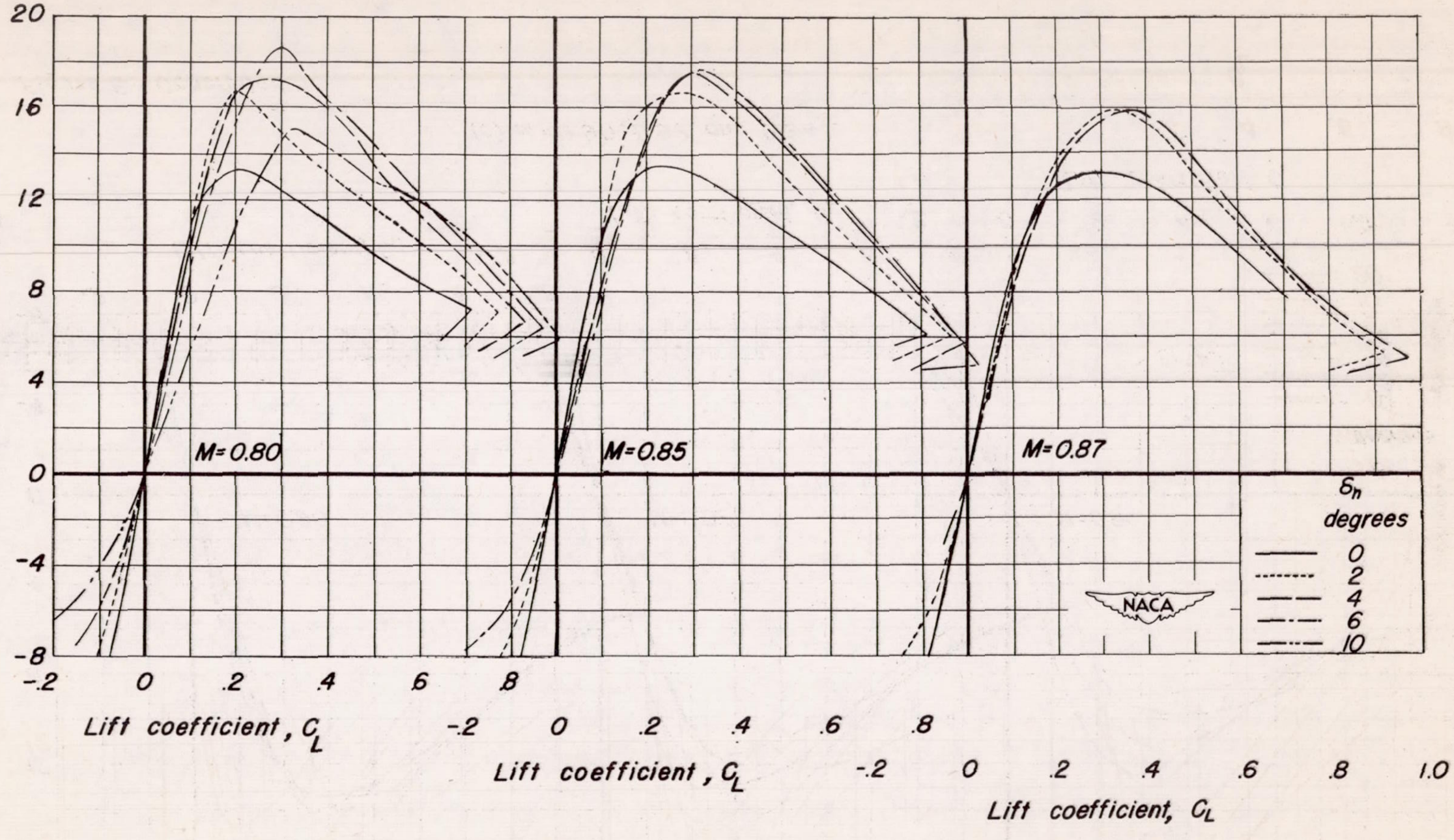

(b) M = 0.80, 0.85, and 0.87.

Figure 6.- Continued.

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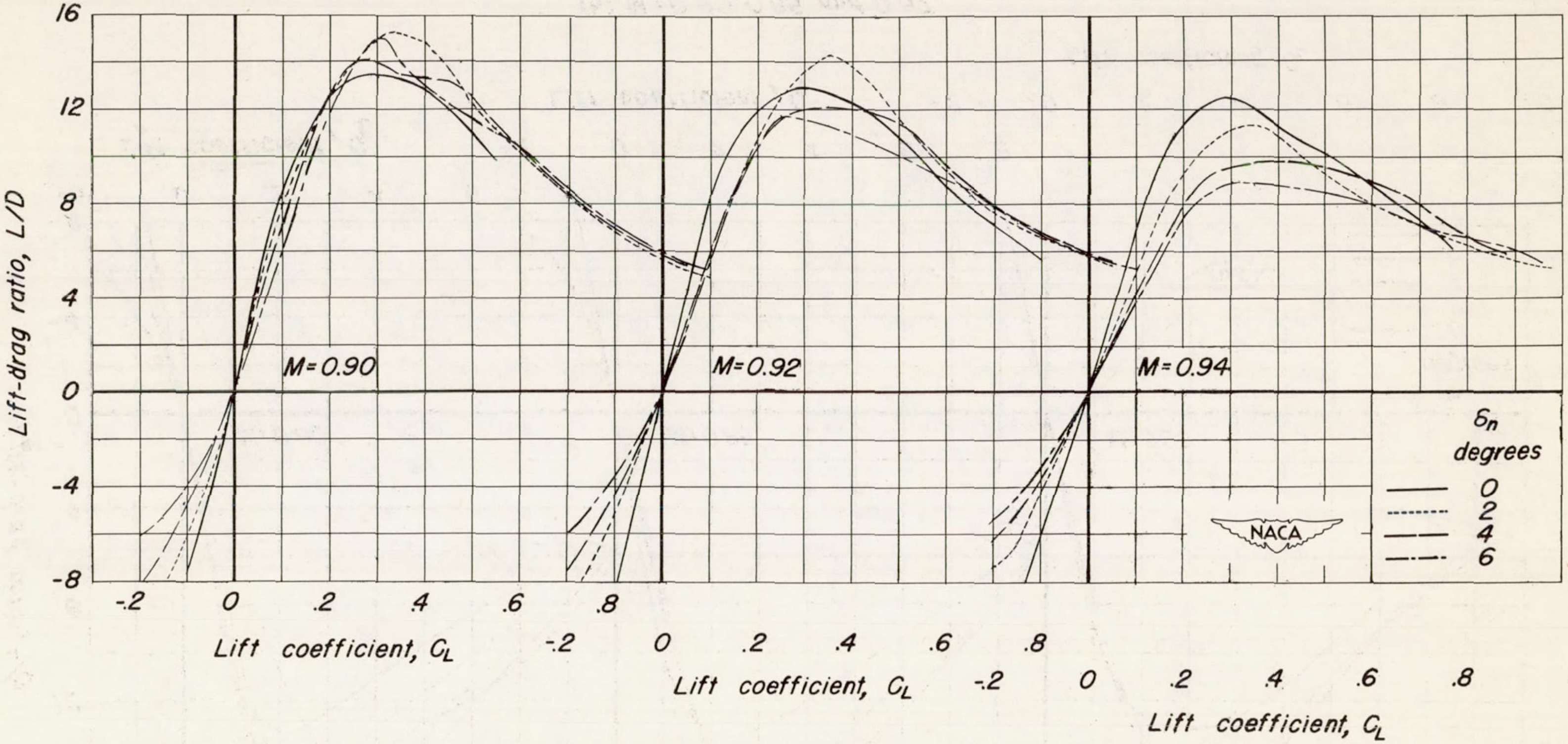

(c) M = 0.90, 0.92, and 0.94.

Figure 6.- Concluded.

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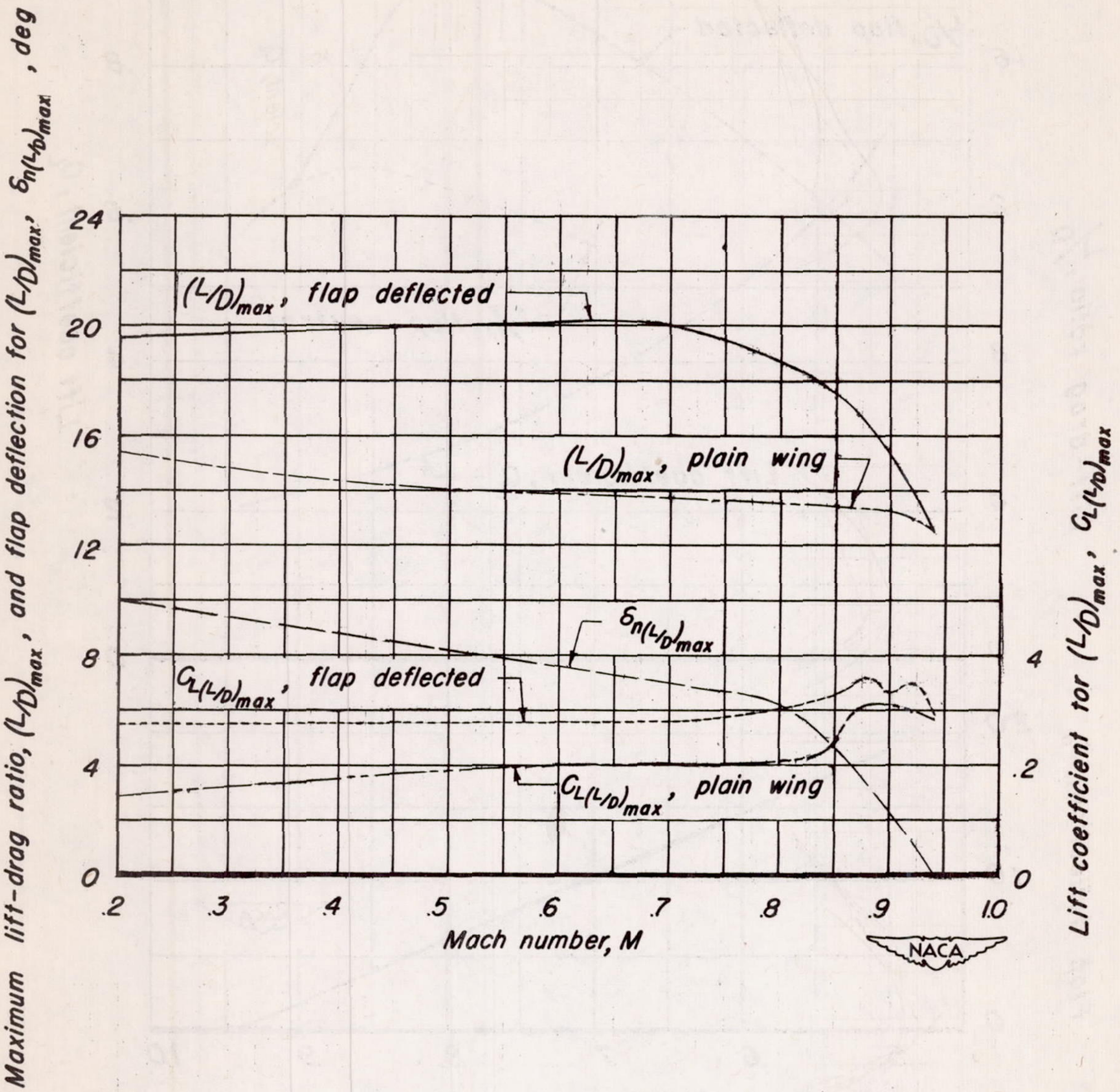
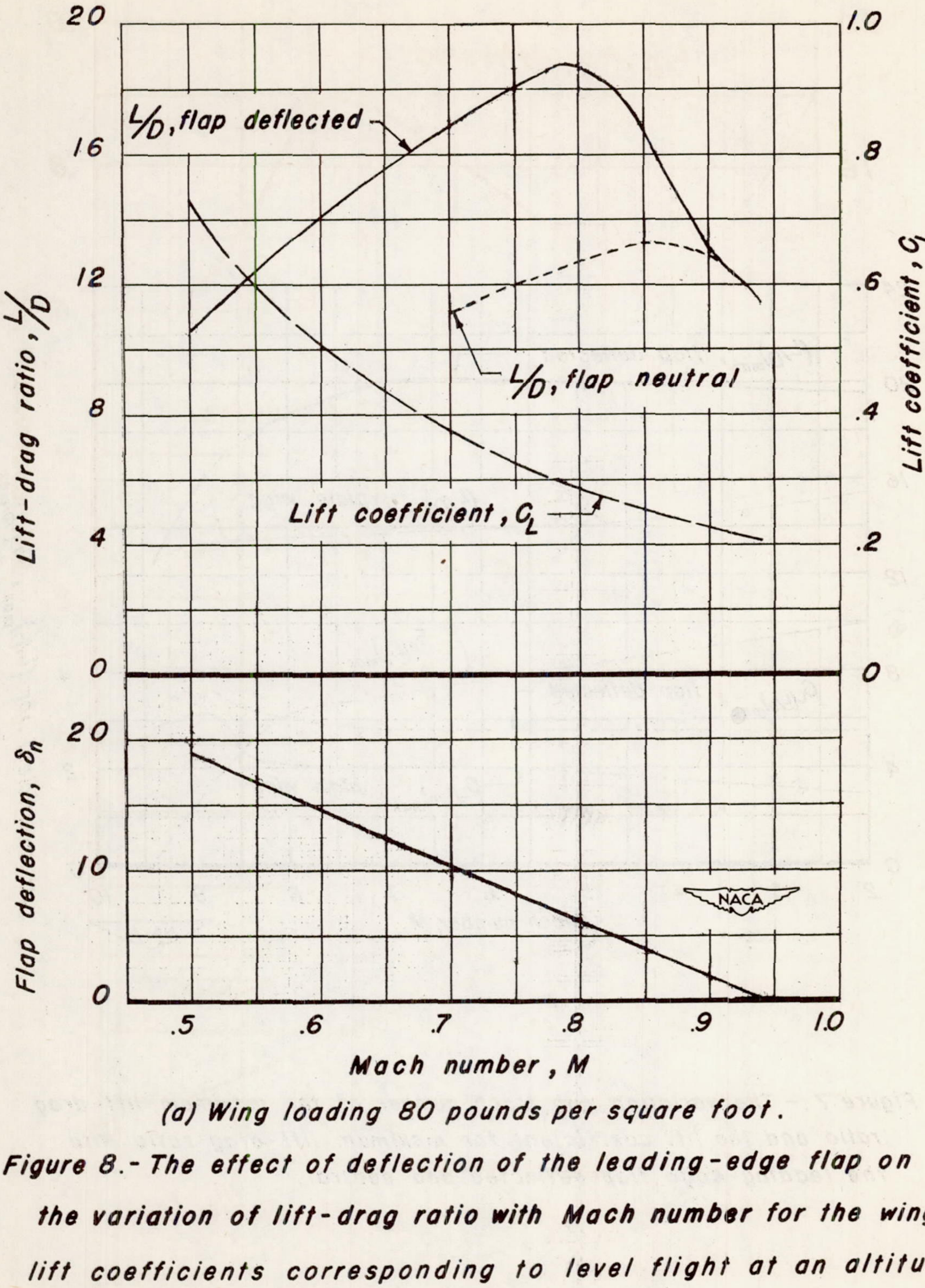
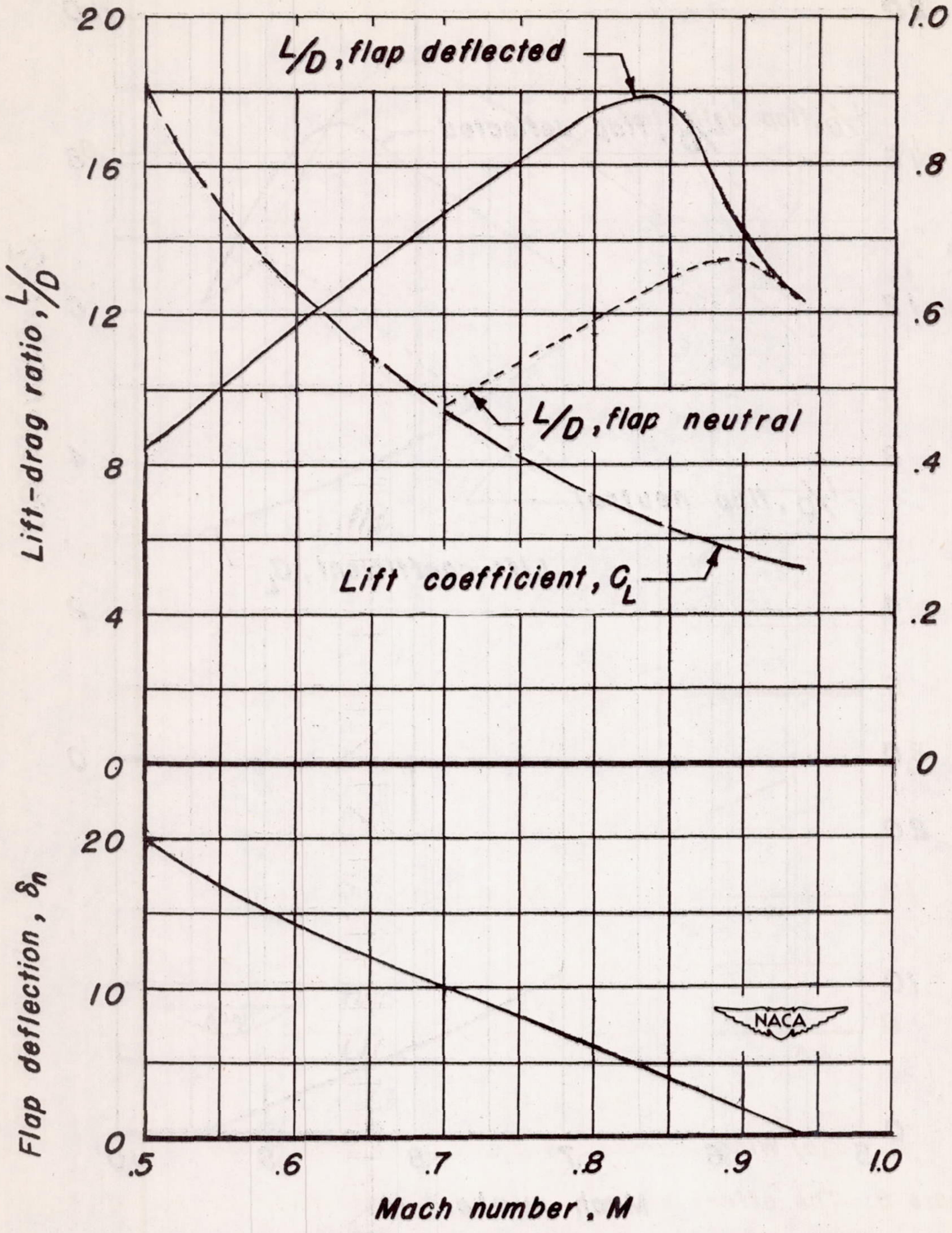


Figure 7.- The variation with Mach number of the maximum lift-drag ratio and the lift coefficient for maximum lift-drag ratio with the leading-edge flap deflected and neutral.



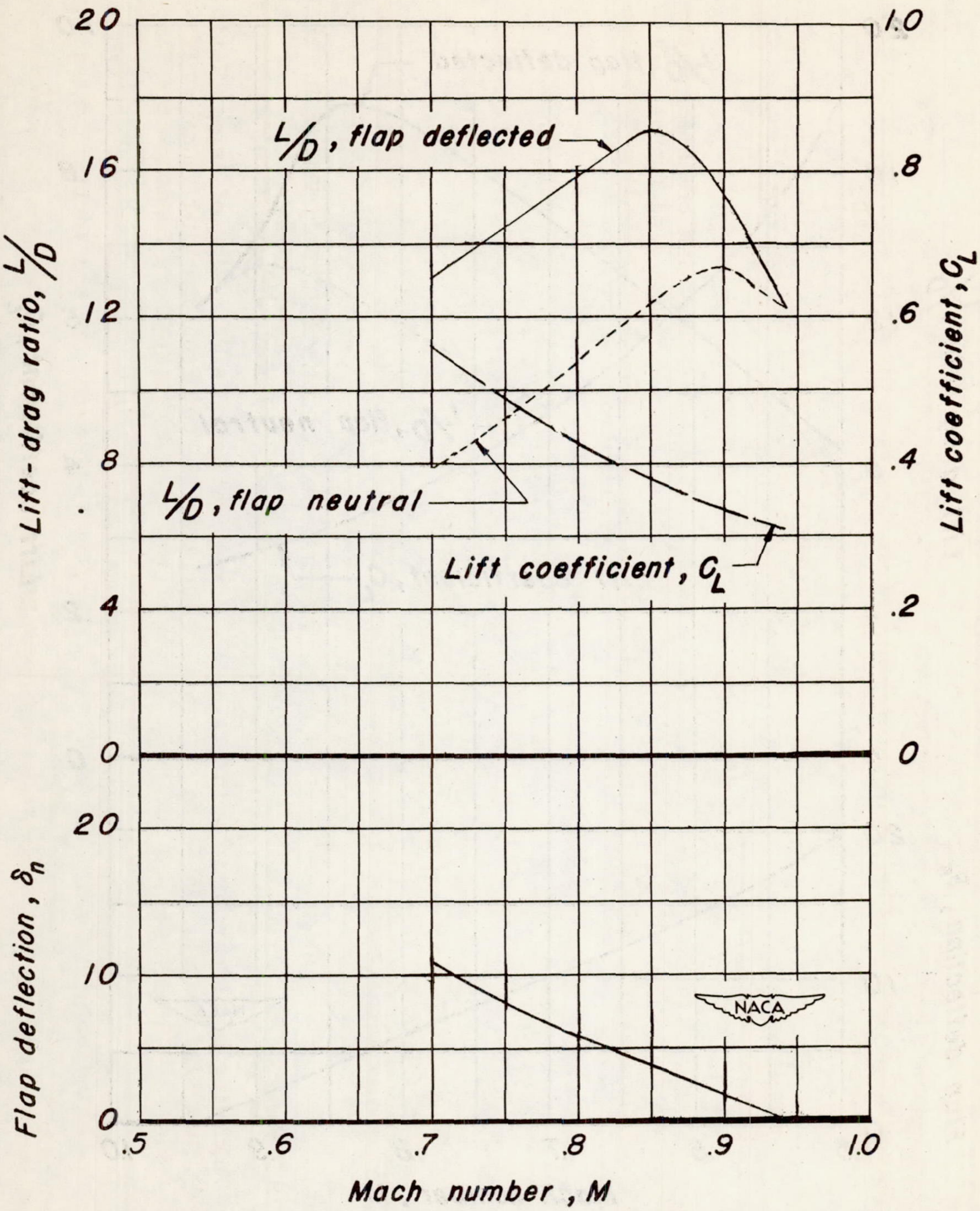
(a) Wing loading 80 pounds per square foot.

Figure 8.- The effect of deflection of the leading-edge flap on the variation of lift-drag ratio with Mach number for the wing lift coefficients corresponding to level flight at an altitude of 30,000 feet.



(b) Wing loading 100 pounds per square foot.

Figure 8.- Continued.



(c) Wing loading 120 pounds per square foot.

Figure 8.- Concluded.