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RESEARCH MEMORANDUM

AERODYNAMIC STUDY OF A WING-FUSELAGE COMBINATION EMPLOYING A WING SWEPT BACK 63°.- EFFECTIVENESS OF AN ELEVON AS A LONGITUDINAL CONTROL AND THE EFFECTS OF CAMBER AND TWIST ON THE MAXIMUM LIFT-DRAG RATIO AT SUPERSONIC SPEEDS

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Moffett Field, Calif.

NATIONAL ADVISORY COMMITTEE
FOR AERONAUTICS

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AERODYNAMIC STUDY OF A WING-FUSELAGE COMBINATION EMPLOYING A WING SWEPT BACK 63°.– EFFECTIVENESS OF AN ELEVON AS A LONGITUDINAL CONTROL AND THE EFFECTS OF CAMBER AND TWIST ON THE MAXIMUM LIFT-DRAG RATIO AT SUPERSONIC SPEEDS

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SUMMARY

An experimental investigation concerned with the measurement of the characteristics of longitudinal-control devices for a wing-fuselage combination employing a wing with the leading edge swept back 63° was conducted. The major portion of the investigation was devoted to tests of a 30-percent-chord, 50-percent-semispan elevon. Some tests were made of upper-surface spoilers. The investigation covered a range of Mach numbers from 1.2 to 1.7 at a Reynolds number of 1.5 million.

Measured values of incremental lift coefficient, pitching-moment coefficient, and hinge-moment coefficient per degree elevon deflection are compared with calculated values of these parameters as obtained through the application of the linearized theory of supersonic flow. Results indicate that, because of separation and consequent spanwise flow within the boundary layer, the lift- and pitch-effectiveness parameters were generally much smaller than linearized theory predicts. Also, a marked loss in effectiveness with increasing angle of attack was apparent at low supersonic Mach numbers. For the pitch-effectiveness parameter, however, this effect decreased with increasing Mach number, becoming relatively insignificant at a Mach number of 1.7. Incremental hinge-moment coefficient per degree elevon deflection, in the vicinity of zero lift, was in good agreement with theory at the design Mach number (1.53).

An evaluation of the capabilities of the elevon as the sole means of trimming a tailless airplane of the present configuration showed that, because of the changes in stability that occur in going from subsonic to supersonic speeds, the longitudinal control provided by the elevon is inadequate for supersonic flight of this wing-fuselage combination.

A boundary-layer fence, situated on the wing at the inboard edge of the elevon and extending one elevon chord length ahead of the hinge line,

installed to divert the spanwise flow within the boundary layer, failed to improve the elevon effectiveness appreciably.

Outboard upper-surface spoilers in heights up to the maximum wing-section thickness were tested successively at 40-, 50-, and 60-percent-chord stations on the wing-fuselage combination. Results of these tests showed the spoiler to be ineffective as a longitudinal-control device.

Of additional interest is a comparison of the results of tests made with elevon undeflected with results obtained from another investigation of a similar configuration employing a cambered and twisted wing. An appreciable increase in maximum lift-drag ratio resulted from the use of the cambered and twisted wing. This improvement decreased with increasing Mach number, ranging from a gain in maximum lift-drag ratio of approximately 2.0 at a Mach number of 1.2 to about 0.6 at 1.7 Mach number.

INTRODUCTION

The results of recent theoretical and experimental investigations have indicated that efficient supersonic flight may be attained with swept-back wings. Jones, in reference 1, has shown that reasonably good aerodynamic efficiency may be expected up to a Mach number of 1.5 with a high-aspect-ratio wing with the leading edge swept back 63°. These predictions have been substantiated by the tests of reference 2. As a result, research on swept wings has been extended to include some study into the possible means of attaining adequate lateral- and longitudinal-control characteristics. The present report presents the results of a wind-tunnel investigation at supersonic speeds of the longitudinal characteristics of a 30-percent-chord, 50-percent-semispan elevon on a wing-fuselage combination employing a wing of aspect ratio 3.5, taper ratio 0.25, and 63° sweepback of the leading edge. The effectiveness of several spoilers was also investigated. The effectiveness of the control surface in providing lateral control will be presented in a subsequent report.

As a basis for comparison, theoretical estimations of three-dimensional control-surface characteristics at supersonic speeds have been made through the application of linearized equations of supersonic flow by the method of reference 3. The approximations, which of necessity are introduced into these theoretical solutions, completely disregard the effects of viscosity, a factor greatly affecting control-surface characteristics. However, a theoretical estimation of these characteristics, as introduced in the following discussion, was made to give a measure of the accuracy with which these control-surface parameters can be predicted through the use of linear-theory solutions.

NOTATION

The following symbols 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_h hinge-moment coefficient $\left(\frac{\text{hinge moment}}{2q\ M_A}\right)$

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

C_{L_δ} elevon lift-effectiveness parameter for constant angle of attack $\left(\frac{\partial C_L}{\partial \delta}\right)_\alpha$, per degree

C_{m_δ} elevon pitch-effectiveness parameter for constant angle of attack $\left(\frac{\partial C_m}{\partial \delta}\right)_\alpha$, per degree

C_{h_δ} rate of change of hinge-moment coefficient with elevon deflection for constant angle of attack $\left(\frac{\partial C_h}{\partial \delta}\right)_\alpha$, per degree

α angle of attack of fuselage center line, degrees

δ angle between wing chord and elevon chord, measured in a plane perpendicular to the elevon hinge line, positive for downward deflection with respect to the wing, degrees

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

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

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

V airspeed, feet per second

ρ mass density of air, slugs per cubic foot

μ viscosity of air, slugs per foot-second a speed of sound, feet per second

S wing area, square feet

$\bar{c}$ wing mean aerodynamic chord $\left(\dfrac{\int_0^{b/2} c^2\, dy}{\int_0^{b/2} c\, dy}\right)$, feet

b wing span, feet

c local wing chord measured parallel to plane of symmetry, feet

M_A first moment of area of elevon surface about hinge line

Coefficients indicated with a prime (') are uncorrected for tunnel pressure gradient and flow inclination.

DESCRIPTION OF APPARATUS

Tunnel

The Ames 6- by 6-foot supersonic wind tunnel, in which these tests were conducted, is described in detail in reference 4. The tunnel is a closed-circuit, variable-pressure, supersonic wind tunnel having a pressure range of approximately 2 to 20 pounds per square inch absolute. The Mach number can be varied continuously from 1.20 to 2.00. Due to certain vibration difficulties of the present model support system, the Mach number range is temporarily limited to a maximum of 1.7, and the test results reported herein extend only over this range.

Model

The model tested was a full-span wing-fuselage combination, the wing of which had an aspect ratio of 3.5, no dihedral, 0° incidence, a taper ratio of 0.25, 63° sweepback of the leading edge, and was symmetrically mounted on the fuselage. Because of the difficulties encountered in constructing a control surface of this scale employing camber and twist, the wing was constructed with no camber or twist. The airfoil section perpendicular to the leading edge was the NACA 0010. A 30-percent-chord elevon was mounted on the outboard 50 percent of the right wing panel only, as shown in the plan view of figure 1. The elevon and main wing panels were of solid steel construction.

The excresence shown at the tip of the right wing serves as a stiffener for the end hinge bearing. The effect of this protuberance on the aerodynamic characteristics of the model is believed negligible.

The fuselage used in these tests was identical to that tested in reference 2 in combination with a twisted and cambered wing of the same 63° swept-back plan form. This body was selected on the basis of minimum wave-drag considerations and had a fineness ratio of 12.5. The body was of hollow-steel construction to permit the installation of the four-component strain-gage balance, as shown in the cutaway schematic drawing of figure 2.

Elevon hinge moments were measured by an electrical strain gage mounted in the main wing panel. Each elevon-deflection angle was fixed by the angle of the hexagonal fitting on the strain gage. A separate gage was provided for each elevon deflection tested. A steel plate covered the recess in the wing panel in which the strain gages were installed. This installation is illustrated in the exploded view of figure 3. Also included in this figure is a sketch showing the relative size and shape of the boundary-layer fence used in the investigation.

TESTS

Range of Tests

Aerodynamic forces on the model were measured at speeds ranging from 1.2 to 1.7 Mach number. Lift, drag, pitching-moment, and hinge-moment measurements were made at nominal angles of attack from 0° to 10°. The elevon deflection was varied in 5° increments from -30° to 30°. The data presented in the report were obtained at a Reynolds number of 1.5 million, although an investigation of possible dynamic scale effect was made which included data at Reynolds numbers of 2.7 and 3.7 million.

Further tests were made to evaluate the effects of a vertical plate, or fence, mounted on the wing at the inboard end of the elevon as a possible means of diverting the spanwise flow in the boundary layer. For these tests, data were taken at several of the elevon deflections indicated above.

Spoiler effectiveness, in providing longitudinal control, was investigated through the same angle-of-attack and speed range as that of the elevon. An outboard 50-percent-semispan spoiler in heights of 50- and 100-percent maximum wing-section thickness was tested successively at 40-, 50-, and 60-percent-chord stations.

Visual-flow studies by means of tufts were made at a few test conditions to determine the nature of the boundary-layer flow over the wing.

Reduction of Data

Since, in the present support system, angle of attack of the model is varied by translation of the rear support strut, the balance moves as an integral part of the model. The balance readings, multiplied by the appropriate calibration constants, therefore, give the normal and chord forces and the pitching moment acting about an arbitrary reference axis. From these values, the lift, drag, and pitching moment about the 25-percent mean aerodynamic chord of the model were calculated. The reference axis about which the hinge moments were measured was coincident with the axis of rotation of the elevon thus giving hinge moments directly.

The angle of attack of the model under aerodynamic load was determined optically by means of a cathetometer. The control-surface deflections, however, could not be determined in this manner, but were measured under static conditions before each test and corrected for deflection under aerodynamic load. These corrections were calculated from the measured values of the hinge moment using elastic constants previously determined by loading the elevon statically at its center of pressure.

Corrections to Data

Certain results obtained in calibrating the tunnel are essential to an estimation of the accuracy of the experimental data obtained therein. These will be discussed insofar as they concern the present tests. A complete analysis of the tunnel calibration is covered in reference 4.

Although vertical pressure gradients of significant magnitude exist in the test section of the Ames 6- by 6-foot wind tunnel, the transverse gradients are of negligible magnitudes which indicates that the flow is essentially two-dimensional. Therefore, as stated in reference 4, the effects of the nonuniformity of the stream on certain model characteristics may be minimized by testing with the plane of the model wing parallel to the two-dimensional-flow plane.

To obtain elevon undeflected data on this wing and fuselage combination for comparison with results of other investigations, tests were made with the model mounted with the wing span vertical. However, to shorten the control-surface-effectiveness tests, the model was mounted with the wing span in the horizontal position to obtain all control-surface data, as changing angle of attack when the model is mounted with the wing span in the vertical position entails changing bent stings. Values of the incremental changes in the aerodynamic coefficients due to elevon deflections obtained with the model mounted with wing horizontal are considered reliable, as it has been shown that the lift-curve and pitching-moment-curve slopes are not influenced by the orientation of the model. (See reference 4.)

The streamwise static-pressure gradient in the test section caused a longitudinal buoyant force which was determined by integrating graphically the product of the static pressure and the change in cross-section area of the fuselage along its length. The measured drag was corrected by this longitudinal force.

Because of appreciable axial variations in stream angle at Mach numbers above and below $M = 1.4$, it is difficult to determine the effective model angle of attack when testing the model mounted with the plane of the wing horizontal. Therefore, the angles of attack referred to in this report are nominal angles referenced to the horizontal and, as such, restrict the significance of the effect of angle of attack on the control-surface-effectiveness parameters to an indication as to trends with Mach number.

As the lift, drag, and pitching-moment strain gages were located inside the model, the necessity for determining force tares due to aerodynamic forces on the sting was eliminated. The effects on the drag of the model due to support interference, however, experienced principally as a change in pressure at the base of the model, were taken into account by means of a base drag correction. Base drags were calculated by multiplying the base area of the body by the difference between free-stream static pressure and measured base pressure.

Precision

The uncertainties involved in determining dynamic pressure and in measuring forces with the strain-gage balance are fully discussed in reference 2. The following table lists the uncertainty introduced into each corrected coefficient by the known uncertainties in the factors making up the various results:

Quantity	Known uncertainty	
	$\alpha = 0^\circ$	$\alpha = 10^\circ$
Lift coefficient	0.0005	0.003
Drag coefficient	.0002	.001
Pitching-moment coefficient	.0002	.0013
Mach number	.01	.01
Reynolds number	0.03×10^6	0.03×10^6

The absence of nonrepeating errors was shown by the excellent agreement of repeated tests.

RESULTS AND DISCUSSION

Before discussing control-surface effectiveness, it is of interest to compare results of tests of the present wing with those of reference 2 for a wing twisted and cambered for uniform load at a lift coefficient of 0.25 to show the effects of camber and twist on the efficiency of this wing-fuselage combination at supersonic speeds.

Characteristics of the Wing With the Elevon Undeflected

As efficient supersonic flight is largely dependent upon the attainment of high lift-drag ratios, a comparison of the aerodynamic characteristics of the present flat wing will be made with that of the cambered and twisted wing of reference 2 insofar as they affect maximum lift-drag ratio. Although the data of reference 2 were obtained at a Reynolds number of 3.7 million, the results are considered comparable to those of the present tests as previous tests show little scale effect between Reynolds numbers of 1.5 million and 4.0 million.

Variations of the angle of attack, pitching-moment coefficient, drag coefficient, and lift-drag ratio with lift coefficient for the Mach number range investigated are shown in figures 4(a) through 4(d) for the flat and the cambered and twisted wings. The theoretical values of these parameters for the flat wing, obtained from the data of reference 5, are presented in these figures for the design Mach number $(M = 1.53)$.

Higher values of minimum drag coefficient and drag due to lift and a lower value of lift-curve slope than those predicted by linear theory are evident from an examination of figure 4. Also, the nonlinear variation of C_m with C_L shows an appreciable center-of-pressure travel not indicated by theory. These differences between experiment and theory are probably attributable to the relatively large areas of separated flow evidenced by the tuft studies of figure 5.

A comparison of maximum lift-drag ratio, minimum-drag coefficient, and lift-curve slope for the flat wing with those for the cambered and twisted wing as functions of Mach number are included in figure 6. These experimental data show an appreciable increase in maximum lift-drag ratio throughout the Mach number range investigated resulting from the use of the cambered and twisted wing. This improvement decreased with increasing Mach number, ranging from a gain of 2.0 at a Mach number of 1.2 to 0.6 at a Mach number of 1.7. The difference in minimum drag for the two wings is of such small magnitude as to be essentially of little significance as regards maximum lift-drag ratio. Also, the slight difference in lift-curve slope of the two wings tested is considered of little importance, since the slope of the lift curve in the range of small lift coefficients (fig. 4(a)) is determined by relatively few test points. Therefore, the improvement in maximum lift-drag ratio must result entirely from the combined effect of the displacement of the minimum of the drag curve to a positive lift coefficient and a reduction in the rate of drag rise with lift coefficient. (See fig. 4(b)).

Control-Surface Effectiveness

Representative basic experimental data for the elevon are presented in figures 7(a) through 7(c). As explained in a preceding section, these data are uncorrected for any induced camber effect due to the existing variation in the stream angle along the test section. However, this deviation in flow inclination does not have an appreciable effect on the incremental values constituting the control-surface-effectiveness parameters. Figures 8, 9, 10, and 11 are cross plots of the basic data showing the variation of lift, pitching-moment, hinge-moment, and drag coefficients with elevon deflection for constant angles of attack up to 10°. All these data were obtained at a Reynolds number of 1.5 million as tests made early in the investigation at Reynolds numbers of 2.7 and 3.7 million (fig. 12) showed no appreciable scale effect on the effectiveness parameters of the elevon in this Reynolds number range.

Lift.– Qualitatively, the lift results are similar to what would be anticipated from theory. No appreciable nonlinear variations of lift coefficient with elevon deflection appear to exist throughout the entire Mach number and angle-of-attack range investigated. (See fig. 8). Also, the variation of the lift-effectiveness parameter C_{L_δ} with Mach number, presented in figure 13, is similar to that predicted by linear theory.

Quantitatively, however, it is noted that, for an angle of attack of 1°, but 64 percent of the predicted value of C_{L_δ} is realized at a Mach number of 1.2, dropping off to 56 percent at a Mach number of 1.7. A very rapid decrease in the lift effectiveness is apparent with increasing angle of attack at a Mach number of 1.2 – an effect which decreases with increasing Mach number. This loss in effectiveness with increasing angle of attack is not surprising, however, in view of tuft studies of which representative photographs are presented in figure 5. A study of the photographs for a Mach number of 1.2 reveals that, although the flow in the boundary layer at an angle of attack of 0° is streamwise over the complete wing, at an angle of attack of 2° (C_L = 0.1) the flow separates near the wing tip, and, with increasing angle of attack, the separated region rapidly envelops the entire elevon area. This would seem to account for the rapid loss in effectiveness with angle of attack.

Aeroelastic effects were ruled out as a factor contributing to the inefficiency of the elevon inasmuch as the measured wing twist was found to be relatively independent of elevon deflection.

Pitching-moment.- An examination of the $C_m{}'$ versus δ curves of figure 9 discloses an appreciable decrease in slope at both positive and negative elevon deflections greater than 20°, suggesting that the magnitude of the previously discussed separation effects increase with increased elevon deflection at constant angle of attack. This tendency is apparent through the entire Mach number range investigated but is more pronounced at the lower speeds and the higher angles of attack.

As shown in figure 14, for an angle of attack of 1°, 80 percent of the theoretical effectiveness in providing longitudinal control is realized at a Mach number of 1.2, the control effectiveness diminishing to approximately 48 percent of that theoretically attainable at a Mach number of 1.7. The ability of the elevon to produce an incremental pitching-moment coefficient drops off rapidly with increasing angle of attack at a Mach number of 1.2. This effect, however, diminishes with increasing speed, becoming relatively small at a Mach number of 1.7.

The value of the pitch-effectiveness parameter C_{m_δ} at a Mach number of 1.2 ($C_{m_\delta} = -0.0049$) compares favorably with the value obtained for a constant-chord (25-percent chord at inboard end to 62.5-percent chord at tip) 50-percent-semispan control surface on the same wing at a Mach number of 0.9 ($C_{m_\delta} = -0.0052$). (See reference 6.) The somewhat higher value obtained for the constant-chord elevon probably is attributable to the greater elevon area at the wing tip rather than a Mach number effect. This would seem to indicate little loss in effectiveness through the speed of sound.

An evaluation of the capabilities of the elevon as the sole means of trimming a tailless airplane of the present configuration involves considerations of the center-of-gravity and neutral-point positions. Data of reference 2 indicate a 22-percent shift in neutral point between low subsonic speeds and a Mach number of 1.7. If a low-speed minimum static margin of 0.05 is assumed, the stability is such that, at a Mach number of 1.7, the elevon, with the maximum deflection of 30°, is capable of trimming the wing-fuselage combination only to a lift coefficient of 0.22. Obviously, therefore, if no efficient means of boundary-layer control can be devised to the advantage of increased control effectiveness, additional means of providing longitudinal control would be necessary for efficient supersonic flight of this wing-fuselage combination.

Elevon hinge moment.- In general, the nonlinearities present in the variation of elevon hinge-moment coefficient with elevon deflection (fig. 10) are not well enough defined nor of sufficient magnitude to be distinguished from the random experimental scatter known to exist. However, at the higher Mach numbers, there does appear to exist a decrease in slope for the high positive elevon deflections.

It is evident from figure 15 that, for the design Mach number (1.53), the magnitude of C_{h_δ}, in the vicinity of zero lift, is in good agreement with theory. The effect of increasing the angle of attack on the parameter C_{h_δ} was to decrease the flap-restoring tendency.

Auxiliary devices.- Tests were conducted to evaluate the effects of a vertical plate in increasing the control effectiveness by diverting the flow in the boundary layer. The plate was attached to the wing at the inboard end of the control surface and extended one elevon chord length ahead of the hinge line. No appreciable change in elevon effectiveness was realized, probably due, as seen in the subsequent tuft studies, to the separation and consequent spanwise flow well ahead of the leading edge of the boundary-layer fence.

This spanwise flow within the boundary layer explains also the relative ineffectiveness of the 50-percent semispan, 50- and 100-percent maximum wing-section-thickness spoilers which were tested successively at 40-, 50-, and 60-percent-chord stations. Since little difference in effectiveness was evident for the three chordwise stations tested, data for but one chordwise position are presented in figure 16. The maximum effectiveness obtainable for the several spoilers tested was comparable to that obtained from but 10° deflection of the present elevon.

Tuft studies made with a sealed elevon-nose gap showed no improvement in the boundary-layer-flow characteristics, indicating that the gap (0.0030 in.) was probably sufficiently small to be effectively sealed.

CONCLUSIONS

Tests made to determine the effectiveness of a constant-percent-chord outboard elevon and upper-surface spoilers as longitudinal-control devices for a wing with the leading edge swept back 63° of symmetrical section in combination with a body of revolution showed the following results covering a range of Mach numbers from 1.2 to 1.7 at a Reynolds number of 1.5 million:

1. Results of tests of the effectiveness of a 30-percent-chord, 50-percent-semispan elevon as a longitudinal control revealed the following:

   (a) As a result of flow separation in the boundary layer, the elevon-effectiveness parameters were generally much smaller than linearized theory predicts.

   (b) At low supersonic Mach numbers, the elevon effectiveness decreased rapidly with increasing angle of attack. This effect decreased with increasing Mach number for C_{m_δ}, however, becoming relatively insignificant at a Mach number of 1.7.

(c) Because of the stability changes that occur in going from subsonic to supersonic speeds, the longitudinal control provided by the elevon is not adequate.

(d) Incremental hinge-moment coefficient per degree elevon deflection was in good agreement with theory at the design Mach number in the vicinity of zero lift. The effect of increasing angle of attack on the C_{h_δ} parameter was to decrease the flap-restoring tendency.

2. Results of an investigation of outboard upper-surface spoilers in heights up to the maximum wing-section thickness, tested successively at 40-, 50-, and 60-percent-chord stations, showed poor effectiveness as a longitudinal control.

A comparison of the results of tests made with elevon undeflected with results from another investigation of a similar configuration employing a cambered and twisted wing revealed an appreciable increase in maximum lift-drag ratio resulting from the use of the cambered and twisted wing. This improvement decreased with increasing Mach number ranging from a gain of $\Delta(L/D)_{max}$ of 2.0 at a Mach number of 1.2 to 0.6 at a Mach number of 1.7.

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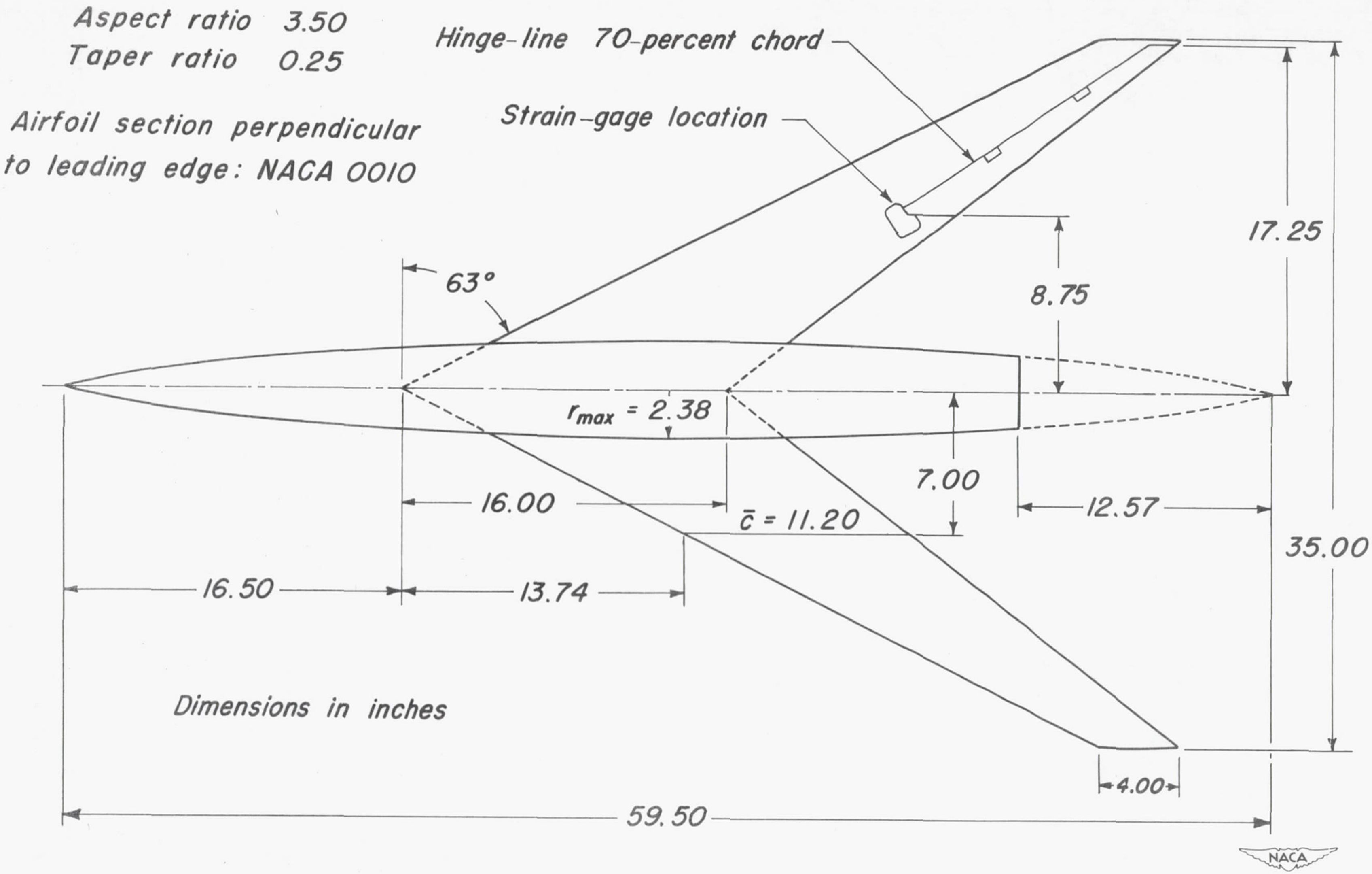


Figure 1.- Sketch of model showing principal dimensions and location of elevon.

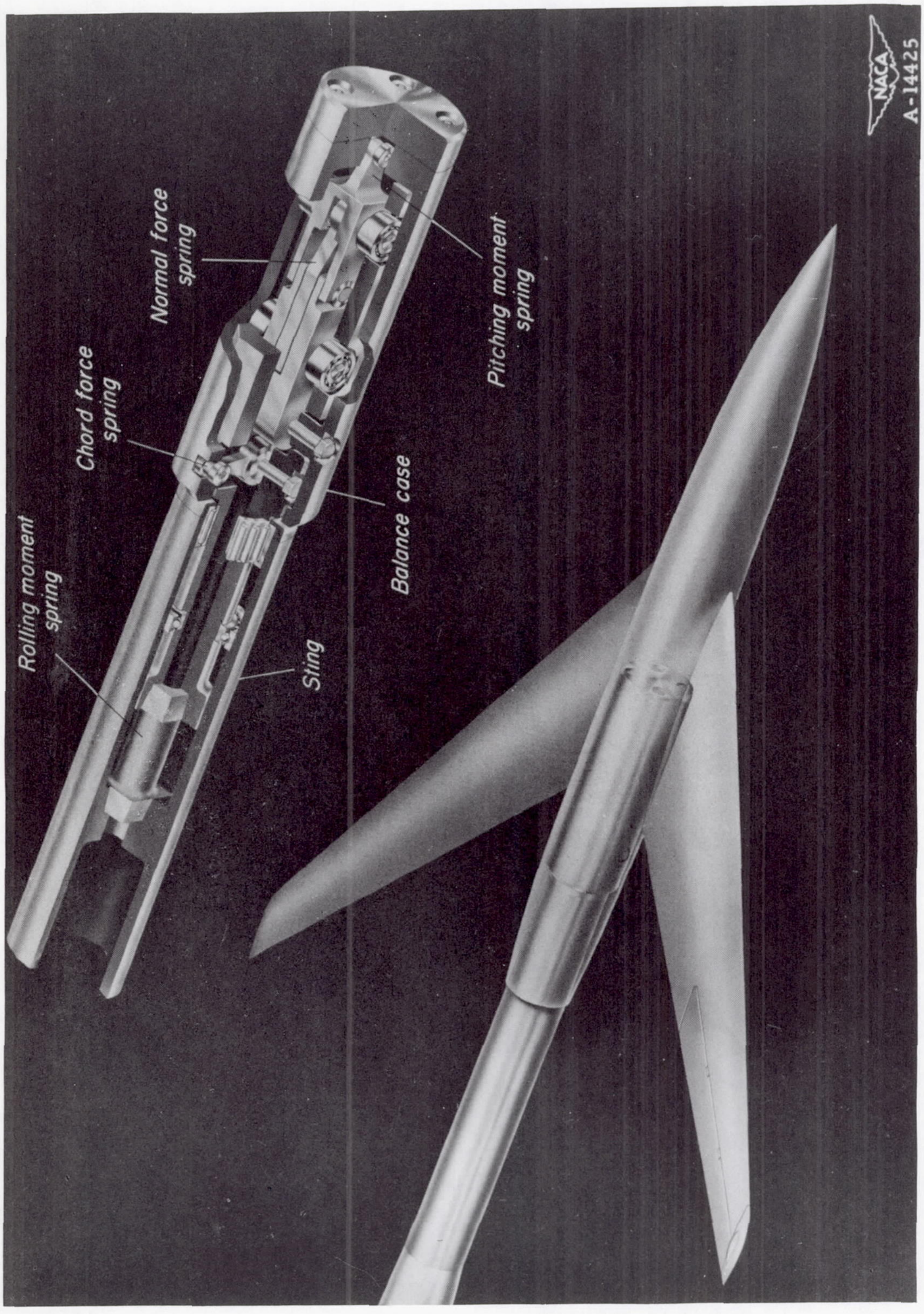


Figure 2.- Schematic drawing of four-component strain-gage-type balance installation.

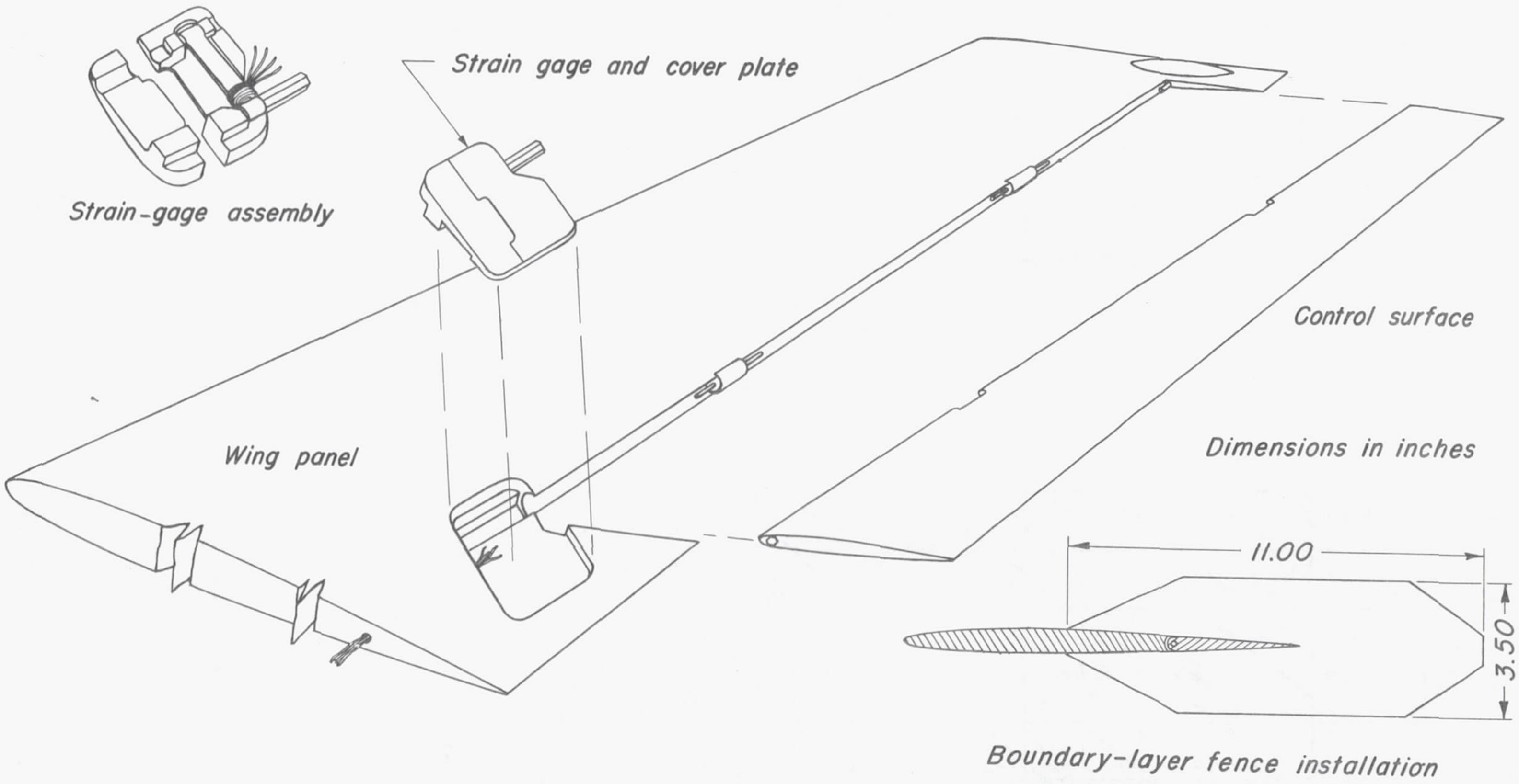
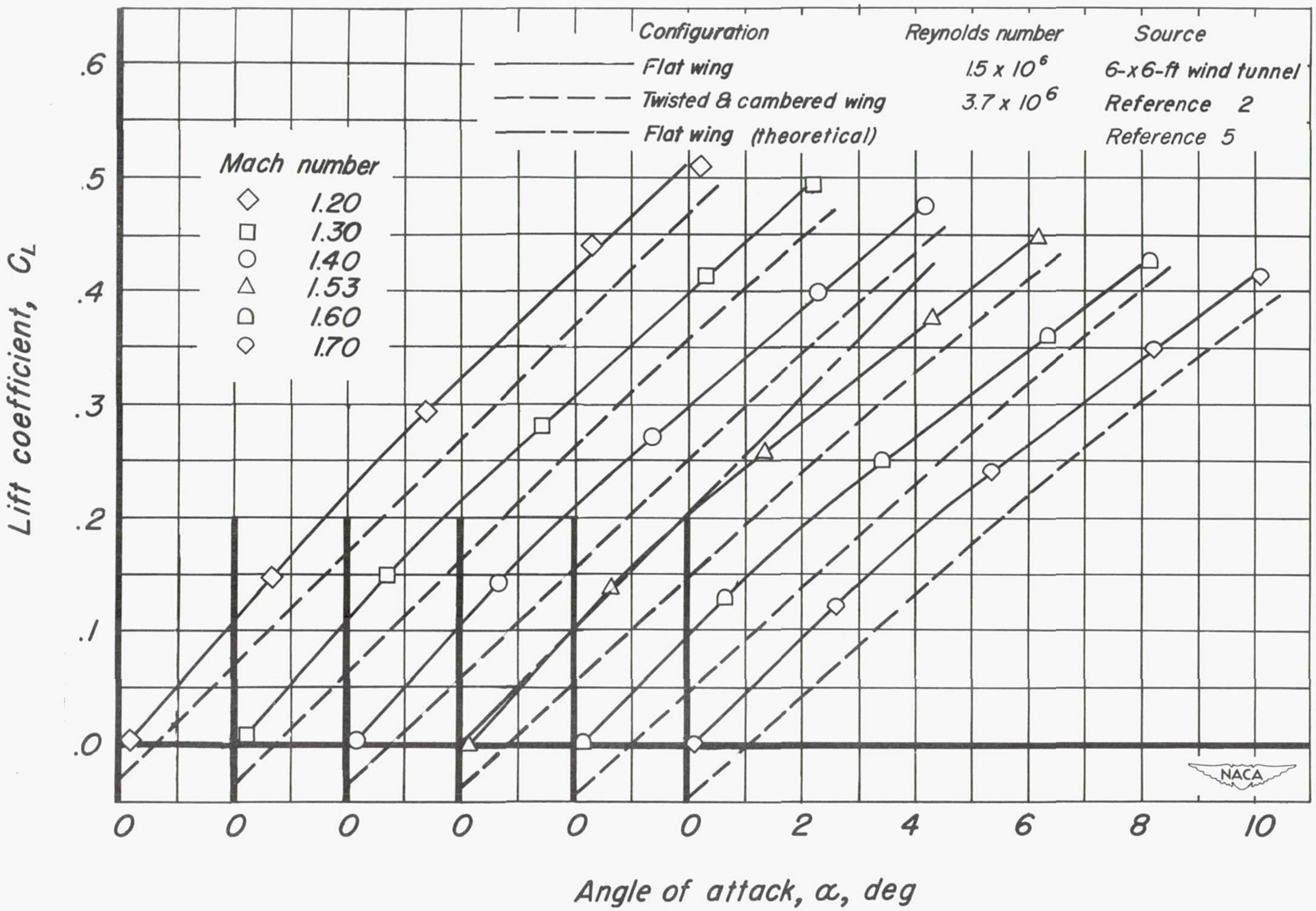
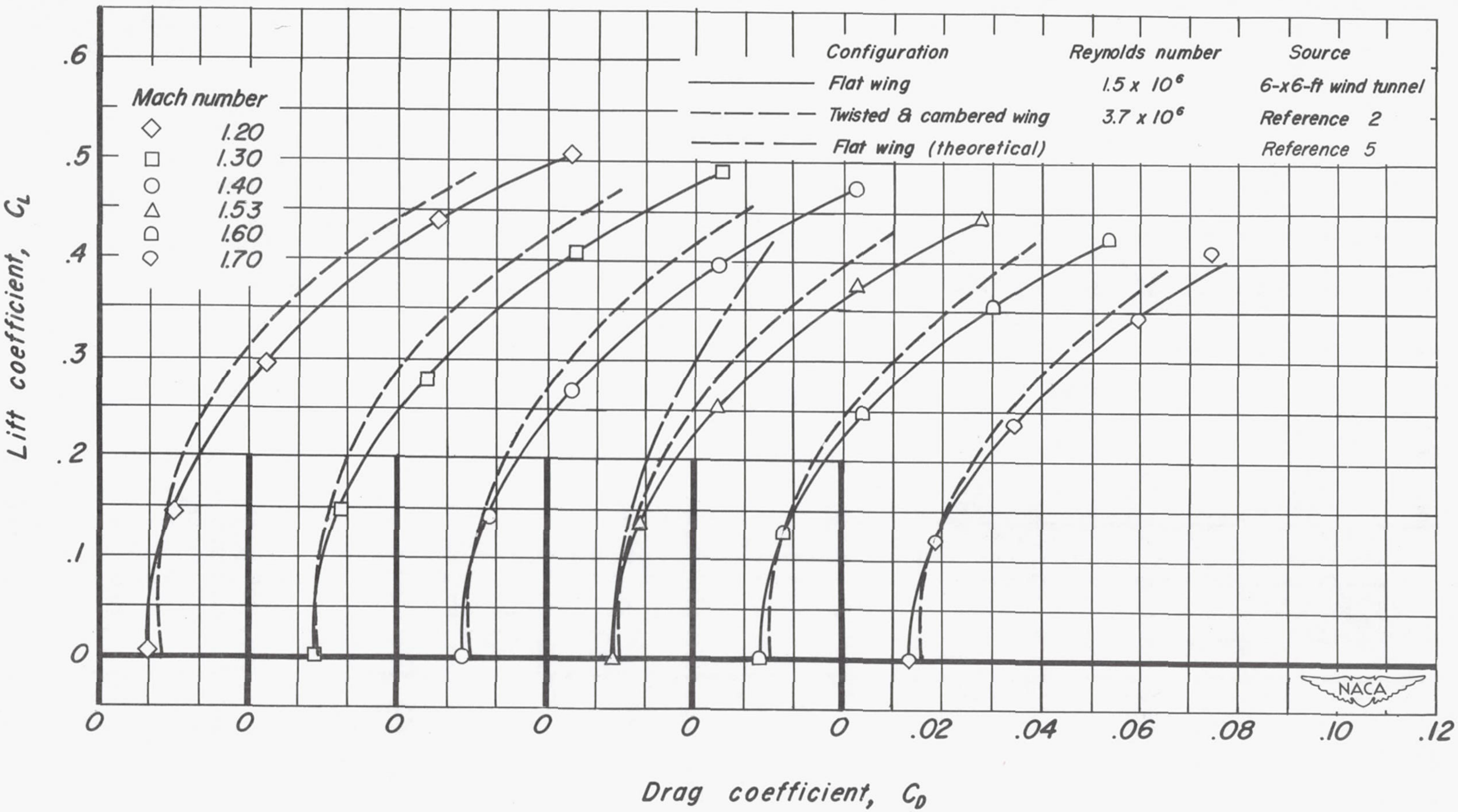


Figure 3.- Sketch of right wing panel showing boundary-layer fence and exploded view of elevon and hinge-moment strain-gage installations.



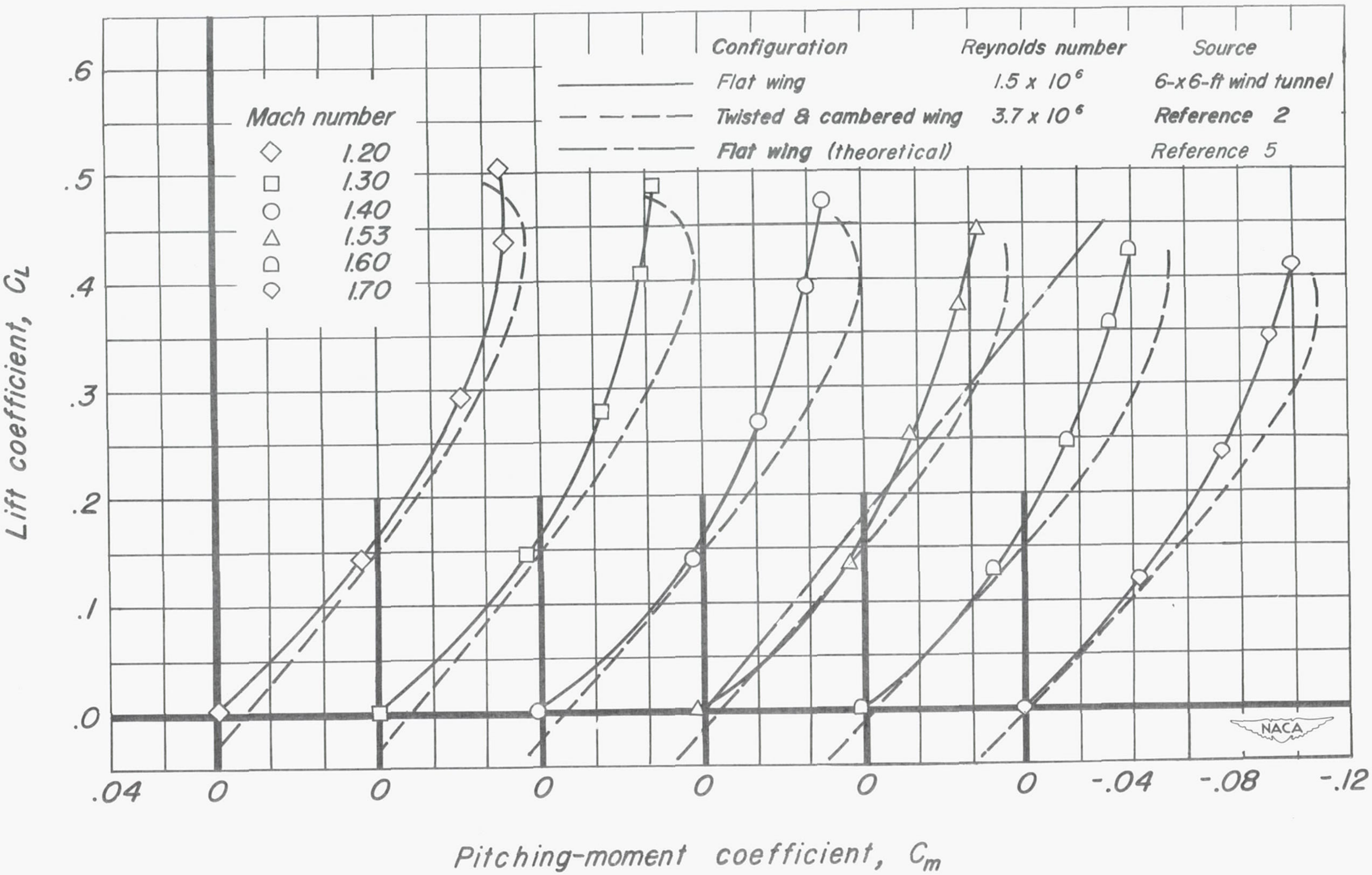
(a) C_L vs α.

Figure 4.— Effect of Mach number on the aerodynamic characteristics of 63° swept-back wing-fuselage combination with elevon undeflected.



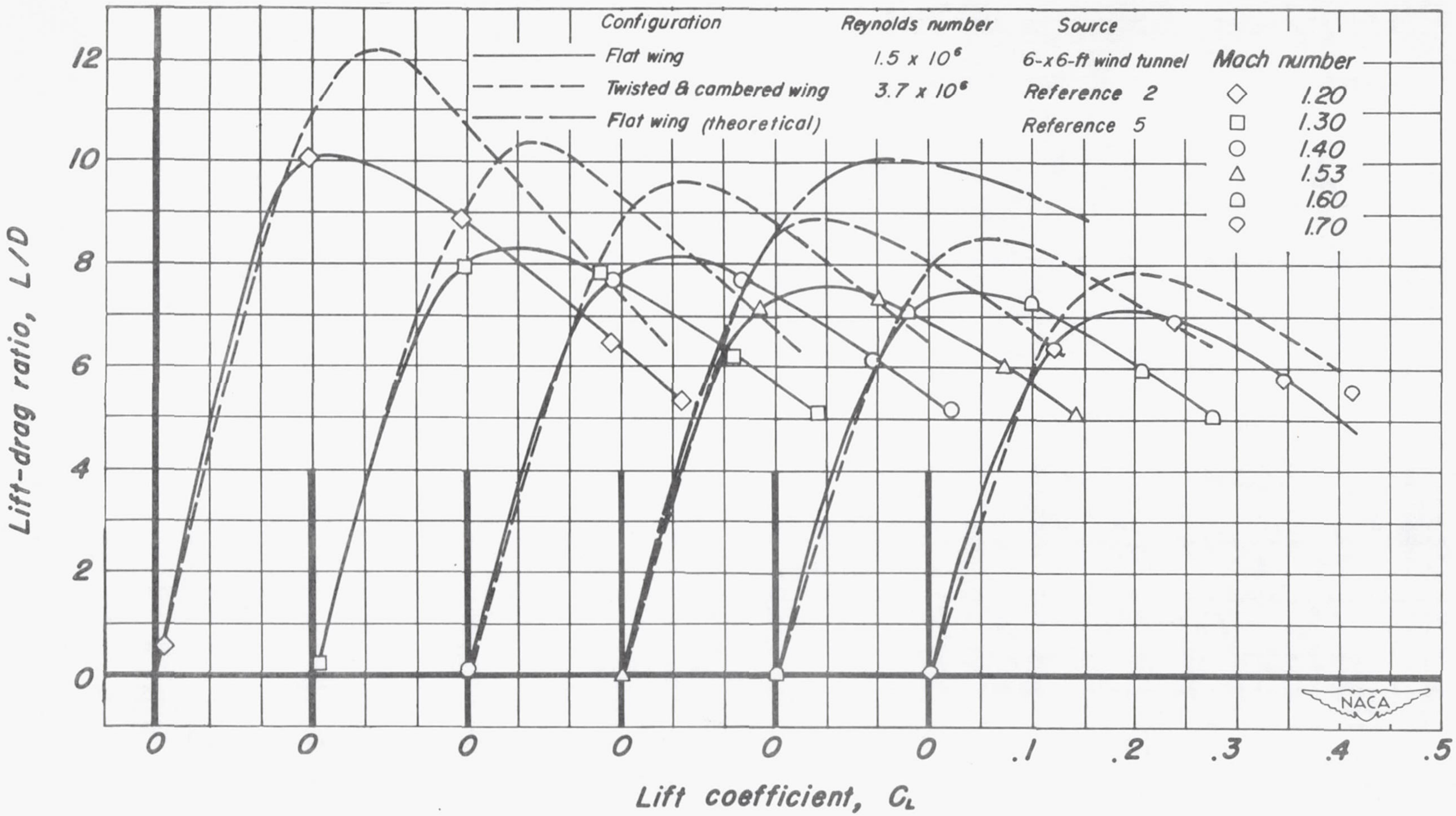
(b) C_D vs C_L.

Figure 4. - Continued.



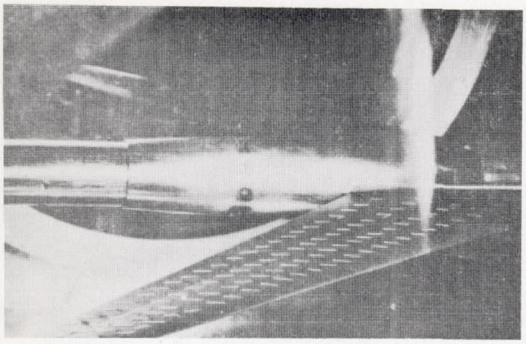
(c) C_m vs C_L.

Figure 4. - Continued.

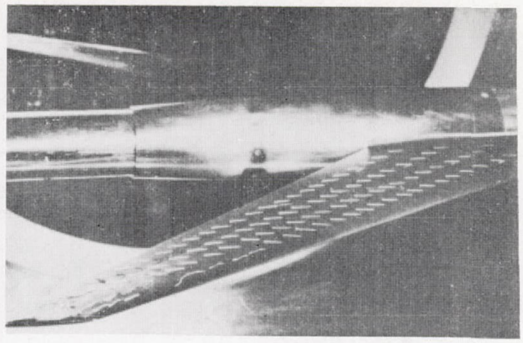


(d) L/D vs C_L.

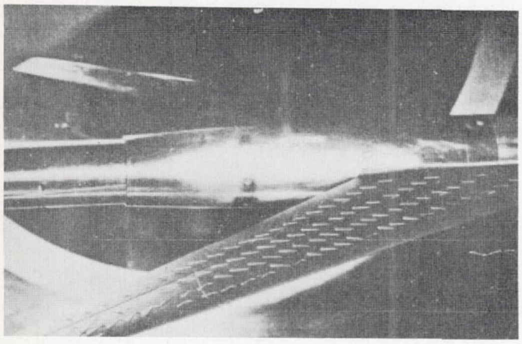
Figure 4. - Concluded.



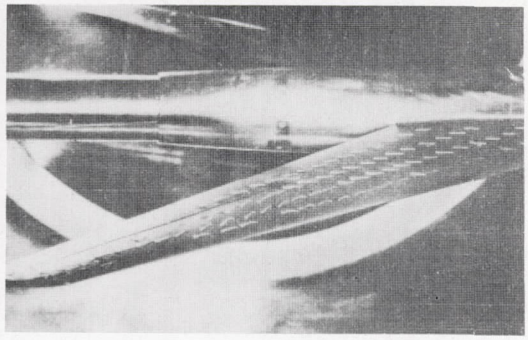
$\alpha = 2^{\circ}$



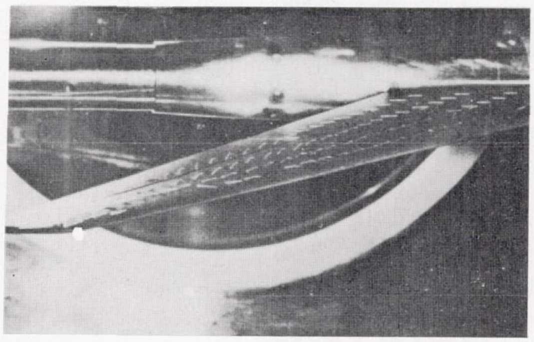
$\alpha = 0^{\circ}$



$\alpha = 4^{\circ}$



$\alpha = 6^{\circ}$



$\alpha = 8^{\circ}$

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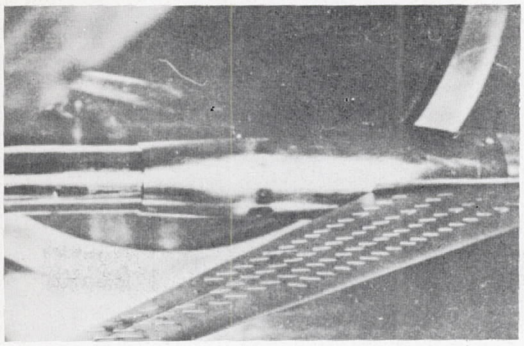
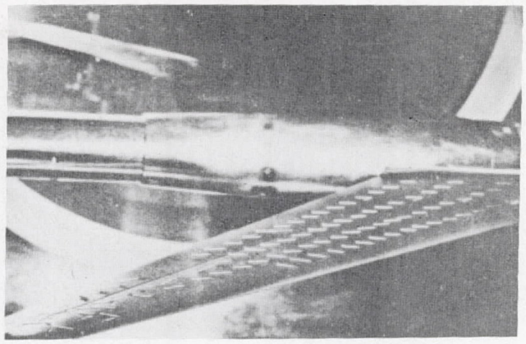
(a) M, 1.20.

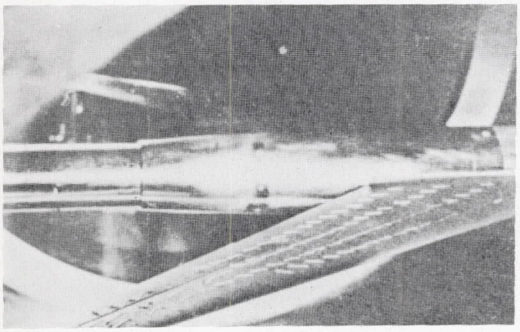
Figure 5.– Wing-flow pattern for various angles of attack of the 63° swept-back wing-fuselage combination.



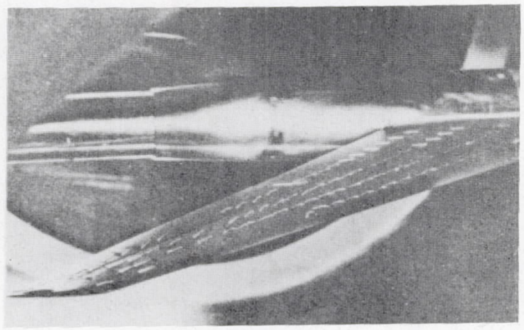
$\alpha = 0^{\circ}$



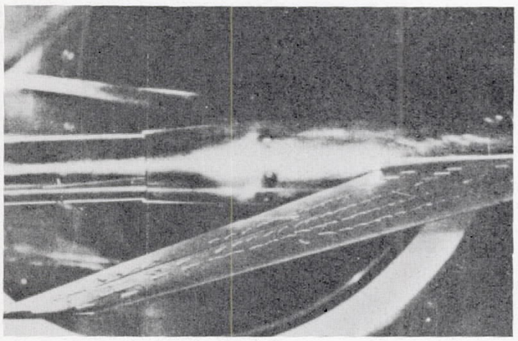
$\alpha = 2^{\circ}$



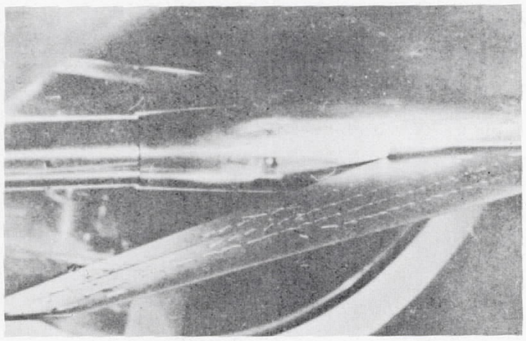
$\alpha = 4^{\circ}$



$\alpha = 6^{\circ}$



$\alpha = 8^{\circ}$

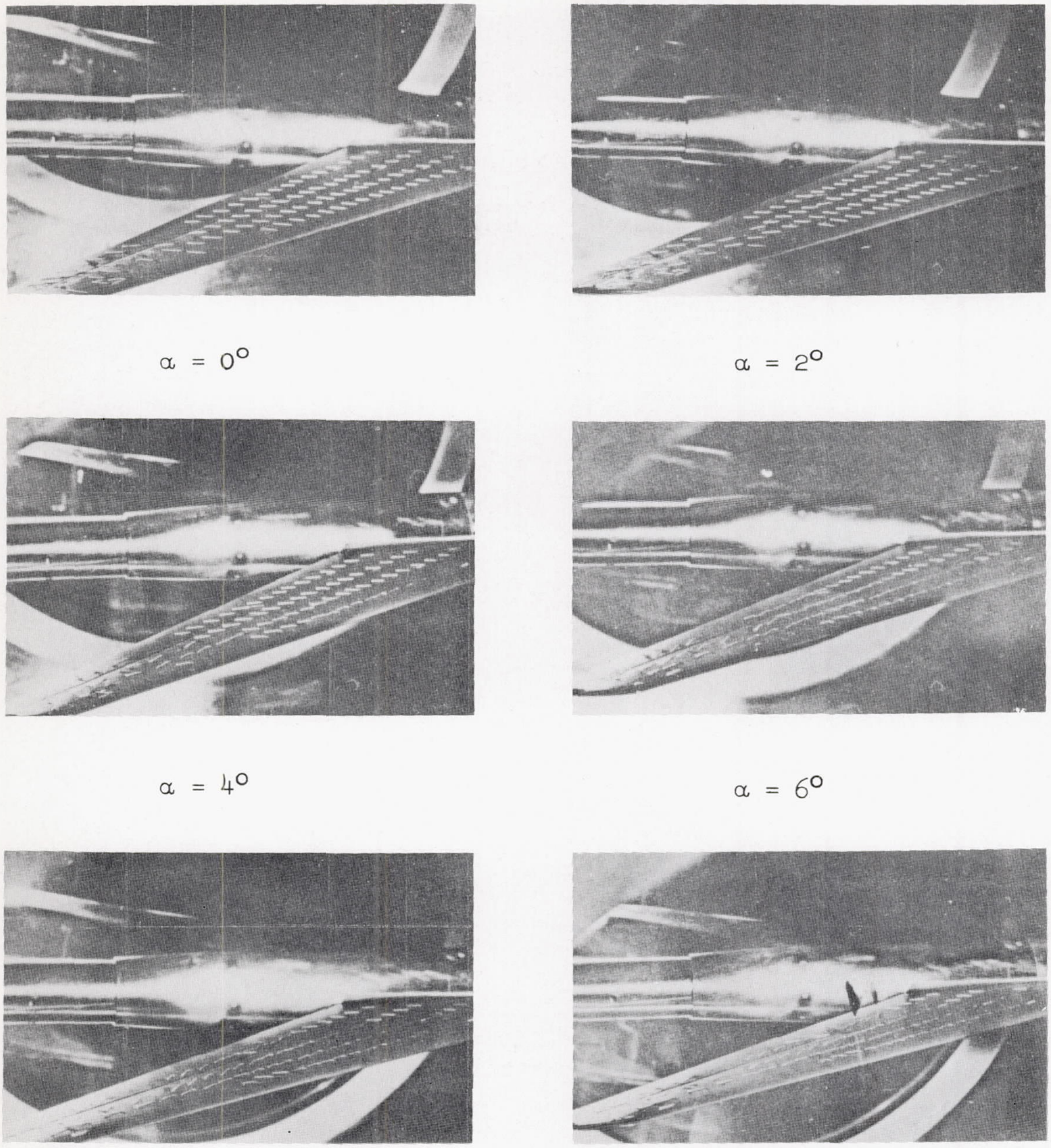


$\alpha = 10^{\circ}$

NACA
A-14466

(b) M, 1.53.

Figure 5.– Continued.



$\alpha = 0^{\circ}$ $\alpha = 2^{\circ}$

$\alpha = 4^{\circ}$ $\alpha = 6^{\circ}$

$\alpha = 8^{\circ}$ $\alpha = 10^{\circ}$

NACA
A-14467

(c) M, 1.70.

Figure 5.- Concluded.

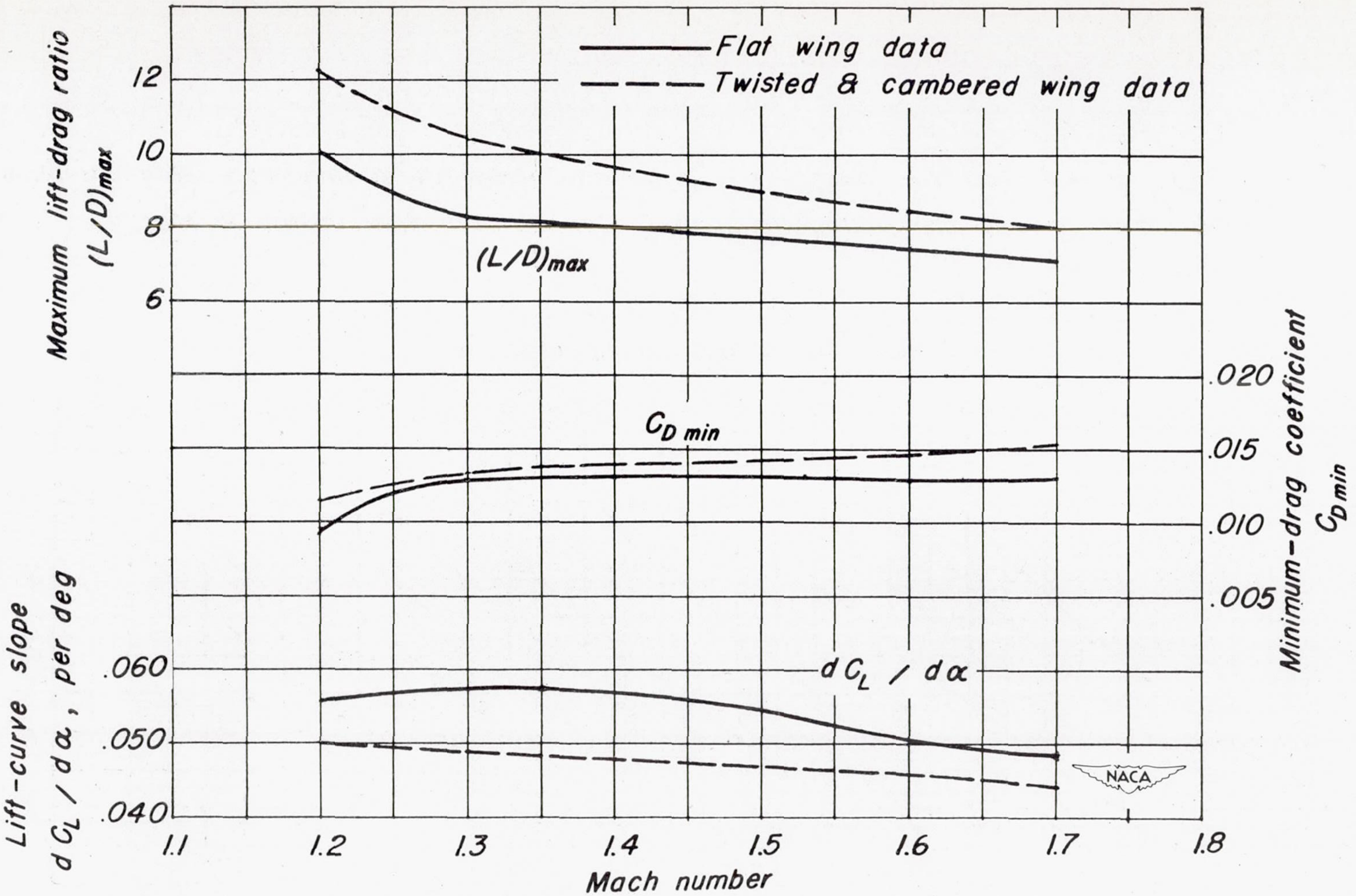
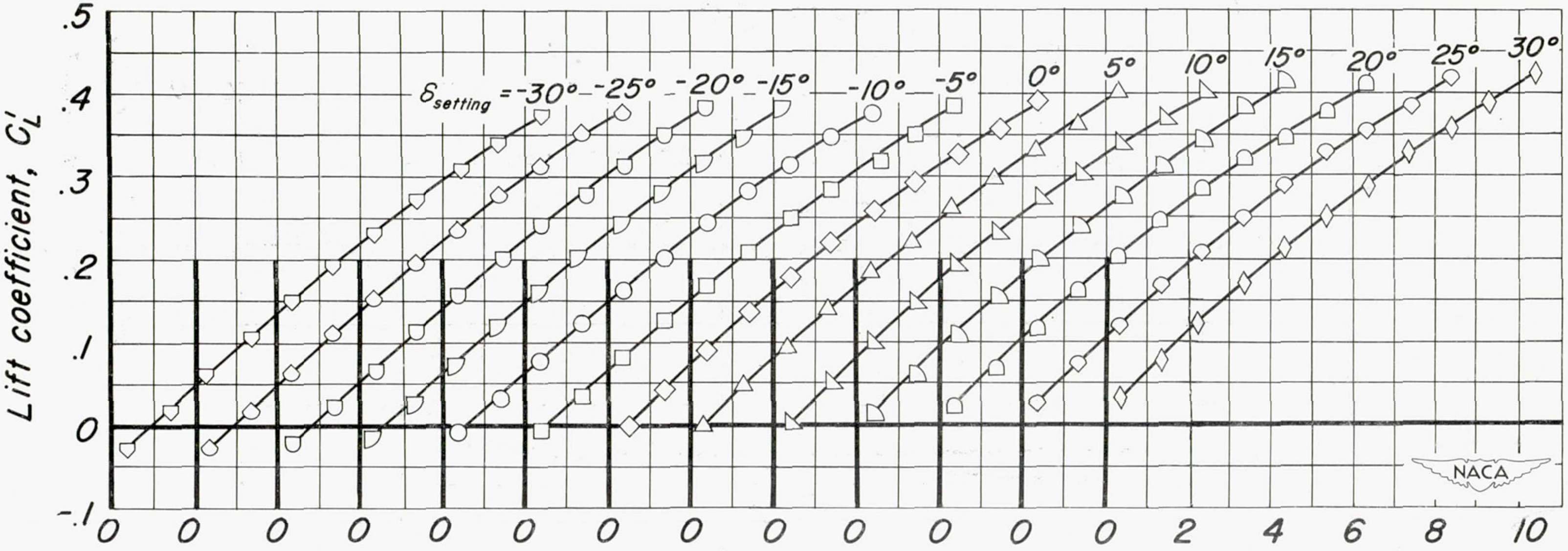


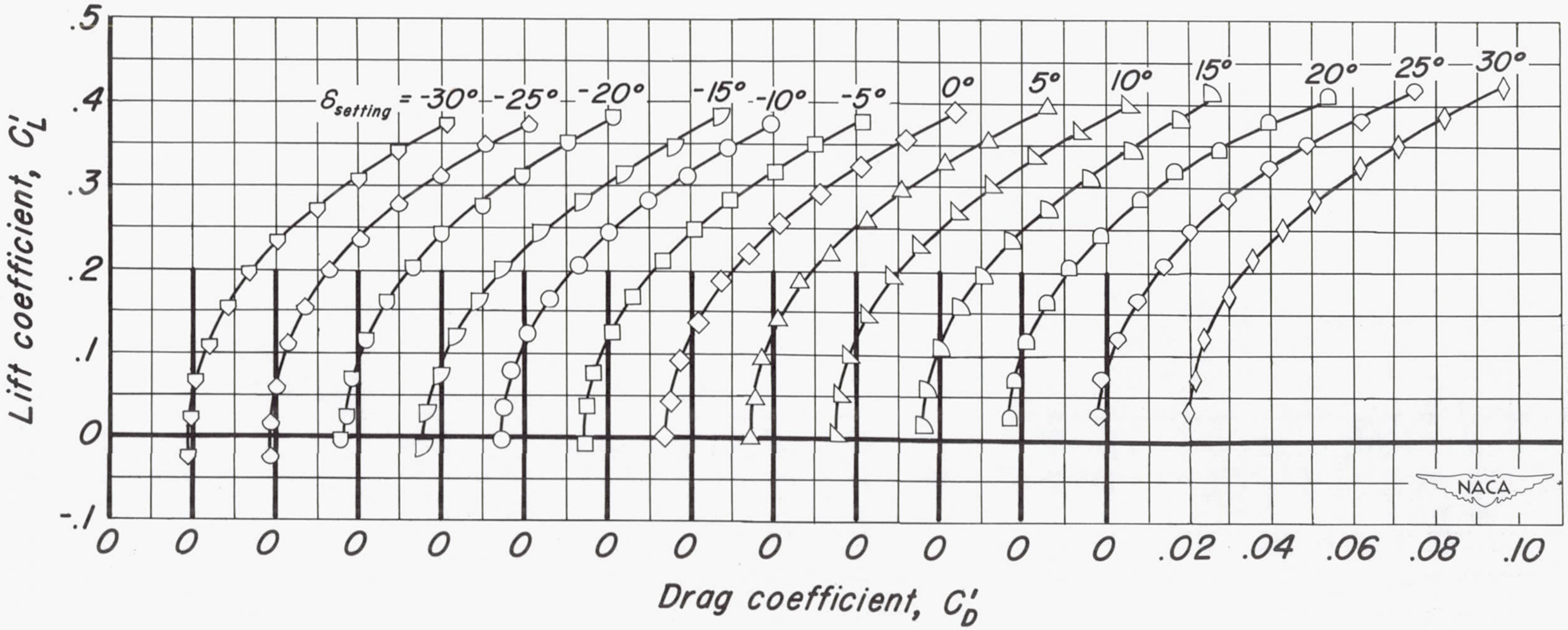
Figure 6.- Variation with Mach number of the maximum lift-drag ratio, the minimum-drag coefficient, and the lift-curve slope for the 63° swept-back wing-fuselage combination.



Angle of attack, α', deg

(a) C_L' vs α'.

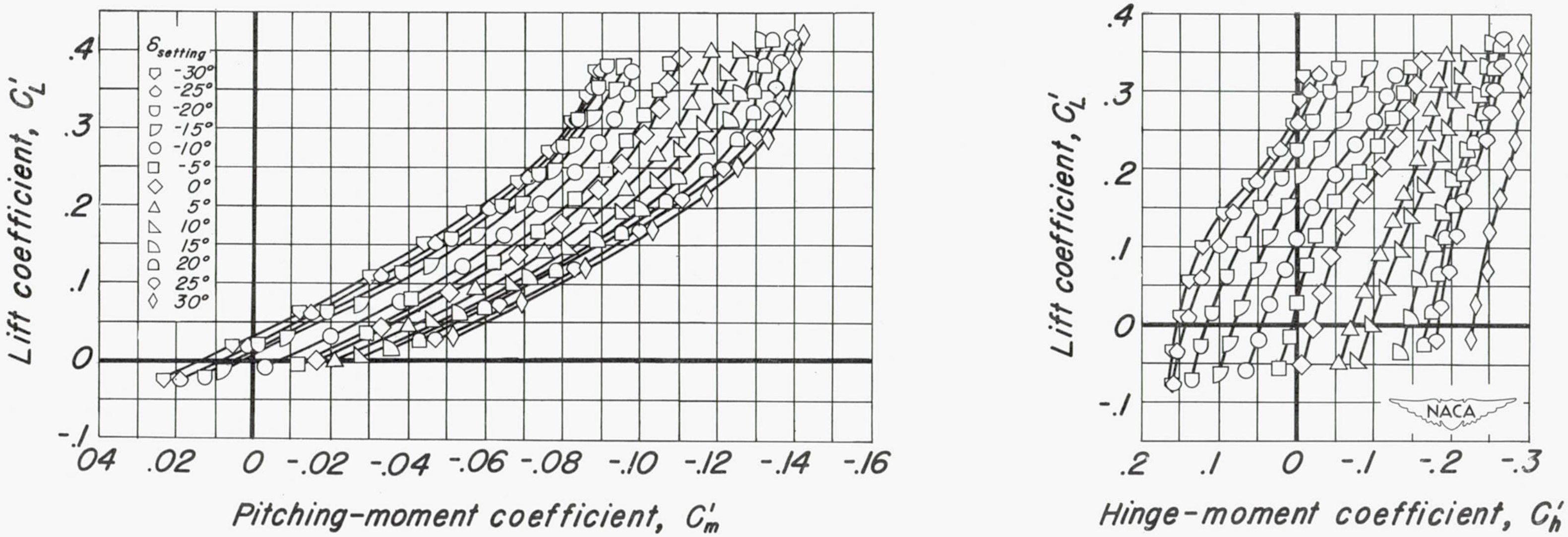
Figure 7.- Effect of elevon deflection on aerodynamic characteristics of 63° swept-back wing-fuselage combination at Mach number of 1.7. Data for one elevon. R, 1.5×10^6.



(b) C_D' vs C_L'.

Figure 7. - Continued.

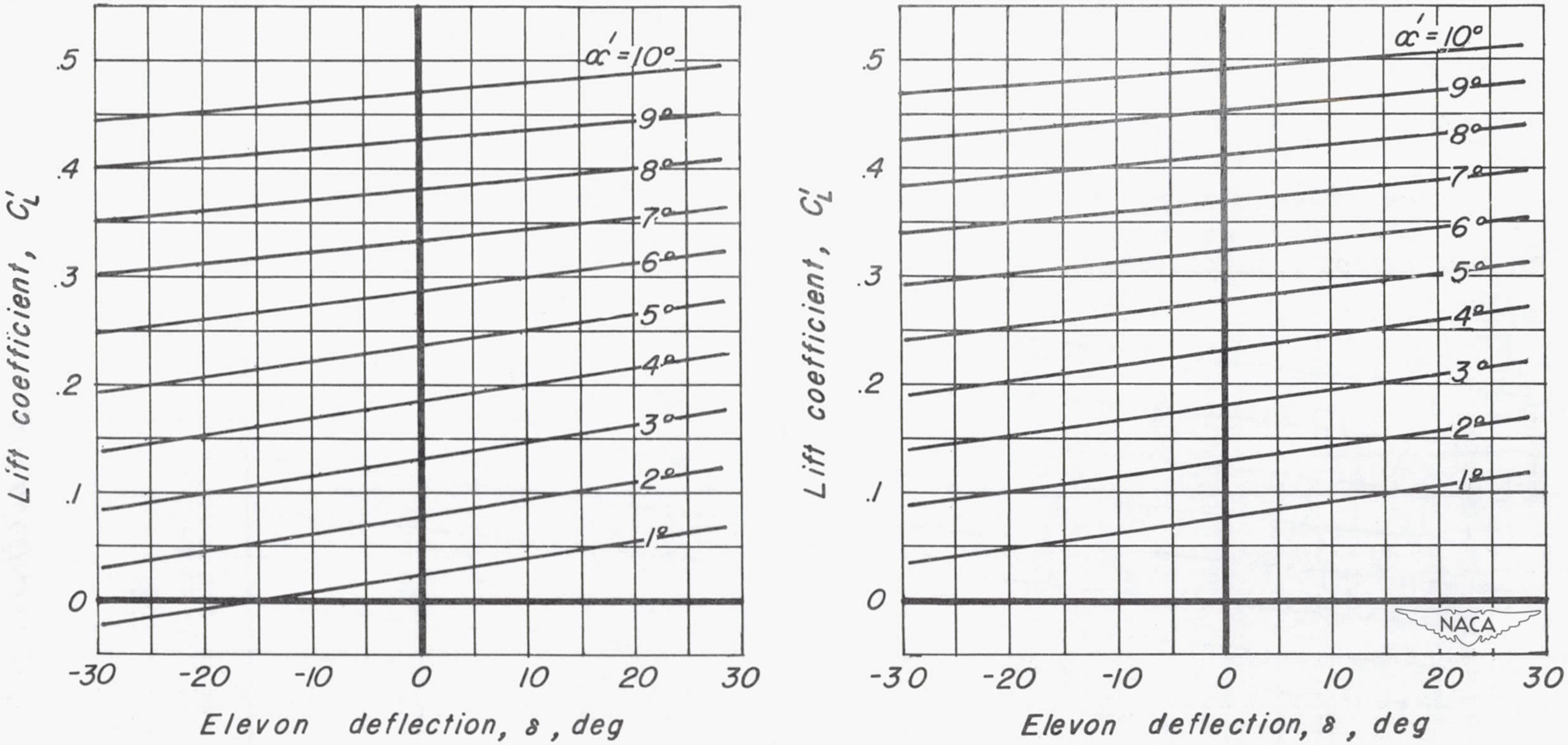
C



(c) C_m' vs C_L'.

(d) C_h' vs C_L'.

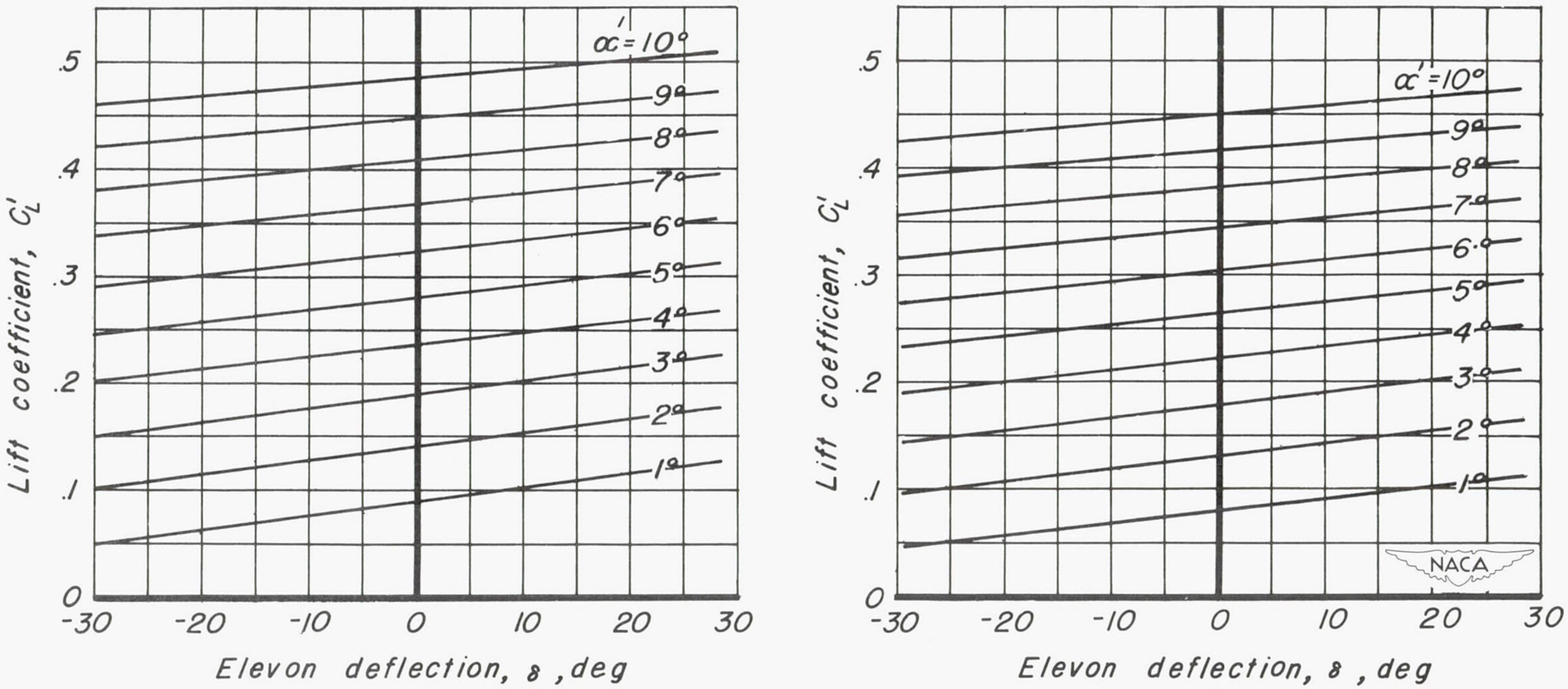
Figure 7.- Concluded.



(a) M, 1.20.

(b) M, 1.30.

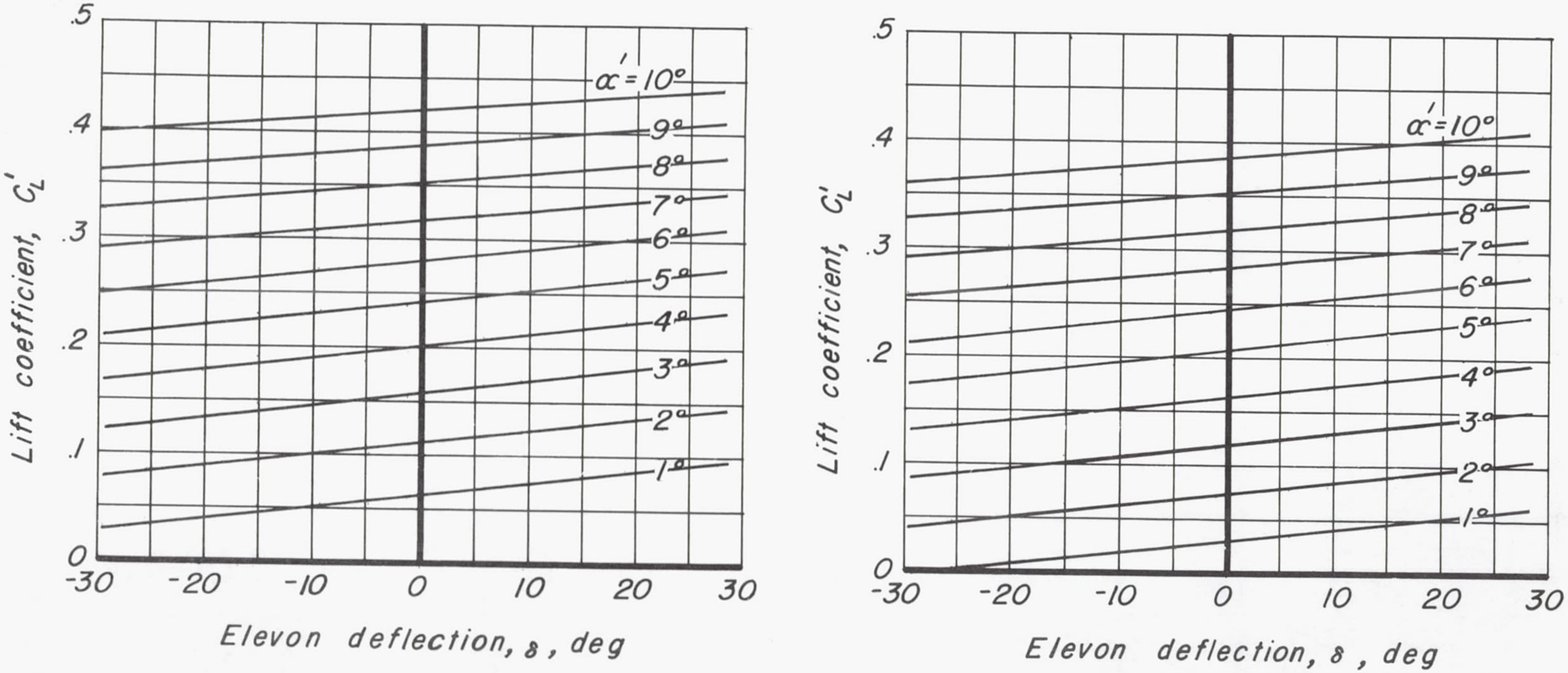
Figure 8. - Variation of lift coefficient with elevon deflection at various Mach numbers for 63° swept-back wing-fuselage combination. Data for one elevon. R, 1.5×10^6.



(c) M, 1.40.

(d) M, 1.53.

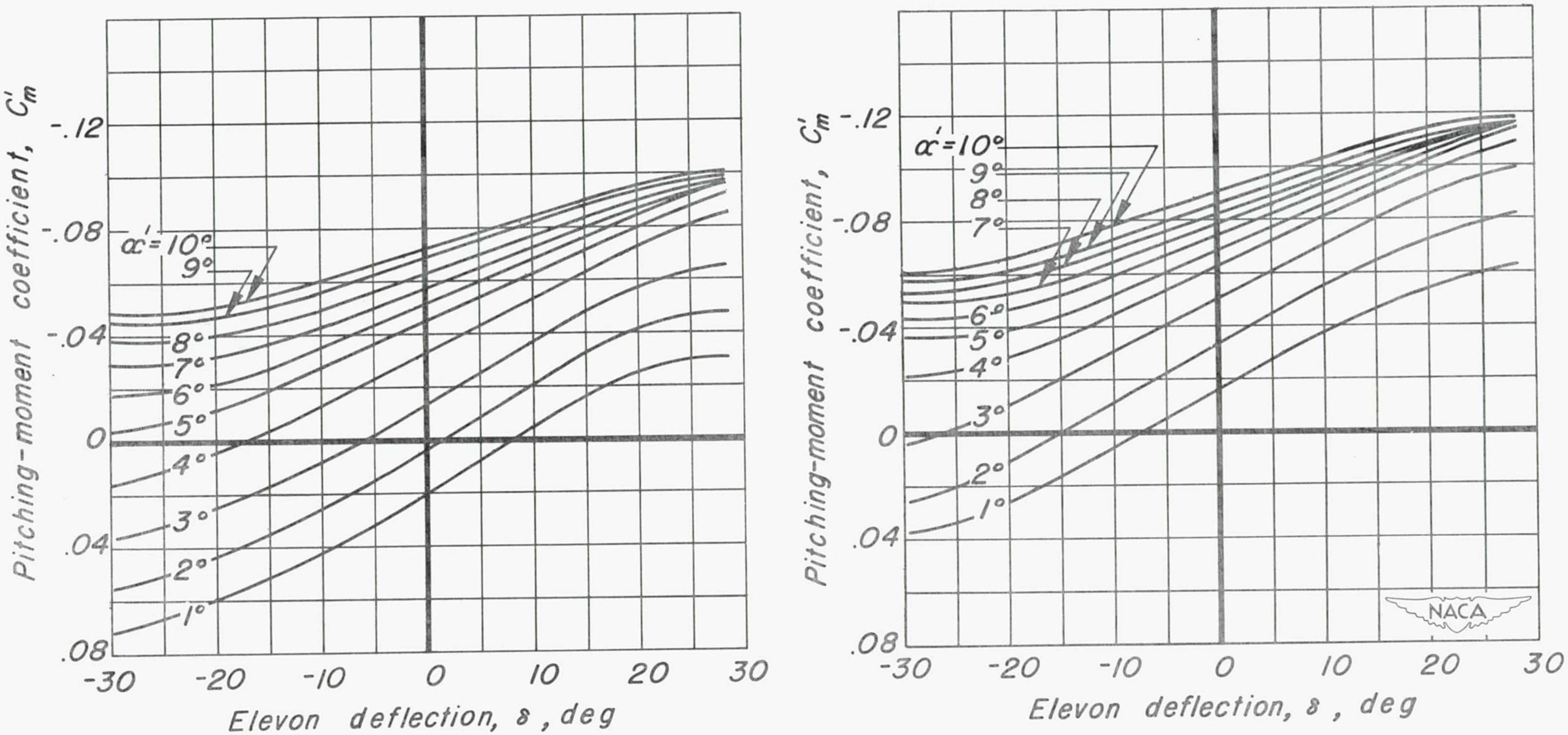
Figure 8.- Continued.



(e) M, 1.60.

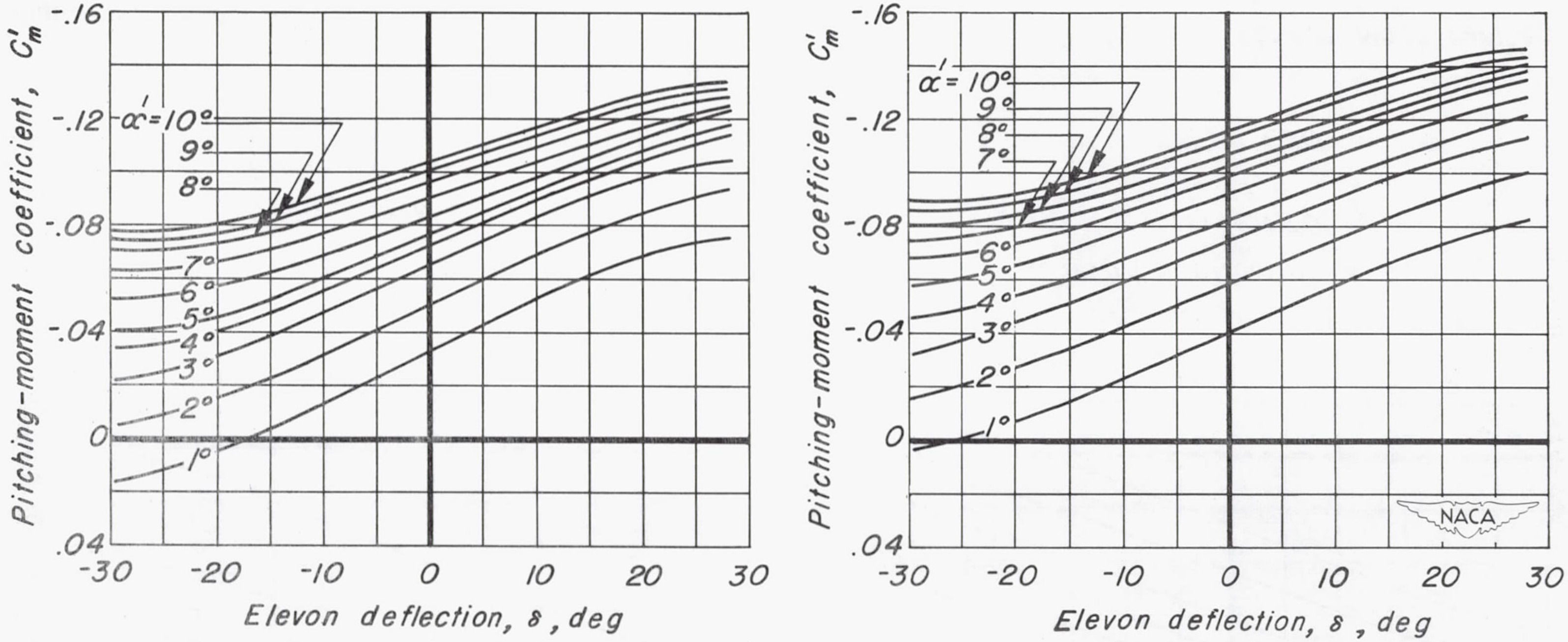
(f) M, 1.70.

Figure 8.-Concluded.



(a) M, 1.20. (b) M, 1.30.

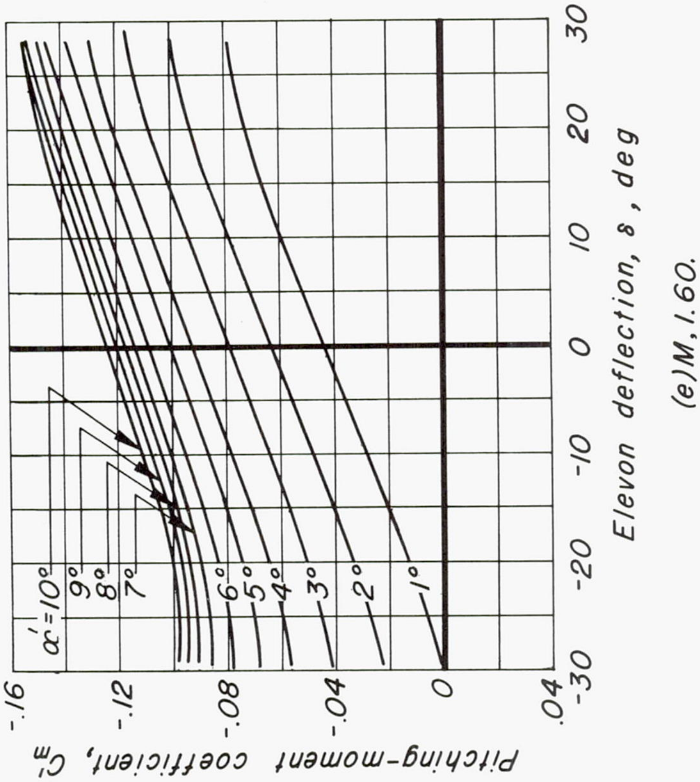
Figure 9.- Variation of pitching-moment coefficient with elevon deflection at various Mach numbers for 63° swept-back wing-fuselage combination. Data for one elevon. R, 1.5×10^6.



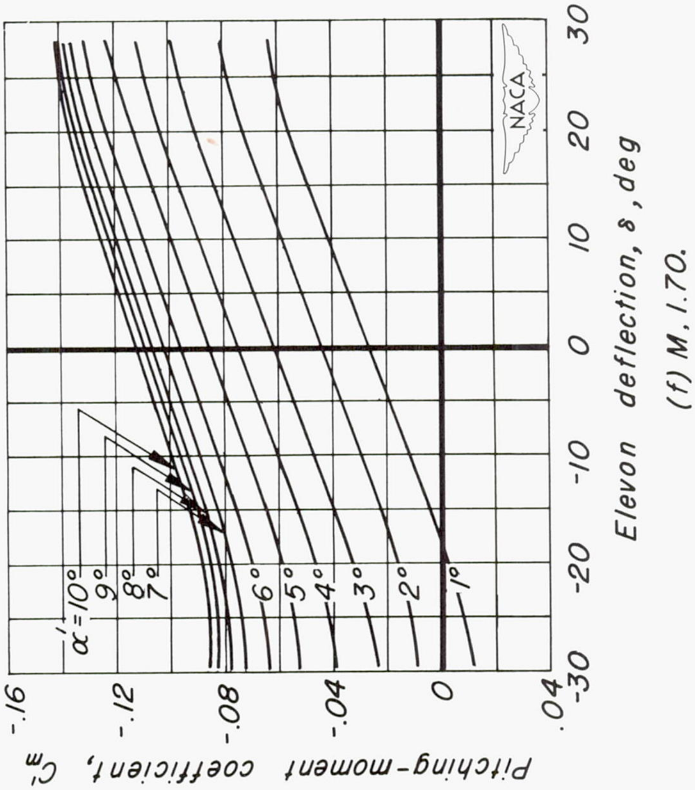
(c) M, 1.40.

(d) M, 1.53.

Figure 9.- Continued.

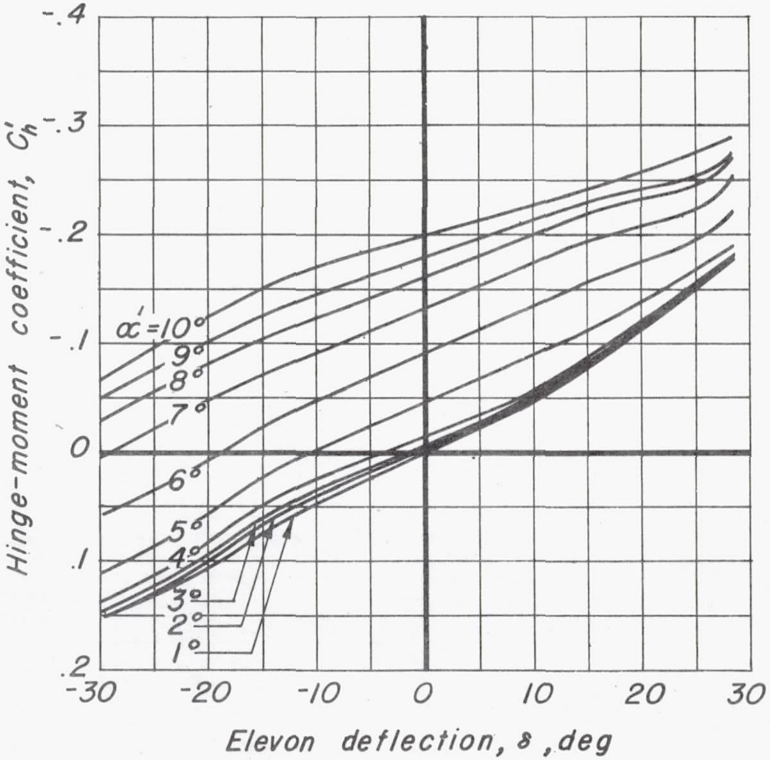


(e) M, 1.60.

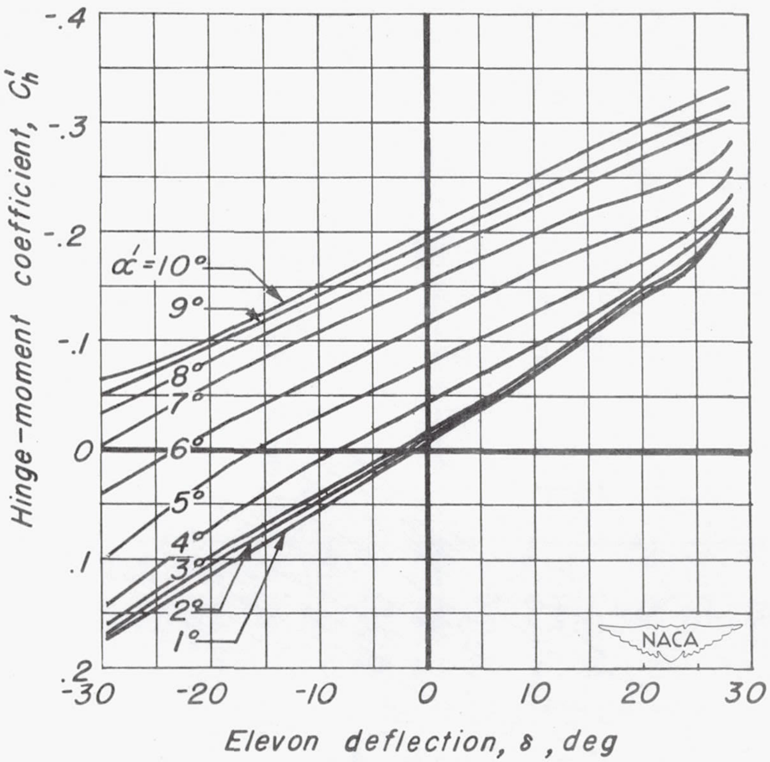


(f) M, 1.70.

Figure 9. - Concluded.

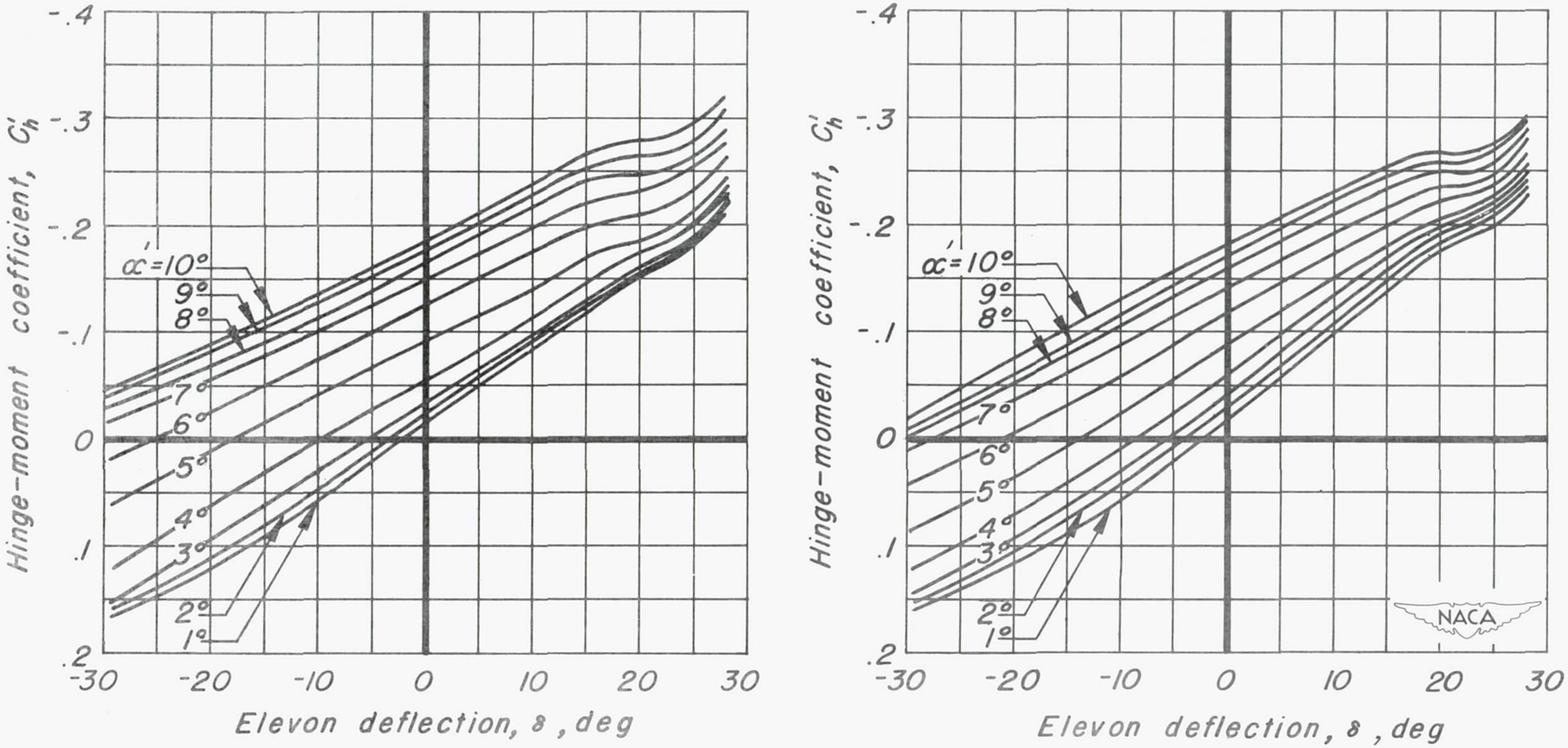


(a) M, 1.20.



(b) M, 1.30.

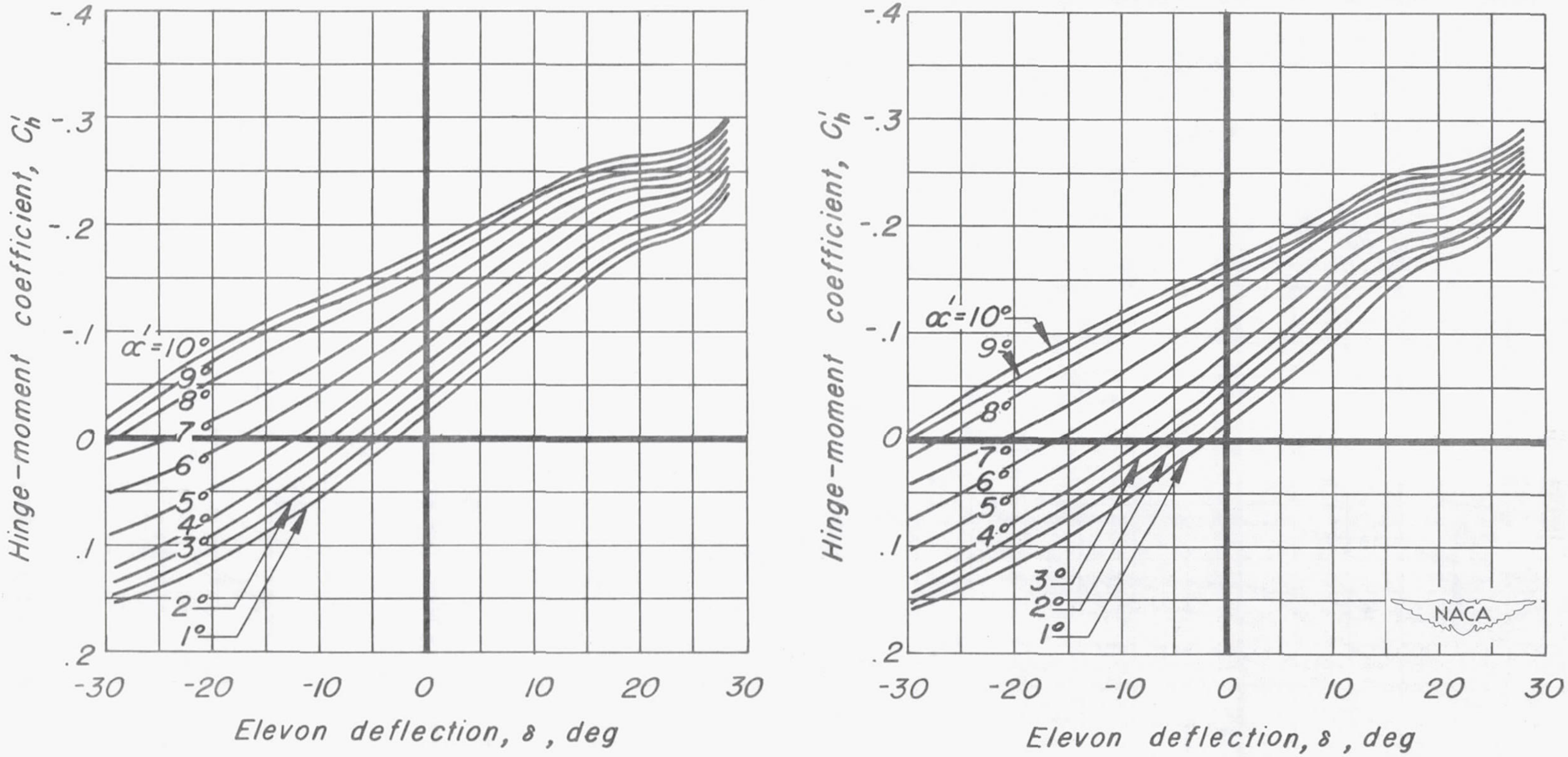
Figure 10.- Variation of hinge-moment coefficient with elevon deflection at various Mach numbers for 63° swept-back wing-fuselage combination. Data for one elevon. R, 1.5×10^6



(c) M, 1.40.

(d) M, 1.53.

Figure .10. - Continued.



(e) M, 1.60.

(f) M, 1.70.

Figure 10.- Concluded.

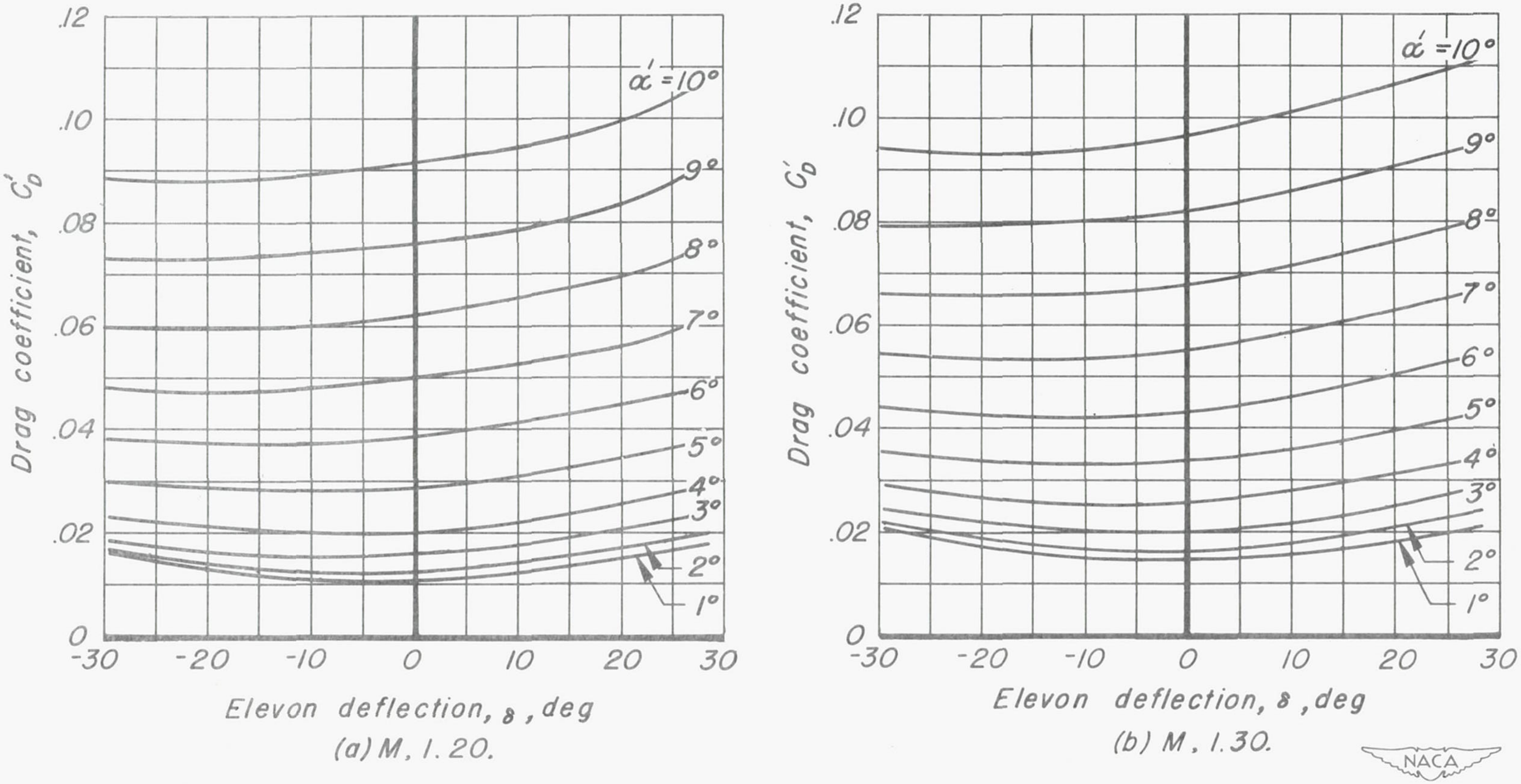
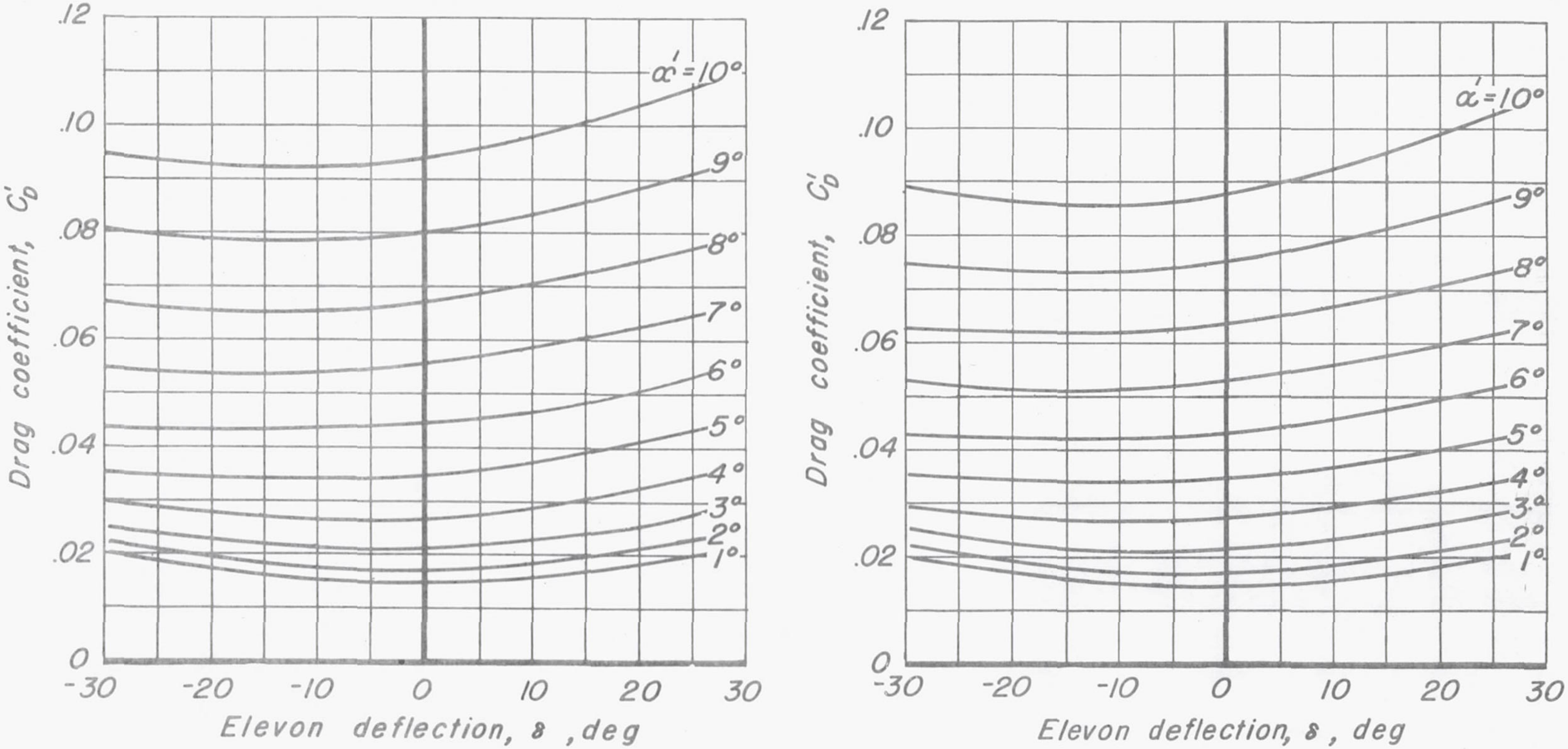


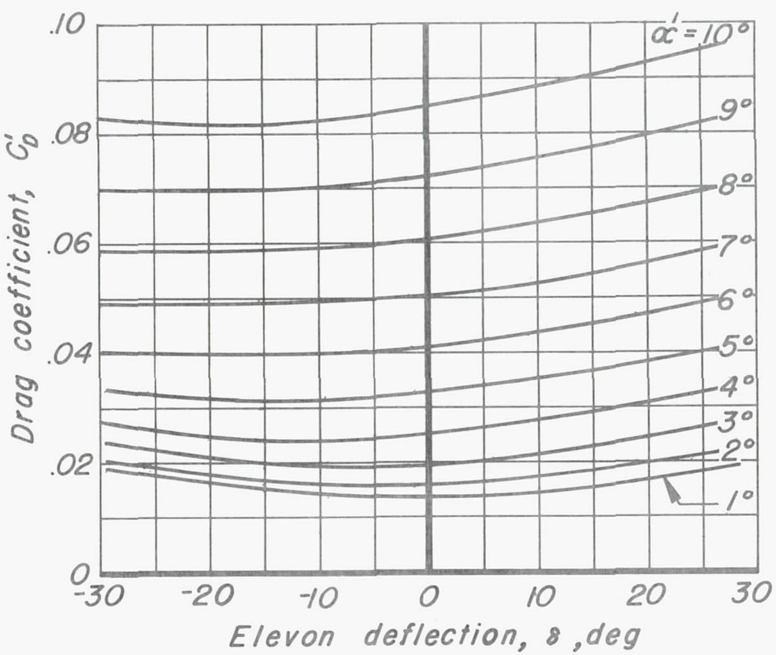
Figure 11.- Variation of drag coefficient with elevon deflection at various Mach numbers for the 63° swept-back wing-fuselage combination. Data for one elevon. R, 1.5 x 10⁶.



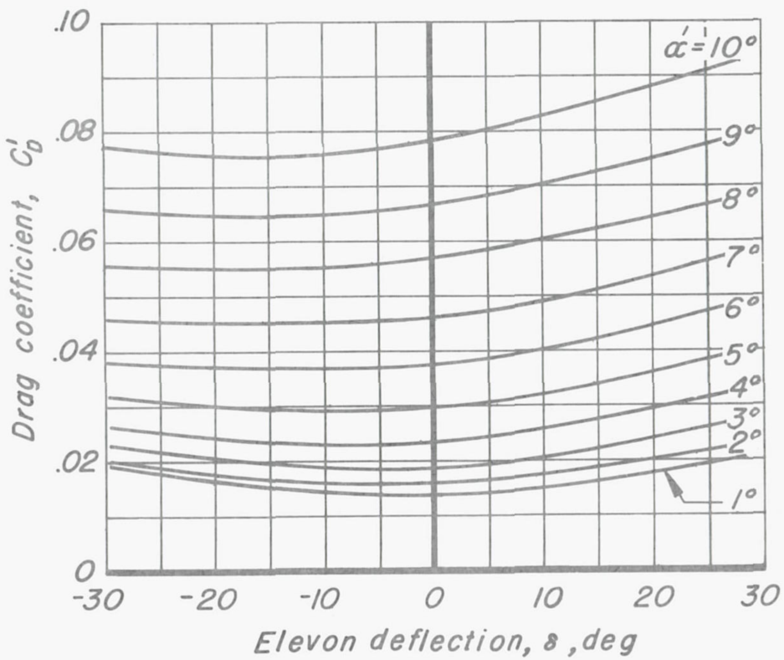
(c) M, 1.40.

(d) M, 1.53.

Figure 11.- Continued.

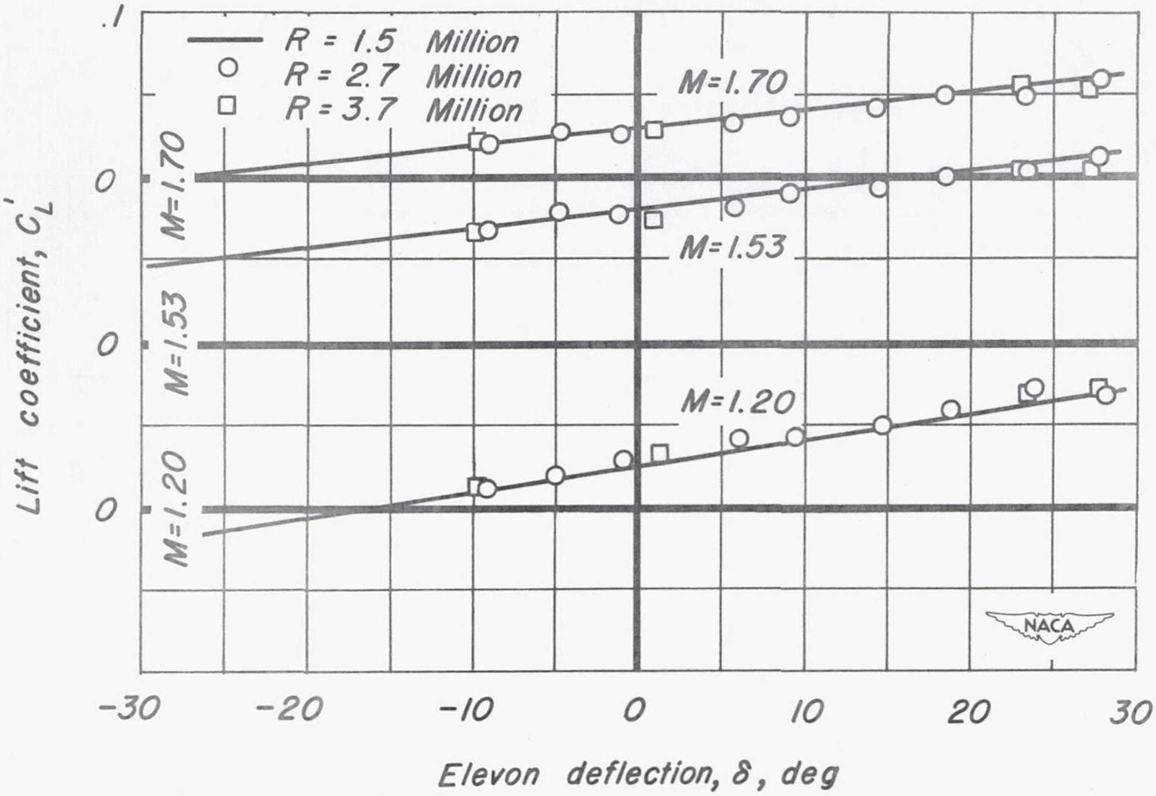


(e) M, 1.60.



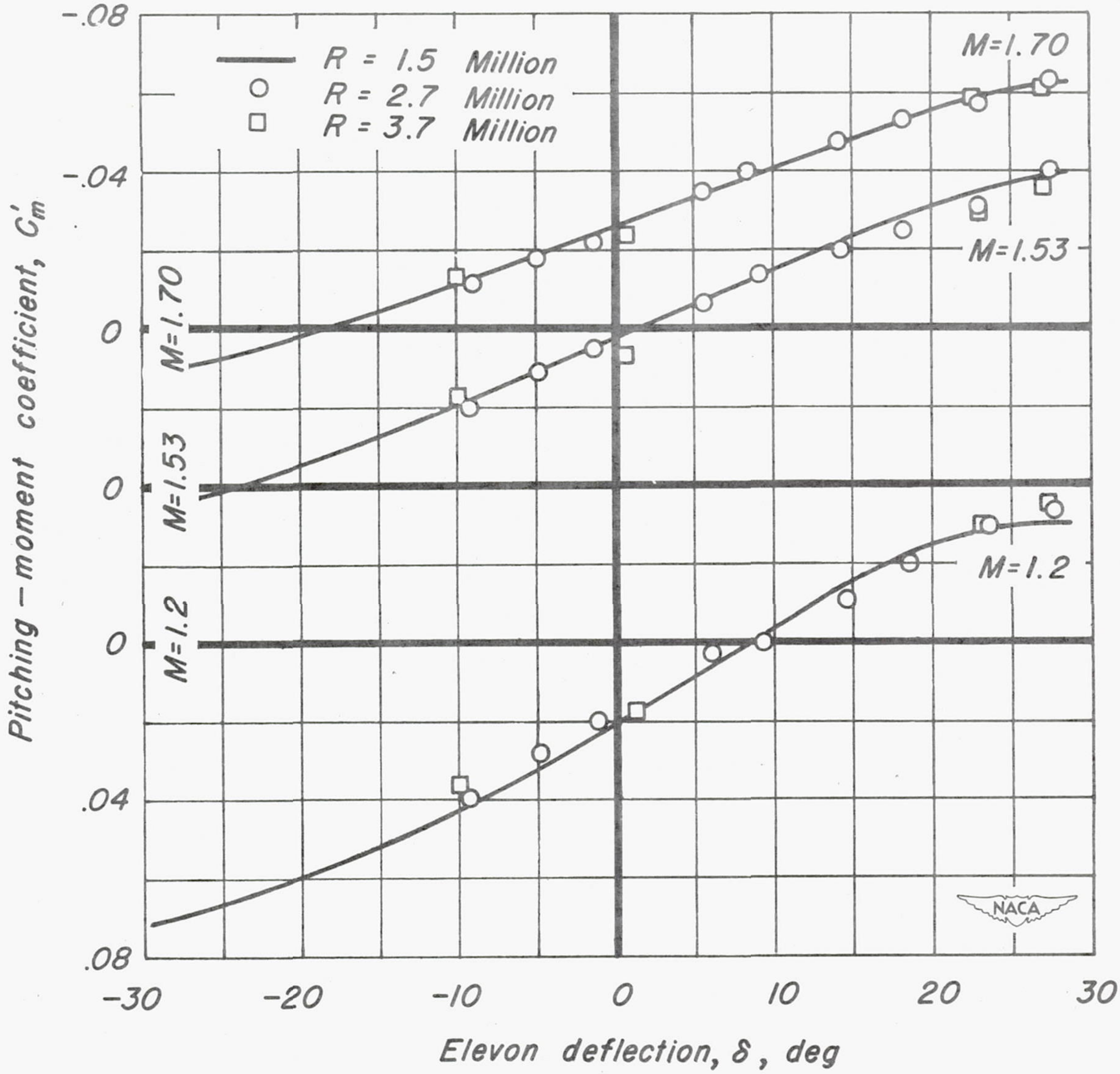
(f) M, 1.70.

Figure 11.– Concluded.



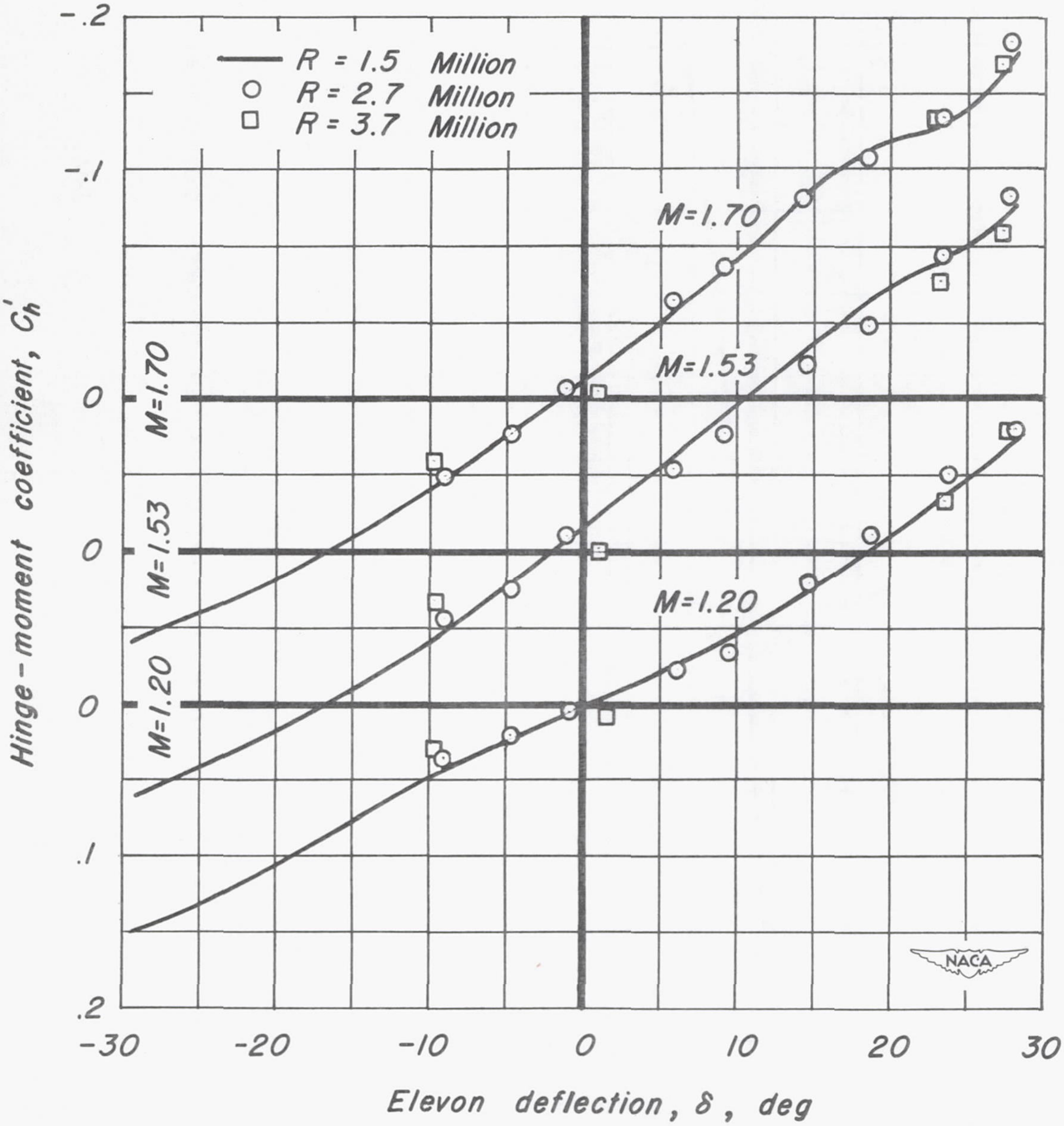
(a) C_L' vs δ.

Figure 12.— Effect of Reynolds number on elevon-effectiveness parameters. Data for one elevon. α, 1°.



(b) C_m' vs δ.

Figure 12.- Continued.



(c) C_h' vs δ.

Figure 12.- Concluded.

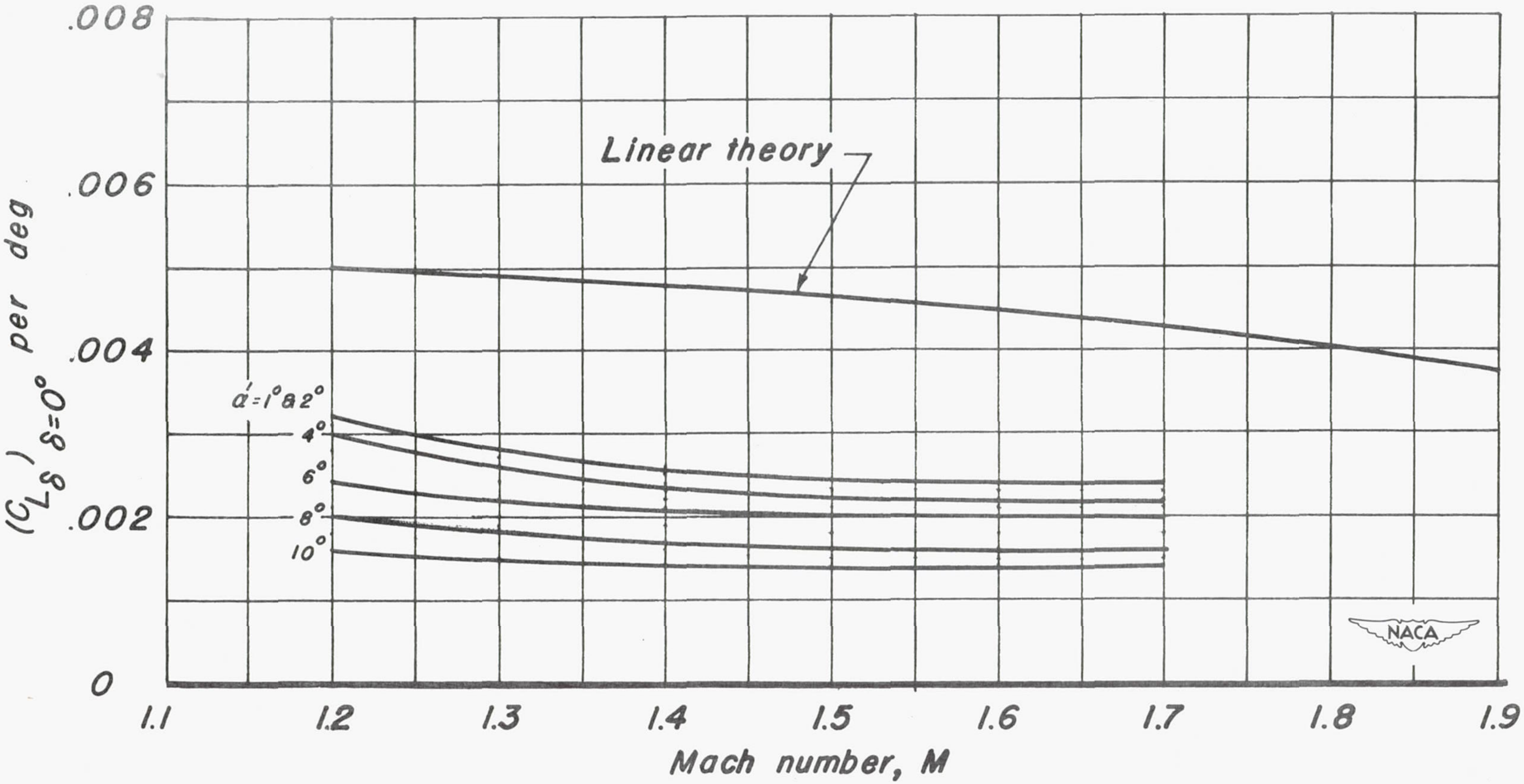


Figure 13.- Variation with Mach number of the lift-effectiveness parameter, C_{L_δ}, for the constant-percent-chord control surface on a 63° swept-back wing-fuselage combination. Data for two elevons. R, 1.5×10^6.

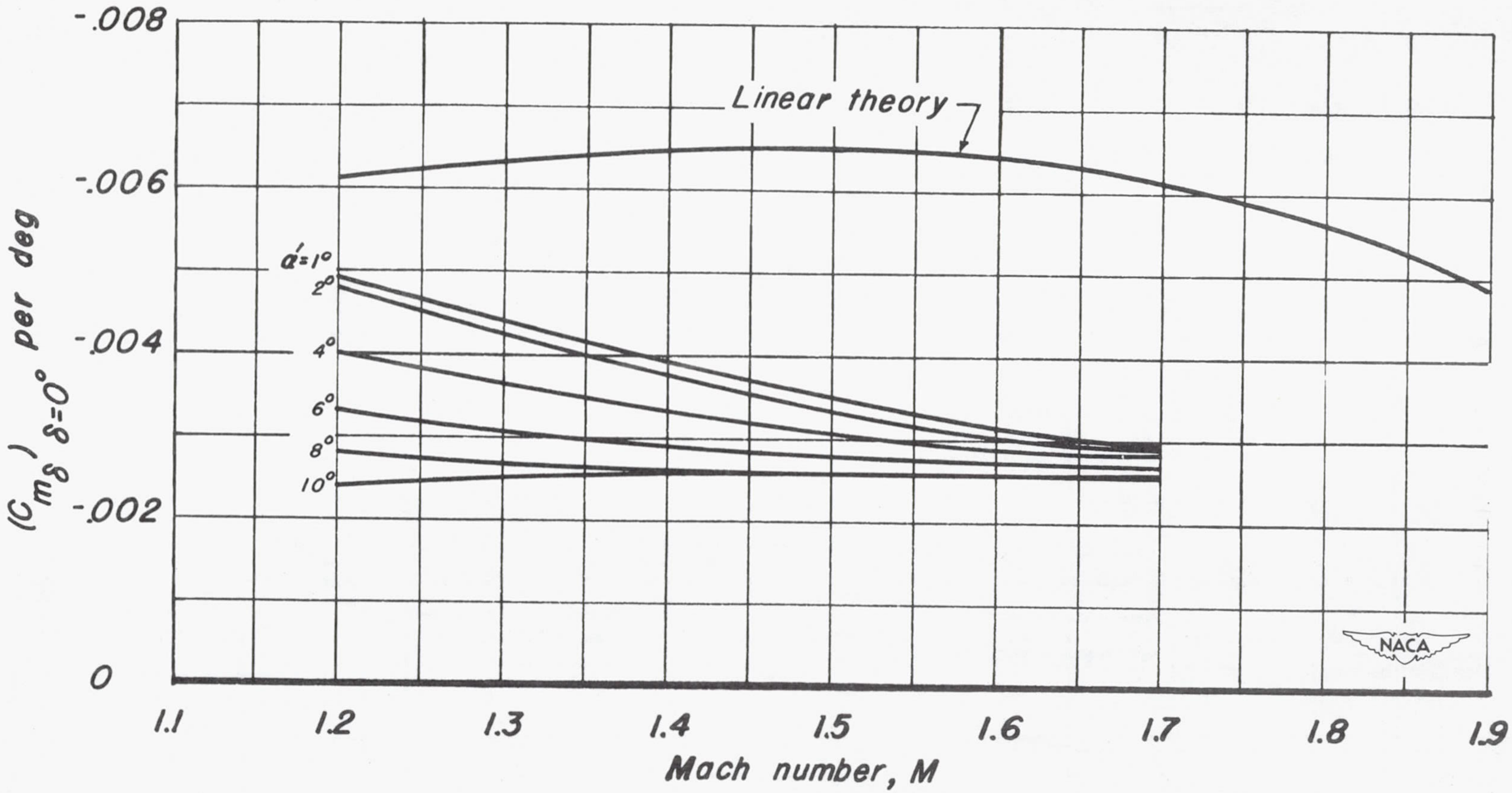


Figure 14.– Variation with Mach number of the pitch-effectiveness parameter, C_{m_δ}, for the constant-percent-chord control surface on a 63° swept-back wing-fuselage combination. Data for two elevons. R, 1.5 x 10^6.

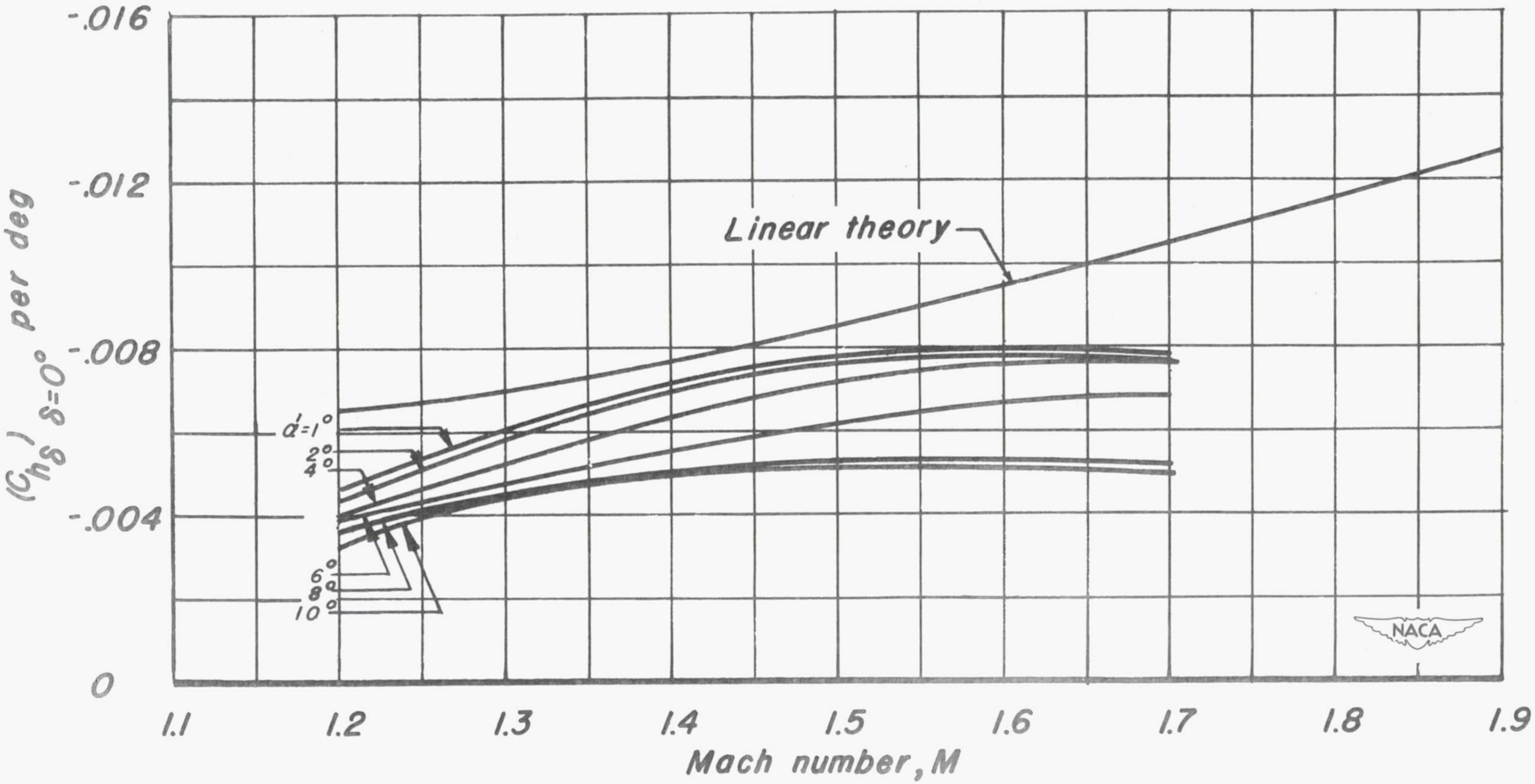


Figure 15.- Variation with Mach number of the rate of change of hinge-moment coefficient with change in elevon deflection on a 63° swept-back wing-fuselage combination. Data for two elevons. R, 1.5×10^6.

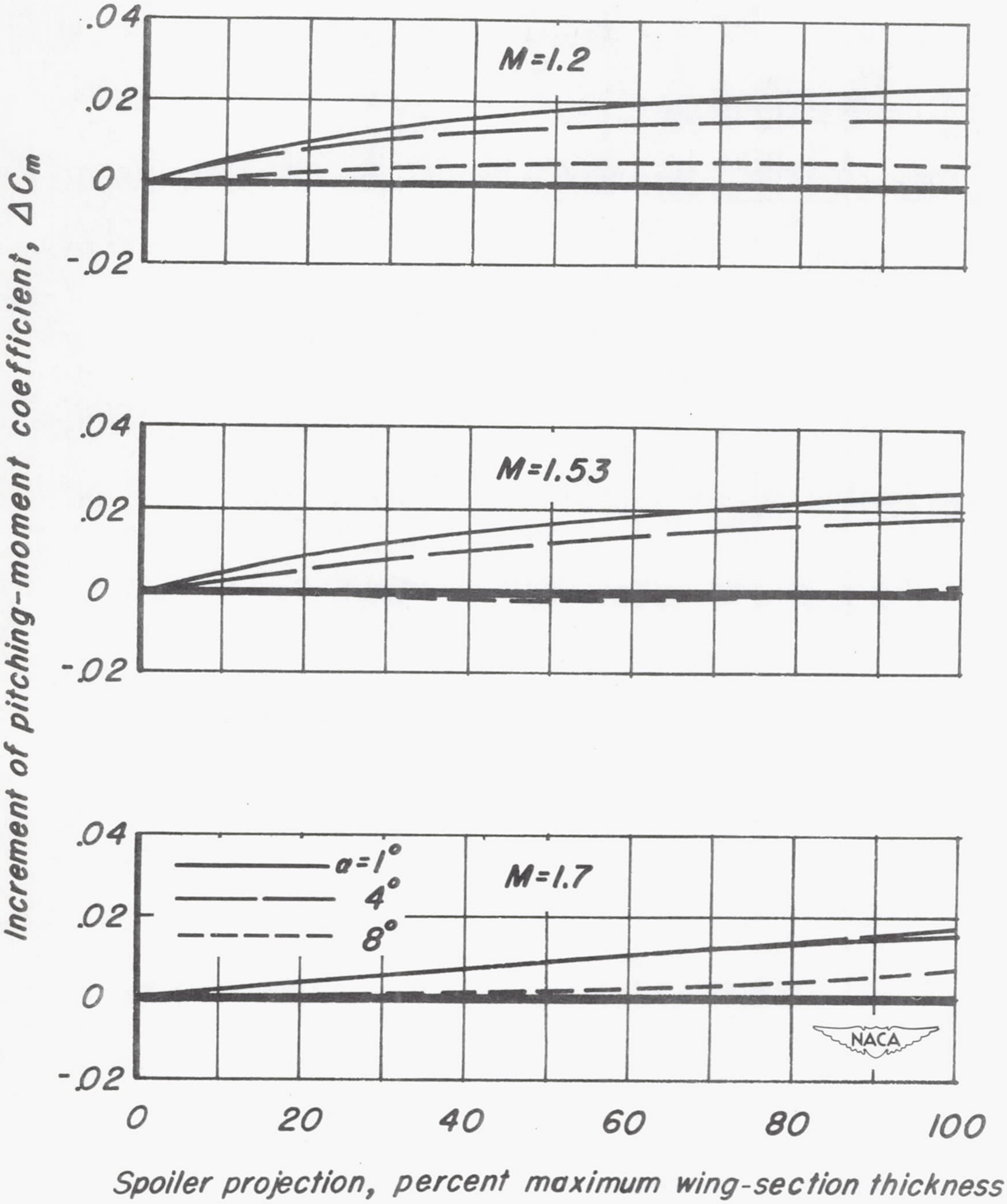


Figure 16.- Effect of upper-surface spoilers on pitching-moment coefficient for various angles of attack and Mach numbers. Spoiler on one wing only. R, 1.5 x 10^6.