NACA

RESEARCH MEMORANDUM

AERODYNAMIC STUDY OF A WING-FUSELAGE COMBINATION EMPLOYING A WING SWEPT BACK 63° - EFFECTIVENESS AT SUPERSONIC SPEEDS OF A 30-PERCENT CHORD, 50-PERCENT SEMISPAN ELEVON AS A LATERAL CONTROL DEVICE

By Robert N. Olson and Merrill H. Mead

Ames Aeronautical Laboratory
Moffett Field, Calif.

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

WASHINGTON

January 18, 1951
Declassified April 8, 1957

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

RESEARCH MEMORANDUM

AERODYNAMIC STUDY OF A WING-FUSELAGE COMBINATION EMPLOYING A WING SWEPT BACK 63° - EFFECTIVENESS AT SUPERSONIC SPEEDS OF A 30-PERCENT CHORD, 50-PERCENT SEMISPAN ELEVON AS A LATERAL CONTROL DEVICE

By Robert N. Olson and Merrill H. Mead

SUMMARY

The effectiveness of a 50-percent-semispan, constant-percent-chord elevon and of upper-surface spoilers as lateral-control devices for a wing-fuselage combination employing a wing swept back 63° has been determined experimentally for the range of Mach numbers from 1.2 to 1.7 at a Reynolds number of 1.5 million. The results are compared with calculated values of the rolling-moment-effectiveness parameter C_{l_δ} as obtained by the application of the linearized theory of supersonic flow.

For the elevon, results indicate that only about half of the rolling-moment effectiveness predicted by linear theory was realized. The variation of Mach number had little effect on the rolling-moment effectiveness of the elevon over the range investigated (Mach numbers of 1.2 to 1.7). Increasing angle of attack in the range of 0° to 10° had a moderate, adverse effect on the rolling-moment effectiveness of the elevon at a Mach number of 1.2; however, this effect diminished with increasing Mach number and became inappreciable in the range of 1.5 to 1.7 Mach number. The lateral-control characteristics of the elevon were little affected by variation of sideslip angle in the range from 5° to -5°. Elevon deflection produced small adverse yawing moments at positive angles of attack, which were of such small magnitude as to be of little concern.

The upper-surface spoilers, having a maximum projection equal to the maximum wing-section thickness, were found to be inferior to the elevons for lateral control of this model because of a rapid loss in effectiveness above an angle of attack of 4°.

The present elevon was found to be more than adequate for rolling control of this wing-fuselage combination if the wing were rigid; however, aeroelastic effects, computed from an approximate strip theory, were found to influence the rolling effectiveness of the elevon to the extent that structural considerations would be of prime importance in the final estimation of required elevon size.

INTRODUCTION

An investigation was made to determine means of attaining adequate lateral and longitudinal control for a wing-fuselage combination designed for efficient flight at supersonic speeds. This wing-fuselage combination, designed according to the theory advanced by Jones in reference 1, employed a wing of aspect ratio 3.5, taper ratio 0.25, and 63° sweepback of the leading edge. The results of wind-tunnel tests at supersonic speeds to determine the effectiveness of a 30-percent chord, 50-percent-semispan elevon as a longitudinal control for this wing-fuselage combination are presented (along with drag and hinge-moment data) in reference 2. The present report presents the results of a wind-tunnel investigation at supersonic speeds to determine the lateral-control characteristics of this elevon. The lateral-control characteristics of upper-surface, 50-percent-semispan, outboard spoilers were also investigated.

NOTATION

All moment coefficients were referred to the stability axes with the origin located at the quarter-chord point of the mean aerodynamic chord projected to the fuselage center line.

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 $pb/2V$, per radian

C_{l_δ} elevon rolling-moment-effectiveness parameter for constant angle of attack $\left(\frac{\partial C_l}{\partial \delta}\right)_\alpha$

C_n yawing-moment coefficient referred to quarter-chord point of mean aerodynamic chord $\left(\frac{\text{yawing moment}}{qSb}\right)$

M Mach number (V/a)

R Reynolds number $(\rho V\bar{c}/\mu)$

S wing area, square feet

V airspeed, feet per second

a speed of sound, feet per second

b wing span, feet

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

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

p angular velocity in roll, radians per second

$\frac{pb}{2V}$ wing-tip helix angle, radians

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

α angle of attack of fuselage center line, degrees

β angle of sideslip, positive with right wing leading, 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

ρ mass density of air, slugs per cubic foot

μ viscosity of air, slugs per foot-second

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

APPARATUS AND TEST METHODS

The investigation was conducted in the Ames 6- by 6-foot supersonic wind tunnel which is equipped with an asymmetric adjustable nozzle permitting a variation in Mach number from 1.2 to 2.0 in the pressure range of 2 to 20 pounds per square inch absolute. However, due to certain vibration difficulties of the present model support system, the Mach number range is temporarily limited to a maximum of 1.7.

The strain-gage balance and instrumentation are described in detail in reference 2.

The model, pertinent dimensions of which are presented with a plan form sketch in figure 1, is shown mounted in the test section in the photograph of figure 2. The wing was untwisted, had 0° incidence, and was composed of NACA 0010 airfoil sections perpendicular to the leading edge. A 30-percent-chord elevon was mounted on the outboard 50 percent of the right wing panel. Spoilers, in heights up to the maximum wing-section thickness, were constructed of aluminum alloy angles and were located successively at 40-, 50-, and 60-percent-chord stations of the outboard half of the right wing panel. The wing and elevon were of solid-steel construction, while the fuselage was of hollow-steel construction to permit the installation of the four-component strain-gage balance. A cutaway schematic drawing showing this installation is presented in reference 2. The fuselage was designed on the basis of minimum wave drag for a given volume and length and had a fineness ratio of 12.5, including that portion of the body cut off to provide a method of attaching the model to the sting support.

To shorten the testing time necessary for the lateral-control-effectiveness investigation, the model was mounted in the test section with the plane of the wing placed vertically. With the model mounted in this manner, the present model support system permits continuous variation of the angle of sideslip during the test. Changing angle of attack, however, entailed changing the model support sting for each desired angle of attack.

Side forces, rolling moments, and yawing moments were measured over a Mach number range from 1.2 to 1.7 at a Reynolds number of 1.5 million. The data were then transferred to stability axes and reduced to final coefficient form. Force measurements were made at nominal angles of sideslip of -5°, -2.5°, 0°, 2.5°, and 5° for angles of attack of 0°, 5°, and 10°. The elevon deflection was varied in 10° increments from 10° to -30°.

The angle of sideslip of the model was determined optically by means of a cathetometer. The control-surface deflections, however, could not be determined during tests but were measured under static conditions before each test and corrected for deflection under aerodynamic loading, using constants determined from static loading tests.

The angle of attack was fixed for each test condition by using a sting bent to the desired angle. Since the angles of attack could not be measured during the test, the angle of attack was measured initially under static conditions and corrected for deflection under aerodynamic load, using constants determined from static loading tests.

REDUCTION OF DATA

Since the force and moment strain gages were located inside the model, there were no direct force tares due to aerodynamic forces on the sting. Effects of support interference, for the present investigation, are confined to changes in base pressure and thus an effect on drag. (See reference 3.)

Although the variations in stream curvature existing in the test section of the Ames 6- by 6-foot wind tunnel (discussed in reference 4) are such that lateral characteristics of a highly swept wing-body combination such as the present configuration, tested at Mach numbers other than 1.4, would be subject to some doubt, values of the incremental aerodynamic coefficients due to elevon deflection are reliable. Because of the axial variations in stream angle at Mach numbers above and below 1.4, however, it is difficult to determine the effective model angle of sideslip when testing with the plane of the wing vertical. Therefore, the angles of sideslip referred to in the report are nominal angles referenced to the horizontal plane and as such restrict the significance of the angle-of-sideslip effects on the control-surface-effectiveness parameters to a qualitative indication as to trends with Mach number.

The total known uncertainties introduced into the aerodynamic coefficients by the factors comprising the various results were determined in the manner fully discussed in reference 5 and are of the following magnitudes:

Quantity	Uncertainty
Rolling-moment coefficient	±0.0008
Yawing-moment coefficient	±0.0001
Mach number	0.01
Reynolds number	0.03×10^6
Angle of attack	±0.05°
Elevon deflection	±0.25°

RESULTS AND DISCUSSION

In evaluating the results of the present investigation, it should be noted that the tests were made at but one Reynolds number (1.5 million).

Previous tests, however, made to determine the effectiveness of this elevon as a longitudinal control (reference 2), showed no appreciable change in the effectiveness and hinge-moment parameters in the Reynolds number range of 1.5 to 3.7 million.

Elevon Lateral-Control Characteristics

Results of the force tests made to determine the lateral-control characteristics of the elevon are shown in figures 3 to 8.[1] Cross plots of the basic data of figures 3, 4, and 5 (figs. 9, 10, and 11) show the variation of rolling-moment coefficients with elevon deflection for constant angles of sideslip for Mach numbers of 1.2 through 1.7.

Rolling moment.- An indication of the effectiveness of the elevon as an aileron control is obtained from the rolling-moment coefficient versus elevon deflection curves of figure 9. The variation of rolling-moment coefficient was generally linear with elevon deflection throughout the Mach number range for elevon deflections between $+10^{\circ}$ and -20°. For negative deflections greater than 20°, however, there is an appreciable decrease in effectiveness indicating probable increased separation effects with increased elevon deflection. The pitching-moment-effectiveness curves (see reference 2) for this same elevon indicate a similar tendency although the lift-effectiveness curves are essentially linear indicating a redistribution of spanwise loading to give a shift in center-of-pressure position rather than a decrease in the lift-effectiveness parameter.

Qualitatively, the effect of positive angles of sideslip (right wing leading) was to increase the rolling-moment effectiveness of the right wing elevon, and, conversely, negative sideslip angles decreased the rolling-moment effectiveness at a Mach number of 1.2. (See fig. 3.) This effect of sideslip angle on rolling-moment effectiveness decreased with increasing Mach number, becoming relatively small at a Mach number of 1.7 for the range of angles of sideslip of 5° to -5°. Since, in the present investigation, the significance of the effects of sideslip are restricted to a qualitative indication as to trends with Mach number (see section on reduction of data), and since the effects of sideslip are small over the range investigated, the C_l' versus δ curves are given for various nominal angles of sideslip at 0° angle of attack only; for the higher angles of attack, data at only 0° sideslip are presented.

[1] The elevon deflection angles shown in these figures ($\delta_{setting}$) are for the unloaded condition; however, the correction due to aerodynamic loading amounted to but 1° at angles of attack of 10° and to smaller amounts at the lower angles of attack. The aileron deflection angles in the subsequent cross plots are fully corrected for this effect of aerodynamic loading (see section on apparatus and test methods).

The results from figures 9 and 11 are summarized and presented in figure 12 in the form of the rolling-moment-effectiveness parameter C_{l_δ}. A theoretical estimation of the variation of this rolling-moment-effectiveness parameter with Mach number was made by the method of reference 6 and is presented with the experimental values in figure 12. As predicted by linear theory, a very gradual loss of C_{l_δ} with increasing Mach number is evident, although only about 50 percent of the predicted effectiveness is realized throughout the speed range investigated for 0° angle of attack. This ratio of experimental to theoretical rolling-moment effectiveness would be expected from the fact that but half the predicted lift effectiveness of the elevon was realized. (See reference 2.) Increasing angle of attack from 0° to 10° had a moderate, adverse effect on the rolling-moment effectiveness of the elevon at a Mach number of 1.2. The magnitude of this adverse effect decreased with increasing Mach number and became negligible at Mach numbers of 1.5 to 1.7.

The significance of the results insofar as lateral control is concerned can be assessed by using the data to determine the effectiveness of the elevons in trimming the wing-body combination to a wings-level attitude in sideslip. By the use of the theoretical lateral-stability derivatives of reference 7, it can be shown that the elevons have sufficient rolling-moment effectiveness to hold a wings-level attitude for the flat wing of the present test to a maximum sideslip angle of between 7° and 9° at a lift coefficient of 0.25. The use of twist and camber in the wing materially improves this condition so that, for the cambered and twisted wing of reference 7, it is estimated that the elevons will hold a wings-level attitude to about 12° sideslip at a lift coefficient of 0.25.

A better quantitative indication of the adequacy of the aileron control can be obtained from the computed values of the helix angle $pb/2V$ produced by 1° elevon deflection. The helix angles generated by the wing tips in a steady roll were calculated using the experimental results of figure 12 and the values of the damping coefficient C_{l_p} computed by the method of reference 8. These values of $\frac{pb/2V}{\delta}$, thus calculated, are for the unyawed condition for 0° angle of attack only. Values of the damping coefficient C_{l_p} used in computing $pb/2V$ varied from −0.252 at a Mach number of 1.2 to −0.282 at a Mach number of 1.7. The wing-tip helix angle per degree elevon deflection, thus derived, reduced with increasing Mach number, with the rate of decrease gradually lessening with increasing Mach number. (See fig. 13.)

For airplanes capable of very high speeds, maximum rolling velocity is believed to be more of a criterion of the required rolling performance than $pb/2V$. By the use of this criterion to evaluate the rolling performance of the elevon (a rigid wing assumed) the present elevon could be reduced in size if used as an aileron only. This supposition is substantiated by the data of figure 14 which show a comparison of the $pb/2V$ obtained from 30° total elevon deflection with that required to attain a rolling velocity of 200° per second with a 40-foot wing-span airplane of the present configuration flying at 60,000 feet altitude.

The foregoing discussion of the adequacy of the elevon in providing lateral control must be modified in light of possible aeroelastic effects. For supersonic speeds, the loss in aileron effectiveness due to bending and torsional deformation of a swept-back wing is much greater than for the equivalent wing at subsonic speeds. The reasons for this are as follows:

Although the rolling moment due to unit aileron deflection is only about half at supersonic speed of what it is at subsonic speed (see reference 10), the loading due to aileron deflection is so distributed that the wing torsional moment (and, therefore, torsional deformation) per degree aileron deflection is about the same in both cases, provided the dynamic pressure is the same. To obtain a given C_l, the aileron deflection at supersonic speeds must be about twice the deflection necessary at subsonic speed, resulting in twice the torsional deformation. Therefore, since the rolling moment due to a given wing twist is somewhat greater at supersonic Mach numbers, aileron reversal occurs at much lower dynamic pressure at supersonic speeds than at subsonic speeds. Calculations show that, for an airplane equipped with a wing similar to that of the present investigation, designed for a maximum load factor of 2.5 cruising at $M = 1.4$ at 60,000 feet altitude, the aileron effectiveness in rolling is reduced by aeroelastic effects to about 50 percent of that for a rigid wing. It appears, therefore, that in the design of ailerons for supersonic swept-wing aircraft considerations of the effects of elastic deformation of the wing are very important.

Yawing Moment.- The yawing-moment-coefficient increment resulting from positive deflection of the right wing elevon was adverse (sign of yawing-moment increment opposite to that of rolling-moment increment) at positive angles of attack. (See figs. 7 and 8.) The magnitude of the adverse yawing-moment-coefficient increment increased as the wing angle of attack increased, but was little affected by Mach number. Adverse yaw tends to retard the forward movement of the upgoing wing, resulting in a loss in $pb/2V$ if a rudder is not used to counteract the yawing moment. However, the adverse yaw existing in the present case does not appear to be serious since estimates show that it may be overcome by use of a rudder.

Spoiler Lateral-Control Characteristics

Results of the investigation of 50-percent-semispan, outboard spoilers tested in heights of 50- and 100-percent maximum wing-section thickness (respectively, 5- and 10-percent of wing chord perpendicular to leading edge) at 40-, 50-, and 60-percent-chord stations showed relatively poor rolling effectiveness. As little difference in rolling-moment effectiveness was evident for the three chordwise stations investigated, data for but one chordwise spoiler location (50-percent-chord station) are presented in figure 15. The maximum rolling effectiveness obtainable for the several spoilers tested was equal to that obtained from about 20° deflection of the elevon; however, a marked, adverse effect of angle of attack at angles above 4° was evident over the entire Mach number range investigated. Thus, as the angle-of-attack effect on the rolling-moment effectiveness of the elevon was only moderate at Mach numbers of 1.2 to 1.4 and insignificant at Mach numbers of 1.5 to 1.7 (fig. 12), the present elevon is markedly superior to the spoilers tested for lateral control of this wing-fuselage combination.

CONCLUSIONS

An investigation of the effectiveness of a constant-percent-chord outboard elevon and upper-surface spoilers as lateral-control devices for a wing of symmetrical section with the leading edge swept back 63°, in combination with a body of revolution, disclosed the following results for the Mach number range of 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 lateral control indicated the following:

(a) The rolling-moment-effectiveness parameter C_{l_δ} was about half that predicted by linear theory.

(b) Variation in Mach number had little effect on the rolling-moment effectiveness of the elevon over the range investigated (M=1.2 to 1.7).

(c) Increasing angle of attack from 0° to 10° had a moderate, adverse effect on the rolling-moment effectiveness of the elevon at a Mach number of 1.2, which decreased with increasing Mach number and became negligible at Mach numbers of 1.5 to 1.7.

(d) For a rigid wing, the present elevon is more than adequate for rolling control of this wing-fuselage combination; however, theoretical calculations showed that aeroelastic effects adversely influenced the rolling effectiveness. The elevon also appears to be satisfactory in trimming to a wings-level condition in sideslip especially for twisted and cambered wings.

(e) Deflection of the elevon produced small adverse yawing moments at positive angles of attack.

(f) The effectiveness of the elevon as a lateral control was little affected by angles of sideslip up to $\pm 5^{\circ}$.

2. Results of the investigation of outboard upper-surface spoilers, tested in heights up to the maximum wing-section thickness and located successively at 40-, 50-, and 60-percent-chord stations, proved the spoilers to be inferior to the elevon for lateral control of the present configuration because of a rapid loss in effectiveness at angles of attack above 4°.

Ames Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Moffett Field, Calif.

REFERENCES

1. Jones, Robert T.: Estimated Lift-Drag Ratios at Supersonic Speed. NACA TN 1350, 1947.

2. Olson, Robert N., and Mead, Merrill H.: 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. NACA RM A50A31a, 1950.

3. Perkins, Edward W.: Experimental Investigation of the Effects of Support Interference on the Drag of Bodies of Revolution at a Mach number of 1.5. NACA RM A8B05, 1948.

4. Frick, Charles W., and Olson, Robert N.: Flow Studies in the Asymmetric Adjustable Nozzle of the Ames 6- by 6-Foot Supersonic Wind Tunnel. NACA RM A9E24, 1949.

5. Hall, Charles F., and Heitmeyer, John C.: Aerodynamic Study of a Wing-Fuselage Combination Employing a Wing Swept Back 63°.– Characteristics at Supersonic Speeds of a Model with the Wing Twisted and Cambered for Uniform Load. NACA RM A9J24, 1950.

6. Frick, Charles W., Jr.: Application of the Linearized Theory of Supersonic Flow to the Estimation of Control-Surface Characteristics. NACA TN 1554, 1948.

7. Lessing, Henry C.: Aerodynamic Study of a Wing-Fuselage Combination Employing a Wing Swept-Back 63°– Effect of Sideslip on Aerodynamic Characteristics at a Mach Number of 1.4 With the Wing Twisted and Cambered. NACA RM A50F09, 1950.

8. Walker, Harold J., and Ballantyne, Mary B.: Pressure Distribution and Damping in Steady Roll at Supersonic Mach Numbers of Flat Swept-Back Wings With Subsonic Edges. NACA TN 2047, 1950.

9. Frick, Charles W., and Chubb, Robert S.: The Longitudinal Stability of Elastic Swept Wings at Supersonic Speeds. NACA TN 1811, 1949.

10. Jones, J. Lloyd, and Demele, Fred A.: Aerodynamic Study of a Wing-Fuselage Combination Employing a Wing Swept Back 63°.– Effects at Subsonic Speeds of a Constant-Chord Elevon on a Wing Cambered and Twisted for a Uniform Load at a Lift Coefficient of 0.25. NACA RM A9I27, 1949.

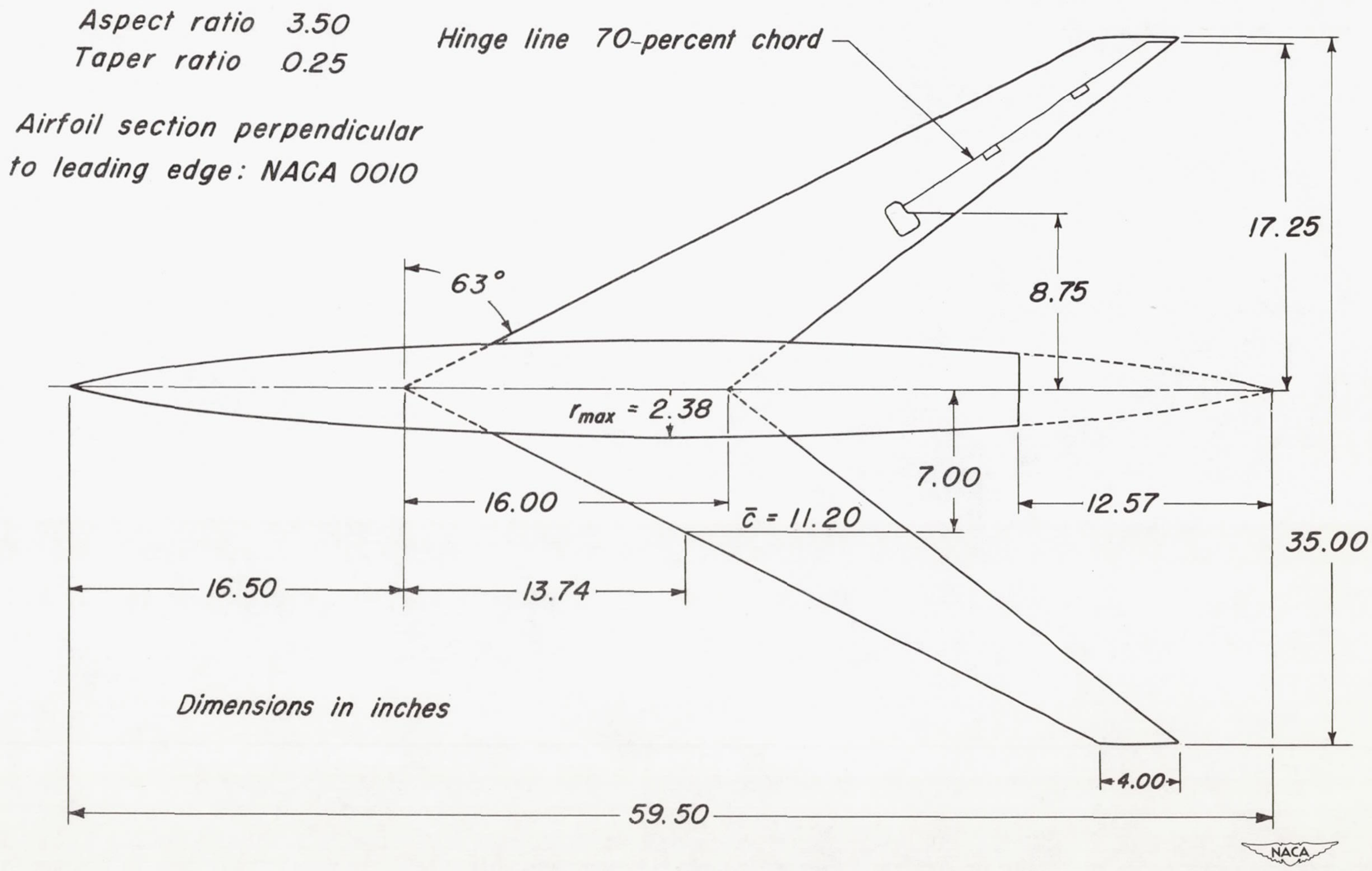


Figure 1.- Sketch of model showing principal dimensions and location of elevon.

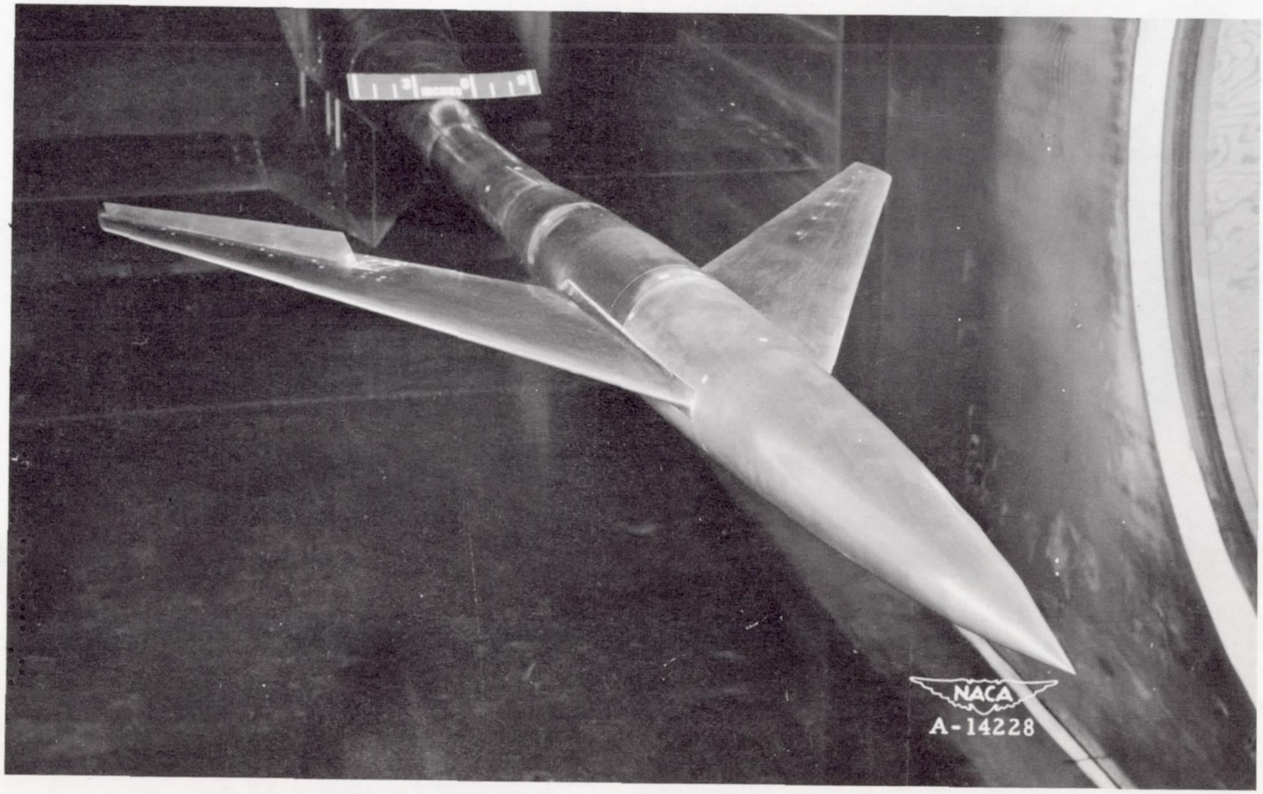


Figure 2.– Model installed in the wind tunnel showing elevon with negative deflection.

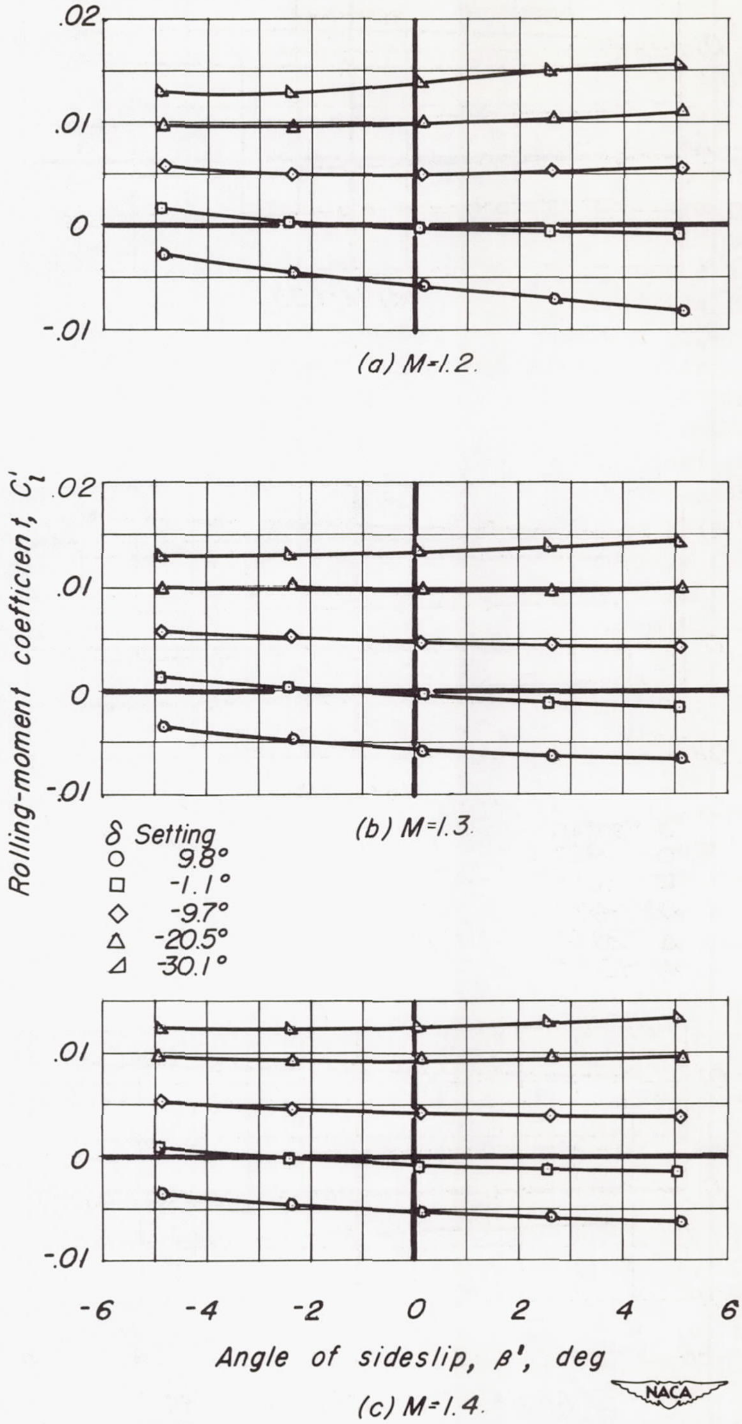
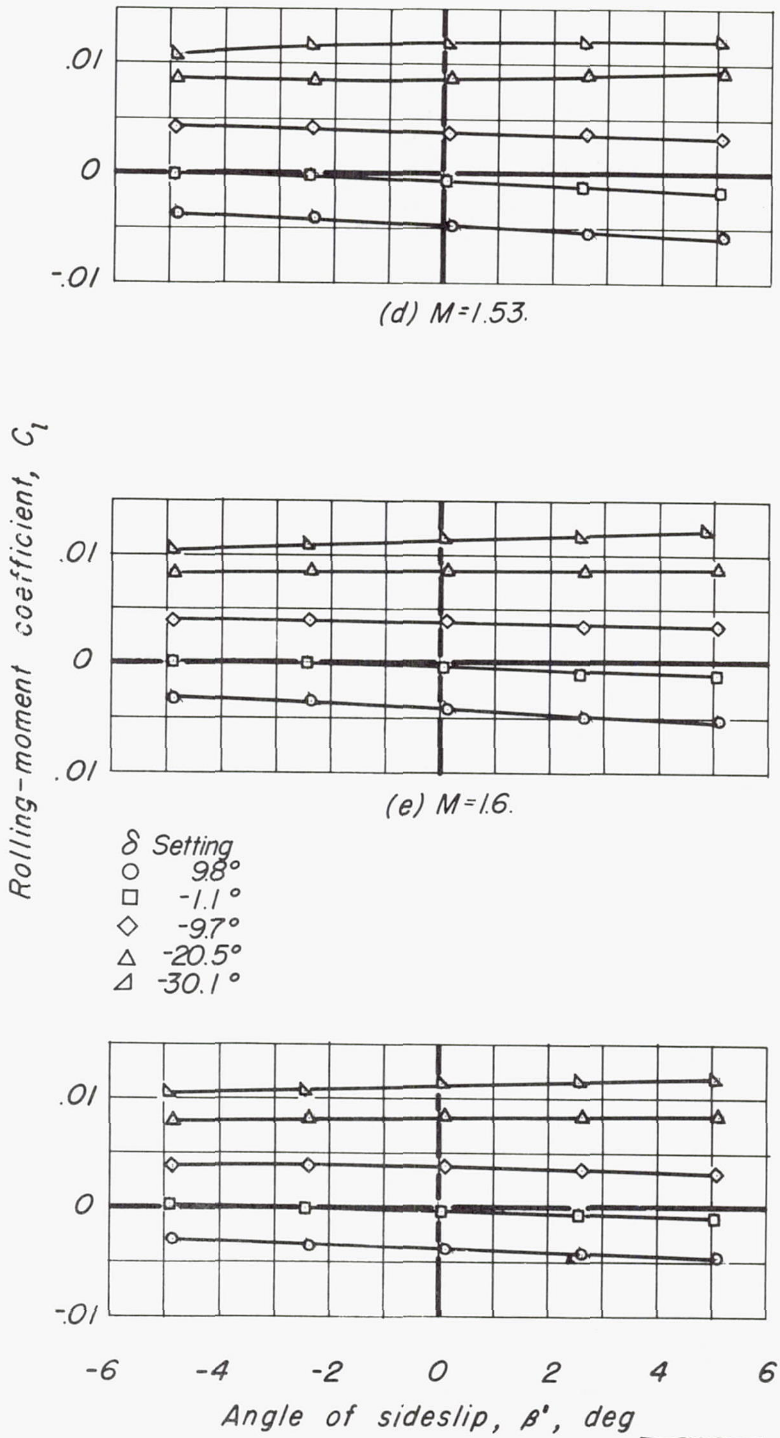


Figure 3.- Effect of elevon deflection on the variation of rolling-moment coefficient with angle of sideslip at various Mach numbers. $\alpha=0°$



(d) M=1.53.

(e) M=1.6.

(f) M=1.7.

Figure 3.– Concluded.

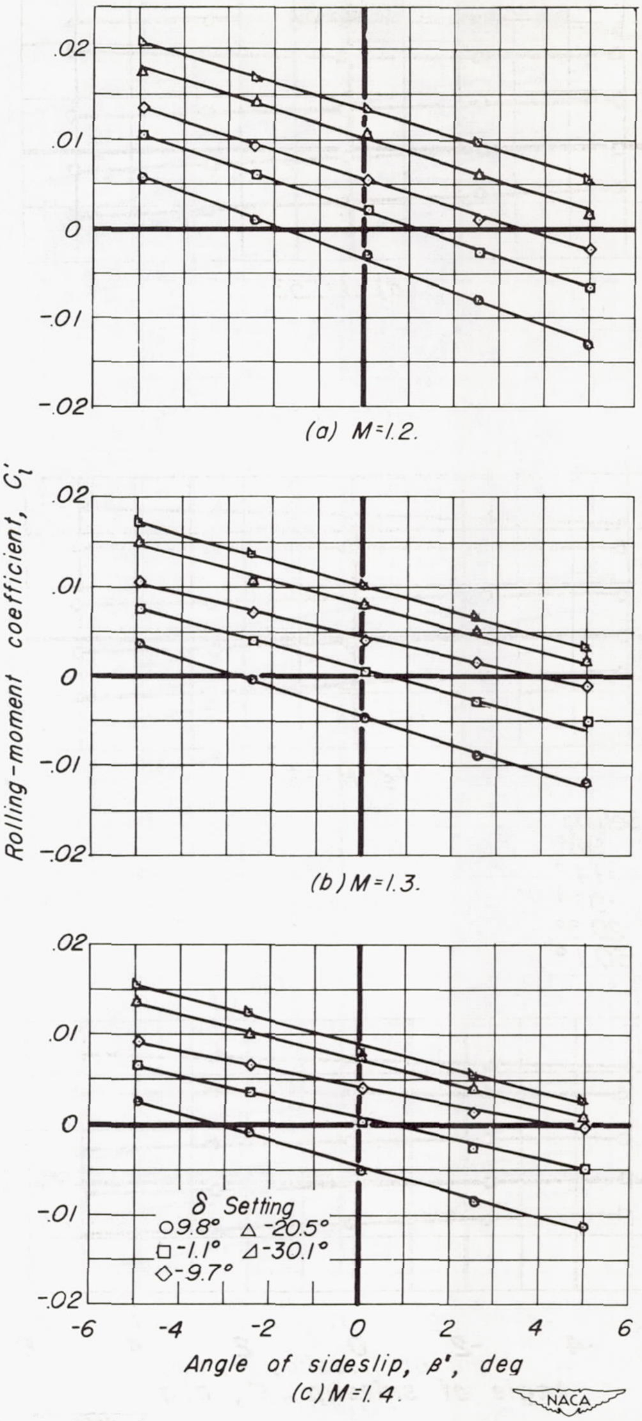
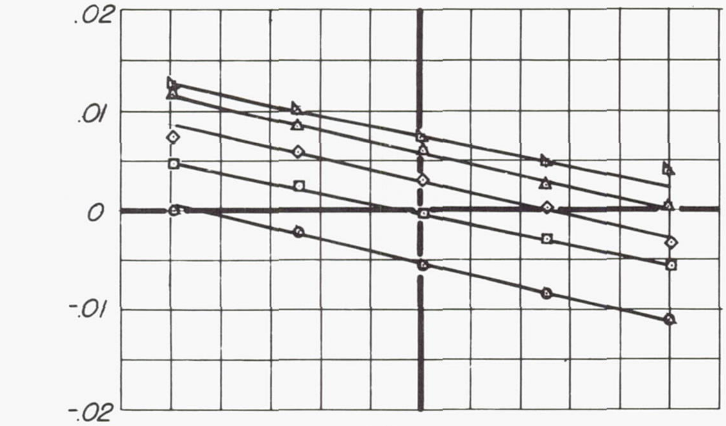
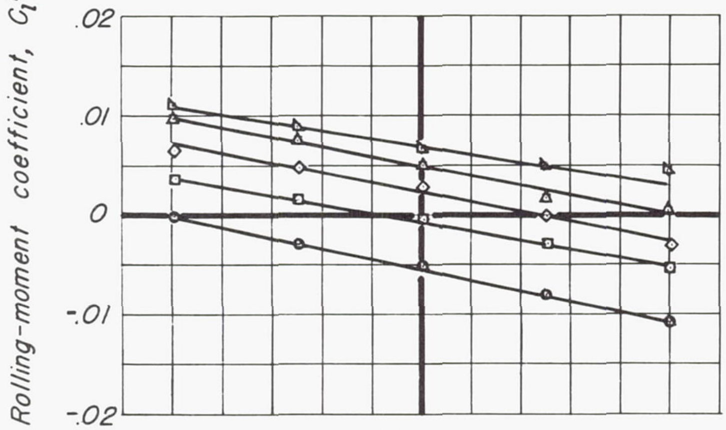


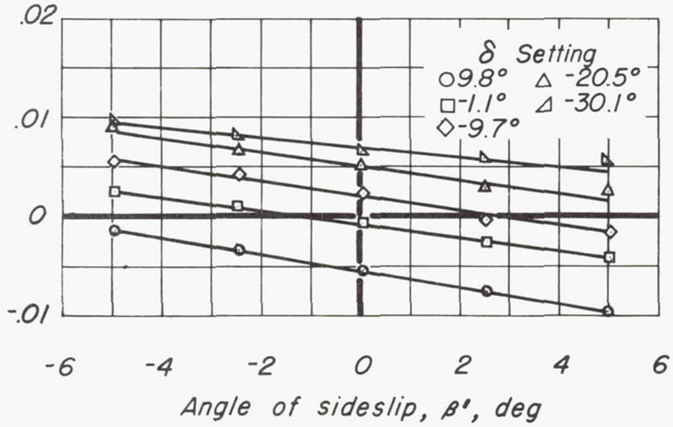
Figure 4.- Effect of elevon deflection on the variation of rolling-moment coefficient with angle of sideslip at various Mach numbers. $\alpha = 5°$.



(d) M=1.53.



(e) M=1.6.



(f) M=1.7.

Figure 4.- Concluded.

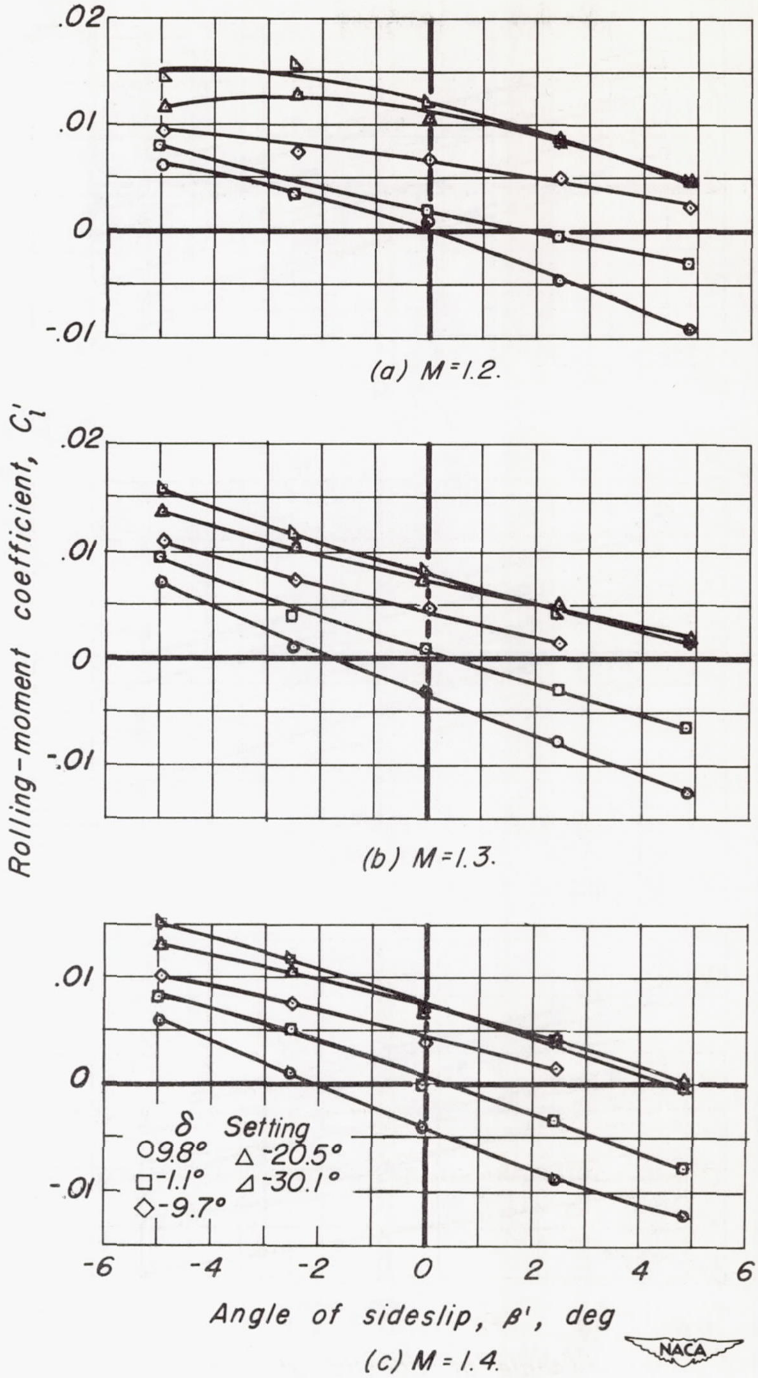
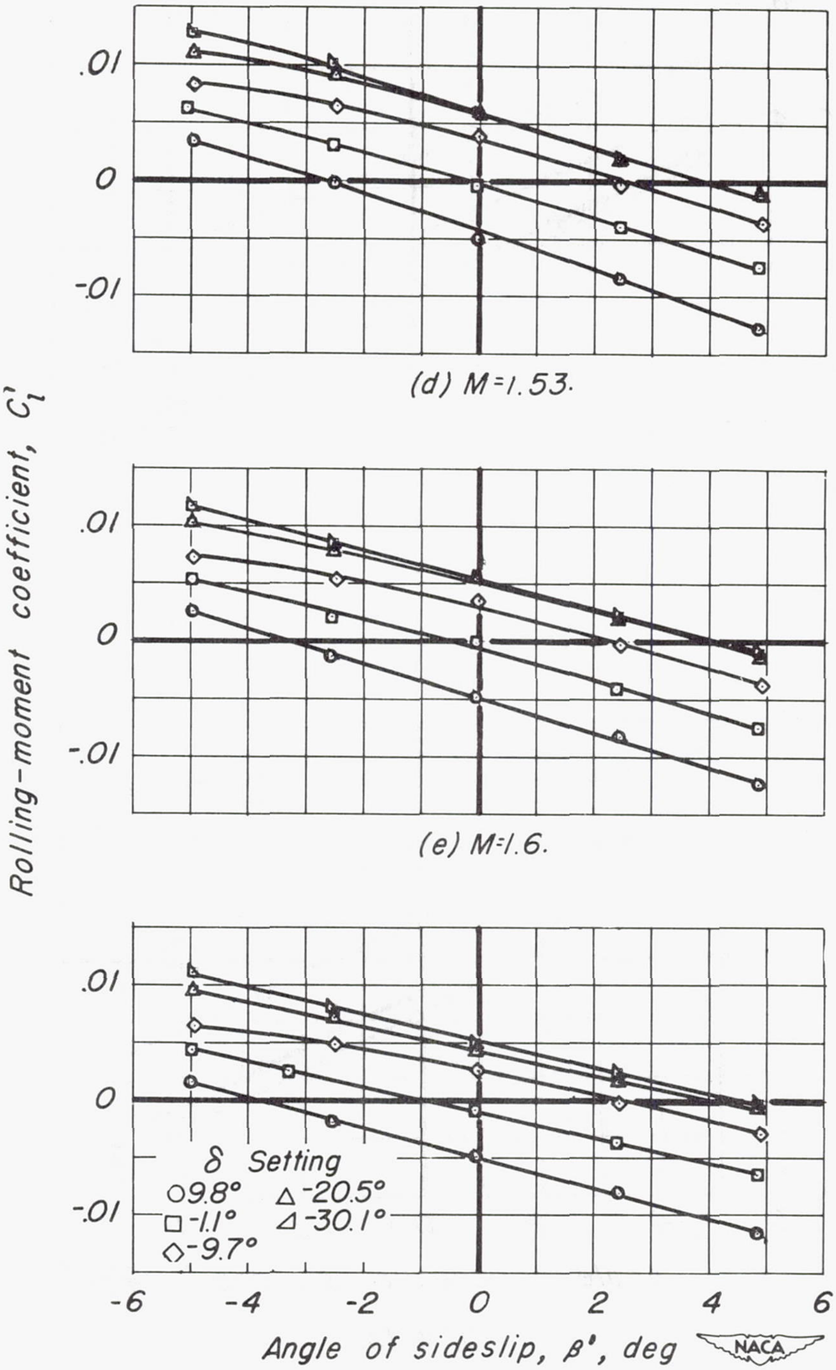


Figure 5.- Effect of elevon deflection on the variation of rolling-moment coefficient with angle of sideslip at various Mach numbers. $\alpha = 10°$.



(f) M=1.7.

Figure 5.- Concluded.

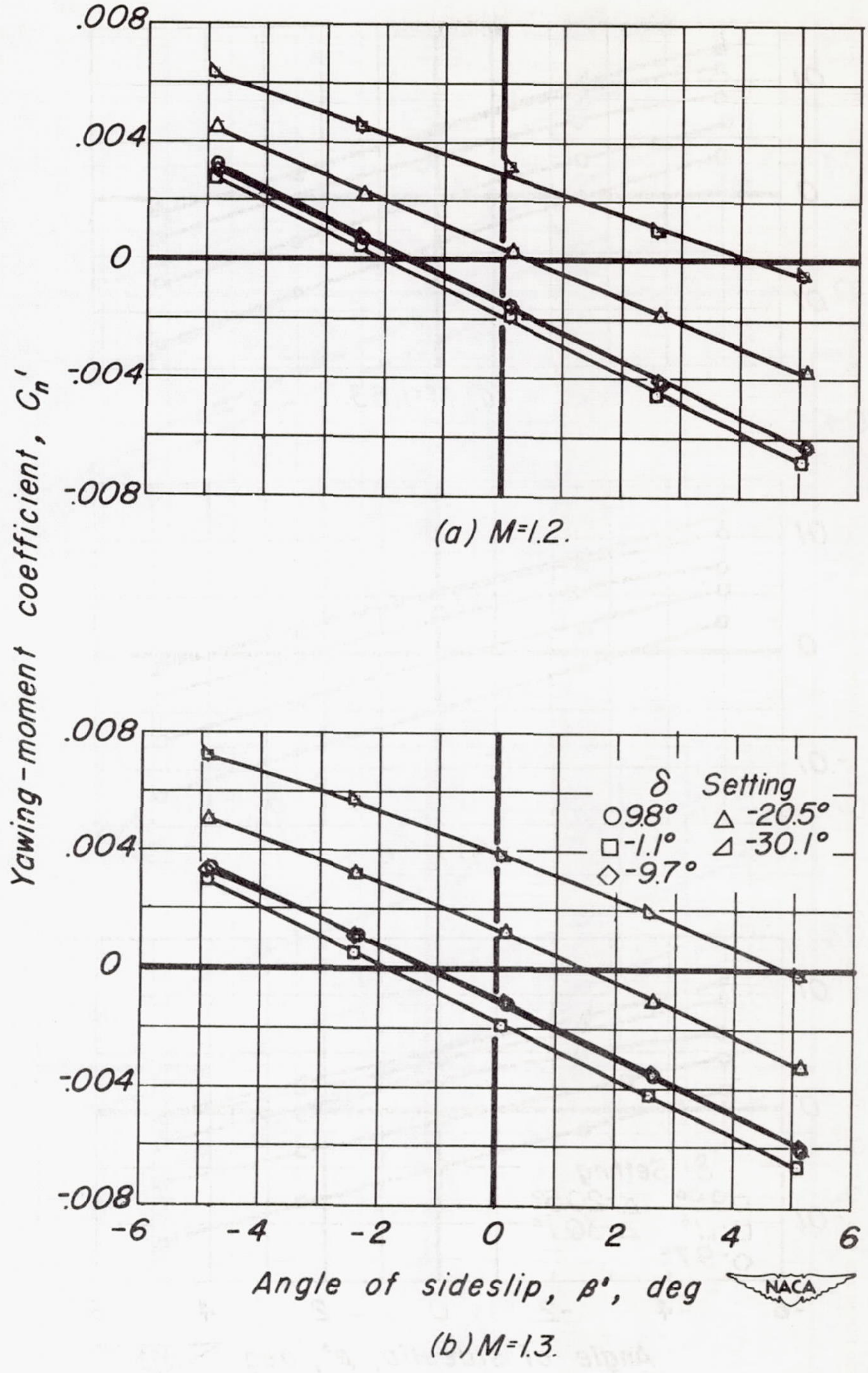
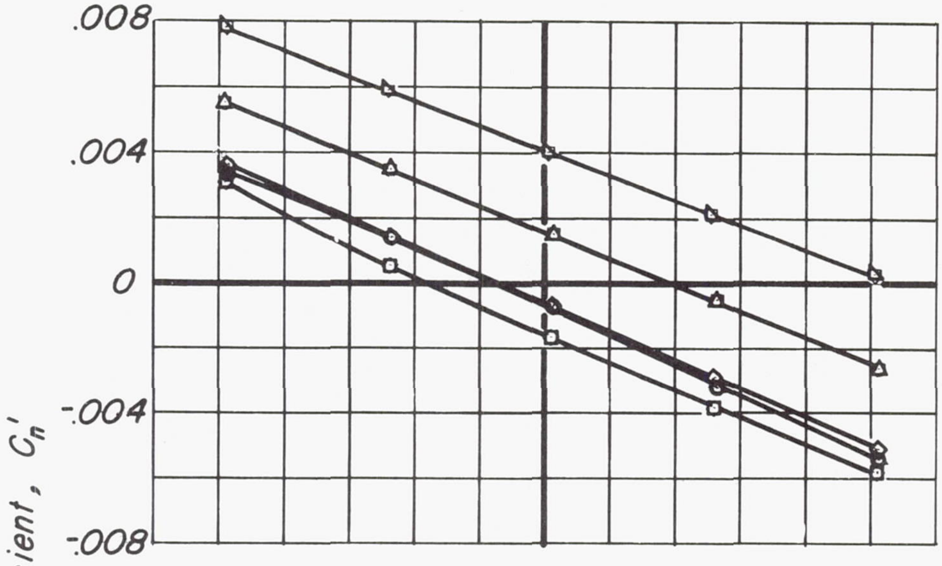
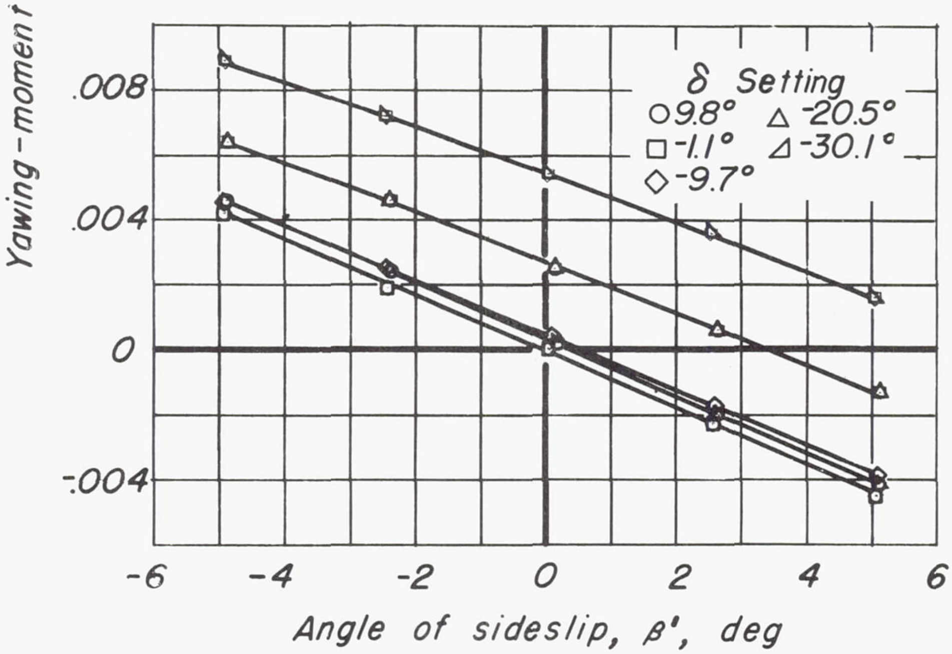


Figure 6.- Effect of elevon deflection on the variation of yawing-moment coefficient with angle of sideslip at various Mach numbers. $\alpha = 0°$.



(c) M=1.4.



(d) M=1.53.

Figure 6.- Continued.

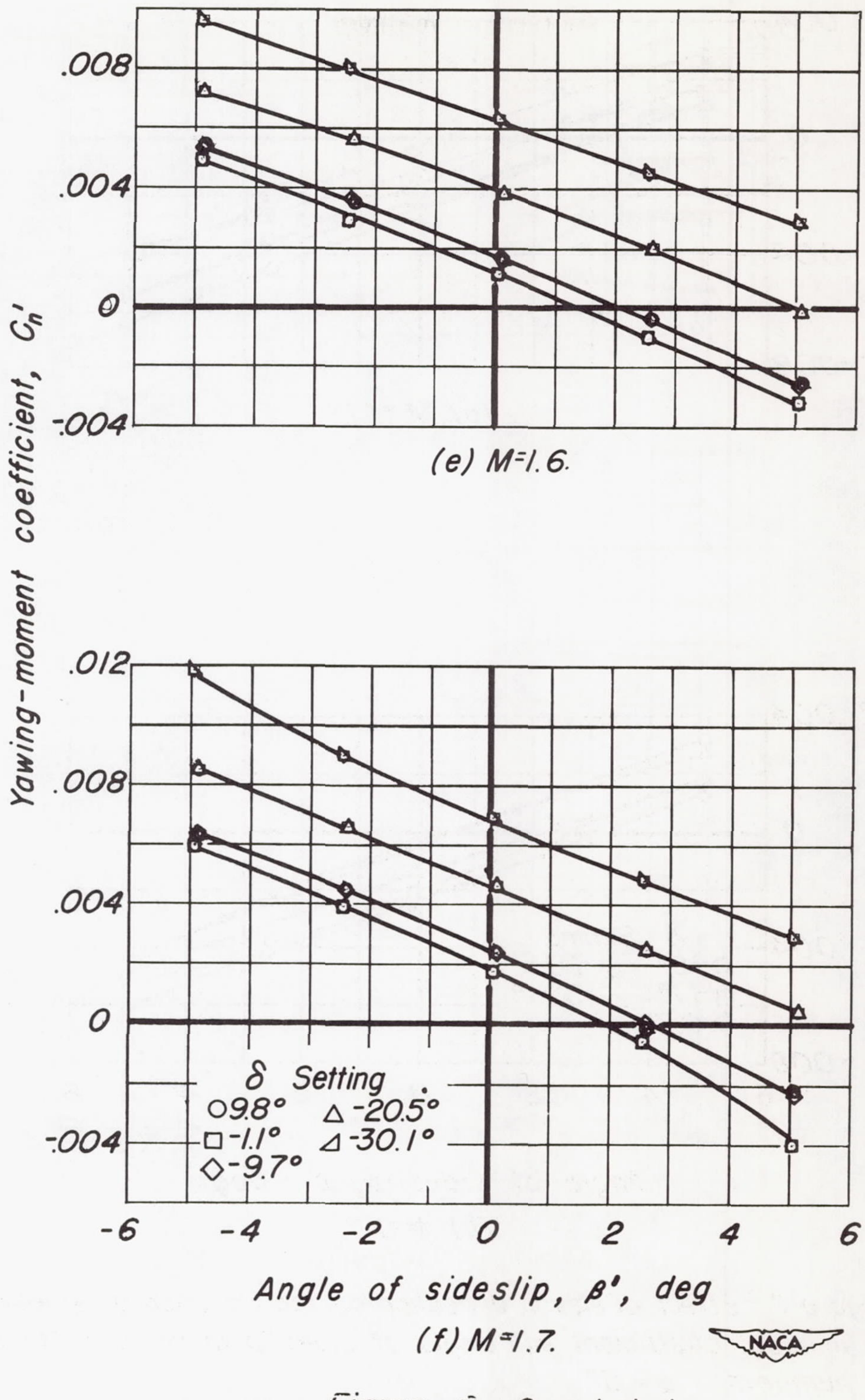


Figure 6.- Concluded.

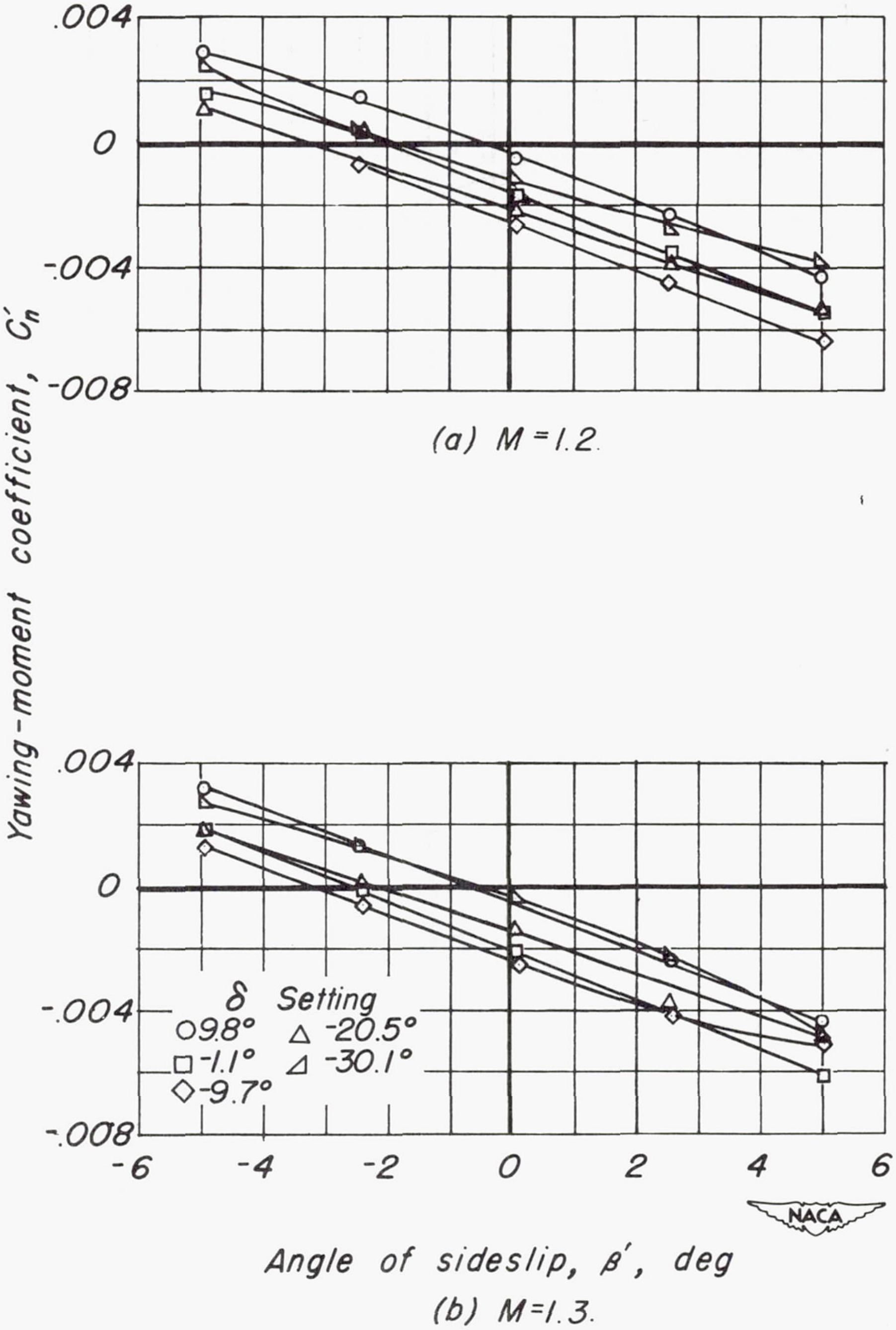
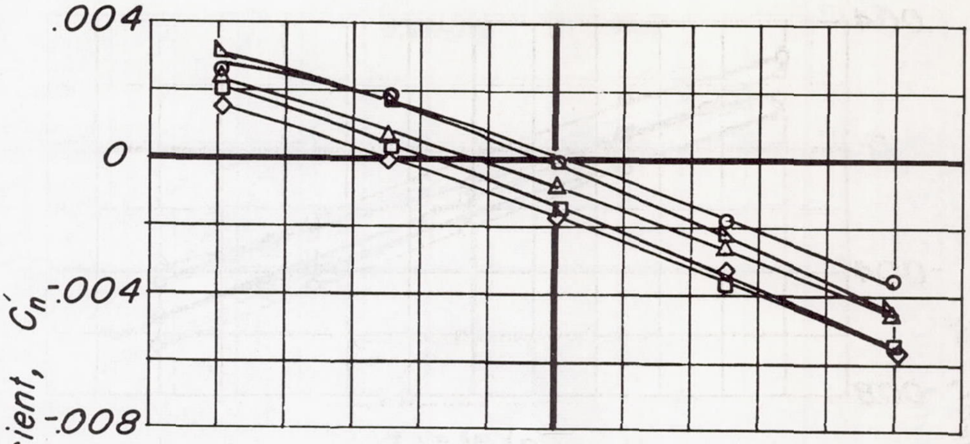
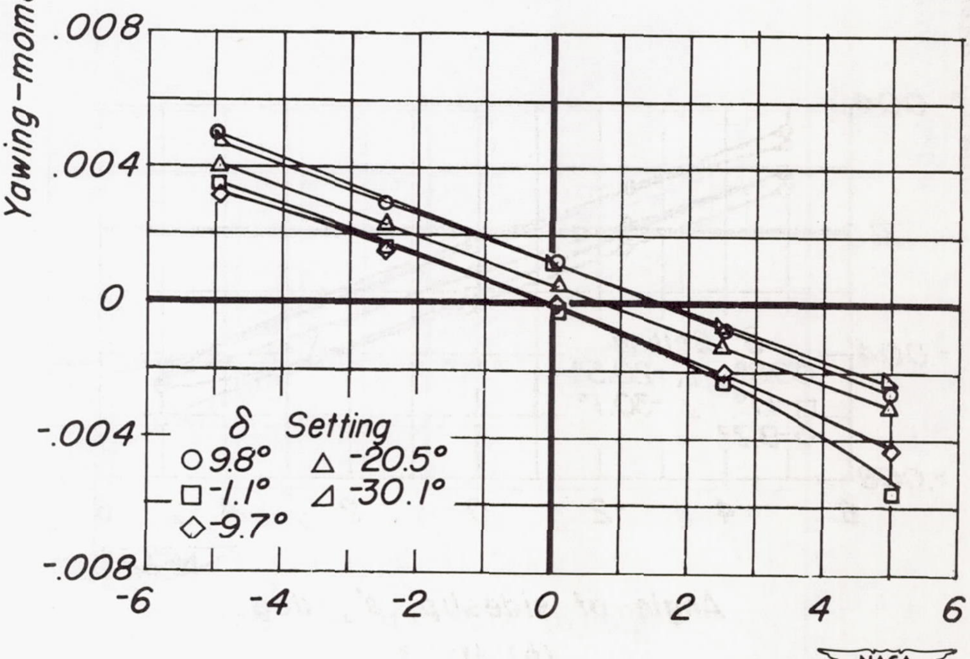


Figure 7.- Effect of elevon deflection on the variation of yawing-moment coefficient with angle of sideslip at various Mach numbers. $\alpha = 5°$.

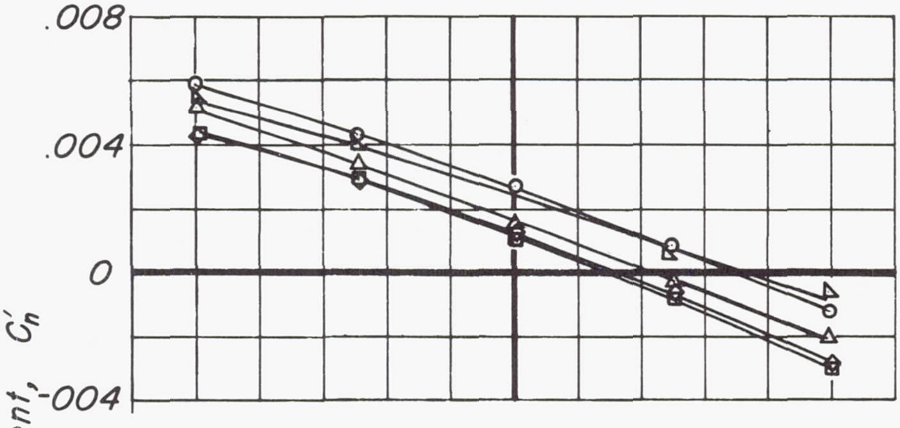


(c) M = 1.4.

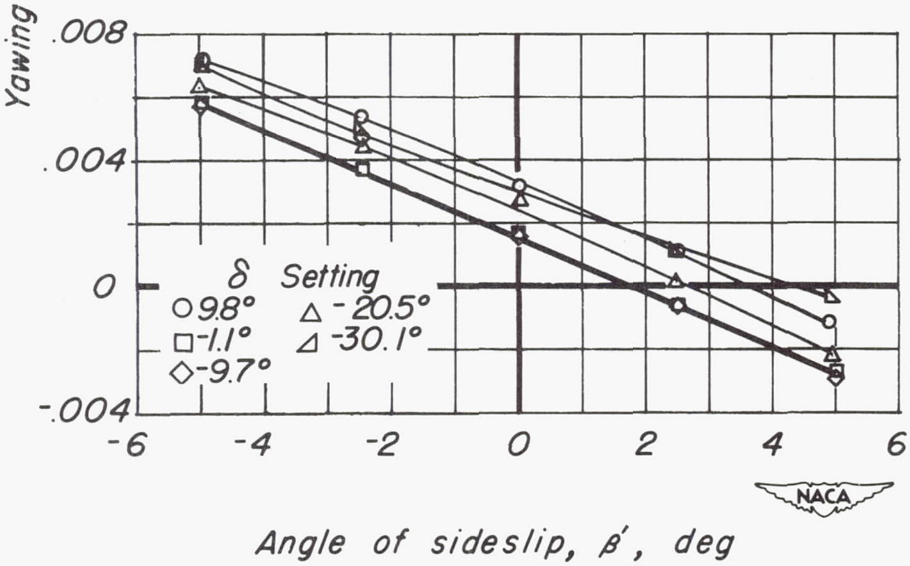


(d) M = 1.53.

Figure 7. - Continued.



(e) M = 1.6.



(f) M = 1.7.

Figure 7.- Concluded.

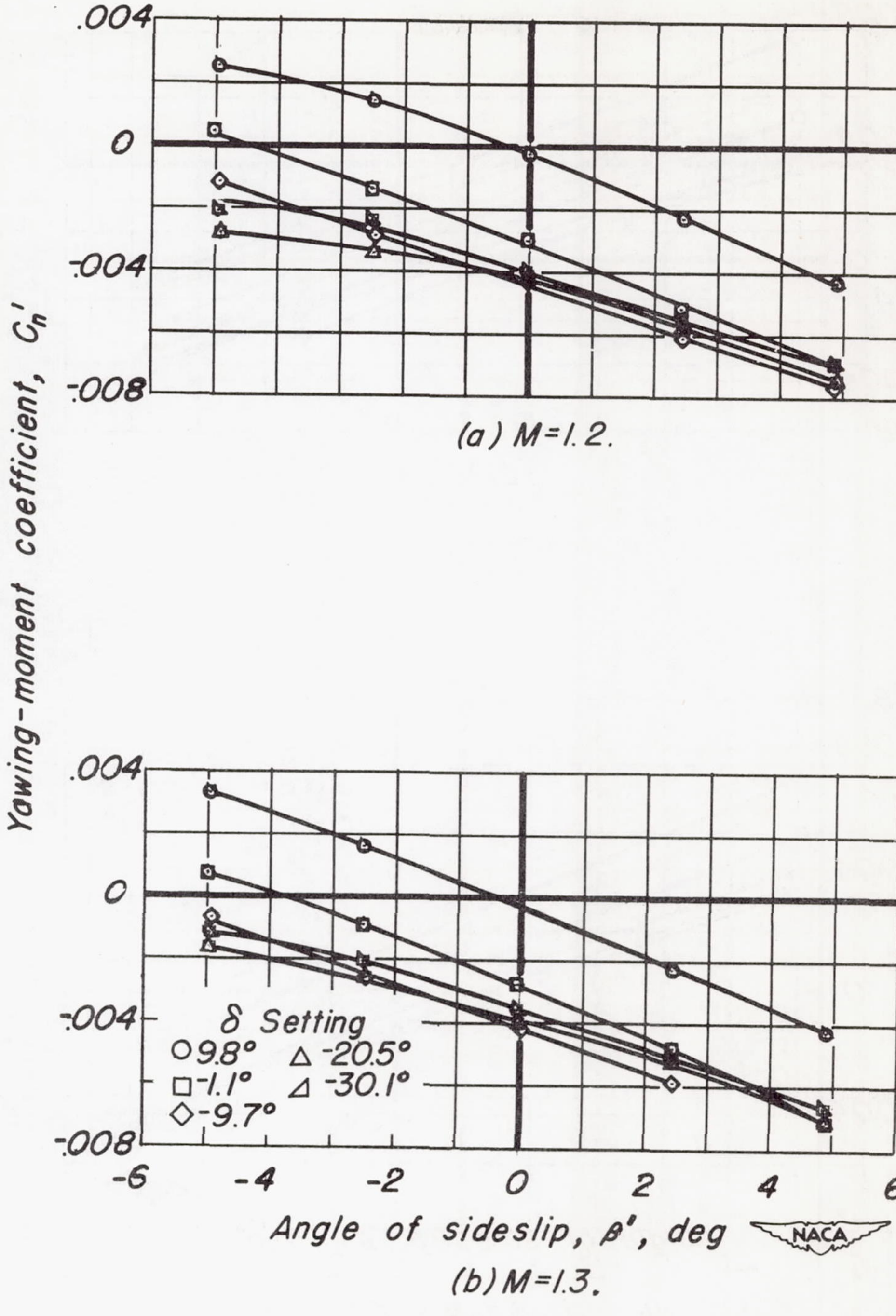


Figure 8.- Effect of elevon deflection on the variation of yawing-moment coefficient with angle of sideslip at various Mach numbers. $\alpha = 10°$.

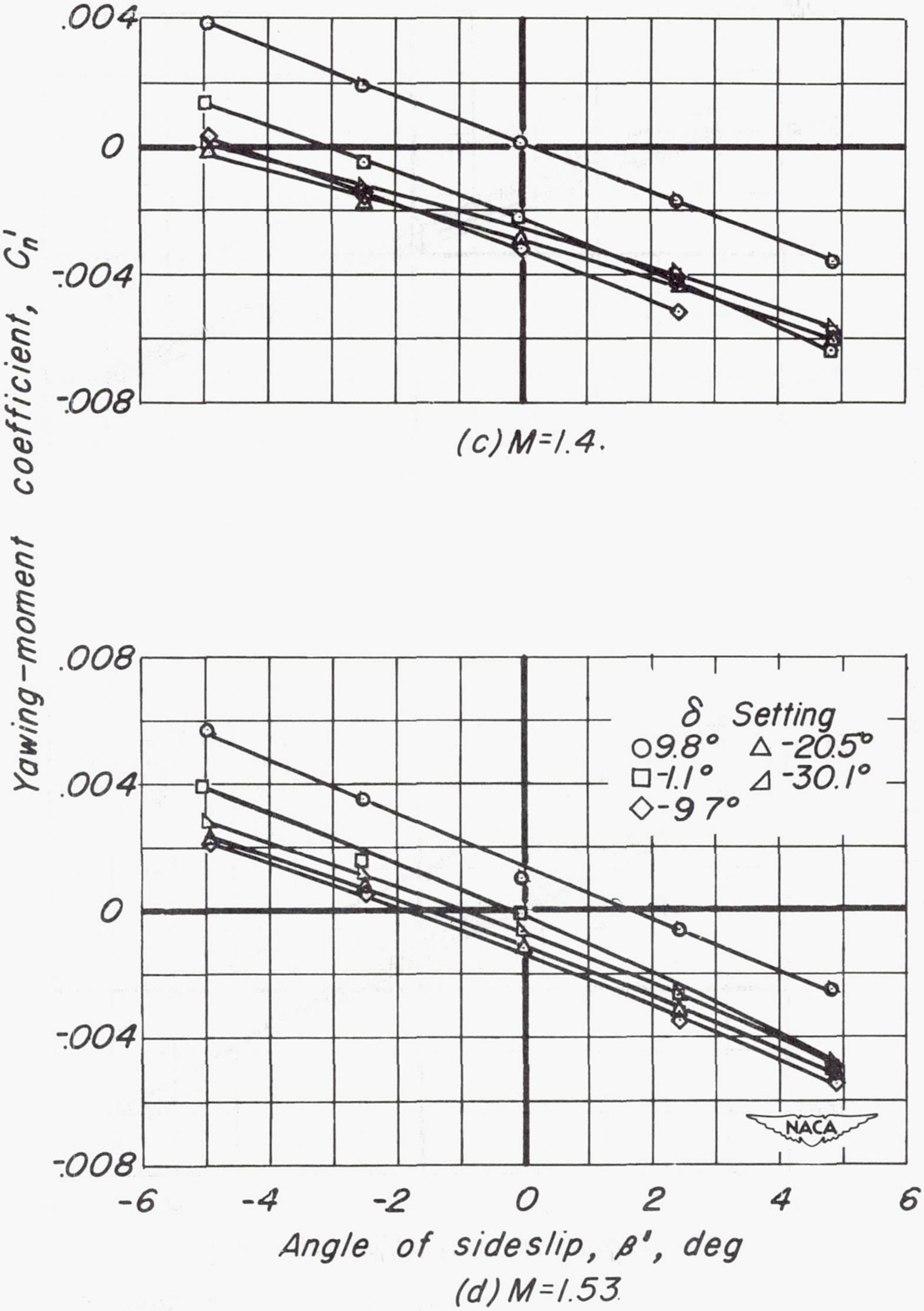
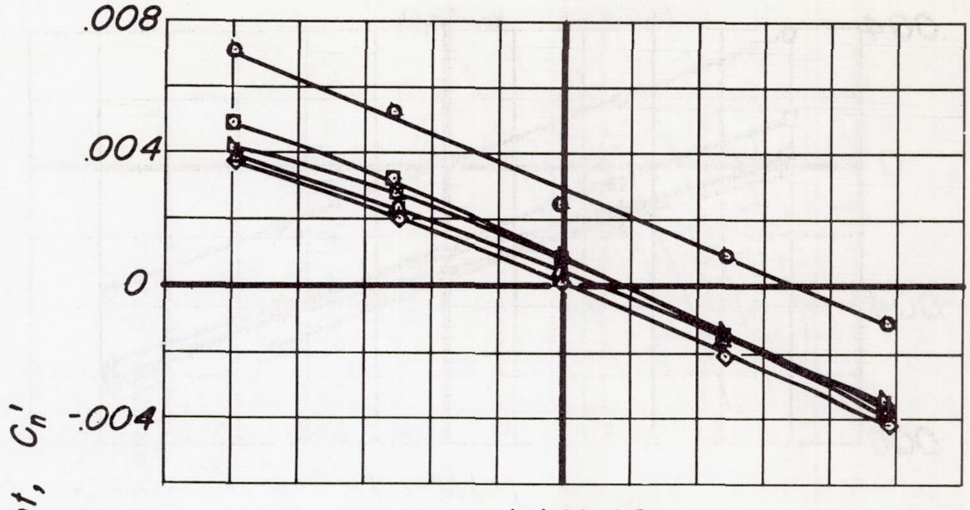
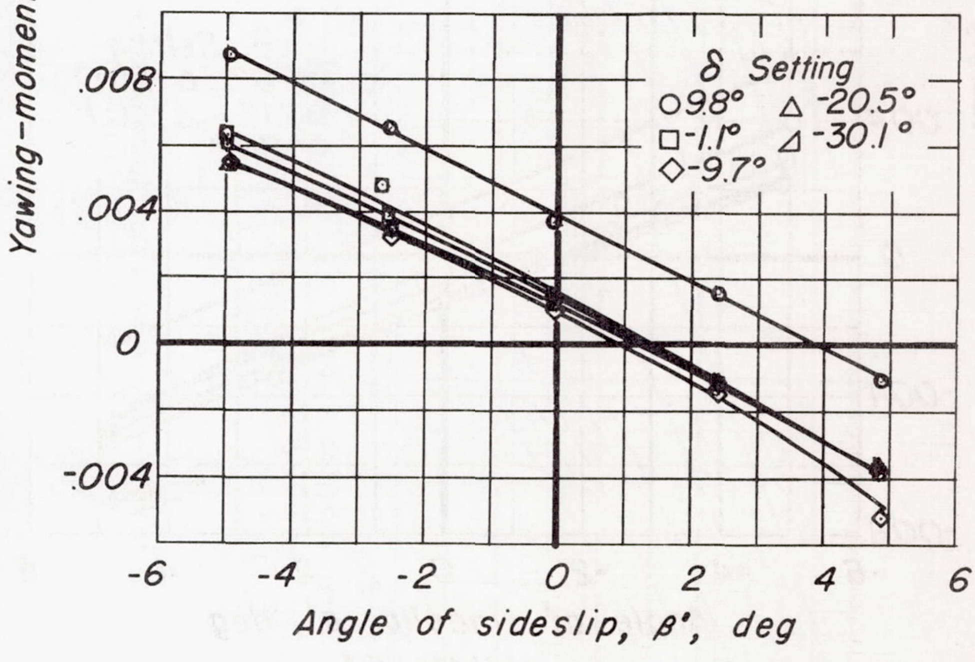


Figure 8.- Continued.



(e) M=1.6.



(f) M=1.7.

Figure 8.- Concluded.

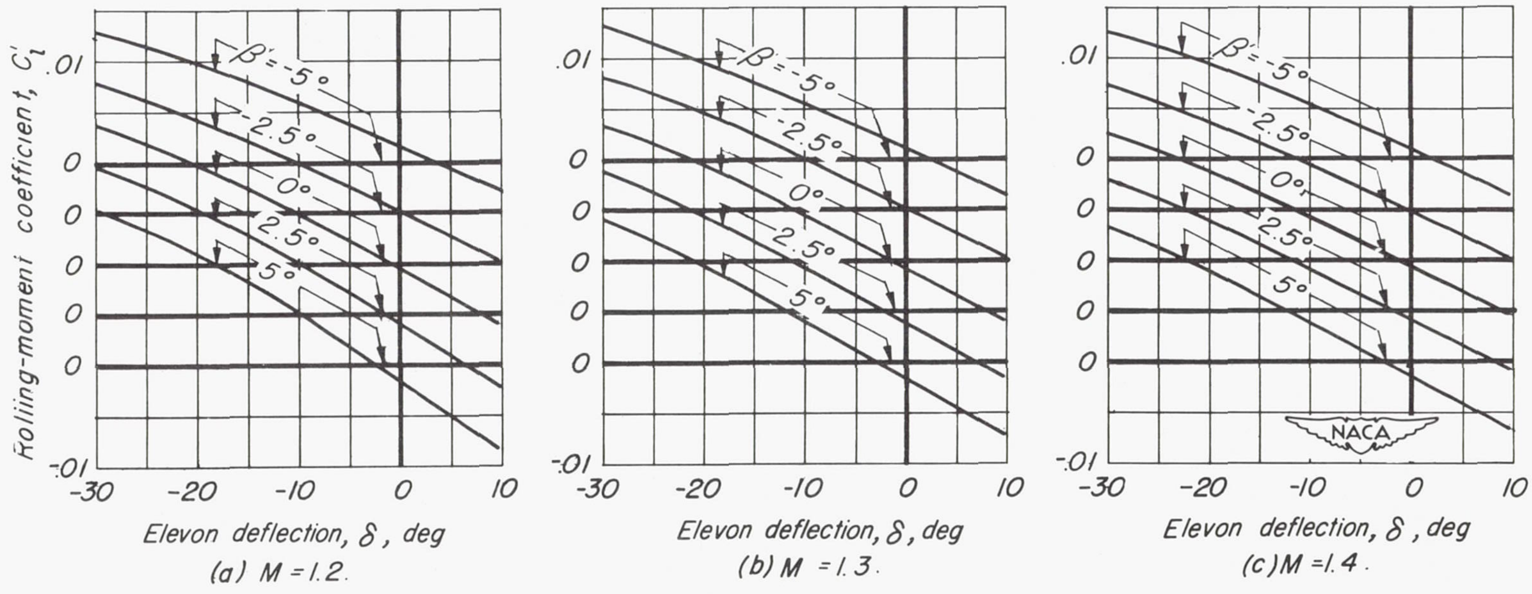


Figure 9. - Variation of rolling-moment coefficient with elevon deflection at various Mach numbers. α = 0°.

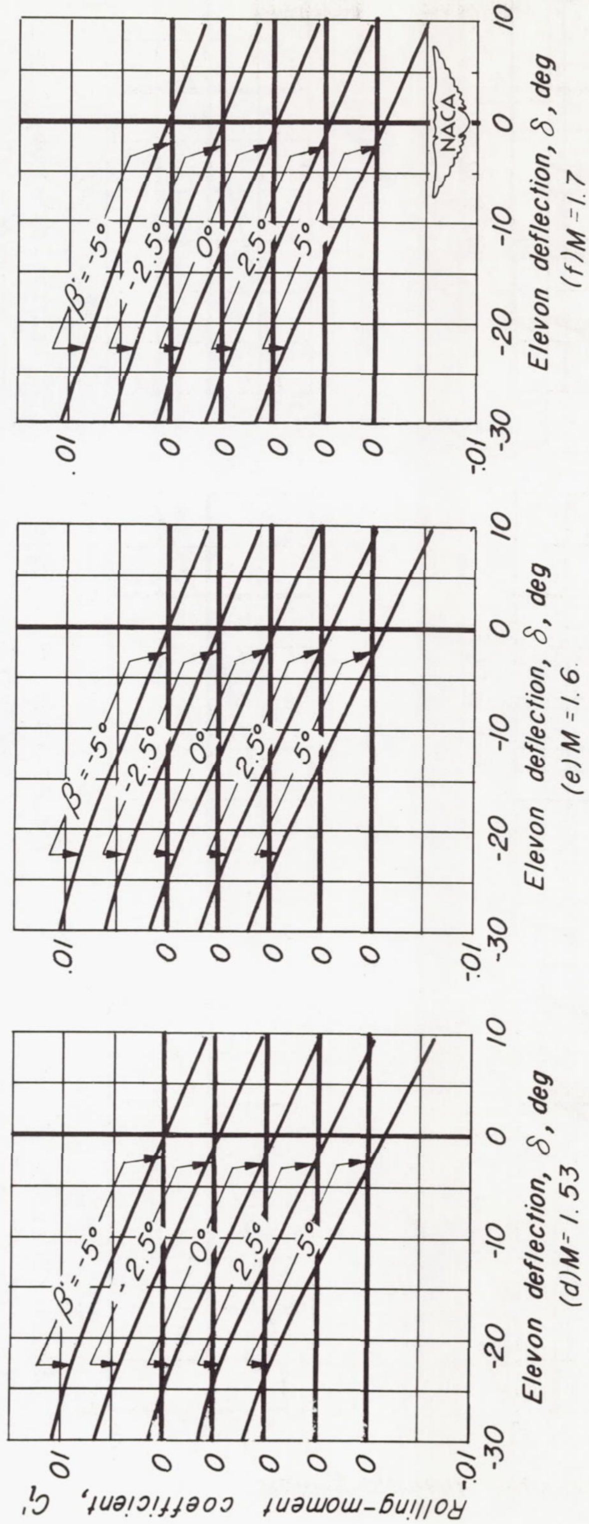


Figure 9.- Concluded.

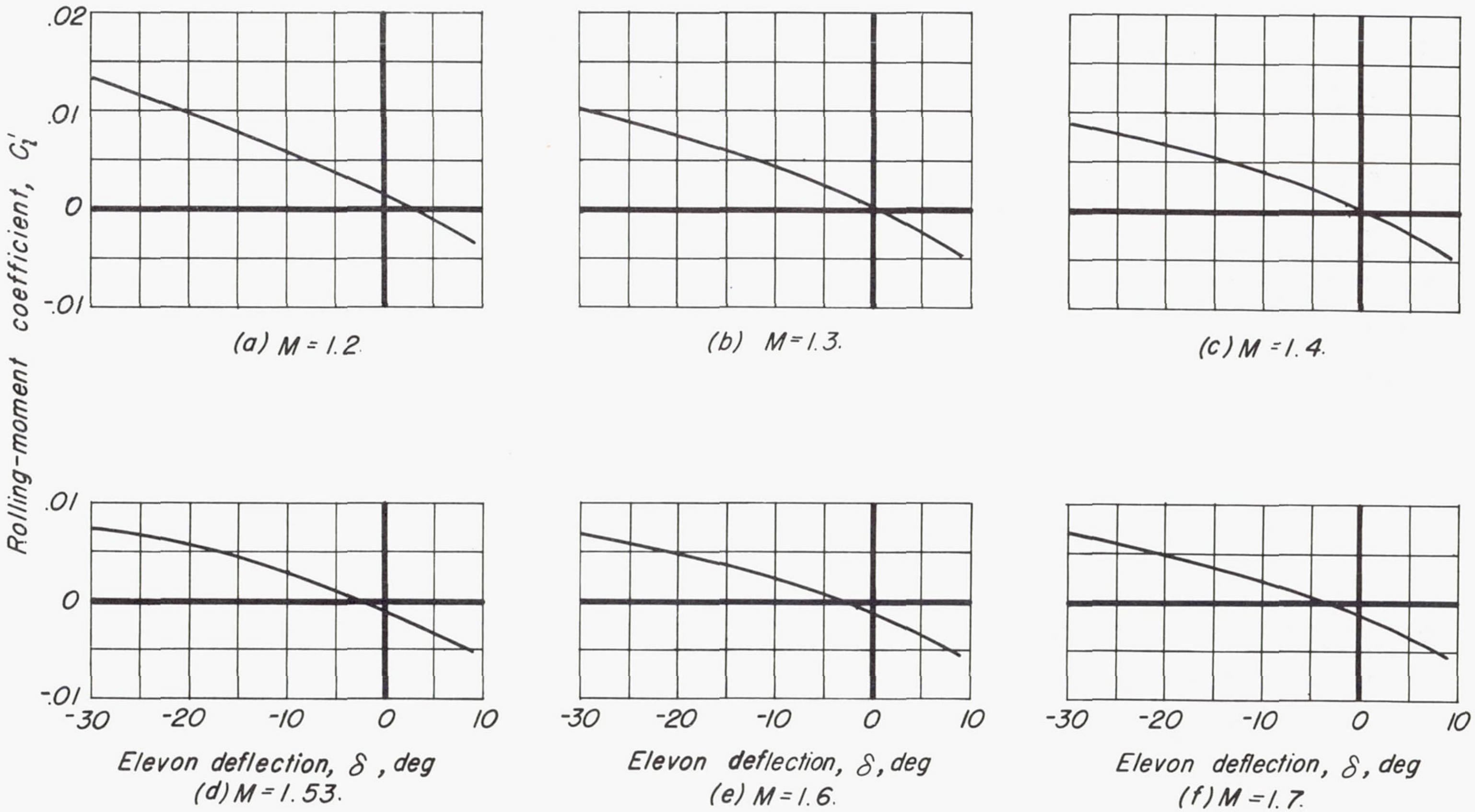


Figure 10.- Variation of rolling-moment coefficient with elevon deflection at various Mach numbers. $\alpha = 5^\circ$, $\beta' = 0^\circ$.

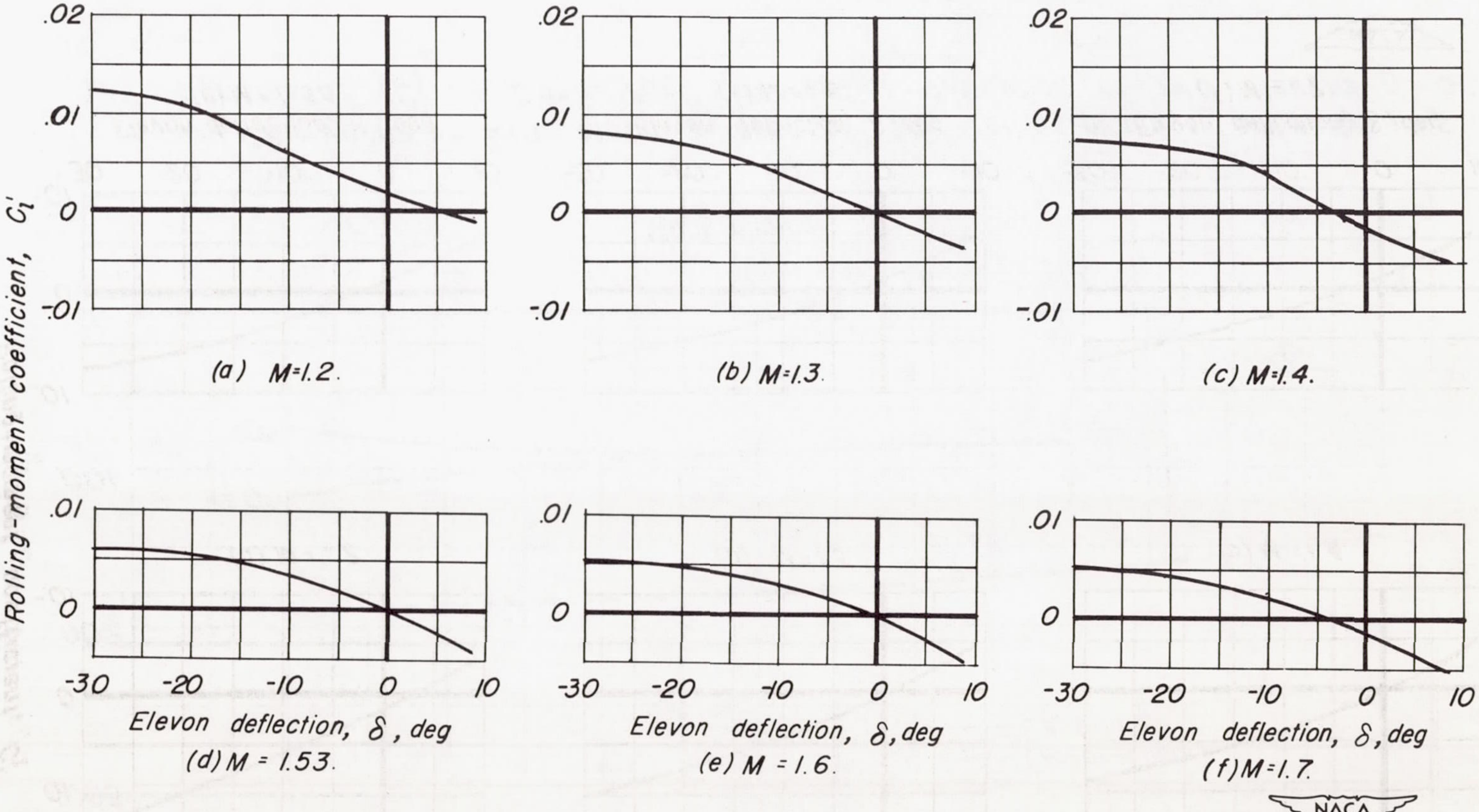


Figure 11.- Variation of rolling-moment coefficient with elevon deflection at various Mach numbers. $\alpha=10°$, $\beta'=0°$.

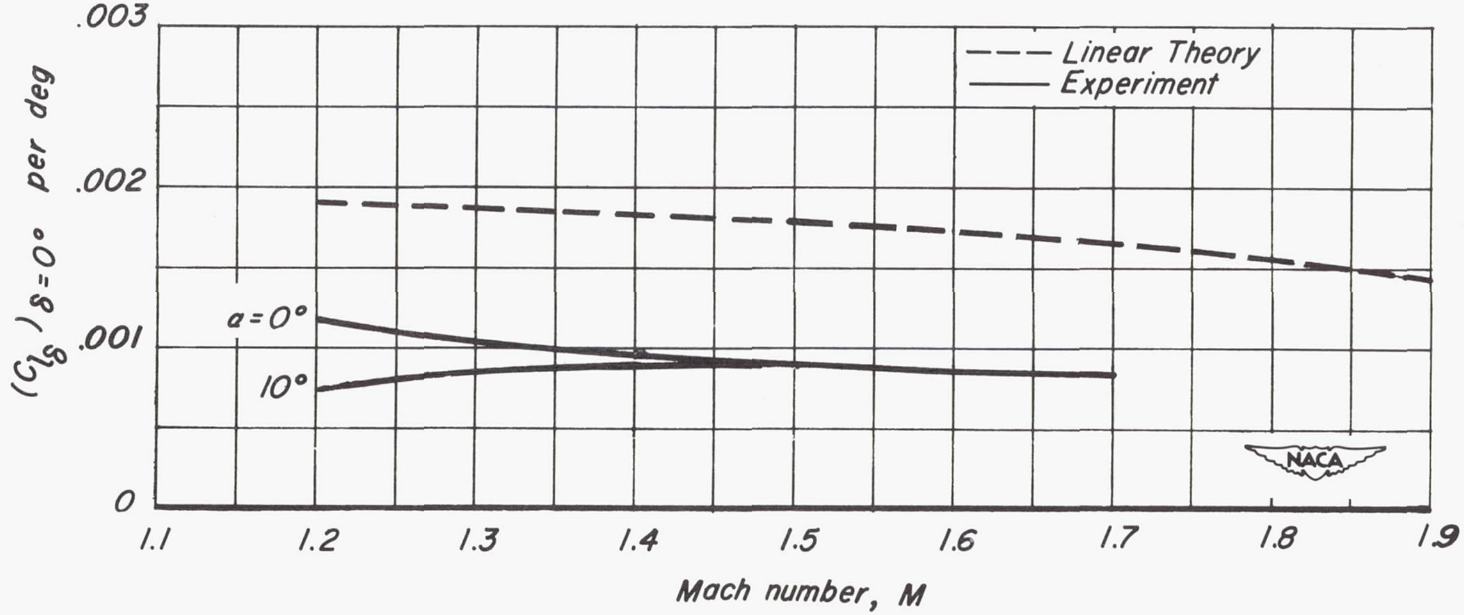


Figure 12.- Variation with Mach number of the rolling-moment- effectiveness parameter, C_{l_δ}. Data for differential deflection of two elevons. $\beta' = 0°$.

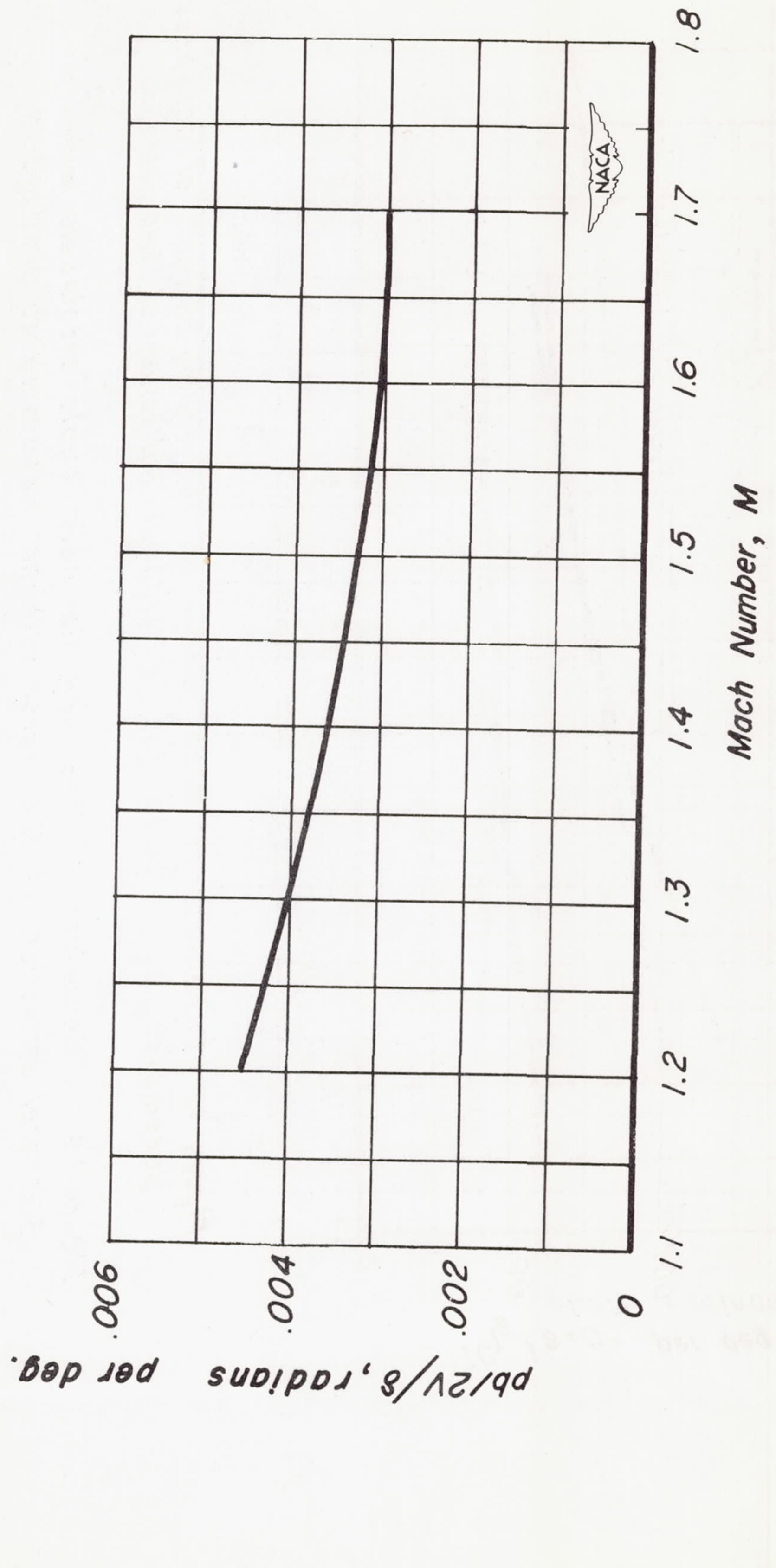


Figure 13. - Variation of the wing-tip helix angle with Mach number. Data for differential deflection of two elevons. $\alpha = 0°$.

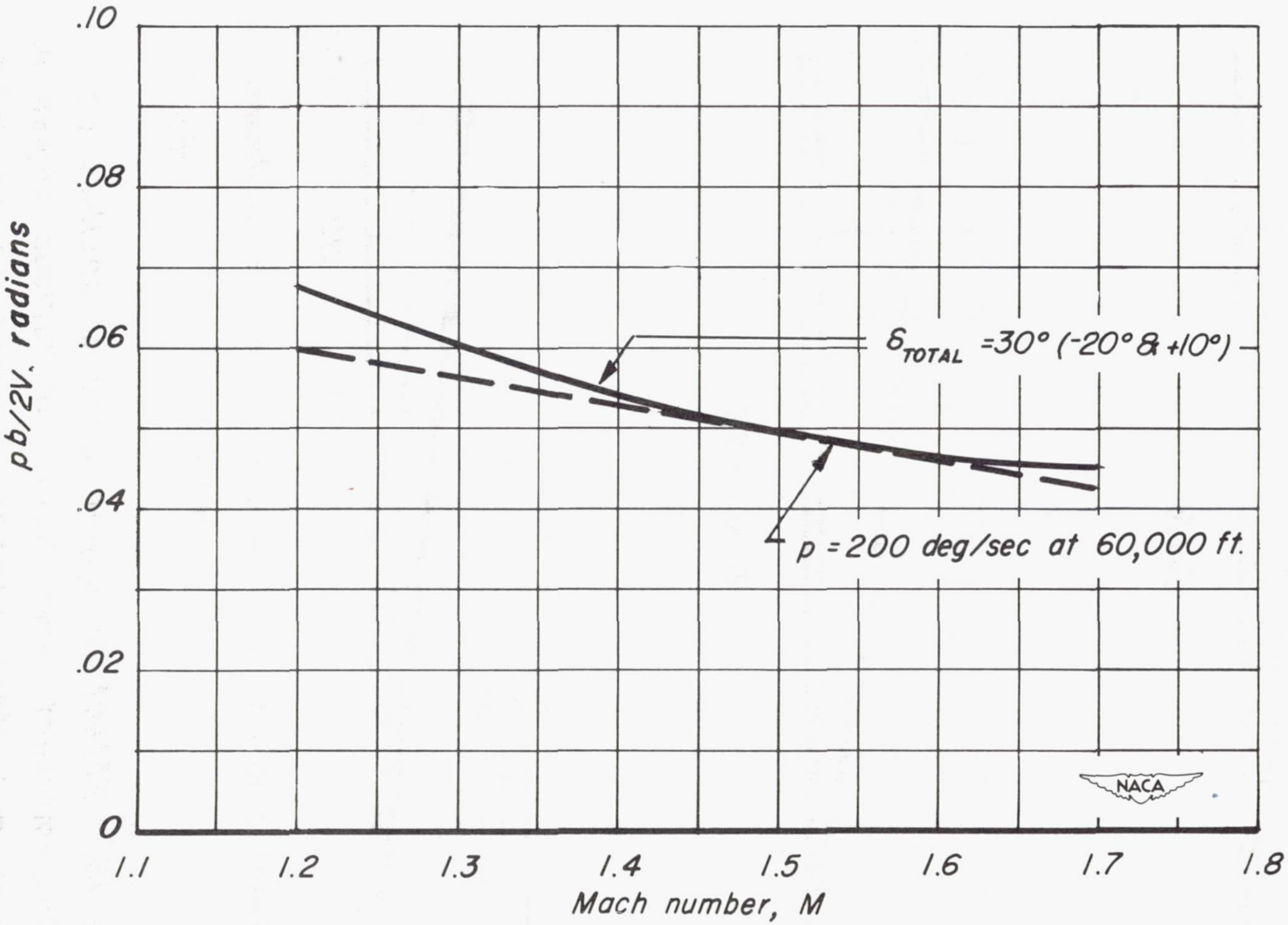


Figure 14.- Comparison of the wing-tip helix angle attainable with 30° total deflection of the elevon with that necessary to produce a wing-tip velocity*of 200° per second for a 40-foot wing span airplane flying at 60,000 feet. $\alpha = 0°$.

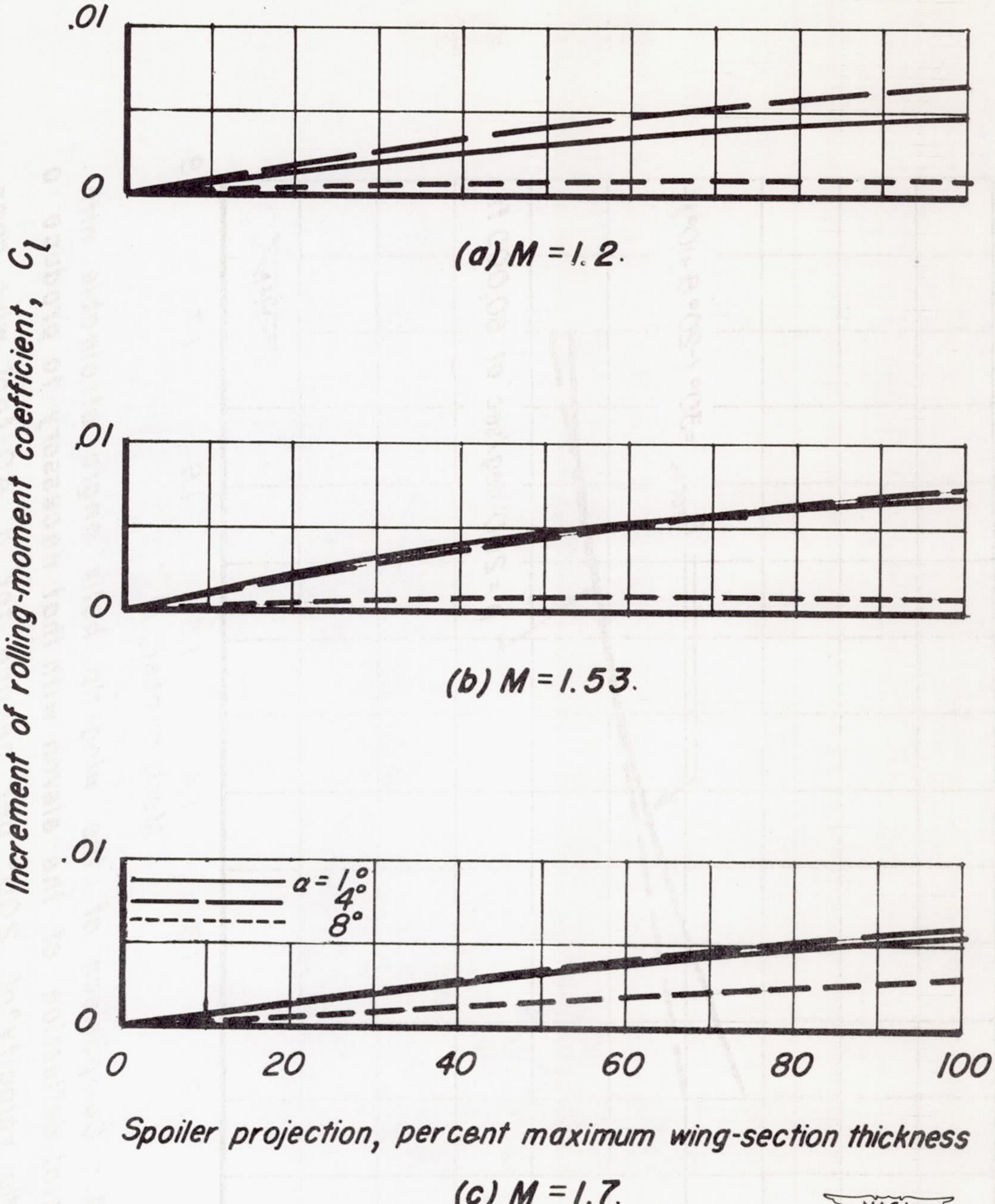


Figure 15. - Effect of upper surface spoilers on rolling-moment coefficient for various angles of attack and Mach number. Spoiler on one wing only.