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COMPARISON OF PITCHING MOMENTS PORDUCED BY PLAIN FLAPS AND BY SPOILERS AND SOME AERODYNAMIC CHARACTERISTICS OF AN NACA 23012 AIRFOIL WITH VARIOUS TYPES OF AILERON

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ADVANCE CONFIDENTIAL REPORT

COMPARISON OF PITCHING MOMENTS PRODUCED BY PLAIN FLAPS AND BY SPOILERS AND SOME AERODYNAMIC CHARACTERISTICS OF AN NACA 23012 AIRFOIL WITH VARIOUS TYPES OF AILERON

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SUMMARY

An analysis and comparison has been made of the pitching-moment characteristics of airfoils with plain flaps and spoilers. Aerodynamic section characteristics of an NACA 23012 airfoil having a retracted slotted flap with a plain, a slot-lip, and a retractable aileron are also presented for a large range of aileron deflections.

The analysis indicated that the pitching moments produced by spoilers were less positive than those produced by plain flaps of equal effectiveness. The data from two isolated cases indicated that the pitching moments created by the spoiler increased less with Mach number than the pitching moments produced by the plain flap. The positive values of the pitching moments produced by both the plain flaps and the spoilers decreased as the devices were located nearer the airfoil leading edge.

INTRODUCTION

The NACA has undertaken a brief investigation of the pitching-moment characteristics caused by various lateral-control devices for application to wing-twist problems in high-speed flight. Pitching-moment data for plain-flap controls have been published previously (see references 1 to 5, for example) and some data for spoiler-type controls have been published in references 5 to 7. The effects of trailing-edge modifications on the pitching-moment characteristics of airfoils with plain flaps have been discussed in reference 8.

Tests in two-dimensional flow of an NACA 23012 airfoil with a plain aileron and with two spoiler-type ailerons (a slot-lip and a retractable aileron) were reported in reference 9, but the pitching-moment data were not presented. The present report gives the section pitching-moment characteristics and other section data for these three arrangements. A brief analysis is also included of various data on the pitching-moment characteristics of airfoils with plain flaps and with spoilers.

COEFFICIENTS AND SYMBOLS

The coefficients and the symbols used herein are defined as follows:

c_l airfoil section lift coefficient (l/qc)

c_{d_o} airfoil section profile-drag coefficient (d_o/qc)

c_m airfoil section pitching-moment coefficient about quarter-chord point of airfoil (m/qc^2)

c_{h_a} aileron section hinge-moment coefficient $\left(h_a/qc_a{}^2\right)$

where

l airfoil section lift

d_o airfoil section profile drag

m airfoil section pitching moment about quarter-chord point

h_a aileron section hinge moment

q dynamic pressure $\left(\frac{1}{2}\rho V^2\right)$

c chord of basic airfoil with flap neutral

c_a chord of aileron

V velocity of free stream

ρ mass density of air

and

α_o angle of attack for airfoil of infinite aspect ratio, degrees

δ_a aileron deflection, degrees; positive when trailing edge moves down

δ_f slotted-flap deflection, degrees; positive when trailing edge moves down

c_s chord of spoiler or retractable aileron

p_s projection from airfoil surface of spoiler or retractable aileron

x distance from airfoil leading edge to flap hinge line or to outer edge of spoiler

$\left(\frac{\partial c_m}{\partial \delta}\right)_{c_l}$ rate of change of pitching-moment coefficient with control deflection at constant lift

$\left(\frac{\partial \alpha_o}{\partial \delta}\right)_{c_l}$ rate of change of angle of attack with control deflection at constant lift

$\left(\frac{\partial c_m}{\partial \alpha_o}\right)_{c_l}$ rate of change of pitching-moment coefficient with effective angle of attack at constant lift

$$\left(\frac{(\partial c_m/\partial \delta)_{c_l}}{(\partial \alpha_o/\partial \delta)_{c_l}}\right)$$

M Mach number (V/a)

a velocity of sound in free stream

APPARATUS, MODEL, AND TESTS

The apparatus, model, and tests are described in reference 9. In brief, the 3- by 7-foot model was built to the NACA 23012 airfoil profile and, when mounted in the Langley 7- by 10-foot tunnel (described in reference 3), completely spanned the test section. The tests were made at a dynamic pressure of 16.37 pounds per square foot, which corresponds to a velocity of about 80 miles per hour and to a test Reynolds number of about 2.19×10^6, based on the chord of the basic airfoil. The effective Reynolds number (for maximum lift coefficients) was about 3.5×10^6, based on a turbulence factor of 1.6 for the Langley 7- by 10-foot tunnel.

The airfoil profile, the slot and flap dimensions, and the arrangements of the plain-flap and spoiler-type ailerons are given in figure 1. The chords of the plain and slot-lip ailerons and the chord of the retractable aileron in its most extended position were 10 percent of the basic airfoil chord. The slotted-flap installation was that designated 2-h in reference 3. All tests reported herein were made with the slotted flap retracted ($\delta_f = 0^\circ$).

METHODS OF ANALYSIS

The primary aerodynamic factor contributing to wing twist during rolling in high-speed flight is the pitching moment produced by the lateral-control device. For normal wings and ailerons, the pitching moment produced by aileron deflection twists the wing in such a way that the lift induced by the twist opposes the lift induced by the aileron deflection and thus effectively reduces the lateral control available. The pitching moment (or the wing twist) produced by a given aileron deflection increases approximately as the square of the speed and at some point the lift induced by the wing twist balances the lift induced by the aileron deflection and the airplane does not roll when the ailerons are deflected. The speed at which the lateral control becomes zero is known as the reversal speed.

In order to judge the relative merits of various lateral-control devices with respect to wing twist, the pitching-moment characteristics must be compared on the basis of equal effectiveness. The pitching-moment parameter used should therefore be based on the change in rolling moment, lift, or effective angle of attack produced by the aileron rather than on the aileron deflection or spoiler projection. The slope $\left(\frac{\partial c_m}{\partial \alpha_o}\right)_{c_l}$ was therefore used to compare all the plain flaps and spoilers on an equal-effectiveness basis, since this parameter indicates the change in pitching-moment coefficient resulting from a unit change in the effective angle of attack of the portion of the wing covered by the aileron.

The slope of the pitching-moment-coefficient curve was taken at constant lift ($c_l \approx 0.1$) because, when the airplane is rolled by the ailerons, the aileron section of the wing operates at nearly constant lift. Although spoiler-type ailerons, since they are used on only one wing at a time, operate farther from conditions of constant lift than the plain-flap ailerons, the parameter at constant lift is still believed to be more nearly representative of actual conditions than a parameter at constant angle of attack.

A logical abcissa against which to plot $\left(\frac{\partial c_m}{\partial \alpha_o}\right)_{c_l}$ for plain flaps would be the flap chord but, when spoiler data must also be presented on a comparable basis, such an abcissa is no longer logical because spoiler chord (or projection) is analogous to flap deflection rather than to flap chord. The data were therefore plotted against the chordwise location of the plain-flap hinge line or of the outer edge of the spoiler. For devices such as the slot-lip ailerons, which were considered to be spoilers, the location used was the average location of the aileron trailing edge over the deflection range considered.

All the finite-span data (references 5 and 6) were converted to section characteristics by use of references 10 and 11. The values of aspect ratio used with the charts of reference 10 in computing section characteristics from the data of reference 6 were corrected for Mach number effects by the method of reference 12. At each value of Mach number, the geometric aspect ratio was multiplied by the factor $\sqrt{1 - M^2}$. This procedure gives an effective reduction in aspect ratio as the Mach number is increased.

RESULTS AND DISCUSSION

Test data.- The aerodynamic section characteristics of an NACA 23012 airfoil having a retracted slotted flap with a plain, a slot-lip, and a retractable aileron are presented in figure 2. The lift and drag (or rolling-moment and yawing-moment) characteristics and the hinge-moment characteristics have been amply discussed in reference 9. The pitching-moment data presented in figure 2, together with other published and unpublished data for Mach numbers up to about 0.3, have been summarized and are presented in figure 3.

Pitching moments produced by plain flaps.- The experimental data on the pitching moments produced by plain flaps shown in figure 3 agree very well with values computed from Glauert's thin-airfoil theory (references 1 and 2) both in magnitude and in variation with x/c. These data indicate that, for equal changes in effective angle of attack (equal rolling moments), wide-chord flaps produced smaller pitching moments than narrow-chord flaps and, consequently, that the use of wide-chord flaps would allow the attainment of higher values of the reversal speed. The use of wide-chord flaps, however, will be limited by whether their hinge moments can be well enough balanced to produce reasonable values of stick force.

It should be noted that the data of reference 3 indicate that the pitching moments produced by plain flaps may be reduced by increasing the angle between the upper and lower surfaces of the flap at the trailing edge.

Pitching moments produced by spoilers.- The experimental data on the pitching moments produced by spoilers form a relatively smooth curve (fig. 3) and indicate that, for equal effectiveness, the spoiler located nearest the airfoil leading edge produces the smallest positive values of $\left(\frac{\partial c_m}{\partial \alpha_0}\right)_{c_l}$. With a spoiler located ahead of about 0.45c, the wing twist might augment rather than reduce the rolling effectiveness. The use of spoilers located so near the airfoil leading edge, however, is not recommended since many previous wind-tunnel and flight investigations have indicated that the tendencies toward lag and erratic action increase as the spoiler is placed nearer the airfoil leading edge.

The locations of the spoiler installations found acceptable have varied from about 0.60c to about 0.85c.

Comparison of pitching moments produced by plain flaps and spoilers.- The data presented in figure 3 indicate that the pitching moments produced by plain flaps and spoilers have about equal variations with flap or spoiler chordwise location and that the values of $\left(\frac{\partial c_m}{\partial \alpha_o}\right)_{c_l}$ are less positive for the spoilers than for the plain flaps. When a comparison is made at chordwise locations normally used - that is, 0.70c to 0.75c for spoilers and 0.80c to 0.85c for plain flaps, the pitching moments produced by spoilers are about one-half or less of the pitching moments produced by plain flaps of the same effectiveness.

Mach number effects.- Data on the effects of Mach number on the pitching moments produced by control surfaces are relatively scarce. A comparison is presented in figure 4, however, of the effects of Mach number on the pitching moments produced by a spoiler aileron on the wing of reference 6 and on the pitching moments produced by a plain flap on an NACA 66,1-115 airfoil tested in the Langley 8-foot high-speed tunnel. The pitching moments produced by the plain flap, in addition to being larger than those produced by the spoiler, also increase with Mach number at a rate greater than that indicated by the Glauert-Prandtl factor $\frac{1}{\sqrt{1 - M^2}}$. The pitching moments produced by the spoiler, however, increase at a rate slightly less than that indicated by $\frac{1}{\sqrt{1 - M^2}}$ over most of the Mach number range tested. Although the data shown in figure 4 are not strictly comparable and are for two isolated cases, there appears to be a possibility that Mach number effects may be smaller on pitching moments produced by spoilers than on pitching moments produced by plain flaps.

CONCLUSIONS

An analysis of data on the pitching-moment characteristics of airfoils with plain flaps and spoilers indicated the following conclusions:

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1. The pitching moments produced by spoilers were less positive than those produced by plain flaps of equal effectiveness.

2. The positive values of the pitching moments produced by both the plain flaps and the spoilers decreased as the devices were located nearer the airfoil leading edge.

3. The data from two isolated cases indicated that an increase in Mach number caused less increase in the pitching moments produced by the spoiler than in those produced by the plain flap.

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REFERENCES

1. Ames, Milton B., Jr., and Sears, Richard I.: Determination of Control-Surface Characteristics from NACA Plain-Flap and Tab Data. NACA Rep. No. 721, 1941.

2. Glauert, H.: Theoretical Relationships for an Aerofoil with Hinged Flap. R. & M. No. 1095, British A.R.C., 1927.

3. Wenzinger, Carl J., and Harris, Thomas A.: Wind-Tunnel Investigation of an N.A.C.A. 23012 Airfoil with Various Arrangements of Slotted Flaps. NACA Rep. No. 664, 1939.

4. Purser, Paul E., and Riebe, John M.: Wind-Tunnel Investigation of Control-Surface Characteristics. XV - Various Contour Modifications of a 0.30-Airfoil-Chord Plain Flap on an NACA 66(215)-014 Airfoil. NACA ACR No. 3L20, 1943.

5. Purser, Paul E., and Turner, Thomas R.: Wind-Tunnel Investigation of Perforated Split Flaps for Use as Dive Brakes on a Rectangular NACA 23012 Airfoil. NACA ACR, July 1941.

6. Laitone, Edmund V.: An Investigation of the High-Speed Lateral-Control Characteristics of a Spoiler. NACA ACR No. 4C23, 1944.

7. Shortal, J. A.: Effect of Retractable-Spoiler Location on Rolling- and Yawing-Moment Coefficients. NACA TN No. 499, 1934.

8. Purser, Paul E., and Johnson, Harold S.: Effects of Trailing-Edge Modifications on Pitching-Moment Characteristics of Airfoils. NACA CB No. L4I30, 1944.

9. Wenzinger, Carl J., and Bamber, Millard J.: Wind-Tunnel Tests of Three Lateral-Control Devices in Combination with a Full-Span Slotted Flap on an N.A.C.A. 23012 Airfoil. NACA TN No. 659, 1938.

10. Weick, Fred E., and Jones, Robert T.: Résumé and Analysis of N.A.C.A. Lateral Control Research. NACA Rep. No. 605, 1937.

11. Pearson, Henry A., and Anderson, Raymond F.: Calculation of the Aerodynamic Characteristics of Tapered Wings with Partial-Span Flaps. NACA Rep. No. 665, 1939.

12. Goldstein, S., and Young, A. D.: The Linear Perturbation Theory of Compressible Flow, with Applications to Wind-Tunnel Interference. R. & M. No. 1909, British A.R.C., 1943.

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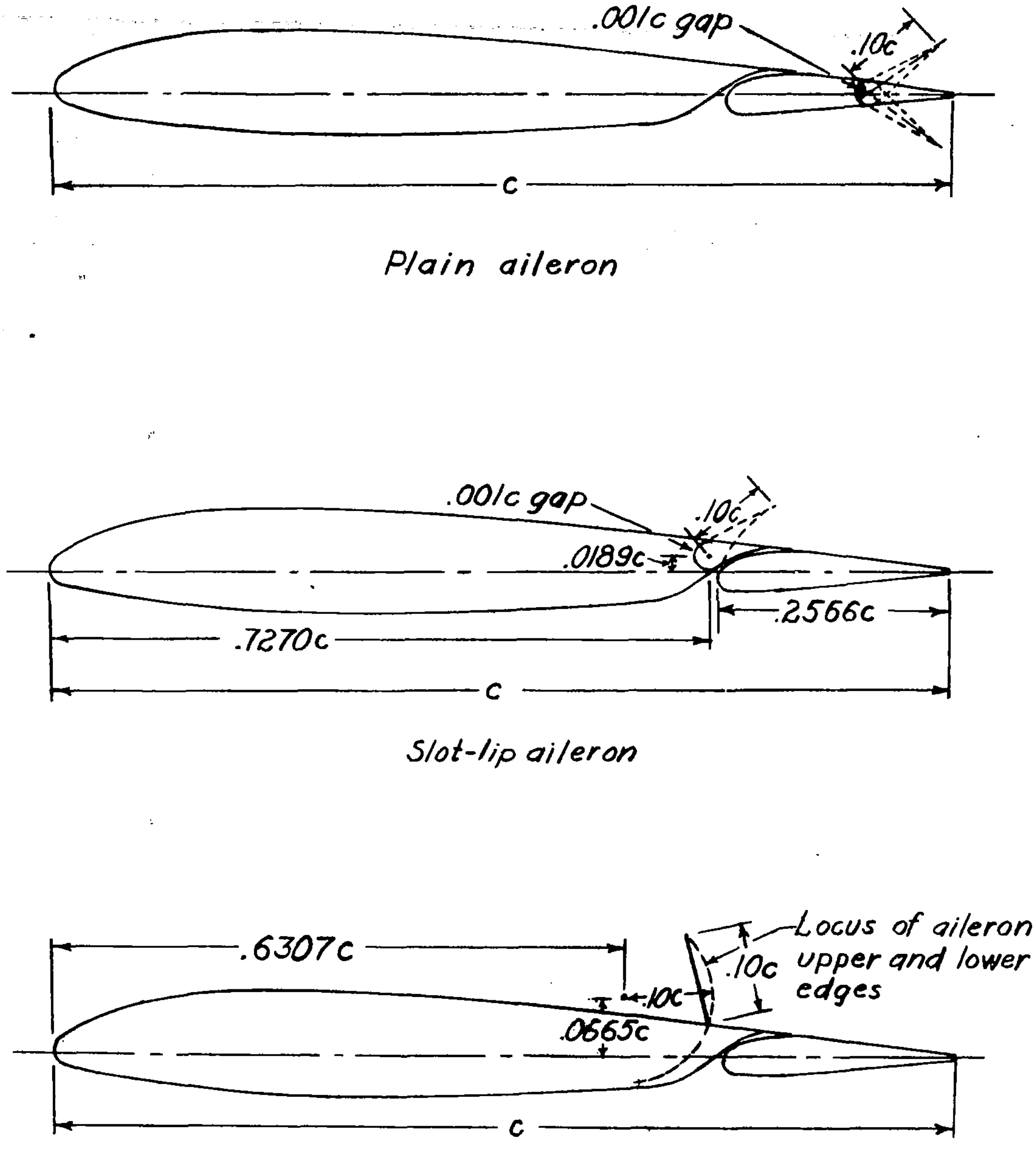

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Figure 1.- The NACA 23012 airfoil with various types of aileron and with a slotted flap.

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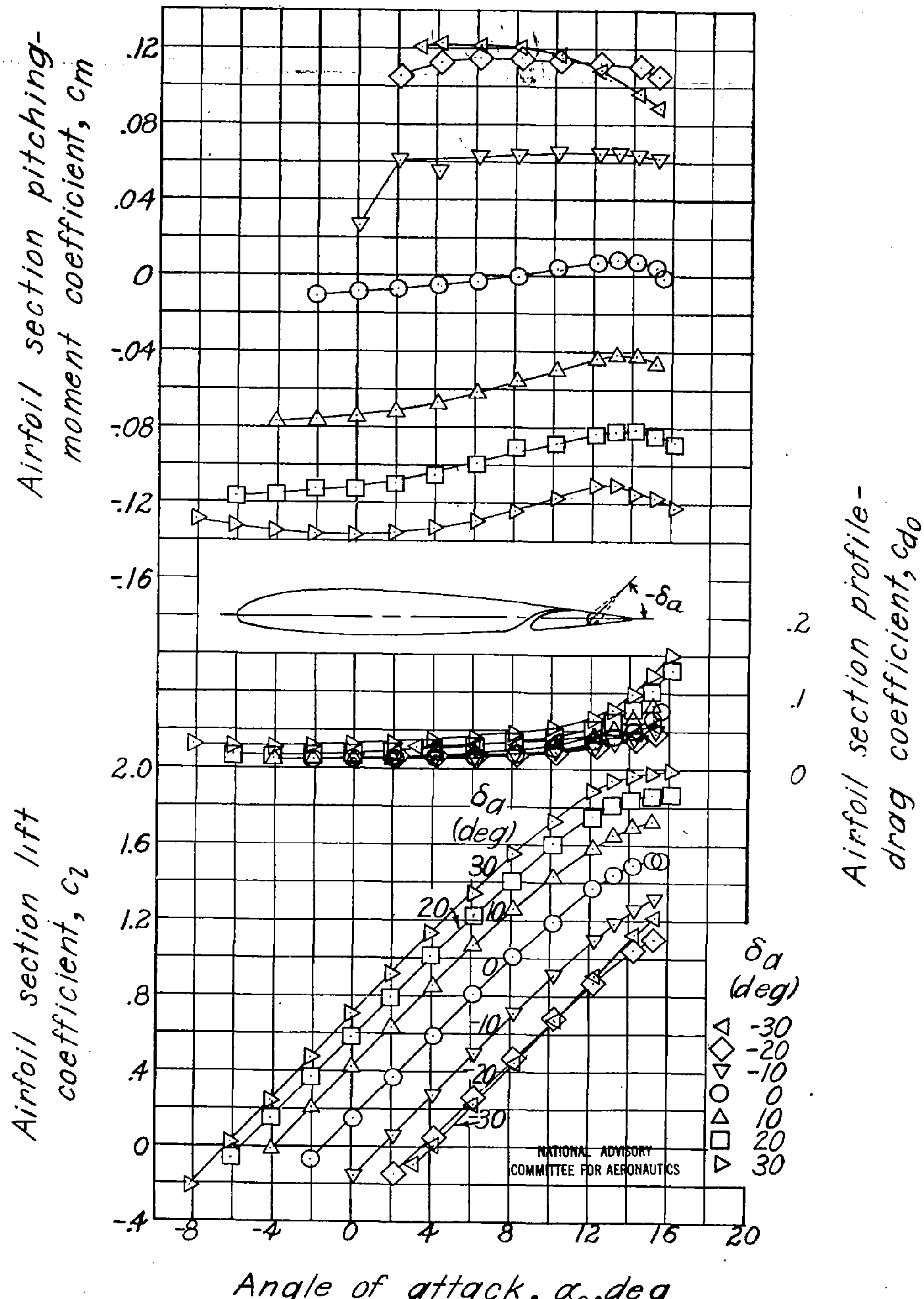

(a) Plain aileron; c_a=0.10c.

Figure 2 .-Aerodynamic section characteristics of NACA 23012 airfoil with various types of aileron. δ_f=0°

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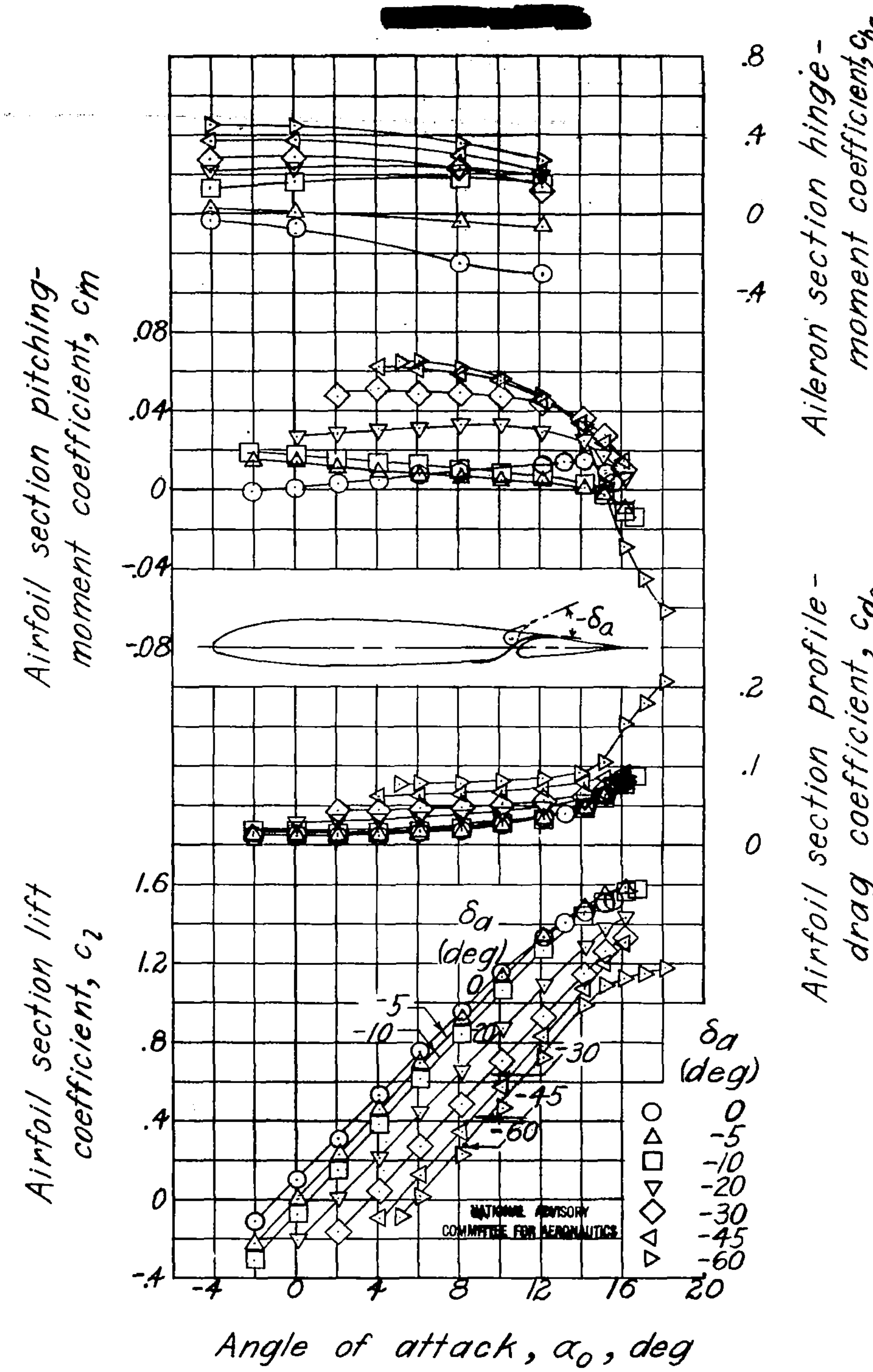

(b) Slot-lip aileron; $c_a = 0.10c$.
Figure 2.-Continued.

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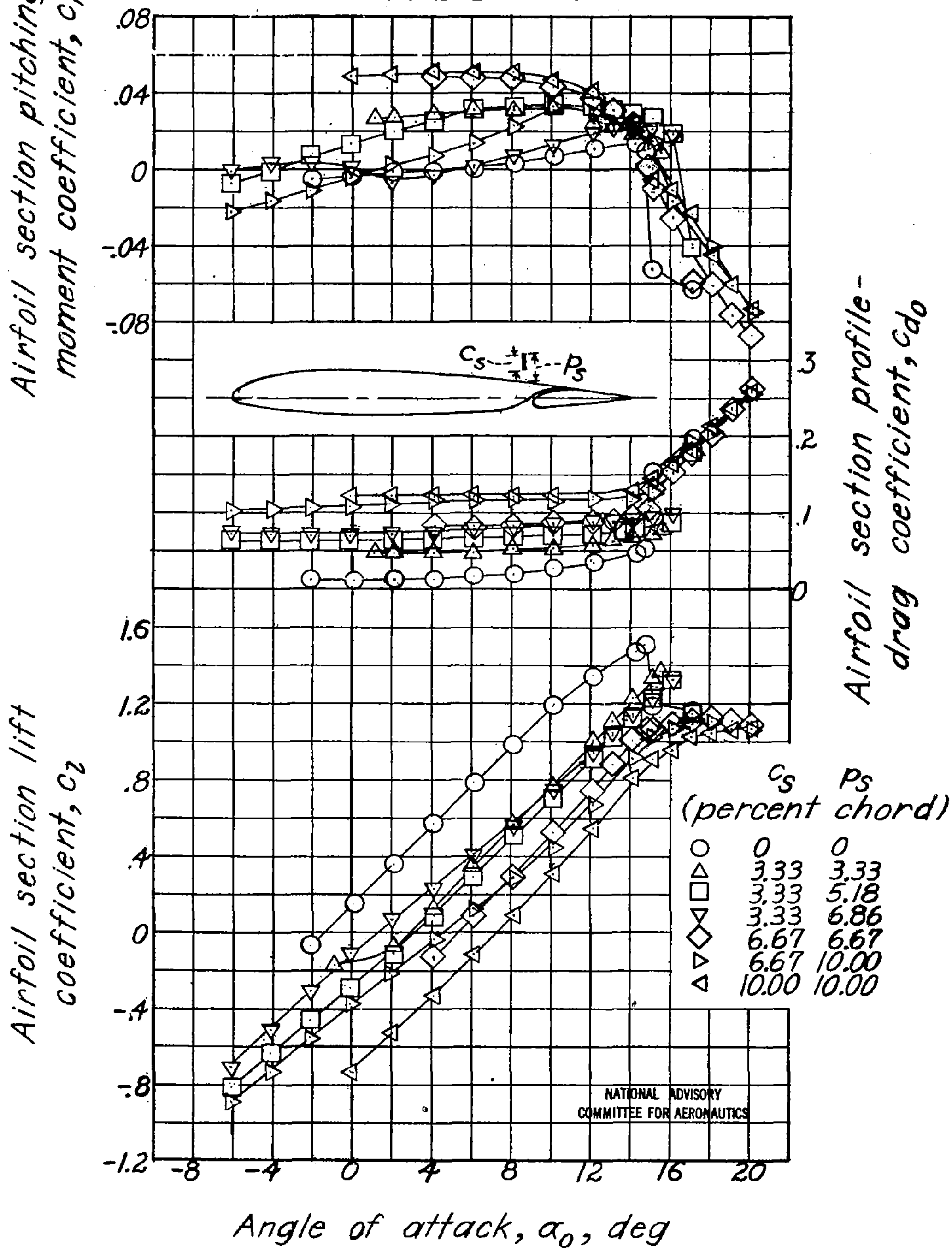

(c) Retractable aileron.
Figure 2.- Concluded.

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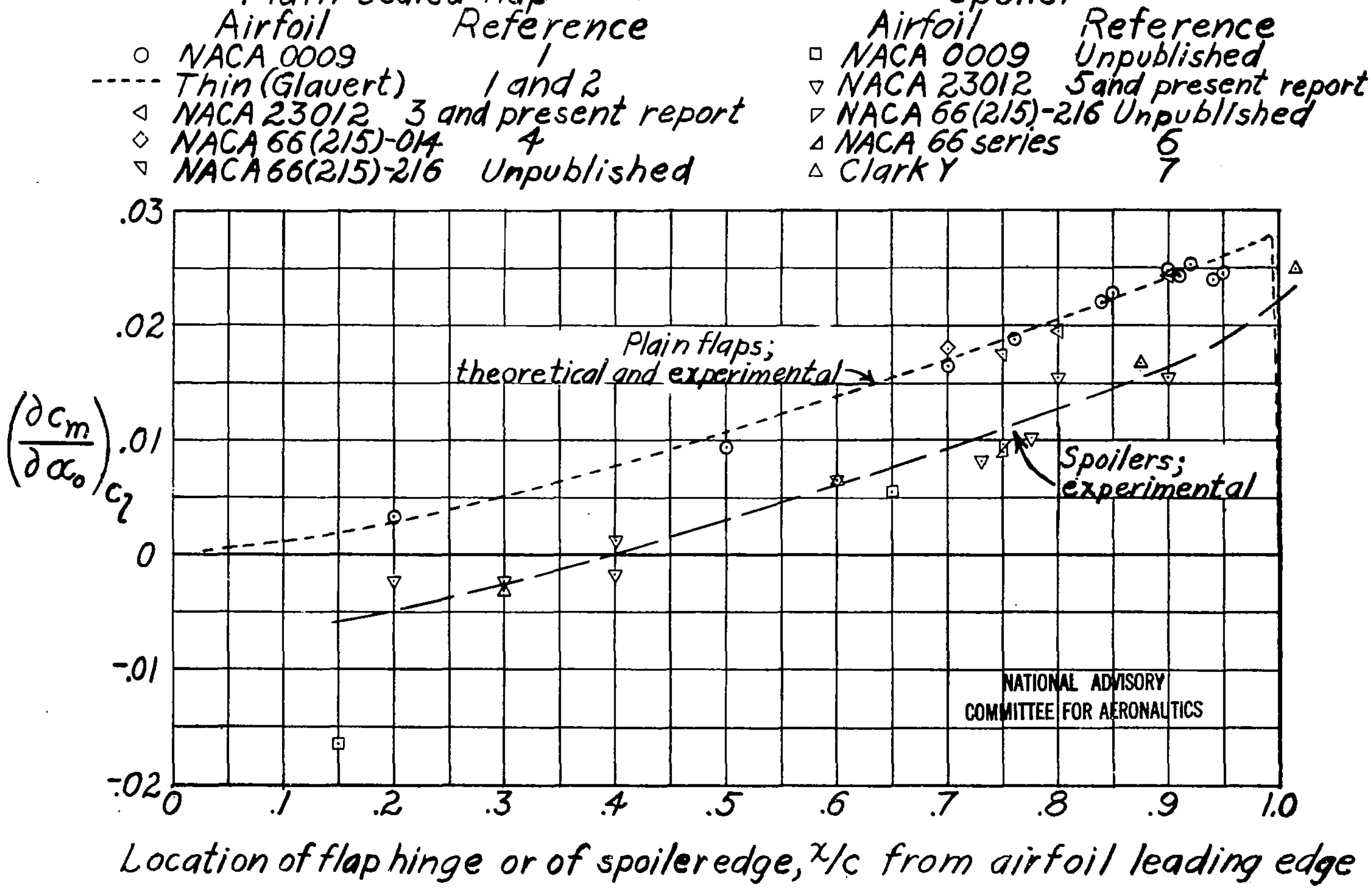

Figure 3.- Effect of chordwise location on the pitching moments produced by plain sealed flaps and by spoilers. $M=0.1$ to 0.3.

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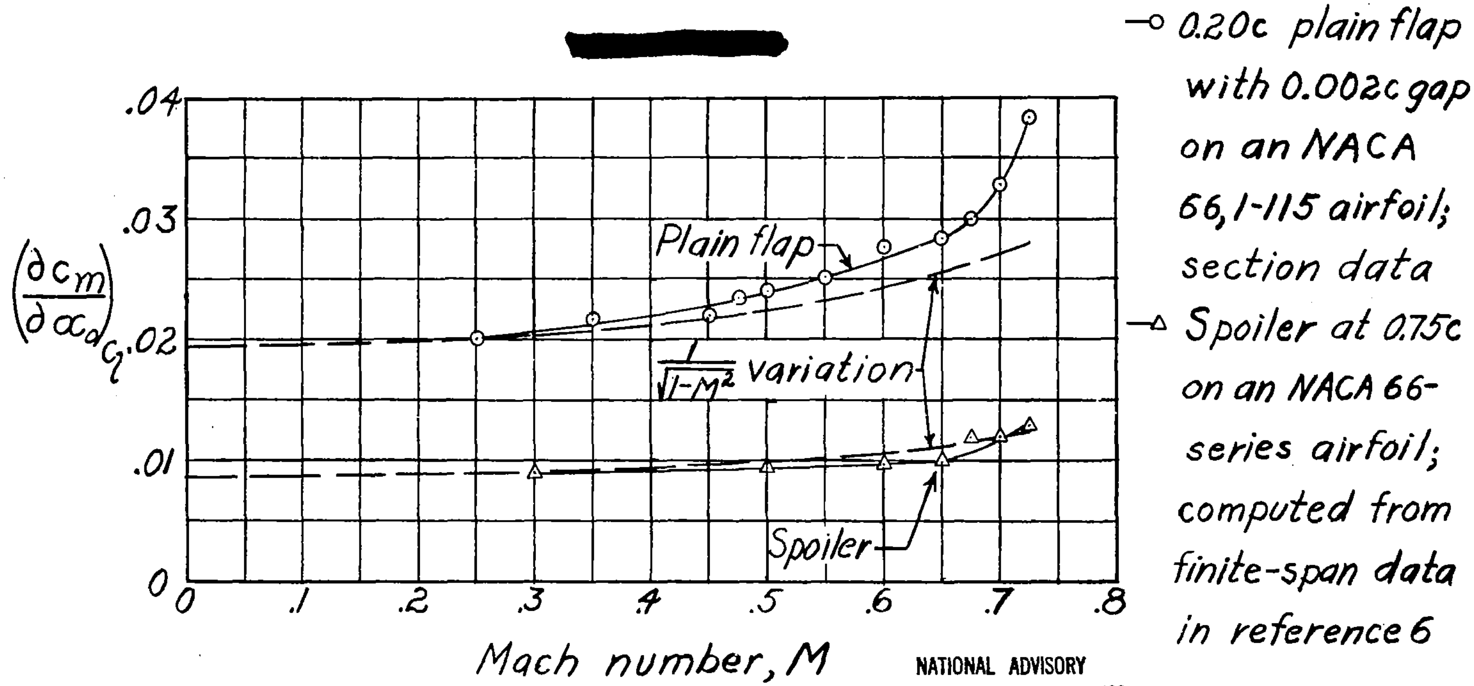

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Figure 4.- Effect of Mach number on the pitching moments produced by a plain flap and by a spoiler.

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