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TECHNICAL NOTE

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INVESTIGATION OF EFFECT OF SPAN, SPANWISE LOCATION, AND CHORDWISE LOCATION OF SPOILERS ON LATERAL CONTROL CHARACTERISTICS OF A TAPERED WING

By Jack Fischel and Vito Tamburello

Langley Memorial Aeronautical Laboratory
Langley Field, Va.

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INVESTIGATION OF EFFECT OF SPAN, SPANWISE LOCATION, AND CHORDWISE LOCATION OF SPOILERS ON LATERAL CONTROL CHARACTERISTICS OF A TAPERED WING

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SUMMARY

A wind-tunnel investigation was made of the effect of span, spanwise location, and chordwise location of spoilers on the lateral control characteristics of an unflapped semispan wing equipped with a simple spoiler having a projection 5 percent of the chord. In determining the effect of spoiler span and spanwise location, the spoiler was mounted at the 70-percent-chord station with the spoiler span increasing from 10 percent of the semispan to 100 percent of the semispan. The chordwise investigation involved moving a 50-percent-semispan spoiler from the 50-percent-chord station to the 80-percent-chord station.

Curves are presented showing the variation of rolling-moment and yawing-moment effectiveness with spoiler span. The results indicated that the variation of rolling-moment effectiveness with spoiler span showed a trend similar to that of ailerons for a geometrically similar wing. This similarity suggests the possibility of employing aileron design data in the preliminary design of spoilers at low angles of attack. For a more exact estimation of the spoiler rolling moment expected at large angles of attack, however, consideration should be given to the change in effectiveness with angle of attack. The spanwise yawing-moment effectiveness for ailerons and spoilers showed the same trend with spanwise location; but because the spoilers gave favorable yawing moments, the spoiler data differed in sign from the aileron data. When the 50-percent-semispan spoiler was moved rearward from the 50-percent-chord station to the 80-percent-chord station on the unflapped wing, both the rolling-moment and yawing-moment coefficients were reduced.

INTRODUCTION

The use of spoilers as lateral-control devices has long been a subject of research for the National Advisory Committee for Aeronautics. Some notable merits of spoilers, such as control at

high angles of attack, favorable yawing moments, and the practicable use of full-span flaps with spoiler arrangements, have been known for some time. In addition, it has been found that spoilers generally provide greater rolling moments when full-span flaps are deflected, particularly when the spoiler moves through an opening (spoiler slot) in the wing. These and other aerodynamic characteristics of spoilers, such as spoiler lag, have been studied and presented in numerous papers. (See references 1 to 5.) Several flight investigations have been made to illustrate the practicability of employing spoilers on airplanes equipped with full-span flaps in order to secure lateral control. (See references 6 to 8.) An investigation reported in reference 9 suggests the use of spoilers in front of ordinary ailerons in order to increase the rolling moments and to decrease the aileron hinge moments in high-speed flight.

The present investigation was made in the Langley 300 MPH 7- by 10-foot tunnel to ascertain the effect of spanwise and chordwise location of spoilers on spoiler effectiveness. An attempt is made to determine whether present aileron design data (such as found in reference 5) can be used to design spoiler-type ailerons. Tests were made with a semispan wing of a 50-percent-semispan spoiler varying in position from the 50-percent-chord station to the 80-percent-chord station, whereas other tests included spoilers mounted at the 70-percent-chord station with the spoiler span increasing from 10 percent of the semispan to 100 percent of the semispan in 10-percent increments. Additional tests were made to study the effect of gaps between spoiler segments.

MODEL AND APPARATUS

The semispan wing was mounted in the Langley 300 MPH 7- by 10-foot tunnel as a reflection-plane model, that is, with its root chord adjacent to one of the tunnel walls (fig. 1). The wing was supported entirely by two struts which, in turn, were mounted on the tunnel balance system. There was a gap of approximately 1/16 inch between the tunnel wall and the root end of the model.

The semispan wing model was built to the dimensions shown in figure 2 and had an NACA 4420 airfoil section at the root and an NACA 4410 airfoil section at the tip. The spoilers were of triangular cross section and were mounted on the wing as shown in figure 2 with the front face of the spoilers approximately normal to the wing surface. The height of all the spoilers measured 5 percent of the airfoil chord, and the spoilers were cut into segments 10 percent of the model semispan.

TESTS

Most of the tests were run at a dynamic pressure of 99 pounds per square foot, which corresponds to a velocity of about 207 miles per hour or a Mach number of 0.27 under standard sea-level conditions. This velocity corresponds to a Reynolds number of about 2.69×10^6 based on a mean aerodynamic chord of 1.604 feet. Additional tests were made with Mach numbers ranging from 0.13 to 0.39, corresponding to Reynolds numbers of 1.40×10^6 to 3.74×10^6, respectively.

The angles of attack for all tests ranged from about -6° to the stall. In the spanwise investigation, three systems of testing were employed with the spoiler mounted at the 70-percent-chord station. The first system involved increasing the spoiler span in 10-percent increments with the outboard end of the spoiler fixed at the wing tip. For simplicity, these spoilers are hereinafter referred to as "outboard spoilers." The second system involved the same process; however, the inboard end of the spoiler was fixed at the wing root. These spoilers are referred to as "inboard spoilers." In the third system, several isolated spoiler spans were tested (some with large gaps between spoiler segments) and are referred to as "isolated spoilers." Complete data are not presented herein for the inboard and isolated spoilers, but reference will be made to the rolling-moment data for these two types of spoilers.

For the chordwise investigation a 50-percent-semispan outboard spoiler was used and tested at the 50-, 60-, 65-, 70-, 75-, and 80-percent-chord stations.

Some additional tests were made with the 50-percent-semispan outboard spoiler mounted at the 70-percent-chord station. These tests involved cutting the spoiler into five equal parts in order to provide gaps of 0.14-, 0.54-, and 1.08-percent semispan between spoiler segments (fig. 2).

SYMBOLS AND CORRECTIONS

C_L lift coefficient $\left(\frac{L}{qS}\right.$ where L is twice lift of semispan model$\left.\right)$

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

C_m pitching-moment coefficient $\left(\frac{M}{qS\bar{c}}\right.$ where M is twice pitching moment of semispan model$\left.\right)$

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

C_n yawing-moment coefficient $\left(\frac{N}{qSb}\right)$

$\bar{c}$ wing mean aerodynamic chord (M.A.C.), feet

$$\left(\frac{2}{S}\int_0^{b/2} c^2\,dy\right)$$

c local wing chord, feet

y distance from plane of symmetry, feet

S twice area of semispan model, square feet

b twice span of semispan model, feet

D twice drag of semispan model, pounds

L rolling moment due to spoiler measured about wind axis in plane of symmetry, foot pounds

N yawing moment due to spoiler measured about wind axis in plane of symmetry, foot pounds

α angle of attack with respect to chord line, degrees

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

V free-stream velocity, feet per second

ρ mass density of air, slugs per cubic foot

A aspect ratio

λ taper ratio $\left(\frac{\text{Tip chord}}{\text{Root chord}}\right)$

δ control deflection, degrees

$\frac{\Delta\alpha}{\Delta\delta}$ change in effective angle of attack caused by control deflection; aileron effectiveness factor

$\Delta\alpha$ change in effective angle of attack, degrees

M Mach number

R Reynolds number

$\frac{C_l}{\Delta\alpha}$ rolling-moment coefficient due to a unit change in effective angle of attack over part of wing span occupied by control surface; rolling-moment effectiveness parameter

$\frac{C_n}{\Delta\alpha}$ yawing-moment coefficient due to a unit change in effective angle of attack over part of wing span occupied by control surface; yawing-moment effectiveness parameter

The forces and moments are presented about the wind axes with the origin at the 30-percent point of the root chord on the chord plane.

The rolling-moment and yawing-moment coefficients represent the aerodynamic moments on a complete wing due to the deflection of the spoiler on one semispan wing. The lift, drag, and pitching-moment coefficients represent the aerodynamic effects that occur on the complete wing as a result of the deflection of the spoilers on both semispan wings.

Jet-boundary corrections were applied to the test data with the use of reference 10. The effects of the jet boundaries became magnified for model configurations having spoiler spans near the reflection plane. Blockage corrections were also applied to the test data by methods of reference 11. The data were not corrected for the tare and interference effects of the model support system.

DISCUSSION

Plain-Wing Characteristics

Lift, drag, and pitching-moment characteristics of the plain wing are presented in figure 3. The value of the lift-curve slope $dC_L/d\alpha$ (0.089) agreed very well with the theoretical value (0.090) for a wing of the same aspect ratio as that of the present wing. (See reference 12.)

Spanwise Investigation

Characteristics of outboard spoilers.- Results of the outboard-spoiler investigation (fig. 4) indicated that increasing the spoiler

span increased the rolling-moment coefficients for spoiler spans up to 0.90b/2 at angles of attack of about 0° and indicated that these increments in rolling-moment coefficient decreased with the larger spoiler spans. The rolling moment produced by a given spoiler remained fairly constant over a large part of the angle-of-attack range but began to decrease at an angle of attack of about 6°, at which point flow separation is believed to occur. Beyond that point, the rolling moment produced by a given spoiler span was greatly diminished.

The yawing-moment coefficients produced by the spoilers were favorable (having the same sign as the rolling-moment coefficients) and increased with spoiler span. As the angle of attack increased, however, the yawing moments approached zero for all cases.

As indicated in reference 2 for rearward spoiler locations, the presence of spoilers produces stalling moments. Figure 4 indicates that the stability (as indicated by the slope of the pitching-moment-coefficient curve against angle of attack) increased as larger spoiler spans were used.

Drag was found to vary linearly with spoiler span. This variation was also generally true of the pitching-moment and lift coefficients. Figure 4 also indicates that the effect of spoilers on pitching moment and drag decreases as the angle of attack increases.

Variation of spoiler effectiveness with spanwise location.- In order to determine the possibility of preparing one design chart of spoiler effectiveness for various spanwise locations from data obtained by the three systems of testing spoilers employed in the present investigation, the rolling-moment coefficients for given spoiler spanwise locations as calculated from the data for spoilers extending inboard from the tip (outboard spoilers) are compared in figure 5 with the measured rolling-moment coefficients of spoilers extending outboard from the root (inboard spoilers) or mounted in isolated locations along the span (isloated spoilers). The rolling moments calculated from the outboard-spoiler data were obtained by intersubtraction of the rolling-moment-coefficient data of figure 4 for the spoiler span and spanwise location concerned. The data of figure 5 show rather close agreement between the values of C_l obtained from inboard and isolated spoilers and the values of C_l calculated from outboard-spoiler data for the same spoiler location and indicate that the rolling effectiveness for various spoiler spanwise locations may be computed from one design chart.

Such a design chart showing the variation of rolling-moment effectiveness parameter and yawing-moment effectiveness parameter $C_l/\Delta\alpha$ and $C_n/\Delta\alpha$, respectively, with spoiler span and spanwise

location is presented in figure 6. The rolling-effectiveness curves were obtained from both the inboard-spoiler and the outboard-spoiler data, whereas the yawing-effectiveness curves were obtained only from the outboard-spoiler data. The data for spoilers of any span are computed by the following equations:

$$\frac{C_l}{\Delta\alpha} = \left(\frac{C_l}{\Delta\alpha}\right)_{\text{full-span spoiler}} \left(\frac{C_{l_{\text{partial-span spoiler}}}}{C_{l_{\text{full-span spoiler}}}}\right)$$

$$\frac{C_n}{\Delta\alpha} = \left(\frac{C_n}{\Delta\alpha}\right)_{\text{full-span spoiler}} \left(\frac{C_{n_{\text{partial-span spoiler}}}}{C_{n_{\text{full-span spoiler}}}}\right)$$

The curves of figure 6 show the rolling-moment and yawing-moment coefficients produced by a unit change of angle of attack over the part of the wing spanned by the spoiler. Although the curves show that $C_l/\Delta\alpha$ increases somewhat with angle of attack for a given spoiler span and projection, the change in effective angle of attack $\Delta\alpha$ over a given spoiler span produced by a spoiler depends on the wing angle of attack so that the final rolling-moment coefficient may become less as α increases. In the present investigation $\Delta\alpha$ was found to decrease as α increased. The yawing-moment coefficients are seen to decrease with an increase in angle of attack, which tends to make the yawing moment less favorable.

Comparison of effectiveness parameters $C_l/\Delta\alpha$ and $C_n/\Delta\alpha$ between spoilers and ailerons for various spanwise locations.- The effectiveness parameters $C_l/\Delta\alpha$ and $C_n/\Delta\alpha$ of a wing equipped with ailerons (reference 5) and having the same geometric characteristics as the present wing are compared in figure 7 with the effectiveness parameters obtained with spoilers in the present investigation.

The rolling-effectiveness curves for both the ailerons and the spoilers show the same trend with spanwise location but differ slightly in magnitude. It should be noted that the aileron rolling effectiveness parameters are theoretical, and the discrepency shown in figure 7 between spoiler and aileron rolling effectiveness parameters is no greater than that shown in reference 5 between experimental and theoretical aileron data. Inasmuch as the values of $C_l/\Delta\alpha$ over the span of a wing should be independent of the type of control surface inducing the change in effective angle of attack and, hence, the roll, it is believed that conventional-aileron design data can be used for preliminary design of spoiler-type ailerons provided the

wing angle of attack is small. For a more exact estimation of the rolling-moment coefficient expected at large angles of attack, however, the present spoiler data should be used for a wing having the same plan form or consideration should be given to the effect of α on $C_l/\Delta\alpha$ for other wing plan forms. As previously indicated, the spoilers provided favorable yawing moments, whereas ailerons provide unfavorable yawing moments; therefore, the curves of $C_n/\Delta\alpha$ for the two types of control differ in sign but show the same trend with spanwise control location. In addition, the spoiler yawing-moment data represent the total yawing moment produced by spoilers, whereas the aileron yawing-moment data represent only the induced yawing moment produced by ailerons. (See reference 5.)

In calculating the rolling-moment or yawing-moment coefficients of wings with ailerons by means of the aforementioned charts of $C_l/\Delta\alpha$ and $C_n/\Delta\alpha$, the aileron effectiveness factor $\Delta\alpha/\Delta\delta$ multiplied by the control deflection δ is utlized to obtain the change in effective angle of attack $\Delta\alpha$ and, thence, the values of C_l and C_n. Spoiler design data cannot employ this simple method of obtaining $\Delta\alpha$, however, since the data of reference 8 and of other investigations appear to indicate that $\Delta\alpha$ for spoilers is a complex function of the wing angle of attack, the spoiler projection, the wing-spoiler configuration employed, and the chordwise spoiler location. Therefore, values of $\Delta\alpha$ as a function of spoiler projection for the particular wing-spoiler combination considered should be obtained from section data for a similar configuration in order to eliminate three-dimensional aerodynamic effects.

Effect of gap between spoiler segments.- The presence of a gap between spoiler segments apparently had an effect only on the rolling-moment coefficients and the drag coefficients (fig. 8). Gaps of less than 0.0054b/2 produced no noticeable effect on the rolling moments, whereas the largest gap decreased the rolling moment about $4\frac{1}{2}$ percent over most of the range of α. This loss in rolling moment is about 1/2 as much as would have been predicted from figure 6.

Chordwise Investigation

Aerodynamic characteristics.- Results of the chordwise investigation of spoilers are presented in figure 9. A rearward movement of spoiler location on the wing produced large decreases in the available rolling moment. The rate of decrease of rolling moment with rearward shift of spoiler location changed throughout the angle-of-attack range so that the minimum rate occurred at the most negative angle of attack, whereas the maximum rate occurred at the largest angle of attack tested. It may be noted that at the most

forward location C_l increased with angle of attack over part of the range of α, whereas at the most rearward location there is a continuous decrease in C_l with increase in angle of attack.

This beneficial effect on the rolling moment resulting from moving the spoiler forward on the wing is also accompanied by the adverse effect of increased lag in the rolling response of the wing. Previous results (reference 13) indicate that spoilers located behind the 60-percent-chord station have negligible lag, but the lag increases as the spoiler is moved forward and would become somewhat objectionable for spoiler locations as far forward as the 50-percent-chord station.

Movement of the spoiler rearward (fig. 9) decreased the favorable yawing-moment coefficients almost linearly. In addition, the yawing-moment coefficients increased positively (became less favorable) with increase in angle of attack.

Linear increments in drag coefficient resulted from moving the spoiler location chordwise. The pitching-moment coefficients became more positive as the spoiler location was moved rearward.

Comparison of available yawing-moment and rolling-moment data for various chordwise locations of spoilers.- The rolling-moment and yawing-moment data for various chordwise spoiler locations obtained from reference 2 are compared in figure 10 with similar data obtained from the present investigation. Since the data of reference 2 are uncorrected and were obtained for a wing under different conditions than those for the present wing, the figure is intended to reveal the qualitative characteristics of the two wings.

The same general characteristics for the two wings are indicated as follows: As the spoiler was moved forward, the favorable yawing moment became greater for both the low and high angle of attack and the rolling moment became greater for the large angle of attack. No forward chordwise location, however, was reached in the present investigation where a decrease in rolling moment occurred for the low angle of attack as indicated for the spoiler at the 0.30c station in reference 2. As indicated in reference 2 and shown in figure 10, the rolling moment increased at the forward location with increase in angle of attack.

Scale effect.- Figures 11(a) to 11(c) show the effect of the variation of Reynolds number and Mach number on the rolling-moment and yawing-moment coefficients for three chordwise spoiler locations (0.60c, 0.70c, and 0.80c). For the low Mach number range covered (0.13 to 0.39), no perceptible effect was produced on the yawing moments; however, there was a small inconsistent variation of rolling moment with Mach number in all three locations.

CONCLUSIONS

Wind-tunnel results of a spanwise and chordwise investigation of plain spoilers of 0.05-chord projection on a semispan wing without flaps led to the following conclusions:

1. The spanwise rolling-moment effectiveness obtained from spoilers showed a trend similar to that of ailerons for a geometrically similar wing. This similarity suggests the possibility of employing aileron design data in the preliminary design of spoilers at low angles of attack. For a more exact estimation of the spoiler rolling moment expected at large angles of attack, however, consideration should be given to the change in effectiveness with angle of attack.

2. The spanwise yawing-moment effectiveness for ailerons and spoilers showed the same trend with spanwise location; but because the spoilers gave favorable yawing moments, the spoiler data differed in sign from the aileron data.

3. When the 50-percent-semispan spoiler was moved rearward from the 50-percent-chord station to the 80-percent-chord station on the unflapped wing, both the rolling-moment and yawing-moment coefficients were reduced.

4. Variation of the Mach number between 0.13 and 0.39 produced no perceptible effect on the yawing-moment coefficients but produced a small inconsistent variation of the rolling-moment coefficients.

Langley Memorial Aeronautical Laboratory
National Advisory Committee for Aeronautics
Langley Field, Va., March 18, 1947

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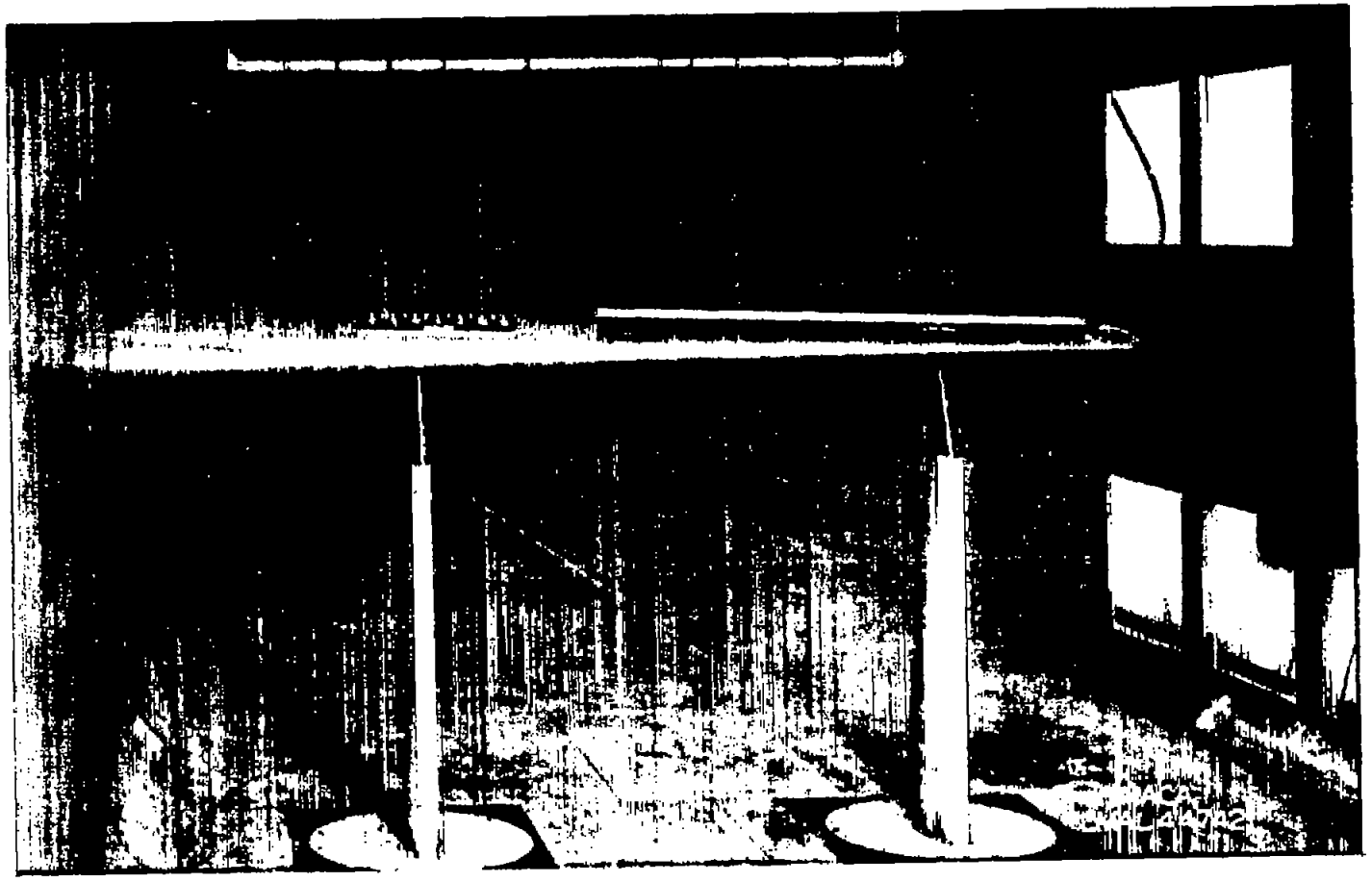

Figure 1.- General setup of spoiler mounted on semispan-wing model.

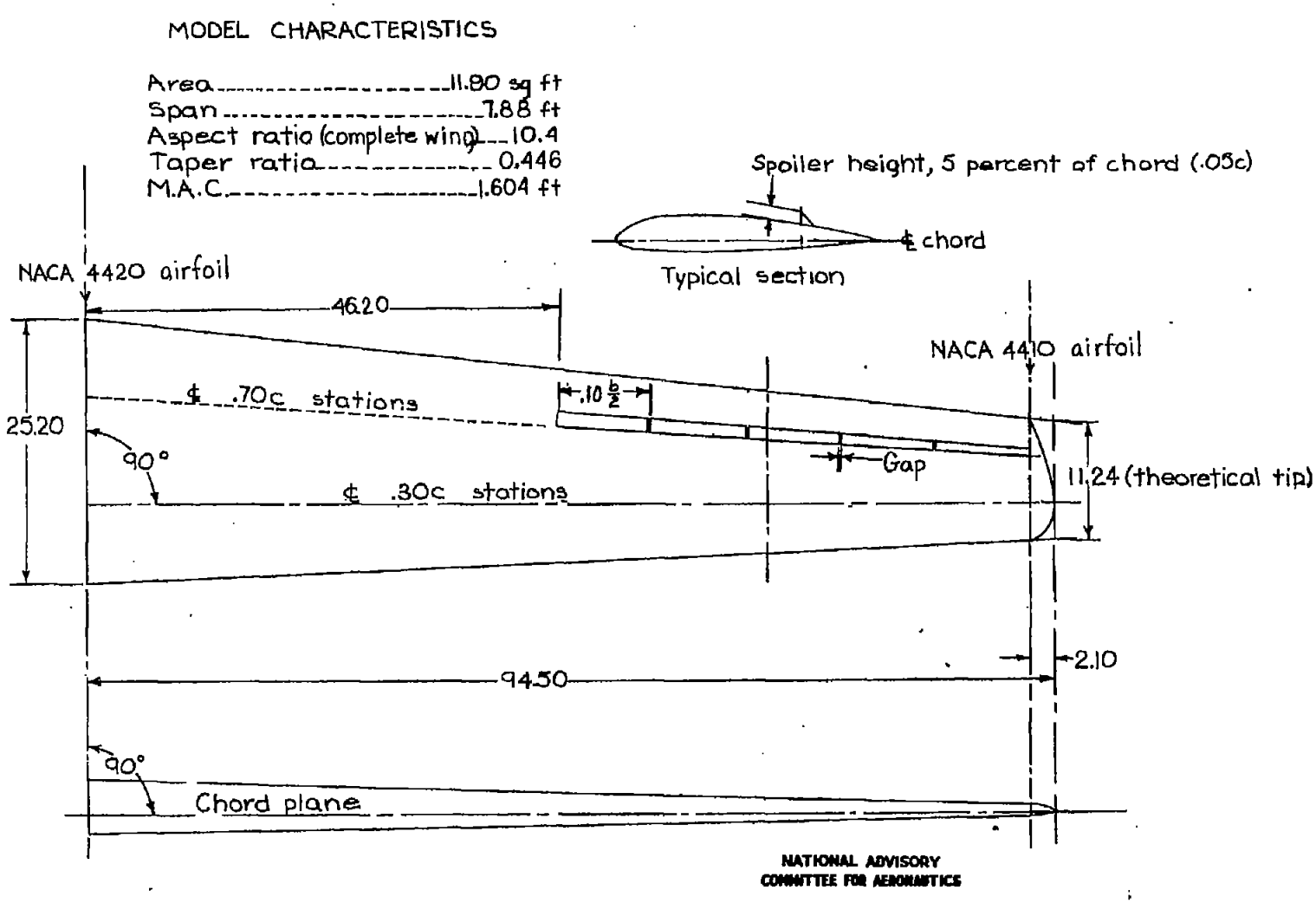

Figure 2.- Diagram of model used in spoiler investigation. Typical spoiler installation (50-percent semispan spoiler). All dimensions are in inches.

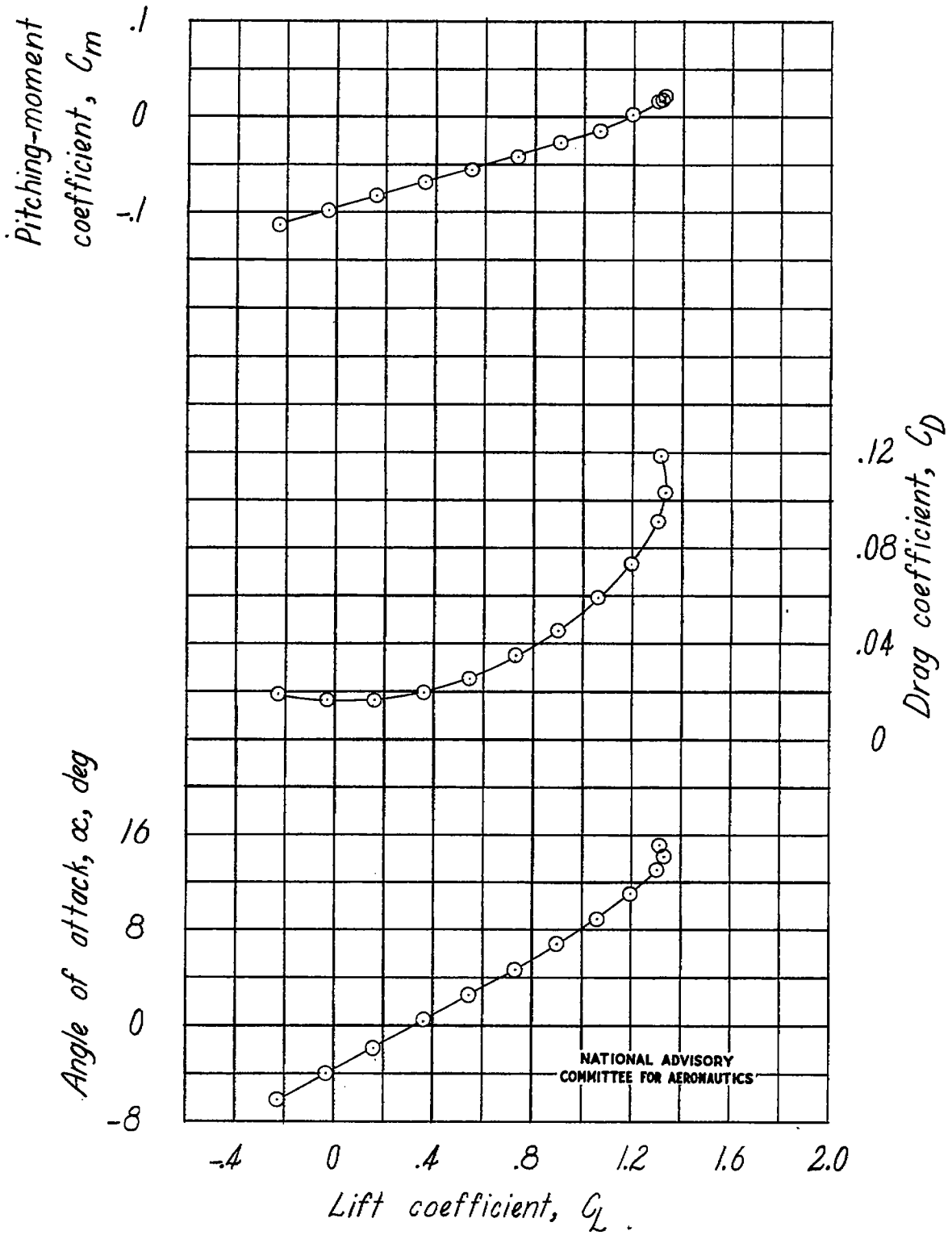

Figure 3.- Aerodynamic characteristics of the plain wing. M = 0.27; R = 2.69 × 10^6.

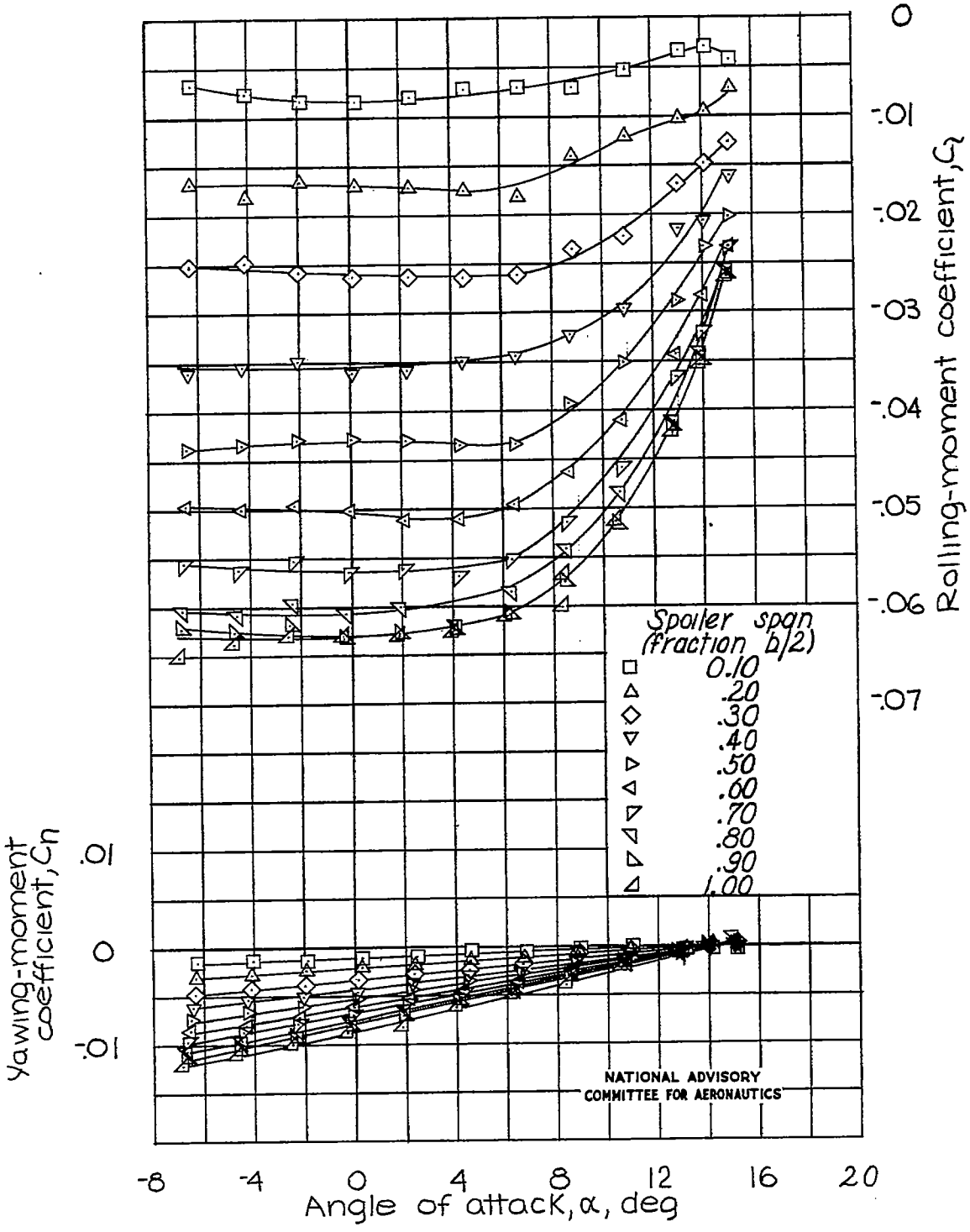

Figure 4.- Variation of aerodynamic characteristics with spoiler span. Outboard spoilers; M = 0.27; R = 2.69×10^6.

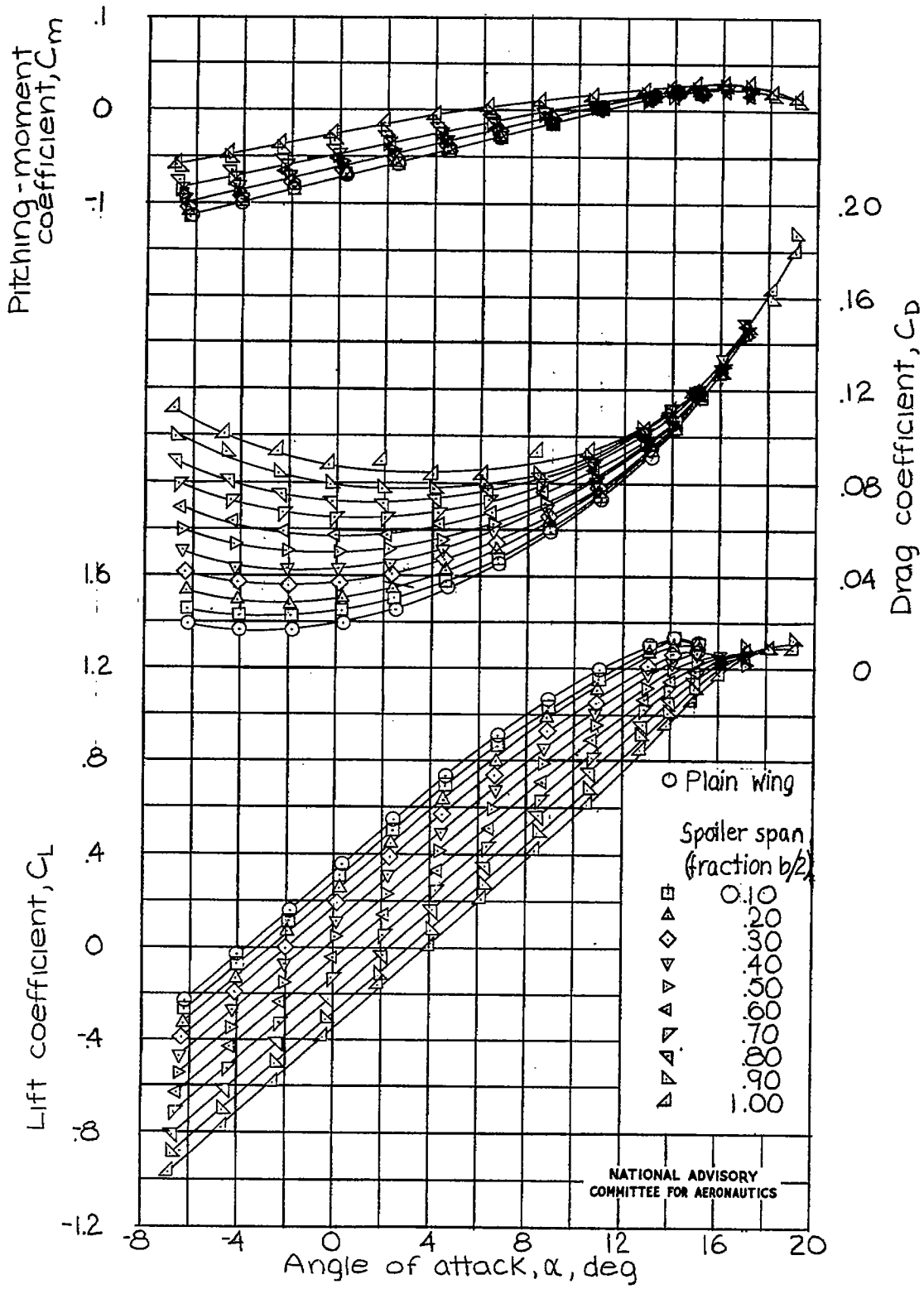

Figure 4.- Concluded.

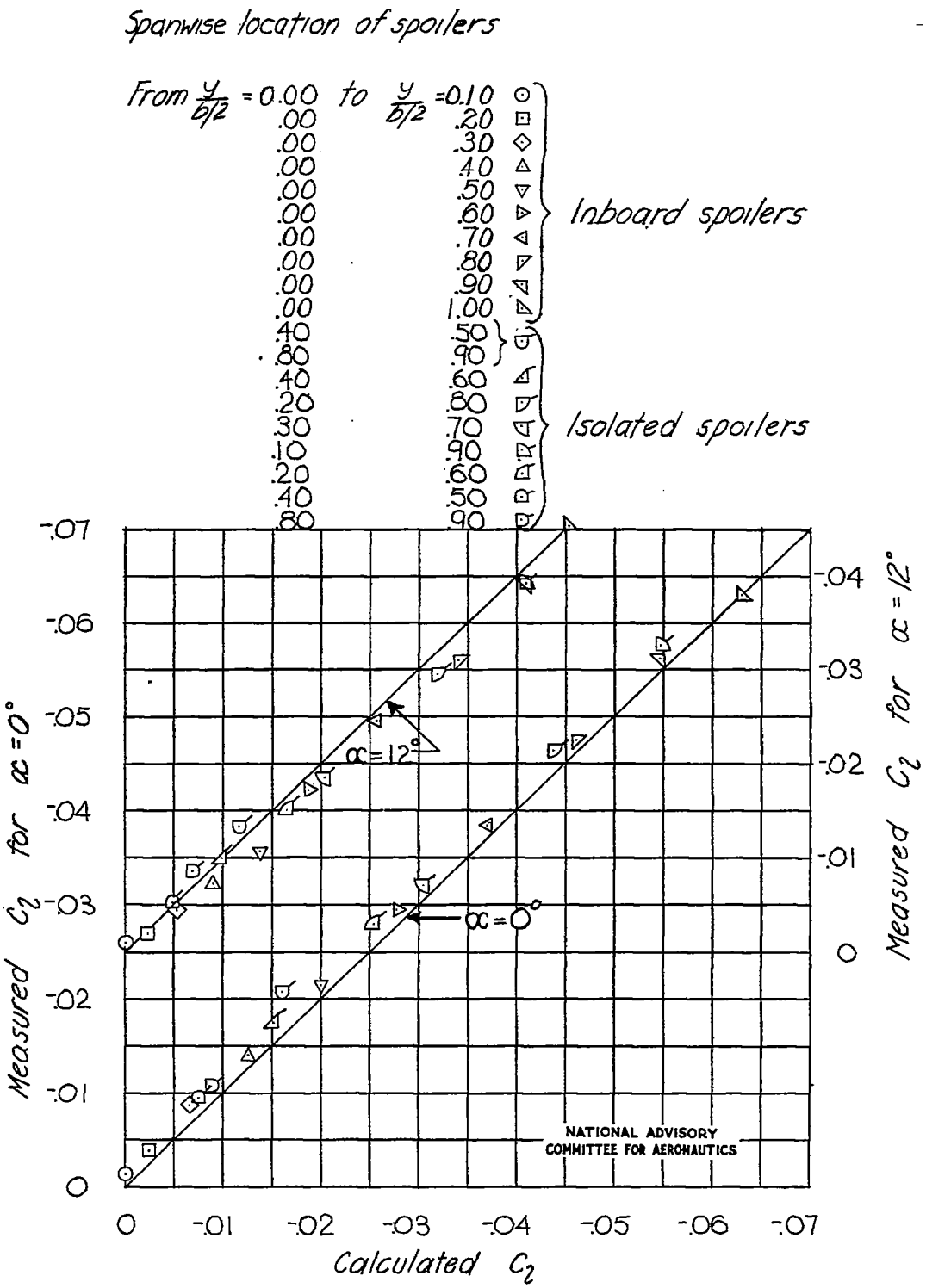

Figure 5.- Comparison of calculated rolling-moment coefficients obtained from outboard spoilers with measured rolling-moment coefficients obtained from inboard or isolated spoilers for different spoiler spanwise locations.

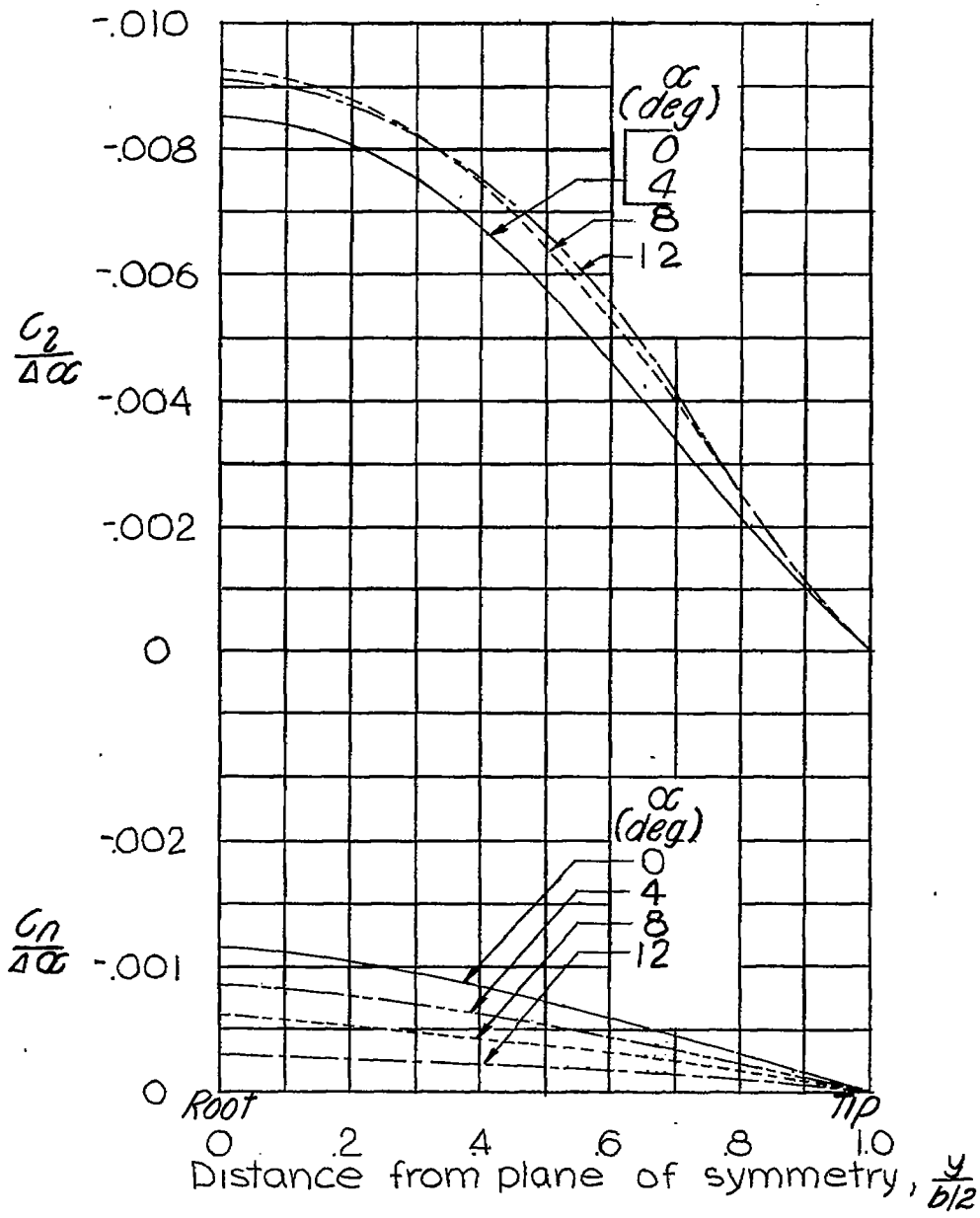

Figure 6.- Variation of rolling-moment and yawing-moment effectiveness parameters with spoiler span and spanwise location for several angles of attack. $M = 0.27$; $R = 2.69 \times 10^6$.

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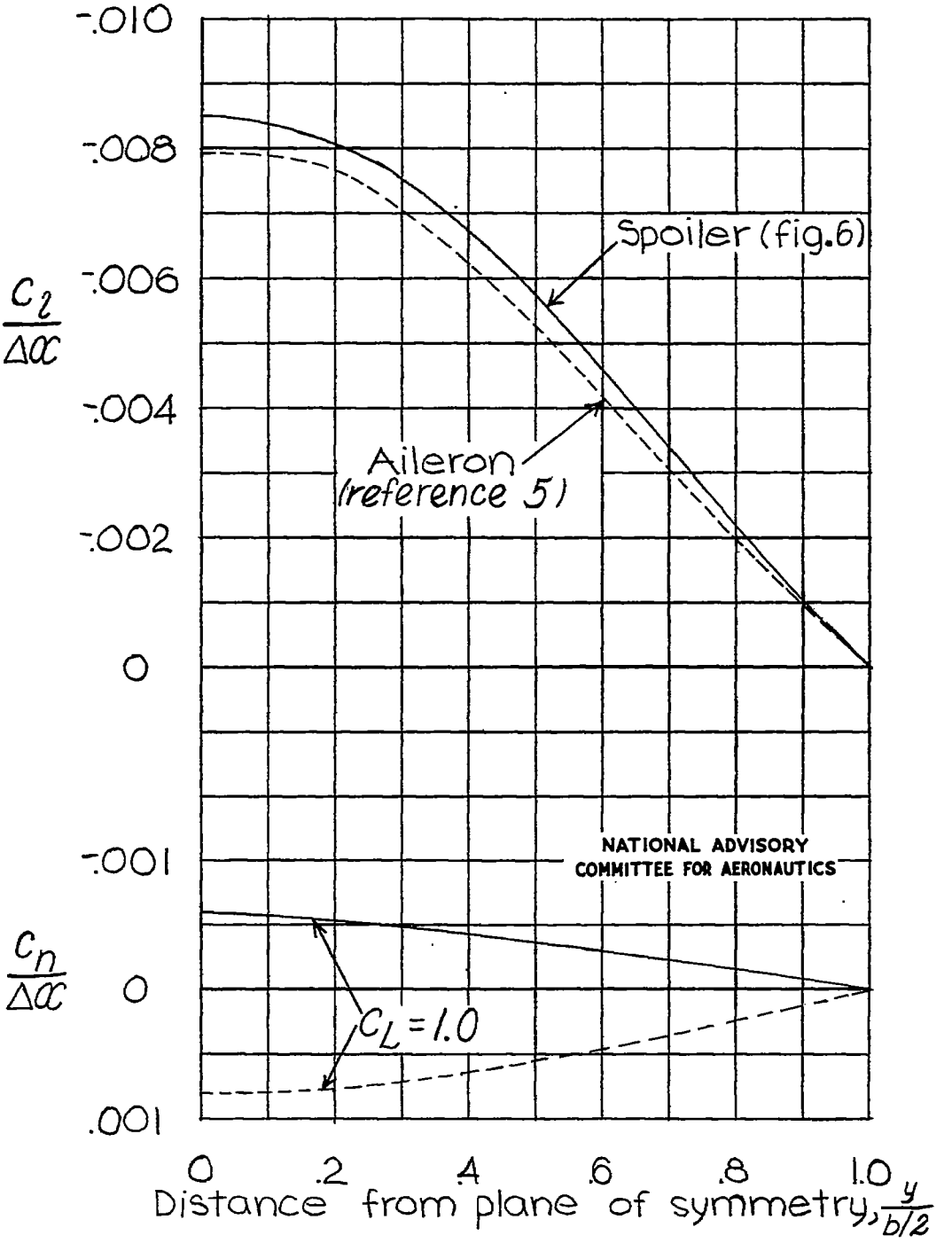


Figure 7.- Comparison of variation of rolling-moment and yawing-moment effectiveness parameters with spanwise location for ailerons (theoretical) and spoilers (experimental). Aileron values extrapolated for a wing of $A = 10$, $\lambda = 0.50$.

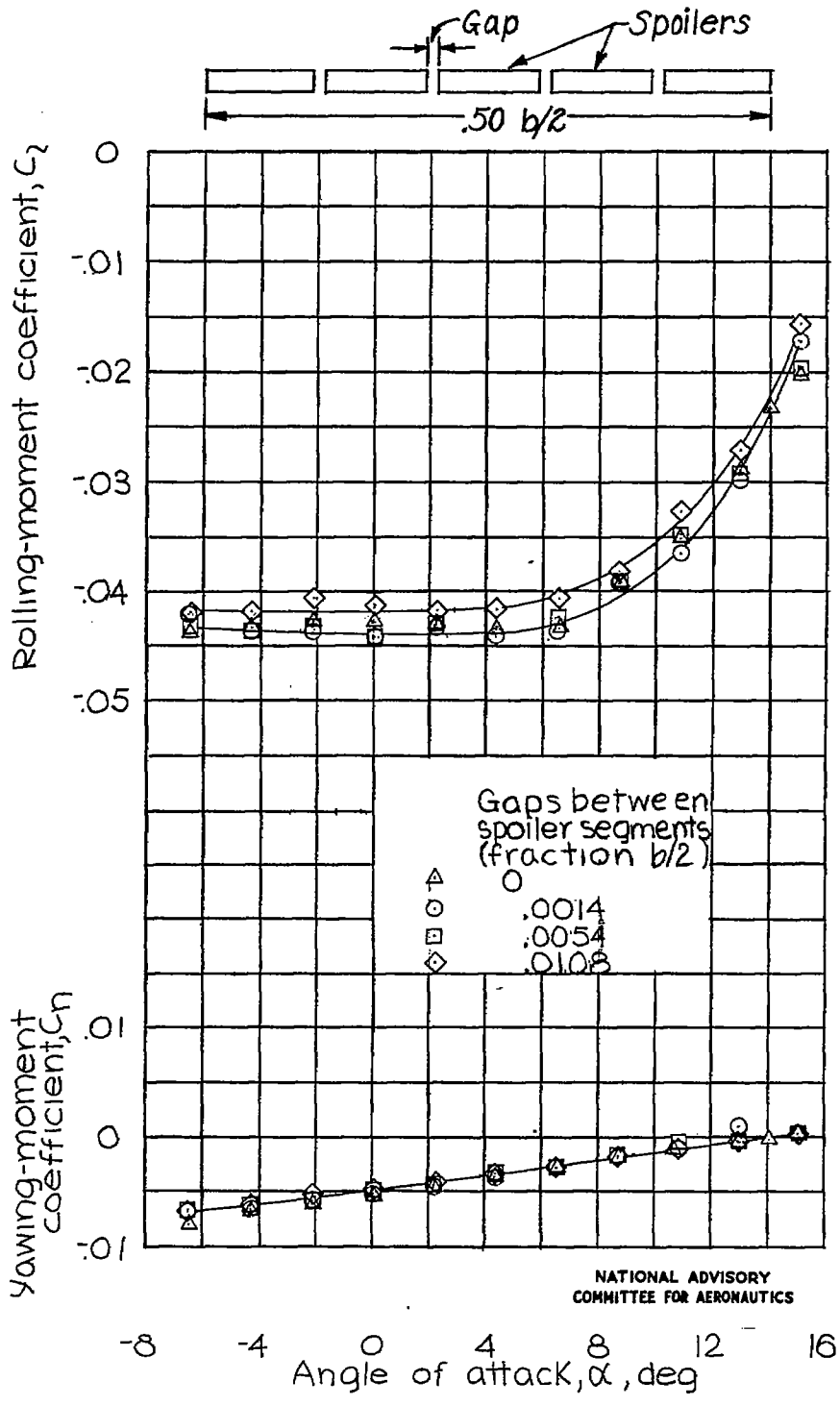
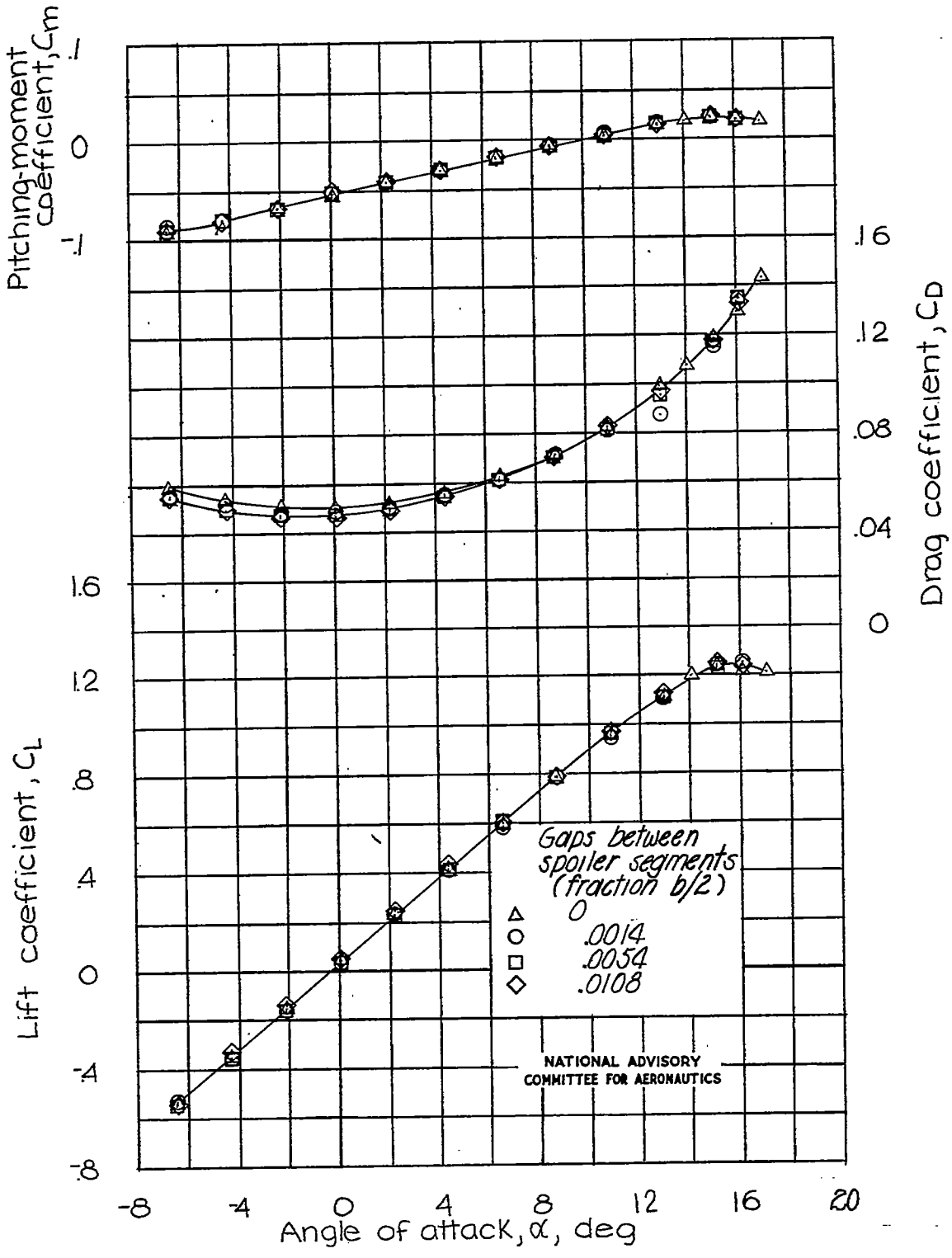


Figure 8.- Aerodynamic characteristics of semispan wing equipped with a 0.50 b/2 outboard spoiler having different gaps between spoiler segments. $M = 0.27$; $R = 2.69 \times 10^6$.



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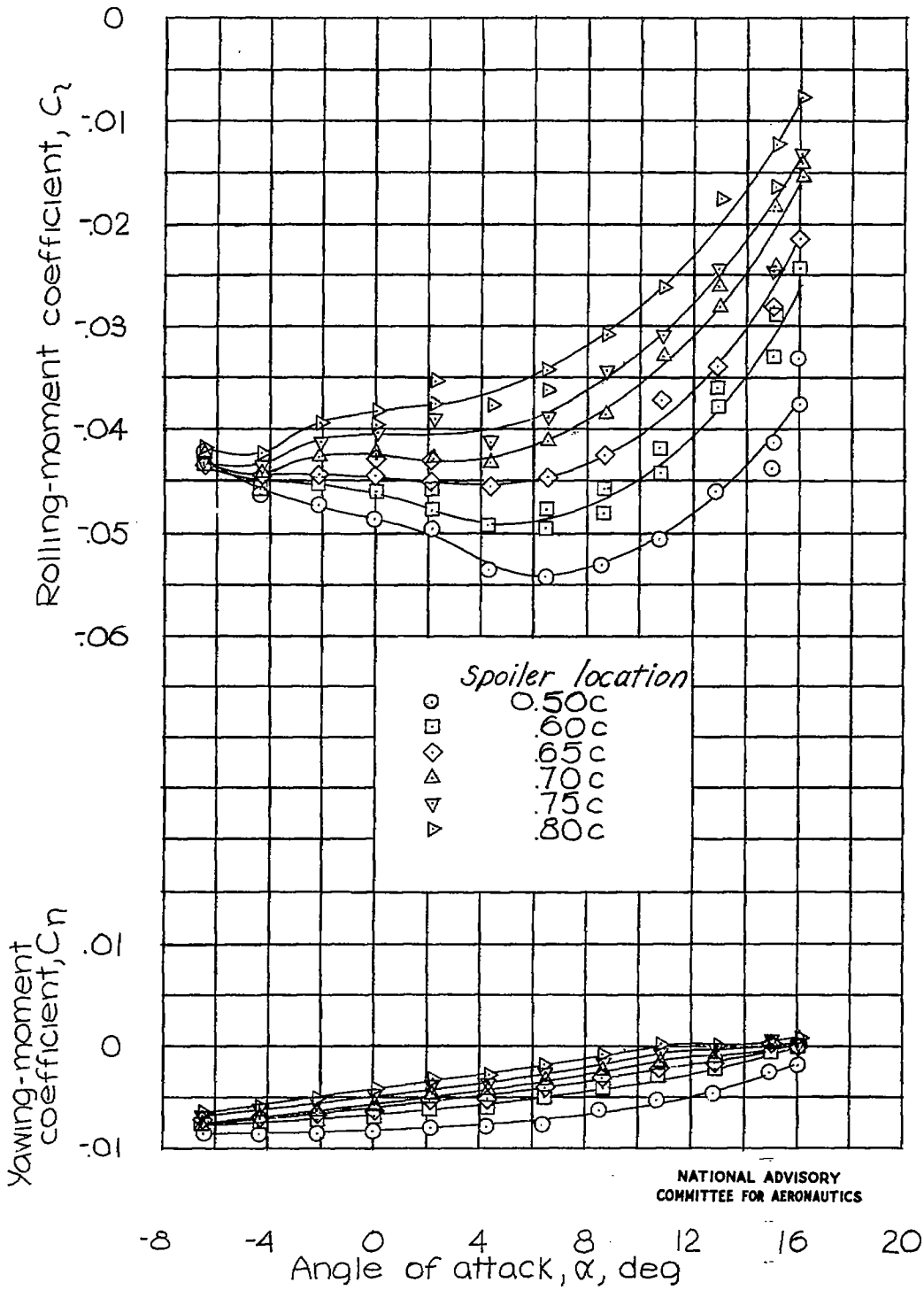


Figure 9.- Variation of aerodynamic characteristics with chordwise location of spoiler. Spoiler length, 0.50 b/2; M = 0.27; R = 2.69×10^6. Outboard spoiler.

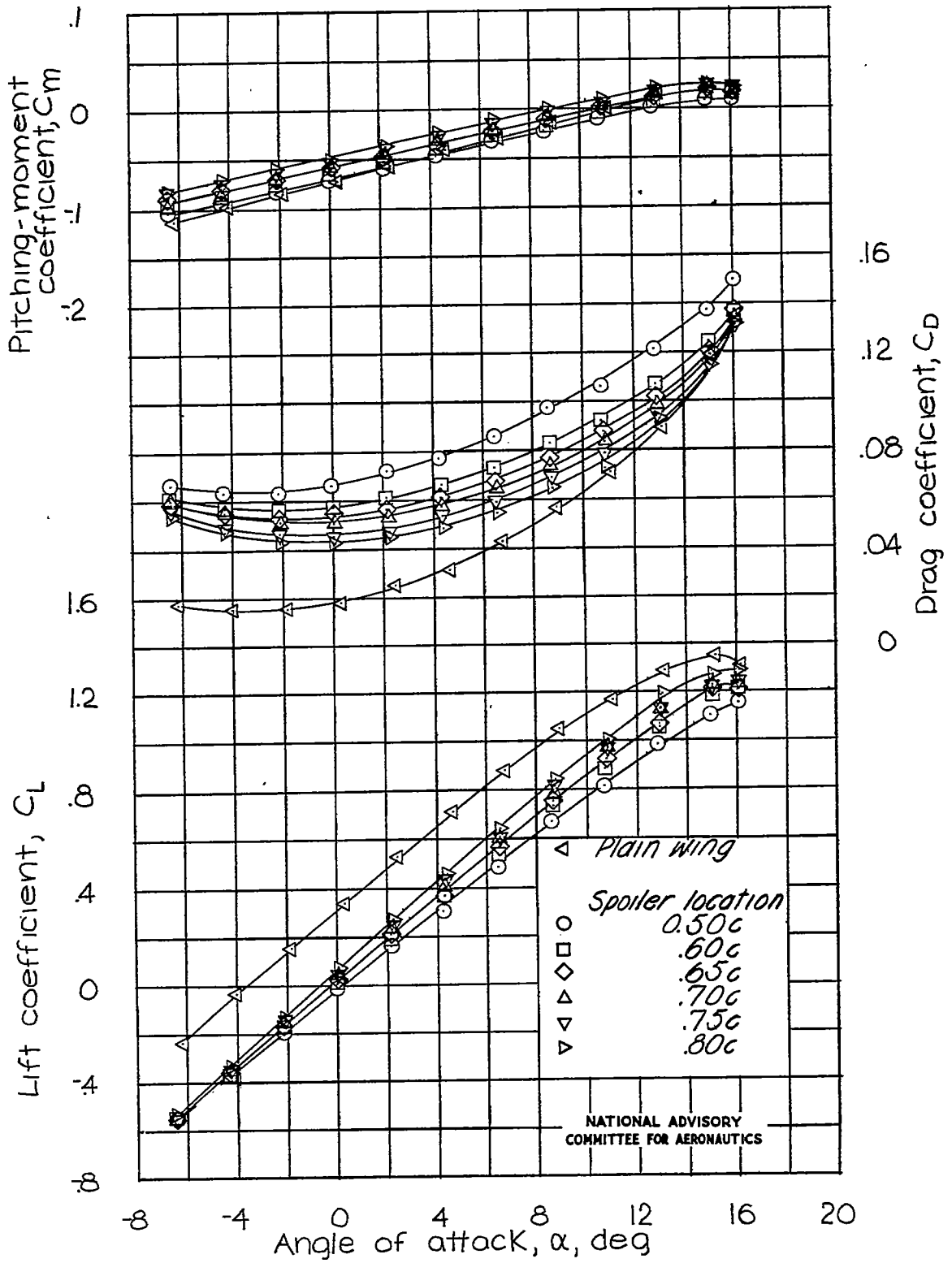


Figure 9.- Concluded.

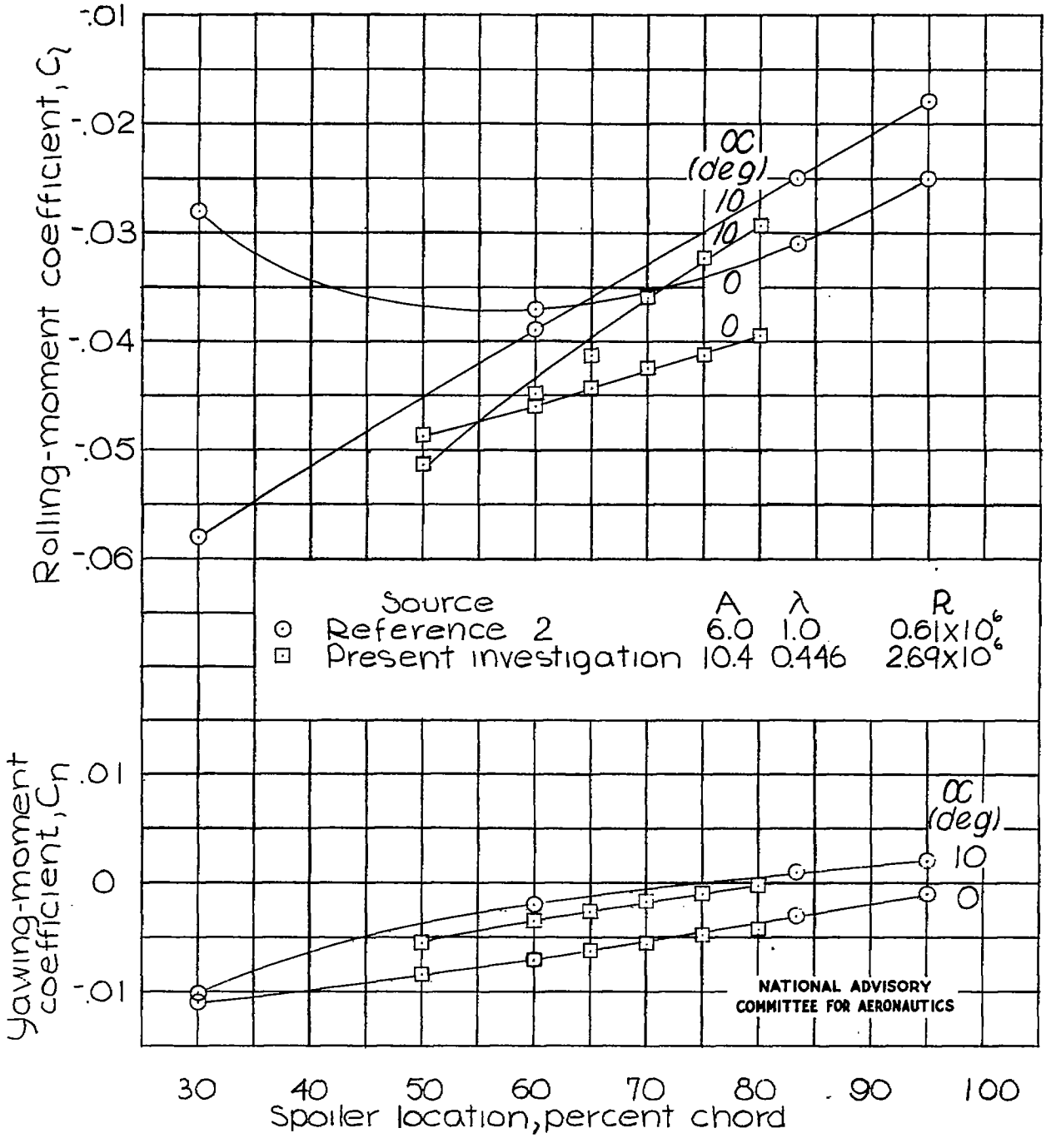
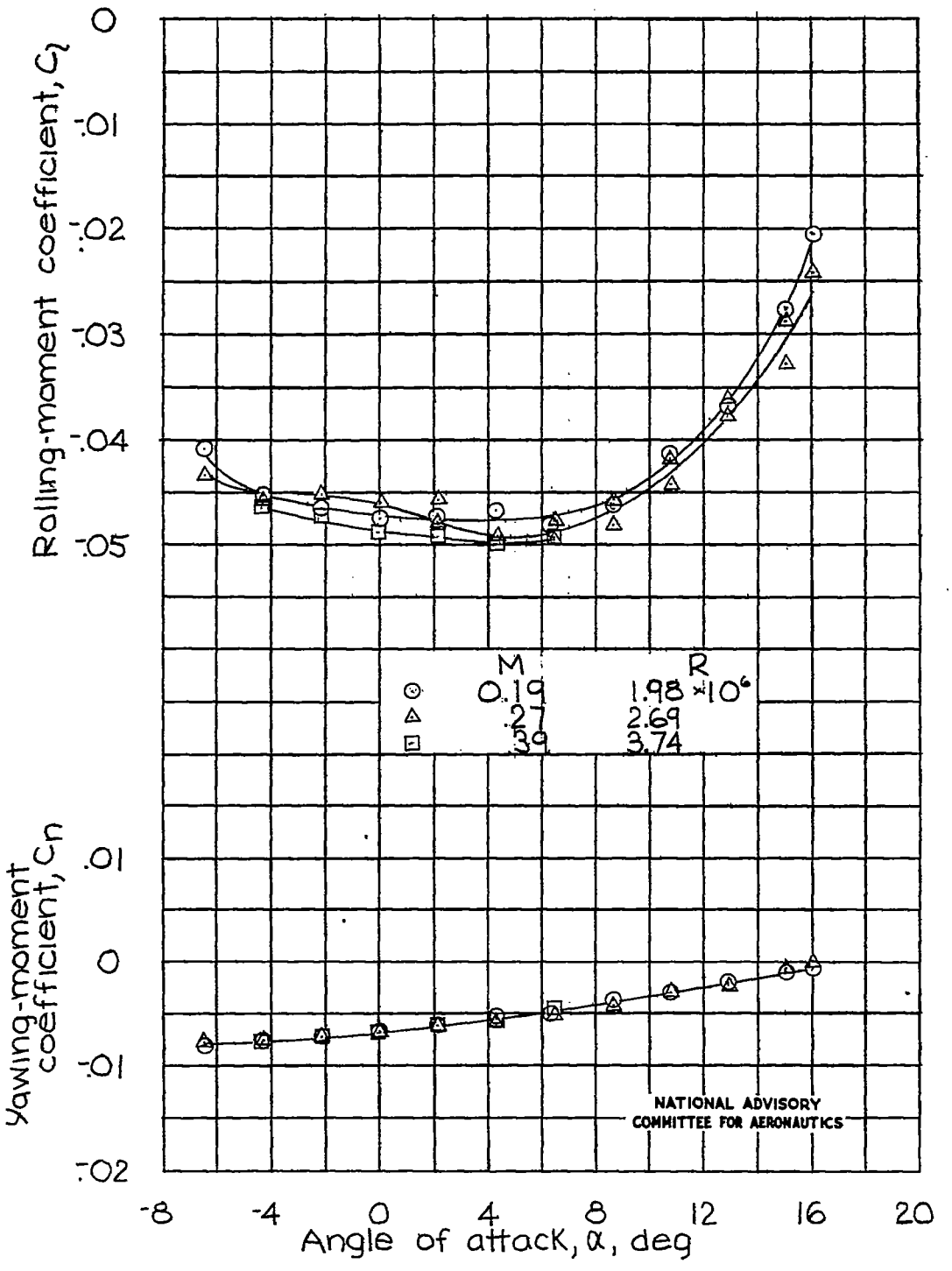
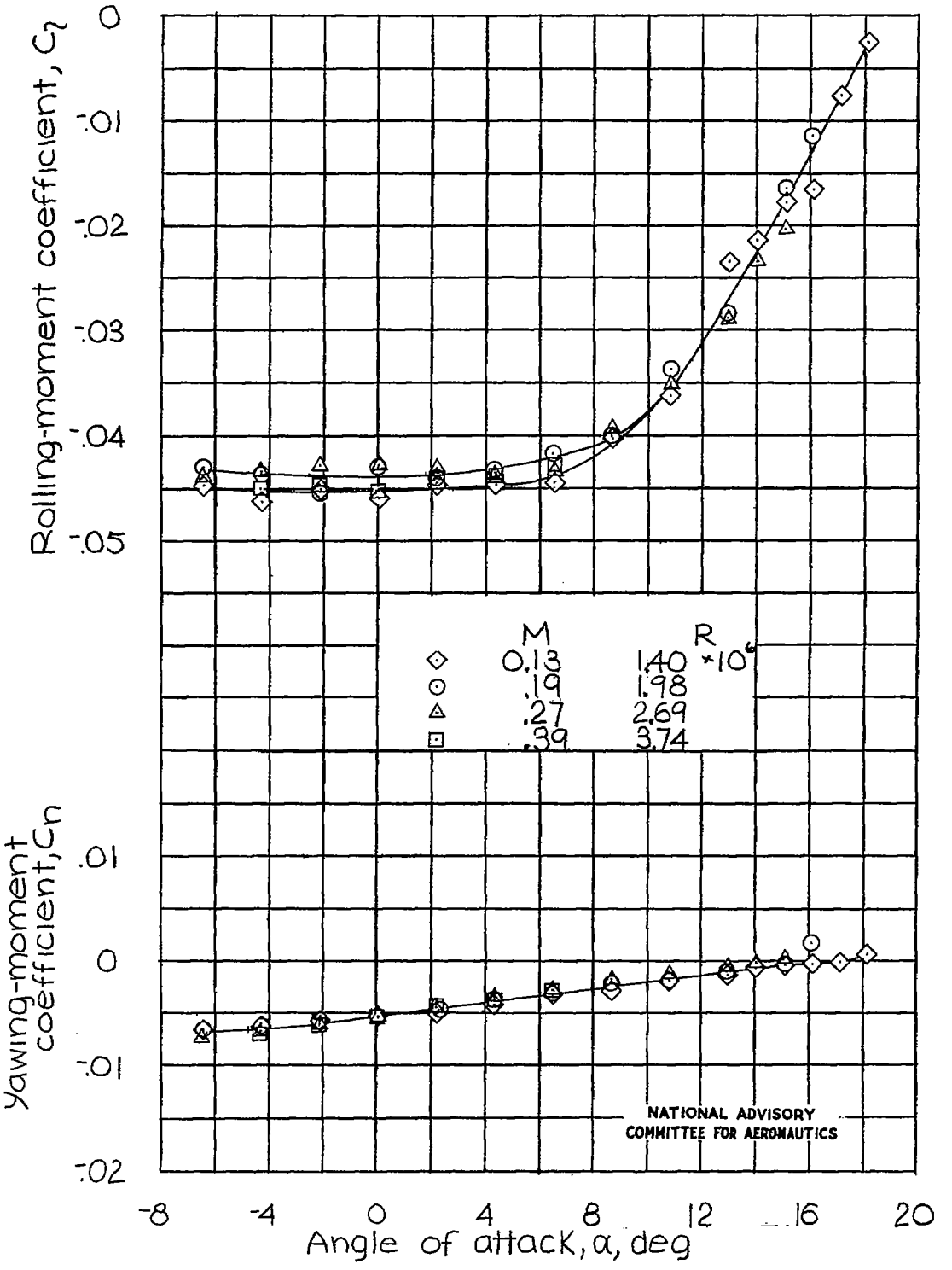


Figure 10.- Variation of rolling-moment and yawing-moment coefficients with chordwise location of spoilers obtained from data of reference 2 as compared with coefficients from present investigation for spoiler span of 0.50 b/2 and spoiler height of 0.05c.



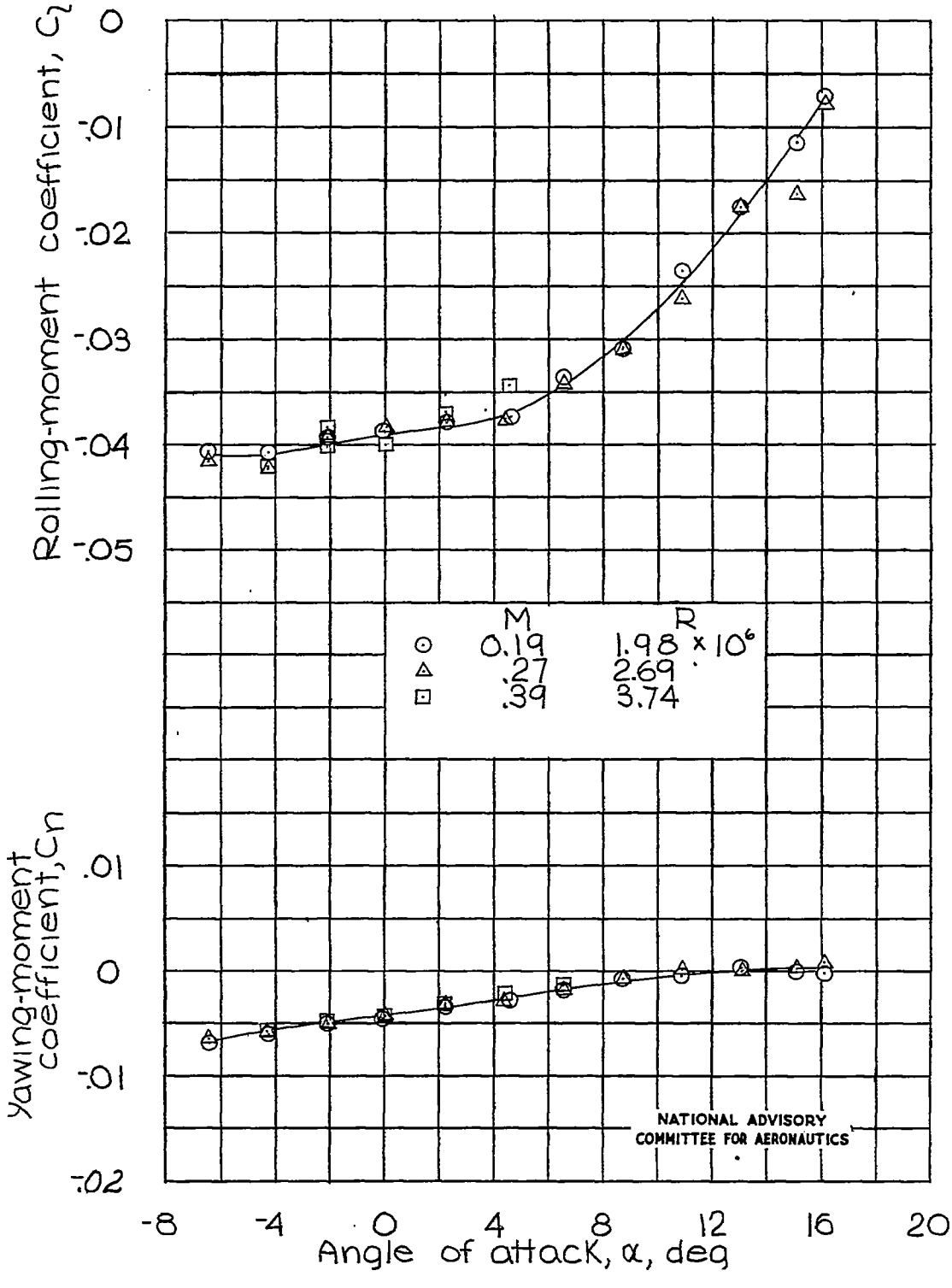
(a) Spoiler location, 0.60c.

Figure 11.- Scale effect on roll and yaw characteristics. Spoiler span, 0.50 b/2; outboard spoiler.



(b) Spoiler location, 0.70c.

Figure 11.- Continued.



(c) Spoiler location, 0.80c.

Figure 11.- Concluded.