NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL NOTE

No. 1409

INVESTIGATION OF A SPOILER-TYPE LATERAL CONTROL SYSTEM ON A WING WITH FULL-SPAN FLAPS IN THE LANGLEY 19-FOOT PRESSURE TUNNEL

By Owen J. Deters and Robert T. Russell

Langley Memorial Aeronautical Laboratory
Langley Field, Va.

Washington

August 1947

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL NOTE No. 1409

INVESTIGATION OF A SPOILER-TYPE LATERAL CONTROL SYSTEM ON A WING WITH FULL-SPAN FLAPS IN THE LANGLEY 19-FOOT PRESSURE TUNNEL

By Owen J. Deters and Robert T. Russell

SUMMARY

Tests of a partial-span model of a large bomber-type airplane were conducted to determine the aerodynamic characteristics of the wing equipped with full-span flaps and a retractable spoiler and aileron lateral control system. The arrangement consisted of (1) a double slotted flap extending over approximately 86 percent of the wing semispan, (2) a 20-percent constant-percentage-chord aileron extending from the outboard end of the flap to the wing tip, and (3) a retractable spoiler, located at the 65-percent wing-chord station and extending from approximately 63 percent of the wing semispan to the wing tip. In addition, tests were made of a wing vent (of 1 and 2 percent of the wing chord located directly behind the spoiler), perforations in the spoiler, a slot or cut-out along the lower edge of the spoiler, and spoilers of various spans.

With full-span flaps deflected and with the 2-percent vent open or closed the initial stalling of the wing occurred at the tips, but with the vents closed there probably would be no appreciable loss in lateral control until maximum lift was reached. The 1-percent vent increased the rolling effectiveness of the spoiler at small spoiler deflections, particularly at high angles of attack with flaps deflected. With flaps deflected the 2-percent vent caused a large reduction in both the wing lift and rolling effectiveness of the spoiler at large angles of attack. However, at small angles of attack the 2-percent vent increased the rolling effectiveness of the spoiler at small spoiler deflections. The simultaneous operation of the spoiler and vent (in contrast to a vent fixed in the wing) would result in a large increase in the effectiveness of the spoiler and would avoid any loss in wing lift as in a fixed vent arrangement.

The tests of the spoiler modifications revealed that (1) the spoiler perforations reduced the rolling-moment and yawing-moment coefficients but caused the spoiler hinge-moment coefficients to

become more positive; (2) the spoiler slot had no notable effect on the rolling-moment and yawing-moment characteristics but produced a positive increase in the spoiler hinge-moment coefficients at large spoiler deflections; (3) the effects produced by the individual modifications were additive when the various modifications were combined. In general, progressively decreasing the spoiler span by removing the segments from the inboard end of the spoiler caused a decrease in rolling effectiveness approximately proportional to the span of the segment.

INTRODUCTION

As the speed and size of airplanes have increased, the problem of providing satisfactory control systems has become increasingly difficult, particularly in the case of lateral controls. As a solution to this problem, a lateral control system consisting of a spoiler and a short span (guide or pilot) aileron has recently been developed (reference 1). The spoiler pilot-aileron control system is composed of a circular-arc-type spoiler as the principal control and an aileron at the wing tip. An advantage of the spoiler pilot-aileron arrangement is that full-span flaps can be used.

The spoiler pilot-aileron arrangement was tested on a model of a projected large bomber-type airplane to provide data for this type of lateral control system. The arrangement consisted of (1) a retractable circular-arc-type spoiler located at the 65-percent-chord station and extending over approximately the outboard 40 percent of the wing semispan, (2) a 20-percent constant-percentage-chord aileron extending from the outboard end of the flap to the wing tip and having an internally sealed aerodynamic balance, and (3) a double slotted flap extending over approximately 86 percent of the wing semispan.

Tests of various modifications to the wing and spoiler and of various arrangements of the spoiler were made to determine their effect on the rolling-moment and yawing-moment characteristics and on the aileron and spoiler hinge-moment characteristics. In addition, tests to determine the lift, drag, and pitching-moment characteristics of the wing were made.

COEFFICIENTS AND SYMBOLS

The measured aerodynamic forces and moments were reduced to standard nondimensional coefficients and corrected so that all coefficients presented herein apply to the complete wing. The pitching-moment, rolling-moment, and yawing-moment coefficients apply to a center-of-gravity location 25 percent of and 5 percent below the mean aerodynamic chord in the plane of symmetry.

The coefficients and symbols used in this report are defined as follows:

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

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

C_m pitching-moment coefficient $\left(\frac{M}{qSc'}\right)$

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

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

C_{h_s} spoiler hinge-moment coefficient $\left(\frac{H_s}{qc_s t_s b_s}\right)$

C_{h_a} aileron hinge-moment coefficient $\left(\frac{H_a}{qb_a \bar{c}_a{}^2}\right)$

L lift

D drag

M pitching moment

L' rolling moment

N yawing moment

H_s spoiler hinge moment, positive when tending to produce a more positive spoiler deflection

H_a aileron hinge moment, positive when tending to produce a more positive aileron deflection

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

b wing span

S wing area

c' mean aerodynamic chord

V airspeed

ρ mass density of air

a velocity of sound

μ viscosity of air

c_a aileron chord

c wing chord

$$c_s t_s b_s = \sum_{\text{Segment 1}}^{\text{Segment 5}} \int_{b_{s_i}}^{b_{s_o}} t_s c_s \, db_s$$

t_s spoiler thickness, normal to spoiler surface

b_s spoiler-segment span

b_{s_i} inboard end of spoiler segment

b_{s_o} outboard end of spoiler segment

c_s spoiler mean radius (fig. 8)

$b_a \bar{c}_a^2$ product of aileron root-mean-square chord squared and aileron span

α angle of attack of root chord, degrees

δ_f full-span-flap deflection, degrees

δ_{f_i} inboard-flap deflection, degrees

δ_{f_o} outboard-flap deflection, degrees

δ_s spoiler deflection, degrees, negative when spoiler is deflected up

δ_a aileron deflection, degrees, positive when trailing edge is moved down

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

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

APPARATUS AND TESTS

Model and Installation

The model simulates the outboard 94.6 percent of the left wing of a projected large bomber-type airplane. The installation of the model in the tunnel and the general dimensions of the model are shown in figures 1 to 4.

A small gap (0.09 ±0.03 in.) was maintained constant between the wing and reflection plane by an automatic telescoping section in the root end of the model. This mechanism was inoperative for most of the tests of the spoiler and aileron, during which the gap was approximately 0.53 inch. However, this increase in the size of the gap would not be expected to have any measurable effect on the rolling-moment, yawing-moment, or hinge-moment characteristics resulting from deflection of the spoiler and aileron.

The aerodynamic forces and moments on the wing model were measured by means of a six-component simultaneously recording balance system. The hinge moments of the spoiler and aileron were measured by means of electric strain gages.

Wing.- The wing model was not a true semispan but represented that part of the airplane wing outboard of the wing-fuselage juncture of the projected airplane. The aspect ratio and taper ratio for the airplane wing are 11.09 and 0.25, respectively, whereas the partial-span model mounted in conjunction with the reflection plane simulated a wing of aspect ratio 10.84 and taper ratio 0.26. The airfoil sections were the NACA 63(420)-422 at the root and the NACA 63(420)-517 at the tip. The wing had 12.15° sweepback of the quarter-chord line, 2° dihedral, and 2° aerodynamic washout between the root and tip.

Wing vent.- The dimensions and geometry of the wing vent are shown in figure 4. The vent width could be adjusted to a value of either 1 percent or 2 percent of the wing chord.

Wing flap.- The full-span double slotted flap consisted of an inboard (from wing root to outboard nacelle) constant-chord flap and an outboard constant-percentage-chord flap. Typical sections of the inboard and outboard flaps are shown in figures 5 and 6, respectively.

Spoiler.- The spoiler was of the retractable circular-arc type, and the arrangement and details are shown in figures 4 and 7 to 9. The spoiler, located at the 65-percent wing-chord station, was composed of five separate segments. The span (perpendicular to the plane of symmetry) of each segment and its identification are given as follows, beginning with the outboard segment:

Spoiler segment	Spoiler span (percent complete wing semispan)
1	4.8
2	5.5
3	6.1
4	7.0
5	7.4

The distance between each spoiler segment was approximately 0.44 percent of the complete wing semispan, thus the spoiler was approximately 32.6 percent of the complete wing semispan. Each segment was attached to a common actuating shaft through which the deflections of the spoiler were remotely controlled. Any segment or combination of segments could be detached from the actuating shaft and fixed in a neutral position (flush with the upper surface of the wing). The spoiler could be deflected in a negative (upward) direction only; the relation between the deflection of the spoiler and its projection above the upper surface of the wing is given in figure 8.

Spoiler modifications.- The modifications to the spoiler consisted of perforations in the spoiler plate and a small cut-out in the lower edge of the spoiler plate which formed a slot between the spoiler and the upper surface of the wing at full deflections of the spoiler. The dimensions and location of these modifications to the spoiler are shown in figure 9. The spoiler was constructed of a basic (0.051-in. thick) plate and a removable (0.018-in. thick) plate fixed to the forward face of the basic plate. The basic plate contained both of the modifications (perforations and slot); and removable plates were provided which contained either of these modifications, or both, or excluded them. By combining the various removable plates with the basic spoiler plate, modifications to the spoiler were effected. A further modification to the spoiler consisted of a bevel on the upper surface of the spoiler as shown in figure 9.

Aileron.- The aileron was a 20-percent constant-percentage-chord aileron having an internally sealed aerodynamic balance of 45 percent of the aileron chord behind the hinge. The aileron extended from the outboard end of the flap to the wing tip as shown in figure 4. The aileron upper and lower surfaces were straight sided as shown in figure 10. The installation of the aileron strain gage at the inboard end of the aileron prevented the internal balance from extending over the inboard end approximatley 4 percent of the aileron span. As a result of leakage at the inboard end of the balance the full effectiveness of the balance was probably not obtained.

Tests

The tests of the wing were divided into two groups: (1) the tests to determine the lift, drag, pitching-moment and stalling characteristics of the wing, and (2) the tests to determine the rolling-moment and yawing-moment characteristics of the wing and the hinge-moment characteristics of the spoiler and aileron.

The dynamic pressure for the tests, excluding those for scale effect, was approximately 105 pounds per square foot which corresponds to a Reynolds number of approximately 8,900,000 and a Mach number of approximately 0.18. The density of the atmosphere was maintained at approximately 0.0050 slug per cubic foot. The range of angles of attack was from -4° through the angle of maximum lift. The range of deflections of the aileron was $\pm 20^{\circ}$ and of the spoiler, 0° to -57.5° (which corresponds to a maximum projection of 0.097c).

CORRECTIONS AND ACCURACY

The corrections to the measured characteristics were determined by the methods of reference 2. Although the methods of reference 2 were derived for conventional ailerons, no appreciable error is introduced by their application to spoiler controls. The corrections to the uncorrected coefficients were obtained from the following relationships:

$$C_D = C_{D_{uncorrected}} + 0.0148 C_L^2$$

$$\alpha = \alpha_{uncorrected} + 0.926 C_L$$

$$C_m = C_{m_{uncorrected}} + 0.0344 C_L$$

$$C_l = 0.814 \left(C_{l_{uncorrected}} - C_{l_{tare}} \right)$$

$$C_n = C_{n_{uncorrected}} - C_{n_{tare}} - 0.0410 C_l C_L$$

The values of lift, drag, and pitching-moment coefficient have not been corrected for the tare and interference effects of the support strut system and therefore are not exact. Incremental values of these coefficients as well as the absolute values of rolling-moment, yawing-moment, and hinge-moment coefficient are considered to be accurate. The estimated limits of accuracy for the test data presented herein were as follows:

ΔC_L	±0.01
ΔC_D	±0.0002
ΔC_m	±0.003
C_l	±0.001
C_n	±0.0005
C_{h_a}	±0.015
C_{h_s}	±0.1
α, degree	±0.1
δ_s, degrees	±1.5
δ_a, degree	±1.0

RESULTS AND DISCUSSION

The results of the tests are presented in figures 11 to 33. The aerodynamic characteristics of the wing with full-span double-slotted flaps are presented first followed by the characteristics of the wing for various configurations of the spoiler and aileron.

Aerodynamic Characteristics of the Wing with Full-Span Double-Slotted Flaps

Effect of the flap and vent. - The aerodynamic characteristics of the wing for various configurations of the flap and wing vent are given in figure 11. Deflections of the full-span flap produced no abnormal changes in the aerodynamic characteristics of the wing.

The effects of opening the 2-percent vent were small at angles of attack less than approximately 8°. The lift coefficient was decreased, the drag coefficient (for a given lift coefficient) was increased, and the pitching-moment coefficients became less negative. At angles of attack greater than 8° these changes in lift, drag, and pitching-moment coefficient resulting from the vent were greatly increased, particularly for large flap deflections.

The increments in maximum lift coefficient between the flap neutral, vent-closed configuration, and various flap and 2-percent vent configurations are given in the following table:

Flap deflection (deg)	2-percent-vent condition	$\Delta C_{L_{max}}$
20	Closed	0.55
20	Open	.50
50	Closed	1.15
50	Open	.93

Of particular interest is the large decrease in maximum lift coefficient (0.22) caused by the vent with flaps deflected 50°.

Stalling characteristics.- The characteristics of the wing stall for several configurations of the full-span flap and 2-percent vent are given in figure 12. With flaps neutral and vent closed the stall began at the outboard nacelle, spread forward and toward the tip, and gradually enveloped the spoiler and aileron. The stall over the inboard part of the wing followed that over the outer panel. With flaps deflected the general stall pattern remained the same but the stall over the outer wing panel occurred abruptly at maximum lift; the inboard part of the wing remained unstalled until after maximum lift was reached. Opening the 2-percent vent caused the wing to stall at a much lower angle of attack in the region behind the spoiler.

Because of the abrupt stall of the wing with full-span flaps deflected and vent closed there would probably be no appreciable loss in lateral control until maximum lift was reached. Since the wing has a moderate amount of sweepback, the loss in lift due to stalling of the wing tips would be detrimental to the longitudinal stability of the airplane.

Aerodynamic Characteristics of the Wing for Various

Configurations of the Spoiler and Aileron

One of the main objections to spoiler control arrangements has been the time delay or lag between the deflection of the spoiler and the development of the resulting rolling moment. Other objections to spoilers of the circular-arc type are their ineffectiveness at small projections (particularly with flaps deflected) and small hinge moments. Because of the relatively high speeds of the projected bomber airplane and the rearward location of the spoiler (65-percent-chord station), lag is not expected to be a serious problem. At low speeds, however, some lag may occur. In order to reduce the lag and ineffectiveness of the spoiler at low speeds a vent (between the upper and lower surfaces of the wing) was located immediately behind the spoiler. This vent would tend to open only as the spoiler deflects. The effects of a vent in improving the spoiler lag and ineffectiveness are demonstrated in references 3 and 4. Although it was not possible to determine the spoiler lag in the present tests, the effects of vents of 1 percent and 2 percent of the wing chord on the aerodynamic characteristics of the wing and spoiler were determined. The aileron at the tip was intended to reduce the lag and increase the effectiveness, as well as to improve the hinge-moment characteristics of the system. The tests of the perforations, slot and spoiler bevel were made to provide further means of improving the characteristics of the spoiler.

In the arrangement of the aileron and spoiler, the aileron was operating in the wake of the spoiler. This condition could cause serious buffeting of the aileron and tests were made therefore to determine the characteristics of the spoiler with that part of the spoiler directly in front of the aileron removed.

<u>Characteristics of the plain spoiler</u>.- The characteristics of the plain spoiler, with flaps neutral and deflected, are shown in figures 13 and 14. With flaps neutral, the variation of rolling-moment coefficient with spoiler deflection was approximately linear. With flaps deflected, a marked increase in the rolling effectiveness of the spoiler occurred between spoiler deflections of -5° and -10°. As the spoiler deflection was increased beyond -10°, the rolling-moment coefficients continued to increase but the slope of the curve was greatly reduced. At low angles of attack with either flap configuration the yawing-moment coefficients were favorable (of the same sign as the rolling-moment coefficient) and varied linearly with spoiler deflection. At high angles of attack the yawing-moment coefficients were adverse at low spoiler deflections, particularly with flaps deflected. The adverse yawing-moments occurred when the adverse induced yawing moment due to the change in induced drag with deflection of the spoiler exceeded the favorable yawing moment caused by the change in profile drag with

deflection of the spoiler. Thus, at high angles of attack where the induced yawing moment was large (since it was dependent upon the wing lift as well as the rolling effectiveness) the total yawing moment was adverse. This condition was more pronounced with flaps deflected as indicated by the large increase in rolling effectiveness at spoiler deflections between -5° and -10°. With flaps neutral, the rolling-moment and yawing-moment coefficients decreased as the angle of attack was increased; however, with flaps deflected, the yawing-moment coefficients decreased but the rolling-moment coefficients increased as the angle of attack was increased.

The aileron hinge-moment coefficients became more negative as the spoiler was deflected from -2.5° to approximately -10° but remained approximately constant with further spoiler deflection. This change in the aileron hinge moments resulted from the increase in the negative pressure over the aileron when the spoiler was deflected. The change in the hinge-moment coefficients was greatest at small angles of attack and large flap and aileron deflections.

In general for all configurations the variation of spoiler hinge-moment coefficient with spoiler deflection was irregular and the values of the coefficients were negative (tending to produce greater spoiler deflections). However, at high angles of attack the magnitude of the coefficients and the irregular variation were reduced.

Effect of the 1-percent vent.- The effect of the 1-percent vent on the characteristics of the plain spoiler was determined from a comparison of figures 13 and 15 for flaps neutral and figures 14 and 16 for flaps deflected. With flaps neutral the vent slightly increased the rolling effectiveness of the spoiler at small spoiler deflections (less than -10°) and decreased the effectiveness at large deflections. With flaps deflected the increase in spoiler effectiveness at small deflections was much greater, particularly at high angles of attack, whereas the reduction in effectiveness at large spoiler deflections was negligible. The vent had no effect on the yawing-moment coefficients.

As was the case for the plain spoiler configuration, the aileron hinge moments usually became more negative as the spoiler deflection was increased. The incremental change in the aileron hinge-moment coefficient (with spoiler deflection) was a measure of the increase in the negative pressures in the region behind the spoiler. The effect of the 1-percent vent was to reduce the change in aileron hinge-moment coefficient resulting from deflection of the spoiler. This effect of the vent (which indicates a reduction in the negative pressure behind the spoiler) occurred, in general, at spoiler deflections less than -10°, and was consistent with the increase in effectiveness of the spoiler at small deflections. It should be noted, however, that the aileron hinge-moment coefficients were an indication of the conditions existing behind the outboard section of the spoiler only, and were not necessarily representative of the conditions over the entire spoiler.

The 1-percent vent had no appreciable effect on the hinge-moment characteristics of the spoiler.

Effect of the 2-percent vent.- The effect of the 2-percent vent was determined from a comparison of figures 13 and 17 for flaps neutral and figures 14 and 18 for flaps deflected. At low angles of attack with flaps neutral and deflected the effect of the 2-percent vent on the rolling-moment and yawing-moment characteristics was similar to that produced by the 1-percent vent. However, at small spoiler deflections, the 2-percent vent was more effective in increasing the rolling-moment coefficients than was the 1-percent vent. At high angles of attack, particularly with flaps deflected, the 2-percent vent greatly reduced the rolling-moment and yawing-moment coefficients.

The aileron hinge-moment characteristics with the 2-percent vent were similar to those of the 1-percent-vent configuration. At high angles of attack with flaps neutral or deflected the region behind the vent was stalled and consequently the change in the aileron hinge-moment coefficient with spoiler deflection was small.

The 2-percent vent had no appreciable effect on the spoiler hinge-moment coefficients with flaps neutral. In the flap deflected configuration, however, the spoiler hinge-moment coefficients became slightly more positive at small spoiler deflections as a result of the vent.

Effect of simultaneous operation of the spoiler and 1-percent or 2-percent vents.- In figures 15 to 18 the data were obtained for an arrangement in which the vent is fixed in the wing. When the vent is not fixed but opens as the spoiler deflects, the loss in lift caused by the vent will occur only over the wing panel on which the spoiler is deflected, thus augmenting the rolling effectiveness of the spoiler. The data for this arrangement are shown in figure 19, in which it is assumed that the 2-percent vent would open instantaneously as the spoiler began to deflect. It should be noted that the rolling-moment coefficients indicated at neutral spoiler deflection would not be obtained in a practical case because the vent would not open instantaneously but at some finite rate as the spoiler deflected. The effect on the rolling-moment and yawing-moment characteristics of the 2-percent vent in this arrangement was determined by a comparison of figures 13 and 19(a) for flaps neutral, and figures 14 and 19(b) for flaps deflected. At all angles of attack and flap and spoiler deflections the rolling effectiveness was increased. The greatest increase occurred at high angles of attack with flaps deflected where the large loss in lift as a result of the vent (as shown in figure 11(a)) greatly increased the rolling effectiveness at small spoiler deflections.

Inasmuch as the effect of instantaneous operation of the vents can be represented as a constant increment of rolling-moment and yawing-moment coefficient the characteristics for the 1-percent vent are not presented in figure form; however, the increments in rolling-moment and yawing-moment coefficients produced by both the 1-percent and 2-percent vents are presented in the following table:

Flap deflection δ_f (deg)	Angle of attack α (deg)	1-percent vent		2-percent vent	
		ΔC_l	ΔC_n	ΔC_l	ΔC_n
0	3.5	-0.0032	-0.0001	-0.0054	-0.0004
0	13.2	-.0033	-.0004	-.0090	.0005
50	4.7	-.0012	-.0002	-.0050	-.0005
50	12.3	-.0032	-.0004	-.0346	-.0013

The increments in rolling-moment and yawing-moment coefficients produced by the 2-percent vent were considerably greater than those produced by the 1-percent vent particularly at high angles of attack with flaps deflected.

It is evident from these data that a vent behind the spoiler must operate in conjunction with the spoiler in order to avoid increases in drag and serious losses in both the lift of the airplane and rolling effectiveness of the spoiler. These effects have been demonstrated in reference 5 where the simultaneous operation of the spoiler and vent was accomplished by the use of a plug-type spoiler.

Effect of the spoiler perforations.- The effect of the perforations on the spoiler and aileron characteristics was determined from a comparison of figures 13 and 20 for flaps neutral and figures 14 and 21 for flaps deflected. With flaps neutral and deflected the perforations generally decreased the rolling-moment and yawing-moment coefficients.

The aileron hinge-moment coefficients were not greatly affected by the perforations. At spoiler deflections greater than approximately -25° the aileron hinge-moment coefficients were slightly less negative for the perforated spoiler.

The spoiler hinge-moment characteristics were greatly improved as a result of the perforations. The effect of the perforations were (1) to reduce greatly the erratic variation of the hinge-moment coefficients with spoiler deflection, and (2) to reduce the hinge-moment coefficients at small deflections and to produce positive hinge-moment coefficients at large spoiler deflections.

Effect of the spoiler slot.- The effect of the spoiler slot on the characteristics of the spoiler and aileron were determined from a comparison of figures 13 and 22 for flaps neutral and figures 14 and 23 for flaps deflected. The effect of the slot on the rolling-moment and yawing-moment characteristics was generally small; the rolling-moment coefficients were slightly reduced at the maximum deflection of the spoiler. The slot had no notable effect on the aileron hinge-moment coefficients.

The spoiler hinge-moment coefficients were, in general, unaffected by the slot at spoiler deflections less than -40°. At spoiler deflections above -40° the hinge-moment coefficients became more positive.

Effect of combinations of vents, perforations, and slot.- The effect of the perforations and 1-percent vent on the characteristics of the spoiler and aileron are determined from a comparison of figures 13 and 24 for flaps neutral and figures 14 and 25 for flaps deflected. The combined effect of the perforation, 1-percent vent, and slot are determined from a comparison of figures 13 and 26 for flaps neutral and figures 14 and 27 for flaps deflected. In general, the effects of the modifications on the rolling-moment, yawing-moment, and hinge-moment characteristics of the spoiler and aileron were additive. That is, the individual effects of each modification discussed previously add to form the characteristics of the spoiler and aileron for each of the various combinations of the 1-percent vent, perforations, and slot.

Effect of the spoiler bevel.- The effect of the 17° bevel on the characteristics of the spoiler and aileron are determined from a comparison of figures 26 and 28(a) with flaps neutral and figures 27 and 28(b) with the flaps deflected. The significant effect of the spoiler bevel was an appreciable reduction in the spoiler hinge-moment coefficients at large deflections of the spoiler. The reduction in the spoiler hinge-moment coefficients became greater as the angle of attack increased and amounted to approximately 35 percent at the highest angle of attack. Further reductions could be made by placing bevels on the perforation holes, particularly those near the upper edge of the spoiler.

Spoiler characteristics for two alternate flap configurations.- The characteristics of the spoiler with full-span flaps deflected 20° and with partial-span flaps deflected 50° are presented in figure 29. With full-span flaps deflected 20° the rolling-moment and yawing-moment coefficients were considerably greater than with flaps neutral. The characteristics of the spoiler with partial-span flaps were approximately the same as with the flaps neutral. Thus the increase in spoiler effectiveness with increased flap span appears to be directly dependent on the lift over that part of the wing spanned by the spoiler.

Inasmuch as the rolling effectiveness of the spoiler for either flap configuration is not appreciably increased by the aileron, the effectiveness of the spoiler with flaps deflected might be greatly improved by extending the span of the flap to the wing tip (providing the aileron can successfully be eliminated). A further advantage of such an arrangement would be an increase in the maximum lift of the wing.

Effect of spoiler span.- The characteristics of the spoiler and aileron with the two outboard segments (directly in front of the aileron) removed are given in figure 30 for flaps neutral and in figure 31 for flaps deflected. The characteristics of the spoiler and aileron for various combinations of spoiler segments with flaps neutral and deflected are presented in figures 30 and 31. The rolling-moment and yawing-moment coefficients were reduced approximately in proportion to the reduction in spoiler span with flaps neutral. In the flap deflected configuration the reduction in rolling and yawing effectiveness was a much smaller percentage of the total rolling-moment and yawing-moment coefficients. The spoiler hinge-moment coefficients became more negative at small spoiler deflections and more positive at large deflections. The upfloating tendency of the aileron resulting from deflection of the spoiler was practically eliminated.

The characteristics of the spoiler and aileron for various combinations of spoiler segments with flaps neutral and deflected are presented in figures 32 and 33, respectively. The effect of progressively removing the spoiler segments from the inboard end of the spoiler (figs. 32 and 33) was to reduce the rolling-moment and yawing-moment coefficients produced by the spoiler. The reduction in effectiveness of the spoiler as a result of removing each segment for all configurations was approximately proportional to the span of the segment with the exception of the two outboard segments in the flap-deflected configuration where the reduction was considerably smaller as noted previously.

The aileron hinge moments became more positive at small spoiler deflections and more negative at large deflections as a result of progressively reducing the spoiler span, particularly in the flap-deflected configuration.

Except for the outboard segment alone the spoiler hinge-moment coefficients generally became more negative as the spoiler span was progressively reduced. The hinge-moment characteristics of the outboard segment alone were rather erratic.

SUMMARY OF RESULTS

The significant test results of the spoiler-pilot-aileron arrangement installed on the model of a large bomber-type airplane may be summarized as follows:

1. With full-span flaps deflected and with the vent (located directly behind the spoiler) open or closed, the initial stalling of the wing occurred at the tips, however with the vents closed there probably would be no appreciable loss in lateral control until maximum lift was reached.

2. The 1-percent vent increased the rolling effectiveness of the spoiler at small spoiler deflections, particularly at the high angles of attack with flaps deflected.

3. With flaps deflected the 2-percent vent caused a large reduction in both the wing lift and rolling effectiveness of the spoiler at large angles of attack. However, at small angles of attack the 2-percent vent increased the rolling effectiveness of the spoiler at small spoiler deflections.

4. The simultaneous operation of the spoiler and vent (in contrast to a vent fixed in the wing) would result in a large increase in the effectiveness of the spoiler and would avoid any loss in wing lift such as resulted with the fixed-vent arrangement.

5. The spoiler perforations reduced the rolling-moment and yawing-moment coefficients but caused the spoiler hinge-moment coefficients to become more positive, particularly at large spoiler deflections.

6. The spoiler slot (located on the lower edge of the spoiler) had no appreciable effect on the rolling-moment and yawing-moment characteristics of the spoiler but produced more positive spoiler hinge-moment coefficients at large spoiler deflections.

7. The effects produced by the individual spoiler modifications were additive when various modifications were combined.

8. In general, progressively decreasing the spoiler span by removing the segments from the inboard end of the spoiler caused a decrease in rolling effectiveness that was approximately proportional to the span of the segment.

Langley Memorial Aeronautical Laboratory
National Advisory Committee for Aeronautics
Langley Field, Va., June 20, 1947

REFERENCES

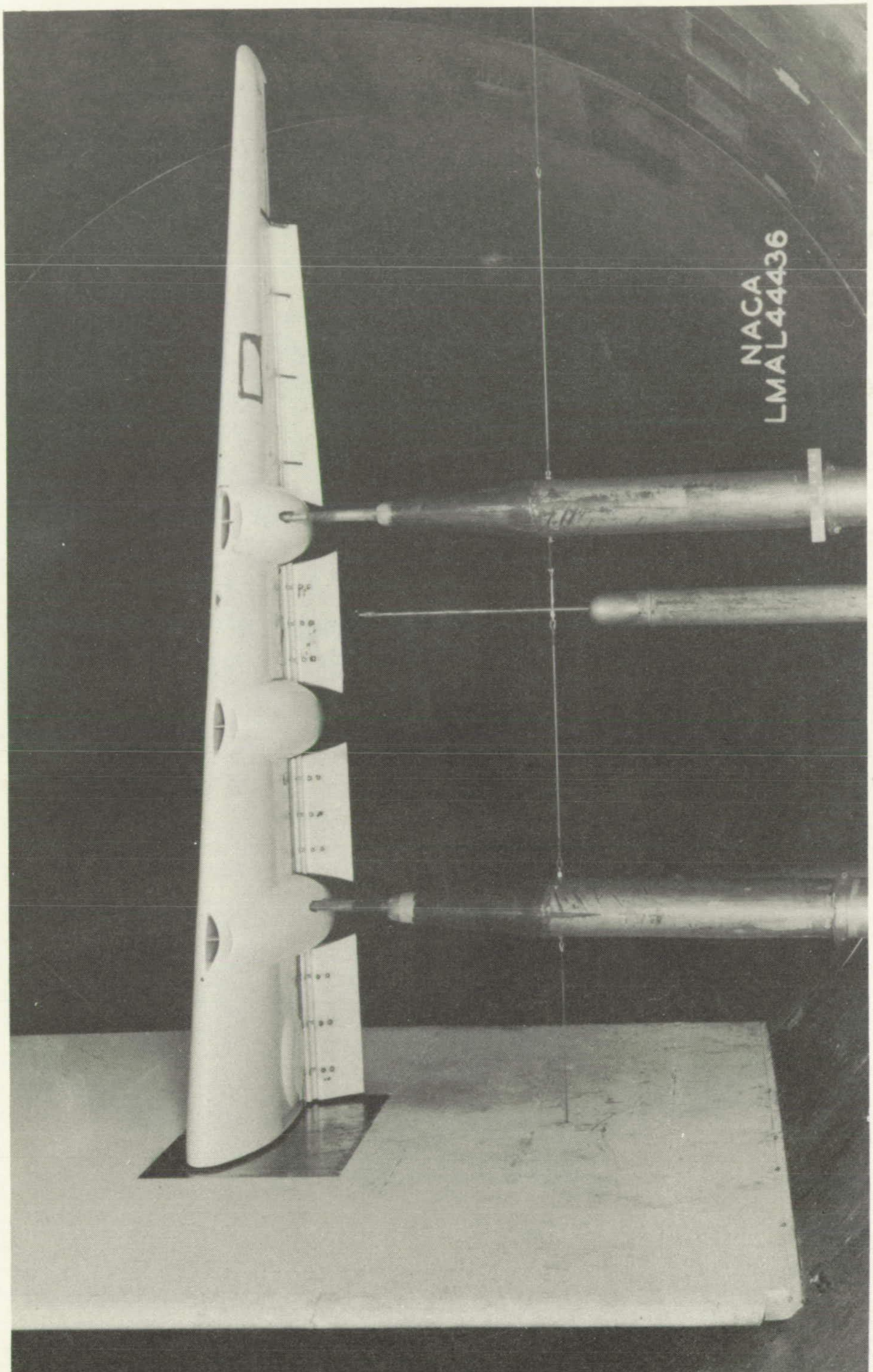
1. Ashkenas, I. L.: The Development of a Lateral-Control System for Use with Large-Span Flaps. NACA TN No. 1015, 1946.

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

3. Weick, Fred E., and Shortal, Joseph A.: Development of the N.A.C.A. Slot-Lip Aileron. NACA TN No. 547, 1935.

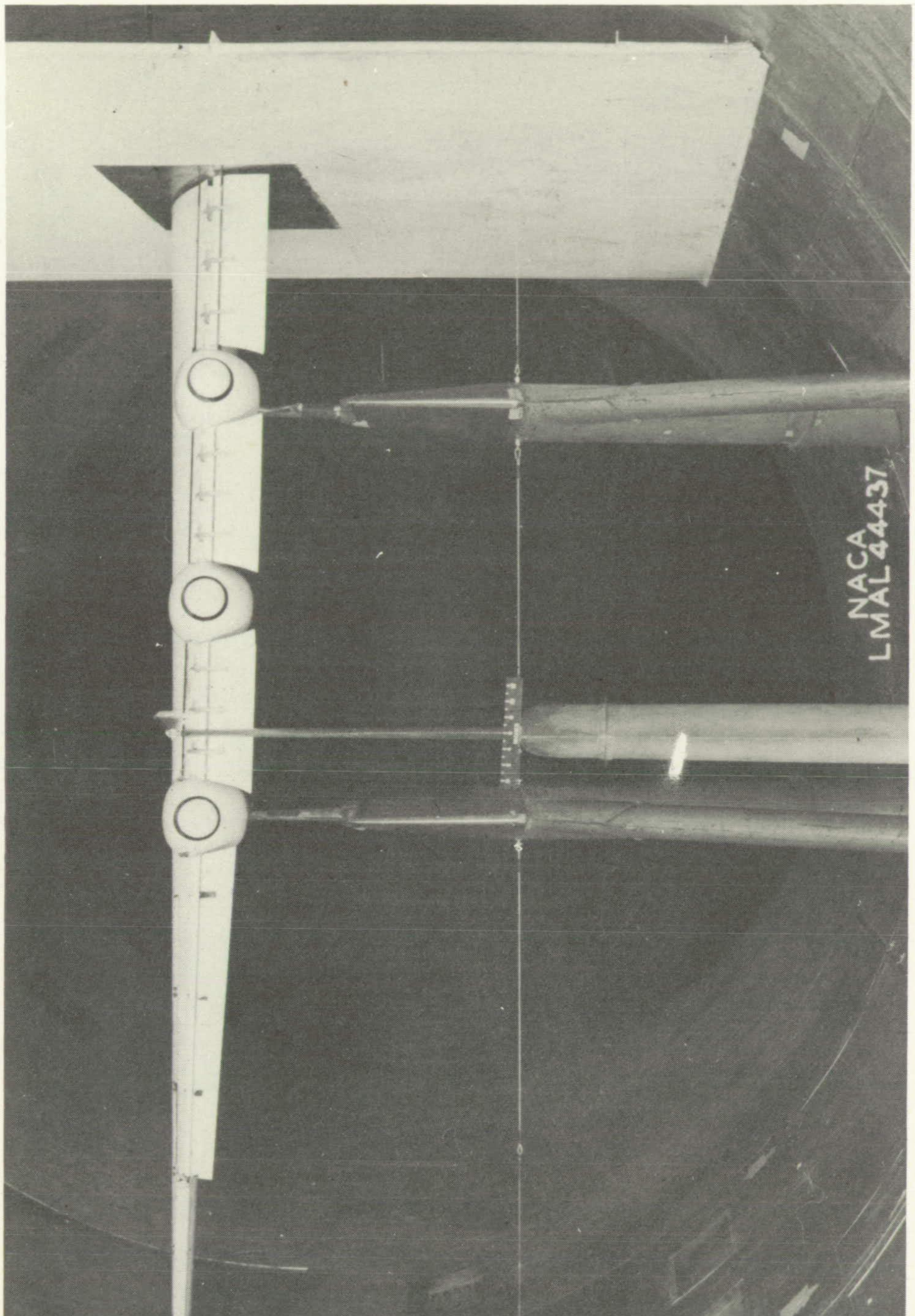
4. Wenzinger, Carl J., and Rogallo, Francis M.: Wind-Tunnel Investigation of Spoiler, Deflector and Slot Lateral-Control Devices on Wings with Full-Span Split and Slotted Flaps. NACA Rep. No. 706, 1941.

5. Rogallo, Francis M., and Swanson, Robert S.: Wind-Tunnel Development of a Plug-Type Spoiler-Slot Aileron for a Wing with a Full-Span Slotted Flap and a Discussion of Its Application. NACA ARR, Nov. 1941.



(a) Front view.

Figure 1.- The reflection plane and the partial-span wing model mounted in the Langley 19-foot pressure tunnel. Full-span flaps deflected 50°.



(b) Rear view.

Figure 1.- Concluded.

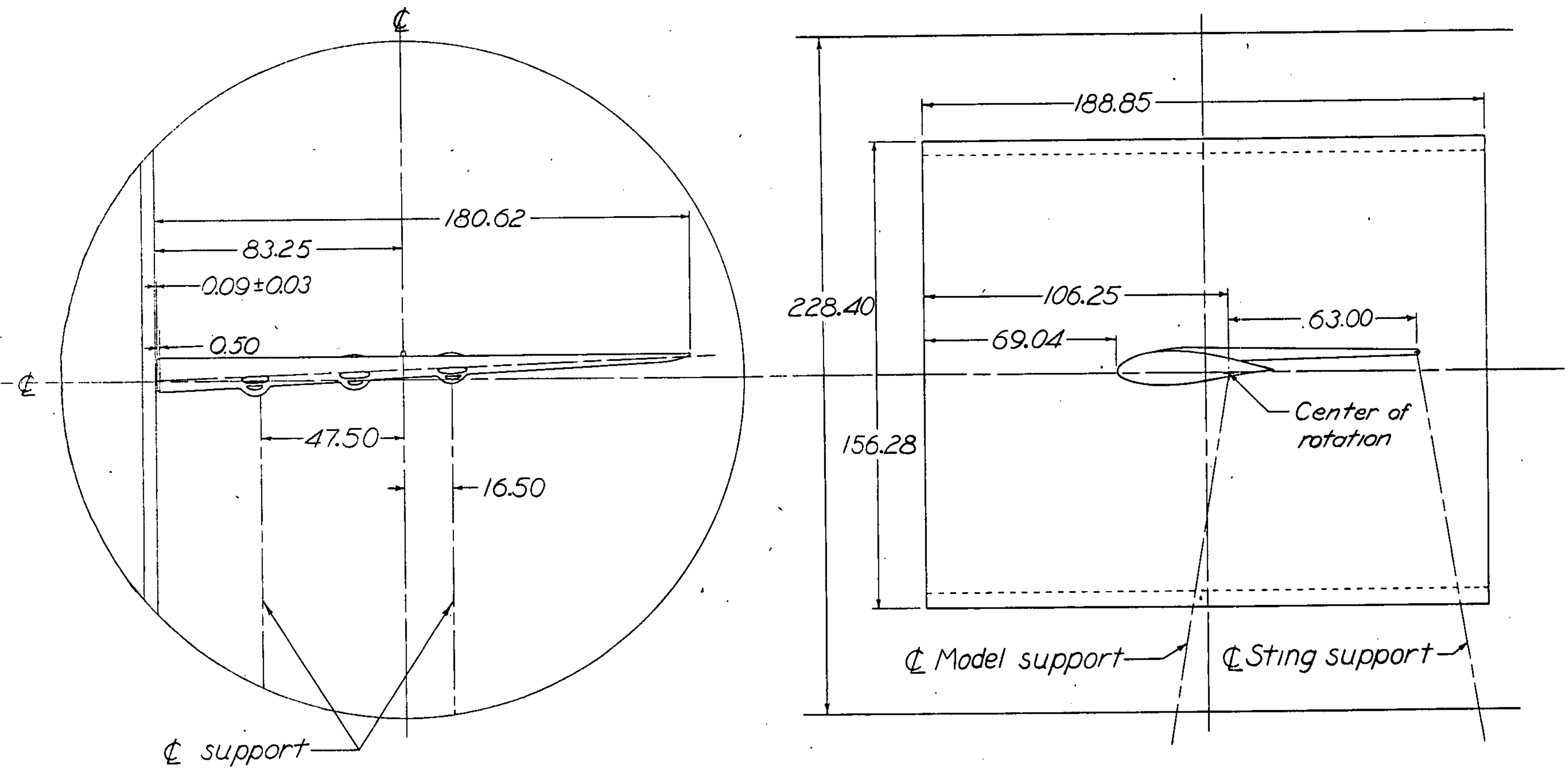


Figure 2.- Arrangement of the partial-span wing model and reflection plane in the Langley 19-foot pressure tunnel. (All dimensions in inches.)

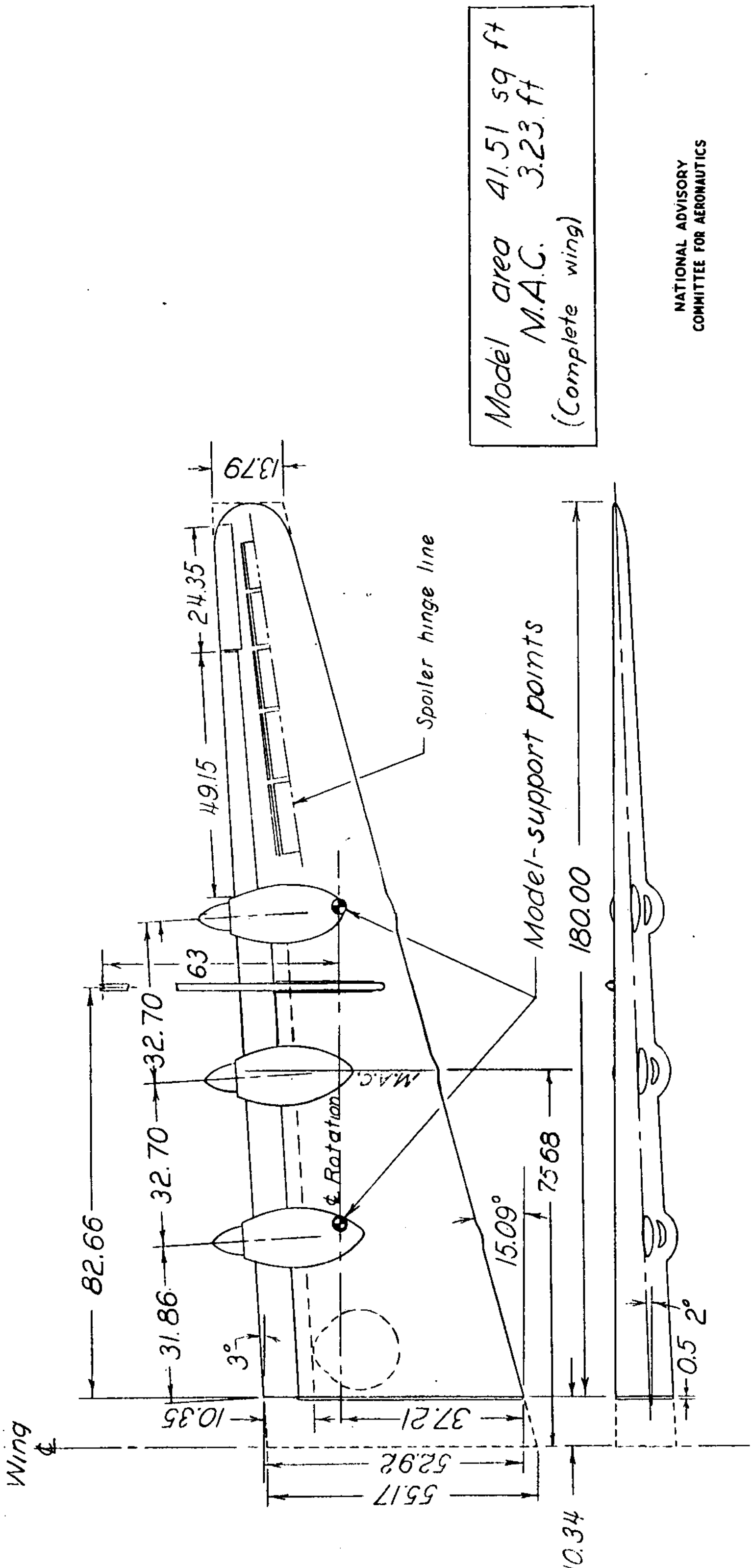
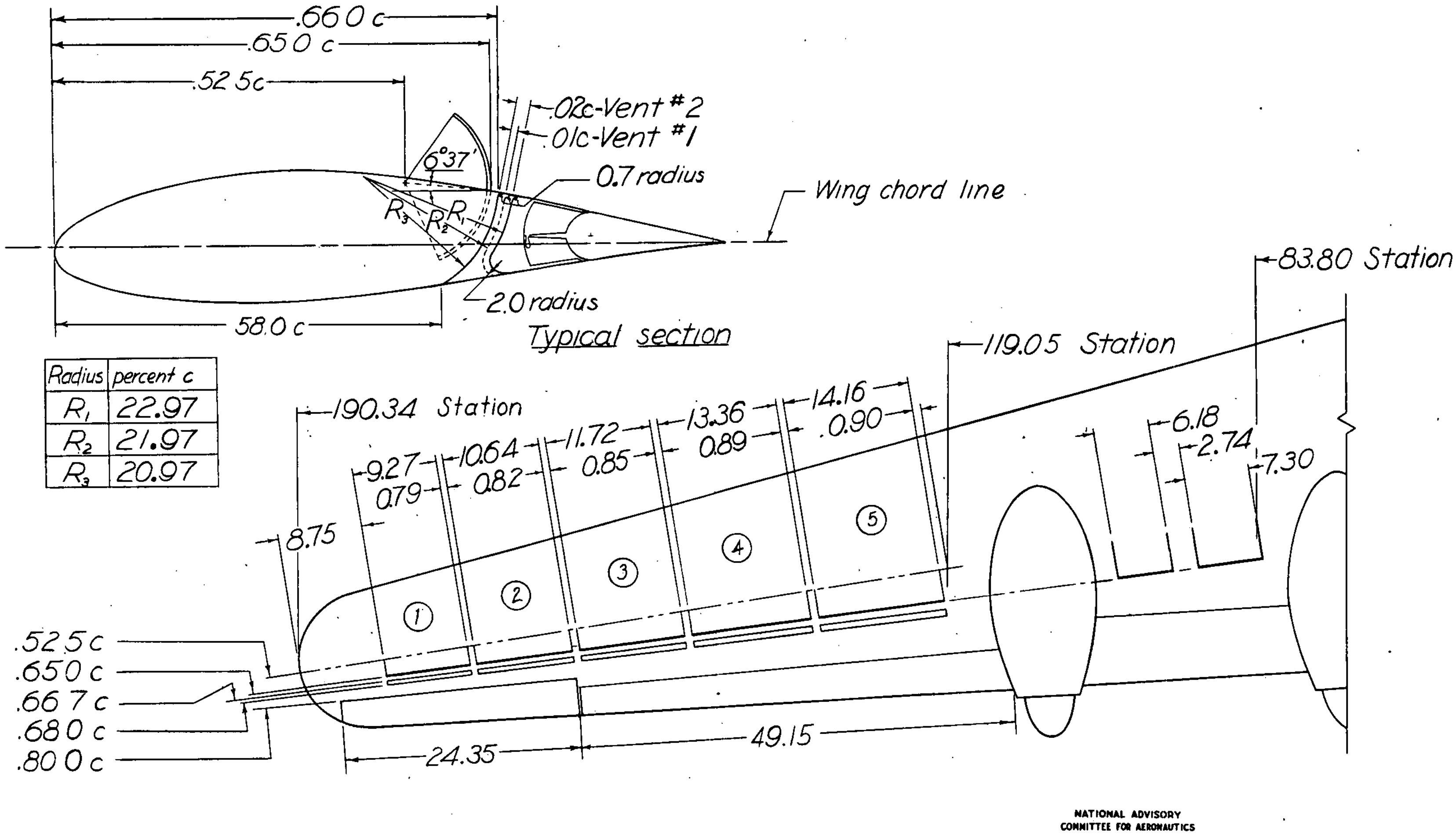
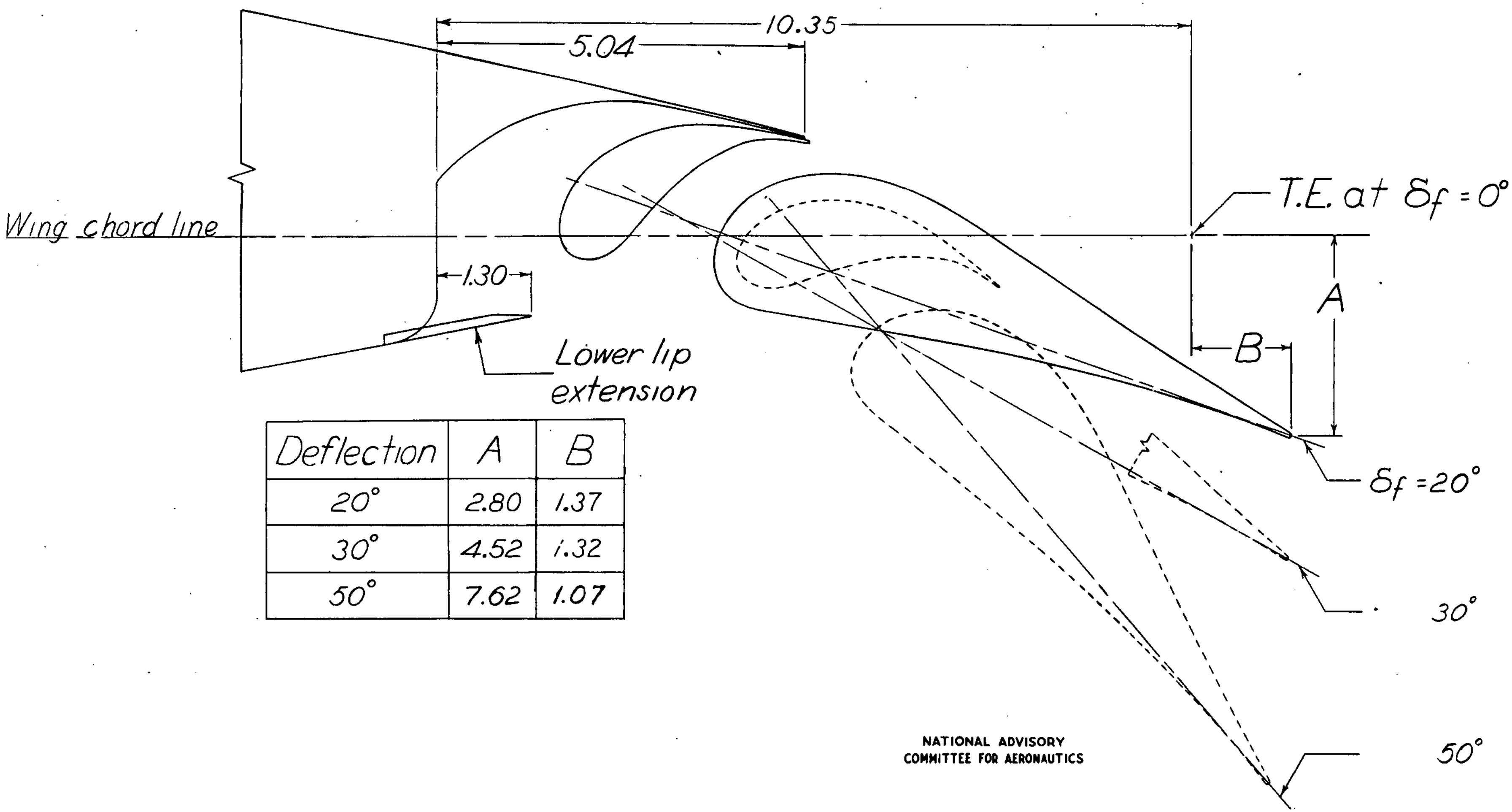


Figure 3.- Plan and elevation of the partial-span wing model. (All dimensions in inches.)



Radius	percent c
R_1	22.97
R_2	21.97
R_3	20.97

Figure 4.- Spoiler and vent arrangement of the partial-span wing model. (All dimensions in inches except as noted.)



Deflection	A	B
20°	2.80	1.37
30°	4.52	1.32
50°	7.62	1.07

Figure 5.- Three inboard double-slotted-flap positions at a typical section of the partial-span wing model. (All dimensions in inches.)

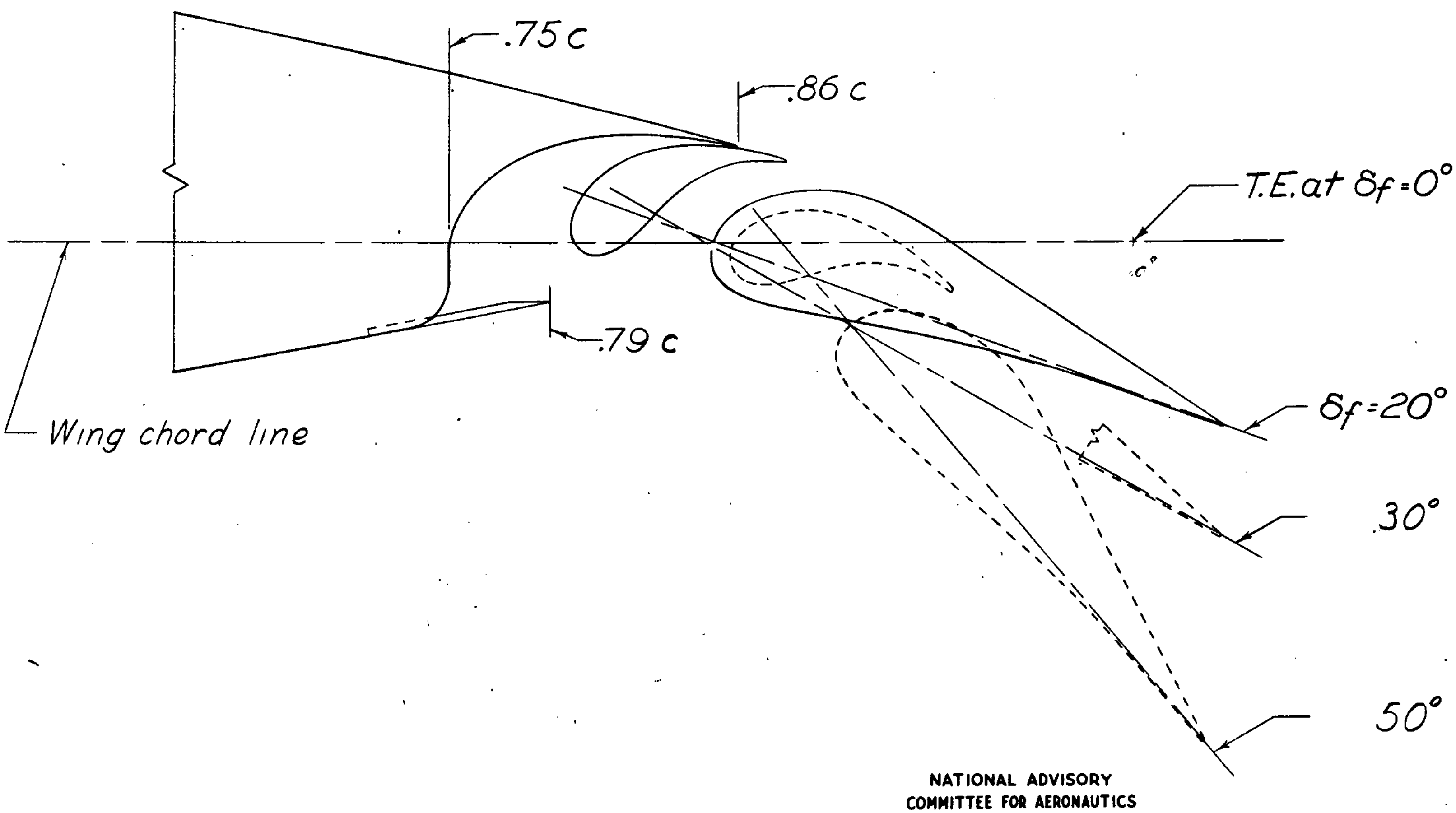
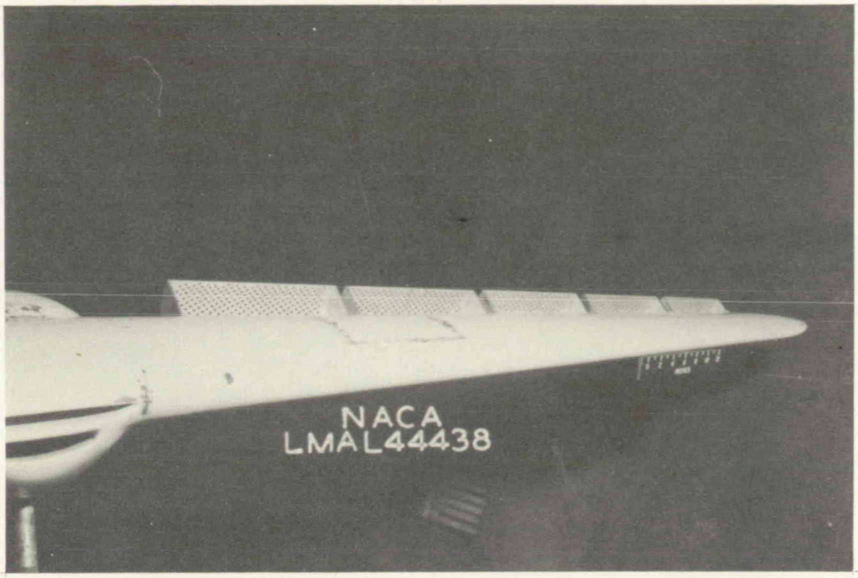


Figure 6.- Three outboard double-slotted-flap positions at a section of the partial-span wing model.



(a) Front view.

(b) Rear view.

Figure 7.- The outer-panel spoiler with perforations at the partial-span wing model.

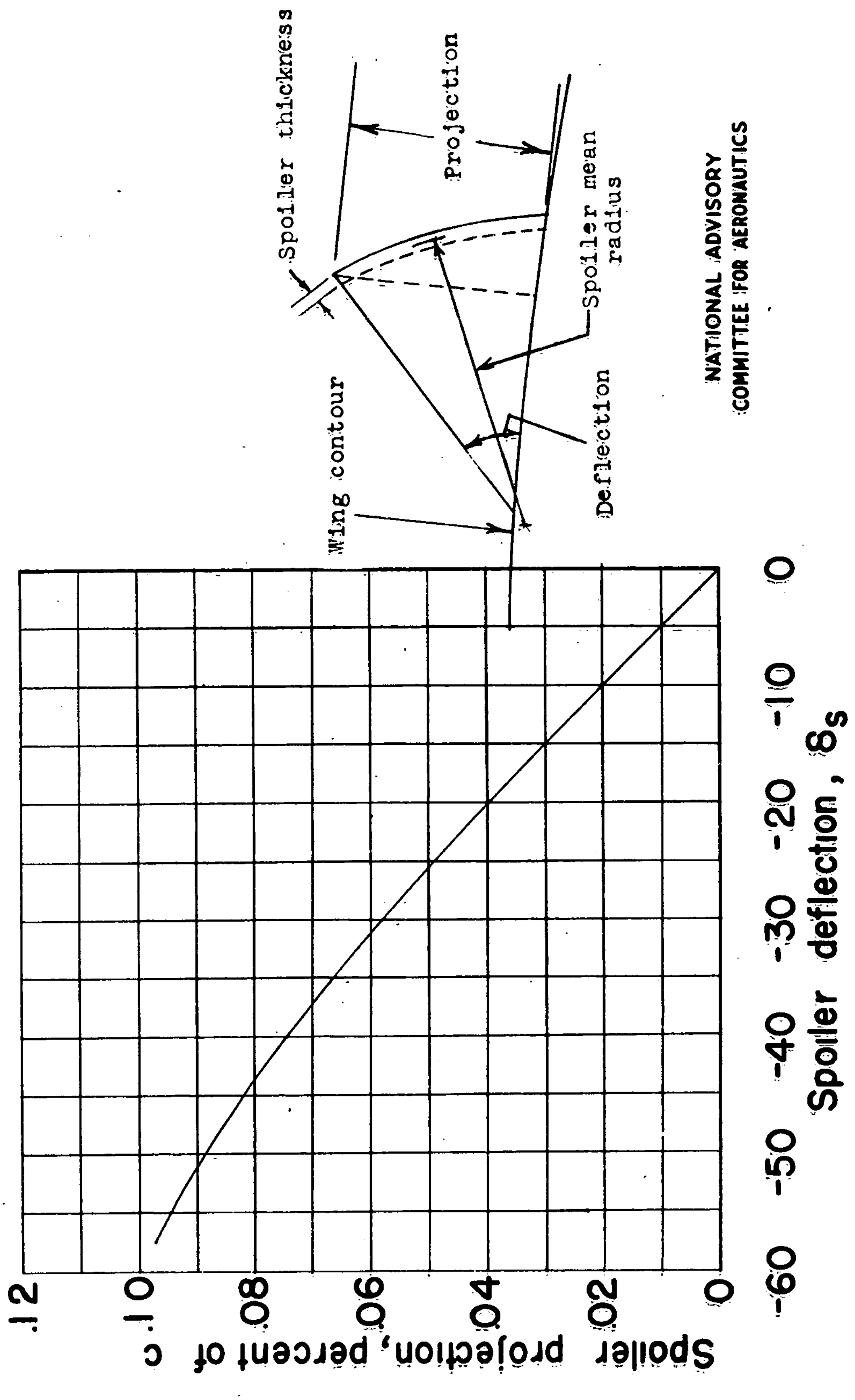


Figure 8.- Spoiler deflection defined in terms of spoiler projection.

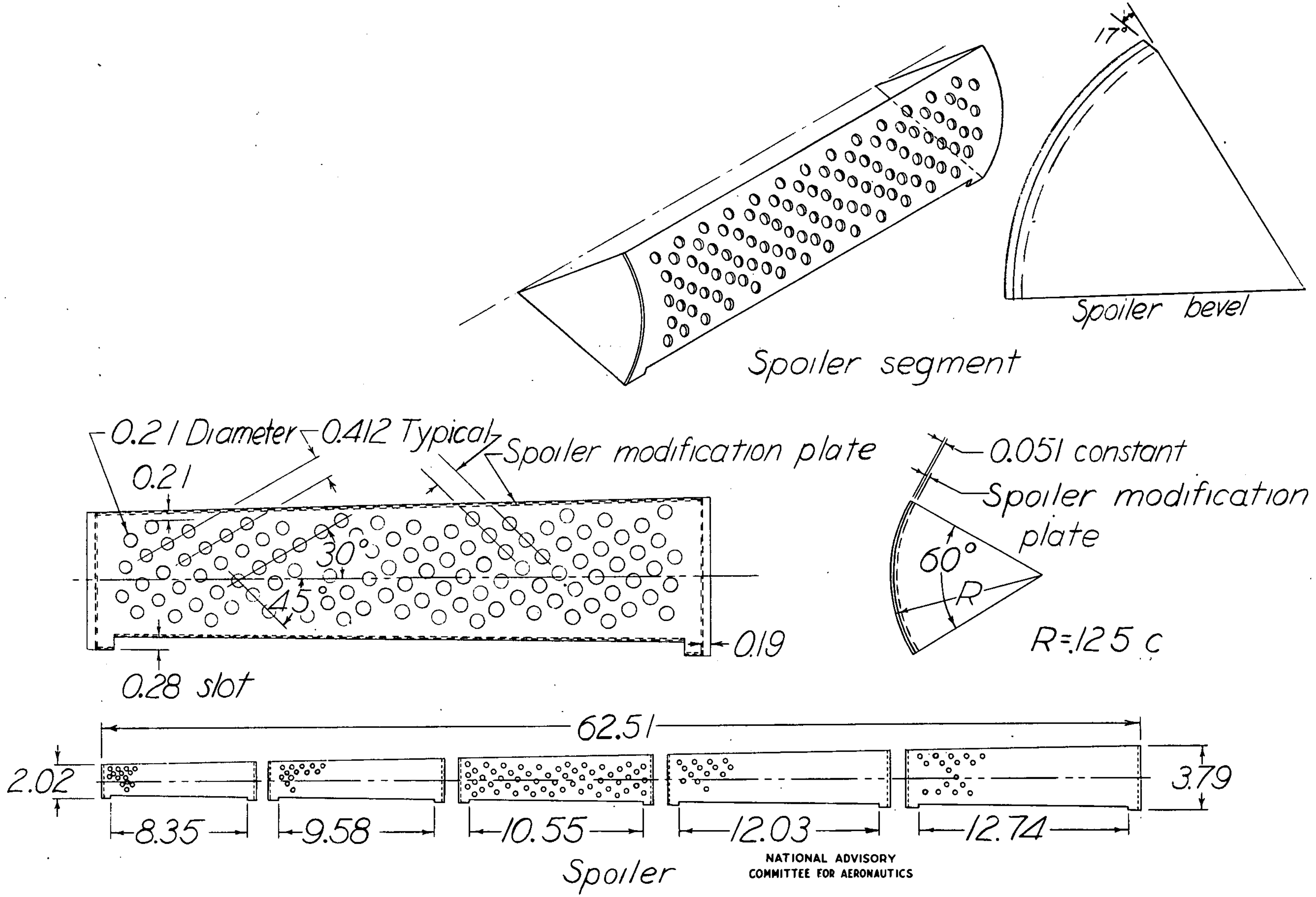
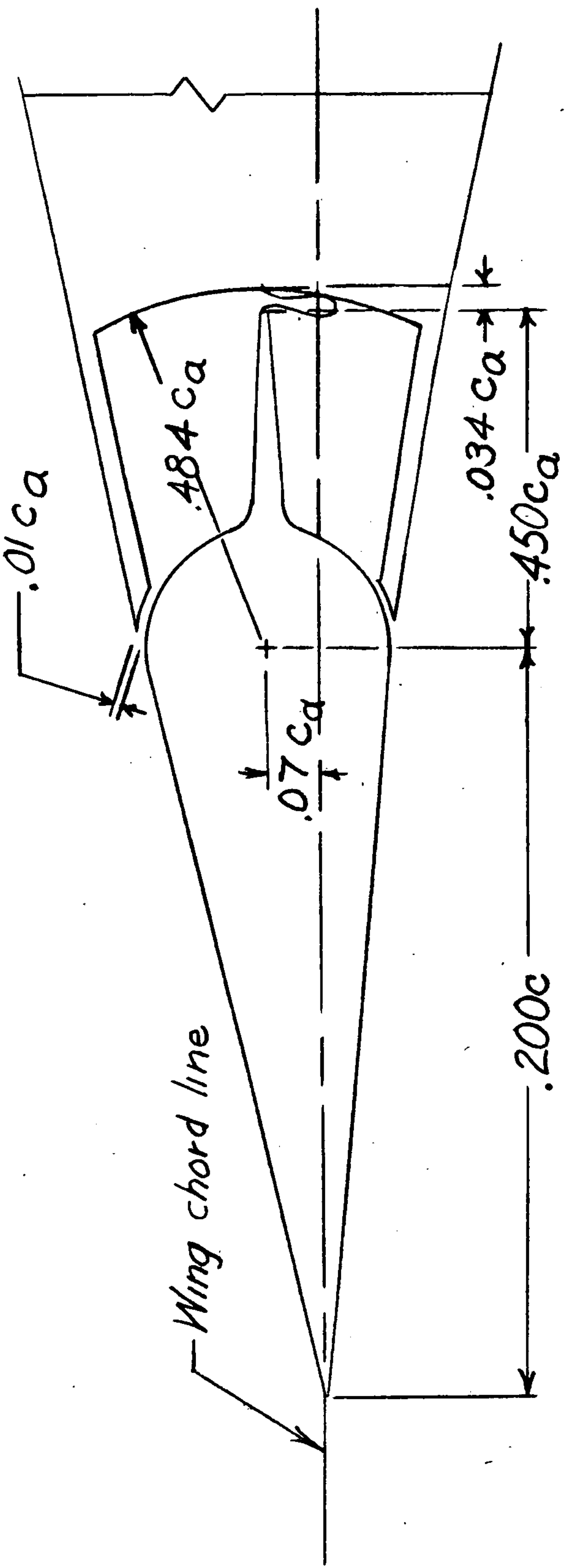
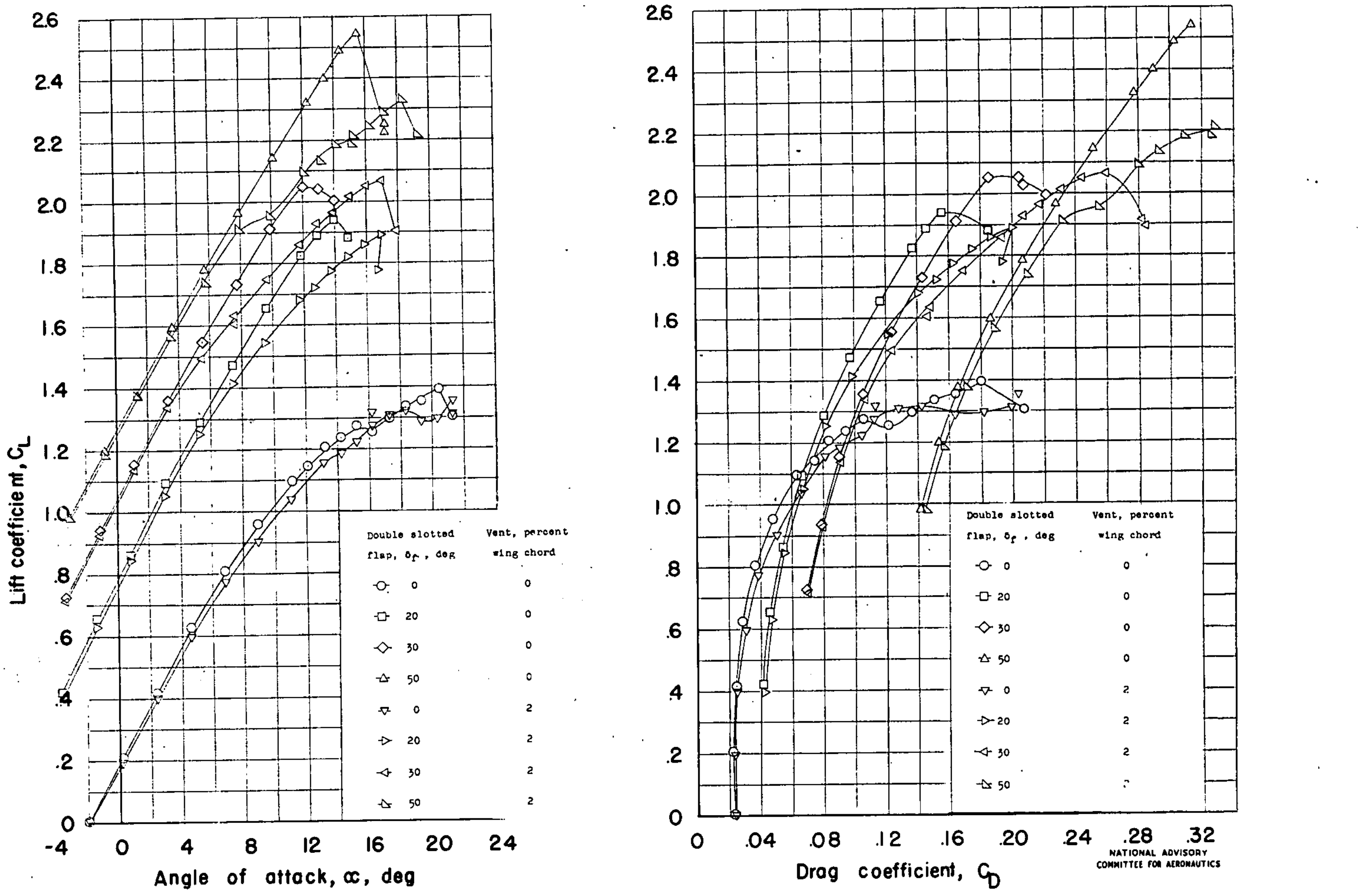


Figure 9.- Details of the spoiler segments of the partial-span wing model. (All dimensions in inches except as noted.)



NATIONAL ADVISORY
COMMITTEE FOR AERONAUTICS

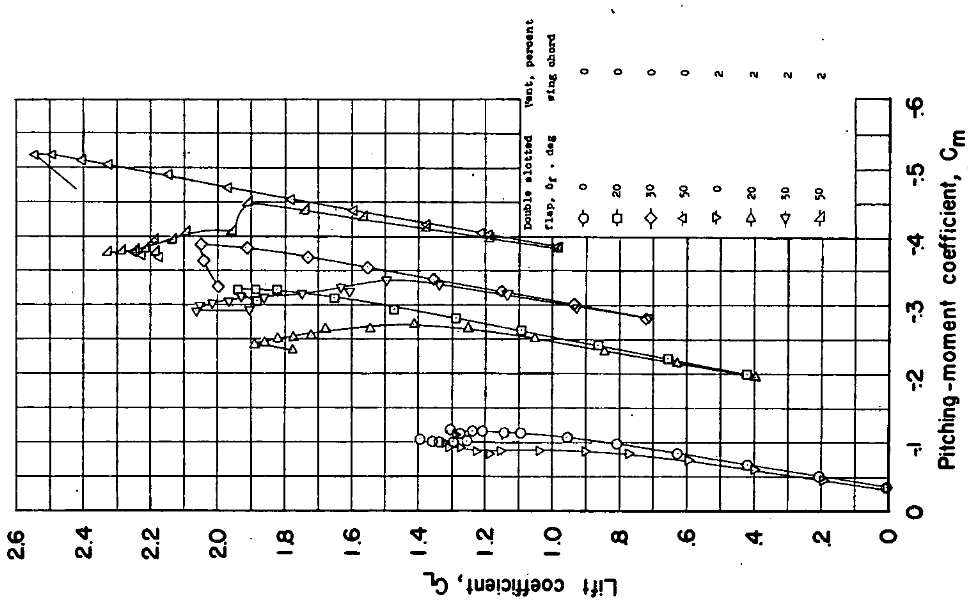
Figure 10.- Typical section of the internally sealed aileron of the partial-span wing model.



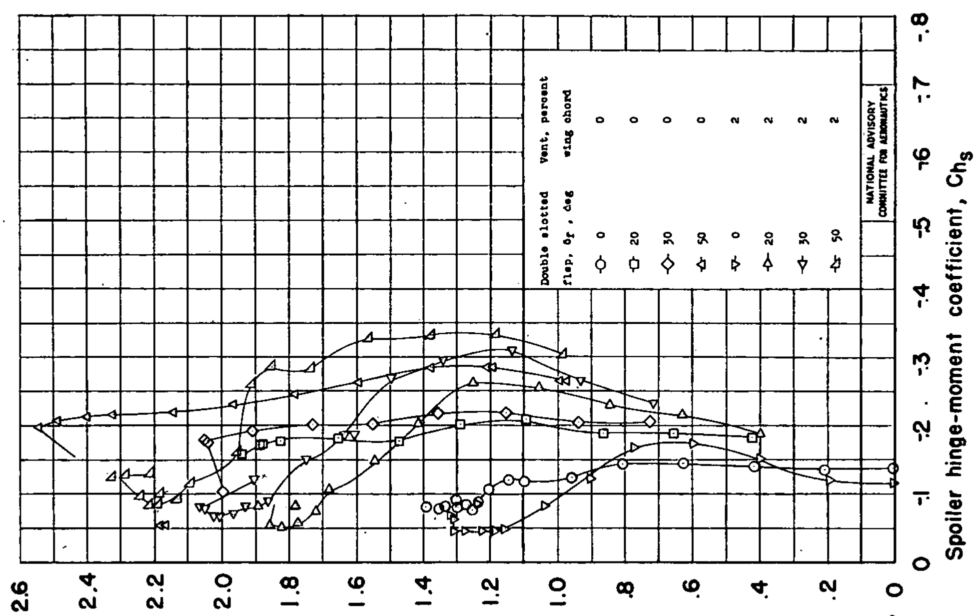
(a) Lift characteristics.

(b) Drag characteristics.

Figure 11.- Aerodynamic characteristics of the partial-span model with various arrangements of flaps and vent. Spoilers neutral; $R \approx 8,900,000$; $M \approx 0.18$.

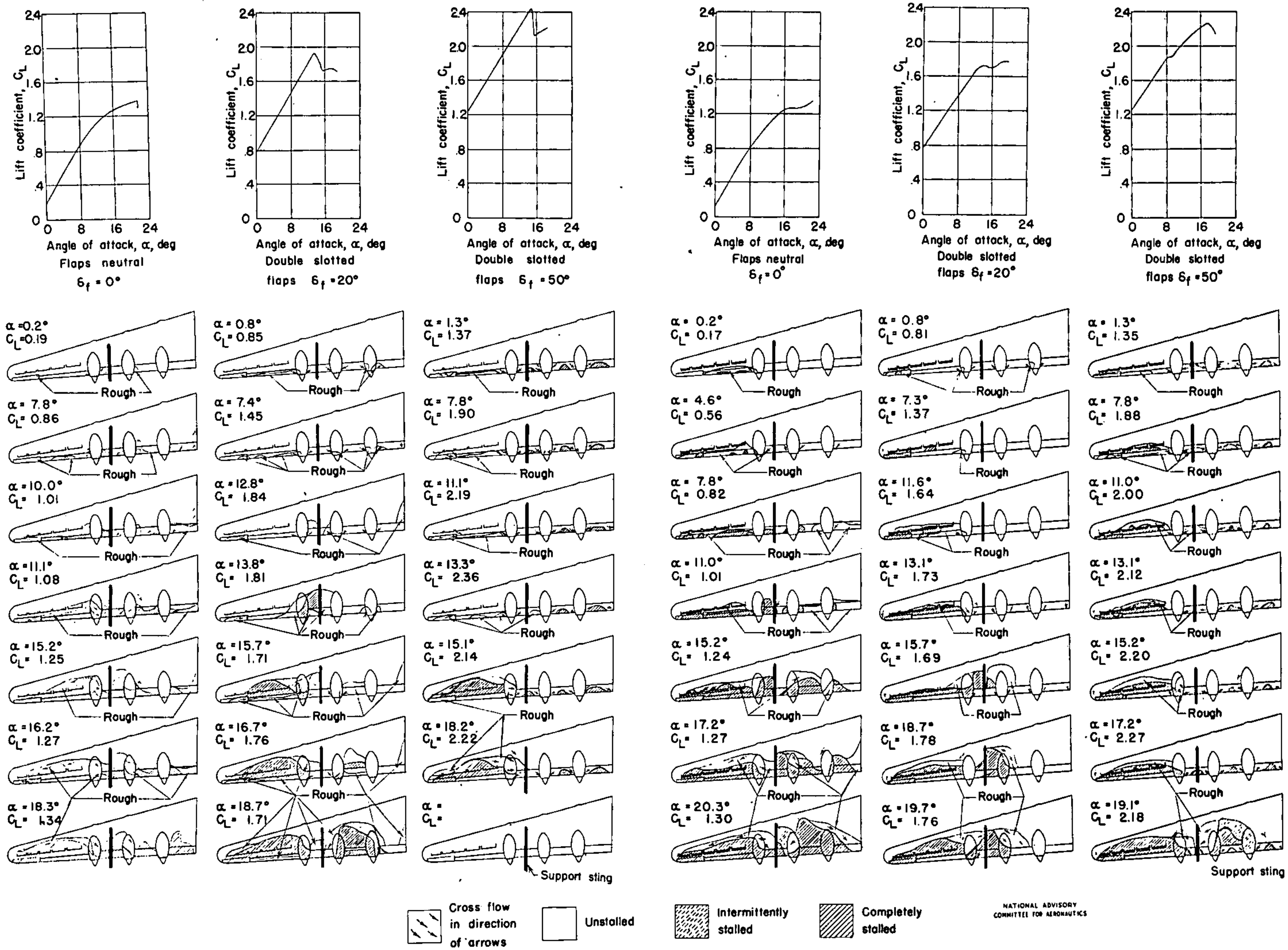


(c) Pitching-moment characteristics.



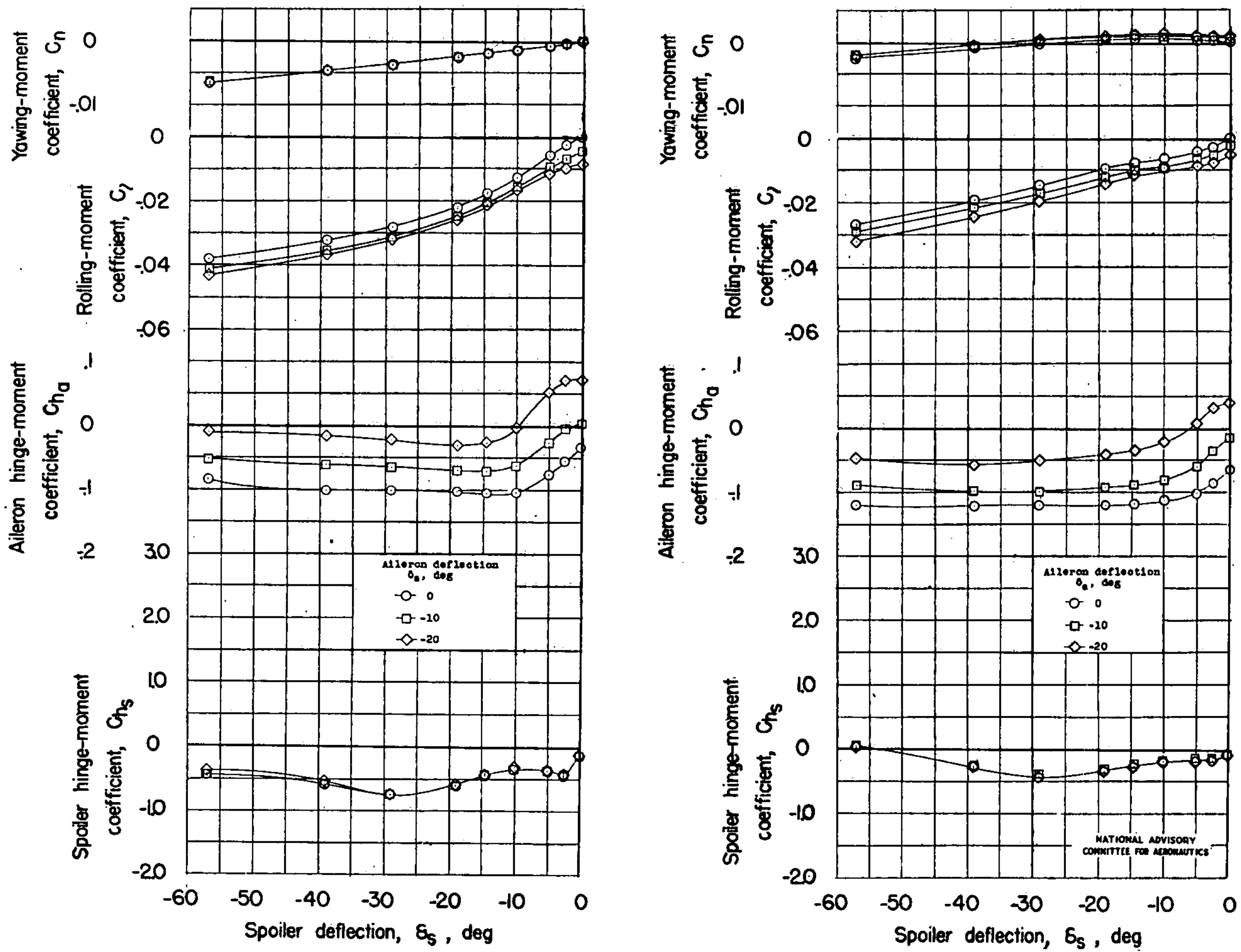
(d) Spoiler hinge-moment characteristics.

Figure 11.- Concluded.



(a) Vent closed. (b) 2-percent vent open.

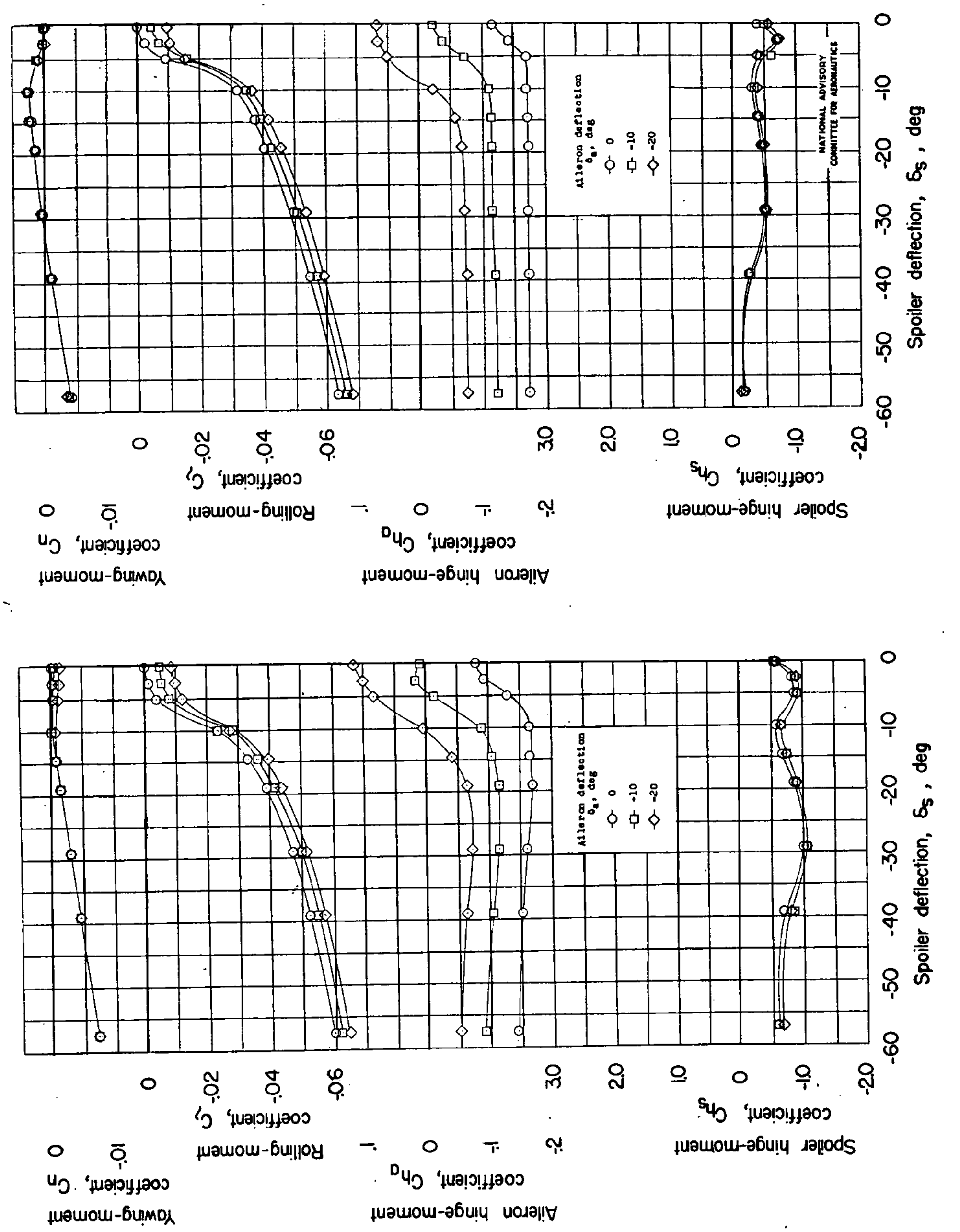
Figure 12.- Stalling characteristics of the partial-span wing model for various flap and vent configurations. $R \approx 8,900,000$; $M \approx 0.18$.



(a) $\alpha = 3.5^{\circ}$.

(b) $\alpha = 13.5^{\circ}$.

Figure 13.- Characteristics of the plain spoiler for various deflections of the aileron. Vent closed; full-span double slotted flaps neutral; $R \approx 8,900,000$; $M \approx 0.18$.



(a) $\alpha = 4.7^{\circ}$.

(b) $\alpha = 12.3^{\circ}$.

Figure 14.- Characteristics of the plain spoiler for various deflections of the aileron. Vent closed; full-span double slotted flaps deflected 50°; $R \approx 8,900,000$; $M \approx 0.18$.

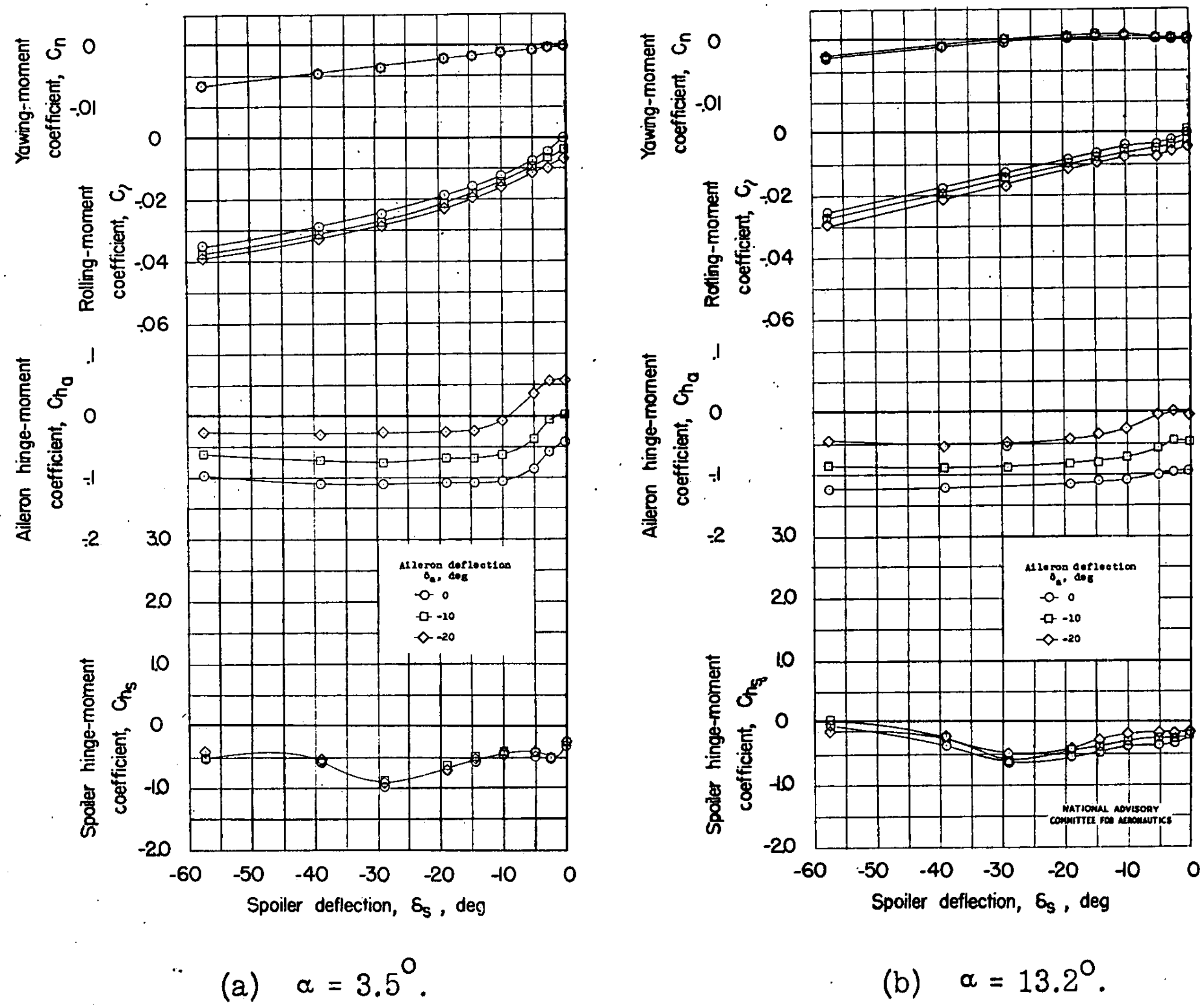
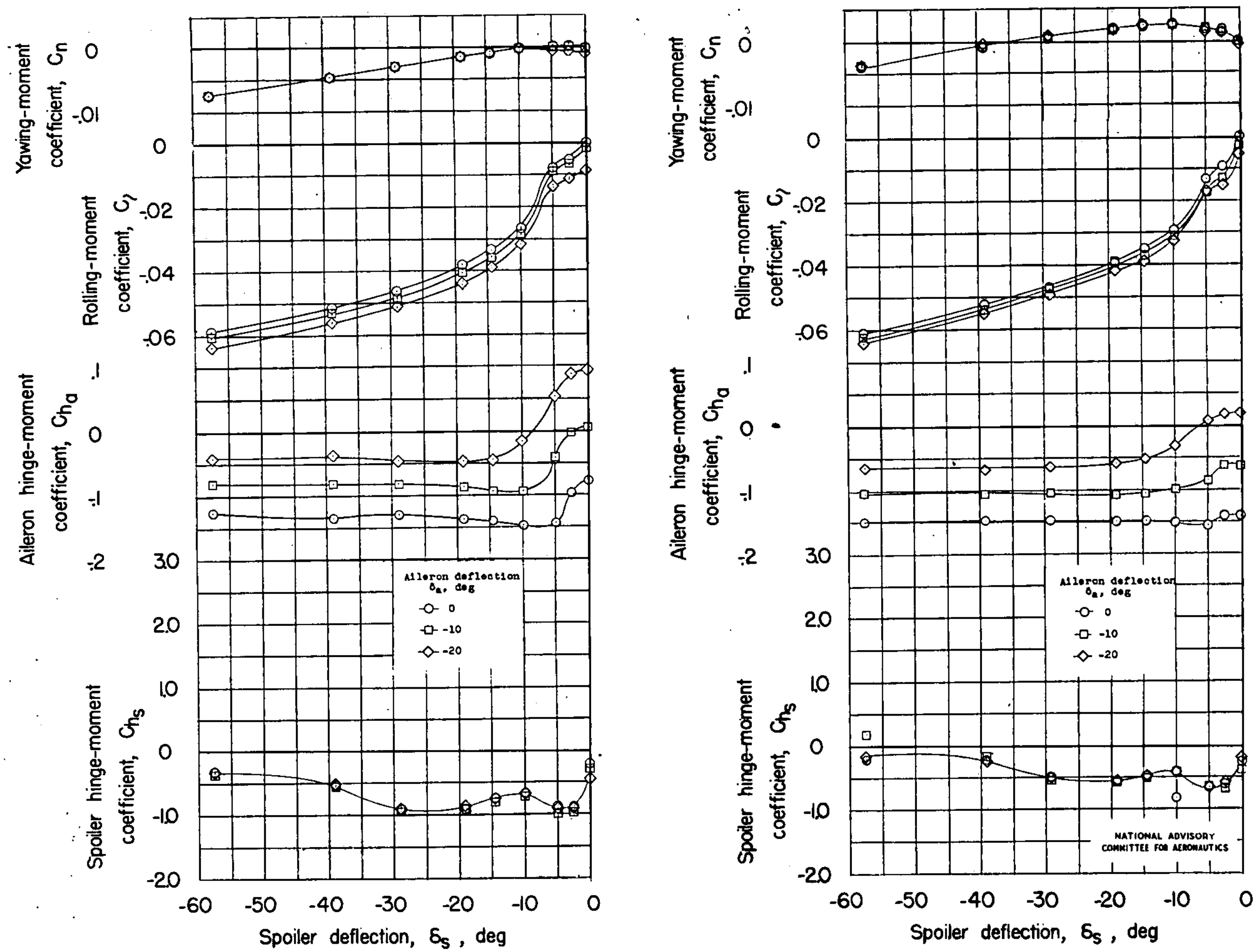


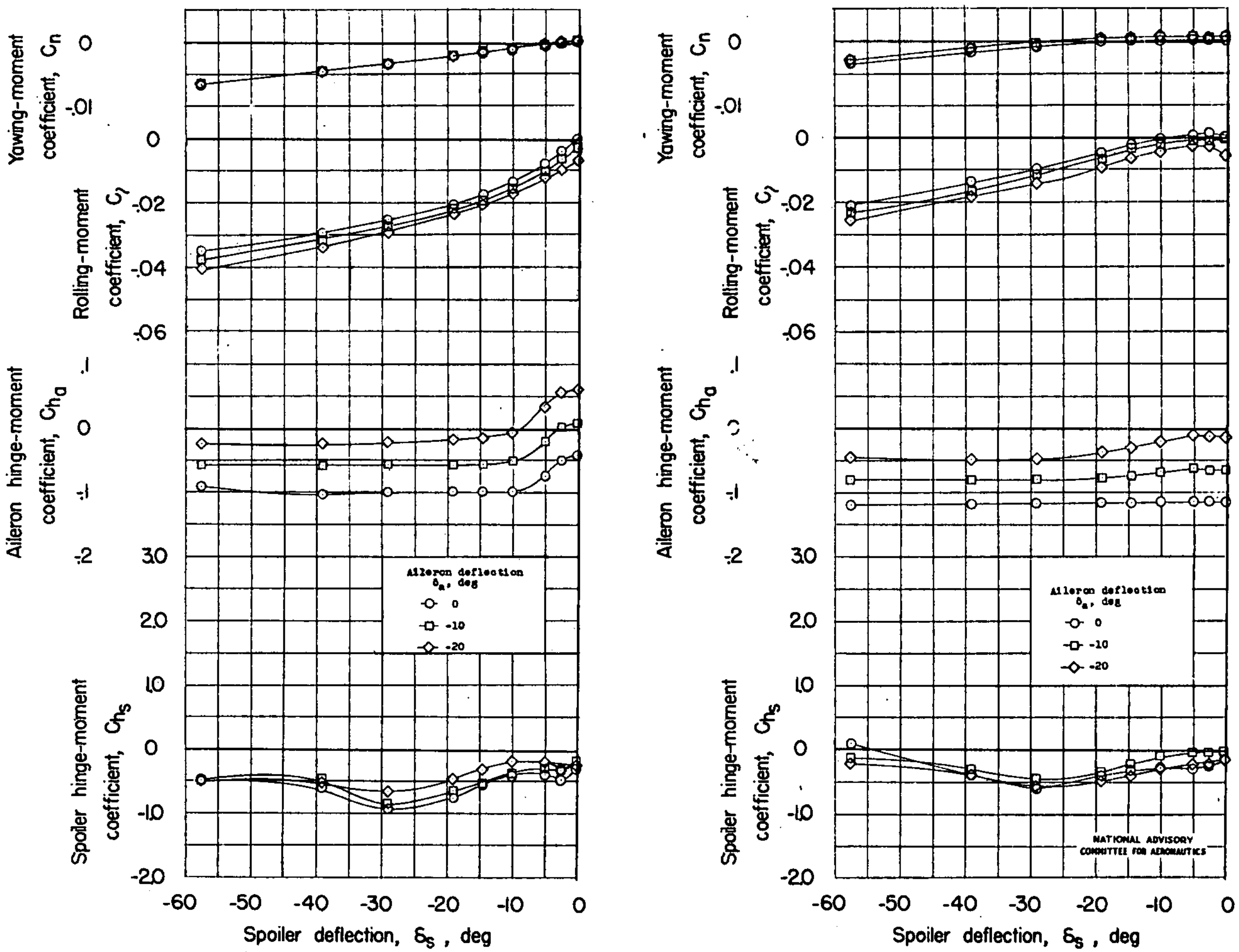
Figure 15.- Characteristics of the plain spoiler for various deflections of the aileron. 1-percent vent; full-span double slotted flaps neutral; $R \approx 8{,}900{,}000$; $M \approx 0.18$.



(a) $\alpha = 4.7^\circ$.

(b) $\alpha = 12.3^\circ$.

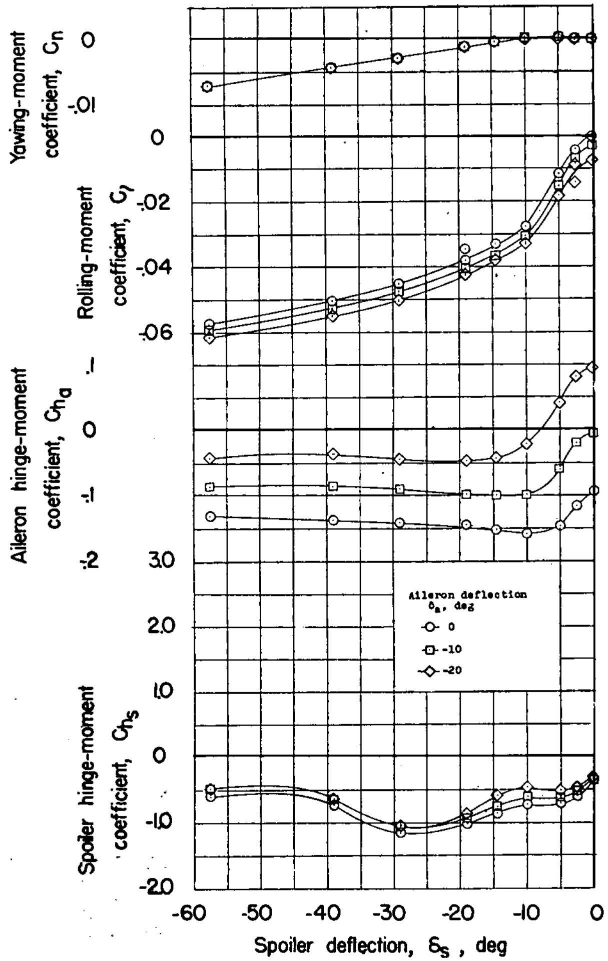
Figure 16.- Characteristics of the plain spoiler for various deflections of the aileron. 1-percent vent; full-span double slotted flaps deflected 50°; $R \approx 8,900,000$; $M \approx 0.18$.



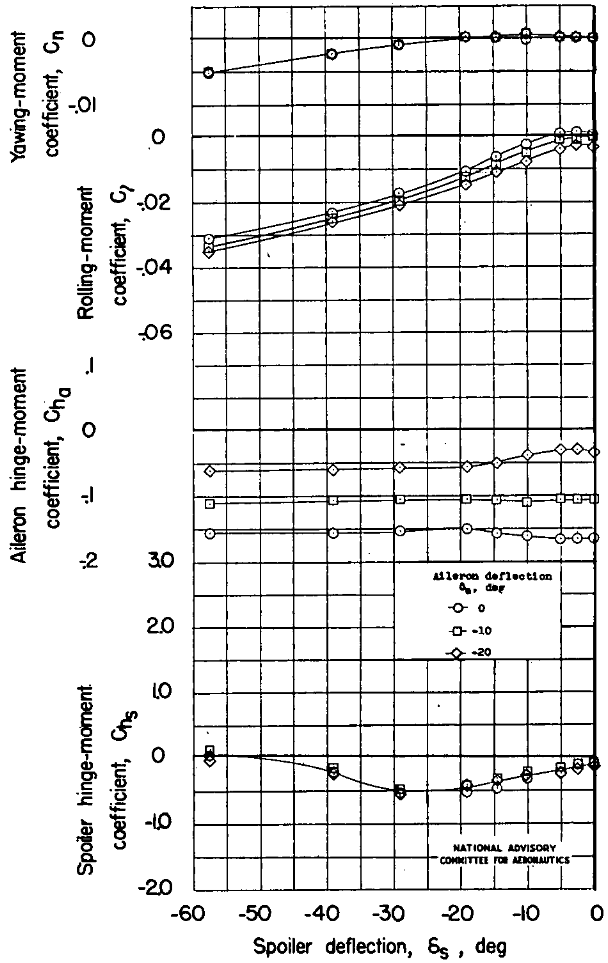
(a) $\alpha = 3.5^{\circ}$.

(b) $\alpha = 13.2^{\circ}$.

Figure 17.- Characteristics of the plain spoiler for various deflections of the aileron. 2-percent vent; full-span double slotted flaps neutral; $R \approx 8,900,000$; $M \approx 0.18$.

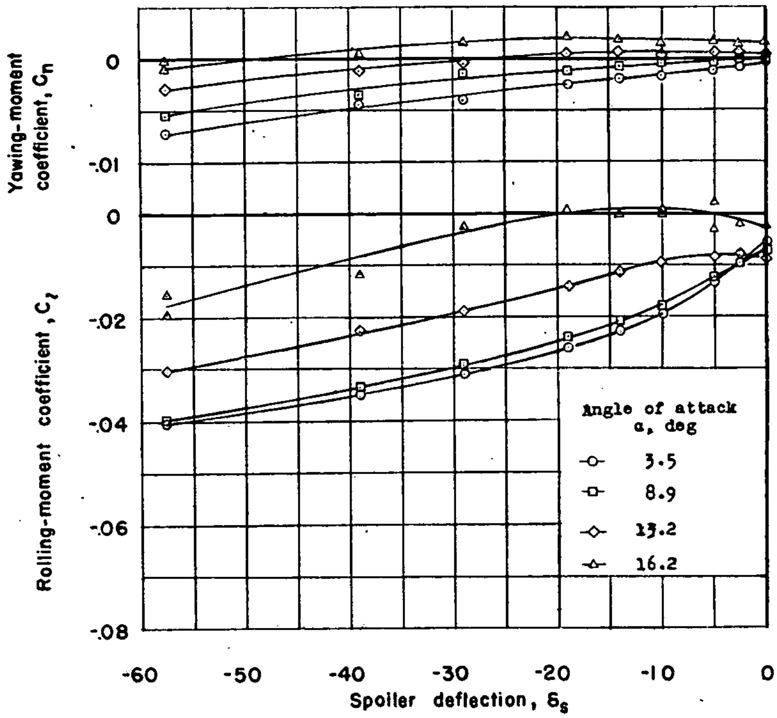


(a) $\alpha = 4.7^{\circ}$.

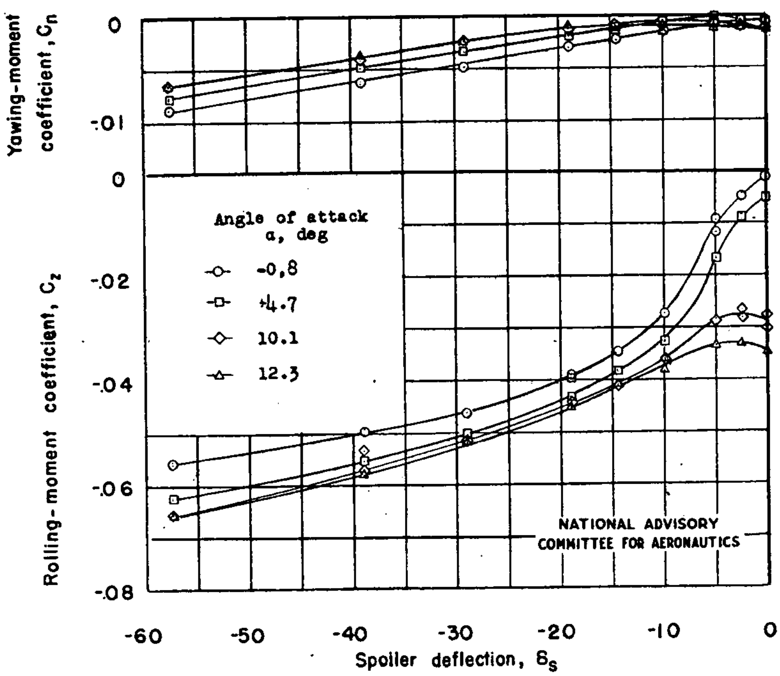


(b) $\alpha = 12.3^{\circ}$.

Figure 18.- Characteristics of the plain spoiler for various deflections of the aileron. 2-percent vent; full-span double slotted flaps deflected 50°; $R \approx 8,900,000$; $M \approx 0.18$.

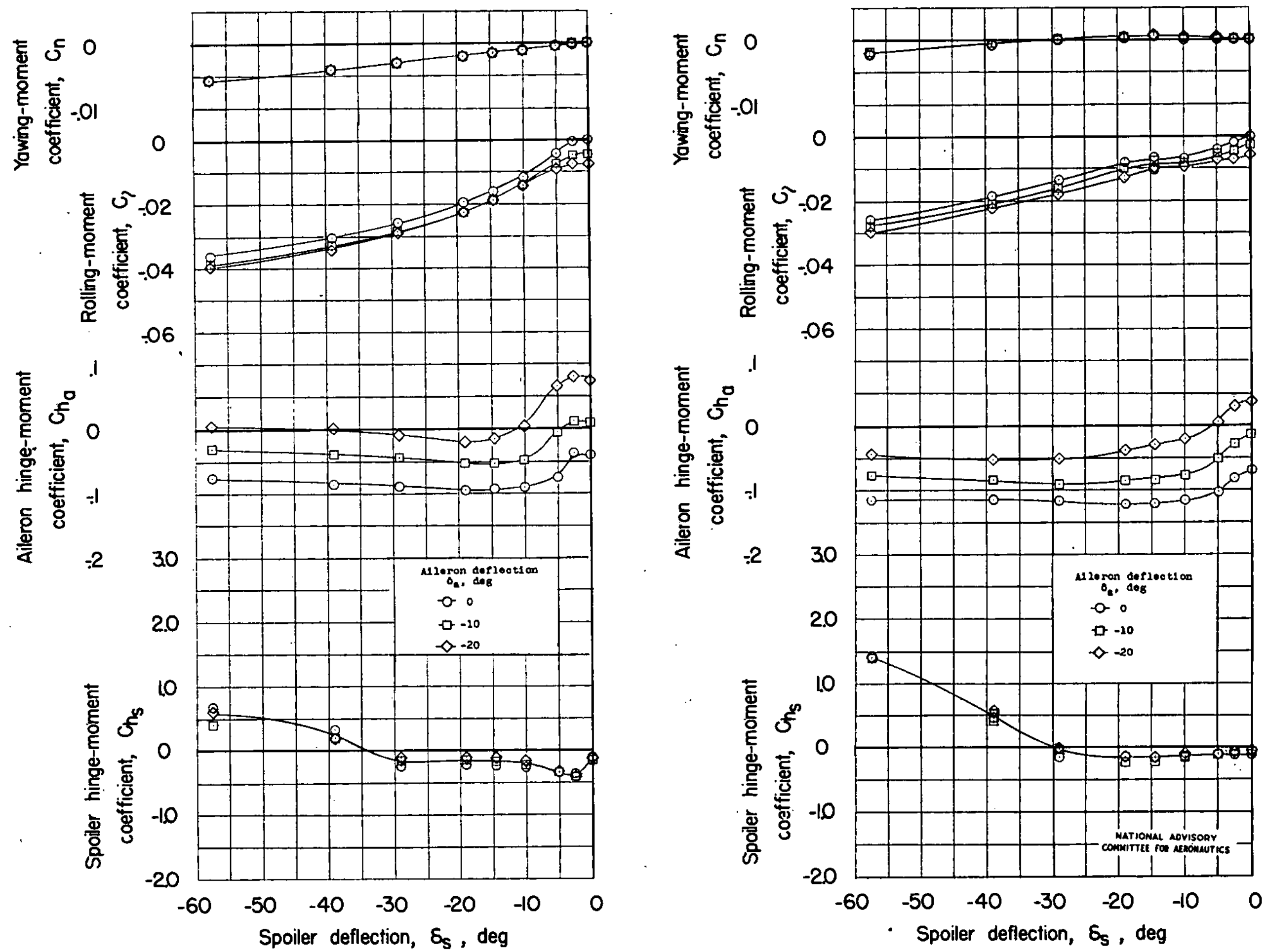


(a) $\delta_f = 0^\circ$.



(b) $\delta_f = 50^\circ$.

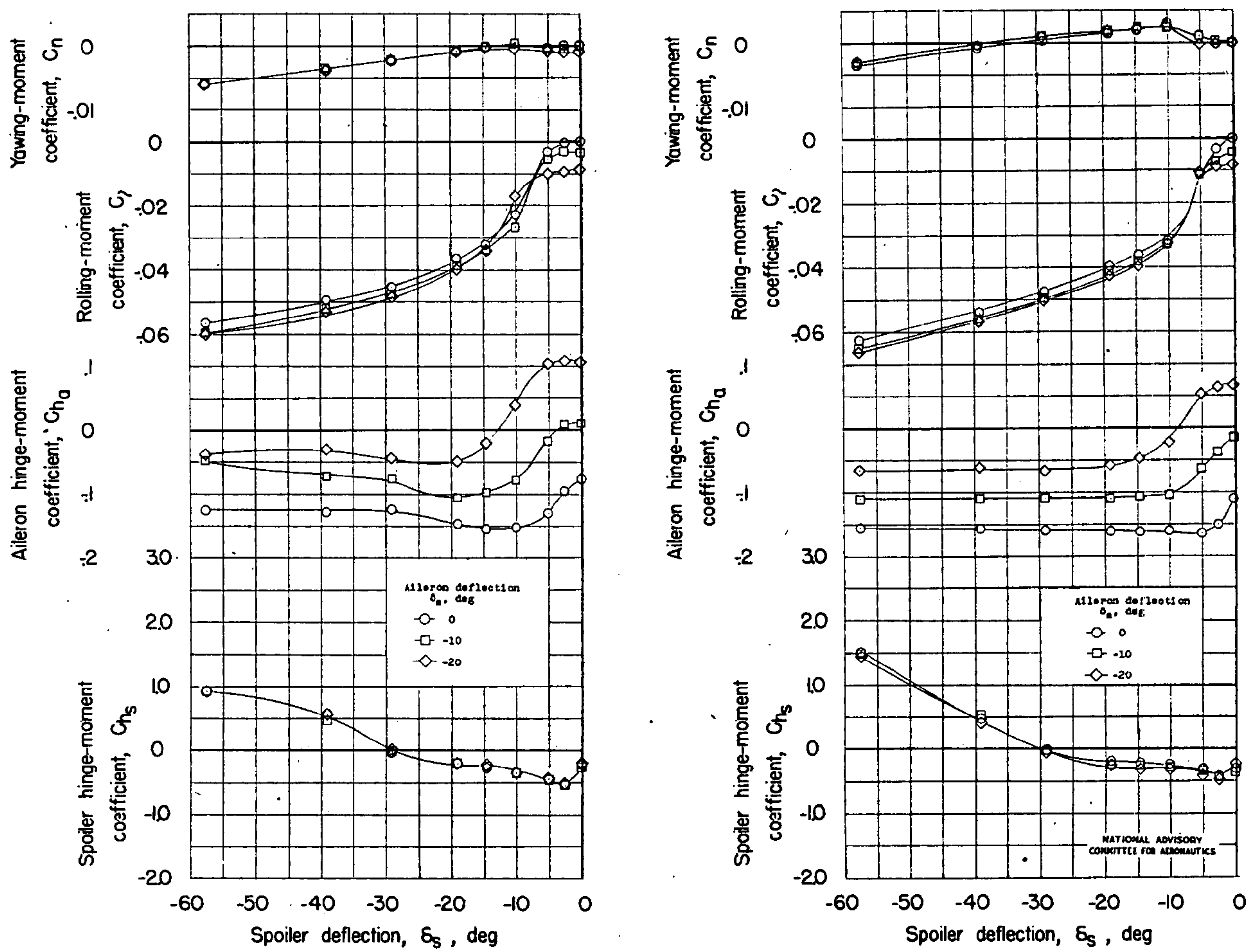
Figure 19.- Effectiveness of the plain spoiler for instantaneous operation of the 2-percent vent at various angles of attack; aileron neutral; R $\approx$ 8,900,000; M $\approx$ 0.18.



(a) $\alpha = 3.5^\circ$.

(b) $\alpha = 13.2^\circ$.

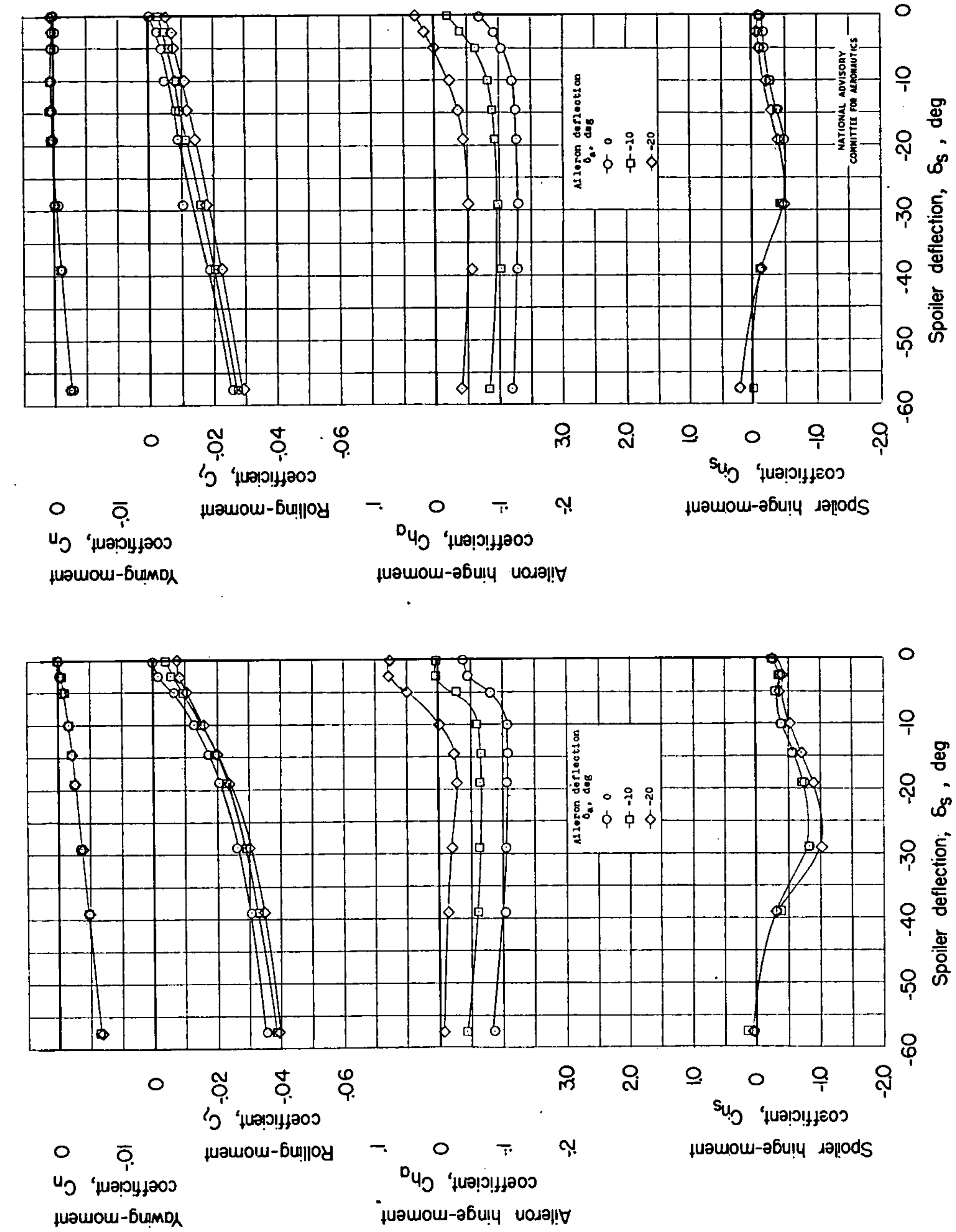
Figure 20.- Characteristics of the spoiler with perforations for various deflections of the aileron. Vent closed; full-span double slotted flaps neutral; $R \approx 8{,}900{,}000$; $M \approx 0.18$.



(a) $\alpha = 4.7^\circ$.

(b) $\alpha = 12.3^\circ$.

Figure 21.- Characteristics of the spoiler with perforations for various deflections of the aileron. Vent closed; full-span double slotted flaps deflected 50°; $R \approx 8,900,000$; $M \approx 0.18$.



(a) $\alpha = 3.5^\circ$.

(b) $\alpha = 13.2^\circ$.

Figure 22.- Characteristics of the spoiler with slot for various deflections of the aileron. Vent closed; full-span double slotted flaps neutral; $R \approx 8,900,000$; $M \approx 0.18$.

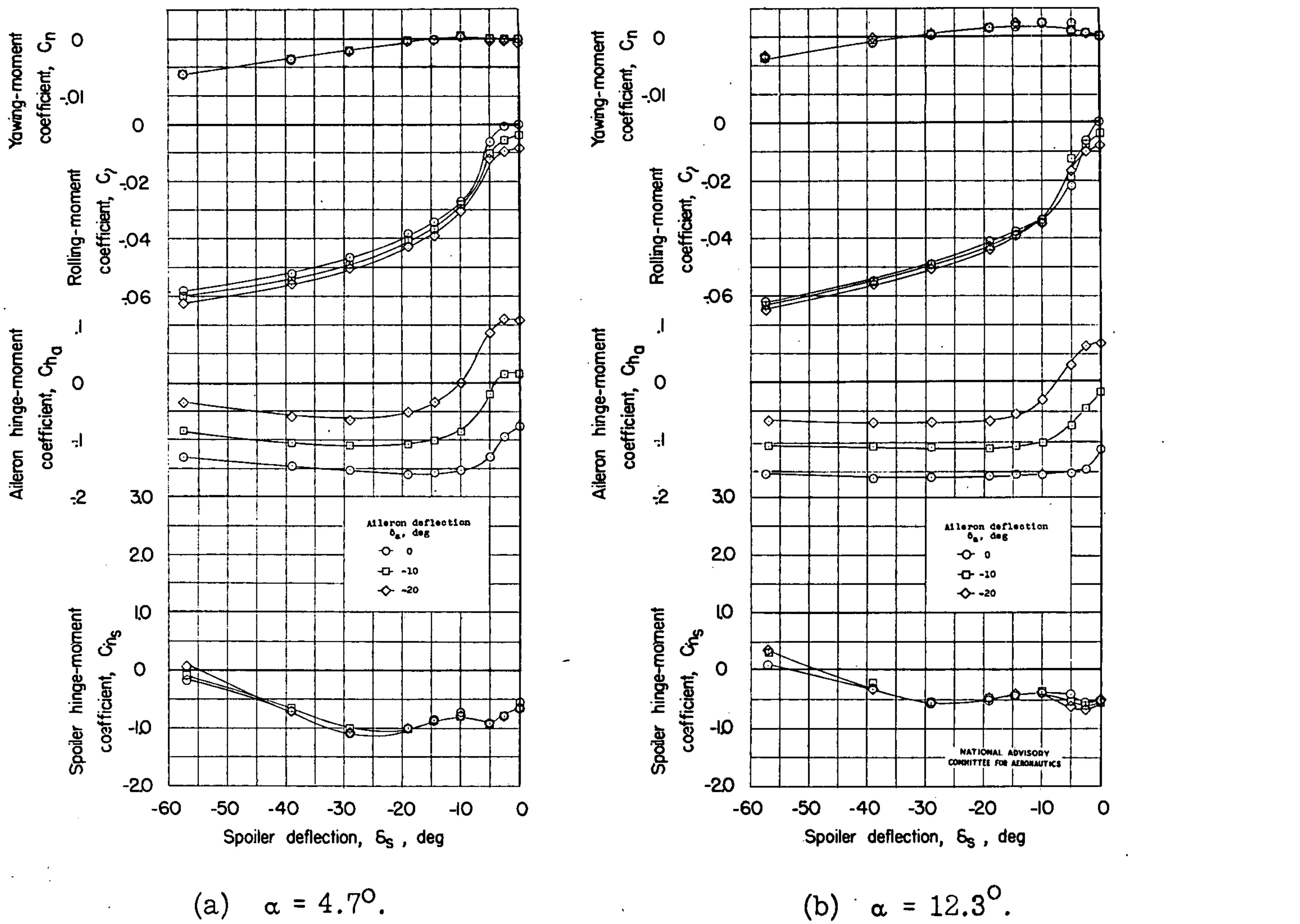


Figure 23.- Characteristics of the spoiler with slot for various deflections of the aileron. Vent closed; full-span double slotted flaps deflected 50°; $R \approx 8{,}900{,}000$; $M \approx 0.18$.

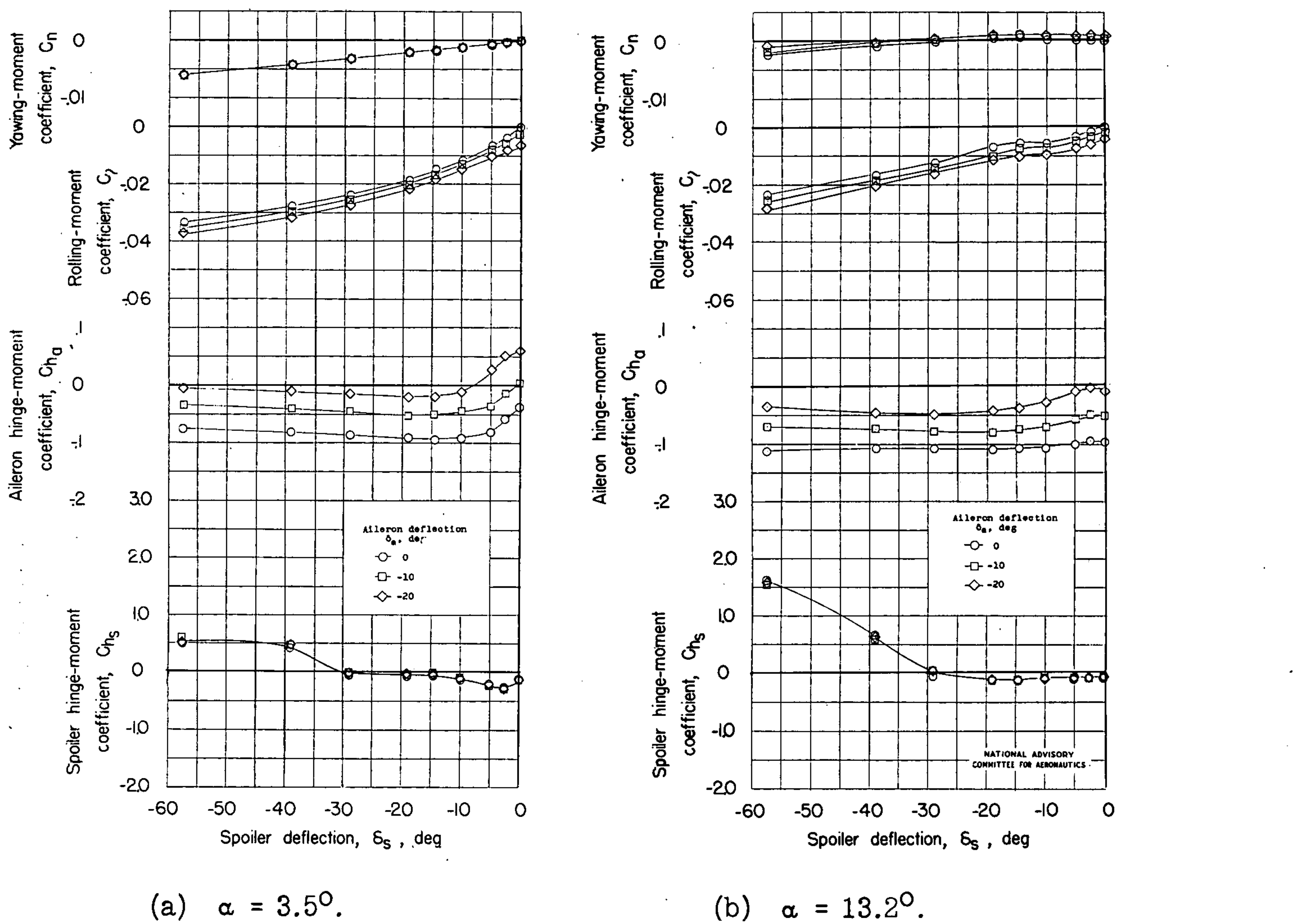
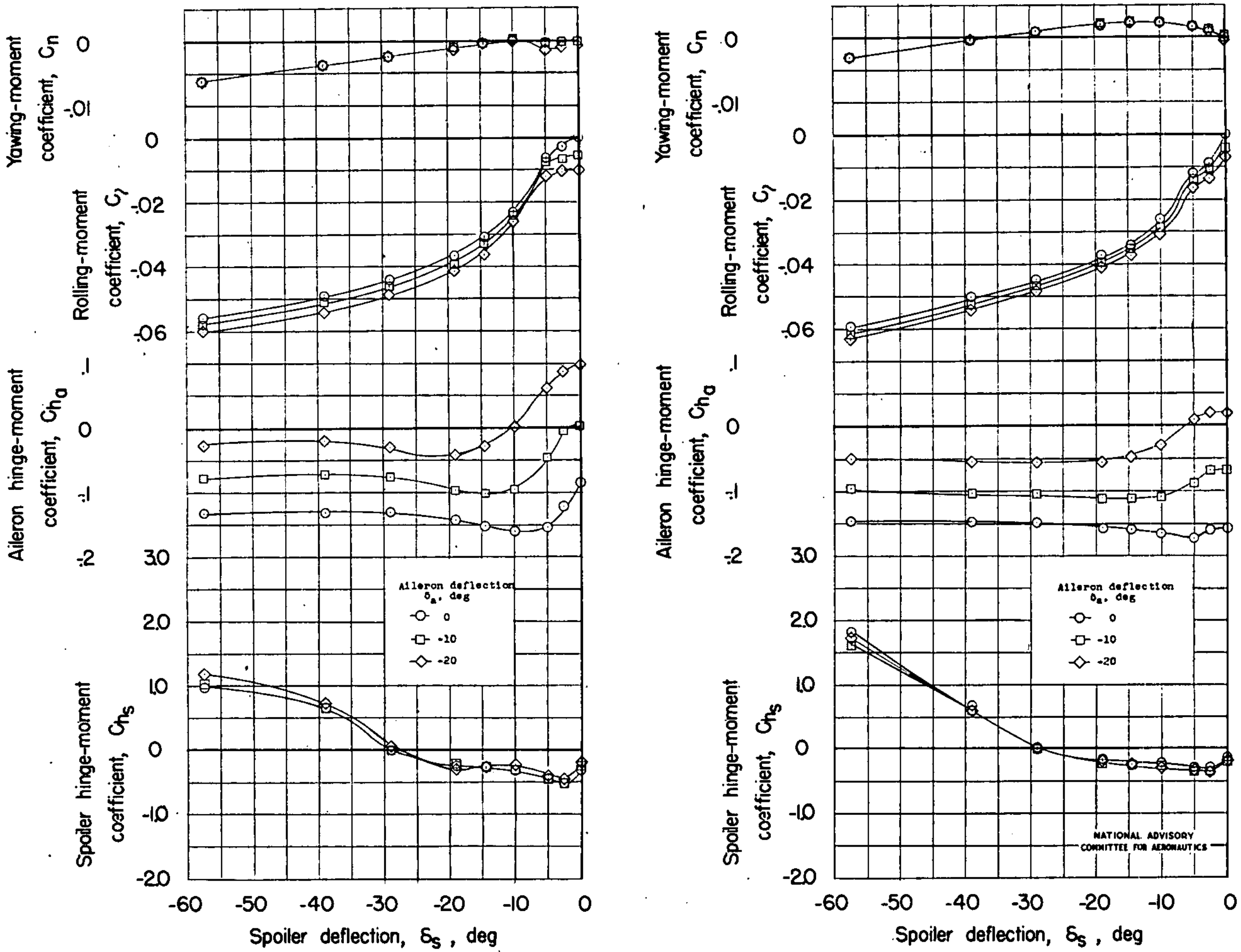


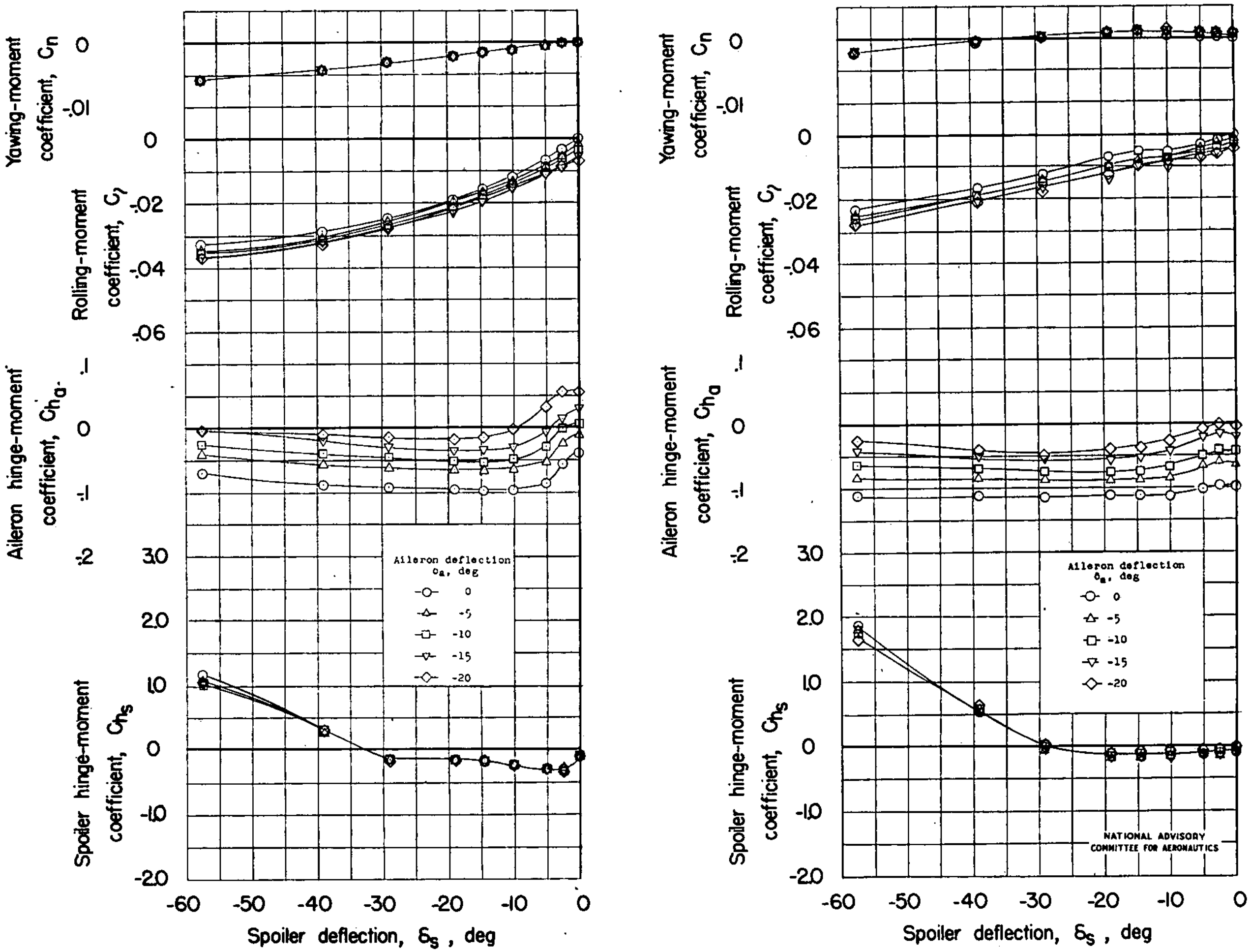
Figure 24.- Characteristics of the spoiler with perforations for various deflections of the aileron. 1-percent vent; full-span double slotted flaps neutral; $R \approx 8{,}900{,}000$; $M \approx 0.18$.



(a) $\alpha = 4.7^{\circ}$.

(b) $\alpha = 12.3^{\circ}$.

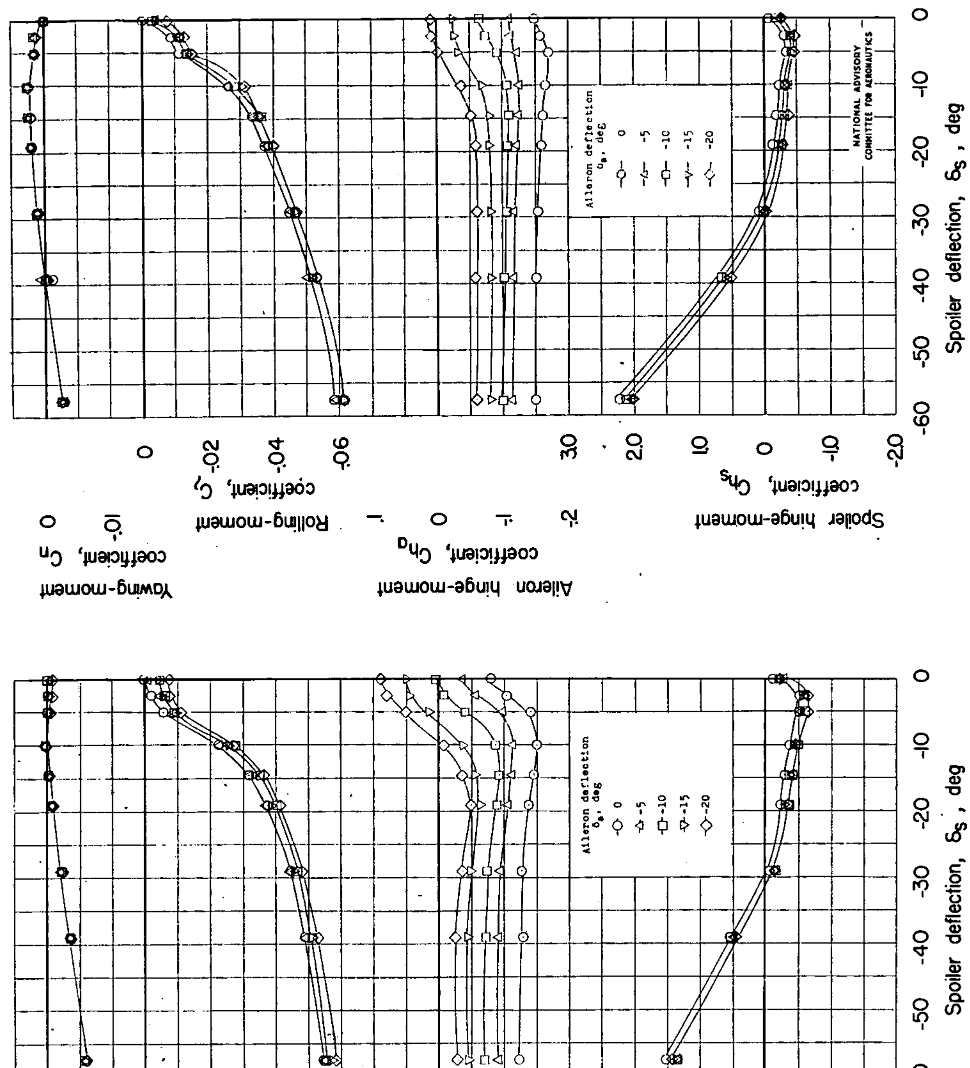
Figure 25.- Characteristics of the spoiler with perforations for various deflections of the aileron. 1-percent vent; full-span double slotted flaps deflected 50°; $R \approx 8,900,000$; $M \approx 0.18$.



(a) $\alpha = 3.5^{\circ}$.

(b) $\alpha = 13.2^{\circ}$.

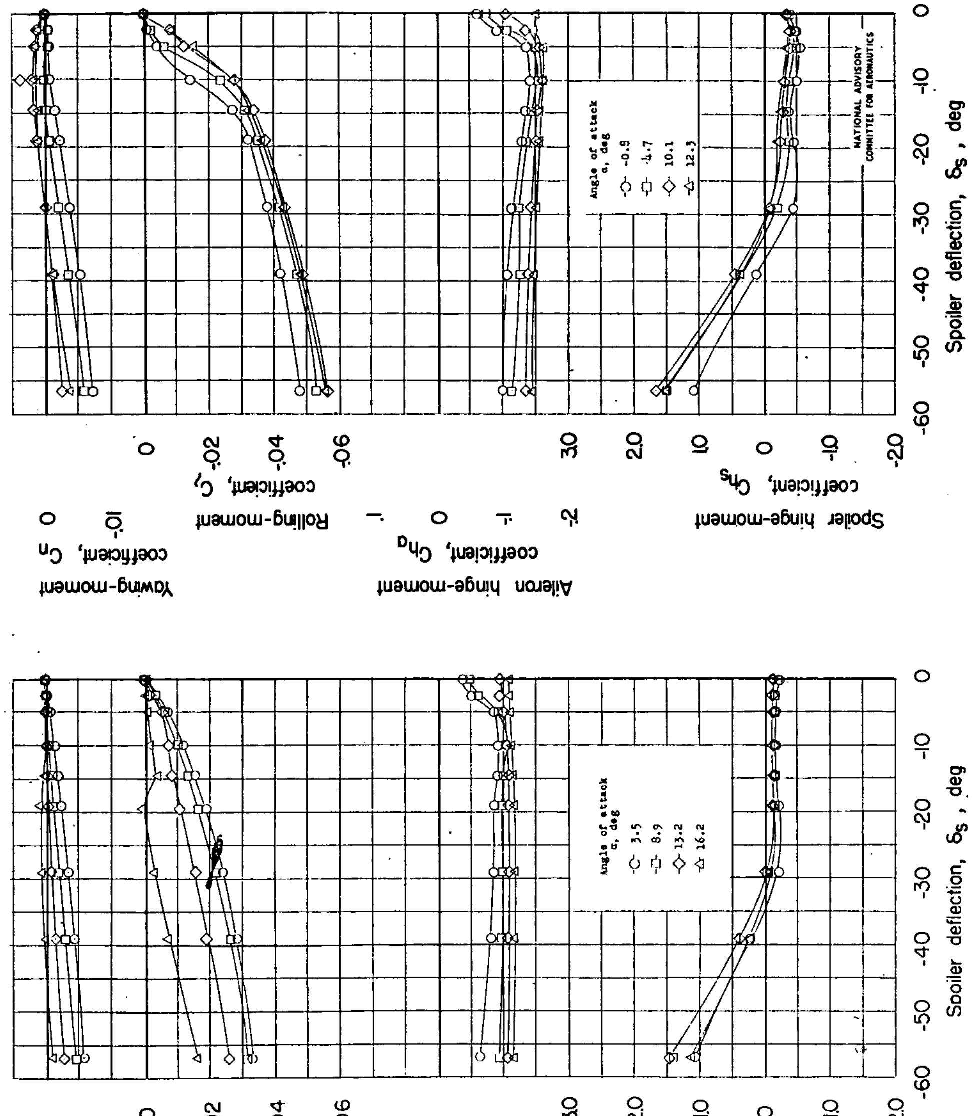
Figure 26.- Characteristics of the spoiler with perforations and slot for various deflections of the aileron. 1-percent vent; full-span double slotted flaps neutral; $R \approx 8,900,000$; $M \approx 0.18$.



(a) $\alpha = 4.7^\circ$.

(b) $\alpha = 12.3^\circ$.

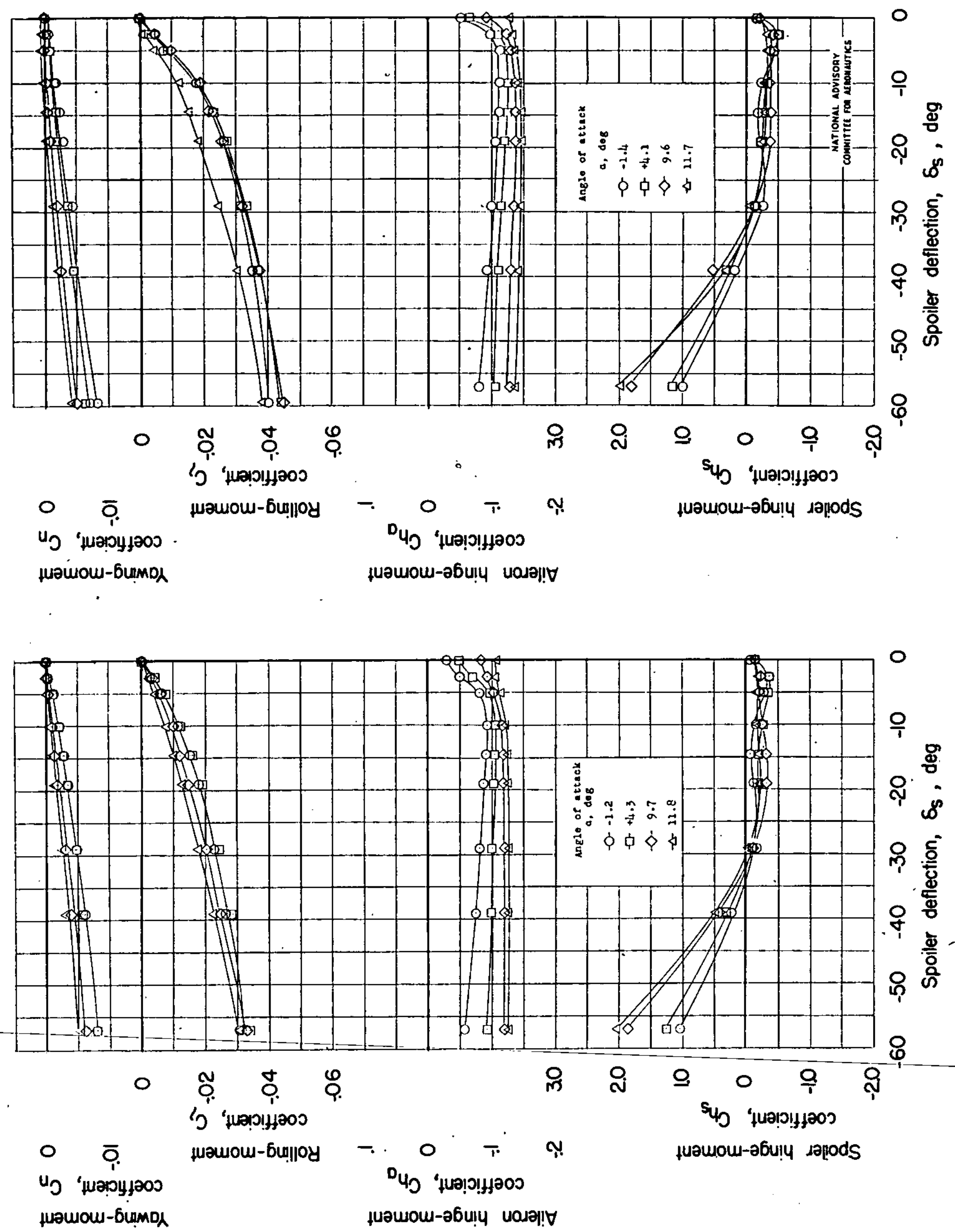
Figure 27.- Characteristics of the spoiler with perforations and slot for various deflections of the aileron. 1-percent vent; full-span double slotted flaps deflected 50°; R ≈ 8,900,000; M ≈ 0.18.



(a) $\delta_f = 0^\circ$.

(b) $\delta_f = 50^\circ$.

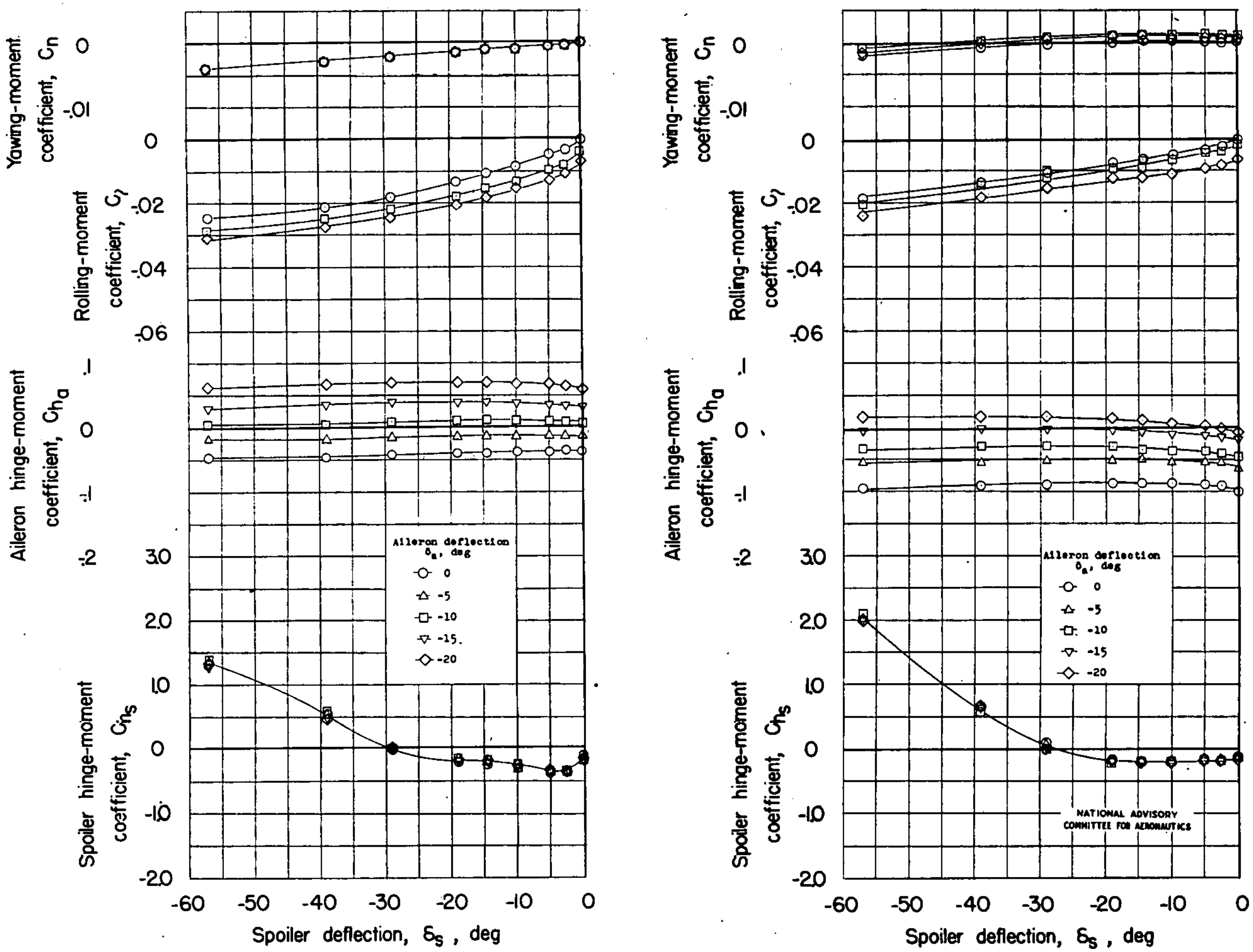
Figure 28.- Characteristics of the spoiler with perforations and slot for several angles of attack. Spoiler upper surface beveled 17°; 1-percent vent; aileron neutral; $R \approx 8{,}900{,}000$; $M \approx 0.18$.



(a) $\delta_{f_i} = 50^\circ$, $\delta_{f_o} = 0^\circ$.

(b) $\delta_f = 20^\circ$.

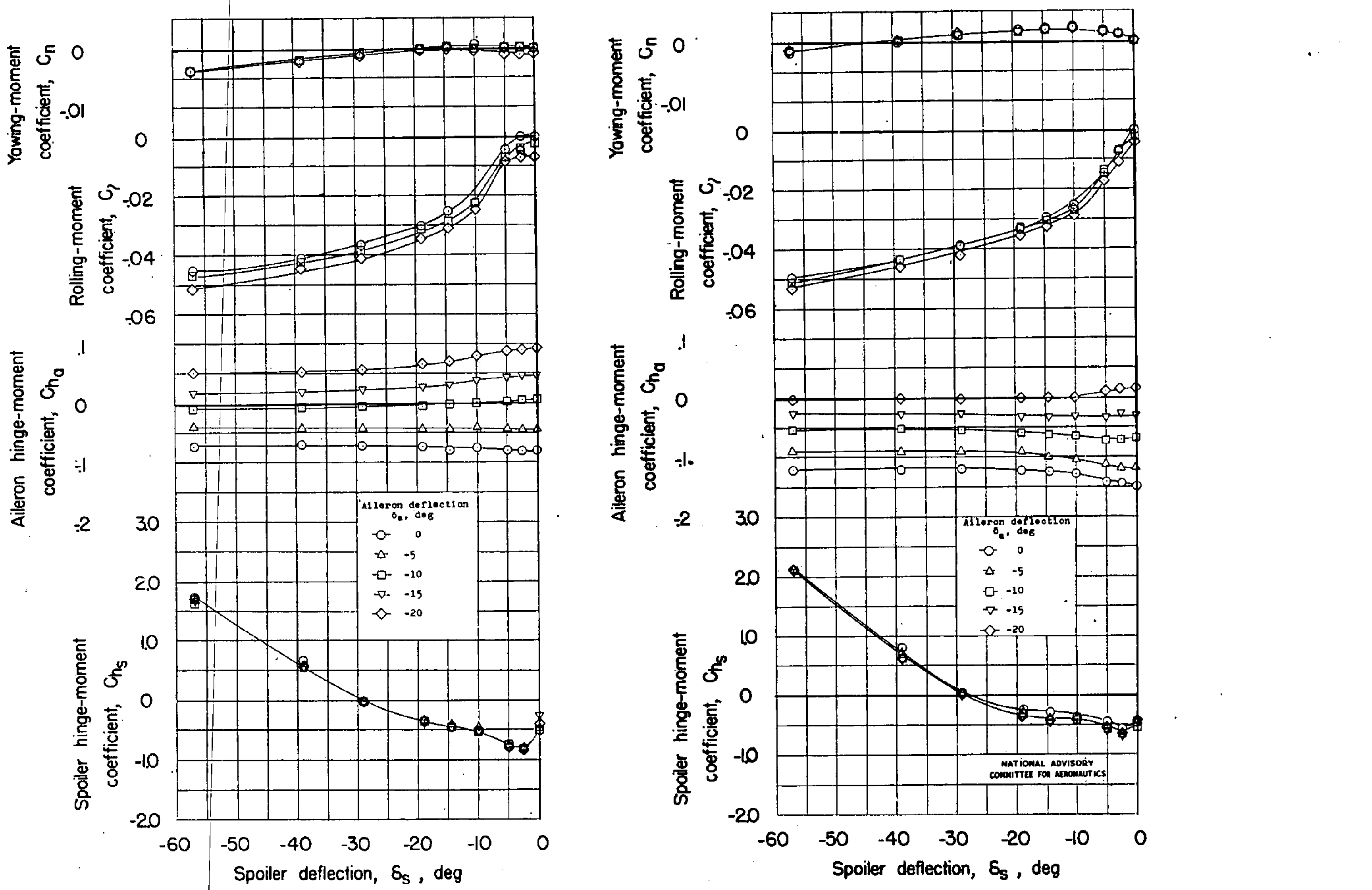
Figure 29.- Characteristics of the spoiler with perforations and slot for various angles of attack. 1-percent vent; aileron neutral; $R \approx 8{,}900{,}000$; $M \approx 0.18$.



(a) $\alpha = 3.5^{\circ}$.

(b) $\alpha = 13.2^{\circ}$.

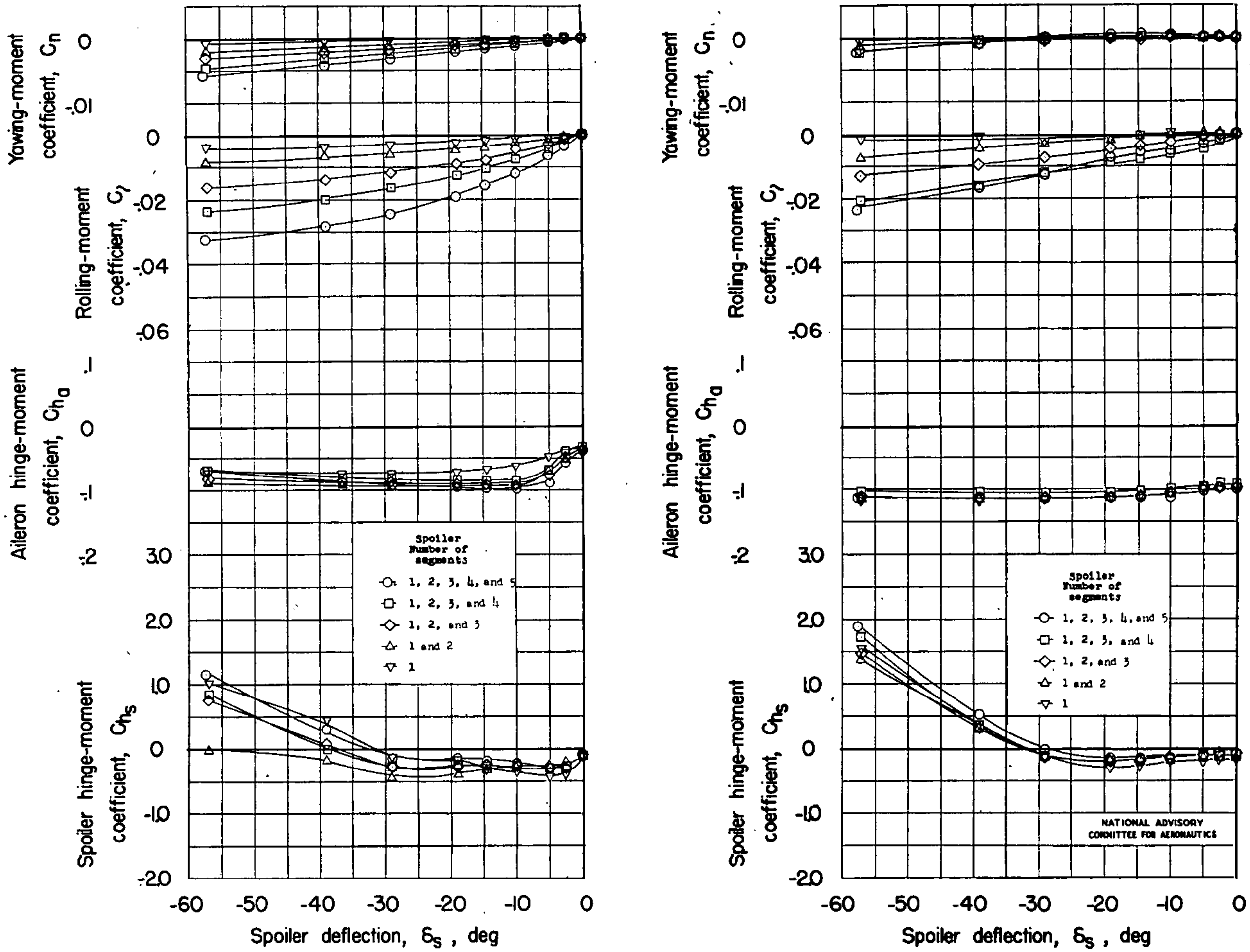
Figure 30.- Characteristics of the aileron and spoiler for various deflections of the aileron; spoiler with perforations and slot and with segments 1 and 2 removed. 1-percent vent; full-span double slotted flaps neutral; $R \approx 8,900,000$; $M \approx 0.18$.



(a) $\alpha = 4.7^\circ$.

(b) $\alpha = 12.3^\circ$.

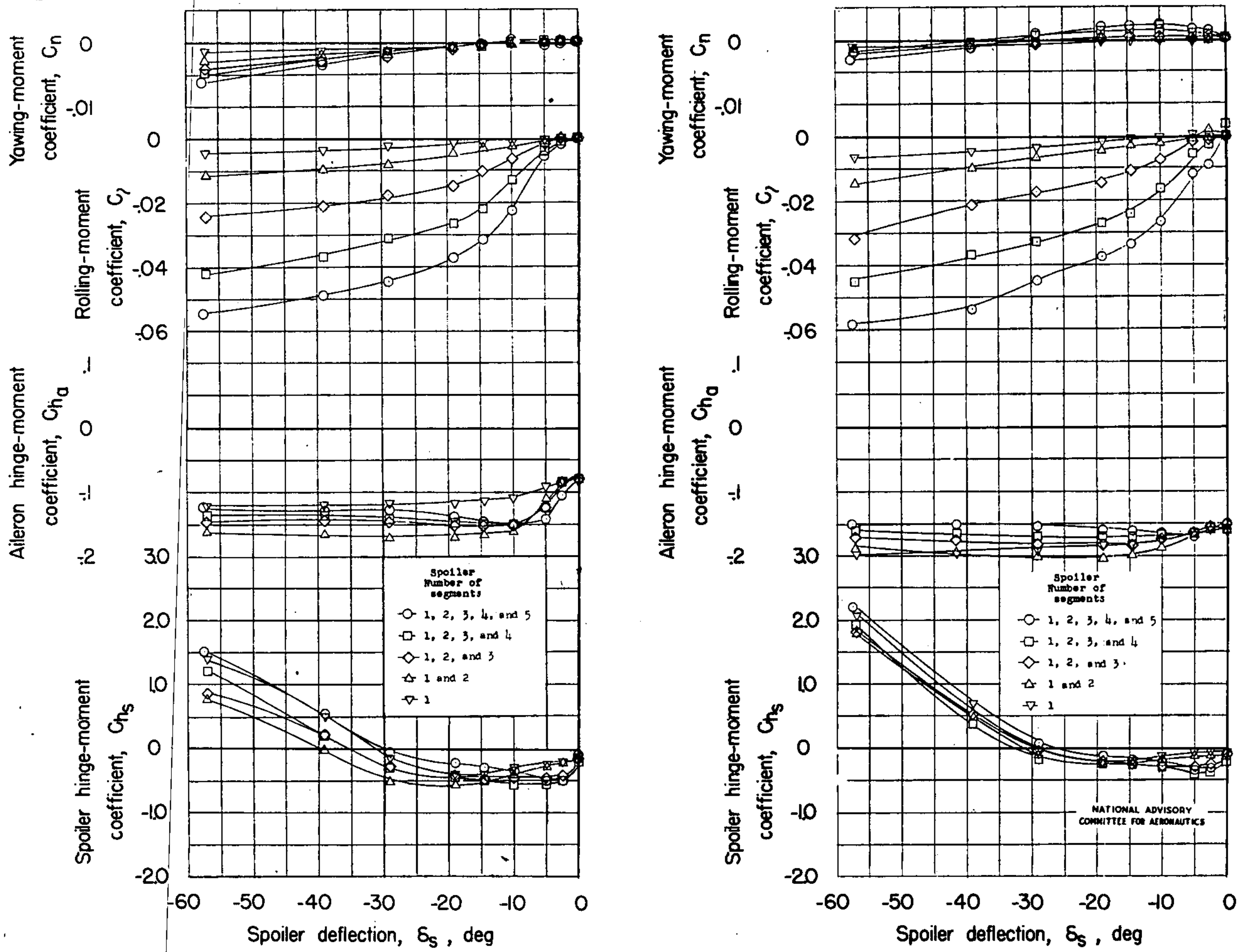
Figure 31.- Characteristics of the aileron and spoiler for various deflections of the aileron; spoiler with perforations and slot and with segments 1 and 2 removed. 1-percent vent; full-span double slotted flaps deflected 50°; $R \approx 8,900,000$; $M \approx 0.18$.



(a) $\alpha = 3.5^\circ$.

(b) $\alpha = 13.2^\circ$.

Figure 32.- Characteristics of the spoiler for various combinations of the spoiler segments. Spoiler with perforations and slot; 1-percent vent; aileron neutral; full-span double slotted flaps deflected 50°; $R \approx 8,900,000$; $M \approx 0.18$.



(a) $\alpha = 4.7^{\circ}$.

(b) $\alpha = 12.3^{\circ}$.

Figure 33.- Characteristics of the spoiler segments. Spoiler with perforations and slot; 1-percent vent; aileron neutral; full-span double slotted flaps deflected 50°; $R \approx 8,900,000$; $M \approx 0.18$.