NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL NOTE

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EFFECT OF SPOILER-TYPE LATERAL-CONTROL DEVICES ON THE TWISTING MOMENTS OF A WING OF NACA 230-SERIES AIRFOIL SECTIONS

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Washington
May 1947

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SUMMARY

The effects of several spoiler arrangements on the spanwise variation of section twisting moments of a wing of NACA 230-series airfoil sections were investigated. The spoilers tested included both plain and perforated spoilers. The tests were conducted at a Reynolds number of 7,350,000 and a Mach number of 0.245; the tests included force and moment measurements and chordwise pressure-distribution measurements at six spanwise stations.

The results of the tests indicated that the influence of a projected spoiler on the section pitching-moment coefficients extended approximately 25 percent of the semispan inboard of the spoiler. The maximum twisting-moment coefficients due to the spoilers at a low angle of attack of the wing were reached at this spanwise location.

A region of negative pressure coefficients existed directly behind the projected spoiler and diminished the positive pitching-moment tendencies. This low pressure region became intensified near the tip and, in some cases, caused negative local twisting moments. Consequently, the smallest maximum twisting moment due to a spoiler for a given rolling moment may be obtained by locating the outboard end of the spoiler as close to the tip as possible to take advantage of the increased balancing moment.

The perforations caused the pressure coefficients directly behind the spoiler to increase, and a greater maximum twisting moment resulted. The rolling moments of the perforated and the plain spoilers, however, were the same within the experimental accuracy of the tests.

Either an extension of the spoiler span inboard from the tip or an increase in spoiler projection increased both the twisting-moment coefficients due to the spoiler and the rolling-moment

coefficients. For a given change in rolling-moment coefficient, however, an extension of the spoiler span resulted in greater increases in twisting moments due to the spoiler than did an increase in spoiler projection.

INTRODUCTION

The wing twisting moments contributed by a projected spoiler are of interest in the consideration of flight at high speed in which twist of the wing may become great enough to cause an appreciable loss in rolling effectiveness (reference 1). An investigation was conducted in the Langley 19-foot pressure tunnel to study the effects of various spoiler projections and spoiler spans on the spanwise variations of section twisting-moment coefficients.

The present paper gives the results of measurements of the aerodynamic characteristics of a wing of NACA 230-series airfoil sections tested with six spoiler configurations. The twisting moments were determined by a spanwise integration of the chordwise loadings at six stations along the left semispan of the wing. The spoiler configurations included plain spoilers which extended 0.2 and 0.4 of the semispan and projected 4 and 8 percent of the local chord from the 70-percent chord line of the left-wing panel. In addition, perforated spoilers 0.2 and 0.4 of the semispan were tested with a projection 8 percent of the local chord.

The tests were conducted at a Mach number of 0.245 and a Reynolds number of 7,350,000. Although the data were obtained at a relatively low Mach number, they are believed to indicate qualitatively the variations of twisting moment with span most likely to be encountered at higher speeds.

SYMBOLS

C_L lift coefficient (Lift/qS)

C_m pitching-moment coefficient (M/qSc')

C_l rolling-moment coefficient (L/qSb)

C_n yawing-moment coefficient (N/qSb)

P	pressure coefficient $\left(\frac{p_l - p_o}{q}\right)$
$c_{m_{c/4}}$	section pitching-moment coefficient about the local-quarter-chord point
$\Delta c_{m_{c/4}}$	increment of section pitching-moment coefficient due to spoiler projection
ΔC	additional twisting-moment coefficient contributed by spoilers $\left(\frac{\tau_{\text{spoiler on}} - \tau_{\text{spoiler off}}}{q\frac{S}{2}c'} = \int_{\frac{y}{b/2}}^{1} \Delta c_{m_{c/4}} \frac{c^2}{\bar{c}c'} \, d\left(\frac{y}{b/2}\right)\right)$
R	Reynolds number $(\rho Vc'/\mu)$
M_o	free-stream Mach number (V/a)
q	dynamic pressure, pounds per square foot $\left(\frac{1}{2}\rho V^2\right)$
S	wing area, square feet
c'	wing mean aerodynamic chord, feet $\left(\frac{2}{S}\int_0^{b/2} c^2 \, dy\right)$
$\bar{c}$	wing mean geometric chord, feet (S/b)
c	local chord, feet
b	wing span, feet
ρ	mass density of air, slugs per cubic foot
M	pitching moment about 0.25c', pound-feet
τ	twisting moment about 0.25c, pound-feet
N	yawing moment, pound-feet

L rolling moment, pound-feet

p_l local static pressure, pounds per square foot

p_o free-stream static pressure, pounds per square foot

x distance from leading edge along the chord, feet

y lateral distance perpendicular to root-chord plane, feet

α angle of attack of wing root chord, degrees

V velocity of free stream, feet per second

μ coefficient of viscosity of air, pound-seconds per square foot

a speed of sound in air, feet per second

MODEL, APPARATUS, AND TESTS

Model and apparatus.- A three-view drawing of the wing is presented as figure 1. Pertinent geometric characteristics are shown in this figure. The root section of the wing is an NACA 23016 airfoil section and the construction tip is an NACA 23009 airfoil section. The wing has a span of 12 feet, an aspect ratio of 6, a taper ratio of 2:1, and 4° of geometric washout. A complete description of the pressure apparatus is given in reference 2. A photograph of the wing mounted in the Langley 19-foot pressure tunnel is shown as figure 2.

The spoilers were so constructed that they simulated circular-arc retractable spoilers (reference 3). They extended 0.2 and 0.4 of the semispan inboard from $0.99\frac{b}{2}$ and projected 0.04 and 0.08 of the local chord. Perforated spoilers were tested with the 0.08c projections only. All the spoilers were mounted on the upper surface of the left-wing panel at the 70-percent chord stations. A photograph of the $0.4\frac{b}{2}$, 0.08c perforated spoiler is shown as figure 3. A cross section of a typical spoiler mounted on the wing is presented in figure 4.

Tests.- All the tests were made with the air in the tunnel compressed to approximately $2\frac{1}{3}$ atmospheres. By proper adjustments to the dynamic pressure, the maximum deviation from a Reynolds number of 7,350,000 was ±10,000 and the maximum deviation from a Mach number of 0.245 was ±0.002 throughout the tests.

The forces and moments were measured by a six-component simultaneous-recording balance system through an angle-of-attack range from -3.7° through the stall.

Pressure-distribution tests were made for all configurations at angles of attack of 0.1°, 12.7°, and 19.0°.

CORRECTIONS AND REDUCTION OF DATA

Corrections.- The angles of attack have been corrected for jet-boundary effects and for air-stream misalignment, and the lift and pitching-moment coefficients have been corrected for model-support interference as determined from tare tests. In addition, the rolling-moment and yawing-moment coefficients have been corrected for model asymmetry and for jet-boundary effects in accordance with the methods of references 4 and 5. The effects of model-support interference on the local static pressures were assumed to be negligible. The pressure coefficient, however, is based on average values of dynamic pressure and static pressure across the span.

Reduction of data.- The force and moment data were reduced to standard nondimensional coefficient form. The wing pitching moments were computed about the quarter-chord point of the mean aerodynamic chord.

The pressure-distribution data were reduced to the form of the pressure coefficient P. The pressure coefficients were plotted against the chord and thickness, and the resulting diagrams were mechanically integrated to furnish the section pitching-moment coefficients. Diagrams of the section pitching-moment coefficients were integrated about the quarter-chord line, which was assumed to be the elastic axis, to obtain the section twisting moments. The elastic axis usually varies within ±0.05c from the quarter-chord line; however, it was pointed out in reference 6 that, in a steady roll, the error involved in computing the twisting moments about the quarter-chord line is negligible. The twisting moments contributed by spoiler projections are presented in the form of a nondimensional coefficient defined as follows:

$$\Delta C_T = \frac{\Delta T}{q\frac{S}{2}c'}$$

where

$$\Delta T = T_{\text{spoiler on}} - T_{\text{spoiler off}}$$

$$= \frac{b}{2}\int_{\frac{y}{b/2}}^{1} \Delta C_{m_{c/4}} q c^2 \, d\left(\frac{y}{b/2}\right)$$

$$S = b\bar{c}$$

so that

$$\Delta C_T = \int_{\frac{y}{b/2}}^{1} \Delta C_{m_{c/4}} \frac{c^2}{\bar{c}c'} \, d\left(\frac{y}{b/2}\right)$$

RESULTS AND DISCUSSION

The results of the tests of a wing of NACA 230-series airfoil sections with and without spoilers are presented in figures 5 to 9. Chordwise-pressure-distribution diagrams for the spoiler off; the 0.08c-projection, $0.4\frac{b}{2}$-span spoiler; and the 0.08c-projection, $0.4\frac{b}{2}$-span perforated spoiler are presented in figure 5. These data are representative of the chordwise pressure distributions obtained for all the spoiler configurations and, inasmuch as they show the maximum effects, are the only ones presented.

The effect of a projected spoiler on the section pitching-moment coefficient can be seen by comparing the pressure distributions without spoilers and the pressure distribution with the $0.08c$-projection, $0.4\frac{b}{2}$-span plain spoiler. (See figs. 5(d) to 5(f).) In front of the spoiler, the pressure coefficients are increased positively on the upper surface and are increased negatively on the lower surface. These changes in pressure distribution ahead of the spoiler cause a positive increase to the spoiler-off pitching-moment coefficient. Behind the spoiler, however, the pressure coefficients are increased negatively on both the upper and lower surfaces. This pressure region contributes a negative increment of pitching-moment coefficient and may be regarded as a balancing moment when compared with the positive increment of pitching moment contributed by the pressure region ahead of the spoiler. The negative pitching moment developed behind the spoiler is greatest near the wing tip. Figure 5 shows that the principal effect of the perforations on the pressure distribution obtained with a projected spoiler occurs in the region directly behind the spoiler. The flow of air through the perforations increases positively the pressure coefficients on the upper surface and, hence, reduces the negative increment of pitching-moment coefficient.

The spanwise variations of section pitching-moment coefficient, obtained from integrations of the chordwise-pressure-distribution data, are presented in figure 6. A comparison of any particular spoiler at the three angles of attack shows an appreciable decrease in the increment of section pitching-moment coefficient near the stall. This decrease is primarily the result of the increase in spoiler-off pitching moment with angle of attack whereas the spoiler-on pitching moment is relatively constant.

The spanwise variations of section pitching-moment coefficient for all spoiler configurations at an angle of attack of 0.1° (fig. 6) were integrated to obtain the spanwise variations of section twisting-moment coefficient in a high-speed-flight attitude (fig. 7). Projecting a spoiler, for most configurations, caused a positive section twisting moment. As indicated in figure 6, the influence of the spoiler on the section pitching-moment coefficient extends approximately $0.25\frac{b}{2}$ inboard of the spoiler. This spanwise location corresponds to the point at which the maximum values of twisting-moment coefficient due to the spoilers $\Delta C_{T_{max}}$ were attained (fig. 7). For each spoiler configuration, the increased balancing moment near the tip reduces the positive twisting moments over the span of the wing. The balancing moment developed by the 0.04c-projection, $0.2\frac{b}{2}$-span spoiler (fig. 7) is actually greater than the positive increment due to the loss in lift (fig. 8), and small negative increments of ΔC_T are obtained.

For the spoiler configurations tested, the ratios of the change in maximum twisting-moment coefficient due to the spoiler per unit change in rolling-moment coefficient $\frac{\Delta\left(\Delta C_{T_{max}}\right)}{\Delta C_l}$ are presented in the following table for $\alpha = 0.1^\circ$:

Configuration	Spoiler projection (fraction of chord)	Spoiler span (fraction of semispan)	$\frac{\Delta\left(\Delta C_{T_{max}}\right)}{\Delta C_l}$
Change in spoiler span from $0.2\frac{b}{2}$ to $0.4\frac{b}{2}$	0.04	---	-0.59
	.08	---	-.66
Change in spoiler projection from 0.04c to 0.08c	----	0.2	-.32
	----	.4	-.51

The values of $\Delta C_{T_{max}}$ and C_l were obtained from figures 7 and 9. When the span of the spoilers of 0.04c and 0.08c projections is increased inboard from $0.2\frac{b}{2}$ to $0.4\frac{b}{2}$, the values of $\frac{\Delta\left(\Delta C_{T_{max}}\right)}{\Delta C_l}$ become -0.59 and -0.66, respectively. When the projection of the spoilers of $0.2\frac{b}{2}$ span and $0.4\frac{b}{2}$ span is increased from 0.04c to 0.08c, the values of $\frac{\Delta\left(\Delta C_{T_{max}}\right)}{\Delta C_l}$ are -0.32 and -0.51, respectively. These ratios indicate that either an increase in span or an increase in projection causes an increase in both $\Delta C_{T_{max}}$ and C_l; but for a given change in rolling-moment coefficient, the increase in span will cause a greater increment of $\Delta C_{T_{max}}$ than will an increase in projection. Although the magnitude of these ratios are applicable only to the projections and spans tested, the trends appear to be generally true. Because of the large balancing moment developed near the tip, the lowest value of $\Delta C_{T_{max}}$ for a given value of C_l can be obtained by locating the outboard end of the spoiler as near the tip as feasible.

Figure 7 shows that perforations caused an increase in $\Delta C_{T_{max}}$ over the value obtained with the plain spoiler although the rolling-moment coefficients (fig. 9) were approximately the same. The increase in $\Delta C_{T_{max}}$ with a perforated spoiler is a result of the reduction in balancing moment due to air flow through the perforations.

Reference 7 contains pressure-distribution diagrams over a wing with an aileron and with a spoiler. The pressure coefficient S of reference 7 is equal to 1 - P in the notation of the present paper, thus a value of S greater than 1 corresponds to a negative value of P. The part of the diagrams ahead of the spoiler is similar to the part ahead of the aileron. The pressure coefficients P over the aileron, however, are positive; whereas the pressure coefficients P behind the spoiler are negative. Pressure-distribution diagrams over an aileron, therefore, do not indicate a balancing moment as they do for a spoiler, which would seem to indicate that the twisting-moment coefficients contributed by an aileron would be more severe than those contributed by a spoiler.

SUMMARY OF RESULTS

The results of tests of several spoiler arrangements on a wing of NACA 230-series airfoil sections may be summarized as follows:

1. The influence of a projected spoiler on the section pitching-moment coefficients extended approximately 25 percent of the semispan inboard of the spoiler. The maximum twisting-moment coefficients of the low-angle-of-attack condition were reached at this spanwise location.

2. A region of negative pressure coefficients existed directly behind the projected spoiler and diminished the positive pitching-moment tendencies. This low pressure region became larger near the tip and, in some cases, caused negative local twisting moments. Consequently, the smallest maximum twisting-moment coefficient due

to a spoiler for a given rolling-moment coefficient may be obtained by locating the outboard end of the spoiler as close to the tip as possible to take advantage of the increased balancing moment.

3. The perforations caused the pressure coefficients directly behind the spoiler to increase, and a greater maximum twisting-moment coefficient resulted. The rolling-moment coefficients of the perforated and the plain spoilers, however, were the same within the experimental accuracy of the tests.

4. Either an extension of the spoiler span inboard from the tip or an increase in spoiler projection increased both the twisting-moment coefficients due to the spoiler and the rolling-moment coefficients. For a given change in rolling-moment coefficient, however, an extension of the spoiler span resulted in greater increases in twisting moments due to the spoiler than did an increase in spoiler projection.

Langley Memorial Aeronautical Laboratory
National Advisory Committee for Aeronautics
Langley Field, Va., January 26, 1947

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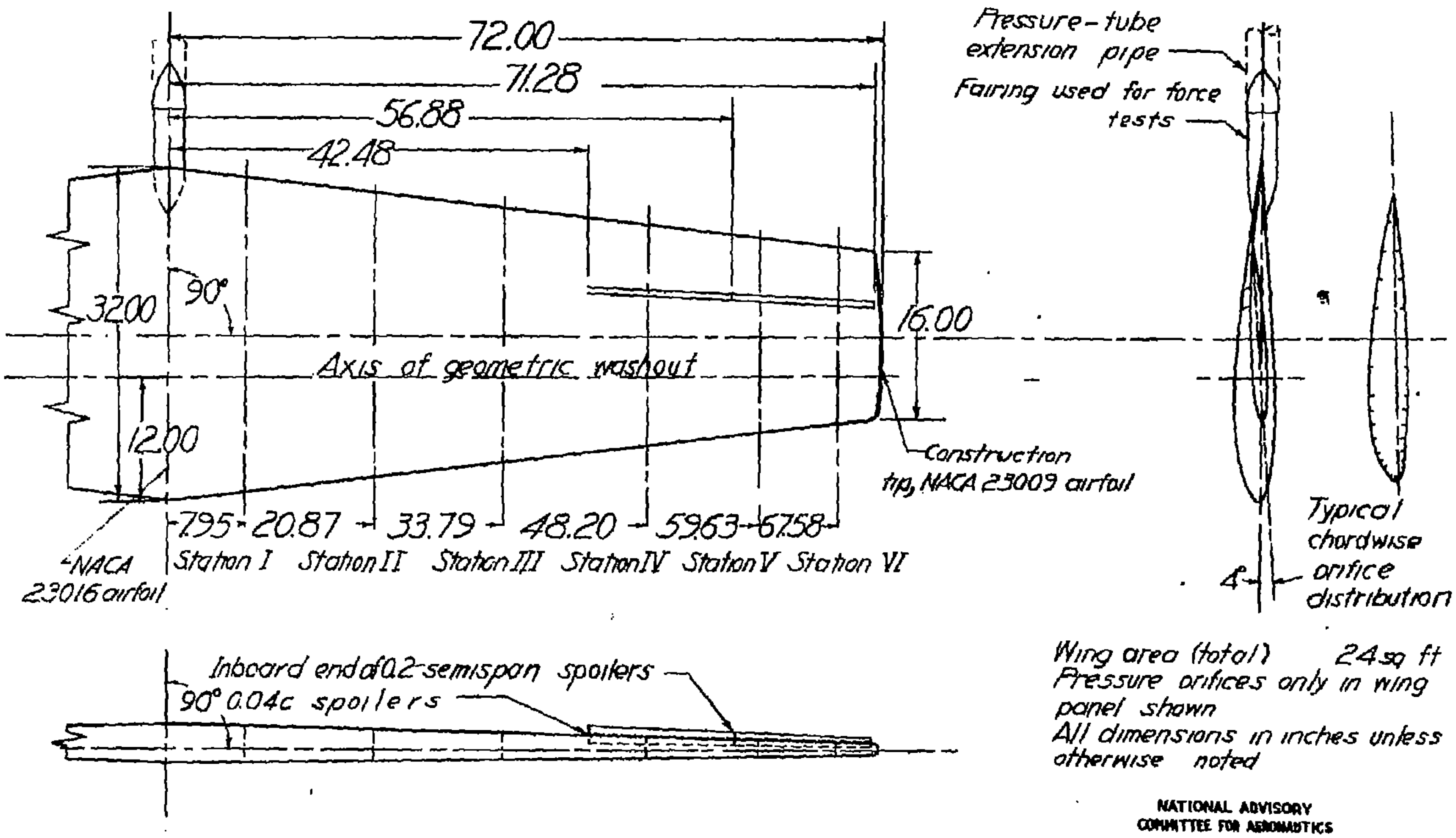

Figure 1.- Layout of wing of NACA 230-series airfoil sections.

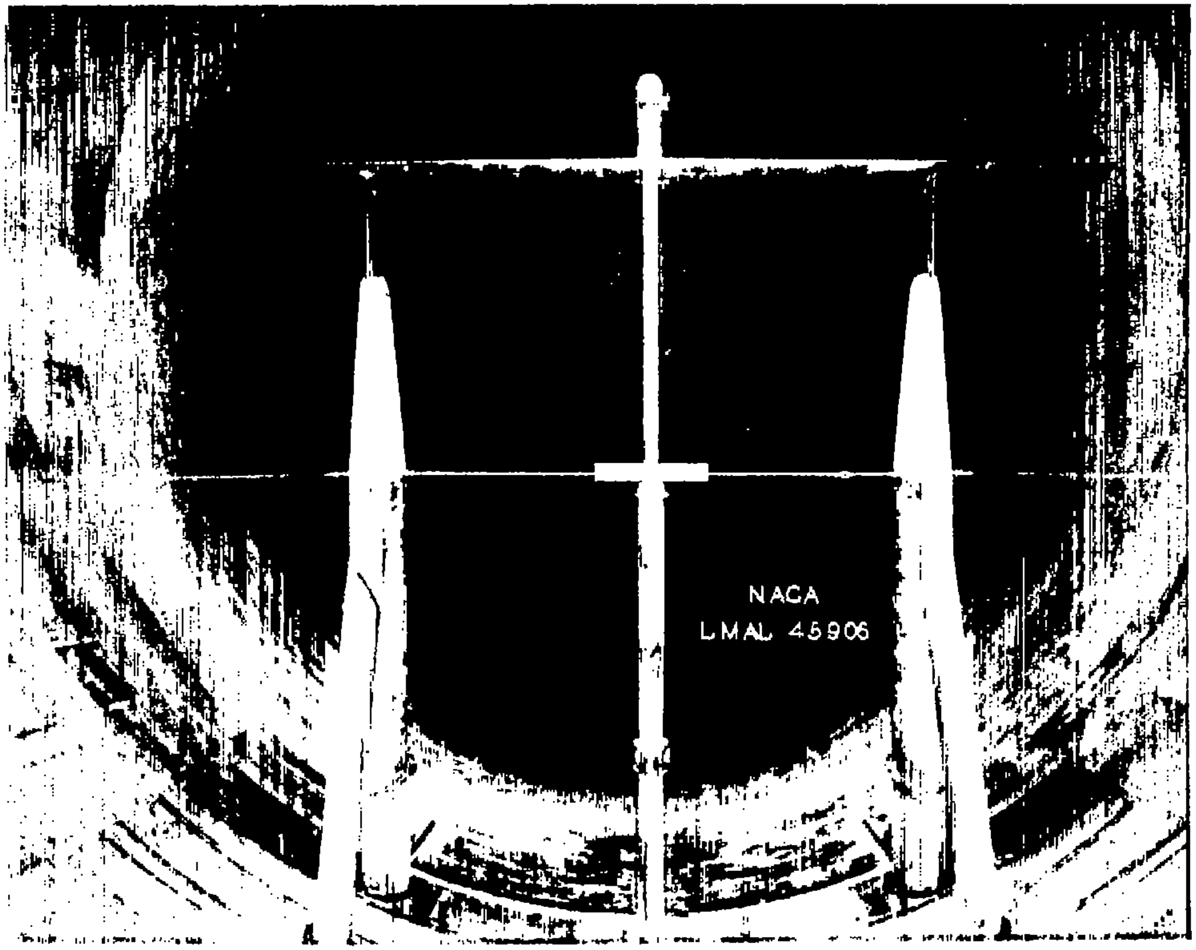

Figure 2.- Wing of NACA 230-series airfoil sections mounted in the Langley 19-foot pressure tunnel. Rear view of pressure-distribution test setup.

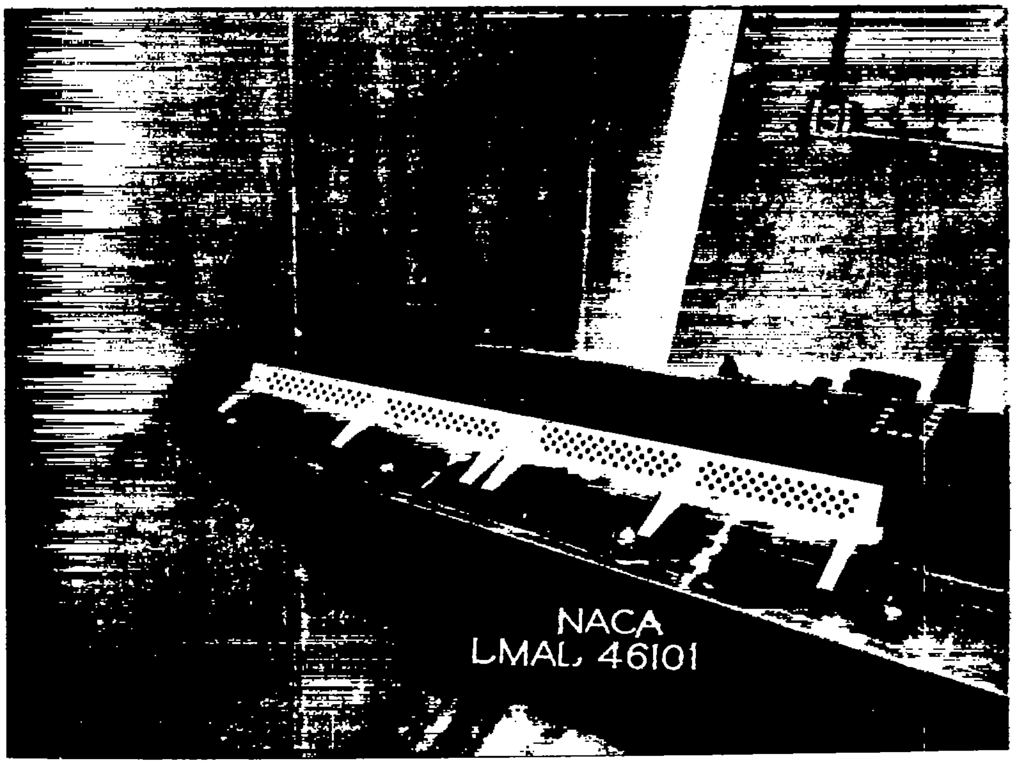

Figure 3.- Perforated spoiler projecting 0.08c and extending $0.4\frac{b}{2}$ mounted on wing of NACA 230-series airfoil sections.

Spoiler	Area reduction due to perforations (percent)
$0.4\frac{b}{2}$ span	15
$0.2\frac{b}{2}$ span	18

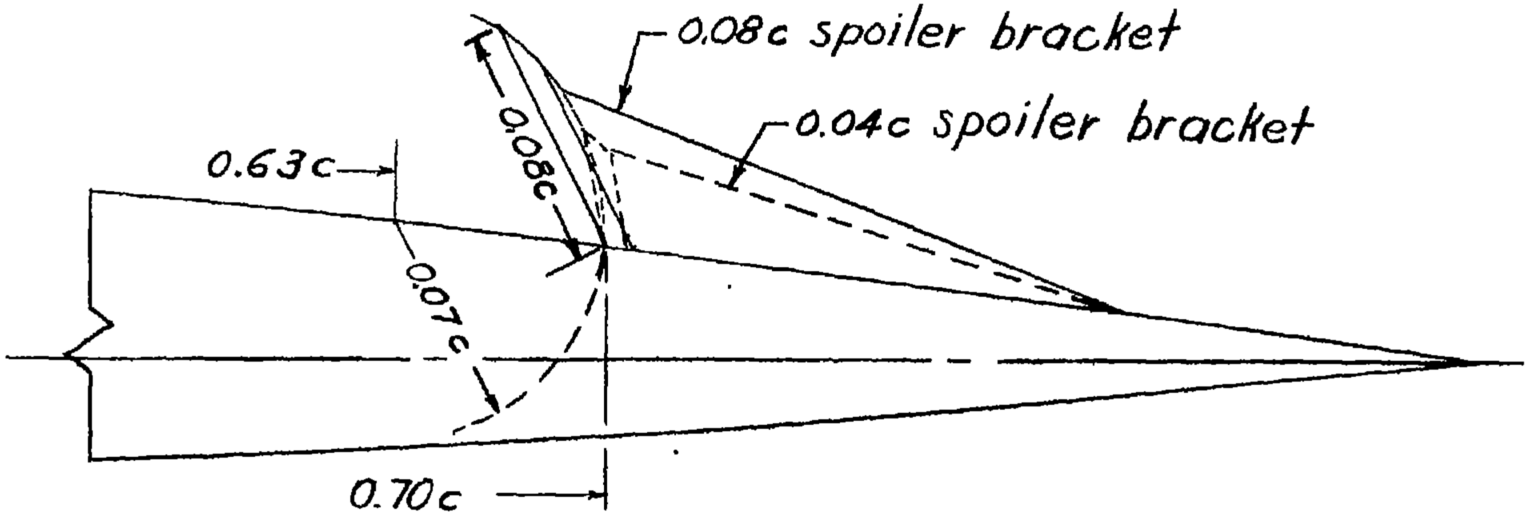

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Figure 4.- Typical section showing spoiler mounted on wing of NACA 230-series airfoil sections.

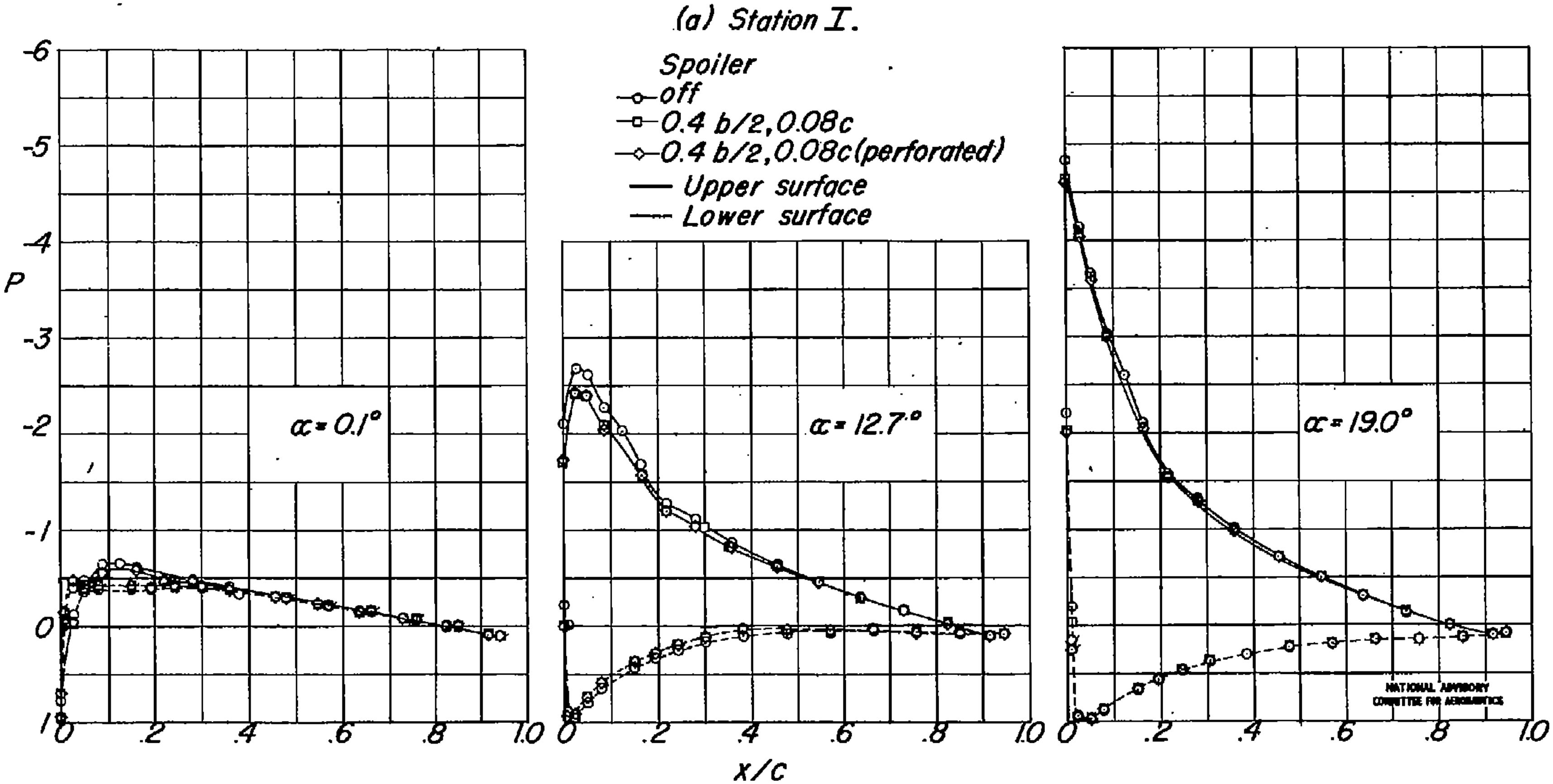
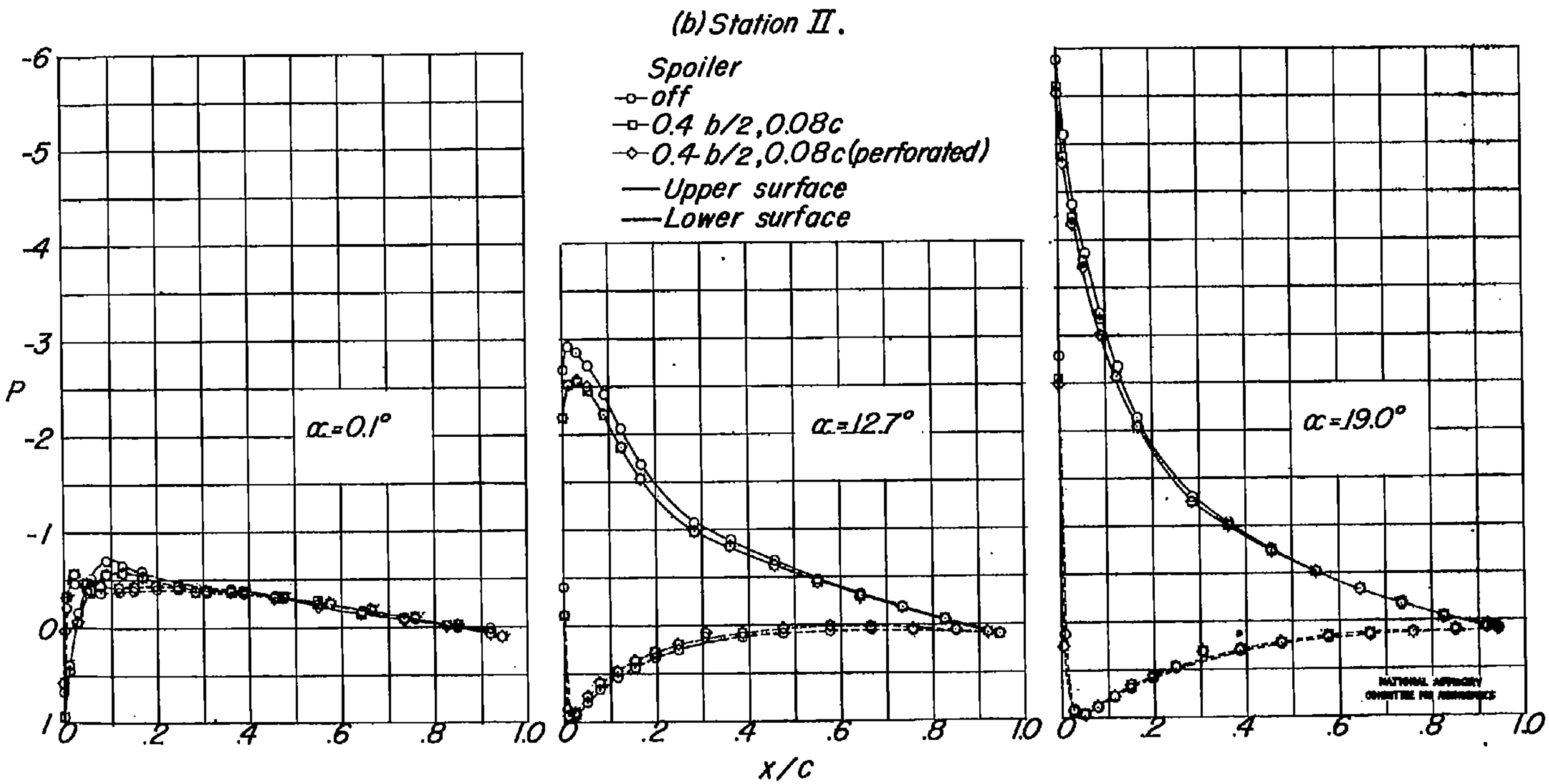


Figure 5.- Chordwise pressure distribution over a wing of NACA 230-series airfoil sections with several spoiler arrangements; R = 7,350,000; M_0 = 0.245.



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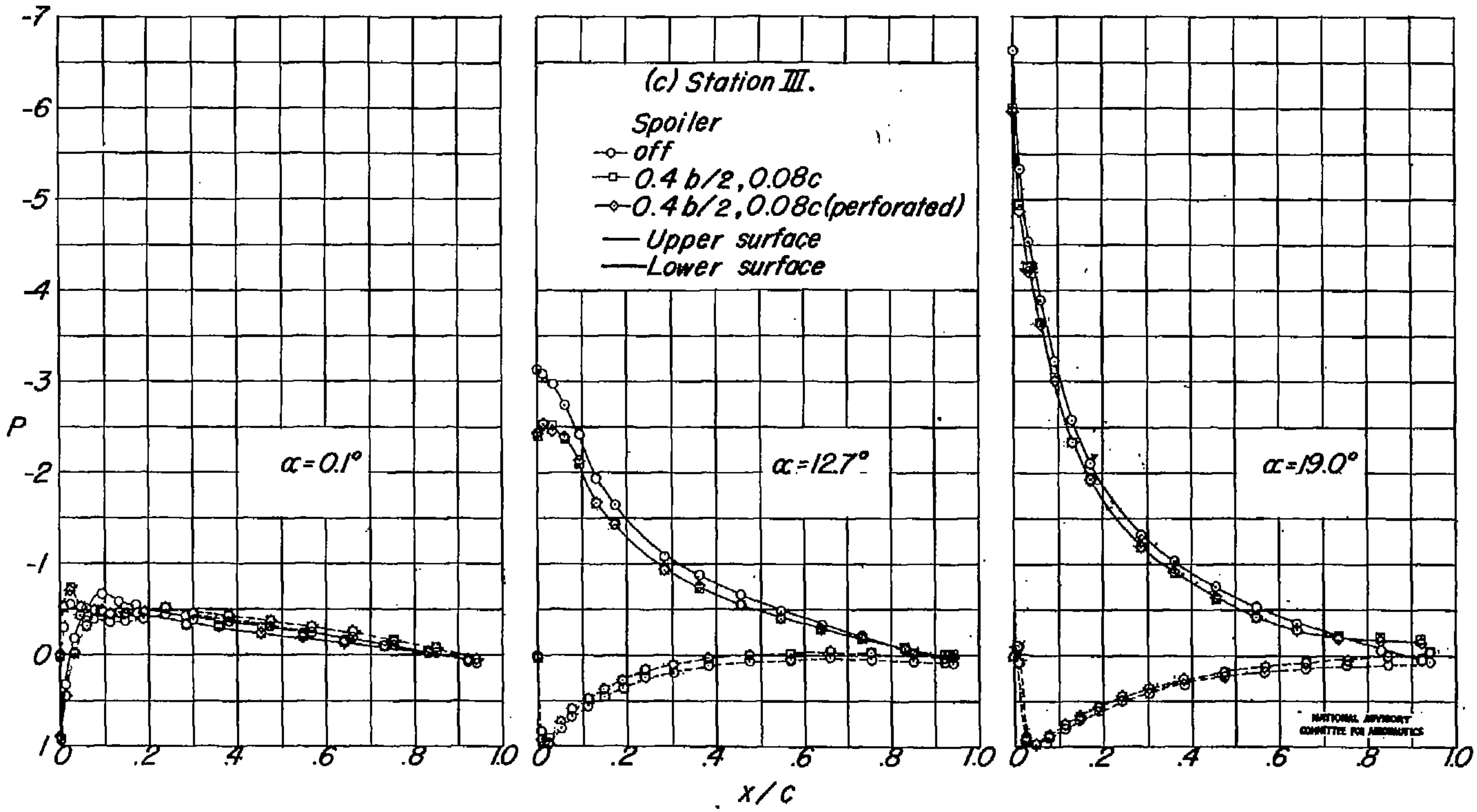

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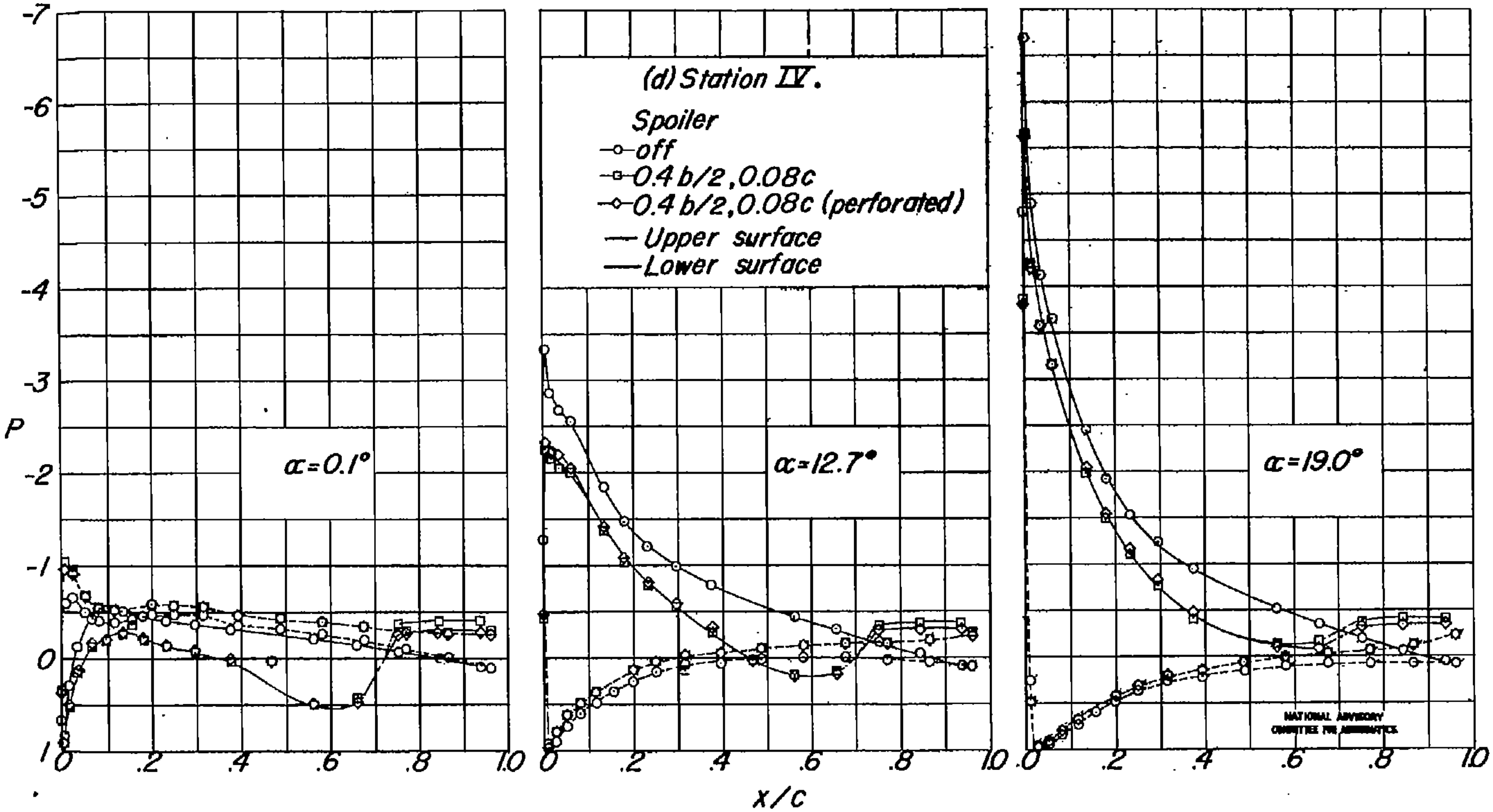

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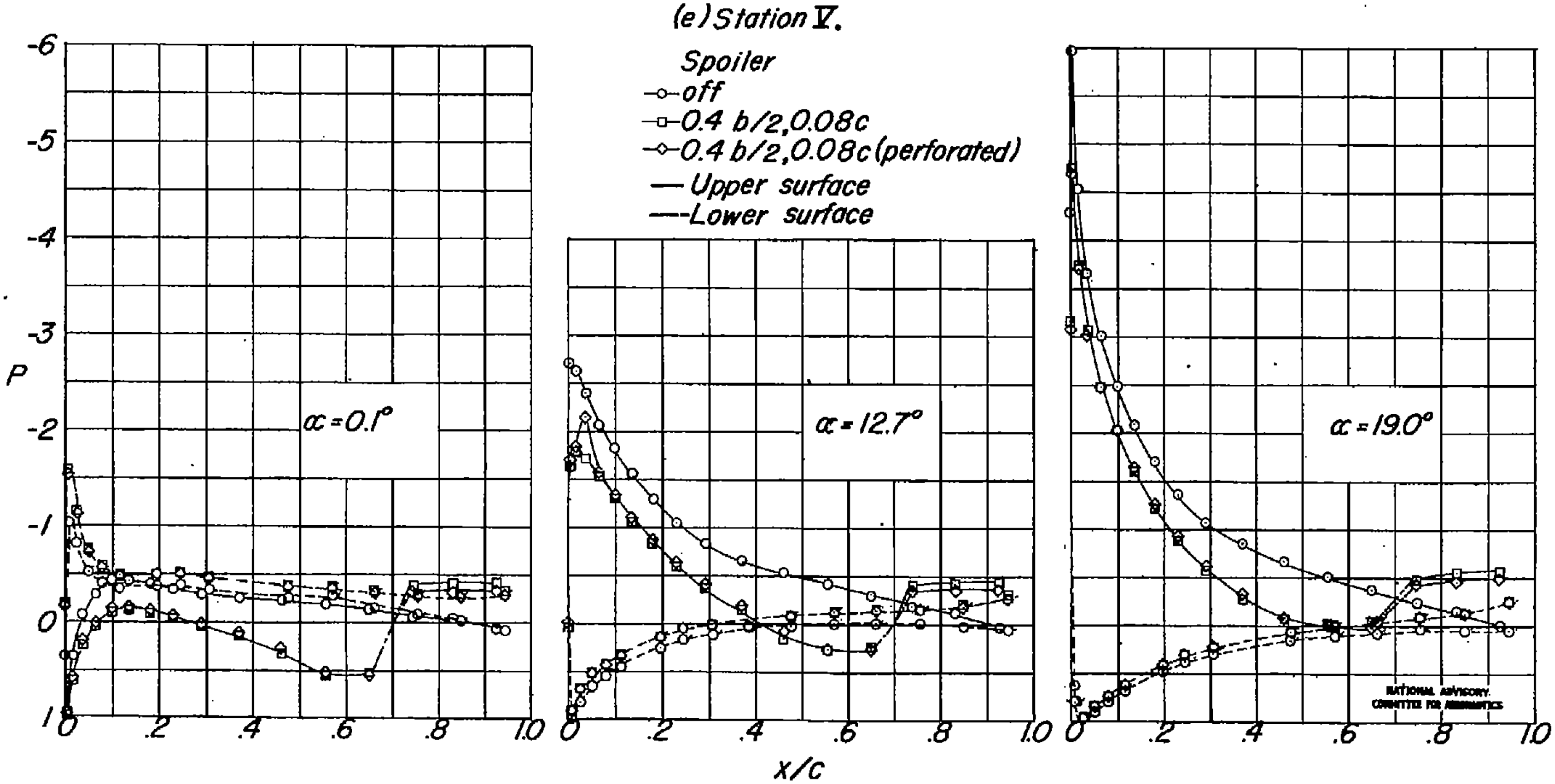

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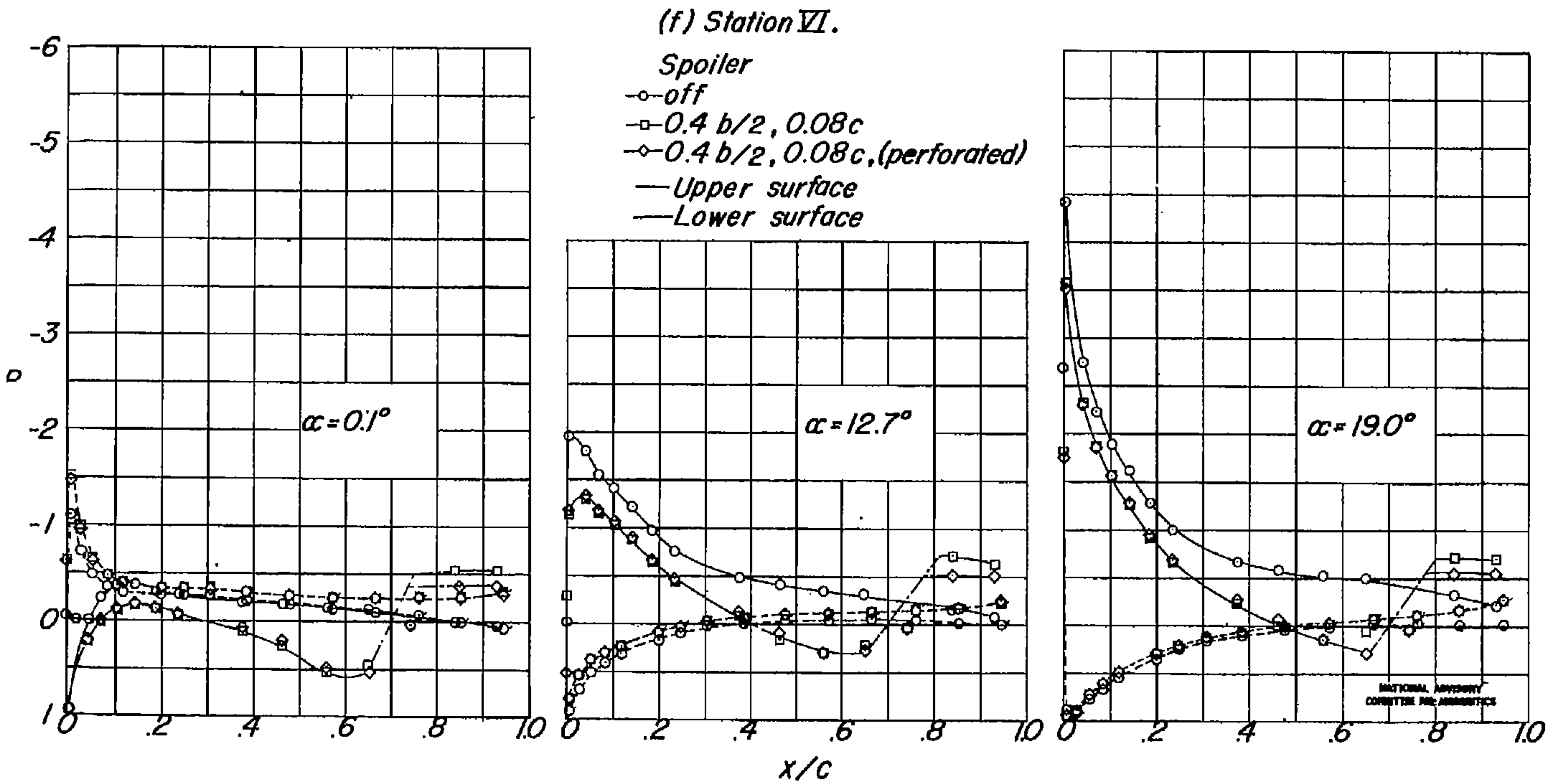

Figure 5.- Concluded.

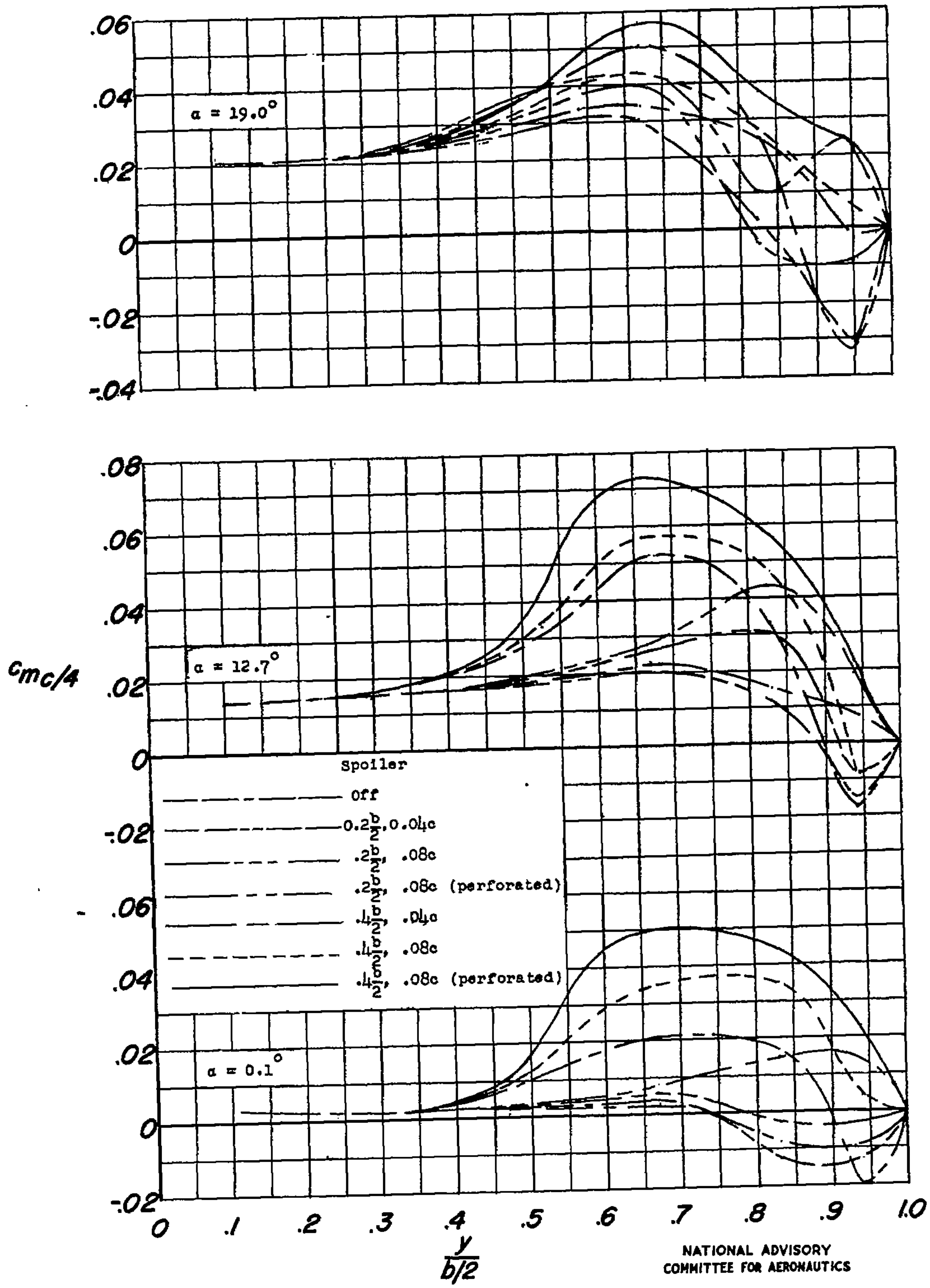

Figure 6.- Spanwise variation of section pitching-moment coefficient of a wing of NACA 230-series airfoil sections with several spoiler arrangements. R = 7,350,000; M_o = 0.245.

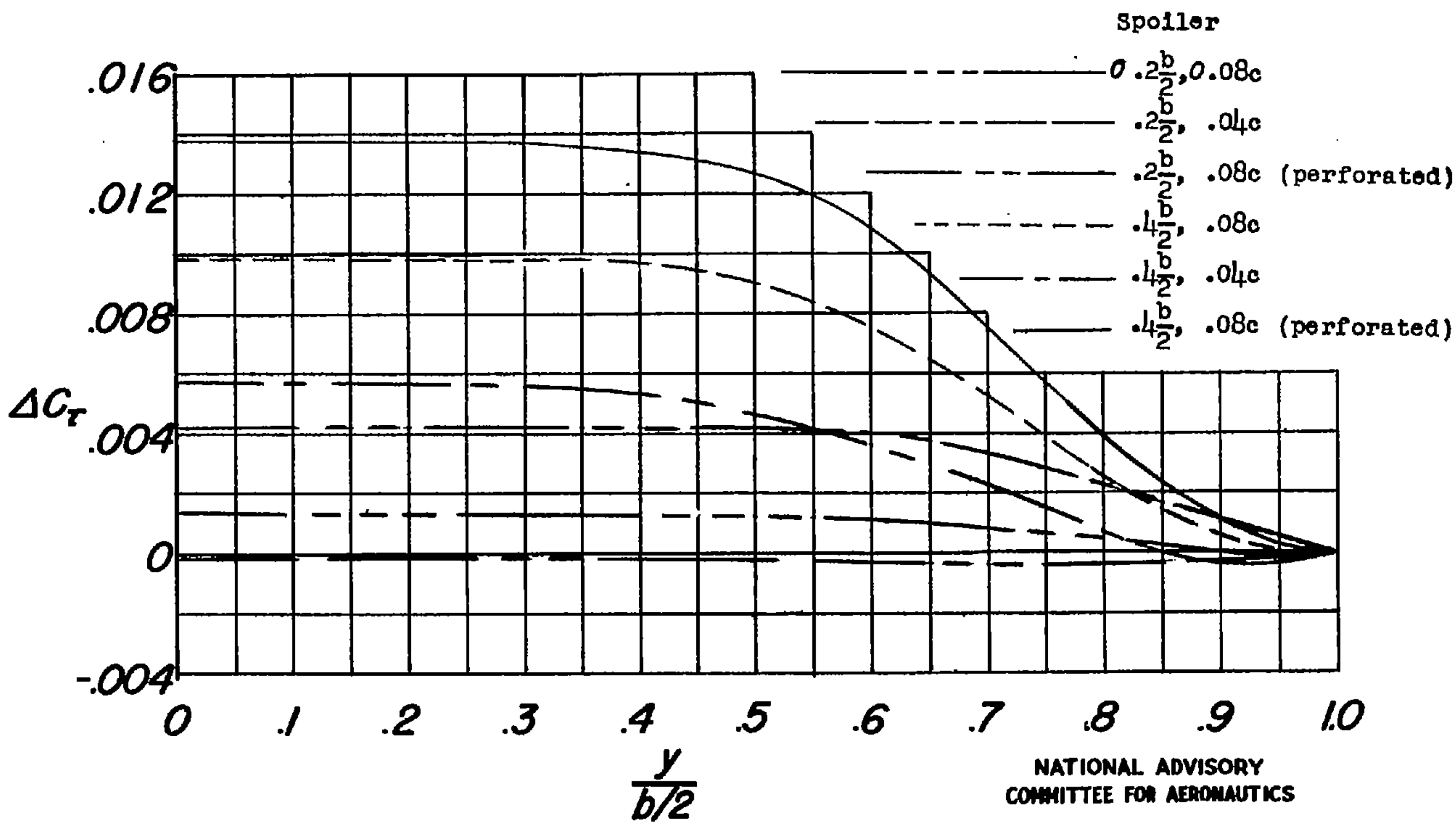

Figure 7.- Spanwise variation of increment of twisting-moment coefficient of a wing of NACA 230-series airfoil sections with several spoiler arrangements. $\alpha = 0.1^{\circ}$; $R = 7,350,000$; $M_o = 0.245$.

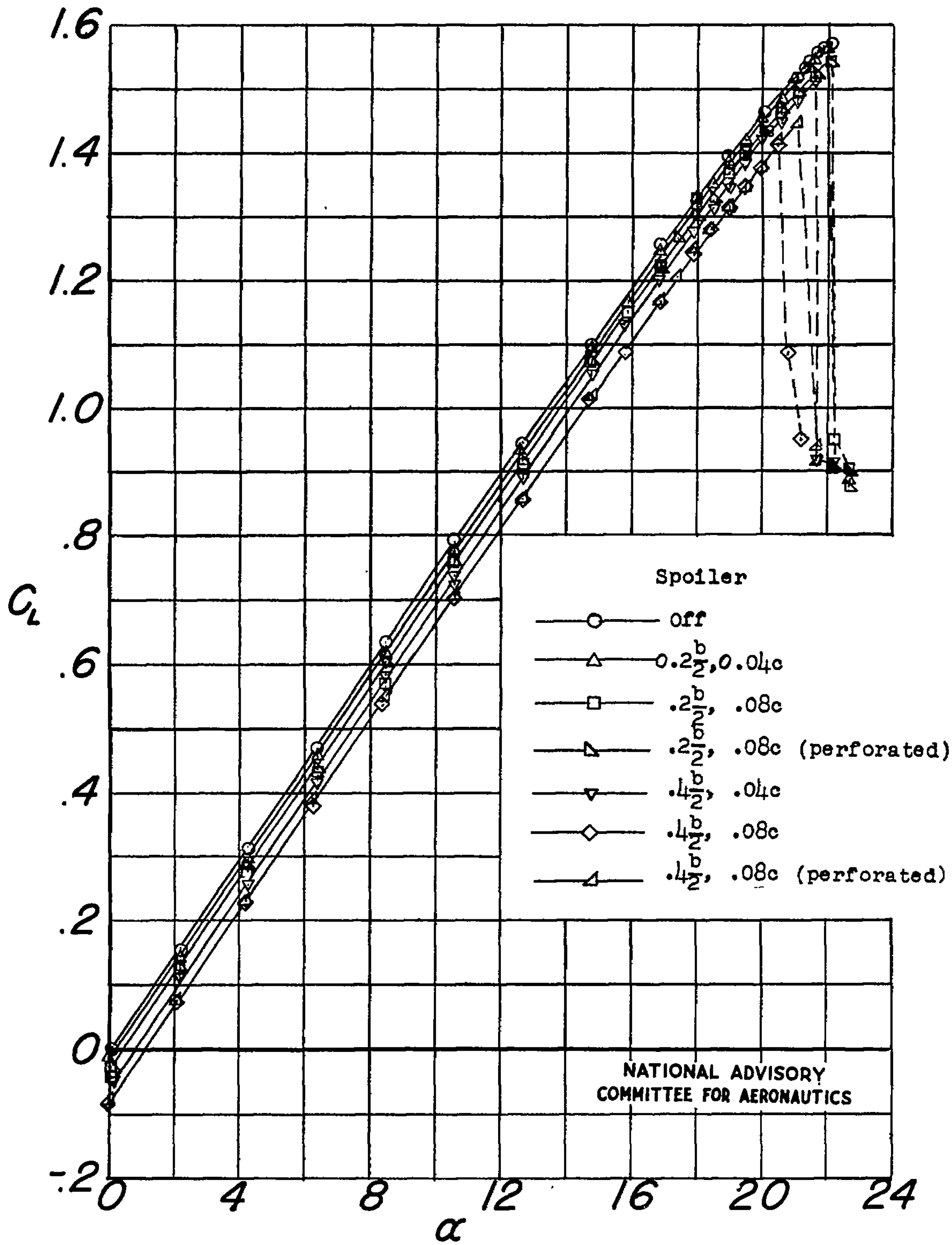

Figure 8.- Variation of lift coefficient with angle of attack of a wing of NACA 230-series airfoil sections with several spoiler arrangements. R = 7,350,000; M_o = 0.245.

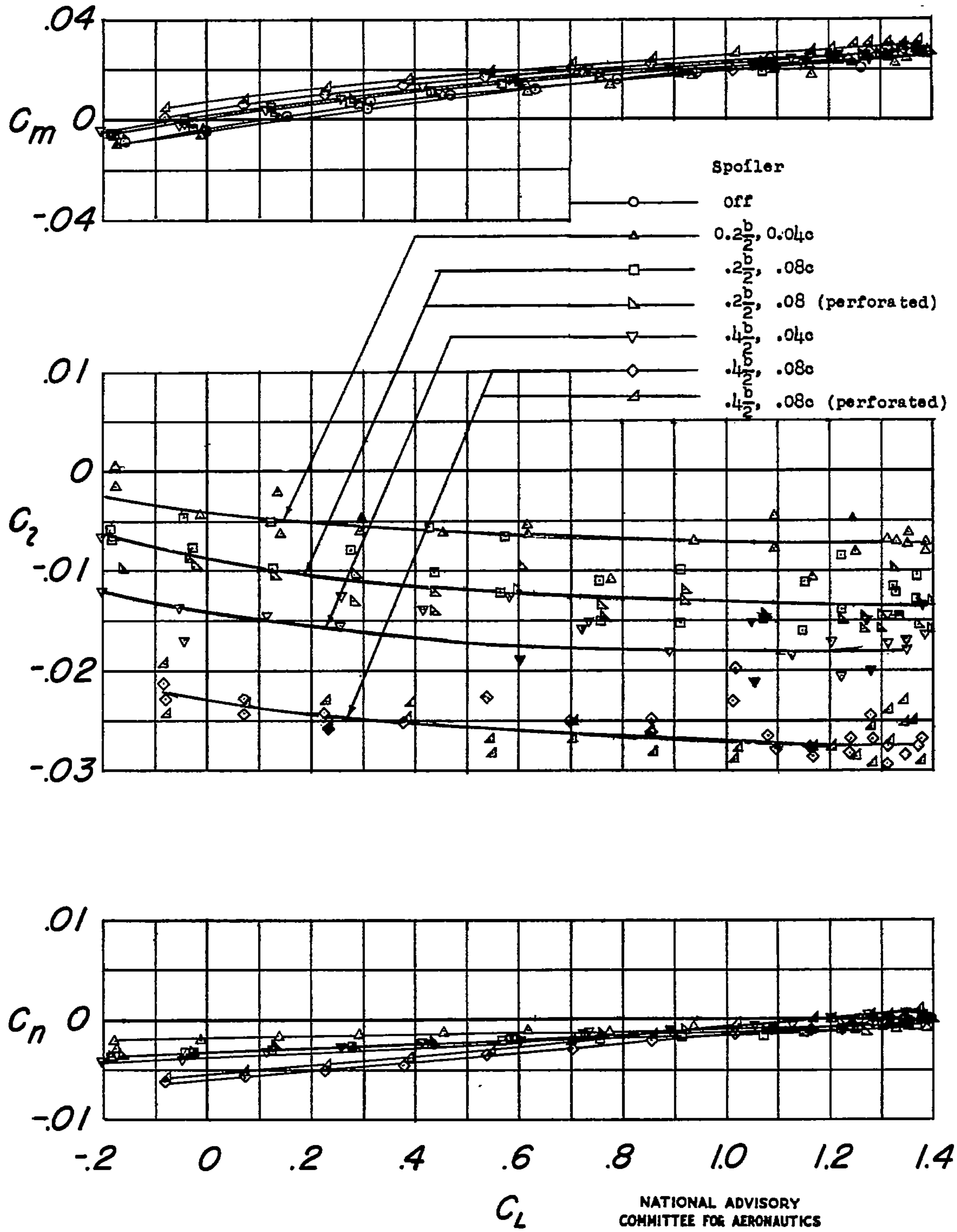

Figure 9.- Aerodynamic characteristics of wing of NACA 230-series airfoil sections with various spoiler arrangements. R = 7,350,000; M_0 = 0.245.