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WIND-TUNNEL INVESTIGATION OF AN NACA 23012 AIRFOIL WITH AN 18.05-PERCENT-CHORD MAXWELL SLAT AND WITH TRAILING-EDGE FLAPS

By Clarence L. Gillis and John W. McKee

Langley Memorial Aeronautical Laboratory
Langley Field, Va.

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

MEMORANDUM REPORT

for the

Bureau of Aeronautics, Navy Department

WIND-TUNNEL INVESTIGATION OF AN NACA 23012 AIRFOIL WITH AN 18.05-PERCENT-CHORD MAXWELL SLAT AND WITH TRAILING-EDGE FLAPS

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SUMMARY

An investigation has been made in the NACA 7- by 10-foot wind tunnel of an NACA 23012 airfoil with an 18.05-percent-chord Maxwell leading-edge slat and with a slotted and a split flap. The purpose of the investigation was to determine the optimum slot gap of the Maxwell slat for, and the aerodynamic section characteristics of, the airfoil with several deflections of both types of flap. Curves of lift, drag, and pitching-moment characteristics for selected optimum arrangements are presented.

As the slot gap was increased up to the optimum, the profile drag increased except in the range near maximum lift coefficient and the pitching moment became increasingly negative. The optimum slot gap of 0.0175c appreciable increased the maximum lift coefficient and angle of attack at the stall. The effectiveness of the slat, however, dropped off with increasing flap deflection.

INTRODUCTION

To increase the efficiency and safety of airplanes, it is desirable to have means of increasing the maximum lift of airfoils and of increasing and regulating the angle at which they stall. Leading-edge slots are one of the few devices that have been found capable of increasing both the maximum lift and the angle of attack at the stall.

The fixed leading-edge slot (reference 1) is an integral part of the wing and has no moving parts. This slot is the simplest type but has the disadvantage of increasing the drag in the normal flying range. It may be advantageous, however, where ruggedness and simplicity are essential. The Handley Page leading-edge slot (references 2 and 3) and the Maxwell leading-edge slot (references 4 and 5) have more favorable characteristics in the slow-speed high angle-of-attack range when they are open, and in addition increase the drag in the normal flying range only slightly when they are closed. The Maxwell slat (fig. 1) may be the simpler in operation, as it is opened by rotating the slat about a fixed point.

This investigation was made to determine the optimum slot gap of the Maxwell slat for, and the aerodynamic section characteristics of, an NACA 23012 airfoil with an 18.05-percent-chord Maxwell slat and with a slotted and a split flap.

MODELS

The airfoil, Maxwell slat, and slotted flap were made to the profiles of table I and figure 2. The 3-foot chord by 7-foot span airfoil was built of laminated mahogany. The full-span slotted flap, type 2-h in reference 6, which had a chord of 9.24 inches (25.66 percent of the airfoil chord) was also constructed of laminated wood. It was mounted on the airfoil by three steel fittings that allowed flap deflections of 0° to 60°. The path of the nose point as shown in table II (the nose point of the flap is defined as the point of tangency of a line drawn perpendicular to the airfoil chord and tangent to the leading edge of the flap when neutral) was the optimum reported in reference 6. The full-span split flap of 7.2 inches chord (20 percent of the airfoil chord) was made of 1/4-inch plywood, and was fastened to the airfoil with screws, the flap angles being maintained by triangular wooden blocks between the flap and airfoil. The forward portion of the full-span Maxwell slat was built of laminated mahogany and the rear portion of dural. It had a chord of 6.5 inches (18.05 percent of the airfoil chord) and was mounted on the airfoil by four steel fittings with provision for changing the slot gap.

TESTS

The tests were made in the NACA 7- by 10-foot wind tunnel (references 6 and 7) at a dynamic pressure of 16.37 pounds per square foot corresponding to an airspeed of 80 miles per hour under standard sea-level conditions. The average test Reynolds number based on the chord of the airfoil with the slat and flap retracted was 2,190,000; due to turbulence in the air stream the effective Reynolds number (for maximum lift coefficients) was approximately 3,500,000. The model completely spanned the closed test section of the wind tunnel except for small clearances at each end so that two-dimensional flow was approximated (reference 6). Sufficient slot gaps of the Maxwell slat were tested with most flap deflections to determine the trend of the characteristics and the optimum slot gap for maximum lift. Data for the airfoil with the slot closed were taken from reference 6, because with the slot closed the basic airfoil contour is established. When the slotted flap was fully retracted, the flap slot gap was sealed and faired to the basic airfoil contour as recommended in reference 6.

RESULTS AND DISCUSSION

Coefficients

All test results are given in standard nondimensional section coefficient form (corrected as explained in reference 6) as follows:

c_l section lift coefficient (l/qc)

c_{d_o} section drag coefficient (d_o/qc)

$c_{m(a.c.)_o}$ section pitching-moment coefficient about the aerodynamic center of the airfoil with flap and slat retracted $\left(m_{(a.c.)_o}/qc^2\right)$ (See reference 6)

where

l section lift

d_o section profile drag

$m_{(a.c.)_o}$ section pitching moment

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

c chord of airfoil with slat and flap retracted

and

c_f flap chord (projected width on airfoil chord line)

c_s slat chord (maximum width)

α_o angle of attack for infinite aspect ratio

δ_f flap deflection

δ_s	deflection of after portion of slat
R_n	radius of rear edge of slot entry
$c_{l_{max}}$	section maximum lift coefficient
$\alpha_{c_{l_{max}}}$	angle of attack for section maximum lift coefficient

Precision

The accuracy of the various measurements is believed to lie within the following limits:

α_o	± 0.10	$c_{d_{o(c_l=1.0)}}$	± 0.0006
$c_{l_{max}}$	± 0.03	$c_{d_{o(c_l=2.5)}}$	± 0.002
$c_{m(a.c.)_o}$	± 0.003	δ_f	$\pm 0.2^\circ$
$c_{d_{o_{min}}}$	± 0.0003	Flap position	$\pm 0.001c$

Slot gap $\pm 0.001c$

No attempt was made to determine the effect of flap or slat fittings.

Effects of Slot Gap on the Plain Airfoil

In figure 3 are shown the effects of the 0.1805c Maxwell slat with various slot gaps on the aerodynamic section characteristics of the airfoil with no flap. The effects are similar to those produced by a 0.30c Maxwell slat as reported in reference 4. The highest $c_{l_{max}}$ was obtained with slot gaps of 0.0175c and 0.02c. The $c_{l_{max}}$ at these two slot gaps was 2.05, at an $\alpha_{c_{l_{max}}}$ of 27.2° and 28.2°, respectively. A noticeable effect of the 0.1805c Maxwell slat in comparison with the 0.30c slat was the more gradual loss of lift at angles of attack near the stall. This effect produced a rounded top on the lift curve and caused $\alpha_{c_{l_{max}}}$ to occur about 3° higher for the 0.1805c slat than for the 0.30c slat, even though the $c_{l_{max}}$ was lower. The pitching moments became increasingly negative as the slot gap was increased, indicating that the center of pressure moved rearward.

The profile drag generally increased with increasing slot gap, this effect being most pronounced near zero lift.

Effect of Slot Gap with Various Configurations

The effect of slot gap on $c_{l_{max}}$ and $\alpha_{c_{l_{max}}}$ of the airfoil and slat with a slotted and a split flap is shown in figure 4 for various flap deflections. A slot gap of 0.0175c appeared to be optimum for maximum lift coefficient at most flap deflections, while a larger gap gave the highest values of $\alpha_{c_{l_{max}}}$. With a 0.0175c slot gap and no flap deflection the $\Delta c_{l_{max}}$ produced by the slot was 0.50, with the $\alpha_{c_{l_{max}}}$ being increased about 12°. With flap deflected for maximum lift, the average $\Delta c_{l_{max}}$ was about 0.07 with a corresponding $\Delta\alpha_{c_{l_{max}}}$ of about 7°. Under the same conditions the 0.30c Maxwell slat gave a $\Delta c_{l_{max}}$ of 0.65 and 0.30, respectively, with an increase of about 10° in the $\alpha_{c_{l_{max}}}$ for all cases (reference 4). It should be noted that although the 0.1805c slat gave an $\alpha_{c_{l_{max}}}$ about 3° higher than that for a 0.30c slat with flap neutral, as mentioned previously, the $\alpha_{c_{l_{max}}}$ at large flap deflections was 2° or 3° lower. With the 0.1805c Maxwell slat, there is a much greater loss of effectiveness at large flap deflections than with the 0.30c slat. The aerodynamic section characteristics of the combinations shown in figure 4, with the optimum slot gap of 0.0175c, are plotted in figures 5 and 6. A comparison of these figures with data given in reference 6 indicates that the 0.1805c Maxwell slat when set at the optimum slot gap increased the pitching-moment coefficients in the high-lift range negatively for all flap deflections.

Comparison of Profile Drag Coefficients

A comparison of the profile drag characteristics of several airfoil slat-flap combinations is shown in figure 7 as envelope polars, the optimum slot gap of 0.0175c being used for the comparison. Below a lift coefficient of 0.8 the plain airfoil has the lowest profile drag. Above a lift coefficient of 0.8 the airfoil with a slotted flap had a lower profile drag coefficient than any of the combinations with the Maxwell slat. With the optimum slot opening, the airfoil with the slotted flap had the lowest profile drag, the airfoil with the split flap had higher profile drag, and the airfoil with no flap had the highest profile drag. This is the same order of the profile drag coefficients for the airfoil with the 0.30c slat (reference 4). The profile drag coefficients of the airfoil with the 0.1805c slat were higher in every case than the corresponding profile drag coefficients of the airfoil with the 0.30c slat.

Effects of Variations of Slot Shape

The effect of varying the radius of the rear edge of the slot entry (R_n, fig. 2) is shown in figure 8. The larger radius had practically no effect on the airfoil with split flap, except to slightly increase the profile drag at high lift coefficients. The only effect of the sharp-edge entry on the airfoil with split flap was a slight increase in profile drag at low lift coefficients. It had, however, a detrimental effect on the $c_{l_{max}}$ and on the profile drag coefficients over the entire lift range of the airfoil with slotted flap. Its effect on the airfoil with no flap was to considerably reduce $c_{l_{max}}$. Changing the shape of the entry had no effect on the pitching-moment coefficients of any of the combinations tested.

The test results with the trailing part of the slat deflected 12° (fig. 2) and with a slot gap of 0.0175c are also shown in figure 8. Deflecting the trailing edge of the slat gave an increment of $c_{l_{max}}$ of about 0.06, which is about two-thirds of the increments of $c_{l_{max}}$ given by adding the slot to the airfoil and flap, at the flap deflection tested. In addition, the profile drag and the pitching moment were decreased by bending the slat.

CONCLUSIONS

For the combinations tested, a slot gap of 0.0175c was the optimum for $c_{l_{max}}$ at most flap deflections. The increment of $c_{l_{max}}$ given by the slot varied from 0.50 with flap neutral to an average of 0.07 with the flap deflected for maximum lift; the angle of attack for maximum lift was increased about 12° and 7°, respectively, for the same conditions. The profile drag generally increased and the pitching moment became more negative with increasing slot gap up to the optimum. Increasing the radius of the rear edge of the slot entry caused no appreciable change in the characteristics, and a sharp corner at this point either had no effect or was detrimental. Deflecting the trailing edge of the slat increased the $c_{l_{max}}$ and decreased the profile drag and pitching moment.

Langley Memorial Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., October 16, 1941.

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TABLE I

Ordinates for airfoil, flap, and slot shapes.

(Stations and ordinates in percent airfoil chord.)

NACA 23012 airfoil		
Station	Upper Surface	Lower Surface
0	—	0
1.25	2.67	-1.23
2.5	3.61	-1.71
5.0	4.91	-2.26
7.5	5.80	-2.61
10	6.43	-2.92
15	7.19	-3.50
20	7.50	-3.97
25	7.60	-4.28
30	7.55	-4.46
40	7.14	-4.48
50	6.41	-4.17
60	5.47	-3.67
70	4.36	-3.00
80	3.08	-2.16
90	1.68	-1.23
95	.92	-.70
100	.13	-.13
L.E. radius = 1.58. Slope of radius through end of chord = 0.305		

Slotted flap 2-h		
Station	Upper Surface	Lower Surface
0	-1.29	-1.29
.40	-.32	-2.05
.72	.04	-2.21
1.36	.61	-2.36
2.00	1.04	-2.41
2.64	1.40	-2.41
3.92	1.94	------
5.20	2.30	-----
5.66	-----	-2.16
6.48	2.53	-----
7.76	2.63	-----
9.03	2.58	-----
10.31	2.46	-----
15.66	1.68	-1.23
20.66	.92	-.70
25.66	.13	-.13
Center of L.E. arc		
0.91	-1.29	
L.E. rad. = 0.91		

TABLE I (cont)

0.18c Maxwell slat		
Station	Upper Surface	Lower Surface
0	-----	0
1.25	2.67	-1.23
1.75	-----	-1.12
2.5	3.61	-.66
4	-----	.53
5	4.91	1.41
6	-----	2.35
7.5	5.80	3.98
8.5	-----	4.75
10	6.43	5.50
12	-----	6.27
15	7.19	7.00
16.5	7.30	7.20
L.E. rad. = 1.58. Slope of radius through end of chord = 0.305		
Hinge radius center		
1.40	-1.00	

TABLE II

Path of nose of slotted flap for various flap deflections. Distances measured from lower edge of lip in percent airfoil chord c.

δ_f, deg	x	y
0	8.36	3.91
10	5.41	3.63
20	3.83	3.45
30	2.63	3.37
40	1.35	2.43
50	.50	1.63
60	.12	1.48

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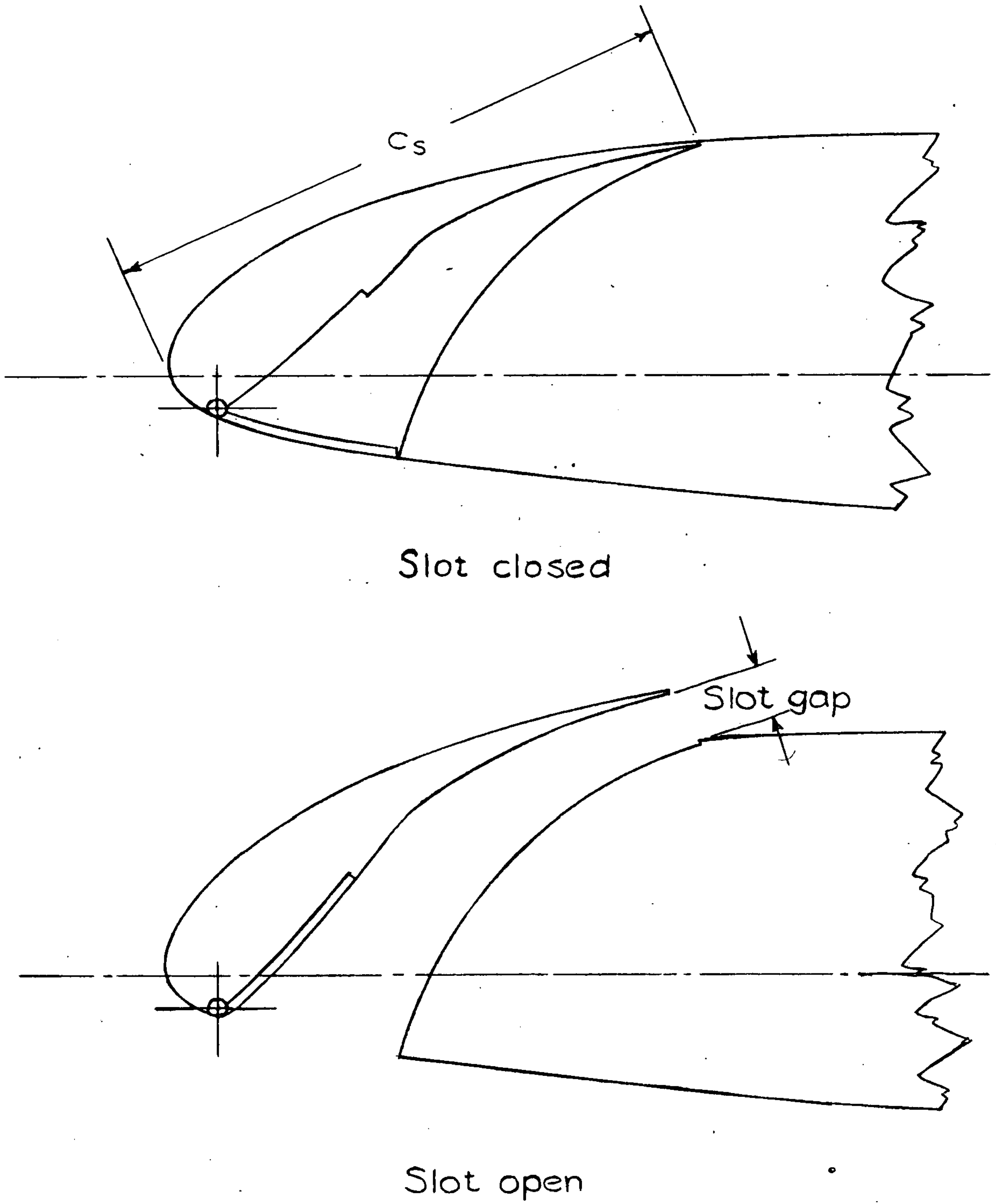
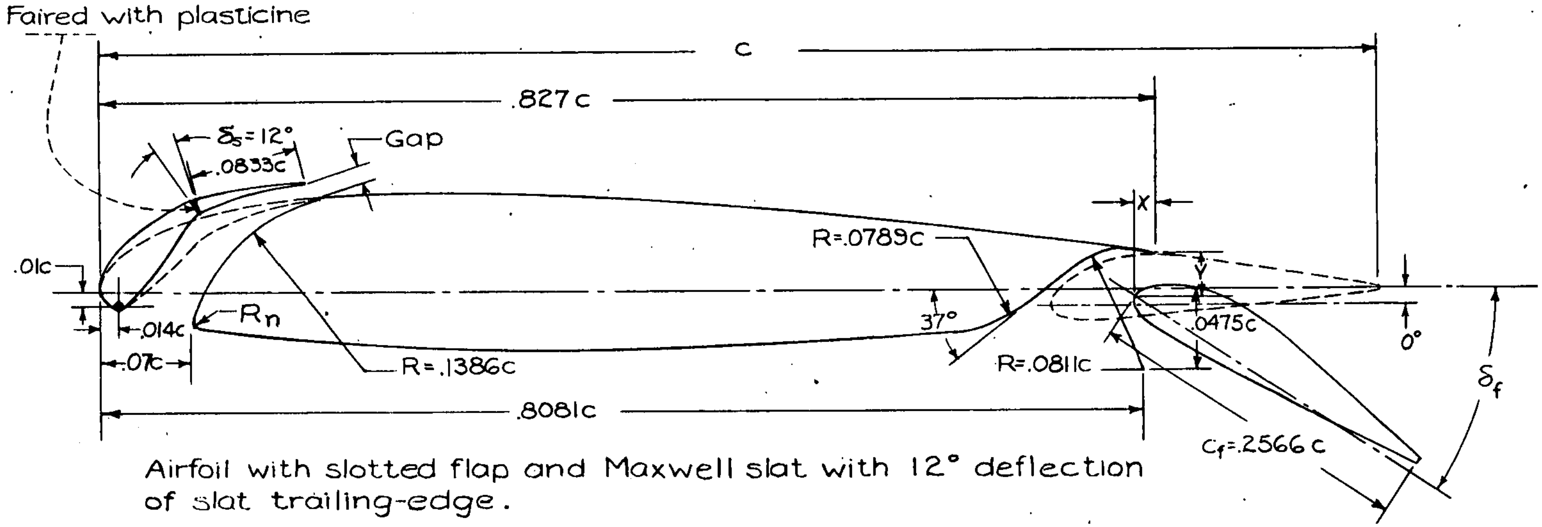
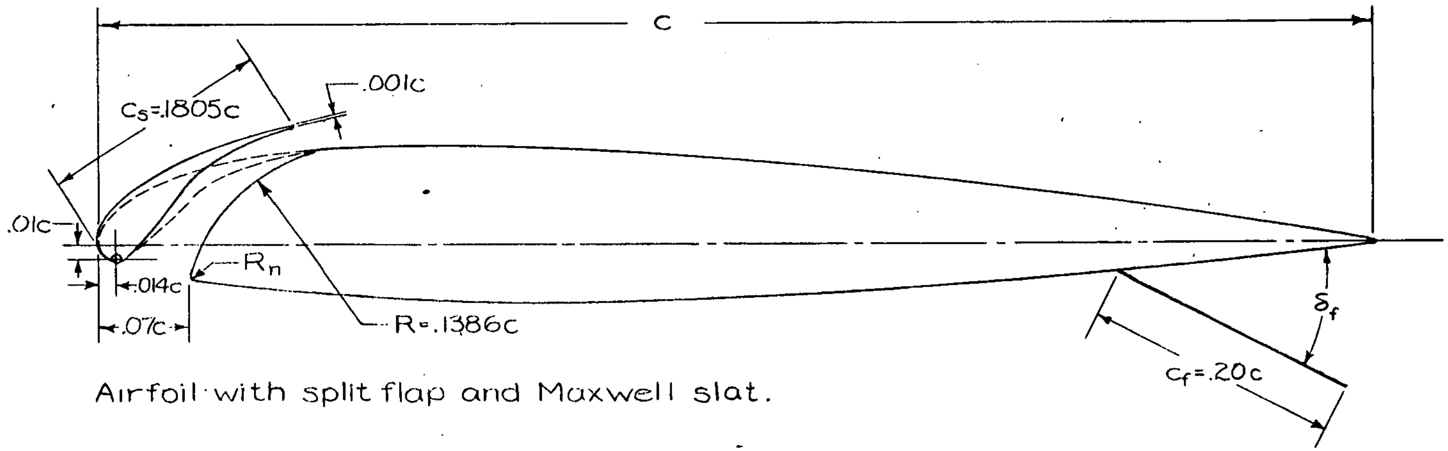


FIGURE 1.- Arrangement of Maxwell slot.



Airfoil with slotted flap and Maxwell slat with 12° deflection of slat trailing-edge.



Airfoil with split flap and Maxwell slat.

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FIGURE 2.- Sections of airfoil with slot and flap arrangements.

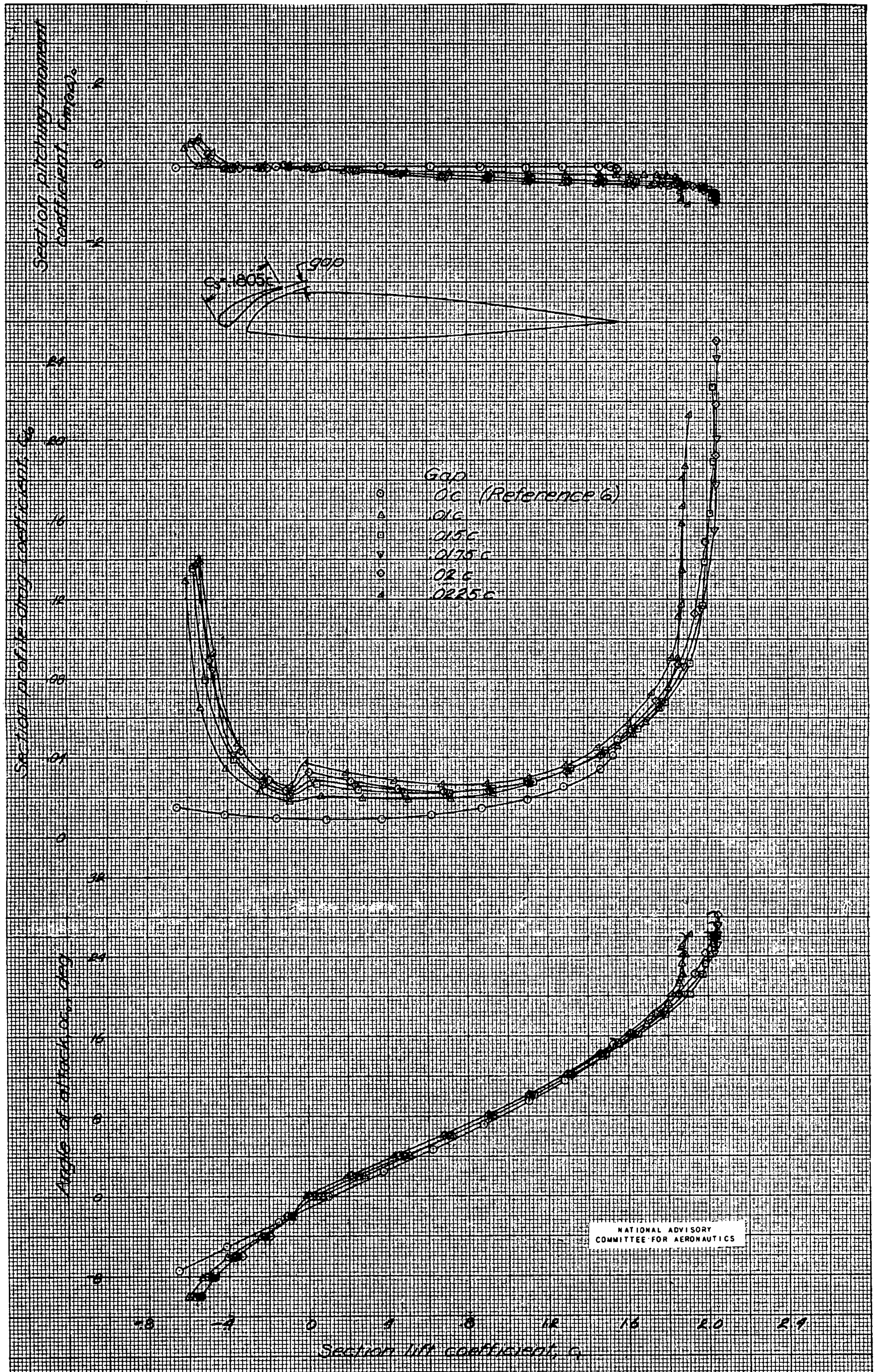

Figure 3.-Aerodynamic section characteristics of NACA 23012 airfoil with a 0.1805c Maxwell slot with various slot gaps. $R_p = 0.0025c$.

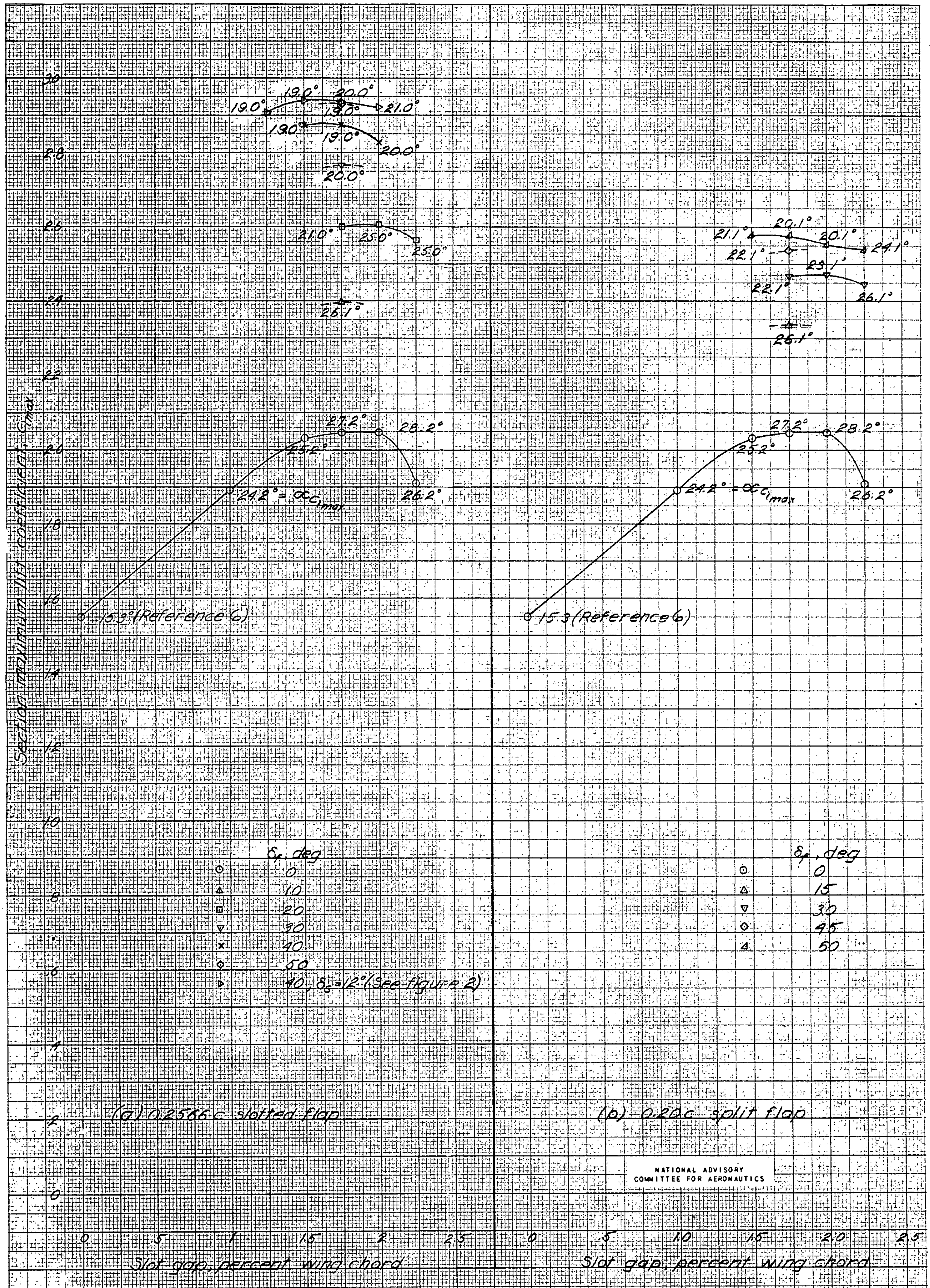

FIGURE 4.- Effect of slot gap on $c_{l_{max}}$ and $\alpha_{c_{l_{max}}}$ of NACA 23012 airfoil with a 0.1805c Maxwell slot and with a slotted and a split flap. R_n=0.0025c.

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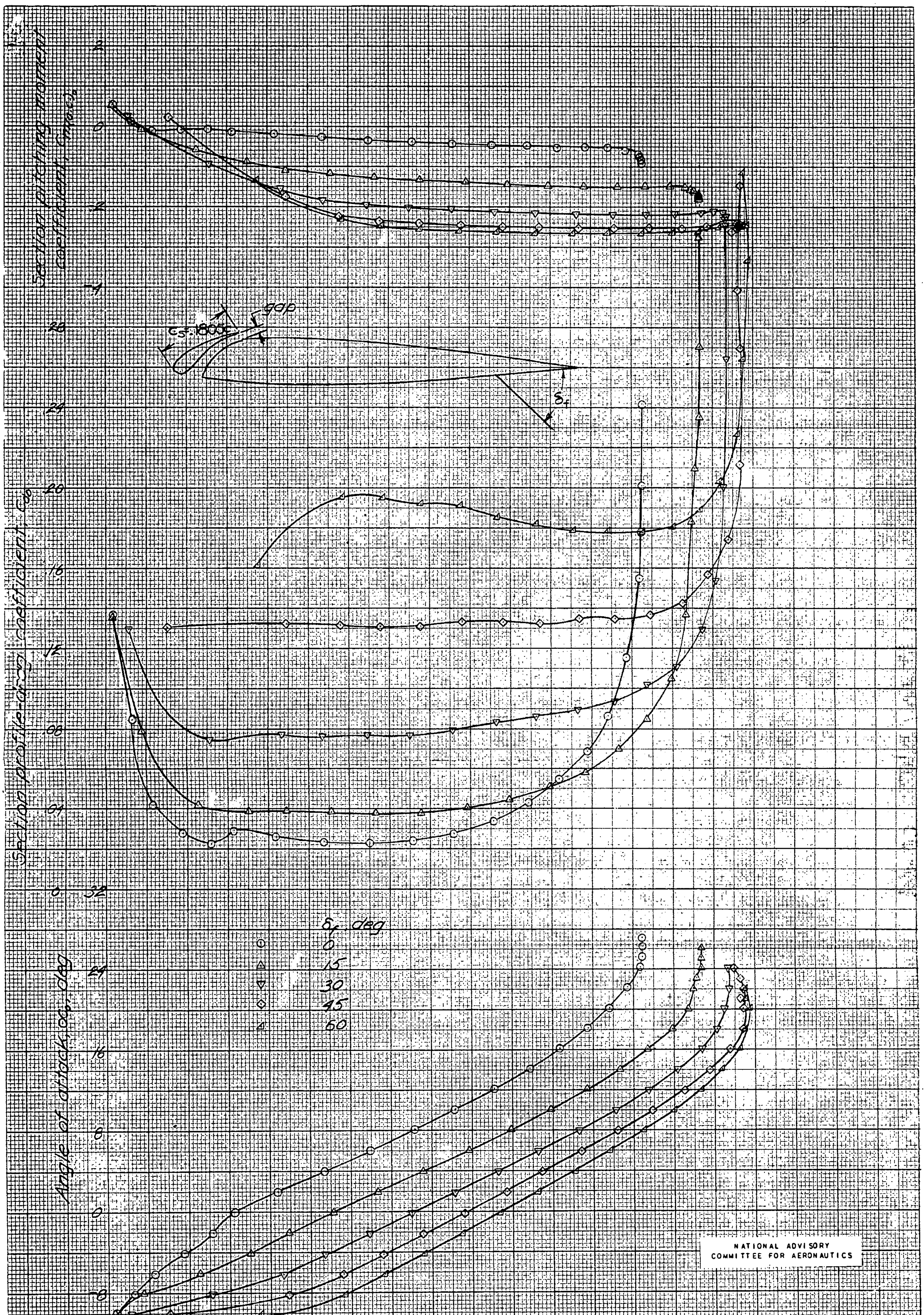

FIGURE 5.- Aerodynamic section characteristics of NACA 23012 airfoil with a 0.20c split flap and a 0.1805c Maxwell slot. Slot gap=0.0175c. R_n=0.0025c.

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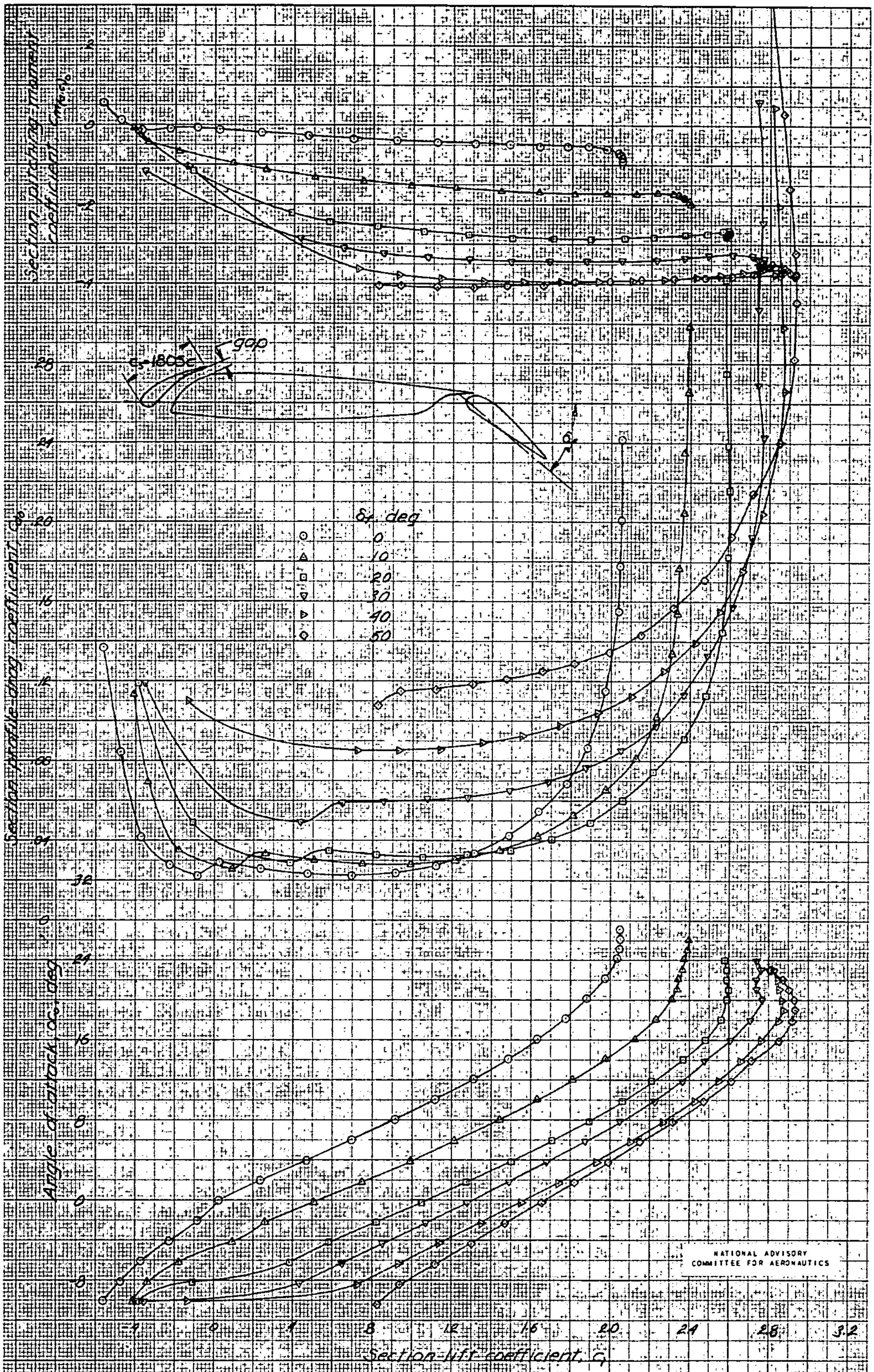

Figure 6.- Aerodynamic section characteristics of NACA 23012 airfoil with a 0.2566c slotted flap and a 0.1805c Maxwell slat. Slot gap = 0.0175c. R_s = 0.0025c.

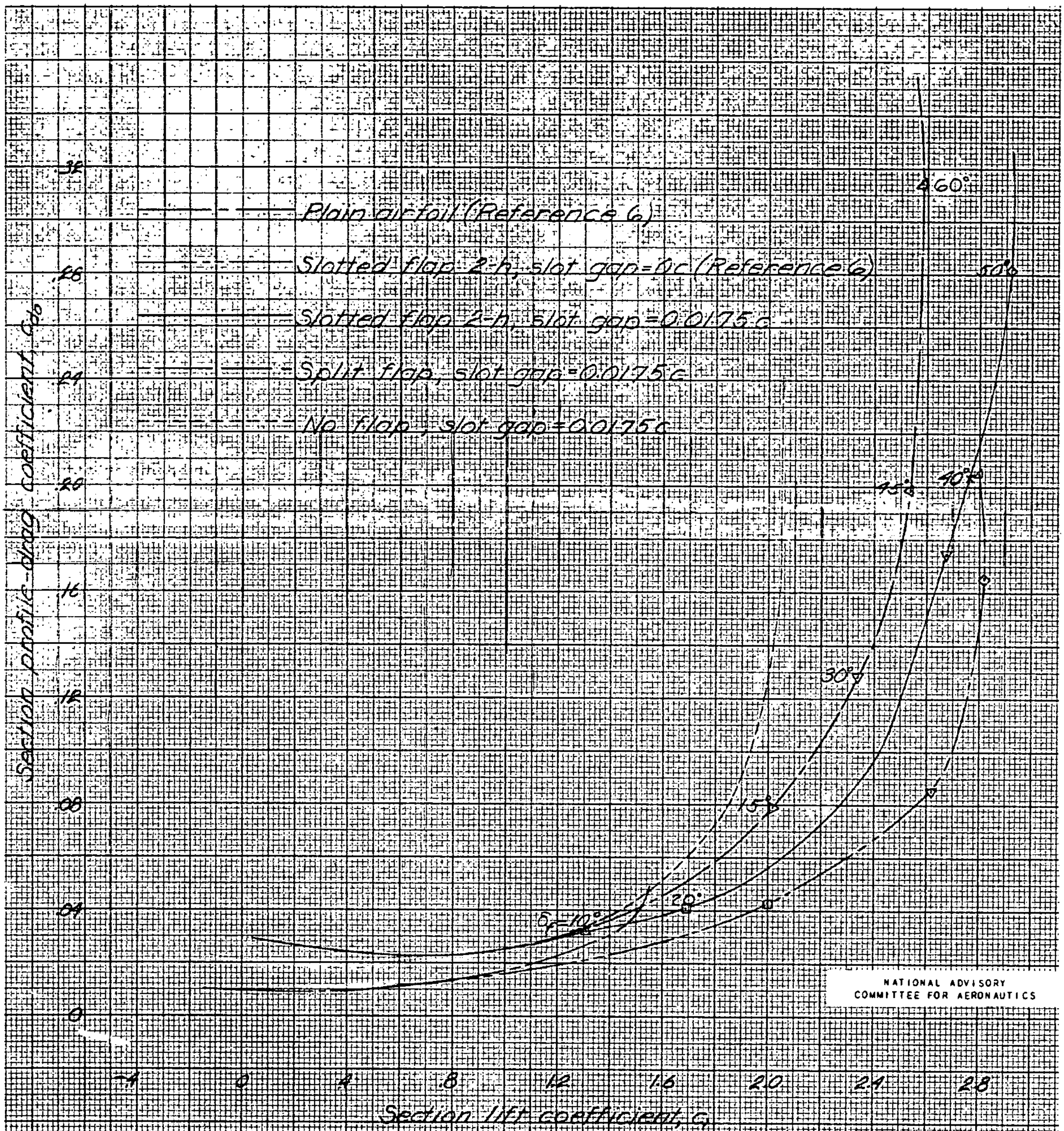

FIGURE 7.- Comparison of profile-drag coefficients of several airfoil-slat-flap combinations.

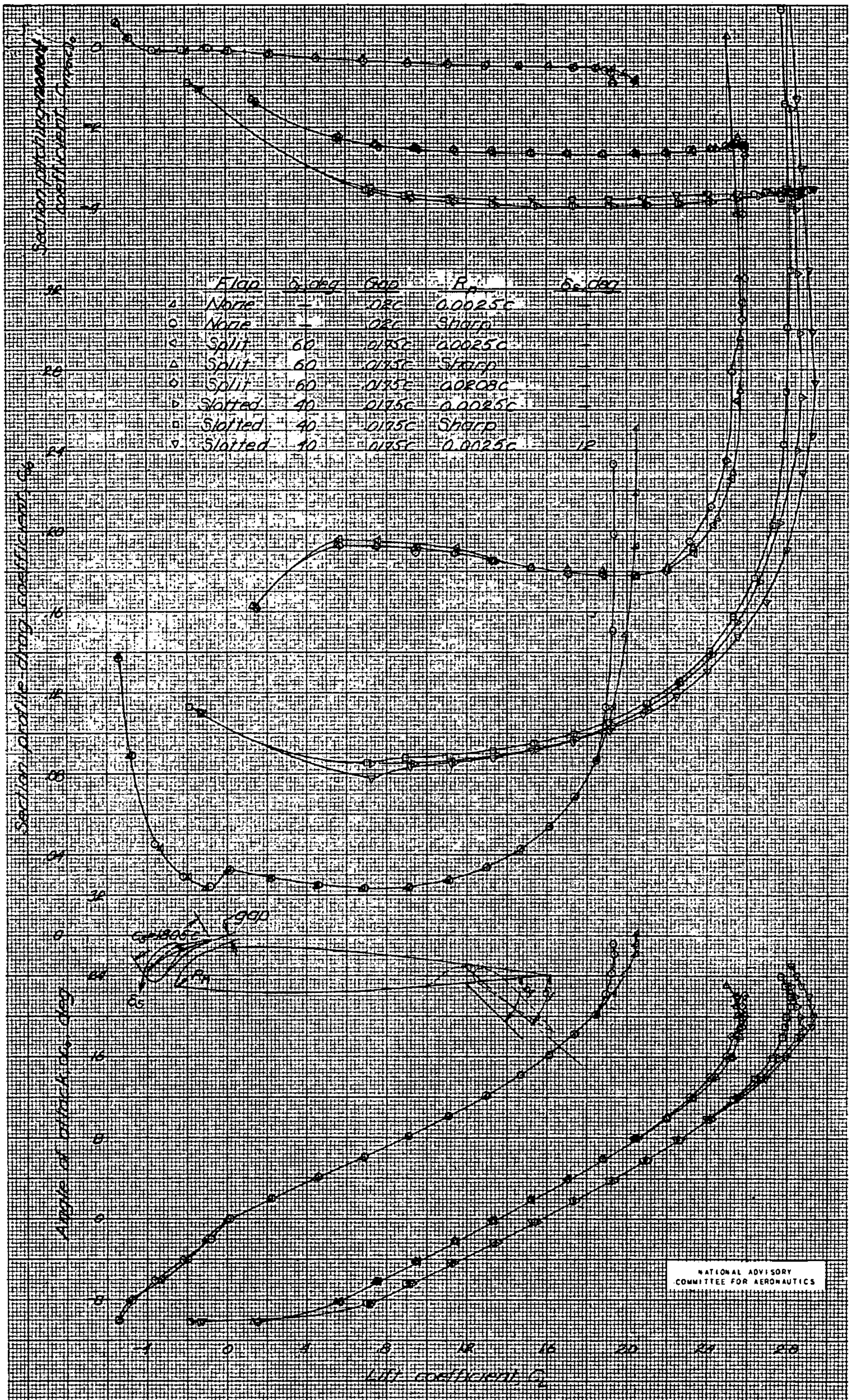

Figure 8.- Effect of several variations of slot shape on the aerodynamic section characteristics of the NACA 23012 airfoil with a 0.1805c Maxwell slot and two flaps.

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ABSTRACT

An investigation was made to determine the optimum slot gap of the Maxwell slat for, and the aerodynamic section characteristics, of the NACA 23012 airfoil with several deflections of a slotted and a split flap. It was found that, for the combinations tested, a slot gap of 0.0175 c was the optimum. This gap appreciably increased the maximum lift coefficient and angle of attack at the stall. The effectiveness of the slat, however, dropped with increasing flap deflection.

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