TECHNICAL NOTES

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

No. 808

WIND-TUNNEL INVESTIGATION OF AN NACA 23012 AIRFOIL WITH SEVERAL ARRANGEMENTS OF SLOTTED FLAPS WITH EXTENDED LIPS

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SUMMARY

An investigation was made in the NACA 7- by 10-foot wind tunnel to determine the effect of slot-lip location on the aerodynamic section characteristics of an NACA 23012 airfoil with a 30-percent-chord slotted flap. Tests were made with slot lips located at 90 and 100 percent of the airfoil chord and with two different flap shapes.

The results are compared with a slotted flap previously developed by the National Advisory Committee for Aeronautics with a slot lip located at 83 percent of the airfoil chord. The extension of the slot lip to the rear increased the section lift and pitching-moment coefficients.

Comparisons made on a basis of pitching moment for a given tail length show that the Fowler type flap, lip extended to trailing edge of the airfoil, has the greatest section lift coefficient. For moderate tail lengths, 2 to 3 chord lengths, there was only a slight difference between the previously developed slotted flap and the slotted flap with slot lip extended to 90 percent of the airfoil chord. Of the three flaps tested, the Fowler flap had the lowest drag coefficient at high lift coefficients. The extension of the lower surface at the leading edge of the slot had a negligible effect on the profile drag of the airfoil-flap arrangement with the flap deflected when the lip terminated at 90 percent of the airfoil chord.

INTRODUCTION

The National Advisory Committee for Aeronautics has undertaken an extensive investigation of high-lift devices to furnish information applicable to the design of more efficient and safer airplanes. Some of the desirable aerodynamic features of high-lift devices are: high lift with variable drag for landing, high lift with low drag for take-off and initial climb, no increase in drag with the device neutral, and small change in pitching moment with the device in operation. One of the most promising devices developed up to the present time is an airfoil in combination with a slotted flap. Aerodynamic and load data are available on 12-percent thick airfoil-flap combinations in references 1 to 6; references 1 and 2 give aerodynamic data for slotted flaps with a short lip extension developed by the NACA; and references 3 and 4 give aerodynamic data for Fowler flaps on which the slot lip extends to the trailing edge of the airfoil. Load data are given in reference 5 for one of the slotted flaps and in reference 6 for the Fowler flap.

The present tests broadened the investigation to include slotted flaps with slot-lip extensions between slotted flap 2-h (reference 1) with the slot lip extended to 83 percent of the airfoil chord and the Fowler type flap.

MODELS

The airfoil model used in these tests has a chord of 3 feet and a span of 7 feet; it conforms to the NACA 23012 airfoil profile (table I) and is made of mahogany and waterproofed wallboard. The basic model is provided with a removable trailing-edge section that allows easy changing of slot-lip length and slot shape. Three flap arrangements were used in the tests: Two of them have slot lips terminating at 0.90c (90 percent of the basic airfoil with flap retracted) and will be called slotted flaps 1-a and 1-b; the third one has the slot lip terminating at 1.00c and is a Fowler flap. (See fig. 1.)

The full-span flaps were built of laminated mahogany with a chord of 0.30c (10.8 in.) and were fastened to the airfoil with several thin-steel fittings. The Fowler flap (fig. 1) conforms to the Clark Y airfoil profile (table I). The two slotted flaps (fig. 1) have a Clark Y profile modified to conform to the NACA 23012 airfoil back of the slot lip with the flap in the fully retracted position and faired to the nose radius of the flap by progressive variation of the Clark Y upper surface ordinates (table I). All the flaps could be moved normal to the airfoil chord, the slotted flaps along a line 0.0025c ahead of the slot lip and the Fowler flap along a line at the 1.00c station. Flap deflections of 60° in 10° increments were possible with all arrangements. No arrangement was made for fully retracting the flaps.

The slot shapes for the two slotted flaps follow the same general profile (table I); for slotted flap 1-a, however, the lower surface of the airfoil extended 0.020c back of the slot entry for slotted flap 1-b, forming a seal when the flap was fully retracted. (See fig. 1.) The slot shape for the Fowler flap is made to clear the flap in the fully retracted position, as shown in figure 1.

TESTS

The models were so mounted in the closed test section of the NACA 7- by 10-foot wind tunnel that they completely spanned the jet except for small clearances at each end. (See references 1 and 7.) The main airfoil was rigidly attached to the balance frame by torque tubes extending through the upper and the lower boundaries of the test section. The angle of attack was changed from outside the tunnel by a calibrated electric drive connected to the torque tubes. Approximately two-dimensional flow is obtained with this test installation and the section characteristics of the model under test can be determined.

For all the tests a dynamic pressure of 16.37 pounds per square foot was maintained; this pressure corresponds to a velocity of about 80 miles per hour under standard conditions and to an average test Reynolds number of about 2,190,000. Because of turbulence in the air stream the effective Reynolds number, based on the chord of the airfoil with flap retracted and a turbulence factor for the tunnel of 1.6, was approximately 3,500,000. (See reference 8.)

Tests were made with the Fowler flap and slotted flap 1-a to determine the optimum gap for conditions of low drag coefficient throughout the lift range and for maximum lift coefficient. Tests were made on slotted flap 1-b with the flap located at the optimum position for slotted flap 1-a. Lift, drag, and pitching moment were measured for the slotted flaps throughout the lift range from approximately zero lift to the stall and for flap deflection from 0° to the deflection for maximum lift at 10° increments. On the Fowler flap similar data were obtained throughout the angle-of-attack range from -6° to the stall and for flap deflections at 10° increments. No tests were made above the stall because of unsteady conditions of the model.

RESULTS AND DISCUSSION

Coefficients

All test results are given in standard nondimensional section coefficient form corrected as explained in reference 1.

c_l section lift coefficient (l/qc)

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

$c_{m_{(a.c.)_o}}$ section pitching-moment coefficient about aerodynamic center of plain airfoil $(m_{(a.c.)_o}/qc^2)$

where

l section lift

d_o section profile drag

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

q dynamic pressure $(1/2\ \rho V^2)$

c chord of basic airfoil with flap retracted

and

α_o angle of attack corrected to infinite aspect ratio

δ_f flap deflection, measured between airfoil chord line and flap chord line

Precision

The accuracy of the various measurements in the tests is believed to be within the following limits:

α_o	$\pm 0.1^\circ$	$c_{d_{o(c_l = 1.0)}}$ . . .	± 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 . . .	$\pm 0.001c$

No attempt was made to determine the effect of hinge fittings because the effect is believed to be small. The relative merits of the several flap arrangements should not be appreciably affected by hinge-fitting drag because similar hinge fittings were used for all.

Plain Airfoil

The complete aerodynamic section characteristics of the plain NACA 23012 airfoil are given in figure 2. These data have been discussed in reference 1 and therefore require no further discussion here.

Fowler Flap

The aerodynamic section characteristics of the NACA 23012 airfoil with a 0.30c Fowler flap at the optimum gap are given in figure 3. The maximum lift coefficient, $c_{l_{max}} = 3.30$, is much higher than that reported in reference 1, where the flap was also of NACA 23012 profile. The pitching moment of this flap arrangement is very high and might limit the use of this flap in some designs.

The effect of slot gap on the aerodynamic section characteristics of the NACA 23012 airfoil with a 0.30c Fowler flap is given in figure 4. The effect of either increasing or decreasing the gap from 0.015c was to decrease the maximum lift and increase the profile drag. These results show the optimum gap to be smaller than for the arrangement reported in reference 1.

No tests were made to determine the adverse effect of a break in the lower surface with flap retracted because a simple member could be made to cover this gap and seal the slot.

Slotted Flaps

The aerodynamic section characteristics of the NACA 23012 airfoil with the two arrangements of slotted flaps with extended lips are given in figures 5 to 10. Figures 5 to 8 give the characteristics for the airfoil-flap arrangements tested and figures 9 and 10 are comparisons of the different arrangements.

The effect of the slot gap on the maximum section lift coefficient of these arrangements is given in figure 9. The maximum values of $\Delta c_{l_{max}}$ for slotted flap 1-a with the 0.01c gap were about the same as for flap 1-a with the 0.02c gap; with the 0.01c gap a flap deflection of 50° was required, whereas a deflection of only 40° was required with the 0.02c gap. Flap 1-a with the 0.30c gap gave maximum lift at a flap deflection of 30° but with a loss of 0.17 in $c_{l_{max}}$ from the values for the smaller gaps. Slotted flap 1-b with a gap of 0.02c gave a slightly lower value of maximum section lift coefficient than slotted flap 1-a with the same gap.

A comparison of profile-drag characteristics for the various arrangements of slotted flaps with extended lips is given in figure 10. Figure 10(a) shows that, throughout the lift range of slotted flap 1-b, there is no appreciable difference in the profile drag for the two flaps but that the profile drag of slotted flap 1-a increases rapidly above the maximum lift of flap 1-b. Figure 10(b) shows that slotted flap 1-a with a gap of 0.02c appears to be most desirable if the criterion of low drag and high lift is used. Slotted flap 1-a with the 0.03c gap had approximately the same profile drag as with the 0.02c gap for values of the lift coefficient less than 2.3. Slotted flap 1-a with the 0.01c gap gave lower profile drags for values of the lift coefficient above 2.8 but had much higher profile drag than the arrangements with larger gaps over the lift range from $c_l = 1.4$ to $c_l = 2.8$.

No tests were made to determine the effect of the break in the lower surface of the airfoil with flap retracted because the effect is thought to be small for slotted flap 1-a, as the lower surface would be sealed under such conditions. Inasmuch as the change in slot shape had no adverse effect on the airfoil-flap characteristics, such tests would have little value.

From the results of these tests it would appear that the Fowler type flap could have a similar seal with no adverse effects on the aerodynamic section characteristics.

Comparison of Three Slotted Flaps

A comparison of increments of section maximum lift coefficients is given in figure 11 for the two flaps tested and for a 0.2566c slotted flap 2-h. (See reference 1.) For the arrangements tested, the maximum lift coefficient increases as the slot lip is moved toward the rear, reaching a maximum value of 3.30 for the Fowler flap.

In order to get a more comprehensive comparison of the three flaps, the value of pitching moment should be accounted for because the pitching moment also increases as the slot lip is moved toward the trailing edge. Tail loads necessary to compensate for the adverse pitching moment were therefore computed, and the effective section maximum lift coefficients as a function of tail length l are shown in figure 12. The tail length in this paper is the distance from the aerodynamic center of the airfoil to the center of pressure of the tail, expressed in airfoil chords. These values are based on a theoretical center of gravity at the aerodynamic center of the wing with the flap fully retracted. If the center of gravity is ahead of the aerodynamic center of the airfoil, the tail load will increase as some function of the increase in tail length and the lift of the wing; but, if the center of gravity is back of the aerodynamic center of airfoil, the tail load will decrease by a similar function. With this method of comparison the Fowler flap also gives greater maximum effective section lift coefficients than the other two flaps, but the slotted flap with extended slot lip is not appreciably better than slotted flap 2-h (reference 1) for a tail length of 2 airfoil chords. For tail lengths of 2.5 chords or more the slotted flap with extended slot lip gives a greater maximum effective section lift coefficient than slotted flap 2-h. It might be possible with a flap of different camber and a gap of

0.015c to obtain higher maximum effective section lift coefficients with the extended-lip slotted flap.

A comparison of profile-drag characteristics for the three flaps is given in figure 13. The plain airfoil has the lowest profile-drag coefficients for lift coefficients less than 0.90. The slotted flap 2-h (reference 1) has the lowest profile-drag coefficients for values from c_l = 0.9 to $c_l = 1.9$. Above a value of $c_l = 1.9$, the Fowler flap has the lowest profile-drag coefficients. In cases where high lift with high drag is needed to make safe landings, the slotted flap with extended lip would be the most satisfactory. Here again by changing the camber and the gap, it might be possible to obtain values of profile-drag coefficient lower than those shown for the slotted flap with extended lip.

CONCLUSIONS

For the arrangements tested, the extension of the slot lip to the rear increased the section coefficients of lift and pitching moment of an NACA 23012 airfoil with slotted flap. The Fowler arrangement gave the largest effective maximum lift coefficient and the lowest drag coefficient at high lift. For tail lengths greater than 2 chord lengths the slotted flap with extended lip gave slightly higher maximum lift coefficients than the slotted flap with a shorter lip extension previously developed by the NACA. The extension of the lower surface at the leading edge of the slot had no appreciable effect on the profile drag of the airfoil-flap arrangement with flap deflected and slightly increased the maximum lift coefficient. Such an arrangement could probably be added to the Fowler flap with little or no effect on the profile-drag characteristics.

Langley Memorial Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., April 12, 1941.

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TABLE I.- ORDINATES FOR AIRFOIL, FLAP, AND SLOT SHAPES

[Stations and ordinates in percent of airfoil chord]

NACA 23012 airfoil			Fowler flap, Clark Y			Slotted flap, modified Clark Y			Slot shape slotted flap	
Station	Upper surface	Lower surface	Station	Upper surface	Lower surface	Station	Upper surface	Lower surface	Station	Ordinate
0	-	0	0	1.05	1.05	0	1.05	1.05	69.96	-3.10
1.25	2.67	-1.23	.375	1.64	.58	.375	1.64	.58	69.96	-1.88
2.5	3.61	-1.71	.75	1.95	.44	.75	1.96	.44	70.83	-.90
5	4.91	-2.26	1.50	2.37	.28	1.50	2.39	.28	72.92	.23
7.5	5.80	-2.61	2.25	2.65	.19	2.25	2.69	.19	77.08	1.25
10	6.43	-2.92	3.00	2.88	.13	3.00	2.92	.13	80.00	1.58
15	7.19	-3.50	4.50	3.21	.05	4.50	3.27	.05	81.25	1.67
20	7.50	-3.97	6.00	3.41	.01	6.00	3.48	.01	83.33	1.79
25	7.60	-4.28	9.00	3.51	0	9.00	3.63	0	85.42	1.88
30	7.55	-4.46	12.00	3.42	0	12.00	3.60	0	86.88	1.90
40	7.14	-4.48	15.00	3.16	0	15.00	3.40	0	90.00	1.59
50	6.41	-4.17	18.00	2.75	0	18.00	3.05	0		
60	5.47	-3.67	21.00	2.20	0	20.00	2.76	0		
70	4.36	-3.00	24.00	1.57	0	21.00	2.57	0		
80	3.08	-2.16	27.00	.84	0	24.00	1.86	0		
90	1.68	-1.23	28.50	.45	0	27.00	1.08	0		
95	.92	-.70	30.00	.04	0	28.50	.70	0		
100	.13	-.13				30.00	.25	0		
L.E. radius: 1.58. Slope of radius through end of chord: 0.305			L.E. radius: 0.45			L.E. radius: 0.45				

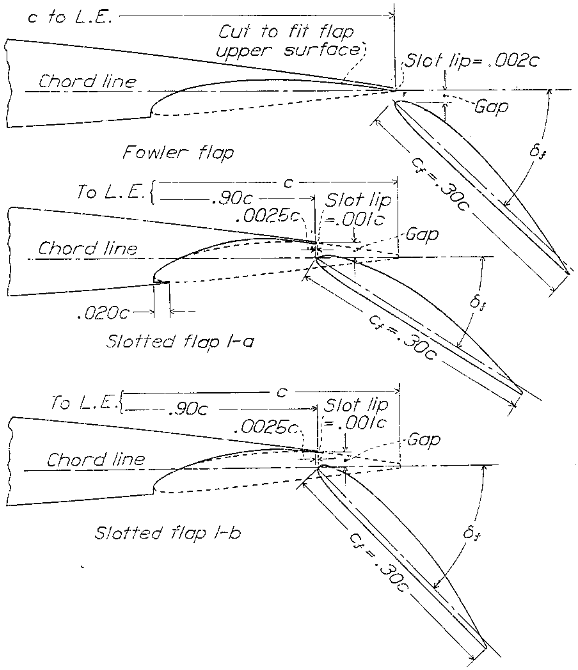
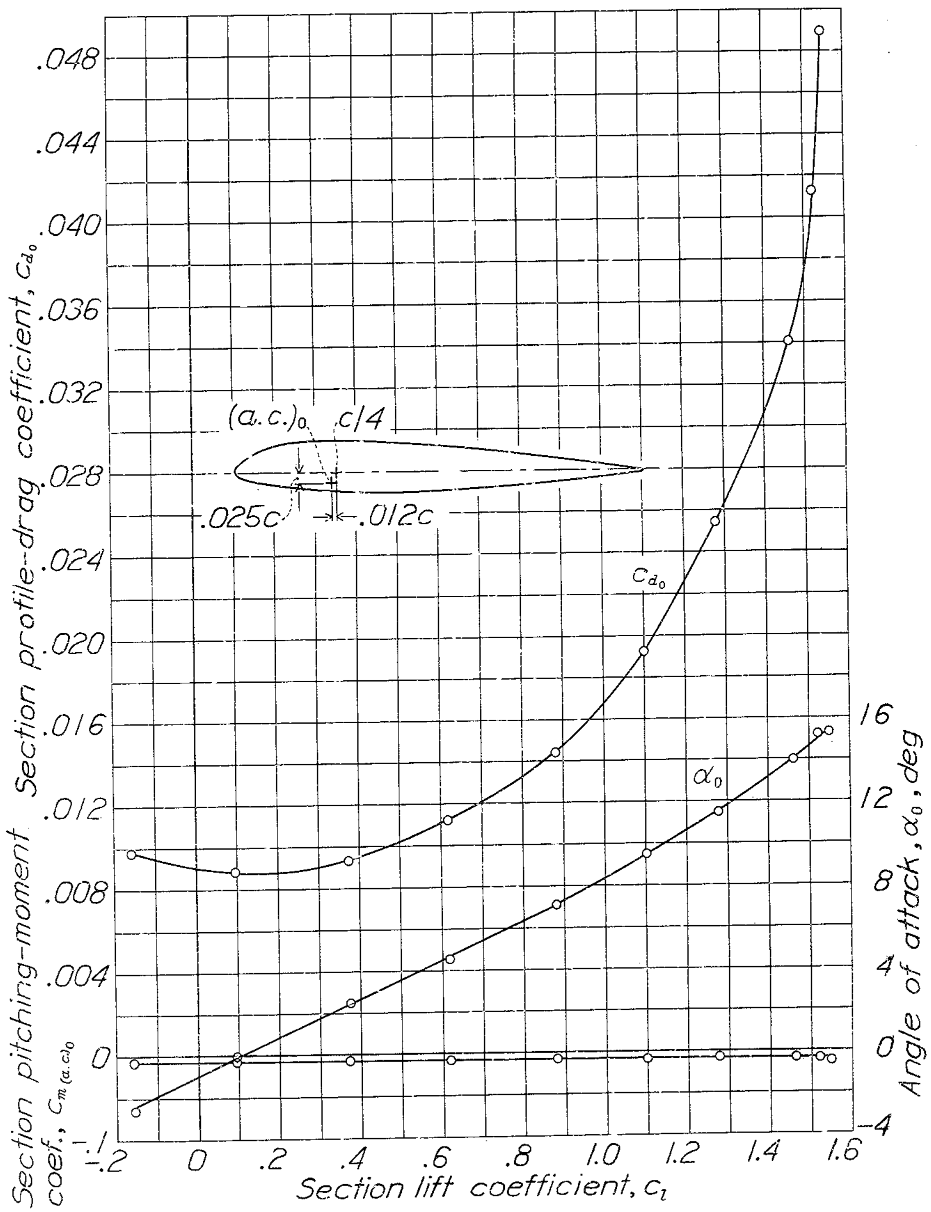


Figure 1.- Sections of NACA 23012 airfoil with arrangements of 0.30c slotted flaps.

Figure 2.- Aerodynamic section characteristics of NACA 23012 plain airfoil.



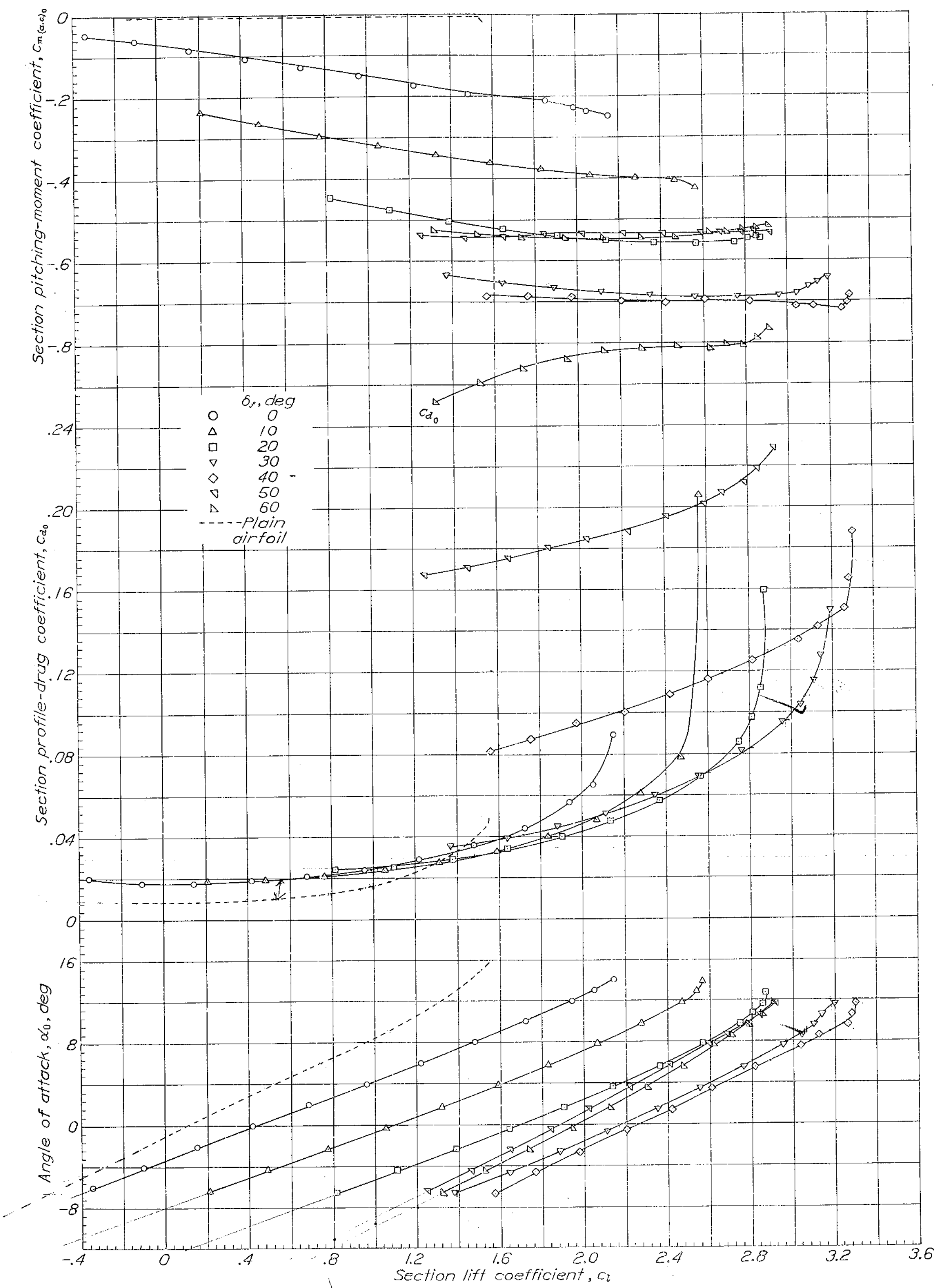


Figure 3.- Aerodynamic section characteristics of an NACA 23012 airfoil with a 0.30c Fowler flap. Slot gap = 0.015c.

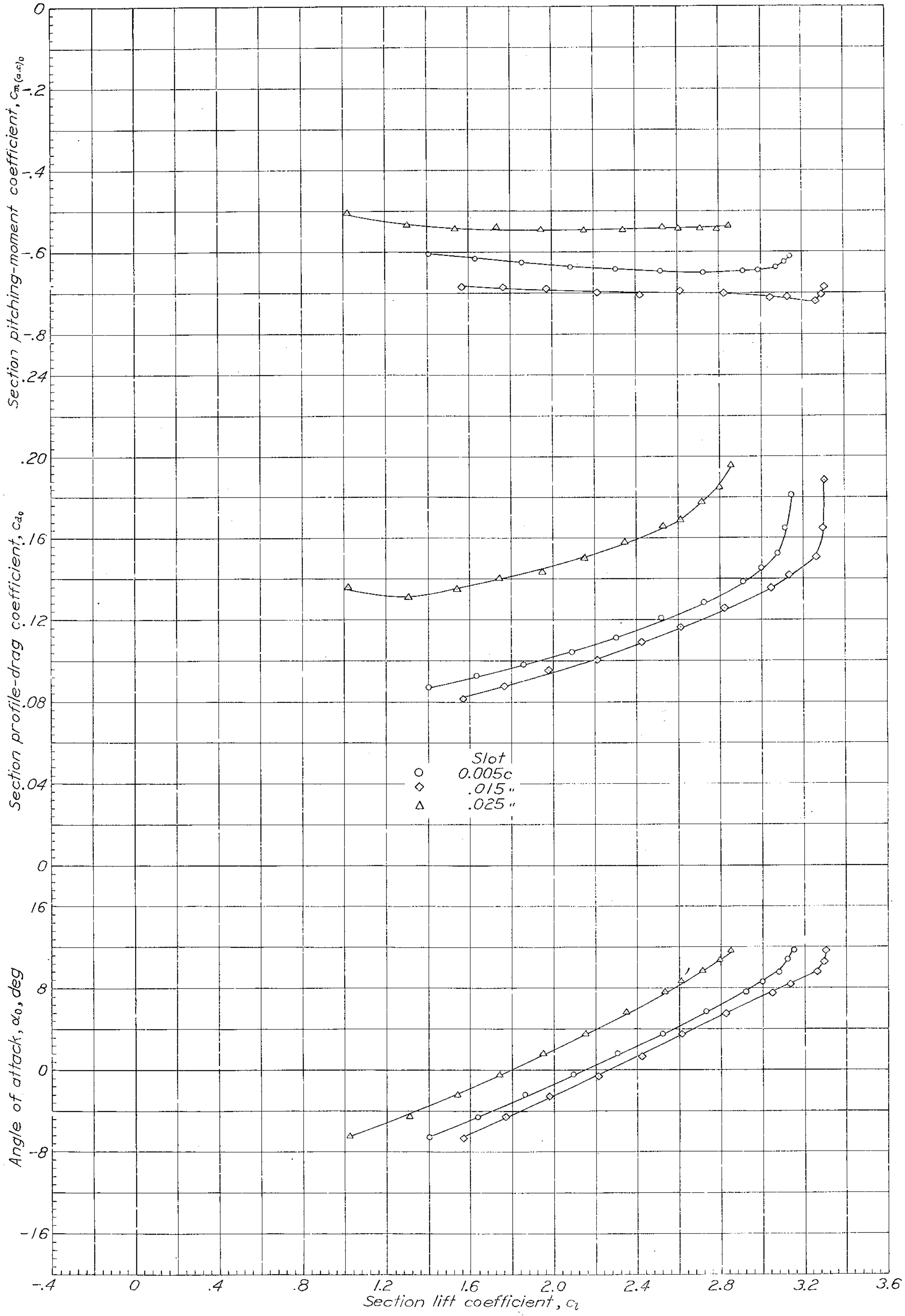


Figure 4.- Comparison of aerodynamic section characteristics of an NACA 23012 airfoil with a 0.30c Fowler flap at three slot gaps. δ_f=40°.

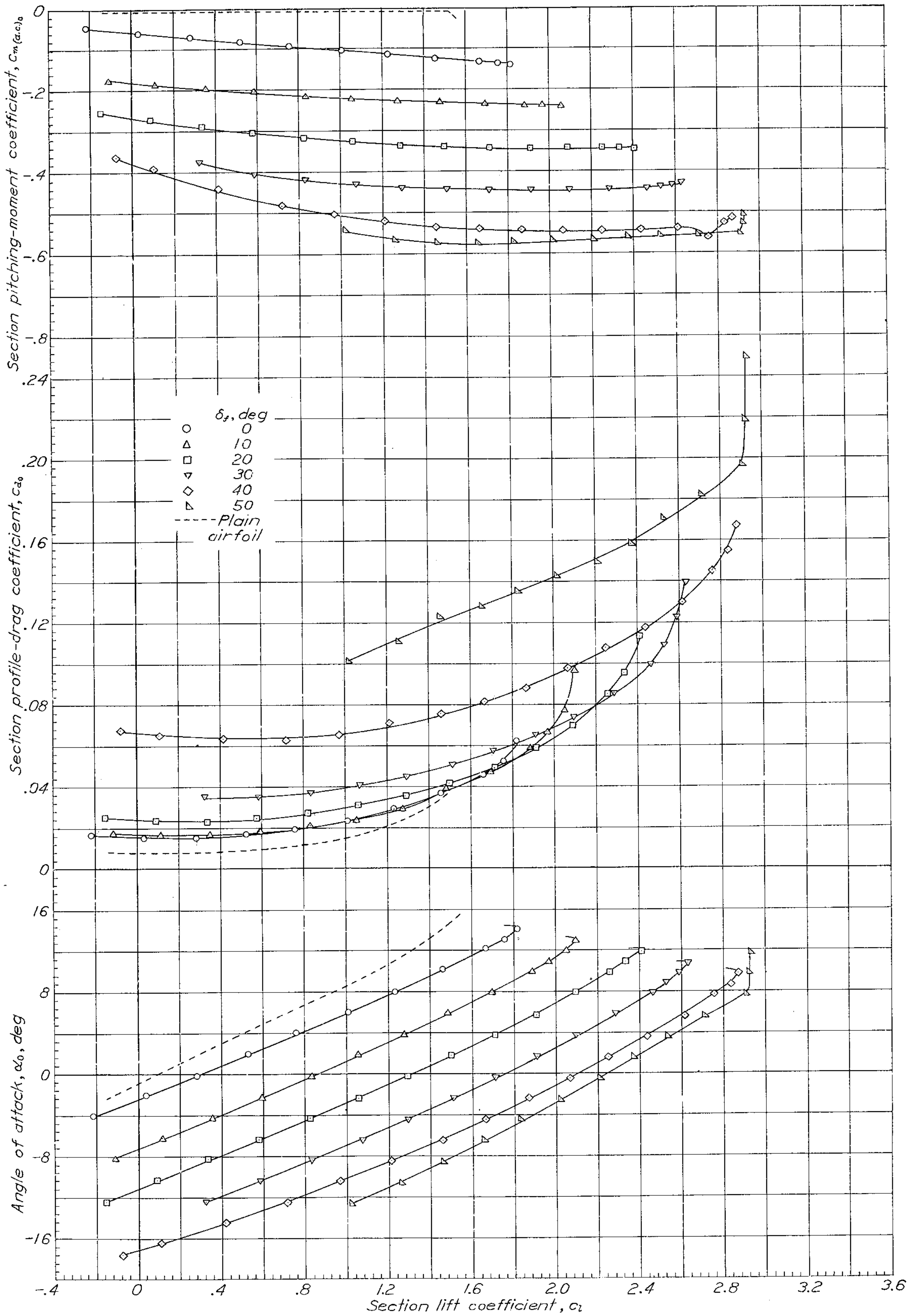


Figure 5.- Aerodynamic section characteristics of an NACA 23012 airfoil with a 0.030c slotted flap 1-a. Slot gap = 0.01c.

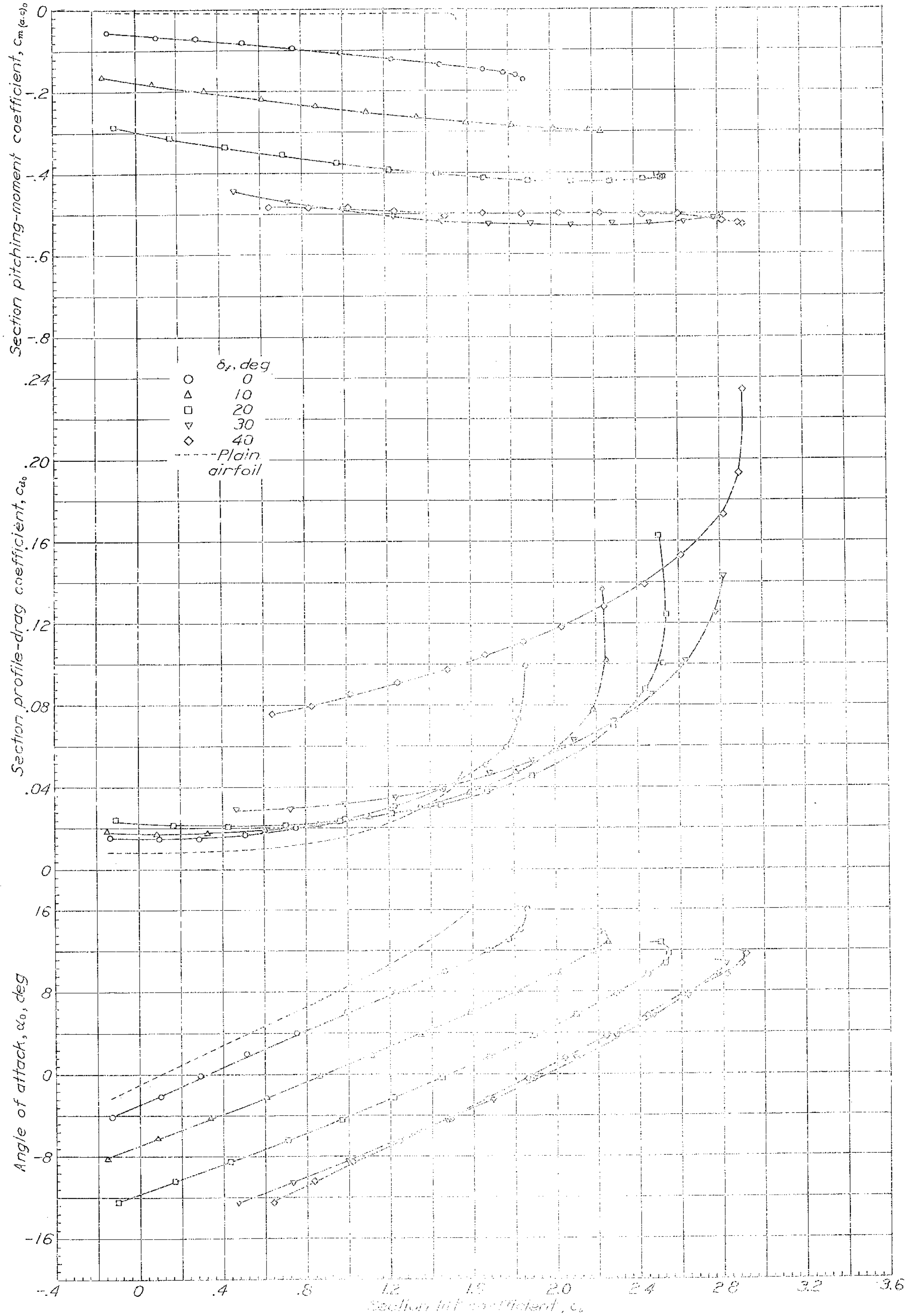


Figure 6.- Aerodynamic section [illegible] with a [illegible] slotted flap [illegible]. Slot gap = 0.03c.

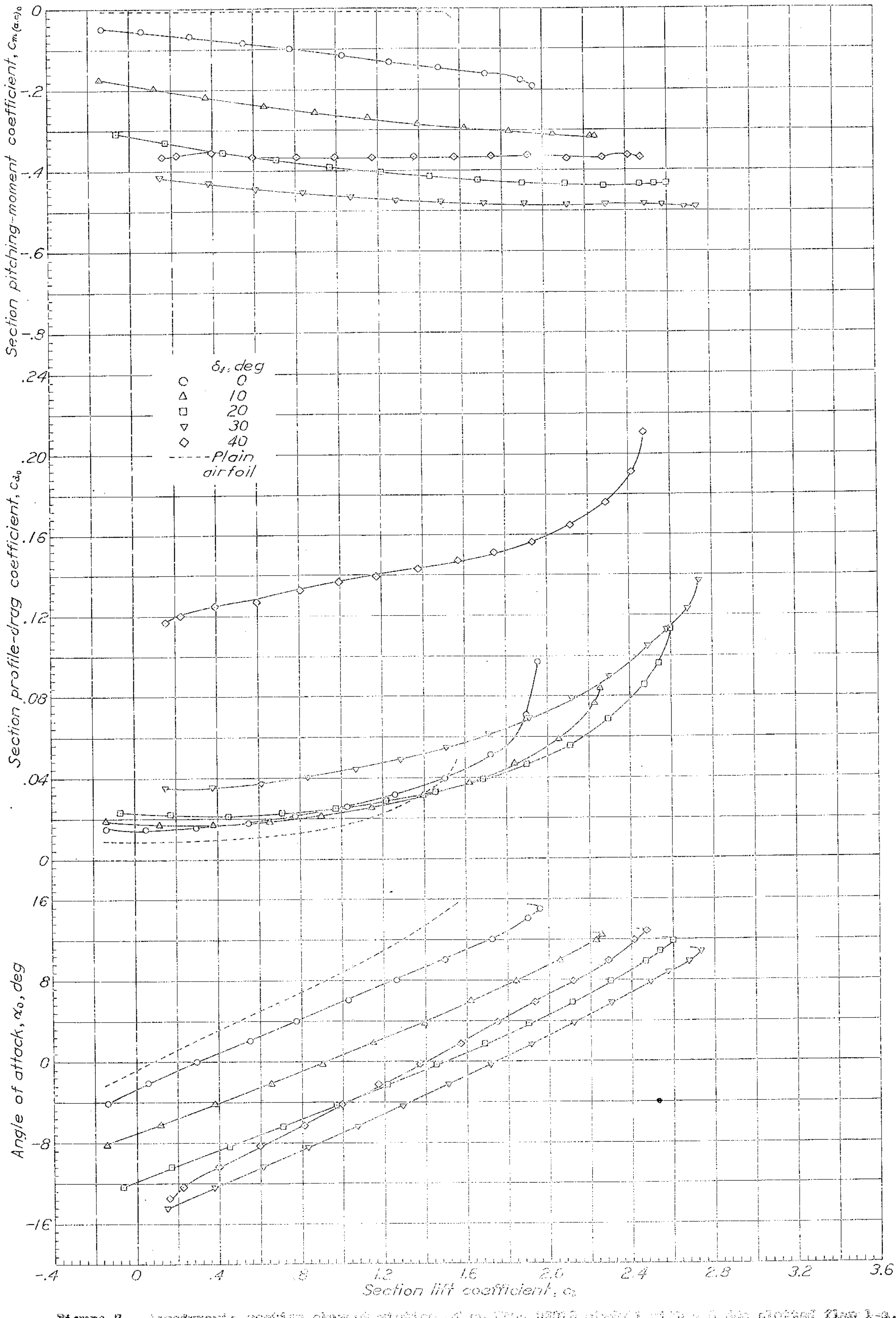


Figure 7.- Aerodynamic section characteristics of an NACA 23021 airfoil with a 0.40c slotted flap 1-a. Slot gap = 0.03c.

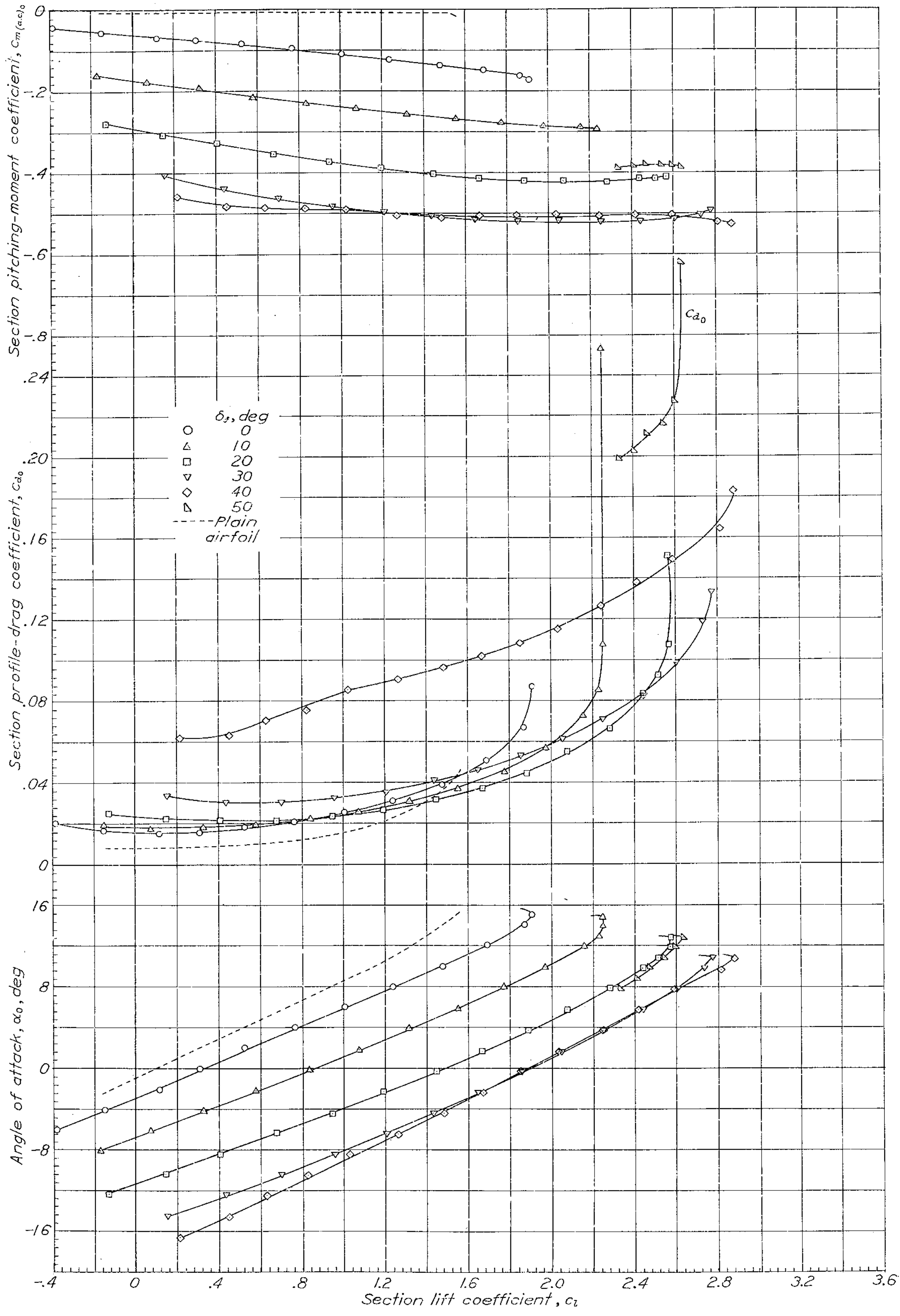


Figure 8.- Aerodynamic section characteristics of an NACA 23012 airfoil with a 0.30c slotted flap 1-b. Slot gap = 0.02c.

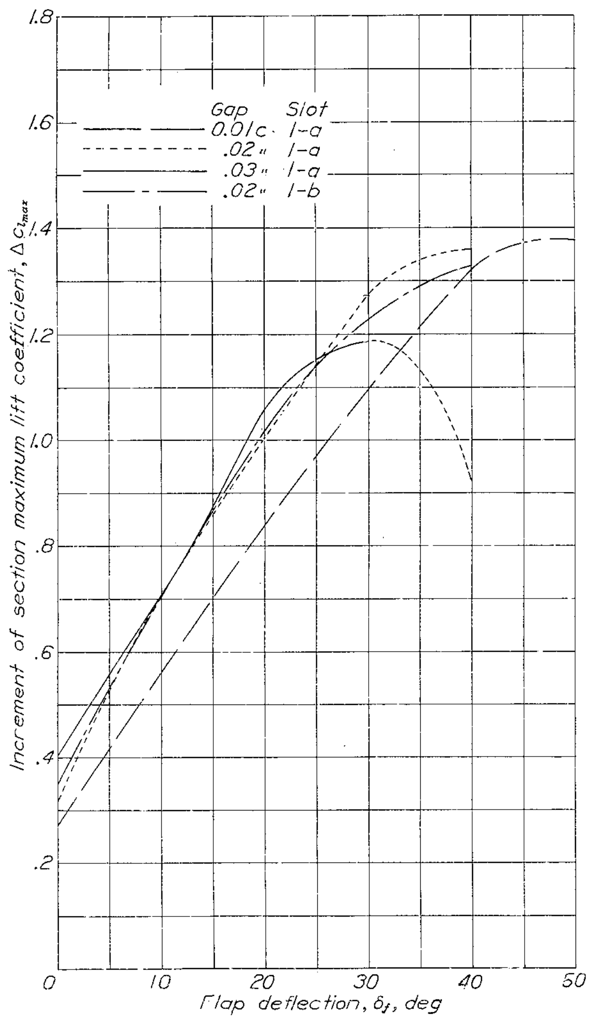


Figure 9.- Comparison of increments of section maximum lift coefficient for slotted flaps with extended slot lip at three hinge locations.

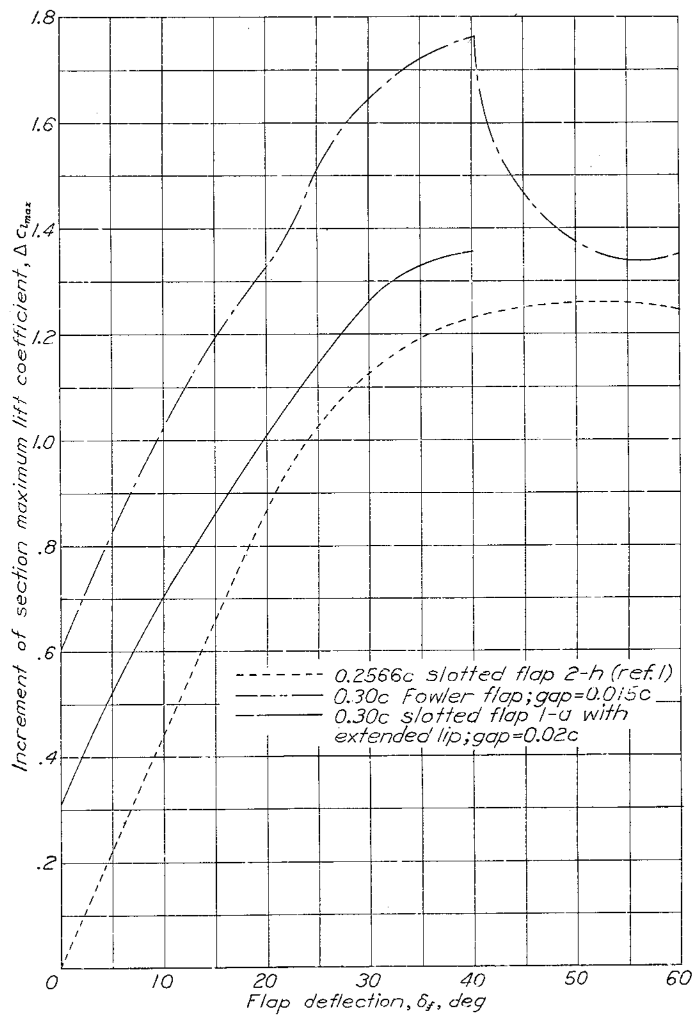
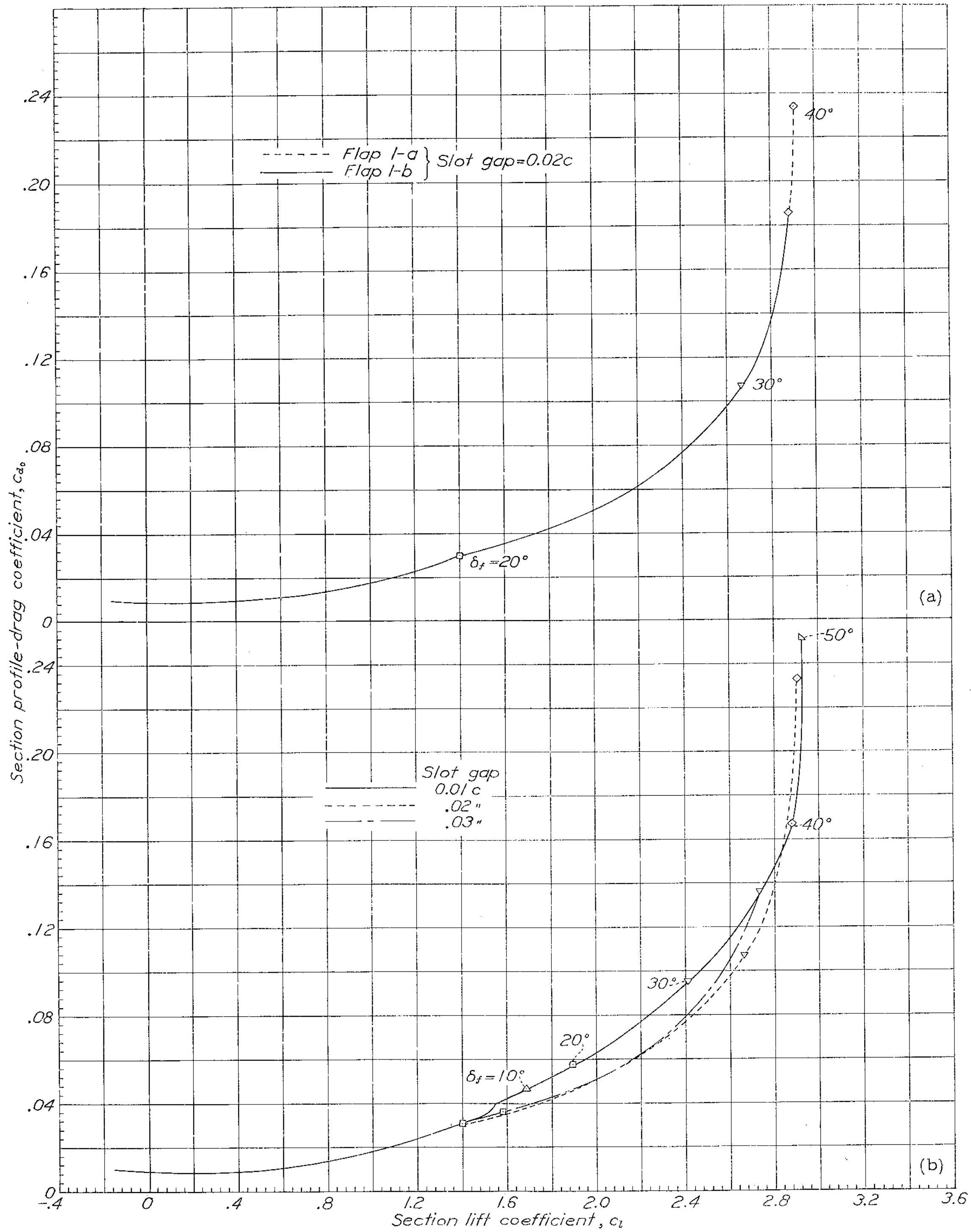


Figure 11.- Comparison of increments of section maximum lift coefficient for three flaps on an NACA 23012 airfoil.



(a) Effect of slot shape. (b) Effect of slot gap on flap 1-a.

Figure 10.- Comparison of 0.30c slotted flaps on an NACA 23012 airfoil with extended slot lip.

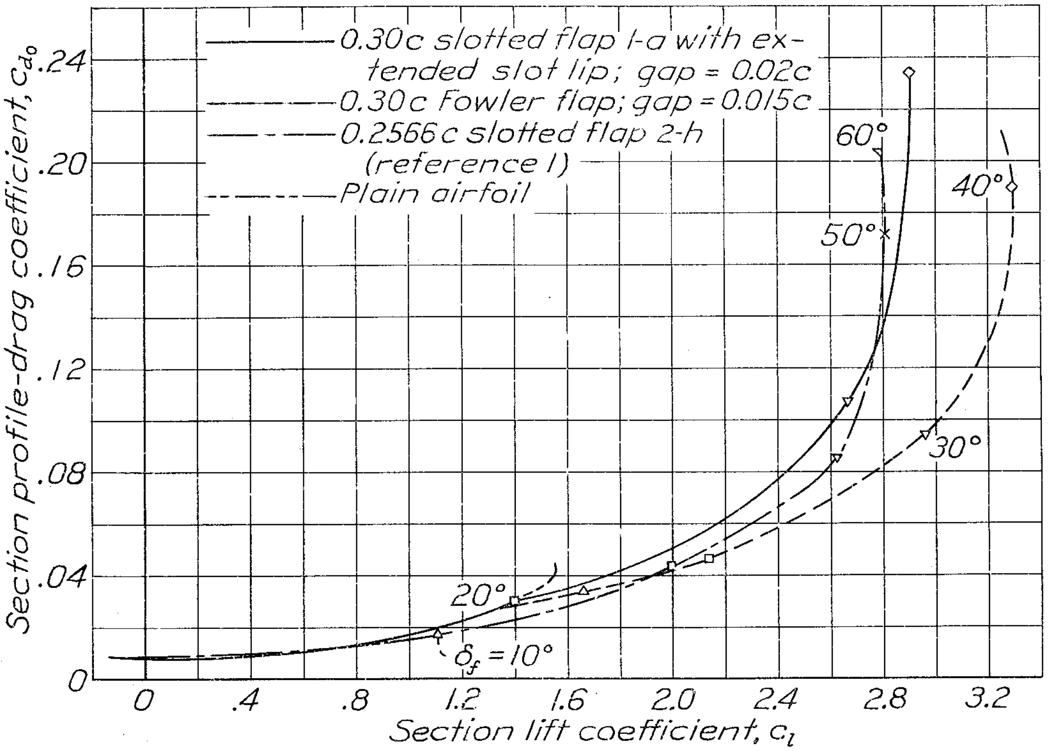


Figure 13.- Comparison of three slotted flaps on an NACA 23012 airfoil.

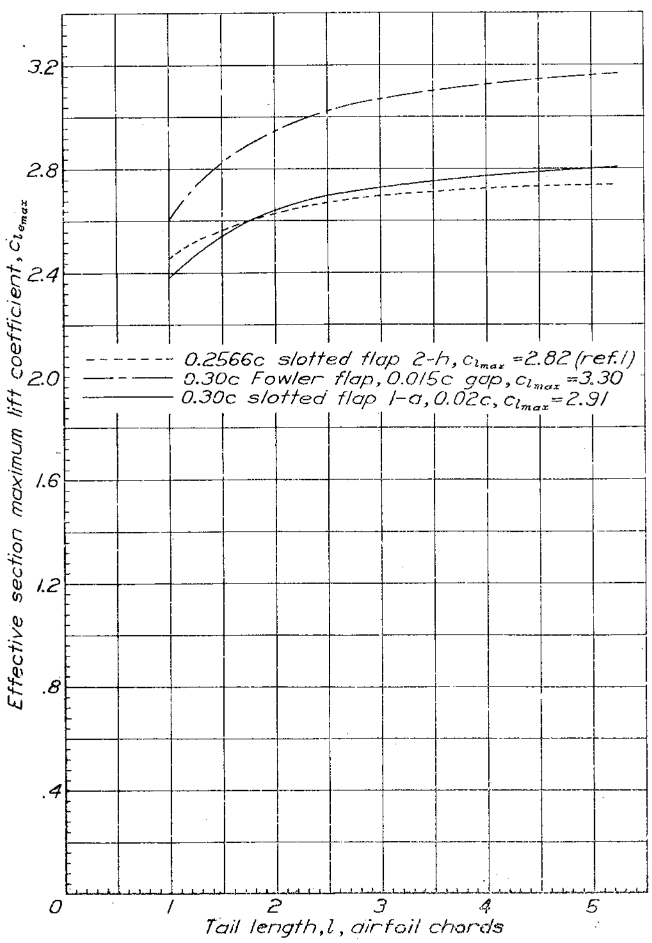


Figure 12.- Effective section maximum lift coefficient for NACA 23012 airfoil with three slotted flaps.

$$c_{l_{e_{max}}} = c_{l_{max}} + \frac{1}{l}\left(c_{m_{0(a.c.)}}\right)_{c_{l_{max}}}$$

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