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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

No. 728

WIND-TUNNEL INVESTIGATION OF AN N.A.C.A. 23021 AIRFOIL WITH TWO ARRANGEMENTS OF A 40-PERCENT-CHORD SLOTTED FLAP

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SUMMARY

An investigation was made in the N.A.C.A. 7- by 10-foot wind tunnel of an N.A.C.A. 23021 airfoil with two arrangements of a 40-percent-chord slotted flap. The effect of slot shape, flap position, and flap deflection on the section aerodynamic characteristics was determined. The envelope polars and the section aerodynamic characteristics are given and are compared with those of an N.A.C.A. 23021 airfoil with a 25.66-percent-chord slotted flap and of an N.A.C.A. 23012 airfoil with a 40-percent-chord slotted flap. Plotted contours of flap-nose positions for maximum lift and minimum drag were used for selecting optimum flap paths.

Both the maximum lift coefficients and the minimum drag coefficients were higher for the N.A.C.A. 23021 airfoil with the 40-percent-chord flap than for the N.A.C.A. 23021 airfoil with the 25.66-percent-chord flap, but the percentage increase in drag was greater than the percentage increase in lift. A comparison of the aerodynamic characteristics of the N.A.C.A. 23021 airfoil with a 40-percent-chord flap and of the N.A.C.A. 23012 airfoil with a 40-percent-chord flap showed that the thick section reached approximately the same maximum lift as the thin section but, as anticipated, had a considerably higher drag coefficient.

INTRODUCTION

The National Advisory Committee for Aeronautics is conducting an extensive investigation to determine the relative merits of various types of lift-increasing devices. For use in take-off, a high-lift device capable of producing high lift with low drag is desirable. For use in landings, however, high lift with variable drag is believed

desirable. The slotted flaps being investigated by the N.A.C.A. are apparently capable of fulfilling these conflicting requirements.

The purpose of the present tests was to determine the aerodynamic characteristics of the N.A.C.A. 23021 airfoil with a 40-percent-chord slotted flap. The section aerodynamic characteristics of the present airfoil-flap combination are compared with those of an N.A.C.A. 23021 airfoil with a 25.66-percent-chord slotted flap and of an N.A.C.A. 23012 airfoil with a 40-percent-chord slotted flap.

MODELS

Plain Airfoil

An N.A.C.A. 23021 airfoil with a 3-foot chord and a 7-foot span was the basic model used in these tests. The ordinates for the N.A.C.A. 23021 airfoil section are given in table I. The nose and the trailing edge of the model were built of solid laminated mahogany and the portion of the airfoil between the nose and the trailing edge was covered with hard composition board. The trailing-edge part of this model is easily removable so that the model can be altered for tests of the different flap arrangements.

Slotted-Flap Arrangements

The flap and the pieces that form the slot shapes were built of solid laminated mahogany. The forward walls of the slot shapes were bolted to the main airfoil in place of the solid trailing edge. The flap was attached to the airfoil by special fittings that permitted the required variations in flap deflection and flap position relative to the slot lip.

Flap.- Flap 1 (fig. 1 and table I) is similar to flap 1 of reference 1. A moderate flap-nose radius was used in order to restrict the size of the break in the lower surface of the airfoil with the flap retracted.

Slot shapes.- Slot shapes a and b (fig. 1) were tested with flap 1. Slot shape b is similar to slot

shape h of reference 1, which gave the lowest drag at high and intermediate lift coefficients. Slot shape a was designed to reduce the break in the lower surface of the airfoil and thereby to minimize its effect on the drag of the airfoil with the flap retracted.

The models were made to a tolerance of ±0.015 inch.

TESTS

The models were mounted vertically in the closed test section of the N.A.C.A. 7- by 10-foot wind tunnel (references 2 and 3) so that they completely spanned the jet except for small clearances at each end. The main airfoil was rigidly attached to the balance frame by torque tubes, which extended through the upper and the lower boundaries of the tunnel. The angle of attack of the model was set from outside the tunnel by rotating the torque tubes with a calibrated drive. Approximately two-dimensional flow is obtained with this type of installation and the section characteristics of the model under test can be determined.

All tests were made at a dynamic pressure of 16.37 pounds per square foot, corresponding to a velocity of approximately 80 miles per hour under standard atmospheric conditions and to an average test Reynolds Number of approximately 2,190,000. Because of the turbulence in the tunnel, the effective Reynolds Number, R_e, (reference 4) was about 3,500,000. For all tests, R_e, is based on the chord of the airfoil with the flap retracted and on a turbulence factor of 1.6 for the tunnel.

Plain airfoil.- The lift, the drag, and the pitching moment of the basic airfoil were obtained throughout the angle-of-attack range from -6° to the stall. Tests were first made with the slot-opening breaks completely faired. The effect of the break in the upper surface of the airfoil and also the combined effects of the breaks in the upper and the lower surfaces were determined by testing the airfoil with these breaks successively uncovered. Tests were also made to determine the effect of the flap hinges with the flap neutral.

Slotted flaps.- Slotted-flap arrangements 1-a and 1-b were tested to determine the optimum positions for maximum

lift at flap deflections from 10° to 50° in 10° increments. The positions for low drag at selected lift coefficients were investigated for only the 10° and the 20° flap deflections. Data were obtained throughout the angles-of-attack range from -6° to the stall.

No scale-effect tests were made because the results of earlier tests of the N.A.C.A. 23021 airfoil with a 25.66-percent-chord slotted flap are considered applicable to the results of the present investigation (reference 1).

RESULTS AND DISCUSSION

Coefficients

All test results are given in standard section nondimensional coefficient form corrected as explained in reference 3.

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 is 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 fully retracted.

and α_o, is angle of attack for infinite aspect ratio.

δ_f, flap deflection.

Precision

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

α_o	±0.1°	$c_{d_{o(c_l = 1.0)}}$	±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	±0.2°
$c_{d_{o_{min}}}$	±0.0003	Flap position	±0.001c

The data for the flap-neutral conditions have been corrected for the effect of the flap-hinge fittings, but no corrections have been made for the effect of the flap-hinge fittings with the flap deflected because the effect was believed to be small. It is thought that the relative merits of the two flap arrangements are not appreciably affected because the same hinge fittings were used for both arrangements.

Plain Airfoil

Aerodynamic characteristics.- The complete section aerodynamic characteristics of the N.A.C.A. 23021 plain airfoil are given in figure 2. Since these data are discussed in reference 1, no further discussion is presented here.

Effect on profile drag of breaks in surface of airfoil at slot openings.- The effect of breaks in both the upper and the lower surface varied with lift coefficient (fig. 3). The value of the increment of profile-drag coefficient, Δc_{d_o}, due to the upper-surface break was 0.0005 at $c_l = 0$ and decreased linearly with lift coefficient to 0.0002 at $c_l = 1.2$. The slot-opening break in the lower surface of the airfoil produced nearly twice the increment of profile-drag coefficient with slot shape b as it did with slot shape a. For slot shape a, the value of the drag-coefficient increment was 0.0014 at $c_l = 0$ and reached a maximum of about 0.0020 at $c_l = 0.85$. For slot shape b, the value of the drag-coefficient increment was 0.0025 at $c_l = 0$ and reached a maximum of nearly 0.0046 at $c_l = 0.80$.

Much of the increase in profile drag caused by the breaks in the lower surface of the airfoil could probably be eliminated by using a door to seal these breaks when the flap is retracted.

Slotted-Flap Arrangements

Determination of optimum arrangements for maximum lift.- The data in this section are presented as contours of position of the flap-nose point relative to the slot lip for a given lift coefficient. The nose point of the flap is defined as the point at which a line drawn perpendicular to the chord line is tangent to the leading-edge arc of the flap when neutral, as shown in figure 1. These data were obtained by determining the lift and the drag coefficients of the airfoil for a large number of positions of the flap-nose point at various flap deflections with each slot arrangement.

Maximum-lift contours for slotted flaps 1-a and 1-b deflected from 10° to 50° in 10° increments are presented in figures 4 and 5, respectively. The highest value of lift coefficient for slotted flap 1-a, 2.79, was obtained with the nose point of the flap located either 2.5 percent c below and 0.5 percent c behind the slot lip or 2.5 percent c below and 1.5 percent c ahead of the slot lip and at a flap deflection of 50°. The highest value of lift coefficient for slotted flap 1-b, 2.87, was obtained with the nose point of the flap located either 2.5 percent c below and 0.5 percent c behind the slot lip of 4.5 percent c below and 1.5 percent c ahead of the slot lip and at a flap deflection of 50°.

The lift-coefficient contours for the 10° and the 20° flap deflections are given only to provide maximum-lift data and are of secondary importance in connection with the choice of the optimum flap positions. The optimum positions of the flap-nose point for these small deflections will probably be chosen from considerations of low drag as well as of mechanical practicability.

During operation with a large flap gap, the air flow tended to become unsteady; that is, the airfoil tended to reach two different values of maximum lift coefficient for a certain position of the flap-nose point. This effect is mentioned in reference 5 and is attributed to the critical air-flow conditions usually associated with large

gaps between the flap and the slot lip. The unsteadiness can probably be avoided by maintaining the size of the gap equal to, or less than, the optimum.

The contours presented in this report facilitate the selection of flap paths that are best from aerodynamic considerations. If it is impracticable to use the best aerodynamic path because of structural disadvantages, the effects produced by a deviation from this path can readily be evaluated. Complete section aerodynamic characteristics for the selected optimum combinations of flap path and flap deflection are given in a later section of this paper.

Determination of optimum arrangements for profile drag.- The optimum positions of the flap-nose point for the low-drag condition were determined. The sole criterion for the choice of these positions was the drag coefficient for a given lift coefficient. The drag data for slotted flaps 1-a and 1-b are therefore presented in figures 6 and 7 as contours of the position of the flap-nose point for constant drag coefficients, at certain selected lift coefficients, $c_l = 1.5$ and 2.0, for the 10° and the 20° flap deflections. By means of these contours, the optimum path for the flap-nose point from a consideration of the lift-drag ratio can be chosen. If structural considerations make impracticable the use of the optimum path, the increase in drag coefficient caused by a deviation from this path can be easily determined.

Section aerodynamic characteristics of selected optimum arrangements.- The complete section aerodynamic characteristics of selected optimum arrangements are given in figures 8 and 9. As previously mentioned, the positions of the flap-nose point for flap deflections less than 30° were chosen from considerations of lowest drag coefficients at specified lift coefficients, $c_l = 1.5$ and 2.0. The arrangements for flap deflections of 30°, 40°, and 50° were chosen from a consideration of maximum lift coefficient. Data are also given for locations of the flap-nose point that are not on the best aerodynamic path because the reproduction of this path by mechanical means may not be feasible. The compromise paths shown in figures 8 and 9 will hereinafter be called the optimum paths. Both structural and aerodynamic features were given consideration in the selection of these paths. The positions of the flap-nose point for the various flap deflections are tabulated in figures 8 and 9 and the paths are plotted on the diagrams.

Section-characteristic data for positions other than those shown are available upon request.

The c_{d_o} curve for slotted flap 1-b at the 30° deflection was quite erratic. This same condition was encountered in the tests reported in reference 5 and was attributed to the critical air flow that is usually present at this deflection when the gap between the flap and the slot lip is wide.

Comparison of selected optimum arrangements.- The envelope polars for flaps 1-a and 1-b given in figure 10 were obtained from the section-characteristic curves in figures 8 and 9. A comparison of the polars shows that the drag coefficients for slotted flap 1-b are lower than those for slotted flap 1-a at corresponding values of section lift coefficient for $c_l > 0.94$. Slotted flap 1-b appears to be more desirable than slotted flap 1-a for take-off at lift coefficients above 0.94. At values of lift coefficient less than 1.1, the profile-drag coefficients for the plain wing are lower than those for either of the two flap arrangements. If a door were used to close the lower slot-opening break, it is believed that the drag coefficients for both arrangements would be about the same as those for the plain airfoil at values of $c_l \leqq 0.94$.

The comparative merits of slotted flaps 1-a and 1-b from considerations of maximum lift coefficient are shown in figure 11, where the increments of maximun lift coefficients, $\Delta c_{l_{max}}$, are plotted against flap deflection when the flap is moved along the optimum path. For all deflections, slotted flap 1-b produced a greater increment of maximum lift than did slotted flap 1-a, and it may also be noted that the maximum increment of maximum lift coefficient is attained at a lower flap deflection with flap 1-b than with flap 1-a.

The diving-moment (negative pitching-moment) coefficients of slotted-flap arrangement 1-b are substantially greater than those of slotted flap 1-a for corresponding lift coefficients. (See figs. 8 and 9.)

Comparison of slotted flaps of different chords.- In figure 12, the envelope polar of the 0.40c slotted flap 1-b is compared with those of the 0.2566c slotted flap 2-b

on the N.A.C.A. 23021 airfoil and of the 0.40c slotted flap 1-b on the N.A.C.A. 23012 airfoil. The 0.2566c slotted flap 2-b on the N.A.C.A. 23021 airfoil was used in the comparison instead of slotted flap 1-b because slotted flap 2-b seemed to be the best of those reported in reference 1. At corresponding values of the lift coefficient, the N.A.C.A. 23021 airfoil with the 0.40c flap has a slightly greater drag than the same airfoil with a 0.2566c flap; however, the value of $c_{l_{max}}$ for the airfoil with the 0.40c flap is also slightly greater than that for the airfoil with the 0.2566c flap. The profile-drag coefficient of the N.A.C.A. 23012 airfoil with the 0.40c flap is lower than that of either of the other two combinations for any given lift coefficient.

At comparable lift coefficients, the pitching-moment coefficients for the N.A.C.A. 23021 airfoil with the 0.40c slotted flap were about the same as those of the airfoil with the 0.2566c flap.

A comparison of the increments of $c_{l_{max}}$ for the 0.2566c and the 0.40c slotted flaps on the N.A.C.A. 23021 airfoil is shown in figure 13. The fairing of the broken-line section of this curve was somewhat arbitrary, but the general contour of the curve was made to conform with that of the curve showing the variation of $\Delta c_{l_{max}}$ with flap chord in figure 13 of reference 5. It should be noted that the gain in $\Delta c_{l_{max}}$ obtained by increasing the flap chord from 25.66 percent to 40 percent is considerably less than the gain obtained by increasing it from 10 percent to 25.66 percent.

CONCLUDING REMARKS

The maximum lift coefficient for the N.A.C.A. 23021 airfoil with the 40-percent-chord flap was somewhat higher than that for the airfoil with the 25.66-percent-chord slotted flap but the profile-drag coefficient at comparable lift coefficients was also higher. For any given angle of attack and flap deflection, the lift coefficient of the N.A.C.A. 23021 airfoil with the 40-percent-chord slotted flap was higher than that of the N.A.C.A. 23021 airfoil with the 25.66-percent-chord slotted flap.

The maximum lift coefficient attained by the N.A.C.A. 23012 airfoil and slotted flap was slightly higher than that obtained with the N.A.C.A. 23021 airfoil and slotted flap and, as expected, the profile-drag coefficient at any given lift coefficient was lowest for the N.A.C.A. 23012 airfoil with the 40-percent-chord slotted flap.

Langley Memorial Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., August 23, 1939.

REFERENCES

1. Wenzinger, Carl J., and Harris, Thomas A.: Wind-Tunnel Investigation of an N.A.C.A. 23021 Airfoil with Various Arrangements of Slotted Flaps. T.R. No. 677, N.A.C.A., 1939.

2. Harris, Thomas A.: The 7 by 10 Foot Wind Tunnel of the National Advisory Committee for Aeronautics. T.R. No. 412, N.A.C.A., 1931.

3. Wenzinger, Carl J., and Harris, Thomas A.: Wind-Tunnel Investigation of an N.A.C.A. 23012 Airfoil with Various Arrangements of Slotted Flaps. T.R. No. 664, N.A.C.A., 1939.

4. Jacobs, Eastman N., and Sherman, Albert: Airfoil Section Characteristics as Affected by Variations of the Reynolds Number. T.R. No. 586, N.A.C.A., 1937.

5. Harris, Thomas A.: Wind-Tunnel Investigation of an N.A.C.A. 23012 Airfoil with Two Arrangements of a Wide-Chord Slotted Flap. T.N. No. 715, N.A.C.A., 1939.

TABLE I

Ordinates for Airfoil and Flap Shapes

(Stations and ordinates in percent of wing chord)

N.A.C.A. 23021 Airfoil		
Station	Upper surface	Lower surface
0	-	0
1.25	4.87	-2.08
2.5	6.14	-3.14
5	7.93	-4.52
7.5	9.13	-5.55
10	10.03	-6.32
15	11.19	-7.51
20	11.80	-8.30
25	12.05	-8.76
30	12.06	-8.95
40	11.49	-8.83
50	10.40	-8.14
60	8.90	-7.07
70	7.09	-5.72
80	5.05	-4.13
90	2.76	-2.30
95	1.53	-1.30
100	.22	- .22
L.E. radius: 4.85. Slope of radius through end of chord: 0.305.		

Flap 1		
Station	Upper surface	Lower surface
0	-2.70	-2.70
.63	0	-
1.25	1.00	-
2.5	2.48	-
5	4.51	-6.14
7.5	5.85	-6.09
10	6.59	-5.72
11	6.70	-
20	5.05	-4.13
30	2.76	-2.30
35	1.53	-1.30
40	.22	- .22
Center of L.E. arc		
3.78	-2.15	
L.E. radius: 3.80		

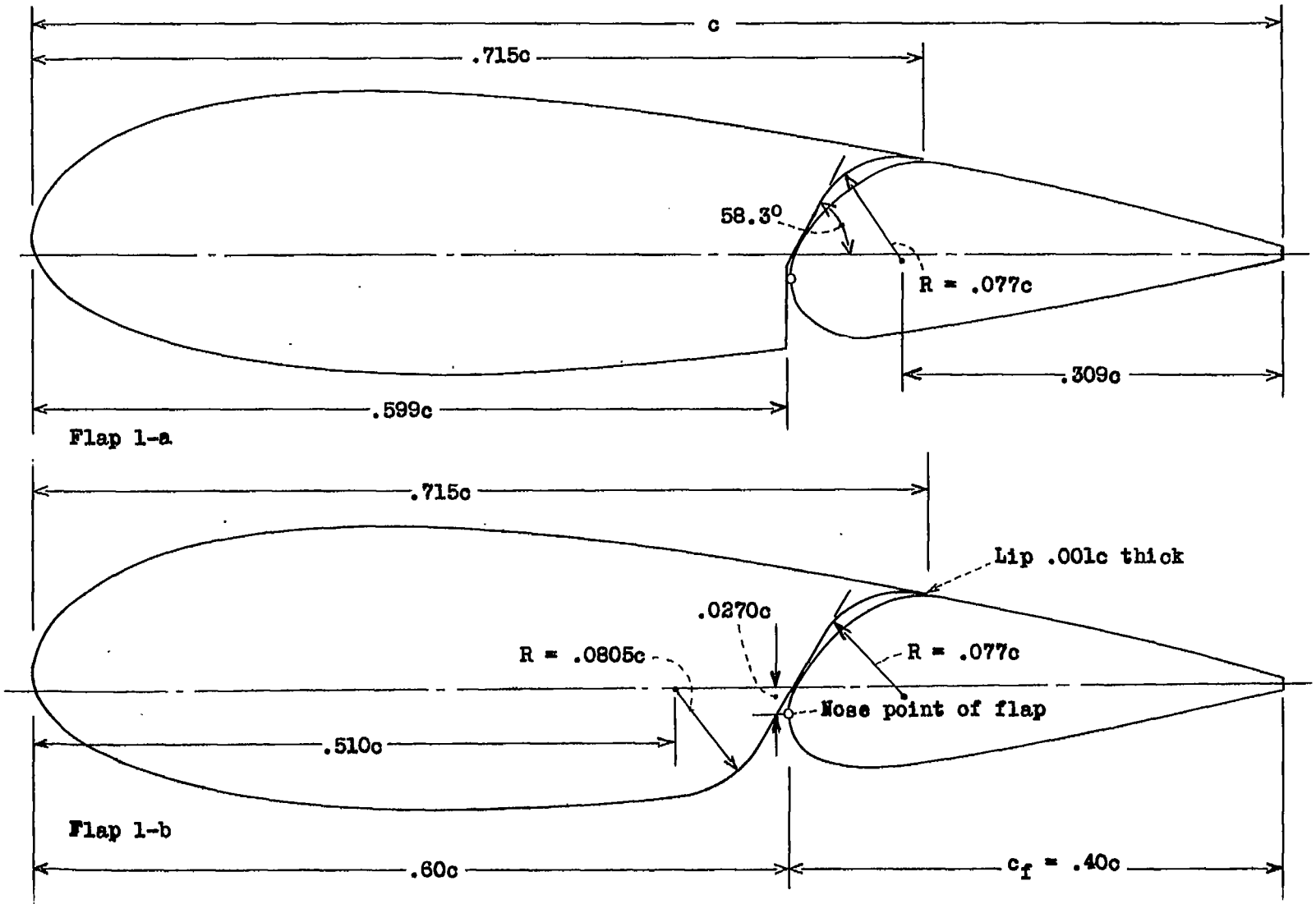


Figure 1.- Sections of N.A.C.A. 23021 airfoil with arrangements of 0.40c slotted flap 1.

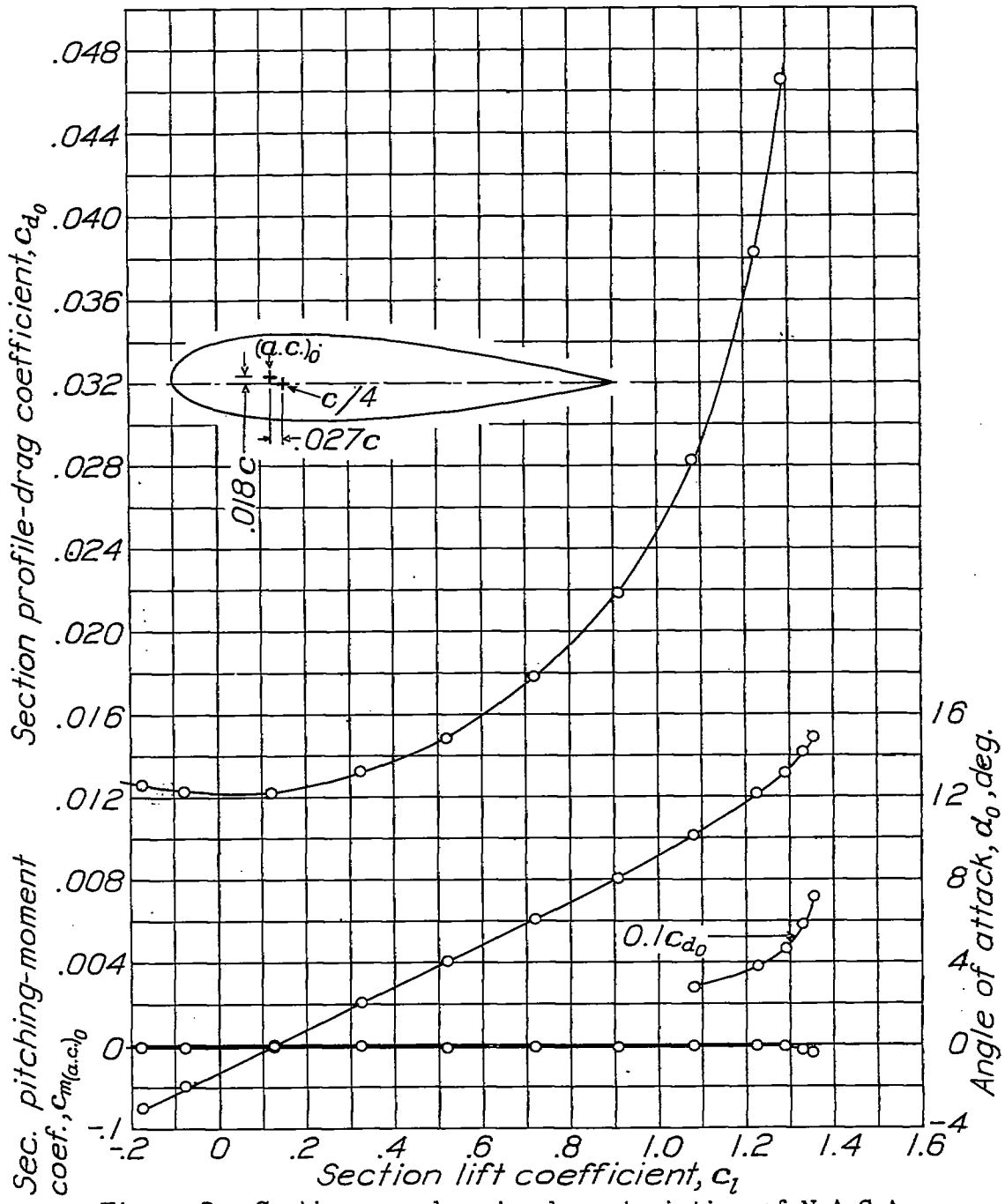


Figure 2.- Section aerodynamic characteristics of N.A.C.A. 23021 plain airfoil.

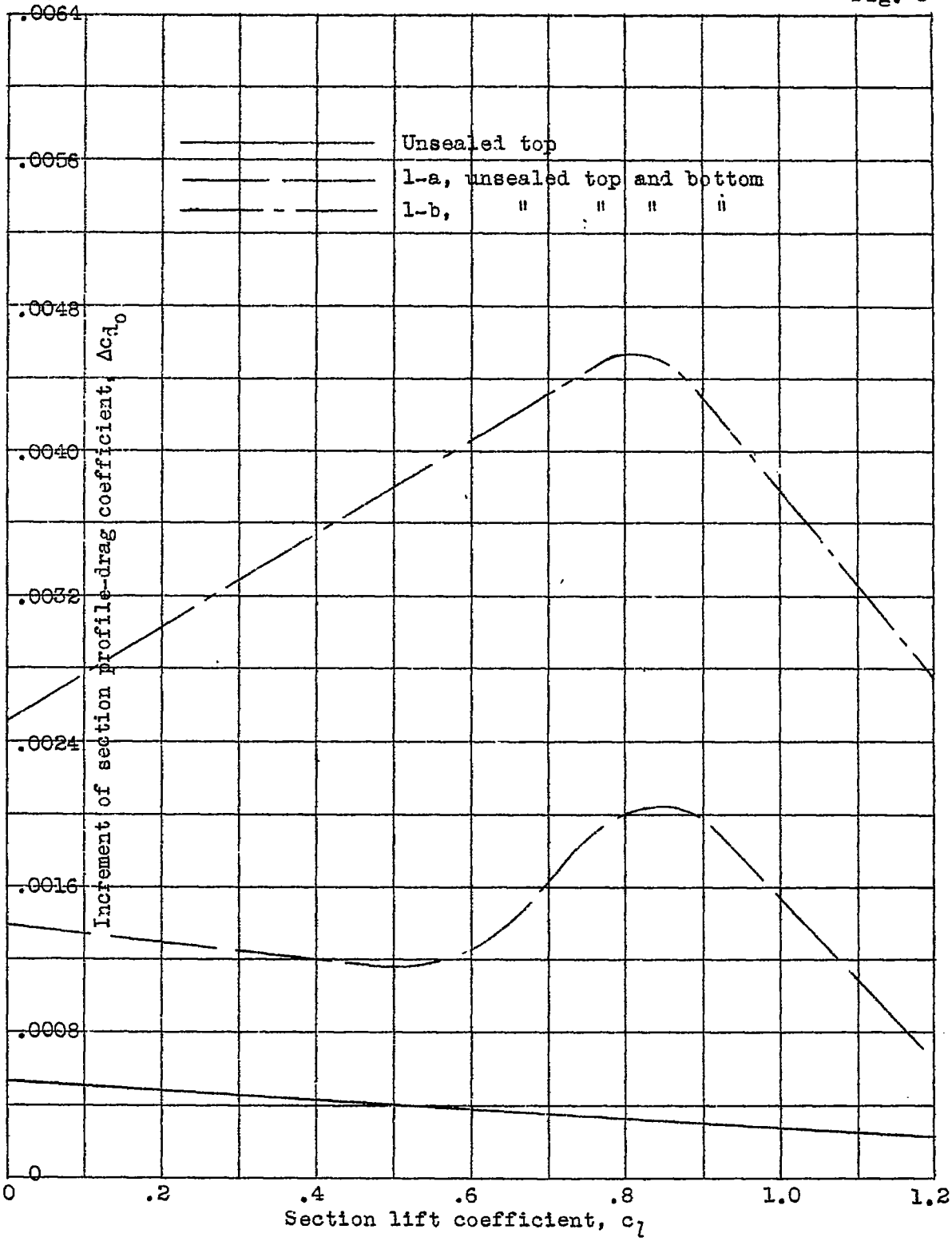


Figure 3.- Effect of slot openings in surfaces of airfoil on section profile-drag coefficients. The 0.40c slotted flaps; δ_f ,0°

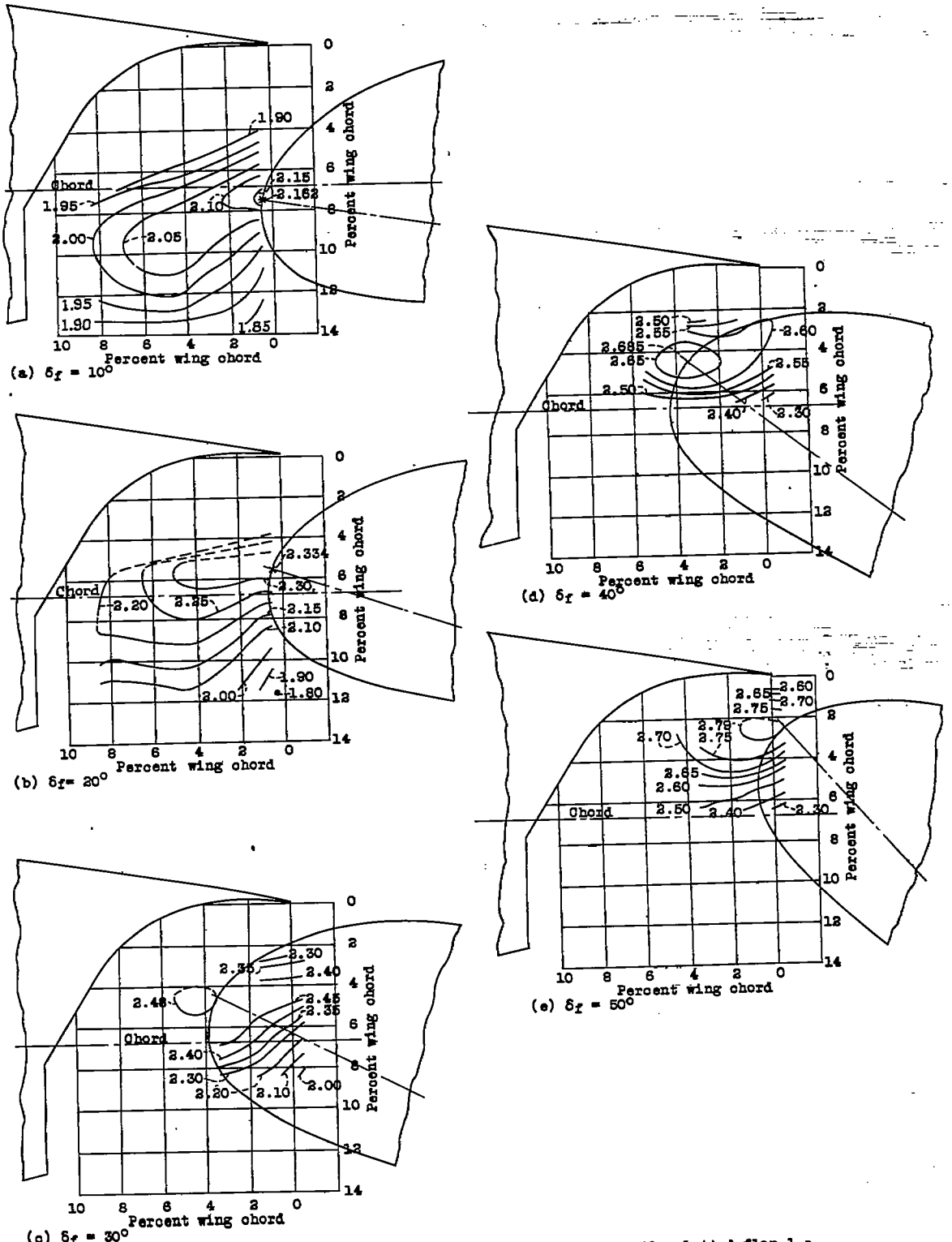


Figure 4.- Contours of flap location for $c_{l_{max}}$. The 0.40c slotted flap 1-a.

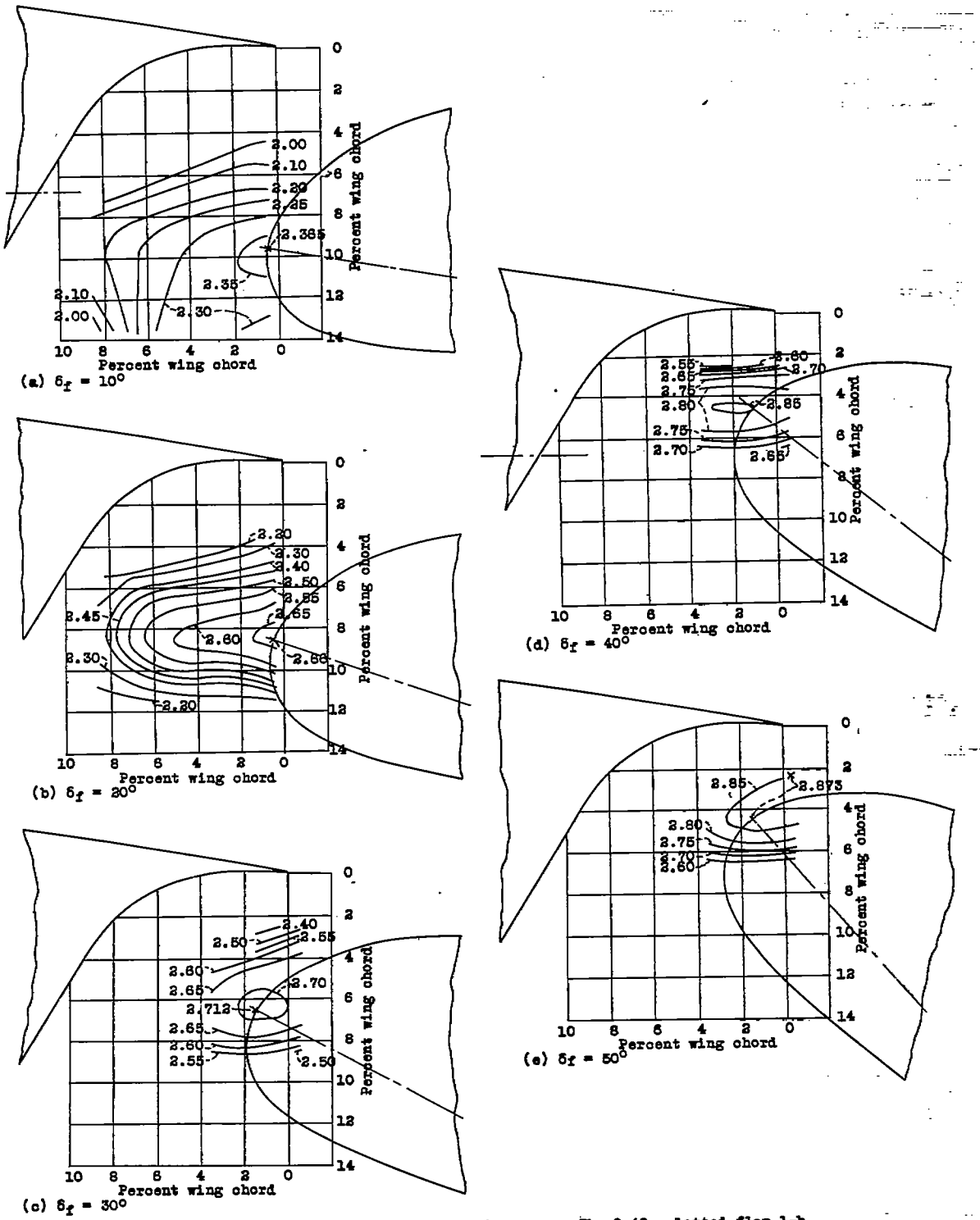
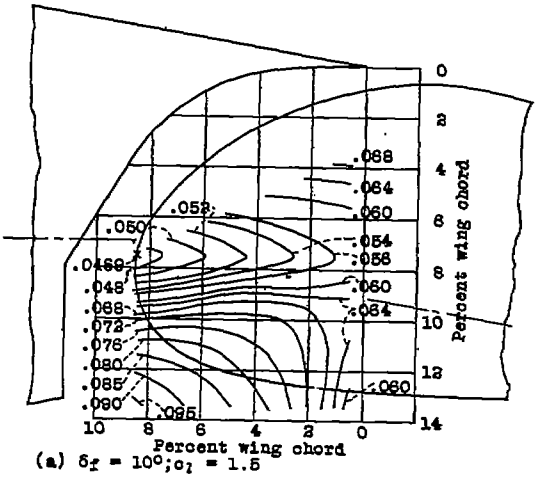
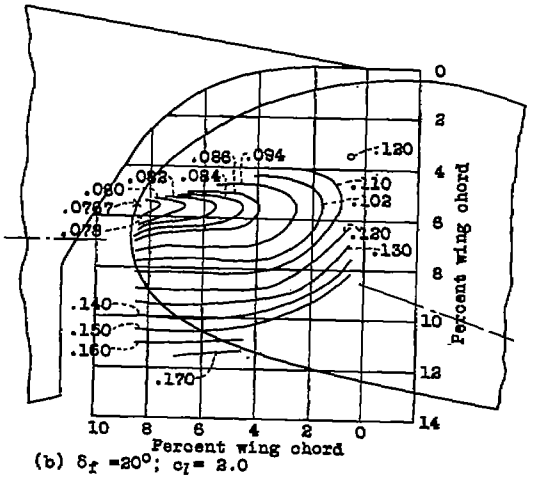


Figure 5.- Contours of flap location for $c_{l_{max}}$. The 0.40c slotted flap 1-b.

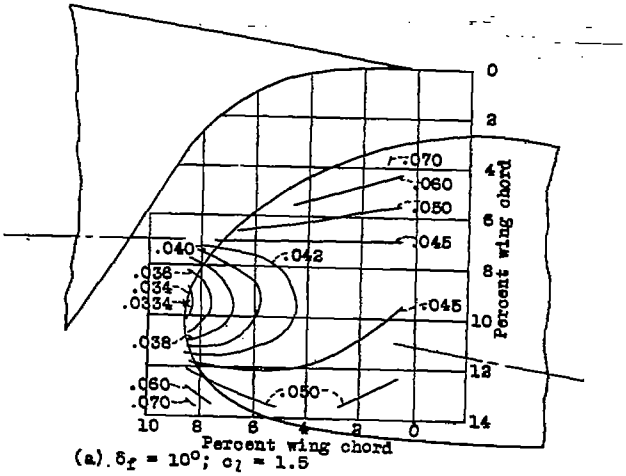


(a) $\delta_f = 10^\circ; c_l = 1.5$

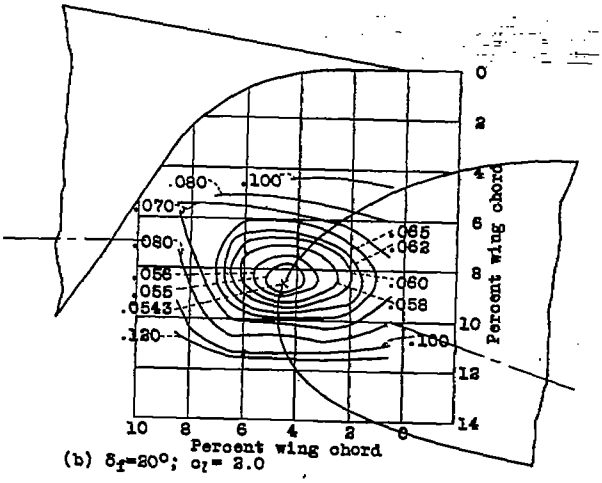


(b) $\delta_f = 20^\circ; c_l = 2.0$

Figure 6.- Contours of flap location for c_{d_0}. The 0.40c slotted flap 1-a.



(a) $\delta_f = 10^\circ; c_l = 1.5$



(b) $\delta_f = 20^\circ; c_l = 2.0$

Figure 7.- Contours of flap location for c_{d_0}. The 0.40c slotted flap 1-b.

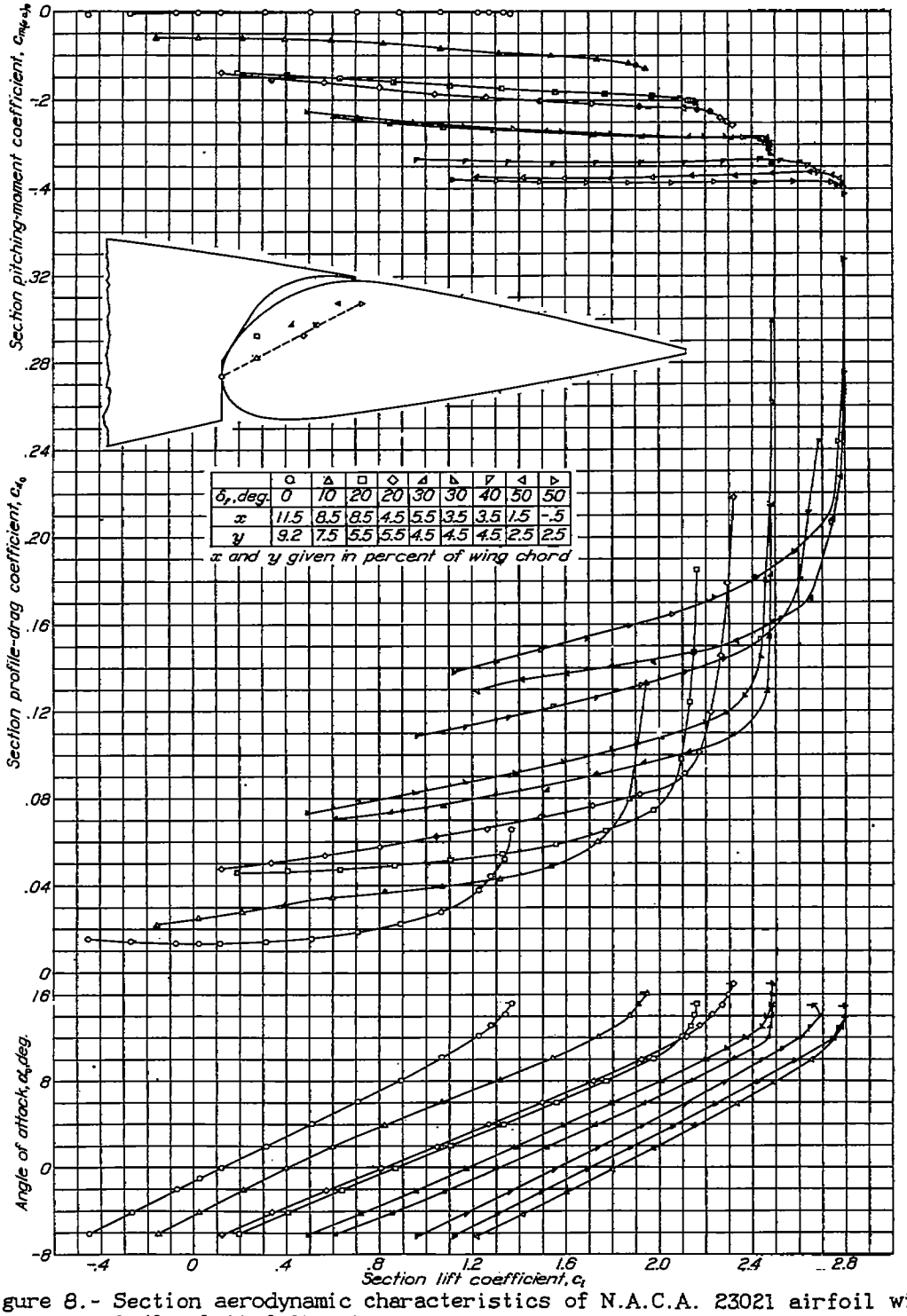


Figure 8.- Section aerodynamic characteristics of N.A.C.A. 23021 airfoil with 0.40c slotted flap 1-a.

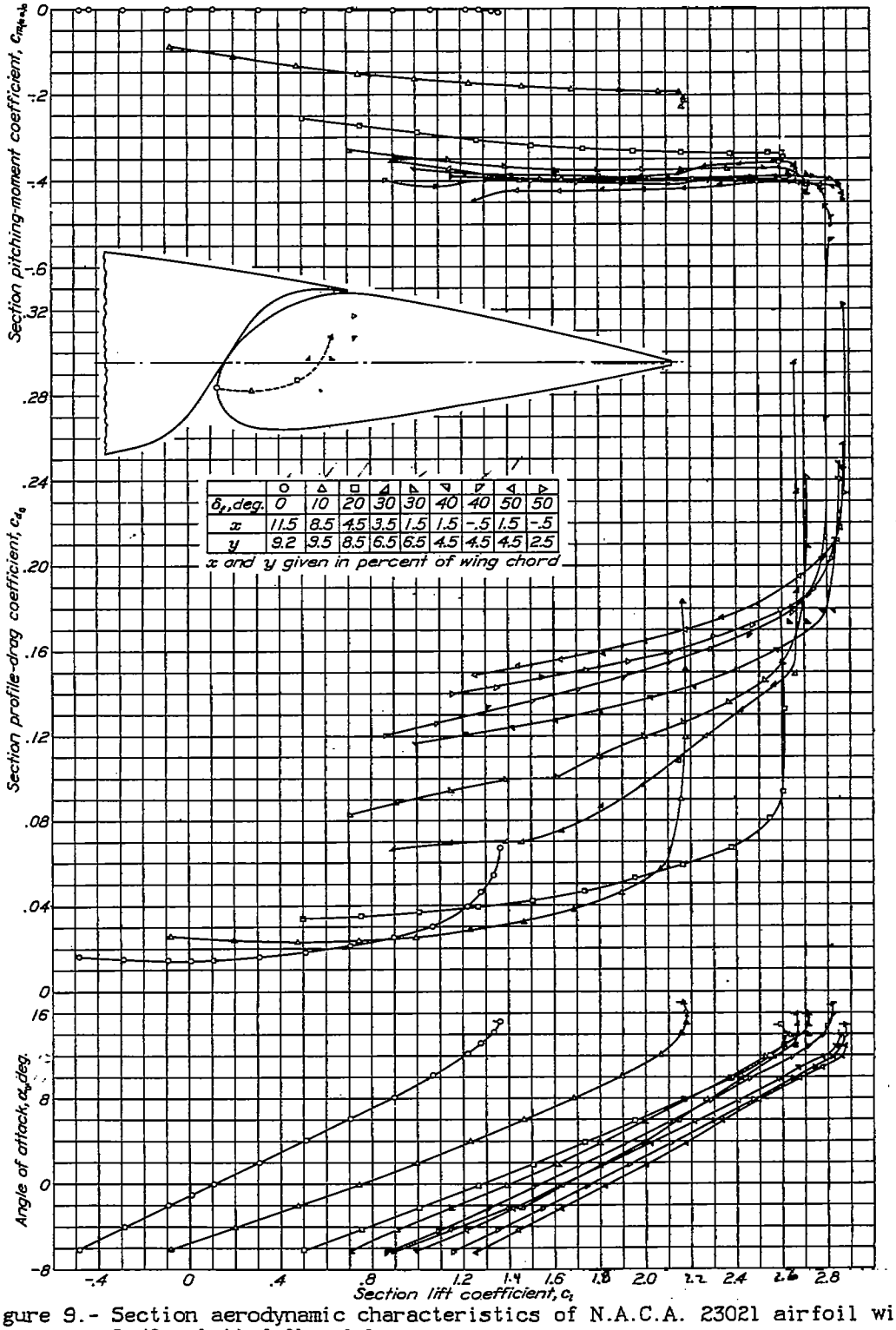


Figure 9.- Section aerodynamic characteristics of N.A.C.A. 23021 airfoil with 0.40c slotted flap 1-b.

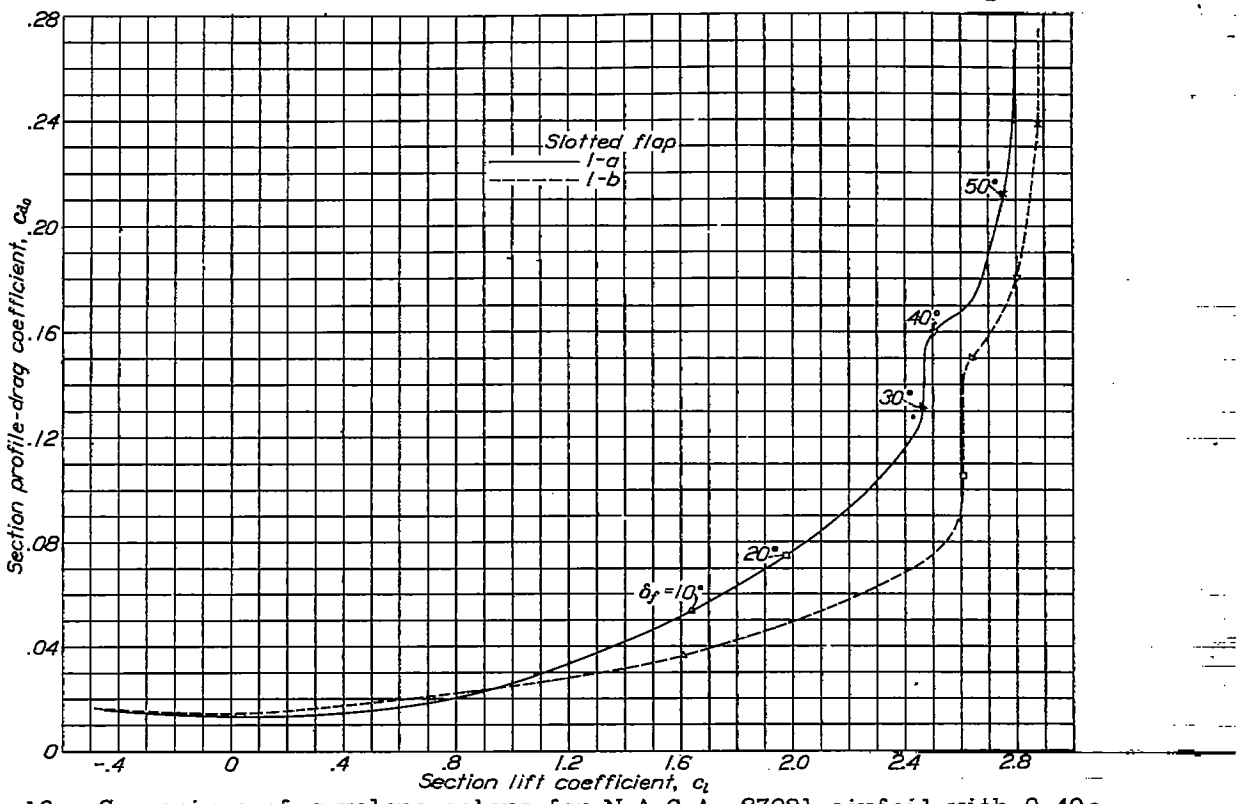


Figure 10.- Comparison of envelope polars for N.A.C.A. 23021 airfoil with 0.40c slotted flaps.

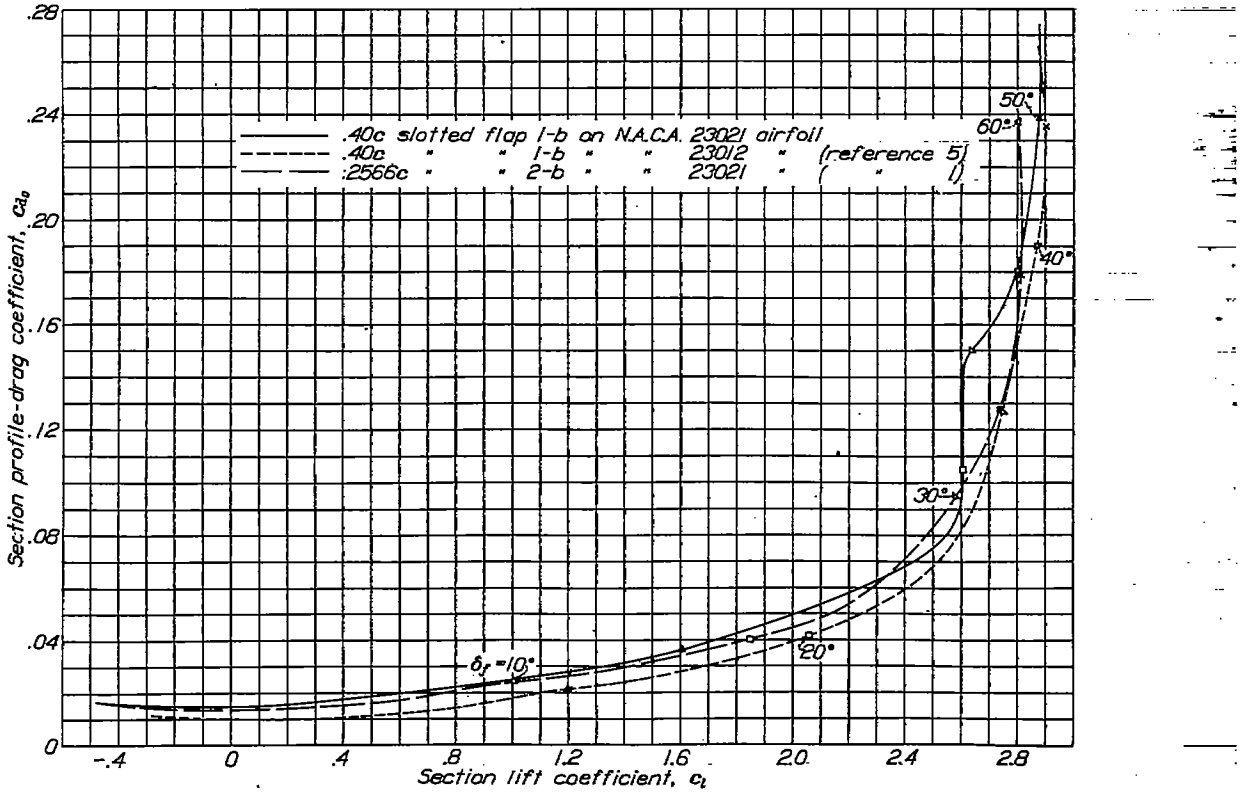


Figure 12.- Comparison of envelope polars for N.A.C.A. 23021 airfoil with 0.2566c and 0.40c slotted flaps and N.A.C.A. 23012 airfoil with 0.40c slotted flap.

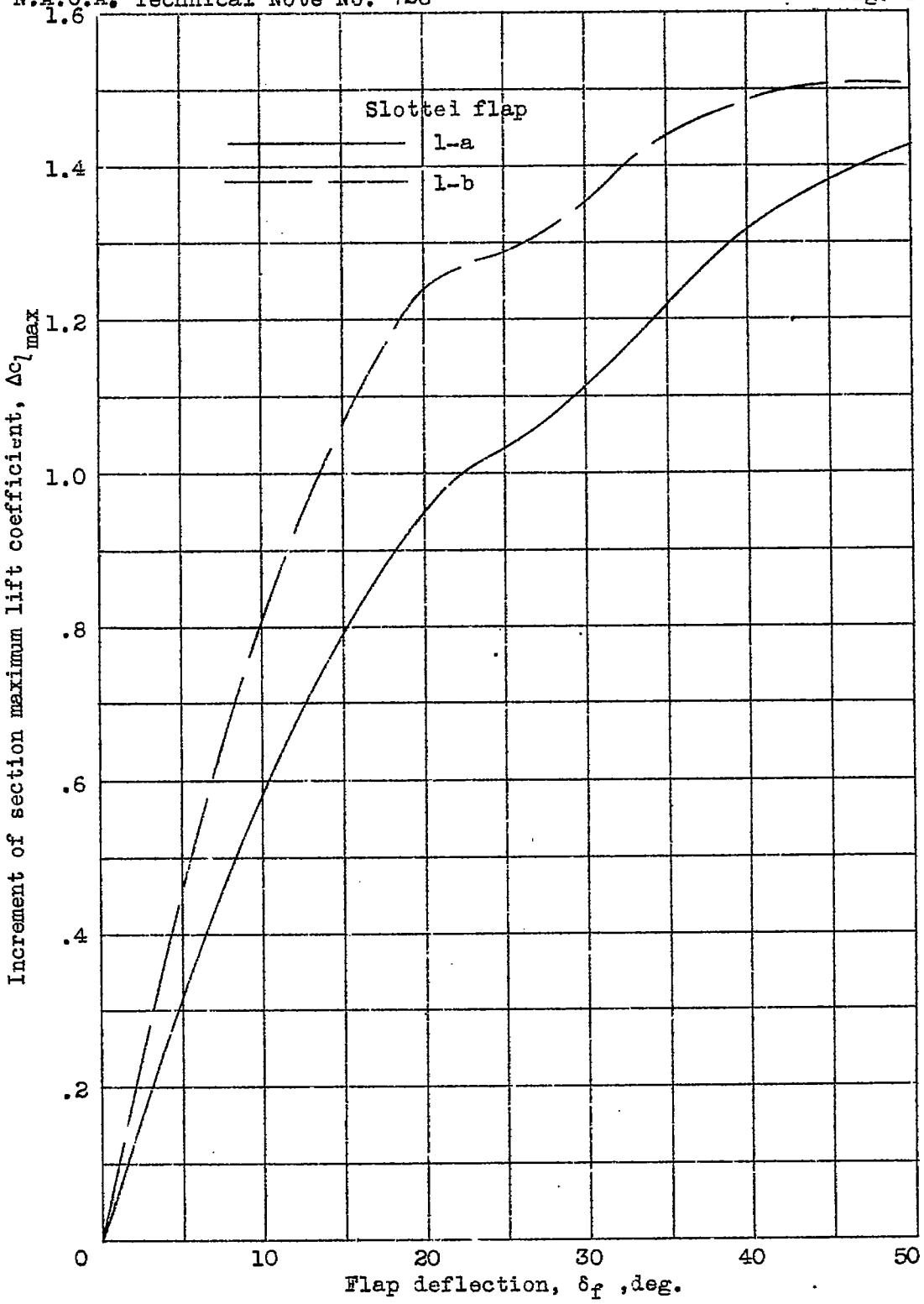


Figure 11.- Comparison of increments of maximum lift coefficient for slotted flaps 1-a and 1-b when moved ani deflected along the selected optimum paths.

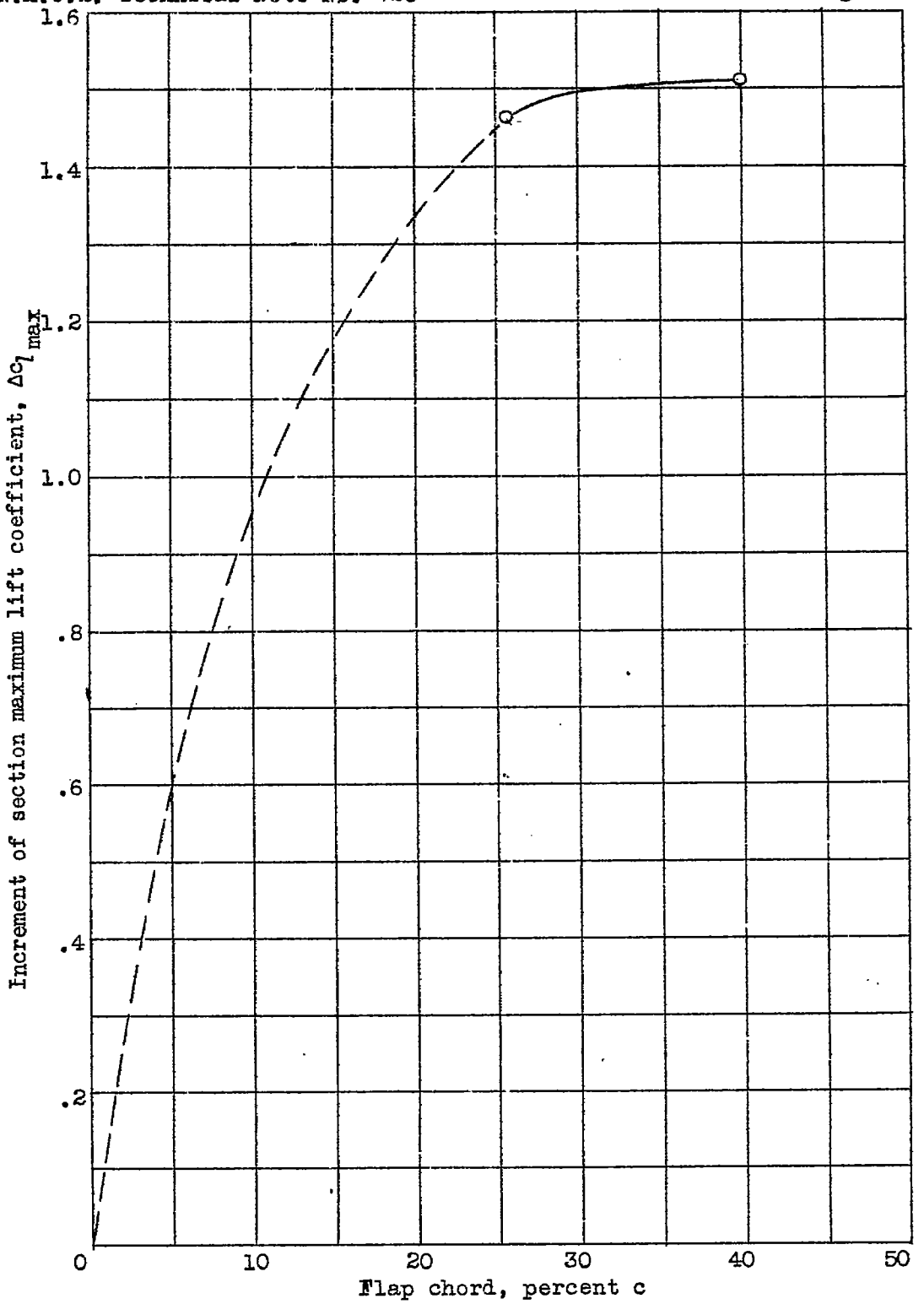


Figure 13.- Variation of increment of section maximum lift coefficient with flap chord. Slotted flaps on N.A.C.A. 23021 airfoil.