TECHNICAL NOTES

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

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WIND-TUNNEL INVESTIGATION OF AN N.A.C.A. 23012 AIRFOIL

WITH TWO ARRANGEMENTS OF A WIDE-CHORD SLOTTED FLAP

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SUMMARY

An investigation has been made in the N.A.C.A. 7-
by 10-foot wind tunnel of a large-chord N.A.C.A. 23012
airfoil with several arrangements of a 40-percent-chord
slotted flap to determine the section aerodynamic char-
acteristics of the airfoil as affected by slot shape,
flap location, and flap deflection. The flap positions
for maximum lift, the polars for arrangements considered
favorable for take-off and climb, and the complete sec-
tion aerodynamic characteristics for selected optimum
arrangements were determined. A discussion is given of
the relative merits of the various arrangements. A com-
parison is made of slotted flaps of different chords on
the N.A.C.A. 23012 airfoil.

The best 40-percent-chord slotted flap is only
slightly superior to the 25-percent-chord slotted flap
from considerations of maximum lift coefficient and low
drag for take-off and initial climb.

INTRODUCTION

The National Advisory Committee for Aeronautics has
undertaken an extensive investigation of various wing-
flap combinations to furnish information applicable to
the aerodynamic and the structural design of high-lift
devices for improving the safety and the performance of
airplanes. A high-lift device capable of producing high
lift with variable drag for landing and high lift with
low drag for take-off and initial climb is believed to be
desirable. Other desirable aerodynamic features are: no
increase in drag with the flap neutral; small change in
pitching moment with flap deflection; low forces required
to operate the flap; and freedom from possible hazard due
to icing.

It is planned in this investigation to test both simple and multiply slotted flaps of different chords on airfoils of different profile. Some promising arrangements of medium-chord slotted flaps have been developed for the N.A.C.A. 23012 and 23021 airfoils. The aerodynamic data for these arrangements are reported in references 1 and 2. Further improvement from considerations of high lift coefficients and low drag at high and intermediate lift coefficients was obtained with the combination of a medium-chord and a small-chord slotted flap (reference 3). Pressure-distribution data are also available for the medium-chord slotted flap on the N.A.C.A. 23012 airfoil. (See reference 4.)

In the present report, the section aerodynamic characteristics are given for the N.A.C.A. 23012 airfoil equipped with a 40-percent-chord slotted flap in combination with two slot shapes.

MODELS

Plain Airfoil

The basic wing, or the plain airfoil, used in these tests was built to the N.A.C.A. 23012 profile and has a chord of 3 feet and a span of 7 feet; the ordinates for the section are given in table I. The model was built of solid laminated pine and had been previously used in the investigation of the medium-chord slotted flap reported in reference 1. The trailing-edge section of this model is easily removable so that the model can be quickly altered for tests of different flap arrangements.

Slotted-Flap Arrangements

The slotted flap and the slot shapes were built of solid laminated beech. The slot shapes were bolted to the main airfoil in place of the solid trailing edge, The flaps were mounted on special hinges that permitted considerable latitude in the location of the flaps with respect to the main airfoil.

Flaps.- Only one flap shape was tested; it is designated flap 1 (fig. 1 and table I). This flap has a small nose radius and was designed to give only a small

break in the lower surface of the airfoil when undeflected. It also lends itself to use with a door to seal the break in the lower surface of the airfoil with the flap undeflected.

Slot shapes.- The two slot shapes shown in figure 1 were used with the flap and are designated a and b. Slot shape a was designed to give a minimum break in the lower surface of the wing and, consequently, to have the smaller effect on the drag with the flap neutral. Slot shape b is similar to slot shape h of reference 1, which gave the lowest drag at intermediate and high lift coefficients for take-off.

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

TESTS

The models were so mounted in the closed test section of the N.A.C.A. 7- by 10-foot wind tunnel that they completely spanned the jet except for small clearances at each end. (See references 1 and 5.) 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.

A dynamic pressure of 16.37 pounds per square foot was maintained for all the tests, which corresponds to a velocity of 80 miles per hour under standard atmospheric conditions and to an average test Reynolds Number of about 2,190,000. Because of the turbulence in the wind tunnel, the effective Reynolds Number R_e (reference 6) was approximately 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.- Tests were first made of the plain airfoil over the complete angle-of-attack range from $-6°$ to the stall.

Slotted flaps.- With each slotted-flap arrangement, tests were made to determine the effect on minimum drag

of the breaks in the wing lower surface at the slot en-
trance with the flap retracted. Tests were also made to
determine the effect of the flap hinges with the flaps in
their retracted positions. The tests of slotted flaps
1-a and 1-b consisted in force measurements with various
flap positions and deflections to determine the optimum
path of the flap from considerations of low drag through-
out the complete lift range and of the highest maximum
lift for each flap deflection. Data were obtained for all
tests throughout the angle-of-attack range from -6° to the
stall at 10° increments of flap deflection from 0° to 50°.
No data were obtained above the stall because of the un-
steady conditions of the model. Lift, drag, and pitching
moments were measured for all positions of the flap over
the complete angle-of-attack range tested.

RESULTS AND DISCUSSION

Coefficients

All test results are given in standard section non-
dimensional coefficient form for the airfoil, corrected
as explained in reference 1.

c_l,   section lift coefficient (l/qc_w).

c_{d_0},   section profile-drag coefficient (d_0/qc_w).

$c_{m(a.c.)_0}$,   section pitching-moment coefficient about aero-
dynamic center of plain wing $(m_{(a.c.)_0}/qc_w^2)$.

where

l is section lift.

d_0,   section profile drag.

$m_{(a.c.)_0}$,   section pitching moment.

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

c_w,   chord of basic airfoil with flap fully retracted.

and

α_0 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_0 - - - - - - - $\pm 0.1^{\circ}$ $c_{d_{0 (c_l = 1.0)}}$ - - - - - ± 0.0006

$c_{l_{max}}$ - - - - - ± 0.03 $c_{d_{0 (c_l = 2.5)}}$ - - - - - - ± 0.002

$c_{m(a.c.)_0}$ - - - - ± 0.003 δ_f - - - - - - - - - - $\pm 0.2^{\circ}$

$c_{d_{0_{min}}}$ - - - - - ± 0.0003 Flap position- - - - - $\pm 0.001 c_w$

Corrections for flap-hinge fittings have been applied to the data for the flap-neutral conditions. No attempt was made to determine the effect of the hinges with the flaps deflected because their effect was believed small and because of the great number of tests required. The relative merits of the two flap arrangements are thought to be not appreciably affected because the same hinge fittings were used with the two airfoil-flap combinations.

Plain Airfoil

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

Effect on profile drag of breaks in surface of airfoil at slot entrance.- The effects of the breaks in the lower surface of the airfoil with the flaps undeflected are shown in figure 3. The break in the wing upper surface only at the slot lip gave an approximately constant increment of section profile-drag coefficient of about 0.0001. The increments of section profile-drag coefficient due to the breaks in the upper and the lower sur-

faces of slotted flap 1-a vary from about 0.0006 at $c_l = 0$ to about 0.0005 at $c_l = 1.0$. For slotted flap 1-b, the increment of section profile-drag coefficient due to the breaks in the upper and the lower surfaces varies from about 0.0013 at $c_l = 0$ to about 0.0011 at $c_l = 1.0$. A door on the wing lower surface may be used to reduce greatly the increased profile-drag coefficient caused by the lower-surface break with either of the flaps.

Slotted Flap Arrangements

<u>Determination of optimum arrangements for maximum lift.</u>- The data presented herein are the results of the maximum-lift investigation of the various flap-and-slot combinations in which the flap, at a given deflection, was located at points over a considerable area with respect to the main airfoil. The data are presented as contours of the position of the nose point of the flap relative to the slot lip for a given lift coefficient. 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 arc of the flap when neutral, as shown in figure 1.

The complete maximum-lift data for slotted flaps 1-a and 1-b deflected 10°, 20°, 30°, 40°, and 50° are given in figures 4 and 5. An inspection of these figures shows that the contours are not closed with all combinations for flap deflections less than 20°. Within this range, the position for maximum lift coefficient is not very critical and only a sufficient number of positions were taken to cover any practicable path along which the flap is likely to be operated. Furthermore, the optimum flap position for these deflections will probably be chosen from considerations of drag and ease of mechanical operation.

The position of the flaps for maximum lift coefficient becomes much more critical for the higher flap deflections and the contours are closed for flap deflections from 30° to 50°. Two values of the maximum lift coefficients were obtained with the 30° and the 40° flap deflections at certain positions and are shown by the broken and the solid lines on the contours. This result is probably due to critical air-flow conditions with gaps larger than the optimum. This unsteady condition has been encountered in the previous tests of the slotted flaps reported in

references 1, 2, and 3 andnhas been associated with large
gaps between the slot lip and the flap. The unsteadiness
is an undesirable condition and may be avoided if the gap
for a given flap deflection is no larger than the optimum.

The maximum lift coefficients for slotted flaps 1-a
and 1-b were obtained with the flap deflected 50° and with
the flap nose point 1.5 percent below and 1.5 percent
ahead of the slot lip. The maximum lift coefficient with
slotted flap 1-a was 2.85 and with slotted flap 1-b was
2.90. With a 40° flap deflection, the maximum lift coef-
ficient for both flaps was obtained with the flap nose
point 1.5 percent below and 0.5 percent behind the slot
lip.

From these contours, it should be possible for the
designer to choose the best path for the flap to follow
from considerations of maximum lift coefficient alone.
If, from structural considerations, it is not possible to
use the best aerodynamic path, the loss caused by using a
compromise path can be immediately evaluated. Complete
section aerodynamic characteristics of selected optimum
arrangements for each flap deflection are given in a
later section of this paper.

Determination of optimum arrangements for profile
drag.- Optimum positions of the flap arrangements for the
conditions of low drag for take-off and initial climb to
clear an obstacle were determined. The sole criterion
for a given lift coefficient was the drag coefficient.
The most important single factor in unassisted take-off
distance is the value of the lift coefficient for take-off
because the higher the lift coefficient, the lower the
take-off speed. It follows that, except for the detrimen-
tal effect of increased drag, the higher the lift coeffi-
cient, the shorter the distance required to clear a given
obstacle. The limiting conditions are the power available
to overcome the drag at the higher lift coefficients and
the excess available lift required from considerations of
safety. The data are given, therefore, as contours of the
nose position of the flap for constant drag coefficients
at certain selected lift coefficients, $c_l = 1.5$, 2.0, and
2.5, and for flap deflections that cover the range for
which the drag coefficient is decreased by deflecting the
flap.

The complete drag data for slotted flaps 1-a and 1-b
are given in figures 6 and 7. Where the minimum drag coef-

ficients were approximately the same for a given lift
coefficient at low flap settings, both sets of data are
given. From these data, optimum paths for the nose point
of the flap may be chosen from consideration of drag coef-
ficients at the various lift coefficients. If it is
structurally impossible to follow the optimum path, the
additional drag coefficient caused by the deviation will
be available. Insufficient data were obtained to close
all the contours, but most of the practicable arrangements
are believed to be within the range covered.

Section aerodynamic characteristics of selected opti-
mum arrangements.- The complete section aerodynamic char-
acteristics of selected optimum arrangements of slotted
flaps 1-a and 1-b are given in figures 8 and 9. The opti-
mum arrangements were chosen from considerations of low
drag coefficients at the specified lift coefficients, 1.5,
2.0, and 2.5, for flap deflections of 10° and 20° and from
considerations of maximum lift coefficient alone for flap
deflections from 30° to 50°. In addition to the optimum
arrangements, data are also given for certain arrangements
that appear structurally simpler. A table included in
each figure shows the nose position of the flap for the
various deflections; the points are plotted on the dia-
grams. The selected "optimum" path referred to herein-
after is shown by the broken line through the points and
is a compromise between aerodynamic and structural consid-
erations. The aerodynamic characteristics shown in these
figures are typical; complete data for other positions of
the flap at the several flap deflections are available up-
on request.

The erratic c_{d_0} for the 30° flap deflection of
slotted flap 1-b is typical of the results for this flap
deflection. The lower values of c_{d_0} over the lift
range from $c_l = 1.4$ ($\alpha = -6°$) to 1.9 ($\alpha = -1°$) have been
disregarded in the selection of the optimum path because
the arrangement would probably be impracticable. In ad-
dition, in a number of tests with larger gaps, two types
of flow were encountered for this lift range; the other
type gave a much higher c_{d_0}. The position for the flap
at the 30° deflection was selected from consideration of
maximum lift coefficient alone.

Comparison of selected optimum arrangements.- In
order to compare the drags of the various flap arrange-
ments, envelope polars are given in figure 10 for the

slotted-flap arrangements of figures 8 and 9. As previously mentioned, the low drag coefficients for the 30° flap deflections have been disregarded in drawing the envelope polars for slotted flap l-b. Figure 10 shows slotted flap l-b to be superior to slotted flap l-a for take-off at any lift coefficient from 1.1 up to the maximum lift coefficient. For lift coefficients less than 1.1, the plain wing has lower drag coefficients than any of the arrangements with the flaps deflected. If a door were used to seal the break in the lower surface of the wing at the slot entrance, both of the slotted-flap arrangements would have approximately the same characteristics as the plain wing for lift coefficients less than 1.1.

A comparison of slotted flap l-a and l-b as lift-increasing devices is shown in figure 11, where the increments of maximum lift coefficient $\Delta c_{l_{max}}$ are plotted against flap deflection when the flap is moved along the optimum path prviously mentioned. Slotted flap l-b is slightly superior to slotted flap l-a for all flap deflections. It is particularly interesting to note that the increment of maximum lift coefficient increases very slightly for flap deflections greater than 30°.

The pitching-moment coefficients for slotted flaps l-a and l-b at comparable lift coefficients are about the same. (See figs. 8 and 9.)

Comparison of slotted flaps of different chord.- A comparison of slotted flap l-b and slotted flap 2-h (25.66-percent-chord slotted flap) of reference 1 is shown by polars in figure 12. From a consideration of c_{d_0} for values of c_l less than 1.5, the two slotted flaps compared are about equal. For higher values of c_l, the 40-percent-chord slotted flap is slightly superior for take-off. In addition, the 40-percent-chord slotted flap for the extreme flap deflection gives higher values of c_{d_0}. It is probable, however, that the operating force would be so much higher for the 40-percent-chord slotted flap that it would be impracticable.

The effect of slotted-flap chord on $\Delta c_{l_{max}}$ is shown in figure 13 where the data for the smaller-chord flaps were taken from references 1 and 3. It is of interest to note that the increase of $c_{l_{max}}$ was only 0.1 for an in-

crease of flap chord from 25 to 40 percent whereas, with
the increase of flap chord from 10 to 25 percent, the gain
in $c_{l_{max}}$ was 0.5.

A comparison of the pitching-moment coefficients for
the 40-percent-chord slotted flap, the 25.66-percent-chord
slotted flap of reference 1, and the 10-percent-chord
slotted flap of reference 3 shows that, for equal lift co-
efficients, the pitching-moment coefficients are about the
same.

CONCLUDING REMARKS

Slotted flap 1-b is superior to 1-a except for low
drag with flap neutral. Slotted flap 1-b is also superior
to slotted flap 2-h of reference 1 from considerations of
maximum lift and of low drag for lift coefficients from
1.5 to 2.5. It should be noted that the gain in aerody-
namic characteristics with the large-chord slotted flap
as compared with the 25.66-percent-chord slotted flap is
slight.

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

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     tion Characteristics as Affected by Variations of
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TABLE I

ORDINATES FOR AIRFOIL AND FLAP SHAPES

(Stations and ordinates in percent of wing chord)

N.A.C.A. 23012 Airfoil		
Station	Upper surface	Lower surface
C	—	0
1.25	2.67	-1.23
2.5	3.61	-1.71
5	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.		

Flap 1		
Station	Upper surface	Lower surface
0	-1.76	-1.76
.63	-.31	-
1.25	.37	-3.17
2.5	1.36	-3.40
5	2.69	-3.36
7.5	3.48	-3.19
10	3.97	-3.00
11	4.05	-
12	4.07	—
20	3.08	-2.16
30	1.68	-1.23
35	.92	-.70
40	.13	-.13
Center of L.E. arc		
1.35	-1.76	
L.E. radius: 1.35		

Flap 1-a

Flap 1-b
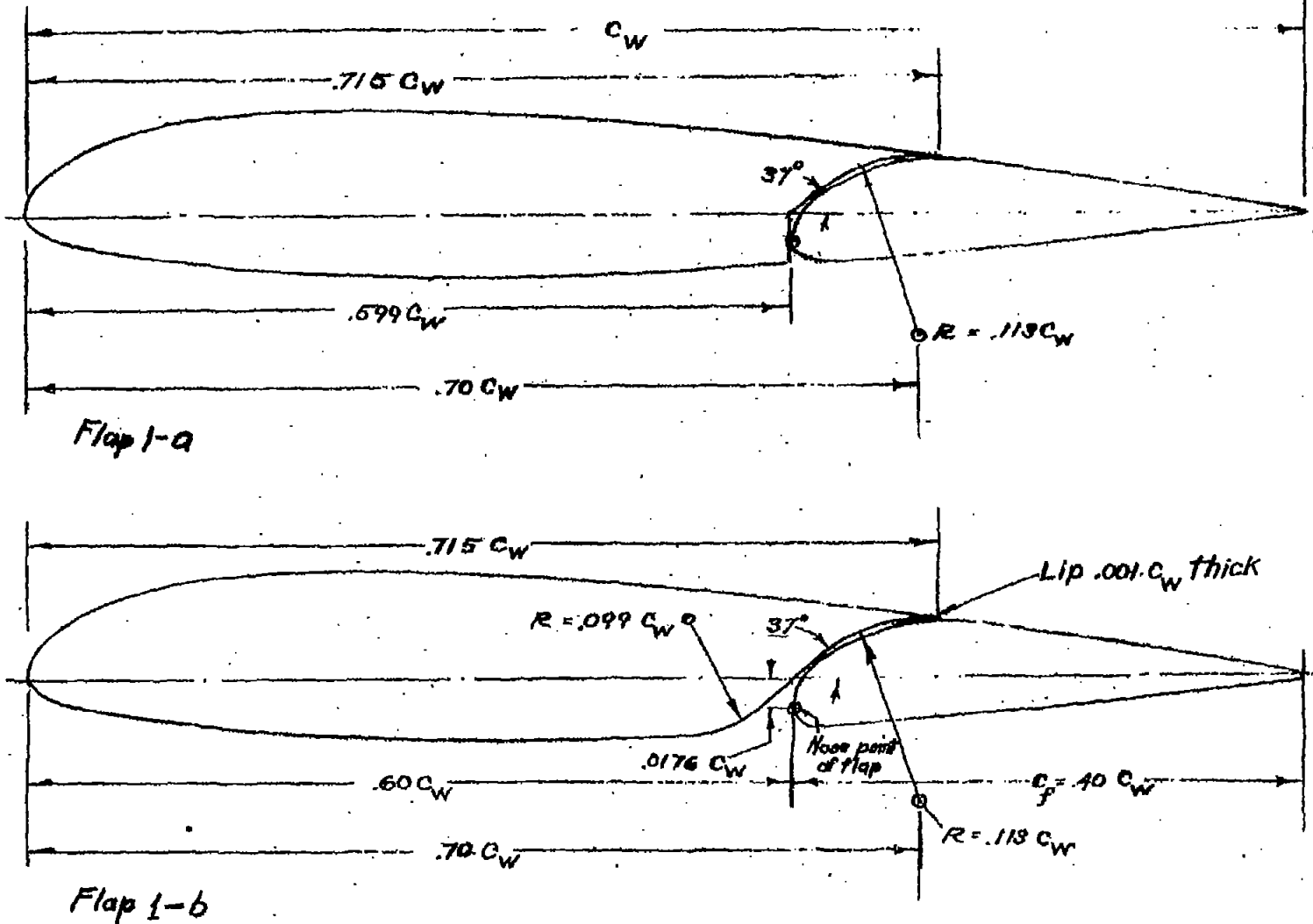
FIGURE 1.—Sections of N.A.C.A. 23012 airfoil with arrangements of 0.40 c_w slotted flap 1.

Fig. 1
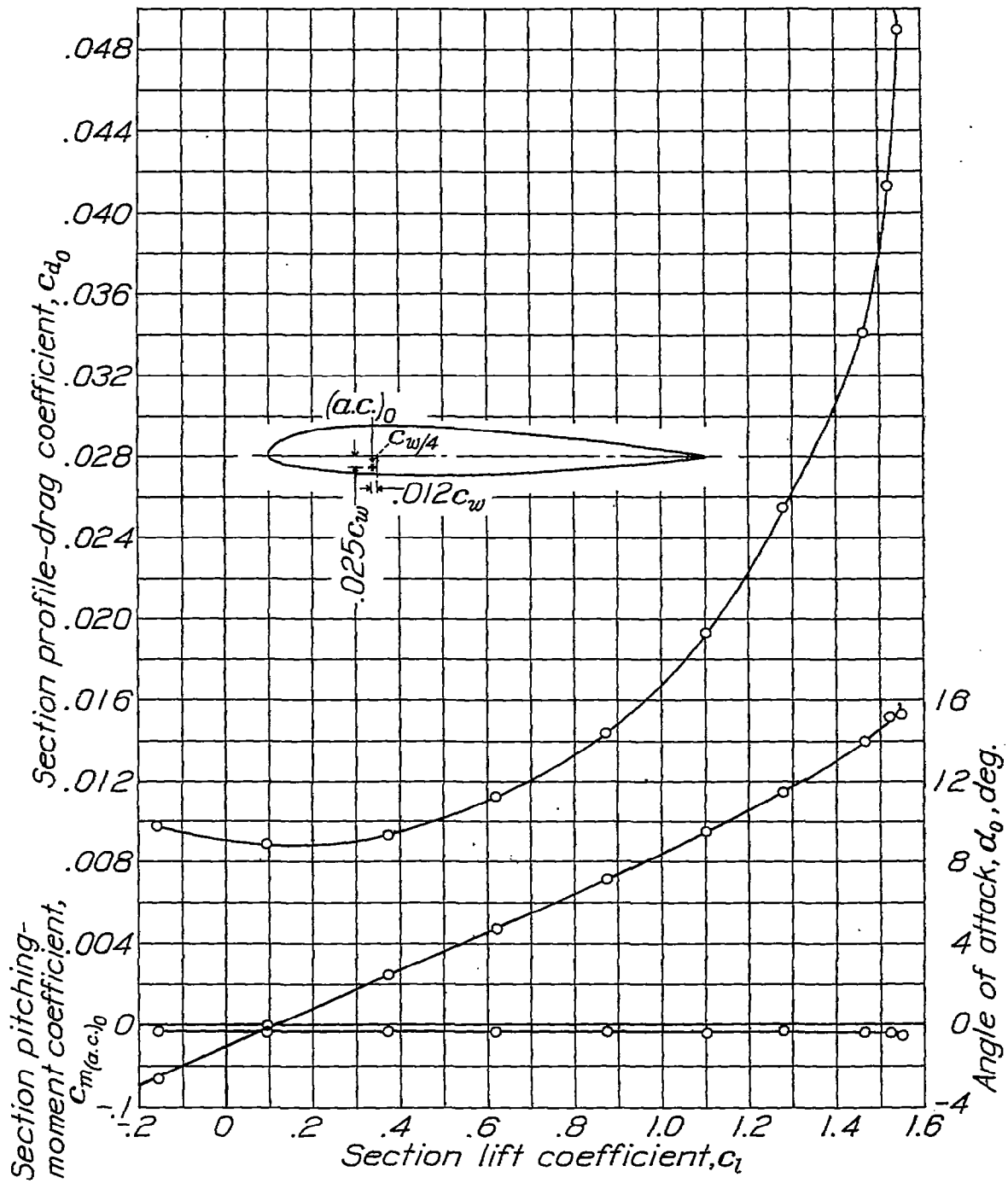
Figure 2.- Section aerodynamic characteristics of N.A.C.A. 23012 plain airfoil.
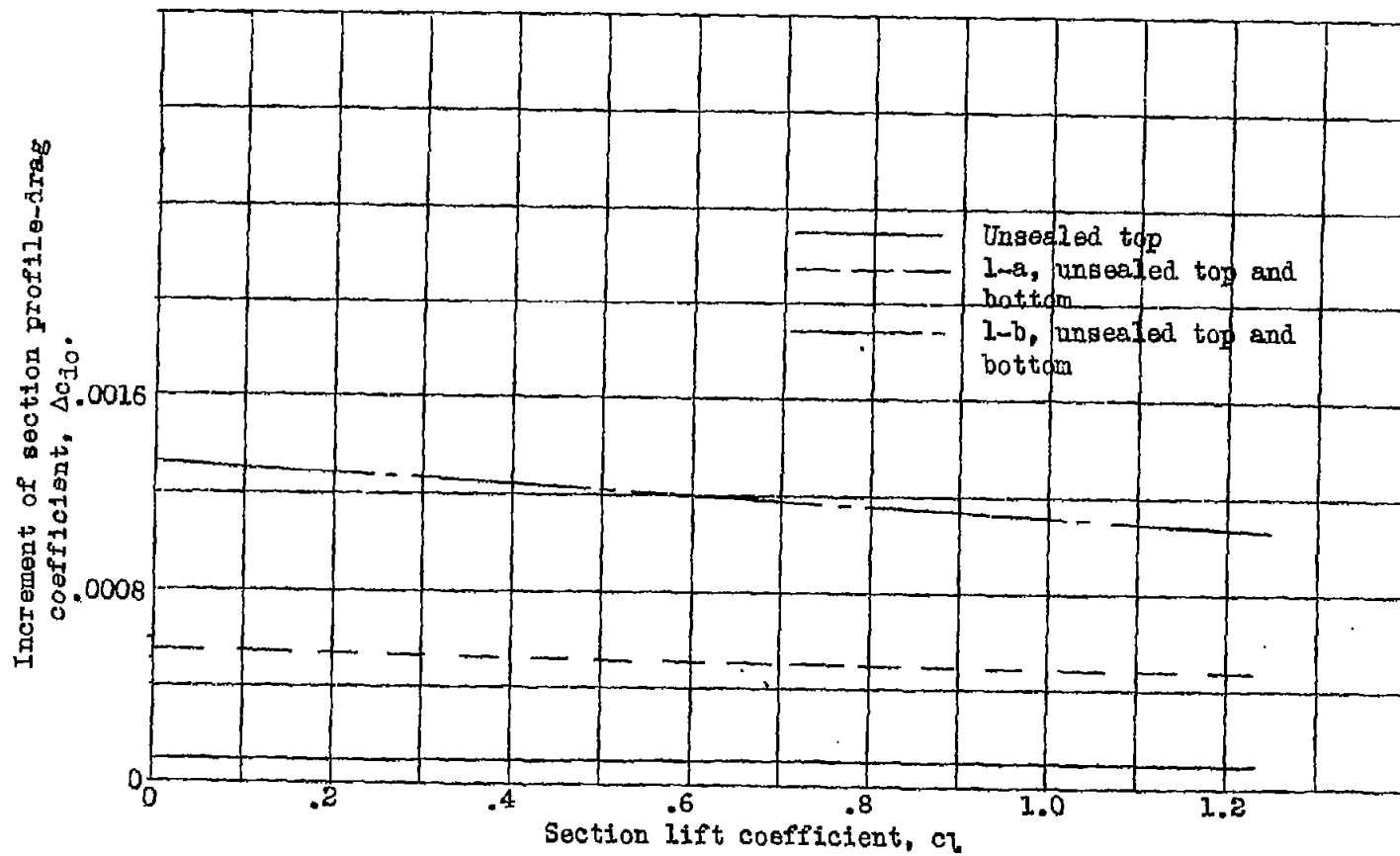
Figure 3.— Effect of slot openings in surfaces of airfoil on section profile-drag coefficient. The 0.40 c_w slotted flap; $\delta_f = 0^0$.

Fig. 3

Fig. 4
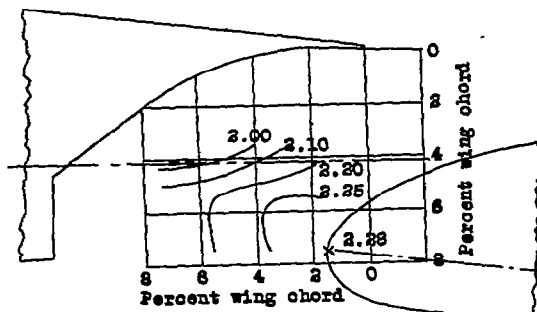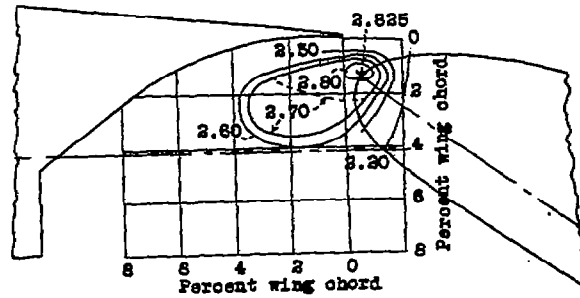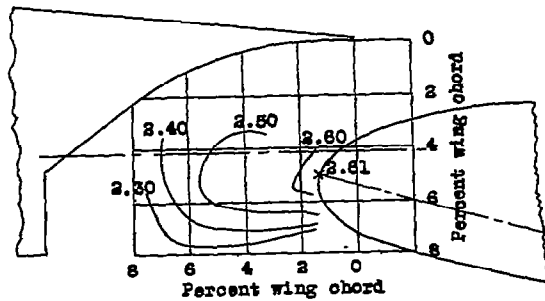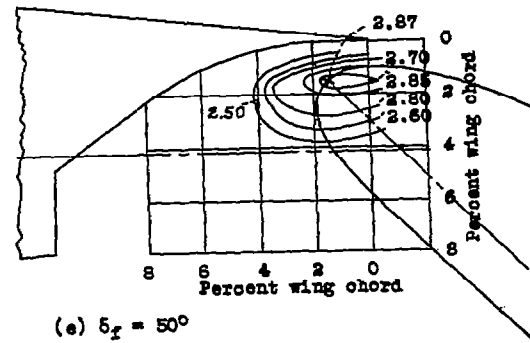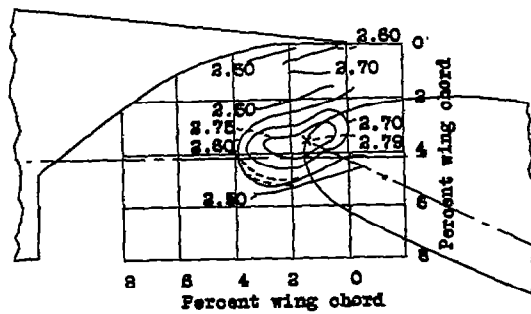
(a) $\delta_f = 10°$

(b) $\delta_f = 20°$

(c) $\delta_f = 30°$

(d) $\delta_f = 40°$

(e) $\delta_f = 50°$

Figure 4.- Contours of flap location for $c_{l_{max}}$. The 0.40 c_w slotted flap 1-a.
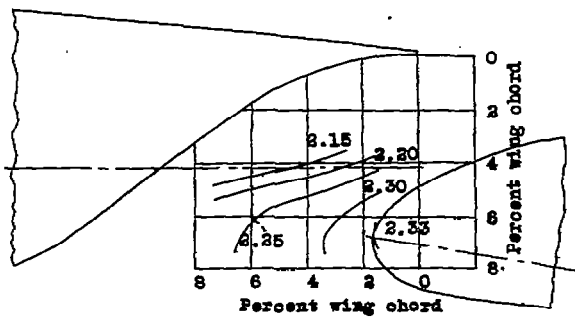
(a) $\delta_f = 10°$
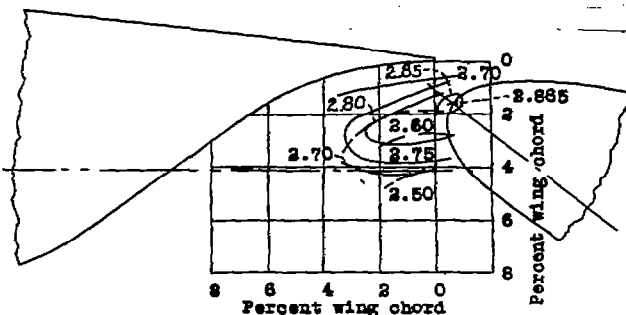
(b) $\delta_f = 20°$

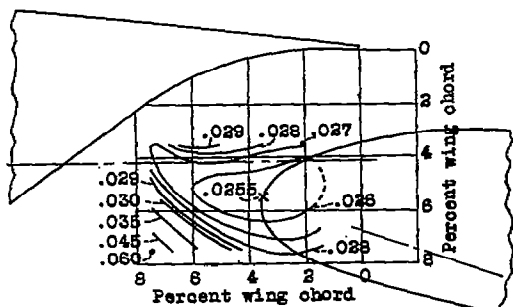(c) $\delta_f = 30°$

(d) $\delta_f = 40°$
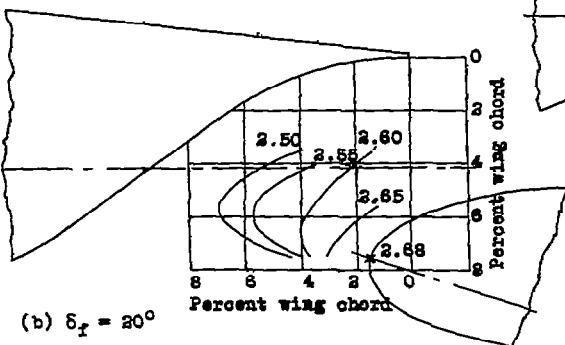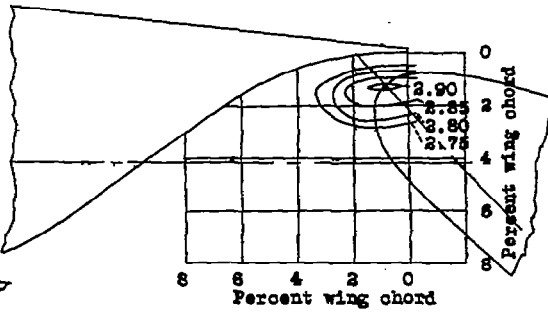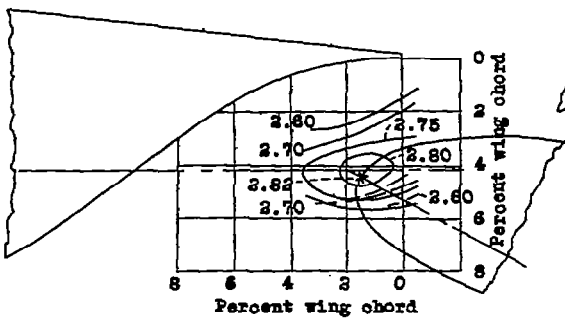
(e) $\delta_f = 50°$

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

(a) c_l=1.5; δ_f=10°

(c) c_l=2.0; δ_f=20°

(b) c_l=1.5; δ_f=20°
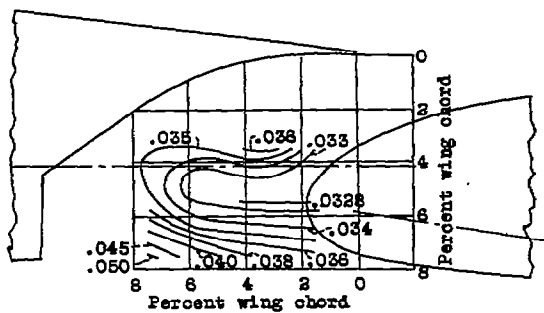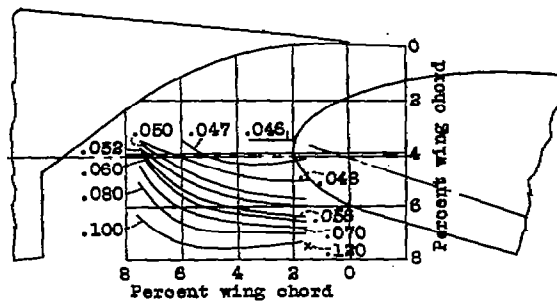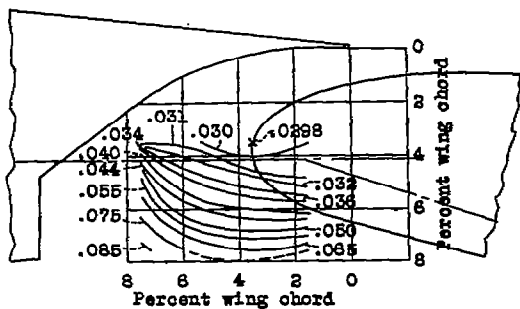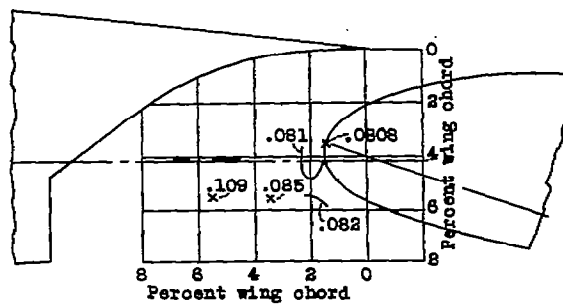
(d) c_l=2.5; δ_f=20°

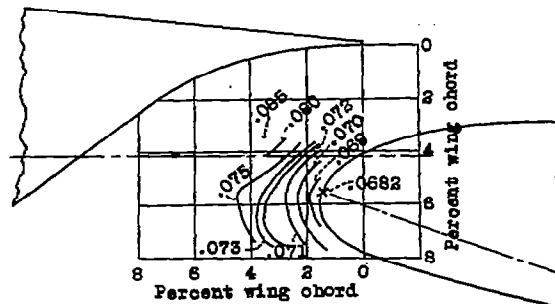Figure 6.— Contours of flap location for c_{d_0}. The 0.40c_w slotted flap 1-a.

(a) c_l=1.5; δ_f=10°

(c) c_l=2.0; δ_f=20°

(b) c_l=1.5; δ_f=20°
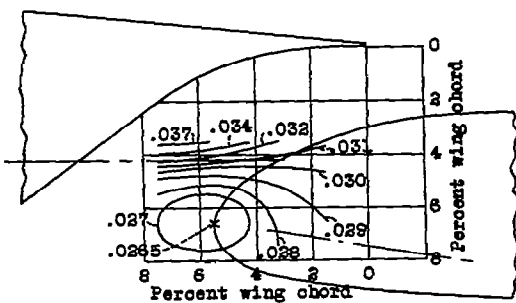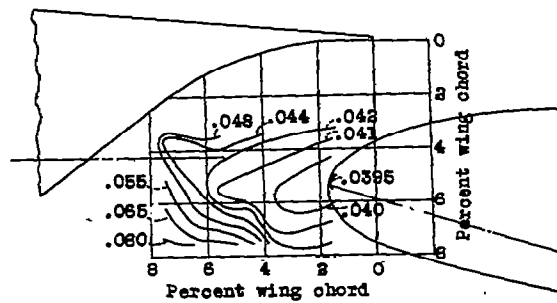
(d) c_l=2.5; δ_f=20°

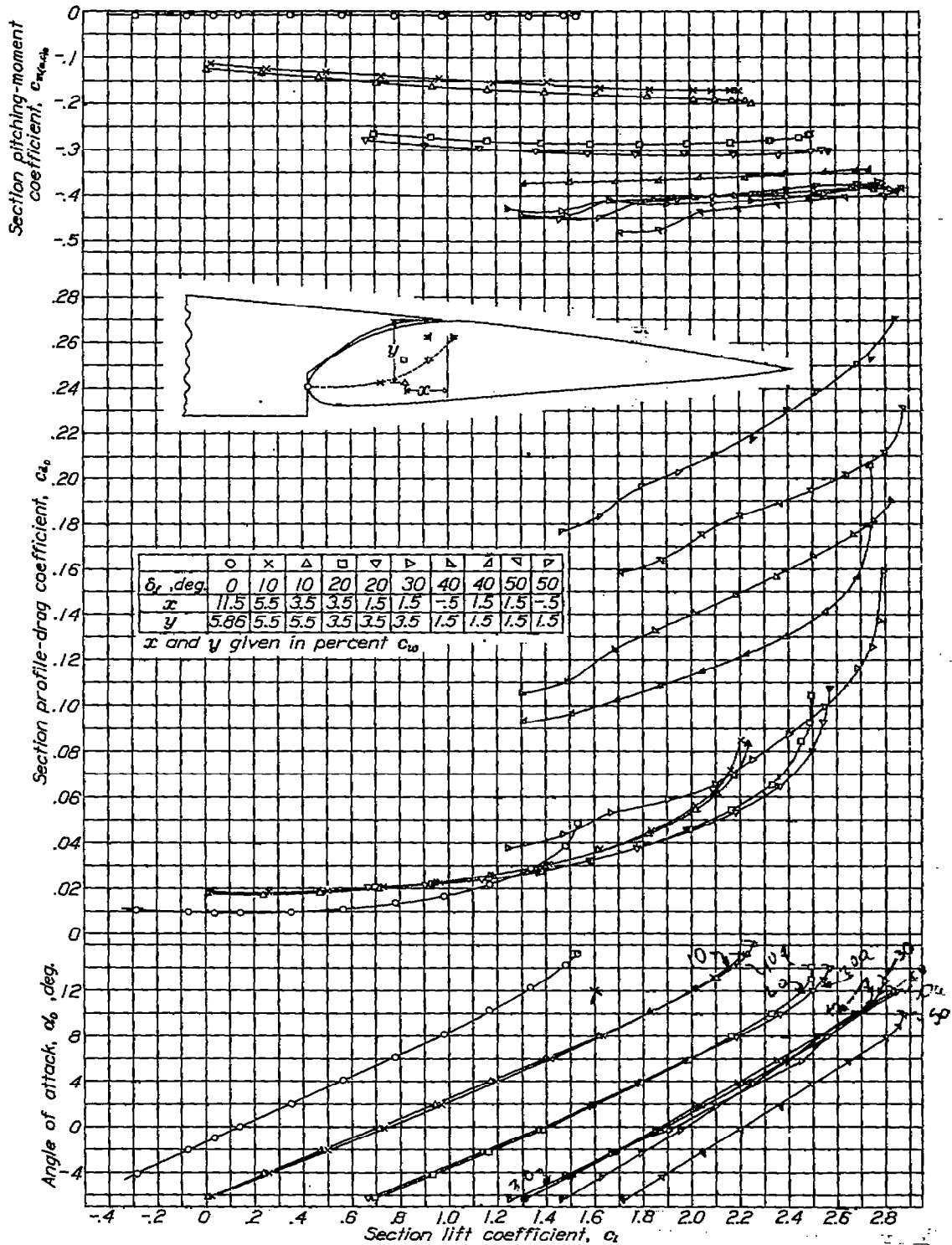Figure 7.— Contours of flap location for c_{d_0}. The 0.40c_w slotted flap 1-b.

Figure 8.- Section aerodynamic characteristics of N.A.C.A. 23012 airfoil
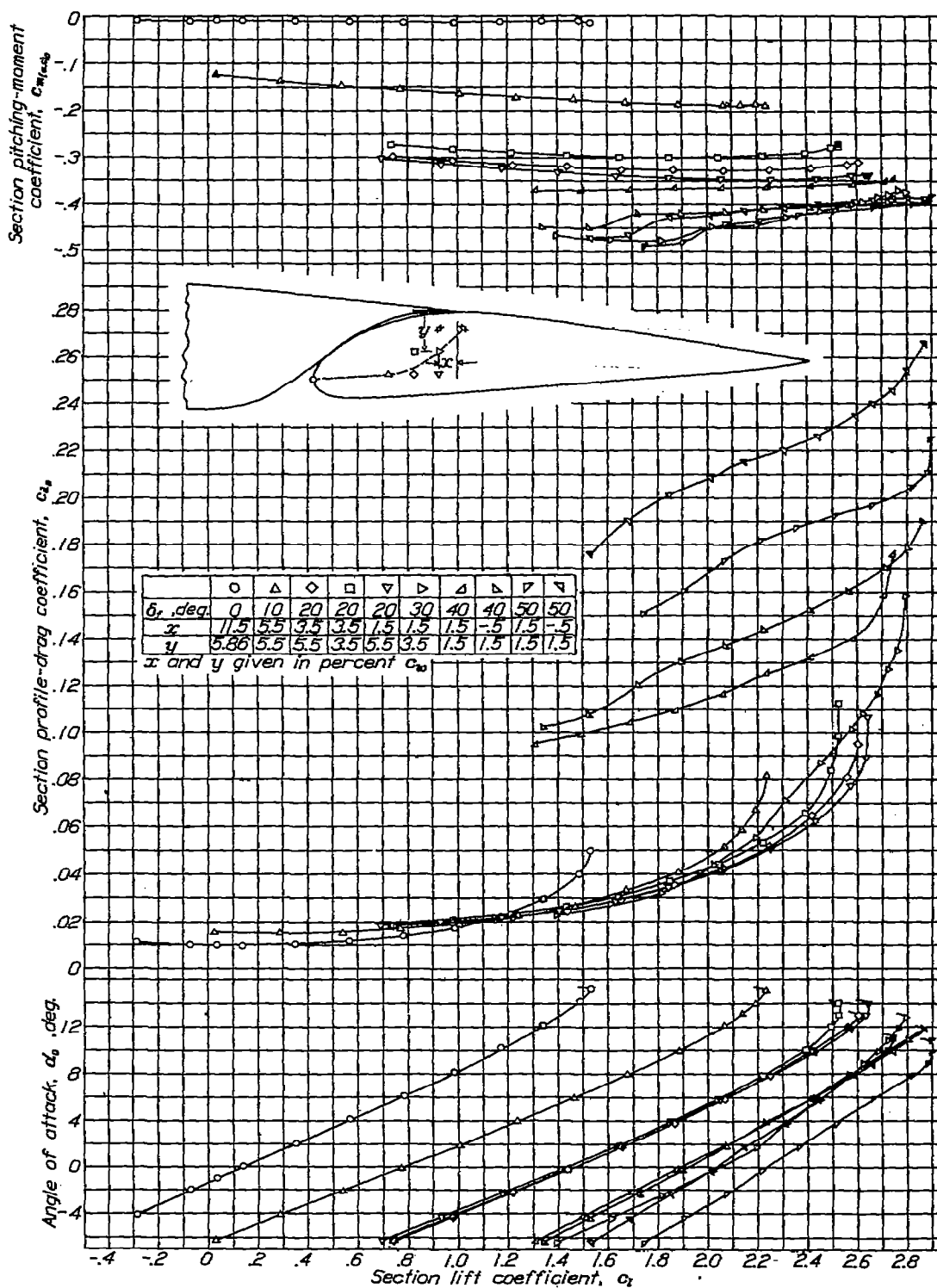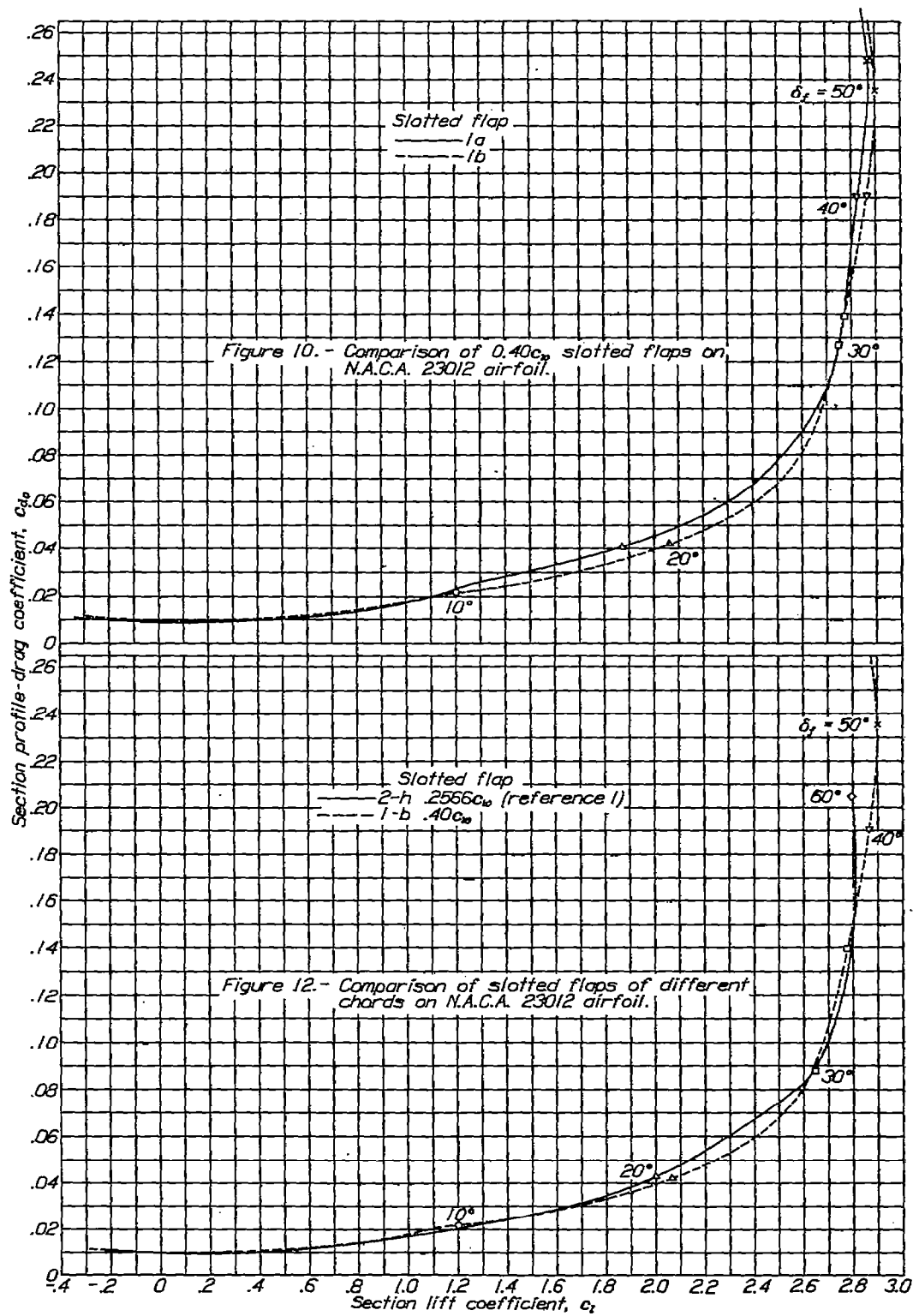with $0.40c_w$ slotted flap I-a.

δ_f ,deg.	O	△	◇	□	▽	▷	◁	◣	▽	◺
δ_f ,deg.	0	10	20	20	20	30	40	40	50	50
x	11.5	5.5	3.5	3.5	1.5	1.5	1.5	-.5	1.5	-.5
y	5.86	5.5	5.5	3.5	5.5	3.5	1.5	1.5	1.5	1.5

x and y given in percent c_w

Figure 9.- Section aerodynamic characteristics of N.A.C.A. 23012 airfoil
with 0.40c_w slotted flap 1-b.

Figure 10.- Comparison of 0.40c_w slotted flaps on N.A.C.A. 23012 airfoil.

Figure 12.- Comparison of slotted flaps of different chords on N.A.C.A. 23012 airfoil.
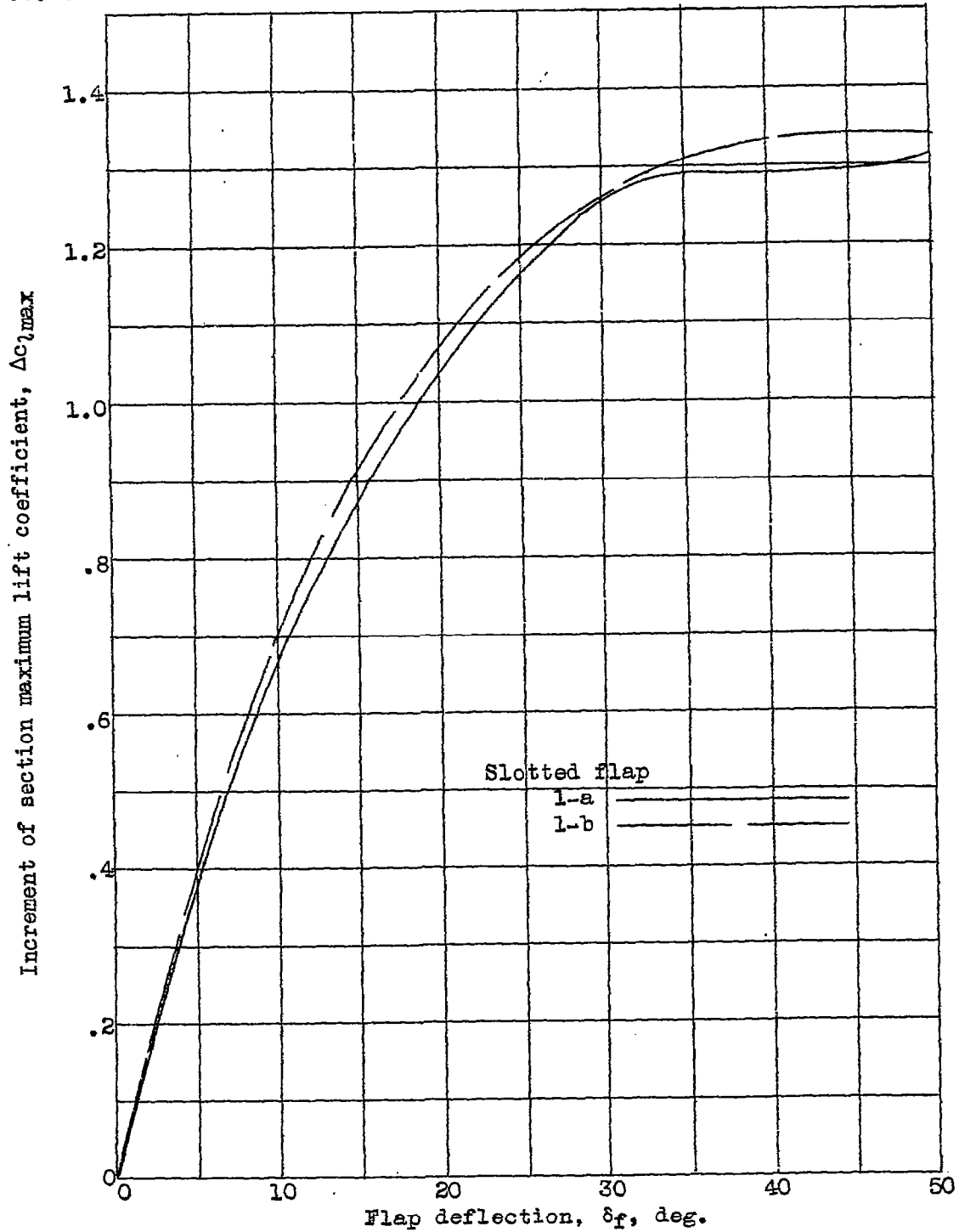
Figure 11.— Comparison of increments of section maximum lift
coefficient for slotted flaps 1-a and 1-b when moved and
deflected along the selected optimum paths.
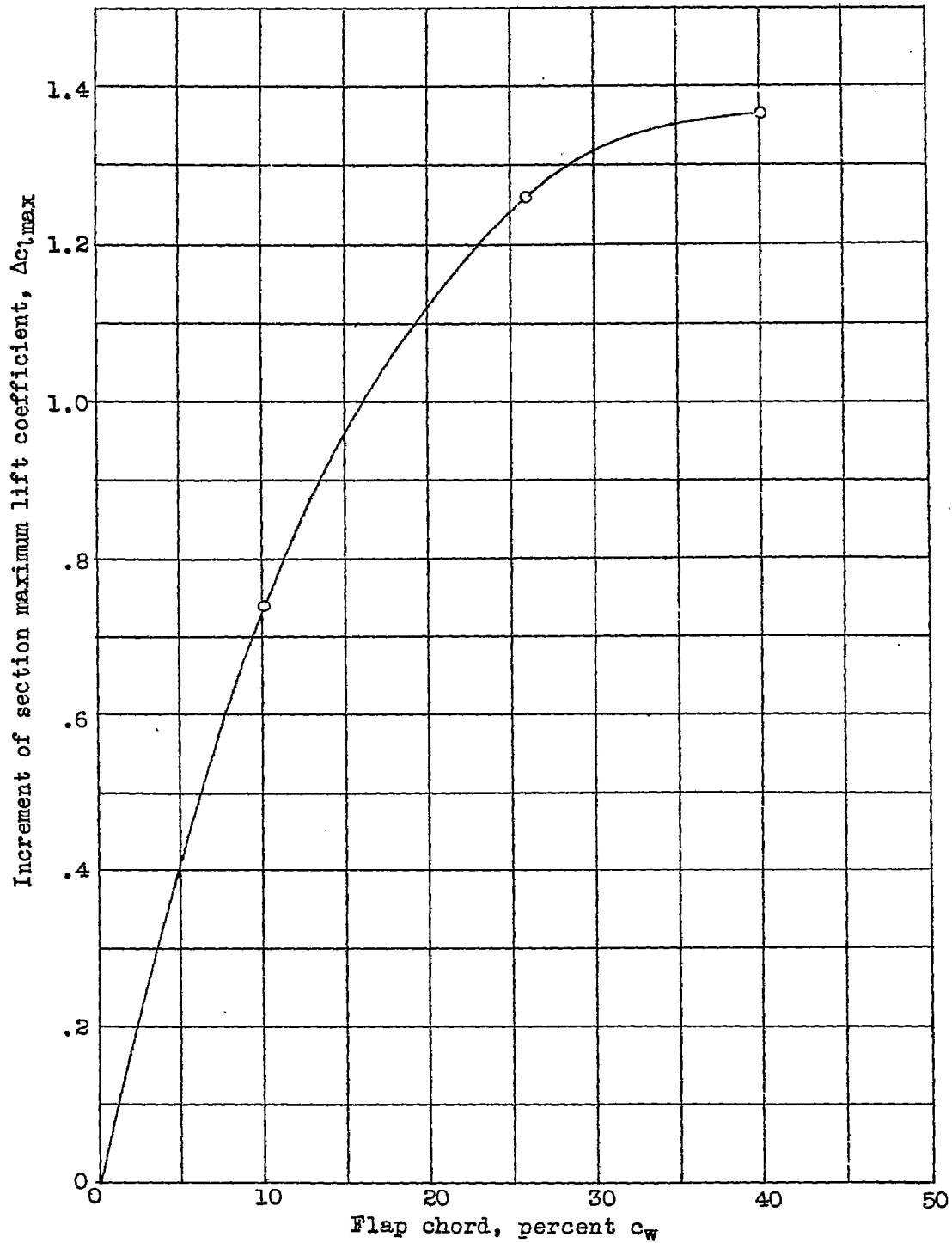
Figure 13.- Variation of increment of section maximum lift
           coefficient with flap chord. Slotted flaps on
N.A.C.A. 23012 airfoil.