# REPORT No. 689

## PRELIMINARY WIND-TUNNEL INVESTIGATION OF AN N. A. C. A. 23012 AIRFOIL WITH VARIOUS ARRANGEMENTS OF VENETIAN-BLIND FLAPS

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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 venetian-blind flaps to determine the aerodynamic section characteristics as affected by the over-all flap chord, the chords of the slats used to form the flap, the slat spacing, the number of slats, and the position of the flap with respect to the wing. Complete section data are given in the form of graphs for all the combinations tested.*

*The optimum arrangement of the venetian-blind flap was a combination in which the flap was located near the wing trailing edge. These arrangements of the venetian-blind flap were superior to any flaps previously tested for producing lift and giving low drag coefficients at high lift coefficients. The wing with this flap, however, had very large pitching-moment coefficients. When operated as split flaps, the venetian-blind flaps were inferior to the simple split flap in producing lift.*


### INTRODUCTION

The National Advisory Committee for Aeronautics is undertaking an extensive investigation of various wing-flap combinations to furnish information applicable to the design of high-lift devices for improving safety in flight. One of the most promising arrangements developed to date in this research is reported in reference 1. The arrangement is a slotted flap capable of giving high maximum lift coefficients, low drag coefficients at moderate and high lift coefficients, and high drag coefficients at high lift coefficients. This combination was still further improved by the addition of an auxiliary slotted flap, the investigation of which is reported in reference 2. The results of these tests indicated that still further improvement might be obtained by the use of a multiply slotted flap. Special types of multiply slotted flap—for example, the venetian-blind flap—have been suggested by E. F. Zap and also in reference 3.

The present report gives the results of an investigation of an airfoil with several arrangements of venetian-blind flaps. The spacing, the chord, the position, and the number of the slats composing the venetian-blind flap were considered. Some data for simple split flaps are also included for comparison with the data for venetian-blind flaps.

### MODELS

#### PLAIN AIRFOIL

The basic wing, or plain airfoil, used in these tests was built to the N. A. C. A. 23012 profile and had a chord of 3 feet and a span of 7 feet; it was previously used for the slotted-flap investigation of reference 1. New trailing-edge pieces were made for the model with necessary cut-outs for the new flaps.

#### VENETIAN-BLIND FLAPS

The venetian-blind flaps were made of small slats arranged to pivot on arms that were, in turn, pivoted to the wing. The deflection of the complete system of flaps is referred to as $\delta_{f_c}$. The deflection of the individual slats on the arms is designated $\delta_f$. When the individual slats are deflected differentially with respect to each other, the subscript carried by $\delta_f$ refers to the number of the slat on the supporting arm starting from the one nearest the axis of the arm. The various arrangements of venetian-blind flaps are shown in figures 1 to 4 with the flap both retracted and in the optimum deflected position as determined from the tests.

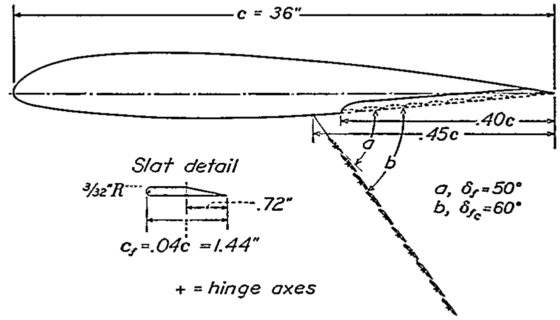
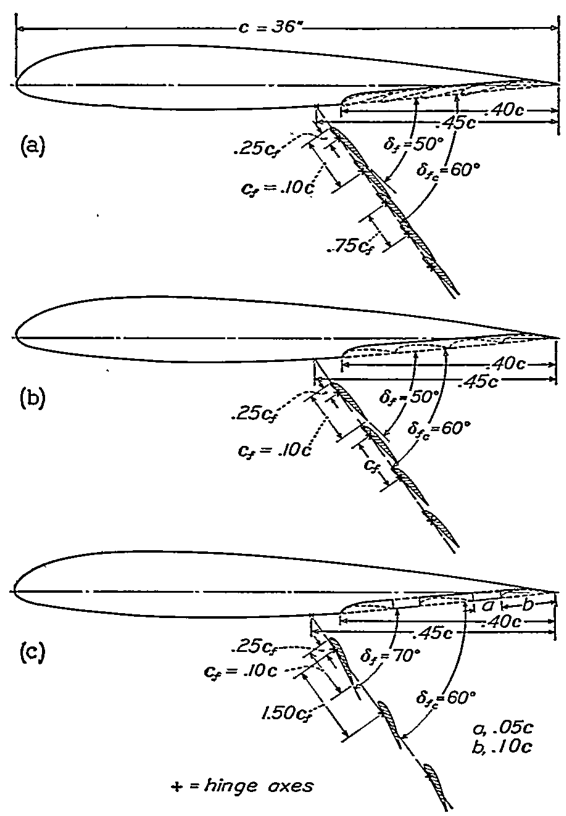



FIGURE 1.—Section of N. A. C. A. 23012 airfoil with a venetian-blind flap hinged at 0.55c; ten 0.04c slats.

The arrangement of the 10-slat venetian-blind flap is shown in figure 1. Each of the slats had a chord 4 percent of the basic wing chord; the sum of the chords of the slats was therefore 40 percent of the wing chord. Each slat was of solid brass with a round nose and a sharp trailing edge, as shown in the detail of figure 1, and was made to pivot on the supporting arm about the midchord point of its lower surface. The supporting arms were, in turn, pivoted 5 percent of the wing chord ahead of the first slat to provide a slot between the slats and the wing when the complete system was deflected.

Several arrangements of a venetian-blind flap with an over-all chord 40 percent of the wing chord are shown in figure 2. In all arrangements, the flap was composed of slats with chords 10 percent of the wing chord. These slats were built of wood to the Clark Y profile. They were pivoted on the supporting arms about the quarter-chord point of their lower surface. The arrangements of the five, the four, and the three slats shown in figure 2 were made to determine the optimum spacing of the slats. The filler blocks shown on the arrangement with three slats retracted were removed for tests with the flap deflected.

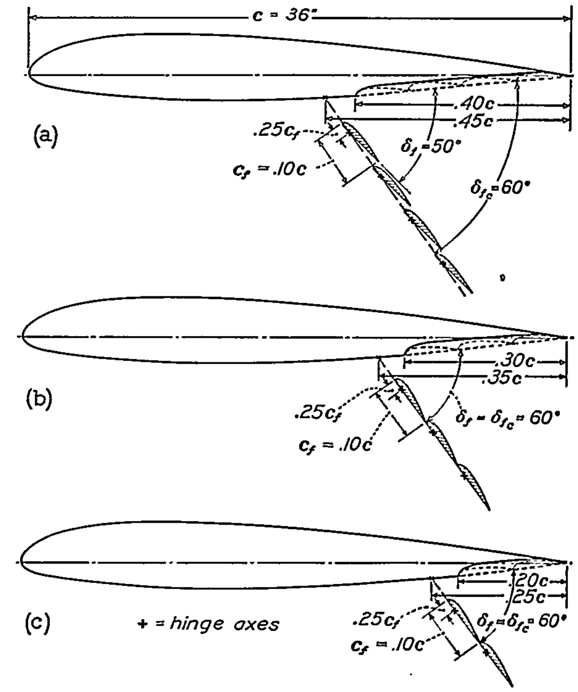
In order to determine the effect of over-all chord of the venetian-blind flap, the models were tested with flap chords 40, 30, and 20 percent of the wing chord, as shown in figure 3. The same Clark Y slats were used for this model as are shown in figure 2. As may be seen from figure 3, the 40-percent-chord flap was composed of four slats, the 30-percent-chord flap was composed of three slats, and the 20-percent-chord flap was composed of two slats.




(a) Five slats spaced $0.75c_f$.
(b) Four slats spaced $1.00c_f$.
(c) Three slats spaced $1.50c_f$.

FIGURE 2.—Sections of N. A. C. A. 23012 airfoil with several arrangements of venetian-blind flaps hinged at different 0.55c; 0.10c slats.

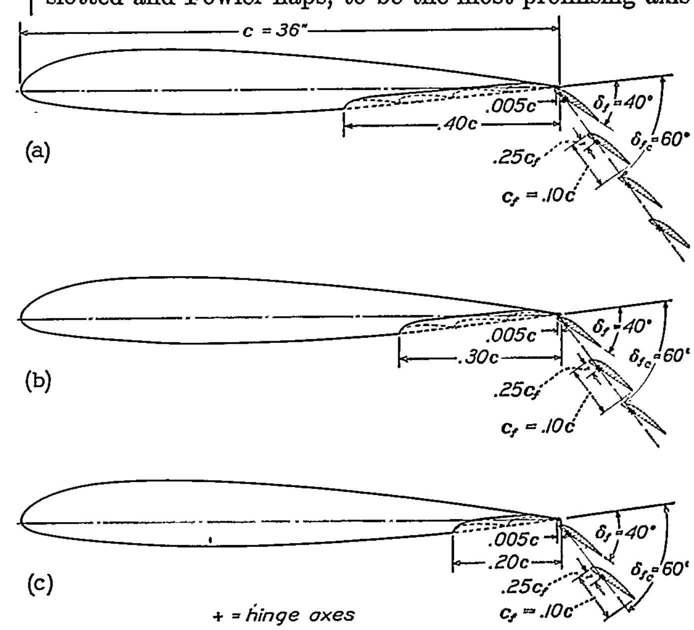
The venetian-blind flaps shown in figure 4 are the same as those shown in figure 3 except for the position of the arm axis, which is on the lower surface of the main




(a) The 0.55c location; four slats.
(b) The 0.65 location; three slats.
(c) The 0.75 location; two slats.

FIGURE 3.—Sections of N. A. C. A. 23012 airfoil with several arrangements of venetian-blind flaps hinged at different axis locations; 0.10c slats.

airfoil one-half of 1 percent of the wing chord ahead of the trailing edge of the wing. This position of the arm axis was estimated, from results of previous tests of slotted and Fowler flaps, to be the most promising axis




(a) Four slats.
(b) Three slats.
(c) Two slats.

FIGURE 4.—Sections of N. A. C. A. 23012 airfoil with several arrangements of venetian-blind flaps hinged at 0.995c; 0.10c slats.

location for the venetian-blind flap. This arrangement provided a gap of about 1 percent of the wing chord between the first slat and the trailing edge of the wing when the arms were deflected to the optimum position.

## TESTS

The models were mounted in the closed test section of the N. A. C. A. 7- by 10-foot wind tunnel so as to span the jet completely except for small clearances at each end. (See references 1 and 4.) 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 may be determined.

A dynamic pressure of 16.37 pounds per square foot was maintained for most of 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 $R_e$ 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.

Each arrangement of the venetian-blind flaps was tested with the flap fully retracted to determine the effect of the breaks in the lower surface of the airfoil on the drag. Tare tests were also made to determine the effect of the supporting arms.

All arrangements of venetian-blind flaps were tested with the arms deflected 30°, 60°, and 90°. For each arm deflection, the slats were deflected various amounts to determine the optimum arrangement from considerations of maximum lift. Tare tests were made to determine the effect of the supporting arms when deflected 60°.

An angle-of-attack range from −4° to the angle of attack for maximum lift was covered in 2° increments for each test. Lift, drag, and pitching moment were measured at each angle of attack.

## RESULTS AND DISCUSSION

### COEFFICIENTS

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

$c_l$ section lift coefficient ($l/qc$).

$c_{d_0}$ section profile-drag coefficient ($d_0/qc$).

$c_{m_{(a.c.)_0}}$ section pitching-moment coefficient about aerodynamic center of plain wing ($m_{(a.c.)_0}/qc^2$).

where

$l$ section lift.

$d_0$ section profile drag.

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

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

$c$ chord of basic airfoil with flap fully retracted.

and $\alpha_0$ angle of attack for infinite aspect ratio.

$\delta_f$ deflection of individual slats.

$\delta_{f_c}$ deflection of complete system of flaps.

### PRECISION

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

| | | | |
|---|---|---|---|
| $\alpha_0$ | ±0.1° | $c_{d_{0(c_l=1.0)}}$ | ±0.0006 |
| $c_{l_{max}}$ | ±0.03 | $c_{d_{0(c_l=2.5)}}$ | ±0.002 |
| $c_{m_{(a.c.)_0}}$ | ±0.003 | $\delta_{f_c}$ | ±2° |
| $c_{d_{0_{min}}}$ | ±0.0003 | $\delta_f$ | ±0.5° |

Slat position ±0.001$c$

The accuracy of the individual slat deflection $\delta_f$ refers to the settings of the slats relative to each other; the accuracy of the setting to the reference line (the lower surface of the wing) is ±2°. Likewise, the accuracy of the slat position is the spacing on the supporting arms.

The data have been corrected for the error due to support interference as determined from special tests with dummy supports in place.

### PLAIN AIRFOIL

The aerodynamic section characteristics of the plain N. A. C. A. 23012 airfoil as determined in the two-dimensional-flow installation are given in figure 5. These data were taken from reference 1 and require no further discussion here.

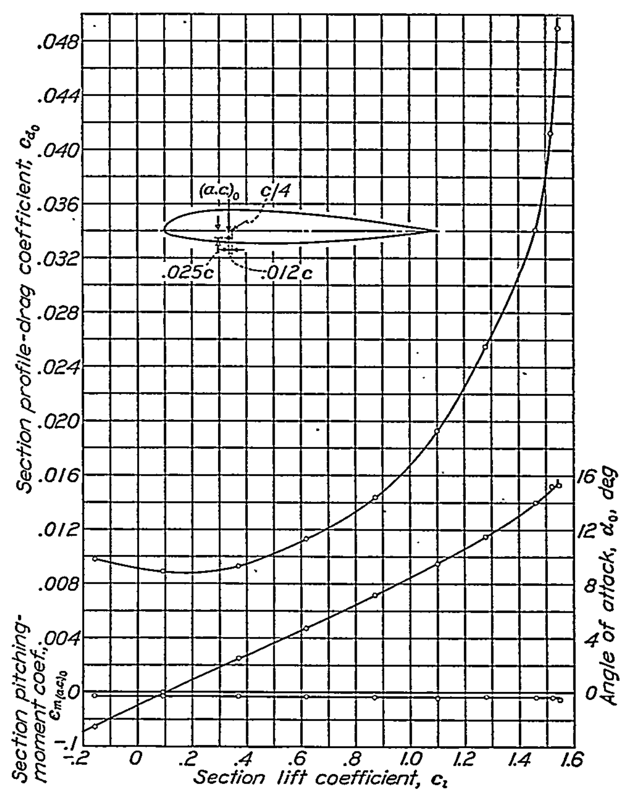



FIGURE 5.—Aerodynamic section characteristics of N. A. C. A. 23012 plain airfoil.

### VENETIAN-BLIND FLAP

**Effect on $c_{d_0}$ of retracted flaps.**—The increments of profile-drag coefficient caused by the breaks in the wing lower surface with the various arrangements of venetian-blind flaps retracted are shown in figure 6. The drag increments were obtained by taking the difference between faired drag curves of the respective combinations (after deduction of the drag due to the slat-supporting arms) and the plain wing. The drag increments are therefore only the increases due to breaks in the wing surface.

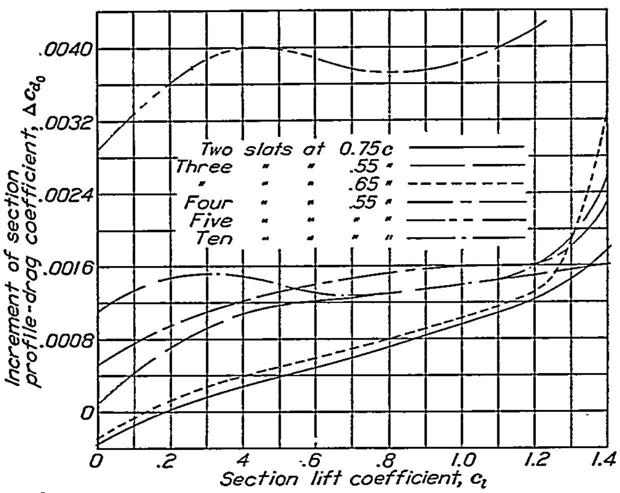



FIGURE 6.—Effect of retracted venetian-blind flaps on profile drag of airfoil.

The flaps composed of two and three slats hinged, respectively, at 0.75*c* and 0.65*c* showed practically no effect on the increment of profile-drag coefficient for lift coefficients less than 0.3 within the experimental accuracy of the tests. The increments of profile-drag coefficient reached about 0.001 for these combinations, however, at a lift coefficient of 1.0.

The flaps composed of three and four slats hinged at 0.55*c* gave an increment of profile-drag coefficient of about 0.0008 at a lift coefficient of 0.2, which increased to about 0.0014 at lift coefficients greater than 0.7.

The flap composed of 10 slats hinged at 0.55*c* gave an approximately constant increment of profile-drag coefficient of about 0.0014. If sufficient care is used in the design and the construction of the slats and the supports, none of these arrangements should be inferior to the arrangement with two slats hinged at the 0.75*c* location.

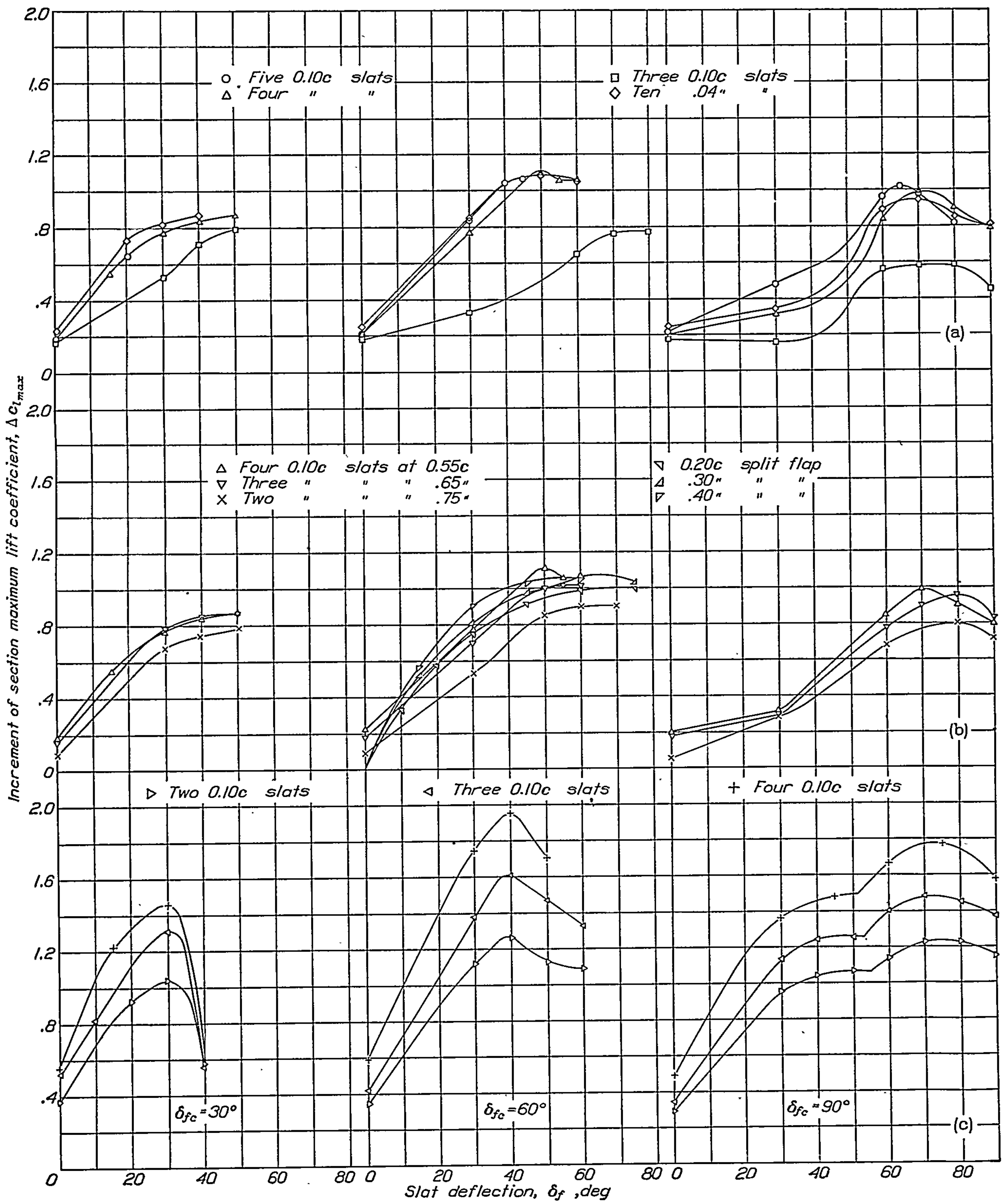
The arrangement with five slats hinged at the 0.55*c* axis gave increments of profile-drag coefficient of from 0.003 to 0.004, which are prohibitive. This arrangement (fig. 2 (a)) appears to be aerodynamically inferior when retracted.

**Effect on $c_{l_{max}}$ of deflecting flaps.**—In order to determine the optimum arrangement of venetian-blind flaps from considerations of maximum lift coefficient, the various arrangements have been compared in figure 7 on the basis of the increase of section maximum lift coefficient $\Delta c_{l_{max}}$ due to deflecting the flap. This $\Delta c_{l_{max}}$ is the difference between the maximum lift coefficients of the wing with the flap deflected and the the flap neutral, both at the same air speed.

The effect on $\Delta c_{l_{max}}$ of varying the spacing and the size of the slats composing the venetian-blind flap is shown in figure 7 (a). The 10-, the 5-, and the 4-slat flap arrangements all give about the same $\Delta c_{l_{max}}$ at a given arm setting. The optimum setting in all cases was with the slat-supporting arms down 60° and with the slats deflected so that the flaps were similar to a 0.45*c* split flap with a gap. The flap arrangement with the three slats was inferior to the other arrangements as a lift-increasing device. It appeared, therefore, that the optimum spacing of the slats (distance between slat hinge axes) was a spacing of one slat-chord length and that there was no advantage of using a large number of small-chord slats instead of a few slats of large chord.

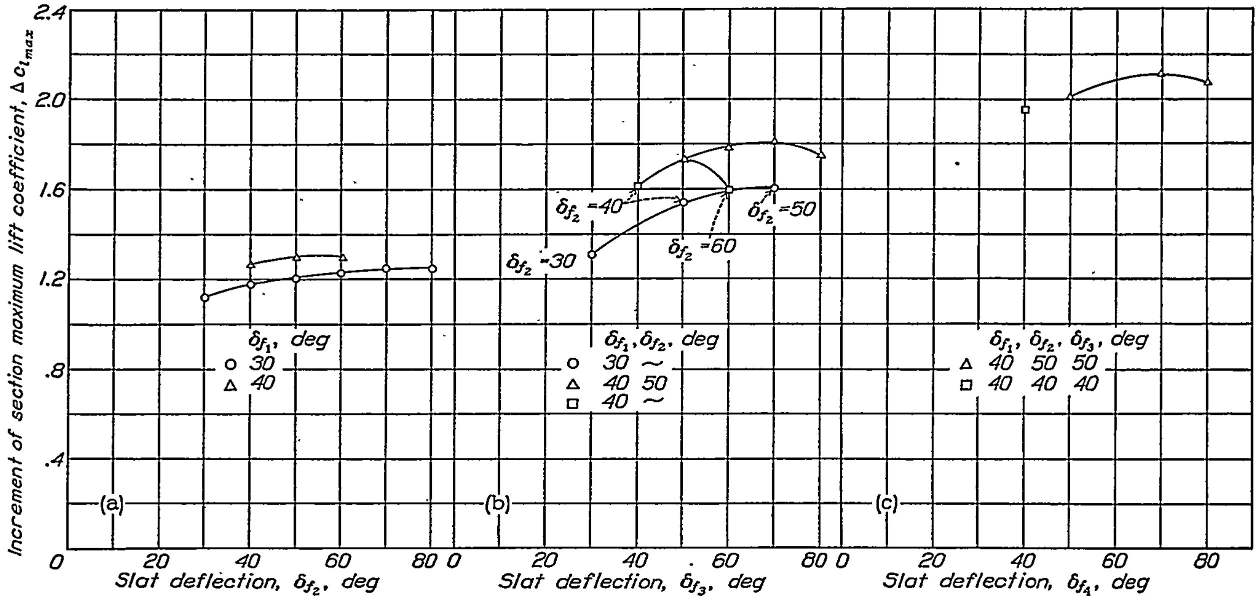
The effect on $\Delta c_{l_{max}}$ of varying the over-all chord of the venetian-blind flap by varying the number of slats is shown in figure 7 (b). The arrangements with three and four slats were slightly superior to the arrangement with two slats. None showed any improvement, however, over a simple split flap of corresponding over-all chord length, as shown by some curves for the simple split flaps, which are plotted for comparison. (See also reference 5.)

When the two-, the three-, or the four-slat flap arrangements were moved to the trailing edge of the wing and deflected (similar to a Fowler flap), the $\Delta c_{l_{max}}$ was greatly increased (fig. 7(c)). The optimum settings for each of the combinations were obtained with the 60° deflection of the supporting arms. In order still further to improve these arrangements, differential slat settings were tried with the combinations deflected 60°. In all cases, the effect was to increase $\Delta c_{l_{max}}$ (fig. 8); the best arrangement was the one with four slats, which gave a $\Delta c_{l_{max}}$ of 2.1. In order to show the effect of over-all flap chord on $\Delta c_{l_{max}}$, the optimum $\Delta c_{l_{max}}$ for each of the three arrangements is plotted against flap chord in figure 9 along with the results of the tests of a Fowler wing from reference 1. When based on the area of the wing with flap retracted, the $\Delta c_{l_{max}}$ increased nearly linearly with flap chord over the complete range tested. When based on the sum of the areas of the wing and the flap, the $\Delta c_{l_{max}}$ will be little increased by using chord lengths of the venetian-blind flaps greater than 0.30*c*. The loading per unit area was about the same for the three- or the four-slat venetian-blind flap as for the corresponding split flaps. (See figs. 7 and 9.) The venetian-blind flap was superior to the Fowler flap (references 1 and 6) of the same over-all chord. It is probable that better arrangements of the venetian-blind flaps can be obtained by a better location of successive slats.




(a) Several arrangements hinged at 0.55c.
(b) Several arrangements hinged at different axis locations.
(c) Several arrangements hinged at 0.995c.

FIGURE 7.—Increments of maximum lift coefficient for various arrangements of venetian-blind flaps.




(a) Two slats. (b) Three slats. (c) Four slats.

**Figure 8.**—Increments of maximum lift coefficients for several arrangements of venetian-blind flaps at 0.995c with differential slat settings; 0.10c slats.

**Aerodynamic characteristics of arrangements hinged at 0.55c.**—The complete aerodynamic section characteristics of the various arrangements of venetian-blind flaps hinged at 0.55c are given in figures 10 to 13. Each of these figures is divided into three parts, the characteristics for one arm setting being given in each part. The characteristics of the arrangements with 10, 5, and 4 slats (figs. 10 to 12) are all about the same. The most striking thing about these results was the large decrease in profile-drag coefficient with lift coefficient for the large flap deflections. The arrangement with three slats (fig. 13) was inferior to the others from considerations of high lift. A slat spacing of one chord length therefore appears to be most desirable because it is least complicated and closer spacing is not beneficial. There being practically no choice aerodynamically between the 10- and the 4-slat flaps, the 4-slat flap is somewhat superior because it is simpler structurally.

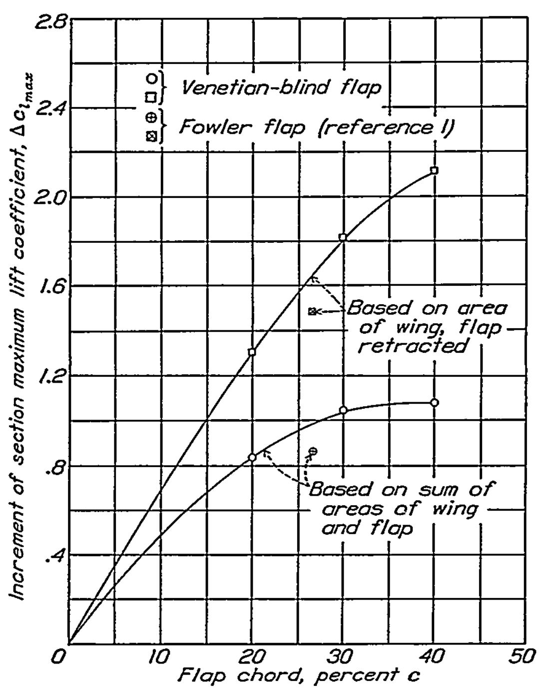
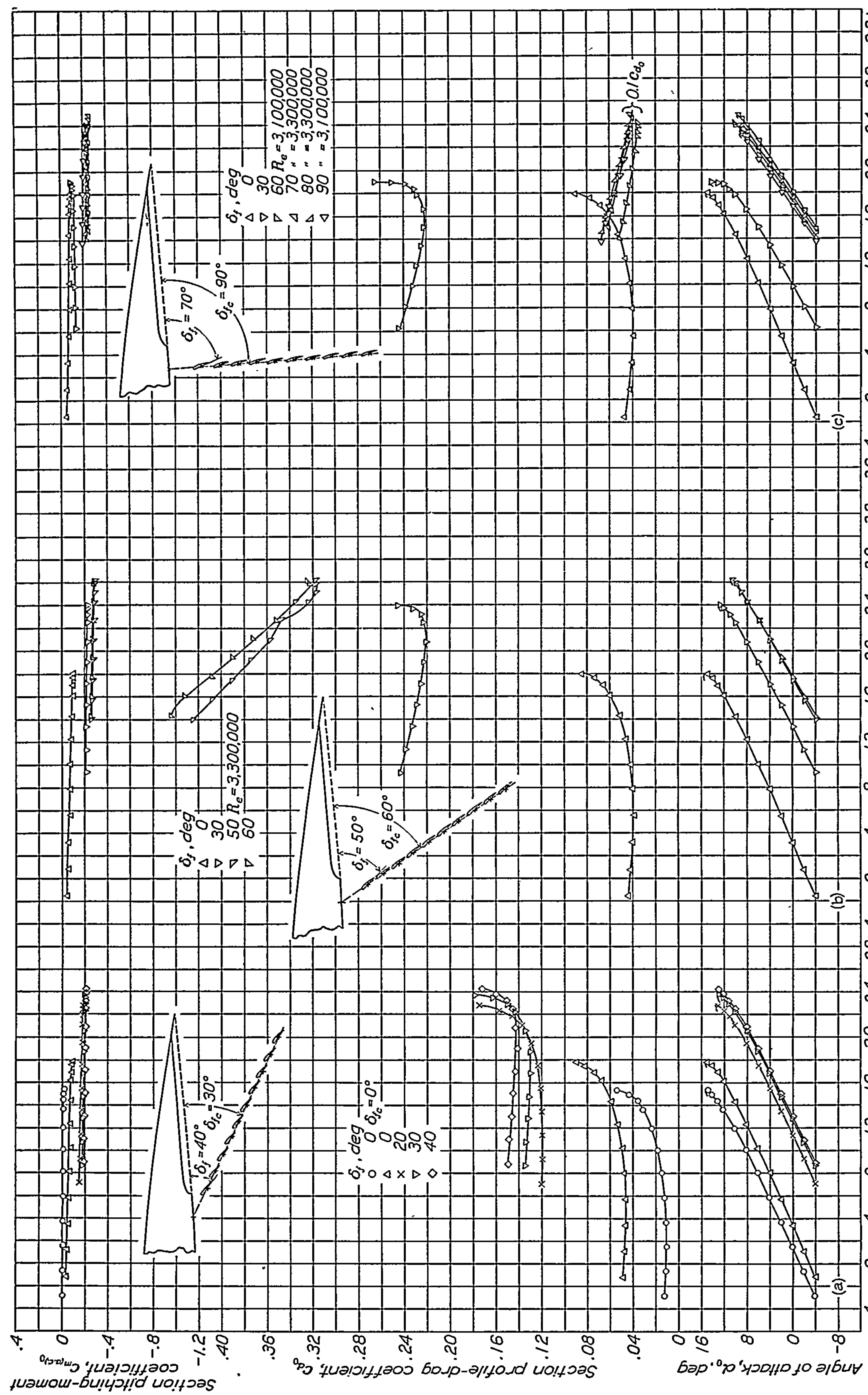



**Figure 9.**—Variation of increment of maximum lift coefficient with chord of venetian-blind flap; 0.10c slats at 0.995c axis.

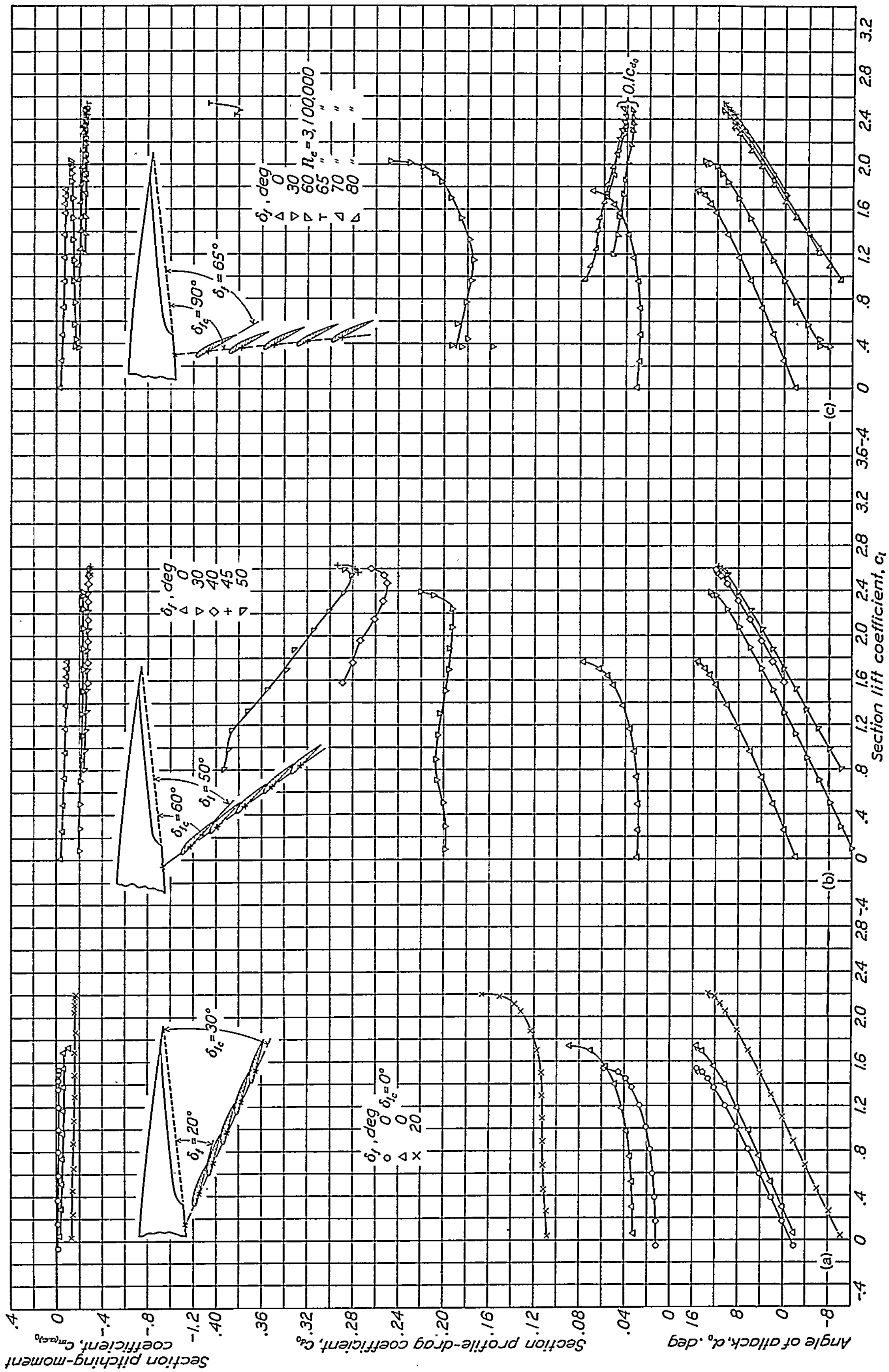
**Aerodynamic characteristics of combinations at different axis locations.**—The aerodynamic section characteristics for the three- and the two-slat flaps hinged, respectively, at 0.65c and 0.75c are given in figures 14 and 15. The characteristics of the two-, the three-, and the four-slat flaps are directly comparable, respectively, with the $0.20c_w$, the $0.30c_w$, and the $0.40c_w$ split flaps of reference 5. The drag was higher for all deflections for the venetian-blind flap than for the simple split flap. The pitching-moment coefficients were about the same as for the split flap of the same chord. The venetian-blind flaps hinged as simple split flaps were therefore inferior to the simple split flap except for very high drags. The four- and the three-slat flaps (figs. 12 and 14) gave both higher drags and larger pitching-moment coefficients than the two-slat flap (fig. 15).

**Aerodynamic characteristics of combinations hinged at 0.995c axis.**—The complete aerodynamic section characteristics for the four-, the three-, and the two-slat flaps are given, respectively, in figures 16 to 18.



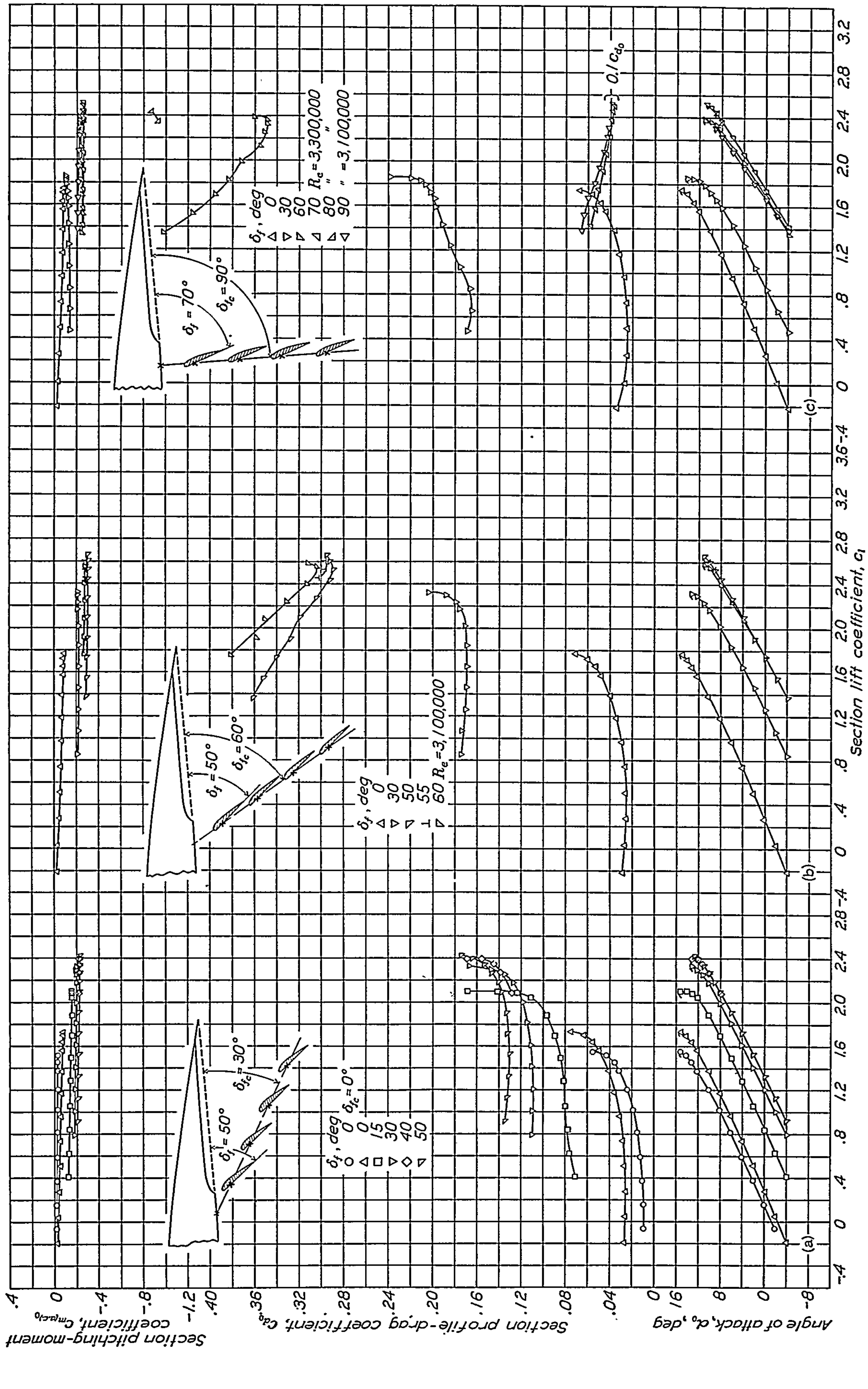

(a) $\delta_{fc}=30°$. (b) $\delta_{fc}=60°$. (c) $\delta_{fc}=90°$.

FIGURE 10.—Aerodynamic section characteristics of N. A. C. A. 23012 airfoil with a venetian-blind flap hinged at 0.55c axis; ten 0.04c slats.




(a) $\delta_{f_c}$=30°. (b) $\delta_{f_c}$=60°. (c) $\delta_{f_c}$=90°.

FIGURE 11.—Aerodynamic section characteristics of N. A. C. A. 23012 airfoil with a venetian-blind flap hinged at 0.55c axis; five 0.10c slats.

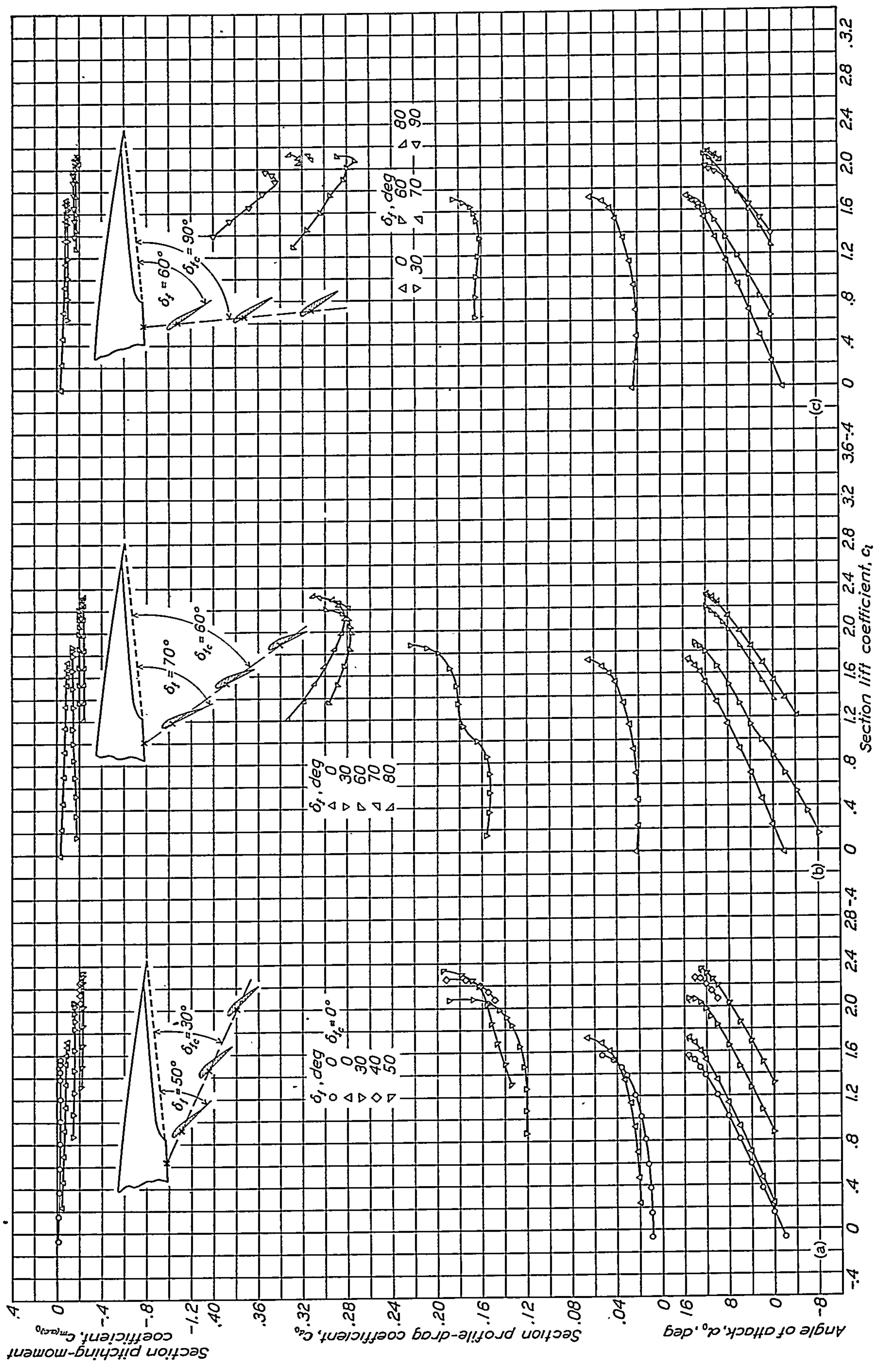



(a) $\delta_{fc}$=30°.

(b) $\delta_f$=60°.

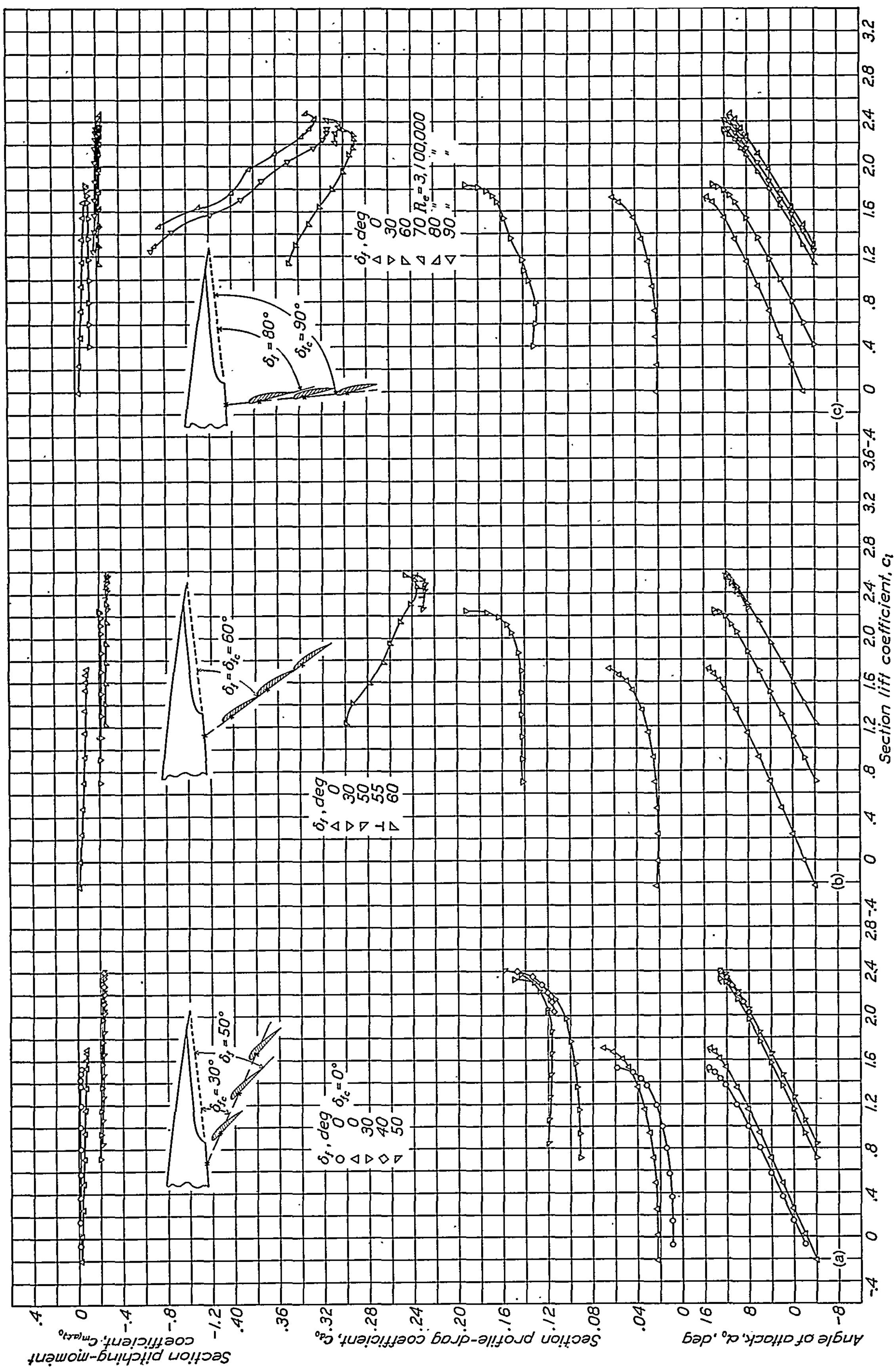
(c) $\delta_{fc}$=90°.

FIGURE 12.—Aerodynamic section characteristics of N. A. C. A. 23012 airfoil with a venetian-blind flap hinged at 0.55c axis; four 0.10c slats.



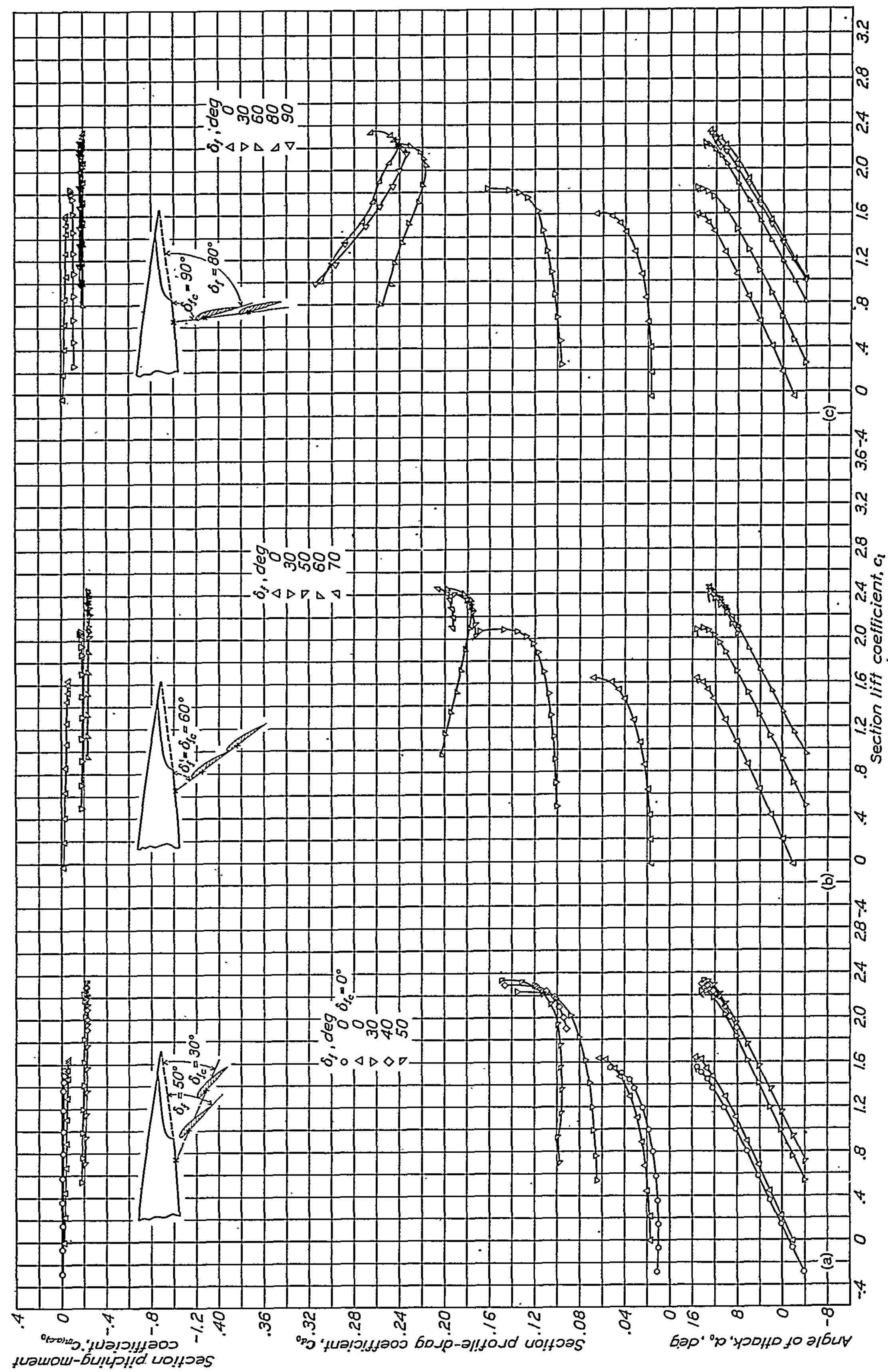

(a) $\delta_{f_c}=30°$.
(b) $\delta_{f_c}=60°$.
(c) $\delta_{f_c}=90°$.

FIGURE 13.—Aerodynamic section characteristics of N. A. C. A. 23012 airfoil with a venetian-blind flap hinged at 0.55c axis; three 0.10c slats.




(a) $\delta_{f_c}$=30°. (b) $\delta_{f_c}$=60°. (c) $\delta_{f_c}$=90°.

FIGURE 14.—Aerodynamic section characteristics of N. A. C. A. 23012 airfoil with a venetian-blind flap hinged at 0.65c axis; three 0.10c slats.



(a) $\delta_{f_c}=30°$. (b) $\delta_{f_c}=60°$. (c) $\delta_{f_c}=90°$.

FIGURE 15.—Aerodynamic section characteristics of N. A. C. A. 23012 airfoil with a venetian-blind flap hinged at 0.75c axis; two 0.10c slats.

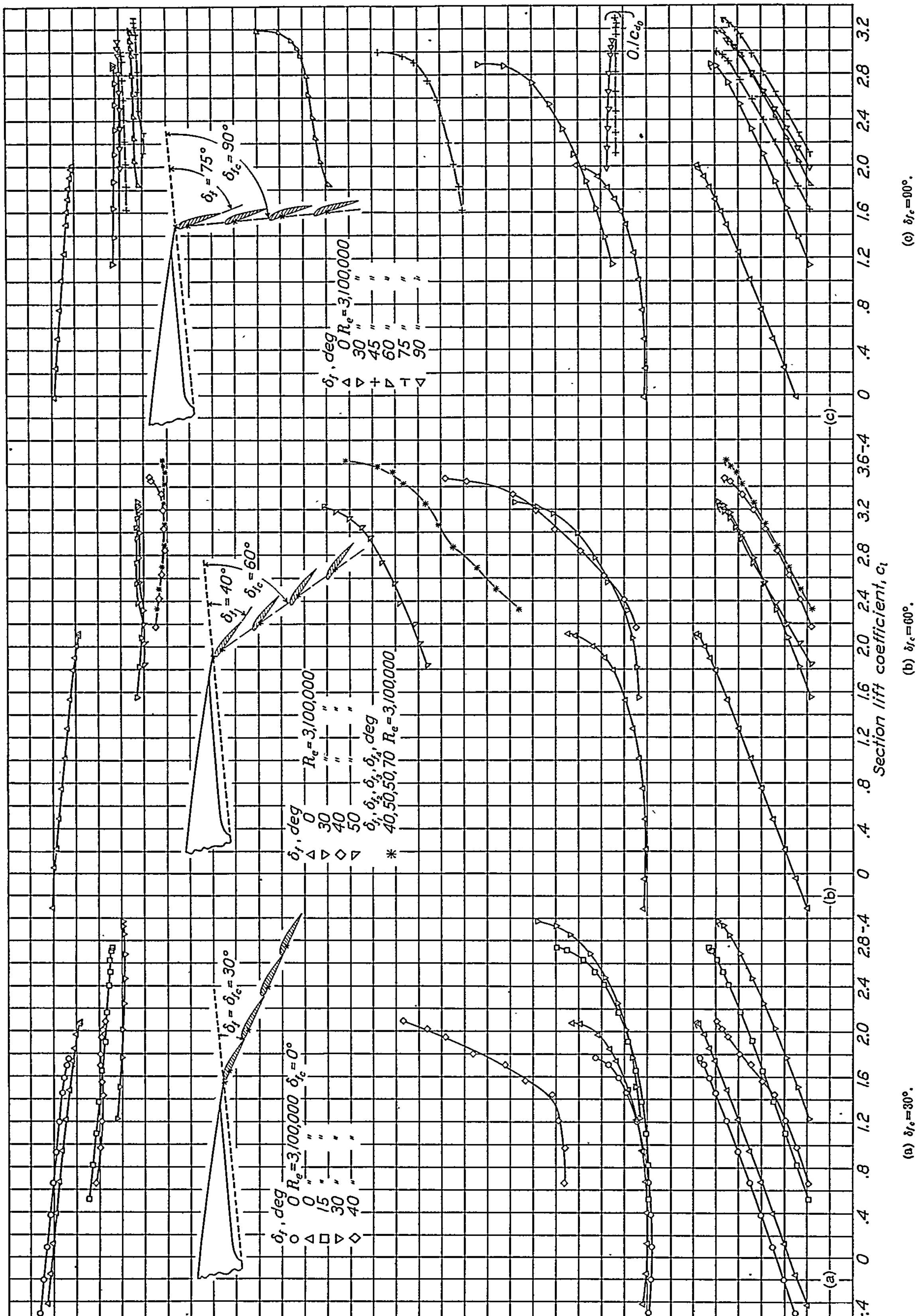
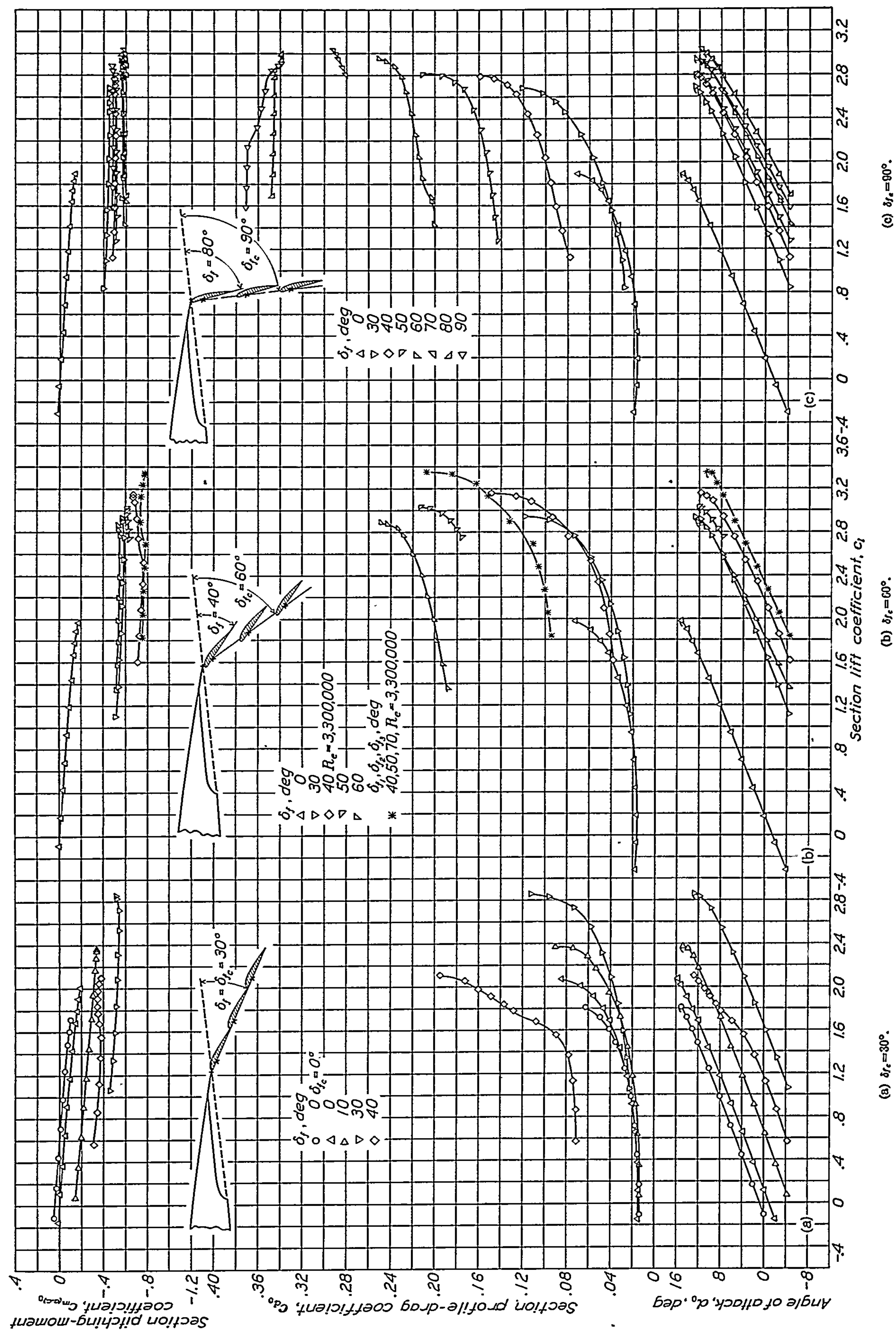
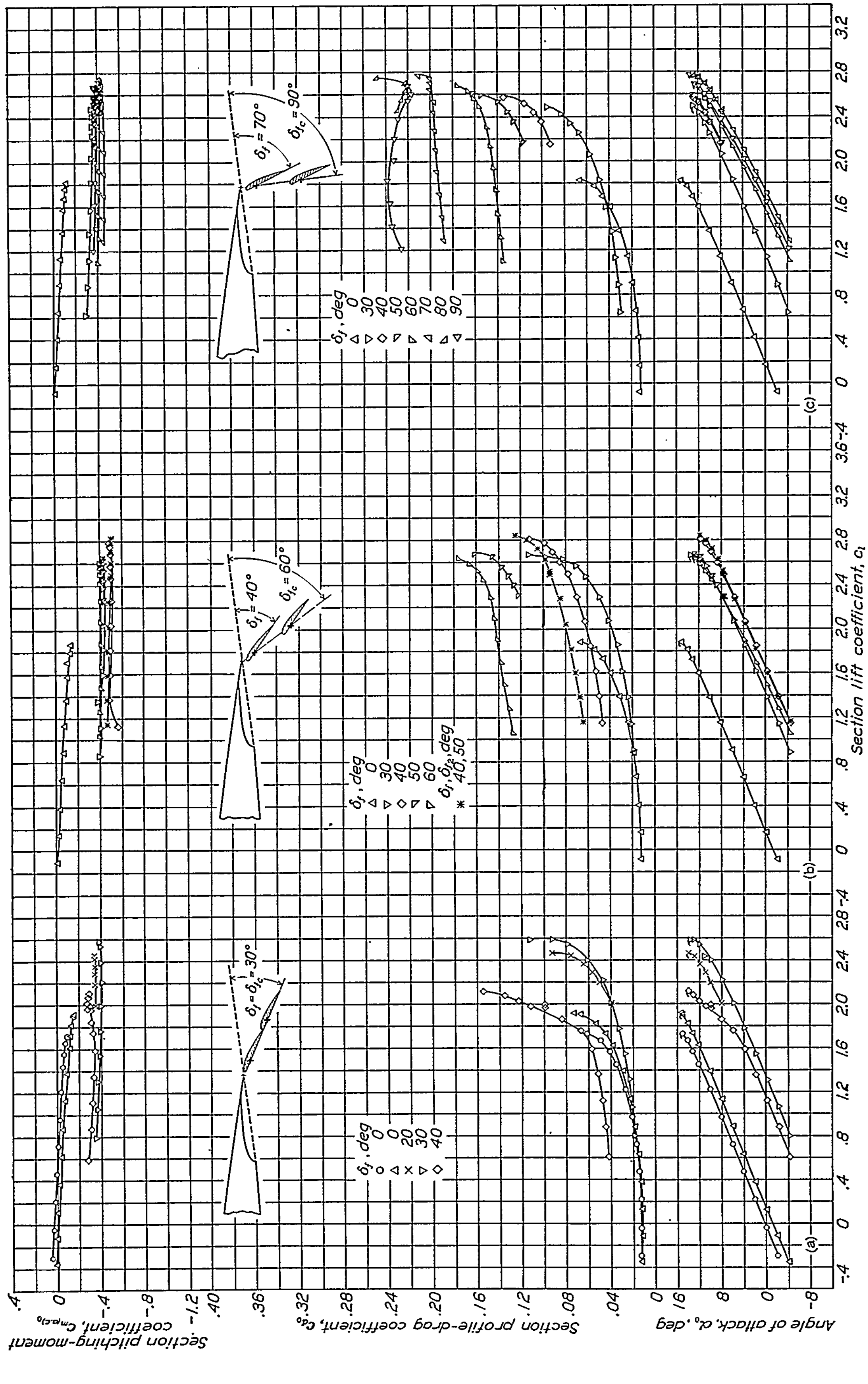



FIGURE 16.—Aerodynamic section characteristics of N. A. C. A. 23012 airfoil with a venetian-blind flap hinged at 0.995c axis; four 0.10c slats.




(a) $\delta_{f_c}=30°$. (b) $\delta_{f_c}=60°$. (c) $\delta_{f_c}=90°$.

FIGURE 17.—Aerodynamic section characteristics of N. A. C. A. 23012 airfoil with a venetian-blind flap hinged at 0.995c axis; three 0.10c slats.




(a) $\delta_{f_c}=30°$. (b) $\delta_{f_c}=60°$. (c) $\delta_{f_c}=90°$.

FIGURE 18.—Aerodynamic section characteristics of N. A. C. A. 23012 airfoil with a venetian-blind flap hinged at 0.905c axis; two 0.10c slats.

These arrangements were the only ones that showed any particular promise from a consideration of high maximum lift. The effects on profile-drag coefficient at various lift coefficients are listed for these arrangements in the following table.

COMPARISON OF VENETIAN-BLIND FLAPS LOCATED AT 0.995$c$

| Number of slats | $\delta_{f_c}$ (deg) | $c_{d_0}$ | | | |
|---|---|---|---|---|---|
| | | $c_l$=1.5 | $c_l$=2.0 | $c_l$=2.5 | $c_l$=3.0 |
| 4 | 30 | 0.026 | 0.038 | 0.058 | --------- |
| 4 | 60 | .027 | .032 | .049 | 0.082 |
| 4 | 90 | .038 | .062 | .099 | .240 |
| 3 | 30 | .026 | .037 | .056 | --------- |
| 3 | 60 | .026 | .036 | .055 | .100 |
| 3 | 90 | .036 | .055 | .086 | .290 |
| 2 | 30 | .027 | .039 | .069 | --------- |
| 2 | 60 | .026 | .038 | .063 | --------- |
| 2 | 90 | .032 | .052 | .095 | --------- |
| 0.2667$c_w$ Fowler flap (reference 1) | | .027 | .040 | .062 | --------- |
| 0.2566$c$ slotted flap (reference 1) | | .026 | .042 | .075 | --------- |

The results from reference 1 for the Fowler flap and the best slotted flap are included in the table for comparison.

At a lift coefficient of 1.5 for the optimum settings, all arrangements of venetian-blind flaps gave results equal to or better than the best slotted flap or the Fowler flap of reference 1. With the supporting arms deflected 60°, all three arrangements of venetian-blind flaps were of about equal merit.

At a lift coefficient of 2.0, the venetian-blind flap with two slats had profile-drag coefficients about 10 percent less than those of the best slotted flap of reference 1. The three- and the four-slat flap arrangements were progressively better than the two-slat arrangement. The venetian-blind flap with four slats had profile-drag coefficients 25 percent less than that of the best slotted flap of reference 1. All the venetian-blind flap arrangements with the best settings were superior to the Fowler flap at a lift coefficient of 2.0. All the arrangements give the lowest drag with the supporting arms deflected 60° at this lift coefficient.

At a lift coefficient of 2.5, the venetian-blind flaps had lower drag coefficients than the best slotted flap of reference 1. The profile-drag coefficient was from 16 percent less for the two-slat arrangement to 35 percent less for the four-slat arrangement than that for the best slotted flap of reference 1. The two-slat arrangement in its best setting, however, was slightly inferior to the Fowler flap of reference 1. The optimum supporting-arm deflection was 60° for this lift coefficient also.

At a lift coefficient of 3.0, the four-slat arrangement had a profile-drag coefficient only 10 percent higher than that of the best slotted flap at a lift coefficient of 2.5.

With the optimum differential setting of the slats (figs. 16 to 18), the variation of angle of attack with lift was approximately linear. This result was not true for the optimum uniform setting of the slats. Apparently, the flow over the slats is controlled much better with the differential angle settings of the slats. It is probable that better differential arrangements may be obtained by a different spacing of the individual slats.

The pitching-moment coefficients of these arrangements (figs. 16 to 18) were about the same as for Fowler flaps of the same over-all chord (references 1 and 6). The pitching-moment coefficients were very large, reaching a value of about 1.0 for the arrangement with four slats.

## CONCLUDING REMARKS

The results of these tests indicated that the venetian-blind flap, when operated near the wing trailing edge, was superior to any previous flap tested as a lift-increasing device and was also superior on the basis of low drag coefficients at high lift coefficients. The wing with this flap, however, had very large pitching-moment coefficients The venetian-blind flaps, when operated as split flaps, produced less lift than simple split flaps of the same over-all chord.

The tests also indicated that the best spacing of the slats in the venetian-blind flap was one slat-chord length and that there was no advantage in using 10 small slats in preference to 4 large slats in a flap of a given over-all chord length. Additional tests are desirable of the 30- and the 40-percent chord venetian-blind flaps operated near the wing trailing edge and using different numbers of slats and slats of different airfoil sections. In these tests, particular attention should be devoted to the differential angle settings of the slats and to the slat spacing.

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National Advisory Committee for Aeronautics,
Langley Field, Va., *January 10, 1939.*

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