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WIND-TUNNEL INVESTIGATION OF A LOW-DRAG

AIRFOIL SECTION WITH A DOUBLE SLOTTED FLAP

By Seymour M. Bogdonoff

Langley Memorial Aeronautical Laboratory
Langley Field, Va.

# NACA

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## SUMMARY

Tests of a 0.309-chord double-slotted flap on an NACA
65,3-118, a = 1.0 airfoil section have been made in the NACA
two-dimensional low-turbulence tunnel and the NACA two-
dimensional low-turbulence pressure tunnel. The purpose of
the investigation was to determine the lift, drag, and pitching-
moment characteristics for a range of flap deflections. The
results indicate that the combination of a low-drag airfoil
and a double-slotted flap of which the two parts moved as a
single unit gave higher maximum lift coefficients than have
been obtained with plain , split, or slotted flaps on low-
drag airfoils. The maximum lift coefficients were almost as
high as those obtained on conventional airfoils of about the
same thickness with 0.40-chord venetian-blind and double-slotted
flaps. The pitching moments were comparable to those obtained
with other high lift devices on conventional airfoils for
similar lift coefficients.

## INTRODUCTION

The NACA has for some time been investigating airfoils
equipped with high lift devices for the purpose of improving
the performance characteristics of these airfoils. The results
of tests of low-drag airfoils equipped with plain, split,
or slotted flaps have been presented in reference 1. The
results of references 2 and 3 show that, on conventional air-
foils, the highest lifts have been obtained with large-chord
venetian-blind and double-slotted flaps. The present inves-
tigation was made to determine the lift, drag, and pitching-
moment characteristics of a low-drag airfoil with a double-
slotted flap at various flap deflections. In addition, the
optimum position for maximum lift and the flap path were to
be found.

## MODEL

The airfoil section tested, an NACA 65,3-118, a = 1.0 section, was equipped with a 0.309-chord double-slotted flap. The wing model, built of wood and reinforced with steel ribs, had a 24-inch chord and was painted and sanded to produce aerodynamically smooth surfaces. The airfoil ordinates are presented in table I and a sketch of the model is shown in figure 1.

The double-slotted flap was made of aluminum and consisted of two parts. The forward portion, which is noted the fore flap, was separated from the main part, designated the rear flap, by a secondary slot. The ordinates for the fore flap and rear flap are presented in table II. The double-slotted flap operated as a single unit, with no relative motion between the fore flap and the rear flap. The operating mechanism and construction was similar to that of an ordinary slotted flap. The long lever links completely closed all gaps and slots when the double-slotted flap was retracted. The flap arrangement and pivot points are shown in figure 1 for the flap retracted and deflected $60^\circ$. The contour of the airfoil cut-out may be obtained by following the flap outline along the flap path.

## TEST PROCEDURE[1]

Tests were made of the model in the NACA two-dimensional low-turbulence tunnel and the NACA two-dimensional low-turbulence pressure tunnel. Section lift coefficients were obtained by measurement of the lift reaction on the floor and ceiling of the tunnel, and section drag coefficients were obtained by the wake-survey method. No drag measurements were made for flap deflections $\delta_f$ above $35^\circ$ because of considerable spanwise variation of drag. Pitching-moment coefficients, $c_{m_{c/4}}$, were measured by means of a calibrated torque rod and were taken about the quarter-chord point of the airfoil.

[1] At the time this report was originally published, some of the corrections required for reducing the test data to free-air conditions had not been determined. The values of section lift coefficient $c_l$ (figs. 2 to 5) should be corrected by the equation

$$c_{l(\text{corrected})} = 0.965c_l + 0.013c_{l_{\alpha}=-1^\circ}$$

where $c_{l_{\alpha}=-1^\circ}$ is the uncorrected section lift coefficient at section angle of attack of $-1^\circ$.

Preliminary tests were made to determine the best position of the fore flap relative to the rear flap on the basis of maximum section lift coefficient $c_{l_{max}}$ obtained at a flap deflection of $65^\circ$. This survey of fore-flap position was limited to those positions at which the flap could be retracted without having the fore flap protrude beyond the airfoil surface. The rear flap and fore flap were then fixed in the best relative position and the procedure was repeated for the unit. The flap path was so chosen that, at $45^\circ$ deflection, the flap was in a position at which both slots were effective and, at $55^\circ$ deflection, the flap was in a position at which maximum lift was reached. One pivot point was used for flap deflections up to $45^\circ$; whereas another pivot point was used for deflections from $45^\circ$ to $65^\circ$. (See fig. 1.)

Lift, drag, and pitching moments were obtained for flap deflections ranging from $0^\circ$ to $65^\circ$. Lift and drag data were obtained at a Reynolds number of 6,000,000 and pitching-moment data were obtained at a Reynolds number of 4,500,000. Scale effect on maximum lift was found for a range of Reynolds numbers from 4,000,000 to 9,000,000.

## RESULTS AND DISCUSSION

The results of the flap-position survey of the double-slotted flap for the flap position that would give maximum lift are presented in figure 2. Section lift characteristics for the combination with the flap deflected through a range of angles from $0^\circ$ to $65^\circ$ are presented in figure 3 for a Reynolds number of approximately 6,000,000. The maximum section lift coefficient obtained was 3.40 at a flap deflection of $65^\circ$, at which an increment in maximum lift coefficient of about 1.79 was obtained. Complete data for only one double-slotted flap are presented, but previous unpublished tests have shown that a decrease in chord of the fore flap gave a decrease in the maximum lift obtainable. The scale effect on maximum lift coefficient was found to be negligible over the range of Reynolds numbers tested. The small jogs in the lift curves, which appear for the $0^\circ$ and $10^\circ$ flap deflections, do not occur at the higher deflections.

Section drag characteristics for the combination for flap deflections from $0^\circ$ to $35^\circ$ are presented in figure 4. These tests were run at a Reynolds number of approximately 6,000,000. For the flap retracted and deflected $10^\circ$, fairly low drag coefficients are obtainable over a range of lift coefficients from about -0.2 to 0.8, which includes the normal high-speed and cruising-flight conditions. The relatively low drag obtained for the $35^\circ$ deflection is probably

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due to the establishment of smooth flow through the main slot. At a flap deflection of 35°, a section lift-drag of approximately 170 may be obtained at a lift coefficient of about 1.6.

For deflections above 35° no drag measurements were taken, but visual observation of the wake-survey manometer indicated that the drags were not excessive. The high lifts with comparatively low drags are the result of unstalled flows over the flap, as was indicated by tuft surveys which showed no separation of the flow over the flap up to a deflection of 65°.

Section pitching-moment characteristics for the airfoil-flap combination for all flap deflections tested are presented in figure 5. Although pitching-moment coefficients were measured at a Reynolds number of 4,500,000, little change in these characteristics is expected for other Reynolds numbers because previous tests of slotted flaps on low-drag wings (reference 1) have shown that, for lifts below maximum, scale effect on pitching moments is very small.

The double-slotted flap tested gave a lift coefficient higher than those obtained on the low-drag airfoils with plain, split, or slotted flaps reported in reference 1. The 0.309-chord double-slotted flap tested on a 18-percent-thick low-drag airfoil gave lifts almost as high as the lifts obtained on conventional 19- and 21-percent-thick airfoils with 0.40-chord venetian blind and double-slotted flaps (references 2 and 3). The increment in maximum lift was 1.79 for the low-drag airfoil and approximately 2.00 for the conventional airfoils. With the flap retracted, the double-slotted flap tested gave plain-wing section drag coefficients without the need of folding doors to close gaps and slots. The pitching moments shown in figure 5 are of about the same magnitude as pitching moments obtained for the 0.40-chord venetian-blind and the double-slotted flaps of references 2 and 3.

CONCLUSIONS

From the results of the tests of a 0.309-chord double-slotted flap on an NACA 65,3-118, a = 1.0 airfoil, the following conclusions were reached:

1. The double-slotted flap tested gave lift coefficients higher than those that have been obtained on NACA

low-drag airfoils with plain, split, or slotted flaps and did not affect the low-drag characteristics of the wing with the flap retracted.

2. The combination tested also offered low drag and moderate lift for the cruising condition and fairly low drag and high lift for take-off and climb conditions.

3. The lift coefficients obtained with the 0.309-chord double-slotted flap were almost as high as those obtained with larger-chord venetian-blind and double-slotted flaps on conventional airfoils of approximately the same thickness as the low-drag airfoil tested.

4. The high lift coefficients obtained with the 0.309-chord double-slotted flap were accompanied by high pitching moments, which were comparable to those obtained with other high lift devices giving similar maximum lift coefficients.


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



## REFERENCES

1. Jacobs, Eastman N., Abbott, Ira H., and Davidson, Milton: Preliminary Low-Drag-Airfoil and Flap Data from Tests at Large Reynolds Numbers and Low Turbulence, and Supplement. NACA A.C.R., March 1942.

2. Wenzinger, Carl J., and Harris, Thomas A.: Preliminary Wind-Tunnel Investigation of an N.A.C.A. 23012 Airfoil with Various Arrangements of Venetian-Blind Flaps. NACA Rep. No. 689, 1940.

3. Harris, Thomas A., and Recant, Isidore G.: Wind-Tunnel Investigation of NACA 23012, 23021, and 23030 Airfoils Equipped with 40-Percent-Chord Double Slotted Flaps. NACA Rep. No. 723, 1941.

## TABLE I

### ORDINATES FOR THE NACA 65,3-118, a = 1.0, AIRFOIL

[Station and ordinates in percent of airfoil chord]

| Upper surface | | Lower surface | |
|---|---|---|---|
| Station | Ordinate | Station | Ordinate |
| 0 | 0 | 0 | 0 |
| .444 | 1.348 | .556 | -1.298 |
| .638 | 1.633 | .812 | -1.563 |
| 1.180 | 2.057 | 1.320 | -1.949 |
| 2.421 | 2.820 | 2.579 | -2.634 |
| 4.910 | 3.988 | 5.090 | -3.672 |
| 7.406 | 4.912 | 7.594 | -4.488 |
| 9.905 | 5.631 | 10.095 | -5.165 |
| 14.909 | 6.903 | 15.091 | -6.231 |
| 19.918 | 7.632 | 20.082 | -7.036 |
| 24.929 | 8.541 | 25.071 | -7.645 |
| 29.942 | 9.054 | 30.058 | -8.082 |
| 34.956 | 9.383 | 35.044 | -8.353 |
| 39.971 | 9.526 | 40.029 | -8.454 |
| 44.986 | 9.464 | 45.014 | -8.368 |
| 50.000 | 9.145 | 50.000 | -8.041 |
| 55.013 | 8.593 | 54.987 | -7.497 |
| 60.024 | 7.853 | 59.976 | -6.781 |
| 65.032 | 6.965 | 64.968 | -5.935 |
| 70.037 | 5.972 | 69.963 | -5.000 |
| 75.039 | 4.904 | 74.961 | -4.008 |
| 80.037 | 3.788 | 79.963 | -2.990 |
| 85.032 | 2.661 | 84.968 | -1.982 |
| 90.023 | 1.582 | 89.977 | -1.066 |
| 95.012 | .650 | 94.988 | -.234 |
| 100.000 | 0 | 100.000 | 0 |

Leading edge radius = 1.92

Slope = 0.042

TABLE II

ORDINATES FOR A 0.309-CHORD DOUBLE-SLOTTED FLAP ON

AN NACA 65,3-118, a = 1.0 AIRFOIL

[Station and ordinates in percent of airfoil chord]

| | Fore flap | | | Rear flap | |
|---|---|---|---|---|---|
| Station | Upper surface | Lower surface | Station | Upper surface | Lower surface |
| 69.083 | -3.125 | ------- | 75.583 | -1.250 | ------- |
| a69.104 | -3.542 | ------- | 75.833 | -.104 | -2.292 |
| 69.167 | -2.417 | -3.729 | 76.250 | .500 | -2.729 |
| 69.375 | -1.792 | -4.104 | 77.083 | 1.167 | -3.146 |
| 69.583 | -1.458 | -4.333 | 78.125 | 1.771 | -3.250 |
| 70.000 | -.708 | -4.500 | 79.167 | 2.188 | -3.167 |
| 70.833 | .188 | -4.438 | 81.250 | 2.583 | -2.729 |
| 72.083 | 1.050 | -2.708 | 83.332 | 2.583 | -2.292 |
| 73.333 | 1.604 | .292 | 85.417 | 2.425 | -1.867 |
| 74.583 | 1.958 | 1.438 | 87.500 | 2.104 | -1.467 |
| 75.208 | 2.125 | 1.771 | 90.083 | 1.582 | -1.058 |
| 75.833 | 2.250 | 2.040 | 95.012 | .650 | -.334 |
| 76.458 | 2.375 | 2.292 | 100.000 | 0 | 0 |
| 76.875 | 2.438 | 2.417 | | | |

aReference point for fig. 2

Flap retracted

Flap deflected 65°

Flap path

Flap deflection, $\delta_f$

Flap pivot from 45° to 65° deflection

Flap pivot from 0° to 45° deflection

0.369
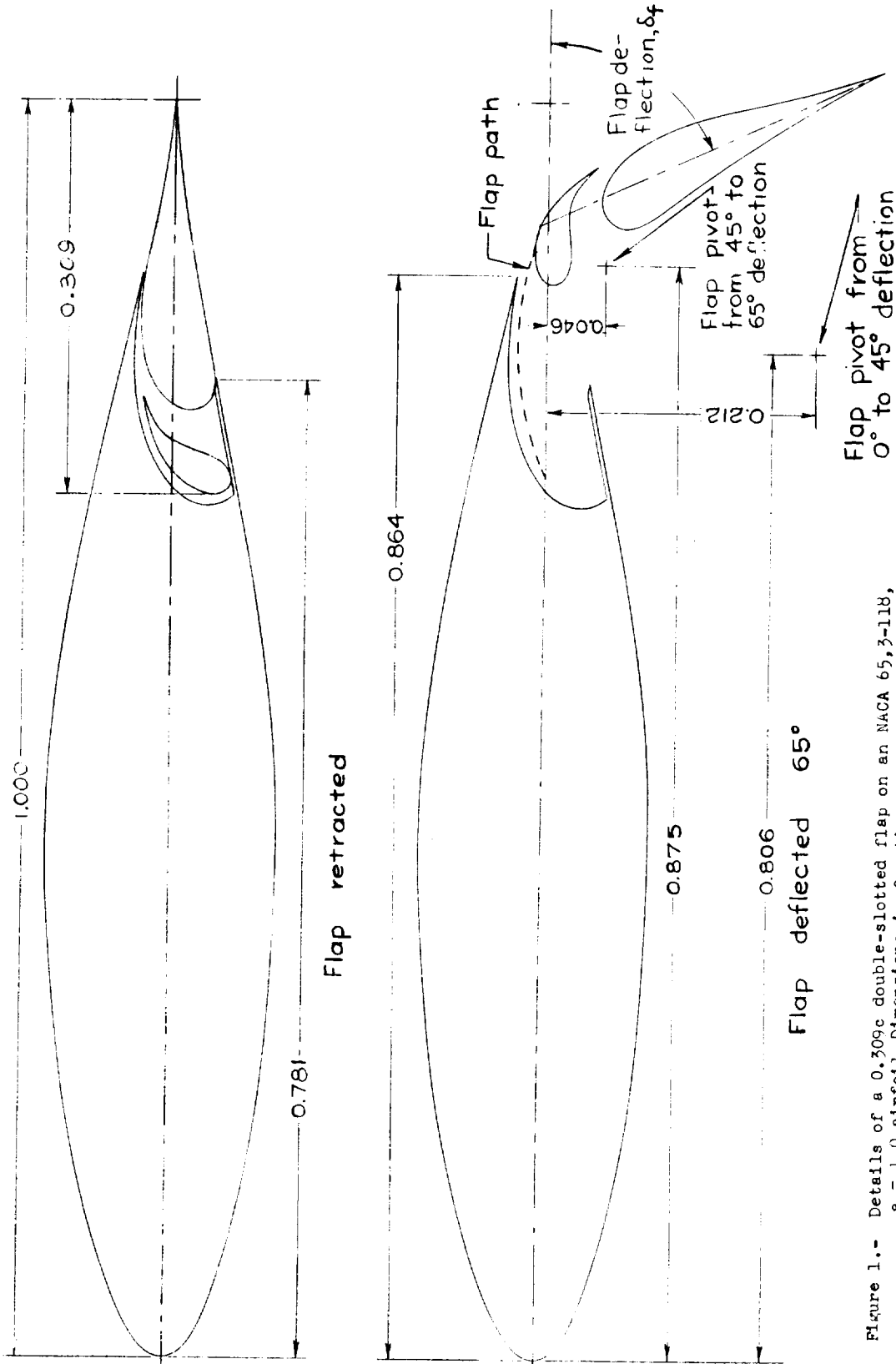
1.000

0.781

0.864

0.875

0.806

0.046

0.046

0.212

Figure 1.- Details of a 0.309c double-slotted flap on an NACA 65,3-118, a = 1.0 airfoil. Dimensions in fraction of chord.

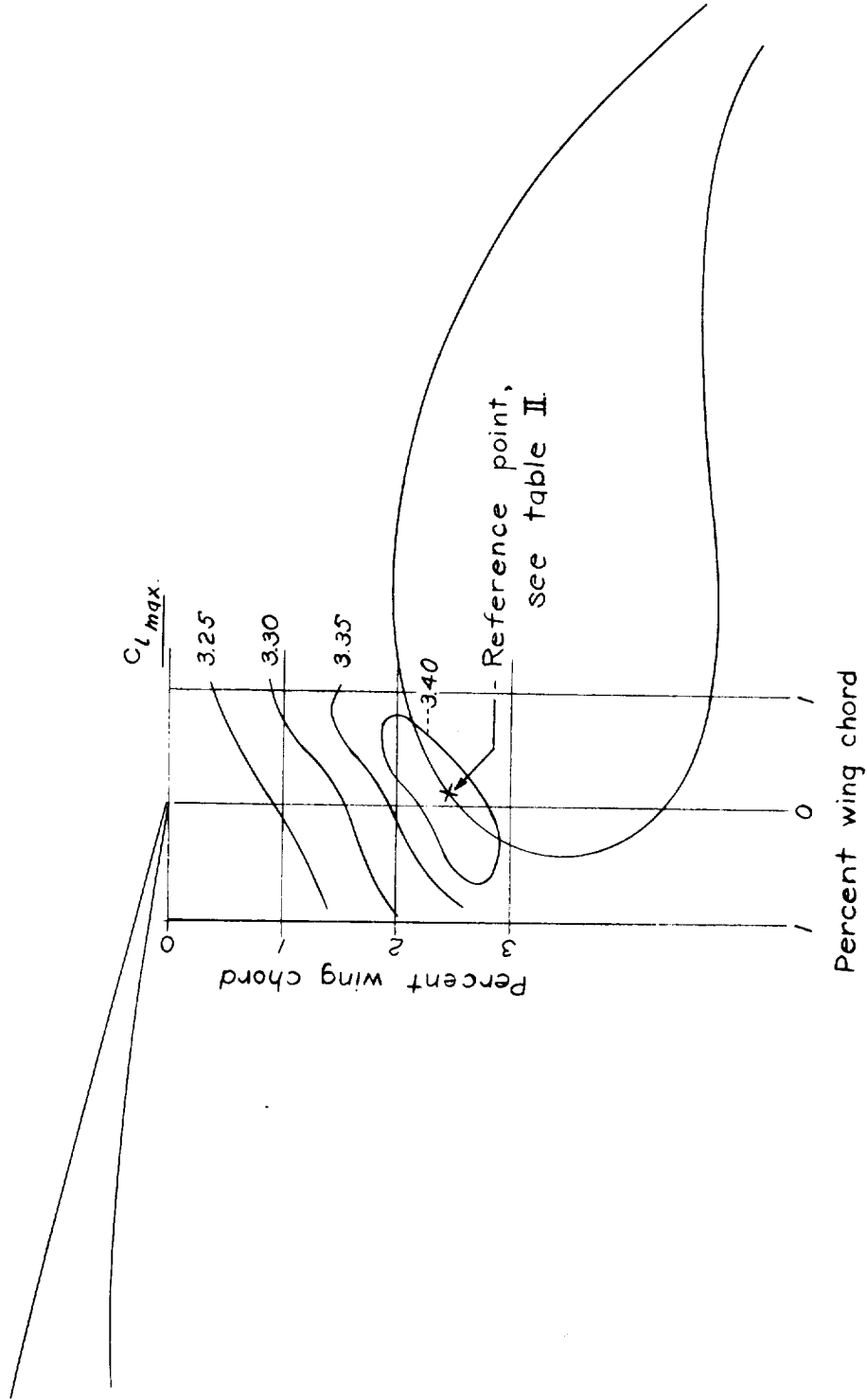Figure 2.- Contours of flap location for $c_{l_{max}}$ for a 0.309c double-slotted flap on an NACA 65,3-118, a = 1.0 airfoil; $\delta_f$, 65°.

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(1 block = 10 divisions on 1/30" Eng.r. Scale)

Section lift coefficient, $c_l$

$\delta_f$ (deg)
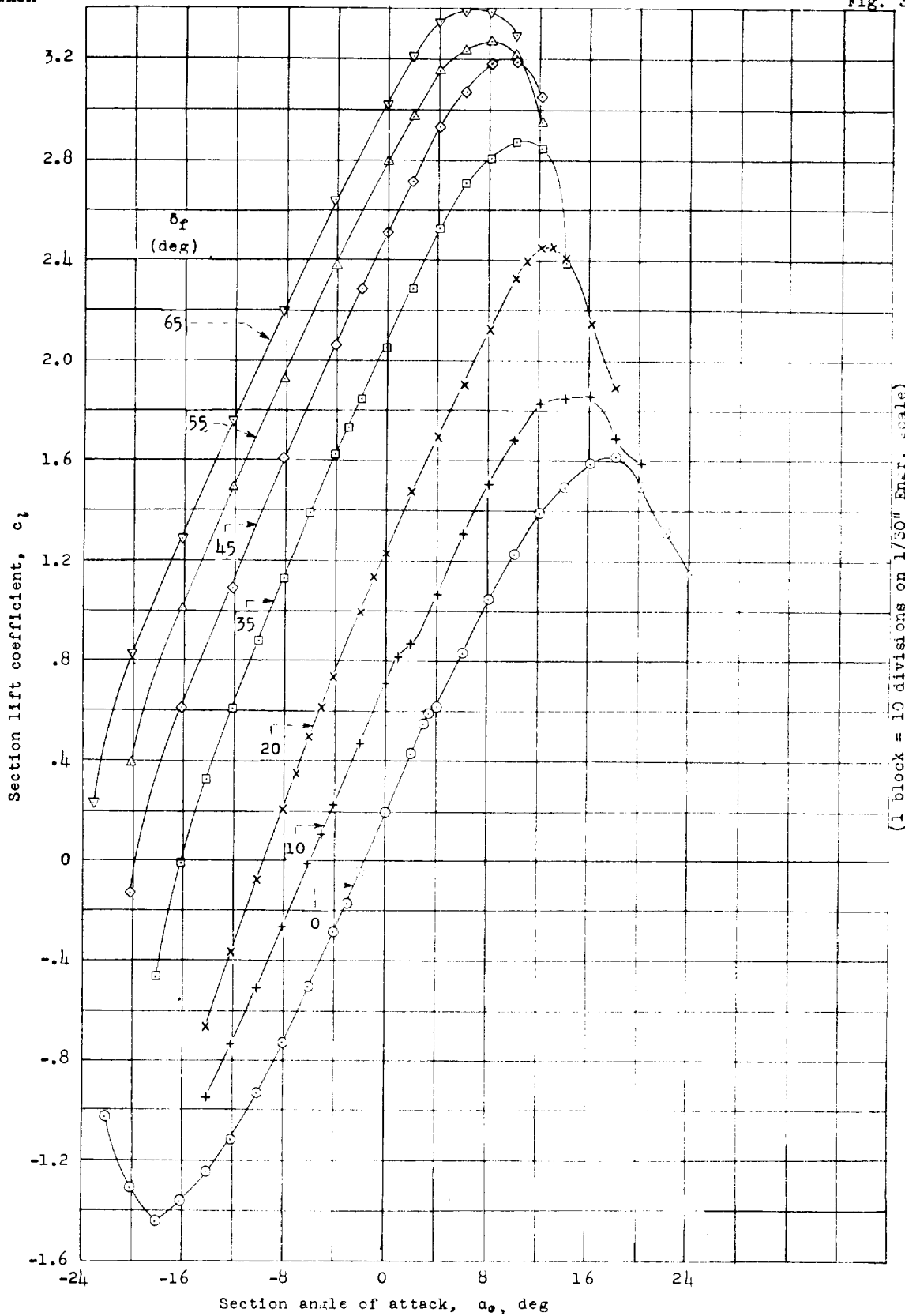
65

55

45

35

20

10

0

Section angle of attack, $a_o$, deg

Figure 3.- Section lift characteristics of an NACA 65,3-118, a = 1.0 airfoil with a 0.309c double-slotted flap at various deflections; R, 6,000,000 (approximately). Tests, TDT 399, 435, 452.
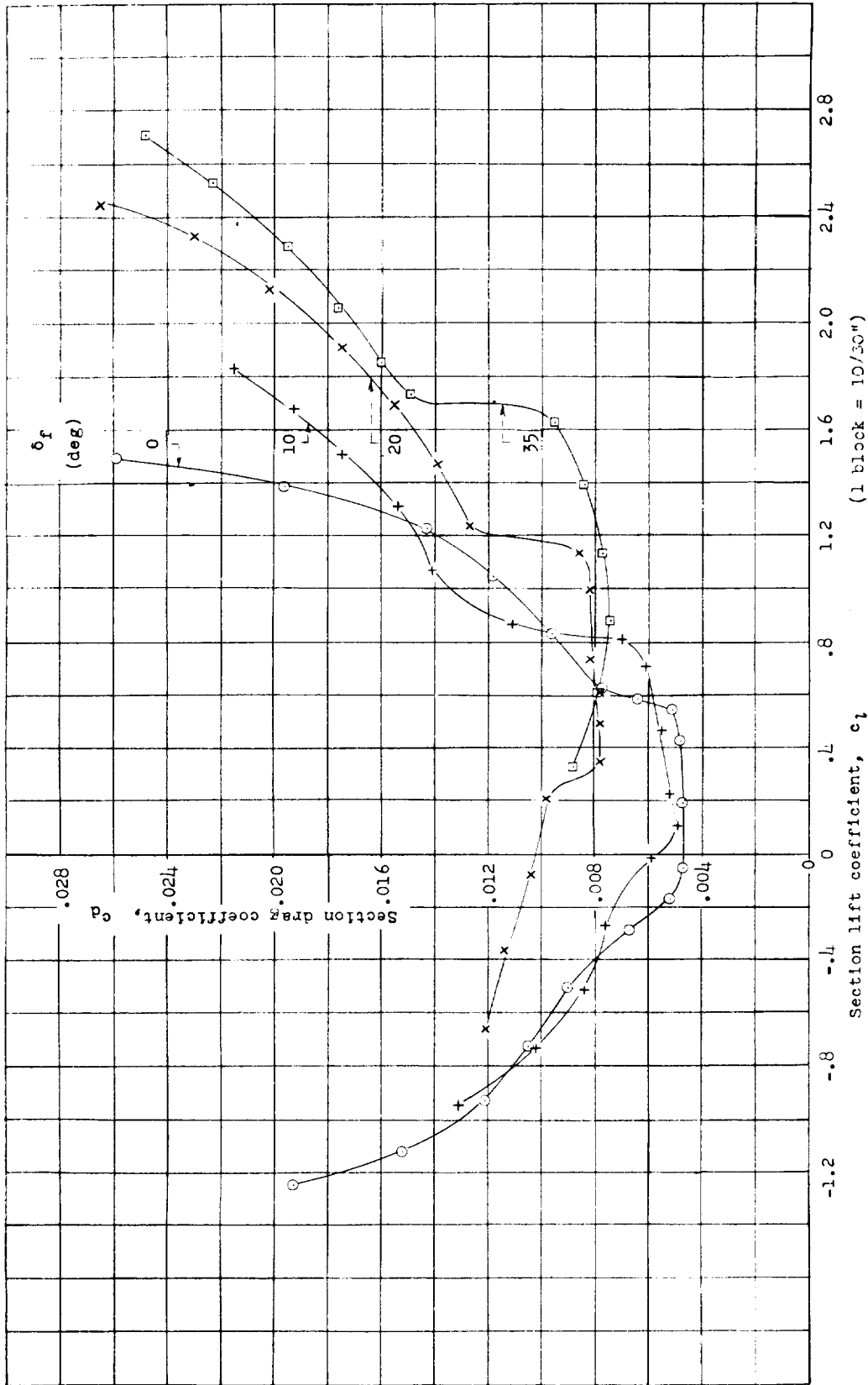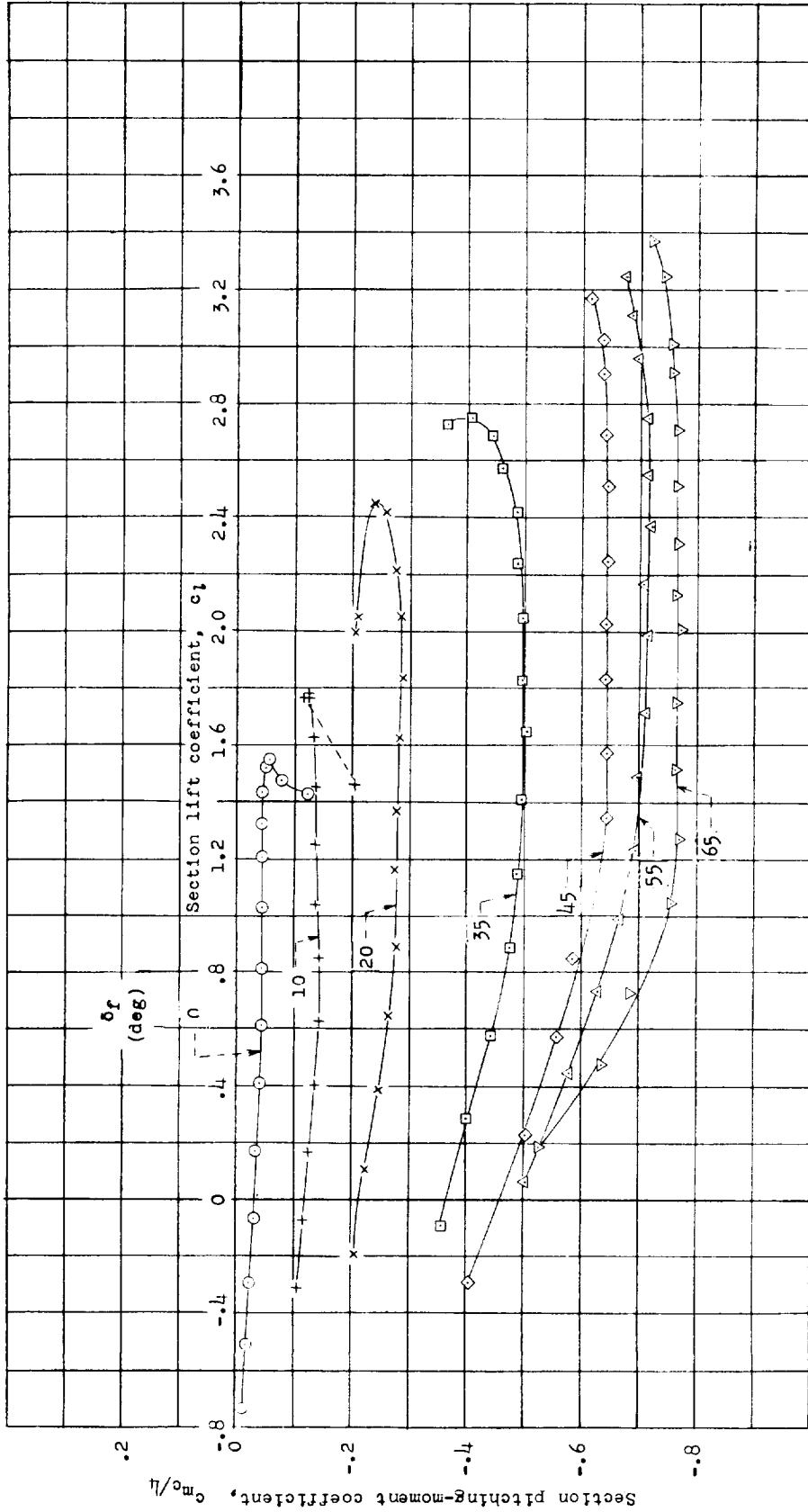
Fig. 4

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Figure 4.- Section drag characteristics of an NACA 65,3-118, a = 1.0 airfoil with a 0.309c double-slotted flap at four deflections; R, 6,000,000 (approximately). Tests, TDT 399, 435.

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Fig. 5



Figure 5.- Pitching-moment characteristics of an NACA 65,3-118, a = 1.0 airfoil with a 0.309c double-slotted flap at various deflections; R, 4,500,000 (approximately). Tests, TDT 460, 462.

(1 block = 10/30")