RM No. L7B18

NACA

RESEARCH MEMORANDUM

TWO-DIMENSIONAL WIND-TUNNEL INVESTIGATION OF MODIFIED NACA $65_{(112)}$-111 AIRFOIL WITH 35-PERCENT-CHORD SLOTTED FLAP TO DETERMINE PITCHING-MOMENT CHARACTERISTICS AND EFFECTS OF ROUGHNESS

By

Stanley F. Racisz

Langley Memorial Aeronautical Laboratory
Langley Field, Va.

NATIONAL ADVISORY COMMITTEE
FOR AERONAUTICS

WASHINGTON

NACA RM No. L7B18

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

RESEARCH MEMORANDUM

TWO-DIMENSIONAL WIND-TUNNEL INVESTIGATION OF MODIFIED NACA $65_{(112)}$-111 AIRFOIL WITH 35-PERCENT-CHORD SLOTTED FLAP TO DETERMINE PITCHING-MOMENT CHARACTERISTICS AND EFFECTS OF ROUGHNESS

By Stanley F. Racisz

SUMMARY

An investigation has been made in the Langley two-dimensional low-turbulence pressure tunnel to develop the optimum configuration of a 0.35-chord slotted flap on an NACA $65_{(112)}$-111 airfoil section modified by removing the trailing-edge cusp. The section pitching-moment characteristics and the effects of standard roughness on the section characteristics were determined for the optimum configuration and for the condition with the flap retracted at Reynolds numbers ranging from 3.0×10^6 to 9.0×10^6. The section pitching-moment coefficient was approximately 0.10 higher than that obtained for the NACA 65-210 airfoil with a 0.250-chord slotted flap and approximately 0.05 lower than that obtained for the NACA 65-210 airfoil section with a 0.312-chord double slotted flap. The lift characteristics were determined at a Reynolds number of 9.0×10^6 for the flap deflected through a developed flap path. At a flap deflection of 20° and at section angles of attack higher than about -4°, two values of the section lift coefficient at each angle of attack were obtained because of inconsistent stalling of the flap although the maximum section lift coefficient remained nearly the same. The decrement in the maximum section lift coefficient obtained by applying standard roughness to the airfoil with the flap deflected 35° was approximately the same as that for the airfoil with the flap retracted.

INTRODUCTION

The modern high performance airplane with its increased wing loading requires the use of thin wing sections equipped with high-lift flaps. Experimental investigations, such as those reported in reference 1, have been made to develop 0.250-chord slotted flaps suitable for use on thin airfoil sections. Such investigations, however, have been made for only a small range of Reynolds numbers (2.4×10^6 to 9.0×10^6), and a very limited amount of data for Reynolds numbers greater than 9.0×10^6 are available for thin airfoils equipped with slotted flaps. From data presented in reference 1, it is seen that large changes in the lift characteristics of a thin airfoil with a slotted flap may occur as the Reynolds number is increased. Some question also exists as to whether or not a flap configuration that is the optimum for high lift at low Reynolds numbers is still the optimum configuration at much higher Reynolds numbers.

An investigation has therefore been conducted in the Langley two-dimensional low-turbulence tunnels in order to develop the optimum configuration of a 0.35-chord slotted flap on a modified NACA $65_{(112)}$-111 airfoil section and to determine whether or not the developed optimum flap configuration is dependent upon the Reynolds number. Measurements to determine the section pitching-moment characteristics, the effects of leading-edge roughness on the lift characteristics, and the lift characteristics for the flap deflected through a developed flap path were also included in this investigation.

The results of the first phase of this investigation, which covered the development of the optimum flap configuration at Reynolds number of 2.4×10^6, have been reported in reference 2. The second phase of the investigation covered the development of the optimum flap configuration at high Reynolds numbers and tests of the airfoil with the flap retracted and the condition with the optimum flap configuration at Reynolds numbers up to 25.0×10^6. The results of those tests have been reported in reference 3. This paper presents the results of tests made to determine the section pitching-moment characteristics, the lift characteristics for a developed flap path, and the effects of leading-edge roughness on the section lift characteristics. These aforementioned tests concluded the investigation.

SYMBOLS

α_o	section angle of attack, degrees
c	airfoil chord
c_d	section drag coefficient
c_l	section lift coefficient
$c_{m_{c/4}}$	section pitching-moment coefficient
R	Reynolds number
x, y	horizontal and vertical positions, respectively, of center of the flap leading-edge radius with respect to upper lip of slot in percent c, positive forward of and below slot lip, respectively, (fig. 1)
δ_f	flap deflection, degrees, angle between airfoil chord line in flap retracted position and airfoil chord line in flap deflected position (fig. 1)

MODEL AND TESTS

The 2-foot chord model tested in this investigation was a modified NACA $65_{(112)}$-111 airfoil section with a 0.35c slotted flap. The airfoil section had been modified by removing the trailing-edge cusp and was therefore similar to an NACA $65_{(112)}$A111 airfoil section (reference 4). Ordinates for the plain airfoil section and the slotted flap are given in tables I and II, respectively. Figure 1 is a sketch of the airfoil and flap and also shows the reference points defining the flap position. A flap path was developed by deflecting the flap through a circular path in such a manner that at a flap deflection of 35° the center of the flap leading-edge radius was located 1.98-percent c behind and 3.21-percent c below the slot lip. This flap deflection and position had been found to be the optimum at high Reynolds numbers (reference 3). The location of the pivot point about which the flap was deflected is shown in figure 2. The model was constructed of aluminum alloy and completely spanned the 3-foot-wide tunnel test section.

Tests were made in the Langley two-dimensional low-turbulence pressure tunnel to determine the scale effects on the section pitching-moment characteristics of the airfoil section with the flap retracted and slot sealed for Reynolds numbers ranging from 3.0×10^6 to 9.0×10^6. Lift measurements were made at a Reynolds number of 9.0×10^6 to determine the section-lift characteristics of the model for flap deflections up to 35°. The effects of standard roughness (reference 5) on the lift characteristics of the optimum flap configuration and on the lift characteristics of the model with the flap retracted and slot sealed were determined for a Reynolds number of 6.0×10^6. The effects of standard roughness on the section drag characteristics of the model with the flap retracted and slot sealed were also determined for a Reynolds number of 6.0×10^6. The test methods and the methods used in correcting the test data to free-air conditions are discussed in reference 5. The magnitude of the corrections used in correcting the test data to free-air conditions was of the order of a few percent. The maximum free-stream Mach number attained during any of the tests did not exceed 0.17.

RESULTS AND DISCUSSION

Pitching-Moment Characteristics

The section pitching-moment characteristics of the airfoil section with the flap retracted and slot sealed and the section lift characteristics obtained from reference 3 are presented in figure 3. The section pitching-moment coefficient at the design lift coefficient is essentially the same as that for the corresponding airfoil section of similar camber and thickness as estimated from figure 54 of reference 5. The data presented in figure 3 indicate that increasing the Reynolds number from 3.0×10^6 to 9.0×10^6 caused only small changes in the section pitching-moment coefficient at angles of attack below the stall.

The section pitching-moment characteristics for the airfoil section with the flap deflected are presented in figure 4. Included with the section pitching-moment data, presented in figure 4, are the section lift characteristics obtained from reference 3. For the flap deflected configuration the slope of the pitching-moment curve becomes positive at angles of attack from about 2° to slightly above the stall, but further increases in the section angle of attack cause a reversal of the slope and the slope of the pitching-moment curve becomes negative. The value of the section pitching-moment coefficient is approximately 0.1 higher than that obtained for the NACA 65-210 airfoil section with a 0.250c slotted flap (slotted flap 1, reference 1) and approximately 0.05 lower than that obtained for the NACA 65-210 airfoil section with a 0.312c double slotted flap (reference 1). The maximum section lift coefficient was, however, approximately 0.1 higher than that obtained for the NACA 65-210 airfoil with the slotted flap and approximately 0.1 lower than that obtained for the NACA 65-210 airfoil with the double slotted flap (reference 1).

Lift Characteristics for Intermediate Flap Deflections

The section lift characteristics of the model with the flap deflected up to 35° for a Reynolds number of 9.0×10^6 are presented in figure 5. Measurements of the lift characteristics for flap deflections greater than 35° were not made because, as discussed in reference 3, increasing the flap deflection beyond 35° gave no increase in the maximum section lift coefficient at a Reynolds number of 9.0×10^6. At a flap deflection of 20° and at section angles of attack higher than about -4°, two values of the section lift coefficient were obtained at each angle of attack, although the values of the maximum section lift coefficients were nearly the same. Reruns of these tests showed that the condition giving the lower lift coefficients was the more stable of the two. Tuft studies at a flap deflection of 20° indicated that the irregular behavior of the lift coefficients was associated with partial stalling of the flap caused by the relatively poor slot shape for this flap deflection.

Effects of Leading-Edge Roughness

The section lift and drag characteristics at a Reynolds number of 6.0×10^6 for the airfoil section with standard roughness are presented in figure 6. Included with the data presented in figure 6 are the section characteristics for the smooth condition which were obtained from reference 3. The decrement in the maximum section lift coefficient caused by leading-edge roughness for the flap-deflected condition is approximately the same as that for the flap-retracted condition. The decrement in maximum section lift coefficient is approximately the same as that obtained for the NACA 65-210 airfoil section with the 0.25c slotted flap designated as slotted flap 1 in reference 1. The minimum section drag coefficients for the smooth condition and the condition with leading-edge roughness are the same as those estimated from consideration of data for similar airfoil sections presented in figures S146c, S147, and S148 of reference 5.

CONCLUSIONS

The results of tests of a modified NACA $65_{(112)}$-111 airfoil section with a 0.35-chord slotted flap indicate the following conclusions:

1. The section pitching-moment coefficient was approximately 0.10 higher than that obtained for the NACA 65-210 airfoil with a 0.250-chord slotted flap and approximately 0.05 lower than that obtained for the NACA 65-210 airfoil section with a 0.312-chord double slotted flap.

2. At a flap deflection of 20° and at section angles of attack higher than about -4°, two values of the section lift coefficient at each angle of attack were obtained because of inconsistent stalling of the flap although the maximum section lift coefficient remained nearly the same.

3. The decrement in the maximum section lift coefficient obtained by applying standard roughness to the airfoil with the flap deflected 35° was approximately the same as that obtained for the airfoil with the flap retracted.

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

Stanley F. Racisz
Stanley F. Racisz
Aeronautical Engineer

Approved:
Clinton H. Dearborn
Clinton H. Dearborn
Chief of Full-Scale Research Division

bw

REFERENCES

1. Cahill, Jones F.: Two-Dimensional Wind-Tunnel Investigation of Four Types of High-Lift Flap on an NACA 65-210 Airfoil Section. NACA TN No. 1191, 1947.

2. Racisz, Stanley F.: Two-Dimensional Wind-Tunnel Investigation of Modified NACA $65_{(112)}$-111 Airfoil with 35-Percent-Chord Slotted Flap to Determine Optimum Flap Configuration at a Reynolds Number of 2.4 Million. NACA RM No. L7A02, 1947.

3. Racisz, Stanley F.: Two-Dimensional Wind-Tunnel Investigation of modified NACA $65_{(112)}$-111 Airfoil with 35-Percent-Chord Slotted Flap at Reynolds Numbers up to 25 Million. NACA RM No. L7A24, 1947.

4. Loftin, Laurence K., Jr.: Theoretical and Experimental Data for a Number of NACA 6A-Series Airfoil Sections. NACA RM No. L6J01, 1946.

5. Abbott, Ira H., von Doenhoff, Albert E., and Stivers, Louis S., Jr.: Summary of Airfoil Data. NACA ACR No. L5C05, 1945.

TABLE I

ORDINATES FOR THE MODIFIED

NACA $65_{(112)}$-111 AIRFOIL SECTION

[Stations and ordinates given in percent airfoil chord]

Upper surface		Lower surface	
Station	Ordinate	Station	Ordinate
0	0	0	0
.463	.871	.538	-.821
.708	1.050	.792	-.979
1.204	1.325	1.292	-1.217
2.450	1.813	2.550	-1.625
4.942	2.546	5.054	-2.229
7.442	3.117	7.558	-2.696
9.942	3.600	10.058	-3.083
14.942	4.371	15.054	-3.700
19.950	4.958	20.050	-4.163
24.958	5.404	25.042	-4.508
29.967	5.725	30.033	-4.754
34.975	5.933	35.025	-4.904
39.983	6.033	40.017	-4.963
44.992	6.000	45.008	-4.904
50.000	5.829	50.000	-4.725
55.008	5.508	54.992	-4.413
60.017	5.087	59.983	-4.017
65.021	4.575	64.979	-3.546
70.025	4.029	69.975	-3.054
75.025	3.429	74.975	-2.533
80.025	2.792	79.975	-1.996
85.025	2.146	84.975	-1.471
90.021	1.483	89.979	-.967
95.017	.796	94.983	-.479
100.004	.054	99.996	-.054
L.E. radius: 0.842			

NATIONAL ADVISORY
COMMITTEE FOR AERONAUTICS

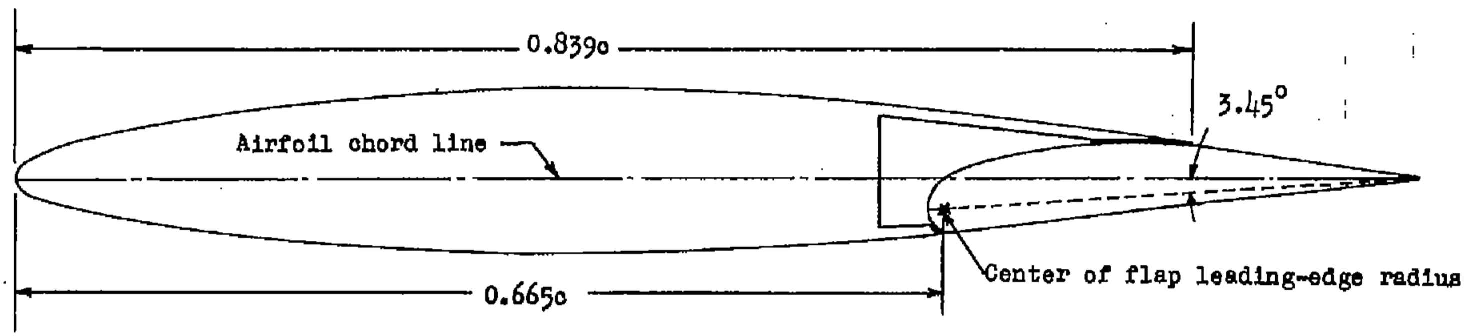
TABLE II

ORDINATES FOR 0.35-CHORD FLAP

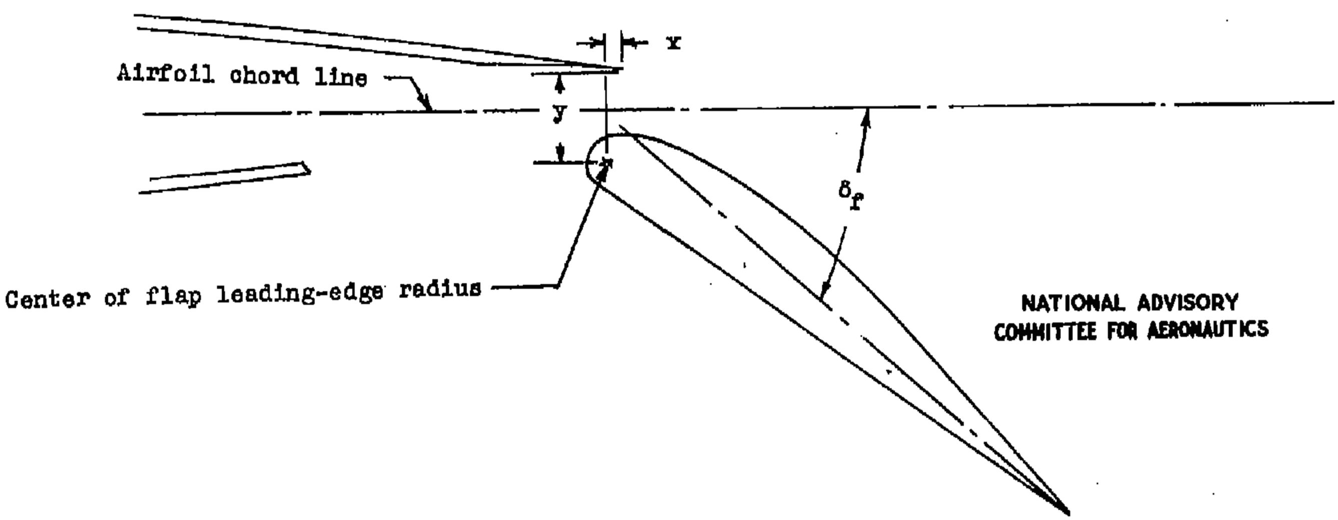
[Lower surface of flap formed by lower surface of plain airfoil. Stations and ordinates given in percent airfoil chord]

Station	Ordinate
65.50	-0.863
66.00	-.367
67.00	.308
68.00	.792
70.00	1.442
72.00	1.846
74.00	2.104
76.00	2.267
78.00	2.346
80.00	2.354
82.00	2.300
84.00	2.183
86.00	2.000
Upper surface fairs into plain airfoil section at station 88.00	
L.E. radius: 1.404 L.E. radius center at station 66.50 and ordinate -1.971	

NATIONAL ADVISORY
COMMITTEE FOR AERONAUTICS



(a) Airfoil with 0.35c slotted flap.



(b) Variables used to define flap configuration.

Figure 1.- Profile of the modified NACA $65_{(112)}$-111 airfoil section with 0.35c slotted flap.

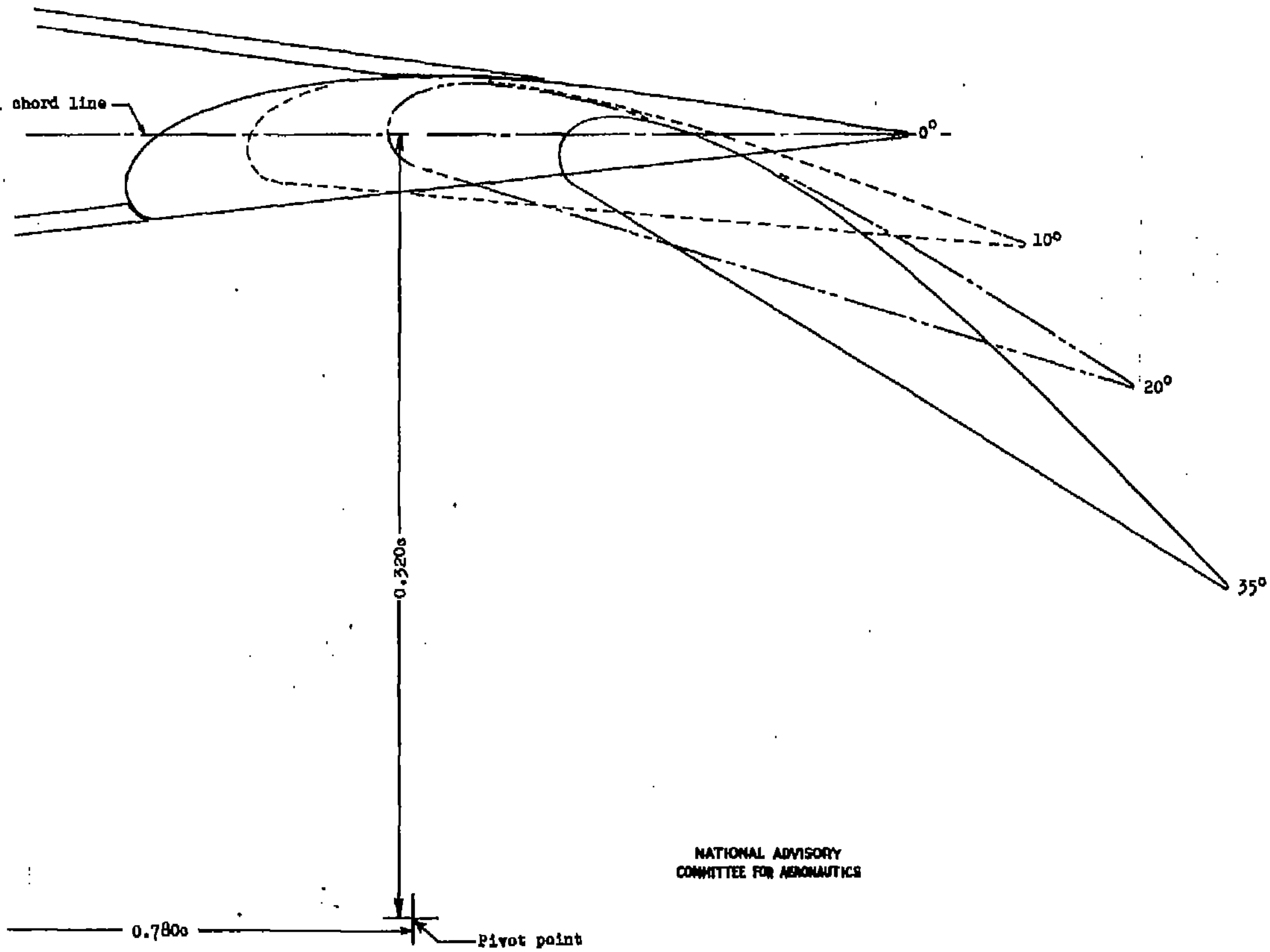


Figure 2 .- Profile of flap showing location of flap pivot point.

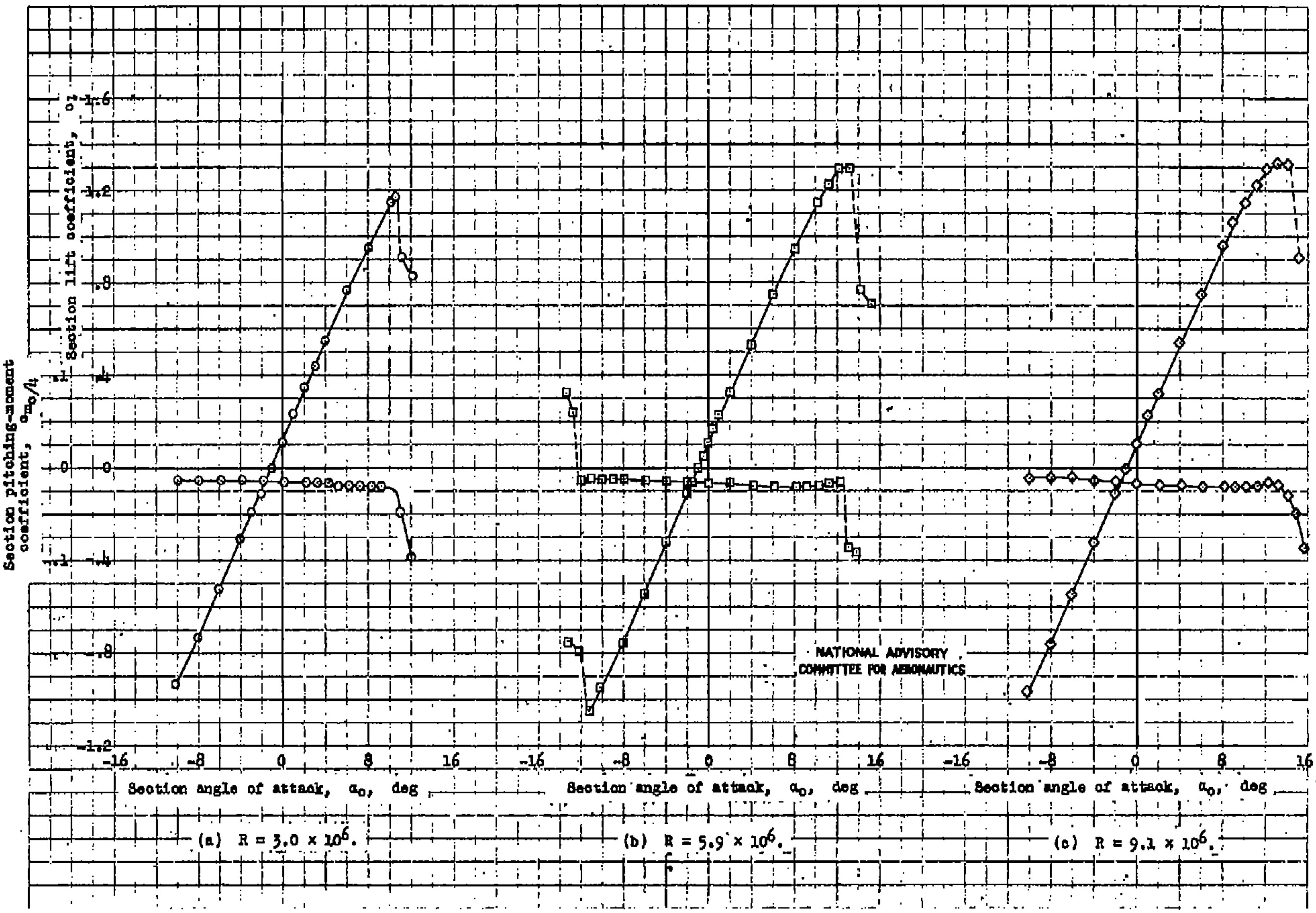


Figure 3 .- Section lift and pitching-moment characteristics of a modified NACA $65_{(112)}$-111 airfoil section with flap retracted and slot sealed.

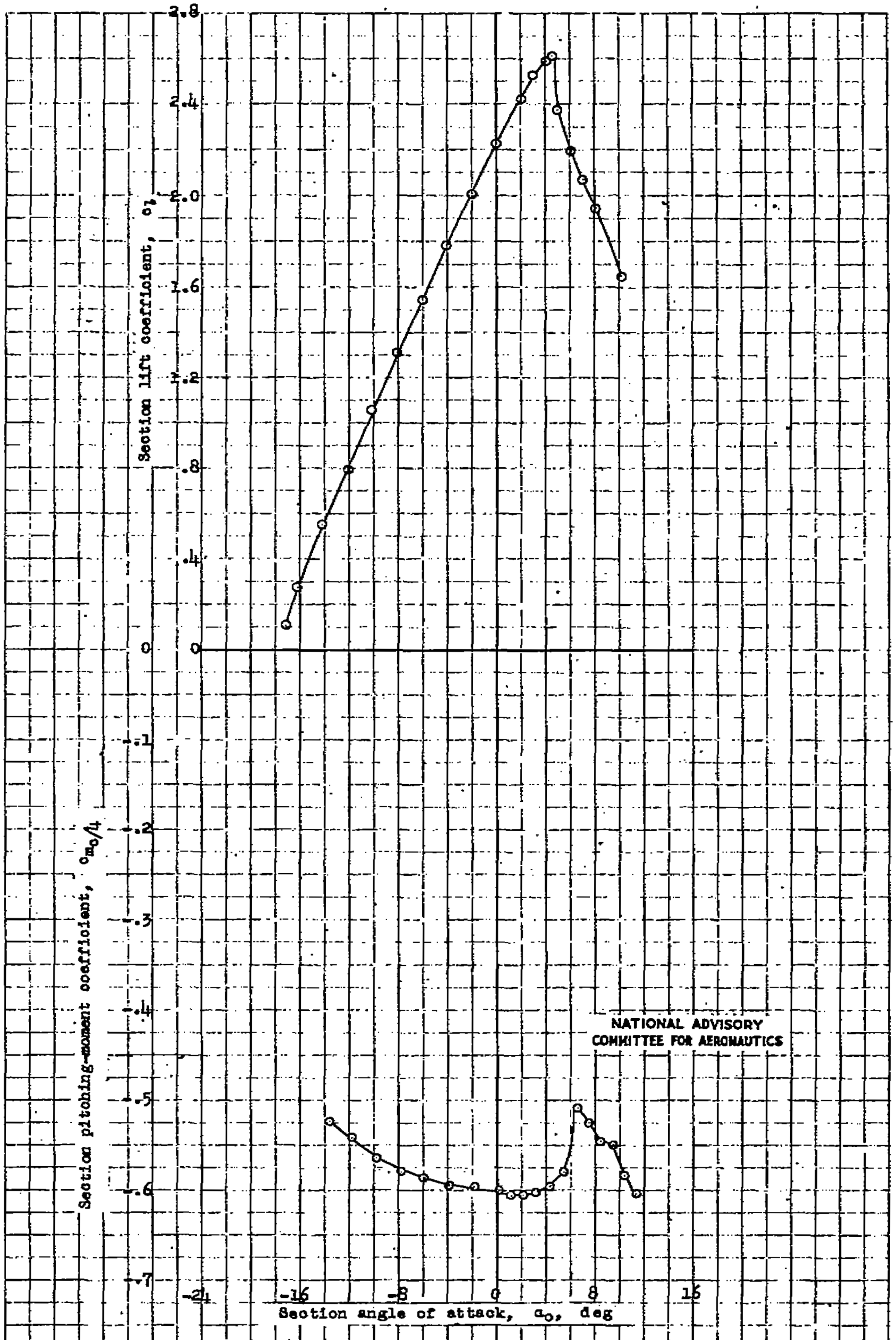


Figure 4 .- Section lift and pitching-moment characteristics of a modified NACA $65_{(112)}$-111 airfoil section with a 0.35c slotted flap. $\delta_f = 35^\circ$; $x = -1.98$ percent c; $y = 3.21$ percent c; $R = 6.0 \times 10^6$.

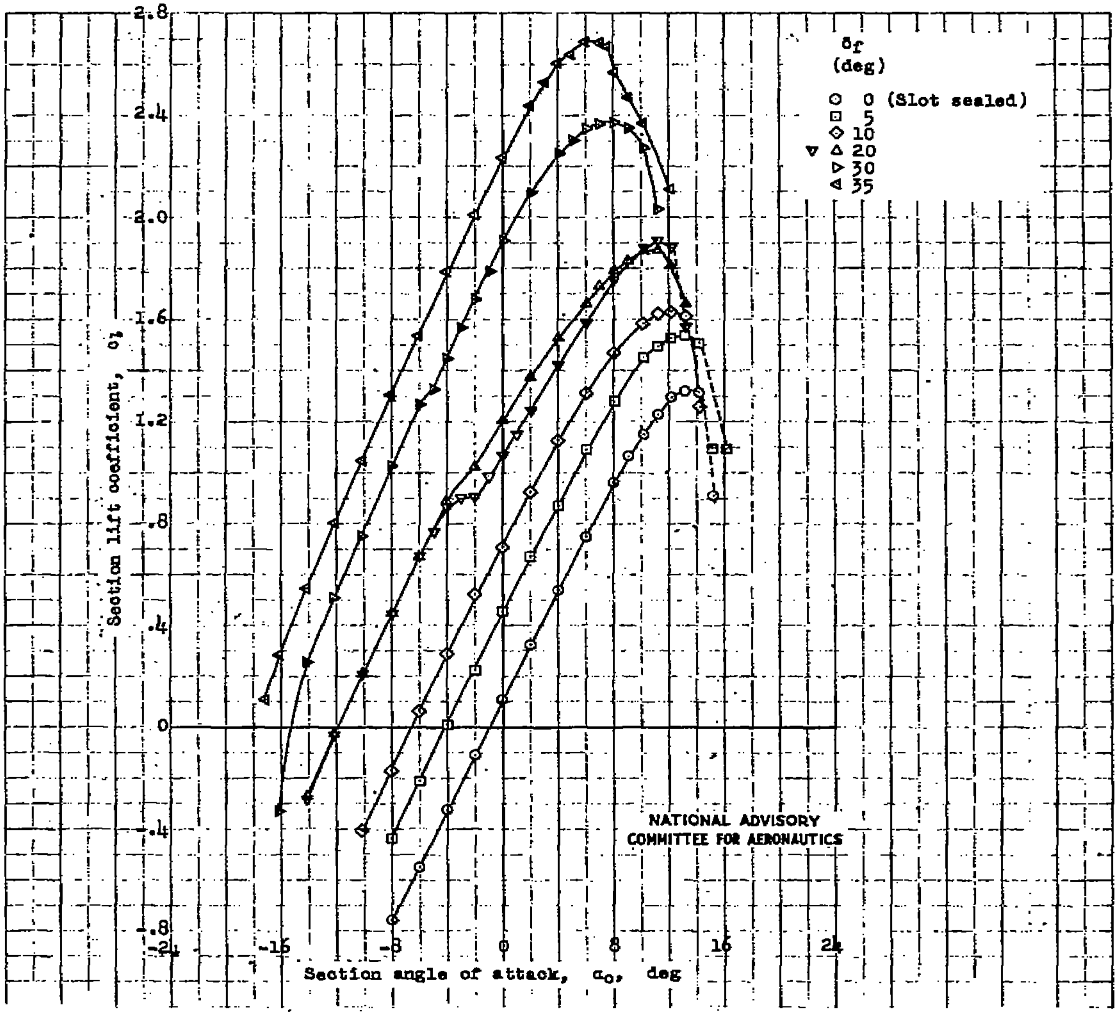


Figure 5 .- Section lift characteristics of a modified NACA $65_{(112)}$-111 airfoil section with a 0.35 slotted flap. $R = 9.0 \times 10^6$.

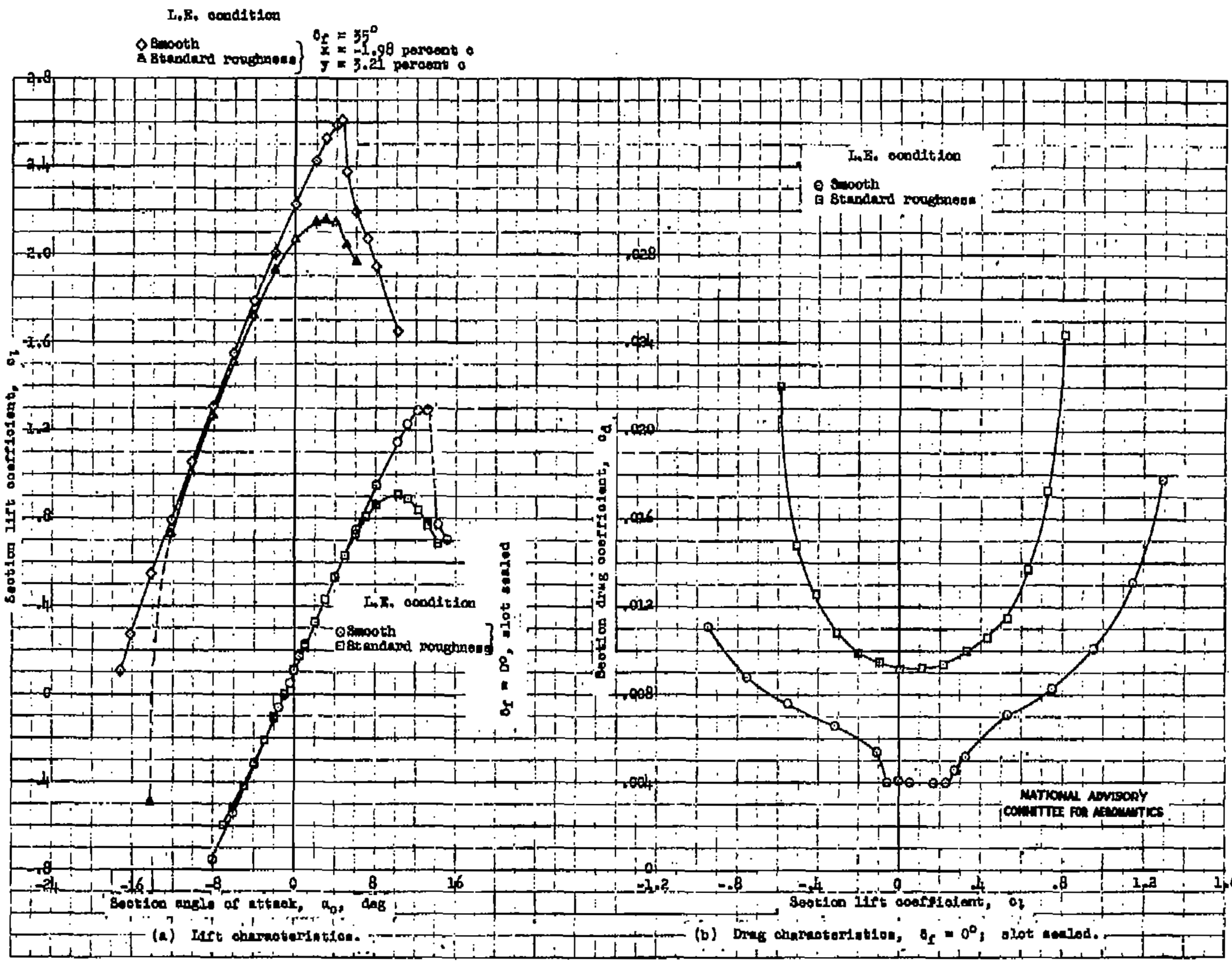


Figure 6.- Section lift and drag characteristics of a modified NACA $65_{(112)}$-111 airfoil section with a 0.35c slotted flap for smooth condition and condition with standard leading-edge roughness. $R = 6.0 \times 10^6$.