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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL NOTE

No. 1071

WIND-TUNNEL INVESTIGATION OF BOUNDARY-LAYER CONTROL BY SUCTION ON THE NACA 653-418, a = 1.0 AIRFOIL SECTION WITH A 0.29-AIRFOIL-CHORD DOUBLE SLOTTED FLAP

By John H. Quinn, Jr.

Langley Memorial Aeronautical Laboratory
Langley Field, Va.

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WIND-TUNNEL INVESTIGATION OF BOUNDARY-LAYER CONTROL BY SUCTION ON THE NACA 653-418, a = 1.0 AIRFOIL SECTION WITH A 0.29-AIRFOIL-CHORD DOUBLE SLOTTED FLAP

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SUMMARY

Tests have been made to find the maximum lift of the NACA 653-418, a = 1.0 airfoil section equipped with a 0.29-airfoil-chord double slotted flap and a boundary-layer suction slot located at 0.45 airfoil chord. The tests were made at Reynolds numbers of 1.9, 3.4, and 6.0×10^6 for flap deflections ranging from 0° to 65° and for flow coefficients ranging from 0 to 0.040. The flow coefficient is defined as the ratio of the quantity rate of air flow through the suction slot to the product of the wing area and free-stream velocity.

At a Reynolds number of 3.4×10^6 a maximum section lift coefficient of 4.16 was obtained with a 65° flap deflection and a flow coefficient of 0.040. With a flap deflection of 0°, a maximum lift coefficient of 2.50 was obtained at the same flow rate. The plain airfoil at a Reynolds number of 6.0×10^6 had a maximum lift coefficient of 1.50, and the wing with flaps deflected 65° without boundary-layer control at the same Reynolds number had a maximum lift coefficient of 3.51. Application of roughness in the form of carborundum particles to the leading edge of the wing decreased the maximum lift coefficient at a Reynolds number of 1.9×10^6 from 3.88 to 3.16 for a flap deflection of 65° and a flow coefficient of 0.024. Without boundary-layer control, roughness decreased the maximum lift coefficient from 3.11 to 2.84.

At a flap deflection of 65°, Reynolds number had little effect on the maximum lift attainable with boundary-layer control above a flow coefficient of

approximately 0.012 at least at Reynolds numbers between 1.9×10^6 and 6.0×10^6. Throughout the range of flow rate for which data were obtained, maximum lift coefficient increased with increasing flow coefficient. In no case did the section angle of attack for maximum lift of any of the configurations tested with boundary-layer control exceed by more than 2° or 3° the section angle of attack for maximum lift at a Reynolds number of 6.0×10^6 for the airfoil with flap retracted and no boundary-layer control.

INTRODUCTION

A recent investigation (reference 1) was conducted on the NACA 65_3-018 airfoil section with boundary-layer control by suction to determine the increment in maximum lift coefficient that could be obtained by controlling the turbulent boundary layer. The suction slots were located at and behind the minimum pressure point. Laminar separation of the flow from the leading edge limited the maximum lift coefficient to approximately 1.85, which was only 0.45 greater than the maximum lift coefficient obtained without boundary-layer control. Abbott, von Doenhoff, and Stivers of the NACA have shown that in general greater maximum lift coefficients may be obtained with high lift devices on relatively thick highly cambered airfoil sections than on thin low-cambered sections, and that laminar separation often limits the maximum lift attainable with the thin low-cambered sections. It seemed likely that further development of boundary-layer control for high lift would result from tests of a cambered wing.

Tests were made, therefore, in the Langley two-dimensional low-turbulence tunnel and the Langley two-dimensional low-turbulence pressure tunnel of the NACA 65_3-418, $a = 1.0$ airfoil section with a single boundary-layer suction slot located at 0.45 airfoil chord and a 0.29-airfoil-chord double slotted flap. Measurements were made of the lift and drag characteristics of this airfoil with various flap deflections and various amounts of flow through the boundary-layer-control slot. In addition, boundary-layer surveys were made at an angle of attack near maximum lift, and pressure losses inside the suction slot were determined for several configurations.

COEFFICIENTS AND SYMBOLS

c_l section lift coefficient

$c_{l_{max}}$ maximum section lift coefficient

c_{d_o} section profile-drag coefficient

Q volume of air removed through suction slot per unit time

U_o free-stream velocity

c airfoil chord

b span over which boundary-layer control is applied

C_Q flow coefficient $\left(\frac{Q}{U_o cb}\right)$

H_o free-stream total pressure

H_b total pressure inside wing duct

q_o free-stream dynamic pressure

q local dynamic pressure

$c_{d_{o_b}}$ blower drag coefficient; that is, profile-drag coefficient equivalent to power required to discharge at free-stream total pressure air removed from boundary layer $\left(\frac{C_Q(H_o - H_b)}{q_o}\right)$

c_{d_T} total drag coefficient $\left(c_{d_o} + c_{d_{o_b}}\right)$

U local velocity outside boundary layer

u local velocity inside boundary layer

y perpendicular distance above airfoil surface

δ boundary-layer total thickness

δ^* boundary-layer displacement thickness $\left(\int_0^\delta \left(1 - \frac{u}{U}\right)dy\right)$

θ boundary-layer momentum thickness $\left(\int_0^\delta \frac{u}{U}\left(1 - \frac{u}{U}\right)dy\right)$

H boundary-layer shape parameter (δ^*/θ)

α_o section angle of attack

δ_f deflection of flap

x chordwise distance measured from leading edge

R Reynolds number

MODEL AND TESTS

The airfoil used in this investigation was of 3-foot chord and was built to the ordinates of the NACA 65$_3$-418, a = 1.0 airfoil section. The model was constructed of laminated mahogany with laminations running in the chordwise direction. Ordinates for this airfoil section are presented in table I. The model was equipped with a 0.29c double slotted flap and a suction slot located at 0.45c. A schematic drawing of the model showing the suction slot, wing duct, and double slotted flap is presented as figure 1. Ordinates for the flap and vane are presented in tables II and III, respectively.

The tests were made in the Langley two-dimensional low-turbulence tunnel (designated LTT) and in the Langley two-dimensional low-turbulence pressure tunnel (designated TDT). The LTT was used for the development of the best flap configuration and for the detailed boundary-layer surveys and pressure measurements; the TDT was used for tests of the most promising configurations at the higher Reynolds numbers. Both the LTT and TDT have test sections 3 feet wide and $7\frac{1}{2}$ feet high and were designed to test models completely spanning the jet in two-dimensional flow.

Lifts were measured by an arrangement designed to integrate the pressures along the floor and ceiling of the tunnel test section. External drag was measured by the wake-survey method.

Air was sucked off the upper surface of the model through the suction slot and into the wing duct. From the wing duct it passed through the tunnel wall and was ducted through a Venturi to the inlet of a blower. The volume rate of flow Q was obtained from measurements of the total and static pressures in the throat of the Venturi. For the no-flow condition, the slot was faired over with plasteline. The loss in total pressure incurred in sucking the air through the slot plus the total-pressure deficiency of the boundary layer was obtained by measuring the pressure inside the wing duct. For some tests the local dynamic pressure outside the boundary layer just ahead of the slot was determined by placing a static pressure tube at $0.44c$. This tube was mounted approximately 3/32 inch above the wing surface and bent to approximate the curvature of the airfoil profile.

In an attempt to find the optimum configuration for the double slotted flap, a number of preliminary tests were made with various deflections and positions of the vane and flap and with the suction slot in operation. With the vane and flap fixed as a unit, a number of horizontal and vertical positions were tested at a deflection of 60°. At the position that gave the largest value of maximum lift, the flap position was fixed while the vane angle and position were varied. This process was then repeated at a flap deflection of 65°. Because the best configuration at a deflection of 65° gave a slightly greater value of maximum lift than that at a 60° deflection, for all subsequent tests the vane and flap were fixed with respect to each other in the best configuration found at a deflection of 65°. A sketch of the configuration at 65° is presented as figure 2. Photographs of the model with the flap deflected 65° are presented as figure 3. All flap deflections hereinafter refer to the angle between the flap chord line and the wing chord line (coincident at 0° deflection). For deflections of less than 20°, for which the vane would be entirely inside the wing, a slight upward movement of the vane would be required in order to permit the flap to retract without

interference; the vane was removed at these deflections to simplify the tests.

An arbitrary flap path was chosen to retract the flap into the wing. The flap moved slightly forward between the 65° and 60° deflections, pivoted about a point near the nose of the vane between deflections of 60° and 40°, and moved forward and upward from 40° to 0°. The positions of the flap nose at various flap deflections are presented in table IV, and sketches of the flap in the various positions are presented as figure 4. The flap nose is the intersection of the flap chord line with the nose of the rear part of the double slotted flap.

RESULTS AND DISCUSSION

The tests of the NACA 65_3-418 airfoil section with boundary-layer control were planned to find not only the effect of boundary-layer control on the lift and drag characteristics of the airfoil but also the relation between changes in the lift and drag characteristics and changes in the nature of the flow in the boundary layer. The discussion is therefore divided into three parts. The first two parts deal with the effect of flow rate on the lift and drag characteristics of the wing with various flap deflections and at different Reynolds numbers and the third part, with the effect of boundary-layer control on the variations of the boundary-layer displacement thickness and shape parameter and the pressure losses in the suction slot.

Lift Characteristics

Variation of lift coefficient with angle of attack.- The lift characteristics of the NACA 65_3-418 airfoil section with boundary-layer control at various flap deflections and Reynolds numbers are presented in figure 5. The predominant effect of boundary-layer control as shown by these data is the extension of the straight part of the lift curve to higher angles of attack than for the airfoil without boundary-layer control. The angle of attack at which maximum lift occurred with boundary-layer control was in no case more than 2° or 3° greater than the angle of attack for maximum lift at a Reynolds number of 6.0×10^6 (fig. 5(b)) for the plain wing. Consistent

increases in maximum lift coefficient were found with increasing rate of flow and with increasing flap deflection up to flap deflections of 45°. At a Reynolds number of 1.9×10^6, little change in maximum lift was found with increasing flap deflection above a deflection of 45°.

Most of the lift data presented in figure 5 show that the lift-curve slope and angle of zero lift for the wing with boundary-layer control differ somewhat from the values found for the no-control condition. In general the lift-curve slope tends to increase and the angle of zero lift tends to become more negative with increasing flow coefficient. The lift-curve slope probably increases because the boundary layer becomes thinner over a large part of the wing as the flow rate increases. The thinner boundary layer had an effect similar to that of increased camber and brought about the downward shift in the angle of zero lift.

Effect of roughness.- Lift data are presented in figure 6 for the airfoil with leading-edge roughness at a flap deflection of 65° and with different flow rates. The roughness consisted of carborundum grains having an average diameter of 0.011-inch applied to both surfaces of the airfoil as far back as 0.078c. As may be seen in figure 6, increasing the flow rate above a value of 0.016 brought about only a small change in maximum lift. Comparison of these curves with those for the smooth wing presented in figure 5(l) shows that roughness decreased the maximum lift coefficient for the no-flow condition from 3.11 to 2.84, and from 3.88 to 3.16 at a flow coefficient of 0.024. Turbulent separation probably occurred upstream of the slot at angles of attack greater than that at which the lift coefficient of 3.16 was obtained. The angle at which maximum lift occurred, approximately 6°, was very low compared with the angle of attack for maximum lift of 17° for the smooth wing at the same flow rate, flap deflection, and Reynolds number.

Variations of $c_{l_{max}}$ with flap deflection.- The variations of maximum lift coefficient with flap deflection are presented in figure 7 for several Reynolds numbers and flow coefficients. The deflection at which the flap caused the largest maximum lift coefficient increased with Reynolds number, and at a flow coefficient of zero an increase in maximum lift coefficient with Reynolds number was observed for all flap deflections for which data were obtained. At a flow coefficient of 0.024, however, a small decrease in maximum lift coefficient with increasing Reynolds number was observed at flap deflections of 0° and 45°.

The highest lift coefficient reached was 4.16, obtained with a flap deflection of 65° and a flow coefficient of 0.040. Without boundary-layer control, the same flap deflection gave a maximum lift coefficient of 3.51, or 0.65 less than with boundary-layer control. With zero flap deflection, the maximum lift coefficients were 2.50 with a flow coefficient of 0.040 and 1.50 without boundary-layer control. The flow coefficient of 0.040 corresponds to a flow with free-stream velocity through an area equal to 4 percent of the wing area.

Variation of $c_{l_{max}}$ with flow rate.- The variations of maximum lift coefficient with flow coefficient for several flap deflections and Reynolds numbers are presented in figure 8. All the data show that, for the range of flow coefficient for which data were obtained, maximum lift coefficient increased with increasing flow coefficient. At a flap deflection of 65° and flow coefficients above approximately 0.012, Reynolds number appeared to have little or no effect on the maximum lift coefficient attainable with boundary-layer control. The TDT data were obtained at a Reynolds number of 6.0×10^6 up to flow coefficients of 0.024, and at a Reynolds number of 3.4×10^6 at higher flow coefficients.

Drag Characteristics

Drag characteristics of the model with and without boundary-layer control at flap deflections from 0° to 40° are presented in figure 9. Both the profile-drag coefficients, obtained from the wake surveys, and the total drag coefficients, obtained by adding the blower drag coefficients to the profile-drag coefficients, are shown.

In calculations of the internal, or blower, drag coefficients the required power was furnished by a machine assumed to be 100-percent efficient. As may be seen in figure 9, at relatively low lift coefficients the total drag with boundary-layer control is greater than that without boundary-layer control. As the lift coefficients increase, however, the total drag for the slot-sealed condition becomes higher than that for a flow coefficient of 0.008.

Boundary Layer and Related Characteristics

Part of boundary layer being removed.- As a measure of the amount of the boundary layer ahead of the slot that is being removed at various flow coefficients, the ratio $Q/U\delta^*b$ has been presented in figure 10 as a function of flow coefficient at a flap deflection of 65° and an angle of attack of 16°. At a flow coefficient of 0.020 the value of $Q/U\delta^*b$ was equal to 0.4. In reference 1 it was found that the suction slots were operating at their maximum effectiveness when $Q/U\delta^*b$ was equal to 1. Extrapolation of the curve of figure 10 would indicate that increases in lift would still be attained above flow coefficients of 0.040, provided the relation found in reference 1 holds true for the present airfoil. The possibility that further increases in maximum lift coefficient could be obtained at higher flow rates was also indicated in figure 8.

Pressure losses in suction slot.- The difference between free-stream total pressure and the pressure inside the duct, in terms of the local dynamic pressure ahead of the slot, is presented as a function of flow coefficient in figure 11 for an angle of attack of 16° and a flap deflection of 65°. The difference between free-stream total pressure and the pressure inside the duct includes the loss in total pressure in the boundary layer up to the slot, the loss through the slot, and the loss in expansion into the duct. At a flow coefficient of 0.020 the pressure drop required was found to be approximately 115 percent of the local dynamic pressure, while at a flow coefficient of 0.008 the drop required was found to be approximately 85 percent of the local dynamic pressure.

The variations with angle of attack of the ratio of the total-pressure loss in the duct to free-stream dynamic pressure are presented in figure 12 for several flap

deflections and flow coefficients. These data are useful in estimating the power requirements for various flow rates and flap deflections. The horsepower required for boundary-layer control can be found directly from this figure by use of the relation:

$$\text{Horsepower} = \frac{Q(H_o - H_b)}{550}$$

where Q is in cubic feet per second and H_o and H_b are in pounds per square foot.

Boundary-layer shape parameter and displacement thickness.- The results of boundary-layer surveys at a flap deflection of 65° and an angle of attack of 16° are presented in figure 13. The variation of the shape parameter H is presented in figure 13(a) and that of the boundary-layer displacement thickness δ^* is presented in figure 13(b). As far back as 0.25c little change in the shape parameter was found to occur between flow coefficients of 0.010 and 0.017. At 0.20c H had attained a value of 1.66. From this point up to the suction slot the value of H decreased, the amount of the decrease depending upon the flow rate. In reference 2 it was pointed out that separation was imminent for values of H greater than 1.8. Because at 0.20c H had attained a value close to 1.8, it is possible that at a slightly higher angle of attack than that for which data are presented separation would occur close to 0.20c. As the flow coefficient was increased, the slot might have an appreciable effect in the neighborhood of 0.20c and serve to delay separation to a slightly higher angle of attack. Tuft studies showed that, as the flow coefficient was increased, a tendency for separation to occur near the trailing edge was eliminated and smooth flow was observed over the entire wing. As the angle of attack was increased in this condition, no fluctuation of the tufts was apparent until the flow appeared to separate from the leading edge. Increasing the flow coefficient still further brought about no change in the nature of the stall but did increase the maximum lift coefficient and extend the straight part of the lift curve to a slightly higher angle of attack. Further straightening of the lift curve, even after turbulent separation at the rear had been eliminated by the boundary-layer control, is ascribed to the reduction of boundary-layer thickness toward the rear.

The boundary-layer displacement thickness (fig. 13(b)) was affected by the suction slot in much the same manner as the shape parameter, because the slot exerted an influence on the displacement thickness as far forward as approximately 0.20c, and directly behind the slot the displacement thickness was extremely small.

The variations with flow coefficient of the shape parameter just upstream and downstream of the slot at an angle of attack of 16° and a flap deflection of 65° are presented in figure 14. The shape parameter was found to decrease consistently as the flow coefficient increased both upstream and downstream of the slot. The value of H was decreased approximately 0.15 in passing over the slot. This decrease appeared to be independent of the flow coefficient.

CONCLUSIONS

The results obtained in tests of an NACA 653-418 airfoil section equipped with a 0.29-airfoil-chord double slotted flap and a boundary-layer suction slot located at 0.45 airfoil chord indicated the following conclusions:

1. A maximum section lift coefficient of 4.16 was obtained at a flap deflection of 65° for a Reynolds number of 3.4×10^6 with boundary-layer control. The flow coefficient for this case was 0.040, corresponding to removal of a quantity of air equal to that which would flow with free-stream velocity through an area equal to 4 percent of the area on which the suction slot was operating. At a flap deflection of 0°, a maximum lift coefficient of 2.50 was obtained for the same amount of air flow at the same Reynolds number.

2. Without boundary-layer control, a maximum lift coefficient of 1.50 was obtained at a flap deflection of 0° and a Reynolds number of 6.0×10^6. At a flap deflection of 65° a maximum lift coefficient of 3.51 was obtained.

3. The maximum lift coefficient was still increasing with flow coefficient at the highest flow coefficient for which data were obtained.

4. At a flap deflection of 65°, Reynolds number appeared to have little effect on the maximum lift coefficients found with boundary-layer control for flow coefficients greater than 0.012, at least between Reynolds numbers of 1.9×10^6 and 6.0×10^6.

5. At a flow coefficient of 0.024, a Reynolds number of 1.9×10^6, and a flap deflection of 65°, roughness applied to the leading edge of the wing reduced the maximum lift coefficient from 3.88 to 3.16. Without boundary-layer control, the maximum lift coefficient was reduced from 3.11 to 2.84.

6. In no case did the section angle of attack for maximum lift of any of the configurations tested with boundary-layer control exceed by more than 2° or 3° the section angle of attack for maximum lift at a Reynolds number of 6.0×10^6 for the airfoil with flap retracted and no boundary-layer control.

Langley Memorial Aeronautical Laboratory
National Advisory Committee for Aeronautics
Langley Field, Va., February 11, 1946

REFERENCES

1. Quinn, John H., Jr.: Tests of the NACA 653-018 Airfoil Section with Boundary-Layer Control by Suction. NACA CB No. L4H10, 1944.

2. von Doenhoff, Albert E., and Tetervin, Neal: Determination of General Relations for the Behavior of Turbulent Boundary Layers. NACA ACR No. 3G13, 1943.

TABLE I

ORDINATES FOR NACA 65_3-418 AIRFOIL SECTION

(Stations and ordinates in percent of wing chord)

Upper Surface		Lower Surface	
Station	Ordinate	Station	Ordinate
0	0	0	0
.278	1.418	.722	-1.218
.503	1.729	.997	-1.449
.973	2.209	1.527	-1.781
2.181	3.104	2.819	-2.360
4.639	4.481	5.361	-3.217
7.123	5.566	7.877	-3.870
9.619	6.478	10.381	-4.410
14.636	7.942	15.364	-5.250
19.671	9.061	20.329	-5.877
24.716	9.914	25.284	-6.334
29.768	10.536	30.232	-6.648
34.825	10.944	35.175	-6.824
39.884	11.140	40.116	-6.856
44.943	11.091	45.057	-6.711
50.000	10.774	50.000	-6.362
55.051	10.198	54.949	-5.818
60.094	9.408	59.906	-5.124
65.126	8.454	64.874	-4.334
70.146	7.368	69.854	-3.480
75.154	6.183	74.846	-2.603
80.147	4.927	79.853	-1.743
85.127	3.638	84.873	-.946
90.092	2.350	89.908	-.282
95.046	1.120	94.954	.144
100.000	0	100.000	0

L.E. radius: 1.96
Slope of radius through L.E.: 0.168

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TABLE II

ORDINATES FOR FLAP FOR NACA 65_3-418 AIRFOIL SECTION

(Stations and ordinates in percent of wing chord)

Upper Surface		Lower Surface	
Station	Ordinate	Station	Ordinate
76.444	-0.139	76.667	-0.972
76.667	.667	77.083	-1.306
77.083	1.250	77.778	-1.556
77.778	1.889	79.167	-1.667
79.167	2.722	80.556	-1.583
80.556	3.278	84.872	-.947
81.944	3.556	89.908	-.283
83.333	3.639	94.953	.144
84.722	3.556	100.000	0
86.111	3.333		
90.092	2.350		
95.047	1.119		
100.000	0		

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TABLE III

ORDINATES FOR VANE FOR NACA 65_3-418 AIRFOIL SECTION

(Stations and ordinates in percent of wing chord)

Upper Surface		Lower Surface	
Station	Ordinate	Station	Ordinate
-0.556	1.167	0	0
0	2.167	.694	-.292
.694	2.569	1.389	-.275
1.389	2.803	2.083	-.042
2.083	2.953	2.778	.217
2.778	3.311	3.472	.478
3.472	3.022	4.167	.722
4.167	2.942	4.861	.931
4.861	2.828	5.556	1.092
5.556	2.611	6.250	1.172
6.250	2.386	6.944	1.153
6.944	2.106	7.639	1.042
7.639	1.778	8.333	.833
8.333	1.336	9.028	.550
9.028	.833	9.722	.181
9.722	.300	10.056	0
10.056	0		

TABLE IV

POSITION OF FLAP NOSE FOR VARIOUS FLAP DEFLECTIONS

(Stations and ordinates in percent of wing chord)

δ_f (deg)	Station	Ordinate
0	76.417	0
10	80.639	-.278
20	85.250	-.389
30	88.500	-1.444
40	92.917	-2.139
45	92.667	-2.444
50	92.444	-2.778
55	92.056	-3.222
60	91.722	-3.611
65	92.972	-3.806

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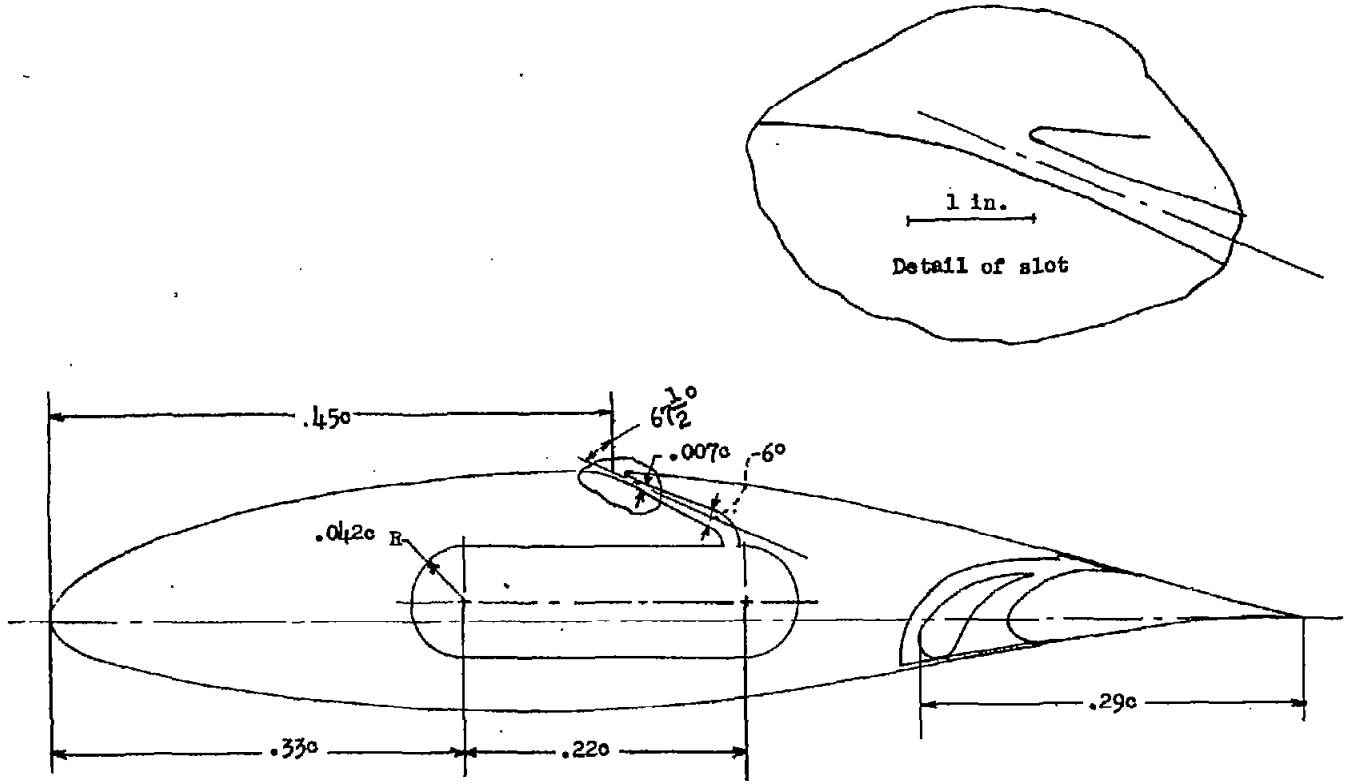

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Figure 1.- Schematic drawing of NACA 65_3-418 airfoil section equipped with boundary-layer control by suction and a 0.29c double slotted flap.

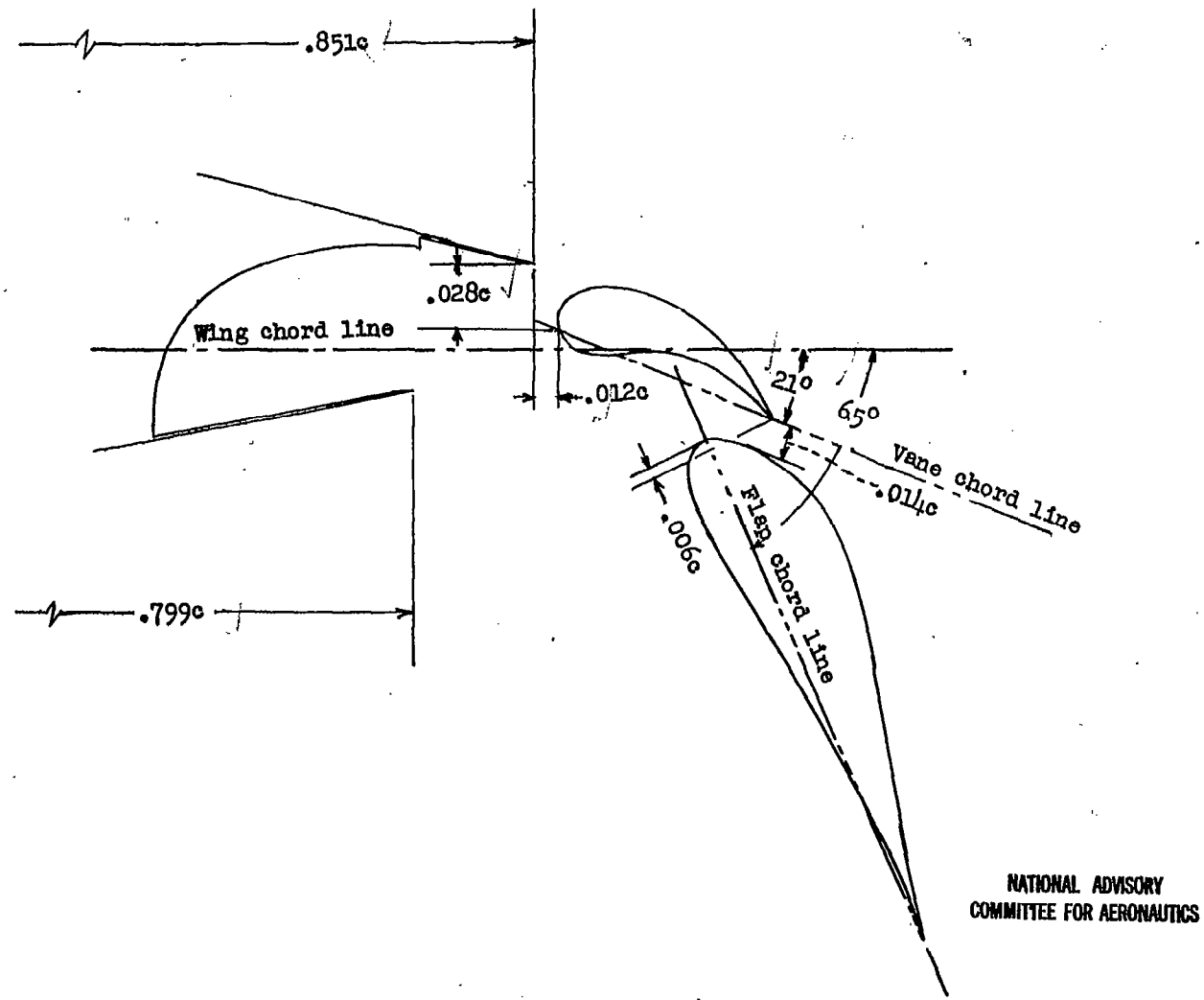
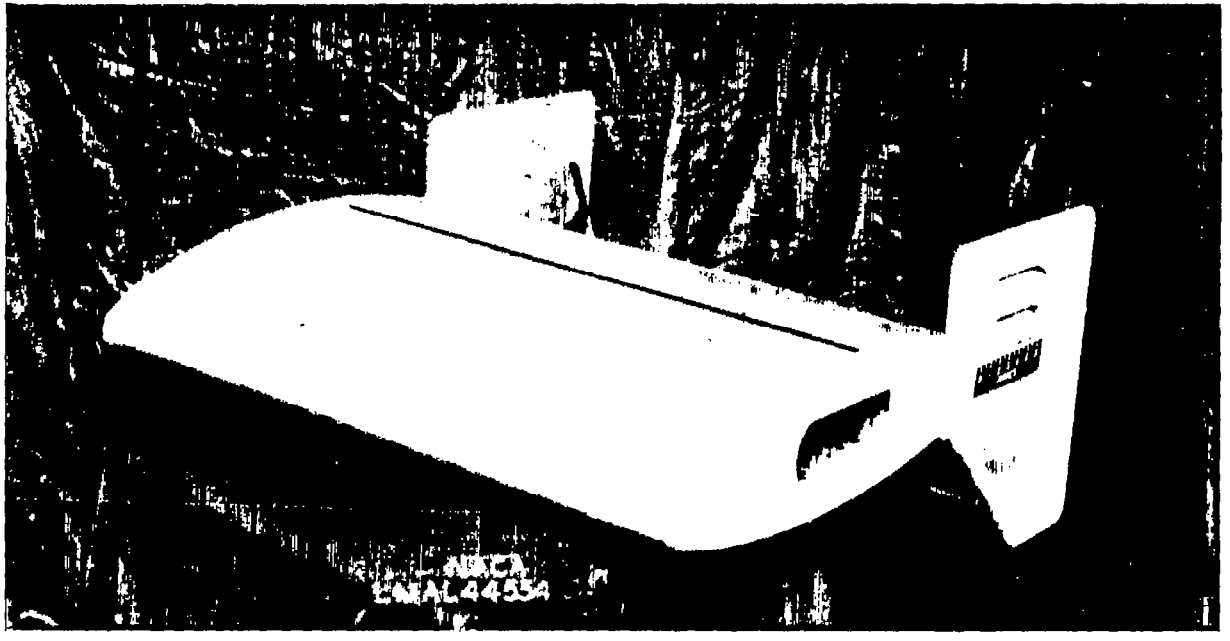
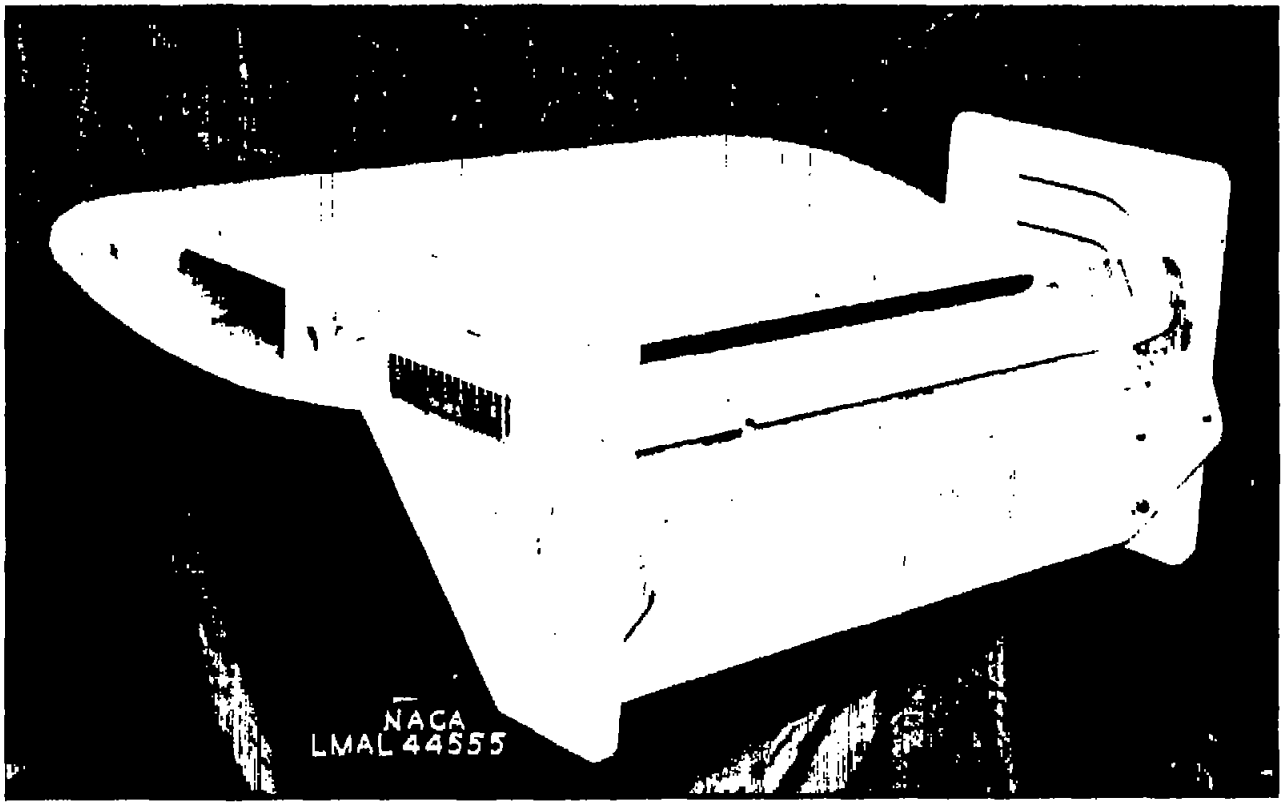


Figure 2.- Optimum configuration of double slotted flap on the NACA 65_3-418 airfoil section.



(a) Front top view.

Figure 3.- NACA 65_3-418 airfoil section with boundary-layer control and double slotted flap. δ_f, 65°.



(b) Rear top view.

Figure 3.- Concluded.

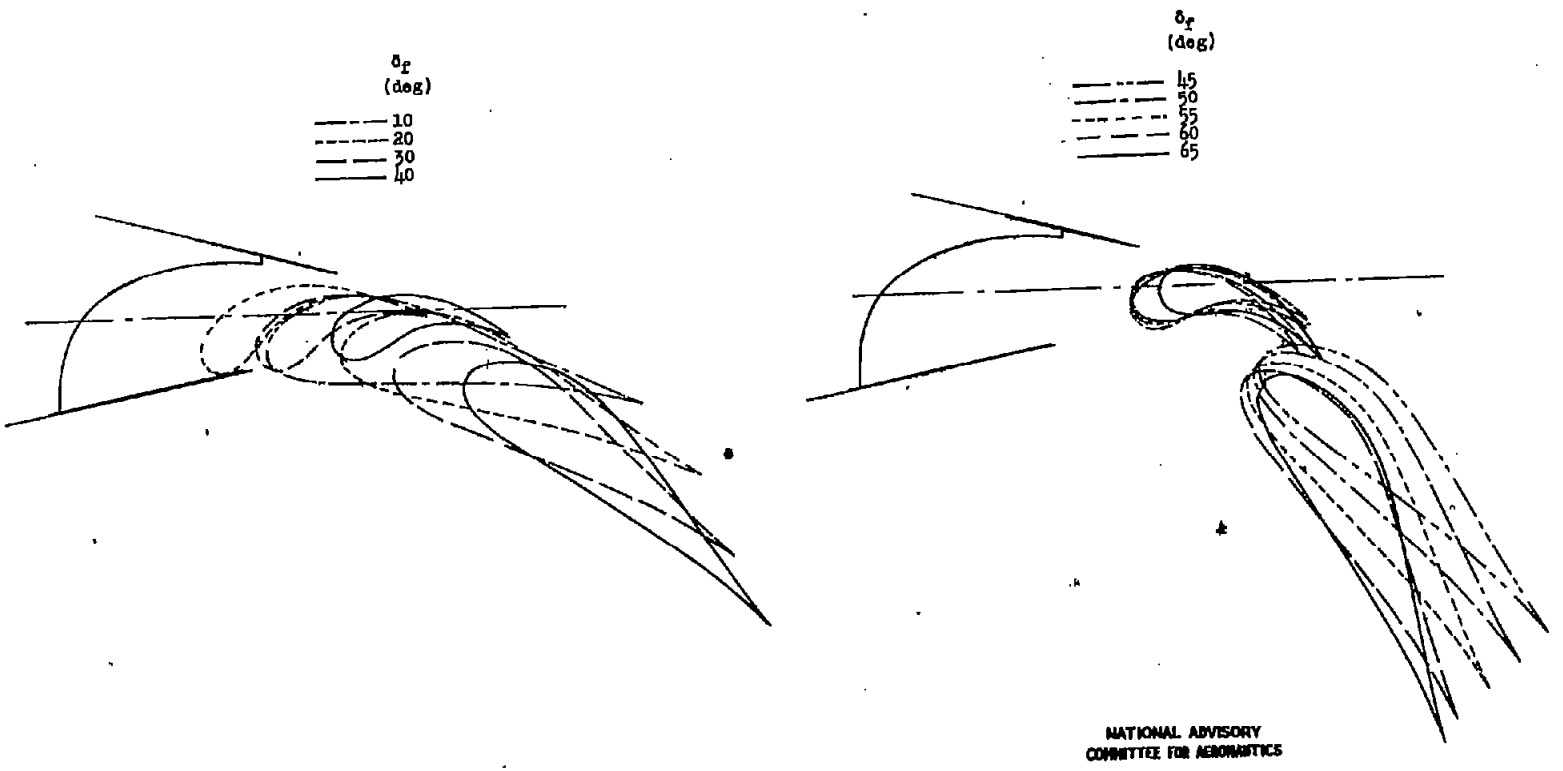
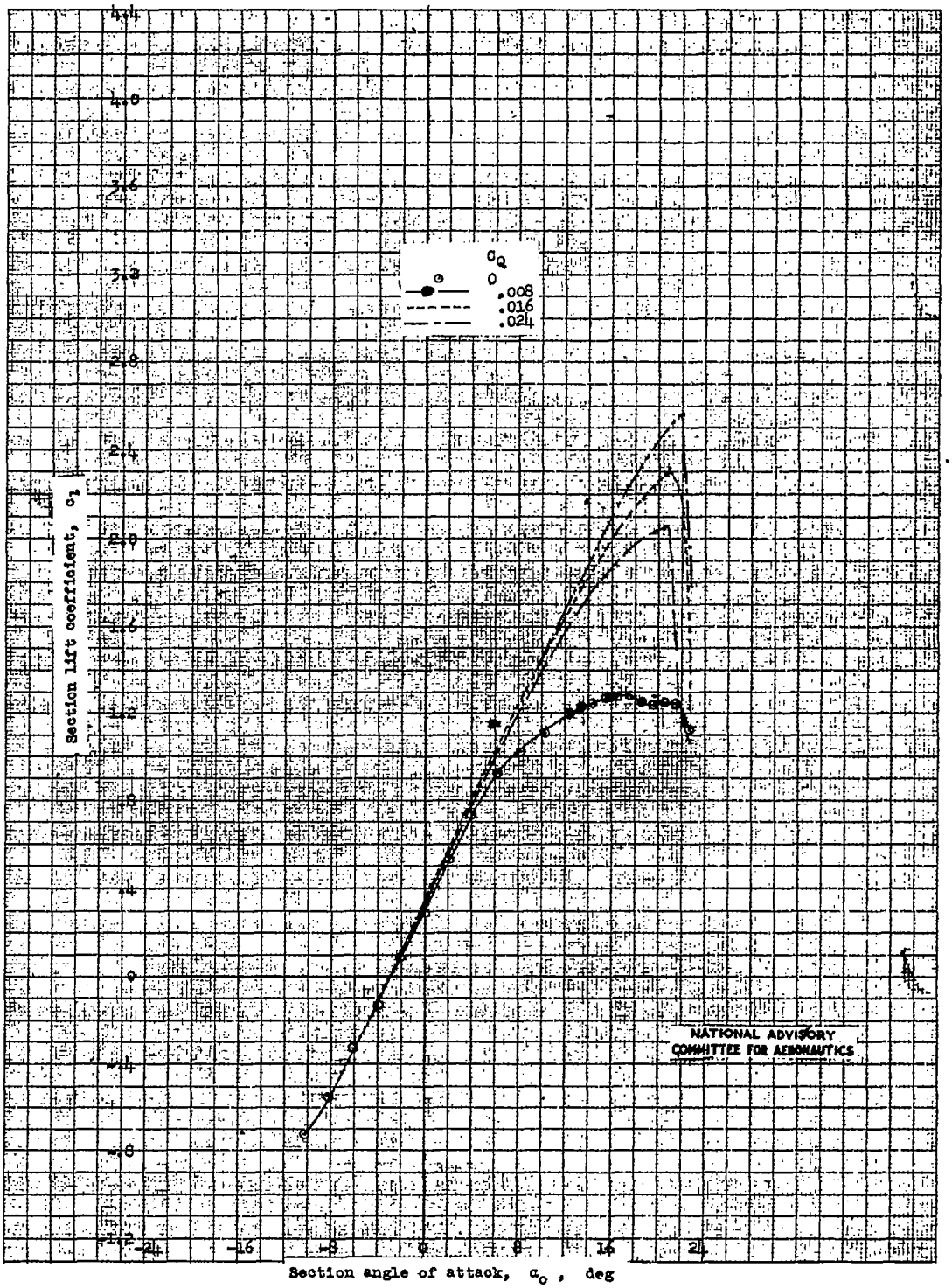
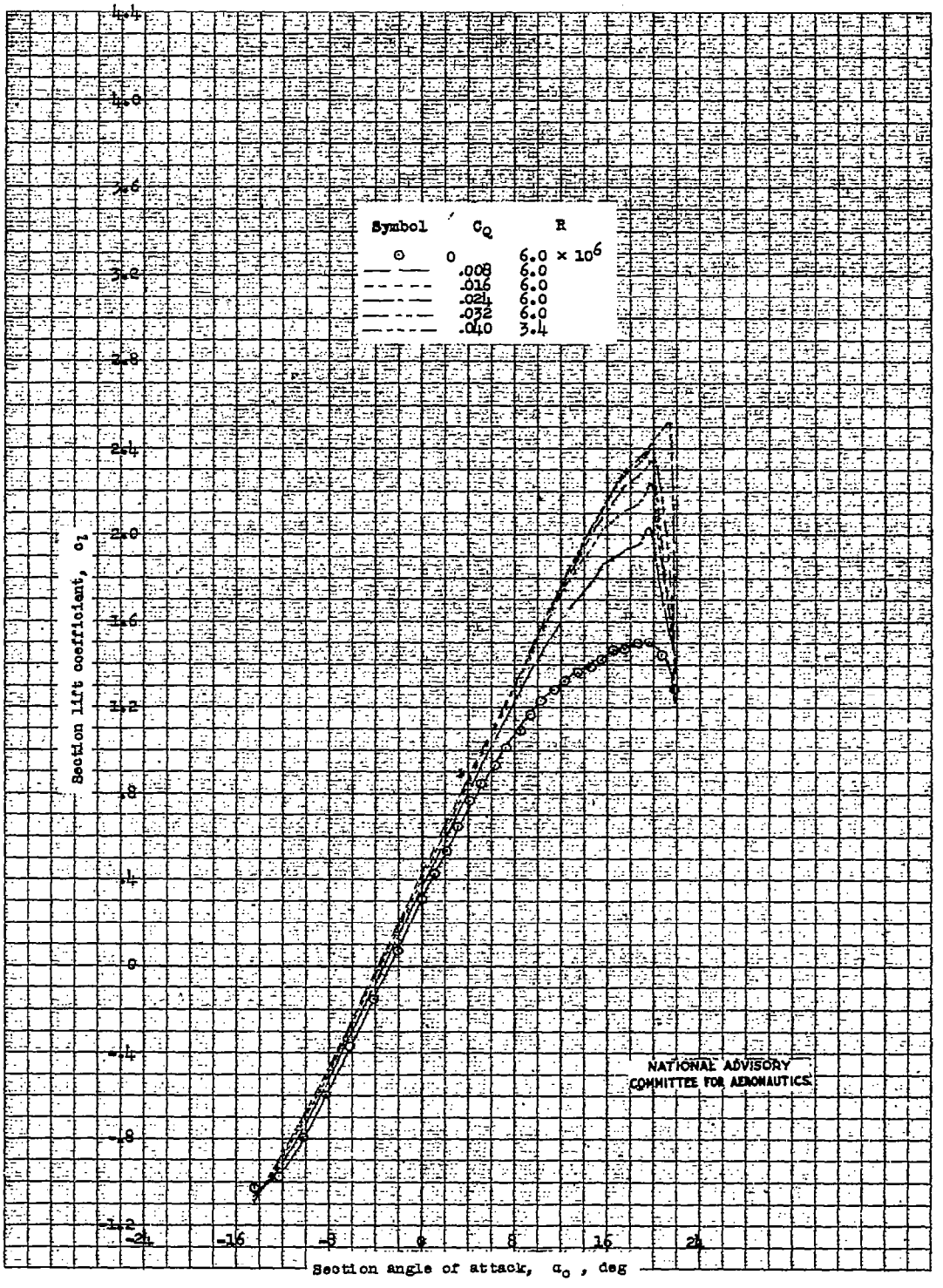


Figure 4.- Double slotted flap in all positions at deflections from 10° to 65°.



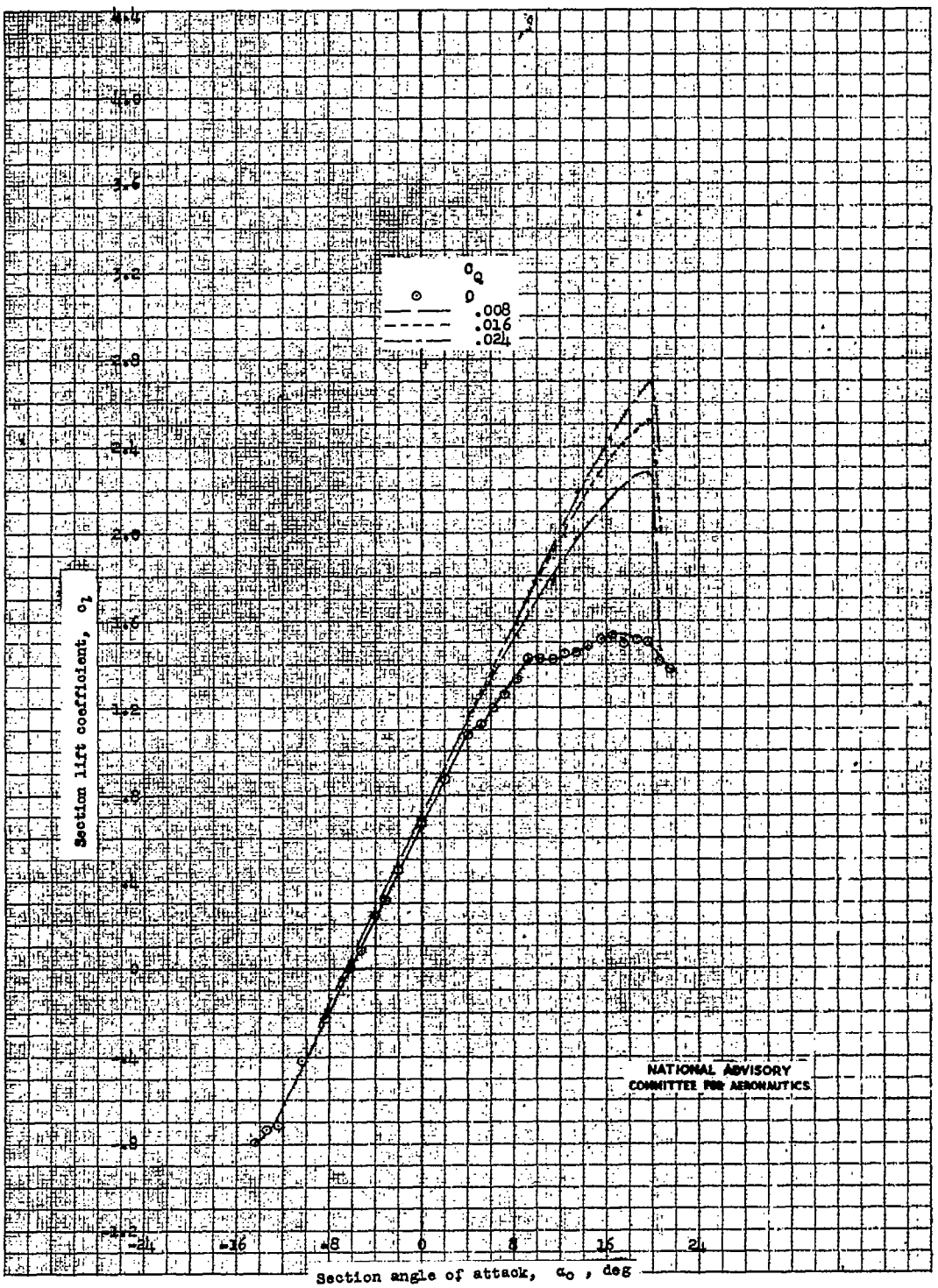
(a) $\delta_f = 0^\circ$; $R = 1.9 \times 10^6$; tests, LTT 402, 406.

Figure 5.- Lift characteristics of the NACA 653-418 airfoil section with a 0.29c double slotted flap and boundary-layer control.



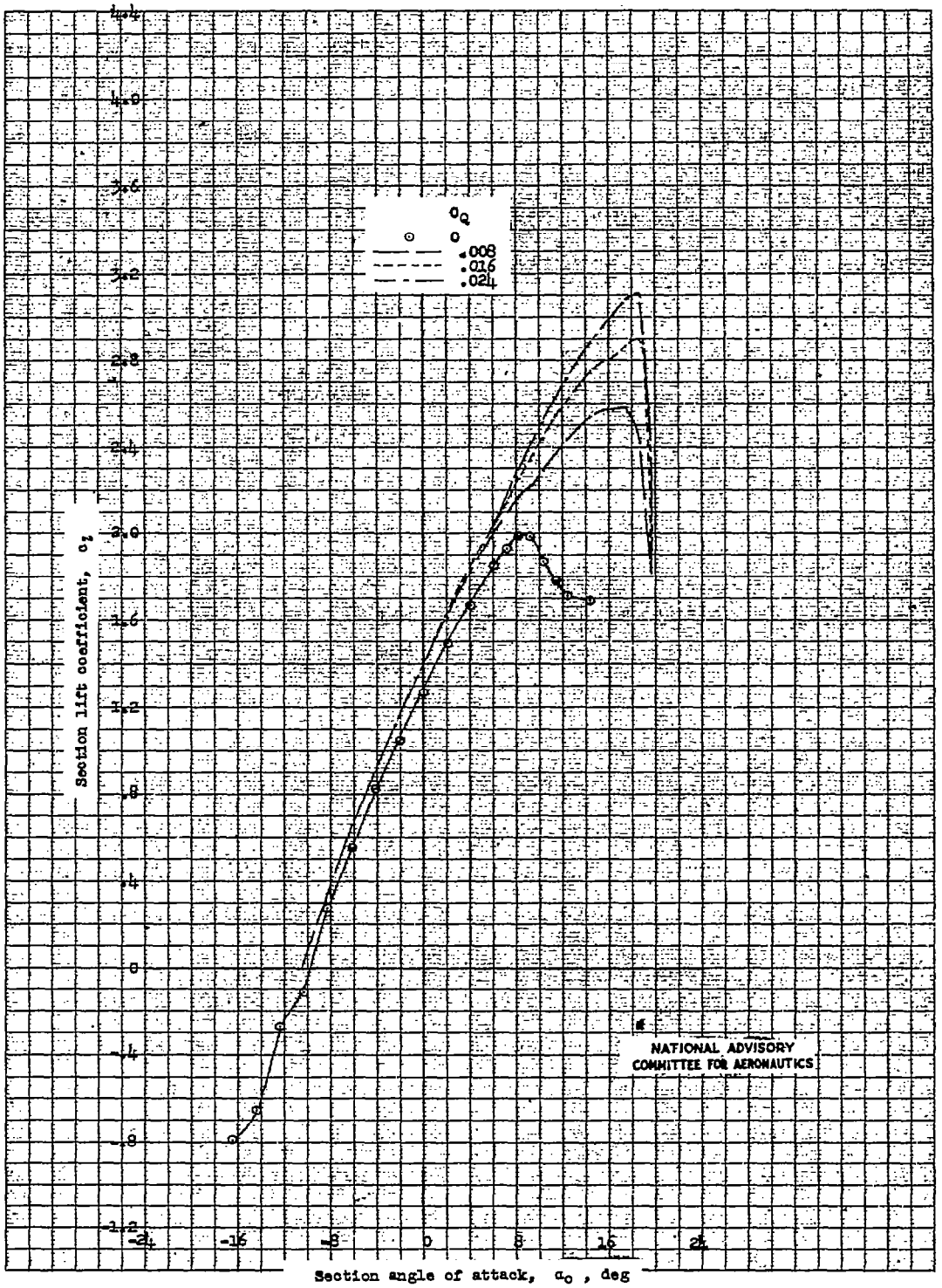
(b) $\delta_f = 0°$; test, TDT 892.

Figure 5.- Continued.



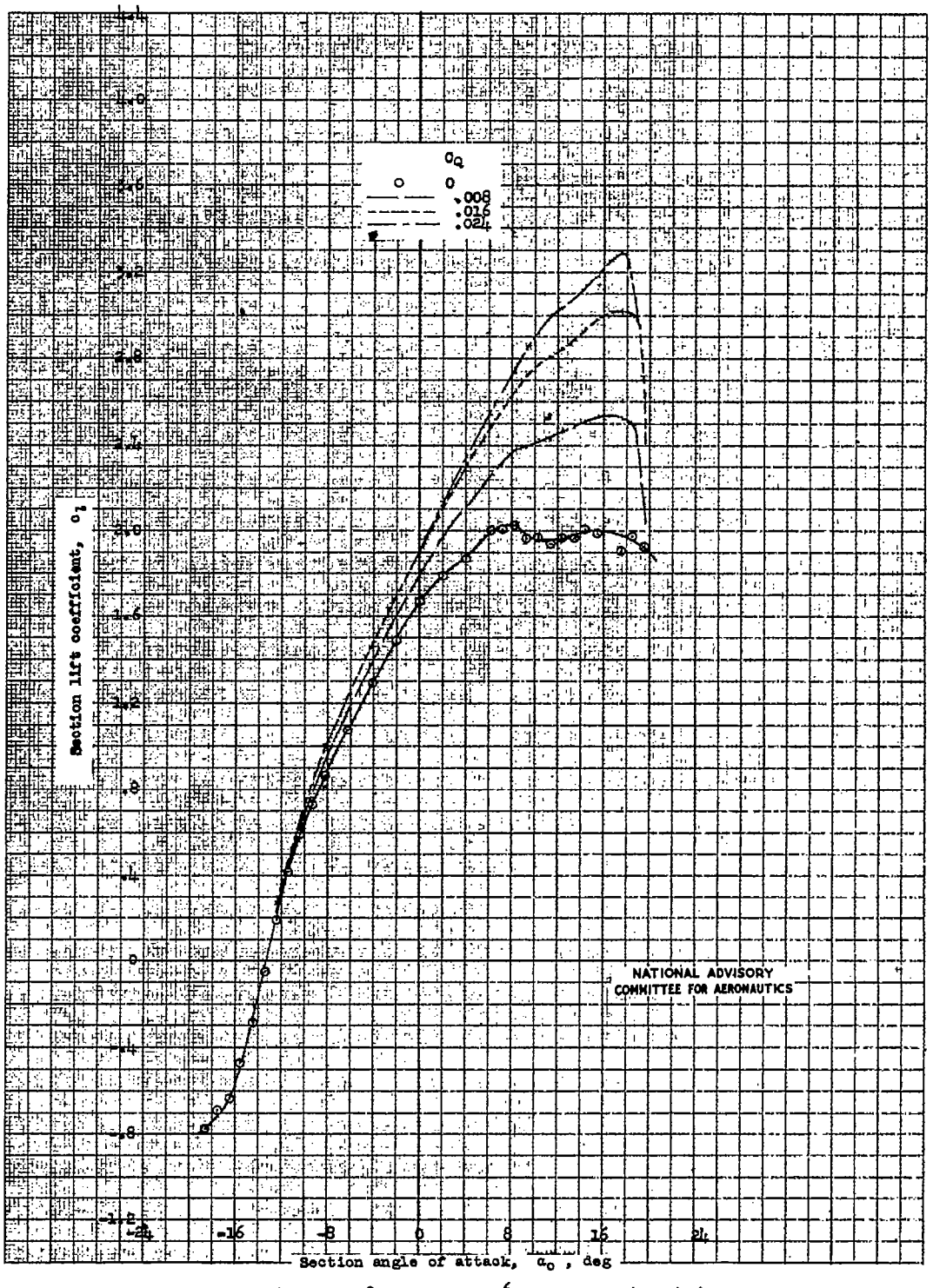
(c) $\delta_f = 10^\circ$; $R = 1.9 \times 10^6$; test, LTT 402, 406.

Figure 5.- Continued.



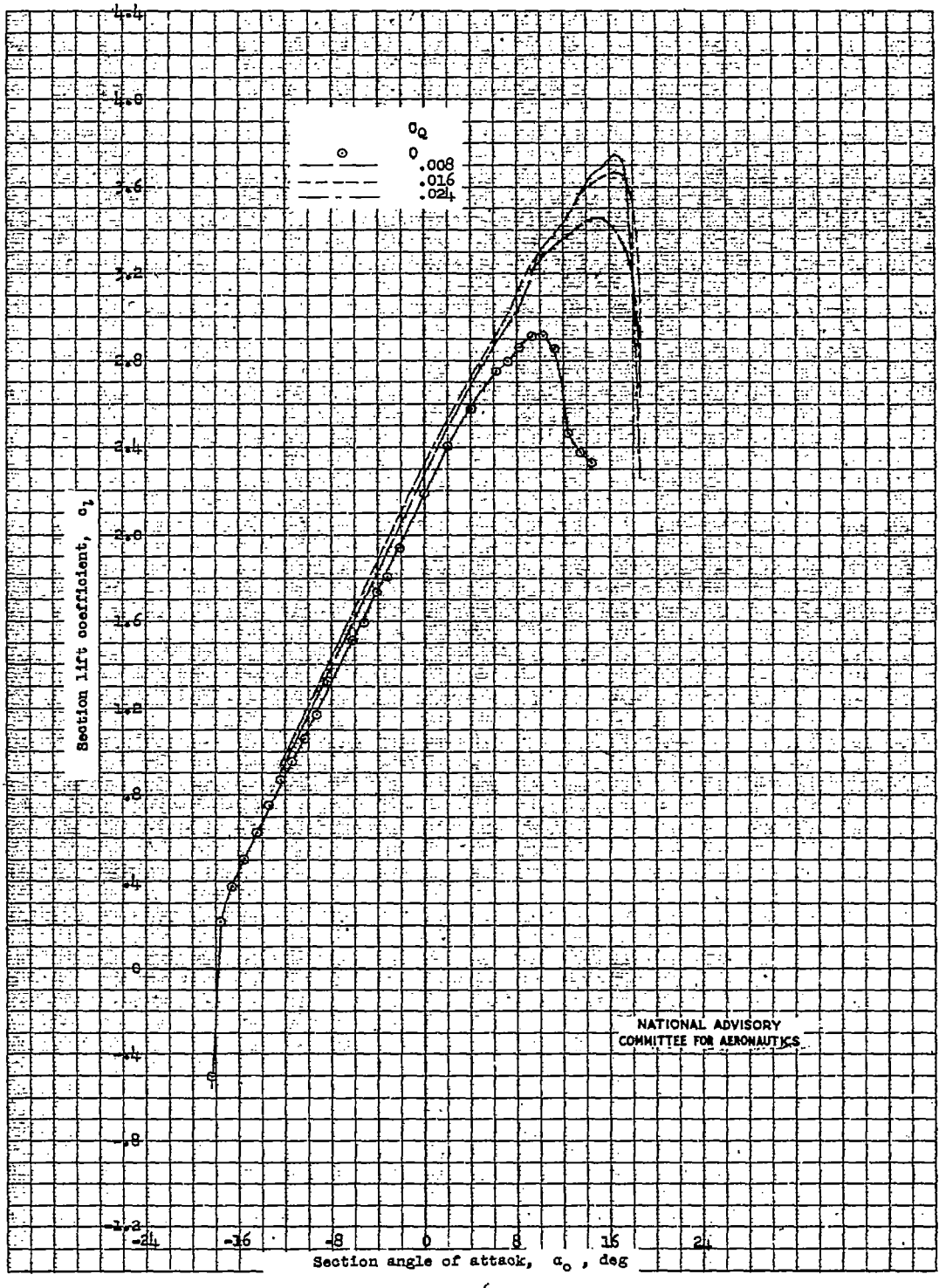
(d) $\delta_f = 20^\circ$; $R = 1.9 \times 10^6$; test, LTT 402, 406.

Figure 5.- Continued.



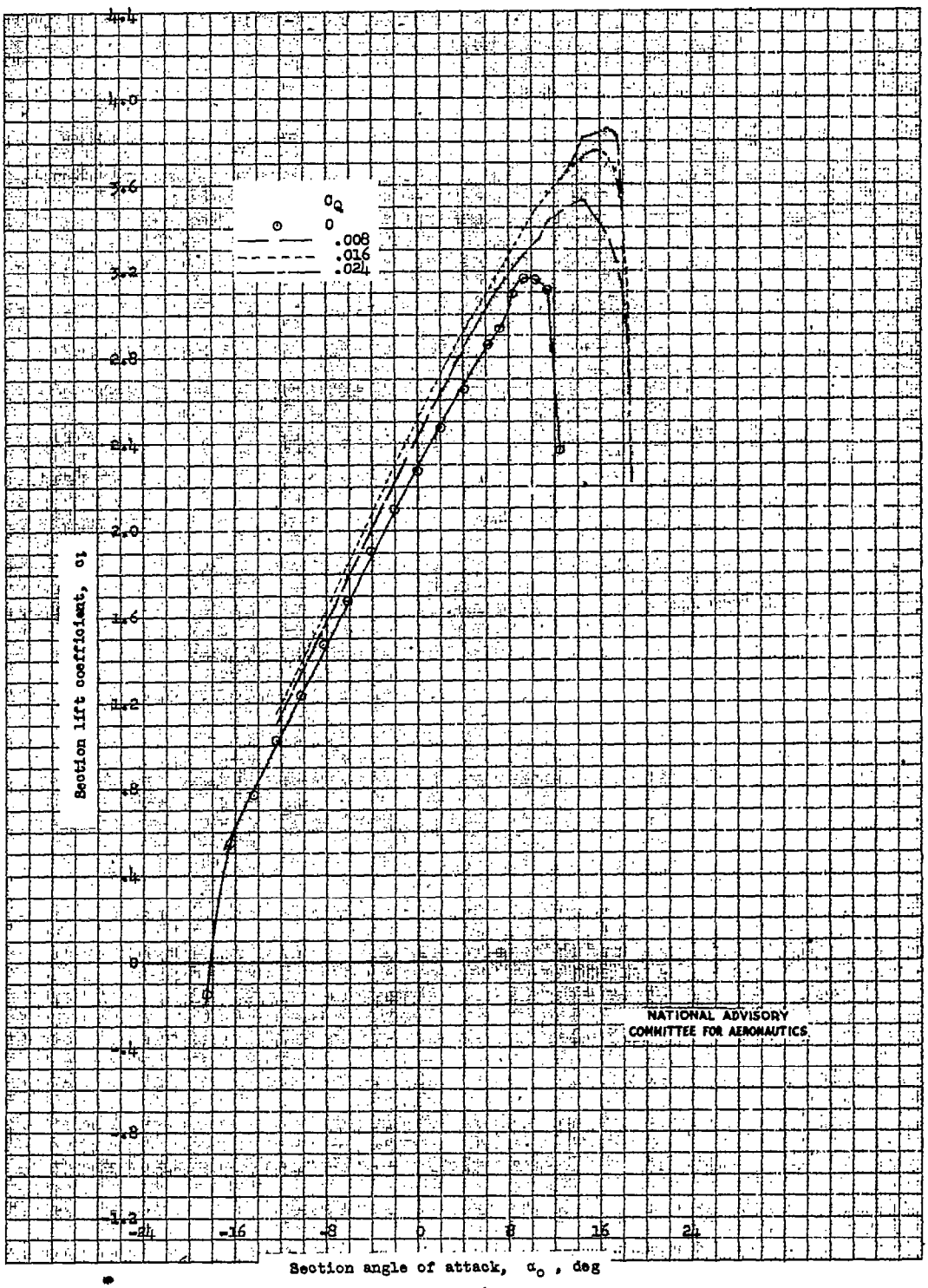
(e) $\delta_f = 30°$; $R = 1.9 \times 10^6$; tests, LTT 402, 406.

Figure 5.- Continued.



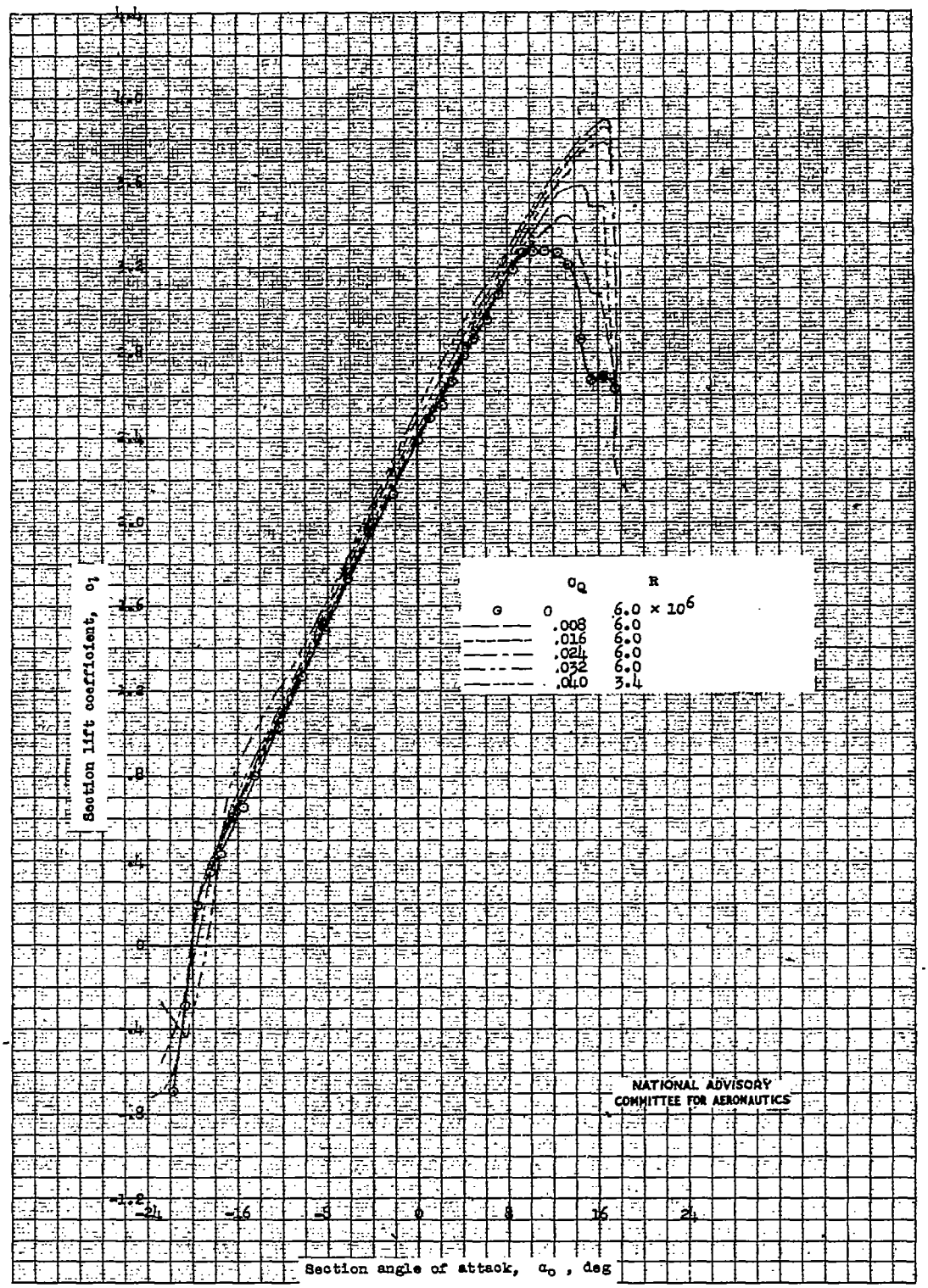
(f) $\delta_f = 40^\circ$; $R = 1.9 \times 10^6$; tests, LTT 402, 406.

Figure 5.- Continued.



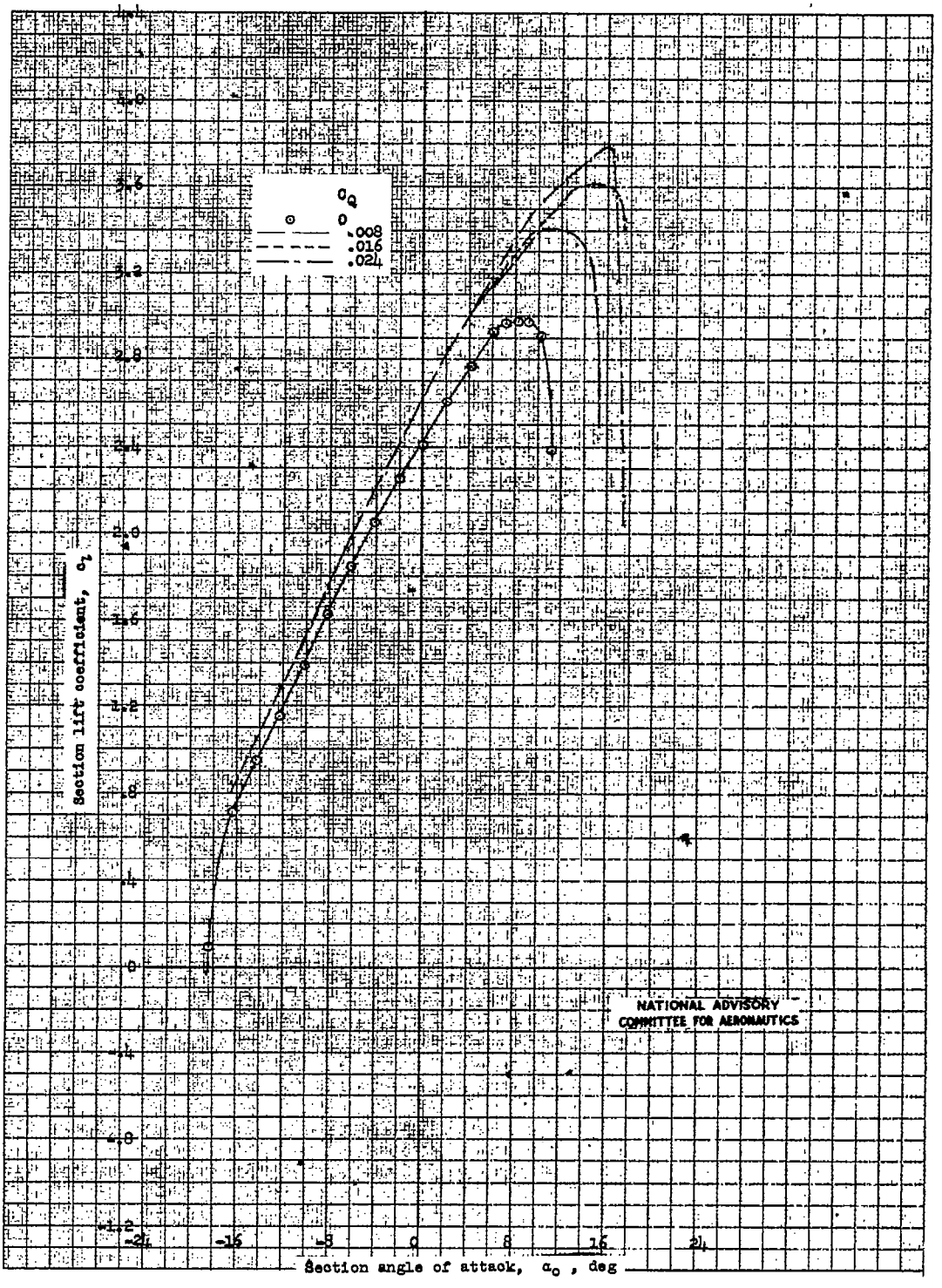
(g) $\delta_f = 45°$; $R = 1.9 \times 10^6$; tests, LTT 402, 406.

Figure 5.- Continued.



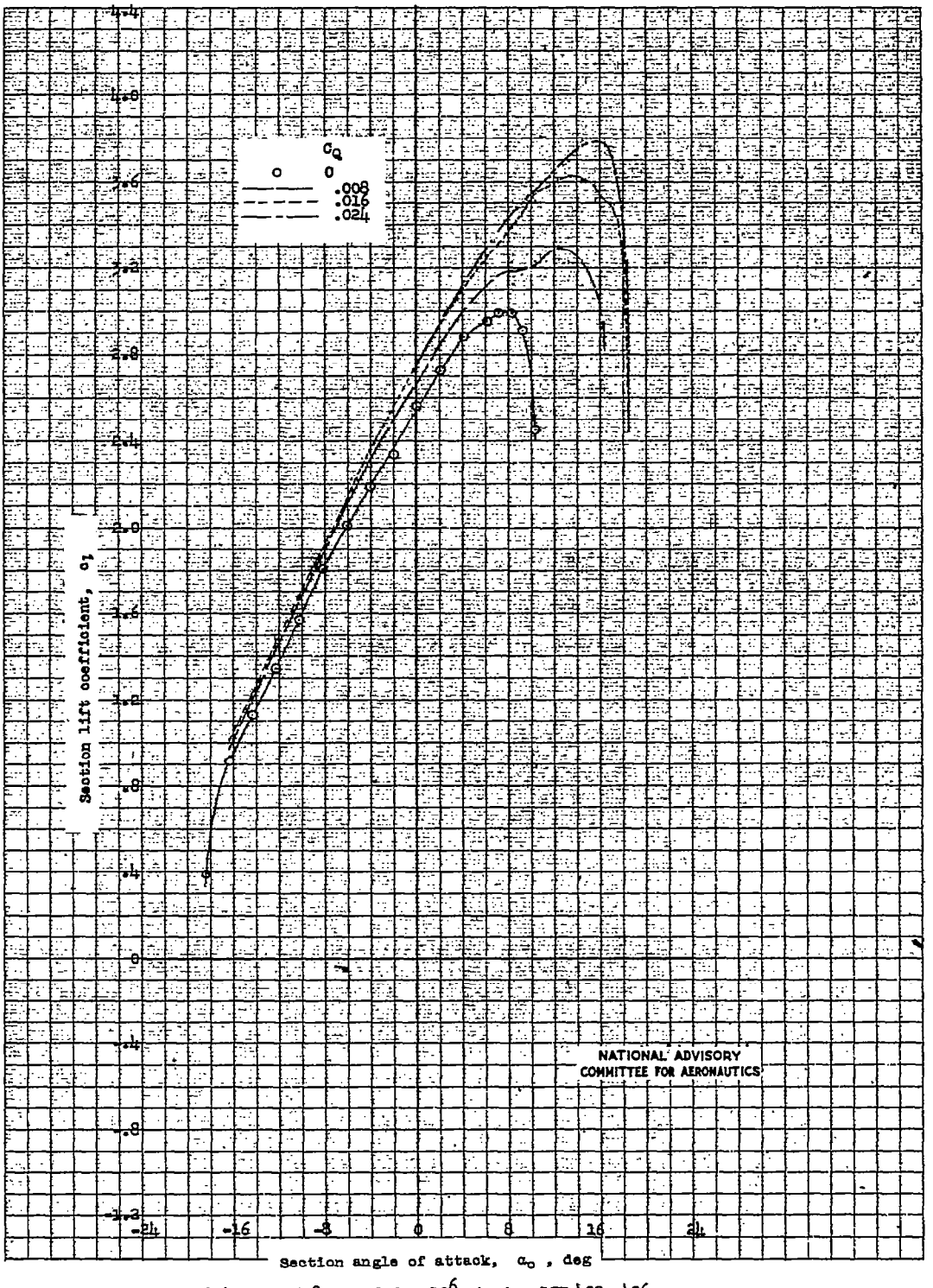
(h) $\delta_f = 45^\circ$; test, TDT 892.

Figure 5.- Continued.



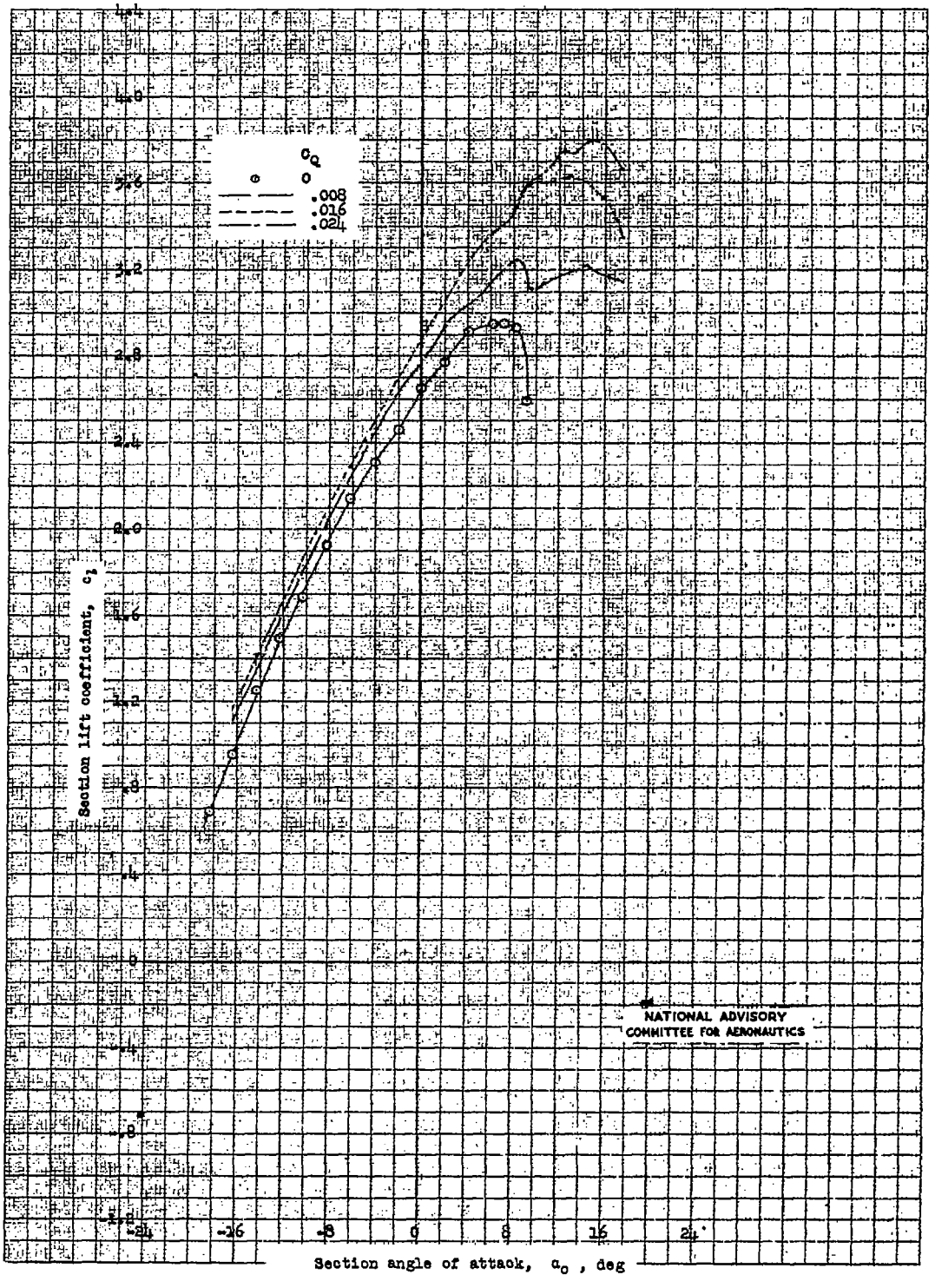
(i) $\delta_f = 50°$; $R = 1.9 \times 10^6$; tests, LTT 402, 406.

Figure 5.- Continued.



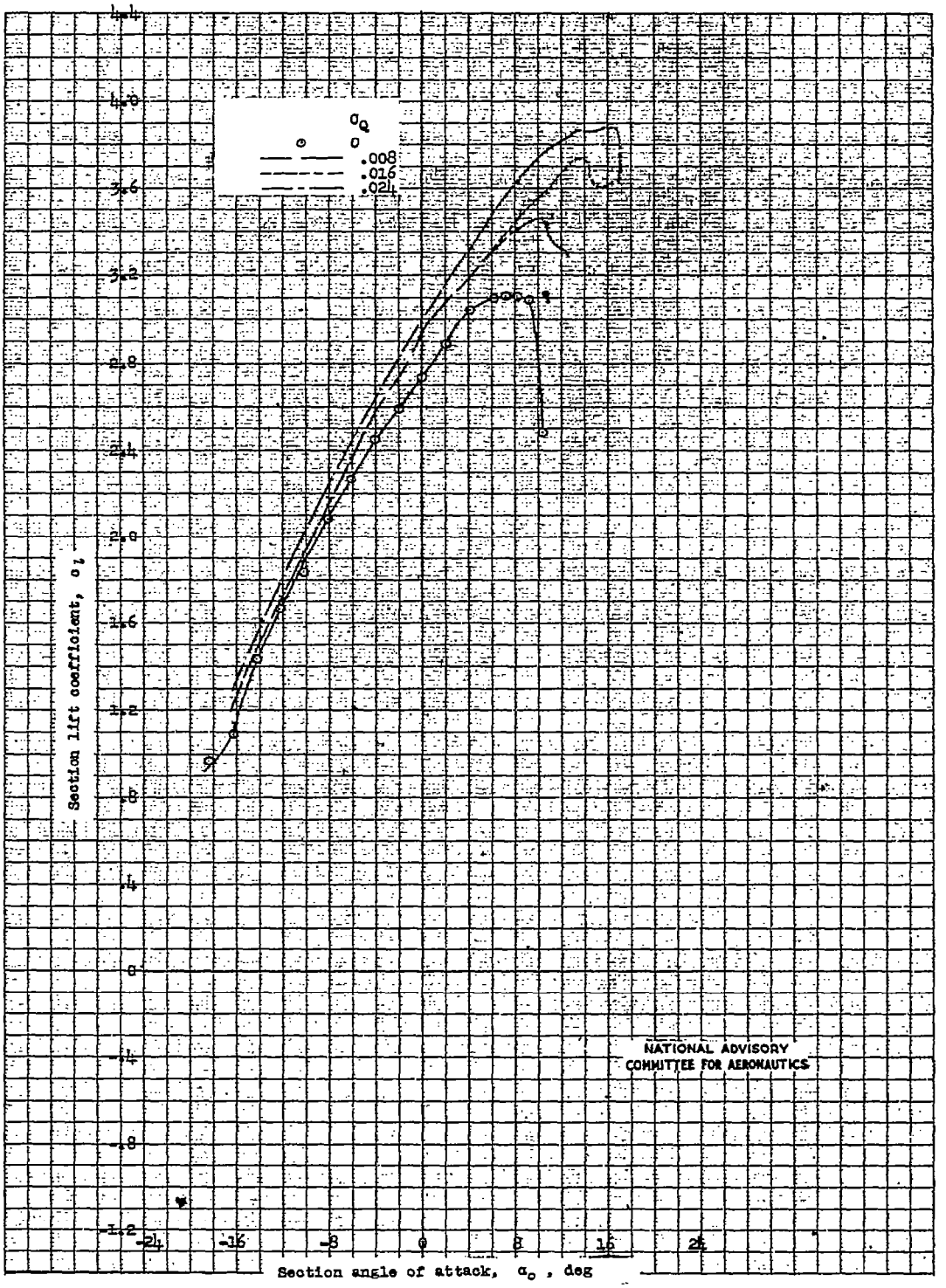
(j) $\delta_f = 55°$; $R = 1.9 \times 10^6$; tests, LTT 402, 406.

Figure 5.- Continued.



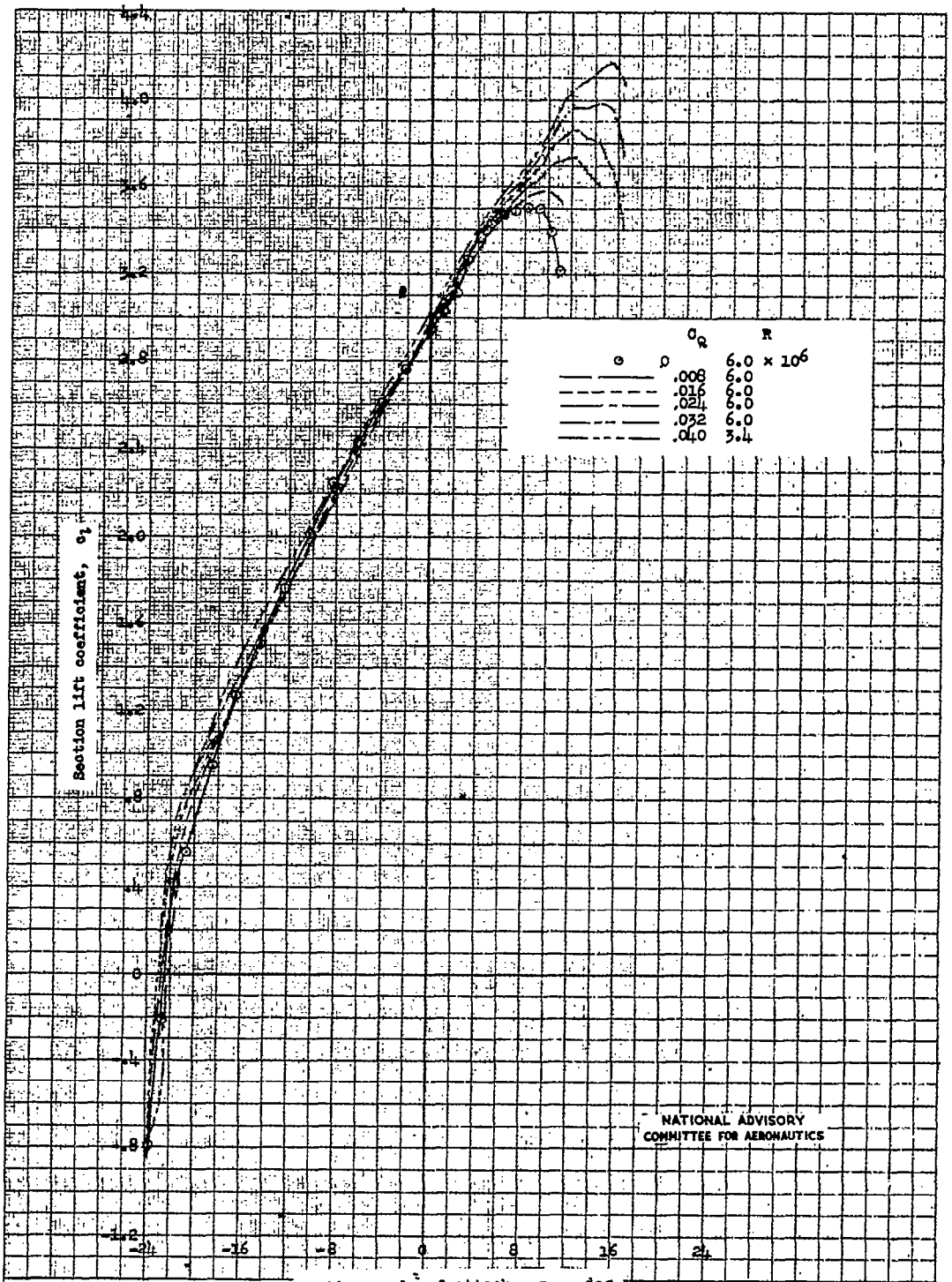
(k) $\delta_f = 60^\circ$; $R = 1.9 \times 10^6$; tests, LTT 402, 406.

Figure 5.- Continued.



(1) $\delta_f = 65^\circ$; $R = 1.9 \times 10^6$; tests, LTT 402, 406.

Figure 5.- Continued.



(m) $\delta_f = 65^\circ$; test, TDT 892.

Figure 5.- Concluded.

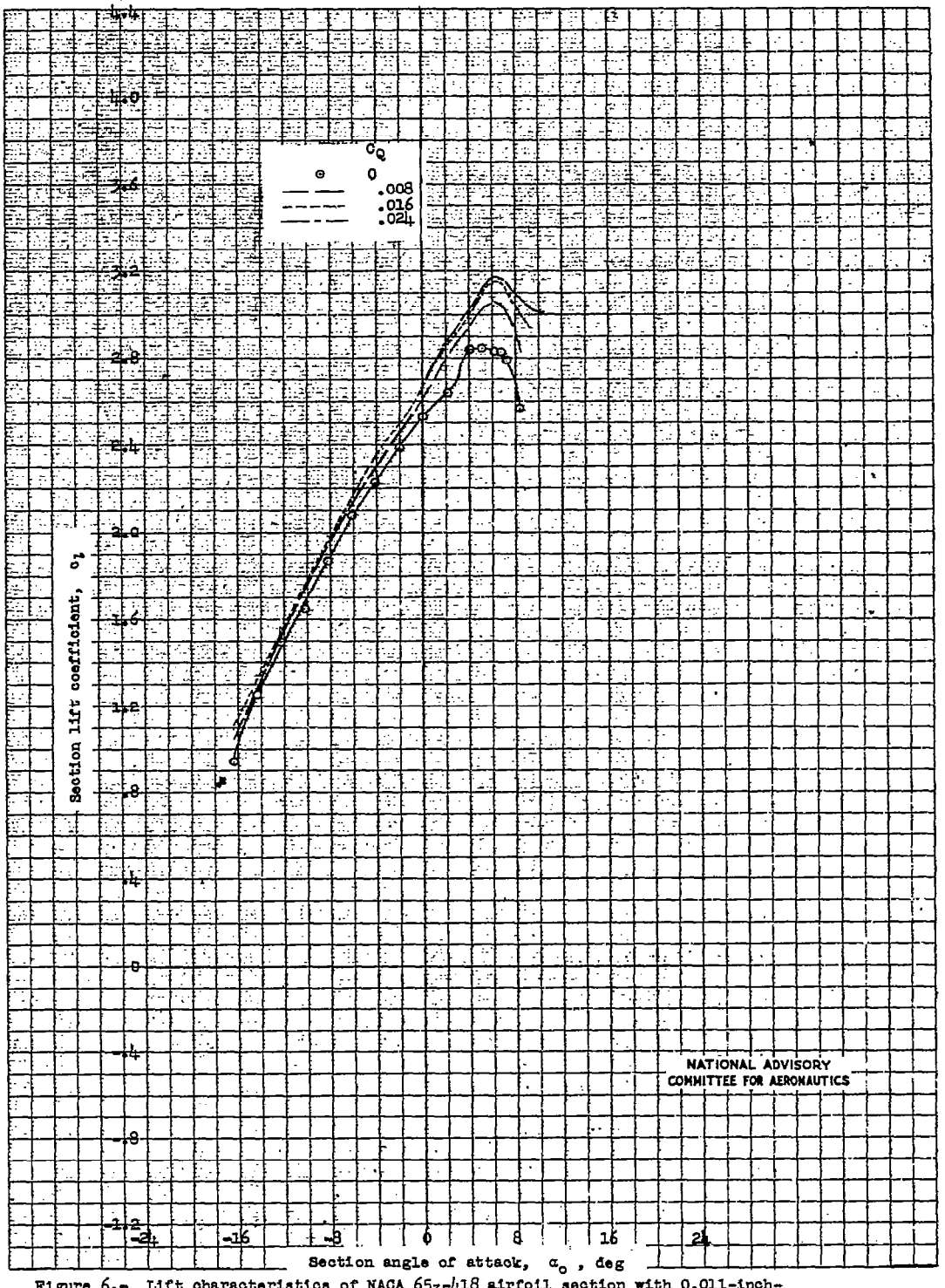


Figure 6.- Lift characteristics of NACA 65_3-418 airfoil section with 0.011-inch-diameter carborundum grains applied to nose, $\delta_f = 65^\circ$; $R = 1.9 \times 10^6$; test, LTT 406.

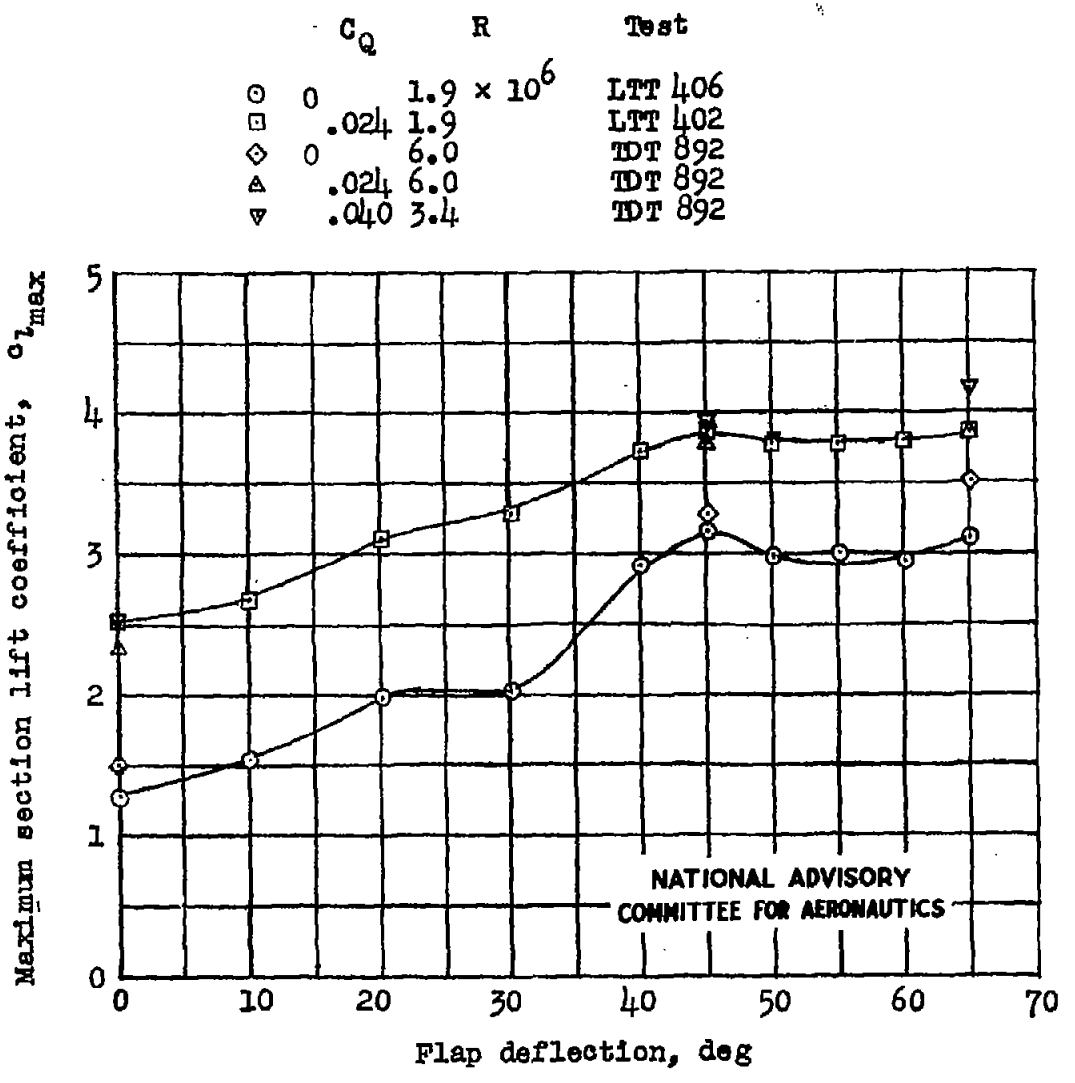


Figure 7.- Flap effectiveness of 0.29c double slotted flap on NACA 65_3-418 airfoil section with and without boundary-layer control.

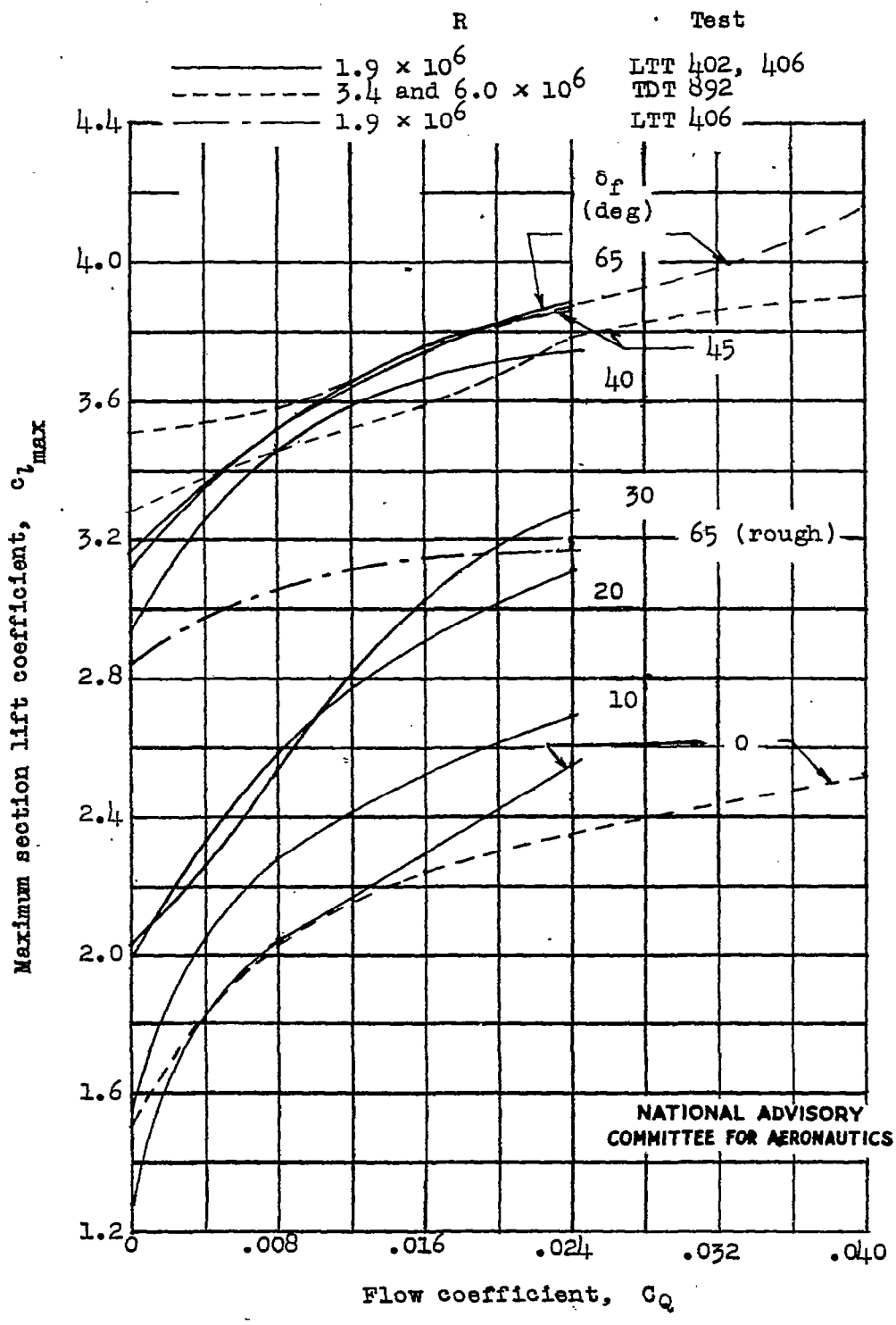
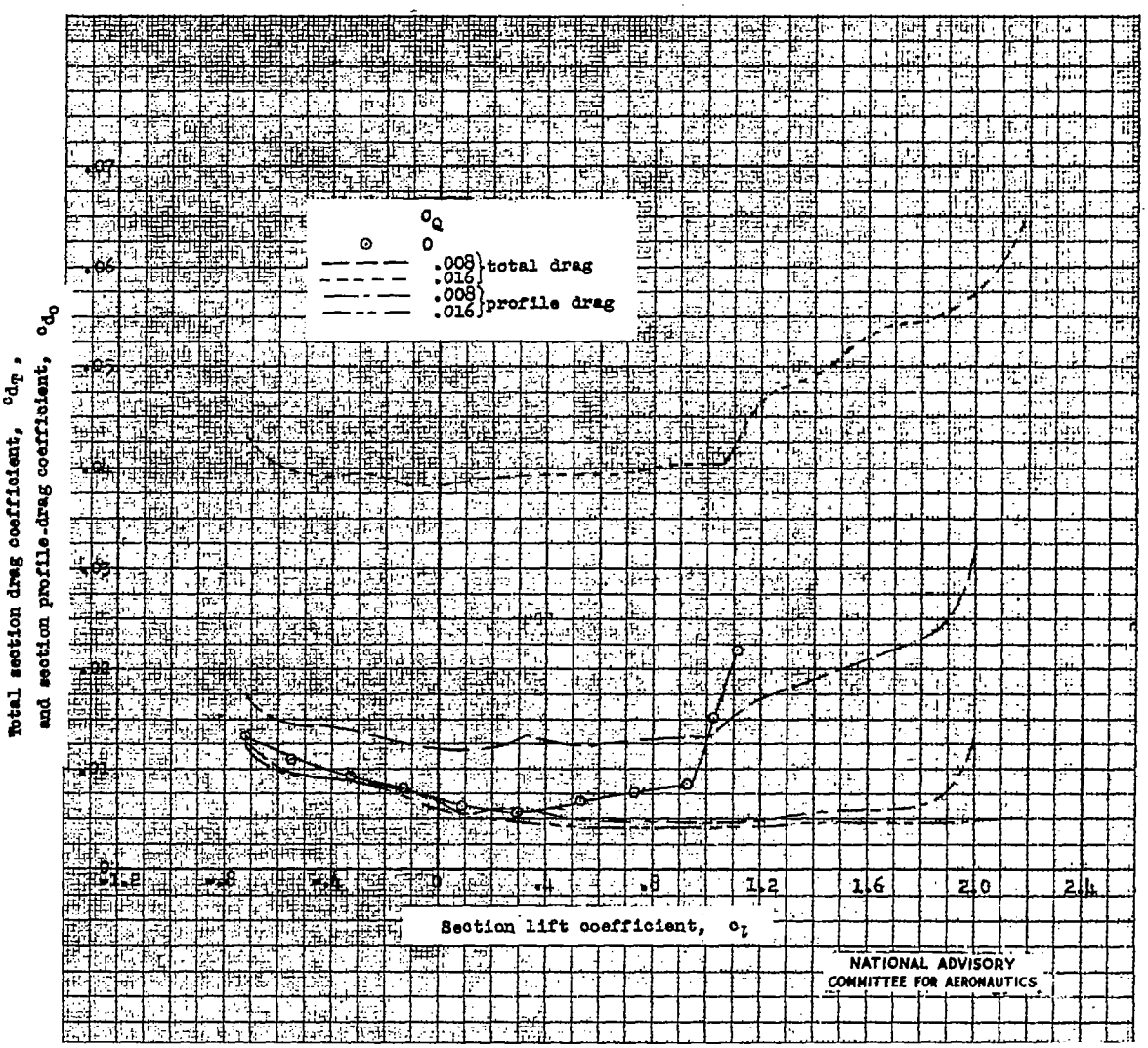
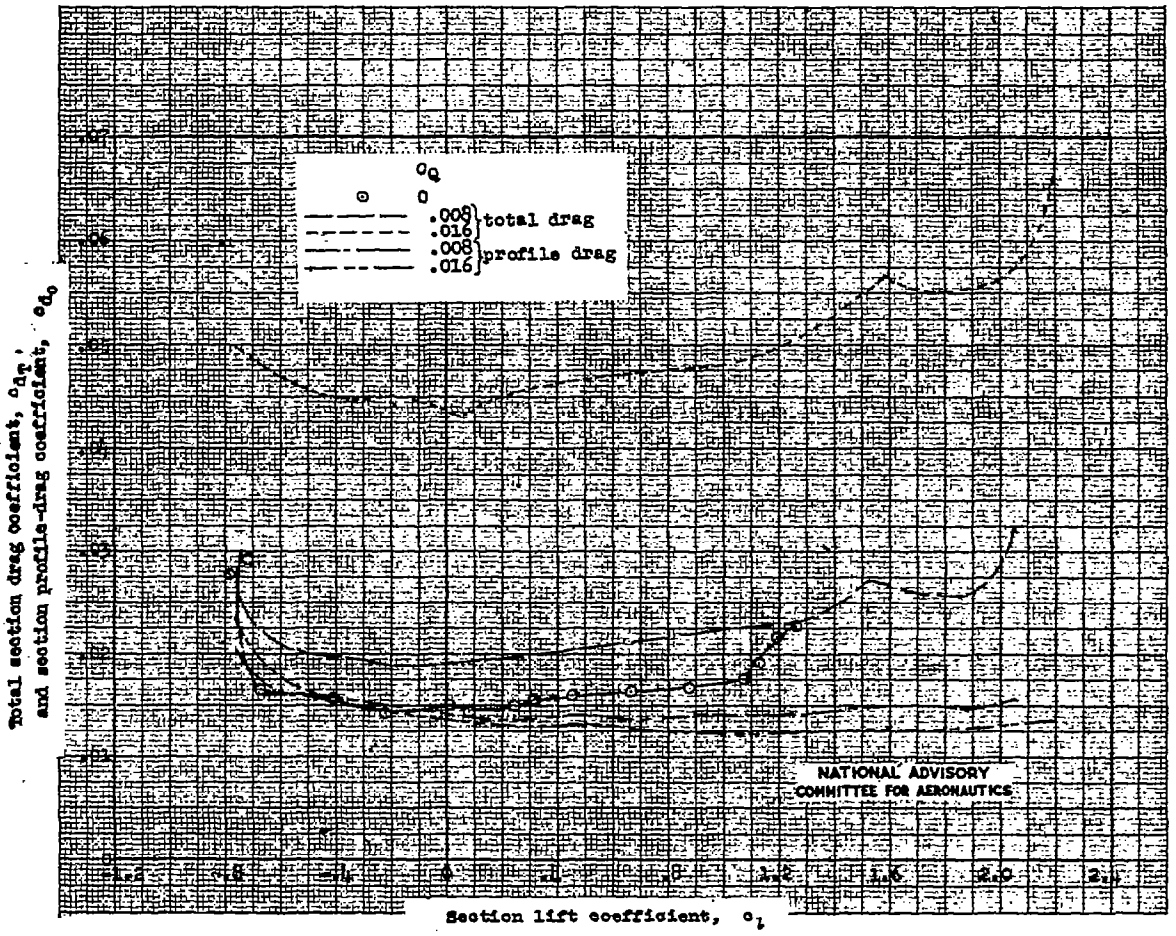


Figure 8.- Variation of maximum section lift coefficient with flow coefficient for various flap deflections and Reynolds numbers.



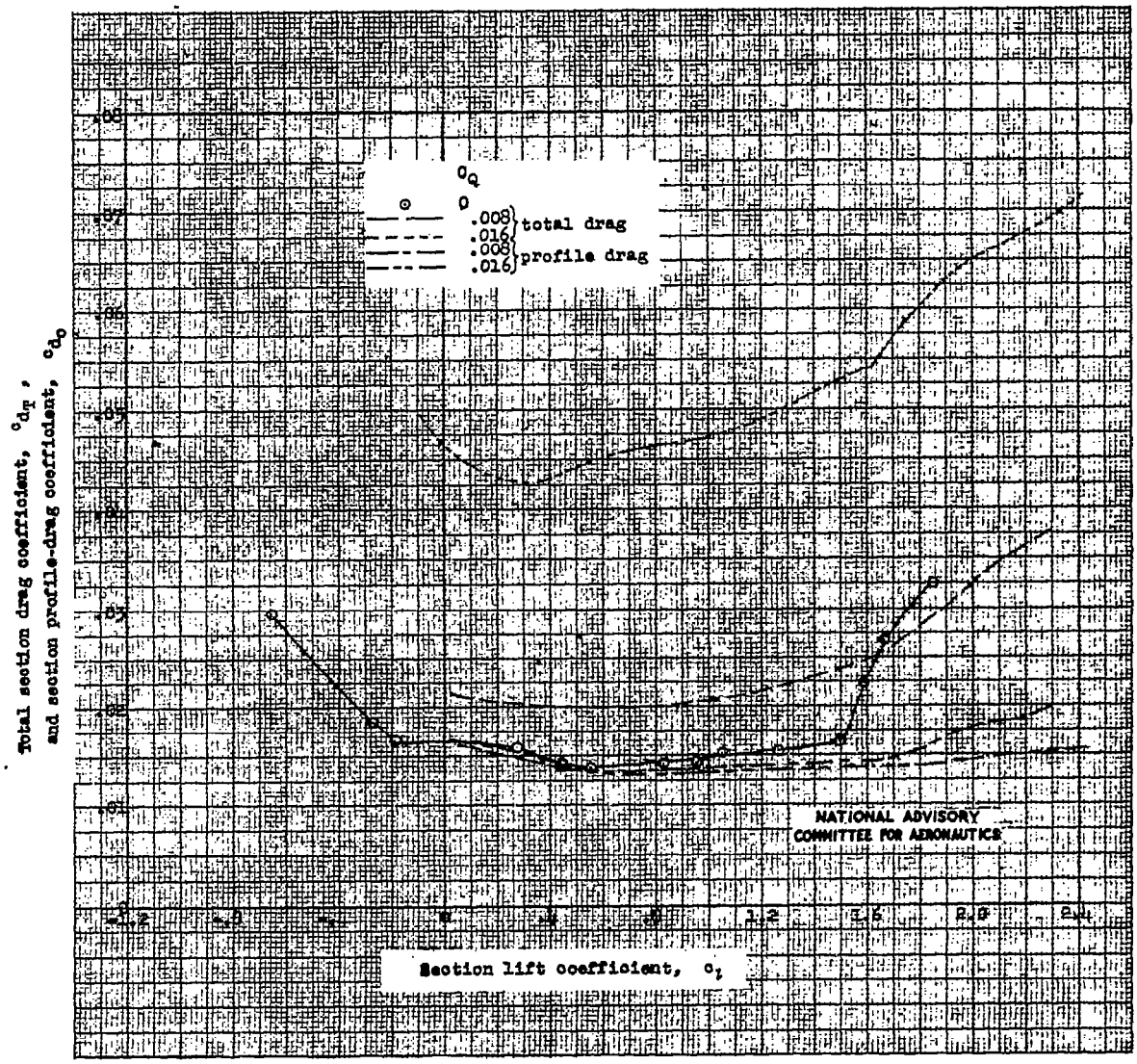
(a) $\delta_f = 0^\circ$.

Figure 9.- Drag characteristics of NACA 65_3-418 airfoil section with and without boundary-layer control at various flap deflections. $R = 1.9 \times 10^6$; test, LTT 406.



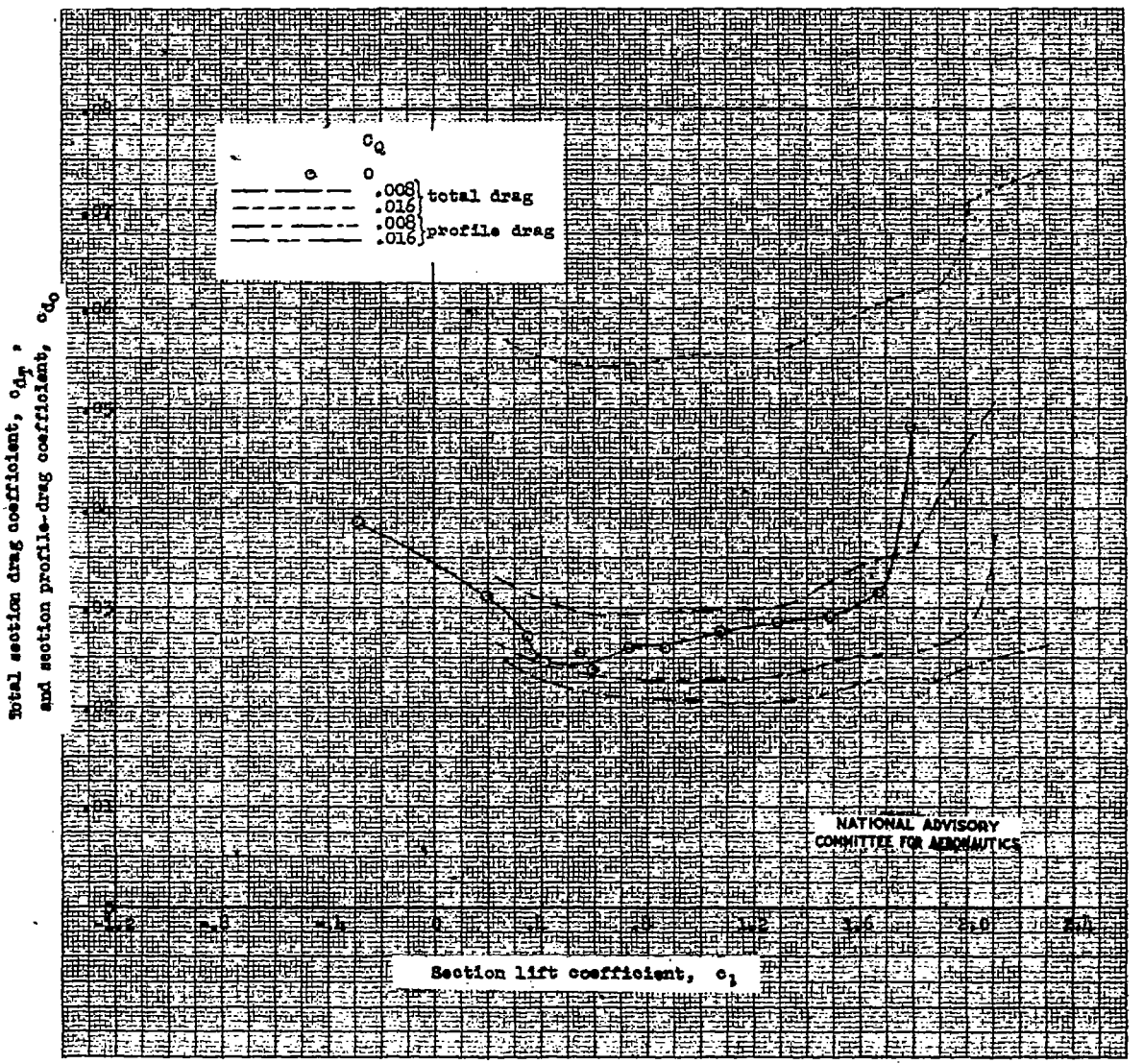
(b) $\delta_f = 10^\circ$.

Figure 9.- Continued.



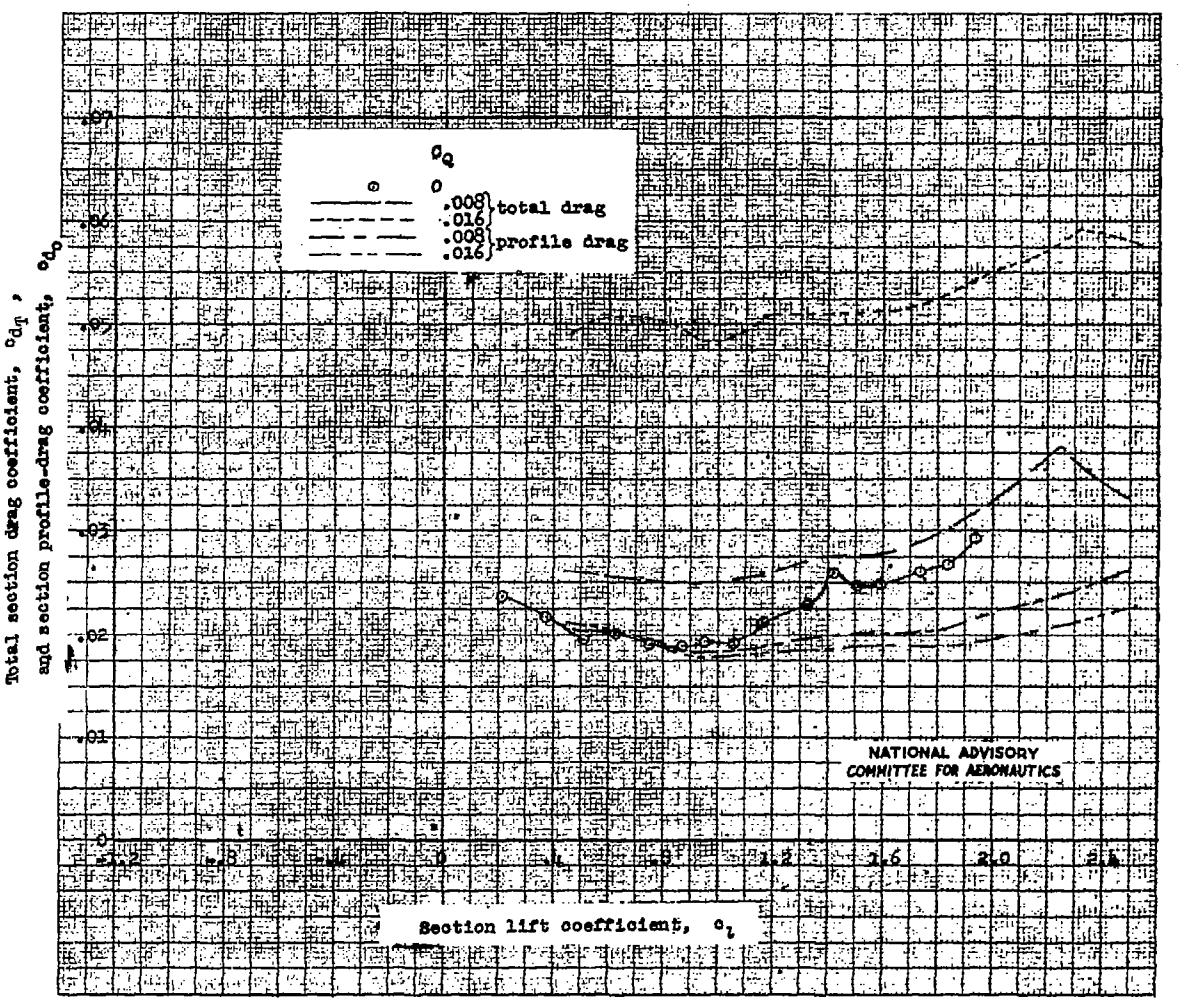
(c) $\delta_f = 20^\circ$.

Figure 9.- Continued.



(d) $\delta_f = 30^\circ$

Figure 9.- Continued.



(e) $\delta_f = 40°$

Figure 9.- Concluded.

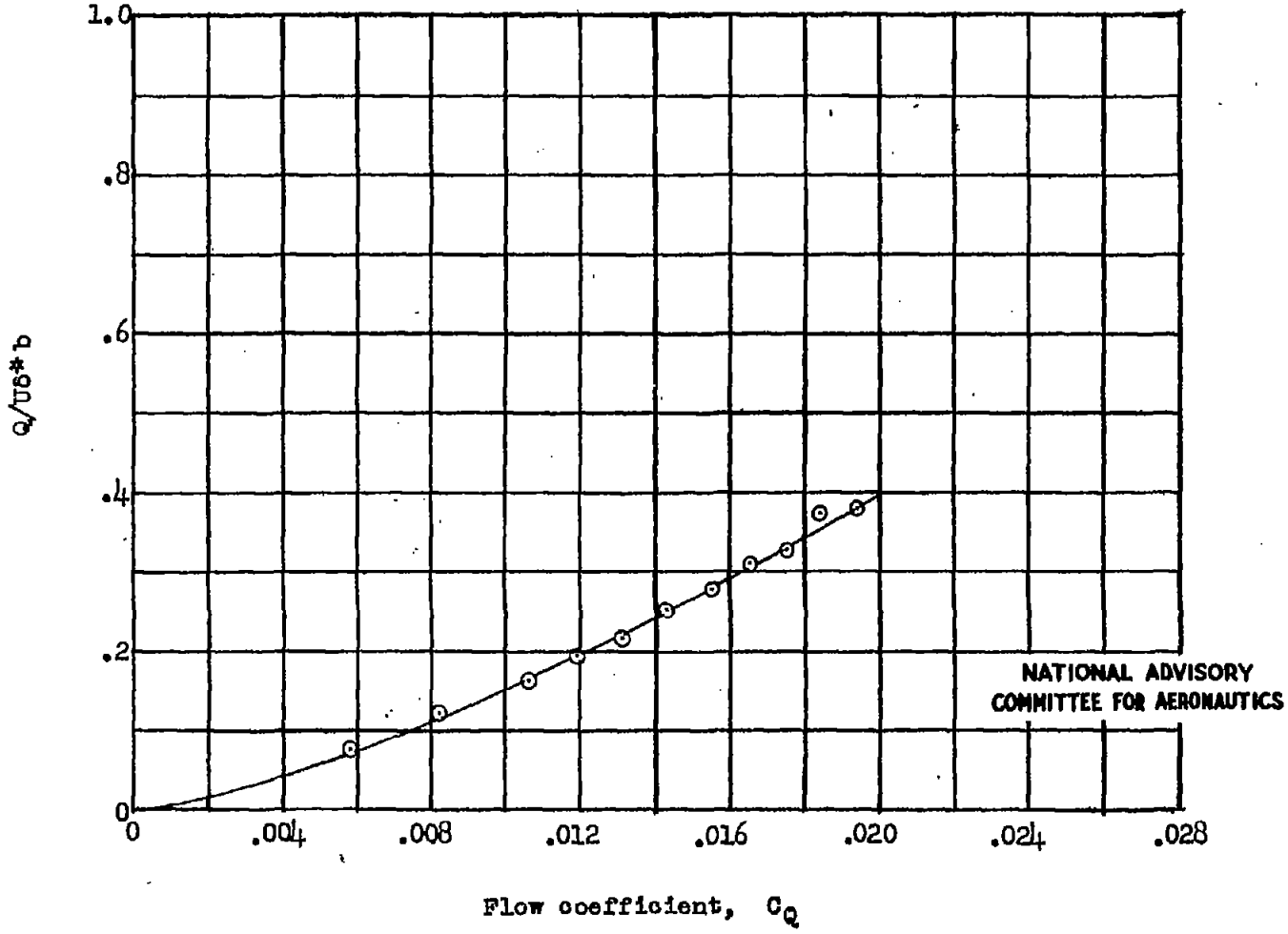


Figure 10.- Variation of $Q/U\,\delta^*b$ at 0.44c with flow coefficient for NACA 65_3-418 airfoil section. $\delta_f = 65^\circ$; $\alpha_o = 16^\circ$; $R = 1.9 \times 10^6$.

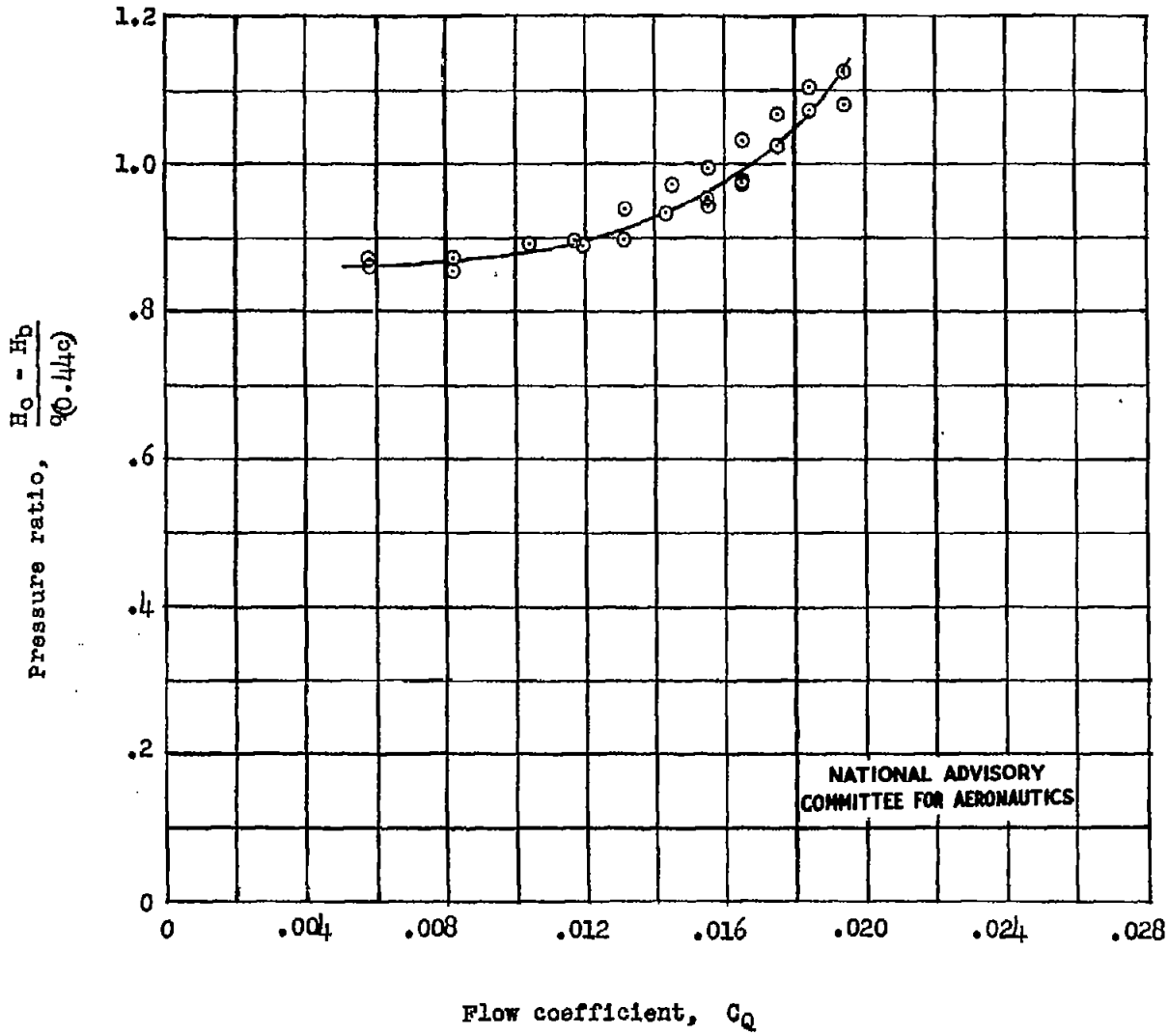
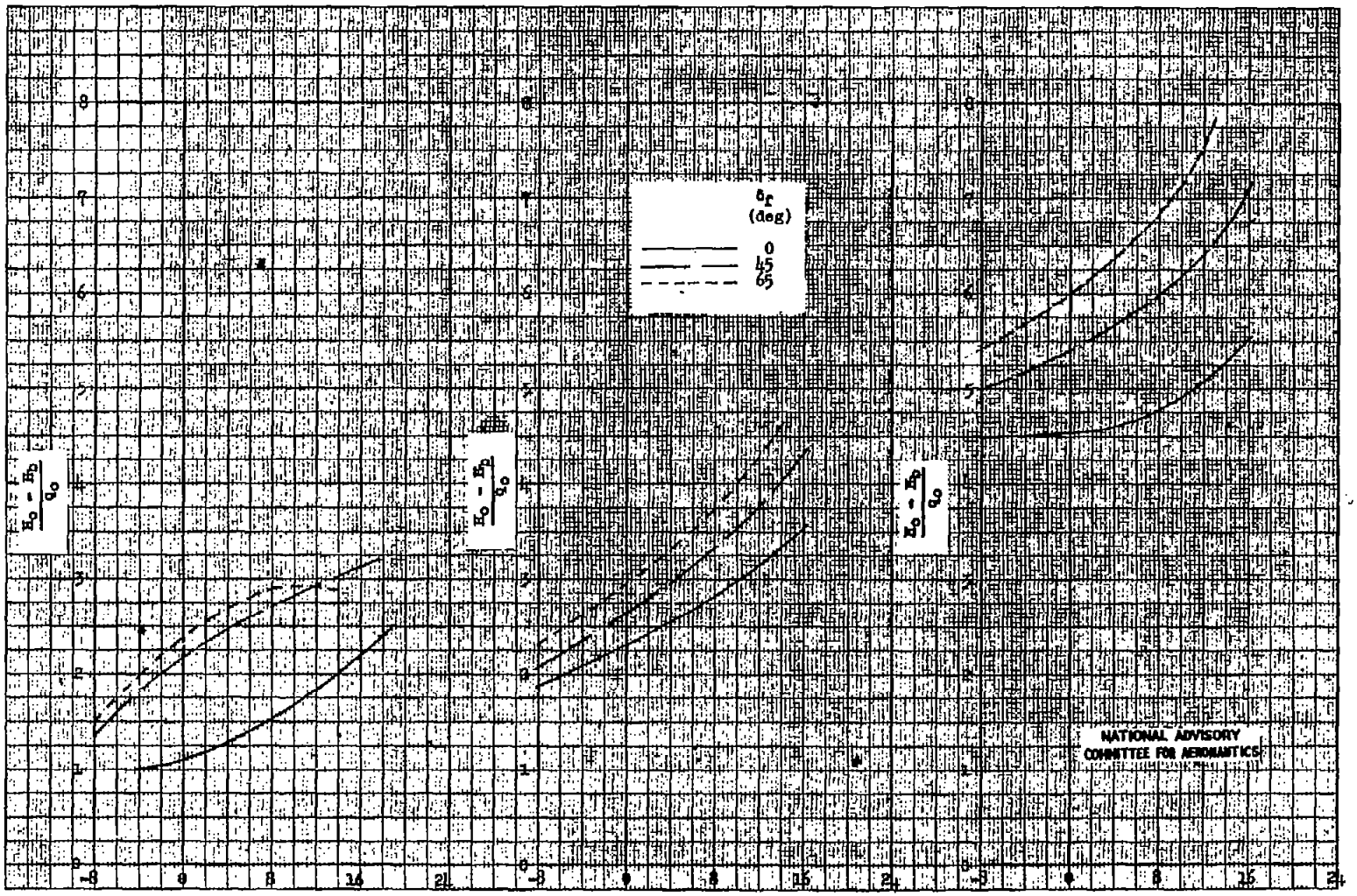


Figure 11.- Ratio of total pressure loss in suction slot to dynamic pressure at 0.44c as a function of flow coefficient. $\delta_f = 65^\circ$; $\alpha_o = 16^\circ$; $R = 1.9 \times 10^6$.

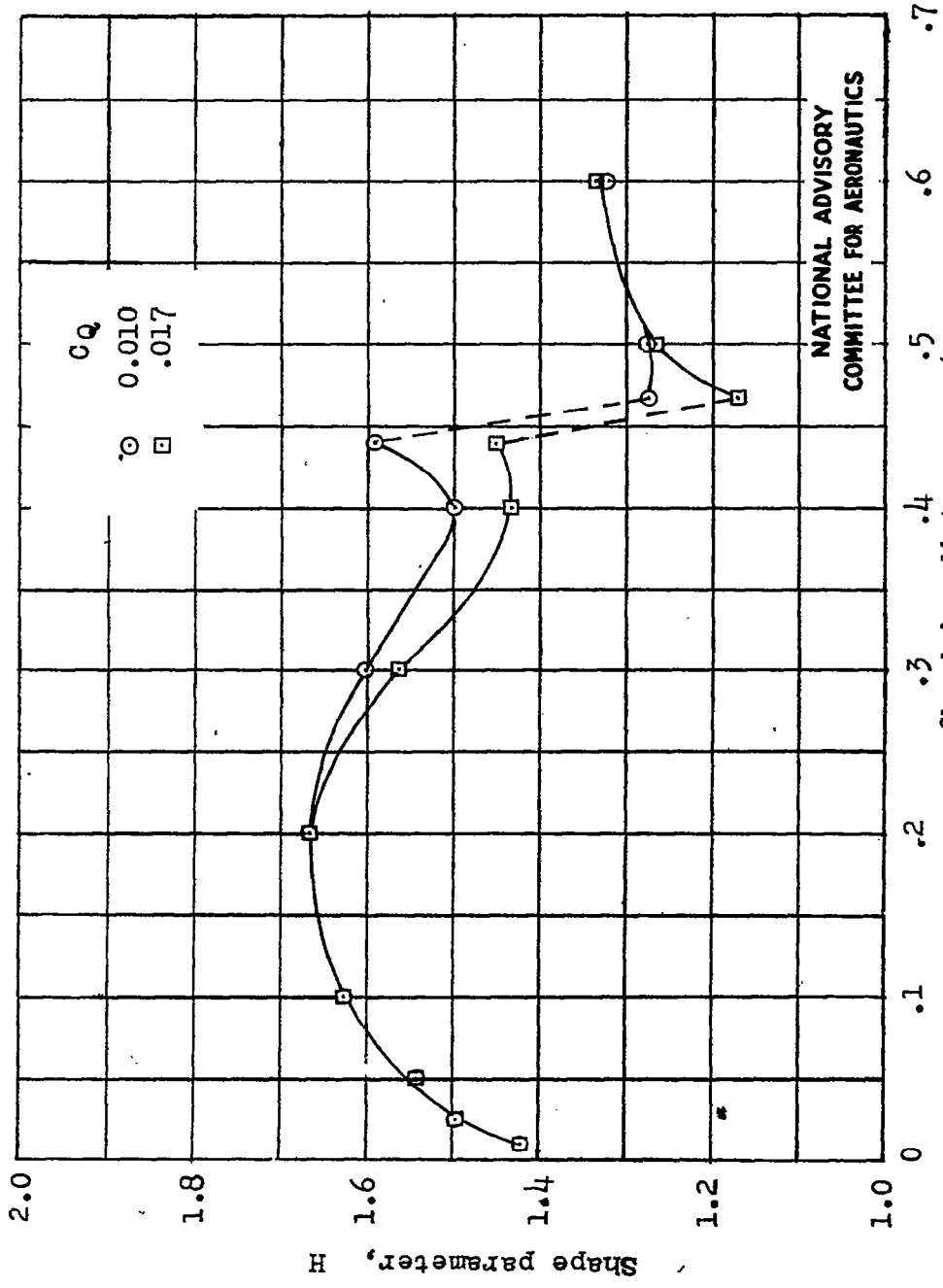


Section angle of attack, α_o, deg
(a) $C_Q = 0.008$.

Section angle of attack, α_o, deg
(b) $C_Q = 0.016$.

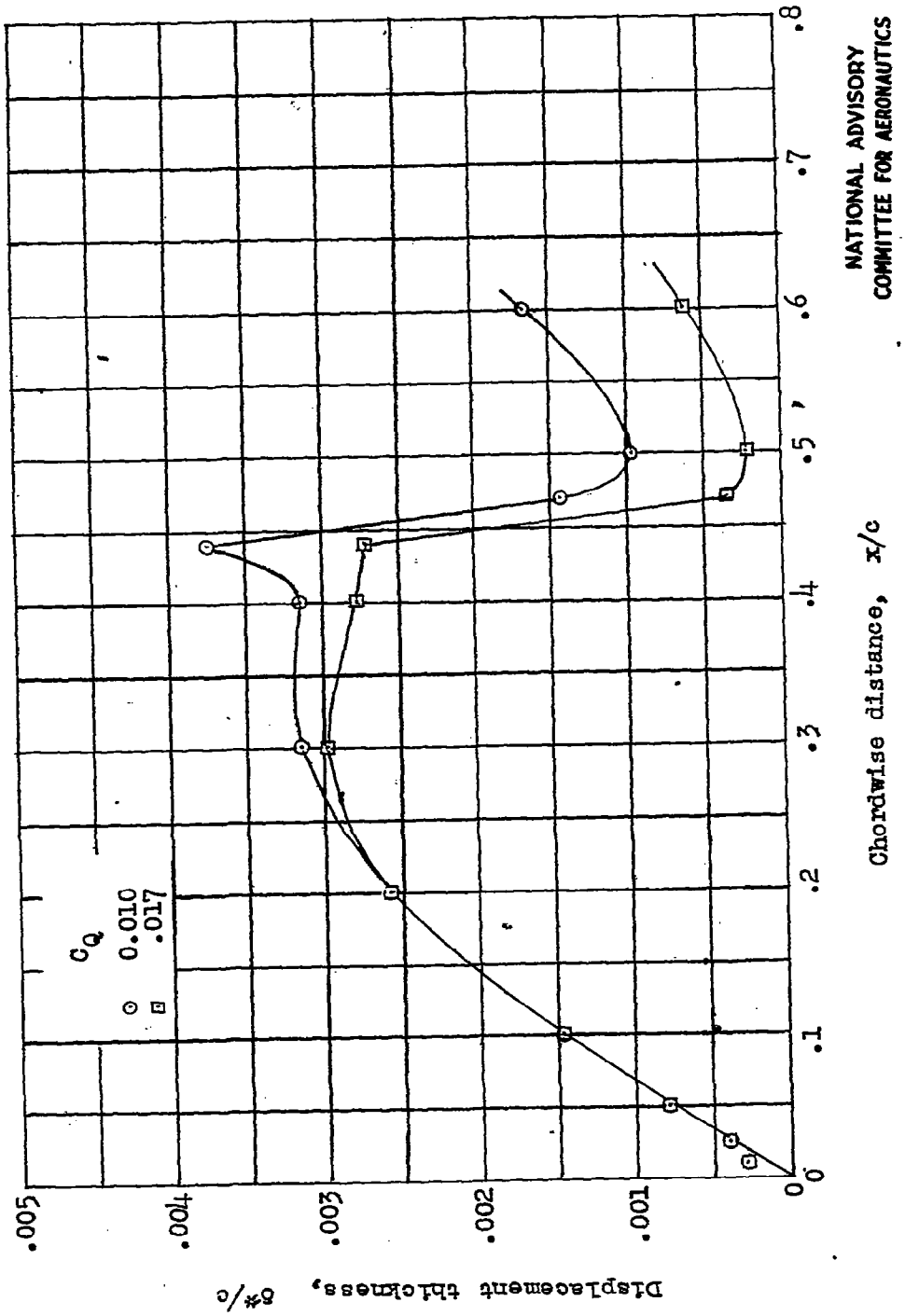
Section angle of attack, α_o, deg
(c) $C_Q = 0.024$.

Figure 12.- Variation of $\frac{H_o - H_b}{q_o}$ with angle of attack for several flow coefficients and flap deflections.
$R = 1.9 \times 10^6$; test, LTT 402.



(a) Variation of shape parameter.

Figure 13.- Variation of boundary-layer shape parameter and displacement thickness along chord of NACA 65_3-418 airfoil section. $\delta_f = 65^\circ$; $\alpha_o = 16^\circ$; $R = 1.9 \times 10^6$.



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(b) Variation of displacement thickness.

Figure 13.- Concluded.

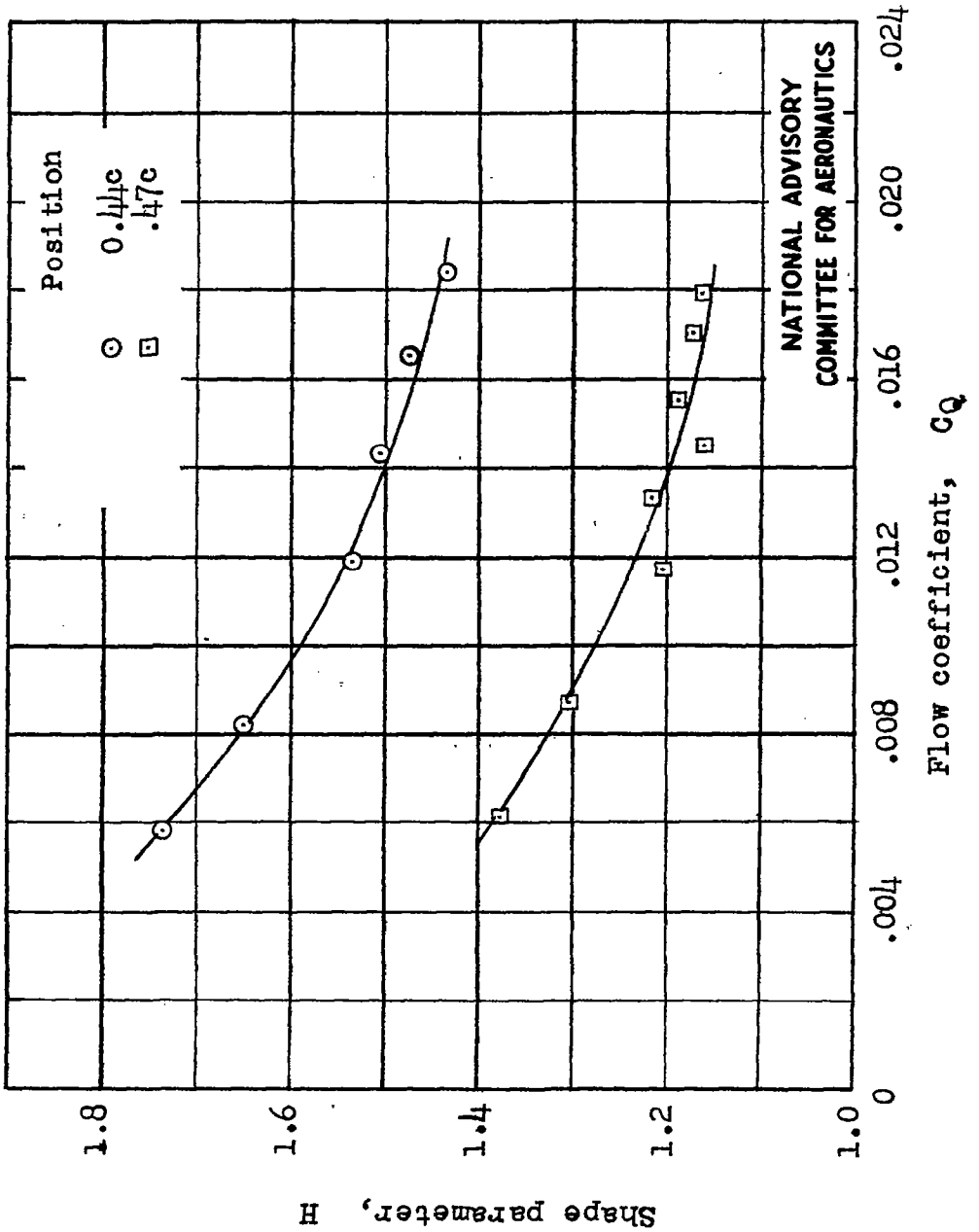

Figure 14.- Variation in boundary-layer shape parameter with flow coefficient just upstream and downstream of suction slot. $R = 1.9 \times 10^6$; $\alpha_o = 16^\circ$; $\delta_f = 65^\circ$.