TECHNICAL NOTES

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

No. 665

TESTS OF N-85, N-86, AND N-87 AIRFOIL SECTIONS

IN THE 11-INCH HIGH-SPEED WIND TUNNEL

By John Stack and W. F. Lindsey
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SUMMARY

Three airfoils, the N-85, the N-86, and the N-87, were tested in the 11-inch high-speed wind tunnel at the request of the Bureau of Aeronautics, Navy Department, to determine the suitability of these sections for use as propeller-blade sections. Further tests of the N.A.C.A. 0009-64 airfoil were also made to measure the aerodynamic effect of thickening the trailing edge in accordance with current propeller practice.

The N-86 and the N-87 airfoils appear to be nearly equivalent aerodynamically and both are superior to the N-85 airfoil. Comparison of these airfoils with the previously developed N.A.C.A. 2409-34 airfoil indicates that the N.A.C.A. 2409-34 is superior, particularly at high speeds. Thickening the trailing edge appears to have a detrimental effect, although the effect may be small if the trailing-edge radius is less than 0.5 percent of the chord.

INTRODUCTION

Investigation of airfoil forms suitable for high-speed applications, such as propeller tips, has indicated that some improvement over conventional forms may be expected through modification of both thickness distribution and camber-line shape (reference 1). Most of the work reported in reference 1 was restricted to a systematic investigation of thickness form, but three cambered airfoils were included in the test program to illustrate the general effect of camber-line shape. All the airfoils tested in that investigation had sharp trailing edges.

On the basis of these and other data, the Bureau of Aeronautics, Navy Department, designed three cambered airfoils that appeared promising as propeller-blade sections and, at the request of the Bureau of Aeronautics, these airfoils have been tested in the N.A.C.A. 11-inch high-speed wind tunnel.

AIRFOILS

The three new airfoils investigated, the N-85, the N-86, and the N-87, have the N.A.C.A. 230 camber line (reference 2). The thickness forms, based on the data presented in reference 1, are: for the N-85 airfoil, the N.A.C.A. 0009-63; for the N-87 airfoil, the N.A.C.A. 0009-34 form except for the nose shape, which was chosen approximately as the mean of the N.A.C.A. 0009-64 and the N.A.C.A. 0009-34 nose forms; and for the N-86 airfoil, approximately a mean of the N-85 and the N-87 forms.

All three airfoils differ slightly at the trailing edge from the basic forms; the new airfoils have thickened trailing edges to agree with current propeller practice. Because the thickened trailing edge would have some effect on the aerodynamic characteristics of the airfoils, it was thought desirable to determine approximately by a few simple tests the changes in the aerodynamic characteristics caused by this modification. Accordingly, tests were made of the N.A.C.A. 0009-64 airfoil with the trailing-edge radius increased to 0.51 and 1.66 percent of the chord. These modifications were made by cutting off a portion of the trailing edge and then smoothly rounding the trailing edge. Modification of the basic airfoil in this manner caused a slight increase in the thickness-chord ratio but the effect of this increase is small.

The basic airfoil forms and the thickness forms for the new airfoils are shown in figure 1. The airfoil ordinates are given in table I.

APPARATUS AND TESTS

The tests were conducted in the N.A.C.A. 11-inch high-speed wind tunnel (reference 3). The airfoils were of 2-inch chord and were made of steel. The method of constructing the airfoils is described in reference 4.

The tests consisted of the measurement of the lift, the drag, and the pitching moment for several speeds in the range extending from 35 percent of the speed of sound to speeds slightly in excess of that at which the compressibility burble occurs. The corresponding Reynolds Number range is from 350,000 to 750,000. The angle-of-attack range extended, in general, from -2° to 12°.

The results are presented in figures 2 to 9. The form of presentation is similar to that of reference 1 and the data are comparable with those presented in references 1 and 3. Figures 2 to 4 show the variation of the force coefficients and the pitching-moment coefficients with the compressibility index M (the ratio of the air-stream speed to the speed of sound) for each of several angles of attack. In the presentation of the pitching-moment-coefficient data, the origin of the axes for each angle of attack has been displaced so that the values may be more easily read. Figures 5 to 7 are cross plots of the data to show the usual polar and lift curves for each of several speeds. The aerodynamic characteristics of the N.A.C.A. 2409-34 airfoil, reported in reference 1, and of the N-86 airfoil are compared in figure 8. The effect of variation of the trailing-edge radius of the N.A.C.A. 0009-64 airfoil is shown in figure 9.

DISCUSSION

Examination of figures 5, 6, and 7 indicates that the N-85 airfoil, except at high lift coefficients, has generally higher drag coefficients than either the N-86 or the N-87 airfoils. At high lift coefficients, the N-85 and the N-86 airfoils are approximately equivalent aerodynamically. At the lower lift coefficients, the N-86 airfoil has appreciably lower drag coefficients.

At low speeds $(M = 0.4)$, the N-86 airfoil has slightly higher maximum lift coefficients than the N-87 but, at higher speeds $(M = 0.6$ and above), the N-87 airfoil becomes superior; this result indicates slightly greater compressibility effects for the N-86 airfoil. The minimum drag values for the N-86 are lower than those for the N-87 and appear to occur at slightly lower lift coefficients. These differences, however, are small.

Comparison with previous work.- The relatively large difference in minimum drag between the N-85 airfoil and the N-86 and the N-87 airfoils substantiates previous work (reference 2) by illustrating that the most important shape change at the higher speeds is the movement of the position of maximum thickness to the rear. Comparison of the aerodynamic characteristics of these airfoils with those of the N.A.C.A. 2409-34 airfoil reported in reference 2 indicates the superiority of the N.A.C.A. 2409-34 airfoil. (See fig. 8.) The effect of compressibility for values of M up to the critical is less for the N.A.C.A. 2409-34 airfoil. At low speeds (M = 0.4), the N-86 airfoil has a higher maximum lift coefficient but the minimum drag values for the N.A.C.A. 2409-34 airfoil are lower over the entire speed range. Above M = 0.4, the maximum lift of the N.A.C.A. 2409-34 airfoil is greater than that for the N-86 airfoil.

The important difference in shape between the N-86 and the N.A.C.A. 2409-34 airfoils is the rearward location of the maximum camber of the N.A.C.A. 2409-34. The data thus indicate that the maximum camber, as well as the maximum thickness, should be located to the rear of the normal position, at least for the Reynolds Numbers at which these tests were made. The problem needs further investigation at higher Reynolds Numbers.

Effect of thickened trailing edge.- Results of tests of the N.A.C.A. 0009-64 airfoil with two modifications of the trailing edge are presented in figure 9. These data indicate that, for the normally rounded trailing edge (0.0051c), the effect on minimum drag at low speeds (M = 0.4) is slight. There is, however, an increase in drag at higher lift coefficients. If the trailing-edge radius is increased to approximately three times the normal value (0.0166c), the minimum drag is considerably increased. At high speeds (M = 0.7), detrimental effects appear at minimum drag for the normally rounded trailing edge.

The effect of the trailing-edge radius in relation to the minimum drag at high speeds may be due either to Reynolds Number effects or to compressibility effects and should probably be investigated at higher Reynolds Numbers.

Langley Memorial Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., August 8, 1938.

REFERENCES

1. Stack, John, and von Doenhoff, Albert E.: Tests of 16 Related Airfoils at High Speeds. T.R. No. 492, N.A.C.A., 1934.

2. Jacobs, Eastman N., and Pinkerton, Robert M.: Tests in the Variable-Density Wind Tunnel of Related Airfoils Having the Maximum Camber Unusually Far Forward. T.R. No. 537, N.A.C.A., 1935.

3. Stack, John: The N.A.C.A. High-Speed Wind Tunnel and Tests of Six Propeller Sections. T.R. No. 463, N.A.C.A., 1933.

4. Jacobs, Eastman N., and Abbott, Ira H.: The N.A.C.A. Variable-Density Wind Tunnel. T.R. No. 416, N.A.C.A., 1932.

TABLE I. - AIRFOIL ORDINATES

[All values in percent chord measured from the chord line; U, upper; L, lower]

Airfoil	N-85		N-86		N-87		N.A.C.A. 2409-34		N.A.C.A. 0009-63		N.A.C.A. 0009-64		N.A.C.A. 0009-34	
Station	U	L	U	L	U	L	U	L	U	L	U	L	U	L
-0.035	0.23	0.23	-	-	-	-	-	-	-	-	-	-	-	-
-.027	-	-	0.18	0.18	-	-	-	-	-	-	-	-	-	-
-.022	-	-	-	-	0.14	0.14	-	-	-	-	-	-	-	-
0	.46	0	.36	0	.29	0	-	0	0	0	0	0	0	0
.25	1.00	-.39	.87	-.35	.75	-.31	-	-	-	-	-	-	-	-
.5	1.31	-.58	1.17	-.53	1.03	-.46	-	-	-	-	-	-	-	-
.75	1.56	-.70	1.40	-.62	1.25	-.54	-	-	-	-	-	-	-	-
1	1.78	-.81	1.60	-.70	1.44	-.60	-	-	-	-	-	-	-	-
1.25	1.98	-.89	1.78	-.76	1.62	-.66	1.00	-0.70	1.44	1.44	1.36	1.36	0.85	0.85
2.5	2.80	-1.15	2.57	-.98	2.35	-.81	1.53	-1.00	1.99	1.99	1.84	1.84	1.26	1.26
5	3.95	-1.42	3.66	-1.18	3.40	-.96	2.39	-1.37	2.71	2.71	2.45	2.45	1.87	1.87
7.5	4.71	-1.61	4.42	-1.34	4.14	-1.08	3.08	-1.63	3.21	3.21	2.86	2.86	2.35	2.35
10	5.25	-1.80	4.96	-1.52	4.68	-1.24	3.67	-1.83	3.57	3.57	3.18	3.18	2.74	2.74
15	5.85	-2.17	5.60	-1.92	5.33	-1.65	4.61	-2.12	4.06	4.06	3.65	3.65	3.37	3.37
20	6.07	-2.54	5.88	-2.35	5.65	-2.12	5.34	-2.31	4.33	4.33	3.97	3.97	3.82	3.82
25	6.11	-2.80	5.99	-2.68	5.82	-2.51	-	-	-	-	-	-	-	-
30	6.05	-2.95	6.01	-2.92	5.90	-2.81	6.23	-2.47	4.50	4.50	4.37	4.37	4.35	4.35
40	5.68	-3.03	5.79	-3.14	5.83	-3.17	6.50	-2.50	4.38	4.38	4.50	4.50	4.50	4.50
50	5.08	-2.87	5.31	-3.10	5.47	-3.26	6.32	-2.42	4.06	4.06	4.37	4.37	4.37	4.37
60	4.32	-2.58	4.63	-2.86	4.87	-3.10	5.77	-2.21	3.54	3.54	3.99	3.99	3.99	3.99
70	3.45	-2.12	3.78	-2.45	4.04	-2.71	4.87	-1.85	2.86	2.86	3.36	3.36	3.36	3.36
80	2.50	-1.62	2.79	-1.91	3.01	-2.13	3.63	-1.37	2.04	2.04	2.49	2.49	2.49	2.49
90	1.49	-1.06	1.68	-1.24	1.80	-1.36	2.03	-.78	1.11	1.11	1.40	1.40	1.40	1.40
100	.50	-.50	.50	-.50	.50	-.50	.09	-.09	.09	.09	.09	.09	.09	.09
L.E. rad.	0.8		0.62		0.5		0.22		0.89		0.89		0.22	
T.E. rad.	.5		.5		.5		-		-		-		-	
Slope of radius through end of chord.	-		-		-		2/20		-		-		-	

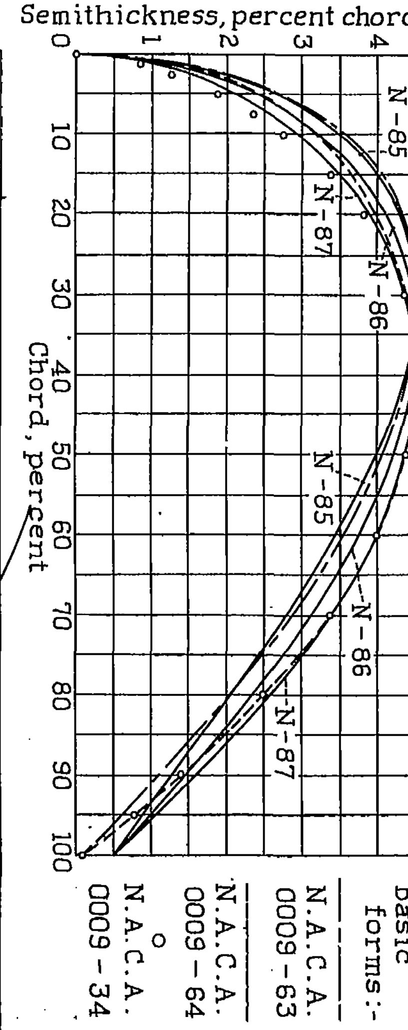

Fig. 1.- Airfoil-thickness forms.

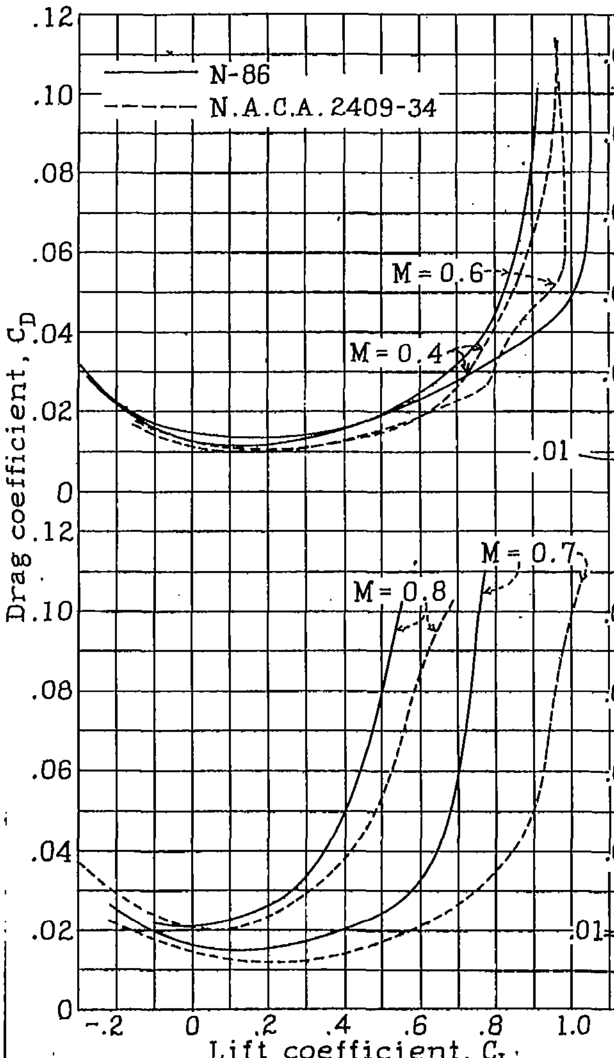

Figure 8.- Comparison of N-86 and N.A.C.A. 2409-34 airfoils.

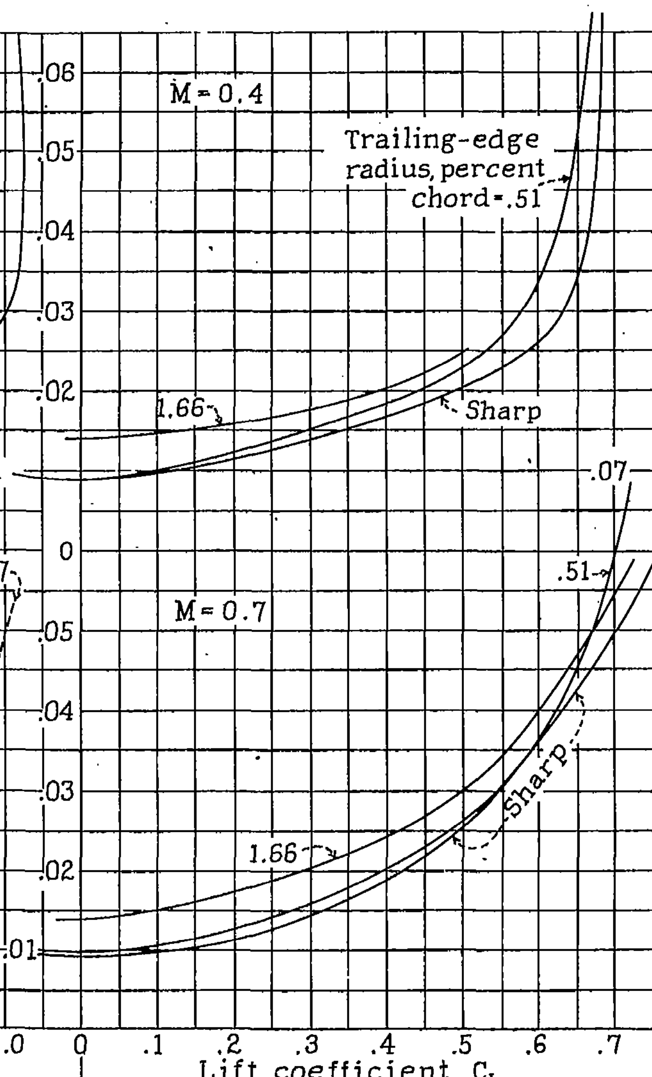

Figure 9.-Effect of variation of trailing-edge radius. N.A.C.A. 0009-64 airfoil.

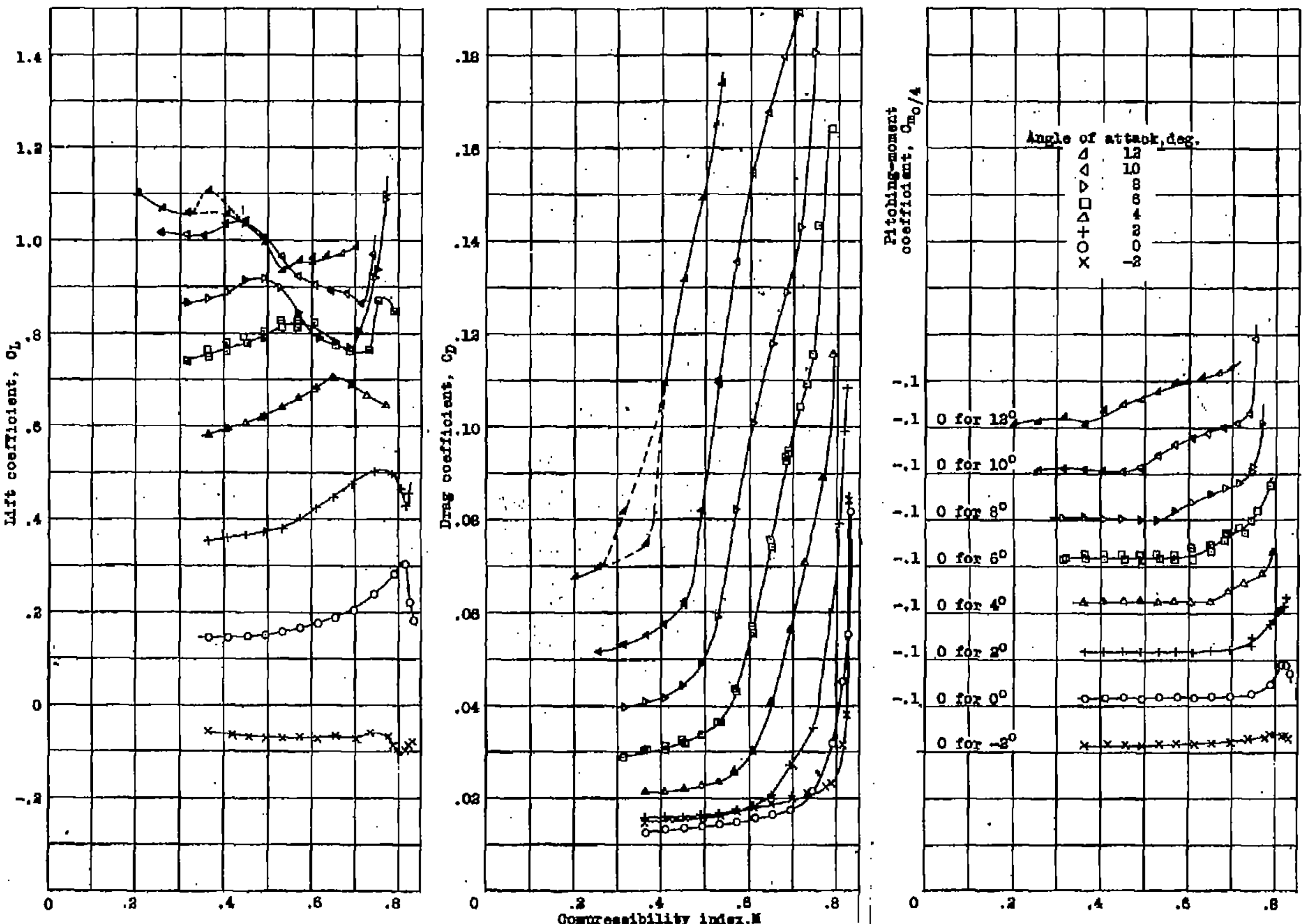

Figure 2.- Effect of compressibility on the aerodynamic characteristics of the N-85 airfoil.

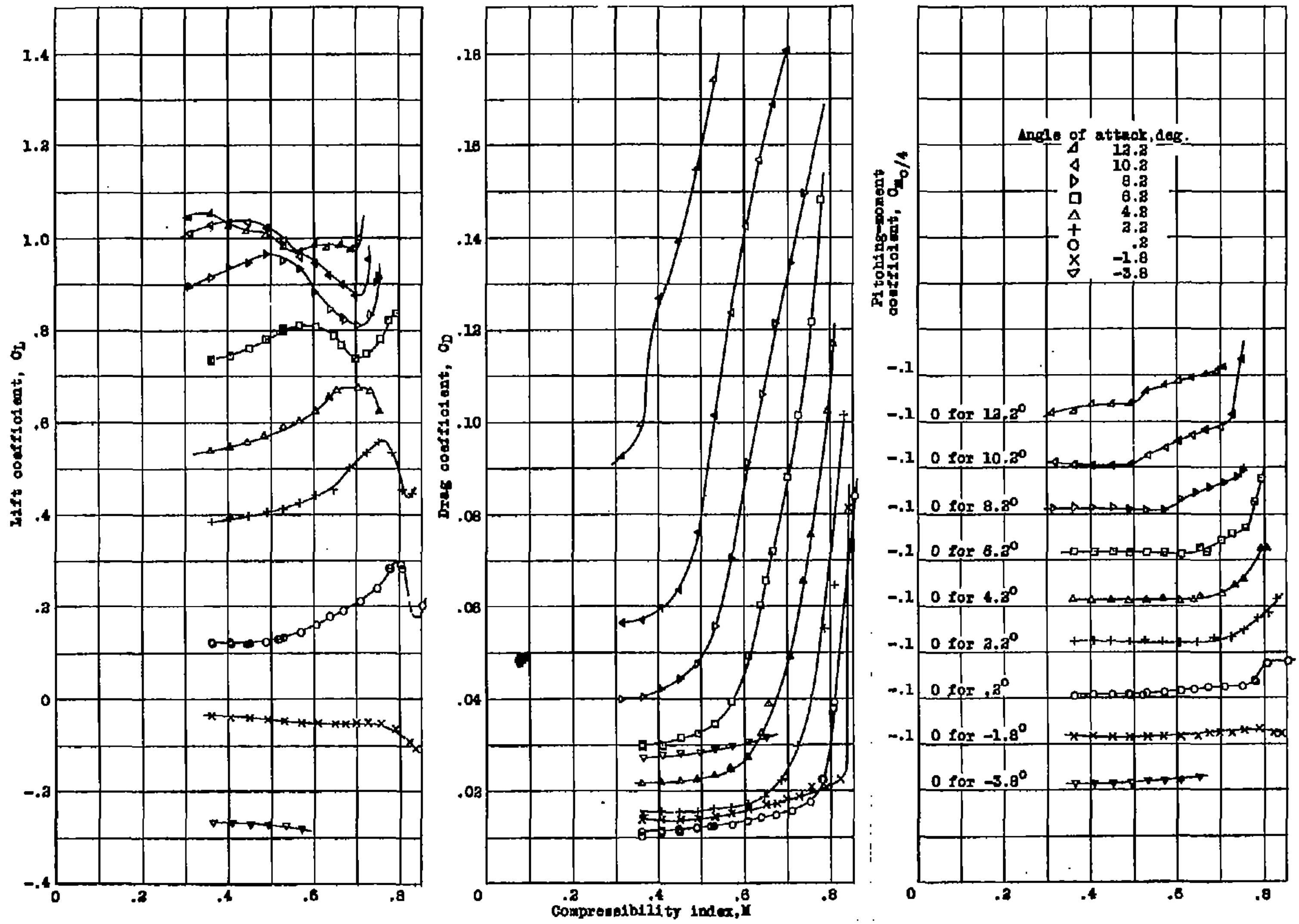

Figure 3.- Effect of compressibility on the aerodynamic characteristics of the N-86 airfoil.

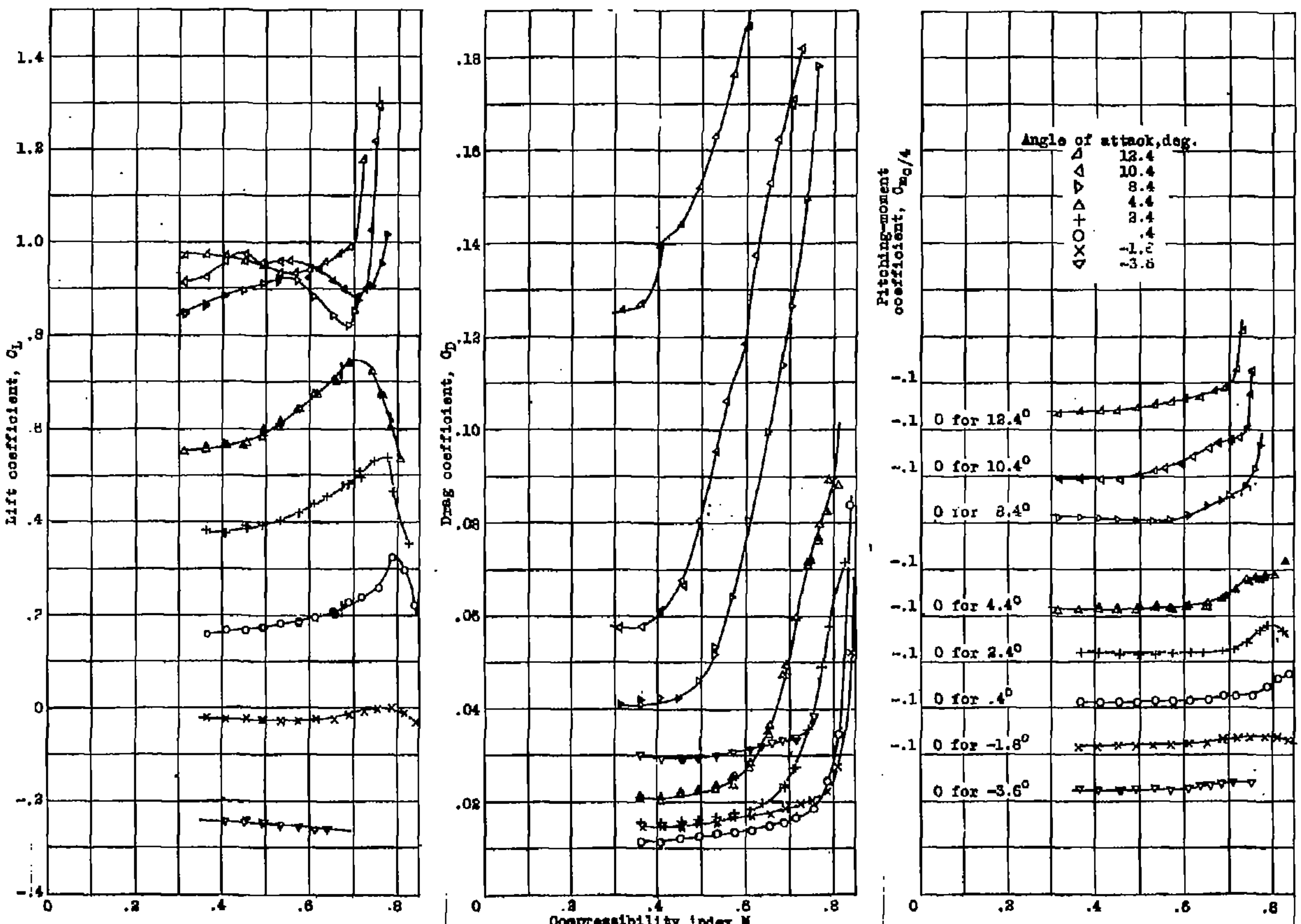

Figure 4.- Effect of compressibility on the aerodynamic characteristics of the N-87 airfoil.

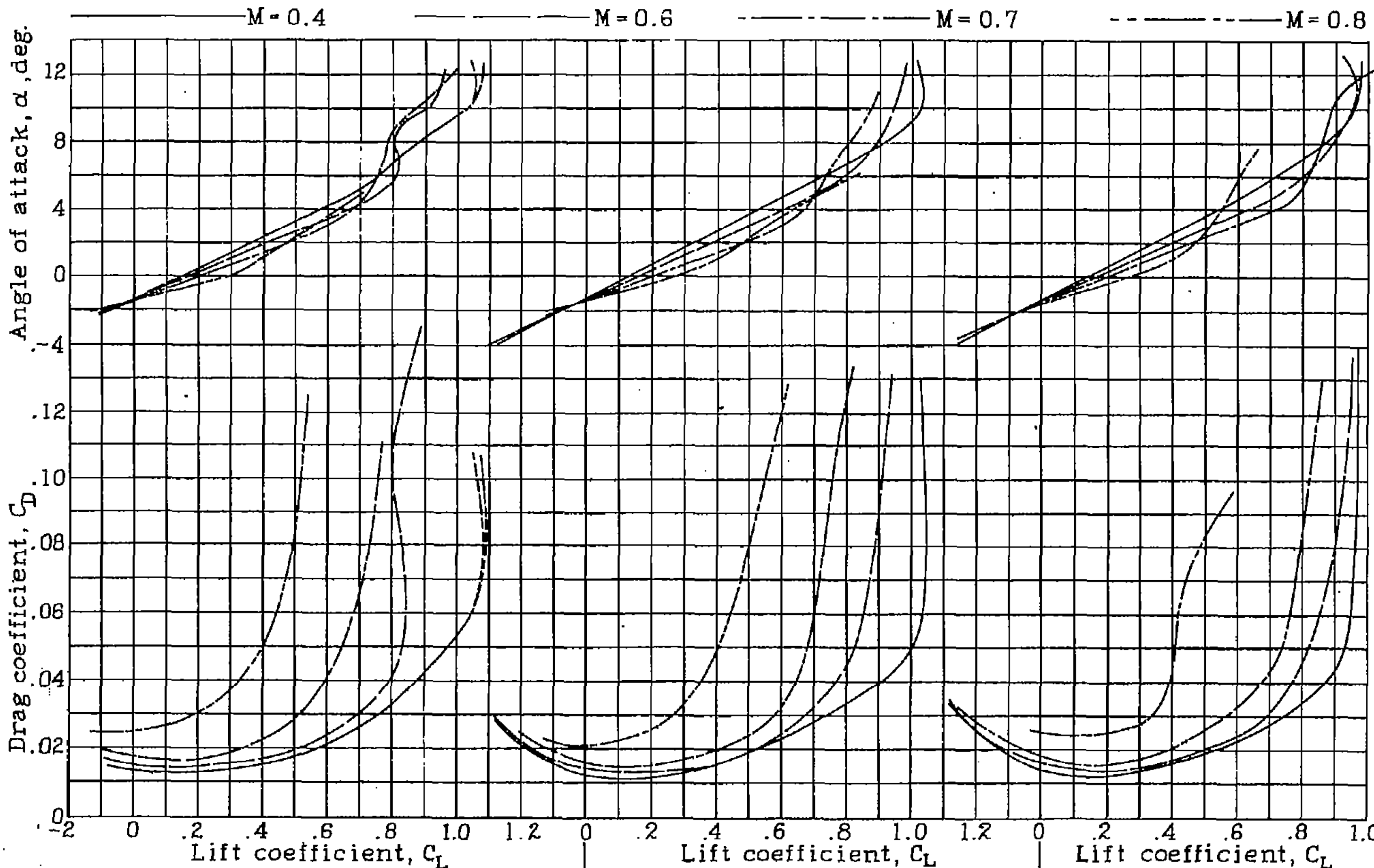

Figure 5.- Aerodynamic characteristics of the N-85 airfoil.

Figure 6.- Aerodynamic characteristics of the N-86 airfoil.

Figure 7.- Aerodynamic characteristics of the N-87 airfoil.