388

388

7995

FLIGHT RESEARCH FILE COPY
PLEASE RETURN TO FILE

TECH LIBRARY KAFB, NM
0144585

TECHNICAL NOTES

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

W L MITCHELL

No. 388

A COMPARISON OF THE AERODYNAMIC CHARACTERISTICS OF THREE NORMAL AND THREE REFLEXED AIRFOILS IN THE VARIABLE DENSITY WIND TUNNEL

By George L. Defoe
Langley Memorial Aeronautical Laboratory

319.98/41

Washington
August, 1931

AFMDC
TECHNICAL LIBRARY
AFL 2811

TECH LIBRARY KAFB, NM
0144585

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL NOTE NO. 388

A COMPARISON OF THE AERODYNAMIC CHARACTERISTICS OF THREE NORMAL AND THREE REFLEXED AIRFOILS IN THE VARIABLE DENSITY WIND TUNNEL

By George L. Defoe

Summary

An investigation was made of the aerodynamic effects of reflexing the trailing edge of three commonly used airfoils. Six airfoils were used in the investigation: three having the normal profiles of the Navy 60, the Boeing 106, and the Göttingen 398, and three having these profiles modified to obtain a reflexed trailing edge with the mean camber line changed to give $C_{m_{c/4}} = 0$.

The tests were conducted at a value of the Reynolds Number of approximately 3,100,000 in the variable density wind tunnel of the National Advisory Committee for Aeronautics. Measurements of lift, drag, and pitching moment were made on each of the six airfoils. The expected reduction of the center of pressure travel was obtained. The maximum lift was reduced approximately 12 per cent and the minimum profile drag approximately 4 per cent.

Introduction

In the past few years several airplanes of the observation and bombing types intended for high-speed diving have been developed and tested in flight. If a normal form of airfoil section is used, the aerodynamic forces on the wing during a dive cause large pitching moments producing high stresses in the airplane structure.

The Navy Department therefore requested the National Advisory Committee for Aeronautics to conduct an investigation on three commonly used airfoil sections in their

normal forms and then with the forms modified toward the trailing edge to produce airfoils having small pitching moments.

Previous work by the British Advisory Committee for Aeronautics in an atmospheric wind tunnel (references 1 and 2) between 1912 and 1914 has shown that, if the correct amount of reverse curvature be placed near the trailing edge of an airfoil, the center of pressure may be considered stationary within practical limits. The reduced center of pressure travel was obtained by sacrificing about 18 per cent of the maximum lift.

Twenty-seven airfoils having a small center of pressure travel were tested during 1924 by the National Advisory Committee for Aeronautics (reference 3) in the variable density wind tunnel. The most favorable sections were found to be those of the M6 type. A small center of pressure travel was found to be generally accompanied by a reduced maximum lift coefficient.

The present investigation is intended to show, by direct comparison, the effects of reflexing the trailing edge of a normal airfoil section on the aerodynamic characteristics: lift, drag, and pitching moment. These characteristics have also been compared with the unpublished results of a recent test of the M6 airfoil. All tests were made at a large value of the Reynolds Number in the variable density wind tunnel of the National Advisory Committee for Aeronautics, Langley Field, Va.

Apparatus and Methods

The normal airfoils used in this investigation were the Navy 60, the Boeing 106, and the Göttingen 398, hereinafter abbreviated the N60, the B106, and the Gött. 398. To obtain the reflexed airfoils, designated N60R, B106R, and Gött. 398R, the normal airfoils were modified by substituting a new mean camber line from the 30 per cent point to the trailing edge. The following form of the equation of the mean camber line was chosen because, according to thin airfoil theory, this equation gives an airfoil having a pitching moment of zero about the quarter-chord point:

$$y = hx\ (1 - x)\ (1 - \frac{8}{7}\ x), \quad \text{where} \quad c = 1, \quad \text{(reference 4).}$$

The x-axis was taken parallel to the chord line of the original section and the origin was taken at the leading edge of the original airfoil. The value of the factor h was so determined that the ordinate of the new mean camber line at the 30 per cent point was equal to the ordinate of the old mean camber line at the same point. The nose ordinates of the profile from $x = 0$ to $x = 0.3$ remained unaltered, and both upper and lower surface ordinates were shifted by the amount of the difference between the old and new mean camber lines. The profiles of both normal and reflexed airfoils are shown in Figure 1, and the ordinates of each airfoil are given in Table I. An airfoil of duralumin was made from each group of ordinates in this table.

The standard method of airfoil test was used; measurements were taken of the lift, drag, and pitching moment at a large value of the Reynolds Number, approximately 3,100,000. The accuracy of these results is of the same order as those discussed in reference 5.

Results

The results of these tests are given in Tables II to VII and are plotted in Figures 2 to 7. The coefficients of the corresponding normal and reflexed airfoils, (the N60 and N60R, the B106 and B106R, the Gött. 398 and Gött. 398R), plotted against angle of attack, are shown in Figures 2 to 4. The profile drag and the moment coefficients plotted against lift coefficient are shown in Figures 5 to 7.

Discussion

The pitching moment coefficients for the reflexed airfoil are practically zero in the range of angle of attack from that of zero lift to $+6^\circ$ for the N60R, from that of zero lift to $+4^\circ$ for the Gött. 398R, and from that of zero lift to $+12^\circ$ for the B106R.

The lift curves for the corresponding normal and reflexed airfoils have the same slope. The angle of zero lift for the reflexed airfoil occurs at a higher angle of attack. The maximum lift is approximately 12 per cent

lower than that of the normal airfoil although it is obtained at approximately the same angle of attack. The useful range of the angle of attack thus differs by the amount of the change of angle of zero lift for the two airfoils.

The minimum profile drag of the reflexed airfoils (figs. 2, 3, and 4) is 4 per cent lower than that of the normal airfoil and occurs at a slightly higher angle of attack. However, if the profile drag coefficients are compared at equal values of the lift coefficient (figs. 5, 6, and 7), the normal airfoil will be seen to have the lower profile drag except at small values of the lift coefficient.

A comparison of the characteristics of these airfoils with those of the N.A.C.A. M6 is given in the following table.

Table of Characteristics

Airfoils	Gött. 398	B106	N60	Gött. 398R	B106R	N60R	M6
$C_{L\ max}$	1.572	1.535	1.616	1.369	1.386	1.407	1.405
$C_{D_o\ min}$	0.0106	.0098	.0099	.0099	.0093	.0092	.0092
C_m at $C_L=0$	-0.082	-.052	-.080	-.007	-.001	-.001	.002
$\frac{C_{L\ max}}{C_{D_o\ min}}$	148.5	161.6	163.3	138.2	149.1	153.0	152.8
Thickness per cent of chord	13.85	13.06	12.45	13.85	13.06	12.45	12.01

The characteristics of the M6 given in the foregoing table were obtained from a test of this airfoil under practically the same conditions as the tests of the normal and reflexed airfoils. The results of this M6 test are unpublished at the present time, but will be published in the near future together with the results of several other well-known airfoils.

A reference to the table of characteristics to compare the N60R and M6 shows that these two airfoils have practically the same characteristics even though the N60R is one-

half per cent thicker than the M6. A comparison of the characteristics of the B106R and of the Gött. 398R with the N60R and the M6, shows the minimum profile drag coefficients of the B106R and the Gött. 398R to be larger than those of the N60R and the M6, possibly due to the greater thickness. The maximum lifts for the B106R and Gött. 398R are lower than those of the N60R and M6. The smaller maximum lift and the higher minimum profile drag account for the factor of general efficiency $\frac{C_{L\ max}}{C_{D_o\ min}}$ being lower for the B106R and the Gött. 398R.

Conclusions

The general conclusions of early tests of reflexed trailing edge airfoils in atmospheric tunnels are substantiated by these tests at a large value of the Reynolds Number - approximately 3,100,000. The reduction of the pitching moment and the accompanying small center of pressure travel were in agreement with theoretical prediction. The maximum lift was reduced approximately 12 per cent and the minimum profile drag only 4 to 5 per cent.

Langley Memorial Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., August 14, 1931.

References

1. Aeronautical Staff in the Engineering Department of the National Physical Laboratory: Experiments on an Aerofoil with Reversed Curvature towards the Trailing Edge. British A.C.A. R. and M. No. 72, Section IX, 1912-1913.

2. Bramwell, F. H.: Further Experiments with Airfoils Having Reversed Curvature towards the Trailing Edge. British A.C.A. R. and M. No. 110, Section III, 1913-1914.

3. Munk, M. M., and Miller, E. W.: Model Tests with a Systematic Series of 27 Wing Sections at Full Reynolds Number. N.A.C.A. Technical Report No. 221, 1925.

4. Glauert, H.: The Elements of Aerofoil and Airscrew Theory. Chapter VII, pp. 91-93, Cambridge, The University Press, 1926.

5. Jacobs, E. N.: Tests of Six Symmetrical Airfoils in the Variable Density Wind Tunnel. N.A.C.A. Technical Note No. 385, 1931.

TABLE I

Ordinates of N60 and N60R

Station per cent of chord	N60 per cent of chord		N60R per cent of chord	
	Upper	Lower	Upper	Lower
0	3.40	3.40	3.40	3.40
1.25	5.60	1.91	5.60	1.91
2.50	6.76	1.46	6.76	1.46
5.00	8.24	.96	8.24	.96
7.50	9.33	.62	9.33	.62
10.00	10.14	.40	10.14	.40
15.00	11.32	.15	11.32	.15
20.00	11.98	.04	11.98	.04
30.00	12.41	.04	12.41	.04
40.00	12.03	.22	11.95	.14
50.00	11.06	.48	10.79	.21
60.00	9.55	.71	9.18	.34
70.00	7.66	.78	7.42	.54
80.00	5.50	.64	5.75	.89
90.00	3.04	.37	4.28	1.61
95.00	1.72	.19	3.66	2.13
100.00	.40	.00	3.20	2.80
L.E. Radius - 1.27 per cent				

TABLE I (Continued)

Ordinates of B106 and B106R

Station per cent of chord	B106 per cent of chord		B106R per cent of chord	
	Upper	Lower	Upper	Lower
0	2.98	2.98	2.98	2.98
1.25	5.26	1.54	5.26	1.54
2.50	6.14	1.04	6.14	1.04
5.00	7.54	.42	7.54	.42
7.50	8.56	.04	8.56	.04
10.00	9.44	-.28	9.44	-.28
15.00	10.62	-.64	10.62	-.64
20.00	11.34	-.90	11.34	-.90
30.00	11.88	-1.18	11.88	-1.18
40.00	11.54	-1.28	11.62	-1.20
50.00	10.54	-1.30	10.70	-1.14
60.00	9.08	-1.22	9.35	-.95
70.00	7.18	-.98	7.66	-.50
80.00	4.96	-.72	5.90	.22
90.00	2.54	-.42	4.23	1.27
95.00	1.29	-.23	3.48	1.96
100.00	.04	-.04	2.84	2.76
	L.E. Radius - 0.70 per cent			

TABLE I (Continued)

Ordinates of Gött. 398 and Gött. 398R

Station per cent of chord	Gött. 398 per cent of chord		Gött. 398R per cent of chord	
	Upper	Lower	Upper	Lower
0.00	3.74	3.74	3.74	3.74
1.25	6.20	1.89	6.20	1.89
2.50	7.40	1.28	7.40	1.28
5.00	9.17	.69	9.17	.69
7.50	10.37	.35	10.37	.35
10.00	11.25	.18	11.25	.18
15.00	12.53	.03	12.53	.03
20.00	13.34	.00	13.34	.00
30.00	13.80	.05	13.80	.05
40.00	13.34	.17	13.30	.13
50.00	12.27	.27	12.08	.08
60.00	10.63	.33	10.39	.09
70.00	8.53	.35	8.42	.24
80.00	6.12	.27	6.50	.65
90.00	3.40	.13	4.77	1.50
95.00	1.92	.06	4.02	2.16
100.00	.40	.00	3.40	3.00
	L.E. Radius - 2.00 per cent			

TABLE II

Coefficients of Airfoil Gött. 398

α	C_L	C_{D_o}	C_m	c.p. per cent of chord from L.E.
-8.1	-0.156	0.0117	-0.086	-
-6.0	- .007	.0112	- .083	-
-3.9	.152	.0106	- .078	76.8
.2	.449	.0111	- .079	42.6
4.3	.745	.0126	- .078	35.5
8.4	1.032	.0159	- .077	32.5
12.5	1.303	.0227	- .078	31.0
16.6	1.514	.0393	- .078	30.3
18.6	1.572	.0638	- .090	30.8
20.6	1.495	.1335	- .111	32.5
24.5	1.392	-	- .137	34.7
30.4	1.139	-	- .166	38.8

TABLE III

Coefficients of Airfoil Gött. 398R

α	C_L	C_{D_o}	C_m	c.p. per cent of chord from L.E.
-4.1	-0.144	0.0106	-0.008	-
-2.1	.006	.0099	- .007	141.6
.1	.167	.0099	- .003	26.8
4.2	.472	.0109	- .004	25.8
8.3	.774	.0130	- .008	26.0
12.4	1.059	.0175	- .014	26.3
16.5	1.311	.0285	- .024	26.8
18.5	1.369	.0551	- .036	27.6
20.5	1.350	.1060	- .057	29.3
22.5	1.316	-	- .072	30.5
24.5	1.274	-	- .088	31.8
30.4	1.037	-	- .122	36.0

TABLE IV

Coefficients of Airfoil B106

α	C_L	C_{D_o}	C_m	c.p. per cent of chord from L.E.
-7.6	-0.231	0.0108	-0.060	-
-5.5	- .084	.0102	- .052	-
-3.5	.064	.0098	- .050	103.7
-1.4	.220	.0097	- .051	48.2
0.6	.370	.0098	- .045	37.2
2.7	.517	.0106	- .046	33.9
6.8	.813	.0127	- .047	30.8
10.9	1.095	.0170	- .046	29.2
15.0	1.352	.0256	- .051	28.8
19.1	1.535	.0533	- .064	29.3
21.1	1.494	-	- .083	30.8
23.1	1.453	-	- .106	32.3
28.9	1.146	-	- .155	37.6

TABLE V

Coefficients of Airfoil B106R

α	C_L	C_{D_o}	C_m	c.p. per cent of chord from L.E.
-4.1	-0.226	0.0099	-0.002	-
-1.1	- .006	.0094	-0.001	-
0	.082	.0093	0	25.0
4.1	.386	.0100	.000	25.0
8.3	.682	.0119	.000	25.0
12.4	.980	.0158	- .002	25.2
16.5	1.247	.0242	- .008	25.6
18.5	1.355	.0335	- .020	26.5
20.5	1.383	.0704	- .031	27.2
22.5	1.320	-	- .057	29.4
24.5	1.286	-	- .071	30.6
30.4	1.007	-	- .122	36.1

TABLE VI

Coefficients of Airfoil N60

α	C_L	C_{D_o}	C_m	c.p. per cent of chord from L.E.
-8.1	-0.196	0.0117	-0.082	-
-5.5	- .006	.0106	- .078	-
-4.0	.114	.0103	- .079	94.8
-1.9	.267	.0101	- .080	55.2
+0.2	.425	.0099	- .079	43.6
2.2	.578	.0105	- .079	38.7
4.3	.731	.0112	- .077	35.5
8.4	1.026	.0138	- .079	32.7
12.5	1.301	.0200	- .084	31.9
16.6	1.542	.0313	- .085	30.6
18.6	1.616	.0493	- .096	31.0
20.6	1.557	-	- .108	32.0
24.5	1.398	-	- .152	35.7

TABLE VII

Coefficients of Airfoil N60R

α	C_L	C_{D_o}	C_m	c.p. per cent of chord from L.E.
-2.0	-0.048	0.0094	-0.001	-
-1.4	.002	.0092	- .001	80.0
0	.112	.0093	.000	25.0
2.1	.265	.0092	- .001	25.4
4.2	.419	.0099	- .001	25.2
8.3	.728	.0116	- .002	25.3
12.4	1.028	.0143	- .007	25.7
16.5	1.305	.0244	- .018	26.4
18.5	1.407	.0386	- .027	27.0
20.5	1.367	.0994	- .054	29.1
24.5	1.256	-	- .091	32.1
30.4	.992	-	- .133	37.2

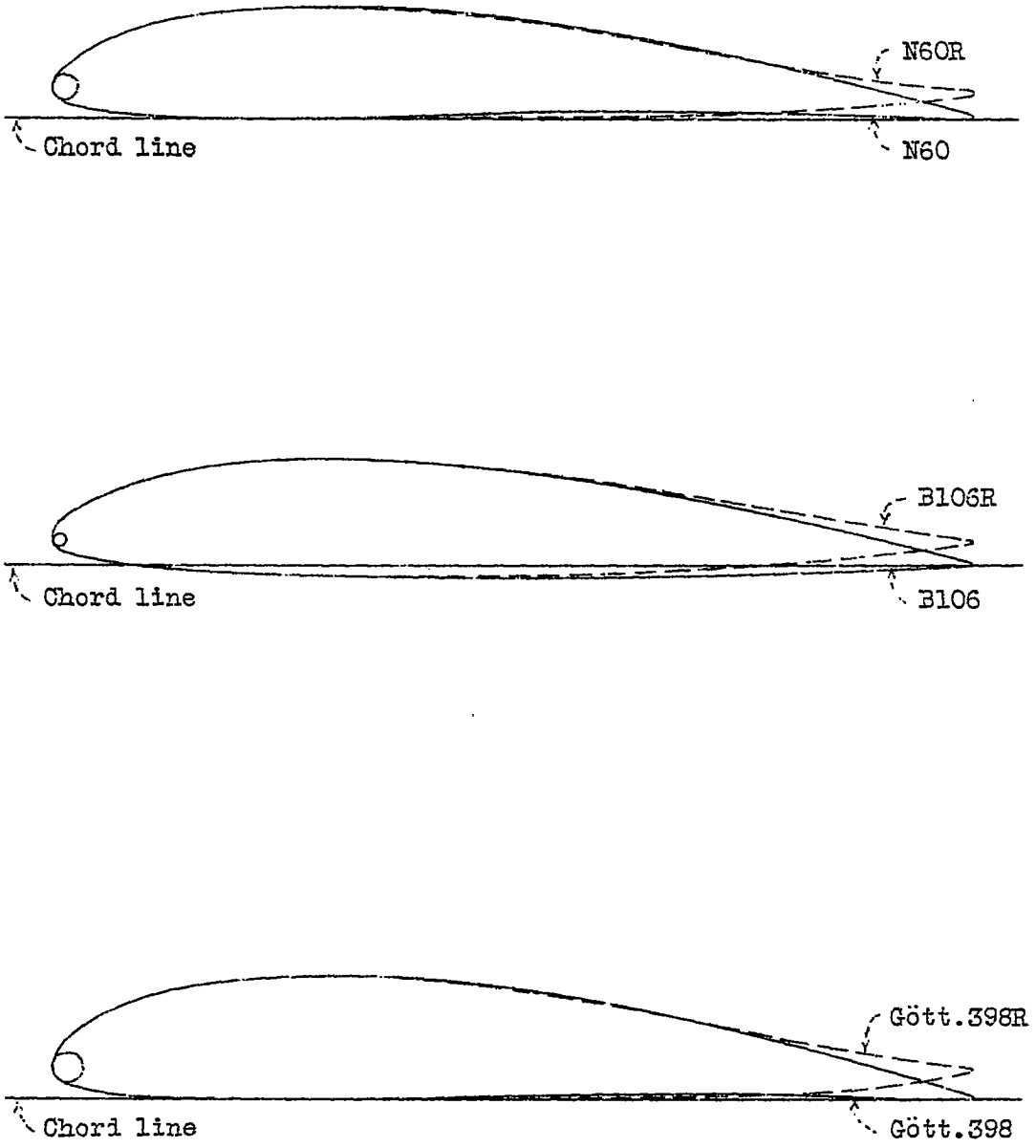

Fig. 1 Profiles of normal and reflexed airfoils.

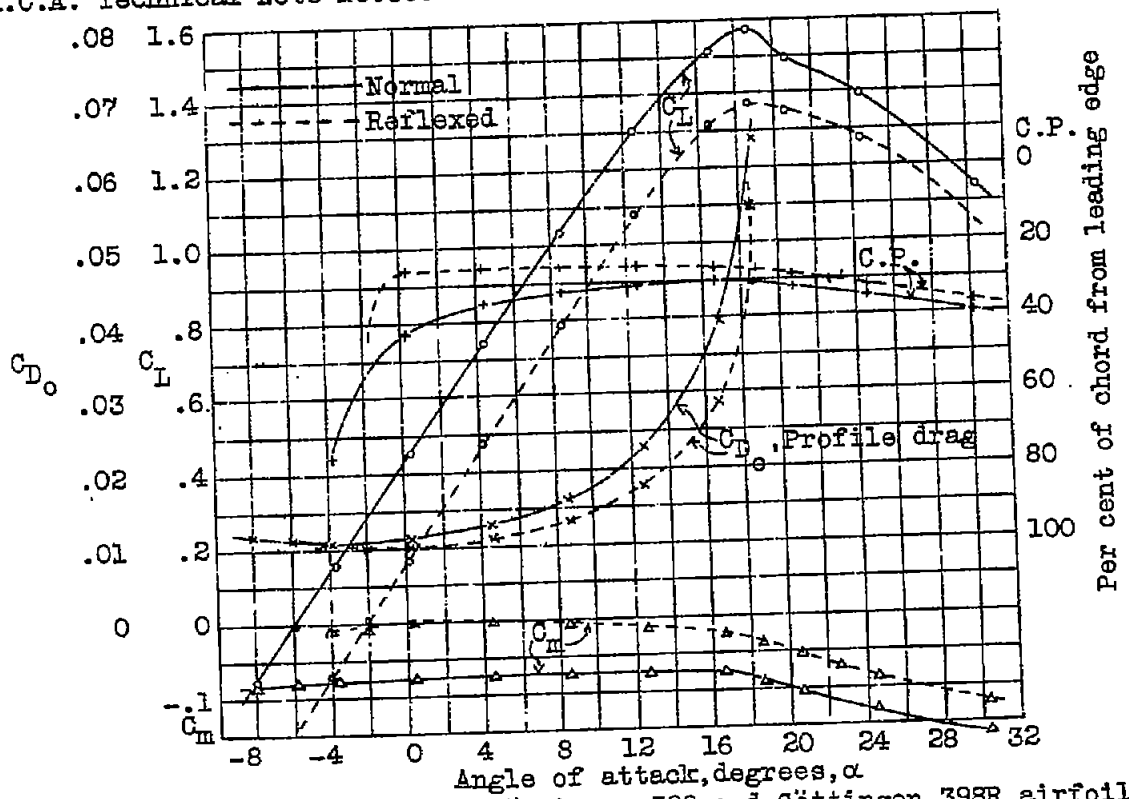

Fig.2 Coefficients of Göttingen 398 and Göttingen 398R airfoils.

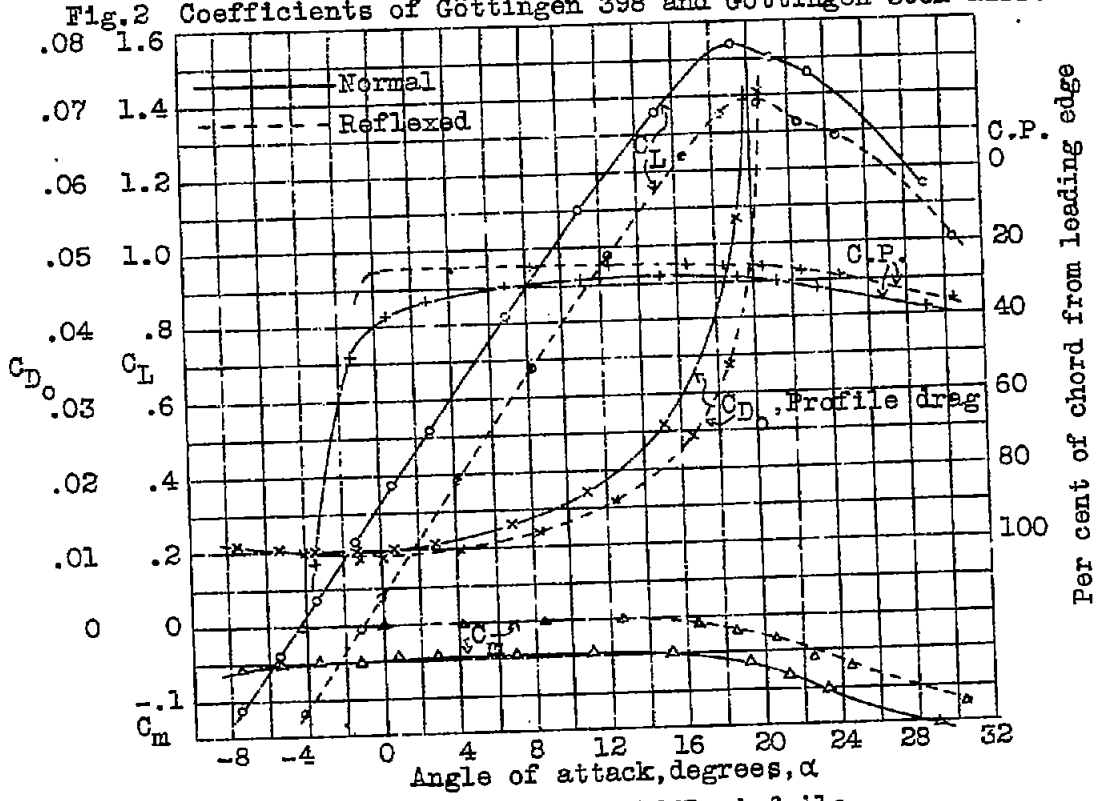

Fig.3 Coefficients of B106 and B106R airfoils.

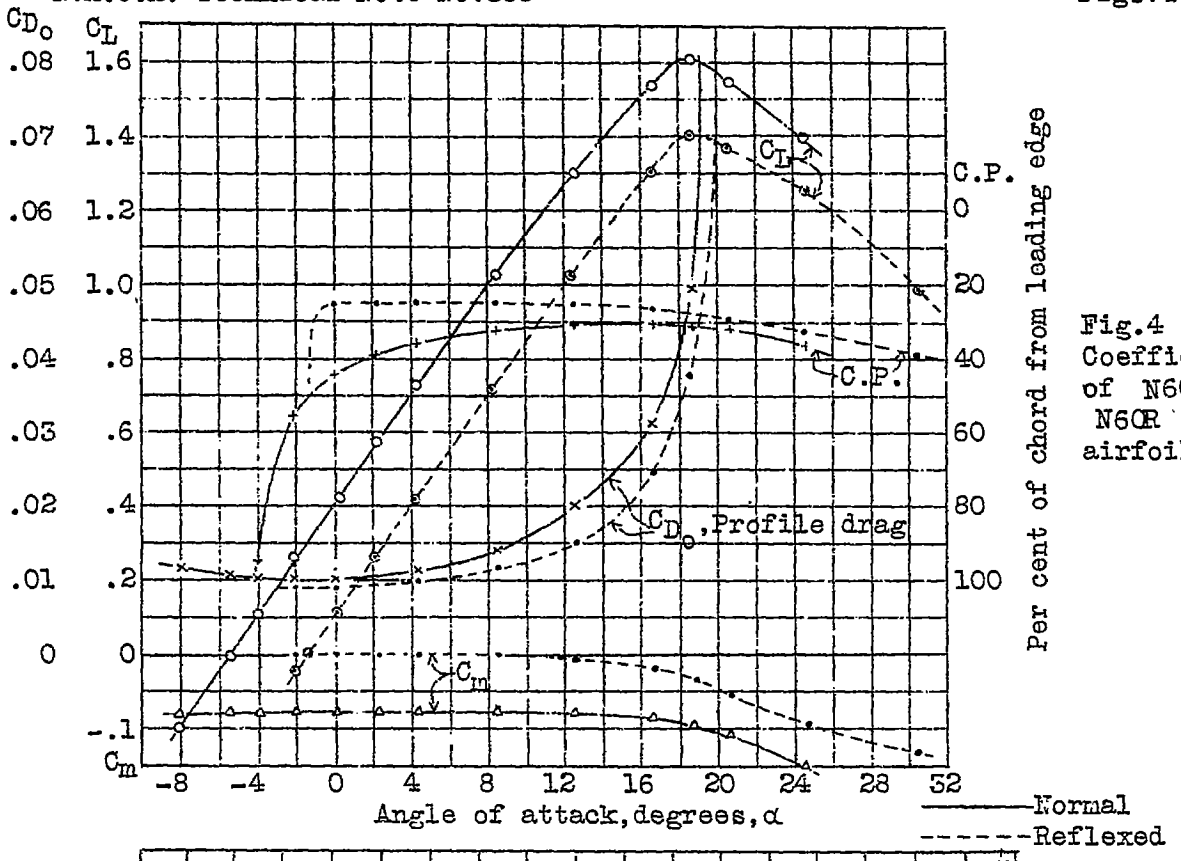

Fig.4 Coefficients of N60 and N60R airfoils.

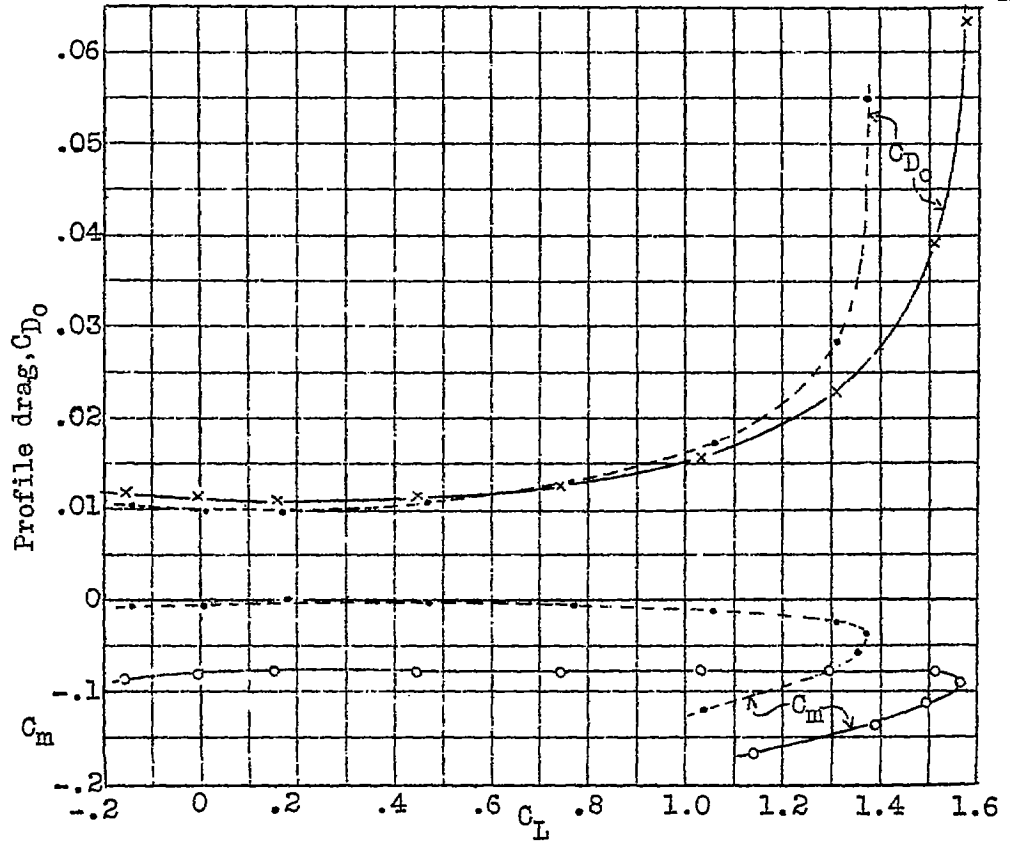

Fig.5 Profile drag and moments of Gött.398 and Gött.398R airfoils.

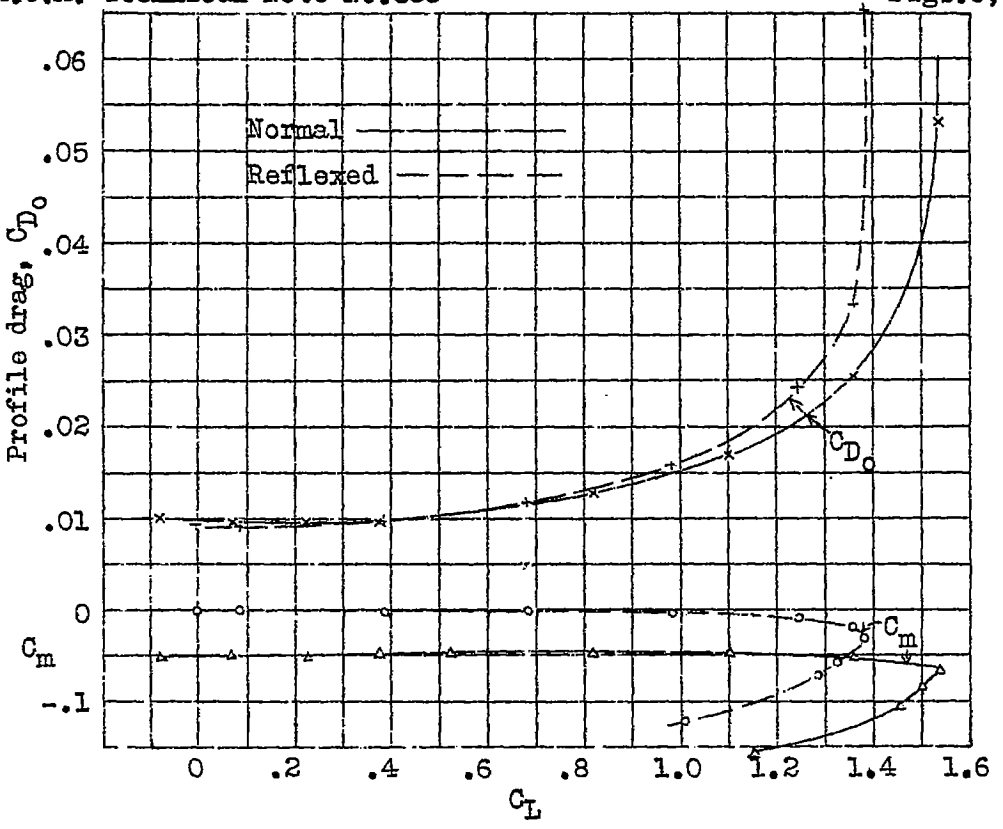

Fig.6 Profile drag and moments of B106 and B106R airfoils.

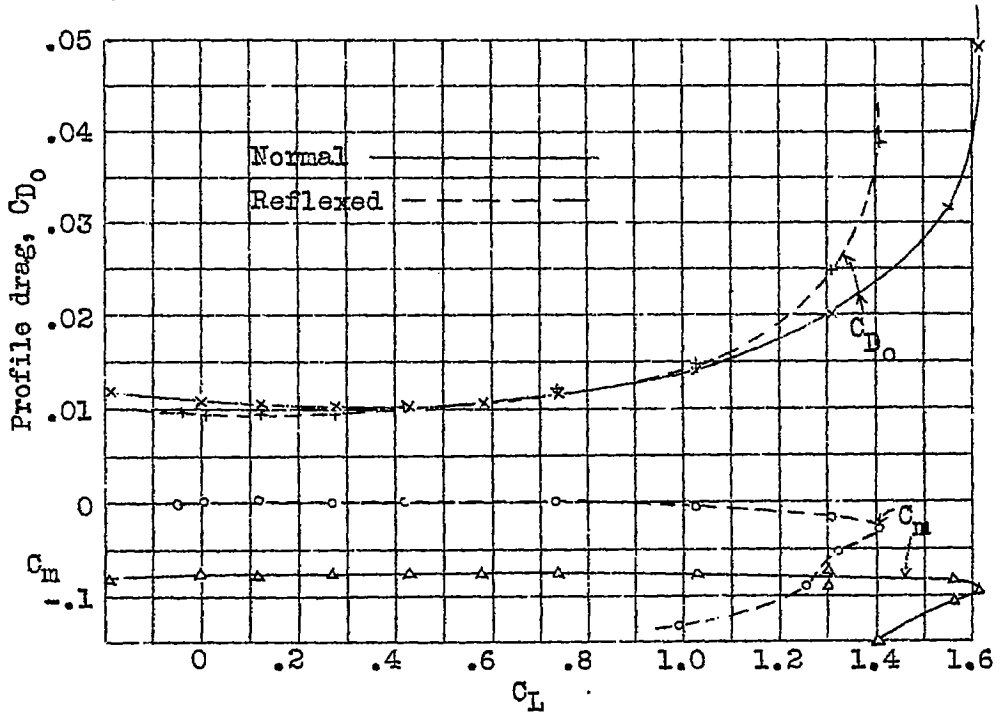

Fig.7 Profile drag and moments of N60 and N60R airfoils.