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NO 9

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

REPORT No. 336

TESTS OF LARGE AIRFOILS IN THE PROPELLER RESEARCH TUNNEL, INCLUDING TWO WITH CORRUGATED SURFACES

By DONALD H. WOOD

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AERONAUTICAL SYMBOLS

1. FUNDAMENTAL AND DERIVED UNITS

	Symbol	Metric		English	
		Unit	Symbol	Unit	Symbol
Length	l	meter	m	foot (or mile)	ft. (or mi.)
Time	t	second	s	second (or hour)	sec. (or hr.)
Force	F	weight of one kilogram	kg	weight of one pound	lb.
Power	P	kg/m/s		horsepower	hp
Speed		km/hr	k. p. h.	mi./hr.	m. p. h.
		m/s	m. p. s.	ft./sec.	f. p. s.

2. GENERAL SYMBOLS, ETC.

W, Weight, $=mg$

g, Standard acceleration of gravity $=9.80665$ m/s$^2=32.1740$ ft./sec.^{2}

m, Mass, $=\frac{W}{g}$

ρ, Density (mass per unit volume).

Standard density of dry air, 0.12497 (kg-m^{-4} s^2) at 15° C and 760 mm $=0.002378$ (lb.-ft.$^{-4}$ sec.^{2}).

Specific weight of "standard" air, 1.2255 kg/m$^3=0.07651$ lb./ft.^{3}

mk^2, Moment of inertia (indicate axis of the radius of gyration, k, by proper subscript).

S, Area.

S_w, Wing area, etc.

G, Gap.

b, Span.

c, Chord length.

b/c, Aspect ratio.

f, Distance from C. G. to elevator hinge.

μ, Coefficient of viscosity.

3. AERODYNAMICAL SYMBOLS

V, True air speed.

q, Dynamic (or impact) pressure $=\frac{1}{2}\rho V^2$

L, Lift, absolute coefficient $C_L=\frac{L}{qS}$

D, Drag, absolute coefficient $C_D=\frac{D}{qS}$

C, Cross-wind force, absolute coefficient $C_C=\frac{C}{qS}$

R, Resultant force. (Note that these coefficients are twice as large as the old coefficients L_C, D_C.)

i_w, Angle of setting of wings (relative to thrust line).

i_t, Angle of stabilizer setting with reference to thrust line.

γ, Dihedral angle.

$\rho\frac{Vl}{\mu}$, Reynolds Number, where l is a linear dimension.

e. g., for a model airfoil 3 in. chord, 100 mi./hr. normal pressure, 0° C: 255,000 and at 15° C., 230,000;

or for a model of 10 cm chord 40 m/s, corresponding numbers are 299,000 and 270,000.

C_p, Center of pressure coefficient (ratio of distance of C. P. from leading edge to chord length).

β, Angle of stabilizer setting with reference to lower wing, $=(i_t-i_w)$.

α, Angle of attack.

ϵ, Angle of downwash.

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Langley Memorial Aeronautical Laboratory

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

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SUMMARY

This report gives the results of the tests of seven 2 by 12 foot airfoils (Clark Y, smooth and corrugated, Göttingen 398, N. A. C. A. M–6, and N. A. C. A. 84). The tests were made in the Propeller Research Tunnel of the National Advisory Committee for Aeronautics at Reynolds Numbers up to 2,000,000. The Clark Y airfoil was tested with three degrees of surface smoothness.

The effect of small variations of smoothness of an airfoil is shown to be negligible. Corrugating the surface causes a flattening of the lift curve at the burble point and an increase in drag at small flying angles.

INTRODUCTION

At the annual conference of the National Advisory Committee for Aeronautics with aircraft manufacturers held at Langley Field, Va., in May, 1928, Col. V. E. Clark and others mentioned the lack of test data on corruguated wings and suggested that tests be made in the Committee's Propeller Research Tunnel. Here a comparatively high Reynolds number may be secured due to the large size of the models that can be used. It also seemed desirable to secure data on some representative wing sections with a view to the possible comparison with existing data from other tunnels.

In the Propeller Research Tunnel with its 20-foot diameter throat, airfoils of 2-foot chord and 12-foot span may be tested up to velocities of 100 M. P. H. This condition gives a Reynolds Number of about 2,000,000, which corresponds quite closely with that attained in the Variable Density Tunnel at 10 atmospheres pressure.

Four airfoils (Clark Y, Göttingen 398, N. A. C. A. M–6, and N. A. C. A. 84) were selected for the present tests. The Clark Y was tested with three degrees of surface smoothness. In addition, two corrugated metal covered Clark Y airfoils, one having Clark Y section at the top of the corrugations and the other Clark Y section under the metal covering, were tested.

Thus, eight separate tests were made at speeds of approximately 80 and 100 M. P. H. The average Reynolds Numbers were 1,575,000 and 1,940,000, respectively.

METHODS AND APPARATUS

SUPPORTS

The Propeller Research Tunnel, where this investigation was conducted, has been described in Reference 1. The regular tunnel equipment was employed so far as possible. Referring to Figure 1, the airfoil to be tested is supported on two heavy, braced bars and fitted to pivot about a point within the airfoil slightly above the chord at the quarter point. A "sting" attached to the center of the airfoil is carried back to a vertical tube to which it is pivoted. A rack and pinion operated by a crank serves to raise and lower this tube, thereby changing the angle of attack of the airfoil. These members are bolted to the floating frame of the balance. The lift and drag forces may then be read on the platform scales on the floor below.

To reduce the tare drag of the system all supporting members were surrounded with fairing attached to the fixed frame of the balance. To reduce interference with the airfoil the fairings were not carried up to the wing, the last 2 feet of the supports being streamlined instead. The effectiveness of this arrangement is indicated by the fact that the tare drag was only 3 pounds at 100 M. P. H. at most angles of attack. This was about 50 per cent of the gross minimum drag.

In measuring this tare drag the set-up was modified so that the wing was supported independently of the supports and sting; hence, the drag measured was that of the supports alone in the presence of the airfoil. This was accomplished by supporting the sting from a tube connecting the front supports within the wing, but not touching it. The wing was then supported by wires and pipes arranged at distances from the supports. This arrangement is shown in Figure 2. The angle of attack could then be easily changed by simply moving the wing and turning the regular crank to bring the sting parallel underneath. Readings on all the balances were taken at several angles and air velocities so that the proper corrections could be made to the lift and drag readings. A small correction to the balance readings was also necessary, due to the different distribution of the weight at the several angles of attack.

CONSTRUCTION OF AIRFOILS

Since the airfoils were to be of 12-foot span and 2-foot chord, the standard ordinates of the airfoil sections in per cent of the chord were reduced to inches on a 2-foot chord. The model

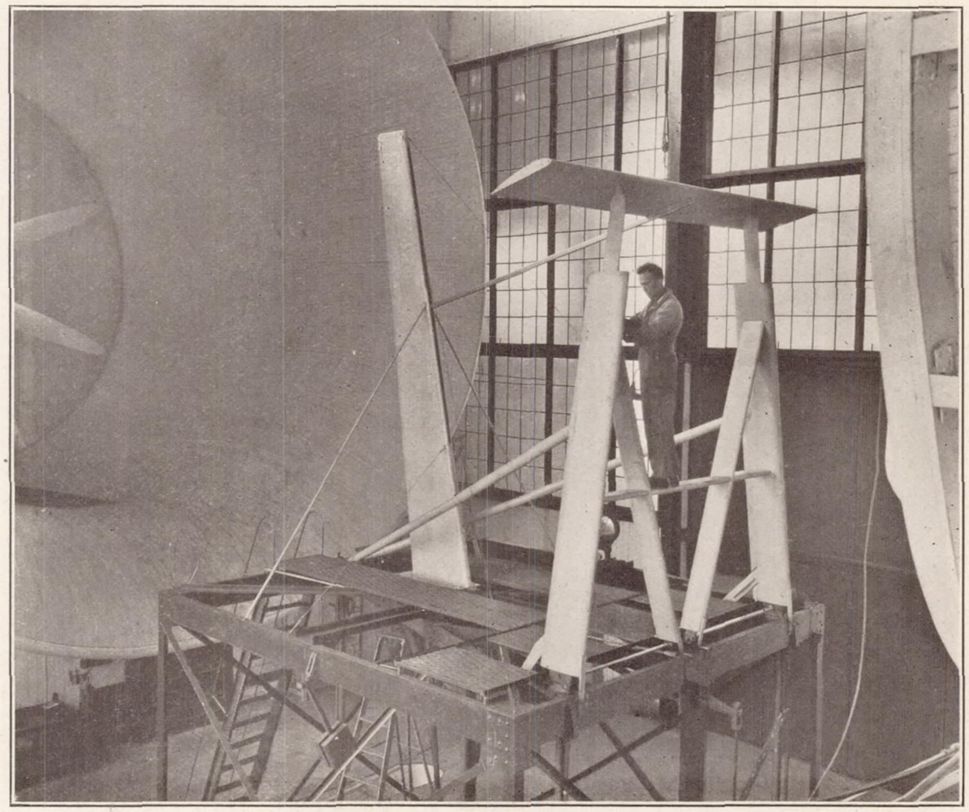

FIGURE 1.—Arrangement for wing tests

maker was given these ordinates to the nearest hundredth of an inch and was asked to work within 3/100 or 1/32 inch. Tables I–VI give the standard, specified, and measured ordinates. The measured values are the average of there measurements at the center span and halfway from the center to each tip. It will be noted that there are differences of as much as 5/100 inch from the specified ordinates. They occur at the leading edge where the surface is well rounded. There is a considerably larger deviation for the thick corruguated airfoil which is accounted for by the difficulty of construction.

The leading and trailing edges were of laminated wood glued and formed to templates. At about the mid-chord a 3-inch wide beam was placed. These three members were spaced by solid ribs at 12-inch intervals along the span. The space between leading and trailing edges on the top and bottom surfaces was originally covered with 1/16-inch 3-ply plywood. After the first airfoil was completed examination showed considerable bowing and buckling of this thin covering. It was decided, however, before discarding this construction, to make a test, thereby determining the effect of these small variations of surface contour. The plywood was then removed and 1/16-inch sheet aluminum substituted and a test made. The whole airfoil was then painted with two coats of brushing lacquer, sanding between coats. This gave a uniform smooth surface, although not as smooth as the bright sheet metal. All screw holes and cracks were filled with litharge and glycerin before painting. In Figure 3 are views of some of the airfoils.

The corrugated airfoils, one of which is illustrated at the bottom of Figure 3, were constructed in the same manner as the plywood airfoil, the corrugated metal covering being screwed to its surface. The metal sheet was of 1/64-inch thick aluminum with the corrugations rolled on a grooved wood form. The dimensions of these corrugations (fig. 4) were found by scaling down the average of several standard wings. Since it is impractical to run the corrugations completely around the leading edge, the sheet was left flat there, the corrugations starting a slight distance back on the top and bottom surfaces. In order to bring the corrugations into a scalloped edge at the rear, they were displaced one-half pitch on the top and bottom surfaces. This

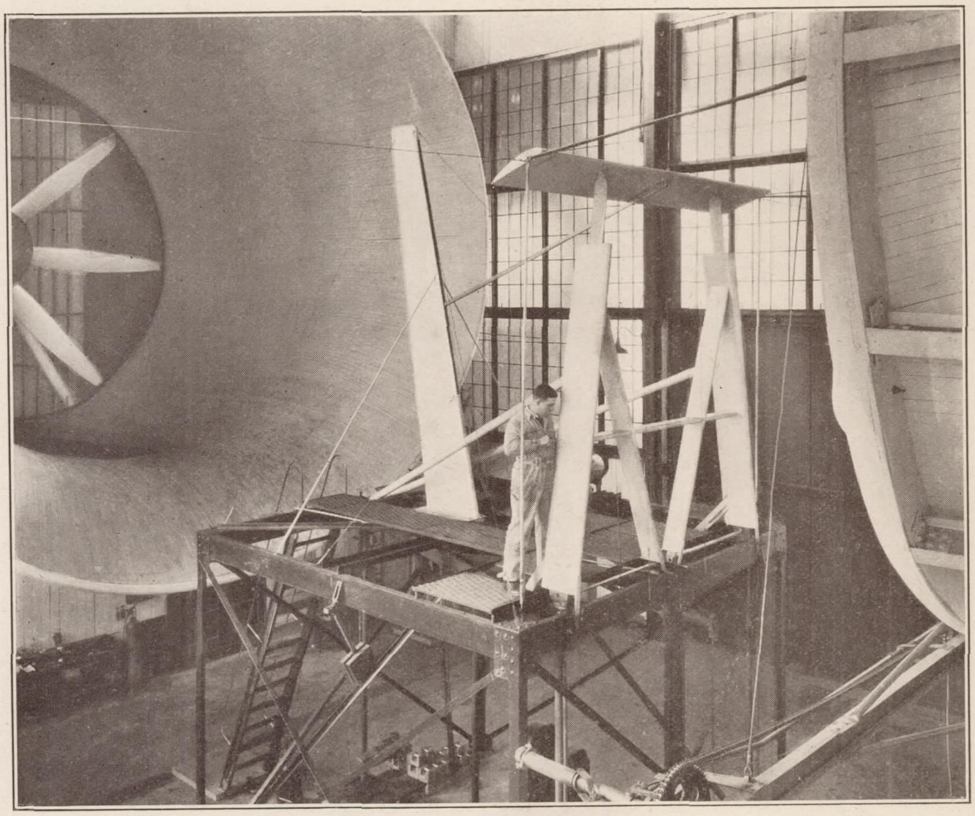

FIGURE 2.—Arrangement for tare drag test

and the leading edge construction necessitated slight departures from the basic Clark Y section. These are indicated in Figure 4.

TESTS

After mounting the airfoil a cover plate was screwed over the pivot-fitting opening, leaving only enough gap to allow the support to clear as the angle of attack was changed. Angles of attack indicated by a pointer on the moving rear support were checked against an inclinometer held on top of the sting just behind the airfoil.

Each test was run at tunnel air speeds of approximately 80 and 100 M. P. H. Air speeds were computed from the readings of a manometer connected to plates set in the walls of the tunnel passages calibrated against Pitot tubes suspended in the air stream at the position of the airfoil. Two readings were taken of front lift, rear lift, drag, and manometer at each angle of attack at each speed, one when the angles were successively increased from $-9°$ to $+35°$, and the second when decreased from $+35°$ to $-9°$. This was done simply to secure two independent readings at each setting.

RESULTS

The results are given in the form of tables and curves of the absolute nondimensional coefficients C_L, C_D, C_M, C_p. From the observed readings these coefficients are computed in the usual manner from the equations

$$C_L = \frac{\text{Lift}}{qS} \qquad q = \text{Dynamic pressure.}$$

$$C_D = \frac{\text{Drag}}{qS} \qquad S = \text{Area of airfoil.}$$

$$C_{M_{c/4}} = \frac{\text{Moment}_{c/4}}{qSc} \qquad c = \text{Chord of airfoil.}$$

$$C_p = .25 - \frac{C_{M_{c/4}}}{C_L}$$

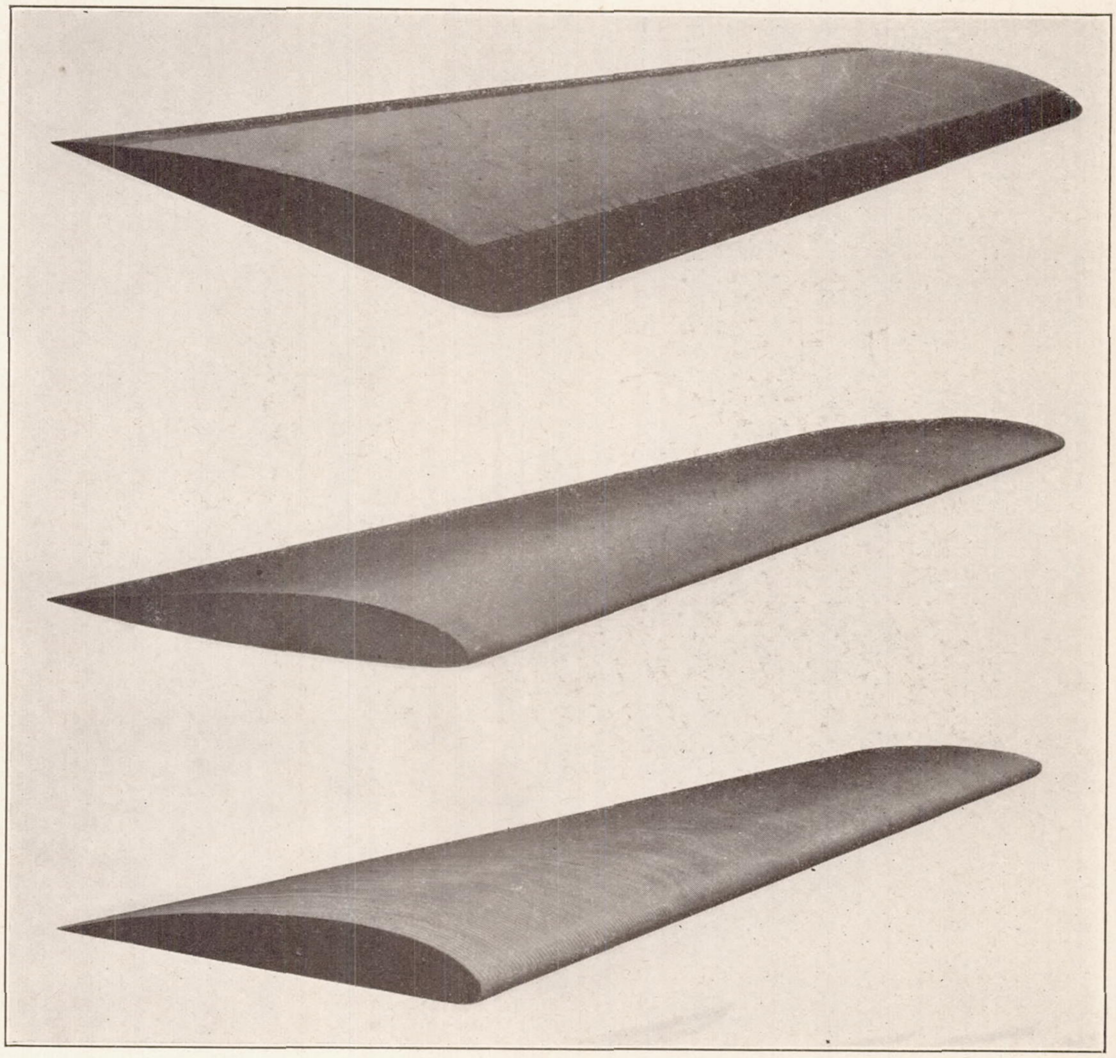

FIGURE 3.—Airfoils

The results have been corrected for boundary interference in accordance with the method given in References 2 and 3. For the open jet the interference amounts to an added downwash or an increase in the induced drag and induced angle of attack. The corrected test points as plotted, therefore, correspond to lower drag values and lower angles of attack than were measured. Since the airfoils were rectangular, the corrected results apply to rectangular wings rather than to elliptical.

The results are given in the form of curves (figs. 5–12) of C_L, C_D, L/D, and C_p against angle of attack, and apply directly to rectangular wings of aspect ratio 6 in free air. Numerical values are given in Tables VII–XIV.

In view of the established rules for aspect ratio correction, another type of diagram has come into quite extensive use, especially in England. In this diagram, Figures 13–18, profile drag C_{D_0}, $C_{M_{c/4}}$ and angle of attack α_0 for infinite aspect ratio are plotted against lift coefficient. By simply adding the induced drag and induced angle of attack corresponding to any given aspect ratio to the values from the curves, the coefficients for that aspect ratio may be determined, thus eliminating the double computation required when converting from aspect ratio 6 to another aspect ratio. Only one curve is given for the Clark Y airfoils, that for the metal covered and painted, as this is comparable with the other airfoils of the series and there were negligible differences in the results for the several surfaces. For handy use the numerical values taken from the faired curves are given in Tables XV–XX. The induced drag for the loading corresponding to the particular wing shape should, of course, be used in deriving the coefficients for any finite aspect ratio.

Some of the characteristics of the airfoils are quite closely related, and, accordingly, the results for the Clark Y with various surfaces have been replotted in Figure 19. A set of points from a test in the old Variable Density Tunnel corrected for tunnel wall interference has been added for comparison. To compare the two corrugated wings with the smooth wing, Figure 20 is given. To aid in the selection of an airfoil for any given speed range, Figures 21 and 22 give $\frac{C_{D_0}}{C_{L_{max.}}}$ against $\frac{C_{L_{max.}}}{C_L}$ or the speed ratio.

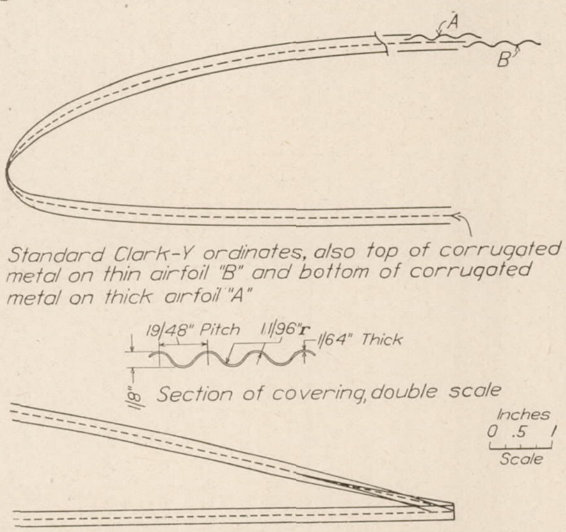

FIGURE 4.—Corrugated airfoils. Clark Y, basic section

DISCUSSION

The reason for testing at two speeds was to determine the presence of scale effect. The differences were so slight that only one curve has been drawn through the points. The scattering of the points is, therefore, more an indication of the precision of the tests. The small forces at low angles of attack limit the precision of the minimum drag coefficient to ±10 per cent.

On examination of the curves a few striking points will be noted. Some of the curves show breaks at the high angles (25° to 30°). It was noted during the tests that these breaks occurred at a higher angle when the angle of attack was being increased than when it was being decreased. The angles were not changed rapidly so the phenomena can not be charged to oscillation of the airfoil. There is probably some effect at these high angles, producing a condition which makes the flow tend to continue in a given way even though the new angle of attack dictates a change. These portions of the curves are mainly useful in discussion of rotary instability.

The N. A. C. A. M–6 shows consistently higher maximum lift at 100 M. P. H. than at 80. Experiments in the Variable Density Tunnel have shown that there is a variation of lift with Reynolds Number which may be quite rapid at certain values. It may be that for this airfoil the lift does increase rapidly at these Reynolds Numbers. The small center of pressure movement confirms other tests on this airfoil.

The effect of the different surfaces on the characteristics of the Clark Y airfoil is shown in Figure 19. Apparently reasonably small deviations from the true smooth surface have slight effect on the aerodynamic characteristics of this airfoil. While the range of surface smoothness was not large, the unpainted plywood was certainly rougher than the doped fabric of a wing as used on airplanes.

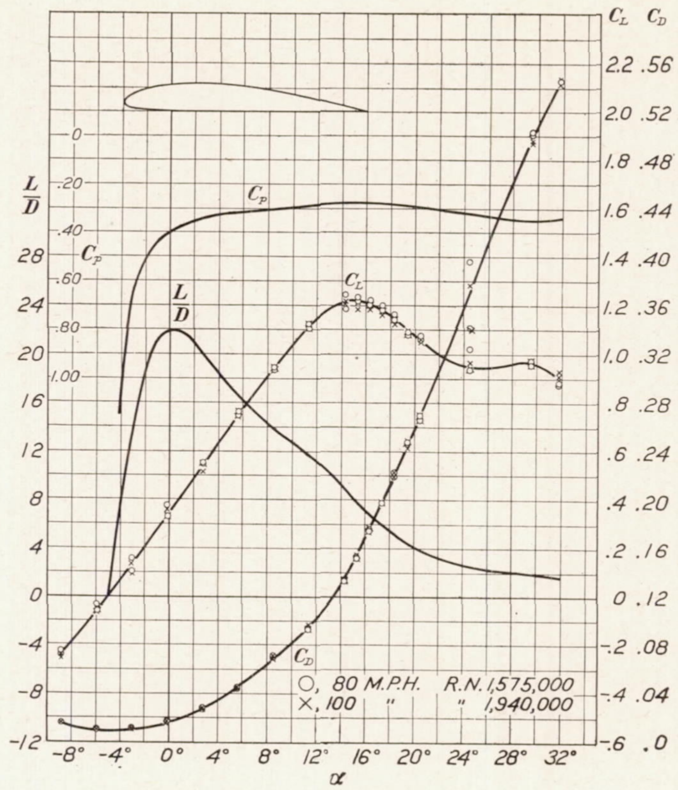

FIGURE 5.—Clark Y, plywood covered. Aspect ratio 6. Free air

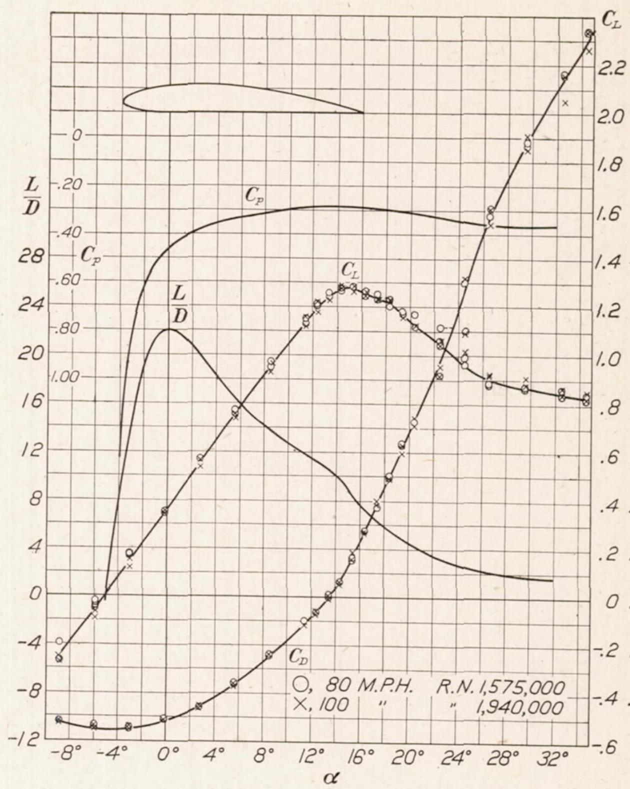

FIGURE 7.—Clark Y, metal covered, painted. Aspect ratio 6. Free air

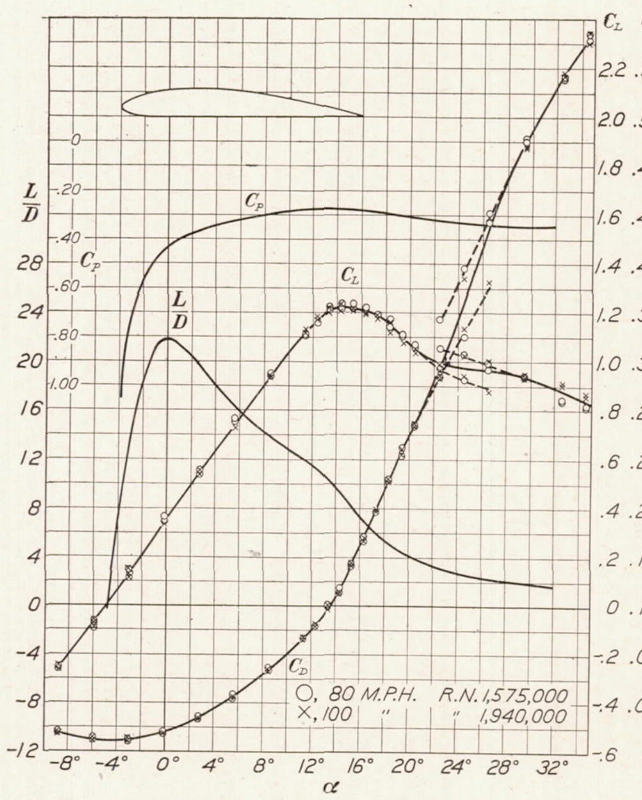

FIGURE 6.—Clark Y, metal covered, unpainted. Aspect ratio 6. Free air

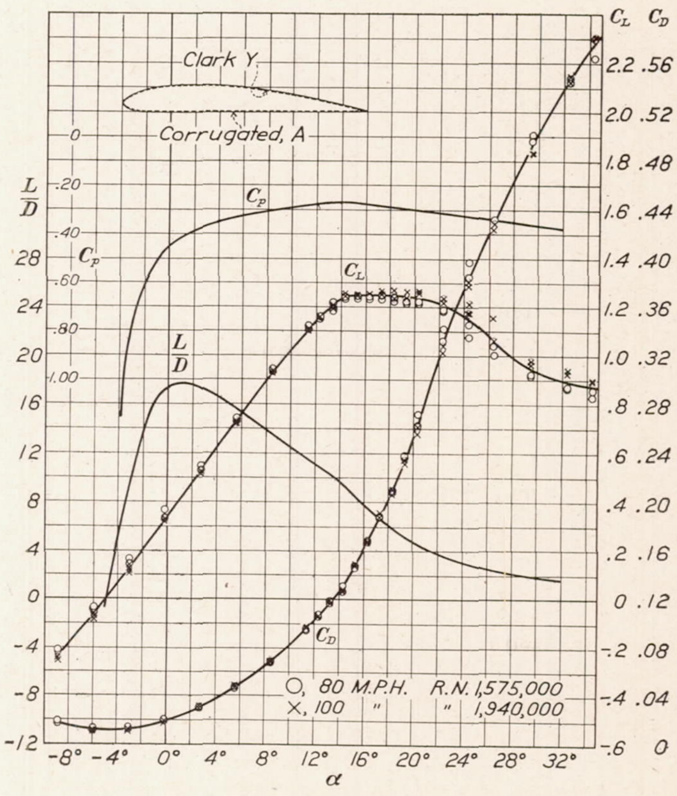

FIGURE 8.—Clark Y, corrugated, A. Aspect ratio 6. Free air

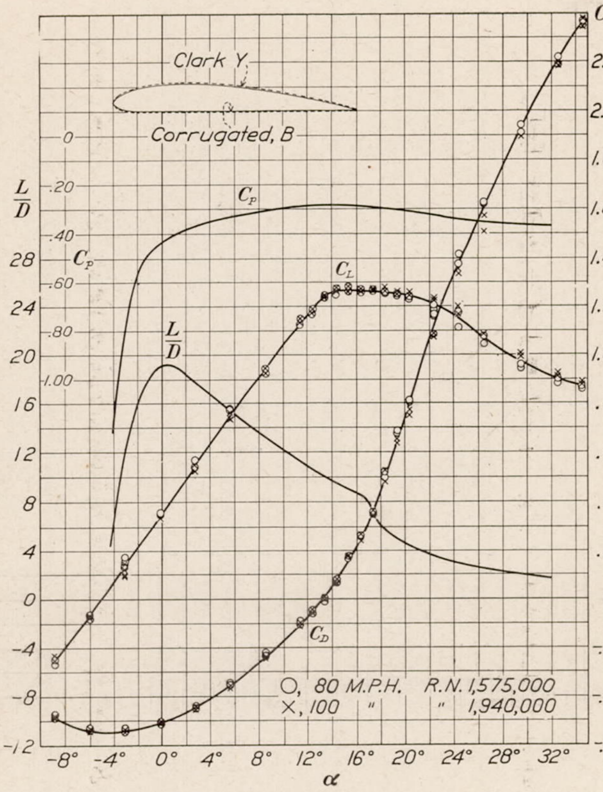

FIGURE 9.—Clark Y, corrugated, B. Aspect ration 6. Free air

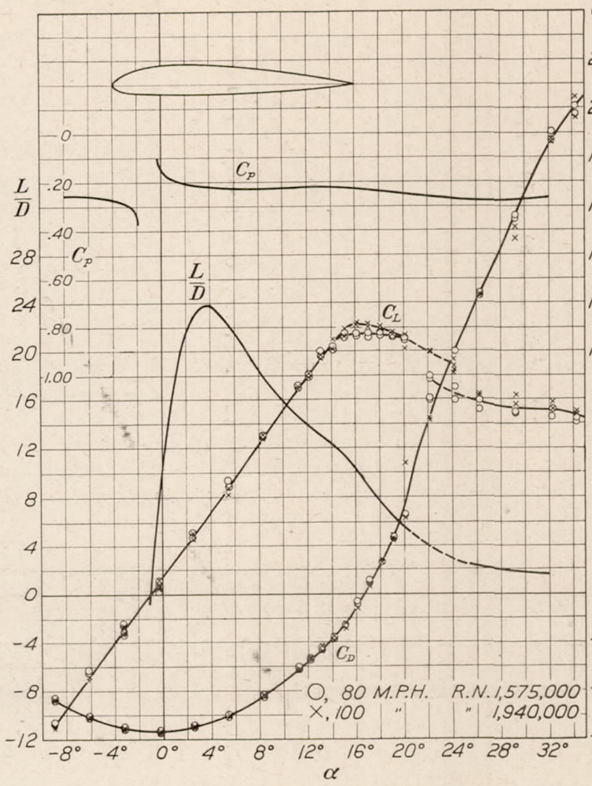

FIGURE 11.—N. A. C. A. M–6, metal covered, painted. Aspect ratio 6. Free air

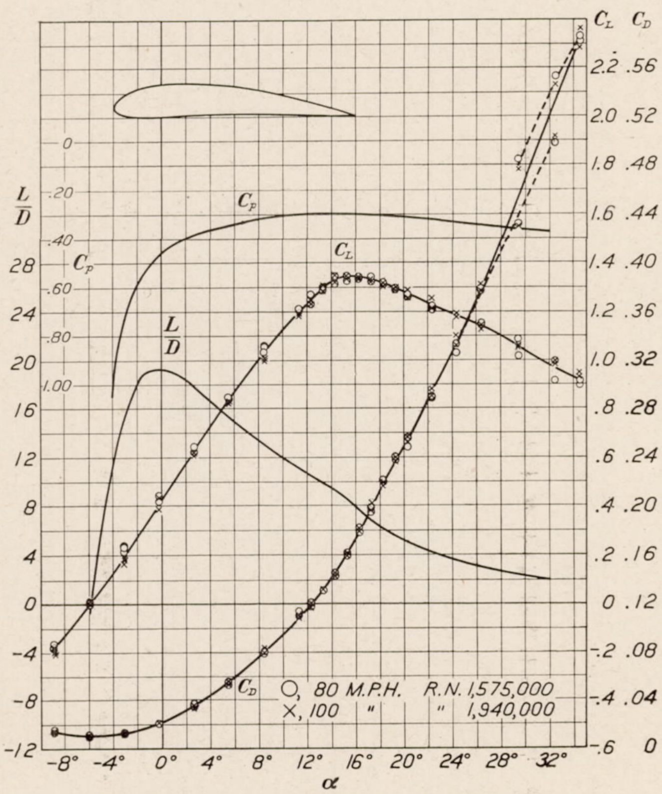

FIGURE 10.—Göttingen 398, metal covered, painted. Aspect ratio 6. Free air

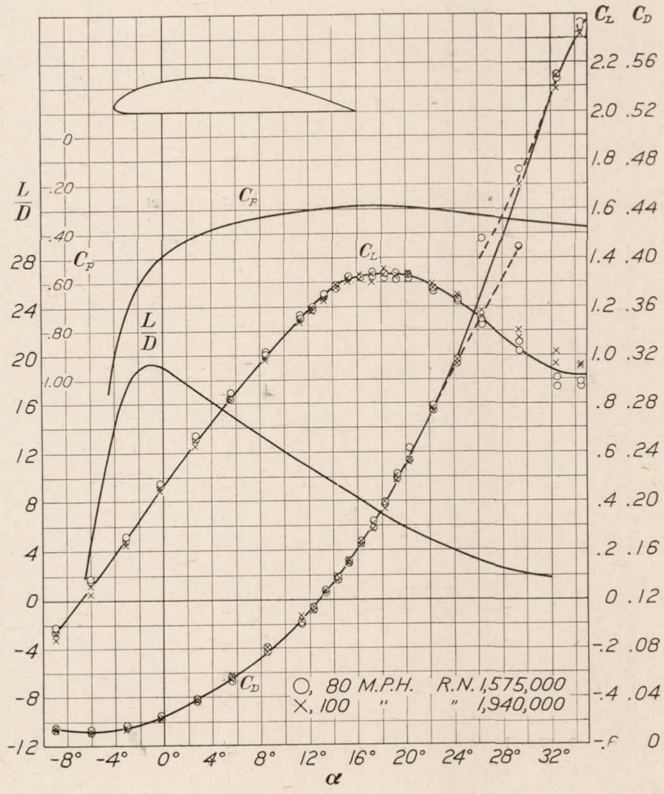

FIGURE 12.—N. A. C. A. 84, metal covered, painted. Aspect ratio 6. Free air

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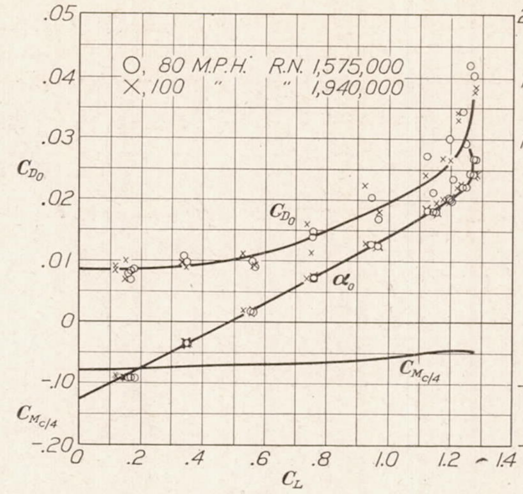

FIGURE 13.—Clark Y, metal covered, painted. Infinite aspect ratio. Free air

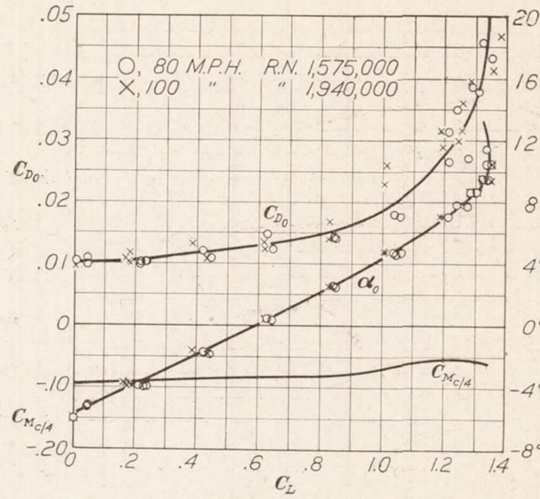

FIGURE 16.—Göttingen 398. Infinite aspect ratio. Free air

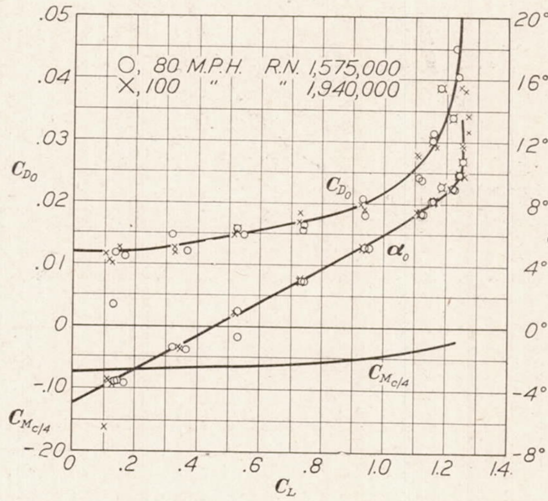

FIGURE 14.—Clark Y, corrugated, A. Infinite aspect ratio. Free air

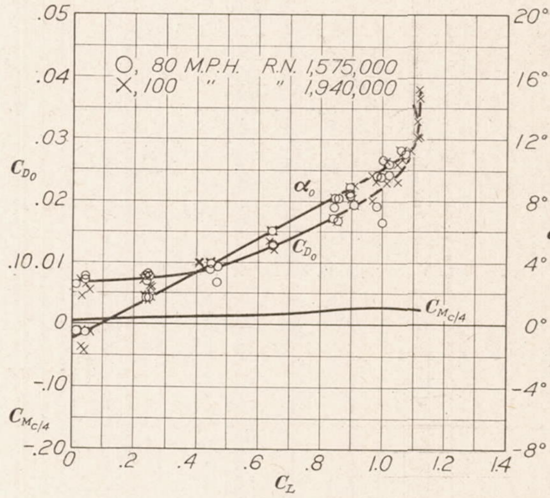

FIGURE 17.—N. A. C. A. M-6. Infinite aspect ratio. Free air

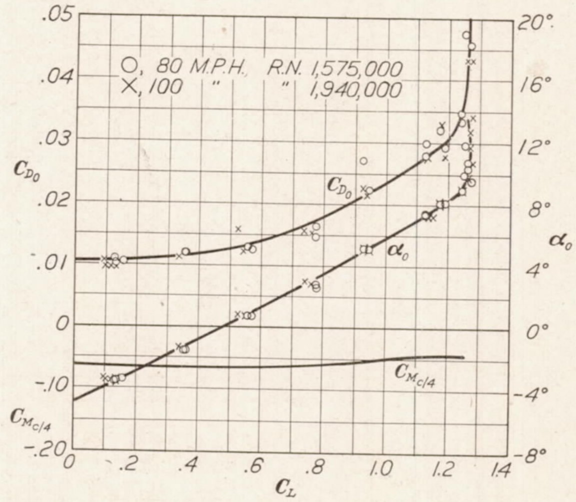

FIGURE 15.—Clark Y, corrugated, B. Infinite aspect ratio. Free air

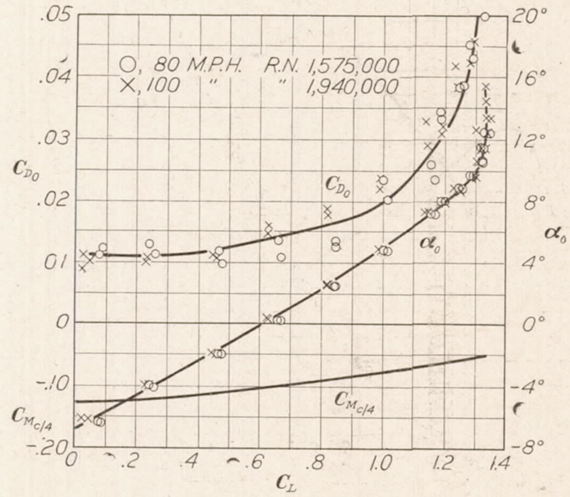

FIGURE 18.—N. A. C. A. 84. Infinite aspect ratio. Free air

Examination of the corrugated Clark Y airfoil in comparison with the smooth Clark Y (fig. 20) reveals a marked flattening of the lift curve for the corrugated sections at the burble point and a lower negative slope beyond the burble. Throughout the normal flying range the slope of the lift curve is unaffected. At any given angle the corrugated surface airfoil shows a

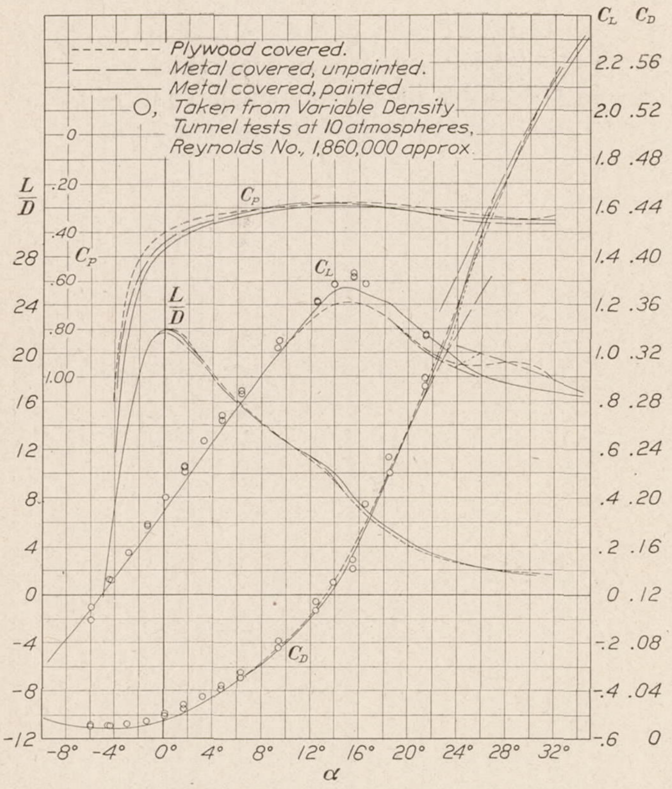

FIGURE 19.—Effect of different surfaces on characteristics of Clark Y. Plywood covered; metal covered, unpainted; metal covered, painted

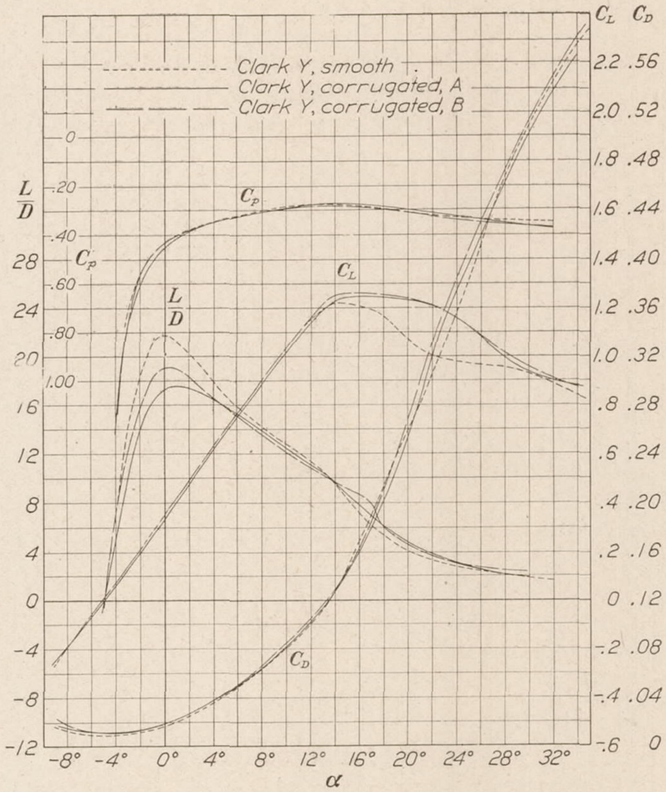

FIGURE 20.—Effect of corrugations in comparison with a smooth Clark Y. Corrugated, A; corrugated, B; metal covered, unpainted, smooth

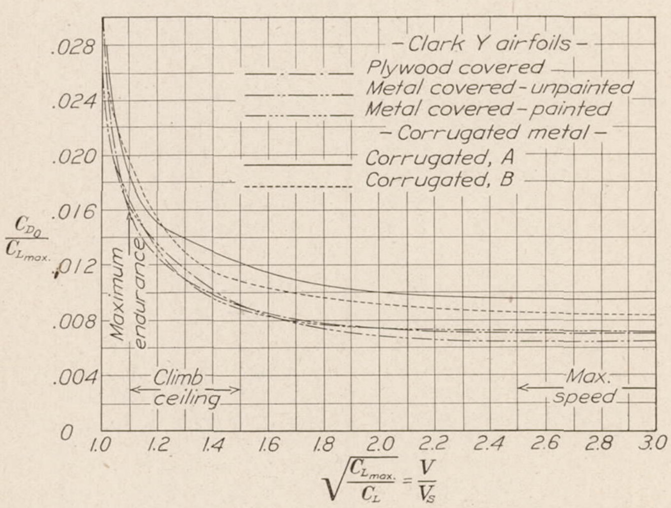

FIGURE 21.—Comparison curves. Profile drag for constant gross load and stalling speed. Clark Y airfoils

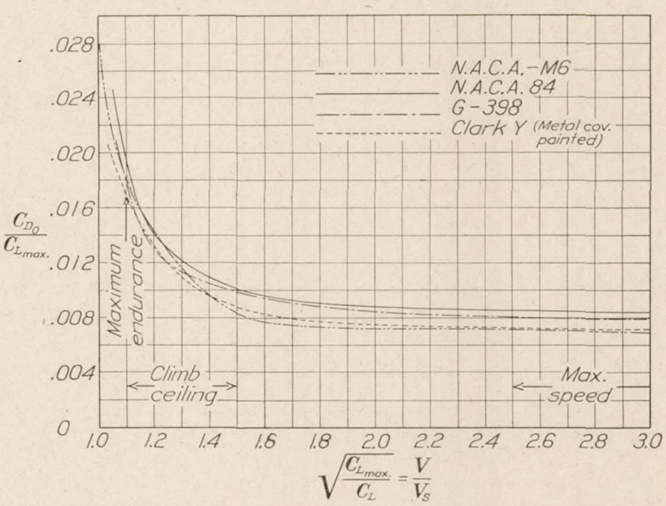

FIGURE 22.—Comparison curves. Profile drag for constant gross load and stalling speed. Different airfoils

slightly higher lift with considerably greater drag so that the Lift/Drag ratio is inferior to that of a smooth airfoil, although only slightly so at 6° and above.

A general flattening of the lift curve is to be noted for all of the airfoils near the burble in contrast to the sharp breaks often found from low-scale tests.

The variable density tunnel test points (fig. 19) indicate a slightly greater slope and a higher maximum lift. The minimum drag is also higher. A comparison with atmospheric tunnel tests on the same airfoil indicates the same scale effect as that predicted by the tests in the variable density tunnel. The agreement is quite in line with what would be expected in different tunnels.

Figures 21 and 22 have been prepared to place the selection or comparison on a common basis. It may be said, in general, that the best airfoil at any given speed is the one which has the lowest profile drag. The actual total drag will be greater by the amount of the induced drag which depends on the effective aspect ratio. It is desirable also to have a high maximum lift to reduce the required wing area. By plotting $\left(\frac{C_{D0}}{C_{L_{max.}}}\right)$ against $\left(\frac{C_L}{C_{L_{max.}}}\right)^{\frac{1}{2}}=\frac{V}{V_S}$, we secure a convenient diagram for comparing the sections on the basis of total profile drag for constant gross load and stalling speed. Since $\frac{C_{D0}}{C_{L_{max.}}}=\left(\frac{D_0}{W}\right)$, the flying condition corresponding to any given speed ratio is indicated on the curves. The values of speed ratio for these conditions are taken from Reference 4. For general use the Clark Y appears the best, while the N. A. C. A. M–6 has the advantage at very high speeds; furthermore, the small center of pressure travel of the M–6 is also of value. The corrugated sections are inferior under all conditions. Too much dependence should not be placed on these diagrams, however, because the particular application may alter the relative position. Tests of a complete model should be the final criterion. Lacking other data, however, the comparison on this basis will be quite useful.

CONCLUSION

In the present tests Reynolds Numbers of 2,000,000 were attained by using large models. This is about 60 per cent of normal full scale.

1. The effect of small variations in the surface of an airfoil on the aerodynamic characteristics is shown to be negligible.

2. Corrugating the surface of an airfoil flattens out the lift curve at the burble point with a small increase of lift; but causes a reduction in effectiveness (L/D) throughout the normal flying range due to the increase of drag. Pressure distribution tests would probably indicate the nature of the holding off of the drop of the lift curve at the burble.

3. A general flattening of the lift curve at the burble is noted for all the airfoils tested rather than the sudden break found in low-scale tests.

4. The results appear to be in good agreement with those from other tests at the same Reynolds Numbers.

Langley Memorial Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., *May 24, 1929.*

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TABLE I

Ordinates of Clark Y airfoil metal covered and painted

2-FOOT CHORD, 12-FOOT SPAN

Distance from leading edge in per cent of chord	Upper surface			Lower surface		
	Standard ordinate in per cent of chord	Specified ordinate for 2-foot chord in inches	Measured ordinate for 2-foot chord in inches	Standard ordinate in per cent of chord	Specified ordinate for 2-foot chord in inches	Measured ordinate for 2-foot chord in inches
0	3.50	0.84	----------	3.50	0.84	----------
1.25	5.45	1.31	1.37	1.93	.46	0.52
2.5	6.50	1.56	1.62	1.47	.35	.37
5	7.90	1.90	1.94	.93	.22	.23
7.5	8.85	2.12	2.16	.63	.15	.15
10	9.60	2.30	2.33	.42	.10	.10
15	10.69	2.57	2.58	.15	.04	.02
20	11.36	2.73	2.71	.03	.01	.00
30	11.70	2.81	2.80	.00	.00	.00
40	11.40	2.74	2.73	.00	.00	.00
50	10.52	2.52	2.50	.00	.00	.00
60	9.15	2.20	2.16	.00	.00	.01
70	7.35	1.76	1.73	.00	.00	−.01
80	5.22	1.25	1.23	.00	.00	.00
90	2.80	.67	.65	.00	.00	.00
95	1.49	.36	.33	.00	.00	.01
100	.12	.03	.03	.00	.00	.01

TABLE II

Ordinates of Clark Y airfoil corrugated metal

Clark Y, Corrugated, A

2-FOOT CHORD, 12 FOOT SPAN

Distance from leading edge in per cent of chord	Upper surface				Lower surface			
	Top of corrugations		Bottom of corrugations		Top of corrugations		Bottom of corrugations	
	Specified ordinate for 2-foot chord in inches	Measured ordinate for 2-foot chord in inches	Specified ordinate for 2-foot chord in inches	Measured ordinate for 2-foot chord in inches	Specified ordinate for 2-foot chord in inches	Measured ordinate for 2-foot chord in inches	Specified ordinate for 2-foot chord in inches	Measured ordinate for 2-foot chord in inches
0	0.84	----------	0.84	----------	0.84	----------	0.84	----------
1.25	1.58	1.59	1.47	1.51	.49	0.57	.57	0.66
2.5	1.84	1.84	1.71	1.74	.35	.40	.46	.49
5	2.16	2.18	2.04	2.08	.22	.25	.33	.34
7.5	2.39	2.41	2.27	2.32	.14	.18	.26	.27
10	2.57	2.60	2.45	2.50	.09	.13	.21	.23
15	2.82	2.85	2.71	2.74	.03	.07	.14	.16
20	2.98	3.01	2.87	2.92	.01	.04	.11	.14
30	3.07	3.11	2.96	3.01	.00	.05	.11	.14
40	3.00	3.02	2.89	2.92	.00	.04	.11	.13
50	2.78	2.83	2.67	2.73	.00	.01	.11	.10
60	2.46	2.49	2.35	2.40	.00	.00	.11	.10
70	2.02	2.06	1.91	1.96	.00	.00	.11	.09
80	1.51	1.53	1.40	1.43	.00	.02	.11	.11
90	.90	.92	.79	.83	.00	.05	.11	.14
95	.54	.59	.43	.49	.00	.07	.11	.16
100	.13	.29	.04	.20	.00	.11	.11	.20

TABLE III

Ordinates of Clark Y airfoil corrugated metal

CLARK Y, CORRUGATED, B

2-FOOT CHORD, 12-FOOT SPAN

Distance from leading edge in per cent of chord	Upper surface				Lower surface			
	Top of corrugations		Bottom of corrugations		Top of corrugations		Bottom of corrugations	
	Specified ordinate for 2-foot chord in inches	Measured ordinate for 2-foot chord in inches	Specified ordinate for 2-foot chord in inches	Measured ordinate for 2-foot chord in inches	Specified ordinate for 2-foot chord in inches	Measured ordinate for 2-foot chord in inches	Specified ordinate for 2-foot chord in inches	Measured ordinate for 2-foot chord in inches
0	0.84	-----------	0.84	-----------	0.84	-----------	0.84	-----------
1.25	1.31	1.37	1.22	1.32	.46	0.50	.56	0.57
2.50	1.56	1.62	1.46	1.54	.35	.39	.48	.46
5	1.90	1.92	1.76	1.83	.22	.28	.35	.36
7.5	2.12	2.16	1.99	2.07	.15	.21	.28	.29
10	2.30	2.33	2.17	2.24	.10	.15	.22	.24
15	2.57	2.58	2.43	2.49	.04	.09	.16	.18
20	2.73	2.74	2.60	2.66	.01	.05	.13	.14
30	2.81	2.83	2.68	2.76	.00	.03	.11	.13
40	2.74	2.74	2.63	2.66	.00	.03	.11	.13
50	2.52	2.54	2.41	2.46	.00	.03	.11	.13
60	2.20	2.23	2.09	2.15	.00	.04	.11	.14
70	1.76	1.81	1.65	1.73	.00	.05	.11	.15
80	1.25	1.32	1.14	1.22	.00	.06	.11	.16
90	.67	.75	.56	.67	.00	.07	.11	.17
95	.36	.47	.25	.37	.00	.08	.11	.17
100	.13	.22	.02	.12	.00	.05	.11	.13

TABLE IV

Ordinates of Göttingen 398 airfoil metal, covered and painted

2-FOOT CHORD, 12-FOOT SPAN

Distance from leading edge in per cent of chord	Upper surface			Lower surface		
	Standard ordinate in per cent of chord	Specified ordinate for 2-foot chord in inches	Measured ordinate for 2-foot chord in inches	Standard ordinate in per cent of chord	Specified ordinate for 2-foot chord in inches	Measured ordinate for 2-foot chord in inches
0	3.74	0.90	-----------	3.74	0.90	-----------
1.25	6.19	1.49	1.54	1.89	.45	0.48
2.5	7.40	1.78	1.83	1.28	.31	.34
5	8.86	2.13	2.20	.69	.17	.18
7.5	10.25	2.46	2.49	.35	.08	.10
10	11.25	2.70	2.71	.27	.06	.06
15	12.54	3.01	3.02	.05	.01	.02
20	13.34	3.20	3.19	.00	.00	.00
30	13.77	3.30	3.30	.05	.01	.01
40	13.34	3.20	3.19	.25	.06	.05
50	12.32	2.96	2.96	.27	.06	.07
60	10.56	2.53	2.55	.29	.07	.09
70	8.45	2.06	2.06	.28	.07	.09
80	6.08	1.46	1.45	.27	.06	.06
90	3.32	.80	.78	.13	.03	.02
95	1.87	.45	.43	.05	.01	.00
100	0.43	.10	.09	.00	.00	.00

TABLE V

Ordinates of N. A. C. A. M-6 airfoil metal, covered and painted

2-FOOT CHORD, 12-FOOT SPAN

Distance from leading edge in per cent of chord	Upper surface			Lower surface		
	Standard ordinate in per cent of chord	Specified ordinate for 2-foot chord in inches	Measured ordinate for 2-foot chord in inches	Standard ordinate in per cent of chord	Specified ordinate for 2-foot chord in inches	Measured ordinate for 2-foot chord in inches
0	0	0	----------	0	0	----------
1.25	1.97	.47	0.52	−1.76	−.42	−0.38
2.5	2.81	.67	.72	−2.20	−.53	−.51
5.0	4.03	.97	1.00	−2.73	−.65	−.65
7.5	4.94	1.19	1.23	−3.03	−.73	−.74
10	5.71	1.37	1.41	−3.24	−.78	−.79
15	6.82	1.64	1.65	−3.47	−.83	−.84
20	7.55	1.81	1.81	−3.62	−.87	−.87
30	8.22	1.97	1.96	−3.79	−.91	−.92
40	8.05	1.93	1.90	−3.90	−.94	−.95
50	7.26	1.74	1.70	−3.94	−.95	−.95
60	6.03	1.45	1.43	−3.82	−.92	−.91
70	4.58	1.10	1.11	−3.48	−.84	−.82
80	3.06	.73	.75	−2.83	−.68	−.65
90	1.55	.37	.42	−1.77	−.42	−.38
95	.88	.21	.24	−1.08	−.26	−.20
100	.26	.06	.09	−.26	−.06	−.01

TABLE VI

Ordinates of N. A. C. A. 84 airfoil metal, covered and painted

2-FOOT CHORD, 12-FOOT SPAN

Distance from leading edge in per cent of chord	Upper surface			Lower surface		
	Standard ordinate in per cent of chord	Specified ordinate for 2-foot chord in inches	Measured ordinate for 2-foot chord in inches	Standard ordinate in per cent of chord	Specified ordinate for 2-foot chord in inches	Measured ordinate for 2-foot chord in inches
0	2.50	0.60	----------	2.50	0.60	----------
1.25	4.85	1.16	1.22	.95	.23	0.28
2.5	6.05	1.45	1.49	.41	.10	.14
5	7.78	1.87	1.91	.10	.02	.05
7.5	9.03	2.17	2.19	.02	.01	.03
10	10.0	2.40	2.42	.00	.00	.01
15	11.5	2.76	2.78	.00	.00	.01
20	12.71	3.05	3.06	.00	.00	.01
30	14.0	3.36	3.35	.00	.00	.01
40	14.11	3.38	3.37	.00	.00	.00
50	13.50	3.24	3.22	.00	.00	.01
60	12.31	2.95	2.92	.00	.00	.01
70	10.32	2.47	2.44	.00	.00	.01
80	7.71	1.85	1.85	.00	.00	.01
90	4.39	1.05	1.08	.00	.00	.03
95	2.41	.58	.61	.00	.00	.04
100	.30	.07	.11	.00	.00	.05

TABLE VII

Clark Y, Plywood Covered

Span, 12 feet. Chord, 2 feet. Area, 24 square feet. Reynolds No. 1,940,000

ASPECT RATIO 6, FREE AIR

α	C_L	C_D	L/D	C_P	$C_{Mc/4}$
°					
−9	−0.245	0.0176	----------	0.046	−0.050
−8	−.184	.0127	----------	−.027	−.051
−6	−.060	.0093	----------	−.616	−.052
−4	.070	.0090	7.78	−1.01	−.053
−2	.209	.0111	18.83	.504	−.053
0	.350	.0160	21.92	.395	−.052
2	.493	.0237	20.80	.353	−.051
4	.637	.0348	18.30	.328	−.050
6	.781	.0485	16.10	.313	−.049
8	.917	.0642	14.28	.303	−.048
10	1.041	.0816	12.76	.292	−.044
12	1.148	.1023	11.21	.281	−.036
14	1.215	.1295	9.39	.275	−.031
16	1.214	.1690	7.19	.276	−.032
18	1.161	.2120	5.48	.281	−.036
20	1.078	.2585	4.17	.291	−.044
22	1.005	.3072	3.27	.303	−.053
24	.957	.3590	2.66	.317	−.064
26	.951	.4115	2.31	.330	−.076
28	.967	.4630	2.09	.340	−.087
30	.959	.5090	1.88	.343	−.089
32	.890	.550	1.62	.334	−.075

TABLE VIII

Clark Y, Metal Covered, Unpainted

Span 12 feet. Chord, 2 feet. Area, 24 square feet. Reynolds No. 1,940,000

ASPECT RATIO 6, FREE AIR

α	C_L	C_D	L/D	C_P	$C_{Mc/4}$
°					
−9	−0.264	0.0160	----------	−0.015	−0.070
−8	−.204	.0129	----------	−.088	−.069
−6	−.073	.0093	----------	−.681	−.068
−4	.063	.0088	7.16	1.314	−.067
−2	.207	.0113	18.33	.564	−.065
0	.353	.0162	21.80	.434	−.065
2	.496	.0243	20.40	.377	−.064
4	.632	.0351	18.00	.350	−.063
6	.767	.0481	15.92	.327	−.059
8	.902	.0634	14.21	.303	−.048
10	1.035	.0801	12.90	.284	−.035
12	1.152	.1000	11.52	.274	−.028
14	1.220	.1266	9.65	.276	−.032
16	1.211	.1686	7.20	.281	−.038
18	1.164	.2136	5.45	.291	−.048
20	1.070	.2581	4.15	.306	−.060
22	1.003	.304	3.30	.322	−.072
24	.978	.356	2.75	.332	−.080
26	.964	.412	2.34	.338	−.085
28	.952	.469	2.03	.340	−.086
30	.928	.509	1.82	.343	−.086
32	.889	.545	1.63	.345	−.084
34	.845	.575	1.47	.339	−.075
35	.825	.589	1.40	.326	−.063

TABLE IX

Clark Y, Metal Covered and Painted

Span, 12 feet. Chord, 2 feet. Area, 24 square feet. Reynolds No. 1,940,000

ASPECT RATIO 6, FREE AIR

α	C_L	C_D	L/D	C_P	$C_{Mc/4}$
°					
−9	−0.255	0.0160	----------	−0.068	−0.081
−8	−.191	.0125	----------	−.179	−.082
−6	−.061	.0093	----------	−1.094	−.082
−4	.076	.0089	8.44	1.318	−.080
−2	.214	.0113	18.95	.614	−.078
0	.356	.0162	21.99	.461	−.075
2	.501	.0242	20.69	.394	−.072
4	.643	.0353	18.20	.357	−.069
6	.783	.0492	15.90	.334	−.066
8	.920	.0655	14.03	.318	−.063
10	1.050	.0828	12.69	.300	−.053
12	1.175	.1025	11.45	.289	−.046
14	1.268	.1266	10.01	.286	−.046
16	1.260	.1658	7.60	.290	−.050
18	1.221	.2101	5.81	.297	−.058
20	1.138	.257	4.43	.311	−.069
22	1.061	.303	3.51	.326	−.081
24	.978	.358	2.73	.343	−.091
26	.909	.422	2.15	.358	−.098
28	.877	.467	1.88	.366	−.102
30	.860	.505	1.70	.367	−.101
32	.842	.540	1.56	.363	−.095
34	.828	.573	1.44	.350	−.083
35	.822	.590	1.39	.341	−.075

TABLE X

Clark Y, Corrugated Metal, A

Span, 12 feet. Chord, 2 feet. Area, 24 square feet. Reynolds No. 1,940000

ASPECT RATIO 6, FREE AIR

α	C_L	C_D	L/D	C_P	$C_{Mc/4}$
°					
−9	−0.246	0.0190	----------	−0.050	−0.074
−8	−.188	.0159	----------	−.143	−.074
−6	−.067	.0124	----------	−.84	−.073
−4	.062	.0120	5.17	1.41	−.072
−2	.197	.0142	13.89	.605	−.070
0	.338	.0195	17.33	.454	−.069
2	.480	.0274	17.51	.386	−.065
4	.620	.0375	16.53	.350	−.062
6	.761	.0498	15.28	.326	−.058
8	.896	.0643	13.93	.308	−.052
10	1.024	.0820	12.49	.293	−.044
12	1.143	.1024	11.18	.278	−.032
14	1.233	.1261	9.78	.268	−.022
16	1.250	.1610	7.75	.274	−.030
18	1.247	.2010	6.20	.288	−.047
20	1.239	.2545	4.85	.299	−.060
22	1.217	.3190	3.80	.310	−.073
24	1.163	.3750	3.10	.322	−.084
26	1.083	.4200	2.58	.339	−.096
28	.996	.4630	2.15	.356	−.105
30	.934	.5030	1.86	.369	−.111
32	.900	.539	1.67	.374	−.112
34	.879	.571	1.54	.375	−.110
35	.871	.583	1.50	.372	−.106

TABLE XI

Clark Y, Corrugated Metal, B

Span, 12 feet. Chord, 2 feet. Area, 24 square feet.
Reynolds No. 1,940,000

ASPECT RATIO 6. FREE AIR

α	C_L	C_D	L/D	C_p	$C_{Mc/4}$
°					
−9	−0.261	0.0238	----------	−0.001	−0.065
−8	−.199	.0180	----------	−.076	−.065
−6	−.068	.0118	----------	−.706	−.065
−4	.070	.0107	6.54	1.179	−.065
−2	.212	.0134	15.82	.561	−.066
0	.354	.0186	19.03	.434	−.065
2	.495	.0269	18.39	.381	−.065
4	.636	.0379	16.77	.351	−.064
6	.778	.0514	15.13	.328	−.061
8	.910	.0673	13.52	.312	−.056
10	1.040	.0855	12.18	.297	−.049
12	1.166	.1060	11.00	.289	−.045
14	1.257	.1302	9.66	.284	−.043
16	1.263	.1635	7.73	.285	−.044
18	1.258	.2090	6.00	.294	−.055
20	1.247	.2682	4.65	.309	−.073
22	1.215	.3326	3.65	.326	−.092
24	1.163	.3860	3.02	.341	−.106
26	1.088	.4302	2.52	.350	−.109
28	1.017	.4735	2.15	.358	−.110
30	.960	.5140	1.87	.365	−.110
32	.910	.5515	1.65	.370	−.109
34	.871	.5838	1.49	.374	−.108
35	.868	.5980	1.45	.373	−.107

TABLE XII

Göttingen 398, Metal Covered and Painted

Span, 12 feet. Chord, 2 feet. Area, 24 square feet.
Reynolds No. 1,940,000

ASPECT RATIO 6, FREE AIR

α	C_L	C_D	L/D	C_p	$C_{Mc/4}$
°					
−9	−0.186	0.0150	----------	−0.261	−0.095
−8	−.129	.0128	----------	−.486	−.095
−6	−.003	.0103	----------	−31.15	−.094
−4	.131	.0113	11.60	.960	−.093
−2	.272	.0151	18.01	.581	−.090
0	.422	.0219	19.27	.458	−.088
2	.578	.0314	18.40	.397	−.085
4	.728	.0435	16.72	.363	−.082
6	.871	.0582	14.97	.340	−.078
8	1.005	.0755	13.31	.318	−.068
10	1.127	.0944	11.92	.301	−.057
12	1.234	.1153	10.69	.295	−.055
14	1.325	.1400	9.47	.293	−.057
16	1.347	.1725	7.82	.296	−.062
18	1.323	.2119	6.25	.302	−.069
20	1.281	.2481	5.16	.310	−.077
22	1.233	.2860	4.32	.320	−.086
24	1.190	.3270	3.64	.331	−.096
26	1.149	.370	3.10	.342	−.105
28	1.100	.419	2.62	.353	−.113
30	1.038	.469	2.21	.364	−.118
32	.979	.520	1.88	.375	−.122
34	.928	.570	1.63	.385	−.125
35	.909	.595	1.53	.388	−.125

TABLE XIII

N. A. C. A. M-6, Metal Covered and Painted

Span, 12 feet. Chord, 2 feet. Area, 24 square feet.
Reynolds No. 1,940,000

ASPECT RATIO 6. FREE AIR

α	C_L	C_D	L/D	C_p	$C_{Mc/4}$
°					
−9	−0.540	0.0330	----------	0.254	0.002
−8	−.471	.0277	----------	.256	.003
−6	−.337	.0182	----------	.262	.004
−4	−.202	.0115	----------	.275	.005
−2	−.067	.0079	----------	.340	.006
0	.068	.0070	9.85	.147	.007
2	.203	.0094	21.60	.206	.009
4	.338	.0142	23.80	.220	.010
6	.476	.0221	21.55	.225	.012
8	.618	.0336	18.40	.226	.015
10	.755	.0475	15.89	.226	.018
12	.893	.0638	13.99	.221	.026
14	1.023	.0824	12.41	.223	.028
16	1.113	.1082	10.28	.228	.024
18	1.094	.1441	7.60	.238	.013
20	1.054	.1912	5.50	.250	.000
22	.995	.262	3.80	.261	−.011
24	.948	.314	3.02	.270	−.019
26	.791	.361	2.19	.278	−.022
28	.770	.405	1.90	.277	−.021
30	.760	.448	1.70	.272	−.017
32	.756	.489	1.55	.263	−.010
34	.737	.518	1.42	.253	−.002
35	.720	.530	1.36	.244	.004

TABLE XIV

N. A. C. A. 84, Metal Covered and Painted

Span, 12 feet. Chord, 2 feet. Area, 42 square feet.
Reynolds No. 1,940,000

ASPECT RATIO 6, FREE AIR

α	C_L	C_D	L/D	C_p	$C_{Mc/4}$
°					
−9	−0.135	0.0140	----------	−0.675	−0.125
−8	−.070	.0126	----------	−1.54	−.126
−6	.054	.0116	4.55	2.59	−.126
−4	.187	.0131	14.29	.908	−.123
−2	.324	.0172	18.83	.614	−.118
0	.461	.0242	19.05	.493	−.112
2	.598	.0339	17.63	.426	−.105
4	.724	.0448	16.16	.384	−.097
6	.849	.0574	14.79	.355	−.089
8	.968	.0719	13.47	.333	−.080
10	1.080	.0896	12.06	.317	−.072
12	1.186	.1102	10.75	.303	−.063
14	1.278	.1341	9.53	.293	−.055
16	1.323	.1610	8.23	.289	−.051
18	1.333	.1928	6.92	.288	−.050
20	1.328	.2295	5.79	.292	−.055
22	1.291	.2698	4.79	.300	−.065
24	1.233	.3126	3.95	.312	−.077
26	1.161	.3610	3.22	.325	−.087
28	1.079	.4159	2.59	.336	−.093
30	1.000	.472	2.12	.349	−.099
32	.943	.530	1.78	.360	−.104
34	.917	.578	1.59	.369	−.109
35	.915	.595	1.54	.371	−.111

TABLE XV

Clark Y, Metal Covered and Painted

Infinite aspect ratio characteristics. Computed from A. R. = 6 tests rectangular loading

$$C_{D_i}=0.0563\ C_L^2$$

$$\alpha_i=3.601\ C_L$$

PLOTTED AS FIGURE 13

C_L	C_{D_o}	α_o	$C_{M_{c/4}}$
		°	
−0.061	0.0091	−5.78	−0.082
.076	.0086	−4.27	−.080
.214	.0087	−2.77	−.078
.356	.0091	−1.28	−.075
.501	.0101	.20	−.072
.643	.0121	1.69	−.069
.783	.0146	3.16	−.066
.920	.0179	4.69	−.063
1.050	.0207	6.22	−.053
1.175	.0249	7.77	−.046
1.268	.0361	9.44	−.046

TABLE XVI

Clark Y, Corrugated Metal, A. Clark Y, Inside of Metal

Infinite aspect ratio characteristics. Computed from A. R. = 6 tests rectangular loading

$$C_{D_i}=0.0564\ C_L^2$$

$$\alpha_i=3.612\ C_L$$

PLOTTED AS FIGURE 14

C_L	C_{D_o}	α_o	$C_{M_{c/4}}$
		°	
−0.067	0.0121	−5.76	−0.073
.062	.0118	−4.22	−.072
.197	.0120	−2.71	−.070
.338	.0131	−1.22	−.069
.480	.0144	.27	−.065
.620	.0158	1.76	−.062
.761	.0171	3.26	−.058
.896	.0190	4.76	−.052
1.024	.0229	6.30	−.044
1.143	.0284	7.87	−.032
1.233	.0405	9.55	−.022
1.250	.0729	11.49	−.030

TABLE XVII

Clark Y, Corrugated Metal, B

Infinite aspect ratio characteristics. Computed from A. R. = 6 tests rectangular loading

$$C_{D_i}=0.0562\ C_L^2$$

$$\alpha_i=3.594\ C_L$$

PLOTTED AS FIGURE 15

C_L	C_{D_o}	α_o	$C_{M_{c/4}}$
		°	
−0.068	0.0115	−5.76	−0.065
.070	.0104	−4.25	−.065
.212	.0109	−2.76	−.066
.354	.0116	−1.27	−.065
.495	.0132	.22	−.065
.636	.0152	1.72	−.064
.778	.0174	3.20	−.061
.910	.0208	4.73	−.056
1.040	.0246	6.26	−.049
1.166	.0295	7.81	−.045
1.257	.0414	9.49	−.043
1.263	.0736	11.46	−.044

TABLE XVIII

Göttingen 398, Metal Covered and Painted

Infinite aspect ratio characteristics. Computed from A. R. = 6 tests rectangular loading

$$C_{D_i}=0.0559\ C_L^2$$

$$\alpha_i=3.575\ C_L$$

PLOTTED AS FIGURE 16

C_L	C_{D_o}	α_o	$C_{M_{c/4}}$
		°	
−0.003	0.0103	−5.99	−0.094
.131	.0103	−4.47	−.093
.272	.0110	−2.97	−.090
.422	.0120	−1.51	−.088
.578	.0127	−.06	−.085
.728	.0139	1.40	−.082
.871	.0158	2.88	−.078
1.005	.0191	4.41	−.068
1.127	.0235	5.98	−.057
1.234	.0302	7.59	−.055
1.325	.0419	9.26	−.057
1.347	.0713	11.19	−.062

TABLE XIX

N. A. C. A. M-6, Metal Covered and Painted

Infinite aspect ratio characteristics. Computed from A. R.=6 tests rectangular loading

$C_{Di}=0.0564\ C_L^2$

$\alpha_i=3.605\ C_L$

PLOTTED AS FIGURE 17

C_L	C_{Do}	α_o	$C_{Mc/4}$
		°	
−0.067	0.0076	−1.76	0.006
.062	.0067	−.24	.007
.203	.0071	1.29	.009
.338	.0078	2.81	.010
.476	.0093	4.33	.012
.618	.0120	5.83	.015
.755	.0153	7.35	.018
.893	.0188	8.86	.026
1.023	.0233	10.40	.028
1.113	.0382	12.09	.024

TABLE XX

N. A. C. A. 84, Metal Covered and Painted

Infinite aspect ratio characteristics. Computed from A. R.=6 tests rectangular loading

$C_{Di}=0.0566\ C_L^2$

$\alpha_i=3.600\ C_L$

PLOTTED AS FIGURE 18

C_L	C_{Do}	α_o	$C_{Mc/4}$
		°	
−0.070	0.0123	−7.75	−0.126
.050	.0114	−6.19	−.126
.187	.0111	−4.67	−.123
.324	.0112	−3.17	−.118
.461	.0122	−1.66	−.112
.598	.0137	−.16	−.105
.724	.0152	1.40	−.097
.849	.0166	2.94	−.089
.968	.0188	4.52	−.080
1.080	.0236	6.11	−.072
1.186	.0307	7.73	−.063
1.278	.0417	9.40	−.055
1.323	.0618	11.23	−.051
1.333	.0920	13.20	−.050

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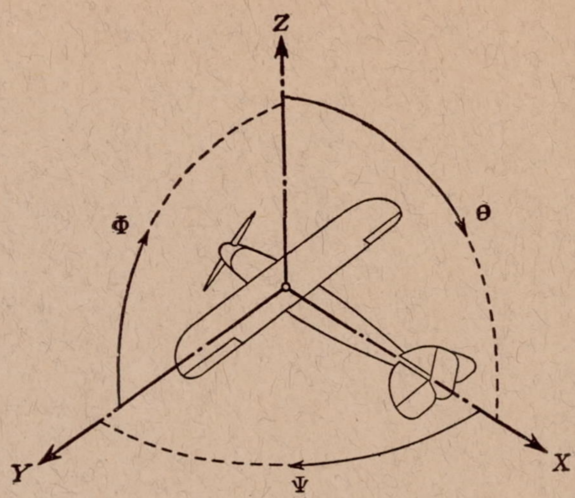

Positive directions of axes and angles (forces and moments) are shown by arrows

Axis		Force (parallel to axis) symbol	Moment about axis			Angle		Velocities	
Designation	Symbol		Designation	Symbol	Positive direction	Designation	Symbol	Linear (component along axis)	Angular
Longitudinal	X	X	rolling	L	$Y \longrightarrow Z$	roll	Φ	u	p
Lateral	Y	Y	pitching	M	$Z \longrightarrow X$	pitch	Θ	v	q
Normal	Z	Z	yawing	N	$X \longrightarrow Y$	yaw	Ψ	w	r

Absolute coefficients of moment

$$C_L=\frac{L}{qbS} \qquad C_M=\frac{M}{qcS} \qquad C_N=\frac{N}{qfS}$$

Angle of set of control surface (relative to neutral position), δ. (Indicate surface by proper subscript.)

4. PROPELLER SYMBOLS

D, Diameter.
p_e, Effective pitch.
p_g, Mean geometric pitch.
p_s, Standard pitch.
p_v, Zero thrust.
p_a, Zero torque.
p/D, Pitch ratio.
V', Inflow velocity.
V_s, Slip stream velocity.

T, Thrust.
Q, Torque.
P, Power.
(If "coefficients" are introduced all units used must be consistent.)
η, Efficiency $= T\,V/P$.
n, Revolutions per sec., r. p. s.
N, Revolutions per minute, r. p. m.
Φ, Effective helix angle $=\tan^{-1}\left(\frac{V}{2\pi rn}\right)$

5. NUMERICAL RELATIONS

1 hp = 76.04 kg/m/s = 550 lb./ft./sec.
1 kg/m/s = 0.01315 hp
1 mi./hr. = 0.44704 m/s
1 m/s = 2.23693 mi./hr.

1 lb. = 0.4535924277 kg
1 kg = 2.2046224 lb.
1 mi. = 1609.35 m = 5280 ft
1 m = 3.2808333 ft.