NATIONAL ADVISORY COMMITTEE

FOR AERONAUTICS

REPORT No. 669

AIRFOIL SECTION DATA OBTAINED IN THE N. A. C. A. VARIABLE-DENSITY TUNNEL AS AFFECTED BY SUPPORT INTERFERENCE AND OTHER CORRECTIONS

By EASTMAN N. JACOBS and IRA H. ABBOTT

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1939

AERONAUTIC SYMBOLS

1. FUNDAMENTAL AND DERIVED UNITS

	Symbol	Metric		English	
		Unit	Abbreviation	Unit	Abbreviation
Length_____	l	meter_____	m	foot (or mile)_____	ft. (or mi.)
Time_____	t	second_____	s	second (or hour)_____	sec. (or hr.)
Force_____	F	weight of 1 kilogram_____	kg	weight of 1 pound_____	lb.
Power_____	P	horsepower (metric)_____	_____	horsepower_____	hp.
Speed_____	V	{kilometers per hour_____	k.p.h.	miles per hour_____	m.p.h.
		{meters per second_____	m.p.s.	feet per second_____	f.p.s.

2. GENERAL SYMBOLS

W, Weight $= mg$

g, Standard acceleration of gravity $= 9.80665$ m/s² or 32.1740 ft./sec.²

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

I, Moment of inertia $= mk^2$. (Indicate axis of radius of gyration k by proper subscript.)

μ, Coefficient of viscosity

ν, Kinematic viscosity

ρ, Density (mass per unit volume)

Standard density of dry air, 0.12497 kg-m⁻⁴-s² at 15° C. and 760 mm; or 0.002378 lb.-ft.⁻⁴ sec.²

Specific weight of "standard" air, 1.2255 kg/m³ or 0.07651 lb./cu. ft.

3. AERODYNAMIC SYMBOLS

S, Area

S_w, Area of wing

G, Gap

b, Span

c, Chord

$\dfrac{b^2}{S}$, Aspect ratio

V, True air speed

q, Dynamic pressure $= \dfrac{1}{2}\rho V^2$

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

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

D_0, Profile drag, absolute coefficient $C_{D0} = \dfrac{D_0}{qS}$

D_i, Induced drag, absolute coefficient $C_{Di} = \dfrac{D_i}{qS}$

D_p, Parasite drag, absolute coefficient $C_{Dp} = \dfrac{D_p}{qS}$

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

R, Resultant force

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

i_t, Angle of stabilizer setting (relative to thrust line)

Q, Resultant moment

Ω, Resultant angular velocity

$\rho\dfrac{Vl}{\mu}$, Reynolds Number, where l is a linear dimension (e.g., for a model airfoil 3 in. chord, 100 m.p.h. normal pressure at 15° C., the corresponding number is 234,000; or for a model of 10 cm chord, 40 m.p.s., the corresponding number is 274,000)

C_p, Center-of-pressure coefficient (ratio of distance of c.p. from leading edge to chord length)

α, Angle of attack

ϵ, Angle of downwash

α_0, Angle of attack, infinite aspect ratio

α_i, Angle of attack, induced

α_a, Angle of attack, absolute (measured from zero-lift position)

γ, Flight-path angle

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By EASTMAN N. JACOBS and IRA H. ABBOTT

Langley Memorial Aeronautical Laboratory

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

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AIRFOIL SECTION DATA OBTAINED IN THE N. A. C. A. VARIABLE-DENSITY TUNNEL AS AFFECTED BY SUPPORT INTERFERENCE AND OTHER CORRECTIONS

By Eastman N. Jacobs and Ira H. Abbott

SUMMARY

The results of an investigation of the effect of support interference on airfoil drag data obtained in the variable-density tunnel are presented. As a result of the support interference, previously published airfoil data from the variable-density tunnel have shown too large drag coefficients and too large a rate of increase of drag coefficient with airfoil thickness. The practical effect of the corrections on the choice of the optimum section is briefly considered and corrected data for a selected list of airfoils are presented as a convenience to the designer. Methods of correcting published data for other airfoils are presented.

INTRODUCTION

Airfoil data obtained in the variable-density tunnel (reference 1) have been published (references 2 to 6) in forms that were considered at the time of publication to be most useful to the airplane designer. In the earlier publications (references 1 and 2) no corrections other than those for tunnel-wall effects and to infinite aspect ratio were applied to the data, and emphasis was placed on the pressing problem of obtaining good comparative data for judging the relative merits of airfoils rather than on obtaining absolute accuracy.

It was recognized that certain consistent errors were present in the data, but it was thought that the effect of these errors on the comparative value of the data was not of primary importance. Support-strut interference, for example, was considered to be a possible source of systematic error, but it was thought that this interference would not affect the order of merit of the airfoils tested except possibly in the case of very sensitive airfoils, which might also be similarly affected by the wing-strut intersections of biplanes common at the time. The turbulence of the air stream was thought not seriously to impair the comparative value of the data and, perhaps, even to be desirable, because the extensive turbulent boundary layers occurring on the models in the tunnel as a result of the turbulence would also be found in practice at high values of the Reynolds Number on conventional airfoils with the usual moderately rough surfaces. It was also considered that errors arising from failure of the conventional airfoil theory to predict section characteristics accurately from the model tests would largely disappear when the data so derived were used to predict the characteristics of wings approximating the same plan form and aspect ratio as the models.

The absolute accuracy of the data was, however, improved from time to time by the investigation of consistent errors. An attempt to evaluate the effect of support interference on the measured drag coefficients was inconclusive (reference 4) and no corrections were applied. The data were further improved by the application of corrections for turbulence and for improvement of the approximations to section characteristics. The corrected coefficients were designated by lower-case symbols, such as c_{d_0}, as contrasted to the older C_{D_0}. One of the chief effects of these corrections was to reduce the profile-drag coefficients, particularly for the thicker airfoils.

As airfoil data at large values of the Reynolds Number became available from the N. A. C. A. full-scale tunnel (reference 7) and from foreign sources (references 8 to 13), even the corrected profile-drag coefficients obtained in the variable-density tunnel appeared to be too large. The discrepancy increased with airfoil thickness. The important practical effect is that the data from the variable-density tunnel apparently showed too large a variation of drag coefficient with airfoil thickness. Correct information regarding this variation may be of primary importance to the airplane designer in choosing the optimum airfoil sections for actual wings.

Further investigations of this subject were undertaken, one of the most important being an investigation of three symmetrical sections, N. A. C. A. 0009, 0012, and 0018, under conditions of low turbulence in the N. A. C. A. full-scale tunnel. Results from this investigation (references 14 and 15) indicate a smaller increase in drag with airfoil thickness than is indicated by the results from the N. A. C. A. variable-density tunnel. Furthermore, comparative tests were made in the two tunnels by applying strings to the surface of the N. A. C. A. 0012 airfoil to move the transition point to a predetermined position. These tests indicated that, for this airfoil, the discrepancies were too large to be ascribed to failure of the effective Reynolds Number concept to correct approximately for the drag as affected by transition.

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Another correction, however, was suggested by the investigation in the full-scale tunnel. Differences between the results from force and momentum methods of measurement suggested the presence of increments of support-interference drag that increased with section thickness. Further tests, made with additional dummy supports, verified the presence of this type of support interference in the full-scale tunnel. Tests were therefore started in the variable-density tunnel to investigate any variation of support interference with airfoil thickness, in spite of the fact that previous investigations (see appendix of reference 4) had shown no definite corrections for two airfoils, the N. A. C. A. 0012 and 4412. Improvements of the balance of the variable-density tunnel were expected to enable greater accuracy than was obtainable from the previous balance arrangement. The results of this investigation indicate that marked increments of support-interference drag, easily measurable, are present in the drag results from the variable-density tunnel, the increment increasing with airfoil thickness.

The purpose of this report is to present the corrections for application to published results from the variable-density tunnel to give more reliable values of section profile-drag coefficient for airfoils of various thicknesses. The practical effect of the corrections on the choice of the optimum section is briefly considered. Comparison is made between some corrected drag data from the variable-density tunnel and from other sources to show the extent of the existing agreement. Corrected data for a selected list of airfoils are also presented as a convenience to the designer.

METHOD

The standard method of testing in the variable-density tunnel, the model supports, and the method of determining the tare forces are described in reference 1. The usual tare tests determine the tare forces on the supports including the interference of the model on the supports. The conventional method of determining the balance-alinement correction by testing a symmetrical airfoil through positive and negative angles of attack determines the effects of balance and air-stream misalinement and any interference of the supports on the model that is equivalent to a change in air-flow direction.

The method selected for investigating the additional interference of the supports on the model was the same as that described in the appendix of reference 4. Tests were made of each airfoil supported by three different methods. Besides the method of using the usual support struts, tests were made with the models mounted on the usual supports with the addition of special supports and with the models mounted only on the special supports. The special supports consisted of three wires attached to the quarter-chord point of the model at each wing tip and of a sting and an angle-of-attack

strut so located as to be as free as possible from aerodynamic interference with the regular supports. The sting was symmetrical with respect to the airfoil and was attached near the trailing edge instead of to the lower surface, as usual.

The tares due to the special supports were determined from data obtained from the tests with the models on the regular supports with and without the special supports. These tares were then applied to the data obtained with the model on the special supports alone; the results were then compared with the data obtained in the customary manner to determine the unevaluated interference caused by the usual supports. This method does not eliminate balance deflections arising from sources other than aerodynamic forces on the model and the supports. A test was accordingly made with no model nor supports in the tunnel; the result showed that no such balance deflections were present.

The scope of the present investigation was limited to the study of the profile drag at low and moderate lift coefficients at the highest value of the test Reynolds Number ordinarily obtained (about 3,000,000). Tests were made of the N. A. C. A. 0012, 0018, 0025, 0030, and 0040 symmetrical airfoils to study the variation of support interference with airfoil thickness. The N. A. C. A. 43012, 43018, and 8318 airfoils were also tested to obtain an indication of the variation of support interference with camber.

RESULTS AND DISCUSSION

MINIMUM PROFILE-DRAG COEFFICIENTS

The effect of the support interference on the measured section minimum profile-drag coefficients is shown in figure 1. The increment of the minimum profile-drag coefficients caused by the support interference is plotted against airfoil thickness for the five symmetrical and the three cambered airfoils tested. The points for the five symmetrical airfoils lie on a fair curve passing through zero at zero airfoil thickness, the scatter of the points being small when consideration is taken of the difficulties involved in these tests. The points obtained for the N. A. C. A. 43012 and 43018 airfoils fall close to but on opposite sides of the curve for the symmetrical airfoils. The camber of these airfoils (4 percent) is about the upper limit of camber for the commonly used airfoils. The point obtained for the N. A. C. A. 8318 airfoil falls 0.0007 above the curve and would seem to indicate an increase in support interference for highly cambered airfoils. In this case, however, the point for the N. A. C. A. 43018 airfoil would be expected to fall between those for the N. A. C. A. 8318 and 0018 airfoils; whereas it falls slightly below that for the symmetrical airfoil. Inasmuch as each point was obtained from the results of three tests, two of which (those with the wire supports) were made with very large tare forces, the displacement of the point for the

N. A. C. A. 8318 airfoil from the fair curve is only of the order of the possible experimental error.

The shape of the curve of figure 1 suggests that the interference may be largely of the nature of a buoyancy effect, in which case the interference should be primarily a function of airfoil thickness; and other factors, such as camber, should ordinarily be minor variables. Accordingly, because the present tests fail to show significant variations with camber and because it is not considered practicable to make such tests for a large number of airfoils, the values obtained from the faired curve of figure 1 will ordinarily be used to correct the measured minimum profile-drag coefficients. These values are thought to represent the correction with sufficient accuracy for most applications of commonly
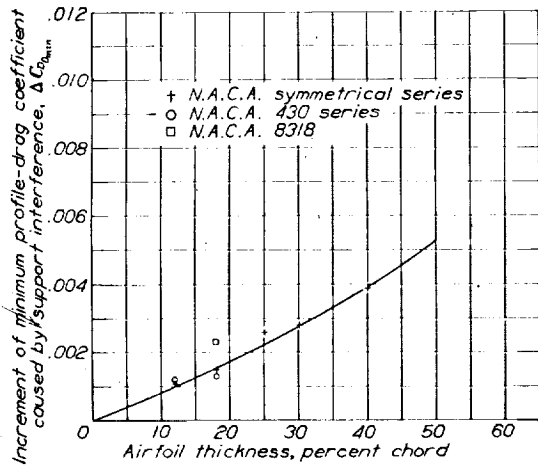
FIGURE 1.—Variation with airfoil thickness of the increment of minimum profile-drag coefficient caused by support interference for the N. A. C. A. variable-density tunnel.

used airfoils. The applicability of these values to data obtained at other values of the Reynolds Number is more doubtful, but such application appears to offer the best approximation possible at this time and, accordingly, will be made.

The corrected minimum profile-drag coefficients for the symmetrical airfoils from 9 to 25 percent thick are given in table I. The second column of this table gives the C_{D_0} values originally published in reference 2. The third column gives the c_{d_0} values taken from reference 5, except for the N. A. C. A. 0025. Some of these c_{d_0} values were obtained by correcting the C_{D_0} values for the drag increment (0.0011) to correct to the effective Reynolds Number and for the tip-drag increment (reference 4). The rest of the c_{d_0} values are from the results of more recent measurements similarly corrected. The fourth column gives the support-interference increments taken from the curve of figure 1. The finally corrected c_{d_0} values of the fifth column were obtained from the third column by correcting the data, according to the procedure suggested

in the appendix (equation (1)), for the support interference and for the revised correction for the effective Reynolds Number. Corresponding values obtained from the support-interference tests are presented in the sixth column. The principal result is presented in the last column and represents the difference in minimum profile-drag coefficients between the data published in references 4 to 6 and those presented herein. Other published data may be corrected by the methods presented in the appendix.

TABLE I

DATA ON CORRECTION OF MINIMUM DRAG OF SYMMETRICAL AIRFOILS

[Effective Reynolds Number, approximately 8,000,000]

N. A. C. A. airfoil	C_{D_0} (reference 2)	c_{d_0} (reference 5)	Support interference (fig. 1)	c_{d_0} (corrected)	c_{d_0} (from support-interference tests)	Correction increments [a]
0006	0.0065	0.0054	0.0005	0.0051	......	0.0003
0009	.0074	.0064	.0007	.0058	......	.0006
0012	.0083	.0069	.0010	.0060	0.0060	.0009
0015	.0093	.0077	.6013	.0064	......	.0013
0018	.0108	.0088	.0016	.0071	.0073	.0017
0021	.0120	.0100	.0018	.0079	......	.0021
0025	.0143	b .0119	.0022	.0092	.0091	.0027

[a] Correction increments are sums of increments resulting from support-interference correction and change in method of correcting for effective Reynolds Number.
[b] Reference 6.
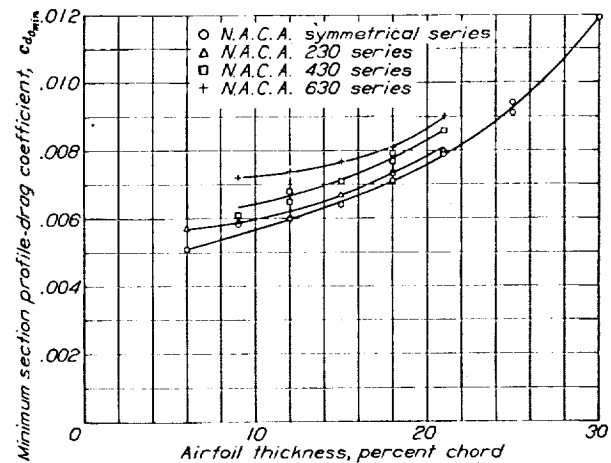
FIGURE 2.—Variation of minimum profile-drag coefficient with airfoil thickness. Effective Reynolds Number, 8,200,000.

The application of these corrections results in a greatly decreased variation of drag with airfoil thickness. This variation is shown for the N. A. C. A. symmetrical, 230, 430, and 630 series airfoils in figure 2, which may be considered a correction of figure 53 of reference 5. It is evident that the smaller increase in drag with section thickness will affect the choice of wing sections. The best simple criterion for the selection of wing sections being considered the speed-range index $c_{l_{max}}/c_{d_{0_{min}}}$, figure 3 has been prepared from the corrected data of figure 2 to be used in connection with

figure 61 of reference 5 to study the effect of the correction on the thickness of the optimum section. The result of the comparison is shown in table II.

TABLE II

EFFECT OF SUPPORT-INTERFERENCE CORRECTION ON OPTIMUM AIRFOIL THICKNESS

N. A. C. A. airfoils	Thickness of section for highest $c_{l_{max}}/c_{d_{0_{min}}}$ (percent chord)	
	From reference 5	Corrected results (fig. 3)
Symmetrical series	11. 5	12
230 series	9. 5	10
430 series	10	10. 5
230 series with 0.2c split flap	11	12. 5

The change in optimum thickness is evidently small for airfoils without flaps. The losses associated with an airfoil that exceeds the optimum thickness, however,
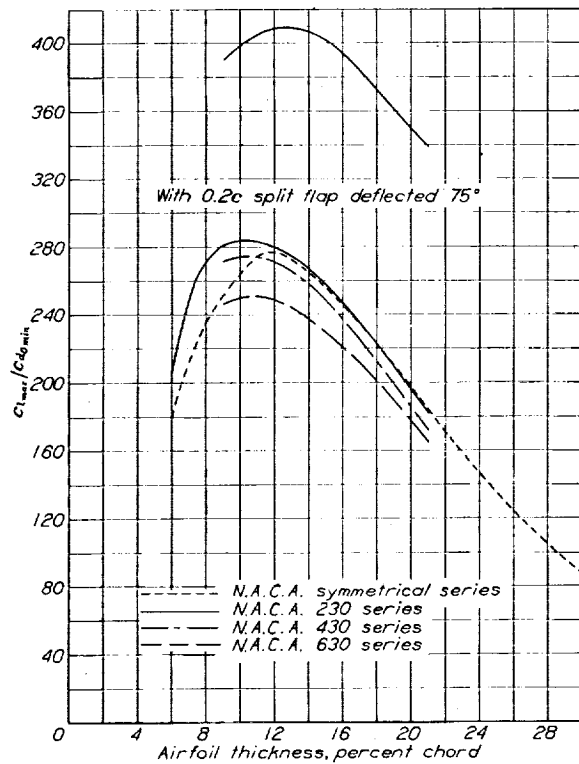
FIGURE 3.—Variation of $c_{l_{max}}/c_{d_{0_{min}}}$ with airfoil thickness.

become less marked so that a compromise airfoil will tend to be thicker by a greater amount than is indicated by table II. This conclusion is particularly significant when full advantage can be taken of the fact that the maximum-lift increment produced by a high-lift device may increase with section thickness. The upper curve

of figure 3 indicates that the optimum thickness for the 230 series may then increase to 12.5 or 13 percent and that the aerodynamic loss associated with thicker sections is considerably smaller than previously indicated.
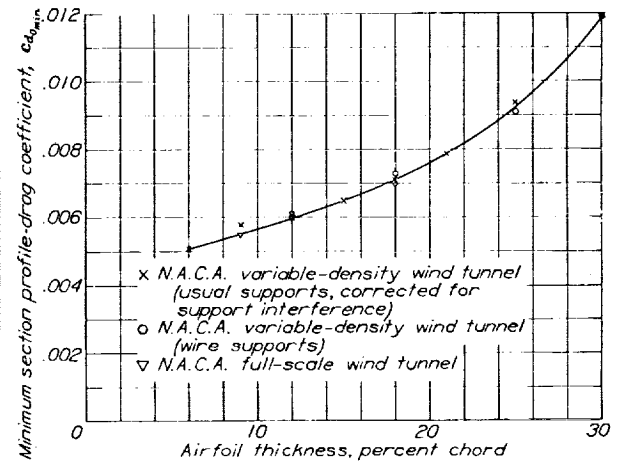
FIGURE 4.—Variation of minimum profile-drag coefficient with thickness for N. A. C. A. symmetrical airfoils. Effective Reynolds Number, 8,200,000.

Comparison of the corrected data from the variable-density tunnel with the available comparable data from other wind tunnels indicates a generally improved agreement. The close agreement obtained for the
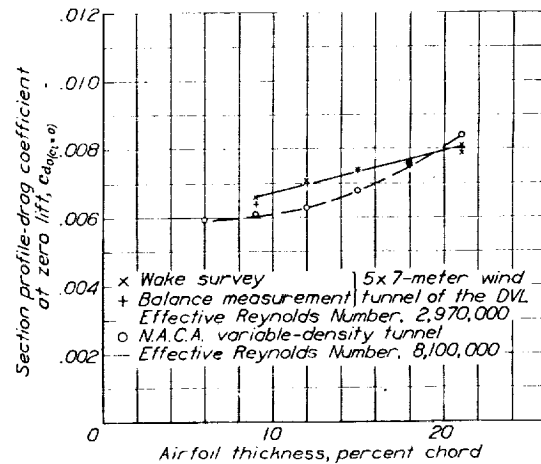
FIGURE 5.—Variation of profile-drag coefficient with thickness for N. A. C. A. 24 series airfoils.

N. A. C. A. 0009, 0012, and 0018 airfoils in the N. A. C. A. variable-density and full-scale tunnels (reference 14) is shown in figure 4.

Figure 5 shows a comparison between the profile-drag coefficients at zero lift for the N. A. C. A. 24 series airfoils as obtained in the variable-density tunnel and in the 5- by 7-meter tunnel of the DVL. The data were not obtained at the same value of the Reynolds Number, but the application of the correction to the

data from the variable-density tunnel has reduced the discrepancies.

Comparisons of minimum profile drag are made for the N. A. C. A. symmetrical series airfoils in figures 6 to 9; comparisons of profile-drag coefficients at zero lift are made for the N. A. C. A. 24 series airfoils in figure 10. In all cases, the data have been corrected to the proper effective Reynolds Number and for tip effects when necessary to make these data comparable with those from the variable-density tunnel. The agreement of the data for the N. A. C. A. 0009, 0012, and

FIGURE 6.—Minimum profile-drag coefficients of N. A. C. A. 0009 airfoil as measured in the N. A. C. A. variable-density and full-scale tunnels.

FIGURE 7.—Minimum profile-drag coefficients of the N. A. C. A. 0012 airfoil as measured in several wind tunnels.

0018 airfoils as obtained in the variable-density and the full-scale tunnels is seen to be generally satisfactory. The agreement of the data for the N. A. C. A. 0012 airfoil (fig. 7) as obtained in the variable-density tunnel and in the British compressed-air tunnel (references 12 and 13) cannot be considered satisfactory. In particular, the results from the compressed-air tunnel do not indicate a decrease of the minimum profile-drag coefficient with increasing Reynolds Numbers at the higher Reynolds Numbers. The agreement of the data obtained in the variable-density and the compressed-air tunnels (reference 12) for the N. A. C. A.

0025 airfoil (fig. 9) is satisfactory. In the case of the N. A. C. A. 24 series airfoils (fig. 10), the chief discrepancy between the data from the variable-density tunnel and those from the 5- by 7-meter tunnel of the DVL (reference 11) is that the data from the DVL tunnel show a smaller rate of drag decrease with increasing Reynolds Number.

These discrepancies in the rate of decrease of the drag with increasing Reynolds Numbers as shown for the N. A. C. A. 0012 airfoil in figure 7 and for the N. A. C. A. 24 series airfoils in figure 10 are particularly important because, for large airplanes, the drag data must be extrapolated. The differences in the data are such as to cast some doubt on the applicability of the recommended extrapolation formula (reference 4), although no better formula can be suggested at this time. The need for additional data obtained at large Reynolds Numbers in tunnels of low turbulence is obvious.

FIGURE 8.—Minimum profile-drag coefficients of the N. A. C. A. 0018 airfoil as measured in the N. A. C. A. variable-density and full-scale tunnels.
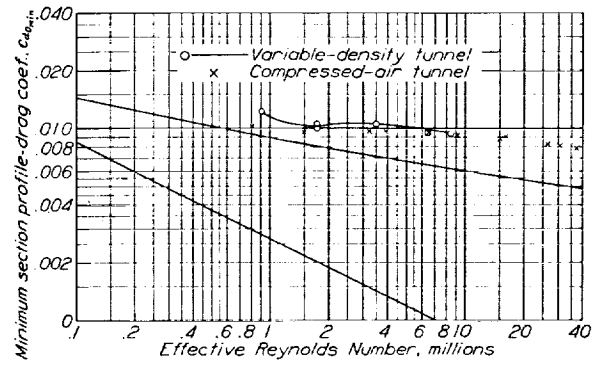
FIGURE 9.—Minimum profile-drag coefficients of the N. A. C. A. 0025 airfoil as measured in the N. A. C. A. variable-density tunnel and in the British compressed-air tunnel.

VARIATION OF SECTION PROFILE-DRAG COEFFICIENT WITH LIFT COEFFICIENT

Curves of section profile-drag coefficient plotted against section lift coefficient with the model mounted on the wire supports and on the usual supports are presented in figures 11 to 17 for seven of the airfoils tested. The data obtained with the models on the
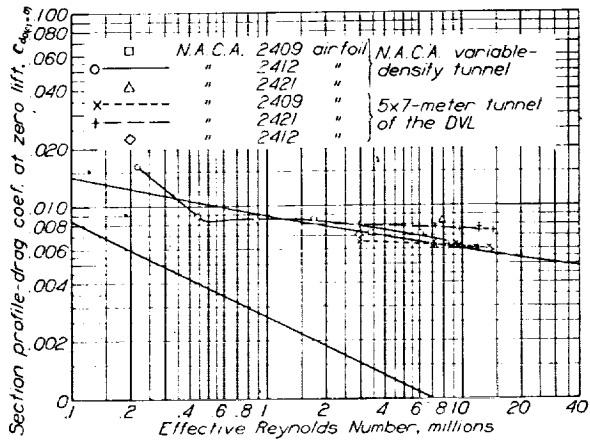
FIGURE 10.—Profile-drag coefficient of N. A. C. A. 24 series airfoils as measured at zero lift in the N. A. C. A. variable-density tunnel and in the 5- by 7-meter tunnel of the DVL.

FIGURE 12.—Variation of profile-drag coefficient with lift coefficient. N. A. C. A. 0018 airfoil. Effective Reynolds Number, 8,200,000.

FIGURE 11.—Variation of profile-drag coefficient with lift coefficient. N. A. C. A. 0012 airfoil. Effective Reynolds Number, 8,200,000.
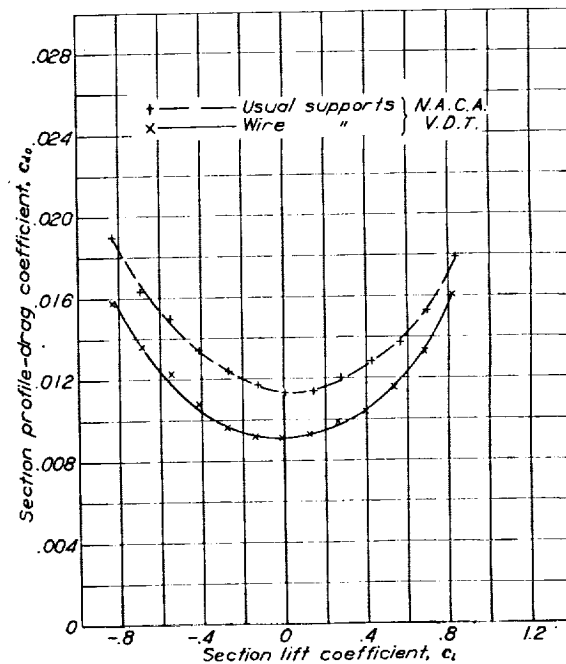
FIGURE 13.—Variation of profile-drag coefficient with lift coefficient. N. A. C. A. 0025 airfoil. Effective Reynolds Number, 8,200,000.

wire supports include all corrections and represent the best available approximation to the actual airfoil section characteristics. The two curves of each figure are comparable except for the presence of support interference in the data obtained with the model on the usual supports. The displacement between the two curves of each figure thus represents the support interference.

The data of figures 11 through 17 show a tendency for the support interference to decrease with increasing lift coefficients, this tendency being more marked for the cambered than for the symmetrical airfoils. This variation, however, is not consistent. The determination of the profile-drag coefficient at other than small lift coefficients from the support-interference tests was complicated by the fact that the air-stream direction at the airfoil was apparently dependent upon the support system used, necessitating the determination of the balance and the air-stream alinement from the tests of the symmetrical airfoils. The data obtained were thought not to justify the application of a varying correction to the profile drag, and it was decided to apply the support-interference correction for the minimum profile-drag coefficient to all measured profile-drag coefficients.

The effect of applying this constant correction may be to indicate an optimum lift coefficient that is somewhat too high and to reduce the profile-drag coefficients at high positive lift coefficients more than is generally justified by these tests. Moreover, the effect of applying a proportional correction instead of a constant increment to the profile-drag coefficients to correct them
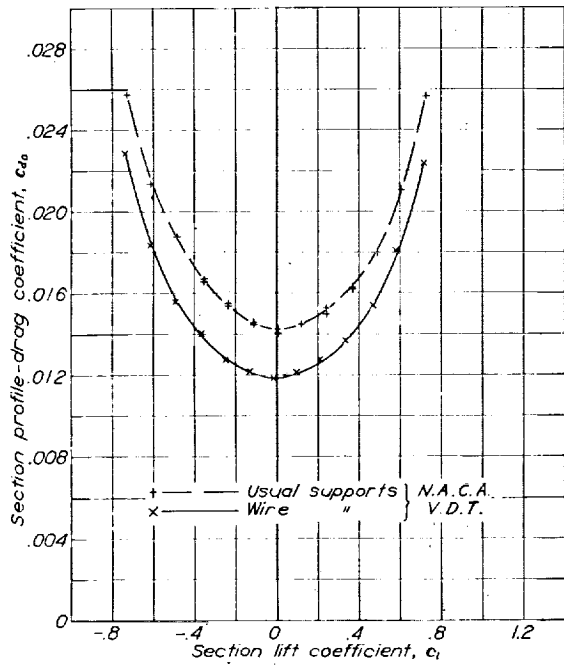
FIGURE 14.—Variation of profile-drag coefficient with lift coefficient. N. A. C. A. 0030 airfoil. Effective Reynolds Number, 8,200,000.
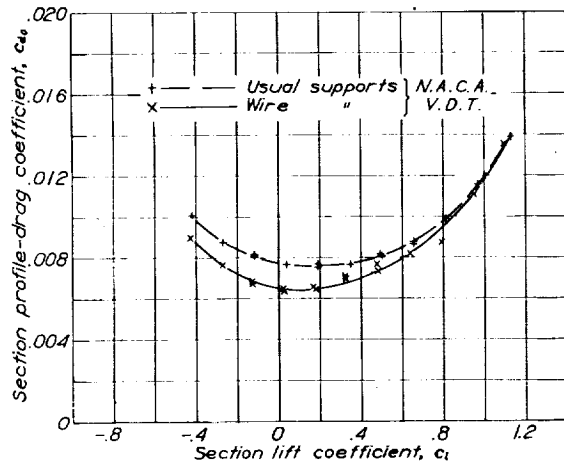
FIGURE 15.—Variation of profile-drag coefficient with lift coefficient. N. A. C. A. 43012 airfoil. Effective Reynolds Number, 8,200,000.

FIGURE 16.—Variation of profile-drag coefficient with lift coefficient. N. A. C. A. 43018 airfoil. Effective Reynolds Number, 8,200,000.
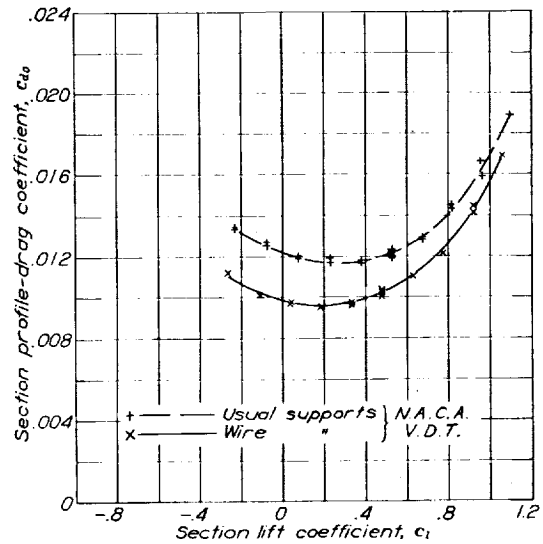
FIGURE 17.—Variation of profile-drag coefficient with lift coefficient. N. A. C. A. 8318 airfoil. Effective Reynolds Number, 8,200,000.

to the effective Reynolds Number is to reduce still further the profile-drag coefficients at large lift coefficients. Figure 11 shows a curve of profile-drag coefficients for the N. A. C. A. 0012 airfoil as obtained from wake surveys in the full-scale tunnel (reference 15) and corrected to the effective Reynolds Number to be comparable with the variable-density-tunnel data. It will be seen that the profile-drag coefficients as obtained in the full-scale tunnel at the higher lift coefficients are lower than those obtained in the variable-density tunnel, indicating that the application of a constant support-interference correction probably does not result in too low profile-drag coefficients at moderate lift coefficients.

DATA FOR COMMONLY USED AIRFOILS

As a convenience to designers, corrected data for a number of commonly used airfoils are presented in figures 18 to 59 and in table III. The left-hand side of each figure presents the data for rectangular airfoils corrected to an aspect ratio of 6 in free air but uncorrected for turbulence effects. The right-hand side of each figure presents the best approximation to the section characteristics, which are corrected as summarized in the appendix. These data supersede previous data published for these airfoils and are recommended for design use until more reliable data are available.

CONCLUDING REMARKS

An investigation of the effect of support interference on airfoil drag data from the N. A. C. A. variable-density tunnel showed the presence in these data of large support-interference increments, increasing with airfoil thickness. The effects of these increments were to make airfoil drag data from the variable-density tunnel appear high and to show too large a rate of drag increase with airfoil thickness. These increments have been evaluated and the corrected data are recommended for immediate use. A large amount of recent data, however, has suggested that these, or other corrections, to airfoil data obtained in the variable-density tunnel will not produce ultimately satisfactory results. It is planned, therefore, to obtain further airfoil section data under test conditions more favorable than those in the variable-density tunnel.

LANGLEY MEMORIAL AERONAUTICAL LABORATORY,
  NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS,
    LANGLEY FIELD, VA., *February 13, 1939.*

Sta.	Up'r	L'w'r
0	3.50	3.50
1.25	5.45	1.93
2.5	6.50	1.47
5.0	7.90	.93
7.5	8.85	.63
10	9.60	.42
15	10.68	.15
20	11.36	.03
30	11.70	0
40	11.40	
50	10.52	
60	9.15	
70	7.35	
80	5.22	
90	2.80	
95	1.49	
100	.12	0
L.E.Rad.: 1.50		

Airfoil: Clark Y   R: 3,170,000
Size: 5"x30"   Vel. (ft/sec.): 68.4
Press. (st'nd. atm.): 21.1
Corrected for tunnel-wall effect

Where tested. L.M.A.L.   V.D.T. 525
R_e: 8,370,000   Date: 3-19-31
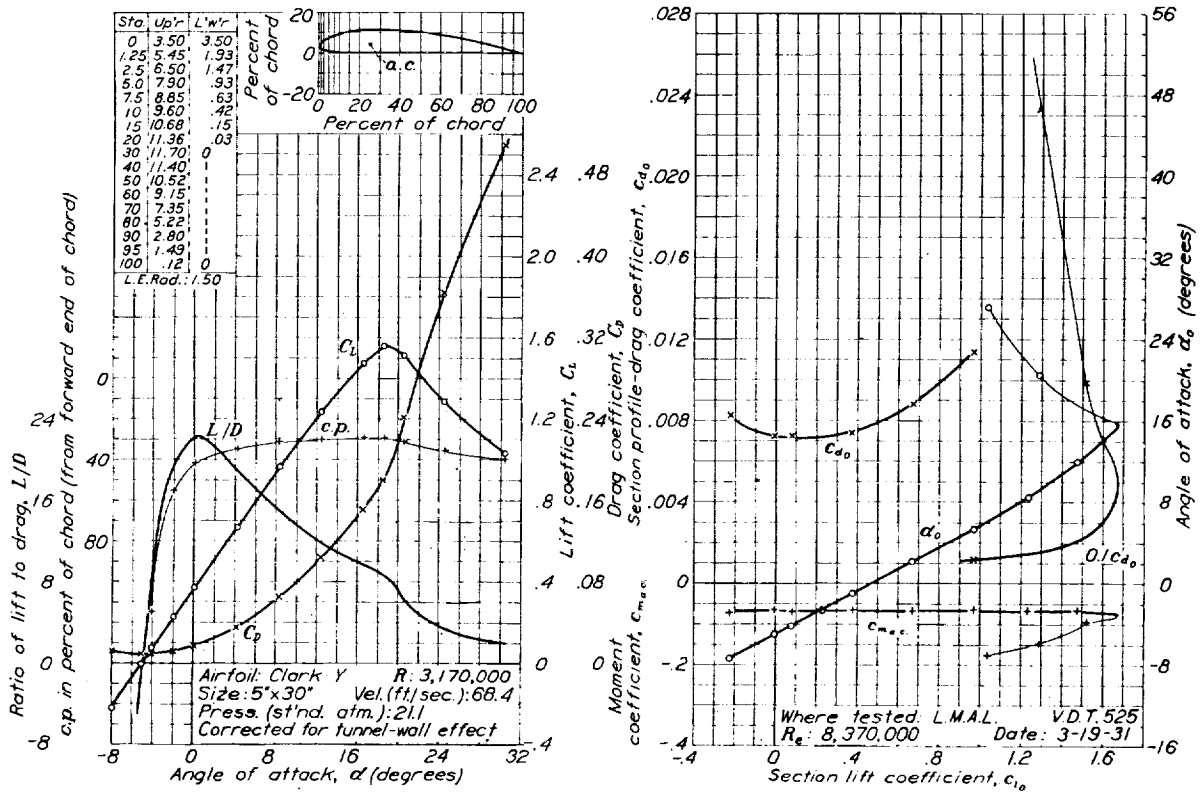
FIGURE 18.—Clark Y airfoil.

Sta.	Up'r	L'w'r
0	3.50	3.50
1.25	5.95	1.43
2.5	7.21	.76
5.0	8.88	-.05
7.5	10.01	-.53
10	10.89	-.87
15	12.17	-1.34
20	12.96	-1.56
30	13.35	-1.65
40	13.01	-1.61
50	12.00	-1.48
60	10.44	-1.29
70	8.39	-1.04
80	5.95	-.74
90	3.20	-.40
95	1.70	-.21
100	.14	-.02

Airfoil: Clark YM-15 R: 3,170,000
Size: 5"x30"   Vel. (ft/sec.): 68.3
Press. (st'nd. atm.): 21.3
Corrected for tunnel-wall effect

Where tested: L.M.A.L.   V.D.T. 700
R_e: 8,370,000   Date: 10-14-31
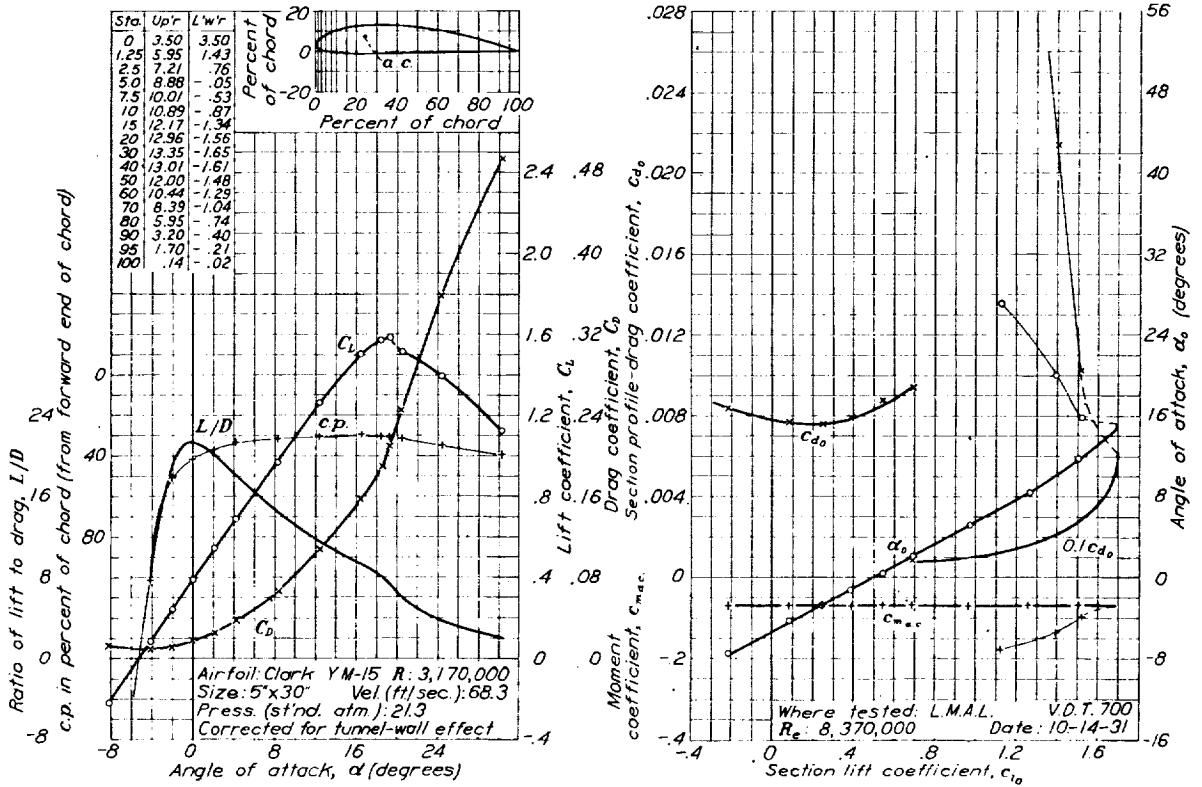
FIGURE 19.—Clark YM-15 airfoil.

Sta.	Up'r	L'w'r
0	3.50	3.50
1.25	6.40	.98
2.5	7.86	.11
5.0	9.78	-.94
7.5	11.06	-1.58
10	12.07	-2.05
15	13.52	-2.63
20	14.41	-3.02
30	14.85	-3.15
40	14.47	-3.07
50	13.35	-2.83
60	11.61	-2.46
70	9.33	-1.98
80	6.62	-1.40
90	3.56	-.75
95	1.90	-.40
100	.15	-.03

Airfoil: Clark YM-18 R: 3,120,000
Size: 5"x30" Vel.(ft./sec.) 69.0
Press.(st'nd): 21.1
Corrected for tunnel-wall effect

Where tested: L.M.A.L. V.D.T. 701
R_e: 8,240,000 Date: 10-15-31
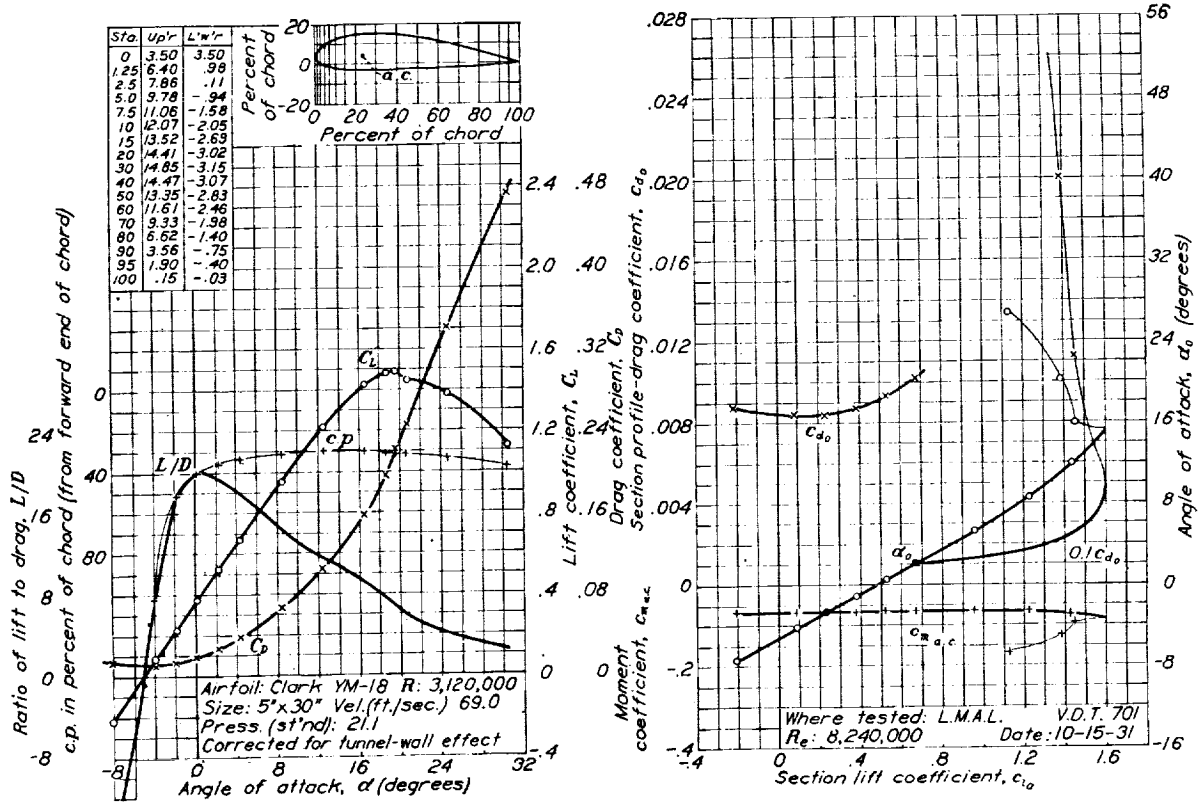
FIGURE 20.—Clark YM-18 airfoil.

Sta.	Up'r	L'w'r
0	3.49	3.49
1.25	5.55	1.92
2.5	6.51	1.47
5.0	7.89	.93
7.5	8.85	.64
10	9.60	.43
15	10.63	.16
20	11.36	.03
30	11.73	.00
40	11.41	.21
50	10.53	.59
60	9.15	.85
70	7.36	.91
80	5.23	.72
90	2.80	.40
95	1.52	.21
100	.10	0

L.E.Rad.: 1.40

Airfoil: C-72 R: 3,020,000
Size: 5"x30" Vel.(ft./sec.):69.9
Press.(st'nd. atm.): 21.0
Corrected for tunnel-wall effect

Where tested: L.M.A.L. V.D.T. 529
R_e: 7,970,000 Date: 3-20-31
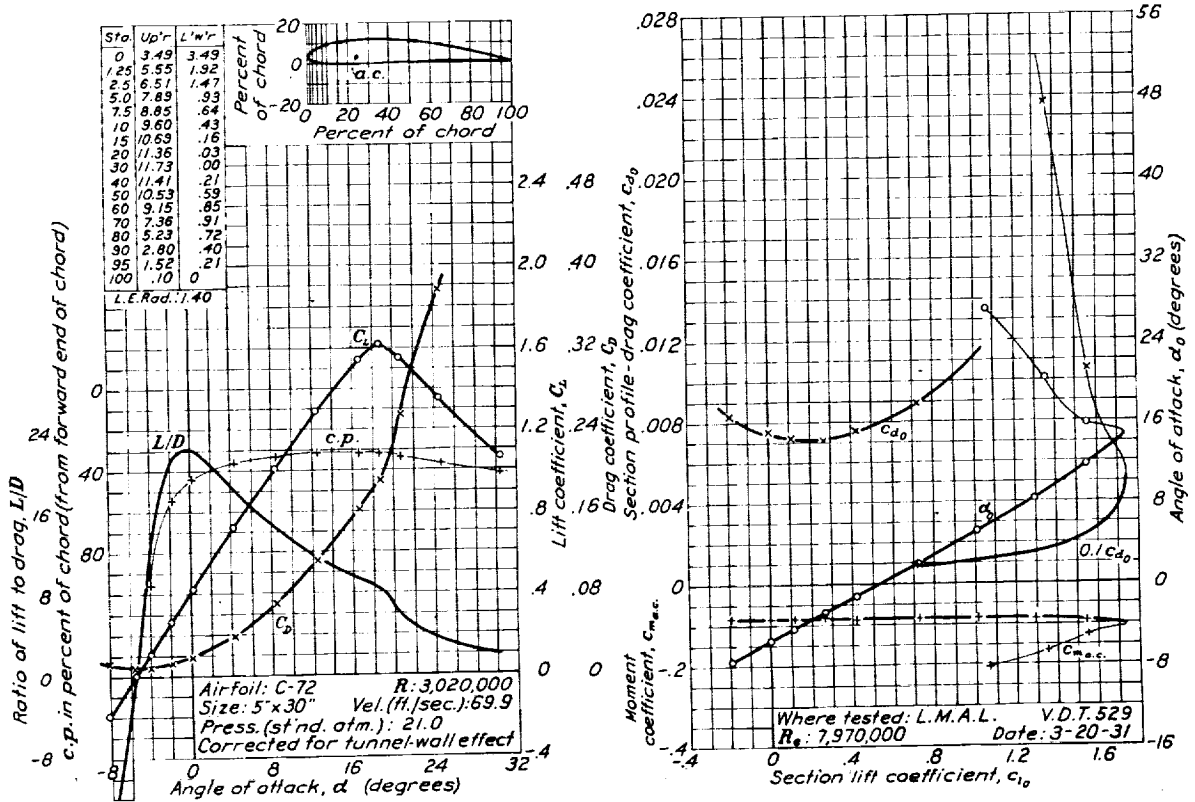
FIGURE 21.—Curtiss C-72 airfoil.

Sta.	Up'r	L'w'r
0	3.20	3.20
1.25	6.25	1.50
2.5	7.65	1.05
5.0	9.50	.55
7.5	10.85	.25
10	11.95	.10
15	13.40	.00
20	14.40	.00
30	15.05	.20
40	14.60	.40
50	13.35	.45
60	11.35	.50
70	8.90	.45
80	6.15	.30
90	3.25	.15
95	1.75	.05
100	.15	0

Göttingen 387   R: 3,180,000
Size: 5"x30"   Vel.(ft/sec.):68.5
Press.(st'nd. atm.): 21.0
Corrected for tunnel-wall effect

Where tested: L.M.A.L.   V.D.T.829
Re: 8,400,000   Date: 4-25-32
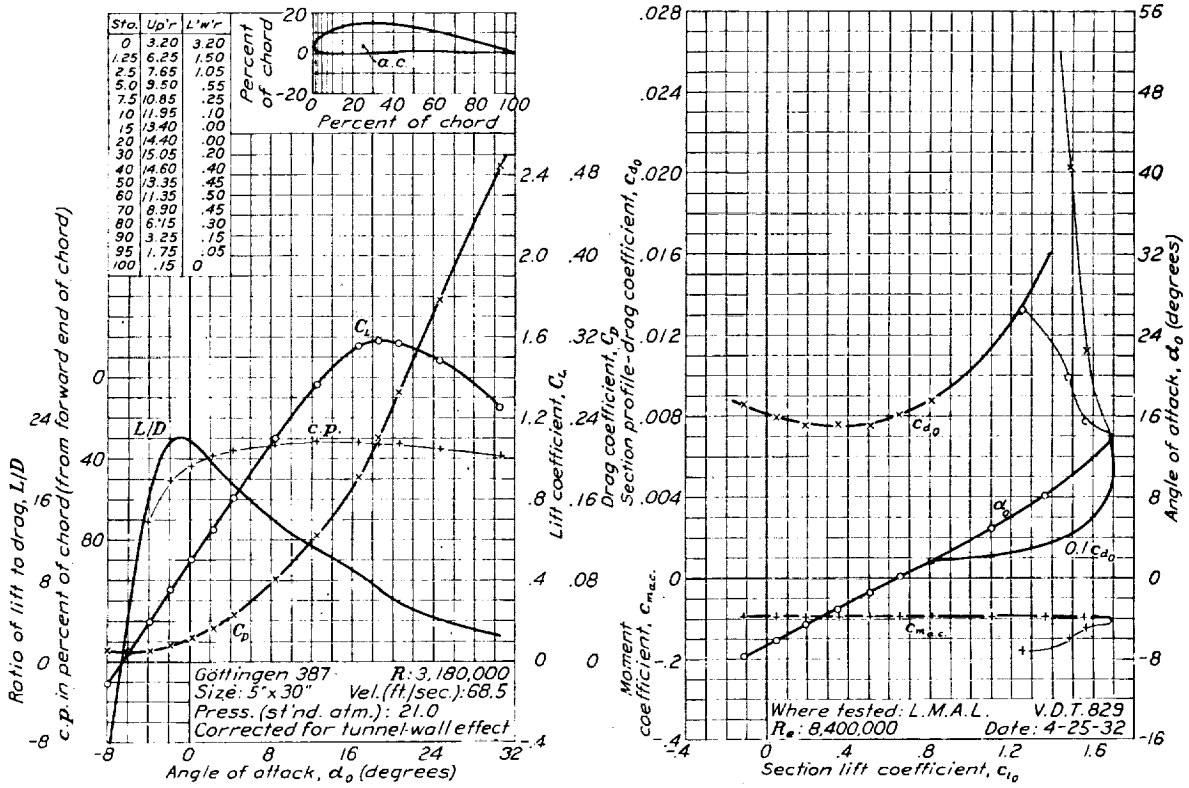
FIGURE 22.—Göttingen 387 airfoil.

Sta.	Up'r	L'w'r
0	3.74	3.74
1.25	6.20	1.89
2.5	7.40	1.28
5.0	9.17	.69
7.5	10.37	.35
10	11.25	.18
15	12.53	.03
20	13.34	.00
30	13.80	.05
40	13.34	.17
50	12.27	.27
60	10.63	.33
70	8.53	.35
80	6.12	.27
90	3.40	.13
95	1.92	.06
100	.40	0

Göttingen 398   R: 3,070,000
Size: 5"x30"   Vel.(ft/sec.): 70.1
Press.(st'nd. atm.): 20.4
Corrected for tunnel-wall effect

Where tested: L.M.A.L.   V.D.T. 524
Re: 8,100,000   Date: 3-18-31
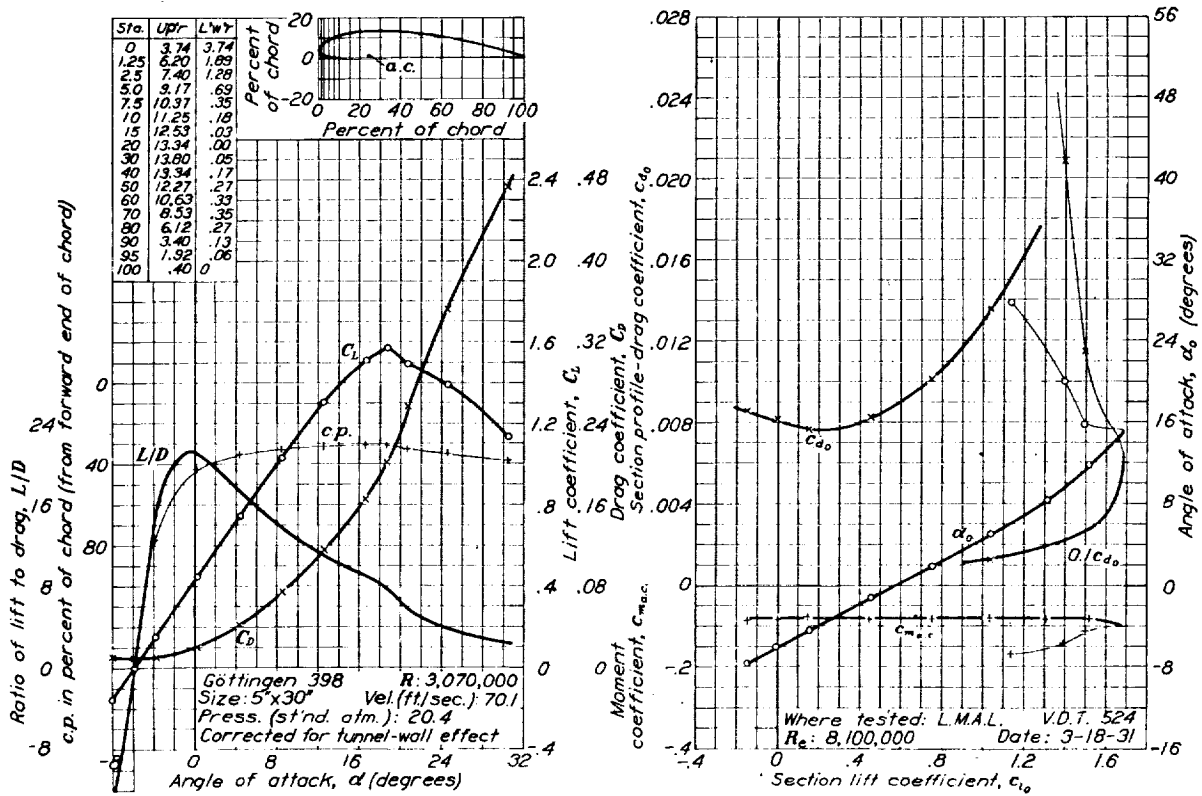
FIGURE 23.—Göttingen 398 airfoil.

Sta	Up'r	L'w'r
0	3.37	3.37
1.25	5.58	1.70
2.5	6.66	1.15
5.0	8.25	.62
7.5	9.33	.32
10	10.13	.16
15	11.28	.03
20	12.01	.00
30	12.42	.05
40	12.01	.15
50	11.04	.24
60	9.57	.30
70	7.68	.32
80	5.51	.24
90	3.06	.12
95	1.73	.05
100	.40	0

Airfoil: N-22   R: 3,070,000
Size: 5"x30" Vel.(ft./sec.): 70.0
Press.(st'nd.atm.):20.5
Corrected for tunnel-wall effect

Where tested: L.M.A.L.   V.D.T. 542
R_e: 8,100,000   Date: 3-28-31

FIGURE 24.—N-22 airfoil.

Sta	Up'r	L'w'r
0	3.50	3.50
1.25	5.45	1.93
2.5	6.50	1.47
5.0	7.90	.93
7.5	8.85	.63
10	9.60	.42
15	10.68	.15
20	11.35	.03
30	11.70	.00
40	11.40	.00
50	10.52	.00
60	9.15	.06
70	7.41	.38
80	5.62	.38
90	3.84	1.02
95	2.93	1.40
100	2.05	1.85
L.E.Rad.: 1.50		

Airfoil: N.A.C.A. CYH   R: 3,050,000
Size: 5"x30"   Vel.(ft/sec.): 69.5
Press.(st'nd. atm.): 21.1
Corrected for tunnel-wall effect

Where tested: L.M.A.L.   V.D.T. 536
R_e: 8,050,000   Date: 3-25-31

FIGURE 25.—N.A.C.A. CYH airfoil.

Sta.	Up'r	L'w'r
0	0	0
1.25	1.97	-1.76
2.5	2.81	-2.20
5.0	4.03	-2.73
7.5	4.94	-3.03
10	5.71	-3.24
15	6.82	-3.47
20	7.55	-3.62
25	8.01	-3.71
30	8.22	-3.79
40	8.05	-3.90
50	7.26	-3.94
60	6.03	-3.82
70	4.58	-3.48
80	3.06	-2.83
90	1.55	-1.77
95	.88	-1.08
100	.26	.26

Airfoil N.A.C.A.-M6   R: 3,030,000
Size:5"x30"   Vel.(ft/sec.):70.0
Press.(st'nd.atm.): 20.9
Corrected for tunnel-wall effect

Where tested: L.M.A.L. Test:V.D.T. 526
R_e: 8,000,000   Date: 3-19-31

FIGURE 26.—N. A. C. A.-M6 airfoil.

Sta.	Up'r	L'w'r
0	1.77	1.77
1.25	3.80	.50
2.5	5.07	.36
5.0	6.94	.19
7.5	8.22	.10
10	9.19	.02
15	10.50	.10
20	11.37	.36
30	11.97	.93
40	11.68	1.14
50	10.86	.75
60	9.54	.28
70	8.09	.06
80	6.10	.01
90	3.69	.12
95	2.26	.33
100	.67	.65

Airfoil: U.S.A.27   R: 3,050,000
Size:5"x30"   Vel.(ft/sec.):69.5
Press.(st'nd.atm.): 20.6
Corrected for tunnel-wall effect

Where tested: L.M.A.L.   V.D.T. 694
R_e: 8,050,000   Date: 10-8-31

FIGURE 27.—U. S. A. 27 airfoil.

Sta.	Up'r	L'w'r
0	4.39	4.33
1.25	8.09	1.62
2.5	9.54	1.00
5.0	11.81	.46
7.5	13.58	.22
10	14.85	.10
15	16.60	.00
20	17.73	.08
30	18.46	.24
40	17.89	.40
50	16.21	.58
60	13.89	.66
70	11.11	.60
80	7.88	.50
90	4.31	.32
95	2.39	.19
100	.43	0

Airfoil: U.S.A. 35-A   R: 3,190,000
Size: 5'x30"   Vel.(ft./sec.):68.4
Press.(st'nd. atm.): 20.8
Corrected for tunnel-wall effect

Where tested: L.M.A.L.   V.D.T. 769
R_e: 8,420,000   Date:3-2-32

FIGURE 28.—U. S. A. 35–A airfoil.

Sta.	Up'r	L'w'r
0	2.76	2.76
1.25	5.15	1.03
2.5	6.11	.63
5.0	7.52	.28
7.5	8.65	.14
10	9.45	.07
15	10.56	.00
20	11.28	.05
30	11.76	.15
40	11.42	.28
50	10.33	.39
60	8.81	.45
70	7.08	.42
80	5.02	.35
90	2.72	.20
95	1.50	.12
100	.25	0

Airfoil: U.S.A.35 B   R:3,150,000
Size: 5'x30"   Vel.(ft./sec.):69.1
Press.(st'nd. atm.): 20.8
Corrected for tunnel-wall effect

Where tested: L.M.A.L.   V.D.T.695
R_e:8,310,000   Date:10-9-31

FIGURE 29.—U. S. A. 35–B airfoil.

Sta.	Up'r	L'w'r
0	0	0
1.25	0.95	-0.95
2.5	1.31	-1.31
5.0	1.78	-1.78
7.5	2.10	-2.10
10	2.34	-2.34
15	2.67	-2.67
20	2.87	-2.87
25	2.97	-2.97
30	3.00	-3.00
40	2.90	-2.90
50	2.65	-2.65
60	2.28	-2.28
70	1.83	-1.83
80	1.31	-1.31
90	.72	-.72
95	.40	-.40
100	(.06)	(-.06)
100	0	0

L.E.Rad.: 0.40

Airfoil: N.A.C.A. 0006 R: 3,210,000
Size: 5"x30"   Vel.(ft./sec.): 68.5
Press.(st'nd.atm.): 20.8
Corrected for tunnel-wall effect

R_e 8,470,000

Where tested: L.M.A.L.   V.D.T. 744
R_e: 8,470,000   Date: 1-4-32

FIGURE 30.—N. A. C. A. 0006 airfoil.

Sta.	Up'r	L'w'r
0	0	0
1.25	1.42	-1.42
2.5	1.96	-1.96
5.0	2.67	-2.67
7.5	3.15	-3.15
10	3.51	-3.51
15	4.01	-4.01
20	4.30	-4.30
25	4.46	-4.46
30	4.50	-4.50
40	4.35	-4.35
50	3.97	-3.97
60	3.42	-3.42
70	2.75	-2.75
80	1.97	-1.97
90	1.09	-1.09
95	.60	-.60
100	(.10)	(-.10)
100	0	0

L.E.Rad.: 0.89

Airfoil: NACA 0009 R: 3,140,000
Size: 5"x30"   Vel.(ft./sec.): 69.6
Press.(st'nd.atm.): 20.2
Corrected for tunnel-wall effect

R_e 8,290,000 3,410,000

Where tested: L.M.A.L.   V.D.T. 1136
R_e: 8,290,000   Date: 5-19-34

FIGURE 31.—N. A. C. A. 0009 airfoil.

Sta.	Up'r	L'w'r
0	0	0
1.25	1.89	-1.89
2.5	2.62	-2.62
5.0	3.56	-3.56
7.5	4.20	-4.20
10	4.68	-4.68
15	5.34	-5.34
20	5.74	-5.74
25	5.94	-5.94
30	6.00	-6.00
40	5.80	-5.80
50	5.29	-5.29
60	4.56	-4.56
70	3.66	-3.66
80	2.62	-2.62
90	1.45	-1.45
95	.81	-.81
100	(.13)	(-.13)
100	0	0
L.E.Rad.: 1.58		

N.A.C.A. 0012   R: 3,170,000
Size: 5"x30"   Vel. (ft./sec.): 69.1
Press. (st'nd. atm.): 20.5
Corrected for tunnel-wall effect.

Where tested: L.M.A.L.   V.D.T. 1237
R_e: 8,370,000   Date: 3-8-35

FIGURE 32.—N. A. C. A. 0012 airfoil.

Sta.	Up'r	L'w'r
0	0	0
1.25	2.37	-2.37
2.5	3.27	-3.27
5.0	4.44	-4.44
7.5	5.25	-5.25
10	5.85	-5.85
15	6.68	-6.68
20	7.17	-7.17
25	7.43	-7.43
30	7.50	-7.50
40	7.25	-7.25
50	6.62	-6.62
60	5.70	-5.70
70	4.58	-4.58
80	3.28	-3.28
90	1.81	-1.81
95	1.01	-1.01
100	(.16)	(-.16)
100	0	0
L.E.Rad.: 2.48		

Airfoil: N.A.C.A. 0015   R: 3,260,000
Size: 5"x30"   Vel. (ft./sec.): 68.9
Press. (st'nd. atm.): 20.0
Corrected for tunnel-wall effect.

Where tested: L.M.A.L.   V.D.T. 1135
R_e: 8,610,000   Date: 5-17-34

FIGURE 33.—N. A. C. A. 0015 airfoil.

Sta.	Up'r	L'w'r
0	0	0
1.25	2.84	-2.84
2.5	3.92	-3.92
5.0	5.33	-5.33
7.5	6.30	-6.30
10	7.02	-7.02
15	8.02	-8.02
20	8.61	-8.61
25	8.91	-8.91
30	9.00	-9.00
40	8.70	-8.70
50	7.94	-7.94
60	6.84	-6.84
70	5.50	-5.50
80	3.94	-3.94
90	2.17	-2.17
95	1.21	-1.21
100	1.19	(-.19)
100	0	0

L.E. Rad.: 3.56

Airfoil: N.A.C.A. 0018   R: 2,970,000
Size: 5"x30"   Vel. (ft./sec.): 71.2
Press. (st'nd. atm.): 20.2
Corrected for tunnel-wall effect

Where tested: L.M.A.L.   V.D.T. 1161
Re: 7,840,000   Date: 8-8-34

FIGURE 34.—N. A. C. A. 0018 airfoil.

Sta.	Up'r	L'w'r
0	0	0
1.25	3.31	-3.31
2.5	4.58	-4.58
5.0	6.22	-6.22
7.5	7.35	-7.35
10	8.20	-8.20
15	9.35	-9.35
20	10.04	-10.04
25	10.40	-10.40
30	10.50	-10.50
40	10.16	-10.16
50	9.26	-9.26
60	7.99	-7.99
70	6.41	-6.41
80	4.59	-4.59
90	2.53	-2.53
95	1.41	-1.41
100	(.22)	(-.22)
100	0	0

L.E. Rad.: 4.85

Airfoil: N.A.C.A. 0021   R: 3,160,000
Size: 5"x30"   Vel.(ft./sec.): 68.9
Press. (st'nd. atm.): 20.8
Corrected for tunnel-wall effect

Where tested: L.M.A.L.   V.D.T. 748
Re: 8,340,000   Date: 1-7-32

FIGURE 35.—N. A. C. A. 0021 airfoil.

Sta.	Up'r	L'w'r
0	0	0
1.25	3.95	-3.95
2.5	5.45	-5.45
5.0	7.41	-7.41
7.5	8.75	-8.75
10	9.76	-9.76
15	11.14	-11.14
20	11.95	-11.95
25	12.38	-12.38
30	12.50	-12.50
40	12.09	-12.09
50	11.03	-11.03
60	9.51	-9.51
70	7.63	-7.63
80	5.46	-5.46
90	3.02	-3.02
95	1.68	-1.68
100	(.26)	(-.26)
100	0	0

L.E. Rad.: 6.88

Airfoil: N.A.C.A. 0025   R: 3,330,000
Size: 5"x30"   Vel.(ft./sec.): 67.3
Press.(st'nd. atm.): 21.0
Corrected for tunnel-wall effect

Where tested: L.M.A.L.   V.D.T. 1543
R_e: 8,790,000   Date: 10-1-37

FIGURE 36.—N. A. C. A. 0025 airfoil.

Sta.	Up'r	L'w'r
0	0	0
1.25	4.74	-4.74
2.5	6.54	-6.54
5.0	8.89	-8.89
7.5	10.50	-10.50
10	11.71	-11.71
15	13.36	-13.36
20	14.34	-14.34
25	14.85	-14.85
30	15.00	-15.00
40	14.51	-14.51
50	13.24	-13.24
60	11.41	-11.41
70	9.16	-9.16
80	6.56	-6.56
90	3.62	-3.62
95	2.02	-2.02
100	(.31)	(-.31)
100	0	0

L.E. Rad.: 9.90

Airfoil: N.A.C.A. 0030   R: 3,190,000
Size: 5"x30"   Vel.(ft./sec.): 69.0
Press.(st'nd. atm.): 20.5
Corrected for tunnel-wall effect

Where tested: L.M.A.L.   V.D.T. 1539
R_e: 8,420,000   Date: 9-17-37

FIGURE 37.—N. A. C. A. 0030 airfoil.

Sta.	Up'r	L'w'r
0	-	0
1.25	2.44	-1.46
2.5	3.35	-1.96
5.0	4.62	-2.55
7.5	5.55	-2.89
10	6.27	-3.11
15	7.25	-3.44
20	7.74	-3.74
25	7.93	-3.94
30	7.97	-4.03
40	7.68	-3.92
50	7.02	-3.56
60	6.07	-3.05
70	4.90	-2.43
80	3.52	-1.74
90	1.93	-.97
95	1.05	-.56
100	(.13)	(-.13)
100	-	0

L.E.Rad.: 1.58
Slope of radius through end of chord: 0.20

Airfoil: N.A.C.A. 2212 R: 3,220,000
Size: 5"x30" Vel.(ft./sec.): 68.4
Press.(st'nd. atm.): 20.8
Corrected for tunnel-wall effect

Where tested: L.M.A.L. V.D.T. 719
R_e: 8,500,000 Date: 12-2-31

FIGURE 38.—N. A. C. A. 2212 airfoil.

Sta.	Up'r	L'w'r
0	-	0
1.25	1.62	-1.23
2.5	2.27	-1.66
5.0	3.20	-2.15
7.5	3.87	-2.44
10	4.43	-2.60
15	5.25	-2.77
20	5.81	-2.79
25	6.18	-2.74
30	6.38	-2.62
40	6.35	-2.35
50	5.92	-2.02
60	5.22	-1.63
70	4.27	-1.24
80	3.10	-.85
90	1.72	-.47
95	.94	-.28
100	(.10)	(-.10)
100	-	0

L.E.Rad.: 0.89
Slope of radius through end of chord: 0.10

Airfoil: N.A.C.A. 2409 R: 3,110,000
Size: 5"x30" Vel.(ft./sec.): 69.3
Press.(st'nd. atm.): 20.8
Corrected for tunnel-wall effect

Where tested: L.M.A.L. V.D.T. 666
R_e: 8,290,000 Date: 9-9-31

FIGURE 39.—N. A. C. A. 2409 airfoil.

Sta.	Up'r	L'w'r
0	—	0
1.25	2.15	-1.65
2.5	2.99	-2.27
5.0	4.13	-3.01
7.5	4.96	-3.46
10	5.63	-3.75
15	6.61	-4.10
20	7.26	-4.23
25	7.67	-4.22
30	7.88	-4.12
40	7.80	-3.80
50	7.24	-3.34
60	6.36	-2.76
70	5.18	-2.14
80	3.75	-1.50
90	2.08	-.82
95	1.14	-.48
100	(.13)	(-.13)
100	—	0

L.E.Rad.: 1.58
Slope of radius through end of chord: 0.10

R_e 8,240,000 3,420,000

Airfoil: N.A.C.A. 2412   R: 3,120,000
Size: 5"x30"   Vel.(ft./sec.): 69.0
Press. (st'nd. atm.): 21.0
Corrected for tunnel-wall effect

Where tested: L.M.A.L.   V.D.T. 1164
R_e: 8,240,000   Date: 8-24-34

FIGURE 40.— N. A. C. A. 2412 airfoil.

Sta.	Up'r	L'w'r
0	—	0
1.25	2.71	-2.06
2.5	3.71	-2.86
5.0	5.07	-3.84
7.5	6.06	-4.47
10	6.83	-4.90
15	7.97	-5.42
20	8.70	-5.66
25	9.17	-5.70
30	9.38	-5.62
40	9.25	-5.25
50	8.57	-4.67
60	7.50	-3.90
70	6.10	-3.05
80	4.41	-2.15
90	2.45	-1.17
95	1.34	-.68
100	(.16)	(-.16)
100	—	0

L.E.Rad.: 2.48
Slope of radius through end of chord: 0.10

Airfoil: N.A.C.A. 2415   R: 3,060,000
Size: 5"x30"   Vel.(ft./sec.): 69.8
Press.(st'nd. atm.): 20.8
Corrected for tunnel-wall effect

Where tested: L.M.A.L.   V.D.T. 668
R_e: 8,080,000   Date: 9-10-31

FIGURE 41.—N. A. C. A. 2415 airfoil.

Sta.	Up'r	L'w'r
0	–	0
1.25	3.28	-2.45
2.5	4.45	-3.44
5.0	6.03	-4.68
7.5	7.17	-5.48
10	8.05	-6.03
15	9.34	-6.74
20	10.15	-7.09
25	10.65	-7.18
30	10.88	-7.12
40	10.71	-6.71
50	9.89	-5.99
60	8.65	-5.04
70	7.02	-3.97
80	5.08	-2.80
90	2.81	-1.53
95	1.55	-.87
100	(.19)	(-.19)
100	–	0

L.E.Rad.: 3.56
Slope of radius
through end of
chord: 0.10

Airfoil: N.A.C.A. 2418 R: 3,060,000
Size: 5"x30" Vel.(ft./sec.): 69.8
Press. (st'nd. atm.): 20.8
Corrected for tunnel-wall effect

Where tested: L.M.A.L. V.D.T. 669
R_e: 8,080,000 Date: 9-11-31

FIGURE 42.—N. A. C. A. 2418 airfoil.

Sta.	Up'r	L'w'r
0	–	0
1.25	1.25	-0.64
2.5	1.88	-.73
5.0	2.79	-.82
7.5	3.53	-.73
10	4.15	-.60
15	5.15	-.25
20	5.90	.12
25	6.42	.46
30	6.76	.74
40	6.90	1.10
50	6.55	1.24
60	5.85	1.27
70	4.85	1.16
80	3.56	.91
90	1.96	.49
95	1.05	.24
100	(.06)	(-.06)
100	–	0

L.E.Rad.: 0.40
Slope of radius
through end of
chord: 0.20

Airfoil: N.A.C.A. 4406 R: 3,100,000
Size: 5"x30" Vel.(ft./sec.): 69.4
Press. (st'nd. atm.): 20.9
Corrected for tunnel-wall effect

Where tested: L.M.A.L. V.D.T. 651
R_e: 8,180,000 Date: 8-21-31

FIGURE 43.—N. A. C. A. 4406 airfoil.

Sta.	Up'r	L'w'r
0	–	0
1.25	1.81	-1.05
2.5	2.61	-1.37
5.0	3.74	-1.65
7.5	4.64	-1.74
10	5.37	-1.73
15	6.52	-1.55
20	7.33	-1.30
25	7.90	-1.02
30	8.25	-.76
40	8.35	-.35
50	7.87	-.07
60	7.00	.14
70	5.76	.26
80	4.21	.26
90	2.33	.14
95	1.26	.03
100	(.09)	(-.09)
100	0	0

L.E.Rad.: 0.89
Slope of radius
through end of
chord: 0.20

R_e
8,080,000
3,340,000

Airfoil: N.A.C.A. 4409 R: 3,060,000
Size: 5"x30"   Vel.(ft./sec.): 69.8
Press.(st'nd. atm.): 20.8
Corrected for tunnel-wall effect

Where tested: L.M.A.L   V.D.T. 1162
R_e: 8,080,000   Date: 8-15-34

FIGURE 44.—N. A. C. A. 4409 airfoil.

Sta.	Up'r	L'w'r
0	–	0
1.25	2.44	-1.43
2.5	3.39	-1.95
5.0	4.73	-2.49
7.5	5.76	-2.74
10	6.59	-2.86
15	7.89	-2.88
20	8.80	-2.74
25	9.41	-2.50
30	9.76	-2.26
40	9.80	-1.80
50	9.19	-1.40
60	8.14	-1.00
70	6.69	-.65
80	4.89	-.39
90	2.71	-.22
95	1.47	-.16
100	(.13)	(-.13)
100	0	0

L.E.Rad.: 1.58
Slope of radius
through end of
chord: 0.20

R_e
7,920,000
3,270,000

Airfoil: N.A.C.A. 4412 R: 3,000,000
Size: 5"x30"   Vel.(ft./sec.): 70.3
Press.(st'nd. atm.): 20.7
Corrected for tunnel-wall effect

Where tested: L.M.A.L.   V.D.T. 1159
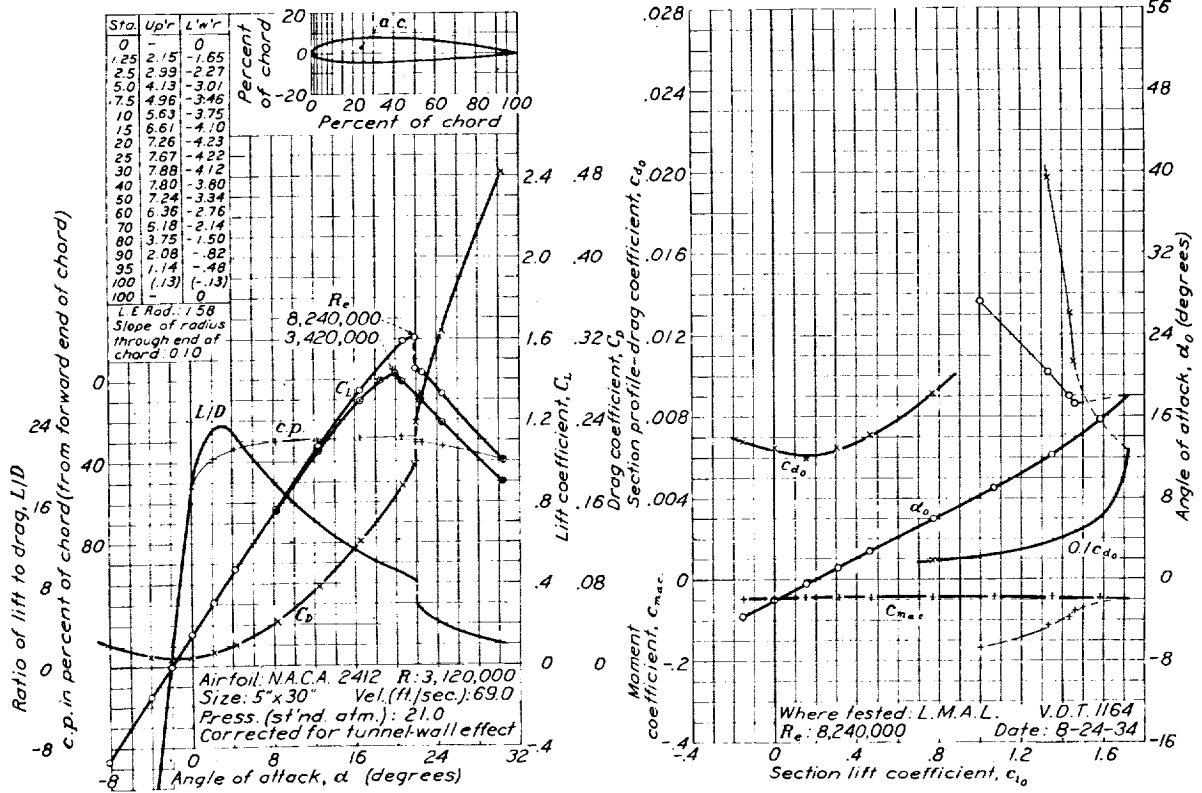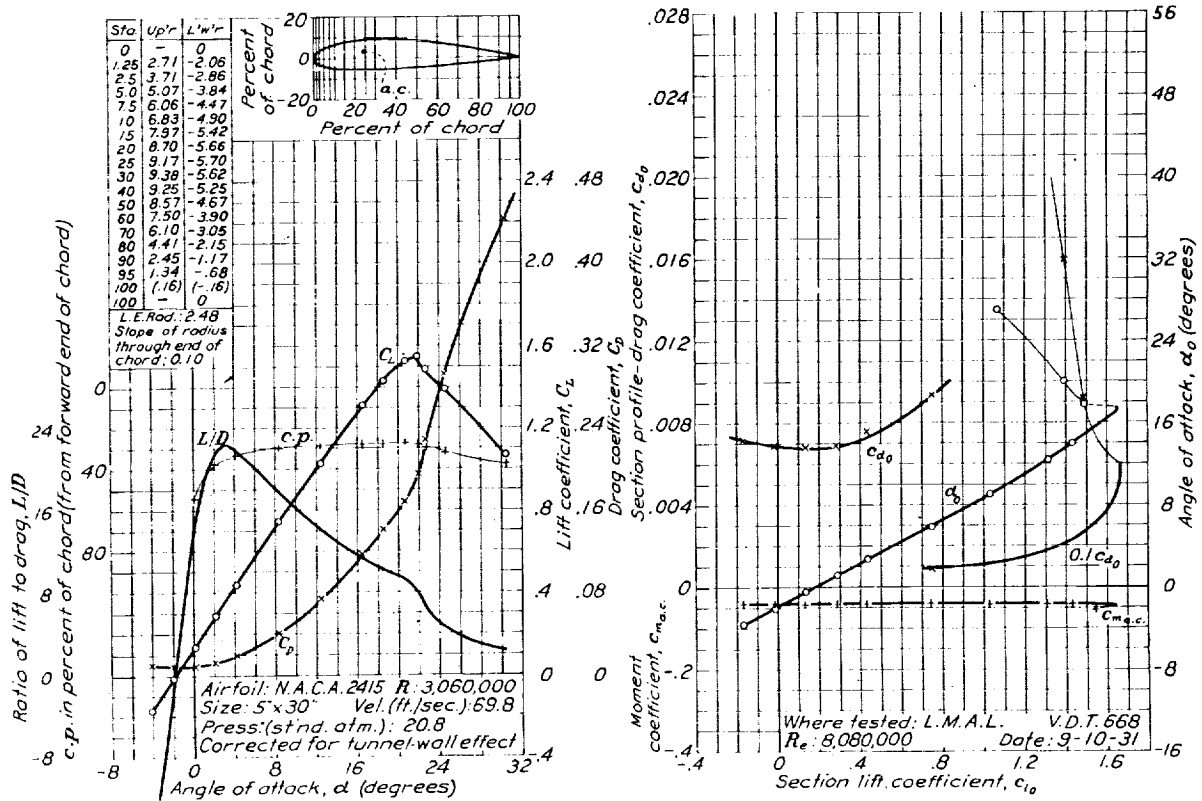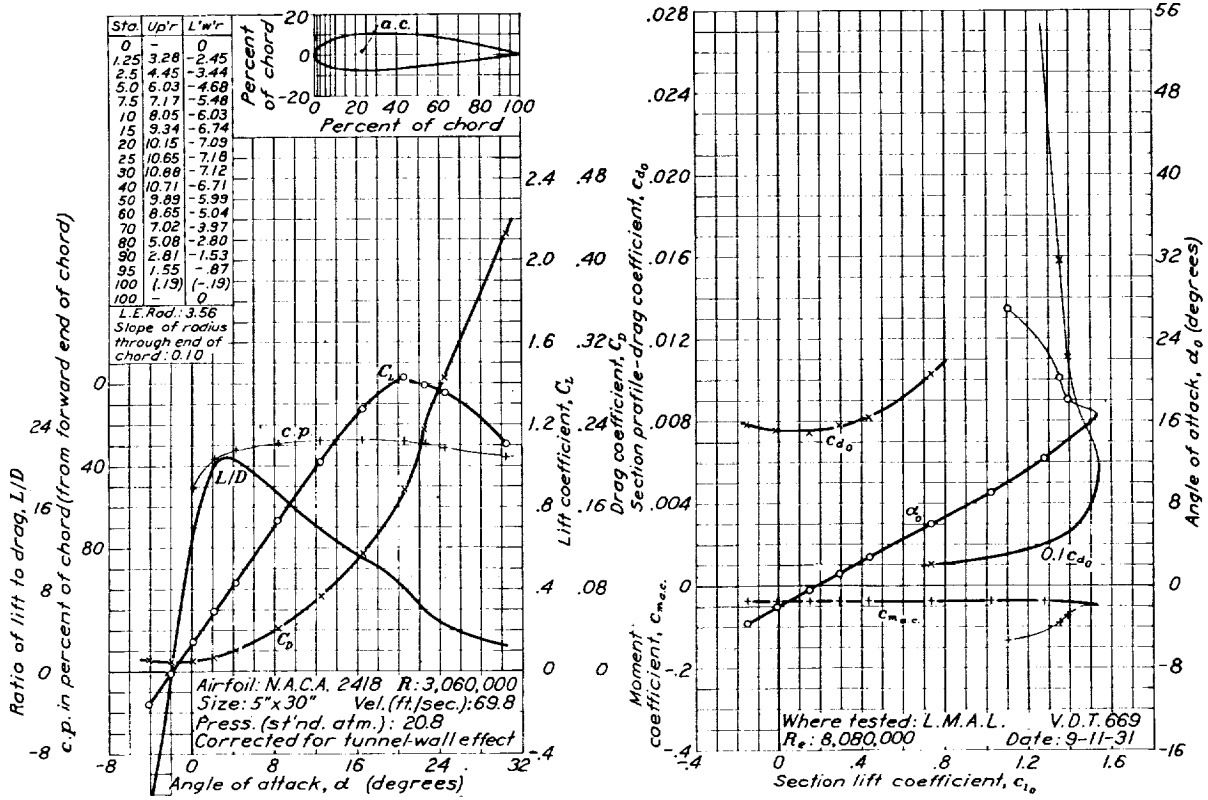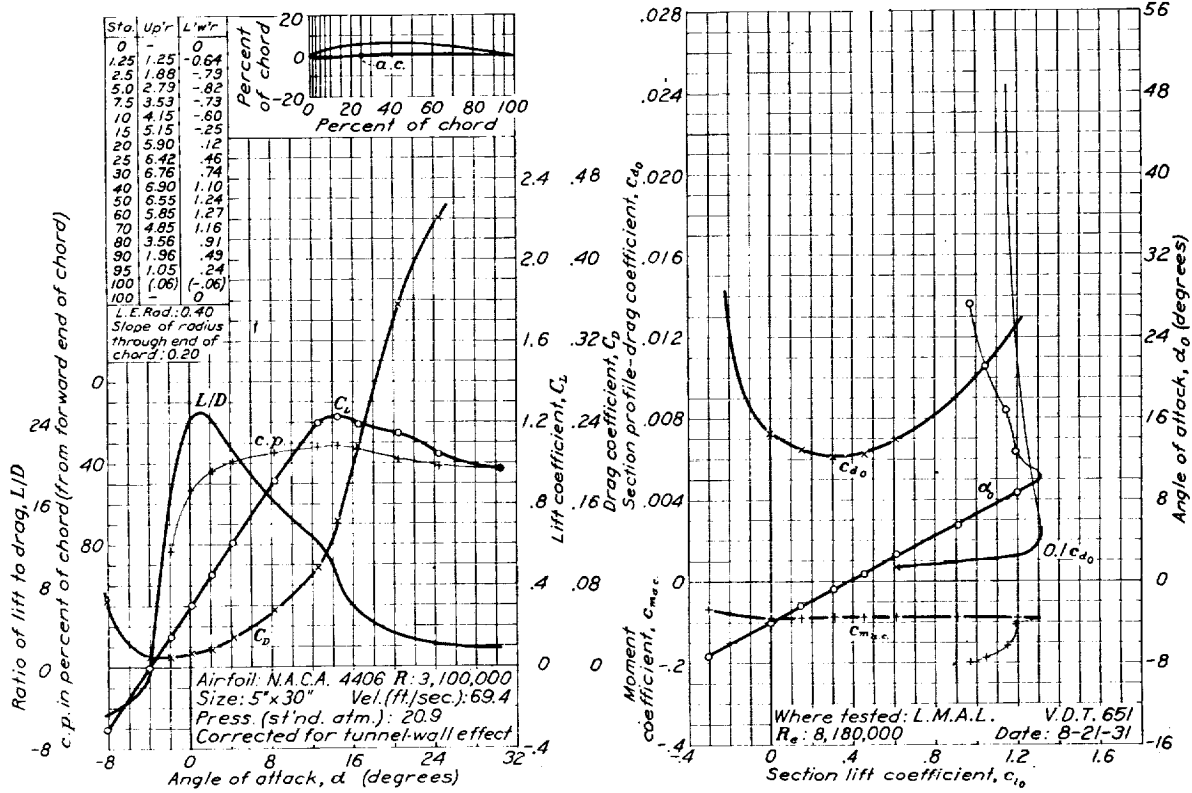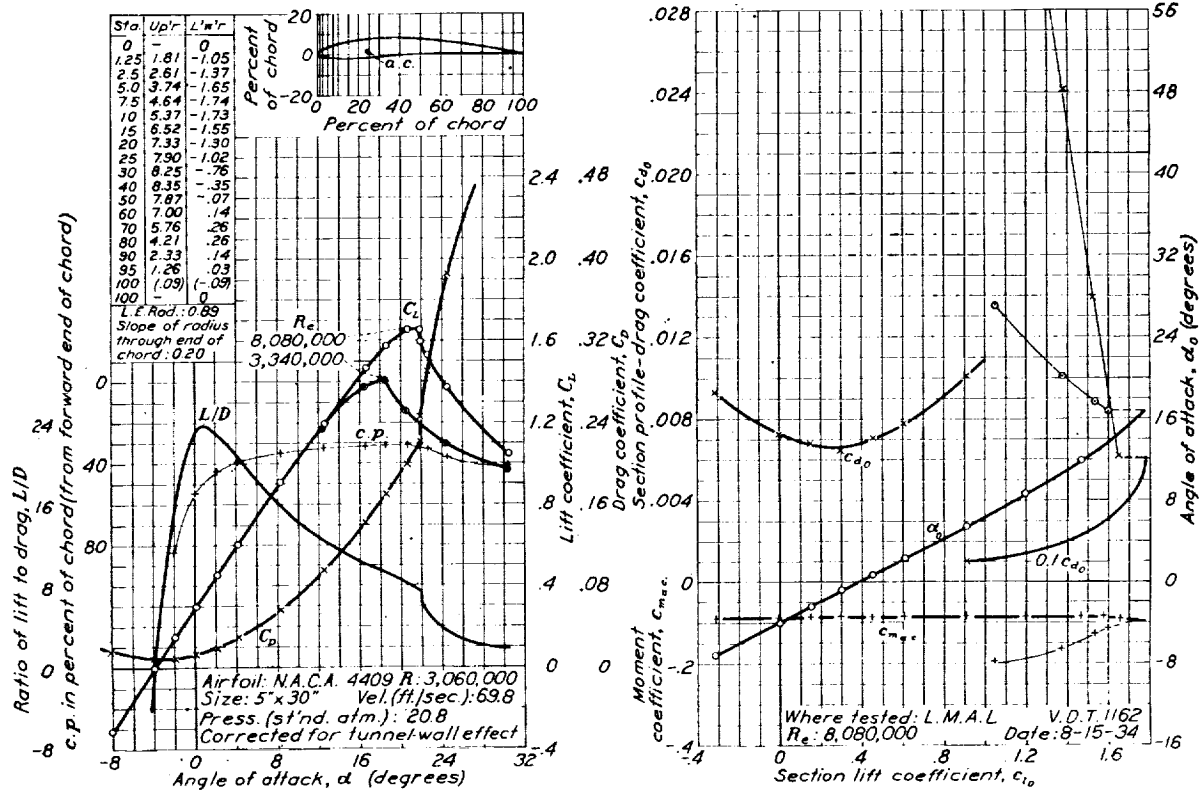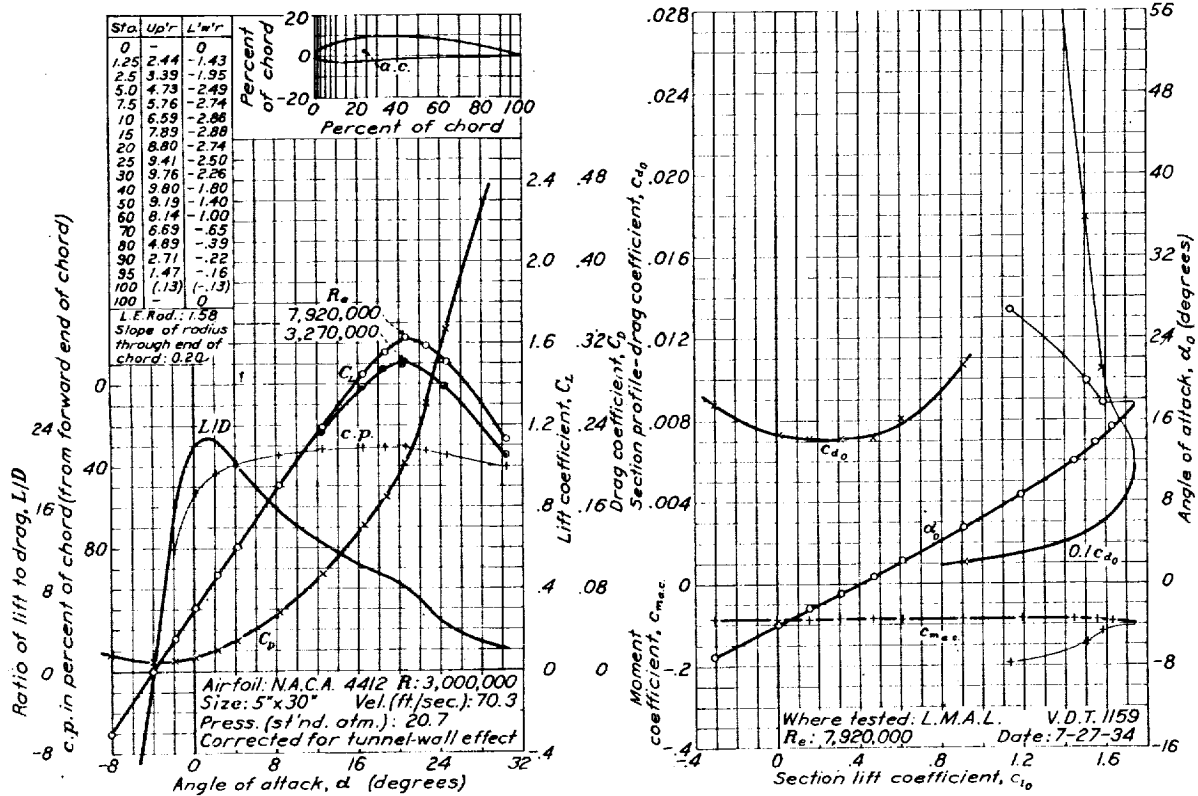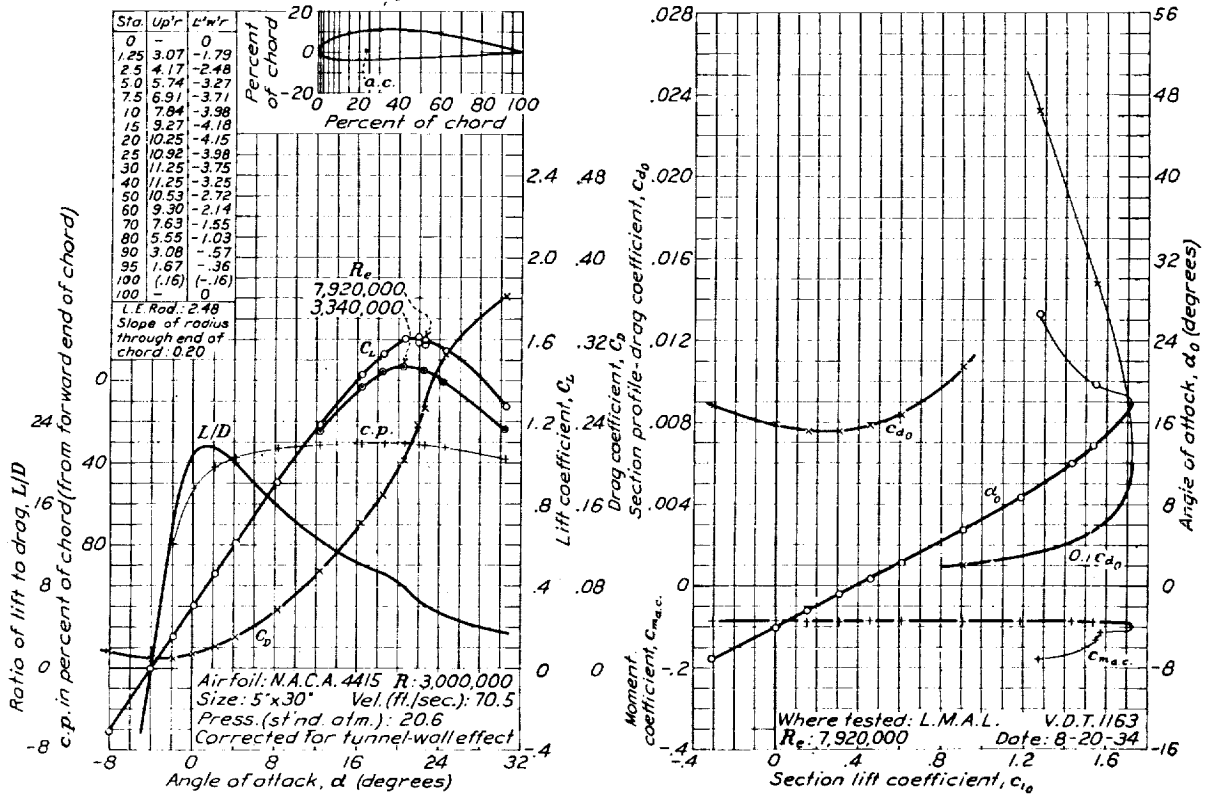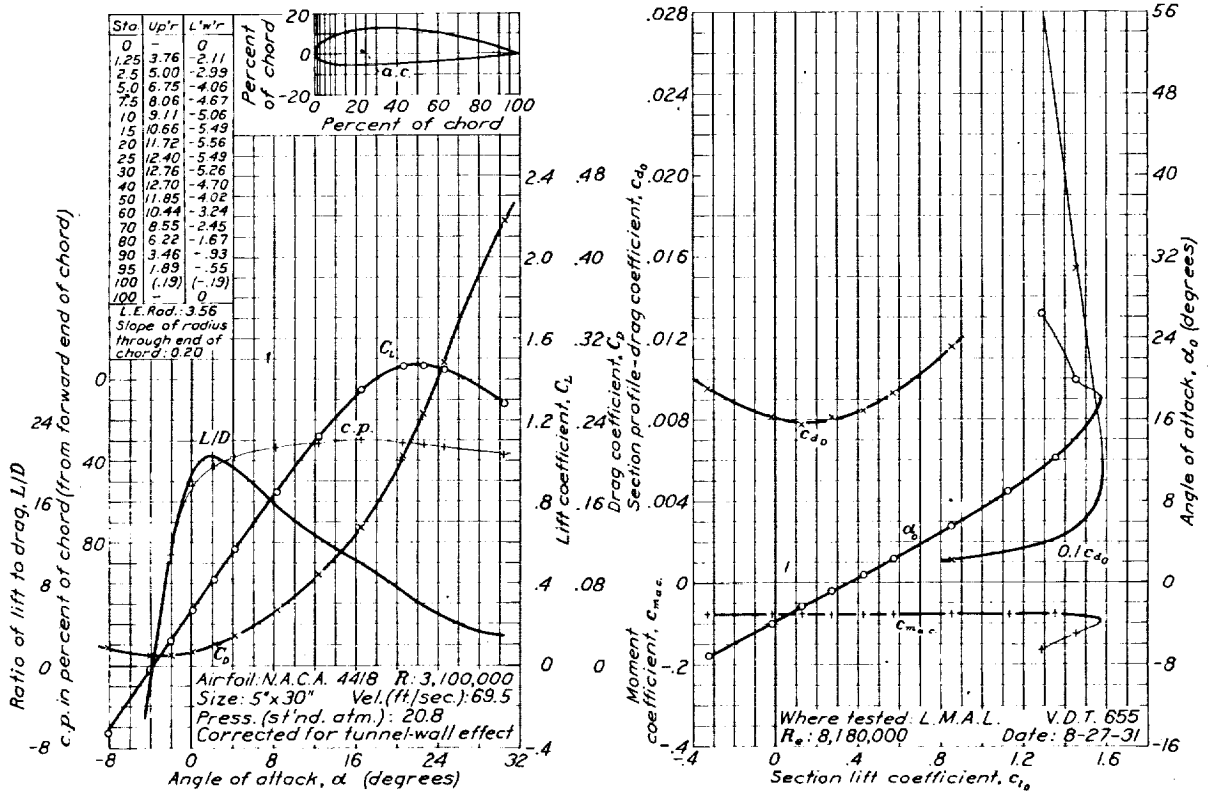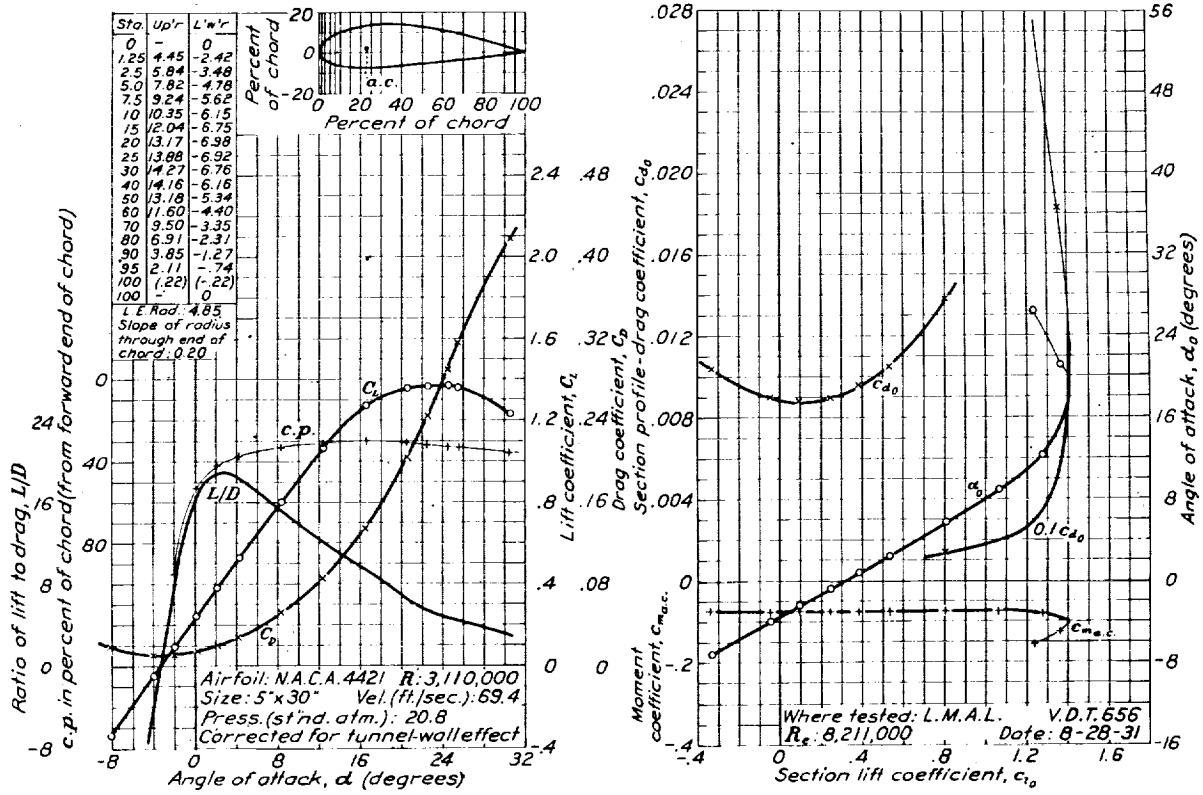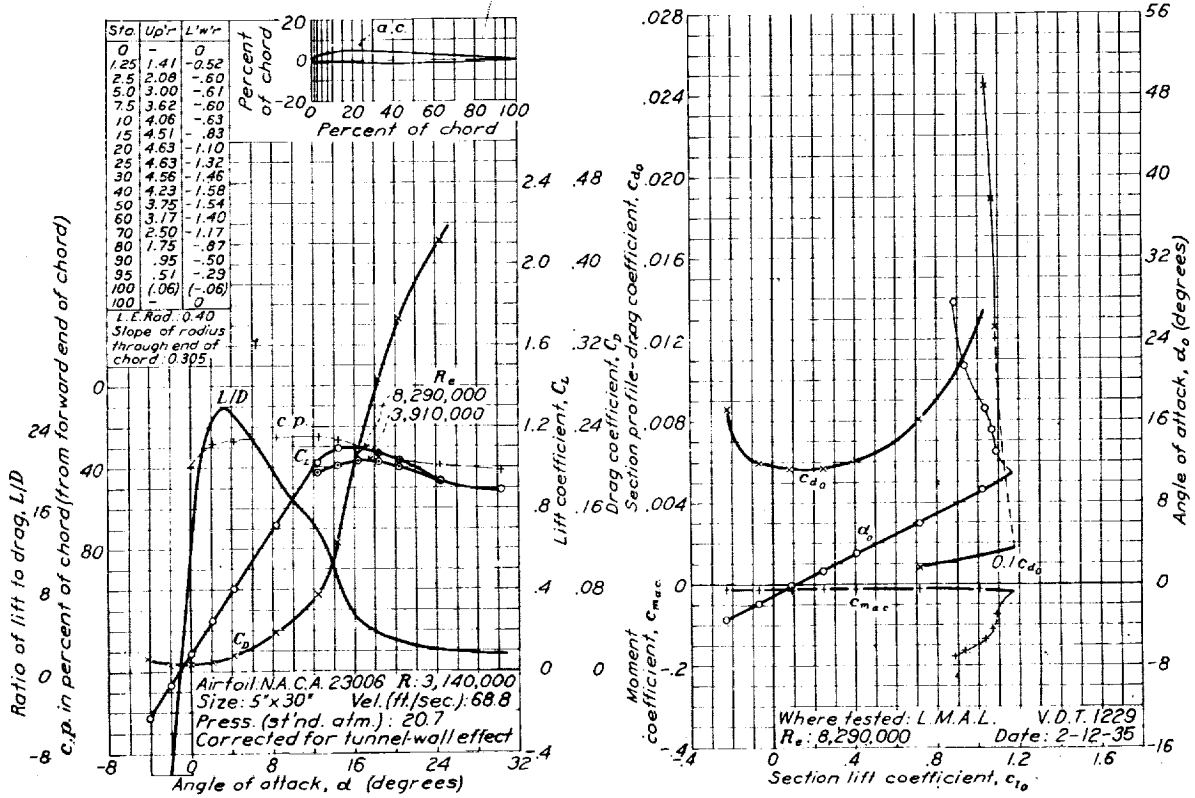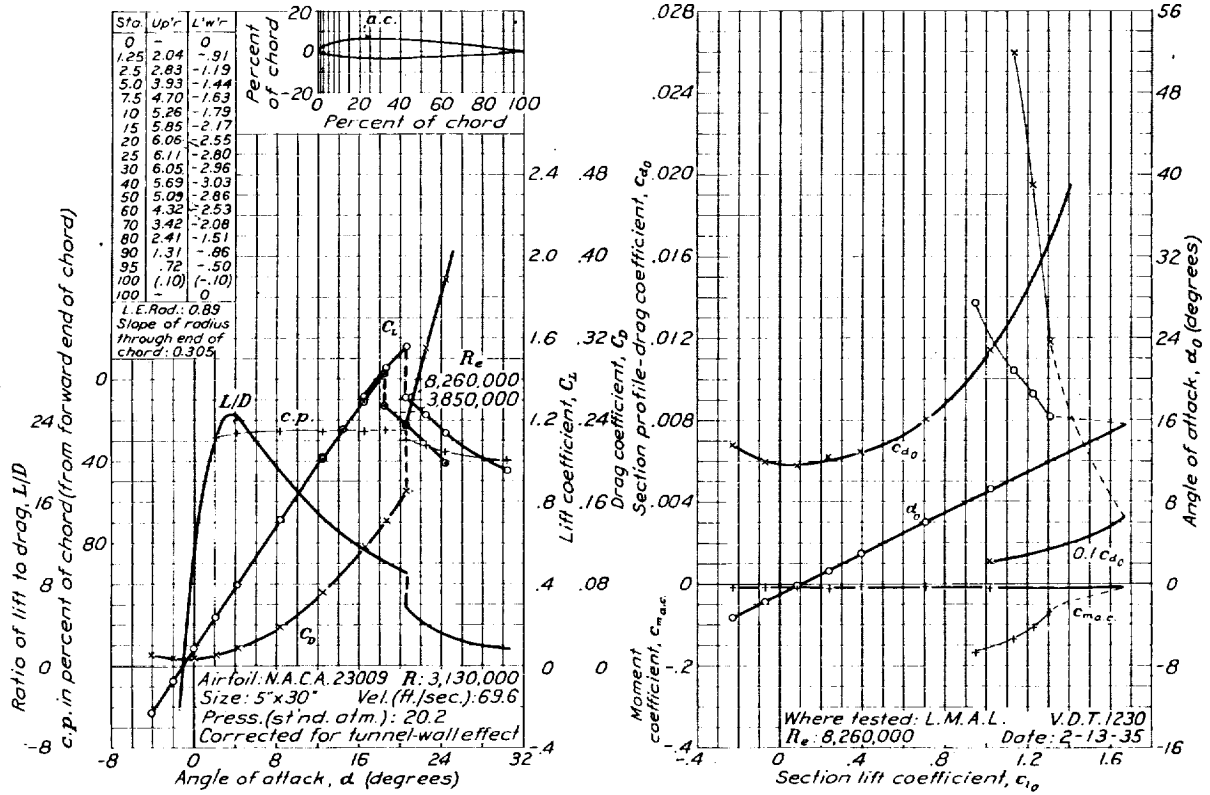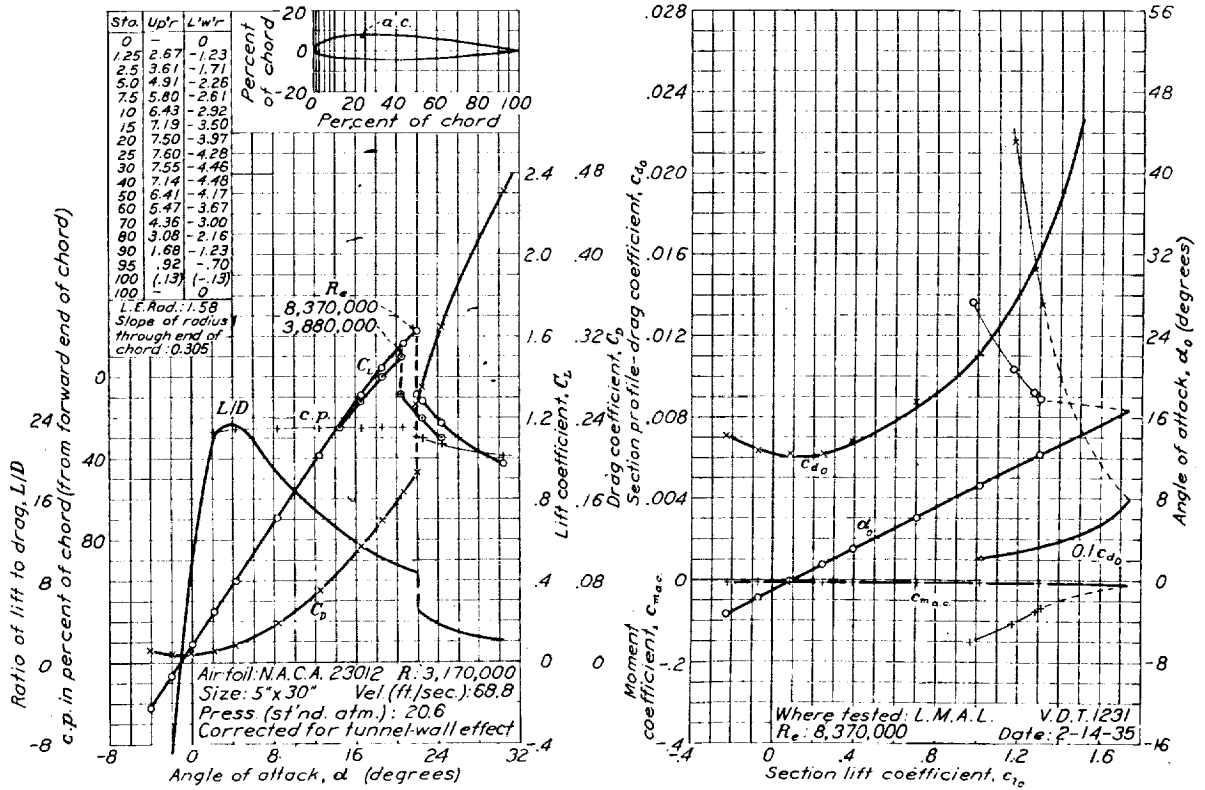R_e: 7,920,000   Date: 7-27-34

FIGURE 45.—N. A. C. A. 4412 airfoil.

FIGURE 46.—N. A. C. A. 4415 airfoil.

FIGURE 47.—N. A. C. A. 4418 airfoil.

Sta.	Up'r	L'w'r
0	–	0
1.25	4.45	-2.42
2.5	5.84	-3.48
5.0	7.82	-4.78
7.5	9.24	-5.62
10	10.35	-6.15
15	12.04	-6.75
20	13.17	-6.98
25	13.88	-6.92
30	14.27	-6.76
40	14.16	-6.16
50	13.18	-5.34
60	11.60	-4.40
70	9.50	-3.35
80	6.91	-2.31
90	3.85	-1.27
95	2.11	-.74
100	(.22)	(-.22)
100	–	0

L.E.Rad.: 4.85
Slope of radius through end of chord: 0.20

Airfoil: N.A.C.A. 4421   R: 3,110,000
Size: 5"x30"   Vel. (ft./sec.): 69.4
Press. (st'nd. atm.): 20.8
Corrected for tunnel-wall effect

Where tested: L.M.A.L.   V.D.T.656
R_e: 8,211,000   Date: 8-28-31

FIGURE 48.—N. A. C. A. 4421 airfoil.

Sta.	Up'r	L'w'r
0	–	0
1.25	1.41	-0.52
2.5	2.08	-.60
5.0	3.00	-.61
7.5	3.62	-.60
10	4.06	-.63
15	4.51	-.83
20	4.63	-1.10
25	4.63	-1.32
30	4.56	-1.46
40	4.23	-1.58
50	3.75	-1.54
60	3.17	-1.40
70	2.50	-1.17
80	1.75	-.87
90	.95	-.50
95	.51	-.29
100	(.06)	(-.06)
100	–	0

L.E.Rad.: 0.40
Slope of radius through end of chord: 0.305

R_e
8,290,000
3,910,000

Airfoil: N.A.C.A. 23006   R: 3,140,000
Size: 5"x30"   Vel. (ft./sec.): 68.8
Press. (st'nd. atm.): 20.7
Corrected for tunnel-wall effect

Where tested: L.M.A.L.   V.D.T.1229
R_e: 8,290,000   Date: 2-12-35

FIGURE 49.—N. A. C. A. 23006 airfoil.

Sta.	Up'r	L'w'r
0	–	0
1.25	2.04	-.91
2.5	2.83	-1.19
5.0	3.93	-1.44
7.5	4.70	-1.63
10	5.26	-1.79
15	5.85	-2.17
20	6.06	-2.55
25	6.11	-2.80
30	6.05	-2.96
40	5.69	-3.03
50	5.09	-2.86
60	4.32	-2.53
70	3.42	-2.08
80	2.41	-1.51
90	1.31	-.86
95	.72	-.50
100	(.10)	(-.10)
100	–	0

L.E.Rad.: 0.89
Slope of radius
through end of
chord: 0.305

Airfoil: N.A.C.A. 23009 R: 3,130,000
Size: 5"x30"   Vel.(ft./sec.): 69.6
Press.(st'nd.atm.): 20.2
Corrected for tunnel-wall effect

R_e
8,260,000
3,850,000

Where tested: L.M.A.L.   V.D.T. 1230
R_e: 8,260,000   Date: 2-13-35

FIGURE 50.—N. A. C. A. 23009 airfoil.

Sta.	Up'r	L'w'r
0	–	0
1.25	2.67	-1.23
2.5	3.61	-1.71
5.0	4.91	-2.26
7.5	5.80	-2.61
10	6.43	-2.92
15	7.19	-3.50
20	7.50	-3.97
25	7.60	-4.28
30	7.55	-4.46
40	7.14	-4.48
50	6.41	-4.17
60	5.47	-3.67
70	4.36	-3.00
80	3.08	-2.16
90	1.68	-1.23
95	.92	-.70
100	(.13)	(-.13)
100	–	0

L.E.Rad.: 1.58
Slope of radius
through end of
chord: 0.305

R_e
8,370,000
3,880,000

Airfoil: N.A.C.A. 23012 R: 3,170,000
Size: 5"x30"   Vel.(ft./sec.): 68.8
Press.(st'nd.atm.): 20.6
Corrected for tunnel-wall effect

Where tested: L.M.A.L.   V.D.T. 1231
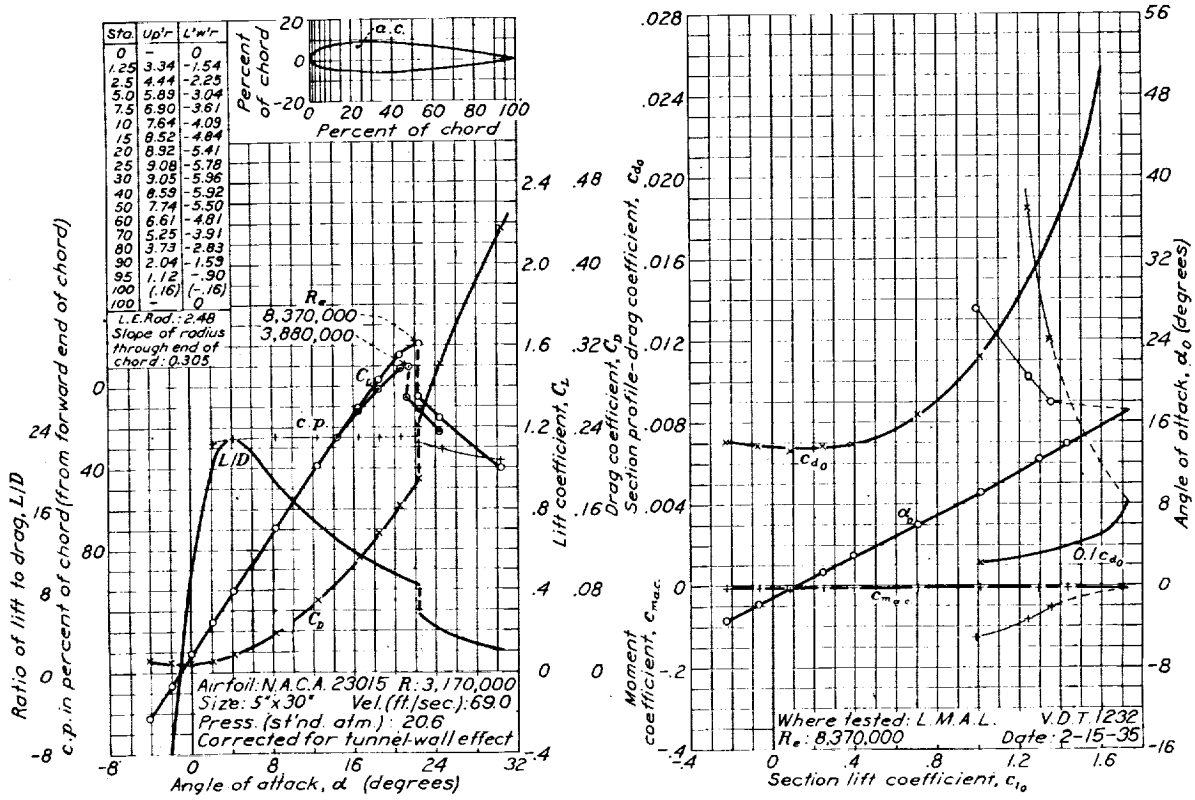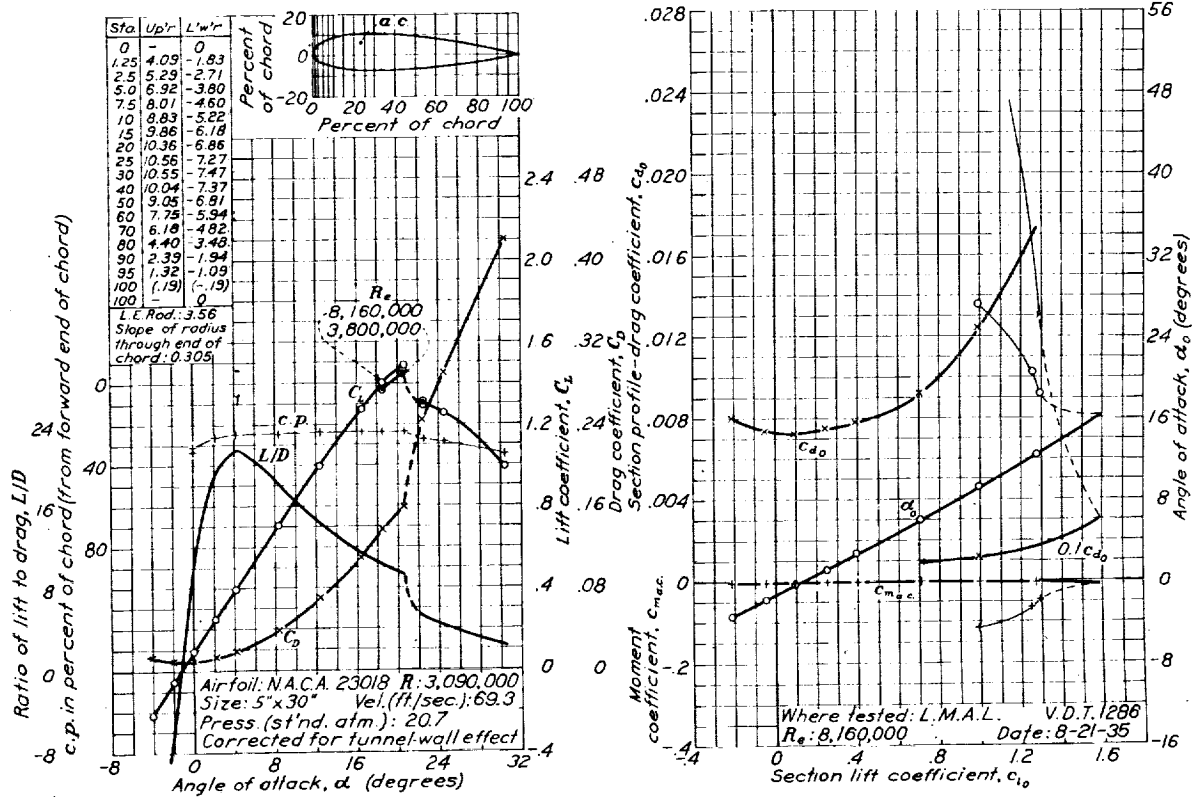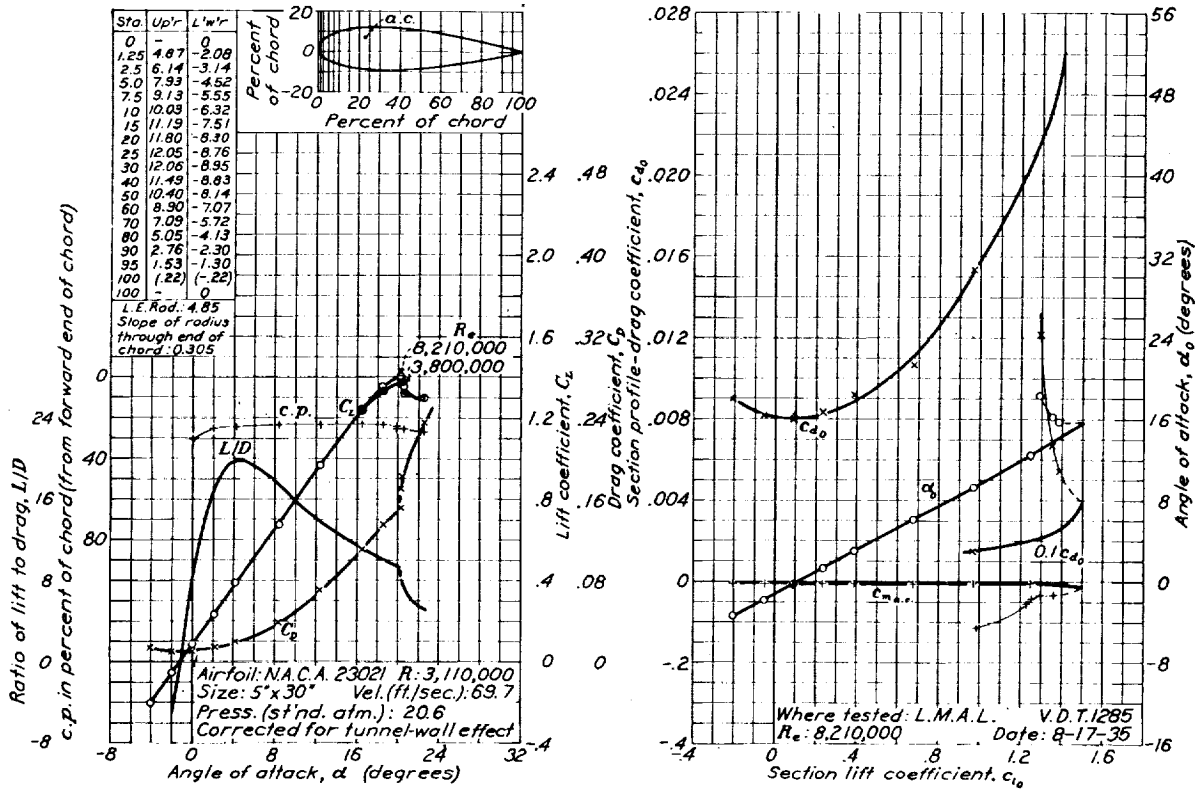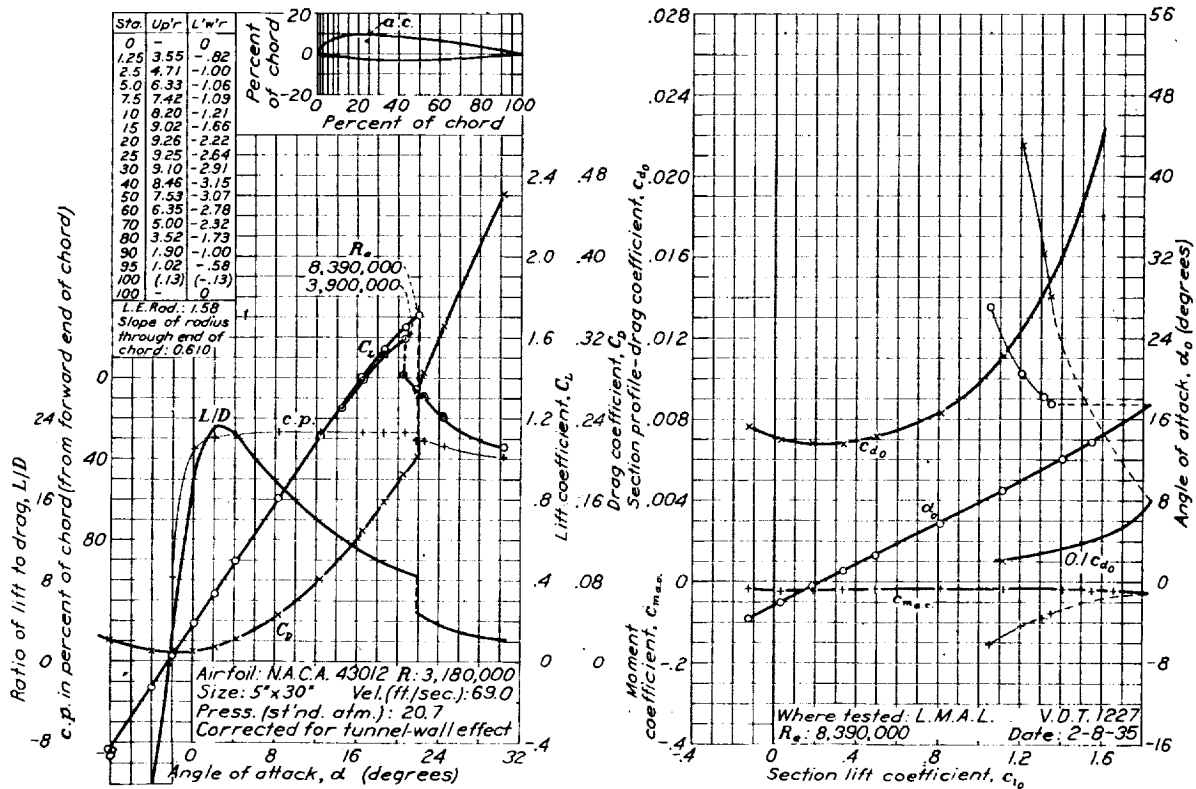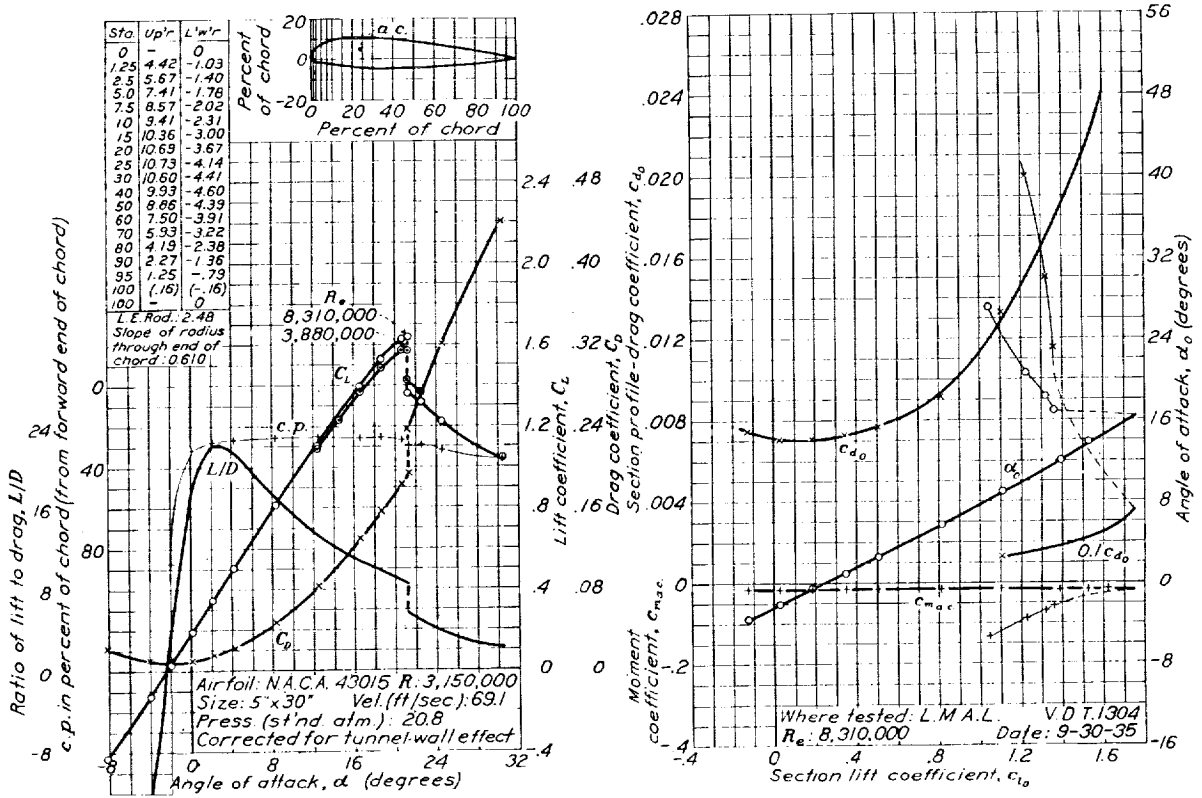R_e: 8,370,000   Date: 2-14-35

FIGURE 51.—N. A. C. A. 23012 airfoil.

FIGURE 52.--N. A. C. A. 23015 airfoil.

FIGURE 53.—N. A. C. A. 23018 airfoil.

Airfoil: N.A.C.A. 23021   R: 3,110,000
Size: 5"x30"   Vel.(ft./sec.): 69.7
Press.(st'nd. atm.): 20.6
Corrected for tunnel-wall effect

Where tested: L.M.A.L.   V.D.T.1285
R_e: 8,210,000   Date: 8-17-35

FIGURE 54.—N. A. C. A. 23021 airfoil.

Airfoil: N.A.C.A. 43012   R: 3,180,000
Size: 5"x30"   Vel.(ft./sec.): 69.0
Press.(st'nd. atm.): 20.7
Corrected for tunnel-wall effect

Where tested: L.M.A.L.   V.D.T.1227
R_e: 8,390,000   Date: 2-8-35

FIGURE 55.—N. A. C. A. 43012 airfoil.

Sta.	Up'r	L'w'r
0	—	0
1.25	4.42	-1.03
2.5	5.67	-1.40
5.0	7.41	-1.78
7.5	8.57	-2.02
10	9.41	-2.31
15	10.36	-3.00
20	10.69	-3.67
25	10.73	-4.14
30	10.60	-4.41
40	9.93	-4.60
50	8.86	-4.39
60	7.50	-3.91
70	5.93	-3.22
80	4.19	-2.38
90	2.27	-1.36
95	1.25	-.79
100	(.16)	(-.16)
100	—	0

L.E. Rad.: 2.48
Slope of radius through end of chord: 0.610

R_e
8,310,000
3,880,000

Airfoil: N.A.C.A. 43015   R: 3,150,000
Size: 5"x30"   Vel. (ft./sec.): 69.1
Press. (st'nd atm.): 20.8
Corrected for tunnel-wall effect

Where tested: L.M.A.L.   V.D.T. 1304
R_e: 8,310,000   Date: 9-30-35

FIGURE 56.—N. A. C. A. 43015 airfoil.

Sta.	Up'r	L'w'r
0	—	0
1.25	5.40	-1.23
2.5	6.67	-1.78
5.0	8.50	-2.44
7.5	9.75	-2.91
10	10.63	-3.38
15	11.69	-4.34
20	12.11	-5.10
25	12.22	-5.62
30	12.10	-5.91
40	11.39	-6.04
50	10.20	-5.71
60	8.67	-5.04
70	6.87	-4.12
80	4.87	-3.02
90	2.63	-1.72
95	1.44	-.99
100	(.19)	(-.19)
100	—	0

L.E. Rad.: 3.56
Slope of radius through end of chord: 0.610

R_e
8,340,000
3,780,000

Airfoil: N.A.C.A. 43018   R: 3,160,000
Size: 5"x30"   Vel. (ft./sec.): 68.9
Press. (st'nd. atm.): 20.8
Corrected for tunnel-wall effect

Where tested: L.M.A.L.   V.D.T. 1295
R_e: 8,340,000   Date: 9-12-35

FIGURE 57.—N. A. C. A. 43018 airfoil.

Sta.	Up'r	L'w'r
0	–	0
1.25	4.46	-.50
2.5	5.64	-.41
5.0	7.77	.03
7.5	9.07	.39
10	9.99	.50
15	10.86	.17
20	11.03	-.48
25	10.91	-.99
30	10.66	-1.38
40	9.80	-1.84
50	8.64	-1.97
60	7.24	-1.90
70	5.69	-1.66
80	3.97	-1.28
90	2.12	-.79
95	1.14	-.48
100	(.13)	(-.13)
100	–	0

L.E. Rad.: 1.58
Slope of radius
through end of
chord: 0.915

Airfoil: N.A.C.A. 63012 R: 3,140,000
Size: 5"x30"   Vel.(ft./sec.):69.3
Press.(st'nd. atm.): 20.6
Corrected for tunnel-wall effect

Where tested: L.M.A.L.   V.D.T.1299
R_e: 8,290,000   Date: 9-18-35

FIGURE 58.—N. A. C. A. 63012 airfoil.

Sta.	Up'r	L'w'r
0	–	0
1.25	6.71	-.80
2.5	8.11	-1.09
5.0	10.10	-1.24
7.5	11.46	-1.34
10	12.48	-1.60
15	13.54	-2.50
20	13.88	-3.37
25	13.88	-3.99
30	13.67	-4.40
40	12.71	-4.72
50	11.33	-4.60
60	9.58	-4.15
70	7.53	-3.48
80	5.32	-2.58
90	2.89	-1.50
95	1.56	-.88
100	(.19)	(-.19)
100	–	0

L.E.Rad.: 3.56
Slope of radius
through end of
chord: 0.915

Airfoil: N.A.C.A. 63018 R: 3,120,000
Size: 5"x30"   Vel.(ft./sec.):69.3
Press.(st'nd. atm.): 20.6
Corrected for tunnel-wall effect

Where tested: L.M.A.L.   V.D.T.1303
R_e: 8,240,000   Date: 9-27-35

FIGURE 59.—N. A. C. A. 63018 airfoil.

SUMMARY OF CORRECTIONS TO AIRFOIL DATA FROM THE N. A. C. A. VARIABLE-DENSITY TUNNEL

As a convenience to designers in correcting previously published data to be comparable with the data published in this report, a brief summary of the corrections now applied to airfoil section data is presented. These corrections apply to data obtained after January 1931 and most of them have been discussed in greater detail in reference 4. The corrections are presented in the order in which they are applied. Information is also given to aid in correcting previously published data.

Corrections for tunnel-wall effects and to infinite aspect ratio.—The formulas for correcting the data for tunnel-wall effects and to infinite aspect ratio are given in reference 1. Second-order effects not allowed for in these formulas have been investigated and found to be negligible for the usual tunnel tests. These corrections have been applied to all published data.

Support-interference correction.—The support-interference increment as obtained from figure 1 for the proper airfoil thickness is deducted from the drag or the profile-drag coefficients. A support-interference increment of the pitching-moment coefficient of 0.002 (see appendix of reference 4) is subtracted from the measured pitching moment. This second correction has already been applied to all published data.

Corrections to section characteristics.—The first-approximation section characteristics as obtained by correcting to infinite aspect ratio are unsatisfactory, first, because the airfoil theory does not represent with sufficient accuracy the flow about the tip portions of rectangular airfoils and, second, because the measured coefficients represent average values for all the sections along the span; whereas each section actually operates at a section lift coefficient that may differ markedly from the wing lift coefficient. The following corrections are therefore applied as a second approximation to the section characteristics.

$$c_{l_{max}} = 1.07 C_{L_{max}}$$
$$a_0 = 0.96 a_0'$$
$$\alpha_0 = \alpha_0' + 0.39 C_L \text{ (deg.)}$$

$$c_{d_0} = C_{D_0} + 0.0016 C_L{}^2 - \frac{1}{3}(t-6)0.0002 (t \gtrless 6)$$

where t is the maximum thickness of the airfoil in percent of its chord and the primed values are those obtained from the first approximation. For some unusual cases, where the lift-curve peaks are very gradually rounding with little loss of lift beyond the stall, the maximum lift coefficients for the sections are increased by 4 percent instead of by 7 percent. The

curve of profile-drag coefficient against lift coefficient is modified at high lift coefficients (usually above about $C_L = 1$) owing to the change of $c_{l_{max}}$ and the variation of c_{d_0} along the span, resulting in final values of c_{d_0} lower than those given by the formula in this range of lift coefficients (reference 4).

Turbulence.—The corrections for turbulence are made by use of the concept of an effective Reynolds Number. The scale effects that appear in the tunnel tend to correspond, in general, with those that would appear in flight at a higher Reynolds Number, which is therefore referred to as the "effective" Reynolds Number. The effective Reynolds Number is obtained by multiplying the test Reynolds Number by the turbulence factor, which is taken as 2.64 for the variable-density tunnel. This correction to the effective Reynolds Number necessitates a correction to the drag coefficient; this correction is applied by multiplying the profile-drag coefficient, after the foregoing corrections have been applied, by the ratio of the turbulent skin-friction coefficient of a flat plate at the effective Reynolds Number to that at the test Reynolds Number. This factor is taken as 0.85 for the usual test Reynolds Number of about 3,000,000. Because of the presence of induced velocities over the airfoil surface, this method is considered more justifiable than the method formerly used of subtracting a constant increment from the drag coefficients (see pp. 19–22, reference 4) but is obviously not applicable when large form drags are involved. For flapped airfoils, an approximate correction may be applied by subtracting the increments determined for the plain airfoil.

Correction of previously published data.—The important previously published airfoil data from the variable-density tunnel may be placed in five groups as regards the corrections needed to make the data comparable with those published herein. The five groups, and the corrections necessary, are as follows:

1. The data of group 1 are uncorrected except for those corrections described herein as having been applied to all published data. The other corrections should be applied in the order listed. These data are subject to a correction arising from a consistent error in measuring the dynamic pressure. If considered of sufficient importance, these data may be corrected by changing the coefficients to correspond to a reduction of measured dynamic pressure of 0.5 percent. (See appendix of reference 4.)

2. The data of group 2 are uncorrected except for those corrections described herein as having been applied to all published data. The other corrections should be applied in the order listed.

3. The data of group 3 are partly corrected. The corrections to section characteristics are satisfactory except for the maximum lift coefficient, which should be increased an additional 4 percent. A correction, no longer considered justifiable, has been applied to the aerodynamic-center position and may be removed by shifting the published positions back from the leading edge by $0.005c$ and by doubling the vertical distance between the aerodynamic-center position and the chord line. The profile-drag coefficients may be corrected for the support interference and the revised correction to the effective Reynolds Number by the following formula:

$$c_{d_0} = 0.85\left(c_{d_{0_{pub}}} + 0.0011 - \Delta C_{D_{0_{min}}}\right) \tag{1}$$

where $\Delta C_{D_{0_{min}}}$ is the proper support-interference increment obtained from figure 1.

4. The only correction needed for the data of group 4 is the correction to the profile-drag coefficients given in equation (1).

5. The data of group 5 need no corrections.

The data of the more important publications are classified in the following table.

CLASSIFICATION OF PUBLISHED AIRFOIL DATA FROM THE N. A. C. A. VARIABLE-DENSITY WIND TUNNEL

| Group | Published source | |
	No. of N. A. C. A. Report	Figure or table
1	460	All material.
2	537	All figures.
	586	Figures 2–24.
3	537	Table II.
	586	All but figures 2–24.
4	610	All material.
	628	Do.
5	631	Table I.

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TABLE III
AIRFOIL SECTION CHARACTERISTICS

Airfoil	N.A.C.A. reference (R=report, N=technical note)	Chord[1]	PD[2]	SE[3]	$C_{l_{max}}$[4]	Effective Reynolds Number (millions)[5]	$c_{l_{max}}$	α_0 (deg.)	a_0 (per deg.)	$c_{l_{opt}}$	$c_{d_{o_{min}}}$	$c_{m_{a.c.}}$	a.c. Ahead	a.c. Above	$c_{l_{max}}/c_{d_{o_{min}}}$	c.p. at $c_{l_{max}}$ (percent c)	m_0 (per radian)	$C_{D_{min}}$	0.15c	0.65c	Maximum	Camber (percent c)
Clark Y	R 416	B	C 10	C 4	D	8.4	1.68	-5.0	0.092	0.12	0.0071	-0.069	1.1	4	237	29	4.07	0.0072	10.53	8.30	11.70	3.9
Clark YM-15	N 412	C	D 10	D 4	C	8.4	1.70	-5.2	.094	.10	.0076	-.068	1.1	7	224	30	4.14	.0079	13.51	10.63	15.00	4.0
Clark YM-18	N 412	C	E 10	E 4	C	8.2	1.60	-5.1	.091	.07	.0085	-.064	1.4	5	188	30	4.04	.0096	16.21	12.72	18.00	4.0
Curtiss C-72	N 412	B	C 10	C 4	D	8.0	1.74	-5.6	.095	.23	.0071	-.084	1.0	3	245	30	4.18	.0075	10.53	7.39	11.73	4.0
Göttingen 387	N 428	B	D 10	D 6	D	8.4	1.70	-6.6	.097	.30	.0076	-.093	.7	4	224	32	4.24	.0081	13.40	9.69	14.85	5.9
Göttingen 393	N 412	B	D 10	D 5	D	8.1	1.68	-6.0	.094	.15	.0076	-.081	.4	1	221	31	4.14	.0079	12.50	9.27	13.75	4.9
N-22	N 412	B	C 10	C 4	D	8.1	1.72	-5.4	.096	.17	.0075	-.075	.6	4	229	30	4.20	.0076	11.25	8.36	12.37	4.5
N.A.C.A. CYH	N 412	B	C 11	C 3	D	8.1	1.58	-2.9	.095	.08	.0055	-.027	.7	6	243	28	4.18	.0066	10.53	8.70	11.70	3.1
N.A.C.A.-M6	N 412	A	C 11	C 3	D	8.0	1.51	-.8	.095	.03	.0066	.002	-.4	0	229	26	4.18	.0066	10.29	9.00	12.01	2.4
U.S.A. 27	N 412	B	C 10	C 6	B	8.1	1.71	-4.7	.094	.30	.0075	-.078	1.8	5	228	30	4.14	.0084	10.40	8.70	11.12	5.6
U.S.A. 35-A	R 628	B	E 10	E 6	D	8.4	1.52	-8.0	.095	.38	.0094	-.111	.8	5	162	34	4.18	.0099	16.60	11.90	18.18	7.3
U.S.A. 35-B	N 412	B	C 10	C 5	B	8.3	1.81	-5.2	.099	.35	.0071	-.076	.5	5	255	30	4.31	.0076	10.56	7.54	11.61	4.6
N.A.C.A. 0006	R 460	A	A 10	A	D	8.5	.91	0	.098	0	.0051	0	0	.7	2	178	35	4.28	.0051	5.35	4.13	6.00	0
N.A.C.A. 0009	R 586	A	B 10	B 0	A	8.3	1.39	0	.098	0	.0058	0	0	1.0	5	240	26	4.28	.0058	8.02	6.20	9.00	0
N.A.C.A. 0012	R 585	A	C 10	C 0	A	8.4	1.66	0	.099	0	.0060	0	0	.6	3	277	26	4.32	.0060	10.69	8.27	12.00	0
N.A.C.A. 0015	R 586	A	D 10	D 0	A	8.6	1.66	0	.097	0	.0064	0	0	1.2	4	259	25	4.24	.0064	13.36	10.33	15.00	0
N.A.C.A. 0018	R 586	A	E 10	E 0	A	7.8	1.53	0	.096	0	.0070	0	0	1.7	4	219	25	4.20	.0070	16.04	12.40	18.00	0
N.A.C.A. 0021	R 460	A	F 10	F 1	A	8.3	1.48	0	.093	0	.0080	0	0	3.0	6	185	24	4.11	.0080	18.71	14.46	21.00	0
N.A.C.A. 0025	... ...	A		E 2	D	8.8	1.26	0	.085	0	.0094	0	0	2.7	5	134	25	3.82	.0094	22.27	17.22	25.00	0
N.A.C.A. 0030	... ...	A		...	D	8.4	1.06	0	.074	0	.0117	-.005	6.9	26	91	19	3.48	.0117	26.72	20.66	30.00	0
N.A.C.A. 2212	R 460	A	C 12	C 3	B	8.4	1.72	-1.8	.099	.12	.0062	-.029	.9	5	277	27	4.31	.0063	10.69	8.25	12.00	2
N.A.C.A. 2409	R 460	A	B 10	B 2	B	8.1	1.62	-1.7	.099	.08	.0060	-.044	.7	4	270	28	4.31	.0061	8.02	6.20	9.00	2
N.A.C.A. 2412	R 586	A	C 10	C 2	B	8.2	1.72	-2.0	.098	.14	.0061	-.043	.5	3	282	28	4.28	.0062	10.71	8.27	12.00	2
N.A.C.A. 2415	R 460	A	D 10	D 2	C	8.0	1.66	-1.7	.097	.10	.0058	-.010	1.4	5	244	28	4.24	.0079	13.39	10.34	15.00	2
N.A.C.A. 2418	R 460	A	E 10	E 2	C	8.0	1.53	-1.9	.094	.06	.0076	-.038	1.1	2	201	27	4.14	.0076	16.08	12.39	18.00	2
N.A.C.A. 4406	R 460	A	A 10	A	D	8.1	1.32	-3.9	.100	.32	.0062	-.087	.4	0	213	32	4.34	.0071	5.40	4.16	6.00	4
N.A.C.A. 4409	R 586	A	B 10	B 4	A	8.1	1.77	-3.9	.096	.26	.0066	-.038	.6	2	268	31	4.20	.0072	8.07	6.21	9.00	4
N.A.C.A. 4412	R 586	A	C 10	C 4	D	7.9	1.74	-4.0	.098	.32	.0071	-.038	.8	2	245	31	4.28	.0073	10.77	8.28	12.00	4
N.A.C.A. 4415	R 586	A	D 10	D 4	D	7.9	1.72	-4.0	.097	.22	.0076	-.085	1.0	1	226	31	4.24	.0079	13.45	10.34	15.00	4
N.A.C.A. 4418	R 460	A	E 10	E 4	D	8.1	1.57	-3.7	.092	.13	.0079	-.078	1.4	1	199	31	4.07	.0081	16.15	12.40	18.00	4
N.A.C.A. 4421	R 460	A	F 10	E 5	D	8.2	1.41	-3.4	.089	.08	.0088	-.071	1.9	2	160	32	3.96	.0089	18.79	14.48	21.00	4
N.A.C.A. 23006	R 610	A	A 12	A	D	8.3	1.17	-1.2	.100	.15	.0057	-.012	1.0	8	205	26	4.34	.0058	5.34	4.13	6.00	1.8
N.A.C.A. 23009	R 610	A	B 12	C 2	A	8.3	1.66	-1.1	.099	.08	.0059	-.009	.9	7	281	25	4.32	.0060	8.02	6.21	9.00	1.8
N.A.C.A. 23012	R 610	A	C 12	D 2	A	8.4	1.74	-1.2	.100	.08	.0060	-.008	1.2	7	260	25	4.34	.0061	10.69	8.25	12.00	1.8
N.A.C.A. 23015	R 610	A	D 12	D 2	A	8.4	1.73	-1.1	.098	.10	.0067	-.008	1.1	6	258	24	4.28	.0068	13.36	10.35	15.00	1.8
N.A.C.A. 23018	R 610	A	E 12	E 2	B	8.2	1.58	-1.2	.097	.08	.0074	-.006	1.7	6	214	24	4.24	.0074	16.04	12.39	18.00	1.8
N.A.C.A. 23021	R 610	A	F 12	E 2	B	8.2	1.50	-1.2	.092	.07	.0080	-.005	2.3	7	188	24	4.07	.0080	18.70	14.44	21.00	1.8
N.A.C.A. 43012	R 610	A	C 12	D 4	A	8.4	1.84	-2.3	.100	.26	.0068	-.019	1.0	7	271	27	4.34	.0071	10.69	8.26	12.00	3.7
N.A.C.A. 43015	R 610	A	D 12	D 4	A	8.3	1.76	-2.3	.101	.18	.0070	-.015	1.2	5	251	26	4.37	.0071	13.36	10.32	15.00	3.7
N.A.C.A. 43018	R 610	A	E 12	E 4	C	8.3	1.63	-2.4	.096	.16	.0078	-.013	1.8	6	209	26	4.20	.0079	16.03	12.40	18.00	3.7
N.A.C.A. 63012	R 610	A	C 12	D 6	A	8.3	1.84	-3.5	.100	.40	.0075	-.033	2.7	13	245	26	4.34	.0087	11.03	8.27	12.00	5.5
N.A.C.A. 63018	R 610	A	E 12	E 7	A	8.2	1.63	-3.4	.097	.15	.0080	-.020	2.1	6	204	26	4.24	.0081	16.04	12.44	18.00	5.5

1 Type of chord. See reference 16.
2 Type of pressure distribution. See reference 16.
3 Type of scale effect on maximum lift. A signifies practically no scale effect. For other designations, see reference 4.
4 Type of lift-curve peak as shown in the sketches:

  A   B   C   D

5 Turbulence factor is 2.64.
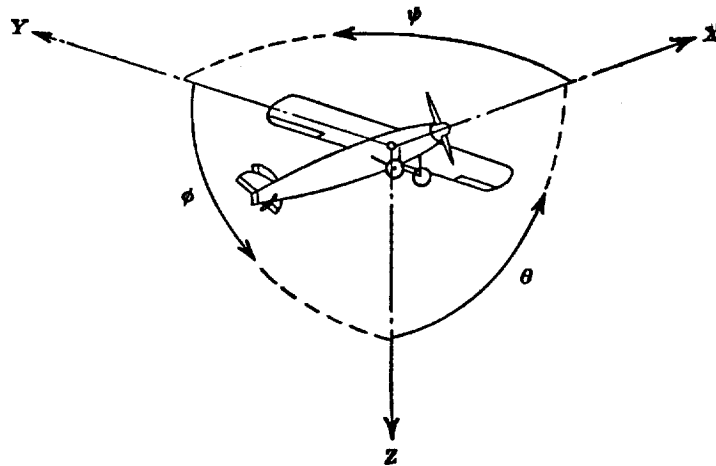
Positive directions of axes and angles (forces and moments) are shown by arrows

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

$$C_l = \frac{L}{qbS} \qquad C_m = \frac{M}{qcS} \qquad C_n = \frac{N}{qbS}$$
(rolling)   (pitching)   (yawing)

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

4. PROPELLER SYMBOLS

D, Diameter
p, Geometric pitch
p/D, Pitch ratio
V', Inflow velocity
V_s, Slipstream velocity

T, Thrust, absolute coefficient $C_T = \frac{T}{\rho n^2 D^4}$

Q, Torque, absolute coefficient $C_Q = \frac{Q}{\rho n^2 D^5}$

P, Power, absolute coefficient $C_P = \frac{P}{\rho n^3 D^5}$

C_s, Speed-power coefficient $= \sqrt[5]{\frac{\rho V^5}{P n^2}}$

η, Efficiency
n, Revolutions per second, r.p.s.

Φ, Effective helix angle $= \tan^{-1}\left(\frac{V}{2\pi rn}\right)$

5. NUMERICAL RELATIONS

1 hp. = 76.04 kg-m/s = 550 ft-lb./sec.
1 metric horsepower = 1.0132 hp.
1 m.p.h. = 0.4470 m.p.s.
1 m.p.s. = 2.2369 m.p.h.

1 lb. = 0.4536 kg.
1 kg = 2.2046 lb.
1 mi. = 1,609.35 m = 5,280 ft.
1 m = 3.2808 ft.