REPORT No. 530

CHARACTERISTICS OF THE N. A. C. A. 23012 AIRFOIL FROM TESTS IN THE FULL-SCALE AND VARIABLE-DENSITY TUNNELS

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SUMMARY

This report gives the results of tests in the N. A. C. A. full-scale and variable-density tunnels of a new wing section, the N. A. C. A. 23012, which is one of the more promising of an extended series of related airfoils recently developed. The tests were made at several values of the Reynolds Number between 1,000,000 and 8,000,000.

The new airfoil develops a reasonably high maximum lift and a low profile drag, which results in an unusually high value of the speed-range index. In addition, the pitching-moment coefficient is very small. The superiority of the new section over well-known and commonly used sections of small camber and moderate thickness is indicated by making a direct comparison with variable-density tests of the N. A. C. A. 2212, the well-known N. A. C. A. family airfoil that most nearly resembles it. The superiority is further indicated by comparing the characteristics with those obtained from full-scale-tunnel tests of the Clark Y airfoil.

A comparison is made between the results for the newly developed airfoil from tests in the N. A. C. A. variable-density and full-scale wind tunnels. When the results from the two tests are interpreted on the basis of an "effective Reynolds Number" to allow for the effects of turbulence, reasonably satisfactory agreement is obtained.

INTRODUCTION

As a continuation of the investigation recently completed of a large family of related airfoils (reference 1), two new series of related airfoils have been built and tested in the variable-density tunnel. The original investigation indicated that the effects of camber in relation to maximum lift coefficients are more pronounced when the maximum camber of the mean line of an airfoil section occurs either forward or aft of the usual positions. The after positions, however, are of lesser interest, owing to adverse effects on the pitching-moment coefficients, and the forward positions could not be satisfactorily investigated with the mean lines available in the original family.

One series of the new airfoils having the forward camber position appears to be of particular interest. The mean-line shapes for this series are designated by numbers thus: 10, 20, 30, 40, and 50, where the second digit (0) represents the numerical designation for the entire series and the first refers to the position of the maximum camber. These positions behind the leading edge are $0.05c$, $0.10c$, $0.15c$, $0.20c$, and $0.25c$, respectively.

The mean line having the shape designation 30 and a camber of approximately $0.02c$ (designated 230) when combined with the usual family thickness distribution of $0.12c$ maximum thickness produces the N. A. C. A. 23012 section. This airfoil section appeared to be one of the most promising investigated in the variable-density tunnel. A preliminary announcement of this section, then referred to as the "N. A. C. A. A–312", was made at the Ninth Annual Aircraft Engineering Research Conference in May 1934.

At the subsequent request of the Bureau of Aeronautics, Navy Department, a 6- by 36-foot model of the N. A. C. A. 23012 airfoil was tested in the N. A. C. A. full-scale tunnel to verify the aerodynamic characteristics found for this airfoil in the variable-density tunnel. This test was made possible through the cooperation of the Chance Vought Corporation, who constructed the wing and supplied it to the Committee for the purpose. The present report has been prepared to present and compare the results of the tests of the N. A. C. A. 23012 section made in the N. A. C. A. variable-density and full-scale tunnels and to compare the results with those for well-known sections.

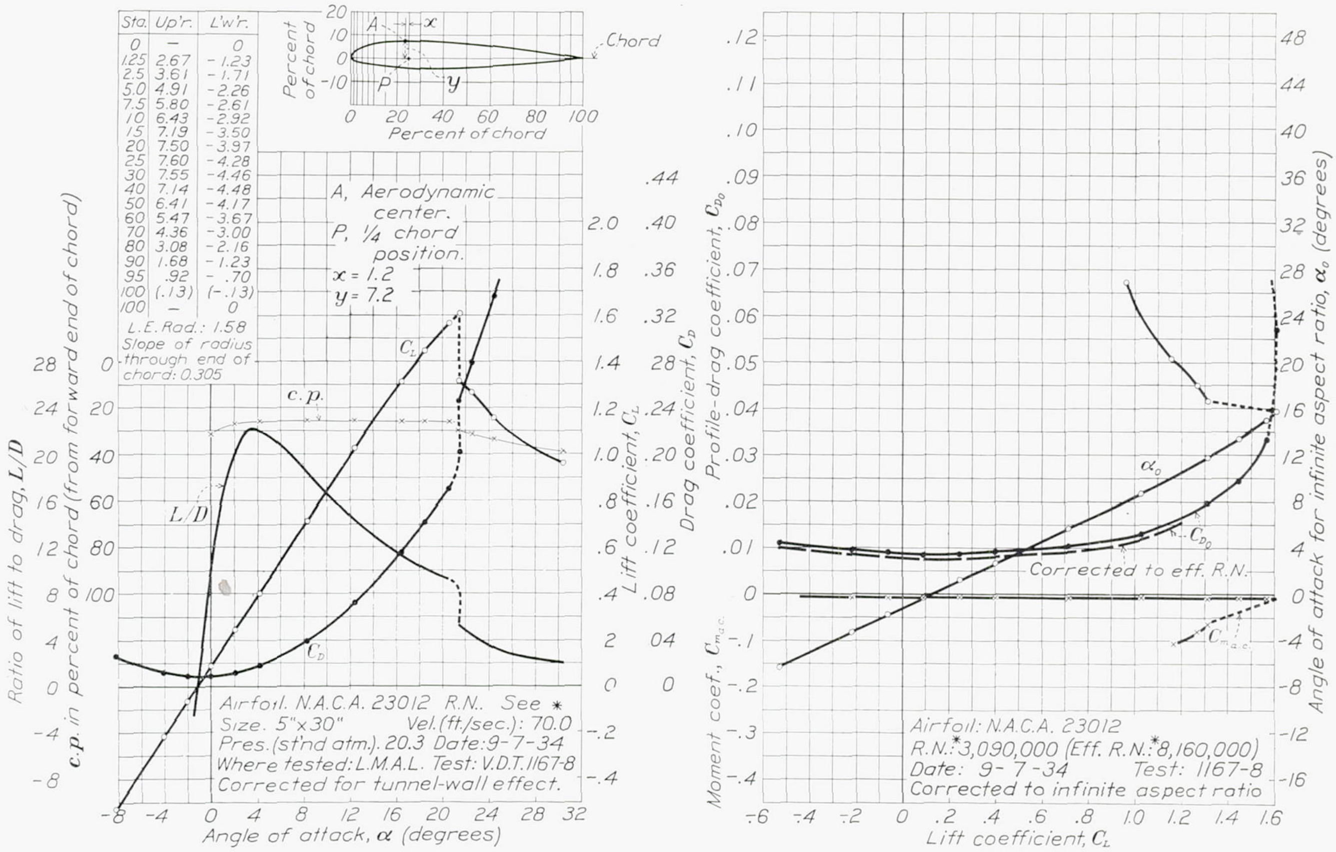

FIGURE 1.—The N. A. C. A. 23012 airfoil. Variable-density wind tunnel; standard test.

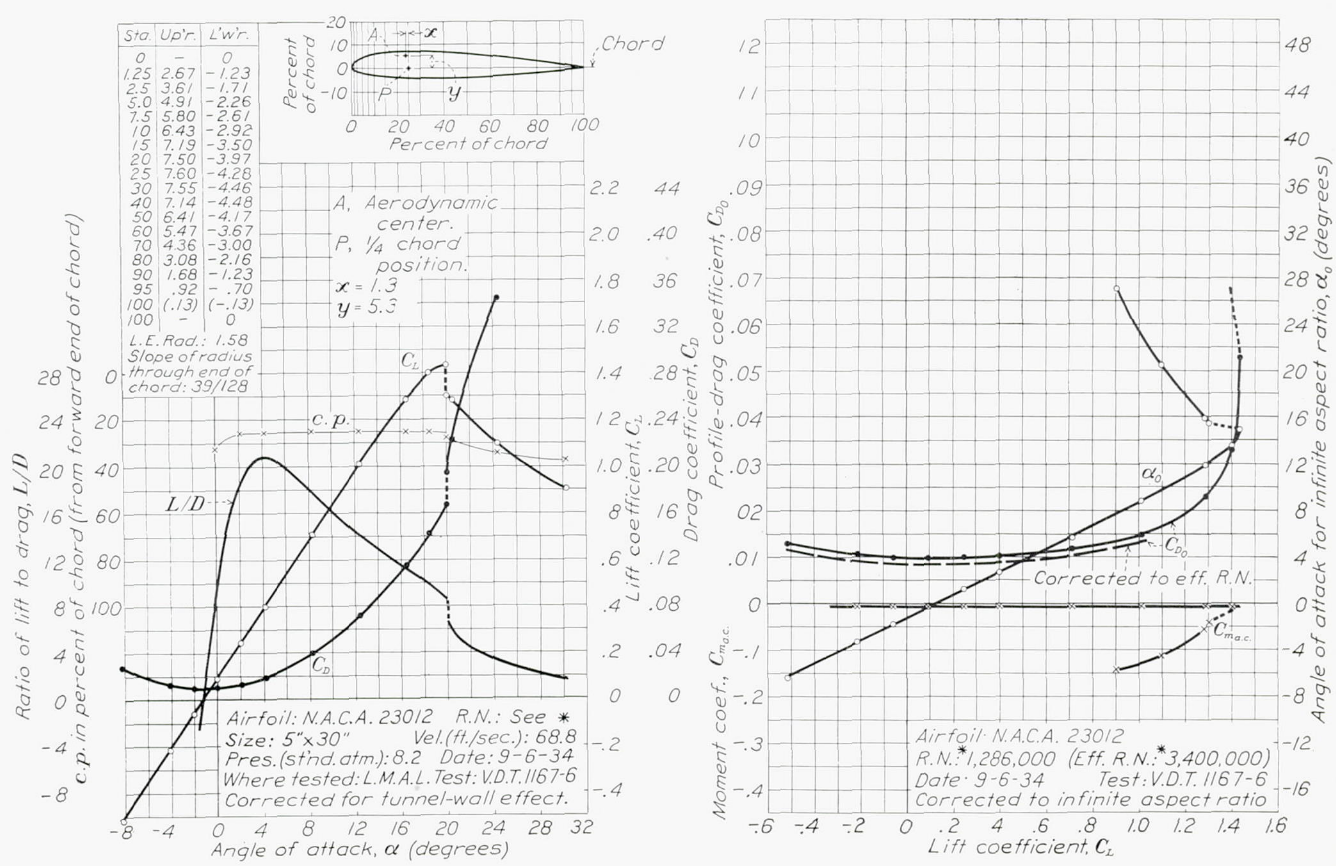

FIGURE 2.—The N. A. C. A. 23012 airfoil. Variable-density wind tunnel: reduced Reynolds Number.

DESCRIPTION OF THE AIRFOIL SECTION

The mean-line shape for the series to which the N. A. C. A. 23012 belongs was derived empirically to have a progressively decreasing curvature from the leading edge aft. Somewhat behind the maximum-camber position, the curvature of the mean line decreases to zero and remains zero from this point aft; that is, the mean line is straight from this point to the trailing edge. The 230 mean line has its maximum camber at a position $0.15c$ behind the leading edge. The camber is not exactly 2 percent but was determined by the condition that the ideal angle of attack for the mean line should correspond to a lift coefficient of 0.3, a value corresponding approximately to the usual conditions of high-speed or cruising flight. The N. A. C. A. 23012 airfoil results from the combination of the 230 mean line with the usual N. A. C. A. thickness distribution of $0.12c$ maximum thickness by the method described in reference 1. The airfoil profile and a table of ordinates at standard stations are presented in figure 1. In order to give a basis for the development of related airfoils of different thicknesses, the ordinates y of the N. A. C. A. 230 mean line are given as follows:

Nose, from $x=0$ to $x=m$

$$y=\frac{1}{6}\,k[x^3-3mx^2+m^2(3-m)x]$$

Tail, from $x=m$ to $x=1$

$$y=\frac{1}{6}\,k\,m^3(1-x)$$

where, for the 230 mean line, $m=0.2025$ and $k=15.957$.

VARIABLE-DENSITY-TUNNEL TESTS AND RESULTS

Routine measurements of lift, drag, and pitching moment were originally made at a Reynolds Number of approximately 3,000,000 to compare the various airfoils of the forward-camber series under the conditions of a standard 20-atmosphere test in the variable-density tunnel. Later the N. A. C. A. 23012 airfoil was retested as a part of a general investigation of scale effect. The data presented in this report were taken from the latter tests which were made at several values of the Reynolds Number between 42,400 and 3,090,000.

The test results obtained in connection with the forward-camber airfoil investigation, as well as the complete results of the scale-effect investigation, are omitted from this report but both sets of results will appear subsequently in reports on the respective subjects. Complete results are given, however, from tests at two values of the Reynolds Number (figs. 1 and 2). Some additional data taken from the available tests at other values of the Reynolds Number are also presented with the discussion to indicate the scale effect for some of the important characteristics.

Descriptions of the variable-density tunnel, methods of testing, standard airfoil models, and the accuracy of the tests are given in references 1 and 2. The systematic errors mentioned in reference 1 have since been largely eliminated by allowing for the deflection of the model supports and correcting for the errors involved in the measurement of the air velocity. As an aid in evaluating differences between results from the two tunnels, the estimated errors from reference 1 are reproduced as follows:

Quantity measured	Accidental errors	Errors due to support interference
α	±0.15°	±0.05°
$C_{L_{max}}$	.01 −.03	.00 −.02
$C_{m_{a.c.}}$	±.003	±.001
$C_{D_0}(C_L=0)$	.0006 −.0002	.0002 .0000
$C_{D_0}(C_L=1)$	.0015 −.0008	±.0010

FULL-SCALE-TUNNEL TESTS AND RESULTS

A description of the full-scale wind tunnel and equipment is given in reference 3. The N. A. C. A. 23012 airfoil was mounted in the tunnel on two supports

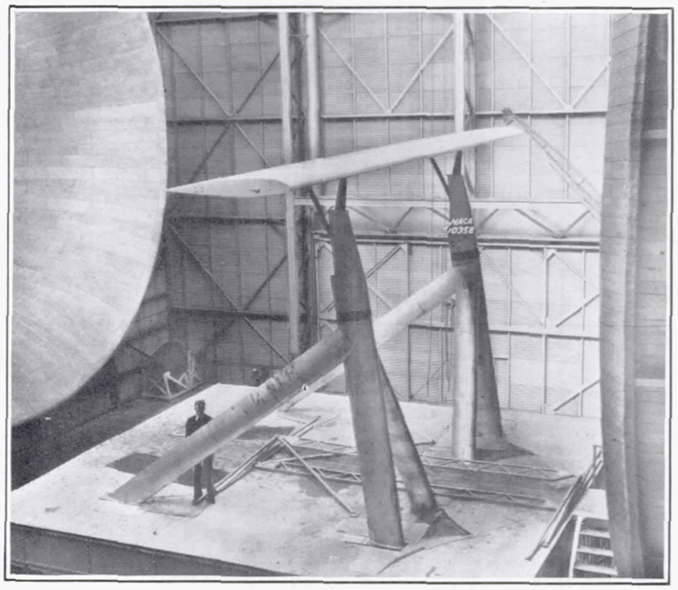

FIGURE 3.—The N. A. C. A. 23012 airfoil mounted in the full-scale wind tunnel.

that attached to the one-quarter-chord point (fig. 3). The general arrangement was similar to that used in testing a series of Clark Y airfoils (reference 4).

The airfoil had a chord of 6 feet and a span of 36 feet. The frame was constructed of wood and covered with sheet aluminum. The surface was smooth and the section throughout was not in error by more than ±0.06 of an inch from the specified ordinates.

The lift, drag, and pitching moments were measured throughout a range of angles of attack from −8°

to 25°. These tests were made at 5 different air speeds between 30 and 75 miles per hour corresponding to values of the Reynolds Number between 1,600,000 and 4,500,000. The maximum lift was not measured at speeds above 75 miles per hour as the wing was not designed for the loads under these conditions. Additional tests to determine the scale effect on minimum drag were made at several speeds up to 120 miles per hour corresponding to a Reynolds Number of 6,600,000.

The interference of the airfoil supports upon the airfoil was determined by adding a duplicate supporting strut at the center of the wing. This "dummy" support was not connected to the airfoil or to the balance and all changes in the measured forces with the strut in place could be attributed to its interference. Doubling the effect of this single dummy support was considered to account for the total interference of the two airfoil supports. All the data are corrected for wind-tunnel effects and tares. The corrections are the same as those used for the corresponding Clark Y airfoil (reference 4).

The results of the full-scale-tunnel tests of the N. A. C. A. 23012 airfoil are given in tables IV to VIII. The values of C_L, α, C_D, L/D, and *c. p.* are tabulated for the airfoil of aspect ratio 6 and values of α_0 and C_{D0} are given for the airfoil of infinite aspect ratio. Values of the pitching-moment coefficient about the aerodynamic center, $C_{m_{a.c.}}$, are considered independent of aspect ratio and are tabulated against C_L. The location of the aerodynamic center (x, y) is given as a fraction of the chord ahead and above the quarter-chord point. A typical plot of the data from table VI is given in figure 4.

Curves summarizing variations of these principal characteristics that change with Reynolds Number are given in figures 5 to 9. Curves obtained from similar full-scale-tunnel tests on the Clark Y airfoil are presented in these figures for purposes of comparison. These curves are presented in semilogarithmic form to assist in extrapolation to higher values of the Reynolds Number. Figure 5 shows the variation of the maximum lift coefficient for the two airfoils; the scale effect on the angle of attack at zero lift for the airfoil section is shown in figure 6; figure 7 gives the effect of Reynolds Number on the slope of the profile-lift curve; and figures 8 and 9 show, respectively, the scale-effect variation of the drag coefficient at zero lift and the minimum-profile-drag coefficient.

A detailed discussion of the precision of airfoil tests in the full-scale tunnel is given in reference 4. In brief, it may be mentioned that a consideration of all

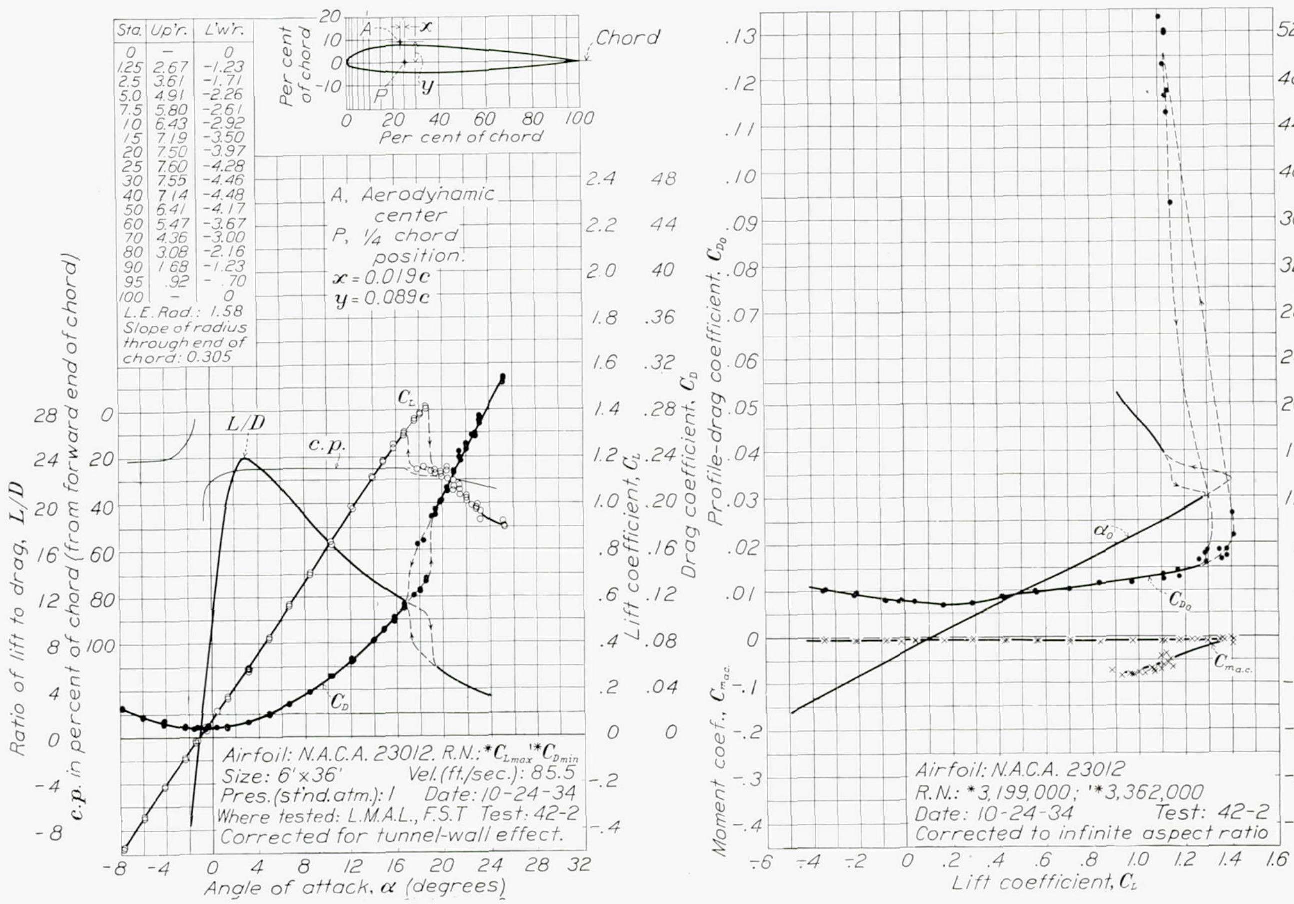

FIGURE 4.—The N. A. C. A. 23012 airfoil. Full-scale wind tunnel.

the contributing errors involved in these tests gives the following estimated precision:

$$\alpha = \pm 0.1^\circ$$

$$C_{L_{max}} = \pm 0.03$$

$$\frac{dC_L}{d\alpha_0} = \pm 0.0015 \text{ per degree}$$

$$C_{D_0}\ (C_L = \ 0) = \pm 0.0004$$

$$C_{D_0}\ (C_L = 1.0) = \pm 0.0015$$

$$C_{m_{a.c.}} = \pm 0.003$$

$$x = \pm 0.005 \text{ chord}$$

$$y = \pm 0.03 \text{ chord}$$

$$\left(\frac{L}{D}\right)_{max} = \pm 1.0$$

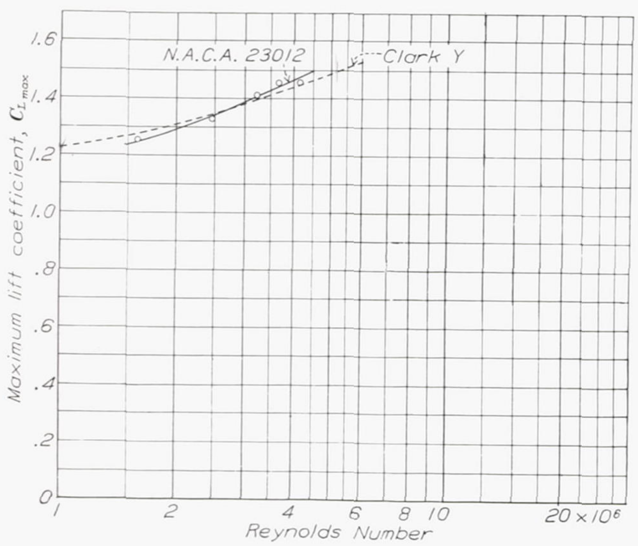

FIGURE 5.—Maximum lift coefficients. Variation with Reynolds Number from tests in the full-scale wind tunnel.

DISCUSSION

Comparison with the Clark Y.—The comparison between the new section and the Clark Y section is entirely based on the test results from the full-scale tunnel. The curves in figure 5 show that the maximum lift coefficients for the two airfoils differ by little more than the experimental error. The scale effect on the maximum lift coefficient for the new airfoil is, however, slightly greater than that for the Clark Y within the range of Reynolds Numbers tested. The results indicate that the coefficient for the N. A. C. A. 23012 is somewhat greater than that for the Clark Y at Reynolds Numbers above 3,000,000. A comparison of the shape of the lift curve of the 23012 (fig. 4) with that of the Clark Y (reference 4) shows that the new airfoil has a sharper break at maximum lift than does the Clark Y.

The curves of the angle of attack of zero lift for the two airfoils are shown in figure 6. The Clark Y has a

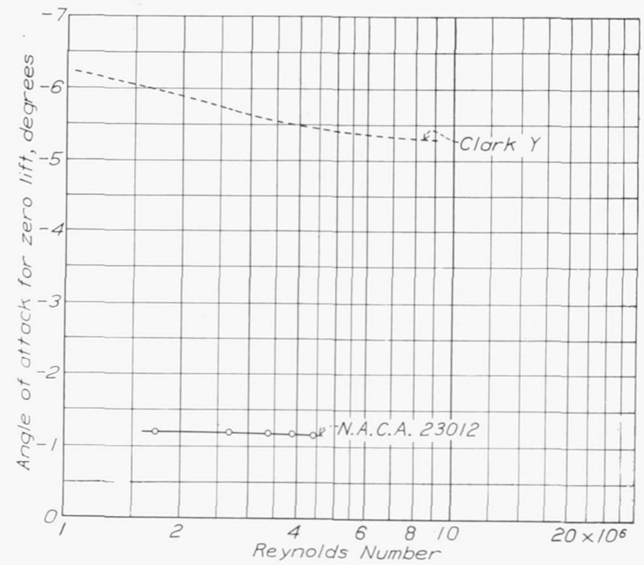

FIGURE 6.—Angle of attack for zero-lift variation. Variation with Reynolds Number from tests in the full-scale wind tunnel.

considerable scale effect; whereas the N. A. C. A. 23012 is unaffected by changes in Reynolds Number. At zero lift a large adverse gradient of pressure exists at the forward portion of the lower surface of the Clark Y that probably results in an early disturbance of the

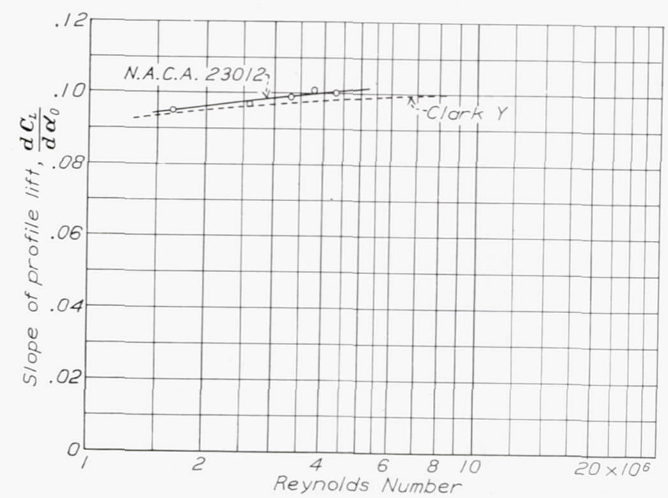

FIGURE 7.—Lift-curve slope. Variation with Reynolds Number from tests in the full-scale wind tunnel.

flow at the leading edge (reference 4). This condition of flow has a critical effect on the angle of zero lift and varies considerably with Reynolds Number. The N. A. C. A. 23012 airfoil has much less camber than the Clark Y and the general profile, which is more nearly symmetrical, sets up a flow about the leading

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edge that is not critical; hence, the effects of scale on the angle of zero lift should be small. This view is supported by the tests in the full-scale and variable-density tunnels.

Figure 7 shows that the slope of the lift curve for the N. A. C. A. 23012 airfoil is slightly higher than that for the Clark Y. Both sets of results indicate that the lift-curve slope increases slightly with Reynolds Number.

The curves of drag coefficient at zero lift (fig. 8) and minimum profile-drag coefficient (fig. 9) show that the drag of the N. A. C. A. 23012 airfoil is definitely lower than that of the Clark Y. These figures also indicate that the drag decreases more rapidly with an increase of Reynolds Number for the new airfoil than for the Clark Y. It should be mentioned that the minimum-profile-drag results are relatively inaccurate as compared with the drag at zero lift so that caution will be used in extrapolating them to higher values of the Reynolds Number.

The remaining important characteristics for one value of the Reynolds Number are presented for comparison in the following table. The method of obtaining the ratios of $C_{L_{max}}/C_{D_{0_{min}}}$ in the table is somewhat fallacious as both the lift and drag values were taken at the same Reynolds Number; whereas in flight the two conditions occur at different air speeds. The comparative ratios indicate, however, that the speed range of the new airfoil is much better than that of the Clark Y. As the result of the smaller camber of the N. A. C. A. 23012 as compared with the Clark Y, $C_{L_{opt}}$, the lift coefficient corresponding to the minimum-profile-drag coefficient, might be expected to be considerably less. Airfoils such as the N. A. C. A. 23012 having the camber well forward tend, however, to have higher optimum lift coefficients than airfoils with usual mean-line shapes. Actually, table I indicates that the optimum lift coefficients for the two sections are nearly equal.

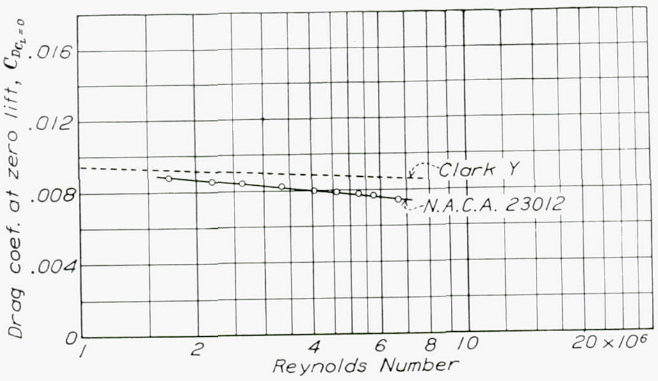

FIGURE 8.—Drag coefficient at zero lift. Variation with Reynolds Number from tests in the full-scale wind tunnel.

TABLE I

FULL-SCALE WIND-TUNNEL TESTS COMPARING N. A. C. A. 23012 AND CLARK Y AIRFOILS

At R. N. = 4,500,000

Characteristic	N. A. C. A. 23012	Clark Y
$C_{L_{max}}$	1.50	1.47
α_{L_0} (degrees)	−1.2	−5.5
$a_0=\frac{dC_L}{d\alpha_0}$ (per degree)	.101	.098
$C_{D_{0_{min}}}$	.0069	.0086
$C_{L_{opt}}$	[1] .19	[1] .20
$C_{m_{a.c.}}$	−[1] .007	−[1] .075
Aerodynamic center $\frac{x}{c}$	[1] .015	[1] .025
Aerodynamic center $\frac{y}{c}$	[1] .06	[1] .11
$C_{L_{max}}/C_{D_{0_{min}}}$	208	161
$C_{D_{min}}$	.0078	.0088
L/D_{max}	25.0	21.5
C_L at $(L/D)_{max}$	[1] .3	[1] .4
c. p. forward position (percent c)	[1] 25.0	[1] 29.5
c. p. at C_L=0.3 (percent c)	[1] 25.7	[1] 48.5

[1] No consistent variation with changes in Reynolds Number.

Following a recently adopted standard procedure, pitching-moment coefficients are referred to the aerodynamic center rather than to the quarter-chord point. This procedure is considered preferable because, by definition, a constant pitching-moment coefficient is obtained throughout the flight range. The average values of the pitching-moment coefficients thus found for the two airfoils together with the mean location of the aerodynamic center are given in the table. The coefficient for the N. A. C. A. 23012 airfoil is very small and is only about 9 percent of the value found for the Clark Y.

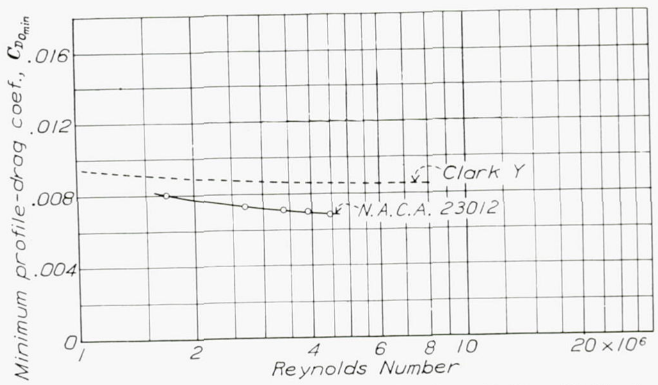

FIGURE 9.—Minimum profile-drag coefficient. Variation with Reynolds Number from tests in the full-scale wind tunnel.

In brief, it may be concluded from the results that the N. A. C. A. 23012 airfoil with the exception of a sharper break in the lift curve is superior in all respects to the Clark Y airfoil.

Comparison with the N. A. C. A. 2212.—Another comparison between the new section and a well-known section is afforded by table II, in which are compared the important characteristics of the N. A. C. A. 23012 and the N. A. C. A. 2212 sections. For this purpose only standard 20-atmosphere test results from the variable-density tunnel corresponding to an "effective Reynolds Number" (discussed later) of approximately 8,000,000 are employed. These are the usual test results from the standard plot in figure 2 except that the drag coefficients have been reduced, as indicated in this figure and discussed later, to allow for the reduction in the skin-friction drag to be expected in passing from the test Reynolds Number to the higher effective Reynolds Number. The Reynolds Number of 8,000,000 at which the comparison is made, corresponds approximately to that for a modern two-engine transport airplane flying near its minimum speed.

TABLE II
COMPARISON OF N. A. C. A. 23012 AND 2212 AIRFOILS

Characteristic	N. A. C. A. 23012	N. A. C. A. 2212
Effective R. N.	8, 160, 000	8, 500, 000
Test R. N.	3, 090, 000	3, 220, 000
$C_{L_{max}}$	1. 61	1. 60
α_{L_0} (degrees)	−1. 2	−1. 8
$a_0=\frac{dC_L}{d_{\alpha_0}}$ (per degree)	. 104	. 103
$C_{D_{0min}}$	. 0074	. 0076
$C_{L_{opt}}$	. 16	. 17
$C_{m_{a.c.}}$	−. 008	−. 029
Aerodynamic center $\frac{x}{c}$	. 012	009
Aerodynamic center $\frac{y}{c}$	. 07	. 05
$C_{L_{max}}/C_{D_{0_{min}}}$	217	210
$C_{D_{min}}$	. 0077	. 0077
$(L/D)_{max}$	23. 8	23. 9
C_L at $(L/D)_{max}$	. 36	. 40
c. p. forward position (percent c)	25. 6	27. 0
c. p. at ¼ $C_{L_{max}}$ (percent c)	25. 9	31. 6

All the important characteristics of the two sections are compared in a form that requires practically no discussion. It will be noted that the characteristics of the N. A. C. A. 23012 are approximately the same as, or slightly superior to, those of the N. A. C. A. 2212 except that the pitching-moment characteristics of the new airfoil are markedly superior. The N. A. C. A. 23012 airfoil should therefore be used in preference to the N. A. C. A. 2212 for airplanes requiring this general type of airfoil section.

Comparison of variable-density-tunnel and full-scale-tunnel results.—The comparison of the results from the two tunnels is made first at one value of the "effective Reynolds Number" by means of table III, which lists all the important characteristics at one value of the Reynolds Number, and later by a more detailed comparison of the characteristics that show marked variations with Reynolds Number within the full-scale range. In the table, the results from the variable-density tunnel were taken directly from figure 2. The results from the full-scale tunnel were taken from curves representing variations of the different characteristics with Reynolds Number.

TABLE III
COMPARISON OF RESULTS FROM TWO TUNNELS
N. A. C. A. 23012 AIRFOILS

Characteristic	Full-scale tunnel	Variable-density tunnel
Effective R. N.	3, 400, 000	3, 400, 000
Test R. N.	3, 090, 000	1, 286, 000
$C_{L_{max}}$	1. 40	1. 43
α_{L_0} (degrees)	−1. 2	−1. 2
$a_0=\frac{dC_L}{d\alpha_0}$ (per degree)	. 099	. 102
$C_{D_{0min}}$	. 0072	. 0084
$C_{L_{opt}}$	. 19	. 16
$C_{m_{a.c.}}$	−. 007	−. 007
Aerodynamic center $\frac{x}{c}$	. 015	. 013
Aerodynamic center $\frac{y}{c}$	. 06	. 05
$C_{D_{min}}$	. 0081	. 0086
$(L/D)_{max}$	24. 1	22. 5
C_L at $(L/D)_{max}$	. 30	. 40

The method of comparison employed utilizes the concept of an effective Reynolds Number in order to allow for the effects of the turbulence present in the wind tunnels. This method, which was first proposed in reference 5 and is discussed in the succeeding paragraphs, appears to be the best at present available for the interpretation of wind-tunnel results as applied to flight.

Marked scale effects, such as the rapid decrease of drag coefficient with Reynolds Number for the sphere, the rapid increase of the maximum lift coefficient for some airfoils, and the increase of drag coefficient for skin-friction plates, are associated with a transition of the boundary-layer flow from laminar to turbulent. Numerous experiments including Reynolds' original classic experiments have indicated that the transition occurs at progressively lower values of the Reynolds Number as the "unsteadiness", or initial turbulence, of the general air stream is increased. Hence, when turbulence is introduced into the air stream of a wind tunnel, these marked scale effects appear at a progressively lower value of the Reynolds Number as the air-stream turbulence is increased. In a wind tunnel having turbulence, the flow that is observed at a given Reynolds Number therefore corresponds approximately to the flow that would be observed in a turbulence-free stream at a higher value of the Reynolds Number. The observed coefficients and scale effects likewise correspond more nearly to a higher value of the Reynolds Number in free air than to the actual test Reynolds Number in the turbulent stream. It is then advisable to refer to this higher value of the Reynolds Number at which corresponding flows would be observed in free air as the "effective Reynolds Number" of the test and to make comparisons and apply the tunnel data to flight at that value of the Reynolds Number.

As regards the relation of the effective Reynolds Number to the test Reynolds Number, it appears that a factor, which will be referred to as the "turbulence factor", may be applied to the test Reynolds Number to obtain the effective Reynolds Number. The value of the turbulence factor for a given wind tunnel may be determined by a comparison of sphere drag tests or airfoil maximum-lift tests in the wind tunnel and in flight. Because the factors determined by the two methods might not agree, the airfoil method is considered preferable; but adequate data on maximum lift coefficients are not available for making the comparison between both the full-scale tunnel and the variable-density tunnel and flight by this method. A value of the factor of 2.4 was tentatively established between the variable-density tunnel and the full-scale tunnel by a comparison of tests of Clark Y airfoils in both tunnels. This value was employed in reference 5, assuming the factor for the full-scale tunnel to be unity (no turbulence).

The assumption that the factor is unity for the full-scale tunnel is approximately correct because differences in the turbulence between the full-scale tunnel and flight produce only small changes in the

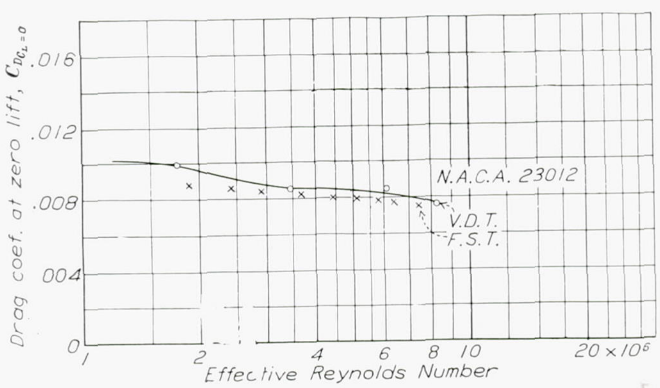

FIGURE 10.—Drag coefficient at zero lift. Comparison of results from variable-density and full-scale wind tunnels.

maximum lift coefficient, probably within the experimental accuracy for most airfoils. Recent comparative sphere tests in the full-scale tunnel and in flight have, however, indicated that the factor for the full-scale tunnel may be taken as approximately 1.1 instead of 1.0 in deriving the factor for the variable-density tunnel. The corresponding value for the variable-density tunnel then becomes 2.4×1.1 or 2.64. These turbulence factors are used throughout this report to derive values of the effective Reynolds Number. Incidentally, it may be noted that sphere tests in the variable-density tunnel and in flight indicate values for the turbulence factor in approximate agreement with the values given; the actual values derived from sphere tests are, however, dependent on the size of the spheres employed.

The results of the test at a given Reynolds Number might be directly applied at the higher effective Reynolds Number; however, one change for which approximate allowance may be made is to be expected in passing to the higher Reynolds Number. The part of the drag associated with skin friction is known to decrease with the Reynolds Number. Therefore, although the conditions as applying to the transition from laminar to turbulent flow may be considered as reproducing those at the higher effective Reynolds Number, the value of the drag coefficient should be reduced in passing to the effective Reynolds Number. The actual value of this increment that should be subtracted is somewhat uncertain, but a value determined as suggested in reference 5 is used in this report for correcting the variable-density-tunnel results. The evaluation of the increment is based on the assumption that at the higher values of the Reynolds Number encountered in flight, when the profile-drag coefficient is of importance, most of the profile drag is due to skin friction from the turbulent boundary layer. The increment may then be determined from Prandtl's analysis of the completely turbulent skin-friction layer (reference 6) as the amount by which the skin-friction-drag coefficient decreases in the Reynolds Number range from the test Reynolds Number to the effective Reynolds Number. Thus, when the standard airfoil test results from the variable-density tunnel at a test Reynolds Number of approximately 3,000,000 are applied to flight at the effective Reynolds Number of approximately 8,000,000, the measured profile-drag coefficients should be corrected by deducting the increment 0.0011.

It should be emphasized that the values employed in this report for both the turbulence factor and the drag increment should be considered as only tentative approximations. The values may be revised as the result of further tests now on the program at the Committee's laboratory. In particular, the fact that the skin-friction coefficient for airfoils tends to be higher than for flat plates (upon which the present value of drag increment is based) agrees with the present results in indicating that the drag increment may be too low.

The comparison between the profile-drag results from the two tunnels may be made on the above-described basis by comparing the dotted curve in figure 2 with the profile-drag curve from the full-scale tunnel in figure 4, although the values of the effective Reynolds Number differ slightly. A better comparison is afforded by the curves in figures 10 and 11 representing variations of certain characteristics with the effective Reynolds Number. It will be noted that the results from the full-scale tunnel indicate somewhat lower profile-drag coefficients but that the differences are smaller at zero lift where the results are more reliable owing to the absence of several more or less uncertain corrections involved in deducing the profile-drag coefficient when the airfoil is developing lift.

The values of the maximum lift coefficient are compared in figure 12 by means of curves representing variations with the Reynolds Number. The agreement between the results from the two tunnels, considering the difficulties of measurement, is reasonably satisfactory. The small discrepancy that remains may indicate either that the value of the turbulence factor should be modified or possibly that an increment corresponding to that used with the drag should be employed.

For the remaining characteristics, tabular values may be directly compared. The results from both tunnels agree in indicating that within the flight range of values of the Reynolds Number investigated the following characteristics for the N. A. C. A. 23012 section show no variations with Reynolds Number sufficiently marked to require their being taken into account in engineering work: angle of zero lift, α_{L_0}; optimum lift coefficient, $C_{L_{opt}}$; pitching-moment co-

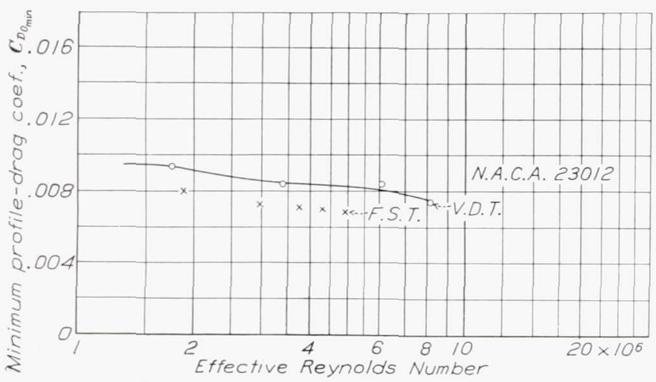

FIGURE 11.—Minimum profile-drag coefficient. Comparison of results from variable-density and full-scale wind tunnels.

efficient about the aerodynamic center, $C_{m_{a.c.}}$; and the corresponding aerodynamic-center position. For these characteristics, the tabular values presented in table III may therefore be directly compared. It will be noted that, in all cases, the values obtained from the two tunnels show reasonably good agreement. The lift-curve slope a_0 shows a slight increase with increasing Reynolds Number in both wind tunnels.

CONCLUSIONS

1. The N. A. C. A. 23012 airfoil section shows characteristics that are generally superior to those of well-known and commonly used sections of small or medium camber and moderate thickness.

2. When airfoil test results at large values of the Reynolds Number from the N. A. C. A. variable-density and full-scale tunnels are interpreted on the basis of an "effective Reynolds Number" to allow for the effects of turbulence, reasonably satisfactory

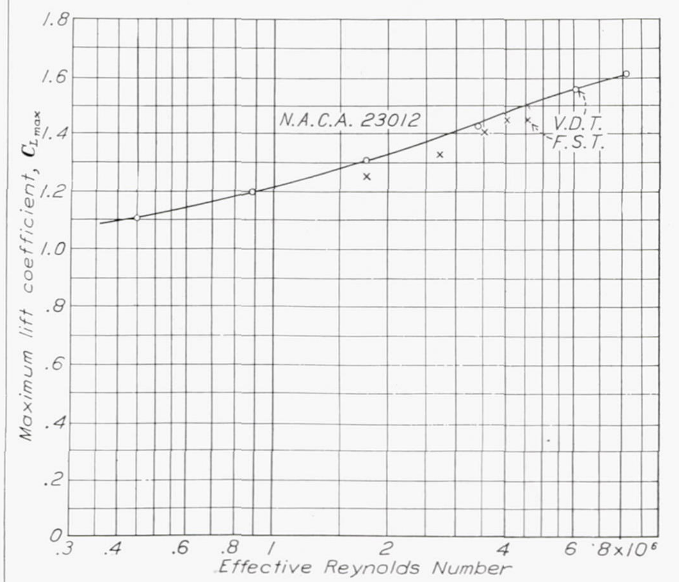

FIGURE 12.—Maximum lift coefficient. Comparison of results from variable-density and full-scale wind tunnels.

agreement may be expected, at least for efficient airfoils of moderate thickness.

LANGLEY MEMORIAL AERONAUTICAL LABORATORY,
NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS,
LANGLEY FIELD, VA., *March 1, 1935.*

REFERENCES

1. Jacobs, Eastman N., Ward, Kenneth E., and Pinkerton, Robert M.: The Characteristics of 78 Related Airfoil Sections from Tests in the Variable-Density Wind Tunnel. T. R. No. 460, N. A. C. A., 1933.
2. Jacobs, Eastman N., and Abbott, Ira H.: The N. A. C. A. Variable-Density Wind Tunnel. T. R. No. 416, N. A. C. A., 1932.
3. DeFrance, Smith J.: The N. A. C. A. Full-Scale Wind Tunnel. T. R. No. 459, N. A. C. A., 1933.
4. Silverstein, Abe: Scale Effect on Clark Y Airfoil Characteristics from N. A. C. A. Full-Scale Wind-Tunnel Tests. T. R. No. 502, N. A. C. A., 1934.
5. Jacobs, Eastman N.: Recent Progress Concerning the Aerodynamics of Wing Sections. Paper presented before A. S. M. E., Berkeley, California, June 19, 1934 (available from the Office of Aeronautical Intelligence, N. A. C. A., Washington, D. C.).
6. Prandtl, L.: Zur Turbulenten Strömung in Rohren und Längs Platten. Ergb. Aero. Vers. zu Göttingen, IV Lieferung, 1932, pp. 18–29.

TABLE IV

FULL-SCALE WIND-TUNNEL DATA

N. A. C. A. 23012

AIRFOIL CHARACTERISTICS

RN: Zero lift—1,726,000; Max. lift—1,593,000

C_L	α	C_D	L/D	c. p.	C_{D_0}	α_0	$C_{m_{a.c.}}$
	°			*Percent*		°	$x=0.0095c$ $y=0.023c$
−0.2	−4.0	0.0126	--------	18.0	0.0104	−3.3	−0.012
−.1	−2.6	.0104	--------	12.0	.0098	−2.3	−.013
0	−1.2	.0088	0	--------	.0088	−1.2	−.012
.1	.2	.0088	11.4	38.5	.0082	−.1	−.013
.2	1.7	.0103	19.4	31.2	.0080	1.0	−.014
.3	3.2	.0131	22.9	29.0	.0081	2.0	−.014
.4	4.5	.0173	23.1	27.9	.0084	3.0	−.014
.5	5.9	.0228	21.9	27.0	.0089	4.0	−.014
.6	7.2	.0300	20.0	26.2	.0098	5.0	−.013
.7	8.5	.0400	18.3	26.0	.0107	6.0	−.012
.8	10.0	.0485	16.5	25.6	.0128	7.1	−.011
.9	11.4	.0597	15.1	25.5	.0146	8.2	−.011
1.0	12.8	.0723	13.8	25.5	.0166	9.3	−.011
1.1	14.3	.0860	12.8	25.5	.0186	10.4	−.011
1.2	15.9	.1020	11.8	25.5	.0208	11.7	−.012
1.26	16.9	.112	11.3	25.5	.0250	12.5	−.012
1.2	17.5	.140	8.6	25.6	.0590	13.1	−.021
1.1	19.6	.194	5.7	30.0	.1267	15.7	−.056
1.0	22.6	.251	4.0	33.0	.195	19.0	−.086
.9	25.8	.320	2.8	35.5	.275	22.5	−.107
.8	27.1	.384	2.1	38.0	.348	24.1	−.118

TABLE V

FULL-SCALE WIND-TUNNEL DATA

N. A. C. A. 23012

AIRFOIL CHARACTERISTICS

RN: Zero lift—2,680,000; Max. lift—2,460,000

C_L	α	C_D	L/D	c. p.	C_{D_0}	α_0	$C_{m_{a.c.}}$
	°			*Percent*		°	$x=0.0145$ $y=0.0680$
−0.2	−4.0	0.0120	--------	19.0	0.010	3.3	−0.010
−.1	−2.6	.0910	--------	13.0	.090	−2.2	−.009
0	−1.2	.0084	0	--------	.0084	−1.2	−.009
.1	.2	.0081	12.4	33.5	.0075	−.1	−.008
.2	1.7	.0094	21.3	28.0	.0072	1.0	−.008
.3	3.1	.0125	24.0	25.5	.0075	2.0	−.009
.4	4.5	.0170	22.8	25.1	.0081	3.0	−.010
.5	5.9	.0240	20.7	25.1	.010	4.1	−.010
.6	7.3	.0320	18.9	25.1	.012	5.1	−.011
.7	8.6	.040	17.5	25.1	.012	6.1	−.011
.8	10.0	.049	16.2	25.1	.013	7.1	−.011
.9	11.4	.059	15.2	25.1	.014	8.1	−.010
1.0	12.8	.071	14.2	25.1	.015	9.1	−.009
1.1	14.1	.083	13.2	25.1	.015	10.1	−.009
1.2	15.5	.097	12.3	25.1	.017	11.1	−.007
1.33	17.8	.121	11.0	25.1	.022	13.2	−.007
1.2	18.0	.152	7.9	25.2	.072	13.9	−.032
1.1	20.3	.210	5.2	29.3	.143	16.5	−.054
1.0	22.1	.246	4.0	32.0	.190	18.5	−.076

TABLE VI.—FULL-SCALE WIND-TUNNEL DATA

N. A. C. A. 23012

AIRFOIL CHARACTERISTICS

RN: Zero lift—3,362,000; Max. lift—3,199,000

C_L	α	C_D	L/D	c. p.	C_{D_0}	α_0	$C_{m_{a.c.}}$
	°			*Percent*		°	$x=0.0191$ $y=0.0887$
−0.2	−4.0	0.0110	--------	20.5	0.0090	−3.3	−0.005
−.1	−2.6	.0090	--------	10.7	.0085	−2.2	−.005
0	−1.2	.0082	0	--------	.0082	−1.2	−.006
.1	.3	.0080	12.5	29.0	.0074	−.1	−.006
.2	1.7	.0094	21.3	26.5	.0072	.9	−.005
.3	3.1	.0125	24.0	25.0	.0075	1.9	−.006
.4	4.4	.0175	22.8	25.0	.0086	2.9	−.007
.5	5.8	.0230	21.7	25.0	.0091	3.9	−.008
.6	7.1	.0300	10.0	25.0	.0101	4.9	−.007
.7	8.4	.0380	18.4	25.0	.0107	5.9	−.008
.8	9.8	.0470	17.0	25.1	.0113	6.9	−.008
.9	11.1	.0575	15.6	25.1	.0121	7.9	−.008
1.0	12.4	.0682	14.7	25.1	.0125	8.9	−.007
1.1	13.8	.0805	13.6	25.2	.0130	9.9	−.006
1.2	15.2	.0945	12.7	25.2	.0142	11.0	−.006
1.3	16.7	.1102	11.8	25.2	.0160	12.1	−.005
1.41	18.6	.134	10.5	26.0	.023	13.5	−.007
1.3	18.9	.153	8.5	27.0	.065	14.2	−.021
1.2	19.0	.180	6.7	28.0	.100	14.8	−.034
1.1	20.3	.212	5.2	30.0	.145	16.3	−.055
1.0	22.3	.252	4.0	31.3	.194	18.8	−.072

TABLE VII.—FULL-SCALE WIND-TUNNEL DATA

N. A. C. A. 23012

AIRFOIL CHARACTERISTICS

RN: Zero lift—3,906,000; Max. lift—3,658,000

C_L	α	C_D	L/D	c. p.	C_{D_0}	α_0	$C_{m_{a.c.}}$
	°			*Percent*		°	$x=0.0147$ $y=0.058$
−2.0	−4.0	0.0114	--------	20.0	0.0092	−3.3	−0.007
−.1	−2.6	.0090	--------	15.5	.0084	−2.3	−.008
0	−1.2	.0080	0	--------	.0080	−1.1	−.008
.1	.3	.0080	12.5	31.9	.0074	.0	−.007
.2	1.8	.0092	21.7	27.2	.0070	1.0	−.008
.3	3.1	.0123	24.4	26.5	.0073	2.1	−.009
.4	4.5	.0170	23.6	25.7	.0081	3.0	−.008
.5	5.8	.0228	21.9	25.5	.0089	4.0	−.008
.6	7.1	.0300	20.0	25.4	.0099	5.0	−.009
.7	8.4	.0380	18.4	25.2	.0107	6.0	−.008
.8	9.7	.0470	17.0	25.2	.0113	6.9	−.009
.9	11.0	.0570	15.8	25.2	.0119	7.8	−.009
1.0	12.3	.0660	14.7	25.3	.0121	8.8	−.009
1.1	13.7	.0800	13.75	25.3	.0125	9.7	−.009
1.2	15.1	.0940	12.8	25.3	.0137	10.7	−.009
1.3	16.6	.1105	11.7	25.3	.0165	11.9	−.009
1.4	18.1	.1285	10.9	25.4	.0194	13.0	−.008
1.46	19.2	.1450	10.1	25.4	.0261	13.8	−.007
1.2	19.6	.1943	6.1	27.0	.1140	15.5	−.039
1.1	20.7	.223	4.9	30.0	.155	16.8	−.063
1.0	22.6	.263	3.8	32.0	.207	19.1	−.079

TABLE VIII

FULL-SCALE WIND-TUNNEL DATA

N. A. C. A. 23012

AIRFOIL CHARACTERISTICS

RN: Zero lift—4,455,000; Max. lift—4,143,000

C_L	α	C_D	L/D	c. p.	C_{D_0}	α_0	$C_{m_{a.c.}}$
	°			*Percent*		°	$x=0.014$ $y=0.049$
−0.2	−3.9	0.0112	--------	18.8	0.0090	−3.2	−0.008
−.1	−2.5	.0090	--------	14.0	.0084	−2.2	−.009
0	−1.2	.0079	0	--------	.0079	−1.2	−.009
.1	.2	.0079	12.67	32.0	.0073	−.2	− 008
.2	1.6	.0090	22.2	27.8	.0068	.8	−.008
.3	3.0	.0120	25.0	26.0	.0070	1.8	−.007
.4	4.3	.0167	23.8	25.5	.0078	2.8	−.007
.5	5.7	.0228	21.9	25.2	.0089	3.8	−.007
.6	7.0	.0298	20.1	25.0	.0097	4.9	−.006
.7	8.3	.0378	18.5	25.0	.0105	5.9	−.007
.8	9.7	.0467	17.1	25.0	.0110	6.9	−.007
.9	11.0	.0565	16.0	25.0	.0114	7.9	−.005
1.0	12.3	.0673	14.9	25.0	.0116	8.9	−.007
1.1	13.7	.0796	13.8	25.0	.0121	9.8	−.006
1.2	15.1	.0928	12.9	25.1	.0125	10.8	−.008
1.3	16.4	.1080	12.0	25.2	.0139	11.8	−.009
1.4	17.9	.1260	11.1	25.4	.0169	13.0	−.009
1.46	19.2	.144	10.1	25.4	.0251	13.9	−.010
1.2	19.6	.197	6.1	26.2	.1168	15.4	−.037
1.1	21.0	.229	4.8	30.0	.162	17.1	−.067