NATIONAL ADVISORY COMMITTEE
FOR AERONAUTICS

REPORT No. 628

AERODYNAMIC CHARACTERISTICS
OF A LARGE NUMBER OF AIRFOILS TESTED IN THE
VARIABLE-DENSITY WIND TUNNEL

BY ROBERT M. PINKERTON and HARRY GREENBERG

1948
### AERONAUTIC SYMBOLS

#### 1. FUNDAMENTAL AND DERIVED UNITS

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Unit</th>
<th>Abbreviation</th>
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<td>ft</td>
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#### 2. GENERAL SYMBOLS

- **W**: Weight
- **F**: Static pressure
- **g**: Standard acceleration of gravity, 9.8067 m/s²
- **m**: Mass
- **I**: Moment of inertia
- **C**: Coefficient of viscosity

#### 3. AERODYNAMIC SYMBOLS

- **S**: Area
- **A**: Span
- **C**: Chord
- **V**: True air speed
- **q**: Dynamic pressure, \( \frac{1}{2} \rho V^2 \)
- **L**: Lift, absolute coefficient, \( C_L = \frac{L}{\frac{1}{2} \rho V^2 A} \)
- **D**: Drag, absolute coefficient, \( C_D = \frac{D}{\frac{1}{2} \rho V^2 A} \)
- **D_p**: Profile drag, absolute coefficient, \( C_{D_p} = \frac{D_p}{\frac{1}{2} \rho V^2 A} \)
- **D_i**: Induced drag, absolute coefficient, \( C_{D_i} = \frac{D_i}{\frac{1}{2} \rho V^2 A} \)
- **C**: Center of-pressure coefficient (ratio of distance from leading edge to chord length)
- **α**: Angle of attack
- **β**: Angle of sideslip
- **γ**: Angle of attack, minimum aspect ratio
- **δ**: Angle of attack, absolute (measured from zero lift position)
- **θ**: Phase-path angle
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LABORATORIES, LANGLEY FIELD, VA.

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By Robert M. Pinkerton and Harry Greenberg

SUMMARY

The aerodynamic characteristics of a large number of miscellaneous airfoils tested in the variable-density tunnel have been reduced to a comparable form and are published in this report for convenient reference. Plots of the standard characteristics are given for each airfoil and, in addition, the important characteristics are given in tabular form. Included also is a tabulation of important characteristics for the related airfoils reported in N. A. C. A. Report No. 460.

This report, in conjunction with N. A. C. A. Report No. 610, makes available in comparable and convenient form the aerodynamic data for airfoils tested in the variable-density tunnel since January 1, 1931.

INTRODUCTION

A large number of miscellaneous airfoils not included in the systematic investigations reported in references 1 and 2 have been tested in the variable-density tunnel. The larger part of these airfoils consists of unrelated sections, tests of which were requested by various agencies; and the results, except those published in reference 3, have not heretofore been available in published form. The rest of the airfoils consist of small groups of related sections tested to study the effects of certain local variations in shape.

One of these local shape variations involved changes of the nose shape, consisting primarily of changes of the leading-edge radius. The effects of these changes were determined by tests of modifications of the Göttingen 398 (reference 4), of the Clark Y (reference 5), and of the N. A. C. A. 2412 (unpublished). References 4 and 5 present data on the effect of sharp leading edges. The modifications to the N. A. C. A. 2412 consisted in varying the leading-edge radius from normal to zero (N. A. C. A. 2412, N. A. C. A. 15, 16, 19, and 20) and in dropping the leading edge from the normal position (N. A. C. A. 17 and 18). A second local shape variation involved the rear portion of the airfoil and consisted in reflexing the mean line. Such modifications were made on the Göttingen 398, the Boeing 106, and the N–60 sections, and the results of the tests were published in reference 6. A series of related forward-camber airfoils having reflexed mean lines was tested, and the results were published in reference 7. Another series of reflexed airfoils, for which the results have not been published, includes the N. A. C. A. 21, 23, 24, 25, 26, and 27 airfoils.

The results of these tests, including both published and unpublished data, have not heretofore been available in comparable form nor convenient for ready reference by the user. It has therefore been deemed desirable to collect these data into one report.

This report, in conjunction with reference 2, makes available, in convenient form, comparable data for sections tested in the variable-density tunnel since January 1, 1931. The important fully corrected characteristics for the miscellaneous sections described earlier and also for the sections reported in reference 1 are tabulated for easy reference. In addition to the tabulated data, plots of standard aerodynamic characteristics are presented for the miscellaneous airfoils.

TESTS AND APPARATUS

Routine airfoil tests were made in the variable-density tunnel at an effective Reynolds Number of approximately 8,000,000. Tests of some of the models were extended through the range of negative angles of attack. Airfoils for which these results were obtained are designated "inverted" sections. The duralumin models were of rectangular plan form with a 5-inch chord and a 30-inch span. A description of the tunnel, the test procedure, and the method of constructing the models is given in reference 8.

The precision of the tests and of the results is discussed in references 1 and 9.

RESULTS

The method chosen to present these results is intended to be convenient for designers. The important characteristics, fully corrected as described in references 9 and 10, are presented in tables I and II and are comparable with those given in reference 2. These important characteristics are:

\( c_{\text{max}} \), the section maximum lift coefficient.

\( \alpha_0 \), the angle of zero lift.
(continued)

... cmax, the pitching-moment coefficient about the section aerodynamic center.

a.c., the aerodynamic center, or the point, with respect to the airfoil section, about which the pitching-moment coefficient tends to remain constant over the range of lift coefficients between zero and maximum lift.

cp, the position of the center of pressure in percentage of the chord behind the leading edge.

m6, the lift-curve slope for aspect ratio 6.

A more complete description of these characteristics is presented in references 9 and 10.

Tables I and II contain these data for available sections tested in the variable-density tunnel, except those given in reference 2. Reference is made to the original publication for the airfoil results that have been previously reported.

Plots of the standard characteristics (figs. 1 to 88) are given for the miscellaneous sections (exclusive of those for the N. A. C. A. 22112, 23112, 24112, and 25112 sections, which are published in reference 7) because they are not available elsewhere. Plots for the sections in table I are given in reference 1.

REFERENCES


CHARACTERISTICS OF AERODYNAMIC TEST IN THE VARIABLE-DENSITY TUNNEL
FIGURE 3.—Boeing 103 A airfoil.

FIGURE 4.—Boeing 103 A airfoil (inverted).
FIGURE 5.—Boeing 106 airfoil.

FIGURE 6.—Boeing 106 airfoil (inverted).
Figure 7.—Boeing 106 R airfoil.

Figure 8.—Boeing 111 airfoil.
CHARACTERISTICS OF AIRFOILS TESTED IN THE VARIABLE-DENSITY TUNNEL

Figure 13.—Sikorsky GS-M airfoil (inverted).

Figure 14.—Sikorsky GS-I airfoil.
CHARACTERISTICS OF AIRFOILS TESTED IN THE VARIABLE-DENSITY TUNNEL

Figure 17.—R. A. F. 31 airfoil.

Figure 18.—U. S. A. 27 airfoil.
FIGURE 19.—U. S. A. 35-A airfoil (inverted).

FIGURE 20.—U. S. A. 35-A airfoil.
CHARACTERISTICS OF AIRFOILS TESTED IN THE VARIABLE-DENSITY TUNNEL

Figure 21.—U. S. A. 35-B airfoil.

Figure 22.—U. S. A. 35-B airfoil (inverted).
CHARACTERISTICS OF AIRFOILS TESTED IN THE VARIABLE-DENSITY TUNNEL

FIGURE 25.—C-72 airfoil (inverted).

FIGURE 26.—C-80 airfoil.
CHARACTERISTICS OF AIRFOILS TESTED IN THE VARIABLE-DENSITY TUNNEL

Figure 29—N-22 airfoil (inverted).

Figure 30—N-60 airfoil.
CHARACTERISTICS OF AIRFOILS TESTED IN THE VARIABLE-DENSITY TUNNEL

FIGURE 33.—N-69 airfoil.

FIGURE 34.—N-71 airfoil.
FIGURE 39.—N-76 airfoil (inverted).

FIGURE 40.—N-80 airfoil.
Figure 43.—N-81 airfoil (inverted).

Figure 44.—Göttingen 387 airfoil.
CHARACTERISTICS OF AIRFOILS TESTED IN THE VARIABLE-DENSITY TUNNEL

Figure 45.—Göttingen 398 airfoil.

Figure 46.—Göttingen 398 airfoil (inverted).
Figure 47.—Göttingen 398-A airfoil.

Figure 48.—Göttingen 398-B airfoil.
CHRACTERISTICS OF AIRFOILS TESTED IN THE VARIALE-DENSITY TUNNEL
FIGURE 51.—Göttingen 420 airfoil.

FIGURE 52.—Göttingen 429-AG airfoil.
CHARACTERISTICS OF AIRFOILS TESTED IN THE VARIABLE-DENSITY TUNNEL

FIGURE 33.—Göttingen 429 airfoil.

FIGURE 34.—Göttingen 436 airfoil.
Figure 55.—Göttingen 436 airfoil (inverted).

Figure 56.—Göttingen 532 airfoil.
CHARACTERISTICS OF AIRFOILS TESTED IN THE VARIABLE-DENSITY TUNNEL

Figure 57.—Göttingen 532 airfoil (inverted).

Figure 58.—Clark Y airfoil.
FIGURE 59.—Clark Y airfoil (inverted).

FIGURE 60.—Clark Y-B airfoil.
FIGURE 63.—Clark Y M-18 airfoil.

FIGURE 64.—Clark Y M-18 (inverted) airfoil.
Ratio of lift to drag, \( L/D \)

c.p. in percent of chord (from forward end of chord)

Moment coeff., \( c_m \)

Profile-drag coefficient, \( c_d \)

Angle of attack for infinite aspect ratio, \( \alpha_\infty \) (deg.)
CHARACTERISTICS OF AIRFOILS TESTED IN THE VARIABLE-DENSITY TUNNEL

Figure 69.—Clark Y-18 airfoil.

Figure 70.—Clark Y-18 airfoil (inverted).
FIGURE 71.—Clark Y-22 airfoil.

FIGURE 72.—N.A. C. A. CYH airfoil.
CHARACTERISTICS OF AIRFOILS TESTED IN THE VARIABLE-DENSITY TUNNEL

Figure 73.—N. A. C. A. CYH airfoil (inverted).

Figure 74.—N. A. C. A. —M6 airfoil.
FIGURE 75.—N. A. C. A. M6 airfoil (inverted).

FIGURE 76.—N. A. C. A. 15 airfoil.
Figure 77.—N. A. C. A. 16 airfoil.

Figure 78.—N. A. C. A. 17 airfoil.
Figure 79.—N. A. C. A. 18 airfoil.

Figure 80.—N. A. C. A. 19 airfoil.
CHARACTERISTICS OF AIRFOILS TESTED IN THE VARIABLE-DENSITY TUNNEL

FIGURE 81.—N. A. C. A. 20 airfoil.

FIGURE 82.—N. A. C. A. 21 airfoil.
Figure 83.—N. A. C. A. 21 airfoil (inverted).

Figure 84.—N. A. C. A. 23 airfoil.
CHARACTERISTICS OF AIRFOILS TESTED IN THE VARIABLE-DENSITY TUNNEL

FIGURE 85.—N. A. C. A. 24 airfoil.

FIGURE 86.—N. A. C. A. 25 airfoil.
### TABLE I.—CHARACTERISTICS OF RELATED N. A. C. A. AIRFOILS REPORTED IN REFERENCE 1

<table>
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<td>B B10 C9 A</td>
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1 Type of chord. See reference 10.  
2 Type of pressure distribution. See reference 10.  
3 Type of scale effect on maximum lift. A signifies practically no scale effect.  
For other designations see reference 9, fig. 47.
# Table II: Characteristics of Miscellaneous Airfoils

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<th>Aircraft</th>
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## Table Notes:

- [Characteristics of miscellaneous airfoils](#)
- Derived and additional characteristics that may be used for structural design.
Positive directions of axes and angles (forces and moments) are shown by arrows.

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<th>Moment about axis</th>
<th>Angle</th>
<th>Velocities</th>
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</table>

Absolute coefficients of moment:
- $C_\tau = \frac{L}{\rho g S}$ (rolling)
- $C_\sigma = \frac{M}{\rho \sigma S}$ (pitching)
- $C_\varphi = \frac{N}{\rho g S}$ (yawing)

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

4. Propeller Symbols

- $D$: Diameter
- $p$: Geometric pitch
- $p_\tau$: Pitch ratio
- $V'$: Inflow velocity
- $V_\infty$: Shipstream velocity
- $T$: Thrust, absolute coefficient $C_T = \frac{T}{\rho m D^2}$
- $Q$: Torque, absolute coefficient $C_Q = \frac{Q}{\rho m D^2}$

4. Numerical Relations

1. $1 \text{ hp} = 75.04 \text{ kg-m/s} = 550 \text{ ft-lb/sec}$
2. $1 \text{ metric horsepower} = 1.355 \text{ hp}$
3. $1 \text{ m.p.h} = 0.4470 \text{ m.p.s}$
4. $1 \text{ m.p.s} = 2.2369 \text{ m.p.h}$

1. $1 \text{ lb} = 0.4536 \text{ kg}$
2. $1 \text{ kg} = 2.2046 \text{ lb}$
3. $1 \text{ m} = 1.8093 \text{ m} = 3.2808 \text{ ft}$
4. $1 \text{ ft} = 0.3048 \text{ m}$