DEVELOPMENT OF A COMPUTER PROGRAM TO OBTAIN ORDINATES FOR NACA 4-DIGIT, 4-DIGIT MODIFIED, 5-DIGIT, AND 16-SERIES AIRFOILS

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**Abstract**

A computer program has been developed to calculate the ordinates and surface slopes of any thickness, symmetrical or cambered NACA airfoil of the 4-digit, 4-digit modified, 5-digit, and 16-series airfoil families. The program is included as an appendix to this report. The program also produces plots of the airfoil non-dimensional ordinates and a punch card output of ordinates in the input format of a readily available program for determining the pressure distributions of arbitrary airfoils in subsonic potential viscous flow.

**16. Key Words (Suggested by Author(s))**

- Airfoils
- Rotors
- Computer program for airfoils

**18. Distribution Statement**

Unclassified – Unlimited

Subject Category 02
DEVELOPMENT OF A COMPUTER PROGRAM TO OBTAIN ORDINATES
FOR NACA 4-DIGIT, 4-DIGIT MODIFIED, 5-DIGIT,
AND 16-SERIES AIRFOILS

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SUMMARY

The analytical design equations for both symmetrical and cambered airfoils in the
NACA 4-digit, 4-digit modified, 5-digit, and 16-series airfoil families have been reviewed.
A computer program has been developed to calculate rapidly the ordinates and surface
slope for these airfoils and the program is included as an appendix to this report. Pro-
visions are made in the program to combine basic airfoil shapes and camber lines from
different series so that nonstandard airfoils can also be generated. The program also
produces plots of the nondimensional airfoil ordinates and a punch card output of the ordi-
nates in the input format of a readily available program for determining the pressure dis-
butions of arbitrary airfoils in subsonic potential viscous flow.

INTRODUCTION

During the 1930's several families of airfoils and camber lines, all of which have
analytic expressions for the ordinates, were developed by the National Advisory Committee
for Aeronautics (NACA). These include the NACA 4-digit airfoils (ref. 1), 4-digit modified
airfoils (ref. 2), 5-digit airfoils (ref. 3), and 16-series airfoils (refs. 4 and 5). Many of
these airfoil shapes have been successfully used over the years as wing and tail sections
for general aviation as well as military aircraft. Some have been and are still being used
as sections for propellers and helicopter rotors.

Numerous specific airfoils of these series have been computed and ordinates pub-
lished over the years. However, when performing parametric studies on effects of such
variables as thickness, location of maximum thickness, leading-edge radius, amount and
location of maximum camber and others, it is not always easy to obtain the ordinates of
the desired shapes rapidly. Because these airfoils all have analytic solutions for the
ordinates, both with and without camber, a computer program can be written to provide
the exact ordinates rapidly and at a low cost. An attempt to do this was made in refer-
ence 6, but some limiting assumptions were made so that exact results are not provided
for some airfoils.
The purpose of this paper is to review the design parameters for all these airfoils and to describe a computer program which will generate exact ordinates for all airfoils of these series with an acceptable expenditure of computer time. The program will also allow combination of any airfoil and any camber line so that many nonstandard airfoils can be described.

SYMBOLS

When two symbols are given for a concept, the symbol in parenthesis is that used in the computer program and on computer-generated plots.

A  camber line designation, fraction of chord from leading edge over which design load is uniform

\( a_0, a_1, a_2, a_3, a_4 \)  constants in airfoil equation

\( b_0, b_1, b_2 \)  constants in camber line equation

\( c \)  (C)  airfoil chord

\( \langle C_L \rangle_{\text{design}} \)  (CLI)  design section lift coefficient

\( d_0, d_1, d_2, d_3 \)  constants in airfoil equation

I  leading-edge index number

\( k_1, k_2 \)  constants

\( m \)  chordwise location for maximum ordinate of airfoil or camber line

\( p \)  maximum ordinate of 2-digit camber line

\( R \)  radius of curvature

\( r \)  chordwise location for zero value of second derivative of 3-digit camber line equation

\( t \)  thickness

\( x \)  (X)  distance along chord

2
y (Y) airfoil ordinate normal to chord, positive above chord
δ local inclination of camber line

Subscripts:
cam cambered
l (L) lower surface
le leading edge
N forward portion of camber line
T aft portion of camber line
t thickness
u (U) upper surface

ANALYSIS

The design equations for the analytic NACA airfoils and camber lines have been presented in references 1 to 5. They are repeated herein to provide a better understanding of the computer program and indicate the use of different design variables. A summary of some of the design equations and ordinates for many airfoils from these families is also presented in references 7 to 9.

Thickness Distribution Equations

4-digit.- Ordinates for the NACA 4-digit airfoil family (ref. 1) are described by an equation of the form:

\[ \pm \frac{y}{c} = a_0 \sqrt{\frac{x}{c}} + a_1 \left( \frac{x}{c} \right) + a_2 \left( \frac{x}{c} \right)^2 + a_3 \left( \frac{x}{c} \right)^3 + a_4 \left( \frac{x}{c} \right)^4 \]

The constants in the equation were determined from the following constraints:

1) Maximum ordinate:

\[ \frac{x}{c} = 0.30 \quad \frac{y}{c} = 0.10 \quad \frac{dy}{dx} = 0 \]
(2) Ordinate at trailing edge:

\[
\frac{x}{c} = 1.0 \quad \frac{y}{c} = 0.002
\]

(3) Trailing-edge angle:

\[
\frac{x}{c} = 1.0 \quad \frac{dy}{dx} = 0.234
\]

(4) Nose shape:

\[
\frac{x}{c} = 0.1 \quad \frac{y}{c} = 0.078
\]

The coefficients listed below were determined to meet these constraints very closely:

\[
a_0 = 0.2969 \\
a_1 = -0.1260 \\
a_2 = -0.3516 \\
a_3 = 0.2843 \\
a_4 = -0.1015
\]

To obtain ordinates for other thickness airfoils in the family, the ordinates for the 0.20-thickness-ratio model are multiplied by the ratio \((t/c)/0.20\). The leading-edge radius of this family is defined as the radius of curvature of the basic equation evaluated at \(\frac{x}{c} = 0\). Because of the term \(a_0\sqrt{x/c}\) in the equation, the radius of curvature is finite at this point and can be shown to be \(a_0^2/2\). Thus, the leading-edge radius varies as the square of the airfoil thickness-chord ratio because the thickness varies linearly with the constants. To define an airfoil in this family, the only input necessary to the computer program is the desired thickness-chord ratio. Symmetric airfoils in this family are designated by a 4-digit number, that is, NACA 0012. The first two digits indicate a symmetric airfoil and the second two, the thickness-chord ratio.

**4-digit modified.** The design equation for the 4-digit airfoil family was modified (ref. 2) so that the same basic shape was retained but variations in leading-edge radius and chordwise location of maximum thickness could be made. Ordinates for these airfoils are determined from the following equations:
From leading edge to maximum thickness,
\[ \pm \frac{Y}{C} = a_0 \sqrt{\frac{x}{C}} + a_1 \left( \frac{x}{C} \right) + a_2 \left( \frac{x}{C} \right)^2 + a_3 \left( \frac{x}{C} \right)^3 \]

From maximum thickness to trailing edge,
\[ \pm \frac{Y}{C} = d_0 + d_1 \left( 1 - \frac{x}{C} \right) + d_2 \left( 1 - \frac{x}{C} \right)^2 + d_3 \left( 1 - \frac{x}{C} \right)^3 \]

The constants in these equations can be determined from the following constraints:

1. Maximum ordinate:
   \[ \frac{X}{C} = m \quad \frac{Y}{C} = 0.1 \quad \frac{dY}{dx} = 0 \]

2. Leading-edge radius:
   \[ \frac{X}{C} = 0 \quad R = \frac{a_0^2}{2} \]

3. Radius of curvature at maximum thickness:
   \[ \frac{X}{C} = m \quad R = \frac{(1 - m)^2}{2d_1(1 - m) - 0.588} \]

4. Ordinate at trailing edge:
   \[ \frac{X}{C} = 1.0 \quad \frac{Y}{C} = d_0 = 0.002 \]

5. Trailing-edge angle:
   \[ \frac{X}{C} = 1.0 \quad \frac{dY}{dx} = d_1 = f(m) \]

Thus, the maximum ordinate, slope, and radius of curvature of the two portions of the surface match at \( \frac{X}{C} = m \). The values of \( d_1 \) were chosen, as stated in reference 2, to avoid reversals of curvature and are given in the following table:

<table>
<thead>
<tr>
<th>m</th>
<th>( d_1 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.2</td>
<td>0.200</td>
</tr>
<tr>
<td>0.3</td>
<td>0.234</td>
</tr>
<tr>
<td>0.4</td>
<td>0.315</td>
</tr>
<tr>
<td>0.5</td>
<td>0.465</td>
</tr>
<tr>
<td>0.6</td>
<td>0.700</td>
</tr>
</tbody>
</table>
By use of these constraints, equations were written for each of the constants (except $d_0$ and $d_1$) in the equation for the airfoil family and are included in the computer program. As in the 4-digit airfoil family, ordinates vary linearly with variations in thickness-chord ratio and any desired thickness shape can be obtained by scaling the ordinates by the ratio of the desired thickness ratio to the design thickness ratio.

These airfoils are designated by a 4-digit number followed by a dash and a 2-digit number (that is, NACA 0012-63). The first two digits are zero for a symmetrical airfoil and the second two digits indicate the thickness-chord ratio. The first digit after the dash is a leading-edge radius index number, and the second is the location of maximum thickness in tenths of chord aft of the leading edge. The leading-edge index is an arbitrary number assigned to the leading-edge radius in reference 2 and is proportional to $a_0$. An index of 0 indicates a sharp leading edge (radius of zero) and an index of 6 corresponds to $a_0 = 0.2969$, the normal design value for the 4-digit airfoil. A value of leading-edge index of 9 for a three times normal leading-edge radius was arbitrarily assigned in reference 2. Values of leading-edge radius for various values of the index number and thickness-chord ratio are listed in table I and plotted in figure 1. The computer program is written so that the desired value of leading-edge radius is the input parameter. The value of $a_0$ is then computed in the program. The index number is only used in the airfoil designation.

16-series.- The NACA 16-series airfoil family is described in references 4 and 5. Although not directly stated in the references, it will be noted from the equation for the ordinates in reference 5 that this series is a special case of the 4-digit modified family. The 16-series are thus defined as having a leading-edge index of 4 and a location of maximum thickness at 0.50 chord. The designation NACA 16-012 airfoil is equivalent to NACA 0012-45. The computer program does not have separate inputs for the 16-series so that the 4-digit modified series must be used to obtain ordinates for these airfoils.

Camber-Line Equations

2-digit.- The NACA 2-digit camber line is described in reference 1. This camber line is formed by two parabolic segments which have a general equation of the form

$$Y = b_0 + b_1\left(\frac{X}{C}\right) + b_2\left(\frac{X}{C}\right)^2.$$  

The constants for the two equations are determined from the following boundary equation:

(1) Camber-line extremities:

$$\frac{X}{C} = 0, \quad \frac{Y}{C} = 0$$

$$\frac{X}{C} = 1.0, \quad \frac{Y}{C} = 0$$
(2) Maximum ordinate:

\[ \frac{x}{c} = m \quad \frac{y}{c} = p \]

\[ \frac{dy}{dx} = 0 \]

From these conditions, the camber-line equations then become

\[ \frac{y}{c} = \frac{p}{m^2} \left[ 2m\left(\frac{x}{c}\right) - \left(\frac{x}{c}\right)^2 \right] \]

forward of maximum ordinate and

\[ \frac{y}{c} = \frac{p}{(1 - m)^2} \left[ (1 - 2m) + 2m\left(\frac{x}{c}\right) - \left(\frac{x}{c}\right)^2 \right] \]

aft of the maximum ordinate. Both the ordinate and slope of the two parabolic segments match at \( \frac{x}{c} = m \). This camber line is designated by a two-digit number and, when used with a 4-digit airfoil, would have the form NACA pmXX where \( p \) is the maximum camber in percent chord; \( m \) is the chordwise location of maximum camber; and \( XX \) is the airfoil thickness in percent chord. Tables of ordinates for some of these camber lines are tabulated in references 8 and 9. The ordinates are linear with amount of camber and these can be scaled up or down as desired.

3-digit.- To provide a camber line with a very far forward location of the maximum camber, the 3-digit camber line was developed and presented in reference 3. This camber line is also made up of two equations so that the second derivative decreases to zero at a point \( r \) aft of the maximum ordinate and remains zero from this point to the trailing edge. The equations for these conditions are as follows:

From \( \frac{x}{c} = 0 \) to \( \frac{x}{c} = r \),

\[ \frac{d^2y}{dx^2} = k_1\left(\frac{x}{c} - r\right) \]

From \( \frac{x}{c} = r \) to \( \frac{x}{c} = 1.0 \),

\[ \frac{d^2y}{dx^2} = 0 \]
The design criteria are as follows:

(1) Camber-line extremities:

\[ \frac{x}{c} = 0 \quad \frac{y}{c} = 0 \]
\[ \frac{x}{c} = 1.0 \quad \frac{y}{c} = 0 \]

(2) At junction point:

\[ \frac{x}{c} = r \]
\[ \left( \frac{y}{c} \right)_N = \left( \frac{y}{c} \right)_T \]
\[ \frac{dy}{dx}_N = \frac{dy}{dx}_T \]

The equation for the camber line then becomes

\[ \frac{y}{c} = \frac{1}{6} k_1 \left[ \left( \frac{x}{c} \right)^3 - 3r \left( \frac{x}{c} \right)^2 + r^2 (3 - r) \left( \frac{x}{c} \right) \right] \]

from \( \frac{x}{c} = 0 \) to \( \frac{x}{c} = r \) and

\[ \frac{y}{c} = \frac{1}{6} k_1 r^3 \left[ 1 - \left( \frac{x}{c} \right) \right] \]

from \( \frac{x}{c} = r \) to \( \frac{x}{c} = 1.0 \). These equations were then solved for values of \( r \) which would give longitudinal locations of the maximum ordinate of 5, 10, 15, 20, and 25 percent chord. The value of \( k_1 \) was adjusted so that a theoretical design lift coefficient of 0.3 was obtained at the ideal angle of attack. The value of \( k_1 \) can be linearly scaled to give any desired design lift coefficient. Values of \( k_1 \) and \( r \) and the camber-line designation were taken from reference 3 and are presented in the following table:

<table>
<thead>
<tr>
<th>Camber-line designation</th>
<th>( x/c ) for maximum camber, m</th>
<th>( r )</th>
<th>( k_1 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>210</td>
<td>0.05</td>
<td>0.0580</td>
<td>361.400</td>
</tr>
<tr>
<td>220</td>
<td>.10</td>
<td>.1260</td>
<td>51.640</td>
</tr>
<tr>
<td>230</td>
<td>.15</td>
<td>.2025</td>
<td>15.957</td>
</tr>
<tr>
<td>240</td>
<td>.20</td>
<td>.2900</td>
<td>6.643</td>
</tr>
<tr>
<td>250</td>
<td>.25</td>
<td>.3910</td>
<td>3.230</td>
</tr>
</tbody>
</table>

The first digit of the 3-digit camber-line designation is defined as two-thirds of the design lift coefficient, the second digit as twice the longitudinal location of maximum thickness in tenths of chord, and the third digit of zero indicates a nonreflexed trailing edge.
3-digit reflex. - For some applications, for example, rotorcraft main rotors, it may be desirable to produce an airfoil with a quarter-chord pitching-moment coefficient of zero. The three-digit reflexed camber line was thus designed to have a theoretical zero pitching moment as described in reference 3. The forward part of the camber line is identical to the 3-digit camber line but the aft portion was changed from a zero curvature segment to a segment with curvature. The equation for the aft portion of the camber line is expressed by \( \frac{d^2y}{dx^2} = k_2 \left( \frac{x}{c} - r \right) \). By using the same boundary conditions as were used for the 3-digit camber line, the equations for the ordinates are

\[
\frac{y}{c} = \frac{1}{6} k_1 \left[ \left( \frac{x}{c} - r \right)^3 - \frac{k_2}{k_1} (1 - r)^2 \frac{x}{c} - r^3 \frac{x}{c} + r^3 \right]
\]

from \( \frac{x}{c} = 0 \) to \( \frac{x}{c} = r \) and

\[
\frac{y}{c} = \frac{1}{6} k_1 \left[ \frac{k_2}{k_1} \left( \frac{x}{c} - r \right)^3 - \frac{k_2}{k_1} (1 - r)^2 \frac{x}{c} - r^3 \frac{x}{c} + r^3 \right]
\]

for \( \frac{x}{c} = r \) to \( \frac{x}{c} = 1.0 \). The ratio \( k_2/k_1 \) is expressed as

\[
\frac{k_2}{k_1} = \frac{3(r - m)^2 - r^3}{1 - r}
\]

Values of \( k_1, k_2/k_1, \) and \( m \) for several camber-line designations from reference 2 are presented in the following table:

<table>
<thead>
<tr>
<th>Camber-line designation</th>
<th>( x/c ) for maximum camber, m</th>
<th>( r )</th>
<th>( k_1 )</th>
<th>( k_2/k_1 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>221</td>
<td>0.10</td>
<td>0.1300</td>
<td>51.99</td>
<td>0.000764</td>
</tr>
<tr>
<td>231</td>
<td>0.15</td>
<td>0.2170</td>
<td>15.793</td>
<td>0.00677</td>
</tr>
<tr>
<td>241</td>
<td>0.20</td>
<td>0.3180</td>
<td>6.520</td>
<td>0.0303</td>
</tr>
<tr>
<td>251</td>
<td>0.25</td>
<td>0.4410</td>
<td>3.191</td>
<td>0.1355</td>
</tr>
</tbody>
</table>

The camber-line designation for this camber line is identical to that for the 3-digit camber line except that the last digit is changed from 0 to 1 to indicate the reflex characteristic.

6- and 6A-series.- The equations for the 6-series camber lines are presented in reference 8. These camber lines are a function of the design lift coefficient \( C_L^{\text{design}} \) and the chordwise extent of uniform loading \( A \). These 16-series cambered airfoils (ref. 4) are derived by using the \( A = 1.0 \) camber line of the series. These equations have been programmed for use with 6-series airfoils in reference 10 and that part of the program has
been incorporated into the present program. As was the case in reference 10, the program is capable of combining up to 10 camber lines of this series to provide many types of loading.

Calculation of Cambered Airfoils

To calculate ordinates for a cambered airfoil, the desired mean line is first computed and then the ordinates of the symmetrical airfoil are measured normal to the mean line at the same chord station. This procedure leads to a set of parametric equations where \((y/c)_t\), \((y/c)_c\) and \(\delta\) are all functions of the original independent variable \(x/c\). The ordinates on the cambered airfoil \((x/c)_u\) and \((y/c)_u\) are given by

\[
\begin{align*}
\left(\frac{x}{c}\right)_u &= \left(\frac{x}{c}\right)_t - \left(\frac{y}{c}\right)_t \sin \delta \\
\left(\frac{y}{c}\right)_u &= \left(\frac{y}{c}\right)_t + \left(\frac{y}{c}\right)_t \cos \delta
\end{align*}
\]

where \(\delta\) is the local inclination of the camber line and \((y/c)_t\) is assumed to be negative to obtain the lower surface ordinates \((x/c)_t\) and \((y/c)_t\). This procedure is also described in reference 1. The local slopes of the cambered airfoil can be shown to be

\[
\frac{dy}{dx}_u = \frac{\tan \delta \sec \delta + \frac{dy}{dx}_t - \left(\frac{y}{c}\right)_t \left(\frac{d\delta}{dx}\right) \tan \delta}{\sec \delta - \frac{dy}{dx}_t \tan \delta - \left(\frac{y}{c}\right)_t \left(\frac{d\delta}{dx}\right)}
\]

and

\[
\frac{dy}{dx}_l = \frac{\tan \delta \sec \delta - \left(\frac{dy}{dx}_t\right) - \left(\frac{y}{c}\right)_t \left(\frac{d\delta}{dx}\right) \tan \delta}{\sec \delta + \frac{dy}{dx}_t \tan \delta - \left(\frac{y}{c}\right)_t \left(\frac{d\delta}{dx}\right)}
\]

by parametric differentiation of \((x/c)_u,l\) and \((y/c)_u,l\) with respect to the original \(x/c\) and use of the relationship

\[
\frac{dy}{dx}_u = \frac{d(y/c)_u/d(x/c)_u}{d(x/c)_u/d(x/c)}
\]

Although specific camber lines are generally used with specific thickness distributions, this program has been written in a general format. As a result, any camber line can be used with either type thickness distribution so that any shape desired can be generated.
RESULTS AND DISCUSSION

Program Capabilities

The computer program which was developed to provide the airfoil shapes described by the equations in the analysis section is listed in the appendix. The output of the program consists of tabulated ordinates, computer-generated plots of the nondimensional ordinates, and punched card listings of the ordinates. The punched cards are in the format of the input of the program described in reference 11 so that pressure distributions over the generated shape may be readily obtained. To show graphically the capabilities of the program, sample computer plots of several airfoil shapes are presented in figures 2 to 10.

Figures 2 and 3 illustrate possible variations in the 4-digit airfoil family, figure 2 showing variations in thickness-chord ratio for symmetrical airfoils and figure 3 showing variations in the amount of camber for a fixed thickness-chord ratio and location of maximum camber. Figures 4 and 5 illustrate possible variations in the 5-digit airfoil family. Variations in the longitudinal location of maximum camber are shown in figure 4 and a comparison of the same airfoil with nonreflex and reflex camber lines is shown in figure 5. Examples of the 4-digit modified-series are shown in figure 6 for symmetrical airfoils and in figure 7 for cambered airfoils. The symmetrical airfoils have variations in the longitudinal position of maximum thickness whereas the cambered airfoils show variations in the longitudinal position of maximum camber.

Examples of 16-series airfoils (which, as previously noted, are special cases of 4-digit modified airfoils) are shown for symmetrical and cambered sections in figures 8 and 9, respectively. Figure 10 presents an example of a combination of a 4-digit modified airfoil with a combination of two 6-series camber lines to give an aft-loaded section. This is shown to give an indication of the types of sections which may be generated by combinations of various thickness distributions and types of camber lines. If a thickness-chord ratio of 0.0 is specified in the input to the program, the shape of just the camber line or combination of camber lines is computed. The results of this procedure are shown in figures 11 and 12.

Sample Output Tabulations

Sample computed ordinates for both a symmetric and a cambered airfoil are presented in tables II and III, respectively. Printed at the top of the first page for each table is the airfoil and camber-line family selected, the airfoil designation, and a list of the input parameters for both airfoil shape and camber line. For the 4-digit modified airfoil family, the coefficients of the airfoil equation are also listed for a shape with a thickness-chord ratio of 0.20. Both nondimensional and dimensional ordinates are listed. The dimensional quantities have the same units as the input value of the chord, which is also
listed at the top of the page. First and second derivatives of the surface ordinates are also presented for symmetrical airfoils, but only first derivatives are tabulated for the cambered airfoils.

Accuracy of Results

All the airfoils and camber lines generated by this program are defined by closed analytical expressions and no approximations have been made in the program. Thus, all results are exact. Many cases have been run and compared with previously published results to check the procedure and in all cases the comparisons were exact except for occasional differences in the last digit due to rounding differences.

CONCLUDING REMARKS

The analytic design equations for both symmetrical and cambered airfoils in the NACA 4-digit, 4-digit modified, 5-digit, and 16-series airfoil families have been reviewed. A computer program has been developed to calculate rapidly the ordinates and surface slope for these airfoils and the program is included as an appendix to this report. Provisions are made in the program to combine basic airfoil shapes and camber lines from different series so that nonstandard airfoils can also be generated. The program will also produce plots of the nondimensional airfoil ordinates and a punch card output of the ordinates in the input format of a readily available program for determining the pressure distributions of arbitrary airfoils in subsonic potential viscous flow.

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August 29, 1975
APPENDIX

COMPUTER PROGRAM FOR ORDINATES OF ANALYTICAL NACA AIRFOILS

The program presented herein is written in the Langley Research Center version of FORTRAN IV and has been used on the Control Data series 6000 computer systems. Both the computational program and a plotting program are presented, although the plotting routine is included as a guide for users only. Several unlisted subroutines are used in the plotting program. The computational program requires about 46000 storage locations, and requires about 8 seconds to compile and about 1.5 seconds to execute each case on the Control Data 6600 computer system.

Card Input Format

The input to the program is in a card format as follows:

CARD 1 – Number of ordinates to be output on punched cards: (Maximum of 32) (right justified in columns 1 to 3).

CARD 2, 3, 4, and 5 – Chordwise location of ordinates to be output on punched cards. (Columns 1 to 10, 11 to 20, etc., with decimal point.)

CARD 6 – Tabulated data printout airfoil title card. Any designation may be used in columns 1 to 80.

CARD 7 – Airfoil thickness series and camber-line series designations are as follows:

<table>
<thead>
<tr>
<th>NACA airfoil family</th>
<th>Card designation*</th>
<th>Columns</th>
</tr>
</thead>
<tbody>
<tr>
<td>4-digit</td>
<td>4-DIGIT</td>
<td>1 to 7</td>
</tr>
<tr>
<td>4-digit modified</td>
<td>4-DIGITMOD</td>
<td>1 to 10</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Camber line</th>
<th>Card designation*</th>
<th>Columns</th>
</tr>
</thead>
<tbody>
<tr>
<td>NACA 2-digit</td>
<td>2-DIGIT</td>
<td>11 to 17</td>
</tr>
<tr>
<td>NACA 3-digit</td>
<td>3-DIGIT</td>
<td>11 to 17</td>
</tr>
<tr>
<td>NACA 3-digit reflex</td>
<td>3-DIGITREF</td>
<td>11 to 20</td>
</tr>
<tr>
<td>NACA 6-series</td>
<td>6-SERIES</td>
<td>11 to 18</td>
</tr>
<tr>
<td>NACA 6A-series</td>
<td>6A-SERIES</td>
<td>11 to 19</td>
</tr>
</tbody>
</table>

*These are hollerith cards; designations must be in exact columns.
APPENDIX

CARD 8 - Airfoil thickness distribution parameter card. (Note that cards 3 to 7 are in floating-point mode. Numbers are entered with a decimal point.)

<table>
<thead>
<tr>
<th>Description</th>
<th>Variable</th>
<th>Columns</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thickness-chord ratio of airfoil (i.e., 0.120)</td>
<td>TOC</td>
<td>1 to 10</td>
</tr>
<tr>
<td>Leading-edge radius to chord ratio. Not used with 4-digit but must be used</td>
<td>LER</td>
<td>11 to 20</td>
</tr>
<tr>
<td>with 4-digit modified</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Basic chordwise increment in x/c for computing ordinates. Usually set to 0.01</td>
<td>DX</td>
<td>21 to 30</td>
</tr>
<tr>
<td>Model chord used for listing ordinates in dimensional units</td>
<td>CHD</td>
<td>31 to 40</td>
</tr>
<tr>
<td>Nondimensional chordwise location of maximum thickness. Used for 4-digit</td>
<td>XM</td>
<td>41 to 50</td>
</tr>
<tr>
<td>modified airfoils only</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Trailing-edge slope of 4-digit modified airfoils. Take values from text or</td>
<td>D1</td>
<td>51 to 60</td>
</tr>
<tr>
<td>reference 2 or input 0.0 and approximate value from equation in reference 7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>will be used</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

CARD 9 - Airfoil camber-line parameter card. Set all values equal to 0.0 for a symmetrical airfoil.

<table>
<thead>
<tr>
<th>Camber line</th>
<th>Description</th>
<th>Variable</th>
<th>Columns</th>
</tr>
</thead>
<tbody>
<tr>
<td>2-digit</td>
<td>Maximum camber ordinate to chord ratio (i.e., 0.04), p</td>
<td>CMB</td>
<td>1 to 10</td>
</tr>
<tr>
<td></td>
<td>Longitudinal location of maximum camber position (i.e., 0.40), m</td>
<td>CM</td>
<td>11 to 20</td>
</tr>
<tr>
<td>3-digit</td>
<td>Value of $k_1$ from text or reference 3 which varies linearly with design</td>
<td>CMB</td>
<td>1 to 10</td>
</tr>
<tr>
<td></td>
<td>lift coefficient</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Value of $r$ from text or reference 3 which is a function of the longitudinal</td>
<td>CM</td>
<td>11 to 20</td>
</tr>
<tr>
<td></td>
<td>location of maximum camber</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
## APPENDIX

<table>
<thead>
<tr>
<th>Camber line</th>
<th>Description</th>
<th>Variable</th>
<th>Columns</th>
</tr>
</thead>
<tbody>
<tr>
<td>3-digit reflex</td>
<td>Value of $k_1$ from text or reference 3 for reflex airfoils which varies linearly with design lift coefficient</td>
<td>CMB</td>
<td>1 to 10</td>
</tr>
<tr>
<td></td>
<td>Value of $r$ from reference 3 for reflex airfoils which is a function of the longitudinal location of maximum camber</td>
<td>CM</td>
<td>11 to 20</td>
</tr>
<tr>
<td></td>
<td>Value of $k_2/k_1$ from reference 3 for reflex airfoils which is a function of longitudinal location of maximum camber</td>
<td>K20K1</td>
<td>21 to 30</td>
</tr>
<tr>
<td>6 series and 6A-series</td>
<td>Design lift coefficient (i.e., 0.20) Camber line chordwise loading (use 0.80 for 6A-series) Number of camber line to be summed (if only one, leave blank or insert 1.0)</td>
<td>CL1</td>
<td>1 to 10</td>
</tr>
<tr>
<td></td>
<td></td>
<td>A</td>
<td>11 to 20</td>
</tr>
<tr>
<td></td>
<td></td>
<td>CMBNMR</td>
<td>21 to 30</td>
</tr>
</tbody>
</table>

**CARDS 10, 11, and 12** – Up to nine additional camber lines may be summed on these cards for the 6-series camber line. These cards are not necessary for only one camber line.

<table>
<thead>
<tr>
<th>Camber line</th>
<th>Description</th>
<th>Variable</th>
<th>Columns</th>
</tr>
</thead>
<tbody>
<tr>
<td>6-series</td>
<td>Design lift for second camber line Loading for second camber line</td>
<td>CLI</td>
<td>1 to 10</td>
</tr>
<tr>
<td></td>
<td>Design lift for third camber line Loading for third camber line</td>
<td>CLI</td>
<td>11 to 20</td>
</tr>
<tr>
<td></td>
<td>Design lift for fourth camber line Loading for fourth camber line</td>
<td>CLI</td>
<td>21 to 30</td>
</tr>
<tr>
<td></td>
<td>Design lift for fifth camber line Loading for fifth camber line</td>
<td>CLI</td>
<td>31 to 40</td>
</tr>
<tr>
<td></td>
<td></td>
<td>A</td>
<td>41 to 50</td>
</tr>
<tr>
<td></td>
<td></td>
<td>A</td>
<td>51 to 60</td>
</tr>
<tr>
<td></td>
<td></td>
<td>A</td>
<td>61 to 70</td>
</tr>
<tr>
<td></td>
<td></td>
<td>A</td>
<td>71 to 80</td>
</tr>
</tbody>
</table>

**CARD 13** – Title card for use in plot of airfoil ordinates. Any designation may be used in columns 1 to 80.
APPENDIX

Program Listing

A program listing follows:

```
PROGRAM ANALIN(INPUT,OUTPUT,TAPES=INPUT,TAPES=OUTPUT,PUNCH)
DIMENSION XL(200), YL(200), YU(200), XU(200)
COMMON MAIN/YSTART(3),CHD,KON
DIMENSION COEFS(4)
DIMENSION XA(32), YAU(32), XAL(32), YAL(32), NAME(2)
DIMENSION CL1(10), A1(10), TANTH(10), YCMB(10), TANTH(10), YCP(10)
1) IF6X4(10)
INTEGER TITLE(8)
COMPLEX ROOTS(3),TEMP(8)
EQUIVALENCE (CL1(1),CMB)
INTEGER SERIEC
REAL K20K1
INTEGER PROFILE, CAMBER
YSTART(1)=1.0
YSTART(2)=4.0
YSTART(3)=7.0
K2D=104H-DIGIT
K2DMD=104H-DIGITMD
K2D=104H2-DIGIT
K3D=104H3-DIGIT
K3D=104H3-DIGITREF
K6S=104H6-SERIES
K6AS=104H6A-SERIES
KON=0
C INPUT PARAMETERS NORMALIZED BY THE CHORD (CHD)
C TOC = T/C, THICKNESS, RLE = LEADING EDGE RADIUS, XM = X(MAX)/CHORD
C DX = INTERVAL/CHORD, CHD = CHORD IN DESIRED UNITS
C CMB = CAMBER CONSTANT K1, CM = X(MAX CAMBER)/CHORD
CALL PSEUDO
CALL LEROY
READ (5+990) N,XA(1),I=1,N)
DI,*=0
20 READ (5+600) (TITLE1),I=1,8)
IF (ENFILE 5) 30,40
30 CALL CALPLT (0,0,999)
STOP
40 CONTINUE
READ (5+600) PROFILE, CAMBER
KON=KON+1
ICKY=0.0
FRAC=1.0
DI=1.0
PRINT B20 PROFILE, CAMBER
PRINT 610 (TITLE1, I=1,8)
IF (PROFILE.EQ.10H4-DIGIT ) READ (5,630) TOC, XLF, DX*CHORD, 5*N, NA
150(1)
XM=0.0
IF (PROFILE.EQ.10H4-DIGITMD) READ (5,630) TOC, XLF, DX*CHORD, 5*N, NA
150(1)
NAME(1)
1) IF (CAYNE*EQ.10H2-DIGIT ) READ (5,630) CMX, CAMBER, EQ.10H1-DIGIT ) READ (5,630)
10) CHM, CMH, CMH, CMH, CMH, CMH, CMH, NAME(2)
1) IF (CAYNE*EQ.10H1-DIGITREF) READ (5,630) CMX, CMH, CMH, CMH, CMH, CMH, CMH, NA
150(2)
1) IF (CAYNE*EQ.10H2-SERIES ) READ (5,630) CMX, CAMBER, EQ.10H1A-SERIES) READ (5,630)
10) CL1(1), A(1), CMVAL, RM, CVH, CMH, CMH, NAME(2)
1) IF (CAYNE*EQ.10H2A-SERIES) READ (5,630) CMX, CAMBER, EQ.10H1A-SERIES) READ (5,630)
10) CMH, CMH, NAME(2)
150(3)
I IF (ICKY.TT.1) 409 (5,640) (CL1(1),A1, I=1,2,ICKY)
150(4)
IF (CAYNE*EQ.10H2-SERIES) READ (5,630) CMX, CL1(1), CMH, NAME(2)
PRINT 590, NAM
```

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IF (ICXY*LE,1) ICXY=1
PI=3.1415926535
E=1.00
U0 50 I=1.10
IF (A(I)=1)
50 CONTINUE

IF (PROFILE.EQ.10H4-DIGIT) PRINT 600, TOC, XLE, XCM
IF (PROFILE.EQ.10H4-DIGIT) PRINT 610, TOC, XLE, XCM, XM

1 (CL(I)=1) CONTENT=1
IF (TACL.TIF) PROFILE*K40
IF (PROFILE.EQ.10H4-DIGIT) GO TO 70

COMPUTED CONSTANTS

A=5.30259,0.2,TOC
U=0.052
IF (U1.GT.0.0) GO TO 60
U1=1.0*(2.24-5.22534/12.32)*X**2)/(1.0+1.478*X)

60 CONTINUE

U3=3.00109*0.5*X/1.0+(1.0+X)*X**2)/(1.0+1.478*X)
U2=1.0*(1.0+X)*X**3/(2.0-3.0*X)/(1.0-X)
A3=0.1*X**4*(1.0+X)+1.0*X**5/(2.0+X)**(3.0+X)**2-3.0*X**4/(2.0+X)
1=2.5

A2=0.10*X**42+5.0*X**3+5.0*X**2+5.0*X+A3
A1=2.5*A0+X**42+5.0*X**3+5.0*X**2+5.0*X+A3

RC IS RADIUS OF CURVATURE AT X=XM
PRINT 730, A0+A1*A2+A3*A4*D1*D2*D3*RC

PROFILE* X LE XM

70 CONTINUE
IF (ABS(CMB)*LE,0.1)**6) PRINT 740
IF (ABS(CMB)*GT.0.1)**6) PRINT 750
X=0.0
Y=0.0
XC=0.0
YC=0.0
XU(1)=0.0
YU(1)=0.0
XL(1)=0.0
YL(1)=0.0
XUC=0.0
YUC=0.0
XLC=0.0
YLC=0.0
XAU(1)=0.0
YAU(1)=0.0
XAL(1)=0.0
YAL(1)=0.0
K=2
IF (CAMBER*EQ.10H2-DIGIT) GO TO 86
IF (CAMBER*EQ.10H3-DIGIT) GO TO 90
IF (CAMBER*EQ.10H3-DIGITREF) GO TO 100
IF (CAMBER*EQ.10H4-SERIES) GO TO 110
IF (CAMBER*EQ.10H5A-SERIES) GO TO 110
PRINT 760
GO TO 190

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80 TANTH0=2*#CMB/CM
  IF (ABS(CMB)+LT+E) TANTH0=E
  YP=10.**10
  YPP=10.**10
  YUP=-1/TANTH0
  YLP=-1/TANTH0
  GO TO 190
90 TANTH0=CMB*CM**2*(3.0-CM)/6.0
  IF (ABS(CMB)+LT+E) TANTH0=E
  YP=10.**10
  YPP=10.**10
  YUP=-1/TANTH0
  YLP=-1/TANTH0
  GO TO 190
100 TANTH0=CMB*(3.0CM**2-K20K1*(1-CM)**3-CM**3)/6
  IF (ABS(CMB)+LT+E) TANTH0=E
  YP=10.**10
  YPP=10.**10
  YUP=-1/TANTH0
  YLP=-1/TANTH0
  GO TO 190
110 L=0
  CL1=CL1(I)
  AS=A(I)
120 L=L+1
  A(I)=A(L)
  CL1(I)=CL1(I)
  K=2
  U=0.005
  V=(A-U)/ABS(A-U)
  OMNL=(1.0-U)*ALOG(1.0-U)
  AMNL=(A-U)*ALOG(ABS(A-U))
  OMNL=ALOG(1.0-U)-1.*
  AMNL=ALOG(ABS(A-U))+V
  OMNL=1.0/(1.0-U)
  AMNL=V/ABS(A-U)
  IF (A+LTE=OR+ABS(1.0-A)+LTE) GO TO 130
  G=-=(A**2*(A**2*LOG(1.0)+0.25)+0.25)/(1.0-A)
  Q=1.0
  H=0.5*(1.0-A)**2*LOG(1.0-A)-0.25*(1.0-A)**2)/(1.0-A)+G
  Z=A(A-U)+AMNL=5*(1.0-U)*OMNL=25*(A-U)**2+25*(1.0-U)**2
  Z=2.5*(A-U)+AMNL=5*(1.0-U)*OMNL=25*(A-U)-(1.0-U)
  Z=2.5*(A-U)+AMNL=5*(1.0-U)*OMNL=25*(A-U)+OMNL=25*(A-U)
  CONTINUE
130 CONTINUE
  IF (A+LTE) GO TO 140
  IF (ABS(A-1.0)+LTE) GO TO 150
140 H=0.0
  Q=1.0
  Z=U*LOG(U)-5*U-5.0*(1.0-U)*OMNL=5.0*OMNL=5.0
  GO TO 160
150 H=0.0
  Q=H
  Z=OMNL
  GO TO 160
160 TANTH0=CL1*(Z)/(1.0-Q*A)-1.*ALOG(U)+H)/P1/(A+1.0)/2.0
  IF (ICKY#GT+1.0 AND=L+1 ICKY) GO TO 120
  IF (ICKY#EQ+1.0) GO TO 180
  DO 170 J=2 ICKY
170 TANTH0(I)=TANTH0(I)+TANTH0(J)
  CONTINUE
180 CONTINUE
  IF (ABS(CMB)+LT+E) TANTH0=E
  YP=10.**10
  YPP=10.**10
  YUP=-1/TANTH0
  YLP=-1/TANTH0
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XLL=X*ALOG(X)
Q=1.0
IF (ABS(1.0-X)XLT=ANDXABS(1.0-X)XLT=) GO TO 330
IF (ABS(1.0-X)XLT=) GO TO 340
IF (AX(A-X)XLT=) GO TO 340
IF (ABS(A-X)XLT=) GO TO 310
IF (ABS(A-X)XLT=) GO TO 320
V=(A-X)/ABS(A-X)
OMXL=1X*AMXL(I+X)*AMXL(I+X)
OMXL=1X*AMXL(ABS(A-X))
OMXL=1X*AMXL(I+X)-1*
AMXL=AMXL(ABS(A-X))V
OMXL=1X(I+X)
Z=Z+1.0*(AX)*AMXL-5*(I+X)*OMXL-25*(A-X)**2+25*(I+X)**2
Z1=Z+1.0*(AX)*AMXL=AMXL-(I+X)*OMXL1+OXM1+(A-X)-(I+X))
Z2=Z+1.0*(AX)*AMXL2-AMXL-5*(I+X)*OMXL2+OMXL1
IF (AX=I+X) GO TO 300
G2=Z+1.0*(S5*AMXL(I+X)-0.250(I+X)/10-A)
H0=5.0*(I+X)**2*AMXL(I+X)-0.250(I+X)**2/10-A)+G
GO TO 350
290 Z=E-5*(I+X)**2*AMXL(I+X)+0.250(I+X)**2
Z1=Z+1.0*(I+X)*AMXL(I+X)-10*(I+X)**2*(I+X)**2
Z2=Z+1.0*(I+X)**2*AMXL(I+X)-0.250*(I+X)**2/10-A)+G
GO TO 350
300 G2=Z+5
H0=5.0
GO TO 350
310 G1=I+X**G
G1=G
Z1=Z+1.0*(I+X)*AMXL(I+X)
Z1=AMXL(I+X)-10*10+I+X)
Z2=Z-10*10+I+X)
GO TO 350
320 G1=Z+5
H0=5.0
Z1=10*10+I+X)
Z2=10*10+I+X)
GO TO 350
330 Z1=10*10+I+X)
Z2=10*10+I+X)
GO TO 350
340 G1=25
H0=5.0
Z1=25
Z2=25
GO TO 350
350 YCP(L)=CL1*(Z/10=0.0)X+XLL+G-H+X)+P1/(A+1)+1/2*
XSV=X
IF (XLT=0.005) X=0.005
TANH(L)=CL1*(Z/10=3A)-1.0-ALOGX1+M/H/PI/(A+1)+1/2*0
X*SV
IF (IF6X(L)=EQ+1) TANH(L)=-5
IF (XSV+0.005) GO TO 360
YCP(L)=0.0
GO TO 380

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APPENDIX

360 CONTINUE
IF (ABS(A1-X)*GTE) GO TO 370
YP2(L)*X/I
GO TO 380
370 PIA*PI*%A1*K2,
YP2(L)*CL1*Z2/(L+0.0*1-1/X/P/A
380 CONTINUE
C
MODIFIED CAMBERLINE OPTION
IF (CAMBER*EQ.180) GO TO 390
GO TO 410
390 YCMB(L)=YCMB(L)*0.97948
TANTH(L)=TANTH(L)*0.97948
YP2(L)=YP2(L)*0.97948
IF (ABS(A1+B)*LT.0) GO TO 400
PRINT 780
READ 600, NPI
IF (KON+EO.0) KON=0
GO TO 20
400 CONTINUE
IF (TANTH(L)*LE.0.24521*CL1) YCMB(L)=2.24521*CL1*(1-X)
IF (TANTH(L)*LE.0.24521*CL1) YP2(L)=0
IF (TANTH(L)*LE.0.24521*CL1) TANTH(L)=0.24521*CL1
IF (TANTH(L)*LE.0.24521*CL1) IF6XA(L)=0
410 CONTINUE
IF (ICL+GTY.1+AND.0+LT.00 ICLK) GO TO 280
IF (ICL+EQ.0) GO TO 430
DO 420 J=2,ICL
YCMB(1)=YCMB(1)+YCMB(J)
TANTH(1)=TANTH(1)+TANTH(J)
YP2(1)=YP2(1)+YP2(J)
420 CONTINUE
430 CONTINUE
F=SQRT(1+TANTH**2)
THP=YP2/F**2
440 CONTINUE
IF (X+GT.*XM) GO TO 550
IF (ABS(X-XM)*LT.0) GO TO 550
SINTH=TANTH/F
COSTH=1/F
I=1+1
XU(I)=X-Y*SINTH
YU(I)=YCMB+Y*COSTH
XL(I)=X+Y*SINTH
YL(I)=YCMB-Y*COSTH
IF (ABS(X-XA(I)).GT.0.0) GO TO 450
XAU(K)=XU(I)
YAU(K)=YU(I)
XAL(K)=XL(I)
YAL(K)=YL(I)
K=K+1
450 CONTINUE
XUC=XU(I)+CHD
YUC=YU(I)+CHD
XLC=XL(I)+CHD
YLC=YL(I)+CHD
IF (ABS(CMB)*LE.0.1**6) GO TO 460
YP=O.0
YLP=YP
IF (ABS(TANTH)*LT.0.1**10) GO TO 460
YPF=(TANTH+F+YP+TANTH*THP)/(F+YP+TANTH*THP)
YLPF=(TANTH+F+YP+TANTH*THP)/(F+YP+TANTH*THP)
460 CONTINUE
IF (X+LE.0.0975) FRAC=0.25
IF (X+LE.0.00025) FRAC=0.025
IF (ABS(CMB).GT.0.1**6) PRINT 790, X+XU(I),YU(I),XUC,YUC,YUP+XL(I)

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XYL(1) : XLC*YLC*YLP
IF (ABS(CMH) .E .LT .*1**6) PRINT 770, X, Y, YPP, YPP*XC.YC
X=XC+HAC*PX
FRAC=1.0
:IF (ABS(X-XM)*.LT.E) GO TO 470
IF (XLTXM) GO TO 200
C
C PROFILE - X GE XM
C
470 CONTINUE
IF (PROFILE.EQ.10H4-DIGIT) GO TO 480
IF (PROFILE.EQ.10H4-DIGITMOD) GO TO 490
PRINT 800
GO TO 500
480 Y=0.29695*QRT(X)-0.12600*X-0.35160*X**2+0.28420*X**3+0.1015*X**4
YP=5.29695*QRT(X)-1.262-3.35160*X+3.28430*X**2+3.1015*X**3
GO TO 500
490 Y=0.1D1*(1+-X)+D2*(1+-X)**2+D3*(1+-X)**3
YP=-1D2+2*D2*(1+-X)-3*D3*(1+-X)**2
YPP=2*D2+6*D3*(1+-X)
500 CONTINUE
Y=YP+TGC/2
YPP=YPP+TGC/2
XC=XC*CHD
YC=YCHD
:IF (CAMBER.EQ.10H2-DIGIT) GO TO 510
IF (CAMBER.EQ.10H3-DIGIT) GO TO 520
IF (CAMBER.EQ.10H3-DIGITREF) GO TO 530
IF (CAMBER.EQ.10H6-SERIES) GO TO 540
IF (CAMBER.EQ.10H6A-SERIES) GO TO 540
PRINT 760
GO TO 560
510 YCBM=CMB(2.0*CMB*X*X)/CMB**2
TANH=2*CMB(1+x/CMB)/CM
IF (XGTCM) YCM=CMB*(1+-2*CMB+2*CMBX-X**2)/(1+-CMB)**2
IF (XGTCM) TANH=(2*CMB-2*X)/CMB/(1+-CMB)**2
F=QRT(1+TANH**2)
THP=-2*CMB/CMB/2/F**2
IF (XGTCM) THP=-2*CMB/(1+-CMB)**2/F**2
GO TO 560
520 YCBM=CMB*(X**3-3.0*CMB*X**2+3.0-CMB/X)/6
TANH=CMB(3.0*CMB*X**2-3.0-CMB*X**2+3-CMB)/6+
IF (XGTCM) YCM=CMB(CMB**3+1--X)/6
IF (XGTCM) TANH=-CMB/CMB**3/6
F=QRT(1+TANH**2)
THP=CMB(1-X)/F**2
IF (XGTCM) THP=0.0
GO TO 560
530 YCBM=CMB*(X-CM)**3-K20K1*(1-CM)**3*K20K1*X-CM**3)/6
TANH=CMB(3*X-CM)**2-K20K1(1-CM)**3-CMB**3/6+
IF (XGTCM) YCM=CMB(1-CM)**3-K20K1**(1-CM)**3*K20K1*X-CM**3)
1**3)/6
IF (XGTCM) TANH=CMB(3*K20K1*X-CM)**2-K20K1*(1-CM)**3/6
F=QRT(1+TANH**2)
THP=CMB(1-X)/F**2
IF (XGTCM) THP=K20K1*CMB*(X-CM)/F**2
GO TO 560
540 GO TO 270
550 CONTINUE
560 CONTINUE
SINTH=TANH/F
COSTH=1/F
I=I+1

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## APPENDIX

```plaintext
XU[1]=X*Y*SIN TH
YU[1]=Y*CMB+Y*COST H
XL[1]=X*Y*SIN TH
YL[1]=Y*CMB-Y*COST H
IF (ABS(X-XA[1]) GT 1.0 GT 6) GO TO 570
XAU[1]=XU[1]
XAL[1]=XL[1]
YAL[1]=YL[1]
KW+1

570 CONTINUE
XUC=XU[1]*CHD
YUC=YU[1]*CHD
XLC=XL[1]*CHD
YL C=YL[1]*CHD
IF (ABS(CMB)*LE+0.1 GT 6) GO TO 580
YUP=0.0
YLP=YUP
IF (ABS(TAN TH)*LT+0.1 GT 10) GO TO 580
YUP=TAN TH*(F YP/TAN TH Y*THP)/(F YP TAN TH Y*THP)
YLP=TAN TH*(F YP/TAN TH Y*THP)/(F YP TAN TH Y*THP)

580 CONTINUE
IF (ABS(CMB)*GT+0.1 GT 6) PRINT 790, X+YU[1],YU[1],XUC*YUC+YUP+XL[1]
1 YL[1],XLC+YLC+YLP
IF (ABS(CMY)*LT+0.1 GT 6) PRINT 770, X+Y+YPP+X+YC
X*X+DX
IF (X+LE+1 GT 470)
PUNCH 600, (TITLE(1), i=1, 8)
PUNCH 810, (XAU[1], i=1, 32)
PUNCH 810, (YAU[1], i=1, 32)
PUNCH 810, (XAL[1], i=1, 32)
PUNCH 810, (YAL[1], i=1, 32)
CALL PLOT (XU+XL*YU+YL+1)
GO TO 20

590 FORMAT (13(8F10.0))
600 FORMAT (8A10)
610 FORMAT (1H +8A10)
620 FORMAT (10H PROFILE , A10, 10H CAMBER, A10)
630 FORMAT (7F10.0, A10)
640 FORMAT (8F10.0)
650 FORMAT (/10X, A10, 10X, A10)
660 FORMAT (19H PROFILE PARAMETERS/ 3H T C , F10.5/ 12H L E RADIUS , F10.5/ 18H BASIC X INTERVAL = F10.5/ 7H CHORD, F10.5/) 1/B18H BASIC X INTERVAL = F10.5/ 5H RADIUS = F10.5/
670 FORMAT (19H PROFILE PARAMETERS/ 5H T C , F10.5/ 12H L E RADIUS = F10.5/ 18H BASIC X INTERVAL = F10.5/ 7H CHORD, F10.5/
2/M THICKNESS = X= F10.5/ 13H CONSTANT D1=F10.5/)
680 FORMAT (23H CAMBER LINE PARAMETERS/ 16H CAMBER(ymax) = F10.5/ 28H P
10ITION OF MAXIMUM CAMBER= F10.5/)
690 FORMAT (23H CAMBER LINE PARAMETERS/ 21H CAMBER PARAMETER K1=F10.5/ 14H POSITION OF ZERO CAMBER LINE CURVATURE= F10.5/)
700 FORMAT (23H CAMBER LINE PARAMETERS/ 21H CAMBER PARAMETER K1=F10.5/
14H POSITION OF ZERO CAMBER LINE CURVATURE= F10.5/ 61H RATIO OF AFT 2 TO FORWARD CAMBER LINE CURVATURE FACTOR, K20X1=F10.5/)
710 FORMAT (23H CAMBER LINE PARAMETERS/ 7X, 3HCL1, 9X, 1HA)
720 FORMAT (2F10.3)
730 FORMAT (10H A0, 1, 2, 3, 4, F13.6/ 10H D0, 1, 2, 3, 4, F13.6/ 4H RC=F13.7/)
740 FORMAT (3X, JMX/C10X, 3HY/C8X, 5HY/DX=6X, 7HY2/DX2=22X, 1HX=12X, 1HY)
750 FORMAT (116H, 14H Cambered)

C

165.

UPPER SURFACE VALUE

23X/C17X/4HUX/C6X/4HYU/C5X*7H XU 3X, 7HY YU 3X, 7HDY2/DUX13X3H
3XLC/C4X/4HUL/C5X*7H XL 3X, 7HYL/DXL)

760 FORMAT (39H BAD HOLLERITH CAMBER /SCALIFICATION)
770 FORMAT (5F13.6)
780 FORMAT (32H MODIFIED CAMBER LINE OPTION ONLY ALLOWED IF A=0*8)
```

Original Page is of poor Quality.
APPENDIX

790 FORMAT (F10*5,10X,4F10*5,E11*2,6X,4F10*5,E11*2) A5140
800 FORMAT (3G16.10,H20) A5150
810 FORMAT (5F10*5) A5160
END

SUBROUTINE PLOT (XU,XL,YU,YL) B 10
COMMON /MAIN/ YSTART(3),CHD,K B 20
DIMENSION XU(1),XL(1),YU(1),YL(1),X(450),Y(450) B 30
DIMENSION TITLE(8),TITLE2(8) B 40
READ 30+(TITLE(N),N=1,8) B 60
IF (MOD(K+3)*EG+1) CALL CALPLT (1*0,0,0,-3) B 70
HGT=0.14 B 80
L=1 B 90
DO 10 N=1,1 B 100
X(N)=XU(N) B 110
Y(N)=YU(N) B 120
X(I+N)=XL(L) B 130
Y(I+N)=YL(L) B 140
10 L=L+1 B 150
M=2*N B 160
XPG=10.0 B 170
XX=XPG/2.0-1.5*(6.0/7.0*HGT) B 180
XDV=0.0 B 190
XTIC=1.0 B 200
YPG=2.0 B 210
YDV=0.0 B 220
YTIC=1.0 B 230
X(M+1)=0.0 B 240
Y(M+1)=0.1 B 250
X(M+2)=1.0/XPG B 260
Y(M+2)=X(M+2) B 270
CALL AXES (0.0,YSTART(K)+90.0,YPG+Y(M+1),Y(M+2),XTIC+YDV+1.0+HGT+1.0) B 280
CALL AXES (0.0,YSTART(K)+90.0,XPG+X(M+1),X(M+2),XTIC+XDV+1.0+HGT+1.0) B 290
YLABEL=YSTART(K)-2.5*HGT B 300
CALL NOTATE (XX*YLABEL+HGT*3*X/C0*3) B 310
YLABEL=YLABEL-1.5*HGT B 320
CALL NOTATE (0.0*YLABEL+HGT+TITLE1*0.0) B 330
YS=YSTART(K)+1.0 B 340
CALL NOTATE (-92.0*YS+HGT*3*Z/C0*0.3) B 350
CALL CALPLT (0.0,YSTART(K)+3) B 360
LAP=0 B 370
CALL LINPLT (X*Y+1.0,LAP+0.1*0) B 380
CALL CALPLT (0.0,YSTART(K)+3) B 390
IF (K+LT+3) GO TO 20 B 400
K=0 B 410
CALL NFRAME B 420
20 CONTINUE B 430
RETURN B 440
C 30 FORMAT (BA10) B 450
END
REFERENCES


### TABLE I. - VALUES OF RATIO OF LEADING-EDGE RADIUS TO CHORD FOR VARIOUS THICKNESS RATIOS AND LEADING-EDGE INDEX NUMBER

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### TABLE II. - SAMPLE COMPUTER PRINTOUT OF ORDINATES

**FOR SYMMETRIC AIRFOIL**

**PROFILE 4-DIGIT** | **CAMBER 2-DIGIT** | **NACA 2312**

### PROFILE PARAMETERS
- T/E = 1.2000
- L/F PARITY = 0.0000
- BASIC X INTERVAL = 0.1000
- CHORD = 4.0000

### CAMBER LINE PARAMETERS
- CAMBER (YMAX) = 0.0000
- POSITION OF MAXIMUM CAMBER = 0.0000

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*Note: The table above represents a sample computer printout of ordinates for a symmetric airfoil profile.*
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**TABLE II.** - Continued

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### TABLE III. - SAMPLE COMPUTER PRINTOUT OF ORDINATES FOR CAMBERED AIRFOILS

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**ORIGINAL PAGE IS OF POOR QUALITY**
### TABLE III - Continued

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Figure 1.- Ratio of airfoil leading-edge radius to chord as a function of the ratio of thickness to chord and leading-edge index I.
Figure 2. Variations in thickness-chord ratio for symmetric 4-digit airfoils.
Figure 3.- Variations in amount of camber for 12-percent-thick 4-digit airfoils with 2-digit camber line.
Figure 5 - Comparison of reflexed and nonreflexed 3-digit camber line on 12-percent-thick airfoil.
Figure 6.- Variations in location of maximum thickness for 12-percent-thick 4-digit modified airfoils.
Figure 7. Variations in location of maximum camber for 12-percent-thick 4-digit modified airfoils with 3-digit camber line.
Figure 8: Variations in thickness-to-chord ratio for symmetric 16-series airfoils.
Figure 9.- Variations in amount of camber for 12-percent-thick 16-series airfoils with 6A-series camber line.
Figure 10 - Combination of two 6-series camber lines with a 10-percent-thick 4-digit modified airfoil.
Figure 11.- 2-digit and 3-digit camber lines.