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A COMPUTERIZED PROCEDURE TO OBTAIN THE COORDINATES AND SECTION CHARACTERISTICS OF NACA DESIGNATED AIRFOILS

DON W. KINSEY, CAPTAIN, USAF
DOUGLAS L. BOWERS

TECHNICAL REPORT AFFDL-TR-71-87

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This report describes the technical and analytical aspects of a computer program written to give airfoil coordinates, incompressible inviscid section characteristics and two-dimensional drag-rise Mach numbers for a large number of National Advisory Committee for Aeronautics (NACA) designated airfoils from a simple one card input. The computer program is a combination of two separate programs. One program gives the airfoil surface coordinates with only the NACA airfoil designation as input, and the other program uses the surface coordinates to predict incompressible, inviscid pressure distribution from which the section characteristics and drag-rise Mach number are determined. The capabilities and accuracies of the computer program are described. This document contains input instructions and other operating procedures necessary to utilize this program. Also included are a program listing, a sample printed output, and a representative output plot.

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FOREWORD

The document was written at the Aeromechanics Branch of the Flight Mechanics Division, Air Force Flight Dynamics Laboratory (AFFDL/FXM), Wright-Patterson AFB, Ohio 45433. The report covers the technical aspects and theories involved in the computer program written by Capt. Don W. Kinsey and Douglas L. Bowers.

The majority of the work was performed during June-September 1970, but the program utilizes some previous work by the authors.

The work was performed under Project 1366, "Aeromechanics Technology for Military Aerospace Vehicles," and Task 136612, "Prediction and Improvement of Aerodynamic Characteristics of Advanced Military Aircraft."

This technical report has been reviewed and is approved.

Philip P. Antonatos

PHILIP P. ANTONATOS
Chief, Flight Mechanics Division
AF Flight Dynamics Laboratory

ABSTRACT

This report describes the technical and analytical aspects of a computer program written to give airfoil coordinates, incompressible inviscid section characteristics and two-dimensional drag-rise Mach numbers for a large number of National Advisory Committee for Aeronautics (NACA) designated airfoils from a simple one card input. The computer program is a combination of two separate programs. On program gives the airfoil surface coordinates with only the NACA airfoil designation as input, and the other program uses the surface coordinates to predict incompressible, inviscid pressure distribution from which the section characteristics and drag-rise Mach number are determined. The capabilities and accuracies of the computer program are described. This document contains input instructions and other operating procedures necessary to utilize this program. Also included are a program listing, a sample printed output, and a representative output plot.

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ILLUSTRATIONS

TABLES

SYMBOLS

a_I	incompressible viscous lift curve slope
a_{IT}	incompressible inviscid lift curve slope
AR	aspect ratio
c	airfoil chord length
C_D	drag coefficient
C_L	lift coefficient
C_{LD}	lift coefficient at drag rise Mach number
C_{LI}	incompressible viscous lift coefficient
C_{LIT}	incompressible inviscid lift coefficient
$C_{m(c/4)}$	quarter chord pitching moment
C_p	pressure coefficient
C_{pcrest}	pressure coefficient at crest position of airfoil
F	$F = \left[\beta_D + 1/2\,(1-\beta_D)\,C_{pcrest}\right]^{-1}$
H	free stream stagnation pressure
M_D	drag rise Mach number
N	an integer N = 32 for this program
n	$n = -1 + (5/2)\tan(\tau_a/2)$
Re	Reynolds number based on approximate drag rise Mach number and chord length
$S^{(1)}(x_\nu)$	$= \sum_{\mu=1}^{N-1} s^{(1)}_{\mu\nu} Z_{t\mu}$
$S^{(2)}(x_\nu)$	$= \sum_{\mu=1}^{N-1} s^{(2)}_{\mu\nu} Z_{t\mu}$
$S^{(3)}(x_\nu)$	$= \sum_{\mu=1}^{N-1} s^{(3)}_{\mu\nu} Z_{t\mu} + s^{(3)}_{N\nu}\sqrt{\rho/2c}$

SYMBOLS (CONTD)

$S^{(4)}(x_\nu)$	$= \sum_{\mu=1}^{N-1} s^{(4)}_{\mu\nu} Z_{s\mu}$
$S^{(5)}(x_\nu)$	$= \sum_{\mu=1}^{N-1} s^{(5)}_{\mu\nu} Z_{s\mu}$
$s^{(1)}_{\mu\nu}$	integration coefficients from reference 2
$s^{(2)}_{\mu\nu}$	integration coefficients from reference 2
$s^{(3)}_{\mu\nu}$	integration coefficients from reference 2
$s^{(4)}_{\mu\nu}$	integration coefficients from reference 3
$s^{(5)}_{\mu\nu}$	integration coefficients from reference 3
V/V_o	ratio of local velocity to the free stream velocity
X	airfoil coordinate distribution along chord line
x_ℓ	airfoil coordinate abscissa for lower surface measured from leading edge
x_u	airfoil coordinate abscissa for upper surface measured from leading edge
y_c	ordinate of mean line measured from chord line
y_ℓ	airfoil coordinate ordinate for lower surface measured from chord line
y_t	ordinate of airfoil surface measured perpendicular to mean line
y_u	airfoil coordinate ordinate for upper surface measured from chord line
Z_s	camber line distribution
Z_t	thickness distribution
α	angle of attack in degrees
α_I	incompressible viscous angle of attack
α_{IT}	incompressible inviscid angle of attack

SYMBOLS (CONTD)

α_{OIT}	incompressible angle of attack at $C_L = 0$
β_D	$=\sqrt{1 - M_D^2}$
ΔX	incremental value for airfoil coordinate distribution
θ_m	angle whose arctangent is the slope of the mean line
θ_s	angle whose arctangent is the slope of the airfoil surface
$\Lambda_{(c/4)}$	quarter chord sweep
λ	taper ratio
μ	summing index for matrix multiplication
ν	chordwise position indicator
τ_a	included angle of airfoil trailing edge
ρ	leading edge radius of airfoil

SECTION I

INTRODUCTION

This report discusses the combination of two separate efforts conducted by the authors. The objective of the first effort was to program the method outlined in Reference 1 on predicting the drag-rise Mach number for two dimensional airfoils. This procedure required the airfoil surface coordinates as an input. Often, however, the coordinates of airfoils of a particular camber and thickness are not readily available. This led to the development of another program that produces the surface coordinates of a National Advisory Committee for Aeronautics (NACA) designated airfoil with the NACA designation as the only input.

The combination of these two programs allows the user to obtain the surface coordinates, incompressible, inviscid section characteristics and two-dimensional drag-rise Mach number for a large number of two-dimensional NACA designated airfoils with only a one card input.

Included in Appendix I are the input instructions, the operating procedures, a program listing, sample printed output, and a representative output plot.

This Fortran IV program was written for the IBM 7094 system and Calcomp 563 Plotter. The deck was later converted for use on the CDC 6600 digital computer at Wright-Patterson Air Force Base, Ohio.

SECTION II

NACA AIRFOIL SURFACE COORDINATES PROGRAM

The NACA family of airfoil sections is obtained from a combination of a mean line (or camber line) and a thickness distribution. The mean line and thickness distribution are combined according to the following equations to produce the airfoil section surface coordinates shown in Figure 1.

$$x_u = X - y_t \sin \theta_m$$
$$y_u = y_c + y_t \cos \theta_m$$
$$x_\ell = X + y_t \sin \theta_m$$
$$y_\ell = y_c - y_t \cos \theta_m$$

For a given chordwise position of X,

y_t is the ordinate of the thickness distribution

y_c is the ordinate of the mean line,

θ_m is the arc tangent of the slope of the mean line,

x_u and y_u are the resulting upper surface coordinates,

x_ℓ and y_ℓ are the resulting lower surface coordinates.

Appendix II contains the thickness and mean line expressions for the NACA airfoil sections within the capability of this program. If other thickness and mean line expressions are developed and become available, they can be incorporated into the program.

NACA sections listed below, with the indicated restrictions, are within the program's capability.

Designation	Example	Remarks
4 digit airfoils	0012	No restrictions
5 digit airfoils	23118	No restrictions

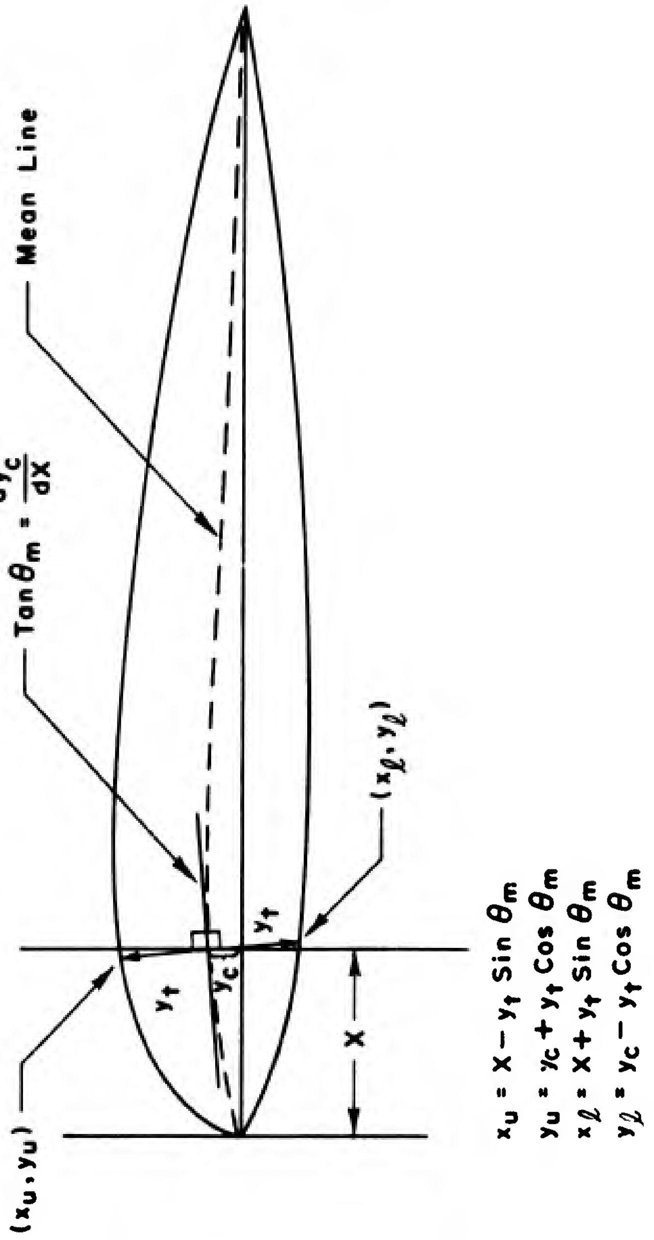


Figure 1. Mean Line and Thickness Combination

Designation	Example	Remarks
4 digit modified	2406-32	Second integer in suffix must be 2, 3, 4, 5 or 6.
5 digit modified	43006-65	Same as 4-digit modified
1-series	16-212	Second integer must be 6, 8 or 9.
6-series	64-005 64A005 64-005 a=.6	Second integer must be 3, 4, 5 or 6.

In order to provide increased accuracy at the leading edge the distribution of points (values for X) defining the surface coordinates was chosen according to the following table:

X (% chord)	ΔX (% chord)
0 - 1.	0.125
1. - 30.	1.0
30. - 80.	5.0
80. - 100.	2.0

Figure 2 shows the surface coordinate distribution for a NACA 2412 airfoil section.

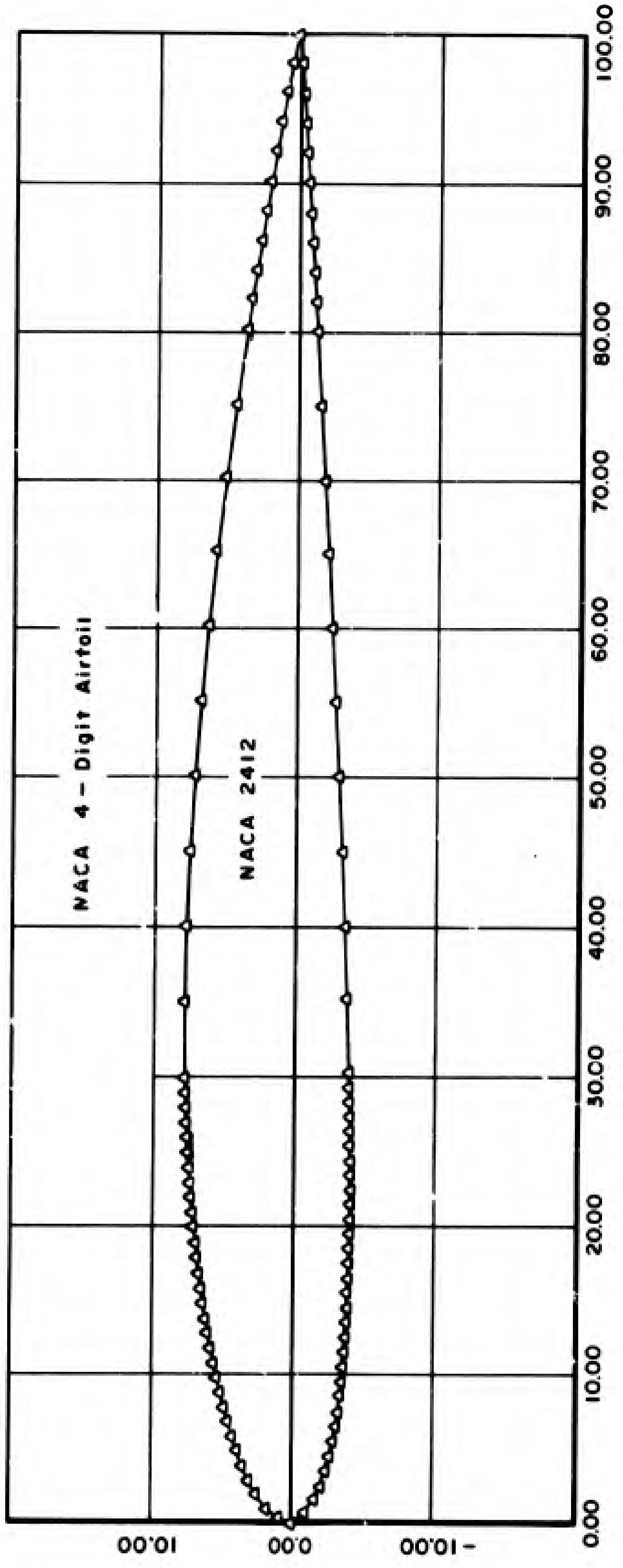


Figure 2. Surface Coordinate Distribution - NACA 2412

SECTION III

DRAG-RISE MACH NUMBER PROGRAM

1. PRESSURE COEFFICIENT CALCULATIONS

The criterion for drag-rise Mach number is defined in Reference 1 as "M_D is the value of free-stream Mach number for which the crest pressure, calculated from the low-speed value by application of the Karman-Tsien compressibility factor, equals 0.515 H." H is the free-stream stagnation pressure (See Figure 3). The crest of the airfoil section is defined as the point where the undisturbed free-stream flow direction is tangent to the surface.

The first step is to define the incompressible, inviscid pressure distribution from which the pressure at the crest can be determined. The method of J. Weber (References 2 and 3) was used for the pressure distribution calculations. This method requires only a knowledge of the airfoil surface coordinates at the chordwise locations defined by

$$X(\nu) = \frac{1}{2}\left(1 + \cos\frac{\nu\pi}{N}\right) \quad \text{where} \quad 0 \leq \nu \leq N$$

N may be any integer, but for this program N is equal to 32. Values for N greater than 32 produced negligible improvement in accuracy at significantly greater computer time and storage requirements.

The theory developed by Weber is essentially a second-order linear theory. The theory gives exact results for elliptical sections and very good results for normal airfoil shapes. Simply stated, the method requires only the multiplication of the column matrix of thickness or camber values by the appropriate matrix of constants given in References 2 and 3. Specifically, the equation for pressure coefficients on a two-dimensional airfoil is given by the equation

$$C_p = 1 - \left(\frac{V(x)}{V_0}\right)^2 = \frac{\left\{\cos\alpha\left[1 + \overset{(1)}{S}(x) \pm \overset{(4)}{S}(x)\right]\right.}{}$$

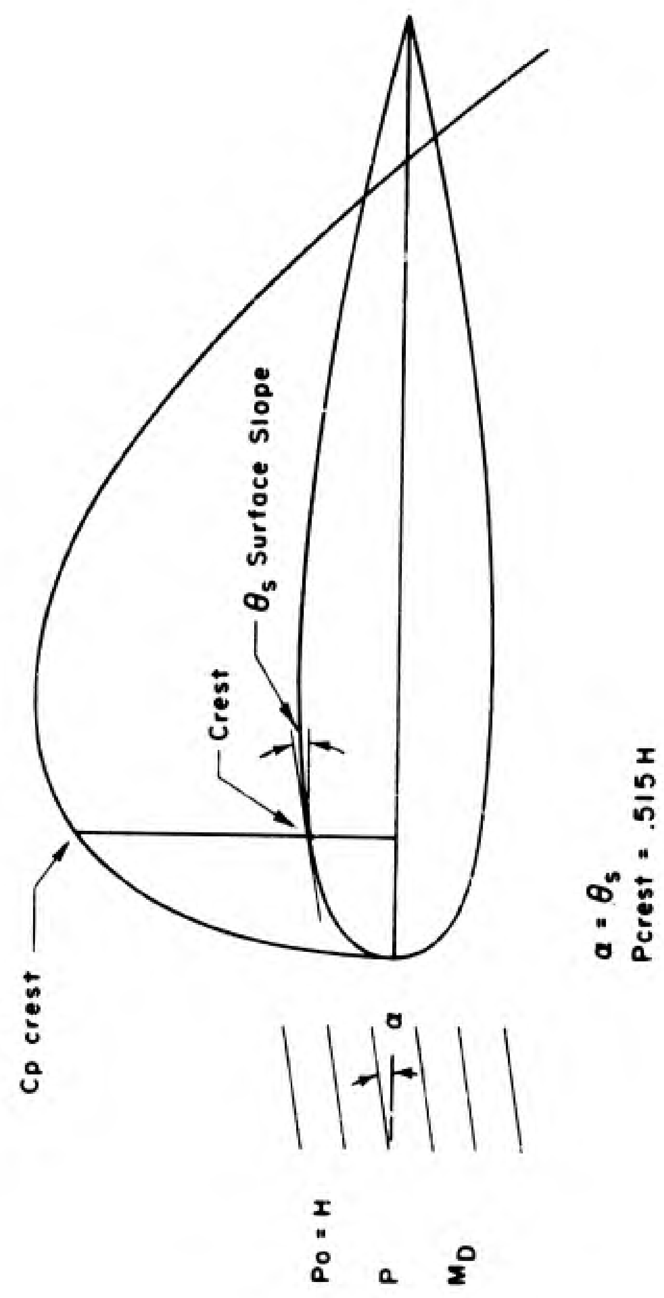


Figure 3. Definition of Terms for M_D Criterion

$$\frac{\pm \sin \alpha \sqrt{\frac{1-x}{x}} \left[1 + \overset{(3)}{S}(x) \right] \Big\}^2}{1 + \left[\overset{(2)}{S}(x) \pm \overset{(5)}{S}(x) \right]^2}$$

For C_p on the upper surface the + is used and for lower surface C_p the - is used.

$$\overset{(1)}{S}(x) = \sum_{\mu=1}^{N-1} \overset{(1)}{s}_{\mu\nu} Z_{i\mu}$$

$$\overset{.)}{S}(x) = \sum_{\mu=1}^{N-1} \overset{(2)}{s}_{\mu\nu} Z_{t\mu}$$

$$\overset{(3)}{S}(x) = \sum_{\mu=1}^{N-1} \overset{(3)}{s}_{\mu\nu} Z_{t\mu} + \overset{(3)}{s}_{N\nu} \sqrt{\frac{\rho}{2C}}$$

$$\overset{(4)}{S}(x) = \sum_{\mu=1}^{N-1} \overset{(4)}{s}_{\mu\nu} Z_{s\mu}$$

$$\overset{(5)}{S}(x) = \sum_{\mu=1}^{N-1} \overset{(5)}{s}_{\mu\nu} Z_{s\mu}$$

where $\overset{(1)}{s}_{\mu\nu}$, $\overset{(2)}{s}_{\mu\nu}$ ---- $\overset{(5)}{s}_{\mu\nu}$ are all N-1 X N

matrices of constants given in References 2 and 3.

Z_s is the camber line description defined as:

$$Z_s = \frac{1}{2} (y_u - y_\ell)$$

and Z_t is the thickness distribution given by:

$$Z_t = \frac{1}{2} (y_u + y_\ell)$$

ρ is the leading edge radius and c is the chord length. If ρ is given in fraction of chord, $\sqrt{\frac{\rho}{2c}}$ becomes $\sqrt{\frac{\rho}{2}}$.

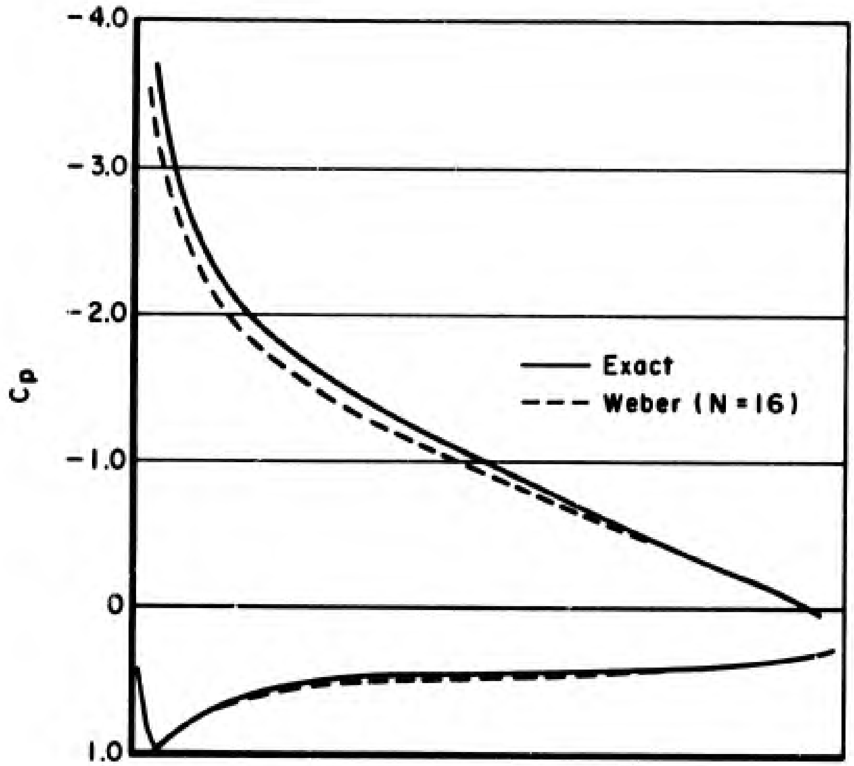
Figure 4 compares Webers method with both a Joukowsky airfoil and a NACA 64_1 - 212 airfoil. The exact solution for the Joukowsky airfoil is derived from a relatively simple analytical expression given in Reference 3, whereas, the NACA 64_1 - 212 solution is from a complex Douglas Neumann potential flow program described in Reference 4. Weber's method gives very good results for both airfoils. As expected, better results are obtained for the NACA 64_1 - 212 airfoil where N = 32 than for the Joukowsky airfoil where N = 16.

The results of the Weber theory should be used with caution near the extreme leading edge of highly cambered airfoils where poor approximations for the thickness and camber distributions may result. This method should not be used for airfoils with surface discontinuities such as slots or flaps. A detailed explanation of the theory is given in References 2 and 3. Both references are required for a complete discussion of the method.

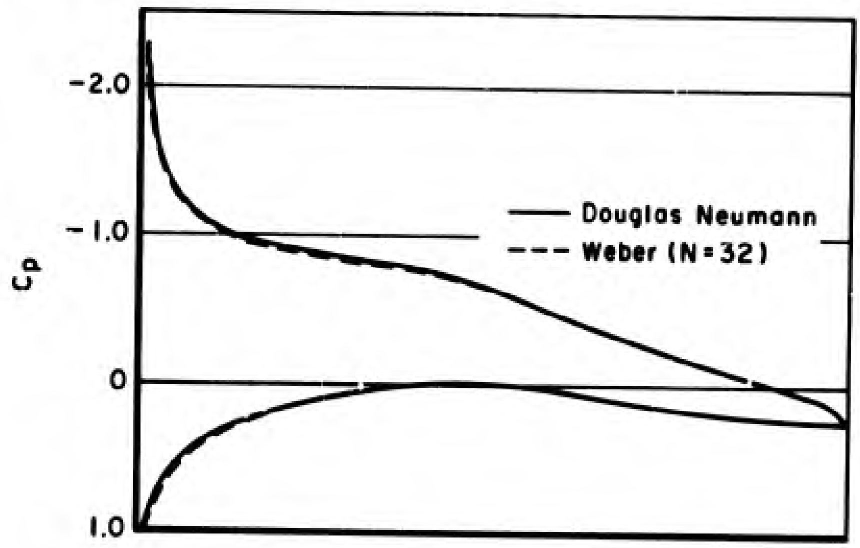
2. DRAG RISE MACH NUMBER CALCULATIONS

The section characteristics for incompressible, inviscid flow are obtained by integration of the pressure coefficients. Trapezoidal integration between successive points on the C_p curve is used by this program. The step-by-step procedure involved in computing M_D is given in Reference 1 and is reproduced in Appendix III. The assumptions and approximations made in the derivation are discussed below. A flow diagram for the computer program is shown in Figure 5.

The first assumption is that for any given value of lift coefficient the same pressure coefficient near the crest will result for both inviscid and viscous flow but each will occur at a different angle of attack. Viscous effects



10% Thick Joukowsky Airfoil with 4% Camber at 10° Angle of Attack



NACA 64_1-212 at 5° Angle of Attack

Figure 4. Comparison of Weber's Method with "Exact" Results

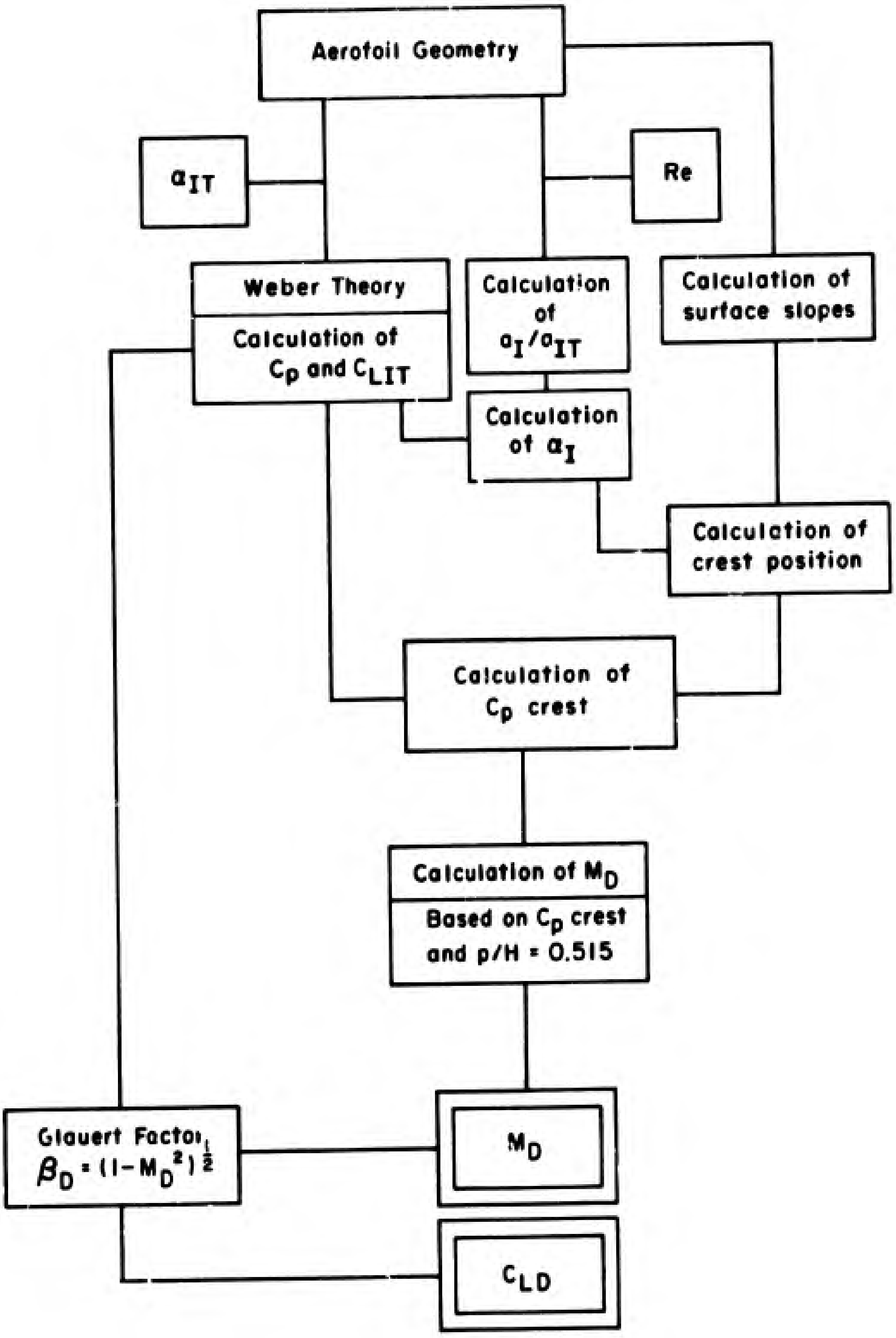


Figure 5. Flow Diagram

on the lift curve slope are assumed to be a function of trailing edge geometry and Reynolds number as shown in the following equation:

$$\frac{a_I}{a_{IT}} = 1 - \left[\ln \frac{Re}{10^6}\right]^n \left[.232 + 1.785 \tan \frac{\tau_a}{2} - 2.95 \tan^2 \frac{\tau_a}{2}\right]$$

Reynolds number is evaluated at the approximate drag-rise Mach number, usually $M_D = .7$. Other terms used in the equation for correcting the lift curve slope for viscous effects are defined in Figure 6.

Assuming the angle of attack (α) for zero lift ($C_L = 0$) in viscous flow coincides with the angle of attack for zero lift in inviscid flow, a C_L and an α for viscous flow may be associated with the pressure coefficient previously defined for inviscid flow as follows:

$$\alpha_I = \left(\frac{C_{LI}}{a_I}\right) + \alpha_{OIT} .$$

The crest position on the airfoil surface can be located from the surface coordinates for any given angle of attack. At this chordwise location the corresponding pressure coefficient is used in the following equation from Reference 1 to define the drag-rise Mach number:

$$C_{P_{crest}} = \frac{0.515\,(1 + 0.2\,M_D^2)^{3.5} - 1}{0.7\,F\,M_D^2}$$

where F is the Karman-Tsien compressibility factor.

$$F = \left[\beta_D + \frac{1}{2}(1 - \beta_D)\,C_{P_{crest}}\right]^{-1}$$

The compressible lift coefficient can be obtained by using the Prandtl-Glauert correction factor.

$$C_{LD} = \frac{C_{LI}}{\beta_D}$$

$$\frac{a_I}{a_{IT}} = 1 - \left[\ln(Re/10^6)\right]^n \left\{.232 + 1.785\,\mathrm{TAN}\,\tau_a/2 - 2.95\,\mathrm{TAN}^2\,\tau_a/2\right\}$$

$$n = -1 + (5/2)\,\mathrm{TAN}\,\tau_a/2$$

T_{90} = Thickness at X = .9c

T_{99} = Thickness at X = .99c

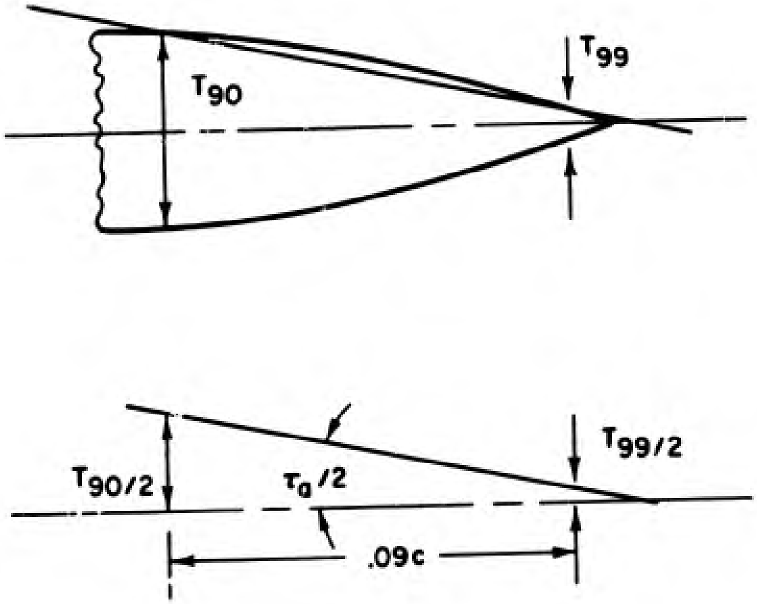


Figure 6. Viscous Effects Correction

The computer program prints a table of values for C_{LD} and M_D so that a curve of C_{LD} vs M_D can be drawn that will readily show the low and high drag regions, as illustrated in Figure 7.

The drag-rise Mach number calculations are seldom valid at angles of attack greater than six degrees. Therefore, the program always gives a table of M_D, C_{LD} and α for one degree increments from a maximum of six degrees to a minimum of α at $C_L \leq 0.0$. The incompressible, inviscid section characteristics are given for whatever angle of attack is input to the program.

One of the fundamental assumptions of this prediction technique is that drag rise occurs when a shock of significant strength develops at the crest position of the airfoil. For some airfoils local supersonic flow produces a weak shock or shocks ahead of the crest position. This condition is referred to as supercritical drag creep and indicates a condition where significant increases in drag occur before the predicted drag rise Mach number. However, the rapid increase in drag is usually delayed until the shock moves back to the crest position. As the angle of attack increases, the distinction between the supercritical drag creep and the rapid drag rise due to the shock at the crest becomes less pronounced. Should the shock upstream of the crest become sufficiently strong to cause separation, the drag increase will be quite rapid and the method fails completely.

Another necessary condition for drag rise prediction is that the subsonic flow around the airfoil must be able to be approximated by a simple correction to the incompressible, inviscid flow. This implies that the method ceases to be valid should separation occur at Mach numbers less than drag rise Mach number.

Reference 1 provides an empirical method of predicting supercritical drag creep based on the slope of the C_p curve upstream of the crest position. The pertinent calculations are made by the computer program and the results are part of the output. The reference did not provide any method of predicting separation. However, from data available an empirical prediction technique based on the location and magnitude of the maximum thickness and the angle of

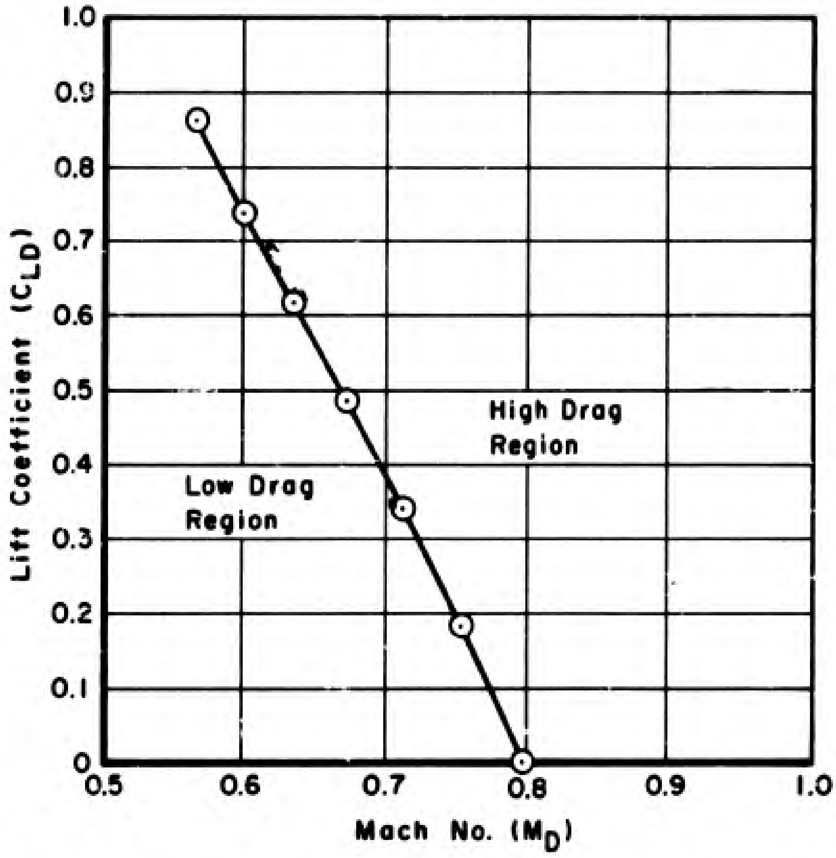


Figure 7. M_D vs. C_{LD} Plot - NACA 0010

attack was formulated and is incorporated in the program. In general, a thin airfoil with maximum thickness near or behind 50% chord location is particularly susceptible to separation. A prediction of either supercritical drag creep or separation should not be regarded as definite errors in M_D prediction but rather as a warning that errors may be present.

SECTION IV

ACCURACIES AND LIMITATIONS

Airfoil coordinates generated with this program were accurate to within 0.35% chord for 6-series airfoils and 0.2% chord for all others, when compared to tabulated coordinates in NACA Report #824 (Reference 5). Much of this error results from the fact that many existing airfoil sections were not derived from exact mathematical expressions. Rather, the coordinates were first established by other means (experimental, pressure distribution, etc.) and then given the NACA designation which most nearly approximated the resulting airfoil (Reference 5).

The Weber theory for pressure coefficient calculations gives excellent results and is widely used in the British Aircraft Industry. A trapezoidal integration technique is used to define C_L, C_D and $C_{m(c/4)}$. The C_L and $C_{m(c/4)}$ are accurate to at least 5% of exact incompressible, inviscid calculations and other widely accepted techniques. The C_D accuracy is difficult to establish since it is strongly dependent on pressure coefficients near the leading edge where pressure coefficient accuracy is not easily obtained.

Accuracy of the drag-rise Mach number is not greatly dependent on any other part of the program with the possible exception of $C_{p\ crest}$. For most airfoils at the moderate angles of attack considered ($\alpha \leq 6°$), the crest location is far enough aft of the leading edge that C_p prediction is quite accurate. Reference 1 promises accuracy of ± .015 for drag-rise Mach number based on the results of tests on 29 airfoils at angles of attack up to 6°. The many airfoils checked with this program were all within that accuracy.

The method for defining drag-rise Mach number was originally designed for straight two-dimensional airfoils only. As mentioned, a large number of test cases have verified this method for these airfoils. However, a limited number of test cases were run for airfoil sections of complete aircraft configurations, both straight and swept wing. The drag-rise Mach numbers were found to correlate better with actual flight tests than most contemporary methods of predicting drag-rise Mach number. The results are shown in Table I. Better than 6% accuracy is obtained for all nine aircraft and better than 2% accuracy is achieved for all except the F-94A.

TABLE I

COMPARISON OF 2-D PROGRAM WITH FLIGHT TEST

				TEST		PROGRAM	
Aircraft	AR	$\Lambda_{(C/4)}$	λ	Airfoil Section	$M_D(C_L=0)$	Airfoil Section	$M_D(C_L=0)$
B-45C	6.74	0	.40	66, 2-215 66, 1-212	0.758	66, 1-212	0.758
F-94A	6.36	0	.38	$65_1$213 a=.5	0.770	65_1-213 a=.5	0.72
F-89	4.46	0	.50	0009-64	0.800	0009-64	0.825
F-86A	4.80	35	.51	0012(9.4)-64m 0011(8.2)-64	0.863	0011-64	0.85
RB-66B	6.75	36	.34	63-009.95(m) 63-008.25	0.840	63-009	0.85
F-101	4.28	36	.28	65A007 m 65A006	0.895	65A006	0.895
F-100A	3.56	45	.30	64A007	0.920	64A007	0.902
F-105	3.18	45	.47	65A-005.5 65A-003.7	0.940	65A005	0.925
F-104	2.45	18.4	.38	Bi-Convex t/c=.0336	0.930	Bi-Convex t/c=.0336	0.907

m- Modified airfoil section

SECTION V

SUMMARY

As a result of this effort, a quick and simple means of obtaining the inviscid, incompressible section characteristics and drag-rise Mach number for two-dimensional arbitrary NACA airfoils is available. This laborsaving program makes available coordinates and characteristics of NACA designated airfoils not obtainable elsewhere without a considerable amount of tedious work. The program has also shown promise in the three-dimensional case for predicting drag-rise Mach number. It is anticipated that the three-dimensional feasibility of this program will be investigated further. The current program, however, offers great potential as an easy method to obtain the coordinates and section characteristics of any NACA designated airfoil.

APPENDIX I

COMPUTER PROGRAM DESCRIPTION

1. CAPABILITY

This program has the capability to handle the following NACA airfoils with given restrictions.

Airfoil Designation	Restriction
4-Digit	None
4-Digit Modified	Position of maximum thickness must be .2, .3, .4, .5 or .6 chord, as indicated in the designation by the second integer in the suffix.
5-Digit	None
5-Digit Modified	Same as 4-Digit Modified
1-Series	Position of minimum pressure must be .6, .8 or .9 chord, as indicated by the second integer in the designation.
6-Series	Position of minimum pressure must be .3, .4, .5 or .6 chord as indicated by the second integer in the designation.

The computations for C_L, C_D, $C_{m(c/4)}$ and C_p are limited to airfoils with infinite aspect ratio (assumes 2-D flow field). The program is not limited by angle of attack; but since incompressible, inviscid flow is assumed, the onset of separation cannot be predicted.

The computations for drag-rise Mach number are seldom valid for angles of attack greater than 6 degrees; therefore, the drag-rise table always starts at 6 degrees and decreases in one degree steps until $C_L \leq 0$.

2. COMPUTER INPUT PROCEDURE

The data deck consists of a minimum of two cards. Card #1 is the card containing the airfoil designation and related constants and card #2 is a blank card. Each additional data case is added before the blank card.

The NACA designation is placed in columns 1-9, starting always in column 1, and a program routing code is placed in column 10. The designations are entered according to one of the following examples where a dash (-) indicates a blank column:

NACA Series	NACA Designation	Col. 1-9	Col. 10
4-Digit	0012	0012	1
4-Digit Modified	2406-32	2406-32	2
5-Digit	23118	23118	3
5-Digit Modified	43006-65	43006-65	4
1-Series	16-212	16-212	5
6-Series	65, 2A212a = .6	65212126	6
	64A212	64-1212	6
	63, 2-212	632-212	6
	64-005	64--005	6

NOTE: This program does not distinguish between 64, 2-210 and 64_2-210. The difference between the coordinates of the two designations is negligible.

Fractional inputs of thickness in hundredths of percent chord are allowed for 4-Digit, 5-Digit and 1-Series airfoils. The fractional part of thickness value is placed immediately to the right of the NACA designation. For example, a 4-Digit symmetrical airfoil with a thickness of 12.25% chord is entered as 001225---1.

In addition to the NACA designation and the routing code, four other variables must be included. In column 15 an integer value of either 1, 2 or 3 must be entered. This integer indicates the method of sweep for the airfoil. A "1" in column 15 indicates an airfoil with no sweep. A "2" indicates an airfoil sheared "ϕ" degrees and a "3" in column 15 indicates an airfoil that is swept "ϕ" degrees. A sheared airfoil has the airfoil section, as defined by the NACA designation, parallel to the free stream flow regardless of leading edge sweep, while the defined section of a swept airfoil is always taken perpendicular to the leading edge. New "corrected" coordinates paralled to the free stream flow direction are computed for swept airfoils. Columns 21-30 contain the value of leading edge shear or sweep, "ϕ" in degrees. Columns 31-40 contain the value of the angle of attack in degrees and columns 41-50 have the chord Reynolds number, calculated at the approximate drag-rise Mach number, usually $M = 0.7$.

An example of one complete data case would be:

	NACA Designation	Routing Code	Sweep Code	Sweep Angle	Angle of Attack	Reynolds Number
Columns	1-9	10	15	21-30	31-40	41-50
Example Values	24012	3	2	10.0	5.0	6000000.

This card describes a 5-digit airfoil with a sheared planform of 10.0 degrees at an angle of attack of 5.0 degrees and a Reynolds number of 6×10^6.

3. COMPUTER OUTPUT DESCRIPTION

The output begins with a listing of the computed coordinates for the NACA designated airfoil. Using a distribution which favors the leading and trailing edge, the program gives 59 ordinates and abscissas for both the upper and lower surface.

Following the listing of the coordinates is a print-out of the input conditions defining method of sweep, leading edge radius, leading edge sweep, Reynolds number and angle of attack. The section characteristics C_L, C_D and $C_{m(c/4)}$ are then printed out along with a table of pressure coefficients for the upper and lower surfaces. Delta C_p, defined as

$$\text{DELTA CP} = C_p\ (\text{upper}) - C_p\ (\text{lower})$$

is also listed. Following the pressure coefficients the theoretical (incompressible, inviscid) lift curve slope is defined along with the lift curve slope corrected for viscous effects. The angle of attack at zero lift and a term designated ALPHA MAX (used to predict separation) are specified.

The drag-rise Mach number table constitutes the last of the output. This table consists of values for drag-rise Mach number (DMACH), lift coefficient corrected for compressible effects (CLD), original angle of attack (ALPHA), angle of attack after viscous corrections (ALPHI), the X-location of the crest position (XCREST), the C_p value at the crest position (CPCREST), and a term DELCP used to predict supercritical drag creep.

This program produces a plot of the airfoil on a labeled axis system. The plotting is done with an IBM 7094 computer and a Calcomp 563 plotter. One data case runs for approximately 80 seconds on this IBM system and plots for 3 minutes. Each additional data case adds 14 seconds computing time and 2 minutes plotting time.

4. SAMPLE COMPUTER OUTPUT

a. Printed Output

The following is a listing of the output for a NACA 65, 2A215 airfoil section. The output is for a wing swept 45°, at an angle of attack of 5° and with a Reynolds number of six million.

b. Output Plot

Following the printed output is a copy of the plotted output which consists of a ten inch plot of the cross section of the 65, 2A215 airfoil.

NACA 65,2A215

UPPER ABSCISSA	UPPER ORDINATE	LOWER ABSCISSA	LOWER ORDINATE
0.00000	0.00000	0.00000	0.00000
[illegible]	.62272	.18961	-.59215
[illegible]	.88112	.33133	-.82549
[illegible]	1.07875	.46735	-1.00015
[illegible]	1.24477	.60069	-1.14457
[illegible]	1.39051	.73231	-1.26974
[illegible]	1.52187	.86296	-1.38128
[illegible]	1.64225	.99262	-1.48253
[illegible]	1.75393	1.12175	-1.57567
[illegible]	1.85850	1.25041	-1.66220
[illegible]	2.57467	2.26952	-2.20724
[illegible]	3.05193	3.27970	-2.60929
[illegible]	3.48350	4.28572	-2.93633
[illegible]	3.85028	5.28931	-3.21572
[illegible]	4.19438	6.29131	-3.46152
[illegible]	4.54005	7.29219	-3.68243
[illegible]	4.79064	8.29223	-3.88361
[illegible]	5.04106	9.29163	-4.06847
[illegible]	5.28437	10.29050	-4.24089
[illegible]	5.51291	11.28895	-4.40152
[illegible]	5.72842	12.28704	-4.55256
[illegible]	5.93239	13.28483	-4.69485
[illegible]	6.12561	14.28235	-4.82937
[illegible]	6.30327	15.27964	-4.95682
[illegible]	6.48785	16.27671	-5.07776
[illegible]	6.65504	17.27360	-5.19262
[illegible]	6.80825	18.27031	-5.30174
[illegible]	6.95886	19.26687	-5.40541
[illegible]	7.10217	20.26328	-5.50383
[illegible]	7.23847	21.25956	-5.59717
[illegible]	7.36776	22.25572	-5.68554
[illegible]	7.49039	23.25175	-5.76903
[illegible]	7.60641	24.24768	-5.84770
[illegible]	7.71593	25.24350	-5.92158
[illegible]	7.81837	26.23923	-5.99067
[illegible]	7.91540	27.23487	-6.05497
[illegible]	8.00653	28.23043	-6.11446
[illegible]	8.09436	29.22591	-6.16903
[illegible]	8.16661	30.22131	-6.21880
[illegible]	8.45454	35.19748	-6.39129
[illegible]	8.57173	40.17278	-6.42786
[illegible]	8.51102	45.14803	-6.31991
[illegible]	8.29373	50.12443	-6.07744
[illegible]	7.90577	55.10270	-5.71512
[illegible]	7.39214	60.08368	-5.25155
[illegible]	6.75819	65.06895	-4.69979
[illegible]	6.21834	70.05645	-4.07728
[illegible]	5.18667	75.04947	-3.40103
[illegible]	4.27639	80.04772	-2.68990
[illegible]	3.84458	82.04855	-2.41941
[illegible]	3.41709	84.05061	-2.14960
[illegible]	2.98164	86.05364	-1.87964
[illegible]	2.55055	88.05785	-1.60952
[illegible]	2.11077	90.06338	-1.33922
[illegible]	1.68023	92.07037	-1.06873
[illegible]	1.25211	94.07910	-.79813
[illegible]	.83047	96.09004	-.52697
[illegible]	.40052	98.10423	-.25553
[illegible]	0.00000	100.00000	0.00000

CORRECTED COORDINATES FOR SWEPT AIRFOILS

UPPER ABSCISSA	UPPER ORDINATE	LOWER ABSCISSA	LOWER ORDINATE
.06170	.44033	.18961	-.41871
.16867	.62305	.32133	-.58371
.28265	.76279	.46735	-.70721
.39935	.88019	.60065	-.80933
.51769	.99326	.77231	-.89794
.63714	1.07612	.86286	-.97671
.75779	1.16124	.99262	-1.04871
.87895	1.24022	1.12175	-1.11417
.99959	1.31416	1.25941	-1.17535
1.98149	1.79228	2.26952	-1.56075
2.97071	2.15904	3.27970	-1.84574
3.96439	2.46320	4.28572	-2.07630
4.96269	2.72892	5.28971	-2.27386
5.95963	2.96630	6.29131	-2.44773
6.95781	3.18201	7.29219	-2.60387
7.95777	3.38042	8.29223	-2.74612
8.95837	3.56456	9.29163	-2.87712
9.95951	3.73661	10.29051	-2.99976
10.96195	3.89321	11.28835	-3.11241
11.96255	4.05361	12.28704	-3.21914
12.96517	4.19476	13.28483	-3.31976
13.96765	4.33146	14.28235	-3.41488
14.97036	4.46129	15.27964	-3.50511
15.97329	4.58477	16.27671	-3.59051
16.97641	4.70229	17.27359	-3.67173
17.97969	4.81416	18.27031	-3.74890
18.98313	4.92066	19.26687	-3.82221
19.98672	5.02199	20.26328	-3.89180
20.99044	5.11832	21.25956	-3.95779
21.99428	5.20979	22.25572	-4.02029
22.99825	5.29651	23.25175	-4.07932
24.00232	5.37854	24.24758	-4.13494
25.00651	5.45596	25.24351	-4.18718
26.01077	5.52881	26.23923	-4.23604
27.01513	5.59709	27.23487	-4.28151
28.01957	5.66083	28.23043	-4.32357
29.02409	5.72007	29.22591	-4.36221
30.02869	5.77466	30.22131	-4.39736
35.05252	5.97825	35.19748	-4.51976
40.07727	6.06112	40.17273	-4.54518
45.10191	6.01812	45.14809	-4.46873
50.12557	5.85752	50.12443	-4.29749
55.14771	5.59019	55.10279	-4.04193
60.16632	5.22706	60.08359	-3.71740
65.18195	4.77876	65.06805	-3.32324
70.19355	4.25551	70.05645	-2.88397
75.20053	3.66753	75.04947	-2.40493
80.20228	3.02396	80.04772	-1.90147
82.20134	2.71853	82.04866	-1.71278
84.19949	2.41735	84.05051	-1.51939
86.19616	2.10834	86.05384	-1.32910
88.19214	1.80751	88.05736	-1.13810
90.18661	1.49887	90.06339	-.94637
92.17063	1.19447	92.07937	-.75570
94.17090	.89037	94.07910	-.56427
96.15966	.58652	96.09034	-.37262
98.14577	.28321	98.10423	-.18067
100.00000	0.00000	100.00000	0.00000

INPUT CONDITIONS

PLANFORM (1-2D,2-SHEARED,3-SWEPT)	L.E. RADIUS	L.E. SWEEP	REYNOLDS NUMBER	ANGLE OF ATTACK
3	.0154947	45.0000000	6000000.	5.000

SECTION CHARACTERISTICS

CL	CD	CM(C/4)
.3117739	.0544605	-.0545753

PRESSURE COEFFICIENTS AND DELTA PRESSURE COEFFICIENT FOR GIVEN ANGLE OF ATTACK

CHORD LOCATION	CP-UPPER	CP-LOWER	DELTA CP
.00241	.71828	.73359	-.01530
.00961	-.01242	.65786	-.67028
.02153	.00436	.36237	-.35801
.03806	-.19025	.32889	-.51914
.05904	-.17847	.22178	-.40025
.08427	-.24805	.20763	-.45568
.11349	-.23975	.15259	-.39234
.14645	-.27926	.14057	-.41983
.18280	-.27921	.10115	-.38036
.22221	-.31114	.08599	-.39713
.26430	-.31842	.05112	-.36954
.30866	-.34814	.03231	-.38045
.35486	-.35841	-.00016	-.35825
.40245	-.38095	-.01775	-.36320
.45099	-.38013	-.03959	-.34054
.50000	-.38281	-.04410	-.33871
.54901	-.36708	-.05183	-.31524
.59755	-.35635	-.04591	-.31044
.64514	-.33060	-.04388	-.28672
.69134	-.31275	-.03011	-.28264
.73570	-.27681	-.02330	-.25352
.77779	-.27115	.00014	-.27129
.81720	-.23417	.01697	-.25114
.85355	-.18967	.03051	-.22017
.88651	-.15106	.04099	-.19205
.91573	-.11587	.05515	-.17102
.94096	-.07777	.06804	-.14581
.96194	-.03874	.08645	-.12520
.97847	.00864	.10744	-.09880
.99039	.06479	.13948	-.07469
.99759	.16071	.20241	-.04170

THEORETICAL LIFT CURVE SLOPE = .05784
ANGLE OF ATTACK AT ZERO LIFT = -.41302

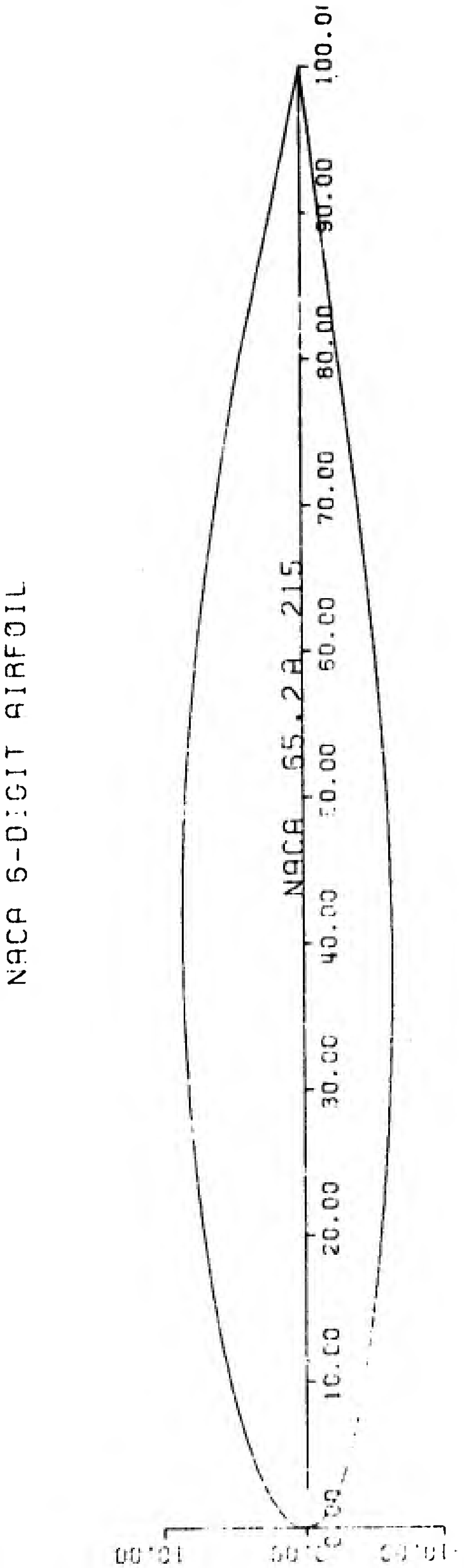
LIFT CURVE SLOPE CORRECTED FOR VISCOUS EFFECTS = .04892
ALPHA MAX = 5.03

DRAG RISE MACH NUMBER TABLE

DMACH	CLD	ALPHA [1]	ALPHI	XCREST	CPCREST	DELCP [2]
.77547	.58278	6.	7.10922	.15219	-.31999	-.02470
.79136	.50597	5.	5.96367	.18816	-.28498	-.00693
.79707	.42225	4.	4.79980	.23013	-.27295	-.03278
.80564	.33375	3.	3.62894	.27526	-.25544	-.02428
.81042	.27908	2.	2.45043	.32047	-.24594	-.04502
.81770	.14974	1.	1.26567	.36390	-.23177	-.05777
.82349	.04751	0.	.08004	.40596	-.22085	-.07640
[illegible]	-.06135	-1.	-1.10736	.44903	-.19715	-.09573

[1] WHEN ALPHA IS GREATER THAN ALPMAX, SEPARATION MAY EXIST RENDERING THE RESULTS INCORRECT.

[2] A VALUE OF DELCP GREATER THAN 0.02 INDICATES A PREMATURE DRAG CREEP CONDITION MAY EXIST.


NACA 6-DIGIT AIRFOIL
NACA 65,2A 215
10.00
20.00
30.00
40.00
50.00
60.00
70.00
80.00
90.00
100.00

5. COMPUTER PROGRAM LISTING

This part contains a listing of the computer program.

```
      PROGRAM MAIN(INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT,PLOT)
C   PLOT SET FOR MAX 10 INCHES BY 2 INCHES
C   PLOT MADE ADJUSTABLE BY CALL AXIS STATEMENTS
      COMMON/BLK01/ X(160)
      COMMON/BLK02/ XU(160),XL(160)
      COMMON/BLK03/ YUN(160),YLN(160)
      COMMON/BLK04/ L,I,J,K,II,JJ,KK,III,JJJ
      COMMON/BLK05/ NA
      COMMON/BLK06/ XUD(70),ZUD(70),XLD(70),ZLD(70)
      COMMON/BLK07/ NOPT
      COMMON/BLK10/ RHO
      COMMON/BLK12/ NCODE2,PHE,ALPHA,RE
      DIMENSION DATA(1024)
      CALL PLOTS(DATA,1024)
   11 READ(5,2) I,J,K,II,JJ,KK,III,JJJ,NA,NCODE2,PHE,ALPHA,RE
    2 FORMAT(8I1,1X,I1,4X,I1,5X,3F10.0)
      IF(EOF (5)) 101,102
  102 NC=I+J+K+II
      IF(NC.LT.1) CALL PLOTE
      IF(NC.LT.1) GO TO 68
      IF(NA.EQ.1) GO TO 12
      IF(NA.EQ.2) GO TO 14
      IF(NA.EQ.3) GO TO 16
      IF(NA.EQ.4) GO TO 18
      IF(NA.EQ.5) GO TO 22
      IF(NA.EQ.6) GO TO 26
   12 WRITE(6,4) I,J,K,II
    4 FORMAT(1H1,4X,6H NACA ,4I1)
      GO TO 60
   14 WRITE(6,20) I,J,K,II,KK,III
   20 FORMAT(1H1,4X,6H NACA ,4I1,3H - ,2I1)
      GO TO 60
   16 WRITE(6,15) I,J,K,II,JJ
   15 FORMAT(1H1,4X,6H NACA ,5I1)
      GO TO 60
   18 WRITE(6,40) I,J,K,II,JJ,III,JJJ
   40 FORMAT(1H1,6H NACA ,5I1,3H - ,2I1)
      GO TO 60
   22 WRITE(6,24) I,J,II,JJ,KK
   24 FORMAT(1H1,4X,6H NACA ,2I1,3H - ,3I1)
      GO TO 60
   26 IF(K.EQ.0.AND.II.EQ.0) GO TO 90
      IF(K.NE.0.AND.II.EQ.0) GO TO 86
      IF(K.EQ.0.AND.II.NE.0) GO TO 82
      WRITE(6,80) I,J,K,JJ,KK,III
   80 FORMAT(1H1,4X,6H NACA ,2I1,1H,,I1,1HA,3I1)
      GO TO 94
   82 WRITE(6,84) I,J,JJ,KK,III
   84 FORMAT(1H1,4X,6H NACA ,2I1,1HA,3I1)
      GO TO 94
   86 WRITE(6,88) I,J,K,JJ,KK,III
   88 FORMAT(1H1,4X,6H NACA ,2I1,1H,,I1,1H-,3I1)
      GO TO 94
   90 WRITE(6,92) I,J,JJ,KK,III
   92 FORMAT(1H1,4X,6H NACA ,2I1,1H-,3I1)
```

```
      GC TO 94
   94 IF(JJJ.LT.1) GO TC 100
      WRITE(6,95) JJJ
   95 FCRMAT(10X,3HA=.,I1)
  100 GC TO 60
   60 DELX=0.00125
      L=2
      X(1)=0.0
    1 X(L)=X(L-1)+DELX
      IF(X(L).GE..01) DELX=.01
      IF(X(L).GT..3) DELX=.05
      IF(X(L).GT..8) DELX=.02
      IF(X(L).GE.1.0)  GO TO 3
      L=L+1
      GC TO 1
    3 CCNTINUE
      IF(NA.EC.1) CALL COORC4
      IF(NA.EC.2) CALL CORD4M
      IF(NA.EC.3) CALL COORD5
      IF(NA.EC.4) CALL CORD5M
      IF(NA.EC.5) CALL COORD1
      IF(NA.EC.6) CALL COCRC6
C   VALUES/ XU,YU,XL,YL -WRITTEN
      WRITE(6,8)
    8 FCRMAT(     12X,15H UPPER ABSCISSA,10X,15H UPPER ORDINATE,10X,
     115H LCWER ABSCISSA,10X,15H LOWER ORDINATE)
      WRITE(6,6)  (XU(M),YUN(M),XL(M),YLN(M),M=1,L)
    6 FCRMAT(     15X,F10.5,15X,F10.5,15X,F10.5,15X,F10.5)
      CALL XNEG
      CALL MONO
      CALL TOLP
   69 GC TO 11
  101  STCP
      END
```

```
      SUBROUTINE TCLP
      COMMON/BLK02/ XU(160),XL(160)
      COMMON/BLK03/ YUN(160),YLN(160)
      COMMON/BLK04/ L,I,J,K,II,JJ,KK,III,JJJ
      COMMON/BLK05/ NA
      DATA BCD/6H      /
      AI=I
      AJ=J
      AK=K
      AII=II
      AJJ=JJ
      AKK=KK
      AIII=III
      AJJJ=JJJ
      CALL PLOT(2.0,4.5,-3)
      CALL AXIS(0.0,0.0,BCD,-6,10.0,0.0,0.0,10.0,10.0)
      CALL AXIS(0.0,-1.0,BCD, 6,2.0,90.0, -10.0,10.0,10.0)
      M=L+1
      N=L+2
      XU(M)=0.0
      XU(N)=10.0
      YUN(M)=0.0
      YUN(N)=10.0
      CALL LINE(XU,YUN,L,1,0,2)
      XL(M)=0.0
      XL(N)=10.0
      YLN(M)=0.0
      YLN(N)=10.0
      CALL LINE(XL,YLN,L,1,0,2)
      CALL SYMBOL(4.2,0.0,.14,5H NACA,0.0,5)
      MCD1=I*10+J
      DMOD1=MCD1
      NCS=I+J
      MCD4=KK*10+III
      MCD5=III*10+JJJ
      DMOD4=MCD4
      DMOD5=MCD5
      IF(NA.GT.2) GO TO 14
      IF(NCS.NE.0) GO TO 11
      NC4S=K*10+II
      DESIG=NC4S
      IF(NC4S.GE.10) GO TO 12
      CALL SYMBOL(5.2,0.0,.14,3H000,0.0,3)
      CALL NUMBER(5.615,0.0,.14,DESIG,0.0,-1)
      IF(MCD4.NE.0) GO TO 7
      GO TO 8
    7 CALL SYMBOL(5.825,0.0,.14,59,0.0,-1)
      CALL NUMBER(5.950,0.0,.14,DMCD4,0.0,-1)
      GO TO 9
   12 DESIG=NC4S
      CALL SYMBOL(5.2,0.0,.14,2H00,0.0,2)
      CALL NUMBER(5.49,0.0,.14,DESIG,0.0,-1)
      IF(MCD4.NE.0) GO TO 7
      GO TO 8
   11 DESIG=1000.0*AI+100.0*AJ+10.0*AK+AII
```

```
      CALL NUMBER(5.2,0.0,.14,DESIG,0.0,-1)
      IF(MOD4.NE.0) GO TO 7
      GO TO 8
   14 DESIG=AI*10000.0+AJ*1000.0+AK*100.0+AII*10.0+AJJ
      IF(NA.EQ.5) GO TO 5
      IF(NA.EQ.6) GO TO 20
      CALL NUMBER(5.2,0.0,.14,DESIG,0.0,-1)
      IF(MOD5.NE.0) GO TO 9
      GO TO 8
    9 CALL SYMBOL(5.950,0.0,.14,59,0.0,-1)
      CALL NUMBER(6.075,0.0,.14,DMOD5,0.0,-1)
      GO TO 8
    5 DESIG=AII*100.0+AJJ*10.0+AKK
      CALL NUMBER(5.2,0.0,.14,DMOD1,0.0,-1)
      IF(DESIG.GE.100.0) GO TO 15
      IF(DESIG.GE.10.0) GO TO 16
      CALL SYMBOL(5.575,0.0,.14,3H-00,0.0,3)
      CALL NUMBER(5.990,0.0,.14,DESIG,0.0,-1)
      GO TO 8
   16 CALL SYMBOL(5.500,0.0,.14,2H-0,0.0,2)
      CALL NUMBER(5.790,0.0,.14,DESIG,0.0,-1)
      GO TO 8
   15 CALL SYMBOL(5.500,0.0,.14,59,0.0,-1)
      CALL NUMBER(5.625,0.0,.14,DESIG,0.0,-1)
      GO TO 8
   20 CALL NUMBER( 5.2,0.0,.14,DMOD1,0.0,-1)
      DESIG=100.0*AJJ+10.0*AKK+AIII
      IF(K.EQ.0.AND.II.EQ.0) GO TO 22
      IF(K.NE.0.AND.II.EQ.0) GO TO 24
      IF(K.EQ.0.AND.II.NE.0) GO TO 26
      CALL SYMBOL(5.375,0.0,.14,2H ,,0.0,2)
      CALL NUMBER(5.669,0.0,.14,AK,0.0,-1)
      CALL SYMBOL(5.857,0.0,.14,1HA,0.0,1)
      IF(DESIG.LT.10.0) GO TO 30
      IF(DESIG.LT.100.0) GO TO 32
      CALL NUMBER(6.249,0.0,.14,DESIG,0.0,-1)
      GO TO 18
   30 CALL SYMBOL(5.997,0.0,.14,2H00,0.0,2)
      CALL NUMBER(6.237,0.0,.14,DESIG,0.0,-1)
      GO TO 18
   32 CALL SYMBOL(5.977,0.0,.14,1H0,0.0,1)
      CALL NUMBER(6.097,0.0,.14,DESIG,0.0,-1)
      GO TO 18
   22 CALL SYMBOL(5.500,0.0,.14,59,0.0,-1)
      IF(DESIG.LT.10.0) GO TO 34
      IF(DESIG.LT.100.0) GO TO 36
      CALL NUMBER(5.625,0.0,.14,DESIG,0.0,-1)
      GO TO 18
   34 CALL SYMBOL(5.625,0.0,.14,2H00,0.0,2)
      CALL NUMBER(5.850,0.0,.14,DESIG,0.0,-1)
      GO TO 18
   36 CALL SYMBOL(5.625,0.0,.14,1H0,0.0,1)
      CALL NUMBER(5.745,0.0,.14,DESIG,0.0,-1)
      GO TO 18
   24 CALL SYMBOL(5.375,0.0,.14,2H ,,0.0,2)
```

```
      CALL NUMBER(5.669,0.0,.14,AK,0.0,-1)
      CALL SYMBOL(5.800,0.0,.14,59,0.0,-1)
      IF(DESIG.LT.10.0) GO TO 39
      IF(DESIG.LT.100.0) GO TO 40
      CALL NUMBER(5.925,0.0,.14,DESIG,0.0,-1)
      GO TO 18
   39 CALL SYMBOL(5.984,0.0,.14,2H00,0.0,2)
      CALL NUMBER(6.297,0.0,.14,DESIG,0.0,-1)
      GO TO 18
   40 CALL SYMBOL(5.984,0.0,.14,1H0,0.0,1)
      CALL NUMBER(6.144,0.0,.14,DESIG,0.0,-1)
      GO TO 18
   26 CALL SYMBOL(5.500,0.0,.14,1HA,0.0,1)
      IF(DESIG.LT.10.0) GO TO 42
      IF(DESIG.LT.100.0) GO TO 44
      CALL NUMBER(5.625,0.0,.14,DESIG,0.0,-1)
      GO TO 18
   42 CALL SYMBOL(5.625,0.0,.14,2H00,0.0,2)
      CALL NUMBER(5.915,0.0,.14,DESIG,0.0,-1)
      GO TO 18
   44 CALL SYMBOL(5.625,0.0,.14,1H0,0.0,1)
      CALL NUMBER(5.745,0.0,.14,DESIG,0.0,-1)
      GO TO 18
   18 IF(JJJ.LT.1) GO TO 8
      CALL SYMBOL(5.200,-.42,.14,3HA=.,0.0,3)
      CALL NUMBER(5.615,-.42,.14,AJJJ,0.0,-1)
      GO TO 8
    8 IF(NA.EQ.1) GO TO 1
      IF(NA.EQ.2) GO TO 2
      IF(NA.EQ.3) GO TO 3
      IF(NA.EQ.4) GO TO 4
      IF(NA.EQ.5) GO TO 6
      IF(NA.EQ.6) GO TO 13
    1 CALL SYMBOL(3.75,2.0,.14,20HNACA 4-DIGIT AIRFOIL,0.0,20)
      GO TO 10
    2 CALL SYMBOL(3.25,2.0,.14,29HNACA 4-DIGIT MODIFIED AIRFOIL,0.0,29)
      GO TO 10
    3 CALL SYMBOL(3.75,2.0,.14,20HNACA 5-DIGIT AIRFOIL,0.0,20)
      GO TO 10
    4 CALL SYMBOL(3.25,2.0,.14,29HNACA 5-DIGIT MODIFIED AIRFOIL,0.0,29)
      GO TO 10
    6 CALL SYMBOL(3.75,2.0,.14,21HNACA 1-SERIES AIRFOIL,0.0,21)
      GO TO 10
   13 CALL SYMBOL(3.75,2.0,.14,20HNACA 6-DIGIT AIRFOIL,0.0,20)
      GO TO 10
   10 CALL PLOT(14.0,-4.5,-3)
      RETURN
      END
```

```
      SUBROUTINE CCCRD4
      COMMON/BLK01/ X(160)
      COMMON/BLK02/ XU(160),XL(160)
      COMMON/BLK03/ YUN(160),YLN(160)
      COMMON/BLK04/ L,I,J,K,II,JJ,KK,III,JJJ
      COMMON/BLK10/ RHO
      AI=I
      AJ=J
      AK=K
      AII=II
      AJJ=JJ
      AKK=KK
      ZM=AI*.01
      ZP=AJ*.1
      T=AK*.1+AII*.01+AJJ*.001+AKK*.0001
      RHO=1.1019*T**2
      DO 2 M=1,L
      YT=(T/.2)*(.2969*SQRT(X(M))-.126*X(M)-.3516*(X(M)**2)+.2843*(X(M)
     $**3)-.1015*(X(M)**4))
      IF(X(M).EQ.ZP) YC=ZM
      IF(X(M).EQ.ZP) ALPHA=0.0
      IF(X(M).LT.ZP) YC=(ZM/(ZP**2))*(2.0*ZP*X(M)-X(M)**2)
      IF(X(M).LT.ZP) ALPHA=ATAN((2.0*ZM/(ZP**2))*(ZP-X(M)))
      IF(X(M).GT.ZP) YC=(ZM/((1.0-ZP)**2))*(1.0-2.0*ZP+2.0*ZP*X(M)-X(M)
     $**2)
      IF(X(M).GT.ZP) ALPHA=ATAN((2.0*ZM /((1.0-ZP)**2))*(ZP-X(M)))
      XU(M)=X(M)-YT*SIN(ALPHA)
      YUN(M)=YC+YT*COS(ALPHA)
      XL(M)=X(M)+YT*SIN(ALPHA)
      YLN(M)=YC-YT*COS(ALPHA)
      XU(M)=XU(M)*100.0
      YUN(M)=YUN(M)*100.0
      XL(M)=XL(M)*100.0
      YLN(M)=YLN(M)*100.0
    2 CONTINUE
      XU(L)=100.0
      YUN(L)=0.0
      XL(L)=100.0
      YLN(L)=0.0
      XU(1)=0.0
      YLN(1)=0.0
      RETURN
      END
```

```
      SUBROUTINE CCCROS
      COMMON/BLK01/ X(160)
      COMMON/BLK02/ XU(160),XL(160)
      COMMON/BLK03/ YUN(160),YLN(160)
      COMMON/BLK04/ L,I,J,K,II,JJ,KK,III,JJJ
      COMMON/BLK10/ RHO
      AI=I
      AJ=J
      AK=K
      AII=II
      AJJ=JJ
      AKK=KK
      AIII=III
      T=AII*.1+AJJ*.01+AKK*.001+AIII*.0001
      RHO=1.1019*T**2
      ZP=AJ*.1/2.0
      A=6.0*ZP-3.0
      B=-2.0+6.0*ZP-3.0*(ZP**2)
      G=B*B/4.0+A*A*A/27.0
      IF(G.LT.0.0) GO TO 4
      D=(-B/2.0+G**.5)**.33
      E=(-B/2.0-G**.5)**.33
      ZM=D+E+1.0
      GO TO 6
    4 PHI=ACOS((-B/2.0)/((-A**3/27.0)**.5))
      ZM=1.0+2.0*((-A/3.0)**.5)*COS(PHI/3.0+4.18879)
    6 XK=(6.0*AI*.01)/(ZP**3-3.0*ZM*(ZP**2)+ZM**2*(3.0-ZM)*ZP)
      DO 2 M=1,L
      IF(AK.NE.0.0) GO TO 10
      YT=(T/.2)*(.2969*SQRT(X(M))-.126*X(M)-.3516*(X(M)**2)+.2843*(X(M)
     $**3)-.1015*(X(M)**4))
      IF(X(M).LT.ZM) YC=(1.0/6.0)*XK*(X(M)**3-3.0*ZM*(X(M)**2)+(ZM**2)
     $*(3.0-ZM)*X(M))
      IF(X(M).LT.ZM) ALPHA=ATAN((1.0/6.0)*XK*(3.0*X(M)**2-6.0*ZM*X(M)+
     $(ZM**2)*(3.0-ZM)))
      IF(X(M).EQ.ZP) YC=AI*.01
      IF(X(M).EQ.ZP) ALPHA=0.0
      IF(X(M).GT.ZM) YC=(1.0/6.0)*XK*(ZM**3)*(1.0-X(M))
      IF(X(M).GT.ZM) ALPHA=ATAN(-(1.0/6.0)*XK*(ZM**3))
      IF(AK.EQ.0.0) GO TO 8
   10 RK=(3.0*((ZM-ZP)**2)-ZM**3)/((1.0-ZM)**3)
      ZMX=AI*.01
      XK=(6.0*ZMX)/((ZP-ZM)**3-RK*((1.0-ZM)**3)*ZP-(ZM**3)*ZP+ZM**3)
      YT=(T/.2)*(.2969*SQRT(X(M))-.126*X(M)-.3516*(X(M)**2)+.2843*(X(M)
     $**3)-.1015*(X(M)**4))
      IF(X(M).LT.ZM) YC=(1.0/6.0)*XK*((X(M)-ZM)**3-RK*X(M)*(1.0-ZM)**3
     $-ZM**3*X(M)+ZM**3)
      IF(X(M).LT.ZM) ALPHA=ATAN((1.0/6.0)*XK*(3.0*(X(M)-ZM)**2-RK*(1.0-
     $ZM)**3-ZM**3))
      IF(X(M).EQ.ZP) YC=AI*.01
      IF(X(M).EQ.ZP) ALPHA=0.0
      IF(X(M).GT.ZM) YC=(1.0/6.0)*XK*(RK*(X(M)-ZM)**3-RK*X(M)*(1.0-ZM)
     $**3-X(M)*ZM**3+ZM**3)
      IF(X(M).GT.ZM) ALPHA=ATAN((1.0/6.0)*XK*(3.0*RK*(X(M)-ZM)**2-RK*(1.
     $0-ZM)**3-ZM**3))
```

```
8   XU(M)=X(M)-YT*SIN(ALPHA)
    YUN(M)=YC+YT*COS(ALPHA)
    XL(M)=X(M)+YT*SIN(ALPHA)
    YLN(M)=YC-YT*COS(ALPHA)
    XU(M)=XU(M)*100.0
    YUN(M)=YUN(M)*100.0
    XL(M)=XL(M)*100.0
    YLN(M)=YLN(M)*100.0
2   CONTINUE
    XU(L)=100.0
    YUN(L)=0.0
    XL(L)=100.0
    YLN(L)=0.0
    XL(1)=0.0
    YLN(1)=0.0
    RETURN
    END
```

```
SUBROUTINE CORD4M
COMMON/BLK01/ X(160)
COMMON/BLK02/ XU(160),XL(160)
COMMON/BLK03/ YUN(160),YLN(160)
COMMON/BLK04/ L,I,J,K,II,JJ,KK,III,JJJ
COMMON/BLK10/ RHO
DIMENSION A(2,2),B(2,1),XN(2,1)
DIMENSION AA(3,3),BA(3,1),XM(3,1)
AI=I
AJ=J
AK=K
AII=II
AJJ=JJ
AKK=KK
AIII=III
ZM=AI*.01
ZP=AJ*.1
ZT=AIII*.1
T=AK*.1+AII*.01
NN=2
NK=1
IF(ZT.GT..18.AND.ZT.LT..22) D1=T
IF(ZT.GT..28.AND.ZT.LT..32) D1=1.17*T
IF(ZT.GT..38.AND.ZT.LT..42) D1=1.575*T
IF(ZT.GT..48.AND.ZT.LT..52) D1=2.325*T
IF(ZT.GT..58.AND.ZT.LT..62) D1=3.5*T
D0=.01*T
A(1,1)=-2.0*(1.0-ZT)
A(1,2)=-3.0*((1.0-ZT)**2)
A(2,1)=(1.0-ZT)**2
A(2,2)=(1.0-ZT)**3
B(1,1)=D1
B(2,1)=T/2.0-D0-D1*(1.0-ZT)
CALL MTXEQ(A,XN,B,NN,NK)
D2=XN(1,1)
D3=XN(2,1)
A0=SQRT(2.0*1.1019*((T*AKK/6.0)**2))
RHO=.5*A0**2
AA(1,1)=0.0
AA(1,2)=2.0
AA(1,3)=6.0*ZT
BA(1,1)=2.0*D2+6.0*D3*(1.0-ZT)+A0/(4.0*ZT**1.5)
AA(2,1)=1.0
AA(2,2)=2.0*ZT
AA(2,3)=3.0*ZT**2
BA(2,1)=-A0/(2.0*ZT**.5)
AA(3,1)=ZT
AA(3,2)=ZT**2
AA(3,3)=ZT**3
BA(3,1)=-A0*ZT**.5+T/2.0
NN=3
NK=1
CALL MTXEQ(AA,XM,BA,NN,NK)
A1=XM(1,1)
A2=XM(2,1)
```

```
      A3=XM(3,1)
      DO 2 M=1,L
      IF(X(M).EQ.ZT) YT=T/2.0
      IF(X(M).EQ.ZP) YC=ZM
      IF(X(M).EQ.ZP) ALPHA=0.0
      IF(X(M).LT.ZP) YC=(ZM/(ZP**2))*(2.0*ZP*X(M)-X(M)**2)
      IF(X(M).LT.ZP) ALPHA=ATAN((2.0*ZM/(ZP**2))*(ZP-X(M)))
      IF(X(M).LT.ZT) YT=A0*X(M)**.5+A1*X(M)+A2*X(M)**2+A3*X(M)**3
      IF(X(M).GT.ZP) YC=(ZM/((1.0-ZP)**2))*(1.0-2.0*ZP+2.0*ZP*X(M)-X(M)
     $**2)
      IF(X(M).GT.ZP) ALPHA=ATAN((2.0*ZM /((1.0-ZP)**2))*(ZP-X(M)))
      IF(X(M).GT.ZT) YT=D0+D1*(1.0-X(M))+D2*(1.0-X(M))**2+D3*(1.0-X(M))
     $**3
      XU(M)=X(M)-YT*SIN(ALPHA)
      YUN(M)=YC+YT*COS(ALPHA)
      XL(M)=X(M)+YT*SIN(ALPHA)
      YLN(M)=YC-YT*COS(ALPHA)
      XU(M)=XU(M)*100.0
      YUN(M)=YUN(M)*100.0
      XL(M)=XL(M)*100.0
      YLN(M)=YLN(M)*100.0
    2 CONTINUE
      XU(L)=100.0
      YUN(L)=0.0
      XL(L)=100.0
      YLN(L)=0.0
      XU(1)=0.0
      YLN(1)=0.0
      RETURN
      END
```

```
      SUBROUTINE CCRD5M
      COMMON/BLK01/ X(160)
      COMMON/BLK02/ XU(160),XL(160)
      COMMON/BLK03/ YUN(160),YLN(160)
      COMMON/BLK04/ L,I,J,K,II,JJ,KK,III,JJJ
      COMMON/BLK10/ RHO
      DIMENSION A(2,2),B(2,1),XN(2,1)
      DIMENSION AA(3,3),BA(3,1),XM(3,1)
      AI=I
      AJ=J
      AK=K
      AII=II
      AJJ=JJ
      AKK=KK
      AIII=III
      AJJJ=JJJ
      T=AII*.1+AJJ*.01
      ZP=AJ*.1/2.0
      ZT=AJJJ*.1
      R=6.0*ZP-3.0
      S=-2.0+6.0*ZP-3.0*(ZP**2)
      G=S*S/4.0+R*R*R/27.0
      IF(G.LT.0.0) GO TO 4
      D=(-S/2.0+G**.5)**.33
      F=(-S/2.0-G**.5)**.33
      ZM=D+F+1.0
      GO TO 6
    4 PHI=ACOS((-S/2.0)/((-R**3/27.0)**.5))
      ZM=1.0+2.0*((-R/3.0)**.5)*COS(PHI/3.0+4.18879)
    6 XK=(6.0*AI*.01)/(ZP**3-3.0*ZM*(ZP**2)+ZM**2*(3.0-ZM)*ZP)
      NN=2
      NK=1
      IF(ZT.GT..18.AND.ZT.LT..22) D1=T
      IF(ZT.GT..28.AND.ZT.LT..32) D1=1.17*T
      IF(ZT.GT..38.AND.ZT.LT..42) D1=1.575*T
      IF(ZT.GT..48.AND.ZT.LT..52) D1=2.325*T
      IF(ZT.GT..58.AND.ZT.LT..62) D1=3.5*T
      D0=.01*T
      A(1,1)=-2.0*(1.0-ZT)
      A(1,2)=-3.0*((1.0-ZT)**2)
      A(2,1)=(1.0-ZT)**2
      A(2,2)=(1.0-ZT)**3
      B(1,1)=D1
      B(2,1)=T/2.0-D0-D1*(1.0-ZT)
      CALL MTXEQ(A,XN,B,NN,NK)
      D2=XN(1,1)
      D3=XN(2,1)
      A0=SQRT(2.0*1.1019*((T*AIII/6.0)**2))
      RHO=.5*A0**2
      AA(1,1)=0.0
      AA(1,2)=2.0
      AA(1,3)=6.0*ZT
      BA(1,1)=2.0*D2+6.0*D3*(1.0-ZT)+A0/(4.0*ZT**1.5)
      AA(2,1)=1.0
      AA(2,2)=2.0*ZT
```

```
      AA(2,3)=3.0*ZT**2
      BA(2,1)=-A0/(2.0*ZT**.5)
      AA(3,1)=ZT
      AA(3,2)=ZT**2
      AA(3,3)=ZT**3
      BA(3,1)=-A0*ZT**.5+T/2.0
      NN=3
      NK=1
       CALL  MTXEQ(AA,XM,BA,NN,NK)
      A1=XM(1,1)
      A2=XM(2,1)
      A3=XM(3,1)
      DO 2 M=1,L
      IF(AK.NE.0.0) GO TO 10
      IF(X(M).EQ.ZT) YT=T/2.0
      IF(X(M).EQ.ZP) YC=AI*.01
      IF(X(M).EQ.ZP) ALPHA=0.0
      IF(X(M).LT.ZM) YC=(1.0/6.0)*XK*(X(M)**3-3.0*ZM*(X(M)**2)+(ZM**2)
     $*(3.0-ZM)*X(M))
      IF(X(M) .LT. ZM) ALPHA=ATAN((1./6.)*XK*(3.*X(M)**2-6.*ZM*X(M)+
     $(ZM**2)*(3.0-ZM)))
      IF(X(M).LT.ZT) YT=A0*X(M)**.5+A1*X(M)+A2*X(M)**2+A3*X(M)**3
      IF(X(M).GT.ZT) YT=D0+D1*(1.0-X(M))+D2*(1.0-X(M))**2+D3*(1.0-X(M))
     $**3
      IF(X(M).GT.ZM) YC=(1.0/6.0)*XK*(ZM**3)*(1.0-X(M))
      IF(X(M).GT.ZM) ALPHA=ATAN(-(1.0/6.0)*XK*(ZM**3))
      IF(AK.EQ.0.0) GO TO 8
   10 RK=(3.0*((ZM-ZP)**2)-ZM**3)/((1.0-ZM)**3)
      ZMX=AI*.01
      XK=(6.0*ZMX)/((ZP-ZM)**3-RK*((1.0-ZM)**3)*ZP-(ZM**3)*ZP+ZM**3)
      IF(X(M).LT.ZT) YT=A0*X(M)**.5+A1*X(M)+A2*X(M)**2+A3*X(M)**3
      IF(X(M).LT.ZM) YC=(1.0/6.0)*XK*((X(M)-ZM)**3-RK*X(M)*(1.0-ZM)**3
     $-ZM**3*X(M)+ZM**3)
      IF(X(M).LT.ZM) ALPHA=ATAN((1.0/6.0)*XK*(3.0*(X(M)-ZM)**2-RK*(1.0-
     $ZM)**3-ZM**3))
      IF(X(M).EQ.ZT) YT=T/2.0
      IF(X(M).EQ.ZP) YC=AI*.01
      IF(X(M).EQ.ZP) ALPHA=0.0
      IF(X(M).GT.ZT) YT=D0+D1*(1.0-X(M))+D2*(1.0-X(M))**2+D3*(1.0-X(M))
     $**3
      IF(X(M).GT.ZM) YC=(1.0/6.0)*XK*(RK*(X(M)-ZM)**3-RK*X(M)*(1.0-ZM)
     $**3-X(M)*ZM**3+ZM**3)
      IF(X(M).GT.ZM) ALPHA=ATAN((1.0/6.0)*XK*(3.0*RK*(X(M)-ZM)**2-RK*(1.
     $0-ZM)**3-ZM**3))
    8 XU(M)=X(M)-YT*SIN(ALPHA)
      YUN(M)=YC+YT*COS(ALPHA)
      XL(M)=X(M)+YT*SIN(ALPHA)
      YLN(M)=YC-YT*COS(ALPHA)
      XU(M)=XU(M)*100.0
      YUN(M)=YUN(M)*100.0
      XL(M)=XL(M)*100.0
      YLN(M)=YLN(M)*100.0
    2 CONTINUE
      XU(L)=100.0
      YUN(L)=0.0


       XL(L)=100.0
       YLN(L)=0.0
       XU(1)=0.0
       YLN(1)=0.0
       RETURN
       END
```

```
      SUBROUTINE COORD1
      COMMON/BLK01/ X(160)
      COMMON/BLK02/ XU(160),XL(160)
      COMMON/BLK03/ YUN(160),YLN(160)
      COMMON/BLK04/ L,I,J,K,II,JJ,KK,III,JJJ
      COMMON/BLK10/ RHO
      DIMENSION A(2,2),B(2,1),XN(2,1)
      DIMENSION AA(3,3),BA(3,1),XM(3,1)
      AI=I
      AJ=J
      AK=K
      AII=II
      AJJ=JJ
      AKK=KK
      AIII=III
      AJJJ=JJJ
      ZT=AJ*.1-.1
      T=AJJ*.1+AKK*.01+AIII*.001+AJJJ*.0001
      NN=2
      NK=1
      IF(J.NE.6) ZT=AJ*.1-.2
      D0=0.0
      IF(J.EQ.6) D1=2.157*T
      IF(J.EQ.6) SM=4.0
      IF(J.EQ.8) D1=3.6833*T
      IF(J.EQ.8) SM=3.0
      IF(J.EQ.9) D1=5.5223*T
      IF(J.EQ.9) SM=3.0
      A(1,1)=-2.0*(1.0-ZT)
      A(1,2)=-3.0*((1.0-ZT)**2)
      A(2,1)=(1.0-ZT)**2
      A(2,2)=(1.0-ZT)**3
      B(1,1)=D1
      B(2,1)=T/2.0-D0-D1*(1.0-ZT)
      CALL MTXEQ(A,XN,B,NN,NK)
      D2=XN(1,1)
      D3=XN(2,1)
      A0=SQRT(2.0*1.1019*((T*SM/6.0)**2))
      RHO=.5*A0**2
      AA(1,1)=0.0
      AA(1,2)= 2.0
      AA(1,3)=6.0*ZT
      BA(1,1)=2.0*D2+6.0*D3*(1.0-ZT)+A0/(4.0*ZT**1.5)
      AA(2,1)=1.0
      AA(2,2)=2.0*ZT
      AA(2,3)=3.0*ZT**2
      BA(2,1)=-A0/(2.0*ZT**.5)
      AA(3,1)=ZT
      AA(3,2)=ZT**2
      AA(3,3)=ZT**3
      BA(3,1)=-A0*ZT**.5+T/2.0
      NN=3
      NK=1
      CALL MTXEQ(AA,XM,BA,NN,NK)
      A1=XM(1,1)
```

```
      A2=XM(2,1)
      A3=XM(3,1)
      LL=L-1
      DO 2 M=2,LL
      YC=-(AII*.1/(4.0*3.14159))*((1.0-X(M))*ALOG(1.0-X(M))+X(M)*ALOG
     1(X(M)))
      ALPHA=ATAN((-AII*.1 /(4.0*3.14159))*(ALOG(X(M))-ALOG(1.0-X(M))))
      IF(X(M).EQ.ZT) YT=T/2.0
      IF(X(M).LT.ZT) YT=A0*X(M)**.5+A1*X(M)+A2*X(M)**2+A3*X(M)**3
      IF(X(M).GT.ZT) YT=D0+D1*(1.0-X(M))+D2*(1.0-X(M))**2+D3*(1.0-X(M))
     9**3
      XU(M)=X(M)-YT*SIN(ALPHA)
      YUN(M)=YC+YT*COS(ALPHA)
      XL(M)=X(M)+YT*SIN(ALPHA)
      YLN(M) = YC-YT * COS (ALPHA)
      XU(M) = XU(M) * 100.0
      YUN(M) = YUN(M)*100.
      YLN(M)=YC-YT*COS(ALPHA)
      XL(M)=XL(M)*100.0
      YLN(M)=YLN(M)*100.0
    2 CONTINUE
      XU(L)=100.0
      YUN(L)=0.0
      XL(L)=100.0
      YLN(L)=0.0
      XU(1)=0.0
      YLN(1)=0.0
      XL(1)=0.0
      YUN(1)=0.0
      RETURN
      END
```

```
      SUBROUTINE COORD6
      COMMON/BLK01/ X(160)
      COMMON/BLK02/ XU(160),XL(160)
      COMMON/BLK03/ YUN(160),YLN(160)
      COMMON/BLK04/ L,I,J,K,II,JJ,KK,III,JJJ
      COMMON/BLK10/ RHO
      DIMENSION A(2,2),B(2,1),XN(2,1)
      DIMENSION AA(3,3),BA(3,1),XM(3,1)
      AI=I
      AJ=J
      AK=K
      AII=II
      AJJ=JJ
      AKK=KK
      AIII=III
      AJJJ=JJJ
      T=AKK*.1+AIII*.01
      NN=2
      NK=1
      IF(J.EQ.3) GO TO 20
      IF(J.EQ.4) GO TO 30
      IF(J.EQ.5) GO TO 40
      ZT=.45
      SM=-1.258
      R=SM*(T-.06) +.873
      D1=R*T
      GO TO 50
   20 ZT=.35
      SM=-.6116
      R=SM*(T-.06)+.46
      D1=R*T
      IF(II.GT.0) D1=T
      GO TO 50
   30 ZT=.40
      SM=-.6888
      R=SM*(T-.06)+.523
      D1=R*T
      IF(II.GT.0) D1=1.04*T
      GO TO 50
   40 ZT=.40
      SM=-.8833
      R=SM*(T-.06)+.65
      D1=R*T
      IF(II.GT.0) D1=1.17*T
      GO TO 50
   50 CONTINUE
      D0=0.0
      A(1,1)=-2.0*(1.0-ZT)
      A(1,2)=-3.0*((1.0-ZT)**2)
      A(2,1)=(1.0-ZT)**2
      A(2,2)=(1.0-ZT)**3
      B(1,1)=D1
      B(2,1)=T/2.0-D0-D1*(1.0-ZT)
      CALL MTXEQ(A,XN,B,NN,NK)
      D2=XN(1,1)
```

```
      D3=XN(2,1)
      RLE=68.682*T**2+.0182*T+.0014
      RLE=RLE*.01
      RHO=RLE
      A0=SQRT(2.0*RLE)
      AA(1,1)=0.0
      AA(1,2)= 2.0
      AA(1,3)=6.0*ZT
      BA(1,1)=2.0*D2+6.0*D3*(1.0-ZT)+A0/(4.0*ZT**1.5)
      AA(2,1)=1.0
      AA(2,2)=2.0*ZT
      AA(2,3)=3.0*ZT**2
      BA(2,1)=-A0/(2.0*ZT**.5)
      AA(3,1)=ZT
      AA(3,2)=ZT**2
      AA(3,3)=ZT**3
      BA(3,1)=-A0*ZT**.5+T/2.0
      NN=3
      NK=1
      CALL MTXEQ(AA,XM,BA,NN,NK)
      A1=XM(1,1)
      A2=XM(2,1)
      A3=XM(3,1)
      ZA=AJJJ*.1
      IF(AJJJ.LT.1.0) ZA=1.0
      IF(ZA.EQ.1.0) GO TO 6
      C=1.0-ZA
      G=(-1.0/C)*((ZA**2)*(.5*ALOG(ZA)-.25)+.25)
      H=(1.0/C)*((.5*C**2)*ALOG(C)-.25*C**2)+G
      AJJ=AJJ*.1
    6 LL=L-1
      DO 2 M=2,LL
      IF(ZA.EQ.1.0) GO TO 5
      S=1.0-X(M)
      D=ZA-X(M)
      YC=(AJJ/(2.0*3.14159*(ZA+1.0)))*((1.0/C)*((.5*D**2)*ALOG(ABS(D))
     $-(.5*S**2)*ALOG(S)+.25*S**2-.25*D**2)-X(M)*ALOG(X(M))+G-X(M)*H)
      ALPHA=ATAN((AJJ/(2.0*3.14159*(1.0+ZA)))*((1.0/C)*(-D*ALOG(ABS(D))
     $+S*ALOG(S))-ALOG(X(M))-1.0-H))
      GO TO 7
    5 YC=-(AJJ*.1/(4.0*3.14159))*((1.0-X(M))*ALOG(1.0-X(M))+X(M)*ALOG
     $(X(M)))
      ALPHA=ATAN((-AJJ*.1 /(4.0*3.14159))*(ALOG(X(M))-ALOG(1.0-X(M))))
    7 IF(X(M).EQ.ZT) YT=T/2.0
      IF(X(M).EQ.ZT) YT=T/2.0
      IF(X(M).LT.ZT) YT=A0*X(M)**.5+A1*X(M)+A2*X(M)**2+A3*X(M)**3
      IF(X(M).GT.ZT) YT=D0+D1*(1.0-X(M))+D2*(1.0-X(M))**2+D3*(1.0-X(M))
     $**3
      XU(M)=X(M)-YT*SIN(ALPHA)
      YUN(M)=YC+YT*COS(ALPHA)
      XL(M)=X(M)+YT*SIN(ALPHA)
      YLN(M)=YC-YT*COS(ALPHA)
      IF(XU(M).GE..80.AND.II.GT.0) GO TO 4
      NC=1
    3 XU(M)=XU(M)*100.0
```

```
      YUN(M)=YUN(M)*100.0
       XL(M)=XL(M)*100.0
      YLN(M)=YLN(M)*100.0
      GO TO 2
    4 IF(NO.NE.1) GO TO 10
      SXU=XL(M)
      SXL=XL(M)
      SYU=YUN(M)
      SYL=YLN(M)
      SMU=-SYU/(1.0-SXU)
      SML=-SYL/(1.0-SXL)
      NO=2
      GO TO 3
   10 XL(M)=XL(M)-SXU
      XL(M)=XL(M)-SXL
      YLN(M)=SMU*XU(M)+SYU
      YLN(M)=SML*XL(M)+SYL
      XL(M)=XL(M)+SXU
      XL(M)=XL(M)+SXL
      GO TO 3
    2 CONTINUE
      XU(L)=100.0
      YLN(L)=0.0
      XL(L)=100.0
      YLN(L)=0.0
       XU(1)=0.0
      YLN(1)=0.0
      XL(1)=0.0
      YLN(1)=0.0
      RETURN
      END
```

```
      SUBROUTINE XNEG
      COMMON/BLK02/ XU(160),XL(160)
      COMMON/BLK03/ YUN(160),YLN(160)
      COMMON/BLK06/ XUD(70),ZUD(70),XLD(70),ZLD(70)
      COMMON/BLK07/ NOPT
      COMMON/BLK12/ NCODE2,PHE,ALPHA,RF
      PHILE=PHE
      THETA=PHE
13    PHILE = PHILE*0.0174533
      THETA = THETA * 0.0174533
      NOPT=1
      XUD(1) =0.0
      XLD(1) = 0.0
      ZUD(1) = 0.0
      ZLD(1) = 0.0
      DO 2 M=1,59
      IF(XU(M).LE.0.0) GO TO 2
      NOPT=NOPT+1
      XUD(NOPT)=XU(M)
      ZUD(NOPT)=YUN(M)
      XLD(NOPT)=XL(M)
      ZLD(NOPT)=YLN(M)
      IF(NCODE2.NE.3) GO TO 2
      CC = SIN(1.570796 - PHILE)/ SIN(1.570796 + PHILE - THETA)
      ZUD(NOPT)=ZUD(NOPT)*CC
      ZLD(NOPT)=ZLD(NOPT)*CC
    2 CONTINUE
      IF(NCODE2.NE.3) GO TO 12
      WRITE(6,4)
    4 FORMAT(1H1,1X,40HCORRECTED COORDINATES FOR SWEPT AIRFOILS)
      WRITE(6,8)
    8 FORMAT(     12X,15H UPPER ABSCISSA,10X,15H UPPER ORDINATE,10X,
     $15H LOWER ABSCISSA,10X,15H LOWER ORDINATE)
      WRITE(6,10)  (XUD(M),ZUD(M),XLD(M),ZLD(M),M=2,NOPT)
   10 FORMAT(15X,F10.5,15X,F10.5,15X,F10.5,15X,F10.5)
   12 DO 14 N=1,NOPT
      XUD(N) = XUD(N)*.01
      ZUD(N)=ZUD(N)*.01
      XLD(N)=XLD(N)*.01
      ZLD(N)=ZLD(N)*.01
   14 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE MTXEQ(A,X,B,N,K)                                       MTXEQ001
C                                                                       MTXEQ002
C     MATRIX EQUATION SOLVER     (7094 FORTRAN IV)                      MTXEQ003
C                                                                       MTXEQ004
C     USAGE...                                                          MTXEQ005
C                                                                       MTXEQ006
C     TO SOLVE THE LINEAR SYSTEM     AX=B                               MTXEQ007
C                                                                       MTXEQ008
C     CALL MTXEQ(A,X,B,N,K)                                             MTXEQ009
C                                                                       MTXEQ010
C        WHERE A MUST BE DIMENSIONED N X N                              MTXEQ011
C              X MUST BE DIMENSIONED N X K                              MTXEQ012
C              B MUST BE DIMENSIONED N X K                              MTXEQ013
C              N IS THE NO. OF EQUATIONS (ROWS IN A,X,B)                MTXEQ014
C              K IS THE NO. OF SOLUTION VECTORS (COLS. IN X,B)          MTXEQ015
C                                                                       MTXEQ016
C     664 CELLS OF BLANK COMMON ARE USED.                               MTXEQ017
C                                                                       MTXEQ018
C     NOTE...   TO CHANGE DIMENSIONS OF ARRAYS C AND PIV, ALSO          MTXEQ019
C            CHANGE VALUES OF NMAX AND NKMAX IN DATA STATEMENT.         MTXEQ020
C                                                                       MTXEQ021
C                                                                       MTXEQ022
      DIMENSION    A(N,N), B(N,K), X(N,K)                               MTXEQ023
      COMMON    ATPE, I, IFROM, IP1, IPIV, ITO,                         MTXEQ024
     1          J, KP, L, NP, NP1, NPJ, NPK, RM                         MTXEQ025
      COMMON      PIV(26), C(24,26)                                     MTXEQ026
      DATA      NMAX, NKMAX/ 24, 26/                                    MTXEQ027
C                                                                       MTXEQ033
C     GET ARGUMENTS N AND K                                             MTXEQ034
C                                                                       MTXEQ035
      NP=N                                                              MTXEQ036
      KP=K                                                              MTXEQ037
C                                                                       MTXEQ038
C     MOVE ARRAYS A(I,J) AND B(I,J) INTO C(I,J)                         MTXEQ039
C                                                                       MTXEQ040
      DO 10 J=1,NP                                                      MTXEQ041
      DO 10 I=1,NP                                                      MTXEQ042
   10 C(I,J)=A(I,J)                                                     MTXEQ043
      DO 20 J=1,KP                                                      MTXEQ044
      NPJ=NP+J                                                          MTXEQ045
      DO 20 I=1,NP                                                      MTXEQ046
   20 C(I,NPJ)=B(I,J)                                                   MTXEQ047
C                                                                       MTXEQ048
C     SET TO PERFORM N ELIMINATION SWEEPS (I=1,N)                       MTXEQ049
C                                                                       MTXEQ050
      NP1=NP+1                                                          MTXEQ051
      NPK=NP+KP                                                         MTXEQ052
      DO 120 I=1,NP                                                     MTXEQ053
      IP1=I+1                                                           MTXEQ054
C                                                                       MTXEQ055
C     SEARCH FOR NEXT PIVOT ROW (I-TH PIVOT IS IN COL. I)               MTXEQ056
C                                                                       MTXEQ057
      ATPE=0.                                                           MTXEQ058
      DO 40 J=I,NP                                                      MTXEQ059
      IF (ABS(C(J,I))-ATPE) 40,30,30                                    MTXEQ060
```

```
 30    ATPF=ABS(C(J,I))                                     MTXEQ061
       IPIV=J                                               MTXEQ062
 40    CONTINUE                                             MTXEQ063
C                                                           MTXEQ064
C      OPERATE ON THE PIVOT ROW                             MTXEQ065
C                                                           MTXEQ066
 50    DO 60 J=IP1,NPK                                      MTXEQ068
 60    PIV(J)=C(IPIV,J)/C(IPIV,I)                           MTXEQ069
C                                                           MTXEQ070
C      PERFORM ELIMINATIONS BELOW THE DIAGONAL (COL. I)     MTXEQ071
C                                                           MTXEQ072
       IFROM=NP                                             MTXEQ073
       ITO=NP                                               MTXEQ074
 70    IF (IFROM-IPIV) 80,100,80                            MTXEQ075
 80    RM=-C(IFROM,I)                                       MTXEQ076
       DO 90 J=IP1,NPK                                      MTXEQ077
 90    C(ITO,J)=C(IFROM,J)+RM*PIV(J)                        MTXEQ078
       ITO=ITO-1                                            MTXEQ079
 100   IFROM=IFROM-1                                        MTXEQ080
       IF (IFROM-I) 110,70,70                               MTXEQ081
C                                                           MTXEQ082
C      PUT THE I-TH PIVOT ROW IN THE VACATED ROW I          MTXEQ083
C                                                           MTXEQ084
 110   DO 120 J=IP1,NPK                                     MTXEQ085
 120   C(I,J)=PIV(J)                                        MTXEQ086
C                                                           MTXEQ087
C      NOW DO THE BACK SOLUTION                             MTXEQ088
C                                                           MTXEQ089
       I=NP                                                 MTXEQ090
 130   IP1=I                                                MTXEQ091
       I=I-1                                                MTXEQ092
       IF (I) 160,160,140                                   MTXEQ093
 140   DO 150 J=NP1,NPK                                     MTXEQ094
       DO 150 L=IP1,NP                                      MTXEQ095
 150   C(I,J)=C(I,J)-C(I,L)*C(L,J)                          MTXEQ096
       GO TO 130                                            MTXEQ097
C                                                           MTXEQ098
C      MOVE THE SOLUTION TO ARRAY X(I,J)                    MTXEQ099
C                                                           MTXEQ100
 160   DO 170 J=1,KP                                        MTXEQ101
       NPJ=NP+J                                             MTXEQ102
       DO 170 I=1,NP                                        MTXEQ103
 170   X(I,J)=C(I,NPJ)                                      MTXEQ104
 180   RETURN                                               MTXEQ105
C                                                           MTXEQ106
       END                                                  MTXEQ114
```

```
      SUBROUTINE MONO
      COMMON/BLK06/ XUD(70),ZUD(70),XLD(70),ZLD(70)
      COMMON/BLK07/ NOPT
      COMMON/BLK10/ RHO
      COMMON/BLK12/ NCODE2,PHF,ALPHA,RE
      DIMENSION                               S50(32),S140(32),SUMM(32)
      DIMENSION S1(32,32),S2(32,32),S3(32,32),S4(32,32),S5(32,32),
     1S14(32,32),S15(32,32) ,ZT(32),ZS(32)
      DIMENSION X(32) ,      CS1(32),CS2(32),CS3(32),CS4(32),CS5(32),RO2
     1V(32),DCP(32),                ZU(32),ZL(32)
      DIMENSION TANTH(70),ALPHAI(15),CPU(15,32),TANALP(15),CMACH(15)
      DIMENSION CLC(15),CL(15),CPL(15,32)
      DIMENSION CA(15),CN(15),CD(15)
   50 PHI=PHF*0.01745329
      SINPHI=  SIN(PHI)
      COSPHI=  COS(PHI)
      PI=3.1415926
      EN=0.5    - PHI/PI
      NN=32
      AN=NN
      NM1=NN-1
      SUMM(1)=0.0
C
C  NOW WE DEFINE THE CONSTANTS NEEDED FOR THE PRESSURE COEFFICIENT EVALUATION.
C (SEE WEBER-A.R.C. R AND M NO. 2918, 1956)
C
      DO 10 M=1,NM1
      RM=M
      SINTM= SIN(RM*PI/AN)
      COSTM= COS(RM*PI/AN)
C
C  S50 MEANS S5 WHEN N=0.0.
C
      S50(M)=(4.*(-1.)**M)/(1.-COSTM)
      DO 10 N=1,NM1
      RN=N
      SINTN= SIN(RN*PI/AN)
      COSTN= COS(RN*PI/AN)
      DIFF = COSTM-COSTN
C
C  WHEN M EQUALS N EQUATIONS BELOW STATEMENT NO. 100 APPLY.
C
      IF(M.EQ.N) GO TO 100
      SGN=(-1.0)**(M-N)
      S1(M,N)=(SGN-1.)*2.*SINTM/(AN*DIFF**2)
      S2(M,N)=(-2.)*SGN*SINTM/(SINTN*DIFF)
      S3(M,N)=S1(M,N)+2.*(1.-SGN)/(AN*SINTM*DIFF)
      S4(M,N)=(2./(AN*SINTN))*((((SGN-1.)*(1.-COSTM*COSTN))/DIFF**2)-(((
     1(-1.)**M)-1.)/(1.-COSTM)))
      S5(M,N)=-2.*SGN/DIFF
      S14(M,N)=0.5 *(COSPHI  **2)*S1(M,N)*DIFF*(((1.-COSTN)*(1.+COSTM))/
     1((1.+COSTN)*(1.-COSTM)))**EN
      GO TO 10
  100 S1(M,N)=AN/SINTN
      S2(M,N)=COSTN/(SINTN **2)
```

```
      S3(M,N)= S1(M,N)
      S4(M,N)=(AN/SINTN)-(2.*(((-1.)**M)-1.)/((AN*SINTN)*(1.-COSTM)))
      S5(M,N)=-S2(M,N)
      S14(M,N)=-SINPHI   *COSPHI
   10 CONTINUE
      DO 20 N=1,31
      SUMM(N)=0.0
      BN=N
      COSTN= COS(BN*PI/AN)
       S3(NN,N) =((-1.)**N-1.)/(AN *(1.+COSTN))
      DO 25 I=1,NM1
      BI=I
      COSTI= COS(BI*PI/AN)
      DIFI=COSTI-COSTN
      SUM3= S1(I,N)*DIFI*((1.0  +COSTI)/(1.0  -COSTI))**EN
   25 SUMM(N)=SUM3+SUMM(N)
C
C  S140 MEANS S14 AT M=0.0.
C
   20 S140(N)= SINPHI   * COSPHI  -( COSPHI  *((((1.0  -COSTN)/(1.0  +COST
     1N))**EN))*(1.0  + COSPHI *0.5   *SUMM(N))
      DO30 M=1,NM1
      DO30 N=1,NM1
      S15(M,N)=0.0
      DO 11 I=1,NM1
      SUM=S14(I,N)*S5(M,I)
   11 S15(M,N)=SUM + S15(M,N)
   30 S15(M,N)=S15(M,N)+S140(N)*S50(M)
   56 DO 12 N=1,32
      AN=33-N
C
C  THIS PROGRAM COMPUTES THE DESIRED RESULTS ONLY AT 32 SPECIFIC POINTS AS
C  DEFINED BY THIS EQUATION  X(N)=...
C  A SECOND ORDER APPROXIMATION IS USED TO LOCATE THE SURFACE COORDINATES (Z)
C  CORRESPONDING TO THE COMPUTED X"S.
C
      X(N)= 0.50*(1.+COS(AN*0.09817477))
      I=1
   16 IF (XUD(I)-X(N))13,14,15
   13 I=I+1
      GO TO 16
   14 ZU(N)=ZUD(I)
      ZT(N)=ZLD(I)
      GO TO 119
   15 IF(I.EQ.NOPT) GO TO 17
      CU=(((ZUD(I+1)-ZUD(I-1))/(XUD(I+1)-XUD(I-1)))-((ZUD(I)-ZUD(I-1))/(
     1XUD(I)-XUD(I-1))))/(XUD(I+1)-XUD(I))
      BU=((ZUD(I)-ZUD(I-1))/(XUD(I)-XUD(I-1)))-CU*(XUD(I)+XUD(I-1))
      AU=ZUD(I)-BU*XUD(I)-CU*(XUD(I)**2)
   17 ZU(N)=AU+BU*X(N)+CU*(X(N)**2)
  119 I=1
   19 IF(XLD(I)-X(N)) 113,114,115
  113  I=I+1
      GO TO 19
  114  ZL(N)=ZLD(I)
```

```
      ZT(N)=0.50*(ZU(N)-ZL(N))
      ZS(N)=0.5*(ZU(N)+ZL(N))
      GO TO 12
 115   IF(I.EQ.NCPT) GO TO 117
      DL=(((ZLD(I+1)-ZLD(I-1))/(XLD(I+1)-XLD(I-1)))-((ZLD(I)-ZLD(I-1))/(
     1XLD(I)-XLD(I-1))))/(XLD(I+1)-XLD(I))
      BL=((ZLD(I)-ZLD(I-1))/(XLD(I)-XLD(I-1)))-DL*(XLD(I)+XLD(I-1))
      AL=ZLD(I)-BL*XLD(I)-DL*(XLD(I)**2)
 117  ZL(N)=AL+BL*X(N)+DL*(X(N)**2)
      ZT(N)=0.50*(ZU(N)-ZL(N))
      ZS(N)=0.5*(ZU(N)+ZL(N))
 12   CONTINUE
C
C  WITH THE COORDINATES AND THE CONSTANTS FOUND EARLIER, WE DEFINE THE CONSTANTS
C  FOR THIS SPECIFIC AIRFOIL.
 54   DO 91 N=1,31
      K=32-N
      CS1(K)=0.0
      CS2(K)=0.0
      CS3(K)=0.0
      CS4(K)=0.0
      CS5(K)=0.0
      RO2V(K)=0.0
 520  DO 71 M=1,NM1
      J=32-M
      SUM1 = S1(M,N)*ZT(J)
      CS1(K)=SUM1+CS1(K)
      SUM2= S2(M,N)*ZT(J)
      CS2(K)=SUM2+CS2(K)
      SUM3= S3(M,N)*ZT(J)
      CS3(K)=SUM3+CS3(K)
 77   SUM4= S4(M,N)*ZS(J)
      CS4(K)=SUM4+CS4(K)
      SUM5= S5(M,N)*ZS(J)
      CS5(K)=SUM5+CS5(K)
      SUM6= S15(M,N)*ZS(J)
      RO2V(K)=SUM6+RO2V(K)
  71  CONTINUE
      CS3(K)=CS3(K)+   S3(32,N)*SQRT(RHO/2.)
 91   CONTINUE
      FPHI=(1./3.141593)*ALOG((1.+SINPHI)/(1.-SINPHI))
      J=1
      NXX=1
      GO TO 86
C
C  THE INFORMATION FROM HERE TO 86 IS NEEDED FOR COMPUTING CMACH AND CLD ONLY.
C
 87   ALPHA=6.0
      NXX=NXX+1
      TANTA=(ZU(26)-ZL(26)-ZU(30)+ZL(30))/((X(30)-X(26))*2.)
      EXPN=2.5*TANTA-1.
      LLL=NCPT-1
      DO 600 I=1,LLL
      IF(ZUD(I+1) .GT. ZUD(I))TMAX=ZUD(I+1)*100.
  600 TANTH(I)=(ZUD(I+1)-ZUD(I))/(XUD(I+1)-XUD(I))
```

```
 86   ALPHAR=ALPHA*0.0174533
      SINALP=SIN(ALPHAR)
      COSALP=COS(ALPHAR)
C
C  PRESSURE COEFFICIENT EQUATIONS DEPENDING ON NCODE2.
C
      GO TO (73,74,75),NCODE2
 73   DO701 N=1,31
      CPU(J,N)=1.-(((COSALP*(1.+CS1(N)+CS4(N))+SINALP*SQRT((1.-X(N))/X(N
     1))*(1.+CS3(N)))**2)/(1.+(CS2(N)+CS5(N))**2))
      CPL(J,N)=1.-(((COSALP*(1.+CS1(N)-CS4(N))-SINALP*SQRT((1.-X(N))/X(N
     1))*(1.+CS3(N)))**2)/(1.+(CS2(N)-CS5(N))**2))
 701  DCP(N)= CPU(J,N)-CPL(J,N)
      GO TO 72
 74   DO 702 N=1,31
      CPU(J,N)=1.-(COSALP**2)*(SINPHI**2)-((COSALP*(COSPHI+CS1(N)+CS4(N)
     1)+SINALP*SQRT((1.-X(N))/X(N))*(1.+(CS3(N)/COSPHI)))**2/(1.+((CS2(N
     2)+CS5(N))/COSPHI)**2))
      CPL(J,N)=1.-(COSALP**2)*(SINALP**2)-((COSALP*(COSPHI+CS1(N)-CS4(N)
     1)-SINALP*SQRT((1.-X(N))/X(N))*(1.+(CS3(N)/COSPHI)))**2/(1.+((CS2(N
     2)-CS5(N))/COSPHI)**2))
 702  DCP(N)= CPU(J,N)-CPL(J,N)
      GO TO 72
 75   DO 703 N=1,31
      CPU(J,N)=1.-((1./(1.+(CS2(N)+CS5(N))**2))*(COSALP*(1.+COSPHI*CS1(N
     1)-FPHI*COSPHI*(CS2(N)/SQRT(1.+CS2(N)**2))+RC2V(N))+SINALP*COSPHI*(
     2((1.-X(N))/X(N))**EN)*(1.+CS3(N)))**2)
      CPL(J,N)=1.-((1./(1.+(CS2(N)-CS5(N))**2))*(COSALP*(1.+COSPHI*CS1(N
     1)-FPHI*COSPHI*(CS2(N)/SQRT(1.+CS2(N)**2))-RC2V(N))-SINALP*COSPHI*(
     2((1.-X(N))/X(N))**EN)*(1.+CS3(N)))**2)
 703  DCP(N)= CPU(J,N)-CPL(J,N)
 72   CONTINUE
C
C  A SIMPLE RECTANGULAR APPROXIMATION IS USED FOR INTERGRATION OF CP CURVE.
C  IT PROVED QUITE ACCURATE FOR MOST CASES.
C
      CA1=0.0
      CA2=0.0
      CA3=0.0
      CA4=0.0
      CN(J)=0.0
      CA(J)=0.0
      CD(J)=0.0
      CL(J)=0.0
      DO 85 N=1,30
 83   AREA=(DCP(N+1)+DCP(N))*(X(N+1)-X(N))/2.
      CN(J)=AREA+CN(J)
      IF(ZU(N+1)-ZU(N)) 1001,84, 1002
 1002 CA1=CA1+(ZU(N+1)-ZU(N))*(CPU(J,N+1)+CPU(J,N))*0.50
      GO TO 84
 1001 CA2=CA2+(ZU(N+1)-ZU(N))*(CPU(J,N+1)+CPU(J,N))*0.50
 84   IF(ZL(N+1)-ZL(N))1003,85 ,1004
 1003 CA3=CA3+(ZL(N+1)-ZL(N))*(CPL(J,N+1)+CPL(J,N))*0.50
      GO TO 85
 1004 CA4=CA4+(ZL(N+1)-ZL(N))*(CPL(J,N+1)+CPL(J,N))*0.50
```

```
85    CONTINUE
      CN(J) = -(CN(J) + .5 * (DCP(1)*X(1) + DCP(31)*(X(32)-X(31))))
      CA1= CA1 + ZU(1)*(1.+CPU(J,1))*0.50
      CA3=CA3+ZL(1)*(1.+CPL(J,1))*0.50
      CA(J)= CA1+CA2-CA3-CA4
      CL(J)=CN(J) * COSALP - CA(J) * SINALP
      CD(J)= CN(J)*SINALP+CA(J)*COSALP
624   CONTINUE
      IF(NXY.GT.1) GO TO 623
      CM=0.0
      DCP(32) = 0.0
      DO 50  N=1,30
      CM1= .5*(DCP(N)+DCP(N+1))*(X(N+1)-X(N))*(.5*(X(N)+X(N+1))-.25)
 50   CM=CM+CM1
      CM= CM+ .5* (DCP(1)*X(1) * (.5*X(1)- .25) + DCP(31)*(X(32)-X(31))
     1  *(.5 * (X(32)+X(31))- .25))
      WRITE(6,311) NCODE2,RHO,PHE,RE ,ALPHA
 311 FORMAT(1H1,     20HINPUT CONDITIONS
     $                         //,8X,8HPLANFORM,24X,11HL.E. RADIUS,15X
     $,10HL.E. SWEEP,11X,15HREYNOLDS NUMBER11X,15HANGLE OF ATTACK /,2X,
     324H(1-2D,2-SHEARED,3-SWEPT)    /11X,1I1,28X,F10.7,18X,F10.7,10X,
     4F10.0,15X,F10.3//)
      WRITE(6,463)          CL(J),CD(J),CM
 463 FORMAT(24H0SECTION CHARACTERISTICS//11X,2HCL,32X,2HCD,21X,7HCM(C/4
     1),/  6X          ,F10.7,25X,F10.7,15X,F10.7)
      WRITE(6,460)
 460 FORMAT(//,1X,78HPRESSURE COEFFICIENTS AND DELTA PRESSURE COEFFICIE
     $NT FOR GIVEN ANGLE OF ATTACK,//,14X,15H CHORD LOCATION,
     $12X,9H CP-UPPER,16X,9H CP-LOWER,16X,9H DELTA CP)
      DO 81 N=1,31
81    WRITE(6,461) X(N),CPU(J,N),CPL(J,N),DCP(N)
 461 FORMAT(15X,F10.5,15X,F10.5,15X,F10.5,15X,F10.5)
      GO TO 87
623   IF (CL(J)) 602,603,603
603   ALPHA=ALPHA-1.0
      J=J+1
      GOTO86
C
C  WITH CP COMPUTED, THE REST FOLLOWS CLOSELY THE PROCEDURE OUTLINED IN
C  T.D. MENC. 6407 OF R.A.C.
C
 602  A1IT=0.0
      ALPO=0.0
      JJ=J
      ALPMAX=TMAX*(1.16667-0.05555*TMAX)
      MM=J-1
      AM=MM
      DO 640 I=1,MM
      AI=I
      M=J-I
      PI=7-J+I
      CON1=(CL(M)-CL(J))/AI
      CON2=PI-(CL(M)/CON1)
      A1IT=(CON1/AM)+A1IT
 640  ALPO=(CON2/AM)+ALPO
```

```
      A1T =A1IT*(1.+((ALOG(RE*1.E-05))**EXPN)*(2.95*(TANTA)**2-1.785*TAN
     1TA-0.232))
      WRITE(6,421) A1IT,A1I,ALP0,ALPMAX
  421 FORMAT(//,6X,30HTHEORETICAL LIFT CURVE SLOPE =,F10.5,15X,  48HLIFT
     $ CURVE SLOPE CORRECTED FOR VISCOUS EFFECTS =,F10.5,/,6X,  30HANGLE
     $ OF ATTACK AT ZERO LIFT =,F10.5,15X,11HALPHA MAX =,F10.2)
      WRITE(6,426)
  426 FORMAT(1H1,   41HDRAG RISE MACH NUMBER TABLE
     $//,35X,1H1,50X,1H2,/,6X,5HDMACH,10X,3HCLD,6X,5HALPHA,5X,5HALPHI,
     $8X,6HXCREST,7X, 7HCPCREST,8X,5HDELCP,/)
      DO 604 K=1,JJ
      ALPHAI(K)=(CL(K)/A1I)+ALP0
      ALPRDN=ALPHAI(K)*0.01745329
      TANALP(K)=SIN(ALPRDN    )/COS(ALPRDN)
      I=1
C
C  TO FIND THE SURFACE SLOPE CORRESPONDING TO THE VISCOUS ANGLE OF ATTACK,
C  A ROUGH ESTIMATE (TANTH) IS USED TO LOCATE THE APPROXIMATE POSITION.
C  THEN A SECOND ORDER CURVE FIT DEFINES THE EXACT LOCATION.
C  THE SAME PROCEDURE IS USED TO FIND XCREST AND CPCREST AS SLOPE.
C
  605 IF(TANTH(I)-TANALP(K)) 606,607,607
  607 I=I+1
      GO TO 605
  606 CU=(((ZUD(I+1)-ZUD(I-1))/(XUD(I+1)-XUD(I-1)))-((ZUD(I)-ZUD(I-1))/(
     1XUD(I)-XUD(I-1))))/(XUD(I+1)-XUD(I))
      BU=((ZUD(I)-ZUD(I-1))/(XUD(I)-XUD(I-1)))-CU*(XUD(I)+XUD(I-1))
      AU=ZUD(I)-BU*XUD(I)-CU*XUD(I)**2
      XALP=(TANALP(K)-BU)/(2.*CU)
      ZALP= AU+BU*XALP+CU*XALP**2
      ZCHECK=ZALP-0.0044
      IF ( ZCHECK .LE. 0.0) ZCHECK = ZUD(1)
      J=1
  635 IF(ZCHECK-ZUD(J)) 627,628,628
  628 J=J+1
      GO TO 635
  627 IF(J.EQ.I   ) GO TO 629
      CU=(((ZUD(J+1)-ZUD(J-1))/(XUD(J+1)-XUD(J-1)))-((ZUD(J)-ZUD(J-1))/(
     1XUD(J)-XUD(J-1))))/(XUD(J+1)-XUD(J))
      BU=((ZUD(J)-ZUD(J-1))/(XUD(J)-XUD(J-1)))-CU*(XUD(J)+XUD(J-1))
      AU=ZUD(J)-BU*XUD(J)-CU*XUD(J)**2
  629 XCHECK=0.5*((-BU/CU)-SQRT((BU/CU)**2-4.*((AU-ZCHECK)/CU)))
      L=1
  608 IF(XALP-X(L)) 609,610,611
  611 L=L+1
      GO TO 608
  610 CPALP =CPU(K,L)
      GO TO 612
  609 CU=(((CPU(K,L+1)-CPU(K,L-1))/(   X(L+1)-   X(L-1)))-((CPU(K,L)-CPU(K
     1,L-1))/(   X(L)-   X(L-1))))/(   X(L+1)-   X(L))
      BU=((CPU(K,L)-CPU(K,L-1))/(   X(L)-   X(L-1)))-CU*(   X(L)+   X(L-1))
      AU=CPU(K,L)-BU*   X(L)-CU*(   X(L)**2)
      CPALP = AU+BU*XALP+CU*XALP**2
      J=1
  630 IF(XCHECK-X(J)) 631,632,632
```

```
632  J=J+1
     GO TO 630
631  IF(J.EQ.L) GO TO 633
     CU=(((CPU(K,J+1)-CPU(K,J-1))/(  X(J+1)-  X(J-1)))-((CPU(K,J)-CPU(K
    1,J-1))/(  X(J)-  X(J-1))))/(  X(J+1)-  X(J))
     BU=((CPU(K,J)-CPU(K,J-1))/(  X(J)-  X(J-1)))-CU*(  X(J)+  X(J-1))
     AU=CPU(K,J)-BU*  X(J)-CU*(  X(J)**2)
633  CPCK= AU+BU*XCHECK+CU*XCHECK**2
     DELCP=CPALP-CPCK
612  CONTINUE
      ALPHA=(CL(K)/A1IT)+ALP0
     DMACH(K)=1./(1.023-0.9507*CPALP-0.4140*CPALP**2-0.1506*CPALP**3-0.
    10212*CPALP**4)
     CLD(K)= CL(K)/SQRT(1.-DMACH(K)**2)
604  WRITE(6,510) DMACH(K),CLD(K), ALPHA,ALPHAI(K),XALP,CPALP,DELCP
 510 FORMAT(2X,F10.5, 4X,F10.5, 5X,F3.0,2X,F10.5, 4X,F10.5, 3X,F10.5,
    94X,F10.5,/)
     WRITE(6,427)
 525 CONTINUE
C
427  FORMAT (2H01/90H  WHEN ALPHA IS GREATER THAN ALPMAX, SEPARATION MA
    1Y EXIST RENDERING THE RESULTS INCORRECT./2H02/90H  A VALUE OF DELC
    2P GREATER THAN 0.07 INDICATES A PREMATURE DRAG CREEP CONDITION MAY
    3 EXIST.)
     RETURN
     END
```

$IBLDR CALCMP 06 MAR 68 CALCMPOO

THIS DECK IS A BINARY DECK CONSISTING OF THE "CALCOMP PACKAGE". THIS "PACKAGE" IS A SET OF SUBROUTINES FOR OPERATING THE ON LINE CALCOMP PLOTTER. THE FOLLOWING IS A LIST OF THOSE SUBROUTINE NAMES WITH THE ONES CALLED BY THIS PROGRAM UNDERLINED.

<u>PLOTE</u>

<u>PLOTS</u>

<u>PLOT</u>

<u>AXIS</u>

<u>LINE</u>

<u>SYMBOL</u>

<u>NUMBER</u>

TPUSED

PLTIMT

FACTOR

OFFSET

WHERE

SCALE

APPENDIX II

EQUATIONS FOR AIRFOIL COORDINATES

4-DIGIT DESIGNATION

Thickness:

$$y_t = (t/.2)\ (0.29690\sqrt{X} - 0.126X - 0.3516X^2 + 0.2843X^3 - 0.1015X^4)$$

t - maximum thickness in fraction of chord.

Mean line:

Ahead of maximum ordinate,

$$y_c = (m/p^2)\ (2\ pX - X^2)$$

Aft of maximum ordinate,

$$y_c = m\ (1 - p)^2 \left[(1 - 2p) + 2\ pX - X^2\right]$$

m - maximum ordinate of mean line in fraction of chord

p - chordwise positior of maximum ordinate

5-DIGIT DESIGNATION

Thickness: same as 4-DIGIT DESIGNATION simple mean line;

Ahead of position of maximum camber,

$$y_c = (K_1/6) \left[X^3 - 3mX^2 + m^2\ (3 - m)\ X\right]$$

Aft of position of maximum camber,

$$y_c = (K_1/6)\ m^3\ (1 - X)$$

Reflex mean line:

Ahead of position of reflex,

$$y_c = (K_1/6) \left[(X - n)^3 - (K_2/K_1)\ (1 - n)^3\ X - n^3 X + n^3\right]$$

Aft of position of reflex,

$$y_c = (K_1/6)\left[(K_2/K_1)(X - n)^3 - (K_2/K_1)(1 - n)^3 X - n^3X + n^3\right]$$

m & n - constants found by evaluating the boundary conditions, i.e, $dy_c/dx = 0$ where x is position of maximum camber.

$$K_2/K_1 = \left[3(m - P)^2 - m^3\right] / (1 - m)^3$$

K_1 - evaluated by substituting for (K_2/K_1) and solving with known y_c.

4-DIGIT & 5-DIGIT MODIFIED DESIGNATIONS

Thickness:

Aft of maximum thickness,

$$y_t = d_o + d_1 (1 - X) + d_2 (1 - X)^2 + d_3(1 - X)^3$$

where coefficients are determined by:

1) $y_t' = - d_1 = f(t)$ at the trailing edge.

2) $y_t' = 0 = - d_1 - 2 d_2 (1 - m) - 3 d_3 (1 - m)^2$ at the position of maximum thickness.

3) $t = d_o + d_1 (1 - m) + d_2 (1 - m)^2 + d_3 (1 - m)^3$

4) $y_t = .01t = d_o$ at $X = 1$.

Ahead of the maximum thickness,

$$y_t = a_o\sqrt{X} + a_1X + a_2X^2 + a_3X^3$$

where the coefficients are determined by:

1) $R_t = a_o^2/2$, $R_t = 1.1019\ (tI/6)^2$, I is given in the designation suffix.

2) $y_t' = 0 = (a_o/2)\sqrt{X} + a_1 + 2a_2X + 3a_3X^2$

3) radius of curvature at the position of maximum thickness.

$$R = (2d_2 + 6d_3 (1 - m))^{-1} = (1 + y'^2)^{3/2}/y_t''$$

$$y_t'' = (-a_o/4X^{3/2}) + 2a_2 + 6a_3X$$

4) $y_t = t = a_o \sqrt{m} + a_1 m + a_2 m^2 + a_3 m^3$ at the position of maximum thickness.

Mean line:

Same as corresponding 4-DIGIT & 5-DIGIT DESIGNATION AIRFOILS.

1-SERIES SECTIONS

Thickness:

Same as 4-DIGIT MODIFIED DESIGNATION thickness equation.

Mean Line:

$$y_c = (-C_{Li}/4\pi) \left[(1-X/c) \ln(1-X/c) + (X/c) \ln (X/c)\right]$$

where C_{Li} is given in the designation.

NOTE: Leading edge radius estimated to be 3 or 4 percent chord.

6-DIGIT SERIES SECTIONS

Thickness:

Same as 4-DIGIT MODIFIED DESIGNATION thickness equation.

Mean Line:

$$y_c = \left[C_{Li}/2\pi(a+1)\right] \left[1/(1-a)\right] \left[.5 (a-X/c)^2 \ln |a-X/c| - .5(1-X/c)^2 \ln (1-X/c) + .25 (1-X/c)^2 - .25 (a-X/c)^2\right] - X/c \ln(X/c) + g - h X/c$$

$$\text{where } g = \left[-1/(1-a)\right]\left[a^2\,((.5)\ \ln\ (a-.25)) + .25\right]$$

$$h = (1/1-a)\left[.5(1-a)^2\ \ln\ (1-a) - .25\ (1-a)^2\right] + g.$$

"a" is defined as point where load distribution changes from uniform to linearly decreasing to zero at the trailing edge. C_{Li} is given in the designation.

APPENDIX III

STEPS IN DRAG-RISE MACH NUMBER PREDICTION

An outline of the individual steps involved in the drag-rise Mach number prediction program are stated below as given in Reference 1:

(1) Determine the chordwise incompressible inviscid pressure distribution for a chosen set of angles of attack (α_{IT}) and integrate each pressure distribution to obtain the lift coefficient (C_{LIT}).

(2) Assume that for any given value of lift coefficient the pressure coefficient in incompressible inviscid flow and in incompressible viscous flow are identical in the vicinity of the crest, but are associated with different angles of attack, namely α_{IT} and α_I respectively. The latter must be determined (Step 5).

(3) From the data obtained above (Step 1), calculate the lift-curve slope in incompressible inviscid flow (a_{IT}) at zero lift.

(4) Determine the lift-curve slope in incompressible viscous flow (a_I) from equation given in Section III or Figure 2, Reference 1, using the value of a_{IT} obtained in Step 3.

(5) Determine the angle in incompressible viscous flow (α_I) corresponding to the values of C_{LI} obtained by the assumption of Step 2 above from

$$\alpha_I = \frac{C_{LI}}{a_I} + \alpha_{OIT}$$

Note: Where low speed experimental data is available, Steps 1 through 5 are unnecessary and the computations can begin with Step 6.

(6) Determine the airfoil upper surface slope (θ_S) for a series of chordwise stations such that the numerical range of θ_S slightly exceeds the numerical range of α_I, taking into account both positive and negative values of α_I.

(7) Determine:

(a) The chordwise position of the crest for each value of α_I - the crest being defined as the point at which the airfoil surface is tangential to the undisturbed freestream flow direction, i.e., $\theta_s = \alpha_I$.

(b) The incompressible pressure coefficient at the crest ($C_{p\,crest}$) for each value of α_I.

(8) Use $C_{p\,crest}$ to determine M_D from Figure 3 in Reference 1 which may be approximated by the equation

$$M_D = 1.023 - 0.907C_{p\,crest} - 0.4140C^2_{p\,crest} - 0.1506C^3_{p\,crest} - 0.0212C^4_{p\,crest}$$

(9) Use the Prandtl-Glauert Compressibility correction factor (β_D), evaluated at the drag-rise Mach number (M_D), to obtain the lift coefficient C_{LD} from

$$C_{LD} = C_{LI}/\beta_D$$

(10) Plot the drag-rise boundary as the locus of the points (C_{LD}, M_D).

REFERENCES

1. "A Method of Estimating Drag-Rise Mach Number for Two-Dimensional Airfoil Sections." Transonic Data Memorandum 6407, Royal Aeronautical Society, London, England, July 1964.

2. Weber, J., "The Calculation of the Pressure Distribution Over the Surface of Two-Dimensional and Swept Wings with Symmetrical Aerofoil Section", A. R. C. R&M. No. 2918, 1956. AD No. 20068.

3. Weber, J., "The Calculation of the Pressure Distribution on the Surface of Thick Cambered Wings and the Design of Wings with Given Pressure Distribution", A. R. C., R&M, No. 3026, 1957. AD No. 65639.

4. Giesing, Joseph P., Potential Flow About Two-Dimensional Airfoils, Douglas Aircraft Company Report No. LB31946, December, 1965.

5. Abbott, Ira H., Von Doenhoff, Albert E., and Stivers, Louis S., "Summary of Airfoil Data." NACA Report No. 824, 1945.

BIBLIOGRAPHY

1. Abbott, Ira H. and Von Doenhoff, Albert E., Theory of Wing Sections Dover Publications, New York, New York, 1959.

2. Abbott, Ira H., Von Doenhoff, Albert E. and Stivers, Louis S., Jr., "Summary of Airfoil Data", NACA Rept. No. 824, 1945.

3. "A Method of Estimating Drag-Rise Mach Number for Two-Dimensional Aerofoil Sections", Transonic Data Memorandum 6407, Royal Aeronautical Society, London, England, July 1964.

4. Brockway, D. J. and Hollenberg, H. O., "A Rapid Method to Determine Drag Divergence Mach Number", NAVAER Report Nr. DR-1806, 1957.

5. Giesing, Joseph P., Potential Flow About Two-Dimensional Airfoils, Douglas Aircraft Company Report No. LB31946, December, 1965.

6. Jacobs, Eastman N., "Preliminary Report on Laminar Flow Airfoils and New Methods Adopted for Airfoil and Boundary-Layer Investigations", NACA ACR, June 1939, (Wartime Rept. No. L-345).

7. Jacobs, Eastman N., Ward, Kenneth E. and Pinkerton, Robert M., "The Characteristics of 78 Related Airfoils Sections from Tests in the Variable-Density Wind Tunnel", NACA Rept. No. 460, 1932.

8. Jacobs, Eastman N. and Pinkerton, Robert M., "Tests in the Variable-Density Wind Tunnel of Related Airfoils Having the Maximum Camber Unusually Far Forward", NACA Rept. No. 537, 1936.

9. Jacobs, Eastman N., Pinkerton, Robert M. and Greensberg, Harry, "Tests of Related Forward-Camber Airfoils in the Variable-Density Wind Tunnels", NACA Rept. No. 610, 1937.

10. Kuethe, A. M. and Schetzer, J. D., Foundations of Aerodynamics, John Wiley & Sons, Inc., New York, New York, 1967.

11. Loftin, Lawrence K., Jr., "Theoretical and Experimental Data for a Number of NACA 6A-Series Airfoils Sections", NACA Rept. No. 903, 1947.

12. Sinnott, C. S., "On the Prediction of Mixed Subsonic/Supersonic Pressure Distributions", Journal of the Aerospace Science, Vol. 27, No. 10, October 1960.

13. Stack, John and Von Doenhoff, Albert E., "Tests of 16 Related Airfoils at High Speeds", NACA Rept. No. 492, 1934.

14. Stack, John, "Tests of Airfoils Designed to Delay the Compressibility Burble", NACA TN No. 976, 1944.

BIBLIOGRAPHY (CONTD)

15. Weber, J., "The Calculation of the Pressure Distributions on the Surface of Thick Cambered Wings and the Design of Wings with Given Pressure Distributions", A.R.C. R.&M. No. 3026, 1957.

16. Weber, J., "The Calculation of the Pressure Distribution Over the Surface of Two-Dimensional and Swept Wings with Symmetrical Aerofoil Sections", A.R.C. R.&M. No. 2918, 1956.

17. Von Mises, Richard, Theory of Flight, Dover Publications, New York, New York, 1959.