NASA Contractor Report 3064

Operational Manual for Two-Dimensional Transonic Code TSFOIL

Stephen S. Stahara

CONTRACT NAS2-8648
DECEMBER 1978

NASA

NASA Contractor Report 3064

Operational Manual for Two-Dimensional Transonic Code TSFOIL

Stephen S. Stahara
Nielsen Engineering & Research, Inc.
Mountain View, California

Prepared for
Ames Research Center
under Contract NAS2-8648

NASA
National Aeronautics
and Space Administration

Scientific and Technical
Information Office

1978

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS (CONCLUDED)

LIST OF TABLES

OPERATIONAL MANUAL FOR TWO-DIMENSIONAL TRANSONIC CODE TSFOIL

By Stephen S. Stahara
Nielsen Engineering & Research, Inc.

1. SUMMARY

A detailed operating manual is presented for the computer code TSFOIL recently developed by Murman, Bailey, and Johnson at NASA/Ames Research Center. This code solves the two-dimensional, transonic, small-disturbance equations for flow past lifting airfoils in both free air and various wind-tunnel environments by using a variant of the finite-difference method initially proposed by Murman and Cole. A description of the theoretical and numerical basis of the code is provided, together with complete operating instructions and sample cases for the general user. In addition, a programmer's manual is also presented to assist the user interested in modifying the code. Included in the programmer's manual are a dictionary of subroutine variables in common and a detailed description of each subroutine.

2. INTRODUCTION

During the past several years, the rapid growth and development of numerical techniques capable of treating the nonlinear equations of transonic flow past aerodynamic configurations has generally resulted in a wealth of research computer programs but a lack of adequately documented user-oriented codes. In light of this, the present work was undertaken with the dual objectives of:

(1) providing a computer code which is capable of solving a general class of two-dimensional, transonic, small-disturbance flows, and which incorporates as many of the recent advances in the theory as possible and

(2) providing a systematically organized, user-oriented code with complete documentation to allow easy extension and modification for new applications and improvements.

A summary of the features and capabilities of the computer program was given in reference 1. This document provides an operational manual of the code, and includes a full description of the method of solution.

Although the basic solution technique used in the program is based on the original work of Krupp and Murman (refs. 2 and 3) various improvements and extensions have been incorporated in the version presented here. These include a simplified procedure for converging to the proper circulation for lifting airfoils (refs. 4 and 5), the appropriate difference operator to be used at shock waves (ref. 6), the evaluation of inviscid drag using momentum contour methods (ref. 7), wind-tunnel wall simulations (ref. 8), calculation of $M_\infty > 1$ transonic flows (ref. 9), the accelerated spread of circulation throughout the flow field for $M_\infty < 1$ free air flows (ref. 10), an analytic mesh (ref. 11) as well as a mesh cutting option to speed convergence, a successive line overrelaxation procedure based on the correction potential (ref. 12), and a pseudo-time term (ref. 12) to aid stability.

The operating manual presented here has been subdivided into two general categories. The first category is presented in section 4 and is a General User's Manual. In that section, a description of the problem solved by the code is given, including a discussion of the differential equation, geometry, boundary conditions, and numerical formulation of the problem, together with a description of the general operating procedure of the code, overall program flow chart, input/output description, error messages, and sample calculations. All the information necessary to run the code are provided in that section. In section 5, a Programmer's Manual is presented to assist the user who wishes to modify the code to incorporate additional features or to extend the code beyond its present capabilities. Included in that section is a dictionary of all subroutine variables which appear in common blocks and a detailed description of the individual subroutines. In order to provide a user-code that will readily accommodate modifications, the program has been modularized in the sense that numerous (53) special-purpose subroutines have been used, rather than one large main program. Consequently, should the user not require some of the special calculations or output provided by the code, deletions can be made simply and directly.

In reference 1, it was noted that a number of computational problems, which are repeated here for convenience, existed in the version of the code then available. Some of those problems have since been alleviated by improvements to that initial version. In particular, the computation of lifting airfoils in supersonic free streams, which had proved troublesome, has been improved by the addition of a pseudo-time term as discussed in detail in section 4.1.5, and also by the introduction of an analytical mesh suggested in reference 11. A characteristic difficulty with $M_\infty > 1$ flows is that the maximum iteration error may initially decrease monotonically to a certain level, and then oscillate about that level, or in more severe cases, diverge. The maximum error almost always occurs at points near the airfoil and close to the bow or trailing edge shocks, or the locations where those shocks cross the mesh outer boundary. Addition of the pseudo-time term has served to stabilize this feature of the calculation, particularly when mesh cutting has been employed and the switch is made to the next finer mesh. Use of the analytic mesh frequently has served to preserve the monotonic convergence behavior of the solution, presumably both by the clustering of points near the leading and trailing edges and the expansion of points near the mesh boundaries.

Addition of these two features has also served to enhance the convergence of $M_\infty < 1$ flows. For example, converged solutions were achieved for a number of transonic flows past the 64A410 airfoil which could not previously be obtained with the earlier version. Also, supercritical flows for which the shock wave on the airfoil upper surface reached the trailing edge had proven difficult to calculate. For these cases, use of the analytic mesh appears to aid convergence considerably.

However, the occurrence of irregularities in the solution near the leading edge, as noted in reference 1, remains in the present version. Although these also appear in Krupp's results (ref. 2), in the current program they are predicted to be somewhat stronger. These dissimilarities may be due to the slight differences in numerical procedures used. Of course, one of the inherent deficiencies in any first-order, small-disturbance theory is the inaccurate treatment of the leading edge. A more accurate treatment, such as those suggested in references 13 and 14, has not been incorporated in the program, although a Reigel's rule option has been added.

The program has been written in FORTRAN IV source language and developed for use on a CDC 7600 computer using the OPT=2 compiler. The memory requirements are $(57K)_8$ and $(30K)_8$ words for small core and large core, respectively.

3. LIST OF SYMBOLS

$A_{j,i}$ coefficient matrix, equation (36)

c airfoil chord

$\overline{C}_i$ column vector containing values of the correction potential $C_{j,i}$ along the i^{th} column of the finite-difference mesh, equation (47)

C_D drag coefficient, equation (34)

$C_{j,i}$ correction potential, equation (42)

C_m pitching-moment coefficient, equation (33)

C_p pressure coefficient, equation (28)

C_{p_u} pressure coefficient associated with the airfoil upper surface

C_{p_ℓ} pressure coefficient associated with the airfoil lower surface

f_i column vector associated with the i^{th} column of the finite-difference grid, equation (46)

F nondimensional wind-tunnel slot parameter, equation (20)

$F_{u,\ell}$ dimensionless affine function describing, respectively, the ordinates of the upper and lower airfoil surface, equation (7)

H ratio of wind-tunnel half height to airfoil chord

$\tilde{H}$ transonically scaled tunnel half height to airfoil chord ratio, equation (22)

i,j indices identifying the grid point at the i^{th} column and j^{th} row

k exponent of Mach number in similarity definition of the small-disturbance equation, equations (2) and (6)

K transonic similarity parameter, equation (5)

L nondimensional spacing of slot centerlines, normalized by c; equation (20)

m exponent of Mach number in similarity definition of transonically scaled y coordinate, equation (4)

M local Mach number, equation (30)

M_∞ free-stream Mach number

n exponent of Mach number in similarity definition of velocity potential, equation (1)

p pressure

P nondimensional experimentally determined wind-tunnel porosity parameter equal to $2\Phi_y(x,\pm H)/\Delta p_{wall}(x,\pm H)/q_\infty$, equation (19)

$\tilde{P}$ transonically scaled wind-tunnel porosity parameter, equation (23)

P_o shock-wave total pressure loss

P_∞ free-stream pressure

q_∞ free-stream dynamic pressure

$R_{j,i}$ residual matrix, equation (45)

S nondimensional slot width, normalized by c; equation (20)

U_∞ free-stream velocity

(x,y) nondimensional Cartesian coordinate system with x axis directed rearward and aligned with the free stream; coordinates normalized by c

(x',y') equal to (cx,cy)

$\tilde{y}$ transonically scaled y coordinate, equation (4)

$y_{u,\ell}$ ordinates of the upper (u) and lower (ℓ) airfoil surface, equation (7)

α angle of attack

Γ circulation, equation (12)

Γ_{ff} far-field circulation, equation (13)

γ ratio of specific heats

δ airfoil thickness ratio

ϵ parameter multiplying pseudo-time term $\Delta t\phi_{xt}/\Delta x$ in small-disturbance partial differential equation, equation (48)

θ local flow angle, equation (29)

$\mu_{j,i}$ switching parameter, equation (37)

Φ disturbance velocity potential, equation (1)

$\bar{\Phi}$ total velocity potential, equation (1)

ϕ dimensionless perturbation velocity potential, equation (1)

ϕ_{ff} asymptotic far-field solution of the perturbation velocity potential

$\Delta\phi(x)$ jump in perturbation velocity potential along trailing vortex wake, equations (14) and (16)

$\Delta\phi_{te}$ jump in perturbation velocity potential at the trailing edge, equation (12)

ω relaxation parameter, equation (44)

ω_e relaxation parameter for elliptic points, equation (44)

ω_Γ relaxation parameter for circulation, equation (13)

4. GENERAL USER'S MANUAL

4.1 Description of Program

This section provides an overall description of the program, a brief discussion of the theoretical and numerical formulation of the problem solved by the code, including a description of the differential equation, airfoil geometry, boundary conditions, and finite-difference method. Also, the general operating procedure of the code is reviewed and an overall program flow chart is provided.

4.1.1 Differential equations and transonic scaling.- The partial differential equation solved by TSFOIL is the transonic small-disturbance equation for the perturbation velocity potential cast in terms of transonic similarity variables. Because of the nonuniqueness of the scaling, various forms have been adopted by different authors. If (Φ,ϕ) are, respectively, the physically and transonically scaled perturbation potentials, the various forms can be combined in the following general manner:

$$\bar{\Phi}(x',y') = cU_\infty[x + \Phi(x,y) + \ldots] = cU_\infty\left[x + \frac{\delta^{2/3}}{M_\infty^n}\phi(x,\tilde{y}) + \ldots\right] \tag{1}$$

where c is the airfoil chord, U_∞ and M_∞, respectively, are the free-stream velocity and Mach number, δ is the airfoil thickness ratio, (x,y) are the physical Cartesian coordinates (x',y') normalized by airfoil chord, and $\tilde{y}$ the transonically scaled y coordinate given below. Now, (Φ,ϕ) satisfy

$$\left[(1 - M_\infty^2)\Phi_x - \frac{\gamma + 1}{2} M_\infty^k \Phi_x^2\right]_x + \left[\Phi_y\right]_y = 0 \tag{2}$$

$$\left[K\phi_x - \frac{\gamma + 1}{2} \phi_x^2\right]_x + \left[\phi_{\tilde{y}}\right]_{\tilde{y}} = 0 \tag{3}$$

where

$$\tilde{y} = \delta^{1/3} M_\infty^m y \tag{4}$$

$$K = \frac{1 - M_\infty^2}{\delta^{2/3} M_\infty^{2m}} \tag{5}$$

and the exponents (k,m,n) are related by

$$k = 2m + n \tag{6}$$

The different forms of the transonic similarity variables depend essentially on the particular choice of the exponents (k,m,n), and Table I provides a summary of the particular values proposed by Cole, Spreiter, or Krupp which have been incorporated into the program. The partial differential equation actually solved by TSFOIL is then equation (3).

4.1.2 Geometry.- The coordinate system used in the program is the Cartesian system shown in figure 4-1, with the airfoil located along the x-axis between 0 and 1, at angle of attack, α, and with a shape given by

$$y_{u,\ell}(x) = \delta F_{u,\ell}(x) \qquad 0 \leq x \leq 1 \tag{7}$$

where (u,ℓ) denotes the upper and lower surfaces, and $F_{u,\ell}(x)$ is a function of order one describing the ordinates of a family of affinely related airfoils. Default profiles incorporated into the program are the parabolic-arc

$$F_{u,\ell}(x) = \pm 2x(1-x) \tag{8}$$

the NACA four-digit series

$$F_{u,\ell}(x) = \pm(1.4845\sqrt{x} - 0.63\,x - 1.758\,x^2 + 1.415\,x^3 - 0.5075\,x^4) \tag{9}$$

and the Korn airfoil described in reference 15. Provision has been made in the program for the user to input a profile of his choice by either a formula or a table of ordinates.

4.1.3 Boundary conditions.- The boundary conditions applied to this problem consist of the flow tangency condition at the airfoil surface, a condition for lifting airfoils assuring the value of circulation be unique, and some far-field conditions to be satisfied on the outer boundaries of the computational mesh. Within the framework of small-disturbance theory, the tangency condition at the airfoil can be linearized and applied along the slit $\tilde{y} = 0$, $0 \leq x \leq 1$ as

$$\phi_{\tilde{y}}(x,0^{+}) = \frac{dF_u(x)}{dx} - \frac{\alpha}{\delta} \tag{10}$$

$$\phi_{\tilde{y}}(x,0^-) = \frac{dF_\ell(x)}{dx} - \frac{\alpha}{\delta} \tag{11}$$

For lifting airfoils, two options have been incorporated in the program to insure that the circulation is unique. The first is the usual Kutta condition which is satisfied by requiring that ϕ_x (pressure) be continuous along the line $\tilde{y} = 0$, $x \geq 1$, and that $\phi_{\tilde{y}}$ (flow angle) be continuous across $\tilde{y} = 0$, $x > 1$. The disturbance potential ϕ remains single-valued by introduction of a cut along the $\tilde{y} = 0$ axis downstream of the airfoil along which ϕ is discontinuous, jumping by the value of the circulation Γ defined by

$$\Gamma = -\oint d\phi = \Delta\phi_{te} \tag{12}$$

where the contour is taken around the airfoil surface, and the resultant integral is equal to the jump in potential at the trailing edge. The circulation Γ_{ff} used in the asymptotic far-field solutions to update the outer boundaries is determined from the relation

$$\Gamma_{ff}^{n+1} = \Gamma_{ff}^{n} - \omega_\Gamma \left(\Gamma_{ff}^{n} - \Delta\phi_{te}^{n}\right) \tag{13}$$

where ω_Γ is the relaxation factor for circulation and n is the iteration count. The updated jump in potential $\Delta\phi(x)$ along the slit $\tilde{y} = 0$, $x > 1$ is calculated by the program according to the formula

$$\Delta\phi(x) = \Delta\phi_{te}^{n} + \frac{x - 1}{x_{max} - 1}\left(\Gamma_{ff}^{n+1} - \Gamma_{ff}^{n}\right) \tag{14}$$

From the results of reference 4, a value of circulation relaxation factor $\omega_\Gamma = 1.0$ (default value) is recommended. This implies that the updated far-field circulation be set equal to the new jump in potential at the trailing edge,

$$\Gamma_{ff}^{n+1} = \Delta\phi_{te}^{n} \tag{15}$$

and that the jump in potential along the trailing vortex wake be held constant and equal to

$$\Delta\phi(x) = \Delta\phi_{te}^{n} \tag{16}$$

Numerical experimentation has shown that the simpler representation of equations (15) and (16) gives the same results and convergence rate as both the method of Krupp (ref. 2) and the closely related procedure of equations (13) and (14).

The second option available to insure uniqueness of circulation is to specify the lift. In this case, the Kutta condition is not satisfied, and the pressure becomes double-valued at the trailing edge. The jump in potential at the trailing edge, as well as the far-field circulation, and the potential jump along the trailing vortex wake are given by

$$\Delta\phi_{te} = \Gamma_{ff} = \Delta\phi(x) = \frac{(C_L)_{SET}}{2} \qquad (17)$$

where $(C_L)_{SET}$ is the specified lift coefficient.

For conditions at the outer boundaries, provision is made in the program to represent free air flows and various wind-tunnel wall simulations for both $M_\infty < 1$ and $M_\infty > 1$. For subsonic free air flows, the program incorporates the asymptotic far-field solution ϕ_{ff} given by a compressible vortex and doublet, while for supersonic free air flows the appropriate far-field conditions incorporated are that the perturbation velocities $\phi_x, \phi_{\tilde{y}}$ vanish at the upstream boundary and that the outgoing wave condition

$$\phi_{\tilde{y}} = \pm\sqrt{K}\;\phi_x \qquad (18)$$

be enforced at the top and bottom boundaries in order to prevent reflected waves. Strictly speaking, for $M_\infty > 1$, no condition is required at the downstream boundary if as we assume it is sufficiently far removed downstream so that the outflow is entirely supersonic. However, for actual numerical application, some condition is needed (ref. 8) to treat subsonic outflow which may develop during the course of the relaxation solution process prior to convergence. By numerical experimentation, the condition $\phi_x = 0$ was found to be satisfactory. Figure 4-2 summarizes these conditions for free air calculations.

For wind-tunnel simulations, the classical homogeneous tunnel wall boundary condition

$$\Phi_x(x,\pm H) \pm FH\Phi_{xy}(x,\pm H) \pm \frac{1}{P}\,\Phi_y(x,\pm H) = 0 \qquad (19)$$

is applied at the tunnel walls $y = \pm H$. Here, H is the ratio of tunnel half height to airfoil chord, F is the tunnel slot parameter, and P is the porosity parameter which accounts for viscous effects in the slot and must be determined experimentally. A simplified analysis has been made by Baldwin, et al. (ref. 16) for the slot parameter F, which he gives as

$$F = \frac{L}{\pi H} \ell n \left[\csc \left(\frac{\pi S}{2L} \right) \right] \tag{20}$$

where L is the spacing between slot centerlines and S is the slot width, both normalized by airfoil chord. The program uses equation (19) in the similarity form

$$\phi_x(x,\pm\tilde{H}) \pm F\tilde{H}\phi_{x\tilde{y}}(x,\pm\tilde{H}) \pm \frac{1}{\tilde{P}} \phi_{\tilde{y}}(x,\pm\tilde{H}) = 0 \tag{21}$$

where $(\tilde{H},\tilde{P})$ are the transonically scaled tunnel half height and porosity given by

$$\tilde{H} = \delta^{1/3} M_\infty^m H \tag{22}$$

$$\tilde{P} = P/(\delta^{1/3} M_\infty^m) \tag{23}$$

The following subcases of equation (19) have been incorporated into the program as separate options

$$\phi_{\tilde{y}}(x,\pm\tilde{H}) = 0 \qquad \text{Solid Wall} \tag{24}$$

$$\phi_x(x,\pm\tilde{H}) = 0 \qquad \text{Free Jet} \tag{25}$$

$$\tilde{P}\phi_x(x,\pm\tilde{H}) \pm \phi_{\tilde{y}}(x,\pm\tilde{H}) = 0 \qquad \text{Ideal Perforated/ Porous Wall} \tag{26}$$

$$\phi_x(x,\pm\tilde{H}) \pm F\tilde{H}\phi_{x\tilde{y}}(x,\pm\tilde{H}) = 0 \qquad \text{Ideal Slotted Wall} \tag{27}$$

while the general case has not yet been included. For tunnel flows, the upstream and downstream conditions used are the following. For $M_\infty < 1$, the asymptotic far-field solution ϕ_{ff} which satisfies equation (19) and the linearized version of the differential equation (3) is used. The case of choked flow, as treated in reference 17, has not been included in the program. For $M_\infty > 1$, the conditions $\phi_x, \phi_{\tilde{y}} = 0$ are enforced at the upstream boundary, while the flow is required to be supersonic at the downstream boundary and the condition $\phi_x = 0$ is employed, as in the supersonic free air calculation. These conditions are summarized in figure 4-3.

4.1.4 Aerodynamic variables.- The aerodynamic quantities of interest output by the program are given below in terms of the small-disturbance similarity potential $\phi(x,\tilde{y})$. These include pressure coefficient, C_p, flow angle, θ, local Mach number, M, shock wave total pressure loss, $[P_O]/P_\infty$, and coefficients of lift, C_L, pitching moment, C_m, and drag, C_D.

$$C_p = \delta^{2/3} M_\infty^{-n} (-2\phi_x) \tag{28}$$

$$\theta = \delta \phi_{\tilde{y}} \tag{29}$$

$$M = \left\{ 1 - \left[K - (\gamma + 1)\phi_x \right] \delta^{2/3} M_\infty^{2m} \right\}^{1/2} \tag{30}$$

$$\frac{[P_O]}{P_\infty} = 1 + \delta^2 \; \frac{\gamma(\gamma + 1)}{12} \; [\phi_x]_s^3 \tag{31}$$

$$C_L = - \int_0^1 (C_{PU} - C_{P\ell})\, dx \tag{32}$$

$$C_m = \int_0^1 (x - x_m)(C_{Pu} - C_{P\ell})\, dx \qquad \text{(positive nose-up)} \tag{33}$$

$$C_D = \delta^{5/3} M_\infty^{-n} \left\{ \oint_C \left[K\phi_x^2 - \phi_{\tilde{y}}^2 - \frac{2}{3} (\gamma + 1)\phi_x^3 \right] d\tilde{y} - \phi_x \phi_{\tilde{y}}\, dx - \frac{\gamma + 1}{6} \int_{S \supset C} [\phi_x]_s^3 \; d\tilde{y} \right\} \tag{34}$$

where $[\phi_x]_s$ is the jump in the streamwise perturbation velocity across a shock.

4.1.5 Numerical formulation.- The numerical formulation of the problem together with the techniques employed to solve it are presented in this section. The numerical solution of the problem is initiated by replacing equation (3) by the following finite-difference form given by Bailey and Ballhaus in reference 18.

$$\Big\{(1-\mu_{j,i})\, A_{j,i}\Big[(\phi_x)_{j,i+1/2} - (\phi_x)_{j,i-1/2}\Big]$$

$$+ \mu_{j,i-1}\, A_{j,i-1}\Big[(\phi_x)_{j,i-1/2} - (\phi_x)_{j,i-3/2}\Big]\Big\} / (x_{i+1/2} - x_{i-1/2})$$

$$+ \Big[(\phi_y)_{j+1/2,i} - (\phi_y)_{j-1/2,i}\Big] / (y_{j+1/2} - y_{j-1/2}) = 0 \qquad (35)$$

where

$$A_{j,i} = 1 - M_\infty^2 - (\gamma + 1)M_\infty^k(\phi_x)_{j,i} \qquad (36)$$

$$\mu_{j,i} = \begin{cases} 0 & \text{for} \quad A_{j,i} > 0 \\ 1 & \text{for} \quad A_{j,i} < 0 \end{cases} \qquad (37)$$

$$(\phi_x)_{j,i+1/2} = \frac{\phi_{j,i+1} - \phi_{j,i}}{x_{i+1} - x_i} \qquad (38)$$

$$(\phi_y)_{j+1/2,i} = \frac{\phi_{j+1,i} - \phi_{j,i}}{y_{j+1} - y_j}\text{ , etc.} \qquad (39)$$

and $(\phi_x)_{j,i}$ in equation (36) is approximated by

$$(\phi_x)_{j,i} = \frac{1}{2}\Big[(\phi_x)_{j,i+1/2} + (\phi_x)_{j,i-1/2}\Big] \qquad (40)$$

This form of the difference equation with the switching parameter $\mu_{j,i}$ encompasses the four operators of Murman's fully conservative relaxation (FCR) method (ref. 15); that is, elliptic ($\mu_{j,i-1} = 0$, $\mu_{j,i} = 0$), hyperbolic ($\mu_{j,i-1} = 1$, $\mu_{j,i} = 1$), parabolic ($\mu_{j,i-1} = 0$, $\mu_{j,i} = 1$), and shock point ($\mu_{j,i-1} = 1$, $\mu_{j,i} = 0$), and for evenly spaced meshes is identical to that method. For unequally spaced meshes, the first term differs from Murman's (ref. 19) by a factor of $(x_i - x_{i-2})/(x_{i+1} - x_{i-1})$ in hyperbolic regions. The finite-difference equation (35) can be cast in the following form

$$
\begin{aligned}
&(1-\mu_{j,i})A_{j,i}(CXXL_i\phi_{j,i-1} - CXXC_i\phi_{j,i} + CXXR_i\phi_{j,i+1}) \\
&+ \mu_{j,i-1}A_{j,i-1}(CXXL_{i-1}\phi_{j,i-2} - CXXC_{i-1}\phi_{j,i-1} + CXXR_{i-1}\phi_{j,i}) \\
&+ CYYD_j\phi_{j-1,i} - CYYC_j\phi_{j,i} + CYYU_j\phi_{j+1,i} = 0 \qquad (41)
\end{aligned}
$$

where the coefficients ($CXXL_i$, $CXXC_i$, etc.) depend on mesh geometry only and can be deduced from equation (35). Although equation (41) forms the basis of the numerical analysis, the solution technique actually employed in the program is similar to that recently suggested by Jameson (ref. 12) in which the difference equation (41) is recast in terms of a correction potential $C_{j,i}$ defined by

$$\phi^{n+1}_{j,i} = \phi^{n}_{j,i} + C_{j,i} \qquad (42)$$

where n represents the current iteration cycle.

The governing equation for $C_{j,i}$ is determined in the following fashion. First, we consider the difference equation (41) in which the values $\phi_{j,i}$ of the potential along the current column are replaced by their provisional values $\tilde{\phi}_{j,i}$, while the values ($\phi^{n+1}_{j,i-1}$, $\phi^{n+1}_{j,i-2}$, $\phi^{n}_{j,i+1}$, $A^{n}_{j,i-1}$, $A^{n}_{j,i}$) are used to evaluate the remaining terms. Similarly, we define a residual $R_{j,i}$ by considering the same equation but with the result $\phi^{n}_{j,i}$ used for $\phi_{j,i}$. By subtracting those two equations and then eliminating $\tilde{\phi}_{j,i}$ by use of the overrelaxation formula

$$\phi^{n+1}_{j,i} = \phi^{n}_{j,i} + \omega\,(\tilde{\phi}_{j,i} - \phi^{n}_{j,i}) \qquad (43)$$

where

$$\omega = \left\{ \begin{array}{lll} \omega_e,\ 1 < \omega_e < 2 & \text{for locally subsonic flow} & (A_{j,i} > 0) \\ & & \\ 1 & \text{for locally supersonic flow} & (A_{j,i} < 0) \end{array} \right\} \qquad (44)$$

the following difference equation results for $C_{j,i}$:

$$
\begin{aligned}
&\left\{ -(1-\mu_{j,i})A^{n}_{j,i}CXXC_i/\omega_e + \mu_{j,i-1}A^{n}_{j,i-1}CXXR_{i-1} \right\} C_{j,i} \\
&\qquad + CYYD_j C_{j-1,i} + CYYU_j\ C_{j+1,i} = -R_{j,i} \qquad (45)
\end{aligned}
$$

We note that in the derivation of equation (45), new values $\phi^{n+1}_{j,i}$ rather than provisional values $\tilde{\phi}_{j,i}$ are used to evaluate ϕ_{yy} at both subsonic and supersonic points. As pointed out in reference 12, this avoids a discontinuity in ϕ_{yy} at a sonic line.

The solution of equation (45) then proceeds by using an iterative successive line over-relaxation (SLOR) algorithm as follows. The system of equations for each vertical line is written as

$$A\overline{C}_i = f_i \tag{46}$$

where $\overline{C}_i$ is the J dimensional column vector

$$\overline{C}_i = \begin{pmatrix} C_{1,i} \\ \cdot \\ \cdot \\ \cdot \\ C_{j,i} \end{pmatrix} \tag{47}$$

A is a $J \times J$ dimensional, diagonally dominant, tridiagonal matrix, and f_i is a J dimensional column vector. The solution process consists of making an initial guess for ϕ, and then successively sweeping the grid from the upstream to downstream boundary, solving for new values of $C_{j,i}$ from equation (46) by direct elimination using the method of triangular decomposition, and then determining new values of ϕ from equation (42). The initial guess for ϕ may be selected from a uniform flow $(\phi = 0)$ or a previous case stored in core or on a peripheral unit. With regard to the over-relaxation parameter ω_e, acceptable values on a fine mesh for ω_e are $1.8 < \omega_e < 1.95$, although optimum values for particular applications must be determined by numerical experimentation.

A mesh refinement option has been incorporated into the program to enhance the rate of convergence. Under this option, the user may elect to initiate the calculation either on a mesh (medium mesh) obtained by deleting every other mesh point of the input mesh (fine mesh), or on an even coarser mesh (coarse mesh) obtained by again deleting every other point on the medium mesh. In the latter case, the iterative solution is started on the coarse mesh, and after appropriate convergence is reached, continued on the medium mesh, and then completed on the input mesh. Also, in order to improve stability and aid convergence, an option has been provided in the program to add the pseudo-time term in the form

$$- \epsilon \frac{\Delta t}{\Delta x} \phi_{xt} \tag{48}$$

where

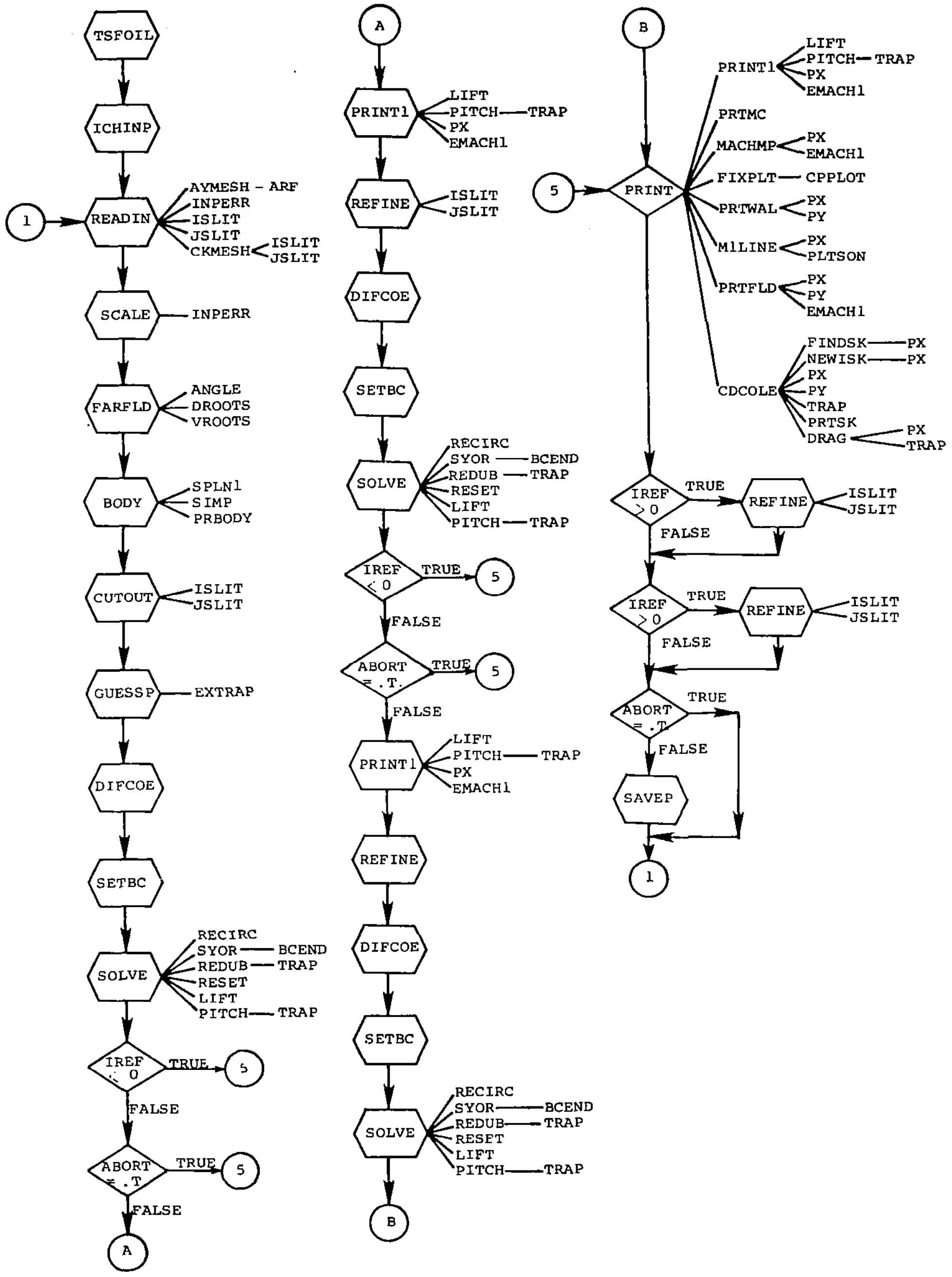
$$\frac{\Delta t}{\Delta x} \phi_{xt} = \frac{\left(\phi^{n+1}_{j,i} - \phi^{n}_{j,i}\right) - \left(\phi^{n+1}_{j,i-1} - \phi^{n}_{j,i-1}\right)}{\left(x_i - x_{i-1}\right)^2} = \frac{C_{j,i} - C_{j,i-1}}{(x_i - x_{i-1})^2} \tag{49}$$

to the left-hand side of equation (45) as suggested in references 12 and 18. The parameter ϵ is an input parameter with a value in the range $0 \leq \epsilon \leq 1$. Considerable improvement in stability and convergence has been obtained in a number of both subsonic and supersonic free-stream calculations when this term is added. However, this result is not true for all cases and extensive numerical experimentation to determine optimum values for ϵ has not yet been carried out. Consequently, the user must, of necessity, determine suitable values for his particular application. An appropriate first guess would be $\epsilon = 0.2$ which is the default value.

Finally, we note that the numerical methods used in this program are of the shock-capturing, rather than shock-fitting type. This means that shock waves are spread over several mesh intervals and do not appear as sharp discontinuities. Calculations have shown (ref. 19) that for subsonic flow downstream of shock waves, four mesh points are sufficient to capture the shock jump; whereas for supersonic downstream flow, six to ten points are required. The latter is due to dissipation effects which dominate the first-order accurate hyperbolic operator in equation (35), and smooth out shocks to that extent. This is a weakness in the method if sharp supersonic oblique shocks are required, and necessitates special indentations of the momentum contours used to calculate the inviscid drag for all cases where $M_\infty > 1$, and also for cases where $M_\infty < 1$ when tail plus wake shocks occur. See subroutine CDCOLE in section 5.2 for a description of the momentum contours incorporated in the program.

4.1.6 Operating procedure.- The general operating procedure of the program is straightforward and is described in this section. First, the main program prints all of the input cards (ECHINP), then reads the input for the first case, checks it for errors, assigns default values to those parameters not specified, and then prints all of the input parameters (READIN). Next, if the input was in physical rather than transonic form, the appropriate scaling is applied to render all the necessary variables into transonic similarity form (SCALE). The unit-strength boundary data on the far-field mesh boundaries are then computed (FARFLD). Next, the geometrical characteristics of the airfoil that are required in the finite-difference calculations are determined (BODY). The medium and coarse meshes are then established if the user has opted to use the mesh refinement option (CUTOUT). Next, the ϕ array is initialized (GUESSP), and then the various difference coefficients that depend on mesh size are calculated for the current mesh (DIFCOE). The I and J indices for solving the difference equations are set, and the airfoil slope boundary condition is multiplied by mesh spacing constants for use in the finite-difference calculation (SETBC). The relaxation solution of the difference equations is then carried out in an iterative fashion by sweeping the flow field from upstream to downstream boundaries with convergence information being output after a specified number of sweeps (SOLVE). If the calculations have been carried out on an intermediate mesh, flow field information on the dividing streamline, including the airfoil, are printed (PRINT1), and then mesh points are added to obtain the next finer mesh (REFINE). The sequence of relaxation calculations are then repeated (DIFCOE, SETBC, SOLVE, PRINT1) until the final mesh is reached. At this point, the final flow information is output (PRINT), the solution stored for later use (SAVEP), and the calculation for the next case begun. If the solution should diverge during the course of the finite-difference calculation (SOLVE), the computation is then aborted, with portions of the final printout (PRINT) provided to assist the user in determining the cause of the difficulty.

4.1.7 Overall program flow chart.- An overall program flow chart is provided below to illustrate the logical flow of the code.



4.2 Program Input

The input required by the program is described in this section. A dictionary of input variables is provided first, followed by a description of the various input control options available to the user. All of the default values of the input variables are given next, followed by a description of the input data format including preparation of a sample run.

4.2.1 Dictionary of input variables.- All variables that are input to this program are described in the following list.

VARIABLE — DESCRIPTION

AK — transonic similarity parameter; equal to $1-M_\infty^2/M_\infty^{2m}\delta^{2/3}$ where m is defined in Table 4-I according to the type of transonic scaling used; input required only if transonic scaling used in input/output; that is, PHYS = .F.

ALPHA — angle of attack, α, in degrees for PHYS = .T.

AMESH (logical) — control option for specification of analytical default mesh; equal to .T. or .F.

BCFOIL (integer) — control option for specification of airfoil geometry; equal to 1, 2, 3, or 4

BCTYPE — control option for type of flow environment; equal to 1, 2, 3, 4, or 5

CLSET — specified lift coefficient; input only if Kutta condition not enforced; that is, KUTTA = .F.

CVERGE — convergence criterion for maximum iteration error in ϕ

DELTA — airfoil thickness ratio δ

DVERGE — divergence criterion for maximum iteration error in ϕ

EMACH — free-stream Mach number, M_∞; because of the particular far-field formulation used in this program, M_∞ can be close but not exactly equal to 1

EPS — coefficient of pseudo-time term $\Delta t\phi_{xt}/\Delta x$ in differential equation

F — slot parameter for ideal slotted wind tunnel

FCR (logical) — control option for specification of type of differencing to be used at shock waves; equal to .T. or .F.

GAM — ratio of specific heats γ

H — ratio of tunnel half height/airfoil chord

ICUT — control option for mesh cutting and refinement; equal to 0, 1, or 2

VARIABLE DESCRIPTION

IMAXI number of x-mesh points in input mesh; IMAXI $\leq$ 100

IMIN value of I index designating the x-mesh point where the finite-difference calculation is to start

IPRTER control option for print frequency of intermediate output

JMAXI number of y-mesh points in input mesh; JMAXI $\leq$ 100

JMIN value of J index designating the y-mesh point where the finite-difference calculation is to start

KUTTA (logical) control for Kutta condition specification; equal to .T. or .F.

MAXIT maximum allowed number of iteration sweeps through the flow field

NL number of ordinate points used to describe airfoil lower surface; NL $\leq$ 100

NU number of ordinate points used to describe airfoil upper surface; NU $\leq$ 100

PHYS (logical) control for specification of the type of scaling (physical or transonic) used in input/output; equal to .T. or .F.

POR porosity factor for ideal porous/perforated wind-tunnel wall

PRTFLO control for printout of final flow field; equal to 1, 2, or 3

PSAVE (logical) control for saving restart block of values on unit 3; equal to .T. or .F.

PSTART (integer) control for initialization of ϕ array; equal to 1, 2, or 3

SIMDEF (integer) control for definition of transonic similarity scaling; equal to 1, 2, 3, or 4

WCIRC relaxation factor for circulation

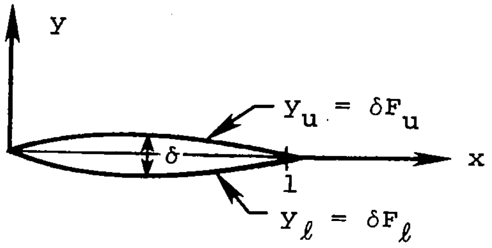
WE(I) vector array of length 3 representing values of the relaxation factor for elliptic points on the coarse, medium, and fine meshes, respectively; if specified, all three values must be given

XGRDIN control for input of user-designated x-grid; equal to .T. or .F.

VARIABLE	DESCRIPTION
XIN(I)	vector array of length IMAXI of user-supplied x-mesh points; normalized by airfoil chord; maximum of 100
XL(I)	vector array of length NL of x-ordinates of the airfoil lower surface; normalized by airfoil chord; maximum of 100
XU(I)	vector array of length NU of x-ordinates of the airfoil upper surface; normalized by airfoil chord; maximum of 100
YGRDIN	control for input of user-designated y-grid; equal to .T. or .F.
YIN(I)	vector array of length JMAXI of user-supplied y-mesh points, normalized by airfoil chord for PHYS = .T.; maximum of 100
YL(I)	vector array of length NL of y-ordinates of the airfoil lower surface; normalized by airfoil chord times thickness ratio; maximum of 100
YU(I)	vector array of length NU of y-ordinates of the airfoil upper surface; normalized by airfoil chord times thickness ratio; maximum of 100

4.2.2 Control options.- Those input variables which allow the user to select the various options incorporated in this program are detailed in this section together with the options they control.

Airfoil geometry option: Four choices are available to the user for the specification of the airfoil geometry. Selection is made according to the value specified (1, 2, 3, or 4) for the integer index BCFOIL. For BCFOIL = 1, the program uses the symmetric NACA four-digit (00XX) series geometry; for BCFOIL = 2, a parabolic-arc profile is used; for BCFOIL = 3, user-supplied values of upper and lower airfoil ordinates (YU(I), YL(L)) versus abcissas (XU(I), XL(I)) are required by the program, which then calculates internally the ordinates and slopes at the input mesh points by cubic spline interpolation--under this geometry option, a default airfoil (Korn) is provided; for BCFOIL = 4, the user provides his own specification (i.e., ordinates and slopes at the input mesh points) of the airfoil geometry. We note that the last option (BCFOIL = 4) is, of course, open (inactive) and requires user-supplied information in subroutine BODY. If a formula is available for the airfoil profile desired, this option should be used. Implementation is straightforward and an illustrative example is given below. Consider the symmetric profile formed by the sinusoidal curve given by:



$$y_{u,\ell}(x) = \pm \frac{\delta}{2} \sin(\pi x)$$

so that

$$F_{u,\ell}(x) = \pm \frac{1}{2} \sin(\pi x)$$

$$\frac{dF_{u,\ell}(x)}{dx} = \pm \frac{\pi}{2} \cos(\pi x)$$

Thus, the following FORTRAN statement changes would be entered into subroutine BODY. Immediately after statement number 400 (see the listing of subroutine BODY in the Appendix), the abnormal stop message and STOP card would be removed and the following statements inserted:

```
      PI = 3.1415927
      IC = 0
      DO 425 I = ILE, ITE
      IC = IC + 1
      Z = XIN(I)
      Z1 = PI * Z
      XFOIL(IC) = Z
      FU(IC) = SIN(Z1)/2.
      FL(IC) = - FU(IC)
      FXU(IC) = PI * COS(Z1)/2.
      FXL(IC) = - FXU(IC)
  425 CONTINUE
```

We note that it is necessary that subroutine BODY define the arrays XFOIL(I), FU(I), FL(I), FXU(IC), and FXL(I) which are, respectively, the x-ordinates of the input x-mesh XIN(I) which fall on the airfoil, the y-ordinates of the airfoil upper and lower surface divided by the thickness ratio, and the slopes of the airfoil upper and lower surface divided by the thickness ratio, all calculated at the XFOIL(I) points.

Flow environment option: To specify the type of flow environment; that is, free air or tunnel simulation conditions, the integer index BCTYPE must be set. Six different choices have been incorporated in the program according to the following schedule:

BCTYPE	Flow Condition
1	Free air
2	Solid wall tunnel
3	Free jet
4	Ideal slotted wall tunnel
5	Ideal porous/perforated wall tunnel
6	General tunnel wall

The program default value is BCTYPE = 1.

Conservative differencing option: An option has been provided for the user to specify whether conservative or nonconservative differencing be used at shock waves. This choice is made according to the logical index FCR:

FCR	Shock Difference Type
.T.	Fully conservative
.F.	Nonconservative

Program default value is FCR = .T.

Mesh refinement option: A convergence acceleration feature has been incorporated in the program which provides the user the option to initiate the iterative solution on a mesh that is coarser than the input mesh (fine mesh) on which the solution is ultimately desired. Provision has been made for two automatic grid reductions (medium and coarse) by the program. Since the grid change is accomplished by the deletion of every other mesh point, the following simple rules should be followed in specifying the input (fine) grid to take full advantage (i.e., two cuts) of this feature.

These rules consist of making the following grid point differences a multiple of four,

IMAXI - ITE
ITE - IMIN
JMAXI - JUP + 1
JLOW - JMIN + 1

which insure that each of the above four grid intervals can be halved twice. See Section 5.1 under COM 1 for a description of these indices.

The control for mesh refinement is made by specification of the integer index ICUT according to:

ICUT	Comment
0	Input mesh used to convergence
1	Input mesh may be cut once
2	Input mesh may be cut twice

We note that for the cases ICUT = 1 or 2, if the grid criteria given above are not met, the program will try to adjust if possible the grid by adding (never deleting) points. However, since the stated conditions are so mild, it is recommended that they be followed directly if the grid refinement option is desired. Program default value is ICUT = 2.

Intermediate printout option: If the user wished to obtain intermediate information concerning the convergence of the solution, an option is provided which will cause a limited printout to occur each time a specified number of iteration sweeps through the flow field are completed. Output includes iteration count, lift and moment coefficients, iteration error in circulation, and absolute values and locations of the maximum iteration error in ϕ, the residual $R_{j,i}$, and the upper and lower surface pressure coefficients. Control is through specification of the integer index IPRTER which causes output print every IPRTERth iteration sweep through the field. Program default value is IPRTER = 0.

Kutta condition enforcement option: If, in lieu of enforcing the Kutta condition, the user wishes to specify instead the lift coefficient, an option has been provided in the program to accommodate this. Control for this option is through the logical index KUTTA where

KUTTA	Comment
.T.	Kutta condition enforced
.F.	Lift coefficient specified; trailing-edge pressure discontinuous

Program default value is KUTTA = .T.

Physical or transonic I/O scaling option: A user choice for the type of scaling used in the input/output is available through the logical index PHYS. The I/O can be in either the usual physical scaled form (PHYS = .T.); that is, lengths normalized by airfoil chord, c, velocities by free-stream velocity, U_∞, pressure by free-stream dynamic pressure, q_∞, etc., or in the appropriate transonically scaled form (PHYS = .F.). If transonic scaling is used, we note the following requirements: the lateral coordinate of the input grid must be scaled according to

$$\tilde{y} = \delta^{1/3} M_\infty^m \, y$$

the angle of attack by

$$\tilde{\alpha} = \alpha/(\delta \cdot 180^\circ/\pi)$$

the half-tunnel height by

$$\tilde{H} = \delta^{1/3} M_\infty^m \, H$$

the lift coefficient CLSET by

$$(\mathrm{CL\tilde{S}ET}) = \mathrm{CLSET}/\delta^{2/3} M_\infty^{-n}$$

the porosity by

$$\tilde{P} = P/\delta^{1/3} M_\infty^m$$

the velocity potential by

$$\tilde{\phi} = \delta^{2/3} M_\infty^{-n} \, \phi$$

and instead of specifying the Mach number, M_∞, the similarity parameter K must be given, where

$$K = \frac{1 - M_\infty^2}{M_\infty^{2m} \, \delta^{2/3}}$$

and where the exponents (m,n) depend upon the choice of scaling and are defined in Table 4-I. Program default value is PHYS = .T.

Flow field printout option: In the final printout of a completed calculation, the user has the choice of obtaining flow field information [i.e., pressure coefficient, flow angle, and either local Mach number (PHYS = .T.) or local similarity parameter (PHYS = .F.)], either throughout or in a limited region of the flow field. This is controlled through the integer index PRTFLO according to

PRTFLO	Flow Field Printout
1	None
2	All
3	Three J lines about $|\phi^{n+1}_{j,i} - \phi^{n}_{j,i}|_{max}$ line

Program default value is PRTFLO = 1.

Result storage option: If at the completion of a calculation the user wishes, in addition to obtaining the printed output, to store the results on tape for future use, an option has been provided whereby the program will write the following information on tape 3:

(1) run title

(2) grid dimensions; IMAXI, JMAXI, IMIN, JMIN

(3) C_L, M_∞, α, δ, airfoil volume, far field doublet strength

(4) X and Y grid arrays

(5) $\phi_{j,i}$

Control is through the logical index PSAVE according to

PSAVE	Storage
.T.	Results stored on tape 3
.F.	No storage

Program default value is PSAVE = .F.

Initialization of ϕ option: Three choices are available for initializing the ϕ array to start the calculation. Selection is made according to the integer index PSTART where

PSTART	Initialization of ϕ
1	Set to zero
2	Read from tape 7
3	Used from previous case

Program default value is PSTART = 1.

Transonic similarity definition option: Four choices are available to the user for the specification of the particular transonic similarity form of the small-disturbance equation to be solved. The first three of these choices (SIMDEF = 1, 2, or 3) have been incorporated into the program and are detailed below. The fourth (SIMDEF = 4) is an open (inactive) option, requiring user-supplied definitions of the various scaling parameters calculated in subroutine SCALE.

The three active options reflect the different scaling rules of Cole, Spreiter, or Krupp and depend essentially upon the choice of values for the exponents (k,m,n) in the following representations of the small-disturbance perturbation velocity potential equation, stretched-lateral coordinate, and transonic similarity parameter; that is,

$$\left[(1 - M_\infty^2)\Phi_x - \frac{\gamma + 1}{2} M_\infty^k \Phi_x^2\right]_x + \Phi_{yy} = 0$$

or

$$\left[K\phi_x - \frac{\gamma + 1}{2} \phi_x^2\right]_x + \phi_{\tilde{y}\tilde{y}} = 0$$

where

$$\Phi(x,y) = \delta^{2/3} M_\infty^{-n} \phi(x,\tilde{y})$$

$$y = \delta^{-1/3} M_\infty^{-m} \tilde{y}$$

$$K = \frac{1 - M_\infty^2}{M_\infty^{2m} \delta^{2/3}}$$

The values of the exponents (k,m,n) for each of the three cases are given in Table 4-I. Selection of the particular scaling rule according to the value of SIMDEF is

SIMDEF	Scaling
1	Cole
2	Spreiter
3	Krupp
4	User defined

Program default value is SIMDEF = 3.

Default grid option: Two different sets of default grids have been incorporated in the program. These are the Krupp mesh defined in reference 2 and an analytical mesh based on a modified version of the grid discussed in reference 11. The program default x-mesh is the Krupp x-mesh XKRUPP(I), given in reference 2, while two default y-meshes are incorporated; that is, the Krupp y-mesh for free air calculations YFREE(I) and a modified y-mesh YTUN(I) for tunnel simulations. To use the analytical mesh, control is through the logical variable AMESH according to

AMESH	Grid Specification
.T.	Analytical mesh used
.F.	Either Krupp or user-specified mesh used

Program default value is AMESH = .F.

Input grid option: If the user wishes not to employ the default grids incorporated in the program, an option has been provided whereby an arbitrary mesh can be conveniently supplied to the program. Control is through the logical variables XGRDIN and YGRDIN according to

XGRDIN	Grid Specification
.T.	x-mesh provided by user in input data
.F.	Default x-mesh used

YGRDIN	Grid Specification
.T.	y-mesh provided by user in input data
.F.	Default y-mesh used

When the grids are user supplied, each element of the grid is defined in the input data, as illustrated in section 4.2.4. We note that the program default x-mesh is the Krupp x-mesh XKRUPP(I) defined in reference 2, while two default y-meshes are incorporated; that is, the Krupp y-mesh for free air calculations YFREE(I) and a modified y-mesh YTUN(I) for tunnel simulations. Program default values are XGRDIN = .F. and YGRDIN = .F.

4.2.3 Default values.- Each input variable has been assigned a default value that is stored in the BLOCK DATA subroutine. Consequently, unless the user wishes to change a variable from its default value, it is not necessary to enter it in the input data block. For convenience, the default values of all the input variables are tabulated below:

Variable	Default Value
AK	0.
ALPHA	0.12
AMESH	.F.
BCFOIL	3
BCTYPE	1
CLSET	0.
CVERGE	0.00001
DELTA	0.115
DVERGE	10.
EMACH	0.75
EPS	0.2
F	0.
FCR	.T.
GAM	1.4
H	0.
ICUT	2
IMAXI	77 (Krupp grid)
IMIN	1
IPRTER	10
JMAXI	56 (Krupp grid)
JMIN	1
KUTTA	.T.
MAXIT	500
NL	75 (Korn airfoil)
NU	100 (Korn airfoil)
PHYS	.T.
POR	0.
PRTFLO	1
PSAVE	.F.
PSTART	1
RIGF	0.
SIMDEF	3

Variable	Default Value
WCIRC	1.
WE(I), (I = 1,2,3)	1.8,1.9,1.95
XGRDIN	.F.
XIN(I)	XKRUPP(I)
XL(I)	(Korn airfoil)
XU(I)	(Korn airfoil)
YGRDIN	.F.
YIN(I)	YFREE(I) or YTUN(I)
YL(I)	(Korn airfoil)
YU(I)	(Korn airfoil)

It is important to realize that the above variables assume their default values only before the first case is run. Input variables, once user specified, are not changed internally by the program; thus, it is unnecessary to respecify them in subsequent cases if their values are to remain constant.

4.2.4 Input data format.- With the exception of a run title card, which is the first card of each case and on which the user can provide any alphanumeric information desired in columns 1 to 80, all of the input data for the program are read in under a NAMELIST format called INP. Consequently, the input format is most easily demonstrated by an example. Consider two cases of simulating the flow of air ($\gamma = 1.4$, default) past an NACA 0010 airfoil in an ideal slotted wall wind tunnel where the slot parameter is 0.07, and the tunnel half-height-to-chord ratio is 6.5. For the first case, the free-stream Mach number is 0.70, the angle of attack is 1.5°, and it is decided to match the measured tunnel lift coefficient of 0.187. The fully conservative equations (default) will be solved on the YTUN (tunnel default) y-grid and the basic Krupp XKRUPP (default) x-grid, employing the mesh refinement option with two grid halvings (default). The maximum number of iteration sweeps allowed will be 250, with intermediate printout desired after every fifth sweep, a convergence criterion on ϕ of 1×10^{-4}, a divergence criterion of 10. (default), with final flow field printout confined to three rows centered about the maximum iteration error in ϕ, and with the final results stored on tape 3. The transonic equation will be used in the similarity form as given by Spreiter, with the input/output in physical scaling terms (default), with the initial guess of ϕ equal to zero (default), and with the circulation relaxation factor equal to 0.9, the three elliptic relaxation factors equal to 1.3, 1.6, and 1.9 for the coarse, medium, and fine grids respectively. The pseudo-time term will be omitted from the differential equation (ϵ = 0.).

For the second case, all of the input parameters will be identical to the first except that the Mach number will be equal to 0.72 and the measured lift coefficient equal to 0.195.

Thus, the input data cards would read (note that with a NAMELIST format, input variable sequencing is arbitrary):

CARD NO. 1 - RUN TITLE CARD

COLUMN NO.

1	80
SAMPLE CALCULATION NO. 1	

CARD NO. 2

COLUMN NO.

2	6	80
$INP	EMACH=.7,F=.07,ALPHA=1.5,H=6.5,DELTA=.1,BCFOIL=1,	

CARD NO. 3

COLUMN NO.

2	80
KUTTA=.F.,CLSET=.187,MAXIT=250,IPRTER=5,CVERGE=.0001,	

CARD NO. 4

COLUMN NO.

2	80
PRTFLO=3,PSAVE=.T.,SIMDEF=2,WCIRC=.9,WE(1)=1.3,WE(2)=1.6,	

CARD NO. 5

COLUMN NO.

2	80
WE(3)=1.9,EPS=0.,	

CARD NO. 6

COLUMN NO.

2	80
$END	

CARD NO. 7 - RUN TITLE CARD

COLUMN NO.

1	80
SAMPLE CALCULATION NO. 2	

CARD NO. 8

COLUMN NO.

2	6	80
$INP	EMACH=.72,CLSET=.195,	

CARD NO. 9

COLUMN NO.

2	80
$END	

CARD NO. 10

COLUMN NO.

1	80
FINISHED	

We comment that the last card in the input data, following the final data card for the last case, must contain the word FINISHED in the first eight columns. This signals the program that there are no further cases to calculate and that the program is to stop.

If for the above cases the user wished to supply his own x- and y-grids, this would have been done by setting the grid input controls XGRDIN and YGRDIN equal to TRUE, specifying in the input the integers IMAXI and JMAXI, subject to the restriction IMAXI, JMAXI $\leq$ 100, and then identifying all of the IMAXI values of XIN(I) and JMAXI values of YIN(I) in the input data. For example, say that the user has an 81×60 (x,y) grid. Then, the card data to be included in the input for the first case would be (using some ficticious values for XIN, YIN):

COLUMN NO.

2	80
XGRDIN=.T.,IMAXI=81,XIN(1)=-3.0,XIN(2)=2.9,...	

⋮ etc.

COLUMN NO.

2	80
XIN(80)=1.9,XIN(81)=2.0,YGRDIN=.T.,JMAXI=60,YIN(1)=-6.5,	

⋮ etc.

COLUMN NO.

2	80
YIN(59)=6.4,YIN(60)=6.5,	

A similar procedure would apply if the user wished to supply his own description of the airfoil surface; that is, arrays XL(I), YL(I), XU(I), and YU(I).

4.3 Error and Information Messages

The error and information messages printed by the program are listed in this section together with a brief explanation of why they occur and what to do when they are encountered. The first group of messages (1 to 12) is concerned with input quantities while the second group (13 to 21) occur during the execution of the program and involve certain limitations inherent in the methods used in this program.

(1) IMAX OR JMAX IS GREATER THAN 100, NOT ALLOWED

This message indicates that the input mesh size limitation IMAX, JMAX $\leq$ 100 has been violated.

(2) X MESH POINTS NOT MONOTONIC INCREASING

This message indicates an error in the input x-mesh that violates the condition $X_i > X_{i-1}$.

(3) Y MESH POINTS NOT MONOTONIC INCREASING

This message indicates an error in the input y-mesh that violates the condition $Y_j > Y_{j-1}$.

(4) MACH NUMBER NOT IN PERMITTED RANGE (0.5,2.0)

This message indicates that the input free-stream Mach number M_∞ is outside the nominally accepted transonic regime. A scheme solving the linear small-disturbance equation, rather than the nonlinear transonic equation solved in this program, should be employed.

(5) ALPHA NOT IN PERMITTED RANGE (-9.0,9.0)

This message indicates that the input angle of attack is beyond the range in which small-disturbance theory is considered valid; that is, $-9^\circ < \alpha < 9^\circ$.

(6) DELTA NOT IN PERMITTED RANGE (0.0,1.0)

This message indicates that the restriction on thickness ratio, $0. < \delta < 1.$, has been violated.

(7) AK = 0. VALUE OF AK MUST BE INPUT SINCE PHYS = .F.

This message indicates that the transonic similarity parameter $K = (1 - M_\infty^2)/M_\infty^{2m}\delta^{2/3}$ has not been input as is required when transonic rather than physical scaling; that is, PHYS = .F., is used in the input/output.

(8) MACH NUMBER TOO CLOSE TO 1., NOT ALLOWED

This message indicates that the input free-stream Mach number M_∞ is too close to one; that is, $|M_\infty - 1.| < 0.001$. This is unallowed since the program incorporates a representation of the far field solution containing the factor $1/\sqrt{K} \sim 1/|M_\infty^2 - 1|^{1/2}$. To correct this a special sonic free-stream far field solution would be required.

(9) ABNORMAL STOP IN SUBROUTINE BCEND
BCTYPE = 6 IS NOT USABLE

This message indicates to the user that the general tunnel wall boundary condition BCTYPE = 6 is an inactive option for which conditions have not yet been worked out.

(10) ABNORMAL STOP IN SUBROUTINE BODY
BCFOIL = 4 IS NOT USABLE

This message indicates to the user that the airfoil geometry specification BCFOIL = 4 is an inactive option requiring user definition. For details on necessary user input, see section 4.2.2.

(11) ABNORMAL STOP IN SUBROUTINE FARFLD
BCTYPE = 6 IS NOT USABLE

See message (9).

(12) ABNORMAL STOP IN SUBROUTINE SCALE
SIMDEF = 4 IS NOT USABLE

This message indicates to the user that the transonic similarity specification SIMDEF = 4 is an inactive option requiring user definition. For details on necessary user input, see section 4.2.2.

(13) NOTE - ONE OR MORE SHOCKS EXTEND OUTSIDE OF CONTOUR
CDWAVE DOES NOT EQUAL TOTAL WAVE DRAG

This message indicates that some of the shock waves present for the case at hand extend beyond the appropriate drag contour incorporated in the program, so that the wave drag calculated by the program does not equal the total wave drag. For details on the drag contours available, see the description of subroutine CDCOLE in section 5.2.

(14) SHOCK WAVE ATTACHED TO BODY. MOMENTUM INTEGRAL CANNOT
BE DONE. DRAG OBTAINED FROM SURFACE PRESSURE INTEGRAL.

This message indicates that, for reasons explained in section 5.2 under subroutine CDCOLE, the momentum integral method for calculating drag cannot be used. The drag is then calculated by integrating the surface pressures on the airfoil.

(15)
```
* * * * *  CAUTION  * * * * *
SOLUTION MAY BE INVALID
DETACHED SHOCK WAVE IS TOO CLOSE TO UPSTREAM BOUNDARY.
MOMENTUM INTEGRAL CANNOT BE DONE.  DRAG OBTAINED FROM
SURFACE PRESSURE INTEGRAL.
```

This message indicates that the bow shock is too close (within three mesh points) of the upstream boundary for the momentum integral along the bow shock to be performed, and that the drag is obtained by integrating the surface pressures on the airfoil. Also, because the bow shock is so close to the upstream boundary, the solution may be inaccurate and it is recommended that the upstream boundary be displaced further from the airfoil and the calculation repeated.

(16)
```
THE INPUT MESH CANNOT BE ADJUSTED FOR CUTOUT, BECAUSE
IMAX OR JMAX IS TOO CLOSE TO THE LIMIT OF 100.
```

This message is written by subroutine CKMESH and indicates that, because the input mesh requirements for grid cutting described in section 4.2.2 under Mesh Refinement Option were not met, subroutine CKMESH has attempted to correct this by adding points. However, either the input X or Y grid is too close to the limit of 100 to allow this, with the result that no points are added, the mesh refinement option is bypassed, and the input mesh is used to convergence.

(17)
```
ABNORMAL STOP IN SUBROUTINE DROOTS.  (0)
NONCONVERGENCE OF ITERATION FOR ALPHA(1)
                                     (2)
```

This message identifies one of the constants ALPHA0, ALPHA1, or ALPHA2 required in the subsonic far-field doublet solution in an ideal slotted wind tunnel, and indicates that the iterative solution for that constant has failed to converge. This error message should not normally occur. If it does, the input values for the tunnel slot parameter F and wall porosity factor P should be checked. See subroutine DROOTS in section 5.2 for details.

(18)

```
* * * * *  CAUTION  * * * * *
SONIC LINE HAS REACHED A BOUNDARY
THIS VIOLATES ASSUMPTIONS USED TO DERIVE BOUNDARY CONDITIONS.
SOLUTION IS PROBABLY INVALID
```

This message indicates that the sonic line has extended out to the top and/or bottom grid boundaries, and that the solution is probably invalid since the assumptions under which the boundary conditions were derived have been violated. For free-stream flows, the difficulty can be remedied by moving the lateral boundaries out further, while for tunnel simulation calculations, this condition indicates that the flow has become choked. For the latter case, the details have not yet been worked out.

(19)

```
* * * * *  CAUTION  * * * * *
NUMBER OF SONIC POINTS EXCEEDED 200. ARRAY DIMENSION
EXCEEDED.  EXECUTION OF SUBROUTINE MILINE TERMINATED
```

This message indicated that the number of sonic points has exceeded 200 and subroutine MILINE, which determines the locations of the sonic lines, has terminated calculation. For the maximum grid size (100×100) allowed in this program, this error message should not occur. If it does, the remainder of the output should be checked for unusual behavior.

(20)

```
* * * * *  CAUTION  * * * * *
MAXIMUM MACH NUMBER EXCEEDS 1.3
SHOCK JUMPS IN ERROR IF UPSTREAM NORMAL MACH NUMBER GREATER
THAN 1.3
```

This message is written by subroutine PRINT1 and indicates that the maximum Mach number along the dividing streamline, which includes the airfoil upper and lower surface, has exceeded 1.3. Consequently, if the normal Mach number just upstream of the shock wave is greater than 1.3 (this can be checked from the output of PRINT1) the shock jumps, as calculated by the program using isentropic small-disturbance theory, will be in error with the true Rankine-Hugoniot value since the usually accepted upper bound for validity of the isentropic assumption has been exceeded.

(21)

```
ABNORMAL STOP IN SUBROUTINE VROOTS
                                (0)
NONCONVERGENCE OF ITERATION FOR BETA(1)
                                (2)
```

This message identifies one of the constants BETA0, BETA1, or BETA2 required in the subsonic far-field vortex solution in an ideal slotted wind tunnel, and indicates that the iterative solution for that constant has failed to converge. This error message should not normally occur. If it does, the input values for the tunnel slot parameter F and wall porosity factor P should be checked. See subroutine VROOTS in section 5.2 for details.

4.4 Program Output

The output generated by the program is described in this section. A general description of the format is provided in the first subsection, followed by a subsection containing several sample cases for user reference.

4.4.1 General description of the output.- The output format of the program is as follows. On the first page a header is printed giving the program name, some general information concerning the problem solved and method used, and identification of the program's authors. On the next page, all of the input cards for the entire run sequence are printed. On the first line of the third page, the information input by the user on the first run title card is printed. Next, all of the input variables described in section 4.2.1 are printed. This includes, of course, variables not specified in the input data and which then assume their default values. On the fourth page the airfoil geometry information required by the program is printed. First, a header is printed to inform the user whether the printout is in physical variables (PHYS = .T.), in which case all of the airfoil geometric characteristics are normalized by the chord; or if the printout is in transonic similarity variables (PHYS = .F.), for which the geometric characteristics are normalized by chord length times thickness ratio. Next, the maximum thickness, airfoil volume (per unit span), and maximum camber are output. Finally, the ordinates and slopes of the upper and lower surface, together with the thickness and camber distributions are provided in tabular form at the input x-mesh points. On the fifth page, intermediate output information for the coarse mesh (if a coarse grid is used) is provided. This includes the elliptic relaxation factor, the value of ϵ (EPS) used, and the maximum number of iterations for this mesh. This is followed by a heading which contains, from left to right, the iteration count (ITERATION), lift coefficient (CL), moment coefficient (CM), I and J locations (IERR,JERR) where the maximum iteration error in ϕ occurs, the absolute magnitude of the maximum iteration error in ϕ (ERROR), the I and J locations (IRL,JRL) of the maximum residual, the absolute magnitude of the maximum residual (BIGRL), the absolute magnitude of the iteration error in circulation (ERCIRC), the I location (ICPU) of the point on the airfoil where the maximum iteration error in upper surface pressure coefficient occurs, the absolute magnitude of the maximum iteration error in upper surface pressure coefficient (CPERRU), and the corresponding results (ICPL,CPERRL) for the maximum iteration error in surface pressure coefficient. A printout of these quantities is provided at every IPRTERth iteration until the solution either converges or diverges, or the iteration limit is reached; at this point, a message is printed indicating which of these three alternatives occurred. On the sixth page, the final output for the coarse mesh is given. This consists of the final coarse-mesh values of the lift and moment coefficients and tabulated values of the pressure coefficient and local Mach number (or local similarity parameter if PHYS = .F.) along the entire length of the dividing (y = 0) streamline, including both the upper and lower surface of the airfoil. In addition, the x- and y-coarse-mesh ordinates are also provided. The format is as follows. First, the lift and moment coefficients are given, together with the value of the critical pressure coefficient. Next, a header is printed which contains, from left to right, the I index of the current x-mesh point (I), the x value of the mesh point (X), the pressure coefficient (CP), and local Mach number (M1) just below the dividing streamline with the additional title $\left(\begin{smallmatrix}\text{LOWER}\\ y\ =\ 0-\end{smallmatrix}\right)$, and then the pressure coefficient (CP) and local Mach number (M1) just above the dividing streamline with the additional title $\left(\begin{smallmatrix}\text{UPPER}\\ y\ =\ 0+\end{smallmatrix}\right)$. Tabulated values of these quantities follow and are provided for each x-mesh point of the coarse grid. Locations of the airfoil leading and trailing edges are indicated in the output. Alongside the table of values, a concomitant printer plot of the tabulated pressure coefficients is given. Finally, all the y-values of the coarse grid y mesh are printed. On the seventh and eighth pages, the intermediate and final output, respectively, for the medium grid (if a medium grid is used) are provided in the same format as described above for the coarse grid. On the eight page, the intermediate output for the fine mesh is given. On the following page, the final print output begins for the fine mesh. On this page, information is provided informing the user whether the printout is in physical or transonic variables, and if it is in physical variables which particular definition of similarity parameters was used. Also indicated is the type of boundary condition specified (free air or type of wind tunnel), whether the difference equations were in conservative form or not, and whether the Kutta condition was enforced or the lift coefficient specified. Next, some limited airfoil geometry and flow field information is given (i.e., free-stream Mach number and airfoil thickness ratio if physical scaling is used, (PHYS = .T.), plus angle of attack and transonic similarity parameter in all cases, and far-field doublet strength and airfoil volume per unit span when $M_\infty < 1$. Finally, if PHYS = .T., the transonic scaling parameters used by the program to scale the pressure, lift, drag, and moment coefficient, the y-ordinate, and the flow angle are printed. On the next page, the fine grid lift and moment coefficients, pressure coefficients and local Mach number on the dividing streamline together with the x- and y-fine mesh ordinates, and a printer plot of the pressure coefficients is given in the format previously described for the coarse grid. On the next page, a flow character map is provided. Each point in the mesh is characterized according to whether it is a parabolic point (P), hyperbolic point (H), shock point (S), or an elliptic point (—). The following page provides a Mach number map of the flow field. Each grid point receives either a number or letter letter designation according to the symbol table provided in the plot. On the next page, a laterally expanded printer plot of the pressure coefficients on the dividing streamline and airfoil surface is provided. For wind-tunnel wall simulation calculation (i.e., BCTYPE $\neq$ 1 or 3), tabulated values of the pressure coefficient and flow angle along the entire length of the wind-tunnel walls ($y = H\underline{+}$) are given next. The format is similar to that provided for output of the pressure distributing along the dividing streamline discussed previously. This consists of tabulated values of the pressure coefficient (CP) and the flow angle (THETA) along the bottom $\left(\begin{array}{c}\text{LOWER}\\ y = -H\end{array}\right.$ and top $\left.\begin{array}{c}\text{UPPER}\\ y = +H\end{array}\right)$ surfaces of the wind tunnel at each of the fine mesh x-grid (X) locations. A printer plot of the pressure coefficients is also provided alongside the tabulated values. On the next two pages, output describing the sonic lines is provided. The first page gives tabulated values of the sonic line coordinates, while the second page provides a printer plot of the sonic lines throughout the flow field. On the following page, flow field output, if requested by the user, is printed. This consists of tabulated values of the pressure coefficient, flow angle, and local Mach number (or local similarity parameter if PHYS = .F.) along the entire length of y = constant lines on the fine mesh. The format is as follows. First, a header is printed which contains, in the first two columns, the I index of the current x-mesh point (I) and the x value of the x-mesh point (X) The next nine columns contain three sets of pressure coefficients (CP), flow angles (THETA), and local Mach numbers (M1) along three different y = constant rows, with an additional title above each of the sets indicating both the

J index and associated y-value of the row. Tabulated values of these quantities follow for each x-mesh point of the fine grid. If the flow field print option PRTFLO = 3 was chosen, the flow field output is confined to three J lines about the location of maximum iteration error in ϕ, and all the flow field output is contained across one page. However, if the entire flow field is to be printed (PRTFLO = 2), then the above format is repeated for three successive rows at a time until the entire field is covered. Following this, the shock wave drag profiles and total pressure loss profiles are given. For each shock wave within the momentum contour, the total wave drag is given together with tabulated values of the shock wave drag (CD(y)) and the total pressure (PO/POINF) as functions of the lateral coordinate (y). On the next page, information regarding the drag coefficient is given. If the drag was calculated by the momentum integral method, the locations of the contour boundaries are given together with the individual contributions to the drag from the integrations of the drag integral along each of these boundaries. In addition, information regarding the number of shock waves inside the contour and the total wave drag are printed. Should any of the shocks extend beyond the momentum contour, a message is printed indicating this and the fact that the wave drag calculated does not equal the total wave drag. Finally, the total of all the separate drag contributions is given. If the momentum integral method could not be used to calculate the drag--either because the bow shock was attached or too close to the nose or because the bow shock was too close to the upstream boundary--a message to that effect is printed and the drag is then calculated by an integration of surface pressures. The time to run the case in seconds is provided on the next page. This would conclude the output for an individual case. The above format is repeated until all cases are run. Following this, a final page of output is printed which consists simply of the word FINISHED, indicating a normal exit from the program.

4.4.2 Sample cases.- In order to provide reference checks on the programs, six sample test cases have been run exercising a representative sample of the various options available. The results are provided in figures 4-4 through 4-9. In each case the input data are provided together with the corresponding output. Because of the large amount of output information, full program output is provided only for the first two cases (figs. 4-4,4-5); however, the abbreviated output given for the remaining cases is sufficient to verify the correctness of the program under those options selected.

4.5 Comparisons with Data and Other Methods

A variety of comparisons of the results predicted by the methods employed in this program have been presented in the literature (refs. 1, 2, 3, 6, 7, 8, 9, and 20). For convenience, several of those comparisons are briefly repeated here in order to provide the user both with a general assessment of the accuracy of the methods used and some idea of the typical solution behavior that can be expected. For further information, the user is referred to the excellent review article by Bailey (ref. 21).

Basically, the comparisons presented here fall into three categories; that is, (1) comparisons with exact (hodograph) inviscid solutions, (2) comparisons with more accurate (full inviscid, full potential) numerical solutions, and (3) comparisons with data. The first two categories serve to assess the accuracy of the numerical technique and the small-disturbance potential approximation, while the third serves to demonstrate the influence of tunnel interference and viscous effects.

In figure 4-10 a comparison is made of the small-disturbance relaxation solutions calculated by the Krupp-Murman techniques (ref. 3) employed in this program with the exact hodograph solutions (ref. 22) for a NLR quasi-elliptical airfoil at $\alpha = 1.32^o$, $M_\infty = 0.7557$. A similar result is shown in figure 4-11 for a Garabedian-Korn airfoil at $\alpha = 0.12^o$, $M_\infty = 0.76$. Also provided in those two figures are relaxation solutions (refs. 23 and 24) for the full potential equation. We note that in both of those cases, the small-disturbance relaxation solutions and the full potential relaxation solutions show a weak shock as compared to the exact hodograph solution, which is for the shock-free design condition. For the Garabedian-Korn airfoil, the small-disturbance solution also predicts a somewhat smaller expansion beyond the nose. The overall agreement, however, between the small-disturbance solutions and the exact and full potential solutions is quite good, particularly in light of the fact that flows past such shock-free airfoils are extremely sensitive to small changes in geometry and flow conditions, and therefore provide an exacting test of the accuracy of any transonic predictive method. Figure 4-12 shows a further comparison of the small-disturbance results predicted by the Krupp-Murman method and a relaxation solution of the full inviscid equations for a subcritical flow (ref. 25). Again, the agreement is very good, even at this low ($M_\infty = 0.63$) a Mach number.

The results presented in the preceding three figures are for shock free flows. For flows containing shock waves, the relaxation methods used above for the full equations do not employ conservative difference operators and consequently do not satisfy the proper shock jump conditions. Some idea of the error involved in solving the exact isentropic equation in nonconservative form (ref. 26) and the calculation of the isentropic solution using a conservative time-dependent procedure (ref. 27) is given in figure 4-13. Also provided is the small-disturbance result predicted by the present program when using the fully conservative (FCR) option. We note that the shock location predicted by the two conservative calculations is essentially in agreement, while the nonconservative result predicts a weaker shock displaced forward of the conservative location. We note that the differences in shock jump values observed above between the two conservative calculations is not due to an accuracy problem in the above computations but is attributable to the difference in pressure jump between the isentropic approximation to the Rankine-Hugoniot relations, which is the jump condition satisfied in the fully conservative time-dependent calculation, and the small-disturbance approximation to the R-H conditions, which is the corresponding shock jump condition satisfied when using the conservative (FCR) option in this program.

Comparisons between the fully conservative (FCR) and not fully conservative (NCR) small-disturbance solutions predicted by the present finite-difference scheme are of interest in order to assess the differences between such calculations. Such results have been discussed previously in reference 19, and figures 4-14 and 4-15 summarize the essential conclusions of that study and provide a further comparison with a more exact result. Figure 4-14 compares the FCR and NCR solutions for the similarity surface pressure distributions for a subsonic free-stream supercritical flow as the finite-difference grid is refined. We note that while the FCR solution approaches the theoretical, small-disturbance shock jump, the NCR solution does not. Figure 4-15 shows the corresponding result for a supersonic free stream and a detached bow wave, and also includes the result of a conservative time-dependent calculation for the exact isentropic equations (ref. 28). While the FCR and the time-dependent method produce essentially the same result, the NCR method yields too great a detachment distance. Furthermore, it was found (ref. 19) that the NCR method predicts shock jumps which are considerably in error for strong oblique shocks, although the results for normal and weak oblique shocks remain reasonable. We note, as pointed out previously (refs. 1 and 21), in many cases of $M_\infty < 1$ transonic flows, the NCR predicted surface pressure distributions are usually in better agreement with experimental data than the FCR results, due to boundary-layer weakening of the shock wave. Unfortunately, this agreement is clearly fortuitous, and because the NCR method does not yield a unique solution nor account for viscous effects in any rational manner, it is not recommended for general use.

In the absence of shock wave-boundary layer separation, it has been suggested (refs. 19 and 29) that the principal viscous effect to account for is the reduction in circulation from the inviscid value determined by the Kutta condition. This effect is illustrated in figure 4-16 where the data from reference 15 is compared with the two FCR small-disturbance solutions found by: (a) specifying the Kutta condition and (b) fixing the circulation at the value determined by the experimental lift. Considerably better agreement with data results in the latter case except, of course, for points near the trailing edge.

Finally, some indication of the effects of wind-tunnel interference at transonic speeds is given in figures 4-17 and 4-18. Figure 4-17 shows the FCR solutions for an NACA 0012 airfoil at $\alpha = 0^o$ in free air and for an ideal slotted wall compared to the data taken in the RAE slotted wind tunnel (ref. 30). A forward movement of the shock due to tunnel interference is indicated. This effect is again shown by the results presented in figure 4-18, where data taken from the NASA/Ames Research Center 2- by 2-Foot Wind Tunnel (ref. 1) is compared with the FCR solutions for free air, an ideal slotted tunnel, and an ideal slotted tunnel with the lift fixed at the experimental value. In this example, the effects of wind-tunnel interference on lift and shock position are of the same magnitude as the viscous effects as evident by their respective changes from the free air to the slotted tunnel Kutta condition result (interference effect), and from the slotted tunnel Kutta condition result to the slotted tunnel fixed C_L result (viscous effect).

4.6 Program Run Times

The development of the structure of the present code as well as the actual debugging process have been carried out on a Control Data Corporation 7600 computer. Therefore, the majority of run time information and experience is for that machine. However, the most crucial time information required by the general user is simply the CPU time required for one iteration sweep of the flow field on a typical fine grid, since this will provide directly an estimate of the maximum run time required for a particular case. The resolution of the default free air grid (77×56) and default tunnel grid (77×48) used in the program is generally sufficient for most engineering applications, so that the time per iteration sweep on these grids should provide a fairly general and useful result. We have determined that the sweep time per iteration on these grids using the FTN, OPT = 2 compiler on the CDC 7600 is approximately 0.04 sec/sweep. Since the medium and coarse meshes contain approximately one-fourth and one-sixteenth as many points, the approximate maximum CPU execution time per case when employing the grid refinement option is

$$\begin{aligned}\text{Maximum CPU Execution Time} &\doteq \text{MAXIT}\cdot(1 + 1/4 + 1/16)\cdot(0.04)\,\text{sec}\\ \text{(CDC 7600; FTN, OPT = 2)} & \\ &\doteq 0.0525\cdot\text{MAXIT sec}\end{aligned}$$

The analogous result for the CDC 6600 is

$$\begin{aligned}\text{Maximum CPU Execution Time} &\doteq 0.310\ \text{MAXIT sec}\\ \text{(CDC 6600; FTN, OPT = 2)} &\end{aligned}$$

We note that on the analytical mesh (81×64), the corresponding CDC 7600 time is approximately 0.055 sec/sweep.

With regard to improving run times, numerical experimentation has shown that by using the mesh refinement option execution times can be reduced by 30 percent to 60 percent in most cases, in comparison to the same calculation started and carried to completion on the fine grid alone. In addition, it was found that a number of cases which diverged when started on the fine mesh, converged smoothly on the final mesh when the mesh refinement option was used. Consequently, the additional programming required for this option appears well worthwhile in terms of enhanced stability and computational time. Finally, we note that a number of proven convergence acceleration techniques, such as the extrapolation methods used by Hafez and Cheng (ref. 31) have not yet been incorporated into the present version of the code. Future use of these improvements, as well as others currently under development--such as direct or semidirect solvers (refs. 32 and 33) and shock fitting (ref. 34)--can undoubtedly augment the methods used in the current program.

4.7 Machine Compatability

The present code has been written in FORTRAN and primarily tested out on a Control Data Corporation 7600 using the FTN, OPT = 2 compiler. Care has been taken in the programming to insure that the code can be easily adapted for use on other machines. All header output statements are written in the universal Hollerith format. Double precision arithmetic is not used. Storage requirements have been reduced as much as possible by the liberal use of common blocks to pass information internally. The code has been successfully check tested on a CDC 6600 and required no changes.

	k	n	m
Cole	0	0	0
Spreiter	2	2/3	2/3
Krupp	7/4	3/4	1/2

Table 4-I.- Exponents for transonic similarity parameters.

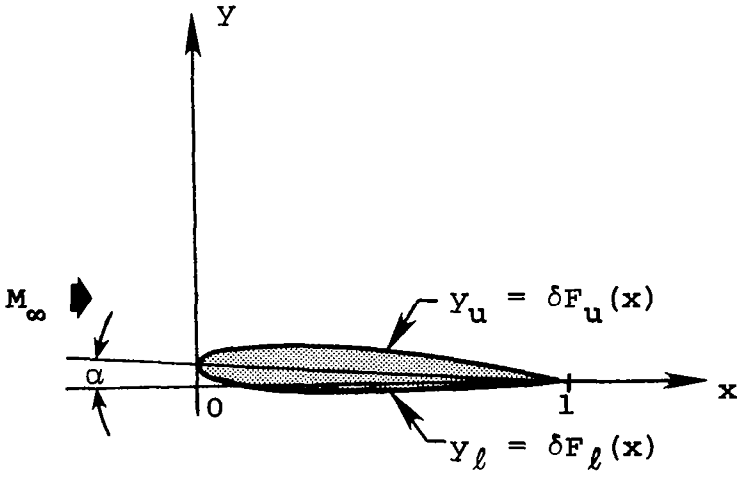
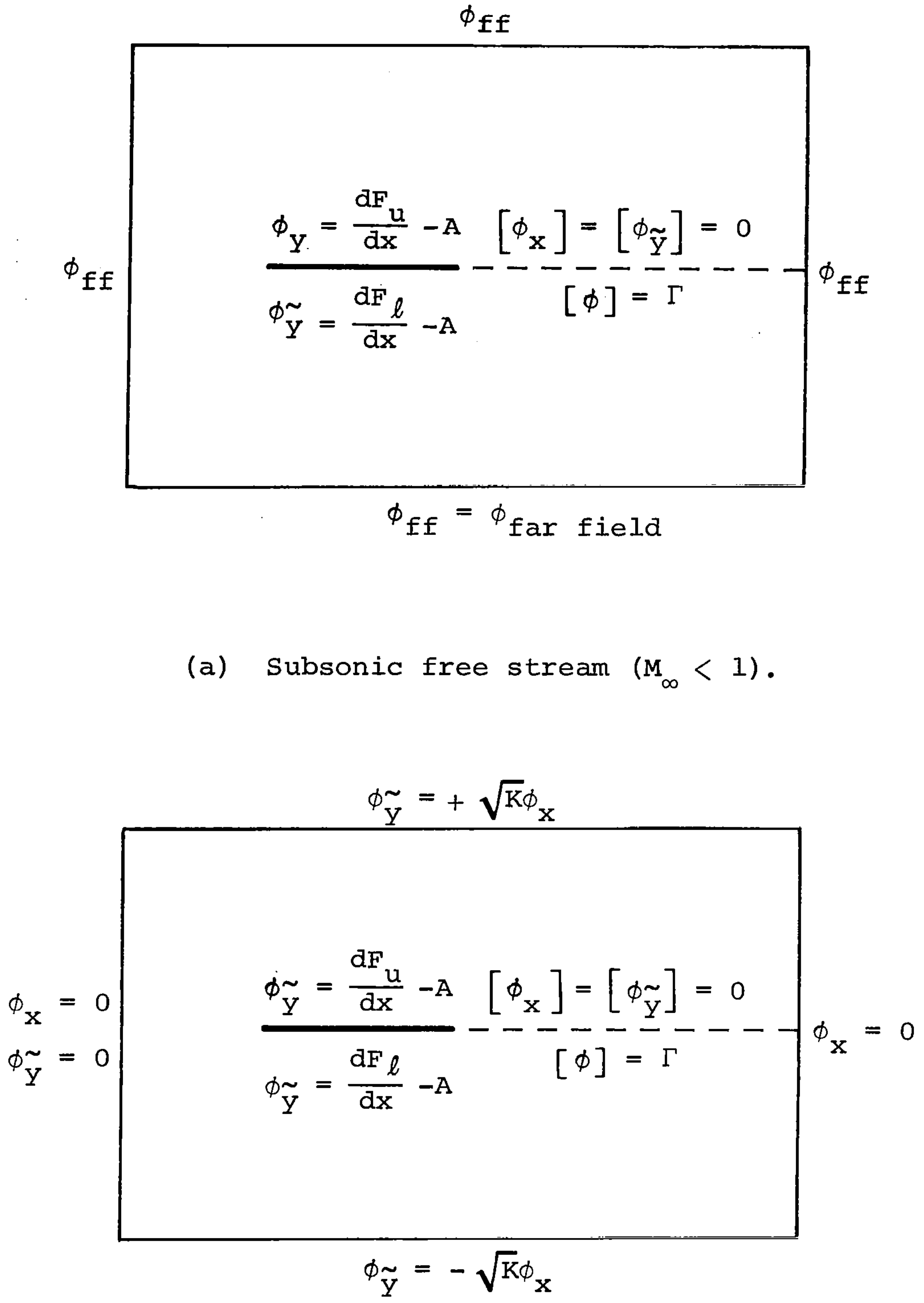


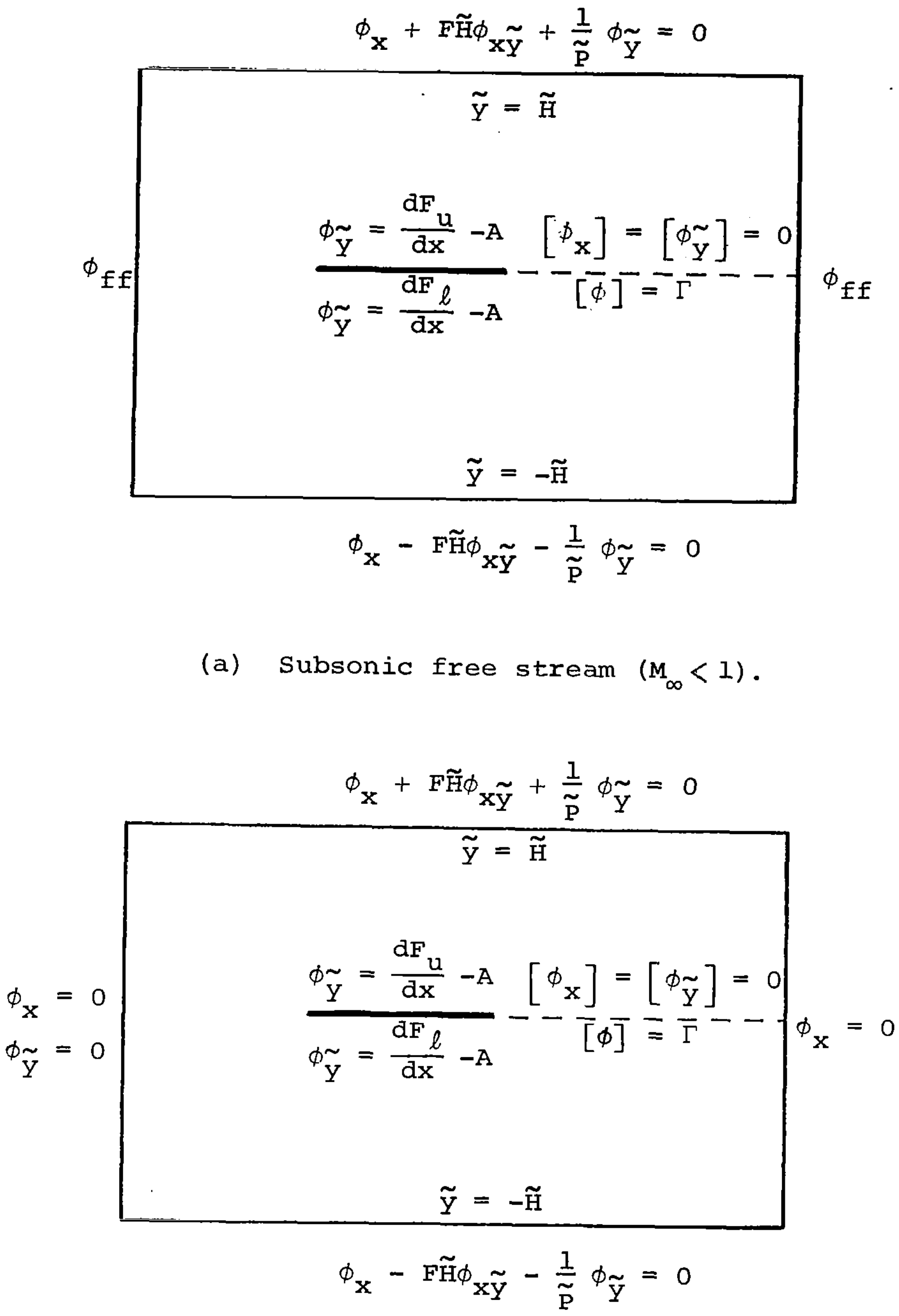
Figure 4-1.- Coordinate system and airfoil geometry.


ϕ_{ff}
ϕ_{ff}
$\phi_y = \frac{dF_u}{dx} - A$
$[\phi_x] = [\phi_{\tilde{y}}] = 0$
ϕ_{ff}
$\phi_{\tilde{y}} = \frac{dF_\ell}{dx} - A$
$[\phi] = \Gamma$
$\phi_{ff} = \phi_{far\ field}$
$\phi_{\tilde{y}} = + \sqrt{K}\phi_x$
$\phi_x = 0$
$\phi_{\tilde{y}} = 0$
$\phi_{\tilde{y}} = \frac{dF_u}{dx} - A$
$[\phi_x] = [\phi_{\tilde{y}}] = 0$
$\phi_x = 0$
$\phi_{\tilde{y}} = \frac{dF_\ell}{dx} - A$
$[\phi] = \Gamma$
$\phi_{\tilde{y}} = - \sqrt{K}\phi_x$

(a) Subsonic free stream ($M_\infty < 1$).

(b) Supersonic free stream ($M_\infty > 1$).

Figure 4-2.- Summary of boundary conditions for free air flows.



$\phi_x + F\tilde{H}\phi_{x\tilde{y}} + \frac{1}{\tilde{P}}\phi_{\tilde{y}} = 0$
$\tilde{y} = \tilde{H}$
$\phi_{\tilde{y}} = \frac{dF_u}{dx} - A$
$[\phi_x] = [\phi_{\tilde{y}}] = 0$
ϕ_{ff}
$[\phi] = \Gamma$
ϕ_{ff}
$\phi_{\tilde{y}} = \frac{dF_\ell}{dx} - A$
$\tilde{y} = -\tilde{H}$
$\phi_x - F\tilde{H}\phi_{x\tilde{y}} - \frac{1}{\tilde{P}}\phi_{\tilde{y}} = 0$
$\phi_x + F\tilde{H}\phi_{x\tilde{y}} + \frac{1}{\tilde{P}}\phi_{\tilde{y}} = 0$
$\tilde{y} = \tilde{H}$
$\phi_{\tilde{y}} = \frac{dF_u}{dx} - A$
$[\phi_x] = [\phi_{\tilde{y}}] = 0$
$\phi_x = 0$
$\phi_{\tilde{y}} = 0$
$[\phi] = \Gamma$
$\phi_x = 0$
$\phi_{\tilde{y}} = \frac{dF_\ell}{dx} - A$
$\tilde{y} = -\tilde{H}$
$\phi_x - F\tilde{H}\phi_{x\tilde{y}} - \frac{1}{\tilde{P}}\phi_{\tilde{y}} = 0$

(a) Subsonic free stream ($M_\infty < 1$).

(b) Supersonic free stream ($M_\infty > 1$).

Figure 4-3.- Summary of boundary conditions for wind-tunnel simulations.

```
SAMPLE CASE 1 - PROGRAM DEFAULT OPTION - KORN AIRFOIL
$INP
$END
```

(a) Input.

```
                 SAMPLE CASE 1 - PROGRAM DEFAULT OPTION - KORN AIRFOIL


                                            INPUT PARAMETERS
                                            ****************

 EMACH =   .75000        POR =  0.00000        IMIN =    1     BCTYPE =  1          AMESH = F

 DELTA =   .11500      CLSET =  0.00000       IMAXI =   77     BCFOIL =  3           PHYS = T

 ALPHA =   .12000        EPS =   .20000        JMIN =    1     PSTART =  1          PSAVE = F

    AK =  0.00000       RIGF =  0.00000       JMAXI =   56     PRTFLO =  1          KUTTA = T

   GAM =  1.40000      WCIRC =  1.00000       MAXIT =  500     IPRTER = 10            FCR = T

     F =  0.00000     CVERGE =   .00001          NU =  100     SIMDEF =  3

     H =  0.00000     DVERGE =     10.0          NL =   75       ICUT =  2

   WE = 1.80,1.90,1.95

  XIN
-1.075000     -.950000     -.825000     -.700000     -.575000     -.450000     -.350000     -.250000
 -.175000     -.125000     -.075000     -.052500     -.035000     -.022500     -.015000     -.007500
 -.002500      .002500      .007500      .012500      .017500      .022500      .027500      .032500
  .037500      .045000      .055000      .065000      .075000      .085000      .097500      .115000
  .140625      .171875      .203125      .234375      .265625      .296875      .328125      .359375
  .390625      .421875      .453125      .484375      .515625      .546875      .578125      .609375
  .640625      .671875      .703125      .734375      .765625      .796875      .828125      .859375
  .885000      .900000      .915000      .930000      .945000      .960000      .975000      .990000
 1.000000     1.010000     1.025000     1.050000     1.090000     1.150000     1.225000     1.300000
 1.400000     1.500000     1.625000     1.750000     1.875000

  YIN
-5.200000    -4.400000    -3.600000    -3.000000    -2.400000    -1.950000    -1.600000    -1.350000
-1.150000     -.950000     -.800000     -.650000     -.550000     -.450000     -.390000     -.340000
 -.300000     -.270000     -.240000     -.210000     -.180000     -.150000     -.125000     -.100000
 -.075000     -.050000     -.030000     -.010000      .010000      .030000      .050000      .075000
  .100000      .125000      .150000      .180000      .210000      .240000      .270000      .300000
  .340000      .390000      .450000      .550000      .650000      .800000      .950000     1.150000
 1.350000     1.600000     1.950000     2.400000     3.000000     3.600000     4.400000     5.200000

   XU
  .000008      .000167      .000391      .000799      .001427      .002153      .003331      .005336
  .008648      .014583      .023481      .033891      .040887      .053973      .056921      .058456
  .059966      .061445      .062909      .065925      .068785      .071482      .074007      .075322
  .076603      .077862      .079112      .080445      .081819      .083269      .084841      .086702
  .088848      .091378      .094413      .098308      .103104      .109010      .116244      .125452
  .136635      .150037      .165853      .184599      .195177      .206361      .218244      .230813
  .244047      .257917      .272371      .287410      .302990      .319057      .335555      .352421
  .369591      .386995      .404133      .421391      .438708      .456013      .473246      .490343
  .507242      .523881      .539536      .554867      .569823      .584351      .598405      .611936
  .624904      .637273      .648435      .659016      .668987      .678321      .687012      .695090
  .706936      .728406      .738649      .761390      .777010      .792241      .809068      .824992
  .836953      .857188      .875621      .898268      .913686      .927686      .939604      .952002
  .971789      .989100      .997860     1.000000

  -YU
  .000787      .003092      .004538      .006137      .007683      .009056      .010675      .012803
  .015607      .019624      .024441      .029035      .031698      .035966      .036837      .037277
  .037700      .038103      .038497      .039276      .039986      .040625      .041195      .041483
  .041756      .042019      .042274      .042539      .042804      .043079      .043368      .043700
  .044072      .044497      .044989      .045595      .046312      .047154      .048132      .049301
  .050626      .052089      .053663      .055351      .056210      .057068      .057918      .058751
  .059559      .060335      .061268      .061751      .062381      .062947      .063445      .063867
  .064213      .064473      .064646      .064733      .064735      .064651      .064477      .064218
  .063871      .063438      .062945      .062376      .061731      .061014      .060232      .059389
  .058496      .057562      .056650      .055721      .054791      .053867      .052965      .052086
  .050722      .048045      .046680      .043441      .041053      .038606      .035768      .032958
  .030775      .026954      .023361      .018848      .015750      .012954      .010567      .008213
  .004559      .001620      .000293     0.000000
```

Figure 4-4.- Sample test case 1 - program default option - subsonic, free air simulation (full output): Korn airfoil, $\delta_T = 0.115$, $\alpha = 0.15^{\circ}$, $M_{\infty} = 0.75$.

```
 XL
0.000000      .000012      .000043      .000183      .000249      .000348      .000455      .000680
 .001011      .001481      .001875      .002316      .003355      .004201      .004747      .005779
 .007035      .008265      .009969      .012286      .015346      .019276      .025335      .029379
 .039095      .052516      .062469      .073329      .085290      .099822      .118563      .140987
 .167184      .202933      .228511      .247895      .263995      .282047      .297145      .310147
 .324075      .344872      .363502      .387544      .404492      .426308      .450016      .475378
 .521837      .549843      .578612      .605305      .623479      .642152      .657543      .671212
 .690340      .708891      .726684      .746683      .768502      .784892      .801149      .819187
 .838548      .858817      .879431      .903723      .926504      .943652      .955063      .973623
 .986187      .996582     1.000000

 YL
0.000000     -.000700     -.001385     -.002368     -.003330     -.003880     -.004379     -.005199
-.006133     -.007183     -.007933     -.008675     -.009776     -.011204     -.011815     -.012861
-.013983     -.014962     -.016175     -.017636     -.019336     -.021258     -.023836     -.025373
-.028634     -.032423     -.034840     -.037182     -.039456     -.041862     -.044483     -.047017
-.049298     -.051443     -.052406     -.052859     -.053062     -.053117     -.053027     -.052849
-.052562     -.051951     -.051218     -.050013     -.049004     -.047495     -.045601     -.043288
-.038336     -.034916     -.031104     -.027333     -.024661     -.021854     -.019517     -.017429
-.014527     -.011771     -.009228     -.006537     -.003868     -.002086     -.000524      .000954
 .002227      .003224      .003885      .004212      .004067      .003657      .003367      .002242
 .001329      .000376     0.000000
```

```
                                        AIRFOIL GEOMETRY OUTPUT
                                        ***********************

PRINTOUT IN PHYSICAL VARIABLES NORMALIZED BY CHORD LENGTH                       MAX THICKNESS =    .11569133
AIRFOIL VOLUME=    .07556017                                                    MAX CAMBER    =    .01954359

 INPUT  GRID          UPPER  SURFACE                   LOWER  SURFACE
     X                 Y          DY/DX                 Y          DY/DX         THICKNESS      CAMBER

  .00250000        .00959171  1.45523110       -.00896517 -1.54389047       .00927844    .00031327
  .00750000        .01470383   .81287528       -.01436528  -.80527524       .01453455    .00016928
  .01250000        .01831605   .65037444       -.01776238  -.58763022       .01803922    .00027684
  .01750000        .02132582   .56042563       -.02041959  -.48511465       .02087270    .00045312
  .02250000        .02395903   .49640664       -.02267782  -.42226950       .02331842    .00064060
  .02750000        .02631987   .44956493       -.02467419  -.37876154       .02549703    .00082284
  .03250000        .02846898   .41150450       -.02648065  -.34495810       .02747482    .00099416
  .03750000        .03044665   .37995980       -.02813392  -.31735008       .02929028    .00115636
  .04500000        .03312592   .33599923       -.03038772  -.28473871       .03175682    .00136910
  .05500000        .03627290   .29719151       -.03305353  -.24997457       .03466322    .00160968
  .06500000        .03904111   .25543566       -.03541151  -.22262497       .03722631    .00181480
  .07500000        .04141318   .21765425       -.03751779  -.19909957       .03946548    .00194769
  .08500000        .04339674   .18054845       -.03940423  -.17678220       .04140049    .00199626
  .09750000        .04547125   .15371664       -.04150110  -.15725685       .04348617    .00198507
  .11500000        .04796777   .13267017       -.04402275  -.13157240       .04599526    .00197251
  .14062500        .05107517   .11107138       -.04698067  -.10553417       .04902792    .00204725
  .17187500        .05422336   .09136735       -.04963896  -.07564901       .05193116    .00229220
  .20312500        .05682572   .07560296       -.05145188  -.04617982       .05413880    .00268692
  .23437500        .05897522   .06223596       -.05256752  -.02573214       .05577137    .00320385
  .26562500        .06073549   .05053493       -.05307432  -.00710822       .05690491    .00383059
  .29687500        .06214320   .03990810       -.05302871   .00999124       .05758595    .00455724
  .32812500        .06323120   .02494726       -.05246013   .02617109       .05784566    .00538553
  .35937500        .06401751   .02066257       -.05139534   .04194706       .05770642    .00631109
  .39062500        .06451653   .01150033       -.04984448   .05725378       .05718051    .00733602
  .42187500        .06473420   .00241416       -.04781989   .07224686       .05627705    .00845715
  .45312500        .06467130  -.00658035       -.04533308   .08089782       .05500219    .00966911
  .48437500        .06431853  -.01596653       -.04240041   .10055528       .05335947    .01095906
  .51562500        .06366431  -.02603701       -.03905118   .11380738       .05135775    .01230657
  .54687500        .06268375  -.03696603       -.03529278   .12643358       .04898827    .01369548
  .57812500        .06133234  -.04979547       -.03117083   .13715576       .04625159    .01508075
  .60937500        .05955542  -.06436061       -.02674112   .14591750       .04314827    .01640715
  .64062500        .05729524  -.08146377       -.02208495   .15119319       .03969010    .01760515
  .67187500        .05451046  -.09802562       -.01732781   .15260505       .03591913    .01859132
  .70312500        .05117016  -.11646991       -.01261849   .14780410       .03189432    .01927583
  .73437500        .04725652  -.13370925       -.00816935   .13583154       .02771293    .01954359
  .76562500        .04280623  -.15103101       -.00420143   .11693724       .02350383    .01930240
  .79687500        .03783843  -.16679849       -.00091374   .09298191       .01937609    .01846235
  .82812500        .03239200  -.18132023        .00157884   .06659416       .01540658    .01698542
  .85937500        .02653266  -.19298838        .00324655   .04018531       .01164305    .01488961
  .88500000        .02150184  -.19909863        .00400325   .01893465       .00874929    .01275254
  .90000000        .01850018  -.20087864        .00419381   .00644729       .00715319    .01134700
  .91500000        .01548642  -.20052560        .00419572  -.00623884       .00564535    .00984107
  .93000000        .01249528  -.19797396        .00400511  -.01924820       .00424508    .00825019
  .94500000        .00955711  -.19341345        .00361309  -.03322763       .00297201    .00658510
  .96000000        .00670666  -.18610192        .00300379  -.04814189       .00185143    .00485522
  .97500000        .00399207  -.17519895        .00215209  -.06622514       .00092000    .00307208
  .99000000        .00147612  -.15923679        .00100946  -.08737525       .00023333    .00124279
 1.00000000       0.00000000  -.13691589       0.00000000  -.11000585      0.00000000   0.00000000
```

Figure 4-4.- Continued.

```
                                              INTERMEDIATE OUTPUT FOR COARSE MESH

        WE =   1.8000     EPS =     .2000     MAXIT FOR THIS MESH =  125

ITERATION     CL          CM      IERR  JERR      ERROR      IRL   JRL       BIGRL        ERCIRC     ICPU     CPERRU     ICPL     CPERRL

    10      .45126     -.16416     12     7    .4684E-01      6     7    .9957E+02    .4366E-01     12    .5703E+00     16    .5936E+00
    20      .52852     -.15065      5     4    .1506E-01      6     7    .1756E+03    .7888E-02     16    .9515E-01      6    .2033E+00
    30      .56601     -.15205      5     7    .7516E-02      6     7    .9360E+02    .5803E-02      8    .1320E+00     10    .3931E-01
    40      .59563     -.15427     10     7    .4266E-02      6     7    .4973E+02    .2151E-02      9    .7349E-01      7    .2837E-01
    50      .60322     -.15424      5     7    .2120E-02      6     7    .2546E+02    .1601E-02      9    .3169E-01      7    .1275E-01
    60      .60992     -.15472     11     7    .1166E-02      6     7    .1350E+02    .7924E-03      9    .1804E-01      7    .7328E-02
    70      .61343     -.15498      5     7    .6631E-03      6     7    .7928E+01    .5202E-03      9    .9775E-02      7    .2819E-02
    80      .61554     -.15512      6     7    .3844E-03      6     7    .4595E+01    .2905E-03      9    .5994E-02      7    .1781E-02
    90      .61678     -.15520      5     7    .2250E-03      6     7    .2686E+01    .1740E-03      9    .3547E-02      7    .1018E-02
   100      .61751     -.15525      5     7    .1318E-03      6     7    .1573E+01    .1014E-03      9    .2103E-02      7    .5931E-03
   110      .61793     -.15528      5     7    .7715E-04      6     7    .9203E+00    .5952E-04      9    .1241E-02      7    .3496E-03
   120      .61818     -.15530      5     7    .4521E-04      6     7    .5391E+00    .3489E-04      9    .7299E-03      7    .2041E-03

                   ******  ITERATION LIMIT REACHED  ******




                                                    FINAL OUTPUT FOR COARSE MESH

FORCE COEFFICIENTS, PRESSURE COEFFICIENT, AND MACH NUMBER
(OR SIMILARITY PARAMETER) ON BODY AND DIVIDING STREAM LINE.
                                                                                     B = BEFORE OR BEHIND AIRFOIL
         CL =   .618266                                                              U = UPPER AIRFOIL SURFACE
         CM =  -.155303                                                              L = LOWER AIRFOIL SURFACE
        CP* =  -.603170                                                              * = CRITICAL PRESSURE

                           LOWER                       UPPER
                           Y=0-                        Y=0+
  I        X          CP          M1              CP          M1

  1   -1.075000      .003088     .748505         .003088     .748505                               B                      *
  2    -.575000      .043372     .728725         .043372     .728725                             B                        *
  3    -.175000      .129825     .684349         .129825     .684349                          B                           *
  4    -.035000      .264500     .608810         .264500     .608810                     B                                *
  5    -.002500      .360806     .548448         .360806     .548448                 B                                    *
                        AIRFOIL LEADING EDGE                                              AIRFOIL LEADING EDGE
  6     .017500      .630016     .324850         .249591     .617627       L              U                               *
  7     .037500      .337262     .563801        -.143732     .816550                  L                 U                 *
  8     .075000      .054363     .723235        -.562652     .985196                             L                      U *
  9     .140625     -.182317     .833511        -.760830    1.055631                                      L               *     U
 10     .265625     -.278642     .874419        -.738598    1.047965                                          L           *    U
 11     .390625     -.230724     .854314        -.739994    1.048448                                        L             *    U
 12     .515625     -.086058     .790520        -.766144    1.057455                                  L                   *     U
 13     .640625      .141348     .678215        -.682882    1.028503                          L                           *  U
 14     .765625      .364488     .546008        -.419234     .930906                 L                             U      *
 15     .885000      .460487     .478009        -.118344     .805195              L                    U                  *
 16     .945000      .447856     .487498         .100112     .699918              L            U                          *
 17    1.000000      .329958     .568480         .208565     .641253                   L   U                              *
                        AIRFOIL TRAILING EDGE                                             AIRFOIL TRAILING EDGE
 18    1.090000      .147296     .675027         .147296     .675027                         B                            *
 19    1.400000      .076301     .712149         .076301     .712149                            B                         *
 20    1.875000      .029479     .735607         .029479     .735607                              B                       *


               Y-GRID VALUES      Y(J) J=   1 TO  14
           -5.200000   -2.400000   -1.150000    -.550000    -.300000    -.180000    -.075000     .075000
             .180000     .300000     .550000    1.150000    2.400000    5.200000
```

Figure 4-4.- Continued.

```
                                        INTERMEDIATE OUTPUT FOR MEDIUM MESH

      WE =   1.9000     EPS =     .2000     MAXIT FOR THIS MESH =  250

ITERATION    CL          CM       IERR  JERR     ERROR      IRL   JRL      BIGRL         ERCIRC     ICPU    CPERRU     ICPL     CPERRL

   10      .61625     -.15287      26    13    .2078E-02    10    11    .5886E+02     .1202E-02    10    .1287E+01    10    .1255E+01
   20      .60949     -.15190       6    14    .6059E-03    10    14    .3003E+02     .1228E-02    19    .1435E-01    16    .1908E-01
   30      .60690     -.15213      19     8    .2952E-03    10    15    .8248E+01     .2461E-03    18    .6059E-02    12    .1703E-01
   40      .60546     -.15221      20    14    .2015E-03    10     6    .4499E+01     .1875E-03    27    .2317E-02    12    .7665E-02
   50      .60507     -.15238       9     7    .1035E-03    10    14    .3935E+01     .5786E-04    14    .2075E-02    11    .2943E-02
   60      .60464     -.15242      23    14    .5786E-04    10    14    .2842E+01     .7117E-04    14    .1198E-02    10    .5465E-03
   70      .60432     -.15242      22    14    .4948E-04    10    14    .2046E+01     .4340E-04    14    .7971E-03    10    .1173E-03
   80      .60414     -.15243      22    14    .3396E-04    10    14    .1612E+01     .2780E-04    19    .4925E-03    10    .1189E-03
   90      .60400     -.15243      22    14    .2403E-04    10    14    .1294E+01     .2180E-04    19    .3568E-03    10    .8284E-04
  100      .60390     -.15242      22    14    .1882E-04    10    14    .1007E+01     .1537E-04    19    .3038E-03    13    .4506E-04
  110      .60382     -.15242      22    14    .1397E-04    10    14    .7818E+00     .1088E-04    19    .2256E-03    12    .4564E-04
  120      .60377     -.15242      11    14    .1063E-04    10    14    .6022E+00     .8490E-05    19    .1755E-03    12    .4414E-04
  130      .60373     -.15241      10    14    .8144E-05    10    14    .4616E+00     .6354E-05    19    .1337E-03    12    .3906E-04

                          ******  SOLUTION CONVERGED  ******



                                                  FINAL OUTPUT FOR MEDIUM MESH

  FORCE COEFFICIENTS, PRESSURE COEFFICIENT, AND MACH NUMBER
  (OR SIMILARITY PARAMETER) ON BODY AND DIVIDING STREAM LINE.

          CL  =    .603729
          CM  =  -.152415
         CP*  =  -.603170

                         LOWER                            UPPER
                         Y=0-                             Y=0+
  I         X          CP          M1                CP          M1

  1    -1.075000    .021647     .739458           .021647     .739458
  2     -.825000    .033335     .733704           .033335     .733704
  3     -.575000    .051951     .724443           .051951     .724443
  4     -.350000    .092701     .703748           .092701     .703748
  5     -.175000    .177867     .658397           .177867     .658397
  6     -.075000    .315444     .577665           .315444     .577665
  7     -.035000    .458494     .479519           .458494     .479519
  8     -.015000    .567892     .388057           .567892     .388057
  9     -.002500    .654248     .296566           .654248     .296566
                      AIRFOIL LEADING EDGE
 10      .007500    .942391    0.000000           .553319     .401445
 11      .017500    .592448     .364386           .172386     .661409
 12      .027500    .381819     .534372          -.080733     .788073
 13      .037500    .205370     .643069          -.308037     .886527
 14      .055000    .038007     .731391          -.588295     .994589
 15      .075000   -.094836     .794536          -.836156    1.081200
 16      .097500   -.204465     .843093          -.907765    1.104959
 17      .140625   -.294229     .880863          -.863369    1.090290
 18      .203125   -.337801     .898621          -.812684    1.073299
 19      .265625   -.340766     .899815          -.773972    1.060136
 20      .328125   -.320584     .891645          -.750194    1.051976
 21      .390625   -.278890     .874522          -.740873    1.048752
 22      .453125   -.213683     .847049          -.746913    1.050839
 23      .515625   -.125367     .808352          -.768921    1.058437
 24      .578125   -.013389     .756447          -.797181    1.068046
 25      .640625    .120502     .689272          -.756741    1.054225
 26      .703125    .263402     .609463          -.590553     .995414
 27      .765625    .385401     .531935          -.408063     .926543
 28      .828125    .455697     .481479          -.251294     .863002
 29      .885000    .476548     .465664          -.091152     .792853
 30      .915000    .473480     .468047           .032375     .734178
 31      .945000    .459460     .478787           .132021     .683184
 32      .975000    .426120     .503409           .223371     .632836
 33     1.000000    .345090     .558744           .282392     .598056
                      AIRFOIL TRAILING EDGE
 34     1.025000    .229962     .629047           .229962     .629047
 35     1.090000    .165655     .665090           .165655     .665090
 36     1.225000    .110601     .694462           .110601     .694462
 37     1.400000    .075623     .712494           .075623     .712494
 38     1.625000    .055038     .722896           .055038     .722896
 39     1.875000    .040203     .730301           .040203     .730301


         Y-GRID VALUES      Y(J) J=   1 TO  28
     -5.200000    -3.600000    -2.400000    -1.600000    -1.150000     -.800000     -.550000     -.390000
      -.300000     -.240000     -.180000     -.125000     -.075000     -.030000      .030000      .075000
       .125000      .180000      .240000      .300000      .390000      .550000      .800000     1.150000
      1.600000     2.400000     3.600000     5.200000
```

B = BEFORE OR BEHIND AIRFOIL
U = UPPER AIRFOIL SURFACE
L = LOWER AIRFOIL SURFACE
* = CRITICAL PRESSURE

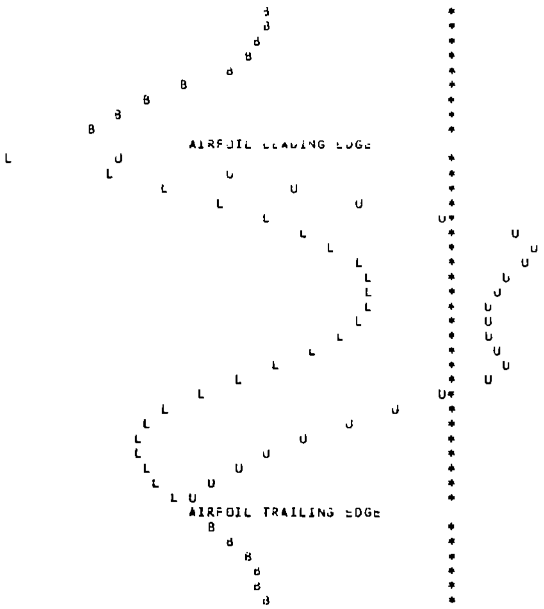


Figure 4-4.- Continued.

```
                                        INTERMEDIATE OUTPUT FOR FINE MESH

         WE =   1.9500      EPS =     .2000      MAXIT FOR THIS MESH =  500

ITERATION     CL           CM       IERR  JERR      ERROR      IRL    JRL      BIGRL          ERCIRC      ICPU      CPERRU      ICPL      CPERRL

   10       .60707     -.15260       9    29     .2196E-02    17     28     .3073E+03      .2779E-03     18     .1740E+01     19     .1765E+01
   20       .60871     -.15277      16    21     .8121E-03    17     28     .1820E+03      .2453E-03     38     .3434E-01     21     .2276E-01
   30       .61016     -.15295      16    31     .4264E-03    17     28     .1302E+03      .2539E-03     42     .2680E-01     20     .1020E-01
   40       .61131     -.15288      37    28     .3469E-03    17     28     .1029E+03      .1811E-03     40     .2136E-01     24     .6068E-02
   50       .61210     -.15264      16    31     .2650E-03    17     28     .8335E+02      .1167E-03     41     .1387E-01     21     .4292E-02
   60       .61290     -.15290      18    29     .2146E-03    17     28     .7003E+02      .1274E-03     41     .1083E-01     25     .2479E-02
   70       .61355     -.15288      18    29     .1854E-03    17     28     .5968E+02      .1127E-03     41     .8645E-02     24     .1864E-02
   80       .61424     -.15294      18    29     .1566E-03    17     28     .5098E+02      .1145E-03     41     .7518E-02     24     .1485E-02
   90       .61480     -.15293      18    29     .1345E-03    17     28     .4363E+02      .8570E-04     42     .6988E-02     24     .1265E-02
  100       .61527     -.15293      18    29     .1160E-03    17     28     .3769E+02      .7737E-04     42     .6363E-02     24     .1060E-02
  110       .61568     -.15294      19    29     .1002E-03    17     28     .3246E+02      .6443E-04     42     .5177E-02     24     .8056E-03
  120       .61601     -.15293      18    29     .8708E-04    17     28     .2829E+02      .5434E-04     42     .4272E-02     24     .7529E-03
  130       .61631     -.15294      18    29     .7521E-04    17     28     .2448E+02      .4896E-04     42     .3698E-02     24     .5851E-03
  140       .61658     -.15294      18    29     .6548E-04    17     28     .2131E+02      .4467E-04     42     .3284E-02     24     .5467E-03
  150       .61682     -.15294      18    29     .5689E-04    17     28     .1850E+02      .3881E-04     42     .2916E-02     24     .4719E-03
  160       .61703     -.15295      18    29     .4939E-04    17     28     .1606E+02      .3344E-04     42     .2509E-02     24     .3959E-03
  170       .61721     -.15295      18    29     .4298E-04    17     28     .1398E+02      .2903E-04     42     .2152E-02     24     .3431E-03
  180       .61736     -.15295      18    29     .3742E-04    17     28     .1218E+02      .2523E-04     42     .1851E-02     24     .2944E-03
  190       .61750     -.15295      18    29     .3261E-04    17     28     .1062E+02      .2218E-04     42     .1593E-02     24     .2502E-03
  200       .61762     -.15295      18    29     .2842E-04    17     28     .9258E+01      .1955E-04     42     .1337E-02     24     .2188E-03
  210       .61773     -.15295      18    29     .2478E-04    17     28     .8072E+01      .1714E-04     42     .1213E-02     24     .1897E-03
  220       .61782     -.15295      18    29     .2161E-04    17     28     .7040E+01      .1495E-04     42     .1058E-02     24     .1645E-03
  230       .61790     -.15295      18    29     .1885E-04    17     28     .6142E+01      .1302E-04     42     .92[illegible]E-03    24     .1429E-03
  240       .61797     -.15295      18    29     .1645E-04    17     28     .5359E+01      .1135E-04     42     .7977E-03     24     .1241E-03
  250       .61803     -.15295      18    29     .1435E-04    17     28     .4677E+01      .9918E-05     42     .6926E-03     24     .1061E-03
  260       .61808     -.15295      18    29     .1253E-04    17     28     .4082E+01      .8674E-05     42     .6129E-03     24     .9429E-04
  270       .61813     -.15295      18    29     .1093E-04    17     28     .3562E+01      .7578E-05     42     .5259E-03     24     .8231E-04
  280       .61817     -.15295      18    29     .9538E-05    17     28     .3109E+01      .6611E-05     42     .4562E-03     24     .7188E-04

                   ******  SOLUTION CONVERGED  ******




                                                            ******************
                                                            *                *
                                                            *  FINAL OUTPUT  *
                                                            *                *
                                                            ******************

   PRINTOUT IN  PHYSICAL  VARIABLES.

   DEFINITION OF SIMILARITY PARAMETERS BY KRUPP

   BOUNDARY CONDITION FOR FREE AIR

   DIFFERENCE EQUATIONS ARE FULLY CONSERVATIVE.

   KUTTA CONDITION IS ENFORCED.

                 MACH =     .7500000
                DELTA =     .1150000
                ALPHA =     .1200000
                    K =    2.4667108
     DOUBLET STRENGTH =     .0755602
       AIRFOIL VOLUME =     .0755602

         PARAMETERS USED TO TRANSFORM VARIABLES
                    TO TRANSONIC SCALING

               CPFACT =     .2934287
               CDFACT =     .0337443
               CMFACT =     .2934287
               CLFACT =     .2934287
                YFACT =    2.3744886
                VFACT =    6.5890146
```

Figure 4-4.- Continued.

```
                                                    FINAL OUTPUT FOR FINE MESH

FORCE COEFFICIENTS, PRESSURE COEFFICIENT, AND MACH NUMBER
(OR SIMILARITY PARAMETER) ON BODY AND DIVIDING STREAM LINE.
                                                                                    B = BEFORE OR BEHIND AIRFOIL
        CL =   .618170                                                              U = UPPER AIRFOIL SURFACE
        CM =  -.152947                                                              L = LOWER AIRFOIL SURFACE
       CP* =  -.603170                                                              * = CRITICAL PRESSURE

                          LOWER                       UPPER
                           Y=0-                        Y=0+
 I         X         CP          M1              CP          M1

  1   -1.075000     .034032     .733359         .034032     .733359                              B            *
  2    -.950000     .038228     .731281         .038228     .731281                              B            *
  3    -.825000     .043603     .728611         .043603     .728611                              B            *
  4    -.700000     .051881     .724478         .051881     .724478                              B            *
  5    -.575000     .064692     .718036         .064692     .718036                              B            *
  6    -.450000     .084149     .708141         .084149     .708141                             B             *
  7    -.350000     .112631     .693401         .112631     .693401                             B             *
  8    -.250000     .156104     .670278         .156104     .670278                            B              *
  9    -.175000     .217044     .636452         .217044     .636452                           B               *
 10    -.125000     .297629     .588744         .297629     .588744                         B                 *
 11    -.075000     .410957     .514216         .410957     .514216                       B                   *
 12    -.052500     .536533     .416334         .536533     .416334                    B                      *
 13    -.035000     .662740     .285993         .662740     .285993                 B                         *
 14    -.022500     .794714    0.000000         .794714    0.000000               B                           *
 15    -.015000     .918801    0.000000         .918801    0.000000            B                              *
 16    -.007500    1.041777    0.000000        1.041777    0.000000          B                                *
 17    -.002500    1.163438    0.000000        1.163438    0.000000       B                                   *
                       AIRFOIL LEADING EDGE                                             AIRFOIL LEADING EDGE
 18     .002500    1.407124    0.000000         .929811    0.000000  L         U                              *
 19     .007500     .840589    0.000000         .364417     .546055              L        U                   *
 20     .012500     .545950     .408049         .069857     .715423                    L         U            *
 21     .017500     .358899     .549707        -.133933     .812186                        L         U        *
 22     .022500     .229092     .629549        -.282545     .876036                          L          U     *
 23     .027500     .134081     .682090        -.393786     .920939                            L          U   *
 24     .032500     .061736     .719528        -.480822     .954598                              L          U *
 25     .037500    -.001223     .755591        -.567411     .986946                               L           *
 26     .045000    -.065930     .781231        -.646691    1.015661                                L          *U
 27     .055000    -.126525     .808871        -.741993    1.049139                                  L        *  U
 28     .065000    -.175851     .830693        -.849193    1.085564                                   L       *     U
 29     .075000    -.215274     .847730        -.938402    1.114969                                   L       *      U
 30     .085000    -.248385     .861778       -1.005396    1.136551                                    L      *        U
 31     .097500    -.281083     .875431       -1.023934    1.142451                                     L     *        U
 32     .115000    -.315831     .889710       -1.008197    1.137445                                      L    *        U
 33     .140625    -.346290     .902045        -.979322    1.128201                                      L    *       U
 34     .171875    -.364996     .909530        -.949933    1.118713                                       L   *       U
 35     .203125    -.371650     .912179        -.923959    1.110261                                       L   *      U
 36     .234375    -.371149     .911985        -.900749    1.102653                                       L   *      U
 37     .265625    -.365818     .909857        -.879032    1.095487                                       L   *     U
 38     .296875    -.355271     .905644        -.859039    1.088532                                      L    *     U
 39     .328125    -.340392     .899666        -.836023    1.081155                                      L    *    U
 40     .359375    -.320565     .891637        -.811060    1.072749                                      L    *    U
 41     .390625    -.295284     .881294        -.781224    1.062614                                     L     *   U
 42     .421875    -.264496     .868532        -.743156    1.049541                                    L      *  U
 43     .453125    -.227512     .852949        -.701266    1.034965                                    L      * U
 44     .484375    -.185257     .834790        -.682262    1.028284                                   L       * U
 45     .515625    -.138117     .814052        -.700964    1.034859                                  L        * U
 46     .546875    -.084282     .789704        -.740014    1.048455                                 L         *  U
 47     .578125    -.023989     .761512        -.782223    1.062955                               L           *   U
 48     .609375     .042142     .729337        -.828561    1.075282                              L            *    U
 49     .640625     .113148     .693130        -.836969    1.081472                             L             *    U
 50     .671875     .187714     .652951        -.775380    1.058947                           L               *   U
 51     .703125     .263107     .609639        -.591990     .995937                          L                *
 52     .734375     .333402     .566279        -.467771     .949627                        L                U *
 53     .765625     .392678     .526951        -.417877     .930377                       L                U  *
 54     .796875     .436745     .495695        -.342758     .900619                      L               U    *
 55     .828125     .464615     .474867        -.257138     .865454                     L              U      *
 56     .859375     .478299     .464299        -.166233     .826483                     L            U        *
 57     .885000     .482335     .461135        -.086461     .793704                     L           U         *
 58     .900000     .481972     .461421        -.026327     .762624                     L          U          *
 59     .915000     .479614     .463270         .025433     .737599                     L        U            *
 60     .930000     .475295     .466639         .076993     .711797                     L       U             *
 61     .945000     .468316     .472032         .128491     .685055                     L      U              *
 62     .960000     .457556     .480228         .180440     .656978                      L    U               *
 63     .975000     .438907     .494111         .232955     .627320                      L   U                *
 64     .990000     .407640     .516972         .282117     .598223                       L U                 *
 65    1.000000     .353399     .553324         .314941     .577981                        LU                 *
                       AIRFOIL TRAILING EDGE                                            AIRFOIL TRAILING EDGE
 66    1.010000     .285580     .596120         .285580     .596120                         B                 *
 67    1.025000     .248178     .618456         .248178     .618456                          B                *
 68    1.050000     .209303     .640847         .209303     .640847                           B               *
 69    1.090000     .170951     .662196         .170951     .662196                           B               *
 70    1.150000     .136726     .680682         .136726     .680682                            B              *
 71    1.225000     .110219     .694661         .110219     .694661                             B             *
 72    1.300000     .090361     .704952         .090361     .704952                             B             *
 73    1.400000     .074751     .712938         .074751     .712938                             B             *
 74    1.500000     .062705     .719039         .062705     .719039                              B            *
 75    1.625000     .053453     .723691         .053453     .723691                              B            *
 76    1.750000     .046830     .727002         .046830     .727002                              B            *
 77    1.875000     .041477     .729668         .041477     .729668                              B            *
```

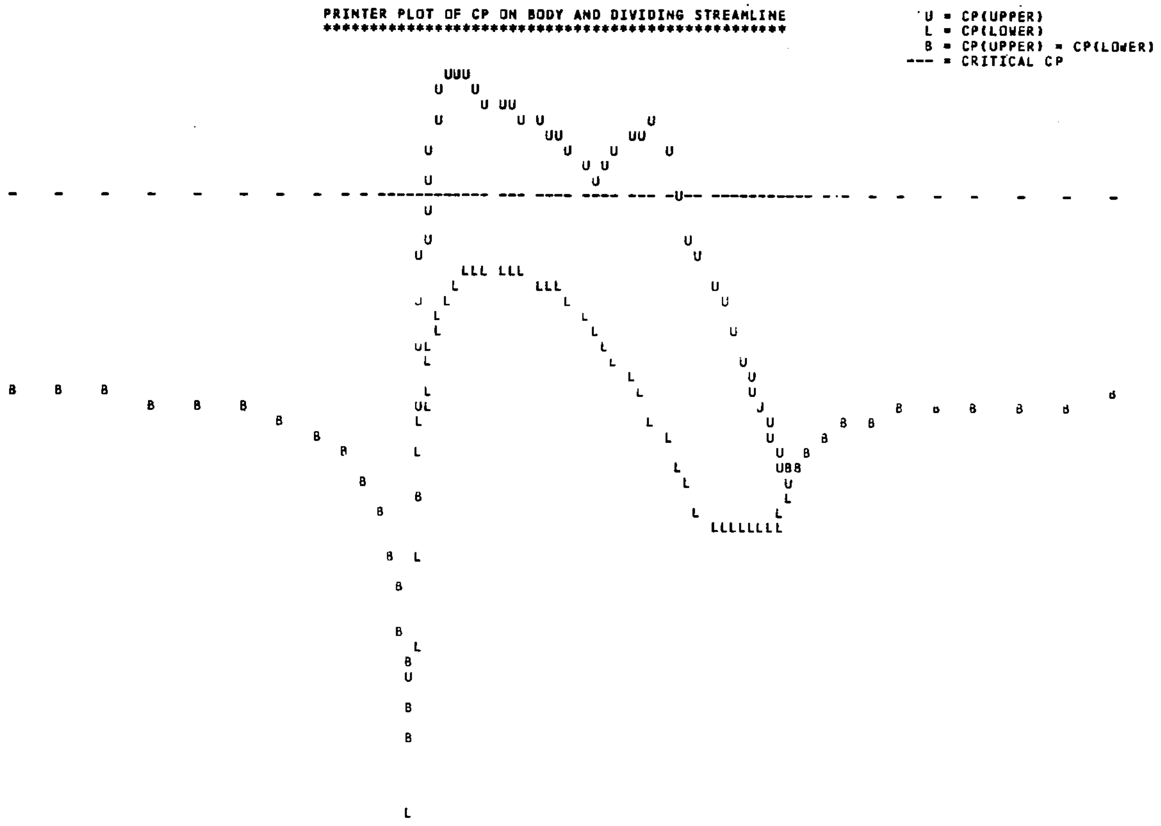
Figure 4-4.- Continued.

```
  Y-GRID VALUES      Y(J) J=    1 TO   56
-5.200000   -4.400000   -3.600000   -3.000000   -2.400000   -1.950000   -1.600000   -1.350000
-1.150000    -.950000    -.800000    -.650000    -.550000    -.450000    -.390000    -.340000
 -.300000    -.270000    -.240000    -.210000    -.180000    -.150000    -.125000    -.100000
 -.075000    -.050000    -.030000    -.010000     .010000     .030000     .050000     .075000
  .100000     .125000     .150000     .180000     .210000     .240000     .270000     .300000
  .340000     .390000     .450000     .550000     .650000     .800000     .950000    1.150000
 1.350000    1.600000    1.950000    2.400000    3.000000    3.600000    4.450000    5.200000



                                        FLOW CHARACTER MAP
                                        ******************

                P = PARABOLIC
                H = HYPERBOLIC
                S = SHOCK
                - = ELLIPTIC

56      ---------------------------------------------------------------------------
55      ---------------------------------------------------------------------------
54      ---------------------------------------------------------------------------
53      ---------------------------------------------------------------------------
52      ---------------------------------------------------------------------------
51      ---------------------------------------------------------------------------
50      ---------------------------------------------------------------------------
49      ---------------------------------------------------------------------------
48      ---------------------------------------------------------------------------
47      ---------------------------------------------------------------------------
46      ---------------------------------------------------------------------------
45      ---------------------------------------------------------------------------
44      ---------------------------------------------------------------------------
43      ---------------------------------------------------------------------------
42      ---------------------------------------------------------------------------
41      ---------------------------------------------------------------------------
40      ----------------------------------PHHHHS-----------------------------------
39      ----------------------------------PHHHHHS----------------------------------
38      ---------------------------------PHHHHHHS----------------------------------
37      --------------------------------PHHHHHHHHS---------------------------------
36      --------------------------------PHHHHHHHHS--PHHS---------------------------
35      -------------------------------PHHHHHHHHHHSPHHHHS--------------------------
34      ------------------------------PHHHHHHHHHHHHHHHHHS--------------------------
33      ------------------------------PHHHHHHHHHHHHHHHHHHS-------------------------
32      -----------------------------PHHHHHHHHHHHHHHHHHHHS-------------------------
31      ---------------------------PHHHHHHHHHHHHHHHHHHHHHS-------------------------
30      --------------------------PHHHHHHHHHHHHHHHHHHHHHHS-------------------------
29      -------------------------PHHHHHHHHHHHHHHHHHHHHHHHS-------------------------
28      ---------------------------------------------------------------------------
27      ---------------------------------------------------------------------------
26      ---------------------------------------------------------------------------
25      ---------------------------------------------------------------------------
24      ---------------------------------------------------------------------------
23      ---------------------------------------------------------------------------
22      ---------------------------------------------------------------------------
21      ---------------------------------------------------------------------------
20      ---------------------------------------------------------------------------
19      ---------------------------------------------------------------------------
18      ---------------------------------------------------------------------------
17      ---------------------------------------------------------------------------
16      ---------------------------------------------------------------------------
15      ---------------------------------------------------------------------------
14      ---------------------------------------------------------------------------
13      ---------------------------------------------------------------------------
12      ---------------------------------------------------------------------------
11      ---------------------------------------------------------------------------
10      ---------------------------------------------------------------------------
 9      ---------------------------------------------------------------------------
 8      ---------------------------------------------------------------------------
 7      ---------------------------------------------------------------------------
 6      ---------------------------------------------------------------------------
 5      ---------------------------------------------------------------------------
 4      ---------------------------------------------------------------------------
 3      ---------------------------------------------------------------------------
 2      ---------------------------------------------------------------------------
 1      ---------------------------------------------------------------------------
```

Figure 4-4.- Continued.

```
                                                        MACH NUMBER MAP
                                                        ***************

SYMBOL       RANGE              SYMBOL       RANGE              SYMBOL       RANGE              SYMBOL       RANGE
  0            M.LE.0.05          A  0.95.LT.M.LE.1.05          K  1.95.LT.M.LE.2.05          U  2.95.LT.M.LE.3.05
  1  0.05.LT.M.LE.0.15            B  1.05.LT.M.LE.1.15          L  2.05.LT.M.LE.2.15          V  3.05.LT.M.LE.3.15
  2  0.15.LT.M.LE.0.25            C  1.15.LT.M.LE.1.25          M  2.15.LT.M.LE.2.25          W  3.15.LT.M.LE.3.25
  3  0.25.LT.M.LE.0.35            D  1.25.LT.M.LE.1.35          N  2.25.LT.M.LE.2.35          X  3.25.LT.M.LE.3.35
  4  0.35.LT.M.LE.0.45            E  1.35.LT.M.LE.1.45          O  2.35.LT.M.LE.2.45          Y  3.35.LT.M.LE.3.45
  5  0.45.LT.M.LE.0.55            F  1.45.LT.M.LE.1.55          P  2.45.LT.M.LE.2.55          Z  3.45.LT.M.LE.3.55
  6  0.55.LT.M.LE.0.65            G  1.55.LT.M.LE.1.65          Q  2.55.LT.M.LE.2.65          *            M.GT.3.55
  7  0.65.LT.M.LE.0.75            H  1.65.LT.M.LE.1.75          R  2.65.LT.M.LE.2.75
  8  0.75.LT.M.LE.0.85            I  1.75.LT.M.LE.1.85          S  2.75.LT.M.LE.2.85
  9  0.85.LT.M.LE.0.95            J  1.85.LT.M.LE.1.95          T  2.85.LT.M.LE.2.95

         888888888888888888888888888888888888888888888888888888888888888888888888888
         888888888888888888888888888888888888888888888888888888888888888888888888888
         888888888888888888888888888888888888888888888888888888888888888888888888888
         888888888888888888888888888888888888888888888888888888888888888888888888888
         888888888888888888888888888888888888888888888888888888888888888888888888888
         888888888888888888888888888888888888888888888888888888888888888888888888888
         888888888888888888888888888888888888888888888888898688888888888888888888888
         888888888888888888888888888888888888888888888888888888888888888888888888888
         888888888888888888888888888888888888888888888888888888888888888888888888888
         888888888888888888888888888888699999999999999999998888888888888888888888888
         788888888888888888888888888888999999999999999999988888888888888888888888877
         777888888888888888888888886899999999999999999999888888888888888888888887777
         777776888888888888888888888889999999999999999999998888886888888888888877777
         777777788888888888888888886999999AAAAAA99999999998888888888888888877777777
         777777778888888888888888889999999AAAAAAAAAAAA99999988888988888888888777777777
         7777777788888888888888888899999AAAAAAAAAAAAAA99998888888888888887777777777
         77777777778888888888888888999999AAAAAAAAAAAAAAA99998888886888888887777777777
         777777777778888888888888888899999AAAAAAAAAAAAAAAA9999988888888888877777777777
         7777777777778888888888868999999AAAAAAAAAAAAAAAAA99998888888888887777777777777
         777777777777788888888888689999AAAAAAAAAAAAAAAAAA99998888888877777777777777
         77777777777777768888888889999AAAAAAAAAAAAAAAAAAA99998888888777777777777777777
         77777777777777778888868889999AAABBBAAAAAAAAAAAAA999988888877777777777777777
         77777777777777777888886899999AAABBBBAAAAAAAAAAAA99998888877777777777777777777
         777777777667777777778888899 9AAABBBBBBBBAAAAAAAAAA99985888777777777777777777
         77777776666666677777888889 9AAABBBBBBBBBAAAAAAAAAAA9998888777777777777777777
         77777776666556666777788899AAABBBBBBBBBBAAAAAAABBAA9999888777777777777777777
         7777777665544455677888 99AAABBBBBBBBBBBBAAAAABBBAA999968877775666777777777777
        +7777777665432 00C1678899AAABBBBBBBBBBBBBAAAAABBBBA99998887777666666777777777
        -7777777665 42C0CC01456777888889999999999888887776655555555555566667777777777
         777777766544322234456667778888999999999999888877766655555555566666777777777
         777777766554444555556666777888899999999998888777766655555555566666677777777
         7777777666555555666666777778888999999998888877776666655555666666666 77777777
         7777777666666666666666677778888999999988888877776666666666666666666777777777
         7777777666666666667777777777888889988888888877776666666666666666677777777777
         7777777666666666777777777777888888888888888877776666666666666666677777777777
         777777766666777777777777777777888888888888887777776666666666666666 7777777777
         77777777777777777777777777777888888888888887777777666666666666666 7777777777
         77777777777777777777777777777888888888688877777777666666666666666 7777777777
         777777777777777777777777777777888888888888887777777666666666666677777777777
         777777777777777777777777777777888888888888777777777776666666677777777777777
         777777777777777777777777777777888888888888777777777777777777777777777777777
         777777777777777777777777777777788888888887777777777777777777777777777777777
         777777777777777777777777777777778888888877777777777777777777777777777777777
         777777777777777777777777777777777777777777777777777777777777777777777777777
         777777777777777777777777777777777777777777777777777777777777777777777777777
         777777777777777777777777777777777777777777777777777777777777777777777777777
         777777777777777777777777777777777777777777777777777777777777777777777777777
         777777777777777777777777777777777777777777777777777777777777777777777777777
         777777777777777777777777777777777777777777777777777777777777777777777777777
         777777777777777777777777777777777777777777777777777777777777777777777777777
         777777777777777777777777777777777777777777777777777777777777777777777777777
         777777777777777777777777777777777777777777777777777777777777777777777777777
         777777777777777777777777777777777777777777777777777777777777777777777777777
         777777777777777777777777777777777777777777777777777777777777777777777777777
         777777777777777777777777777777777777777777777777777777777777777777777777777
                         L                                             T
```

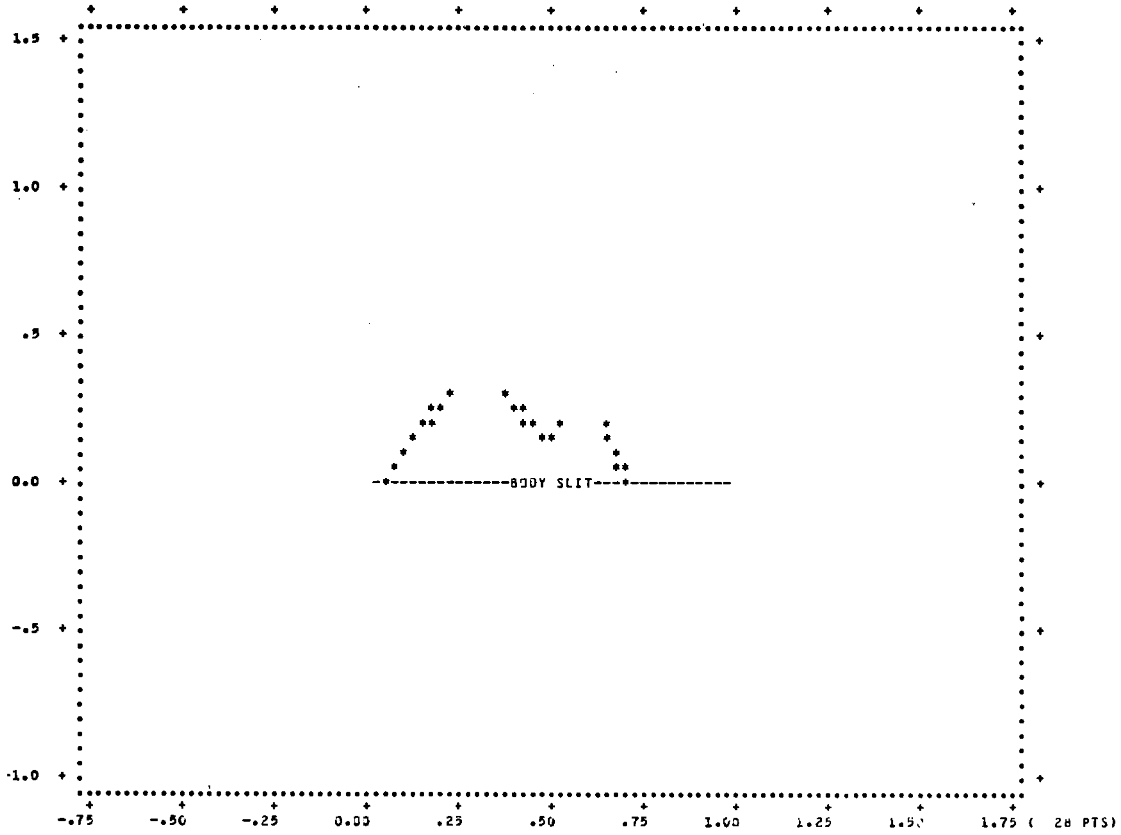
Figure 4-4.- Continued.



```
                                                    SONIC LINE OUTPUT
                                                    *****************
SONIC LINE COORDINATES

      Y          X-SONIC

    .30000     .23428     .37126
    .27000     .20723     .39561
    .24000     .18509     .41554
    .21000     .16381     .43445
    .18000     .14349     .45086     .52727     .63785
    .15000     .12669     .48161     .48789     .65392
    .12500     .11184     .66557
    .10000     .09882     .67579
    .07500     .08642     .68326
    .05000     .07393     .68982
    .03000     .06287     .69457
    .01000     .04913     .69902
 BODY LOCATION
```

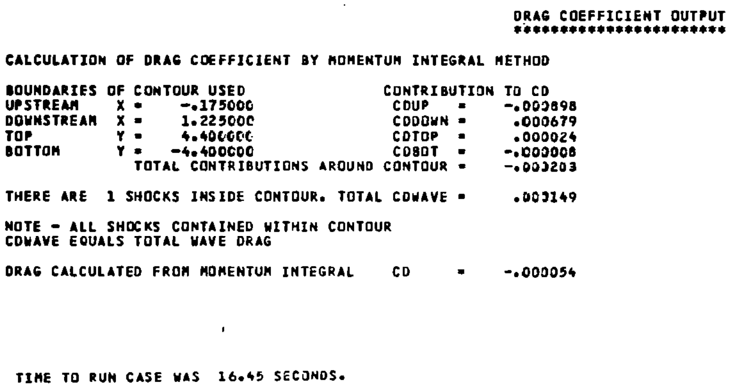
Figure 4-4.- Continued.

```
                              SONIC LINE OUTPUT
                              *****************

          SONIC LINE PLOT          Y VS X          * = SONIC POINT
```



```
                    SHOCK WAVE DRAG AND TOTAL PRESSURE PROFILE OUTPUT
                    *************************************************

INVISCID WAKE PROFILES FOR INDIVIDUAL SHOCK WAVES WITHIN MOMENTUM CONTOUR

SHOCK   1
WAVE DRAG FOR THIS SHOCK=     .000149
     Y           CD(Y)        PO/POINF

  0.00000000   .00141537   .99907800
   .01000000   .00138826   .99909566
   .03000000   .00133509   .99913029
   .05000000   .00123760   .99919380
   .07500000   .00107690   .99929848
   .10000000   .00089976   .99941387
   .12500000   .00033395   .99978246
   .15000000   .00030070   .99980412
   .18000000   .00003761   .99997550
```

Figure 4-4.- Continued.



```
                                                          DRAG COEFFICIENT OUTPUT
                                                          ***********************

CALCULATION OF DRAG COEFFICIENT BY MOMENTUM INTEGRAL METHOD

BOUNDARIES OF CONTOUR USED               CONTRIBUTION TO CD
UPSTREAM     X =     -.175000             CDUP    =     -.000898
DOWNSTREAM   X =     1.225000             CDDOWN =       .000679
TOP          Y =     4.400000             CDTOP   =      .000024
BOTTOM       Y =    -4.400000             CDBOT   =     -.000008
              TOTAL CONTRIBUTIONS AROUND CONTOUR =      -.000203

THERE ARE  1 SHOCKS INSIDE CONTOUR. TOTAL CDWAVE =       .000149

NOTE - ALL SHOCKS CONTAINED WITHIN CONTOUR
CDWAVE EQUALS TOTAL WAVE DRAG

DRAG CALCULATED FROM MOMENTUM INTEGRAL    CD      =     -.000054



 TIME TO RUN CASE WAS  16.45 SECONDS.
```

(b) Output.

Figure 4-4.- Concluded

```
SAMPLE CASE 2 - SUBSONIC-NACA0006 AIRFOIL-SOLID TUNNEL WALL SIMULATION
$INP
 BCTYPE=2, H=2.0, ALPHA=2.0, BCFOIL=1, DELTA=0.06, EMACH=0.75,
$END
```

(a) Input.

```
         SAMPLE CASE 2 - SUBSONIC - NACA0006 AIRFOIL - SOLID TUNNEL WALL SIMULATION


                                          INPUT PARAMETERS
                                          ****************

   EMACH =   .75000        POR =  0.00000        IMIN =    1     BCTYPE =  2         AMESH = F

   DELTA =   .06000      CLSET =  0.00000       IMAXI =   77     BCFOIL =  1          PHYS = T

   ALPHA =  2.00000        EPS =   .20000        JMIN =    1     PSTART =  1         PSAVE = F

      AK =  0.00000       RIGF =  0.00000       JMAXI =   48     PRTFLO =  1         KUTTA = T

     GAM =  1.40000      WCIRC =  1.00000       MAXIT =  500     IPRTER = 10           FCR = T

       F =  0.00000     CVERGE =   .00001          NU =  100     SIMDEF =  3

       H =  2.00000     DVERGE =     10.0          NL =   75       ICUT =  2

     WE = 1.80,1.90,1.95

   XIN
 -1.075000     -.950000     -.825000     -.700000     -.575000     -.450000     -.350000     -.250000
  -.175000     -.125000     -.075000     -.052500     -.035000     -.022500     -.015000     -.007500
  -.002500      .002500      .007500      .012500      .017500      .022500      .027500      .032500
   .037500      .045000      .055000      .065000      .075000      .085000      .097500      .115000
   .140625      .171875      .203125      .234375      .265625      .296875      .328125      .359375
   .390625      .421875      .453125      .484375      .515625      .546875      .578125      .609375
   .640625      .671875      .703125      .734375      .765625      .796875      .828125      .859375
   .885000      .900000      .915000      .930000      .945000      .960000      .975000      .990000
  1.000000     1.010000     1.025000     1.050000     1.090000     1.150000     1.225000     1.300000
  1.400000     1.500000     1.625000     1.750000     1.875000

   YIN
 -2.000000    -1.800000    -1.600000    -1.400000    -1.200000    -1.000000     -.800000     -.650000
  -.550000     -.450000     -.390000     -.340000     -.300000     -.270000     -.240000     -.210000
  -.180000     -.150000     -.125000     -.100000     -.075000     -.050000     -.030000     -.010000
   .010000      .030000      .050000      .075000      .100000      .125000      .150000      .180000
   .210000      .240000      .270000      .300000      .340000      .390000      .450000      .550000
   .650000      .800000     1.000000     1.200000     1.400000     1.600000     1.800000     2.000000




                                          AIRFOIL GEOMETRY OUTPUT
                                          ***********************

PRINTOUT IN PHYSICAL VARIABLES NORMALIZED BY CHORD LENGTH                       MAX THICKNESS =   .06001529
AIRFOIL VOLUME=    .04108985                                                    MAX CAMBER    =  0.00000000

 INPUT  GRID          UPPER   SURFACE                 LOWER   SURFACE
     X                  Y          DY/DX                 Y          DY/DX           THICKNESS     CAMBER

   .00250000         .00435834    .85237420         -.00435834   -.85237420        .00435834   0.00000000
   .00750000         .00742429    .47487803         -.00742429   -.47487803        .00742429   0.00000000
   .01250000         .00946951    .35793589         -.00946951   -.35793589        .00946951   0.00000000
   .01750000         .01108950    .29523886         -.01108950   -.29523886        .01108950   0.00000000
   .02250000         .01245756    .25448155         -.01245756   -.25448155        .01245756   0.00000000
   .02750000         .01365308    .22514572         -.01365308   -.22514572        .01365308   0.00000000
   .03250000         .01472030    .20264561         -.01472030   -.20264561        .01472030   0.00000000
   .03750000         .01568694    .18462015         -.01568694   -.18462015        .01568694   0.00000000
   .04500000         .01698765    .16315384         -.01698765   -.16315384        .01698765   0.00000000
   .05500000         .01850460    .14124882         -.01850460   -.14124882        .01850460   0.00000000
   .06500000         .01982871    .12421584         -.01982871   -.12421584        .01982871   0.00000000
   .07500000         .02099952    .11038471         -.02099952   -.11038471        .02099952   0.00000000
   .08500000         .02204384    .09879605         -.02204384   -.09879605        .02204384   0.00000000
   .09750000         .02320018    .08657702         -.02320018   -.08657702        .02320018   0.00000000
   .11500000         .02458752    .07246479         -.02458752   -.07246479        .02458752   0.00000000
   .14062500         .02622499    .05601496         -.02622499   -.05601496        .02622499   0.00000000
   .17187500         .02772009    .04030395         -.02772009   -.04030395        .02772009   0.00000000
```

Figure 4-5.- Sample test case 2 - subsonic, solid wall wind-tunnel simulation (full output): NACA 0006 airfoil, $\delta = 0.06$, $\alpha = 2^\circ$, $M_\infty = 0.75$, $H = 2$.

```
 .20312500        .02877607   .02769939       -.02877607  -.02769939         .02877607  0.00000000
 .23437500        .02947346   .01723458       -.02947346  -.01723458         .02947346  0.00000000
 .26562500        .02986957   .00834494       -.02986957  -.00834494         .02986957  0.00000000
 .29687500        .03000765   .00067163       -.03000765  -.00067163         .03000765  0.00000000
 .32812500        .02992166  -.00602902       -.02992166   .00602902         .02992166  0.00000000
 .35937500        .02963913  -.01193168       -.02963913   .01193168         .02963913  0.00000000
 .39062500        .02918287  -.01716743       -.02918287   .01716743         .02918287  0.00000000
 .42187500        .02857204  -.02183858       -.02857204   .02183858         .02857204  0.00000000
 .45312500        .02782297  -.02602777       -.02782297   .02602777         .02782297  0.00000000
 .48437500        .02694961  -.02980377       -.02694961   .02980377         .02694961  0.00000000
 .51562500        .02596392  -.03322534       -.02596392   .03322534         .02596392  0.00000000
 .54687500        .02487618  -.03634383       -.02487618   .03634383         .02487618  0.00000000
 .57812500        .02369511  -.03920504       -.02369511   .03920504         .02369511  0.00000000
 .60937500        .02242811  -.04185046       -.02242811   .04185046         .02242811  0.00000000
 .64062500        .02108131  -.04431829       -.02108131   .04431829         .02108131  0.00000000
 .67187500        .01965969  -.04664409       -.01965969   .04664409         .01965969  0.00000000
 .70312500        .01816718  -.04886135       -.01816718   .04886135         .01816718  0.00000000
 .73437500        .01660666  -.05100187       -.01660666   .05100187         .01660666  0.00000000
 .76562500        .01498005  -.05309608       -.01498005   .05309608         .01498005  0.00000000
 .79687500        .01328833  -.05517327       -.01328833   .05517327         .01328833  0.00000000
 .82812500        .01153160  -.05726182       -.01153160   .05726182         .01153160  0.00000000
 .85937500        .00970906  -.05938931       -.00970906   .05938931         .00970906  0.00000000
 .88500000        .00816435  -.06118182       -.00816435   .06118182         .00816435  0.00000000
 .90000000        .00723859  -.06225749       -.00723859   .06225749         .00723859  0.00000000
 .91500000        .00629651  -.06335622       -.00629651   .06335622         .00629651  0.00000000
 .93000000        .00533777  -.06448088       -.00533777   .06448088         .00533777  0.00000000
 .94500000        .00436194  -.06563430       -.00436194   .06563430         .00436194  0.00000000
 .96000000        .00336858  -.06681931       -.00336858   .06681931         .00336858  0.00000000
 .97500000        .00235719  -.06803871       -.00235719   .06803871         .00235719  0.00000000
 .99000000        .00132724  -.06929527       -.00132724   .06929527         .00132724  0.00000000
1.00000000        .00063000  -.07015500       -.00063000   .07015500         .00063000  0.00000000
```

```
                                   INTERMEDIATE OUTPUT FOR COARSE MESH

      WE =   1.8000      EPS =     .2000      MAXIT FOR THIS MESH =  125

ITERATION    CL        CM      IERR  JERR     ERROR      IRL    JRL      BIGRL        ERCIRC     ICPU    CPERRU     ICPL    CPERRL

    10     .15585    .00554    18     6    .3094E-01     6     3     .1787E+03    .2912E-01    17    .9193E+00    17    .9637E+00
    20     .23112   -.00064    16     6    .1695E-01     6     1     .1617E+03    .1632E-01     5    .9392E-01     9    .9380E-01
    30     .28076   -.00255     5     1    .1505E-01     6     6     .2157E+03    .1172E-01    15    .5416E-01     6    .6963E-01
    40     .31805   -.00266     4     1    .1155E-01     6     6     .1703E+03    .8320E-02     8    .9809E-01    17    .1973E-01
    50     .34353   -.00316     6     1    .7618E-02     6     6     .1203E+03    .5963E-02     7    .5577E-01     8    .1352E-01
    60     .36199   -.00335     5     1    .5974E-02     6     6     .9540E+02    .4317E-02     8    .4575E-01     6    .8552E-02
    70     .37539   -.00345     5     1    .4401E-02     6     6     .7173E+02    .3147E-02     8    .3373E-01    16    .4243E-02
    80     .38526   -.00348     5     1    .3308E-02     6     6     .5425E+02    .2329E-02     8    .3152E-01    16    .3706E-02
    90     .39258   -.00354     4     1    .2445E-02     6     6     .4031E+02    .1719E-02     8    .2123E-01    16    .2102E-02
   100     .39797   -.00360     5     1    .1804E-02     6     6     .2988E+02    .1272E-02     7    .1530E-01    16    .1873E-02
   110     .40201   -.00363     5     1    .1362E-02     6     6     .2262E+02    .9612E-03     7    .1222E-01    16    .1599E-02
   120     .40501   -.00364     5     1    .9915E-03     6     6     .1653E+02    .7084E-03     7    .9687E-02    16    .9024E-03

                    ******  ITERATION LIMIT REACHED  ******
```

Figure 4.5.- Continued

```
                                                   FINAL OUTPUT FOR COARSE MESH

FORCE COEFFICIENTS, PRESSURE COEFFICIENT, AND MACH NUMBER
(OR SIMILARITY PARAMETER) ON BODY AND DIVIDING STREAM LINE.
                                                                                   B = BEFORE OR BEHIND AIRFOIL
        CL =    .406213                                                            U = UPPER AIRFOIL SURFACE
        CM =   -.003640                                                            L = LOWER AIRFOIL SURFACE
       CP* =   -.603170                                                            * = CRITICAL PRESSURE

                          LOWER                       UPPER
                          Y=0-                        Y=0+
 I        X          CP          M1          CP          M1

 1   -1.075000   -.018071    .758688      -.018071    .758688                               B                     *
 2    -.575000    .003535    .748289       .003535    .748289                              B                      *
 3    -.175000    .053214    .723811       .053214    .723811                            B                        *
 4    -.035000    .126463    .686128       .126463    .686128                         B                           *
 5    -.002500    .167177    .664260       .167177    .664260                        B                            *
                       AIRFOIL LEADING EDGE                                              AIRFOIL LEADING EDGE
 6     .017500    .622808    .332800      -.281638    .875648       L                                U            *
 7     .037500    .414301    .511853      -.590233    .995297               L                                     *
 8     .075000    .219522    .635038      -.782709   1.063121                      L                              *      U
 9     .140625    .054571    .723130      -.721086   1.041887                            L                        *    U
10     .265625   -.033574    .766063      -.534411    .974745                               L                   U *
11     .390625   -.049898    .773752      -.390402    .919604                                L            U       *
12     .515625   -.039715    .768965      -.293284    .880471                               L          U          *
13     .640625   -.019512    .759376      -.208677    .844903                               L       U             *
14     .765625    .008226    .746012      -.127227    .839185                              L     U                *
15     .885000    .045206    .727812      -.045285    .771587                            L    U                   *
16     .945000    .086691    .706838       .030511    .735098                           L U                       *
17    1.000000    .147981    .674659       .129331    .684611                         B                           *
                       AIRFOIL TRAILING EDGE                                             AIRFOIL TRAILING EDGE
18    1.090000    .101108    .699402       .101108    .699402                          B                          *
19    1.400000    .043505    .728659       .043505    .728659                            B                        *
20    1.875000    .012993    .743691       .012993    .743691                              B                      *


              Y-GRID VALUES     Y(J) J=    1 TO  12
           -2.000000   -1.200000    -.550000    -.300000    -.180000    -.075000     .075000     .180000
             .300000     .550000    1.200000    2.000000
```

```
                                                 INTERMEDIATE OUTPUT FOR MEDIUM MESH

        WE =   1.9000      EPS =     .2000      MAXIT FOR THIS MESH =   250

ITERATION     CL          CM     IERR  JERR     ERROR      IRL    JRL       BIGRL        ERCIRC      ICPU     CPERRU     ICPL     CPERRL

   10       .40866      .00109     9    10    .2390E-02     9    10     .1190E+03    .1412E-03     33    .1184E+01    10    .9603E+00
   20       .40958      .00085    16    13    .2956E-02    10    12     .7445E+02    .4803E-03     11    .5513E-01    11    .1081E-01
   30       .41075      .00088    16    13    .3343E-02    10    12     .5778E+02    .4971E-03     18    .7830E-02    30    .1852E-02
   40       .41180      .00091    16    13    .3685E-02    10    12     .5043E+02    .5936E-03     18    .8490E-02    15    .1417E-02
   50       .41275      .00093    16    13    .4000E-02    10    12     .4128E+02    .7167E-03     18    .7555E-02    12    .1576E-02
   60       .41357      .00093    15    13    .4271E-02    10    12     .3488E+02    .8125E-03     18    .5412E-02    12    .9930E-03
   70       .41433      .00095    15    13    .4503E-02    10    12     .3000E+02    .8960E-03     18    .4472E-02    12    .5217E-03
   80       .41500      .00096    17    13    .4711E-02    10    12     .2635E+02    .9789E-03     18    .4304E-02    12    .3527E-03
   90       .41558      .00097    17    13    .4918E-02    10    12     .2318E+02    .1051E-02     18    .3345E-02    12    .3272E-03
  100       .41610      .00098    17    13    .5091E-02    14    13     .2091E+02    .1115E-02     18    .2808E-02    31    .1526E-03
  110       .41655      .00098    17    13    .5233E-02    14    13     .2128E+02    .1169E-02     18    .2338E-02    33    .2811E-03
  120       .41695      .00099    17    13    .5360E-02    14    13     .2161E+02    .1216E-02     18    .2325E-02    31    .1228E-03
  130       .41729      .00099    17    13    .5471E-02    14    13     .2189E+02    .1260E-02     18    .1917E-02    33    .9545E-04
  140       .41759      .00100    17    13    .5568E-02    14    13     .2214E+02    .1298E-02     18    .1500E-02    31    .9442E-04
  150       .41785      .00100    17    13    .5650E-02    14    13     .2235E+02    .1330E-02     18    .1272E-02    33    .7375E-04
  160       .41808      .00100    17    13    .5718E-02    14    13     .2252E+02    .1358E-02     18    .1112E-02    33    .1564E-03
  170       .41828      .00100    17    13    .5780E-02    14    13     .2268E+02    .1382E-02     18    .9912E-03    31    .5764E-04
  180       .41845      .00101    17    13    .5836E-02    14    13     .2282E+02    .1405E-02     18    .9825E-03    10    .3538E-04
  190       .41860      .00101    17    13    .5885E-02    14    13     .2295E+02    .1424E-02     18    .7393E-03    33    .6389E-04
  200       .41873      .00101    17    13    .5926E-02    14    13     .2305E+02    .1441E-02     18    .5804E-03    33    .4837E-04
  210       .41885      .00101    17    13    .5958E-02    14    13     .2313E+02    .1454E-02     18    .5411E-03    29    .1043E-03
  220       .41895      .00101    17    13    .5988E-02    14    13     .2321E+02    .1466E-02     16    .5547E-03    25    .4029E-04
  230       .41904      .00101    17    13    .6019E-02    14    13     .2328E+02    .1478E-02     18    .5364E-03    33    .4540E-04
  240       .41911      .00101    17    13    .6044E-02    14    13     .2335E+02    .1488E-02     18    .3696E-03    33    .5441E-04
  250       .41917      .00101    17    13    .6064E-02    14    13     .2340E+02    .1496E-02     18    .2408E-03    33    .3656E-04

                   ******  ITERATION LIMIT REACHED  ******
```

Figure 4.5.- Continued

```
                                                     FINAL OUTPUT FOR MEDIUM MESH

  FORCE COEFFICIENTS, PRESSURE COEFFICIENT, AND MACH NUMBER
  (OR SIMILARITY PARAMETER) ON BODY AND DIVIDING STREAM LINE.
                                                                                     B = BEFORE OR BEHIND AIRFOIL
          CL =   .419173                                                             U = UPPER AIRFOIL SURFACE
          CM =   .001013                                                             L = LOWER AIRFOIL SURFACE
         CP* =  -.603170                                                             * = CRITICAL PRESSURE

                            LOWER                       UPPER
                            Y=0-                        Y=0+
   I        X          CP          M1              CP          M1

    1  -1.075000     .002005     .749030         .002005     .749030                               B                 *
    2   -.825000     .007070     .746573         .007070     .746573                               B                 *
    3   -.575000     .016663     .741899         .016663     .741899                               B                 *
    4   -.350000     .040483     .730162         .040483     .730162                              B                  *
    5   -.175000     .093139     .703522         .093139     .703522                            B                    *
    6   -.075000     .181941     .656149         .181941     .656149                          B                      *
    7   -.035000     .273822     .603231         .273822     .603231                       B                         *
    8   -.015000     .338124     .563247         .338124     .563247                     B                           *
    9   -.002500     .376340     .538078         .376340     .538078                    B                            *
                         AIRFOIL LEADING EDGE                                             AIRFOIL LEADING EDGE
   10    .007500     .918258    0.000000        -.153460     .820859    L                               U            *
   11    .017500     .667224     .280249        -.482750     .955330           L                                 U   *
   12    .027500     .508325     .440221        -.797783    1.068251                L                                *     U
   13    .037500     .376881     .537713        -.980251    1.128499                    L                            *          U
   14    .055000     .253899     .615092        -.963540    1.123116                       L                         *          U
   15    .075000     .158315     .669080        -.966368    1.124029                          L                      *          U
   16    .097500     .080143     .710190        -.965500    1.123748                             L                   *          U
   17    .140625     .010780     .744769        -.932189    1.112946                               L                 *         U
   18    .203125    -.034680     .766586        -.756319    1.054080                                L                *   U
   19    .265625    -.055329     .776294        -.518140     .968672                                 L            U  *
   20    .328125    -.061852     .779335        -.415366     .929397                                 L         U     *
   21    .390625    -.060557     .778732        -.381778     .916197                                 L        U      *
   22    .453125    -.054680     .775990        -.336338     .898030                                 L       U       *
   23    .515625    -.045948     .771899        -.291638     .879793                                L       U        *
   24    .578125    -.035322     .766890        -.248523     .861837                                L     U          *
   25    .640625    -.023147     .761111        -.207236     .844284                                L    U           *
   26    .703125    -.009215     .754443        -.165908     .826340                               L    U            *
   27    .765625     .007169     .746525        -.123632     .807573                               L   U             *
   28    .828125     .027703     .736482        -.077478     .786573                              L  U               *
   29    .885000     .050578     .725130        -.030166     .764448                              L U                *
   30    .915000     .074440     .713096         .008169     .746039                             L U                 *
   31    .945000     .100658     .699635         .051955     .724441                            LU                   *
   32    .975000     .141788     .677979         .109049     .695272                           LU                    *
   33   1.000000     .199429     .646411         .192314     .650391                         B                       *
                         AIRFOIL TRAILING EDGE                                            AIRFOIL TRAILING EDGE
   34   1.025000     .153756     .671547         .153756     .671547                          B                      *
   35   1.090000     .092927     .703631         .092927     .703631                            B                    *
   36   1.225000     .052008     .724415         .052008     .724415                             B                   *
   37   1.400000     .030676     .735017         .030676     .735017                              B                  *
   38   1.625000     .019647     .740438         .019647     .740438                              B                  *
   39   1.875000     .011119     .744604         .011119     .744604                               B                 *


                Y-GRID VALUES     Y(J) J=   1 TO  24
             -2.000000   -1.600000   -1.200000    -.800000    -.550000    -.390000    -.300000    -.240000
              -.180000    -.125000    -.075000    -.030000     .030000     .075000     .125000     .180000
               .240000     .300000     .390000     .550000     .800000    1.200000    1.600000    2.000000


                                               INTERMEDIATE OUTPUT FOR FINE MESH

        WE =   1.9500     EPS =    .2000     MAXIT FOR THIS MESH =  500

ITERATION     CL         CM    IERR  JERR     ERROR     IRL  JRL       BIGRL       ERCIRC    ICPU     CPERRU    ICPL     CPERRL

   10      .42002     .00324     9    25    .2361E-02    17    24    .4833E+03   .8166E-04     33   .1201E+01     18   .1378E+01
   20      .42058     .00327    17    17    .9564E-03    17    24    .2836E+03   .1431E-03     36   .5844E-01     23   .1734E-01
   30      .42107     .00340    72    36    .4896E-03    17    24    .1970E+03   .1355E-03     36   .3232E-01     19   .7999E-02
   40      .42159     .00343    16    28    .3429E-03    17    24    .1457E+03   .1307E-03     36   .2675E-01     21   .5662E-02
   50      .42210     .00340    16    27    .2593E-03    17    24    .1133E+03   .1346E-03     36   .1063E-01     23   .2689E-02
   60      .42258     .00342    16    28    .2195E-03    17    24    .9633E+02   .1238E-03     36   .1309E-01     22   .1462E-02
   70      .42302     .00343    16    27    .1850E-03    17    24    .8260E+02   .1140E-03     36   .1178E-01     20   .1052E-02
   80      .42343     .00342    21     1    .1725E-03    17    24    .7436E+02   .1075E-03     36   .8355E-02     24   .1060E-02
   90      .42383     .00341    18     1    .1598E-03    17    24    .6547E+02   .1002E-03     36   .6372E-02     21   .6330E-03
  100      .42419     .00342    12     1    .1416E-03    17    24    .5967E+02   .9275E-04     36   .6639E-02     28   .2572E-03
  110      .42453     .00342    16     4    .1294E-03    17    24    .5527E+02   .8777E-04     36   .5201E-02     24   .2063E-03
  120      .42485     .00342    14     4    .1171E-03    17    24    .5109E+02   .8375E-04     36   .4900E-02     57   .2704E-03
  130      .42516     .00343    15     6    .1083E-03    17    24    .4761E+02   .7901E-04     36   .4828E-02     24   .1983E-03
  140      .42545     .00343    18     1    .1093E-03    17    24    .4397E+02   .7460E-04     36   .4103E-02     62   .2563E-03
  150      .42572     .00344    18     3    .9330E-04    17    24    .4065E+02   .7007E-04     36   .4285E-02     52   .1146E-03
  160      .42598     .00344    16     2    .8833E-04    17    24    .3785E+02   .6584E-04     36   .3810E-02     24   .9666E-04
```

Figure 4.5.- Continued

```
 170     .42622     .00345    14    1   .8200E-04   17   24   .3500E+02   .6218E-04   36   .3572E-02   57   .1552E-03
 180     .42645     .00345    15    1   .7606E-04   17   24   .3257E+02   .5819E-04   36   .3298E-02   24   .1096E-03
 190     .42666     .00345    18    1   .7052E-04   17   24   .3017E+02   .5459E-04   36   .2904E-02   62   .1790E-03
 200     .42686     .00345    18    1   .6571E-04   17   24   .2802E+02   .5117E-04   36   .2866E-02   52   .7496E-04
 210     .42705     .00345    16    1   .6247E-04   17   24   .2629E+02   .4805E-04   36   .2544E-02   43   .4596E-04
 220     .42722     .00346    14    1   .5839E-04   17   24   .2449E+02   .4525E-04   36   .2460E-02   57   .1085E-03
 230     .42739     .00346    15    1   .5414E-04   17   24   .2293E+02   .4229E-04   36   .2265E-02   18   .5778E-04
 240     .42754     .00346    18    1   .5041E-04   17   24   .2134E+02   .3968E-04   36   .2027E-02   62   .1241E-03
 250     .42769     .00346    18    1   .4707E-04   17   24   .1988E+02   .3713E-04   36   .2047E-02   18   .5211E-04
 260     .42782     .00346    16    1   .4479E-04   17   24   .1871E+02   .3483E-04   36   .1807E-02   18   .3307E-04
 270     .42795     .00346    14    1   .4169E-04   17   24   .1746E+02   .3278E-04   36   .1750E-02   57   .7669E-04
 280     .42807     .00347    21    1   .3889E-04   17   24   .1638E+02   .3062E-04   36   .1619E-02   18   .4585E-04
 290     .42818     .00347    18    1   .3623E-04   17   24   .1527E+02   .2871E-04   36   .1448E-02   62   .8897E-04
 300     .42828     .00347    18    1   .3386E-04   17   24   .1425E+02   .2686E-04   36   .1466E-02   18   .4030E-04
 310     .42838     .00347    16    1   .3224E-04   17   24   .1343E+02   .2519E-04   36   .1297E-02   18   .2604E-04
 320     .42847     .00347    14    1   .3003E-04   17   24   .1255E+02   .2370E-04   36   .1258E-02   57   .5507E-04
 330     .42856     .00347    21    1   .2802E-04   17   24   .1178E+02   .2213E-04   36   .1164E-02   18   .3435E-04
 340     .42864     .00347    18    1   .2612E-04   17   24   .1099E+02   .2075E-04   36   .1041E-02   62   .6419E-04
 350     .42872     .00347    18    1   .2441E-04   17   24   .1026E+02   .1941E-04   36   .1055E-02   18   .2982E-04
 360     .42879     .00347    16    1   .2325E-04   17   24   .9671E+01   .1820E-04   36   .9338E-03   18   .1934E-04
 370     .42885     .00347    14    1   .2166E-04   17   24   .9042E+01   .1713E-04   36   .9358E-03   57   .3978E-04
 380     .42892     .00347    21    1   .2022E-04   17   24   .8494E+01   .1599E-04   36   .8393E-03   18   .2516E-04
 390     .42897     .00347    18    1   .1884E-04   17   24   .7924E+01   .1499E-04   36   .7513E-03   62   .4641E-04
 400     .42903     .00348    18    1   .1762E-04   17   24   .7400E+01   .1403E-04   36   .7616E-03   18   .2174E-04
 410     .42908     .00348    16    1   .1678E-04   17   24   .6977E+01   .1315E-04   36   .6742E-03   18   .1410E-04
 420     .42913     .00348    14    1   .1563E-04   17   24   .6525E+01   .1237E-04   36   .6541E-03   57   .2877E-04
 430     .42917     .00348    21    1   .1460E-04   17   24   .6130E+01   .1155E-04   36   .6062E-03   18   .1825E-04
 440     .42922     .00348    18    1   .1360E-04   17   24   .5720E+01   .1083E-04   36   .5426E-03   62   .3359E-04
 450     .42925     .00348    18    1   .1272E-04   17   24   .5342E+01   .1013E-04   36   .5502E-03   18   .1575E-04
 460     .42929     .00348    16    1   .1212E-04   17   24   .5037E+01   .9499E-05   36   .4870E-03   18   .1021E-04
 470     .42933     .00348    14    1   .1129E-04   17   24   .4711E+01   .8938E-05   36   .4726E-03   57   .2082E-04
 480     .42936     .00348    21    1   .1054E-04   17   24   .4426E+01   .8347E-05   36   .4380E-03   18   .1321E-04
 490     .42939     .00348    18    1   .9824E-05   17   24   .4130E+01   .7826E-05   36   .3920E-03   62   .2430E-04

                   ******  SOLUTION CONVERGED  ******




                                              ******************
                                              *                *
                                              *  FINAL OUTPUT  *
                                              *                *
                                              ******************

PRINTOUT IN  PHYSICAL  VARIABLES.

DEFINITION OF SIMILARITY PARAMETERS BY KRUPP

BOUNDARY CONDITION FOR SOLID WALL

DIFFERENCE EQUATIONS ARE FULLY CONSERVATIVE.

KUTTA CONDITION IS ENFORCED.

            MACH =     .7500000
           DELTA =     .0600000
           ALPHA =    2.0000000
               K =    3.8061213
DOUBLET STRENGTH =     .0516114
  AIRFOIL VOLUME =     .0410899

       PARAMETERS USED TO TRANSFORM VARIABLES
                TO TRANSONIC SCALING

          CPFACT =     .1901683
          CDFACT =     .0114101
          CMFACT =     .1901683
          CLFACT =     .1901683
           YFACT =    2.9495264
           VFACT =    3.4377467
```

Figure 4.5.- Continued

```
                                   FINAL OUTPUT FOR FINE MESH

FORCE COEFFICIENTS, PRESSURE COEFFICIENT, AND MACH NUMBER
(OR SIMILARITY PARAMETER) ON BODY AND DIVIDING STREAM LINE.

        CL =    .429390
        CM =    .003479
       CP* =  -.603170

                            LOWER                               UPPER
                            Y=0-                                Y=0+
 I        X            CP           M1                 CP           M1

 1   -1.075000      .008699      .745782            .008699      .745782
 2    -.950000      .010789      .744765            .010789      .744765
 3    -.825000      .013555      .743416            .013555      .743416
 4    -.700000      .018026      .741232            .018026      .741232
 5    -.575000      .025241      .737693            .025241      .737693
 6    -.450000      .036605      .732086            .036605      .732086
 7    -.350000      .053754      .723540            .053754      .723540
 8    -.250000      .080668      .709922            .080668      .709922
 9    -.175000      .119291      .689909            .119291      .689909
10    -.125000      .171516      .661886            .171516      .661886
11    -.075000      .246613      .619373            .246613      .619373
12    -.052500      .331554      .567461            .331554      .567461
13    -.035000      .419085      .508452            .419085      .508452
14    -.022500      .511797      .437351            .511797      .437351
15    -.015000      .597950      .358868            .597950      .358868
16    -.007500      .678353      .265456            .678353      .265456
17    -.002500      .748611      .139665            .748611      .139665
                         AIRFOIL LEADING EDGE
18     .002500     1.322901     0.000000            .076052      .712276
19     .007500      .946407     0.000000          -.456347      .945253
20     .012500      .729237      .183192          -.807212     1.071447
21     .017500      .579391      .377158         -1.005689     1.136645
22     .022500      .470207      .470577         -1.024078     1.142497
23     .027500      .388169      .530045         -1.046277     1.149522
24     .032500      .325069      .571591         -1.074236     1.158309
25     .037500      .269801      .605644         -1.080525     1.160277
26     .045000      .213693      .638358         -1.077035     1.159185
27     .055000      .162263      .666937         -1.071090     1.157324
28     .065000      .122016      .688475         -1.067760     1.156280
29     .075000      .091169      .704537         -1.066786     1.155974
30     .085000      .065166      .717797         -1.065945     1.155711
31     .097500      .039543      .730629         -1.062680     1.154686
32     .115000      .012083      .744134         -1.054815     1.152213
33     .140625     -.015048      .757241         -1.042097     1.148202
34     .171875     -.037047      .767705         -1.025352     1.142901
35     .203125     -.052108      .774788         -1.001581     1.135333
36     .234375     -.061703      .779266          -.845911     1.084467
37     .265625     -.067407      .781916          -.515745      .967774
38     .296875     -.070239      .783228          -.346674      .902194
39     .328125     -.070906      .783537          -.370809      .911845
40     .359375     -.069920      .783081          -.371587      .912154
41     .390625     -.067660      .782033          -.360922      .907904
42     .421875     -.064411      .780525          -.344785      .901435
43     .453125     -.060386      .778653          -.326101      .893886
44     .484375     -.055747      .776489          -.306299      .885815
45     .515625     -.050613      .774087          -.286087      .877501
46     .546875     -.045066      .771484          -.265806      .869079
47     .578125     -.039155      .768700          -.245599      .860605
48     .609375     -.032899      .765743          -.225498      .852092
49     .640625     -.026289      .762606          -.205458      .843520
50     .671875     -.019282      .759267          -.185381      .834843
51     .703125     -.011800      .755685          -.165116      .825993
52     .734375     -.003719      .751796          -.144455      .816871
53     .765625      .005148      .747507          -.123119      .807343
54     .796875      .015074      .742675          -.100721      .797218
55     .828125      .026472      .737088          -.076713      .786220
56     .859375      .039336      .730731          -.051494      .774500
57     .885000      .051919      .724459          -.028437      .763627
58     .900000      .062681      .719051          -.009777      .754713
59     .915000      .073340      .713655           .007891      .746175
60     .930000      .085997      .707194           .027957      .736357
61     .945000      .101577      .699159           .051517      .724660
62     .960000      .121871      .688551           .080671      .709920
63     .975000      .150702      .673194           .119856      .689612
64     .990000      .192528      .650271           .173673      .660703
65    1.000000      .249123      .617902           .243370      .621269
                         AIRFOIL TRAILING EDGE
66    1.010000      .215841      .637137           .215841      .637137
67    1.025000      .165663      .665085           .165663      .665085
68    1.050000      .123379      .687757           .123379      .687757
69    1.090000      .089664      .705311           .089664      .705311
70    1.150000      .064386      .718191           .064386      .718191
71    1.225000      .047177      .726829           .047177      .726829
72    1.300000      .035460      .732653           .035460      .732653
73    1.400000      .026855      .736900           .026855      .736900
74    1.500000      .020585      .739979           .020585      .739979
75    1.625000      .015970      .742237           .015970      .742237
76    1.750000      .012765      .743802           .012765      .743802
77    1.875000      .010204      .745050           .010204      .745050
```

```
B = BEFORE OR BEHIND AIRFOIL
U = UPPER AIRFOIL SURFACE
L = LOWER AIRFOIL SURFACE
* = CRITICAL PRESSURE
```

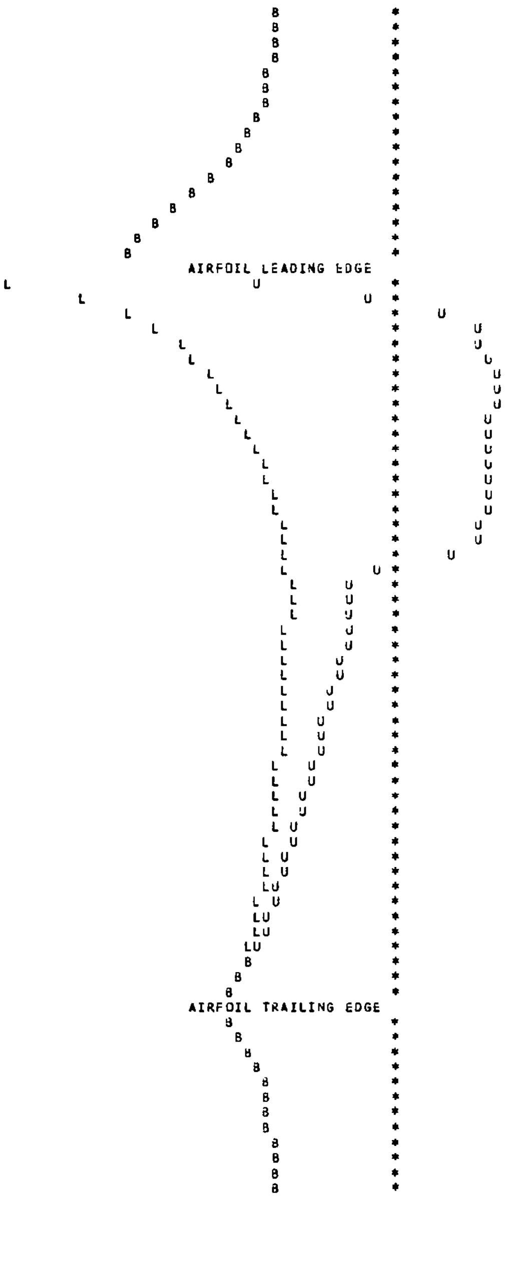


Figure 4.5.- Continued

```
  Y-GRID VALUES      Y(J) J=   1 TO  48
-2.000000   -1.800000   -1.600000   -1.400000   -1.200000   -1.000000    -.800000    -.650000
 -.550000    -.450000    -.390000    -.340000    -.300000    -.270000    -.240000    -.210000
 -.180000    -.150000    -.125000    -.100000    -.075000    -.050000    -.030000    -.010000
  .010000     .030000     .050000     .075000     .100000     .125000     .150000     .180000
  .210000     .240000     .270000     .300000     .340000     .390000     .450000     .550000
  .650000     .800000    1.000000    1.200000    1.400000    1.600000    1.800000    2.000000
```

```
                                    FLOW CHARACTER MAP
                                    ******************

              P = PARABOLIC
              H = HYPERBOLIC
              S = SHOCK
              - = ELLIPTIC

 48     ---------------------------------------------------------------------------
 47     ---------------------------------------------------------------------------
 46     ---------------------------------------------------------------------------
 45     ---------------------------------------------------------------------------
 44     ---------------------------------------------------------------------------
 43     ---------------------------------------------------------------------------
 42     ---------------------------------------------------------------------------
 41     ---------------------------------------------------------------------------
 40     ---------------------------------------------------------------------------
 39     ---------------------------------------------------------------------------
 38     ---------------------------------------------------------------------------
 37     ---------------------------------------------------------------------------
 36     --------------------------------PS-----------------------------------------
 35     -------------------------------PHHS----------------------------------------
 34     -------------------------------PHHS----------------------------------------
 33     ------------------------------PHHHS----------------------------------------
 32     -----------------------------PHHHHHS---------------------------------------
 31     ----------------------------PHHHHHHS---------------------------------------
 30     ---------------------------PHHHHHHHS---------------------------------------
 29     --------------------------PHHHHHHHHS---------------------------------------
 28     ------------------------PHHHHHHHHHHS---------------------------------------
 27     -----------------------PHHHHHHHHHHHS---------------------------------------
 26     --------------------PHHHHHHHHHHHHHHS---------------------------------------
 25     ------------------PHHHHHHHHHHHHHHHHS---------------------------------------
 24     ---------------------------------------------------------------------------
 23     ---------------------------------------------------------------------------
 22     ---------------------------------------------------------------------------
 21     ---------------------------------------------------------------------------
 20     ---------------------------------------------------------------------------
 19     ---------------------------------------------------------------------------
 18     ---------------------------------------------------------------------------
 17     ---------------------------------------------------------------------------
 16     ---------------------------------------------------------------------------
 15     ---------------------------------------------------------------------------
 14     ---------------------------------------------------------------------------
 13     ---------------------------------------------------------------------------
 12     ---------------------------------------------------------------------------
 11     ---------------------------------------------------------------------------
 10     ---------------------------------------------------------------------------
  9     ---------------------------------------------------------------------------
  8     ---------------------------------------------------------------------------
  7     ---------------------------------------------------------------------------
  6     ---------------------------------------------------------------------------
  5     ---------------------------------------------------------------------------
  4     ---------------------------------------------------------------------------
  3     ---------------------------------------------------------------------------
  2     ---------------------------------------------------------------------------
  1     ---------------------------------------------------------------------------
```

```
                                        MACH NUMBER MAP
                                        ***************

SYMBOL       RANGE             SYMBOL       RANGE             SYMBOL       RANGE             SYMBOL       RANGE
  0              M.LE.0.05       A   0.95.LT.M.LE.1.05       K   1.95.LT.M.LE.2.05       U   2.95.LT.M.LE.3.05
  1   0.05.LT.M.LE.0.15          B   1.05.LT.M.LE.1.15       L   2.05.LT.M.LE.2.15       V   3.05.LT.M.LE.3.15
  2   0.15.LT.M.LE.0.25          C   1.15.LT.M.LE.1.25       M   2.15.LT.M.LE.2.25       W   3.15.LT.M.LE.3.25
  3   0.25.LT.M.LE.0.35          D   1.25.LT.M.LE.1.35       N   2.25.LT.M.LE.2.35       X   3.25.LT.M.LE.3.35
  4   0.35.LT.M.LE.0.45          E   1.35.LT.M.LE.1.45       O   2.35.LT.M.LE.2.45       Y   3.35.LT.M.LE.3.45
  5   0.45.LT.M.LE.0.55          F   1.45.LT.M.LE.1.55       P   2.45.LT.M.LE.2.55       Z   3.45.LT.M.LE.3.55
  6   0.55.LT.M.LE.0.65          G   1.55.LT.M.LE.1.65       Q   2.55.LT.M.LE.2.65       *             M.GT.3.55
  7   0.65.LT.M.LE.0.75          H   1.65.LT.M.LE.1.75       R   2.65.LT.M.LE.2.75
  8   0.75.LT.M.LE.0.85          I   1.75.LT.M.LE.1.85       S   2.75.LT.M.LE.2.85
  9   0.85.LT.M.LE.0.95          J   1.85.LT.M.LE.1.95       T   2.85.LT.M.LE.2.95
```

Figure 4.5.- Continued

```
 8888888888888888888888888888888888888888888888888888888888888888888888888888
 8888888888888888888888888888888888888888888888888888888888888888888888888888
 8888888888888888888888888888888888888888888888888888888888888888888888888888
 8888888888888888888888888888888888888888888888888888888888888888888888888888
 8888888888888888888888888888888888888888888888888888888888888888888888888888
 8888888888888888888888888888888888888888888888888888888888888888888888888888
 8888888888888888888888888888888899999888888888888888888888888888888888888888
 8888888888888888888888888999999999999999988888888888888888888888888888888888
 8888888888888888888889999999999999999999998888888888888888888888888888888887
 8888888888888888889999999999999999999999999888888888888888888888888888887777
 88888888888888888999999999999999A99999999998888888888888888888888888887777777
 88888888888888888999999999999999AAA9999999999888888888888888888888887777777777
 88888888888888888999999999999999AAAAA999999999888888888888888888888888777777777
 88888888888888888999999999999AAAAAA999999999888888888888888888887777777777777
 8877777888888888889999999999AAAAAAA999999999988888888888888888877777777777777
 7777778888888888889999999999AAAAABBA999999999988888888888888887777777777777777
 777777778888888888999999999AAAABBBA999999999998888888888888877777777777777777
 77777777788888888899999999AAAABBBBA999999999998888888888888877777777777777777
 77777777778888888899999999AAAABBBBBA9999999999998888888888877777777777777777777
 77777777777888888899999999AAAABBBBBBA999999999999888888888877777777777777777777
 77777777777778888899999AAABBBBBBBBBA999999999998888888888777777777777777777777
 777777777777777888999AAABBBBBBBBBBBA99999999999888888888877777777777777777777
 77777777776667778899AABBBBBBBBBBBBBA99999999999888888888877777777777777777777
+7777777776665555679ABBBBBBBBBBBBBBBA99999999999988888888877777766777777777777
-7777777776553000003455666777777888888888888888888887777777777776677777777777
 7777777776554433344455566677777788888888888888888877777777777777777777777777
 7777777766655555555555666667777778888888888888888877777777777777777777777777
 7777777766665555566666666677777776888888888888888777777777777777777777777777
 7777777766666666666666666677777777888888888888888777777777777777777777777777
 7777777776666666666666666777777777788888888888888777777777777777777777777777
 7777777776666666666666666777777777778888888888887777777777777777777777777777
 7777777777666666666677777777777777777888888888887777777777777777777777777777
 7777777777777777777777777777777777777788888888877777777777777777777777777777
 7777777777777777777777777777777777777788888887777777777777777777777777777777
 7777777777777777777777777777777777777777788877777777777777777777777777777777
 7777777777777777777777777777777777777777777777777777777777777777777777777777
 7777777777777777777777777777777777777777777777777777777777777777777777777777
 7777777777777777777777777777777777777777777777777777777777777777777777777777
 7777777777777777777777777777777777777777777777777777777777777777777777777777
 7777777777777777777777777777777777777777777777777777777777777777777777777777
 7777777777777777777777777777777777777777777777777777777777777777777777777777
 7777777777777777777777777777777777777777777777777777777777777777777777777777
 7777777777777777777777777777777777777777777777777777777777777777777777777777
 7777777777777777777777777777777777777777777777777777777777777777777777777777
 7777777777777777777777777777777777777777777777777777777777777777777777777777
 7777777777777777777777777777777777777777777777777777777777777777777777777777
 7777777777777777777777777777777777777777777777777777777777777777777777777777
                 L                                              T
```

Figure 4.5.- Continued

```
PRINTER PLOT OF CP ON BODY AND DIVIDING STREAMLINE                U = CP(UPPER)
**************************************************                L = CP(LOWER)
                                                                  B = CP(UPPER) = CP(LOWER)
                                                                --- = CRITICAL CP
```

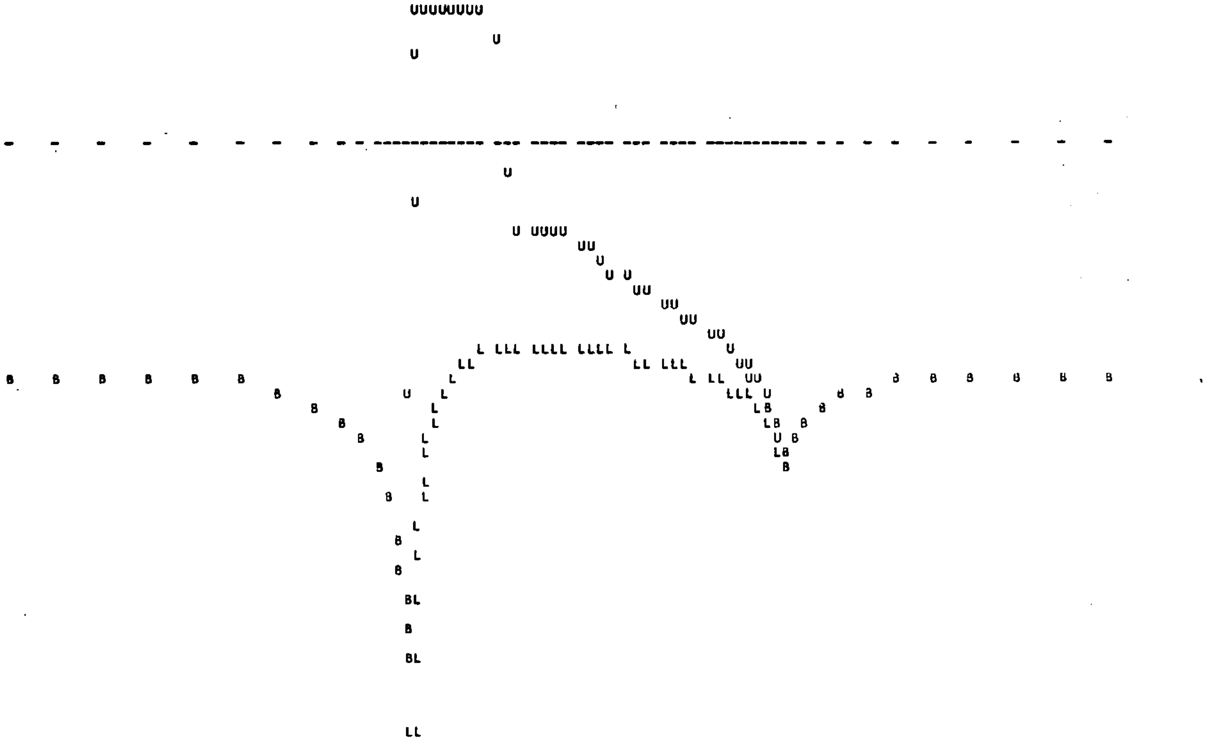


Figure 4.5.- Continued

```
SOLID WALL BOUNDARY CONDITION.

        H (TUNNEL HALF HEIGHT) = 2.000000                 SCALED H =   .678075

                              CP* = -.603170

                                  LOWER                       UPPER
                                  Y=-H                        Y=+H
I          X            CP          THETA            CP          THETA

 2      -.950000      .035447     0.000000        -.048436     0.000000
 3      -.825000      .037896     0.000000        -.054969     0.000000
 4      -.700000      .040216     0.000000        -.062600     0.000000
 5      -.575000      .042319     0.000000        -.071347     0.000000
 6      -.450000      .044013     0.000000        -.080584     0.000000
 7      -.350000      .045193     0.000000        -.089420     0.000000
 8      -.250000      .045920     0.000000        -.097374     0.000000
 9      -.175000      .046272     0.000000        -.103624     0.000000
10      -.125000      .046393     0.000000        -.108106     0.000000
11      -.075000      .046424     0.000000        -.111338     0.000000
12      -.052500      .046424     0.000000        -.113315     0.000000
13      -.035000      .046423     0.000000        -.114488     0.000000
14      -.022500      .046467     0.000000        -.115272     0.000000
15      -.015000      .046502     0.000000        -.115802     0.000000
16      -.007500      .046556     0.000000        -.116193     0.000000
17      -.002500      .046618     0.000000        -.116499     0.000000
18       .002500      .046618     0.000000        -.116793     0.000000
19       .007500      .046614     0.000000        -.117086     0.000000
20       .012500      .046610     0.000000        -.117374     0.000000
21       .017500      .046605     0.000000        -.117657     0.000000
22       .022500      .046599     0.000000        -.117936     0.000000
23       .027500      .046592     0.000000        -.118211     0.000000
24       .032500      .046584     0.000000        -.118481     0.000000
25       .037500      .046511     0.000000        -.118810     0.000000
26       .045000      .046392     0.000000        -.119248     0.000000
27       .055000      .046319     0.000000        -.119739     0.000000
28       .065000      .046268     0.000000        -.120228     0.000000
29       .075000      .046213     0.000000        -.120697     0.000000
30       .085000      .046132     0.000000        -.121181     0.000000
31       .097500      .046007     0.000000        -.121754     0.000000
32       .115000      .045836     0.000000        -.122479     0.000000
33       .140625      .045612     0.000000        -.123327     0.000000
34       .171875      .045341     0.000000        -.124126     0.000000
35       .203125      .045037     0.000000        -.124714     0.000000
36       .234375      .044707     0.000000        -.125044     0.000000
37       .265625      .044354     0.000000        -.125113     0.000000
38       .296875      .043982     0.000000        -.124916     0.000000
39       .328125      .043593     0.000000        -.124455     0.000000
40       .359375      .043189     0.000000        -.123733     0.000000
41       .390625      .042770     0.000000        -.122760     0.000000
42       .421875      .042338     0.000000        -.121547     0.000000
43       .453125      .041895     0.000000        -.120104     0.000000
44       .484375      .041444     0.000000        -.118445     0.000000
45       .515625      .040984     0.000000        -.116585     0.000000
46       .546875      .040517     0.000000        -.114542     0.000000
47       .578125      .040046     0.000000        -.112330     0.000000
48       .609375      .039570     0.000000        -.109967     0.000000
49       .640625      .039091     0.000000        -.107469     0.000000
50       .671875      .038610     0.000000        -.104855     0.000000
51       .703125      .038125     0.000000        -.102141     0.000000
52       .734375      .037638     0.000000        -.099344     0.000000
53       .765625      .037147     0.000000        -.096481     0.000000
54       .796875      .036652     0.000000        -.093566     0.000000
55       .828125      .036155     0.000000        -.090612     0.000000
56       .859375      .035683     0.000000        -.087767     0.000000
57       .885000      .035321     0.000000        -.085425     0.000000
58       .900000      .035062     0.000000        -.083725     0.000000
59       .915000      .034822     0.000000        -.082286     0.000000
60       .930000      .034581     0.000000        -.080849     0.000000
61       .945000      .034329     0.000000        -.079424     0.000000
62       .960000      .034078     0.000000        -.078002     0.000000
63       .975000      .033840     0.000000        -.076570     0.000000
64       .990000      .033649     0.000000        -.075253     0.000000
65      1.000000      .033496     0.000000        -.074181     0.000000
66      1.010000      .033284     0.000000        -.073129     0.000000
67      1.025000      .032962     0.000000        -.071619     0.000000
68      1.050000      .032482     0.000000        -.069191     0.000000
69      1.090000      .031747     0.000000        -.065429     0.000000
70      1.150000      .030694     0.000000        -.060213     0.000000
71      1.225000      .029391     0.000000        -.054143     0.000000
72      1.300000      .027857     0.000000        -.047599     0.000000
73      1.400000      .026028     0.000000        -.040577     0.000000
74      1.500000      .023890     0.000000        -.033290     0.000000
75      1.625000      .021453     0.000000        -.025941     0.000000
76      1.750000      .018888     0.000000        -.018997     0.000000
```

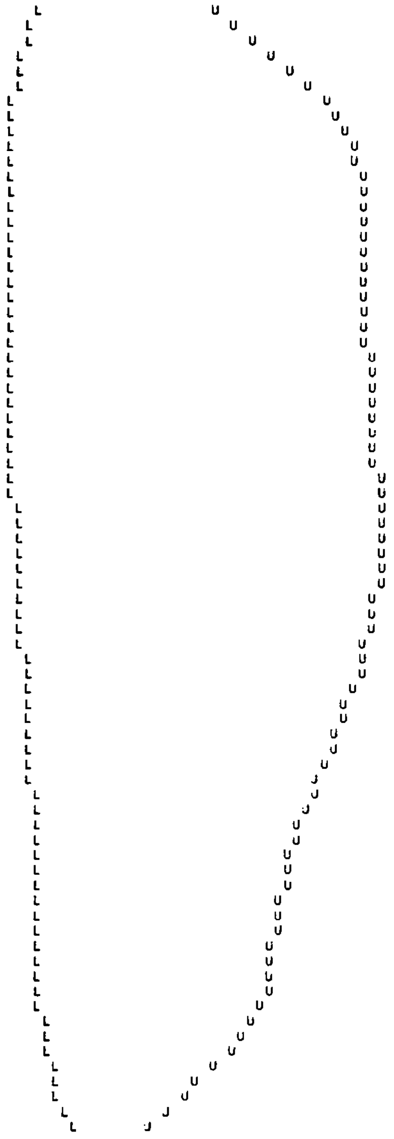


Figure 4.5.- Continued

```
                                                        SONIC LINE OUTPUT
                                                        *****************
SONIC LINE COORDINATES

     Y          X-SONIC

  .30000     .17004     .17632
  .27000     .13900     .21245
  .24000     .12090     .22340
  .21000     .10553     .23204
  .18000     .09171     .23862
  .15000     .07840     .24356
  .12500     .06694     .24689
  .10000     .05546     .24968
  .07500     .04410     .25205
  .05000     .03266     .25408
  .03000     .02244     .25549
  .01000     .01172     .25674
 BODY LOCATION
```

```
                                                        SONIC LINE OUTPUT
                                                        *****************
```

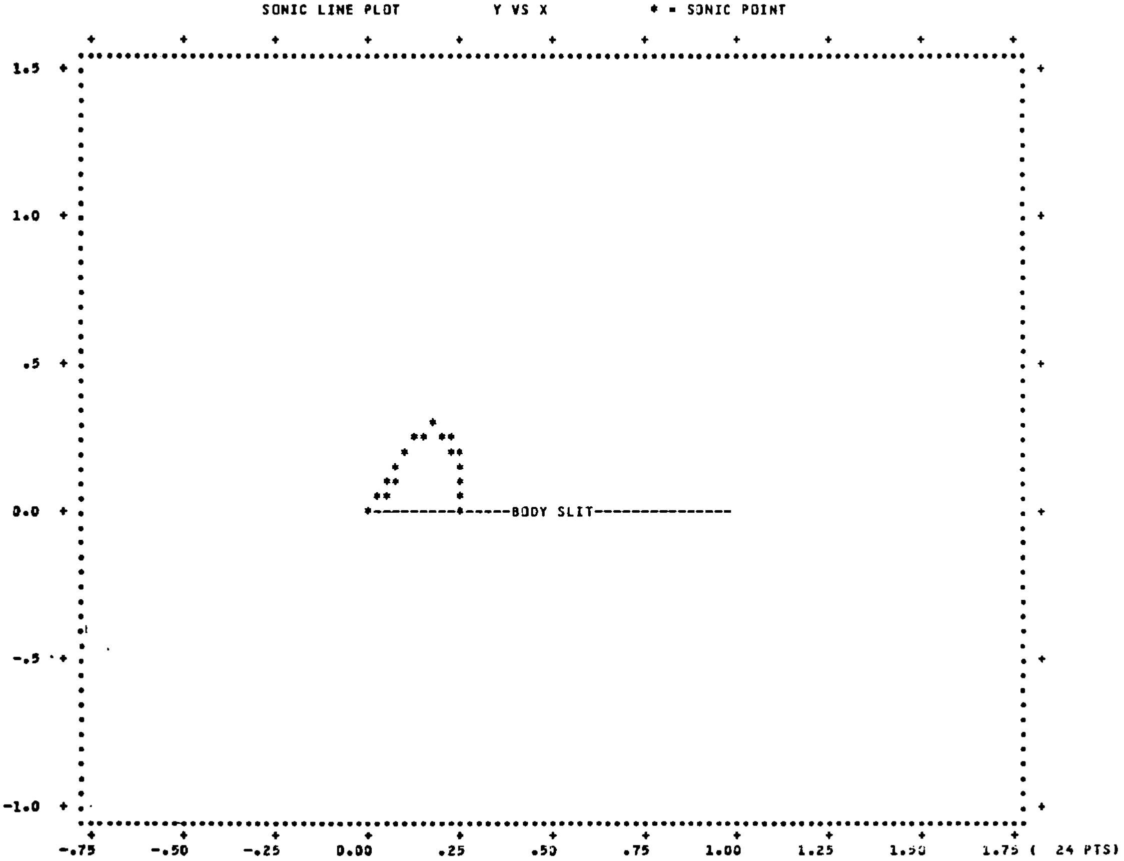


Figure 4.5.- Continued

```
                                   SHOCK WAVE DRAG AND TOTAL PRESSURE PROFILE OUTPUT
                                   *************************************************

INVISCID WAKE PROFILES FOR INDIVIDUAL SHOCK WAVES WITHIN MOMENTUM CONTOUR

SHOCK  1
WAVE DRAG FOR THIS SHOCK=     .001058
     Y         CD(Y)        PO/POINF

  0.00000000   .00790009   .99485370
   .01000000   .00769835   .99498512
   .03000000   .00730523   .99524120
   .05000000   .00677634   .99558573
   .07500000   .00597943   .99610486
   .10000000   .00509296   .99668233
   .12500000   .00417618   .99727954
   .15000000   .00328669   .99785897
   .18000000   .00232634   .99848457
   .21000000   .00102329   .99933340
   .24000000   .00066724   .99956534
   .27000000   .00040805   .99973419
   .30000000   .00000895   .99999417
```

```
                                                       DRAG COEFFICIENT OUTPUT
                                                       ***********************

CALCULATION OF DRAG COEFFICIENT BY MOMENTUM INTEGRAL METHOD

BOUNDARIES OF CONTOUR USED               CONTRIBUTION TO CD
UPSTREAM    X =     -.175000              CDUP   =    -.000055
DOWNSTREAM  X =     1.225000              CDDOWN =     .000219
TOP         Y =     1.800000              CDTOP  =     .000140
BOTTOM      Y =    -1.800000              CDBOT  =     .000029
              TOTAL CONTRIBUTIONS AROUND CONTOUR =     .000333

THERE ARE  1 SHOCKS INSIDE CONTOUR. TOTAL CDWAVE =     .001058

NOTE - ALL SHOCKS CONTAINED WITHIN CONTOUR
CDWAVE EQUALS TOTAL WAVE DRAG

DRAG CALCULATED FROM MOMENTUM INTEGRAL    CD     =     .001391
```

```
TIME TO RUN CASE WAS  23.04 SECONDS.
```

(b) Output.

Figure 4.5.- Concluded

```
SAMPLE CASE 3 - SUBSONIC-NACA0006 AIRFOIL-SLOTTED TUNNED WALL SIMULATION
$INP
 BCTYPE=4, F=0.066, EPS=0.9, H=2.0, ALPHA=2.0, DELTA=0.06, EMACH=0.75,
 BCFOIL=1,
$END
```

(a) Input.

```
                    SAMPLE CASE 3 - SUBSONIC - NACA0006 AIRFOIL - SLOTTED TUNNEL WALL SIMULATION


                                             INPUT PARAMETERS
                                             ****************

 EMACH =   .75000         POR =  0.00000         IMIN =    1      BCTYPE =  4          AMESH = F

 DELTA =   .06000       CLSET =  0.00000        IMAXI =   77      BCFOIL =  1           PHYS = T

 ALPHA =  2.00000         EPS =   .90000         JMIN =    1      PSTART =  1          PSAVE = F

    AK =  0.00000        RIGF =  0.00000        JMAXI =   48      PRTFLO =  1          KUTTA = T

   GAM =  1.40000       WCIRC =  1.00000        MAXIT =  500      IPRTER = 10            FCR = T

     F =   .06600      CVERGE =   .00001           NU =  100      SIMDEF =  3

     H =  2.00000      DVERGE =     10.0           NL =   75        ICUT =  2

    WE = 1.80,1.90,1.95

  XIN
 -1.075000     -.950000     -.825000     -.700000     -.575000     -.450000     -.350000     -.250000
  -.175000     -.125000     -.075000     -.052500     -.035000     -.022500     -.015000     -.007500
  -.002500      .002500      .007500      .012500      .017500      .022500      .027500      .032500
   .037500      .045000      .055000      .065000      .075000      .085000      .097500      .115000
   .140625      .171875      .203125      .234375      .265625      .296875      .328125      .359375
   .390625      .421875      .453125      .484375      .515625      .546875      .578125      .609375
   .640625      .671875      .703125      .734375      .765625      .796875      .828125      .859375
   .885000      .900000      .915000      .930000      .945000      .960000      .975000      .990000
  1.000000     1.010000     1.025000     1.050000     1.090000     1.150000     1.225000     1.300000
  1.400000     1.500000     1.625000     1.750000     1.875000

  YIN
 -2.000000    -1.800000    -1.600000    -1.400000    -1.200000    -1.000000     -.800000     -.650000
  -.550000     -.450000     -.390000     -.340000     -.300000     -.270000     -.240000     -.210000
  -.180000     -.150000     -.125000     -.100000     -.075000     -.050000     -.030000     -.010000
   .010000      .030000      .050000      .075000      .100000      .125000      .150000      .180000
   .210000      .240000      .270000      .300000      .340000      .390000      .450000      .550000
   .650000      .800000     1.000000     1.200000     1.400000     1.600000     1.800000     2.000000
```

Figure 4-6.- Sample test case 3 - subsonic, slotted tunnel wall simulation (abbreviated output): NACA 0006 airfoil, $\delta = 0.06$, $\alpha = 2^\circ$, $M_\infty = 0.75$, H = 2., F = 0.066.

```
                                      INTERMEDIATE OUTPUT FOR COARSE MESH

      WE =   1.8000     EPS =    .9000     MAXIT FOR THIS MESH =  125

ITERATION     CL           CM      IERR  JERR      ERROR      IRL    JRL       BIGRL         ERCIRC      ICPU     CPERRU      ICPL     CPERRL

   10       .15802      .00490      18     6    .3662E-01      6      1    .3173E+03    .2974E-01     14    .5451E+00     17    .5356E+00
   20       .23257      .00309      13     6    .1839E-01      6      6    .2311E+03    .1551E-01      6    .1129E+00      8    .9997E-01
   30       .27626      .00252       5     3    .1299E-01      6      6    .2310E+03    .9457E-02      8    .6227E-01      6    .5455E-01
   40       .30252      .00261       4     3    .7720E-02      6      6    .1355E+03    .5715E-02      7    .8538E-01      7    .1226E-01
   50       .31826      .00275       4     3    .4461E-02      6      6    .7757E+02    .3441E-02      7    .5491E-01     16    .6528E-02
   60       .32783      .00287       4     3    .2748E-02      6      6    .4782E+02    .2085E-02      7    .3151E-01     16    .2990E-02
   70       .33361      .00295       4     3    .1661E-02      6      6    .2892E+02    .1263E-02      8    .2550E-01     16    .2014E-02
   80       .33712      .00301       4     3    .1016E-02      6      6    .1768E+02    .7692E-03      8    .1238E-01     16    .1289E-02
   90       .33927      .00306       4     3    .6170E-03      6      6    .1072E+02    .4686E-03      8    .8183E-02     16    .6482E-03
  100       .34057      .00308       4     3    .3735E-03      6      6    .6490E+01    .2848E-03      8    .5041E-02     16    .4496E-03
  110       .34136      .00310       4     3    .2292E-03      6      6    .3985E+01    .1741E-03      8    .3077E-02     16    .2877E-03
  120       .34185      .00311       4     3    .1385E-03      6      6    .2409E+01    .1057E-03      8    .1952E-02     16    .1513E-03

                    ******  ITERATION LIMIT REACHED  ******
```

```
                                      INTERMEDIATE OUTPUT FOR MEDIUM MESH

      WE =   1.9000     EPS =    .9000     MAXIT FOR THIS MESH =  250

ITERATION     CL           CM      IERR  JERR      ERROR      IRL    JRL       BIGRL         ERCIRC      ICPU     CPERRU      ICPL     CPERRL

   10       .34350      .00632      10    10    .1818E-02     10     10    .1131E+03    .1769E-03     33    .1253E+01     10    .9536E+00
   20       .34382      .00646      20    13    .8586E-03     10     12    .4597E+02    .1370E-03     13    .3599E-01     12    .7775E-02
   30       .34436      .00653      12     6    .4063E-03     10     12    .2603E+02    .1698E-03     13    .4033E-01     30    .2813E-02
   40       .34487      .00661      12    13    .3335E-03     10     12    .2686E+02    .1326E-03     13    .2359E-01     20    .1627E-02
   50       .34534      .00672      12    13    .2844E-03     10     12    .1859E+02    .1101E-03     13    .2592E-01     13    .2228E-02
   60       .34570      .00683      12    13    .2442E-03     10     12    .1174E+02    .9147E-04     13    .3768E-01     12    .1587E-02
   70       .34604      .00700      12    13    .1631E-03     10     12    .8725E+01    .8511E-04     13    .5264E-01     12    .7022E-03
   80       .34632      .00703       9     6    .7737E-04     10     12    .5746E+01    .6756E-04     15    .4058E-02     12    .3445E-03
   90       .34654      .00703      29    12    .6318E-04     10     12    .4240E+01    .5085E-04     17    .1175E-02     10    .1572E-03
  100       .34670      .00703      25    12    .4706E-04     10     12    .3643E+01    .3917E-04     17    .6566E-03     10    .1056E-03
  110       .34683      .00703       8     5    .3855E-04     10     12    .3127E+01    .3062E-04     17    .6272E-03     10    .9317E-04
  120       .34693      .00703       8     5    .3134E-04     10     12    .2579E+01    .2404E-04     17    .5831E-03     10    .4480E-04
  130       .34700      .00703       8     6    .2481E-04     10     12    .2056E+01    .1883E-04     17    .5074E-03     12    .3616E-04
  140       .34707      .00703       8     6    .1945E-04     10     12    .1614E+01    .1489E-04     17    .4045E-03     12    .3116E-04
  150       .34711      .00703       8     6    .1537E-04     10     12    .1268E+01    .1178E-04     17    .3178E-03     12    .2196E-04
  160       .34715      .00703       8     6    .1210E-04     10     12    .9984E+00    .9260E-05     17    .2536E-03     12    .1759E-04
  170       .34718      .00703       8     6    .9471E-05     10     12    .7830E+00    .7283E-05     17    .1958E-03     12    .1465E-04

                    ******  SOLUTION CONVERGED  ******
```

```
                                      INTERMEDIATE OUTPUT FOR FINE MESH

      WE =   1.9500     EPS =    .9000     MAXIT FOR THIS MESH =  500

ITERATION     CL           CM      IERR  JERR      ERROR      IRL    JRL       BIGRL         ERCIRC      ICPU     CPERRU      ICPL     CPERRL

   10       .34784      .00843      22    21    .1502E-02     22     21    .3997E+03    .1223E-03     32    .1350E+01     19    .1377E+01
   20       .34818      .00863      18    18    .8631E-03     17     24    .2342E+03    .8694E-04     33    .6335E-01     24    .1425E-01
   30       .34846      .00871      16    13    .5411E-03     17     24    .1839E+03    .6781E-04     33    .2755E-01     20    .7369E-02
   40       .34876      .00876      18    10    .3373E-03     17     24    .1338E+03    .8625E-04     33    .1253E-01     22    .4629E-02
   50       .34909      .00881      16     8    .2559E-03     17     24    .9943E+02    .8524E-04     34    .7367E-02     21    .2729E-02
   60       .34939      .00884      22     6    .1932E-03     17     24    .7891E+02    .7604E-04     34    .5215E-02     24    .1586E-02
   70       .34966      .00885      15     6    .1620E-03     17     24    .6697E+02    .6681E-04     34    .5597E-02     24    .8226E-03
   80       .34991      .00887      15     8    .1336E-03     17     24    .5874E+02    .6875E-04     34    .5249E-02     24    .5288E-03
   90       .35016      .00891      16    23    .1150E-03     17     24    .5220E+02    .6301E-04     34    .5443E-02     24    .6467E-03
  100       .35038      .00892      16    25    .9682E-04     17     24    .4351E+02    .5444E-04     34    .5184E-02     24    .7227E-03
  110       .35057      .00894      16    25    .8170E-04     17     24    .3689E+02    .4820E-04     34    .4149E-02     24    .5616E-03
  120       .35075      .00895      16    25    .6700E-04     17     24    .3018E+02    .4409E-04     34    .3341E-02     24    .4923E-03
  130       .35090      .00895      14    23    .5502E-04     17     24    .2489E+02    .3939E-04     34    .2677E-02     24    .3747E-03
  140       .35104      .00896      14    20    .4620E-04     17     24    .2086E+02    .3470E-04     34    .2081E-02     24    .2390E-03
  150       .35116      .00896      14    14    .3943E-04     17     24    .1774E+02    .3063E-04     34    .1739E-02     24    .1622E-03
```

Figure 4.6.- Continued

```
160    .35127    .00897    16    8    .3511E-04    17    24    .1549E+02    .2739E-04    34    .1480E-02    24    .1049E-03
170    .35137    .00897    14    8    .3158E-04    17    24    .1368E+02    .2421E-04    34    .1232E-02    24    .8295E-04
180    .35145    .00897    15    9    .2801E-04    17    24    .1218E+02    .2141E-04    34    .1389E-02    24    .5460E-04
190    .35153    .00897    14   10    .2501E-04    17    24    .1098E+02    .1898E-04    34    .9305E-03    24    .4003E-04
200    .35159    .00898    14   11    .2228E-04    17    24    .9843E+01    .1686E-04    34    .8768E-03    24    .4295E-04
210    .35165    .00898    14   12    .1984E-04    17    24    .8786E+01    .1503E-04    34    .7859E-03    24    .4234E-04
220    .35171    .00898    14   13    .1757E-04    17    24    .7784E+01    .1336E-04    34    .7002E-03    24    .4176E-04
230    .35175    .00898    15   12    .1555E-04    17    24    .6895E+01    .1186E-04    34    .6328E-03    24    .3995E-04
240    .35180    .00898    14   11    .1386E-04    17    24    .6122E+01    .1053E-04    34    .5613E-03    24    .3403E-04
250    .35183    .00898    14   11    .1230E-04    17    24    .5436E+01    .9348E-05    34    .4991E-03    24    .2911E-04
260    .35187    .00898    14   11    .1094E-04    17    24    .4843E+01    .8294E-05    34    .4476E-03    24    .2570E-04
270    .35190    .00899    14   12    .9695E-05    17    24    .4293E+01    .7362E-05    34    .3901E-03    24    .2339E-04

            ******  SOLUTION CONVERGED  ******


                                      ******************
                                      *                *
                                      *  FINAL OUTPUT  *
                                      *                *
                                      ******************

PRINTOUT IN  PHYSICAL  VARIABLES.

DEFINITION OF SIMILARITY PARAMETERS BY KRUPP

BOUNDARY CONDITION FOR SLOTTED WALL

DIFFERENCE EQUATIONS ARE FULLY CONSERVATIVE.

KUTTA CONDITION IS ENFORCED.

              MACH =    .7500000
             DELTA =    .0600000
             ALPHA =   2.0000000
                 K =   3.8061213
  DOUBLET STRENGTH =    .0462335
    AIRFOIL VOLUME =    .0410899

         PARAMETERS USED TO TRANSFORM VARIABLES
                TO TRANSONIC SCALING

            CPFACT =    .1901683
            CDFACT =    .0114101
            CMFACT =    .1901683
            CLFACT =    .1901683
             YFACT =   2.9495264
             VFACT =   3.4377467
```

Figure 4.6.- Continued

FINAL OUTPUT FOR FINE MESH

```
FORCE COEFFICIENTS, PRESSURE COEFFICIENT, AND MACH NUMBER
(OR SIMILARITY PARAMETER) ON BODY AND DIVIDING STREAM LINE.
                                                                      B = BEFORE OR BEHIND AIRFOIL
        CL =   .351895                                                U = UPPER AIRFOIL SURFACE
        CM =   .1008985                                               L = LOWER AIRFOIL SURFACE
       CP* =  -.603170                                                * = CRITICAL PRESSURE

                             LOWER                      UPPER
                             Y=0-                       Y=0+
 I       X            CP          M1            CP          M1

 1   -1.075000      .016669     .741896       .016669     .741896
 2    -.950000      .019421     .740549       .019421     .740549
 3    -.825000      .022801     .738892       .022801     .738892
 4    -.700000      .027756     .736456       .027756     .736456
 5    -.575000      .035234     .732764       .035234     .732764
 6    -.450000      .046499     .727168       .046499     .727168
 7    -.350000      .063082     .718850       .063082     .718850
 8    -.250000      .088844     .705733       .088844     .705733
 9    -.175000      .125833     .686461       .125833     .686461
10    -.125000      .176177     .659327       .176177     .659327
11    -.075000      .249250     .617827       .249250     .617827
12    -.052500      .332512     .566849       .332512     .566849
13    -.035000      .418874     .508602       .418874     .508602
14    -.022500      .510796     .438180       .510796     .438180
15    -.015000      .596657     .360172       .596657     .360172
16    -.007500      .677417     .266732       .677417     .266732
17    -.002500      .748961     .138754       .748961     .138754
                     AIRFOIL LEADING EDGE
18     .002500     1.306960    0.000000       .101284     .699310
19     .007500      .929753    0.000000     -.405071      .925371
20     .012500      .712684     .213460     -.789476     1.065427
21     .017500      .563201     .392416    -1.027202     1.143488
22     .022500      .454480     .482546    -1.025281     1.142879
23     .027500      .372922     .540376    -1.034301     1.145643
24     .032500      .310278     .580900    -1.051762     1.151251
25     .037500      .255468     .614166    -1.051694     1.151230
26     .045000      .199869     .646164    -1.043051     1.148504
27     .055000      .148925     .674151    -1.033673     1.145539
28     .065000      .109046     .695273    -1.027877     1.143702
29     .075000      .078450     .711054    -1.023921     1.142447
30     .085000      .052623     .724107    -1.018759     1.140807
31     .097500      .027129     .736765    -1.009135     1.137744
32     .115000     -.000250     .750121     -.989874     1.131587
33     .140625     -.027365     .763118     -.941996     1.116137
34     .171875     -.049406     .773522     -.699662     1.034403
35     .203125     -.064523     .780577     -.455088      .944771
36     .234375     -.074153     .785039     -.425290      .933262
37     .265625     -.079852     .787667     -.425726      .933431
38     .296875     -.082633     .788946     -.407657      .926384
39     .328125     -.083200     .789207     -.384459      .917257
40     .359375     -.082061     .788684     -.360129      .907587
41     .390625     -.079594     .787548     -.335998      .897692
42     .421875     -.076083     .785930     -.312526      .888361
43     .453125     -.071744     .783925     -.289854      .879057
44     .484375     -.066738     .781606     -.267992      .869991
45     .515625     -.061185     .779025     -.246889      .861149
46     .546875     -.055165     .776217     -.226462      .852583
47     .578125     -.048728     .773204     -.206611      .844016
48     .609375     -.041892     .769991     -.187218      .835641
49     .640625     -.034645     .766570     -.168147      .827323
50     .671875     -.026941     .762916     -.149242      .818994
51     .703125     -.018697     .758987     -.130317      .810570
52     .734375     -.009781     .754715     -.111142      .801945
53     .765625     -.000000     .750000     -.091427      .792979
54     .796875      .010931     .744695     -.070787      .783482
55     .828125      .023440     .738579     -.048681      .773182
56     .859375      .037484     .731650     -.025441      .762203
57     .885000      .051138     .724850     -.004147      .752003
58     .900000      .062750     .719017      .013139      .743619
59     .915000      .074192     .713222      .029565      .735565
60     .930000      .087708     .706316      .048293      .726272
61     .945000      .104256     .697767      .070397      .715149
62     .960000      .125654     .686556      .097899      .701064
63     .975000      .155784     .670451      .135092      .681552
64     .990000      .199113     .646588      .186521      .653613
65    1.000000      .257277     .613097      .253477      .615341
                     AIRFOIL TRAILING EDGE
66    1.010000      .225079     .631856       .225079     .631856
67    1.025000      .175309     .659805       .175309     .659805
68    1.050000      .133274     .682519       .133274     .682519
69    1.090000      .099656     .700154       .099656     .700154
70    1.150000      .074308     .713163       .074308     .713163
71    1.225000      .056868     .721978       .056868     .721978
72    1.300000      .044790     .728019       .044790     .728019
73    1.400000      .035714     .732527       .035714     .732527
74    1.500000      .028897     .735894       .028897     .735894
75    1.625000      .023731     .738436       .023731     .738436
76    1.750000      .020086     .740224       .020086     .740224
77    1.875000      .017179     .741646       .017179     .741645
```

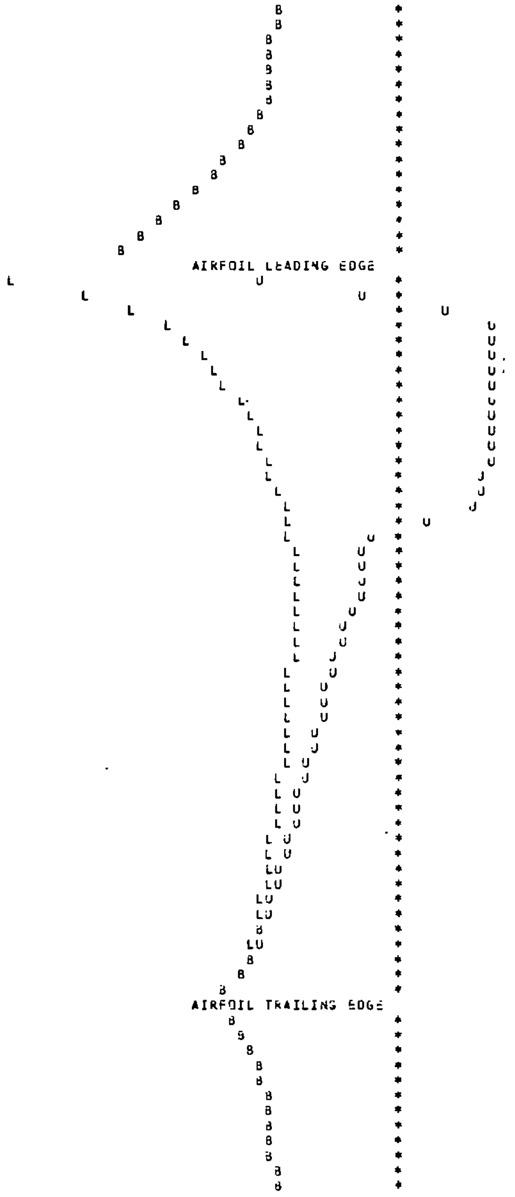


Figure 4.6.- Continued

```
   Y-GRID VALUES      Y(J) J=   1 TO  48
 -2.000000   -1.800000   -1.600000   -1.400000   -1.200000   -1.000000    -.800000    -.650000
  -.550000    -.450000    -.390000    -.340000    -.300000    -.270000    -.240000    -.210000
  -.180000    -.150000    -.125000    -.100000    -.075000    -.050000    -.030000    -.010000
   .010000     .030000     .050000     .075000     .100000     .125000     .150000     .180000
   .210000     .240000     .270000     .300000     .340000     .390000     .450000     .550000
   .650000     .800000    1.000000    1.200000    1.400000    1.600000    1.800000    2.000000



                                                       SONIC LINE OUTPUT
                                                       *****************
 SONIC LINE COORDINATES

     Y           X-SONIC

   .18000     .11078     .13374
   .15000     .08704     .15473
   .12500     .07326     .16311
   .10000     .05973     .16909
   .07500     .04625     .17383
   .05000     .03394     .17785
   .03000     .02284     .18058
   .01000     .01204     .18304
  BODY LOCATION



                                         SHOCK WAVE DRAG AND TOTAL PRESSURE PROFILE OUTPUT
                                         *************************************************
 INVISCID WAKE PROFILES FOR INDIVIDUAL SHOCK WAVES WITHIN MOMENTUM CONTOUR

 SHOCK   1
 WAVE DRAG FOR THIS SHOCK=      .000342
      Y           CD(Y)          PO/POINF

   0.00000000   .00387993    .99747253
    .01000000   .00368048    .99760245
    .03000000   .00330232    .99784879
    .05000000   .00284000    .99814996
    .07500000   .00220718    .99856219
    .10000000   .00162955    .99893847
    .12500000   .00102354    .99933324
    .15000000   .00058815    .99961687
    .18000000   .00001299    .99999154



                                                     DRAG COEFFICIENT OUTPUT
                                                     ***********************
 CALCULATION OF DRAG COEFFICIENT BY MOMENTUM INTEGRAL METHOD

 BOUNDARIES OF CONTOUR USED                CONTRIBUTION TO CD
 UPSTREAM     X =     -.175000              CDUP   =     -.001618
 DOWNSTREAM   X =     1.225000              CDDOWN =      .001502
 TOP          Y =     1.800000              CDTOP  =      .000100
 BOTTOM       Y =    -1.800000              CDBOT  =      .000030
                 TOTAL CONTRIBUTIONS AROUND CONTOUR =      .000015

 THERE ARE  1 SHOCKS INSIDE CONTOUR. TOTAL CDWAVE =      .000342

 NOTE - ALL SHOCKS CONTAINED WITHIN CONTOUR
 CDWAVE EQUALS TOTAL WAVE DRAG

 DRAG CALCULATED FROM MOMENTUM INTEGRAL    CD     =      .000357



TIME TO RUN CASE WAS  13.41 SECONDS.
```

(b) Output.

Figure 4.6.- Concluded

```
SAMPLE CASE 4 - SUPERSONIC-NACA0006 AIRFOIL-FREE AIR SIMULATION
$INP
 EMACH=1.1, BCTYPE=1, AMESH=.TRUE., BCFOIL=1, ALPHA=2.0,
 DELTA=0.06,
$END
```

(a) Input.

```
                    SAMPLE CASE 4 - SUPERSONIC - NACA0006 AIRFOIL - FREE AIR SIMULATION


                                                 INPUT PARAMETERS
                                                 ****************

EMACH =  1.10000         POR =  0.00000       IMIN =    1     BCTYPE =  1          AMESH = T

DELTA =   .06000       CLSET =  0.00000      IMAXI =   81     BCFOIL =  1           PHYS = T

ALPHA =  2.00000         EPS =   .20000       JMIN =    1     PSTART =  1          PSAVE = F

   AK =  0.00000        RIGF =  0.00000      JMAXI =   64     PRTFLD =  1          KUTTA = T

  GAM =  1.40000       WCIRC =  1.00000      MAXIT =  500     IPRTER = 10            FCR = T

    F =  0.00000      CVERGE =   .00001         NU =  100     SIMDEF =  3

    H =  0.00000      DVERGE =     10.0         NL =   75       ICUT =  2

 WE = 1.80,1.90,1.95

 XIN
-4.826958     -1.472160     -1.170661      -.972966      -.839857      -.653409      -.479854      -.295592
 -.178882      -.114702      -.075551      -.050198      -.032930      -.020518      -.011063      -.003465
  .003024       .008803       .014240       .019568       .025061       .030961       .037514       .043413
  .054966       .067013       .082363       .101517       .124201       .149372       .175856       .202583
  .229179       .255353       .281029       .306213       .330950       .355299       .379323       .403081
  .426629       .450015       .473280       .496462       .519582       .542669       .565744       .588907
  .611881       .634971       .658084       .681229       .704417       .727663       .750988       .774418
  .797988       .821742       .845736       .870039       .894736       .919931       .945757       .972377
 1.000000      1.028899      1.059441      1.092135      1.127723      1.167351      1.212946      1.268145
 1.341184      1.456833      1.671514      1.876313      2.042561      2.209055      2.406774      2.702997
 4.890373

 YIN
-5.200000     -2.594100     -1.722837     -1.285224     -1.021360      -.843611      -.715701      -.618741
 -.542402      -.480484      -.429040      -.385439      -.347855      -.314984      -.285869      -.259767
 -.236188      -.214639      -.194799      -.176391      -.159191      -.143013      -.127702      -.113124
 -.099167      -.085732      -.072733      -.060093      -.047742      -.035615      -.023653      -.011800
  .011800       .023653       .035615       .047742       .060093       .072733       .085732       .099167
  .113124       .127702       .143013       .159191       .176391       .194799       .214639       .236188
  .259787       .285869       .314984       .347855       .385439       .429040       .480484       .542402
  .618741       .715701       .843611      1.021360      1.285224      1.722837      2.594100      5.200000
```

Figure 4-7.- Sample test case 4 - supersonic, free air simulation (abbreviated output): NACA 0006 airfoil, δ = 0.06, α = 2°, M_∞ = 1.1

```
                                    INTERMEDIATE OUTPUT FOR COARSE MESH

      WE =   1.8000      EPS =     .2000      MAXIT FOR THIS MESH =  125

ITERATION    CL          CM       IERR  JERR      ERROR      IRL    JRL       BIGRL        ERCIRC      ICPU      CPERRU      ICPL     CPERRL

    10     .20042     -.03457      21     8    .2493E+00      5      8    .1462E+03    .1586E+00     16     .9529E+00      5    .8323E+00
    20     .24402     -.04272      21     8    .5993E+00     19      8    .2842E+03    .3296E+00     17     .1506E+00     17    .2731E+00
    30     .24571     -.04315      21     8    .6895E+00     19      8    .3269E+03    .3786E+00      7     .1666E-01     17    .3869E-01
    40     .24593     -.04329      21     8    .7282E+00     19      8    .3450E+03    .3993E+00      7     .9445E-02     17    .1759E-01
    50     .24609     -.04337      21     8    .7485E+00     19      8    .3546E+03    .4102E+00      7     .5367E-02     17    .9690E-02
    60     .24628     -.04340      21     8    .7597E+00     19      8    .3599E+03    .4163E+00      7     .3091E-02     17    .5582E-02
    70     .24651     -.04343      21     8    .7659E+00     19      8    .3629E+03    .4197E+00      7     .1824E-02     17    .3323E-02
    80     .24675     -.04344      21     8    .7694E+00     19      8    .3646E+03    .4217E+00      7     .1077E-02     17    .2061E-02
    90     .24699     -.04345      21     8    .7714E+00     19      8    .3656E+03    .4229E+00      7     .6639E-03     17    .1344E-02
   100     .24722     -.04345      21     8    .7726E+00     19      8    .3662E+03    .4236E+00      7     .4274E-03     17    .9347E-03
   110     .24746     -.04346      21     8    .7733E+00     19      8    .3666E+03    .4240E+00      7     .2917E-03     17    .7025E-03
   120     .24769     -.04347      21     8    .7737E+00     19      8    .3669E+03    .4243E+00      7     .2142E-03     17    .5756E-03

                   ******  ITERATION LIMIT REACHED  ******
```

```
                                    INTERMEDIATE OUTPUT FOR MEDIUM MESH

      WE =   1.9000      EPS =     .2000      MAXIT FOR THIS MESH =  250

ITERATION    CL          CM       IERR  JERR      ERROR      IRL    JRL       BIGRL        ERCIRC      ICPU      CPERRU      ICPL     CPERRL

    10     .20335     -.04097       7     3    .7331E-02     10      4    .9920E+02    .1117E-02      9     .9316E+00      9    .1051E+01
    20     .20638     -.04052       3     2    .5565E-02      9     16    .8568E+02    .1369E-02     12     .2749E-01     11    .2953E-01
    30     .20844     -.04075       3    31    .2818E-02      9     16    .8194E+02    .5154E-03     12     .1124E-01      9    .2596E-02
    40     .20930     -.04087       8     5    .2218E-02      9     16    .8346E+02    .2110E-03     12     .7557E-03     11    .2425E-02
    50     .20959     -.04086      11    17    .1931E-02      9     16    .7515E+02    .5549E-04     12     .5386E-02     12    .1298E-02
    60     .20964     -.04084      11    17    .1658E-02      9     16    .6432E+02    .3121E-05     12     .6797E-02     11    .2239E-02
    70     .20961     -.04083      11    17    .1424E-02      9     16    .5472E+02    .1176E-04     12     .5713E-02     11    .2119E-02
    80     .20957     -.04082      11    17    .1204E-02      9     16    .4612E+02    .1733E-04     12     .5028E-02     11    .1972E-02
    90     .20952     -.04081      11    17    .1013E-02      9     16    .3871E+02    .1911E-04     12     .4262E-02     11    .1734E-02
   100     .20945     -.04080      11    17    .8491E-03      9     16    .3242E+02    .2209E-04     12     .3576E-02     11    .1486E-02
   110     .20938     -.04078      11    17    .7106E-03      9     16    .2710E+02    .3016E-04     12     .2993E-02     11    .1259E-02
   120     .20929     -.04075      11    17    .5941E-03      9     16    .2264E+02    .3756E-04     12     .2522E-02     11    .1061E-02
   130     .20914     -.04070      20    31    .5555E-03      9     16    .1890E+02    .5812E-04     12     .2180E-02     11    .8925E-03
   140     .20890     -.04061      20    31    .6622E-03      9     16    .1580E+02    .1057E-03     12     .1655E-02     11    .7511E-03
   150     .20853     -.04048      20    31    .4417E-03      9     16    .1325E+02    .1192E-03     12     .1236E-02     11    .6344E-03
   160     .20832     -.04043      11    31    .3168E-03      9     16    .1122E+02    .5837E-04     12     .7503E-03     11    .5417E-03
   170     .20820     -.04043      11    17    .2534E-03      9     16    .9630E+01    .3379E-04     12     .2615E-03     11    .4766E-03
   180     .20815     -.04044      11    17    .2148E-03      9     16    .8136E+01    .1126E-04     12     .2391E-03     11    .4237E-03
   190     .20813     -.04045      11    17    .1786E-03      9     16    .6772E+01    .2139E-05     12     .5430E-03     11    .3546E-03
   200     .20813     -.04045      11    17    .1474E-03      9     16    .5597E+01    .1071E-05     12     .6500E-03     11    .2821E-03
   210     .20813     -.04045      11    17    .1222E-03      9     16    .4639E+01    .1731E-05     12     .5592E-03     11    .2256E-03
   220     .20812     -.04045      11    17    .1016E-03      9     16    .3857E+01    .1591E-05     12     .4359E-03     11    .1852E-03
   230     .20812     -.04045      11    17    .8447E-04      9     16    .3208E+01    .1191E-05     12     .5543E-03     11    .1543E-03
   240     .20812     -.04045      11    17    .7019E-04      9     16    .2665E+01    .9100E-06     12     .2975E-03     11    .1237E-03
   250     .20811     -.04045      11    17    .5830E-04      9     16    .2213E+01    .7523E-06     12     .2497E-03     11    .1071E-03

                   ******  ITERATION LIMIT REACHED  ******
```

Figure 4.7.- Continued

```
                                      INTERMEDIATE OUTPUT FOR FINE MESH

          WE =   1.9500      EPS =     .2000      MAXIT FOR THIS MESH =   500

ITERATION    CL          CM       IERR  JERR      ERROR      IRL      JRL        BIGRL          ERCIRC     ICPU      CPERRU      ICPL       CPERRL

    10     .20800     -.04152       8    33    .3659E-02     17       32      .4072E+03      .4022E-03      17     .1117E+01      17      .1205E+01
    20     .20842     -.04162      20     2    .2342E-02     17       32      .3603E+03      .5969E-04      22     .1483E-01      20      .6978E-02
    30     .20867     -.04169      16     2    .2189E-02     17       32      .3412E+03      .1103E-03      22     .3726E-02      21      .2398E-02
    40     .20900     -.04175      15    63    .1956E-02     17       32      .3311E+03      .1033E-03      22     .5761E-03      21      .1220E-02
    50     .20925     -.04180       7    63    .1974E-02     17       32      .3232E+03      .9063E-04      17     .4130E-03      21      .8942E-03
    60     .20964     -.04192       7    63    .2111E-02     17       32      .3177E+03      .1520E-03      65     .6989E-03      61      .7539E-03
    70     .21010     -.04203       7    63    .1849E-02     17       32      .3139E+03      .1642E-03      22     .7163E-03      55      .7985E-03
    80     .21050     -.04210       7    63    .1687E-02     17       32      .3094E+03      .1295E-03      65     .4117E-03      29      .7730E-03
    90     .21081     -.04211       7     2    .1570E-02     17       32      .3003E+03      .9688E-04      22     .5194E-03      23      .1168E-02
   100     .21102     -.04209       7     2    .1534E-02     17       32      .2898E+03      .6191E-04      22     .6198E-03      22      .1362E-02
   110     .21114     -.04206       7     2    .1490E-02     17       32      .2807E+03      .3105E-04      22     .4980E-03      21      .1237E-02
   120     .21118     -.04204      18    35    .1403E-02     17       32      .2729E+03      .8525E-05      22     .4905E-03      21      .9446E-03
   130     .21118     -.04201      18    34    .1370E-02     17       32      .2670E+03      .3906E-05      22     .5049E-03      21      .6682E-03
   140     .21116     -.04199      18    33    .1341E-02     17       32      .2617E+03      .1122E-04      22     .5486E-03      65      .5126E-03
   150     .21112     -.04197       6    59    .1318E-02     17       32      .2562E+03      .1371E-04      22     .5972E-03      65      .5115E-03
   160     .21108     -.04196       6     5    .1290E-02     17       32      .2500E+03      .1213E-04      22     .8304E-03      22      .5493E-03
   170     .21106     -.04195      17    33    .1242E-02     17       32      .2428E+03      .7663E-05      22     .9660E-03      22      .6203E-03
   180     .21105     -.04194      17    33    .1204E-02     17       32      .2353E+03      .7947E-06      22     .1042E-02      22      .5567E-03
   190     .21105     -.04194       7     3    .1174E-02     17       32      .2274E+03      .2841E-05      22     .1072E-02      22      .7056E-03
   200     .21105     -.04194      17    33    .1121E-02     17       32      .2191E+03      .4266E-05      22     .1113E-02      22      .7487E-03
   210     .21107     -.04194      17    33    .1076E-02     17       32      .2103E+03      .1089E-04      22     .1150E-02      22      .8348E-03
   220     .21112     -.04195      17    33    .1029E-02     17       32      .2011E+03      .1948E-04      22     .1138E-02      22      .8817E-03
   230     .21119     -.04195      17    33    .9823E-03     17       32      .1919E+03      .2638E-04      22     .1084E-02      22      .9617E-03
   240     .21128     -.04196      17    33    .9361E-03     17       32      .1829E+03      .3127E-04      22     .1002E-02      22      .9127E-03
   250     .21139     -.04198      18    33    .8913E-03     17       32      .1741E+03      .4182E-04      22     .8891E-03      22      .9131E-03
   260     .21152     -.04199      18    33    .8488E-03     17       32      .1657E+03      .4887E-04      22     .7453E-03      22      .8937E-03
   270     .21167     -.04200      19    33    .8087E-03     17       32      .1578E+03      .5334E-04      22     .6116E-03      22      .8642E-03
   280     .21182     -.04202      18    34    .7735E-03     17       32      .1534E+03      .5200E-04      22     .5164E-03      22      .8353E-03
   290     .21197     -.04203      18    34    .7345E-03     17       32      .1434E+03      .5151E-04      22     .4579E-03      21      .7850E-03
   300     .21212     -.04205      18    34    .7006E-03     17       32      .1368E+03      .5187E-04      22     .4145E-03      21      .7252E-03
   310     .21227     -.04208       8    63    .6727E-03     17       32      .1309E+03      .5478E-04      22     .3503E-03      21      .6594E-03
   320     .21243     -.04210       8    63    .6701E-03     17       32      .1253E+03      .5755E-04      22     .2838E-03      21      .6250E-03
   330     .21260     -.04212       8    63    .6693E-03     17       32      .1200E+03      .5968E-04      22     .2191E-03      21      .5956E-03
   340     .21278     -.04215       8    63    .6703E-03     17       32      .1151E+03      .6176E-04      65     .1853E-03      21      .5736E-03
   350     .21296     -.04218       8    63    .6725E-03     17       32      .1105E+03      .6371E-04      17     .1773E-03      21      .5443E-03
   360     .21314     -.04221       8    63    .6779E-03     17       32      .1064E+03      .6591E-04      17     .1813E-03      21      .5047E-03
   370     .21333     -.04224       8    63    .6858E-03     17       32      .1026E+03      .6812E-04      17     .1309E-03      21      .4601E-03
   380     .21353     -.04227       8    63    .6955E-03     17       32      .9910E+02      .7194E-04      17     .1767E-03      21      .4337E-03
   390     .21374     -.04231      19    62    .5174E-03     17       32      .9550E+02      .7299E-04      17     .1858E-03      21      .4269E-03
   400     .21386     -.04232      16    61    .4732E-03     17       32      .9176E+02      .2842E-04      17     .1727E-03      21      .4146E-03
   410     .21387     -.04230       8     2    .4572E-03     17       32      .8812E+02      .6921E-05      64     .2339E-03      21      .3726E-03
   420     .21380     -.04226       8     2    .4533E-03     17       32      .8445E+02      .3613E-04      64     .2506E-03      21      .3314E-03
   430     .21365     -.04222       9     2    .4496E-03     17       32      .8066E+02      .5889E-04      22     .3240E-03      21      .2942E-03
   440     .21345     -.04217       8     2    .4464E-03     17       32      .7689E+02      .7515E-04      22     .4911E-03      21      .2439E-03
   450     .21322     -.04212       8     2    .4436E-03     17       32      .7312E+02      .8509E-04      22     .6244E-03      22      .1620E-03
   460     .21296     -.04207       8     2    .4413E-03     17       32      .6952E+02      .9023E-04      22     .5903E-03      65      .1538E-03
   470     .21270     -.04203       8     2    .4385E-03     17       32      .6624E+02      .9303E-04      22     .5413E-03      65      .1572E-03
   480     .21243     -.04198       8     2    .4365E-03     17       32      .6327E+02      .9444E-04      22     .6668E-03      17      .1369E-03
   490     .21216     -.04193       8     2    .4329E-03     17       32      .6058E+02      .9582E-04      22     .6359E-03      17      .1516E-03
   500     .21188     -.04188       9     2    .4199E-03     17       32      .5787E+02      .9712E-04      22     .6139E-03      17      .1630E-03

                    ******  ITERATION LIMIT REACHED  ******


                                              ******************
                                              *                *
                                              *  FINAL OUTPUT  *
                                              *                *
                                              ******************

PRINTOUT IN  PHYSICAL  VARIABLES.

DEFINITION OF SIMILARITY PARAMETERS BY KRUPP

BOUNDARY CONDITION FOR FREE AIR

DIFFERENCE EQUATIONS ARE FULLY CONSERVATIVE.

KUTTA CONDITION IS ENFORCED.


             MACH =   1.1000000
            DELTA =    .0600000
            ALPHA =   2.0000000
                K =  -1.2456397

        PARAMETERS USED TO TRANSFORM VARIABLES
                  TO TRANSONIC SCALING

           CPFACT =    .1426887
           CDFACT =    .0085613
           CMFACT =    .1426887
           CLFACT =    .1426887
            YFACT =   2.4354913
            VFACT =   3.4377467
```

Figure 4.7.- Continued

```
                                                    FINAL OUTPUT FOR FINE MESH

FORCE COEFFICIENTS, PRESSURE COEFFICIENT, AND MACH NUMBER
(OR SIMILARITY PARAMETER) ON BODY AND DIVIDING STREAM LINE.

        CL =    .211883
        CM =  -.041882
       CP* =    .148116

                                LOWER                          UPPER
                                Y=0-                           Y=0+
  I        X           CP           M1             CP           M1

  1   -4.826958   -0.000000    1.100000       -0.000000    1.100000
  2   -1.472160   -0.000000    1.100000       -0.000000    1.100000
  3   -1.170661     .000000    1.100000         .000000    1.100000
  4    -.972966     .000000    1.100000         .000000    1.100000
  5    -.809857     .009657    1.093759         .009657    1.093759
  6    -.653469     .165719     .987442         .165719     .937442
  7    -.479854     .335488     .856937         .335488     .856937
  8    -.295092     .391359     .809399         .391359     .809399
  9    -.178882     .458584     .748207         .458584     .748207
 10    -.114702     .527590     .679689         .527590     .679689
 11    -.075551     .597217     .602709         .597217     .602709
 12    -.050198     .669409     .510788         .669409     .510788
 13    -.032930     .745001     .392083         .745001     .392083
 14    -.020518     .825003     .200750         .825003     .200750
 15    -.011063     .911035    0.000000         .911035    0.000000
 16    -.003465    1.005732    0.000000        1.005732    0.000000
                          AIRFOIL LEADING EDGE
 17     .003024    1.205373    0.000000         .891538    0.000000
 18     .008803     .801151     .272247         .451359     .755304
 19     .014240     .614255     .582325         .259810     .917409
 20     .019568     .502088     .705787         .154067     .995772
 21     .025061     .426305     .778190         .073903    1.051294
 22     .030961     .370353     .827592         .025077    1.083719
 23     .037614     .325600     .865079         .006239    1.095991
 24     .045413     .286976     .896171        -.017892    1.111471
 25     .054966     .251249     .924000        -.042969    1.127352
 26     .067013     .216453     .950321        -.066554    1.142086
 27     .082363     .181768     .975852        -.089946    1.156515
 28     .101517     .146271    1.001306        -.113000    1.170561
 29     .124201     .110795    1.026116        -.134861    1.183726
 30     .149372     .080210    1.047033        -.154744    1.195574
 31     .175806     .055675    1.063515        -.172279    1.205927
 32     .202583     .034856    1.077363        -.187484    1.214832
 33     .229179     .017186    1.088868        -.200598    1.222461
 34     .255353     .002066    1.098668        -.211931    1.229015
 35     .281029    -.011002    1.107068        -.221781    1.234684
 36     .306213    -.022414    1.114351        -.230405    1.239625
 37     .330950    -.032473    1.120732        -.238012    1.243968
 38     .355299    -.041416    1.126375        -.244774    1.247815
 39     .379323    -.049426    1.131405        -.250826    1.251249
 40     .403081    -.056650    1.135922        -.256280    1.254335
 41     .426629    -.063204    1.140005        -.261224    1.257126
 42     .450015    -.069181    1.143715        -.265729    1.259664
 43     .473280    -.074658    1.147106        -.269856    1.261985
 44     .496460    -.079703    1.150219        -.273656    1.264117
 45     .519582    -.084375    1.153095        -.277172    1.266087
 46     .542669    -.088726    1.155767        -.280444    1.267918
 47     .565740    -.092806    1.158267        -.283508    1.269630
 48     .588807    -.096660    1.160623        -.286398    1.271243
 49     .611881    -.100329    1.162862        -.289145    1.272774
 50     .634971    -.103852    1.165007        -.291780    1.274241
 51     .658084    -.107262    1.167081        -.294332    1.275659
 52     .681229    -.110593    1.169103        -.296828    1.277046
 53     .704417    -.113879    1.171093        -.299295    1.278415
 54     .727663    -.117150    1.173071        -.301760    1.279781
 55     .750988    -.120440    1.175058        -.304248    1.281158
 56     .774418    -.123784    1.177074        -.306785    1.282561
 57     .797988    -.127220    1.179141        -.309400    1.284006
 58     .821742    -.130788    1.181284        -.312120    1.285507
 59     .845736    -.134531    1.183528        -.314979    1.287082
 60     .870039    -.138498    1.185902        -.318012    1.288752
 61     .894736    -.142744    1.188438        -.321263    1.290539
 62     .919931    -.147334    1.191172        -.324783    1.292471
 63     .945757    -.152342    1.194149        -.328632    1.294581
 64     .972377    -.157863    1.197422        -.332891    1.296910
 65    1.000000    -.107273    1.167088        -.204855    1.224927
                          AIRFOIL TRAILING EDGE
 66    1.028899    -.078862    1.149701        -.078862    1.149701
 67    1.059441    -.051269    1.132559        -.051269    1.132559
 68    1.092135    -.044428    1.128269        -.044428    1.128269
 69    1.127723    -.041877    1.126665        -.041877    1.126665
 70    1.167351    -.040240    1.125634        -.040240    1.125634
 71    1.212946    -.038992    1.124848        -.038992    1.124848
 72    1.268145    -.038174    1.124332        -.038174    1.124332
 73    1.341184    -.038225    1.124365        -.038225    1.124365
 74    1.456833    -.039577    1.125217        -.039577    1.125217
 75    1.671524    -.038742    1.124691        -.038742    1.124691
 76    1.876313    -.032662    1.120852        -.032662    1.120852
 77    2.042561    -.023734    1.115191        -.023734    1.115191
 78    2.209055    -.015180    1.109739        -.015180    1.109739
 79    2.406774    -.010460    1.106721        -.010460    1.106721
 80    2.702997    -.022405    1.114345        -.022405    1.114345
 81    4.890373    -.048029    1.130529        -.048029    1.130529
```

```
B = BEFORE OR BEHIND AIRFOIL
U = UPPER AIRFOIL SURFACE
L = LOWER AIRFOIL SURFACE
* = CRITICAL PRESSURE
```

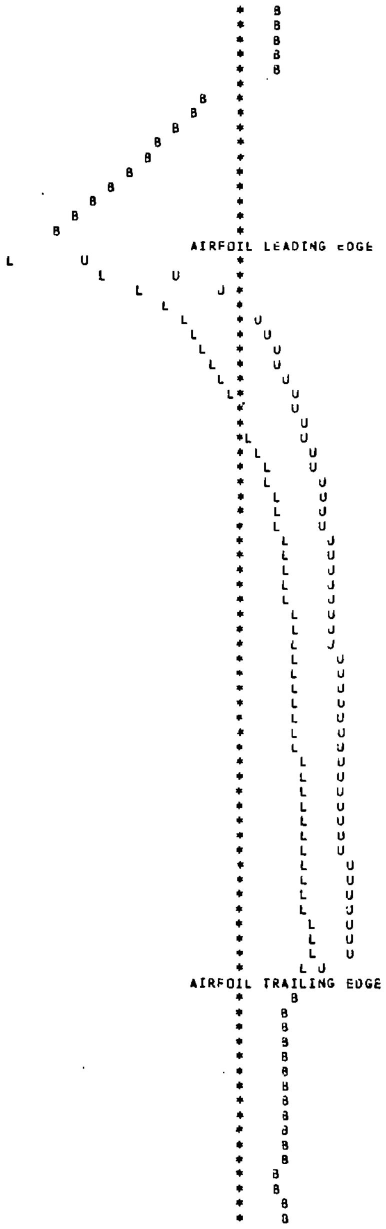


Figure 4.7.- Continued

```
   Y-GRID VALUES        Y(J) J=   1 TO  64
-5.200000   -2.594100   -1.722837   -1.285224   -1.021060    -.843611    -.715701    -.618741
 -.542402    -.480484    -.429040    -.385439    -.347855    -.314984    -.285869    -.259787
 -.236188    -.214639    -.194799    -.176391    -.159191    -.143013    -.127702    -.113124
 -.099167    -.085732    -.072733    -.060093    -.047742    -.035615    -.023653    -.011800
  .011800     .023653     .035615     .047742     .060093     .072733     .085732     .099167
  .113124     .127702     .143013     .159191     .176391     .194799     .214639     .236188
  .259787     .285869     .314984     .347855     .385439     .429040     .480484     .542402
  .618741     .715701     .843611    1.021060    1.285224    1.722837    2.594100    5.200000
```

```
                                                SONIC LINE OUTPUT
                                                *****************
SONIC LINE COORDINATES

     Y           X-SONIC

  2.59410    -.27198     .49553
  1.72284    -.43613     .43866
  1.28522    -.52395     .35835
  1.02106    -.56660     .30646
   .84361    -.59380     .27041
   .71570    -.61232     .24028
   .61874    -.62540     .21731
   .54240    -.63493     .19866
   .48048    -.64203     .18360
   .42904    -.64744     .17036
   .38544    -.65163     .15928
   .34786    -.65494     .14896
   .31498    -.65758     .14051
   .28587    -.65969     .13261
   .25979    -.66143     .12487
   .23619    -.66287     .11832
   .21464    -.66409     .11214
   .19480    -.66512     .10597
   .17639    -.66601     .09993
   .15919    -.66678     .09471
   .14301    -.66744     .08941
   .12770    -.66803     .08378
   .11312    -.66854     .07868
   .09917    -.66900     .07364
   .08573    -.66940     .06801
   .07273    -.66975     .06281
   .06009    -.67006     .05705
   .04774    -.57034     .05109
   .03561    -.67058     .04429
   .02365    -.67079     .03677
   .01180    -.67097     .02738
 BODY LOCATION
  -.01180    -.67125     .11132
  -.02365    -.67135     .12039
  -.03561    -.67142     .12902
  -.04774    -.67147     .13734
  -.06009    -.67149     .14460
  -.07273    -.67148     .15168
  -.08573    -.67144     .15940
  -.09917    -.67136     .16640
  -.11312    -.67124     .17292
  -.12770    -.67108     .18000
  -.14301    -.67087     .18736
  -.15919    -.67059     .19436
  -.17639    -.67025     .20119
  -.19480    -.66982     .20911
  -.21464    -.66929     .21710
  -.23619    -.66862     .22503
  -.25979    -.66780     .23383
  -.28587    -.66677     .24336
  -.31498    -.66547     .25306
  -.34786    -.66380     .26439
  -.38544    -.66165     .27640
  -.42904    -.65878     .29019
  -.48048    -.65487     .30519
  -.54240    -.64940     .32332
  -.61874    -.64169     .34473
  -.71570    -.63059     .37075
  -.84361    -.61418     .40162
 -1.02106    -.58911     .44366
 -1.28522    -.54893     .49611
 -1.72284    -.47480     .56551
 -2.59410    -.30048     .63440
```

Figure 4.7.- Continued

```
                                              SHOCK WAVE DRAG AND TOTAL PRESSURE PROFILE OUTPUT
                                              *************************************************

INVISCID WAKE PROFILES FOR INDIVIDUAL SHOCK WAVES WITHIN MOMENTUM CONTOUR

SHOCK  1
WAVE DRAG FOR THIS SHOCK=      .007130
     Y           CD(Y)        PO/POINF

 -2.59410019    .00101194    .99927456
 -1.72283680    .00085003    .99939063
 -1.28522355    .00138639    .99900612
 -1.02106025    .00160950    .99884618
   -.84361099   .00179065    .99871632
   -.71570104   .00195214    .99860055
   -.61874102   .00209990    .99849462
   -.54240166   .00223585    .99839717
   -.48048365   .00181152    .99870136
   -.42904031   .00190076    .99863739
   -.38543890   .00197252    .99858594
   -.34785516   .00203096    .99854405
   -.31498449   .00207900    .99850961
   -.28586858   .00211879    .99848108
   -.25978714   .00215191    .99845734
   -.23618771   .00217958    .99843750
   -.21463894   .00220274    .99842090
   -.19479857   .00222211    .99840701
   -.17639103   .00223829    .99839541
   -.15919133   .00225174    .99838577
   -.14301344   .00226283    .99837783
   -.12770160   .00227186    .99837135
   -.11312379   .00227907    .99836618
   -.09916674   .00228468    .99836216
   -.08573207   .00228882    .99835919
   -.07273320   .00229164    .99835717
   -.06009296   .00229324    .99835603
   -.04774152   .00229369    .99835570
   -.03561482   .00229305    .99835616
   -.02365311   .00229137    .99835736
   -.01179972   .00228868    .99835929
    .01179972   .00228027    .99836532
    .02365311   .00227454    .99836943
    .03561482   .00226775    .99837430
    .04774152   .00225986    .99837995
    .06009296   .00225080    .99838645
    .07273320   .00224050    .99839383
    .08573207   .00222884    .99840219
    .09916674   .00221572    .99841160
    .11312379   .00220096    .99842218
    .12770160   .00218439    .99843406
    .14301344   .00216578    .99844740
    .15919133   .00214485    .99846240
    .17639103   .00212127    .99847930
    .19479857   .00209464    .99849839
    .21463894   .00206445    .99852004
    .23618771   .00203007    .99854468
    .25978714   .00199072    .99857289
    .28586858   .00194540    .99860538
    .31498449   .00189283    .99864307
    .34785516   .00183133    .99868716
    .38543890   .00234772    .99831697
    .42904031   .00224426    .99839113
    .48048365   .00213317    .99847078
    .54240166   .00201386    .99855631
    .61874102   .00188553    .99864830
    .71570104   .00174673    .99874781
    .84361099   .00159398    .99885731
  1.02106025    .00141739    .99898390
  1.28522355    .00118417    .99915109
  1.72283680    .00080469    .99942313
  2.59410019    .00067653    .99951501

 SHOCK WAVE EXTENDS OUTSIDE CONTOUR
 PRINTOUT OF SHOCK LOSSES ARE NOT AVAILABLE FOR REST OF SHOCK


                                                                  DRAG COEFFICIENT OUTPUT
                                                                  ***********************

CALCULATION OF DRAG COEFFICIENT BY MOMENTUM INTEGRAL METHOD

BOUNDARIES OF CONTOUR USED                   CONTRIBUTION TO CD
UPSTREAM      X =   -1.170661                 CDUP    =    0.000000
DOWNSTREAM    X =     .727663                 CDDOWN  =     .011058
TOP           Y =    2.594100                 CDTOP   =     .004202
BOTTOM        Y =   -2.594100                 CDBOT   =     .005083
BODY AFT OF X =       .727663                 CDBODY  =     .007620
                 TOTAL CONTRIBUTIONS AROUND CONTOUR =       .027963

THERE ARE  1 SHOCKS INSIDE CONTOUR. TOTAL CDWAVE =          .007130

NOTE - ONE OR MORE SHOCKS EXTEND OUTSIDE OF CONTOUR
CDWAVE DOES NOT EQUAL TOTAL WAVE DRAG

DRAG CALCULATED FROM MOMENTUM INTEGRAL     CD      =        .035093


TIME TO RUN CASE WAS  32.44 SECONDS.
```

(b) Output.

Figure 4.7.- Concluded

```
SAMPLE CASE 5 - SUPERSONIC-NACA0006 AIRFOIL-FREE JET SIMULATION
$INP
 BCTYPE=3, H=2.0, EMACH=1.1, AMESH=.TRUE., ALPHA=2.0, DELTA=0.06,
 BCFOIL=1,
$END
```

(a) Input.

```
                SAMPLE CASE 5 - SUPERSONIC - NACA0006 AIRFOIL - FREE JET SIMULATION


                                     INPUT PARAMETERS
                                     ****************

EMACH =  1.10000        POR =  0.00000       IMIN =    1      BCTYPE =  3        AMESH = T

DELTA =   .06000      CLSET =  0.00000      IMAXI =   81      BCFOIL =  1         PHYS = T

ALPHA =  2.00000        EPS =   .20000       JMIN =    1      PSTART =  1        PSAVE = F

   AK =  0.00000       RIGF =  0.00000      JMAXI =   64      PRTFLO =  1        KUTTA = T

  GAM =  1.40000      WCIRC =  1.00000      MAXIT =  500      IPRTER = 10          FCR = T

    F =  0.00000     CVERGE =   .00001         NU =  100      SIMDEF =  3

    H =  2.00000     DVERGE =     10.0         NL =   75        ICUT =  2

  WE = 1.80,1.90,1.95

  XIN
-4.826958   -1.472160   -1.170661    -.972966    -.809857    -.553469    -.479854    -.295292
 -.178882    -.114702    -.075551    -.050198    -.032930    -.020518    -.011063    -.003465
  .003024     .008603     .014240     .019568     .025061     .030961     .037514     .049413
  .054966     .067013     .082363     .101517     .124201     .149372     .175306     .202533
  .229179     .255353     .281029     .306213     .330950     .355299     .379323     .403081
  .426629     .450015     .473280     .496460     .519582     .542669     .565740     .589307
  .611881     .634971     .658084     .681229     .704417     .727663     .750988     .774418
  .797988     .821742     .845736     .870039     .894736     .919931     .945757     .972377
 1.000000    1.028899    1.059441    1.092135    1.127723    1.167351    1.212946    1.268145
 1.341184    1.456833    1.671514    1.876313    2.042561    2.209055    2.406774    2.732997
 4.890373

  YIN
-1.000000    -.906455    -.821465    -.744089    -.673514    -.609036    -.550046    -.496010
 -.446463    -.400997    -.359253    -.320914    -.285702    -.253369    -.223696    -.196488
 -.171573    -.148797    -.128025    -.109135    -.092019    -.076584    -.062744    -.050426
 -.039566    -.030108    -.022004    -.015212    -.009701    -.005441    -.002413    -.000603
  .000603     .002413     .005441     .009701     .015212     .022004     .031068     .039566
  .050426     .062744     .076584     .092019     .109135     .128025     .148797     .171573
  .196488     .223696     .253369     .285702     .320914     .359253     .400997     .446463
  .496010     .550046     .609036     .673514     .744089     .821465     .906455    1.000000
```

Figure 4-8.- Sample test case 5 - supersonic, free jet simulation (abbreviated output): NACA 0006 airfoil, $\delta = 0.06$, $\alpha = 2°$, $M_\infty = 1.1$, $H = 2$.

```
                                        INTERMEDIATE OUTPUT FOR COARSE MESH

       WE =   1.8000      EPS =     .2000     MAXIT FOR THIS MESH =  125

ITERATION    CL         CM      IERR  JERR     ERROR      IRL   JRL      BIGRL        ERCIRC     ICPU    CPERRU     ICPL     CPERRL

   10      .29775    -.05325     20     8    .4890E+00    19     9    .2022E+04    .6227E+00    16    .1481E+01    17    .2013E+01
   20      .23063    -.04624     20     8    .3057E+00    19     9    .1396E+04    .4300E+00    17    .1172E+00    17    .2672E+00
   30      .21871    -.04396     20     8    .2199E+00    19     9    .1055E+04    .3237E+00    17    .2847E-01    17    .5594E-01
   40      .22180    -.04418     20     8    .2045E+00    19     9    .1115E+04    .3408E+00     6    .5387E-02    17    .1493E-01
   50      .22250    -.04427     20     8    .2081E+00    19     9    .1136E+04    .3472E+00     6    .3617E-02    17    .6052E-02
   60      .22250    -.04426     20     8    .2072E+00    19     9    .1140E+04    .3482E+00     6    .1766E-02     7    .1398E-02
   70      .22246    -.04424     20     8    .2063E+00    19     9    .1140E+04    .3481E+00     6    .8315E-03     7    .6876E-03
   80      .22245    -.04424     20     8    .2058E+00    19     9    .1140E+04    .3481E+00     6    .4169E-03     7    .3419E-03
   90      .22244    -.04423     20     8    .2056E+00    19     9    .1140E+04    .3482E+00     6    .2220E-03     7    .1713E-03
  100      .22244    -.04423     20     8    .2055E+00    19     9    .1140E+04    .3482E+00     6    .1078E-03     7    .8622E-04
  110      .22244    -.04423     20     8    .2054E+00    19     9    .1140E+04    .3482E+00     6    .5469E-04     7    .4348E-04
  120      .22244    -.04423     20     8    .2054E+00    19     9    .1140E+04    .3482E+00     6    .2771E-04     7    .2196E-04

                    ******  ITERATION LIMIT REACHED  ******
```

```
                                        INTERMEDIATE OUTPUT FOR MEDIUM MESH

       WE =   1.9000      EPS =     .2000     MAXIT FOR THIS MESH =  250

ITERATION    CL         CM      IERR  JERR     ERROR      IRL   JRL      BIGRL        ERCIRC     ICPU    CPERRU     ICPL     CPERRL

   10      .17667    -.03404     37    16    .3445E-01    35    16    .1868E+04    .3594E-01     9    .1368E+01     9    .1212E+01
   20      .17601    -.03392     10    17    .3936E-02     9    16    .1796E+03    .1148E-03    33    .1547E-01    33    .3606E-01
   30      .17701    -.03391     10    17    .3056E-02     9    16    .1384E+03    .3180E-03    25    .5453E-02    11    .8569E-02
   40      .17760    -.03374     10    17    .2310E-02     9    16    .1048E+03    .1822E-03    23    .5505E-02    11    .7405E-02
   50      .17806    -.03357     10    17    .1736E-02     9    16    .7884E+02    .1528E-03    23    .4134E-02    11    .5999E-02
   60      .17844    -.03344     10    17    .1294E-02     9    16    .5884E+02    .1218E-03    22    .2965E-02    11    .4781E-02
   70      .17871    -.03334     10    17    .9553E-03     9    16    .4349E+02    .8333E-04    22    .2136E-02    11    .3711E-02
   80      .17890    -.03327     10    17    .7030E-03     9    16    .3204E+02    .5892E-04    22    .1541E-02    11    .2772E-02
   90      .17904    -.03322     10    17    .5155E-03     9    16    .2352E+02    .4277E-04    22    .1117E-02    11    .2075E-02
  100      .17914    -.03318     10    17    .3770E-03     9    16    .1721E+02    .3095E-04    22    .8113E-03    11    .1538E-02
  110      .17921    -.03316     10    17    .2752E-03     9    16    .1257E+02    .2247E-04    22    .5995E-03    11    .1132E-02
  120      .17926    -.03314     10    17    .2006E-03     9    16    .9168E+01    .1632E-04    22    .4265E-03    11    .8214E-03
  130      .17930    -.03312     10    17    .1462E-03     9    16    .6680E+01    .1184E-04    22    .3125E-03    11    .6087E-03
  140      .17933    -.03311     10    17    .1064E-03     9    16    .4864E+01    .8588E-05    22    .2264E-03    11    .4446E-03
  150      .17935    -.03311     10    17    .7742E-04     9    16    .3540E+01    .6234E-05    22    .1646E-03    11    .3243E-03
  160      .17936    -.03310     10    17    .5632E-04     9    16    .2575E+01    .4529E-05    22    .1195E-03    11    .2363E-03
  170      .17937    -.03310     10    17    .4096E-04     9    16    .1873E+01    .3294E-05    22    .8694E-04    11    .1721E-03
  180      .17938    -.03309     10    17    .2978E-04     9    16    .1362E+01    .2396E-05    22    .6319E-04    11    .1253E-03
  190      .17939    -.03309     10    17    .2165E-04     9    16    .9971E+00    .1743E-05    22    .4592E-04    11    .9119E-04
  200      .17939    -.03309     10    17    .1573E-04     9    16    .7196E+00    .1268E-05    22    .3337E-04    11    .6634E-04
  210      .17940    -.03309     10    17    .1144E-04     9    16    .5230E+00    .9215E-06    22    .2425E-04    11    .4825E-04
  220      .17940    -.03309     10    17    .8310E-05     9    16    .3801E+00    .6697E-06    22    .1762E-04    11    .3508E-04

                    ******  SOLUTION CONVERGED  ******
```

Figure 4-8.- Continued

```
                                        INTERMEDIATE OUTPUT FOR FINE MESH

        WE =   1.9500     EPS =     .2000     MAXIT FOR THIS MESH =   500

ITERATION    CL          CM       IERR   JERR      ERROR       IRL     JRL       BIGRL          ERCIRC      ICPU      CPERRU      ICPL      CPERRL

    10      .17816     -.03330      8     33     .3351E-02     16      32     .3816E+03      .2225E-04     17     .1178E+01     17     .1371E+01
    20      .17814     -.03325     15     18     .1189E-02     17      32     .2861E+03      .9872E-06     22     .6199E-02     21     .9104E-02
    30      .17821     -.03319     17     36     .9006E-03     17      32     .2281E+03      .4088E-04     24     .2580E-02     21     .4984E-02
    40      .17843     -.03320     80     32     .7876E-03     17      32     .1934E+03      .8575E-04     65     .1624E-02     20     .2726E-02
    50      .17867     -.03322     18     35     .6715E-03     17      32     .1713E+03      .8253E-04     65     .1430E-02     22     .1591E-02
    60      .17886     -.03322     17     35     .5803E-03     17      32     .1480E+03      .5796E-04     36     .1152E-02     22     .1976E-02
    70      .17901     -.03320     17     36     .4923E-03     17      32     .1254E+03      .4850E-04     27     .1025E-02     22     .1920E-02
    80      .17913     -.03318     17     36     .4137E-03     17      32     .1053E+03      .4173E-04     27     .8778E-03     21     .1749E-02
    90      .17924     -.03317     17     36     .3473E-03     17      32     .8846E+02      .3559E-04     27     .7117E-03     21     .1446E-02
   100      .17933     -.03316     17     36     .2928E-03     17      32     .7466E+02      .3017E-04     27     .5928E-03     21     .1178E-02
   110      .17941     -.03315     17     36     .2470E-03     17      32     .6301E+02      .2511E-04     27     .5037E-03     21     .9950E-03
   120      .17947     -.03314     17     36     .2082E-03     17      32     .5314E+02      .2100E-04     27     .4273E-03     21     .8425E-03
   130      .17953     -.03313     17     36     .1755E-03     17      32     .4480E+02      .1762E-04     27     .3602E-03     21     .7144E-03
   140      .17957     -.03313     17     36     .1479E-03     17      32     .3776E+02      .1487E-04     27     .3350E-03     21     .6031E-03
   150      .17961     -.03312     17     36     .1246E-03     17      32     .3182E+02      .1249E-04     26     .2574E-03     21     .5096E-03
   160      .17964     -.03312     17     36     .1049E-03     17      32     .2681E+02      .1048E-04     26     .2168E-03     21     .4301E-03
   170      .17967     -.03311     17     36     .8838E-04     17      32     .2258E+02      .8925E-05     26     .1827E-03     21     .3626E-03
   180      .17969     -.03311     17     36     .7446E-04     17      32     .1902E+02      .7546E-05     26     .1536E-03     21     .3057E-03
   190      .17971     -.03311     17     36     .6273E-04     17      32     .1603E+02      .6363E-05     26     .1293E-03     21     .2582E-03
   200      .17973     -.03310     17     36     .5284E-04     17      32     .1350E+02      .5359E-05     26     .1093E-03     21     .2181E-03
   210      .17974     -.03310     17     36     .4451E-04     17      32     .1138E+02      .4477E-05     26     .9214E-04     21     .1833E-03
   220      .17975     -.03310     17     36     .3750E-04     17      32     .9586E+01      .3750E-05     26     .7788E-04     21     .1541E-03
   230      .17976     -.03310     17     36     .3159E-04     17      32     .8077E+01      .3154E-05     26     .6574E-04     21     .1298E-03
   240      .17977     -.03310     17     36     .2661E-04     17      32     .6804E+01      .2657E-05     26     .5543E-04     21     .1093E-03
   250      .17978     -.03310     17     36     .2242E-04     17      32     .5733E+01      .2239E-05     26     .4668E-04     21     .9211E-04
   260      .17978     -.03310     17     36     .1889E-04     17      32     .4829E+01      .1887E-05     26     .3933E-04     21     .7764E-04
   270      .17979     -.03310     17     36     .1591E-04     17      32     .4069E+01      .1589E-05     26     .3313E-04     21     .6543E-04
   280      .17979     -.03309     17     36     .1340E-04     17      32     .3427E+01      .1338E-05     26     .2791E-04     21     .5514E-04
   290      .17979     -.03309     17     36     .1129E-04     17      32     .2887E+01      .1127E-05     26     .2352E-04     21     .4646E-04
   300      .17980     -.03309     17     36     .9511E-05     17      32     .2432E+01      .9468E-06     26     .1981E-04     21     .3914E-04

                    ******   SOLUTION CONVERGED   ******




                                                           ******************
                                                           *                *
                                                           *  FINAL OUTPUT  *
                                                           *                *
                                                           ******************

 PRINTOUT IN  PHYSICAL  VARIABLES.

 DEFINITION OF SIMILARITY PARAMETERS BY KRUPP

 BOUNDARY CONDITION FOR FREE JET

 DIFFERENCE EQUATIONS ARE FULLY CONSERVATIVE.

 KUTTA CONDITION IS ENFORCED.

             MACH =   1.1000000
            DELTA =    .0600000
            ALPHA =   2.0000000
                K =  -1.2456397

        PARAMETERS USED TO TRANSFORM VARIABLES
                   TO TRANSONIC SCALING

           CPFACT =    .1426887
           CDFACT =    .0085613
           CMFACT =    .1426887
           CLFACT =    .1426887
            YFACT =   2.4354913
            VFACT =   3.4377467
```

Figure 4-8.- Continued

```
                                                    FINAL OUTPUT FOR FINE MESH

FORCE COEFFICIENTS, PRESSURE COEFFICIENT, AND MACH NUMBER
(OR SIMILARITY PARAMETER) ON BODY AND DIVIDING STREAM LINE.
                                                                                   B = BEFORE OR BEHIND AIRFOIL
        CL =   .179798                                                             U = UPPER AIRFOIL SURFACE
        CM =  -.033093                                                             L = LOWER AIRFOIL SURFACE
       CP* =   .148116                                                             * = CRITICAL PRESSURE

                          LOWER                       UPPER
                          Y=0-                        Y=0+
 I        X          CP          M1              CP          M1

 1   -4.826958   -0.000000    1.100000       -0.000000    1.100000                            *  B
 2   -1.472160   -0.000000    1.100000       -0.000000    1.100000                            *  B
 3   -1.170661   -0.000000    1.100000       -0.000000    1.100000                            *  B
 4    -.972966   -0.000000    1.100000       -0.000000    1.100000                            *  B
 5    -.809857     .000000    1.100000         .000000    1.100000                            *  B
 6    -.653469     .004128    1.097336         .004128    1.097336                            *  B
 7    -.479854     .160203     .991394         .160203     .991394                            *
 8    -.295092     .356900     .844091         .356900     .844091                       B    *
 9    -.178882     .428632     .776067         .428632     .776067                      B     *
10    -.114702     .505191     .702663         .505191     .702663                    B       *
11    -.075551     .581942     .620416         .581942     .620416                  B         *
12    -.050198     .664116     .518082         .664116     .518082                 B          *
13    -.032930     .757480     .368831         .757480     .368831              B             *
14    -.020518     .873372    0.000000         .873372    0.000000            B               *
15    -.011063    1.039884    0.000000        1.039884    0.000000        B                   *
16    -.003465    1.326950    0.000000        1.326950    0.000000  B                         *
                       AIRFOIL LEADING EDGE                                             AIRFOIL LEADING EDGE
17     .003024    1.330277    0.000000         .926890    0.000000  L        U                *
18     .008803     .699742     .466796         .308148     .879264                L       U   *
19     .014240     .522078     .685413         .163714     .958881                    L      U*
20     .019568     .437645     .767791         .100125    1.033461                     L      *U
21     .025061     .381418     .818065         .060113    1.060552                       L    * U
22     .030961     .337251     .855477         .030570    1.080119                        L   * U
23     .037614     .298972     .886631         .004678    1.096981                        L   *  U
24     .045413     .263379     .914646        -.019436    1.112487                         L  *  U
25     .054966     .228482     .941305        -.043288    1.127552                          L *   U
26     .067013     .193095     .967588        -.067548    1.142703                           L*   U
27     .082363     .156126     .994305        -.092332    1.157976                            *    U
28     .101517     .116170    1.022395        -.117106    1.173045                            *     U
29     .124201     .078579    1.048136        -.140930    1.187355                            *L    U
30     .149372     .047527    1.068932        -.162869    1.200383                            * L    U
31     .175806     .020784    1.086523        -.182423    1.211875                            *  L   U
32     .202583    -.002261    1.101456        -.199570    1.221864                            *  L   U
33     .229179    -.022176    1.114203        -.214566    1.230534                            *  L    U
34     .255353    -.039540    1.125193        -.227748    1.238105                            *   L   U
35     .281029    -.054875    1.134814        -.239443    1.244783                            *   L   U
36     .306213    -.068600    1.143356        -.249931    1.250742                            *   L   U
37     .330950    -.081026    1.151034        -.259440    1.256120                            *    L   U
38     .355299    -.092383    1.158008        -.268151    1.261026                            *    L   U
39     .379323    -.102844    1.164394        -.276263    1.265545                            *    L   U
40     .403081    -.112545    1.170285        -.283701    1.269738                            *    L   U
41     .426629    -.121598    1.175756        -.290724    1.273653                            *     L  U
42     .450015    -.130095    1.180868        -.297333    1.277326                            *     L  U
43     .473280    -.138113    1.185672        -.303577    1.280787                            *     L   U
44     .496460    -.145719    1.190211        -.309496    1.284059                            *     L   U
45     .519582    -.152972    1.194523        -.315129    1.287165                            *     L   U
46     .542669    -.159922    1.198641        -.320510    1.290125                            *     L   U
47     .565740    -.166619    1.202595        -.325677    1.292961                            *      L  U
48     .588807    -.173105    1.206412        -.330667    1.295694                            *      L  U
49     .611881    -.179424    1.210119        -.335517    1.298345                            *      L  U
50     .634971    -.185614    1.213740        -.340265    1.300935                            *      L  U
51     .658084    -.191712    1.217297        -.344948    1.303484                            *      L   U
52     .681229    -.197753    1.220810        -.349600    1.306012                            *      L   U
53     .704417    -.203771    1.224299        -.354256    1.308537                            *      L   U
54     .727663    -.209796    1.227783        -.358949    1.311077                            *       L  U
55     .750988    -.215858    1.231278        -.363710    1.313649                            *       L  U
56     .774418    -.221990    1.234803        -.368571    1.316269                            *       L  U
57     .797988    -.228221    1.238376        -.373562    1.318954                            *       L  U
58     .821742    -.234586    1.242014        -.378715    1.321721                            *       L  U
59     .845736    -.241120    1.245738        -.384067    1.324589                            *       L  U
60     .870039    -.247866    1.249571        -.389656    1.327575                            *       L  U
61     .894736    -.254872    1.253539        -.395528    1.330708                            *        L  U
62     .919931    -.262194    1.257673        -.401736    1.334011                            *        L  U
63     .945757    -.269905    1.262012        -.408346    1.337519                            *        L  U
64     .972377    -.278091    1.266602        -.415441    1.341274                            *        L  U
65    1.000000    -.234942    1.242217        -.303550    1.280772                            *       L U
                       AIRFOIL TRAILING EDGE                                            AIRFOIL TRAILING EDGE
66    1.028899    -.189936    1.216262        -.189936    1.216262                            *      B
67    1.059441    -.188360    1.215343        -.188360    1.215343                            *      B
68    1.092135    -.191908    1.217411        -.191908    1.217411                            *      B
69    1.127723    -.196275    1.219951        -.196275    1.219951                            *      B
70    1.167351    -.201266    1.222848        -.201266    1.222848                            *      B
71    1.212946    -.207003    1.226169        -.207003    1.226169                            *       B
72    1.268145    -.213838    1.230114        -.213838    1.230114                            *       B
73    1.341184    -.222620    1.235165        -.222620    1.235165                            *       B
74    1.456833    -.233196    1.241221        -.233196    1.241221                            *       B
75    1.671514    -.237715    1.243799        -.237715    1.243799                            *       B
76    1.876313    -.227569    1.238002        -.227569    1.238002                            *       B
77    2.042561    -.200768    1.222559        -.200768    1.222559                            *      B
78    2.209055    -.147135    1.191054        -.147135    1.191054                            *     B
79    2.406774    -.010744    1.106902        -.010744    1.106902                            *  B
80    2.702997     .095516    1.036618         .095516    1.036618                            *B
81    4.890373     .107149    1.028631         .107149    1.028631                            *B
```

Figure 4-8.- Continued

```
***** CAUTION *****
MAXIMUM MACH NUMBER EXCEEDS 1.3
SHOCK JUMPS IN ERROR IF UPSTREAM NORMAL MACH NUMBER GREATER THAN 1.3


               Y-GRID VALUES      Y(J) J=    1 TO  64
             -2.000000    -1.812909    -1.642930    -1.488178    -1.347027    -1.218072    -1.100091     -.992019
              -.892925     -.801993     -.718505     -.641829     -.571404     -.506738     -.447391     -.392976
              -.343146     -.297595     -.256050     -.218269     -.184038     -.153167     -.125487     -.100852
              -.079132     -.060216     -.044007     -.030425     -.019401     -.010882     -.004827     -.001205
               .001205      .004827      .010882      .019401      .030425      .044007      .060216      .079132
               .100852      .125487      .153167      .184038      .218269      .256050      .297595      .343146
               .392976      .447391      .506738      .571404      .641829      .718505      .801993      .892925
               .992019     1.100091     1.218072     1.347027     1.488178     1.642930     1.812909     2.000000



                                                     SONIC LINE OUTPUT
                                                     *****************
SONIC LINE COORDINATES

     Y           X-SONIC

  1.48818    -.13536   -.08245
  1.34703    -.21078    .00350
  1.21807    -.25496    .07413
  1.10009    -.29580    .12619
   .99202    -.32908    .15905
   .89293    -.35538    .17072
   .80199    -.37752    .17473
   .71851    -.39664    .17536
   .64183    -.41325    .17391
   .57140    -.42762    .17022
   .50674    -.43996    .16407
   .44739    -.45044    .15576
   .39298    -.45923    .14623
   .34315    -.46649    .13688
   .29759    -.47241    .12701
   .25605    -.47714    .11763
   .21827    -.48100    .10839
   .18404    -.48425    .09894
   .15317    -.48675    .09039
   .12549    -.48866    .08137
   .10085    -.49009    .07344
   .07913    -.49114    .06502
   .06022    -.49189    .05720
   .04401    -.49242    .04965
   .03042    -.49278    .04218
   .01940    -.49301    .03503
   .01088    -.49316    .02832
   .00483    -.49324    .02229
   .00121    -.49329    .01756
 BODY LOCATION
  -.00121    -.49331    .08738
  -.00483    -.49335    .09073
  -.01088    -.49339    .09566
  -.01940    -.49343    .10152
  -.03042    -.49343    .10968
  -.04401    -.49336    .11789
  -.06022    -.49318    .12649
  -.07913    -.49283    .13660
  -.10085    -.49225    .14599
  -.12549    -.49135    .15642
  -.15317    -.49005    .16675
  -.18404    -.48823    .17659
  -.21827    -.48576    .18767
  -.25605    -.48247    .19783
  -.29759    -.47834    .20829
  -.34315    -.47335    .21825
  -.39298    -.46705    .22703
  -.44739    -.45923    .23562
  -.50674    -.44969    .24283
  -.57140    -.43823    .24803
  -.64183    -.42465    .25085
  -.71851    -.40872    .25089
  -.80199    -.39017    .24703
  -.89293    -.36854    .23650
  -.99202    -.34294    .21289
 -1.10009    -.31114    .17028
 -1.21807    -.26934    .10499
 -1.34703    -.22295    .02188
 -1.48818    -.15083   -.07634
```

Figure 4-8.- Continued

```
                                                SHOCK WAVE DRAG AND TOTAL PRESSURE PROFILE OUTPUT
                                                *************************************************

       INVISCID WAKE PROFILES FOR INDIVIDUAL SHOCK WAVES WITHIN MOMENTUM CONTOUR

       SHOCK  1
       WAVE DRAG FOR THIS SHOCK=     .003882
            Y          CD(Y)        PO/POINF

        -1.48817799   .00002216    .99998411
        -1.34702736   .00023112    .99983431
        -1.21807223   .0002703C    .99980623
        -1.10009107   .00065835    .99952804
         -.99201912   .00082368    .99940952
         -.89292538   .0C09840(    .99929459
         -.80199344   .00114331    .99918038
         -.71850542   .00130623    .99906359
         -.64182864   .00147691    .99894123
         -.57140431   .00165876    .99881087
         -.50673795   .00185440    .99867062
         -.44739136   .00206558    .99851923
         -.39297572   .00229307    .99835615
         -.34314575   .00253636    .99818173
         -.29759466   .00279343    .99799745
         -.25604987   .00209871    .99849548
         -.21826935   .00222358    .99840596
         -.18403842   .00233062    .99832923
         -.15316703   .00241893    .99826592
         -.12548743   .00248856    .99821600
         -.10085215   .00254057    .99817872
         -.07913226   .0025769(    .99815268
         -.06021592   .00260013    .99813602
         -.04400713   .00261318    .99812667
         -.03042464   .00261893    .99812254
         -.01940111   .00262001    .99812176
         -.01088238   .00261862    .99812276
         -.00482689   .00261645    .99812432
         -.0012(527   .00261469    .99812558
          .00120527   .00261332    .99812657
          .00482689   .00261097    .99812825
          .01088238   .00260628    .99813161
          .01940111   .00259806    .99813751
          .03042464   .00258470    .99814708
          .04400713   .00256419    .99816178
          .06021592   .00253427    .99818323
          .07913226   .00249261    .99821310
          .10085215   .00243711    .99825289
          .12548743   .00236613    .99830377
          .15316703   .00227878    .99836639
          .18403842   .00217499    .99844080
          .21826935   .00205554    .99852643
          .25604987   .00272972    .99804312
          .29759466   .0024823C    .99822049
          .34314575   .00224928    .99838753
          .39297572   .00203275    .99854276
          .44739136   .00183322    .99868580
          .50673795   .0016500(    .99881715
          .57140431   .00148143    .99893800
          .64182864   .00132508    .99905008
          .71850542   .00117782    .99915564
          .80199344   .00103586    .99925741
          .89292538   .00089479    .99935854
          .99201912   .00074998    .99946236
         1.10009107   .0005978C    .99957145
         1.21807223   .00026902    .99980715
         1.34702736   .00023089    .99983448
         1.48817799   .00002755    .99998025

       SHOCK WAVE EXTENDS OUTSIDE CONTOUR
       PRINTOUT OF SHOCK LOSSES ARE NOT AVAILABLE FOR REST OF SHOCK


                                                             DRAG COEFFICIENT OUTPUT
                                                             ***********************

   CALCULATION OF DRAG COEFFICIENT BY MOMENTUM INTEGRAL METHOD

   BOUNDARIES OF CONTOUR USED             CONTRIBUTION TO CO
   UPSTREAM    X =   -1.170661             CDUP    =     0.000000
   DOWNSTREAM  X =     .727663             CDDOWN  =     .017504
   TOP         Y =    1.488178             CDTOP   =     .002420
   BOTTOM      Y =   -1.488178             CDBOT   =     .003498
   BODY AFT OF X =     .727663             CDBODY  =     .010822
               TOTAL CONTRIBUTIONS AROUND CONTOUR  =     .K34245

   THERE ARE  1 SHOCKS INSIDE CONTOUR. TOTAL CDWAVE =     .003882

   NOTE - ONE OR MORE SHOCKS EXTEND OUTSIDE OF CONTOUR
   CDWAVE DOES NOT EQUAL TOTAL WAVE DRAG

   DRAG CALCULATED FROM MOMENTUM INTEGRAL    CD     =     .038127


    TIME TO RUN CASE WAS  20.11 SECONDS.
```

(b) Output.

Figure 4-8.- Concluded

```
SAMPLE CASE 6 - SUPERSONIC-NACA0006 AIRFOIL-POROUS TUNNEL WALL SIMULATION
$INP
 BCTYPE=5, POR=0.25, MAXIT=1000, AMESH=.TRUE., ALPHA=2.0, EMACH=1.1,
 H=2.0, DELTA=0.06, BCFOIL=1,
$END
```

(a) Input.

```
SAMPLE CASE 6 - SUPERSONIC - NACA0006 AIRFOIL - POROUS TUNNEL WALL SIMULATION


                              INPUT PARAMETERS
                              ****************

EMACH =  1.10000       POR =    .25000      IMIN =    1     BCTYPE =  5        AMESH = T

DELTA =   .06000     CLSET =  0.00000      IMAXI =   81     BCFOIL =  1         PHYS = T

ALPHA =  2.00000       EPS =    .20000      JMIN =    1     PSTART =  1        PSAVE = F

   AK =  0.00000      RIGF =  0.00000      JMAXI =   64     PRTFLO =  1        KUTTA = T

  GAM =  1.40000     WCIRC =  1.00000      MAXIT = 1000     IPRTER = 10          FCR = T

    F =  0.00000    CVERGE =    .00001        NU =  100     SIMDEF =  3

    H =  2.00000    DVERGE =      10.0        NL =   75       ICUT =  2

   WE = 1.80,1.90,1.95

  XIN
 -4.826958   -1.472160   -1.170661    -.972966    -.809857    -.653469    -.479854    -.293092
  -.178882    -.114702    -.075551    -.050198    -.032930    -.020518    -.011063    -.003465
   .003024     .008803     .014240     .019568     .025761     .030961     .037614     .045413
   .054966     .067013     .082363     .101517     .124201     .149372     .175836     .202583
   .229179     .255353     .281029     .306213     .330950     .355299     .379323     .403081
   .426629     .450015     .473280     .496404     .519582     .542669     .565749     .589807
   .611881     .634971     .658084     .681229     .704417     .727663     .750982     .774418
   .797988     .821742     .845736     .870039     .894736     .919931     .945757     .972377
  1.000000    1.028399    1.059441    1.092135    1.127723    1.167351    1.212946    1.268149
  1.341184    1.456833    1.671514    1.876313    2.042561    2.209065    2.436774    2.752997
  4.890373

  YIN
 -1.000000    -.906455    -.821465    -.744089    -.673514    -.609036    -.550046    -.496010
  -.446463    -.400997    -.359253    -.320914    -.285702    -.253369    -.223696    -.196488
  -.171573    -.148797    -.128025    -.109135    -.092019    -.076584    -.062744    -.050426
  -.039566    -.030108    -.022004    -.015212    -.009701    -.005441    -.002413    -.000603
   .000603     .002413     .005441     .009701     .015212     .022004     .030108     .039566
   .050426     .062744     .076584     .092019     .109135     .128025     .148797     .171573
   .196488     .223696     .253369     .285702     .320914     .359253     .400997     .446463
   .496010     .550046     .609036     .673514     .744089     .821465     .906455    1.000000


                     INTERMEDIATE OUTPUT FOR COARSE MESH


      WE =   1.8000      EPS =    .2000      MAXIT FOR THIS MESH =  250

ITERATION   CL        CM       IERR  JERR     ERROR     IRL   JRL     BIGRL       ERCIRC    ICPU   CPERRU    ICPL   CPERRL

   10     .24718   -.04579     21    16    .9428E-01    5     8    .1692E+03   .2631E-01    15   .1559E+01   17   .1494E+01
   20     .22445   -.04678     21     8    .1393E+00   19     8    .2409E+03   .7539E-01     7   .5343E-01    6   .5860E-01
   30     .21628   -.04569      5     9    .5930E-02    5     8    .4444E+02   .4663E-02    17   .2719E-01   17   .3673E-01
   40     .21568   -.04584      5     9    .3268E-02    5     8    .2445E+02   .1434E-03     5   .7394E-02    7   .9736E-02
   50     .21551   -.04588      5     9    .1808E-02    5     8    .1351E+02   .5288E-04     6   .4341E-02    6   .5392E-02
   60     .21546   -.04591      5     8    .1007E-02    5     8    .7522E+01   .4593E-05     5   .2511E-02    6   .2888E-02
   70     .21546   -.04594      5     8    .5620E-03    5     8    .4195E+01   .3777E-05     6   .1430E-02    6   .1593E-02
   80     .21547   -.04595      5     8    .3133E-03    5     8    .2338E+01   .2880E-05     5   .3179E-03    6   .3820E-03
   90     .21548   -.04596      5     8    .1747E-03    5     8    .1304E+01   .1664E-05     5   .4566E-03    6   .4695E-03
  100     .21548   -.04597      5     8    .9745E-04    5     8    .7271E+00   .9199E-06     5   .2576E-03    6   .2726E-03
  110     .21548   -.04597      5     8    .5436E-04    5     8    .4056E+00   .5072E-06     5   .1439E-03    6   .1519E-03
  120     .21548   -.04597      5     8    .3032E-04    5     8    .2262E+00   .2806E-06     6   .8029E-04    6   .8473E-04
  130     .21549   -.04597      5     8    .1692E-04    5     8    .1262E+00   .1557E-06     5   .4480E-04    6   .4726E-04
  140     .21549   -.04597      5     8    .9436E-05    5     8    .7040E-01   .8562E-07     5   .2499E-04    6   .2636E-04

          ******  SOLUTION CONVERGED  ******
```

Figure 4-9.- Sample test case 6 - supersonic, perforated/porous wall simulation (abbreviated output): NACA 0006 airfoil, $\delta = 0.06$, $\alpha = 2°$, $M_\infty = 1.1$, $H = 2$.

```
                                        INTERMEDIATE OUTPUT FOR MEDIUM MESH

         WE =   1.9000     EPS =     .2000     MAXIT FOR THIS MESH =   500

ITERATION    CL          CM       IERR  JERR     ERROR      IRL    JRL       BIGRL        ERCIRC     ICPU     CPERRU     ICPL     CPERRL

   10      .21231     -.04389     41    16    .7013E-02     10      4     .5456E+02     .5279E-03     9     .1035E+01     9     .1089E+01
   20      .21428     -.04363      9     1    .2508E-02      9     16     .5810E+02     .5714E-03     9     .5194E-02    10     .1830E-01
   30      .21537     -.04365      8     4    .1432E-02      9     16     .6361E+02     .2881E-03    10     .2365E-02    10     .4220E-02
   40      .21586     -.04368      9    14    .1207E-02      9     16     .5724E+02     .1219E-03    11     .1980E-02     9     .6817E-03
   50      .21605     -.04372      9    17    .1051E-02      9     16     .4990E+02     .4649E-04    12     .1275E-02    11     .1060E-02
   60      .21613     -.04374      9    17    .9196E-03      9     16     .4361E+02     .1941E-04    13     .8333E-03    11     .1004E-02
   70      .21616     -.04376     10    17    .8019E-03      9     16     .3799E+02     .1036E-04    13     .5903E-03    11     .9613E-03
   80      .21619     -.04378     10    17    .6966E-03      9     16     .3298E+02     .6725E-05    13     .5929E-03    11     .3777E-03
   90      .21620     -.04379     10    17    .6034E-03      9     16     .2856E+02     .5051E-05    13     .5157E-03    11     .7820E-03
  100      .21621     -.04381     10    17    .5220E-03      9     16     .2470E+02     .3547E-05    13     .4433E-03    11     .6867E-03
  110      .21622     -.04382     10    17    .4537E-03      9     16     .2132E+02     .2503E-05    13     .3997E-03    11     .6019E-03
  120      .21623     -.04383     10    17    .3885E-03      9     16     .1837E+02     .1915E-05    13     .3374E-03    11     .5270E-03
  130      .21623     -.04384     10    17    .3345E-03      9     16     .1582E+02     .1538E-05    13     .2914E-03    11     .4583E-03
  140      .21624     -.04384     10    17    .2878E-03      9     16     .1360E+02     .1267E-05    13     .2515E-03    11     .3971E-03
  150      .21624     -.04385     10    17    .2474E-03      9     16     .1169E+02     .1057E-05    13     .2163E-03    11     .3433E-03
  160      .21624     -.04386     10    17    .2125E-03      9     16     .1004E+02     .8867E-06    13     .1867E-03    11     .2963E-03
  170      .21624     -.04386     10    17    .1825E-03      9     16     .8621E+01     .7775E-06    13     .1604E-03    11     .2552E-03
  180      .21625     -.04386     10    17    .1567E-03      9     16     .7401E+01     .8181E-06    13     .1377E-03    11     .2190E-03
  190      .21625     -.04387     10    17    .1344E-03      9     16     .6351E+01     .7808E-06    13     .1189E-03    11     .1889E-03
  200      .21625     -.04387     10    17    .1153E-03      9     16     .5447E+01     .6944E-06    13     .1020E-03    11     .1623E-03
  210      .21625     -.04287     10    17    .9888E-04      9     16     .4671E+01     .6028E-06    13     .8822E-04    11     .1393E-03
  220      .21625     -.04388     10    17    .8477E-04      9     16     .4004E+01     .5186E-06    13     .7555E-04    11     .1195E-03
  230      .21626     -.04388     10    17    .7266E-04      9     16     .3432E+01     .4446E-06    13     .6482E-04    11     .1027E-03
  240      .21626     -.04388     10    17    .6227E-04      9     16     .2941E+01     .3806E-06    13     .5559E-04    11     .8808E-04
  250      .21626     -.04388     10    17    .5336E-04      9     16     .2521E+01     .3256E-06    13     .4766E-04    11     .7555E-04
  260      .21626     -.04388     10    17    .4571E-04      9     16     .2159E+01     .2786E-06    13     .4085E-04    11     .6476E-04
  270      .21626     -.04388     10    17    .3916E-04      9     16     .1849E+01     .2363E-06    13     .3511E-04    11     .5554E-04
  280      .21626     -.04389     10    17    .3355E-04      9     16     .1594E+01     .2039E-06    13     .3003E-04    11     .4760E-04
  290      .21626     -.04389     10    17    .2873E-04      9     16     .1357E+01     .1744E-06    13     .2570E-04    11     .4079E-04
  300      .21626     -.04389     10    17    .2461E-04      9     16     .1162E+01     .1493E-06    13     .2202E-04    11     .3493E-04
  310      .21626     -.04389     10    17    .2108E-04      9     16     .9953E+00     .1277E-06    13     .1885E-04    11     .2995E-04
  320      .21626     -.04389     10    17    .1805E-04      9     16     .8523E+00     .1093E-06    13     .1615E-04    11     .2565E-04
  330      .21626     -.04389     10    17    .1546E-04      9     16     .7299E+00     .9354E-07    13     .1384E-04    11     .2197E-04
  340      .21626     -.04389     10    17    .1324E-04      9     16     .6250E+00     .8006E-07    13     .1185E-04    11     .1882E-04
  350      .21626     -.04389     10    17    .1133E-04      9     16     .5352E+00     .6852E-07    13     .1015E-04    11     .1612E-04
  360      .21626     -.04389     10    17    .9705E-05      9     16     .4583E+00     .5865E-07    13     .8592E-05    11     .1380E-04

                    ******  SOLUTION CONVERGED  ******



                                        INTERMEDIATE OUTPUT FOR FINE MESH

        WE =   1.9500     EPS =     .2000     MAXIT FOR THIS MESH = 1000

ITERATION    CL          CM       IERR  JERR     ERROR      IRL    JRL       BIGRL        ERCIRC     ICPU     CPERRU     ICPL     CPERRL

   10      .21464     -.04406      9    33    .3748E-02     17     32     .5463E+03     .1834E-03    17     .1133E+01    17     .1344E+01
   20      .21513     -.04427     17    17    .2078E-02     17     32     .4921E+03     .1254E-03    22     .4269E-02    20     .5186E-02
   30      .21533     -.04431     19    12    .1893E-02     17     32     .4637E+03     .4542E-04    23     .8846E-03    20     .2133E-02
   40      .21544     -.04429     18    37    .1715E-02     17     32     .4461E+03     .3481E-04    43     .6133E-03    21     .9796E-03
   50      .21551     -.04426     18    35    .1651E-02     17     32     .4298E+03     .2214E-04    31     .7471E-03    23     .1133E-02
   60      .21556     -.04423     17    35    .1574E-02     17     32     .4098E+03     .1361E-04    27     .4866E-03    22     .1008E-02
   70      .21560     -.04421     17    36    .1497E-02     17     32     .3898E+03     .1540E-04    24     .5932E-03    21     .1633E-02
   80      .21564     -.04419     18    37    .1440E-02     17     32     .3752E+03     .1262E-04    27     .4499E-03    21     .1043E-02
   90      .21567     -.04417     18    35    .1392E-02     17     32     .3632E+03     .8310E-05    26     .4583E-03    22     .9184E-03
  100      .21569     -.04415     18    36    .1347E-02     17     32     .3516E+03     .7620E-05    25     .3990E-03    21     .8334E-03
  110      .21571     -.04414     18    35    .1307E-02     17     32     .3413E+03     .6661E-05    26     .3752E-03    22     .7365E-03
  120      .21573     -.04413     18    35    .1270E-02     17     32     .3316E+03     .4733E-05    25     .3525E-03    22     .5975E-03
  130      .21574     -.04411     18    35    .1234E-02     17     32     .3224E+03     .2818E-05    26     .3258E-03    22     .6459E-03
```

Figure 4-9.- Continued

```
 140     .21575   -.04410   18   35   .1200E-02   17   32   .3137E+03   .5540E-05   25   .3083E-03   22   .6665E-03
 150     .21577   -.04410   18   35   .1168E-02   17   32   .3054E+03   .7294E-05   26   .2968E-03   22   .5811E-03
 160     .21578   -.04409   18   35   .1136E-02   17   32   .2969E+03   .4139E-05   26   .2946E-03   22   .5758E-03
 170     .21580   -.04408   18   35   .1103E-02   17   32   .2885E+03   .5502E-05   26   .3001E-03   22   .5865E-03
 180     .21582   -.04407   18   35   .1070E-02   17   32   .2798E+03   .4956E-05   26   .3264E-03   22   .5972E-03
 190     .21583   -.04406   18   34   .1035E-02   17   32   .2708E+03   .3619E-05   26   .3693E-03   22   .6317E-03
 200     .21584   -.04404   18   34   .9933E-03   17   32   .2612E+03   .4095E-05   26   .3979E-03   22   .6801E-03
 210     .21585   -.04403   18   34   .9603E-03   17   32   .2513E+03   .3742E-05   26   .4057E-03   22   .7070E-03
 220     .21586   -.04402   18   35   .9219E-03   17   32   .2413E+03   .4323E-05   26   .4021E-03   22   .7126E-03
 230     .21587   -.04401   18   35   .8842E-03   17   32   .2314E+03   .2866E-05   25   .3866E-03   22   .6995E-03
 240     .21588   -.04400   18   35   .8474E-03   17   32   .2218E+03   .1877E-05   25   .3687E-03   22   .6731E-03
 250     .21589   -.04398   18   35   .8116E-03   17   32   .2125E+03   .3031E-05   26   .3536E-03   22   .6479E-03
 260     .21589   -.04397   18   35   .7759E-03   17   32   .2035E+03   .1034E-05   26   .3373E-03   22   .6253E-03
 270     .21589   -.04396   18   35   .7434E-03   17   32   .1947E+03   .2244E-06   26   .3228E-03   22   .5982E-03
 280     .21589   -.04395   18   35   .7110E-03   17   32   .1863E+03   .7190E-06   26   .3082E-03   22   .5740E-03
 290     .21589   -.04394   18   35   .6794E-03   17   32   .1780E+03   .8900E-06   26   .2954E-03   22   .5532E-03
 300     .21588   -.04392   18   35   .6489E-03   17   32   .1701E+03   .2203E-05   25   .2841E-03   22   .5272E-03
 310     .21588   -.04391   18   35   .6197E-03   17   32   .1625E+03   .9953E-06   25   .2703E-03   22   .5041E-03
 320     .21588   -.04390   18   35   .5916E-03   17   32   .1551E+03   .2114E-05   25   .2587E-03   22   .4835E-03
 330     .21587   -.04389   18   35   .5646E-03   17   32   .1481E+03   .2136E-05   25   .2476E-03   22   .4591E-03
 340     .21586   -.04388   18   35   .5387E-03   17   32   .1413E+03   .1718E-05   25   .2337E-03   22   .4392E-03
 350     .21586   -.04387   18   35   .5137E-03   17   32   .1347E+03   .2892E-05   25   .2251E-03   22   .4244E-03
 360     .21585   -.04386   18   35   .4898E-03   17   32   .1285E+03   .2826E-05   25   .2149E-03   21   .4057E-03
 370     .21584   -.04385   18   35   .4665E-03   17   32   .1224E+03   .2596E-05   25   .2074E-03   22   .3910E-03
 380     .21583   -.04385   18   34   .4441E-03   17   32   .1165E+03   .3320E-05   25   .2041E-03   21   .3728E-03
 390     .21582   -.04384   18   34   .4229E-03   17   32   .1110E+03   .3006E-05   24   .1959E-03   21   .3499E-03
 400     .21581   -.04383   18   34   .4026E-03   17   32   .1057E+03   .2687E-05   24   .1843E-03   22   .3329E-03
 410     .21581   -.04382   18   34   .3833E-03   17   32   .1006E+03   .3066E-05   24   .1766E-03   21   .3187E-03
 420     .21580   -.04382   18   34   .3651E-03   17   32   .9585E+02   .2643E-05   24   .1650E-03   21   .3011E-03
 430     .21579   -.04381   18   34   .3477E-03   17   32   .9128E+02   .2395E-05   24   .1585E-03   22   .2875E-03
 440     .21578   -.04380   18   34   .3311E-03   17   32   .8694E+02   .2234E-05   24   .1525E-03   21   .2759E-03
 450     .21578   -.04380   18   34   .3153E-03   17   32   .8280E+02   .2154E-05   24   .1434E-03   21   .2604E-03
 460     .21577   -.04379   18   35   .3000E-03   17   32   .7879E+02   .2199E-05   24   .1378E-03   22   .2538E-03
 470     .21577   -.04379   18   35   .2853E-03   17   32   .7491E+02   .2124E-05   25   .1345E-03   22   .2492E-03
 480     .21576   -.04378   18   35   .2712E-03   17   32   .7121E+02   .1989E-05   25   .1283E-03   21   .2363E-03
 490     .21575   -.04378   18   34   .2578E-03   17   32   .6770E+02   .1934E-05   24   .1230E-03   21   .2228E-03
 500     .21575   -.04377   18   34   .2452E-03   17   32   .6441E+02   .1663E-05   24   .1160E-03   21   .2113E-03
 510     .21574   -.04377   18   34   .2333E-03   17   32   .6130E+02   .1634E-05   25   .1097E-03   21   .1994E-03
 520     .21574   -.04376   18   34   .2220E-03   17   32   .5832E+02   .1608E-05   25   .1062E-03   21   .1897E-03
 530     .21574   -.04376   18   35   .2113E-03   17   32   .5552E+02   .1307E-05   25   .1000E-03   22   .1828E-03
 540     .21573   -.04375   18   34   .2013E-03   17   32   .5288E+02   .1291E-05   25   .9573E-04   21   .1726E-03
 550     .21573   -.04375   18   34   .1917E-03   17   32   .5037E+02   .1165E-05   25   .9223E-04   21   .1634E-03
 560     .21573   -.04375   18   34   .1826E-03   17   32   .4797E+02   .1022E-05   25   .8716E-04   22   .1568E-03
 570     .21572   -.04374   18   34   .1740E-03   17   32   .4571E+02   .1003E-05   25   .8389E-04   21   .1494E-03
 580     .21572   -.04374   18   34   .1659E-03   17   32   .4359E+02   .8897E-06   25   .8017E-04   22   .1411E-03
 590     .21572   -.04374   18   34   .1581E-03   17   32   .4155E+02   .7831E-06   25   .7669E-04   22   .1360E-03
 600     .21571   -.04373   18   34   .1508E-03   17   32   .3964E+02   .7307E-06   25   .7369E-04   21   .1293E-03
 610     .21571   -.04373   18   34   .1439E-03   17   32   .3782E+02   .6647E-06   25   .7041E-04   22   .1227E-03
 620     .21571   -.04373   18   34   .1373E-03   17   32   .3608E+02   .6042E-06   25   .6797E-04   22   .1184E-03
 630     .21571   -.04373   18   34   .1311E-03   17   32   .3445E+02   .4745E-06   25   .6521E-04   22   .1121E-03
 640     .21571   -.04373   18   34   .1250E-03   17   32   .3285E+02   .5335E-06   25   .6463E-04   22   .1082E-03
 650     .21571   -.04372   17   35   .1192E-03   17   32   .3134E+02   .5012E-06   25   .6196E-04   22   .1055E-03
 660     .21571   -.04372   17   35   .1137E-03   17   32   .2989E+02   .4702E-06   25   .5931E-04   22   .1011E-03
 670     .21570   -.04372   17   35   .1085E-03   17   32   .2851E+02   .4174E-06   25   .5621E-04   22   .9681E-04
 680     .21570   -.04372   17   35   .1036E-03   17   32   .2724E+02   .3787E-06   26   .5399E-04   22   .9092E-04
 690     .21570   -.04372   17   35   .9902E-04   17   32   .2603E+02   .3358E-06   26   .5210E-04   22   .8697E-04
 700     .21570   -.04371   17   35   .9466E-04   17   32   .2489E+02   .3035E-06   26   .5126E-04   22   .8269E-04
 710     .21570   -.04371   17   35   .9059E-04   17   32   .2382E+02   .2698E-06   25   .4855E-04   22   .7897E-04
 720     .21570   -.04371   17   35   .8680E-04   17   32   .2282E+02   .2374E-06   26   .4694E-04   22   .7513E-04
 730     .21570   -.04371   17   35   .8334E-04   17   32   .2192E+02   .2066E-06   25   .4549E-04   22   .7095E-04
 740     .21570   -.04371   17   35   .8017E-04   17   32   .2108E+02   .1622E-06   26   .4443E-04   22   .6649E-04
 750     .21570   -.04371   17   35   .7724E-04   17   32   .2026E+02   .1445E-06   25   .4403E-04   22   .6557E-04
 760     .21570   -.04371   17   35   .7398E-04   17   32   .1946E+02   .1290E-06   26   .4304E-04   22   .6453E-04
 770     .21570   -.04370   17   35   .7099E-04   17   32   .1867E+02   .1124E-06   25   .4160E-04   22   .6284E-04
 780     .21570   -.04370   17   35   .6810E-04   17   32   .1791E+02   .9616E-07   26   .4000E-04   22   .6075E-04
 790     .21570   -.04370   17   35   .6532E-04   17   32   .1718E+02   .8166E-07   26   .3838E-04   22   .5650E-04
 800     .21570   -.04370   17   35   .6264E-04   17   32   .1648E+02   .6987E-07   26   .3683E-04   22   .5625E-04
 810     .21570   -.04270   17   35   .6007E-04   17   32   .1580E+02   .6071E-07   26   .3535E-04   22.  .5409E-04
 820     .21570   -.04370   17   35   .5758E-04   17   32   .1515E+02   .5348E-07   26   .3393E-04   22   .5282E-04
 830     .21570   -.04370   17   35   .5520E-04   17   32   .1452E+02   .4751E-07   26   .3257E-04   22   .5001E-04
 840     .21570   -.04370   17   35   .5290E-04   17   32   .1391E+02   .4243E-07   26   .3126E-04   22   .4807E-04
 850     .21570   -.04370   17   35   .5069E-04   17   32   .1333E+02   .3811E-07   26   .3000E-04   22   .4619E-04
 860     .21570   -.04370   17   35   .4857E-04   17   32   .1278E+02   .4450E-07   26   .2875E-04   22   .4436E-04
 870     .21570   -.04370   17   35   .4653E-04   17   32   .1224E+02   .4052E-07   26   .2754E-04   22   .4261E-04
 880     .21570   -.04370   17   35   .4457E-04   17   32   .1172E+02   .3643E-07   26   .2639E-04   22   .4091E-04
 890     .21570   -.04369   17   35   .4259E-04   17   32   .1123E+02   .3294E-07   26   .2531E-04   22   .3927E-04
 900     .21570   -.04369   17   35   .4088E-04   17   32   .1075E+02   .2980E-07   26   .2426E-04   22   .3769E-04
 910     .21570   -.04369   17   35   .3915E-04   17   32   .1030E+02   .2694E-07   26   .2326E-04   22   .3616E-04
 920     .21570   -.04369   17   35   .3748E-04   17   32   .9859E+01   .2438E-07   26   .2229E-04   22   .3469E-04
 930     .21569   -.04369   17   35   .3588E-04   17   32   .9439E+01   .2209E-07   26   .2136E-04   22   .3327E-04
 940     .21569   -.04369   17   35   .3435E-04   17   32   .9036E+01   .2000E-07   25   .2047E-04   22   .3191E-04
 950     .21569   -.04369   17   35   .3288E-04   17   32   .8649E+01   .1810E-07   26   .1961E-04   22   .3059E-04
 960     .21569   -.04369   17   35   .3147E-04   17   32   .8278E+01   .1638E-07   26   .1878E-04   22   .2933E-04
 970     .21569   -.04369   17   35   .3012E-04   17   32   .7922E+01   .1482E-07   26   .1799E-04   22   .2811E-04
 980     .21569   -.04369   17   35   .2832E-04   17   32   .7581E+01   .1339E-07   26   .1723E-04   22   .2694E-04
 990     .21569   -.04369   17   35   .2758E-04   17   32   .7254E+01   .1209E-07   25   .1649E-04   22   .2581E-04
1000     .21569   -.04369   17   35   .2638E-04   17   32   .6941E+01   .1091E-07   25   .1579E-04   22   .2473E-04

                  ******  ITERATION LIMIT REACHED  ******
```

Figure 4-9.- Continued

```
                                                            ******************
                                                            *                *
                                                            *  FINAL OUTPUT  *
                                                            *                *
                                                            ******************
PRINTOUT IN  PHYSICAL  VARIABLES.

DEFINITION OF SIMILARITY PARAMETERS BY KRUPP

BOUNDARY CONDITION FOR POROUS WALL

DIFFERENCE EQUATIONS ARE FULLY CONSERVATIVE.

KUTTA CONDITION IS ENFORCED.

            MACH =   1.1000000
           DELTA =    .0600000
           ALPHA =   2.0000000
               K =  -1.2456397

       PARAMETERS USED TO TRANSFORM VARIABLES
                TO TRANSONIC SCALING

          CPFACT =    .1426887
          CDFACT =    .0085613
          CMFACT =    .1426887
          CLFACT =    .1426887
           YFACT =   2.4354913
           VFACT =   3.4377467
```

Figure 4-9.- Continued

```
                                                    FINAL OUTPUT FOR FINE MESH


FORCE COEFFICIENTS, PRESSURE COEFFICIENT, AND MACH NUMBER
(OR SIMILARITY PARAMETER) ON BODY AND DIVIDING STREAM LINE.
                                                                                    B = BEFORE OR BEHIND AIRFOIL
        CL =   .215695                                                              U = UPPER AIRFOIL SURFACE
        CM =  -.043689                                                              L = LOWER AIRFOIL SURFACE
       CP* =   .148116                                                              * = CRITICAL PRESSURE

                          LOWER                       UPPER
                          Y=0-                        Y=0+
 I        X           CP          M1              CP          M1

  1   -4.826958   -0.000000    1.100000       -0.000000    1.100000                            *  B
  2   -1.472160   -0.000000    1.100000       -0.000000    1.100000                            *  B
  3   -1.170661     .000000    1.100000         .000000    1.100000                            *  B
  4    -.972966     .000000    1.100000         .000000    1.100000                            *  B
  5    -.809857     .000000    1.100000         .000000    1.100000                            *  B
  6    -.653469     .137155    1.007740         .137155    1.007740                            *
  7    -.479854     .314178     .874388         .314178     .874388                        B   *
  8    -.295092     .386917     .813280         .386917     .813280                       B    *
  9    -.178882     .454829     .751757         .454829     .751757                     B      *
 10    -.114702     .525108     .682273         .525108     .682273                    B       *
 11    -.075551     .597971     .601822         .597971     .601822                  B         *
 12    -.050198     .677483     .499457         .677483     .499457                 B          *
 13    -.032930     .768879     .346229         .768879     .346229               B            *
 14    -.020518     .883189    0.000000         .883189    0.000000            B               *
 15    -.011063    1.048274    0.000000        1.048274    0.000000         B                  *
 16    -.003465    1.332789    0.000000        1.332789    0.000000   B                        *
                       AIRFOIL LEADING EDGE                                              AIRFOIL LEADING EDGE
 17     .003024    1.356567    0.000000         .910249    0.000000  L         U               *
 18     .008803     .727384     .422738         .294086     .890529               L         U  *
 19     .014240     .549219     .656743         .152382     .996971                   L        *
 20     .019568     .464576     .742529         .091298    1.039498                     L      *U
 21     .025061     .408406     .794328         .053712    1.064822                      L     * U
 22     .030961     .364450     .832633         .025855    1.083209                       L    * U
 23     .037614     .326508     .864334         .001710    1.098697                        L   *  U
 24     .045413     .291394     .892669        -.020795    1.113321                         L  *  U
 25     .054966     .257163     .919452        -.042874    1.127292                          L *   U
 26     .067013     .222728     .945629        -.065286    1.141299                          L *   U
 27     .082363     .187851     .971423        -.088190    1.155438                           L*    U
 28     .101517     .152341     .997000        -.110994    1.169345                            *    U
 29     .124201     .116842    1.021930        -.132710    1.182437                            *L    U
 30     .149372     .085611    1.043369        -.152511    1.194250                            *L    U
 31     .175806     .060522    1.060279        -.170003    1.204568                            * L    U
 32     .202583     .039583    1.074188        -.185190    1.213493                            * L    U
 33     .229179     .021880    1.085807        -.198299    1.221127                            *  L   U
 34     .255353     .006760    1.095635        -.209535    1.227690                            *  L   U
 35     .281029    -.006289    1.104045        -.219493    1.233369                            *  L    U
 36     .306213    -.017666    1.111326        -.228130    1.238323                            *  L    U
 37     .330950    -.027676    1.117694        -.235756    1.242682                            *   L   U
 38     .355299    -.036555    1.123311        -.242541    1.246545                            *   L   U
 39     .379323    -.044482    1.128303        -.248618    1.249997                            *   L   U
 40     .403081    -.051600    1.132766        -.254094    1.253099                            *   L   U
 41     .426629    -.058026    1.136781        -.259056    1.255903                            *   L    U
 42     .450015    -.063857    1.140411        -.263575    1.258451                            *   L    U
 43     .473280    -.069173    1.143711        -.267719    1.260779                            *   L    U
 44     .496460    -.074046    1.146727        -.271514    1.262916                            *    L   U
 45     .519582    -.078534    1.149499        -.275031    1.264668                            *    L   U
 46     .542669    -.082692    1.152060        -.278301    1.266719                            *    L   U
 47     .565740    -.086565    1.154441        -.281358    1.268429                            *    L   U
 48     .588807    -.090196    1.156668        -.284236    1.270036                            *    L   U
 49     .611881    -.093622    1.158766        -.286963    1.271558                            *    L   U
 50     .634971    -.096881    1.160758        -.289569    1.273017                            *    L   U
 51     .658084    -.100006    1.162665        -.292030    1.274407                            *    L   U
 52     .681229    -.103032    1.164509        -.294522    1.275765                            *    L   U
 53     .704417    -.105993    1.166309        -.296920    1.277097                            *    L   U
 54     .727663    -.108921    1.168088        -.299300    1.278417                            *    L   U
 55     .750988    -.111852    1.169865        -.301687    1.279742                            *    L   U
 56     .774418    -.114821    1.171663        -.304109    1.281081                            *    L    U
 57     .797988    -.117865    1.173524        -.306594    1.282456                            *     L   U
 58     .821742    -.121024    1.175410        -.309171    1.283679                            *     L   U
 59     .845736    -.124339    1.177408        -.311874    1.285371                            *     L   U
 60     .870039    -.127857    1.179524        -.314740    1.286951                            *     L   U
 61     .894736    -.131632    1.181791        -.317811    1.288641                            *     L   U
 62     .919931    -.135725    1.184244        -.321138    1.290470                            *     L   U
 63     .945757    -.140212    1.186927        -.324733    1.292471                            *     L   U
 64     .972377    -.145186    1.189893        -.328821    1.294684                            *     L   U
 65    1.000000    -.097086    1.160883        -.188877    1.215645                            *    L U
                       AIRFOIL TRAILING EDGE                                            AIRFOIL TRAILING EDGE
 66    1.028899    -.043830    1.127893        -.043830    1.127893                            *   B
 67    1.059441    -.033450    1.121355        -.033450    1.121355                            *   B
 68    1.092135    -.029416    1.118797        -.029416    1.118797                            *   B
 69    1.127723    -.026085    1.116684        -.026085    1.116684                            *   B
 70    1.167351    -.022915    1.114670        -.022915    1.114670                            *  B
 71    1.212946    -.019723    1.112638        -.019723    1.112638                            *  B
 72    1.268145    -.016427    1.110536        -.016427    1.110536                            *  B
 73    1.341184    -.013170    1.108455        -.013170    1.108455                            *  B
 74    1.456833    -.010805    1.106942        -.010805    1.106942                            *  B
 75    1.671514    -.008974    1.105758        -.008974    1.105758                            *  B
 76    1.876313    -.007730    1.104970        -.007730    1.104970                            *  B
 77    2.042561    -.009657    1.106206        -.009657    1.106206                            *  B
 78    2.209055    -.017748    1.111379        -.017748    1.111379                            *  B
 79    2.406774    -.034402    1.121952        -.034402    1.121952                            *   B
 80    2.702997    -.043931    1.127956        -.043931    1.127956                            *   B
 81    4.890373    -.041606    1.126494        -.041606    1.126494                            *   B
```

Figure 4-9.- Continued

```
   Y-GRID VALUES      Y(J) J=   1 TO  64
-2.000000   -1.812909   -1.642930   -1.488178   -1.347027   -1.218072   -1.100091    -.992019
 -.892925    -.801993    -.718505    -.641829    -.571404    -.506738    -.447391    -.392976
 -.343146    -.297595    -.256050    -.218269    -.184038    -.153167    -.125487    -.100852
 -.079132    -.060216    -.044007    -.030425    -.019401    -.010882    -.004827    -.001205
  .001205     .004827     .010882     .019401     .030425     .044007     .060216     .079132
  .100852     .125487     .153167     .184038     .218269     .256050     .297595     .343146
  .392976     .447391     .506738     .571404     .641829     .718505     .801993     .892925
  .992019    1.100091    1.218072    1.347027    1.488178    1.642930    1.812909    2.000000
```

```
                                                   SONIC LINE OUTPUT
                                                   *****************
SONIC LINE COORDINATES

     Y          X-SONIC

  2.00000    -.33996     .57889
  1.81291    -.38427     .52907
  1.64293    -.42050     .48093
  1.48818    -.45417     .43681
  1.34703    -.48533     .39794
  1.21807    -.50724     .36341
  1.10009    -.52586     .33294
   .99202    -.54224     .30665
   .89293    -.55682     .28327
   .80199    -.56980     .26189
   .71851    -.58131     .24204
   .64183    -.59143     .22341
   .57140    -.60026     .20628
   .50674    -.60789     .19055
   .44739    -.61441     .17532
   .39298    -.61993     .16192
   .34315    -.62455     .14836
   .29759    -.62839     .13645
   .25605    -.63155     .12429
   .21827    -.63411     .11383
   .18404    -.63617     .10299
   .15317    -.63781     .09339
   .12549    -.63910     .08355
   .10085    -.64010     .07490
   .07913    -.64086     .06589
   .06022    -.64144     .05780
   .04401    -.64187     .04983
   .03042    -.64218     .04207
   .01940    -.64240     .03470
   .01088    -.64255     .02781
   .00483    -.64265     .02163
   .00121    -.64270     .01685
 BODY LOCATION
  -.00121    -.64274     .10545
  -.00483    -.64279     .10899
  -.01088    -.64286     .11434
  -.01940    -.64295     .12085
  -.03042    -.64304     .12907
  -.04401    -.64312     .13853
  -.06022    -.64315     .14789
  -.07913    -.64310     .15936
  -.10085    -.64295     .17058
  -.12549    -.64265     .18276
  -.15317    -.64214     .19541
  -.18404    -.64137     .20856
  -.21827    -.64026     .22239
  -.25605    -.63873     .23687
  -.29759    -.63671     .25172
  -.34315    -.63408     .26775
  -.39298    -.63073     .28396
  -.44739    -.62656     .30142
  -.50674    -.62142     .32005
  -.57140    -.61521     .33958
  -.64183    -.60780     .36022
  -.71851    -.59906     .38225
  -.80199    -.58889     .40608
  -.89293    -.57719     .43225
  -.99202    -.56385     .46132
 -1.10009    -.54874     .49293
 -1.21807    -.53167     .52827
 -1.34703    -.51218     .56770
 -1.48818    -.48915     .61174
 -1.64293    -.45651     .65995
 -1.81291    -.41901     .71061
 -2.00000    -.37572     .76136
```

Figure 4-9.- Continued

```
                                          SHOCK WAVE DRAG AND TOTAL PRESSURE PROFILE OUTPUT
                                          *************************************************

  INVISCID WAKE PROFILES FOR INDIVIDUAL SHOCK WAVES WITHIN MOMENTUM CONTOUR

  SHOCK  1
  WAVE DRAG FOR THIS SHOCK=     .006437
       Y          CD(Y)       PO/POINF

   -1.81290940   .00074477   .99946609
   -1.64293038   .00077644   .99944339
   -1.48817799   .00104243   .99925270
   -1.34702736   .00120194   .99913836
   -1.21807223   .00134241   .99903765
   -1.10009107   .00147094   .99894551
    -.99201912   .00159340   .99885773
    -.89292538   .00171416   .99877115
    -.80199344   .00183630   .99868360
    -.71850542   .00196176   .99859365
    -.64182864   .00209155   .99850061
    -.57140431   .00222580   .99840437
    -.50673795   .00236387   .99830539
    -.44739136   .00250436   .99820468
    -.39297572   .00264520   .99810371
    -.34314575   .00278373   .99800440
    -.29759466   .00291688   .99790895
    -.25604987   .00304137   .99781970
    -.21826935   .00315408   .99773891
    -.18403842   .00325233   .99766847
    -.15316703   .00333429   .99760971
    -.12548743   .00339920   .99756319
    -.10085215   .00344746   .99752858
    -.07913226   .00348062   .99750482
    -.06021592   .00350102   .99749019
    -.04400713   .00351149   .99748268
    -.03042464   .00351495   .99748020
    -.01940111   .00351407   .99748083
    -.01088238   .00351110   .99748297
    -.00482689   .00350777   .99748535
    -.00120527   .00350529   .99748713
     .00120527   .00350345   .99748845
     .00482689   .00350038   .99749065
     .01088238   .00349447   .99749488
     .01940111   .00348451   .99750202
     .03042464   .00346887   .99751324
     .04400713   .00344554   .99752997
     .06021592   .00341232   .99755377
     .07913226   .00336708   .99758621
     .10085215   .00330802   .99762855
     .12548743   .00323402   .99768160
     .15316703   .00314487   .99774551
     .18403842   .00304139   .99781969
     .21826935   .00292531   .99790290
     .25604987   .00279911   .99799338
     .29759466   .00266567   .99808903
     .34314575   .00252802   .99818772
     .39297572   .00238897   .99828739
     .44739136   .00225099   .99838631
     .50673795   .00211595   .99848312
     .57140431   .00198513   .99857690
     .64182864   .00185909   .99866726
     .71850542   .00173771   .99875427
     .80199344   .00162012   .99883857
     .89292538   .00150465   .99892135
     .99201912   .00138875   .99900443
    1.10009107   .00126890   .99909035
    1.21807223   .00114057   .99918235
    1.34702736   .00099855   .99928416
    1.48817799   .00074008   .99946945
    1.64293038   .00072907   .99947735
    1.81290940   .00067902   .99951322

  SHOCK WAVE EXTENDS OUTSIDE CONTOUR
  PRINTOUT OF SHOCK LOSSES ARE NOT AVAILABLE FOR REST OF SHOCK

                                                            DRAG COEFFICIENT OUTPUT
                                                            ***********************

CALCULATION OF DRAG COEFFICIENT BY MOMENTUM INTEGRAL METHOD

BOUNDARIES OF CONTOUR USED                  CONTRIBUTION TO CD
UPSTREAM     X =    -1.170661                COUP    =     0.000000
DOWNSTREAM   X =      .727663                CDDOWN =       .009068
TOP          Y =     1.812909                CDTOP   =      .005569
BOTTOM       Y =    -1.812909                CDBOT   =      .007056
BODY AFT OF X =       .727663                CDBODY =       .007356
                 TOTAL CONTRIBUTIONS AROUND CONTOUR =       .029048

THERE ARE  1 SHOCKS INSIDE CONTOUR. TOTAL CDWAVE =          .006437

NOTE - ONE OR MORE SHOCKS EXTEND OUTSIDE OF CONTOUR
CDWAVE DOES NOT EQUAL TOTAL WAVE DRAG

DRAG CALCULATED FROM MOMENTUM INTEGRAL    CD     =          .035485


 TIME TO RUN CASE WAS  62.07 SECONDS.
```

(b) Output.

Figure 4-9.- Concluded

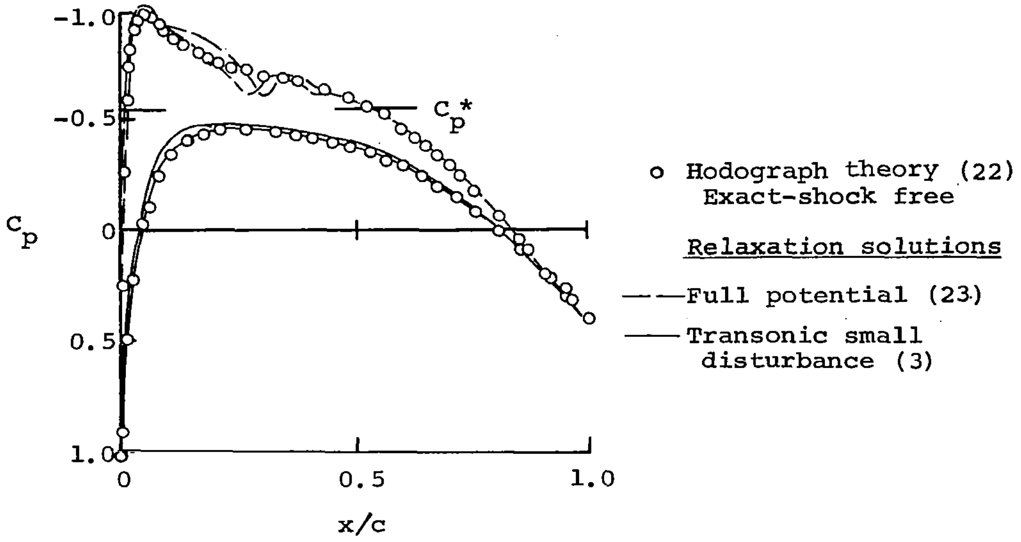


Figure 4-10.- Comparison of hodograph and relaxation solutions for the surface pressure distribution on a NLR quasi-elliptical airfoil with $\delta = 0.1212$, $\alpha = 1.32^{\circ}$ and $M_{\infty} = 0.7557$.

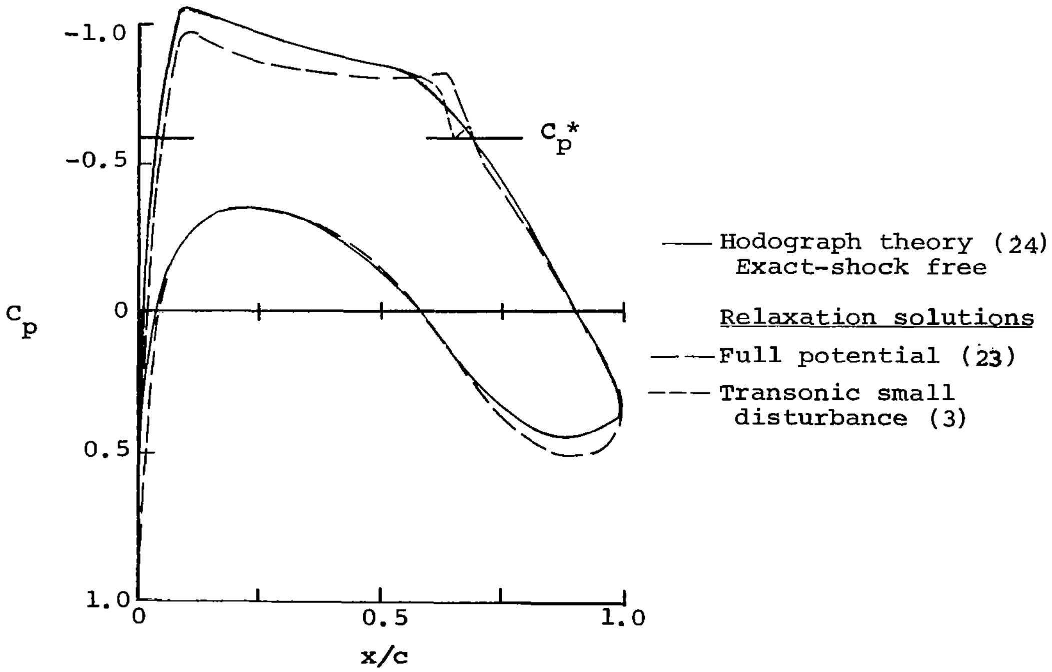


Figure 4-11.- Comparison of hodograph and relaxation solutions for the surface pressure distribution on a Korn airfoil with $\delta = 0.115$, $\alpha = 0.12^{\circ}$, and $M_{\infty} = 0.75$.

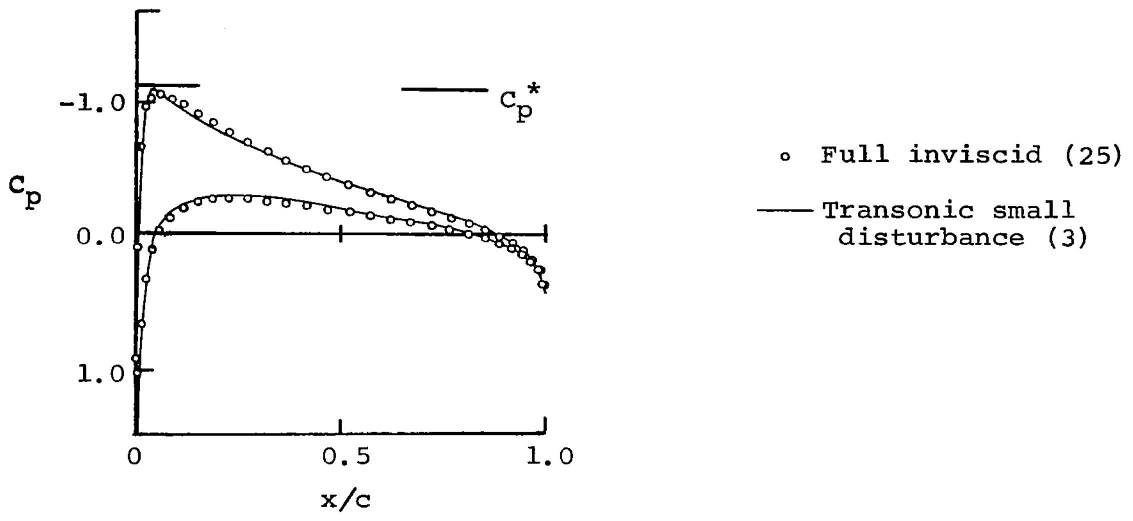


Figure 4-12.- Comparison of relaxation solutions for the surface pressure distribution of a NACA 0012 airfoil at $\alpha = 2^o$, $M_\infty = 0.630$.

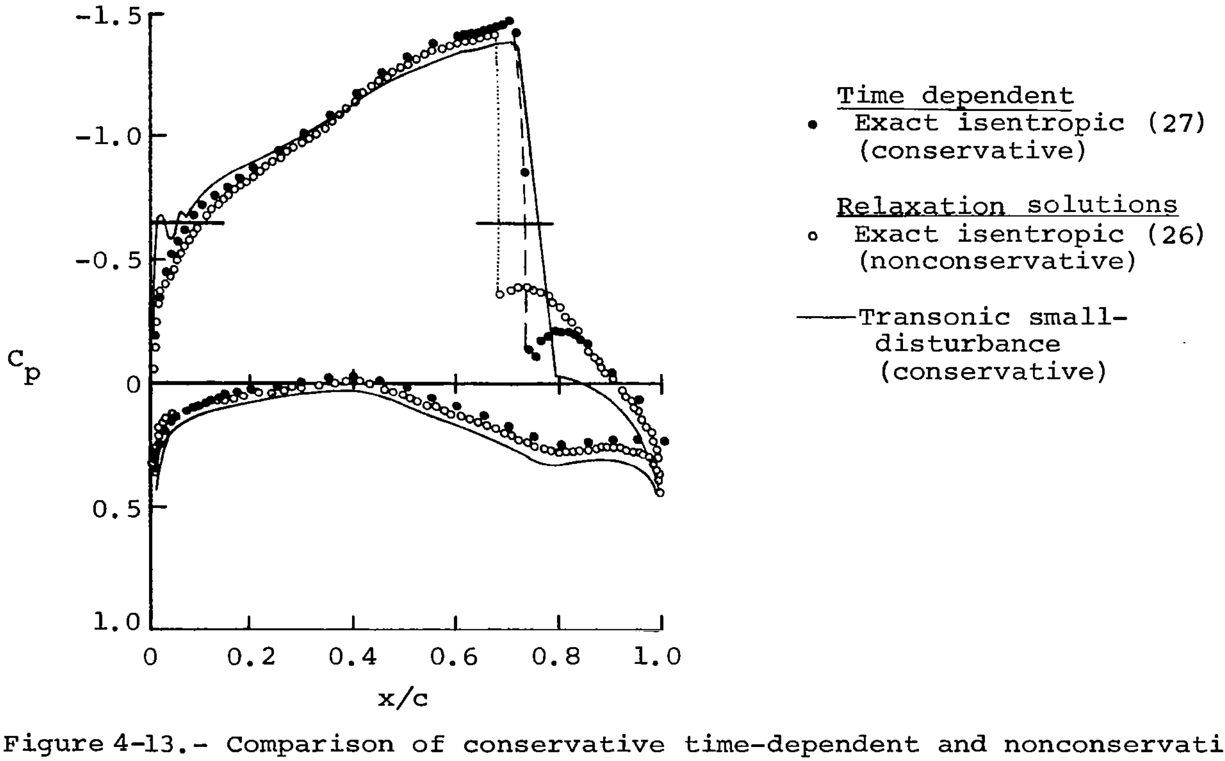


Figure 4-13.- Comparison of conservative time-dependent and nonconservative relaxation solutions of exact isentropic equation and the small-disturbance conservative solution for the surface pressure distribution on an NACA 64A410 airfoil at $M_\infty = 0.735$ and $\alpha = 1^o$.

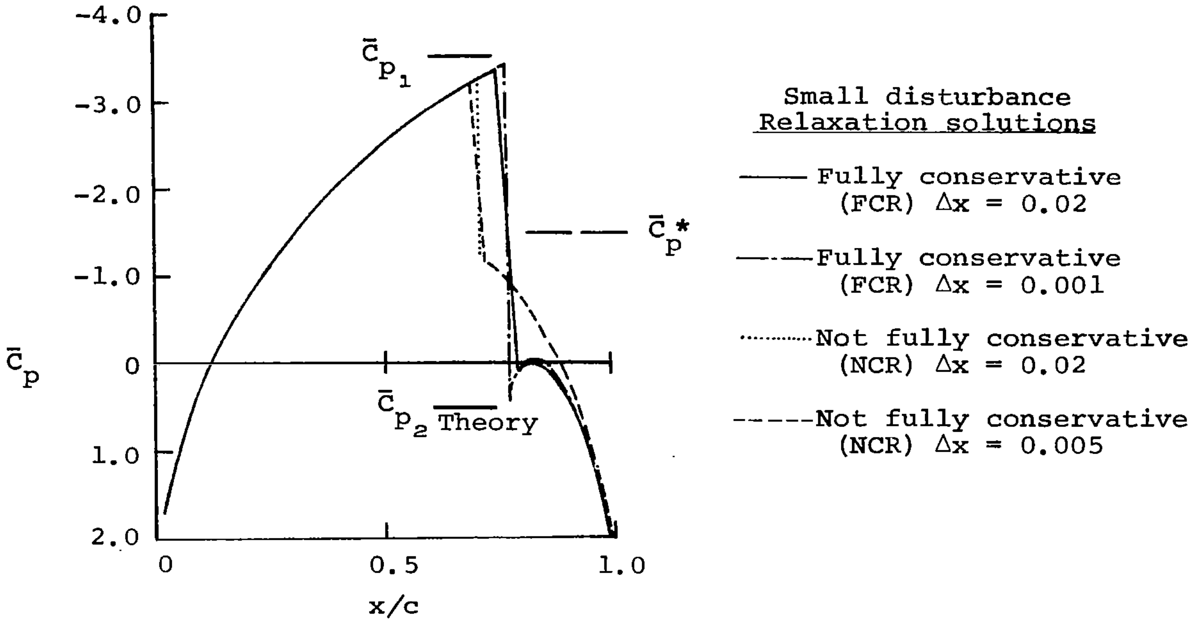


Figure 4-14.- Comparison of FCR and NCR solutions for the similarity surface pressure distribution on a parabolic arc airfoil with $\delta = 0.06$ and $M_\infty = 0.872$. (19)

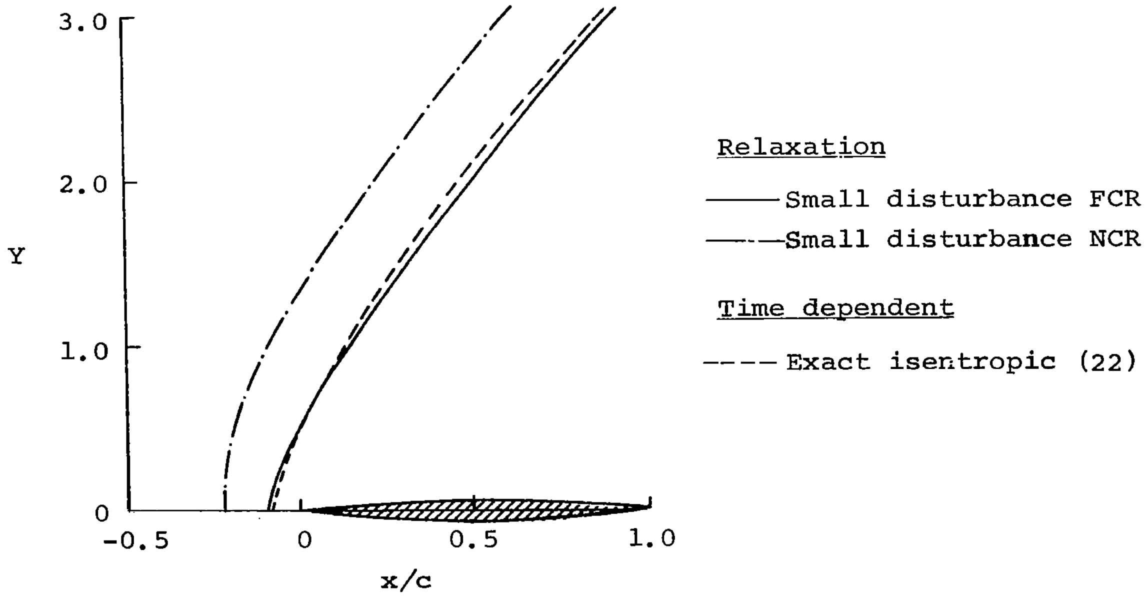


Figure 4-15.- Comparison of various solutions for the detached bow shock wave location for a parabolic arc airfoil with $\delta = 0.06$ and $M_\infty = 1.15$. (19)

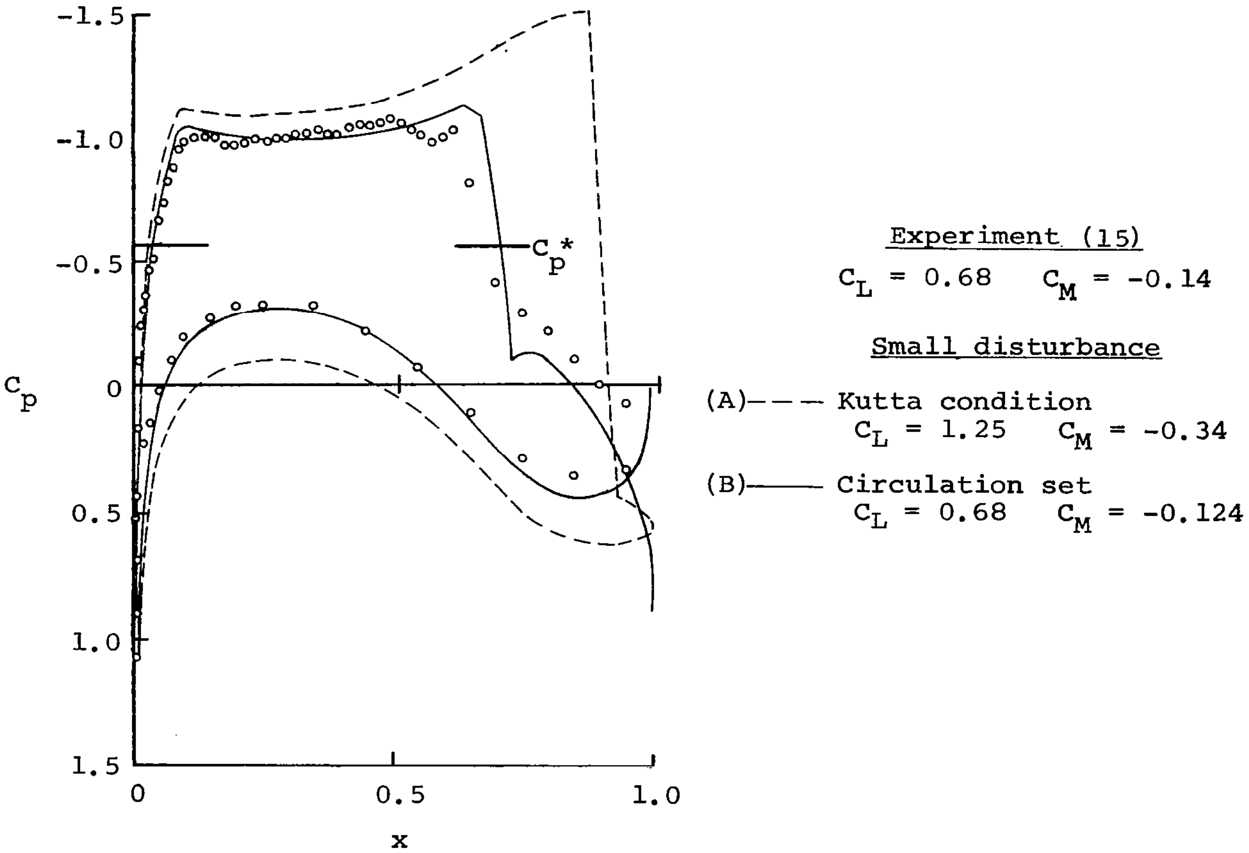


Figure 4-16.- Comparison of small disturbance FCR solutions with data for the surface pressure distribution on a Garabedian-Korn airfoil at α = 1.38°, M_∞ = 0.768. (19)

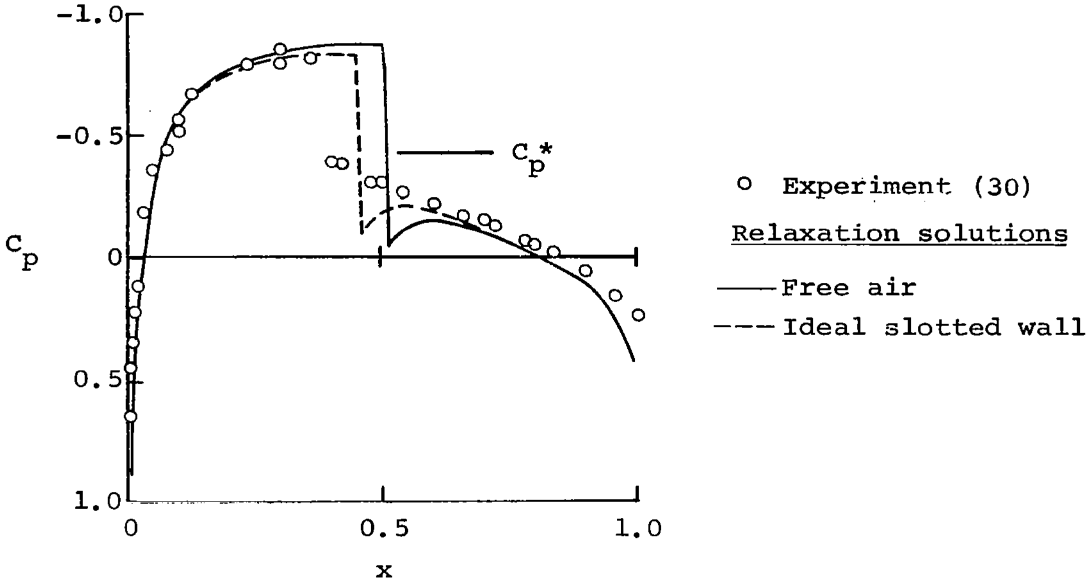


Figure 4-17.- Comparison of small disturbance FCR solutions with data for the surface pressure on a NACA 0012 at $\alpha = 0^{\circ}$ and $M = 0.8$. (19)

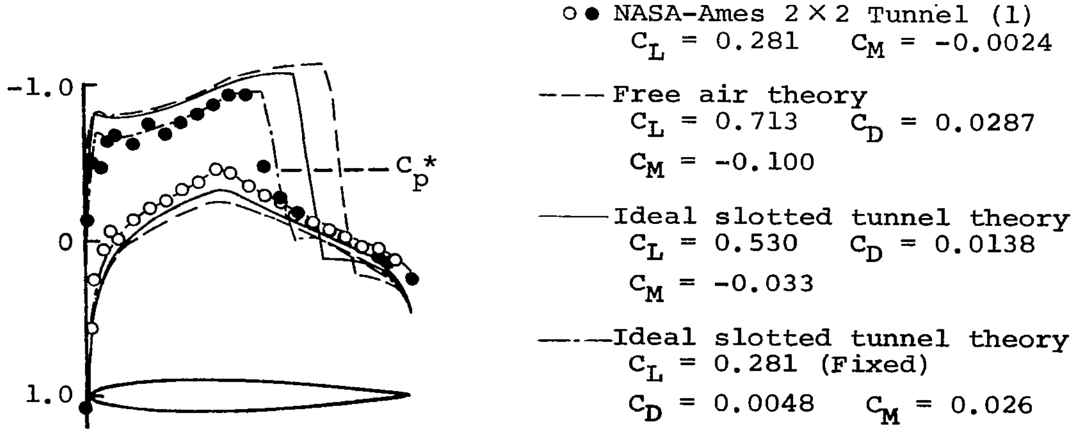


Figure 4-18.- Comparison of free-air and wind-tunnel small disturbance FCR solutions for the surface pressure distribution on a NACA 64A010 airfoil at $\alpha = 2.0^{\circ}$ and $M_{\infty} = 0.802$.

5. PROGRAMMER'S MANUAL

This section of the operational manual provides detailed information concerning the programming structure of the code, and is intended primarily to assist those users interested in modifying or extending the program. Included in this section are a dictionary of all subroutine variables that appear in common blocks in the program and a detailed description of the individual subroutines. These should provide all the information necessary to alter the code in a rapid and error-free fashion.

5.1 Dictionary of Subroutine Variables in Common

This section provides a dictionary of all subroutine variables which appear in common blocks in the program. The dictionary is arranged serially according to the named common block number rather than alphabetically in order to provide a more rapid access to the information.

VARIABLE	COMMON BLOCK	DESCRIPTION AND COMMENTS
	COMMON	
P(100,101)		array containing the small-disturbance velocity potential ϕ used in current calculation
X(100)		array containing the x-location of mesh points used in current calculation
Y(100)		array containing the y-location of mesh points used in current calculation
	COM 1	
IDOWN		downstream limit of I index for solution of difference equations; equal to IMAX - 1 for subsonic free streams, and IMAX otherwise
ILE		value of I index associated with the mesh point at the leading edge (x = 0.) or mesh point on the body closest to leading edge
IMAX		number of x-mesh points in current calculation
IMIN		value of I index designating the x-mesh point where the calculation is to start; user-option input, default value equal to 1

VARIABLE COMMON BLOCK DESCRIPTION AND COMMENTS

COM 1 (cont'd)

ITE value of I index associated with the mesh point at the trailing edge (x = 1.) or mesh point on body closest to trailing edge

IUP upstream limit of I index for solution of difference equations; equal to IMIN + 1 for subsonic free streams and IMIN + 2 otherwise

JBOT lower limit of J index for solution of finite-difference equations; equal to JMIN + 1 for free-air subsonic calculations, free-jet calculations, and porous tunnel wall calculations where the scaled porosity is greater than 1.5; equal to JMIN otherwise

JLOW value of J index associated with the row of mesh points immediately below the body

JMAX number of y-mesh points in current calculation

JMIN value of J index designating the y-mesh point where the calculation is to start; user-option input, default value equal to 1

JTOP upper limit of J index for solution of finite-difference equations; equal to JMAX - 1 for free-air subsonic calculations, free-jet calculations, and porous tunnel wall calculations where the scaled porosity is greater than 1.5; equal to JMAX otherwise

JUP value of J index associated with the row of mesh points immediately above the body

COM 2

AK transonic similarity parameter; equal to $(1 - M_\infty^2)/M_\infty^{2m}\delta^{2/3}$ where m is equal to zero for Cole scaling, 2/3 for Spreiter scaling, and 1/2 for Krupp scaling

ALPHA angle of attack; user-option input, default value equal to 0.12°

DUB strength of doublet characterizing far-field behavior; set equal to airfoil volume for nonlifting free-air flows; equal to volume $+ (\gamma+1)/4 \iint \phi_x^2 \, dx \, dy$ otherwise

GAM1 equal to $\gamma + 1$

RTK equal to $\sqrt{|AK|}$

VARIABLE	COMMON BLOCK	DESCRIPTION AND COMMENTS
	COM 3	
ABORT (logical)		program control for terminating calculation if solution diverges
ICUT		control for mesh cut and refinement; equal to 0, input mesh used to convergence; equal to 1, input mesh may be cut once; equal to 2, input mesh may be cut twice; user-option input, default value equal to 2
IREF		internal program control for mesh cutting
KSTEP		internal program control for index increment for mesh cutting
	COM 4	
XIN(100)		array of x-ordinates of user-supplied x-grid; set equal to XKRUPP if default x-grid chosen
YIN(100)		array of y-ordinates of user-supplied y-grid; set equal to YFREE or YTUN if default y-grid chosen
AMESH (logical)		control for use of analytical default mesh calculated by AYMESH; user-option input, default value is FALSE
	COM 5	
XDIFF(100)		array of difference coefficients for determining ϕ_x; equal to 1./(X(I) - X(I-1))
YDIFF(100)		array of difference coefficients for determining ϕ_y; equal to 1./(Y(J) - Y(J-1))
	COM 6	
CAMBER(100)		array of ordinates of airfoil camber-line distribution
FL(100)		array of y-ordinates of airfoil lower surface
FU(100)		array of y-ordinates of airfoil upper surface
FXL(100)		array of slopes (dF_ℓ/dx) of airfoil lower surface
FXU(100)		array of slopes (dF_u/dx) of airfoil upper surface
IFOIL		number of mesh points on airfoil; equal to ITE - ILE + 1

VARIABLE	COMMON BLOCK	DESCRIPTION AND COMMENTS
	COM 6 (con't)	
THICK(100)		array of ordinates of airfoil thickness distribution
VOL		volume of airfoil/unit span
XFOIL(100)		array of x-ordinates of mesh points on airfoil
	COM 7	
CJLOW		difference coefficient for extrapolation formulas to obtain airfoil lower surface properties; equal to -Y(JLOW-1)/(Y(JLOW) - Y(JLOW-1))
CJLOW1		difference coefficient for extrapolation formulas to obtain airfoil lower surface properties; equal to -Y(JLOW)/(Y(JLOW) - Y(JLOW-1))
CJUP		difference coefficient for extrapolation formulas to obtain airfoil upper surface properties; equal to Y(JUP+1)/(Y(JUP+1) - Y(JUP))
CJUP1		difference coefficient for extrapolation formulas to obtain airfoil upper surface properties; equal to Y(JUP)/(Y(JUP+1) - Y(JUP))
	COM 8	
CVERGE		convergence criterion for maximum iteration error of ϕ; user-option input, default value equal to 0.00005
DVERGE		divergence criterion for maximum iteration error ϕ; user-option input, default value equal to 10.
EPS		coefficient of pseudo-time term $\Delta t\phi_{xt}/\Delta x$ in differential equation; value between 0. and 1.; default value equal to 0.
IPRTER		control for print frequency of y-line in mesh where error is largest; for example, IPRTER = 10 implies line will be printed every 10th iteration; user-option input, default value equal to 10
MAXIT		control for maximum number of iteration cycles allowed on each mesh; user-option input, default value equal to 500

VARIABLE   COMMON BLOCK   DESCRIPTION AND COMMENTS

COM 8 (cont'd)

WE(3)   relaxation factor at elliptic points on the coarse, medium, and fine mesh, respectively; user-option input, default values in order are 1.8, 1.9, and 1.95; if user-specified, all three values must be given

COM 9

BCFOIL (integer)   control for airfoil geometry options; equal to 1 for symmetric NACA four-digit (00XX) series; equal to 2 for parabolic arc; equal to 3 for user-specified ordinates, program calculates ordinates and slopes at mesh points by cubic spline interpolation; equal to 4 for complete user-supplied description; user-option input, default value is 3 and program uses Korn airfoil ordinates

NL   number of ordinate points used to describe airfoil lower surface; default value (for Korn airfoil) is 75

NU   number of ordinate points used to describe airfoil upper surface; default value (for Korn airfoil) is 100

RIGF   Reigles rule nose correction factor for modifying airfoil slopes; user-option input, default value is 0.0

XL(100)   array of x-ordinates for airfoil lower surface; user-supplied if BCFOIL = 3, unless default (Korn) airfoil is used

XU(100)   array of x-ordinates for airfoil upper surface; user-supplied if BCFOIL = 3, unless default (Korn) airfoil is used

YL(100)   array of y-ordinates for airfoil lower surface; user-supplied if BCFOIL = 3, unless default (Korn) airfoil is used

YU(100)   array of y-ordinates for airfoil upper surface; user-supplied if BCFOIL = 3, unless default (Korn) airfoil is used

COM 10

GAM   ratio of specific heats; user-option input, default value equal to 1.4

JMXF   number of y-mesh points for basic Krupp free-air grid; equal to 57

JMXT   number of y-mesh points for basic wind-tunnel grid; equal to 49

VARIABLE	COMMON BLOCK	DESCRIPTION AND COMMENTS
	COM 10 (cont'd)	
XGRDIN		control for input of x-grid; equal to TRUE if x-grid is user-specified; equal to FALSE if default x-grid (XKRUPP) is used; default value equal to FALSE
XKRUPP(100)		array of x-ordinates for basic Krupp free-air grid
YFREE(100)		array of y-ordinates for basic Krupp free-air grid
YGRDIN		control for input of y-grids; equal to TRUE if y-grid is user-speicified; equal to FALSE if either default y-grid (YFREE or YTUN) is used; default value equal to FALSE
YTUN(100)		array of y-ordinates for basic wind-tunnel grid
	COM 11	
ALPHAO		value of angle of attack (ALPHA) from previous calculation
CLOLD		value of lift coefficient (CL) from previous calculation
DELTAO		value of thickness ratio (DELTA) from previous calculation
DUBO		value of far-field doublet strength (DUB) from previous calculation
EMACHO		value of Mach number (EMACH) from previous calculation
IMAXI		number of x-mesh points; less than or equal to 100; user-option input, default value is 77 for basic Krupp grid
IMAXO		number of x-mesh points (IMAX) used in previous calculation
IMINO		value of I index (IMIN) where previous calculation was initiated
JMAXI		number of y-mesh points; less than or equal to 100; user-option input, default value is 57 (JMXF) for basic Krupp free-air grid or 49 (JMXT) for basic wind-tunnel grid

VARIABLE	COMMON BLOCK	DESCRIPTION AND COMMENTS
	COM 11 (cont'd)	
JMAXO		number of y-mesh points (JMAX) used in previous calculation
JMINO		value of J index (JMIN) where calculation was initiated
PSAVE (logical)		control for saving restart block of values on unit 3; equal to TRUE for final results of current calculation to be saved; user-option input, default value is FALSE
PSTART (integer)		control for initializing velocity potential ϕ array; equal to 1, ϕ set to zero; equal to 2, ϕ read from tape unit 7; equal to 3, ϕ used from previous case; user-option input, default value equal to 1
TITLE(8)		user-input alphanumeric array containing run title information
TITLEO(8)		alphanumeric array containing run title information from previous run
VOLO		value of airfoil volume (per unit span) from previous calculation
XOLD(100)		array of x-mesh ordinates from previous calculation
YOLD(100)		array of y-mesh ordinates from previous calculation
	COM 12	
F		wind-tunnel slot parameter; user-option input, default value equal to 0.
H		wind-tunnel half height to chord ratio; user-option input, default value equal to 0.
HALFPI		equal to $\pi/2$
PI		equal to π
RTKPOR		equal to $\sqrt{\lvert AK \rvert}\,/\,POR$
TWOPI		equal to 2π

VARIABLE	COMMON BLOCK	DESCRIPTION AND COMMENTS
	COM 13	
CDFACT		transonic scale factor for drag coefficient; equal to $\delta^{4/3}M_\infty^{-n}$ where n equals 0 for Cole scaling, 2/3 for Spreiter scaling, and 3/4 for Krupp scaling
CLFACT		transonic scale factor for lift coefficient; equal to $\delta^{2/3}M_\infty^{-n}$ (see CDFACT)
CMFACT		transonic scale factor for moment coefficient; equal to $\delta^{2/3}M_\infty^{-n}$ (see CDFACT)
CPFACT		transonic scale factor for pressure coefficient; equal to $\delta^{2/3}M_\infty^{-n}$ (see CDFACT)
CPSTAR		critical pressure coefficient
	COM 14	
CLSET		specified lift coefficient; used if Kutta condition is FALSE; user-option input, default value equal to 0.
FCR (logical)		control for fully conservative differencing; equal to TRUE for fully conservative form; otherwise, difference equations not conservative at shock waves; user-option input, default value equal to TRUE
KUTTA (logical)		control for Kutta condition specification; equal to TRUE for Kutta condition enforcement; equal to FALSE for lift-coefficient specification; user-option input, default value equal to TRUE
WCIRC		relaxation factor for circulation; user-option input, default value equal to 1.
	COM 15	
B		constant in subsonic far-field doublet solution for various wind-tunnel walls; equal to 0.5 for solid wall; equal to 0. for free-jet, slotted, or perforated/porous walls
BETA0		constant in subsonic far-field vortex solution for various wind-tunnel walls; calculated by VROOTS for ideal slotted tunnel wall; equal to $\pi/2$ for solid wall; equal to 0. for free jet; equal to $\tan^{-1}$(RTK/POR) for ideal perforated/porous wall

VARIABLE	COMMON BLOCK	DESCRIPTION AND COMMENTS
	COM 15 (cont'd)	
BETA1		see BETA0
BETA2		see BETA0
PSI0		constant in subsonic far-field vortex solution for various wind-tunnel walls; calculated by VROOTS for ideal slotted tunnel wall; equal to 1. for solid wall, free-jet, and ideal perforated/porous wall
PSI1		see PSI0
PSI2		see PSI0
	COM 16	
ALPHA0		constant in subsonic far-field doublet solution for various wind-tunnel walls; calculated by DROOTS for ideal slotted tunnel wall; equal to π for solid wall; equal to $\pi/2$ for free-jet; equal to $\pi/2 - \tan^{-1}$(RTK/POR) for ideal perforated/porous wall
ALPHA1		see ALPHA0
ALPHA2		see ALPHA0
JET (real)		constant in subsonic far-field vortex solution for various wind-tunnel walls; equal to 0. for solid and ideal perforated/porous wall; equal to 0.5 for free-jet and ideal slotted walls
OMEGA0		constant in subsonic far-field doublet solution for various wind-tunnel walls; calculated by DROOTS for ideal slotted tunnel wall; equal to 1. for solid wall, free-jet, and ideal perforated/porous walls
OMEGA1		see OMEGA0
OMEGA2		see OMEGA0
XSING		x-location of vortex and doublet used to determine far-field behavior on outer boundaries; equal to 0.5
	COM 17	
CYYBLC		special ϕ_{yy} difference coefficient at airfoil lower surface; equal to -CYYBLU/(Y(JLOW) - Y(JLOW-1))

VARIABLE	COMMON BLOCK	DESCRIPTION AND COMMENTS
	COM 17 (cont'd)	
CYYBLD		special ϕ_{yy} difference coefficient at airfoil lower surface; equal to -CYYBLC
CYYBLU		special ϕ_{yy} difference coefficient at airfoil lower surface; equal to -2./(Y(JLOW) + Y(JLOW-1))
CYYBUC		special ϕ_{yy} difference coefficient at airfoil upper surface; equal to CYYBUD/(Y(JUP+1) - Y(JUP))
CYYBUD		special ϕ_{yy} difference coefficient at airfoil upper surface; equal to -2./(Y(JUP+1) + Y(JUP))
CYYBUU		special ϕ_{yy} difference coefficient at airfoil upper surface; equal to -CYYBUC
FXLBC(100)		array containing body-slope boundary condition on lower surface multiplied by mesh spacing constant CYYBLU
FXUBC(100)		array containing body-slope boundary condition on upper surface multiplied by mesh spacing constant CYYBUD
ITEMP1		dummy index
ITEMP2		dummy index
	COM 18	
DCIRC		iteration error in circulation; equal to $\Delta\phi^{n+1}_{te} - \Delta\phi^{n}_{te}$
ERROR		absolute value of the maximum iteration error in ϕ; that is, $\|\phi^{n}_{j,i} - \phi^{n-1}_{j,i}\|_{max}$
I1		dummy I index used to alternate storage in arrays POLD (J,I) and EMU (J,I)
I2		dummy I index used to alternate storage in arrays POLD (J,I) and EMU (J,I)
IERROR		value of I index where maximum iteration error in ϕ occurs
JERROR		value of J index where maximum iteration error in ϕ occurs
OUTERR (logical)		internal program control for printout of iteration count, CL, CM, CD, IERROR, JERROR, ERROR, and ERCIRC
POLD(100,2)		array used to store current and previous column of $\phi_{j,i}$

VARIABLE	COMMON BLOCK	DESCRIPTION AND COMMENTS
	COM 18 (cont'd)	
VC(100)		array used to store current column of 2•$(1-M_L^2)$/ $(X_{i+1}-X_{i+1})$; equal to C1(I) - (CXL(I)•POLD(J,I2) + CXC(I)•P(J,I) + CXR(I)•P(J,I+1))
	COM 19	
WI		reciprocal of elliptic relaxation factor for current mesh
DIAG(100)		array of diagonal elements of tridiagonal matrix equation for column solution of ϕ
RHS(100)		array for the right-hand side column vector of tridiagonal matrix equation for column solution of ϕ
SUB(100)		array of sub-diagonal elements of tridiagonal matrix equation for column solution of ϕ
SUP(100)		array of super-diagonal elements of tridiagonal matrix equation for column solution of ϕ
	COM 20	
XMID(100)		array of x-mesh points obtained by deleting every other point in input array XIN starting with I = IMIN + 1
YMID(100)		array of y-mesh points obtained by deleting every other point in input array YIN starting with J = JMIN + 1
	COM 22	
CXC(100)		centered ϕ_x difference coefficient devided by X(I+1) - X(I-1) for IMIN + 1 $\leq$ I $\leq$ IMAX - 1; equal to -CXL(I) - CXR(I)
CXL(100)		left-biased ϕ_x difference coefficient divided by X(I+1) - X(I-1) for IMIN + 1 $\leq$ I $\leq$ IMAX - 1; equal to -0.5*(γ+1)/((X(I) - X(I-1))*(X(I+1) - X(I-1)))
CXR(100)		right-biased ϕ_x difference coefficient divided by X(I+1) - X(I-1) for IMIN + 1 $\leq$ I $\leq$ IMAX - 1; equal to 0.5*(γ+1)/((X(I+1) - X(I))*(X(I+1) - X(I-1)))
CXXC(100)		centered ϕ_{xx} difference coefficient multiplied by X(I+1) - X(I-1) for IMIN + 1 $\leq$ I $\leq$ IMAX - 1; equal to -CXXL(I) - CXXR(I)

VARIABLE	COMMON BLOCK	DESCRIPTION AND COMMENTS
	COM 22 (cont'd)	
CXXL(100)		left-biased ϕ_{xx} difference coefficient multiplied by X(I+1) - X(I-1) for IMIN + 1 $\leq$ I $\leq$ IMAX - 1; equal to 2./(X(I) - X(I-1))
CXXR(100)		right-biased ϕ_{xx} difference coefficient multiplied by X(I+1) - X(I-1) for IMIN + 1 $\leq$ I $\leq$ IMAX - 1; equal to 2./(X(I+1) - X(I))
C1(100)		equal to AK/(X(I+1) - X(I-1))
	COM 23	
CYYC(100)		centered ϕ_{yy} difference coefficient; equal to -CYYD(J) - CYYU(J) for JMIN + 1 $\leq$ J $\leq$ JMAX - 1
CYYD(100)		down-biased ϕ_{yy} difference coefficient; equal to 2./((Y(J) - Y(J-1))*(Y(J+1) - Y(J-2))) for JMIN + 1 $\leq$ J $\leq$ JMAX - 1
CYYU(100)		up-biased ϕ_{yy} difference coefficient; equal to 2./((Y(J+1) - Y(J))*(Y(J+2) - Y(J-2))) for JMIN + 1 $\leq$ J $\leq$ JMAX - 1
IVAL		index identifying the current column location; equal to I
	COM 24	
DBOT(100)		array of subsonic, far-field, unit-strength doublet values on bottom boundary
DDOWN(100)		array of subsonic, far-field, unit-strength doublet values on downstream boundary
DTOP(100)		array of subsonic, far-field, unit-strength doublet values on top boundary
DUP(100)		array of subsonic, far-field, unit-strength doublet values on upstream boundary
VBOT(100)		array of subsonic, far-field, unit-strength vortex values on bottom boundary
VDOWN(100)		array of subsonic, far-field, unit-strength vortex values on downstream boundary
VTOP(100)		array of subsonic, far-field, unit-strength vortex values on top boundary
VUP(100)		array of subsonic, far-field, unit-strength vortex values on upper boundary

VARIABLE	COMMON BLOCK	DESCRIPTION AND COMMENTS
	COM 25	
CPL(100)		array of pressure coefficient values on $y = 0^-$ lines from $\mathrm{IMIN} \leq \mathrm{I} \leq \mathrm{IMAX}$
CPU(100)		array of pressure coefficient values on $y = 0^+$ line from $\mathrm{IMIN} \leq \mathrm{I} \leq \mathrm{IMAX}$
	COM 26	
PJUMP(100)		array of values for the jump in potential across the wake from $\mathrm{ITE} \leq \mathrm{I} \leq \mathrm{IMAX}$; equal to CIRCTE + (X(I) - 1.)*(CIRCFF-CIRCTE)/X(IMAX1 - 1.)
	COM 27	
CL		lift coefficient
DELRT2		equal to $(\delta)^{2/3}$
DELTA		airfoil thickness ratio δ; user-option input, default value equal to 0.115
EMACH		free-stream Mach number M_∞; user-option input, default value equal to 0.75
EMROOT		equal to $(M_\infty)^{2/3}$
PHYS (logical)		control for transonic scaling used for input/output; equal to TRUE for physically scaled values and FALSE for transonically scaled values; user-option input, default value equal to TRUE
PRTFLO (integer)		control for print option of final flow field; equal to 1 for no flow field printout, equal to 2 for entire flow field printout, equal to 3 for printout of 3J lines around maximum error; user-option input, default value equal to 1
SIMDEF (integer)		control for transonic similarity scaling definition; equal to 1 for Cole scaling, equal to 2 for Spreiter scaling, equal to 3 for Krupp scaling, equal to 4 for user-supplied scaling; user-option input, default value equal to 3
SONVEL		perturbation velocity at sonic point; equal to AK/GAM1
VFACT		transonic scale factor for flow angle deflection; equal to $\delta\cdot(180^\circ/\pi)$

VARIABLE	COMMON BLOCK	DESCRIPTION AND COMMENTS
	COM 27 (cont'd)	
YFACT		transonic scale factor for lateral coordinate; equal to $\delta^{-1/3}M_{\infty}^{-m}$ where m equals 0 for Cole scaling, 2/3 for Spreiter scaling, and 1/2 for Krupp scaling
	COM 28	
BCTYPE (integer)		input control for type of flow to be computed; equal to 1 for free air, 2 for solid wall tunnels, 3 for free jet, 4 for ideal slotted-wall tunnel, and 5 for ideal perforated/porous wall tunnel; user-option input, default value equal to 1
CIRCFF		circulation in far field
CIRCTE		jump in potential at the trailing edge, $\Delta\phi_{te}$
FHINV		equal to 1./(F*H)
POR		wall porosity factor; user-option input, default value equal to 0.
	COM 30	
		common block COM 30 is a scratch common used to shorten storage requirements; all variables appearing in COM 30 are used internally only within each subroutine and not passed for use to other subroutines
	COM 32	
BIGRL		maximum residual of finite difference equation; equal to $(R_{j,i})_{max}$
IRL		value of I index where maximum residual occurs
JRL		value of J index where maximum residual occurs
	COM 33	
THETA(100,100)		array containing values of the angle used to update the potential for subsonic free-air flows by spreading the circulation rapidly through the flow field; calculated by ANGLE; equal to $1/2\pi \tan^{-1}(\sqrt{K}\,\tilde{y}/(X_i\text{-XSING}))$
	SPLN	
A(200)		coefficient array for cubic-fit, continuous derivative interpolation formula for fitting tabulated airfoil ordinates

VARIABLE	COMMON BLOCK	DESCRIPTION AND COMMENTS
	SPLN (cont'd)	
B(200)		coefficient array for cubic-fit, continuous derivation interpolation formula for fitting tabulated airfoil ordinates
DY1		slope of airfoil upper or lower surface at leading edge
DY2		slope of airfoil upper or lower surface at trailing edge
DYP		slope of airfoil at XP calculated by cubic spline interpolation SPLN1
K1		index for internal control of SPLN1 subroutine; equal to 1 implies first derivative specified, equal to 2 implies second derivative specified
K2		index for internal control of SPLN1 subroutine; equal to 1 implies first derivative specified, equal to 2 implies second derivative specified
XP		x-location of current mesh point on airfoil XIN(I), ILE $\leq$ I $\leq$ ITE
YP		y-ordinate of airfoil at XP calculated by cubic spline interplation

5.2 Description of Individual Subroutines

This section provides a description of the individual subroutines in the program, including the main program. The descriptions are ordered alphabetically according to subroutine name.

5.2.1 Subroutine ANGLE.- Subroutine ANGLE computes the quantity THETA(J,I) at the input mesh points (I,J) according to

$$\mathrm{THETA(J,I)} = \frac{1}{2\pi} \tan^{-1}\left(\frac{\sqrt{K}\,\tilde{y}_j}{x_i - \mathrm{XSING}}\right)$$

where XSING = 0.5. For $R = \sqrt{\tilde{y}_j^2 + (x_i - \mathrm{XSING})^2} \leq 1$, the quantity is reduced by THETA(J,I) = R*THETA(J,I). These values are used in subroutine SOLVE to enhance the convergence characteristics of subsonic free-air flows by transmitting the effect of updated circulation throughout the flow field. This is accomplished by updating the potential at the end of each iteration sweep in x by

$$\phi^{n+1}_{j,i} = \phi^{n+1}_{j,i} + (\Gamma^{n+1} - \Gamma^{n})\cdot \mathrm{THETA(J,I)}$$

5.2.2 Subroutine ARF(X).- Subroutine ARF(X) evaluates the error function

$$\mathrm{ARF(X)} = \frac{2}{\sqrt{\pi}} \int_{0}^{X} e^{-t^2} dt$$

by using the rational fraction approximation given in the Handbook of Mathematical Functions, AMS 55, edited by M. Abramowitz and L. A. Stegun, Fifth Printing, August 1966, p. 299, Equation 7.1.26.

5.2.3 Subroutine AYMESH.- Subroutine AYMESH computes an analytical $(\mathbf{x},\tilde{y})$ mesh based in part on the formulation in reference 11. That mesh formulation was designed for $M_\infty < 1$ free-air flows; however, it can be used for $M_\infty > 1$ flows as well as for wind tunnel environments. A coordinate tranformation in $\mathbf{x}$ is made according to the following formula:

$$X(\mathbf{x}) = (1 - a_0) \left\{ a_1 \mathbf{x} e^{-(a_2\mathbf{x})^2} + \left[1 - e^{-(a_7 x)^2}\right] \frac{2}{\sqrt{\pi}} \int_{0}^{a_4 x} e^{-t^2} dt \right\}$$

$$+ \frac{2a_0}{\pi} \tan^{-1}\left[a_5 (x + a_0)\right]$$

An initial $\mathbf{x}^{(1)}$ mesh is chosen by setting

$$x_I^{(1)} = \tan\left[\frac{\pi}{2}\left(\frac{I - 201}{200}\right)\right]_{I=201}^{401}$$

$$x_I^{(1)}\Big]_{I=1}^{200} = -x_{402-I}^{(1)}$$

Corresponding $X_I^{(1)} (x_I^{(1)})$ are then computed from the above stretching with the following coefficient values: $a_0 = 0.225$, $a_1 = 1.4$, $a_2 = 1.6$, $a_4 = 0.75$, $a_5 = 30.0$, $a_6 = 0.603$, and $a_7 = 2.0$. Then, for a fixed ΔX increment equal to $\Delta X = 2/(\mathrm{IMAXI}-1)$, the corresponding x_i points are found by using a quadratic interpolation scheme with the $X^{(1)}$, $x^{(1)}$ arrays. The final x_i mesh is found by using $x_i = x_i + a_3$ where $a_3 = 0.6188$.

The $\tilde{y}$ array definition depends on whether the calculation is for free air or a tunnel environment. For free air

$$\tilde{y}_j = 5.3 \frac{\tan\left[\frac{\pi}{2} \cdot \frac{j - \frac{JMAXI}{2}}{\left(\frac{JMAXI}{2} + 1\right)}\right]}{\tan\left[\frac{\pi}{2} \cdot \frac{\frac{JMAXI}{2}}{\frac{JMAXI}{2} + 1}\right]} , \quad \frac{JMAX}{2} + 1 \leq j \leq JMAXI$$

$$\tilde{y}_j = -\tilde{y}_{JMAXI+1-j} , \quad 1 \leq j \leq \frac{JMAXI}{2}$$

while for a tunnel environment

$$\tilde{y}_j = \tan^2\left[\frac{\pi}{2} \cdot \frac{j - \frac{JMAXI}{2}}{JMAXI}\right], \quad \frac{JMAX}{2} + 1 \leq j \leq JMAXI$$

$$\tilde{y}_j = -\tilde{y}_{JMAXI+1-j} , \quad 1 \leq j \leq \frac{JMAXI}{2}$$

The default values for IMAXI and JMAXI used with this analytical mesh are IMAXI = 81, JMAXI = 64. These values produce a mesh sufficiently fine for almost all aerodynamic applications and permit the mesh halving option to be used twice; that is, fine to medium to coarse.

5.2.4 Subroutine BCEND (I,JEND,L).- Subroutine BCEND modifies the diagonal DIAG(J) and right-hand side RHS(J) elements of the tridiagonal matrix in the tridiagonal matrix equation for the residual of the velocity potential along a column to include the boundary conditions along the botton (J = JBOT) and top (J = JTOP) rows. The routine first sets the index I (I = IVAL) to correspond to the current column being solved by SYOR and then branches to the appropriate modification of the type of flow environment being considered according to the following schedule:

For the top boundary,

BCTYPE	JTOP	DIAG MODIFICATION	RHS MODIFICATION
1(K) > 0)	JMAXI-1	----	----
1(K) < 0)	JMAX	$\frac{-\sqrt{-K}\cdot CYYU(JTOP)}{x_i - x_{i-1}}$	$\frac{\sqrt{-K}\cdot CYYU(JTOP)\cdot(\phi_{JMAX,i} - \phi_{JMAX,i-1})}{x_i - x_{i-1}}$ $+ CYYU(JTOP)\cdot\phi_{JTOP+1,i}$
2	JMAX	----	----
3(K > 0)	JMAX-1	----	$CYYU(JTOP)\left(\frac{\Gamma_{ff}}{4} + \phi_{JTOP+1,i}\right)$
3(K < 0)	JMAX-1	----	$CYYU(JTOP)\cdot\phi_{JTOP+1,i}$
4(K > 0)	JMAX	$\frac{-\ CYYU(JTOP)}{FH}$	$CYYU(JTOP)\left[\frac{1}{FH}\left(\frac{\Gamma_{ff}}{4} + \phi_{JTOP,i}\right) + \phi_{JTOP,1,i}\right]$
4(K < 0)	JMAX	$\frac{-\ CYYU(JTOP)}{FH}$	$CYYU(JTOP)\ \left[\frac{1}{FH}\ \phi_{JTOP,i} + \phi_{JTOP+1,i}\right]$
5(POR > 1.5)	JMAX-1	----	$CYYU(JTOP)\left(\phi^{(n-1)}_{JMAX,i} - \phi^{(n)}_{JTOP+1,i}\right)$ ($\phi_{JMAX,i}$ from eqs. (A), (B))
5(POR < 1.5)	JMAX	$-\ \frac{POR\cdot CYYU(JTOP)}{x_i - x_{i-1}}$	$\frac{POR\cdot CYYU(JTOP)\ (\phi_{JMAX,i} - \phi_{JMAX,i-1})}{x_i - x_{i-1}}$ $+ CYYU(JTOP)\cdot\phi_{JTOP+1,i}$

and for the bottom boundary

BCTYPE	JBOT	DIAG MODIFICATION	RHS MODIFICATION
1(K > 0)	JMIN+1	----	----
1(K < 0)	JMIN	$\frac{-\sqrt{-K}\cdot \text{CYYD(JBOT)}}{x_i - x_{i-1}}$	$\frac{-\sqrt{-K}\cdot \text{CYYD(JBOT)}\cdot\phi_{\text{JMIN},i} - \phi_{\text{JMIN-1},i}}{x_i - x_{i-1}}$ $+ \text{CYYD(JBOT)}\cdot\phi_{\text{JBOT-1},i}$
2	JMIN	----	----
3(K > 0)	JMIN+1	----	$\text{CYYD(JBOT)}\left(\frac{3\Gamma_{ff}}{4} + \phi_{\text{JBOT-1},i}\right)$
3(K < 0)	JMIN+1	----	$\text{CYYD(JBOT)}\cdot\phi_{\text{JBOT-1},i}$
4(K > 0)	JMIN	$\frac{-\text{CYYD(JBOT)}}{\text{FH}}$	$\text{CYYD(JBOT)}\left[\frac{1}{\text{FH}}\left(\frac{3\Gamma_{ff}}{4} + \phi_{\text{JBOT},i}\right) + \phi_{\text{JBOT-1},i}\right]$
4(K < 0)	JMIN	$\frac{-\text{CYYD(JBOT)}}{\text{FH}}$	$\text{CYYD(JBOT)}\left[\frac{1}{\text{FH}}\phi_{\text{JBOT},i} + \phi_{\text{JBOT-1},i}\right]$
5(POR > 1.5)	JMIN+1	----	$\text{CYYD(JBOT)}\left(\phi^{(n-1)}_{\text{JMIN},i} - \phi^{(n)}_{\text{JBOT-1},i}\right)$ ($\phi_{\text{JMIN},i}$ from eqs. (A), (B))
5(POR < 1.5)	JMIN	$\frac{-\text{POR}\cdot\text{CYYD(JBOT)}}{x_i - x_{i-1}}$	$\frac{\text{POR}\cdot\text{CYYD(JBOT)}\,(\phi_{\text{JMIN},i} - \phi_{\text{JMIN},i-1})}{x_i - x_{i-1}}$ $+ \text{CYYD(JBOT)}\cdot\phi_{\text{JBOT-1},i}$

where for BCTYPE = 5, superscript n refers to the iteration count,

$$\phi^{(n)}_{j,i} = \phi^{(n)}_{j,i-1} \mp \frac{x_i - x_{i-1}}{POR} (\phi^{(n)}_y)_{j,i-1/2} \qquad (A)$$

and

$$(\phi^{(n)}_y)_{\substack{JMAX\\JMIN},i-1/2} = \frac{1}{2}\left\{ \frac{\phi^{(n)}_{\substack{JMAX\\JMIN},i} - \phi^{(n)}_{\substack{JMAX-1\\JMIN+1},i}}{Y_{\substack{JMAX\\JMIN}} - Y_{\substack{JMAX-1\\JMIN+1}}} + \frac{\phi^{(n)}_{\substack{JMAX\\JMIN},i-1} - \phi^{(n)}_{\substack{JMAX-1\\JMIN+1},i-1}}{Y_{\substack{JMAX\\JMIN}} - Y_{\substack{JMAX-1\\JMIN+1}}} \right\} \qquad (B)$$

where the (-) sign in equation (A) corresponds to the top (J = JTOP) boundary. This modification applies only for i = IUP, at which point all of the $\phi^{(n)}_{JMAX,i}$ and $\phi^{(n)}_{JMIN,i}$ values are set for the current iteration ' x sweep. No modification is necessary for i > IUP.

For BCTYPE = 6, the difference equations have not yet been worked out. Consequently, the user must insert the appropriate information required; otherwise, an error message is printed and an abnormal stop occurs.

5.2.5 Subroutine BLOCK DATA.- Subroutine BLOCK DATA is a storage subroutine which contains all of the default values for the various parameters and arrays required as input to the program.

5.2.6 Subroutine BODY.- Subroutine BODY determines the body geometry information required for the boundary conditions and output. Four user-option choices of body description are programmed and available according to the input control BCFOIL as follows:

BCFOIL	AIRFOIL
1	NACA 00XX series
2	Parabolic-arc
3	User-supplied ordinates (default = Korn)
4	User specification

The subroutine computes the body ordinates and slopes at the input x-mesh locations and normalizes them by the thickness ratio δ. For BCFOIL = 3, a cubic spline interpolation is used for both slopes and ordinates, Next, the body volume per unit span, camber and thickness distributions are computed, then the airfoil upper and lower airfoil slopes are recomputed using a Reigel's rule nose correction RIGF according to

$$\text{FXU(I)} = \frac{\text{FXU(I)}}{\sqrt{1 + \text{RIGF}(\delta \cdot \text{FXU(I)})^2}}$$

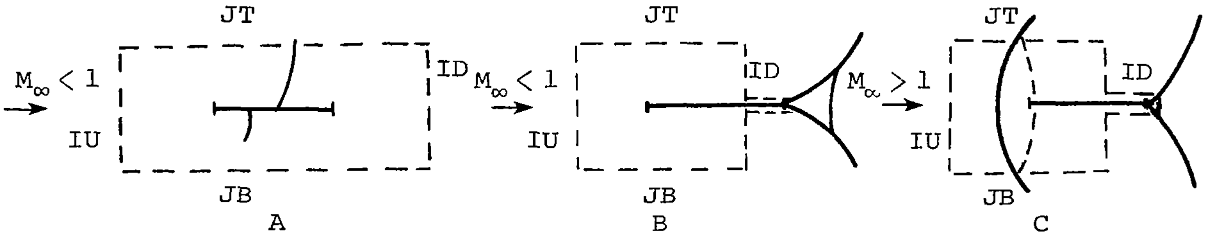
$$\text{FXL(I)} = \frac{\text{FXL(I)}}{\sqrt{1 + \text{RIGF}(\delta \cdot \text{FXL(I)})^2}}$$

where $0 \leq \text{RIGF} \leq 1$ and is user-specified. Finally, subroutine PRBODY is called to output the calculated information.

5.2.7 Subroutine CDCOLE.- Subroutine CDCOLE computes the airfoil inviscid drag by the momentum integral method; that is, by integrating around a contour enclosing the body and along all shocks inside the contour according to the following formulation:

$$\frac{C_D}{2\delta^{5/3} M_\infty^{-n}} = \oint_C \left[\left(K \frac{u^2}{2} - \frac{v^2}{2} - \frac{\gamma+1}{3} u^3\right) d\tilde{y} - (uv)\,dx\right] - \frac{\gamma+1}{12} \int_{S \supset C} [u]^3 d\tilde{y}$$

where $\tilde{y}$ is the transonically scaled y coordinate, n depends on the transonic scaling used (see Table 4-I), and $[u]$ is the jump in ϕ_x across the shock waves S contained within the contour C. Sample contours incorporated in the program are shown below:



where for the subsonic contours A and B, the upstream boundary is set at IU = (IMIN + ILE)/2 and the top and bottom boundaries at JT = JMAX - 1 and JB = JMIN + 1, respectively. For situations where the velocity at the upper surface of the trailing edge is less than sonic, as in contour A, the downstream boundary is set at ID = (IMAX + ITE)/2. Otherwise, ID is the I index at the x-mesh point closest to the three-quarter chord point on the airfoil, X(I) $\leq$ 0.75, as shown in contours B and C. For supersonic free streams, as in contour C, the upper and lower boundaries are set to encompass the subsonic region ahead of the airfoil. We note that the reason for indenting the contours B and C in the manner shown is to avoid placing the drag contour behind an oblique supersonic shock;

that is, a shock whose downstream flow is supersonic, since the present method uses a first-order accurate hyperbolic operator which tends to dissipate the shock structure over six to ten mesh points. This is an inherent weakness in the present method if sharp supersonic oblique shocks are required.

Subroutine CDCOLE first fixes the locations of the contour boundaries according to the above criteria. In the case of a supersonic free stream, before the calculations are initiated, a check is made to insure that the bow shock is not attached or located too close to the body nose or too close to the upstream boundary. If it is, a message is printed to that effect, the drag computed by a surface pressure integration, and the subroutine exited. If not, the subroutine proceeds to calculate the contour drag integral on the upstream, top, bottom, downstream, and body boundaries, and also on the shocks within the contour using in all cases a trapezoidal rule integration. After the computations are completed, information is printed regarding the drag contribution from each boundary, the total contour drag, the number of shock waves within the contour, the total wave drag, and a message stating whether all the shocks are contained within the contour or whether one or more of the shocks extend beyond the boundaries.

5.2.8 Subroutine CKMESH.- Subroutine CKMESH checks the number of points in both the input x-mesh and the y-mesh. If necessary, the x-mesh is adjusted to contain an odd number of points before the tail and an odd number after the tail, and the y-mesh adjusted to contain an even number of points above and below the airfoil. In counting points in the x-mesh, the point at the trailing edge (I = ITE) is included in both the sets before and after the tail. If the addition of the extra point(s) causes either IMAX or JMAX to exceed 100, a message to that effect is printed, no points are added, and the subroutine exited.

5.2.9 Subroutine CPPLOT.- Subroutine CPPLOT produces a printer plot of the pressure coefficient on the dividing streamline ($y = 0\pm$) ahead of, on, and behind the airfoil. The character "U" is printed for the pressure coefficient on the airfoil upper surface, "L" for the lower surface, "B" for points before and behind the airfoil, and "---" for the critical (sonic) pressure coefficient.

5.2.10 Subroutine CUTOUT.- Subroutine CUTOUT reduces the number of input mesh points to establish a coarse grid for the first attempt at a solution. The x-mesh and the y-mesh are halved, and if possible halved again. If it is desired to use the input mesh to convergence or if the input mesh cannot be refined, the XIN and YIN arrays are loaded into the working arrays X and Y and the routine exited. Otherwise, CUTOUT eliminates half the points in both the x-mesh and y-mesh and adjusts the indices IMAX and JMAX, keeping the first and last points of the meshes at the same location as they were originally.

If it is desired to perform only one grid halving (ICUT = 1), the subroutine loads the remaining points into the X- and Y-arrays and exits. If two mesh cuts are desired (ICUT = 2) and if after the first cut there are an odd number of points before and after the airfoil and an even number below and above the airfoil, the mesh is again halved and the points are loaded into the X- and Y-arrays. After each halving, subroutines ISLIT and JSLIT are called to adjust the I indices at the leading and trailing edges and the J indices immediately above and below the airfoil.

5.2.11 Subroutine DIFCOE.- Subroutine DIFCOE computes on the current (X,Y) mesh the difference coefficients throughout the flow field, including the boundaries, that are required for determining the various finite-difference forms of ϕ_x, ϕ_{xx}, and ϕ_{yy} needed for the solution of the partial differential equation for ϕ. In addition, the difference coefficients required to determine the velocities (ϕ_x, ϕ_y), together with special coefficients needed for extrapolation of flow field properties to the airfoil surface, and special difference coefficients for determining ϕ_{yy} near the airfoil surface are also computed and stored.

5.2.12 Function subroutine DRAG(CDFACT).- Function subroutine DRAG computes the pressure drag by integrating $\phi_x \cdot \phi_y$ around the airfoil surface. The pressure drag is defined as

$$\frac{C_D}{2\delta^{5/3} M_\infty^{-n}} = -\oint_{\text{airfoil}} \phi_x \phi_{\tilde{y}} \, dx$$

or equivalently,

$$\frac{C_D}{2 \cdot \text{CDFACT}} = -\int_0^1 \left[\phi_x^+ \frac{dF_u}{dx} - \phi_x^- \frac{dF_\ell}{dx} \right] dx$$

where $\tilde{y}$ is the transonically scaled y-coordinate, CDFACT $(=\delta^{5/3} M_\infty^{-n})$ is the appropriate transonic scaling factor for the drag coefficient, and

$F_{u,\ell}$ are the affine ordinates describing the airfoil upper and lower surface. The subroutine uses the latter form and computes the integral by a trapezoidal rule integration through subroutine TRAP.

5.2.13 Subroutine DROOTS.- Subroutine DROOTS computes the constants ALPHA0, ALPHA1, ALPHA2, OMEGA0, OMEGA1, and OMEGA2 which are required for the subsonic far-field doublet in an ideal slotted wind tunnel (BCTYPE = 4). The ALPHA's are computed in an iterative fashion as follows:

$$\text{ALPHA0}^{n} = \frac{\pi}{2} - \tan^{-1}\left[\text{F*ALPHA0}^{n-1} - \frac{\sqrt{K}}{\tilde{P}}\right]$$

$$\text{ALPHA1}^{n} = \frac{\pi}{2} - \tan^{-1}\left[\text{F*(ALPHA1}^{n-1} - \pi) - \frac{\sqrt{K}}{\tilde{P}}\right]$$

$$\text{ALPHA2}^{n} = \frac{\pi}{2} - \tan^{-1}\left[\text{F*(ALPHA2}^{n-1} - 2\pi) - \frac{\sqrt{K}}{\tilde{P}}\right]$$

where F is the tunnel slot parameter, $\tilde{P}$ is the transonically scaled wall porosity factor, and K is the transonic similarity parameter. One hundred iterations are allowed for convergence, with the error criterion,

$$|\text{ALPHA}^{n} - \text{ALPHA}^{n-1}| < 10^{-5}$$

If any ALPHA fails to converge within 100 iterations, an error message is printed and the program stops. If all three alphas converge, then the OMEGA's are computed as follows:

$$\text{OMEGA0} = \left(1 + \frac{F}{1 + \text{ctn}^{2}(\text{ALPHA0})}\right)^{-1}$$

with analogous formula for OMEGA1 and OMEGA2.

5.2.14 Subroutine ECHINP.- Subroutine ECHINP reads and prints all of the input cards that are used for the runs to follow.

5.2.15 Function subroutine EMACH1(U).- Function subroutine EMACH1 computes either the local Mach number or the transonic similarity parameter based on local velocity. If the input logical variable PHYS = .T., the local Mach number is calculated and set equal to EMACH1 according to $\text{EMACH1(U)} = [1 - (\text{AK} - (\gamma+1)\text{U})\delta^{2/3}M^{2m}]^{1/2}$ where m depends on the transonic scaling used (see Table 4-I). For PHYS = .F., the local transonic similarity parameter is computed and set equal to EMACH1; that is, EMACH1(U) = AK - $(\gamma + 1)$U.

5.2.16 Subroutine EXTRAP.- Subroutine EXTRAP provides initial values of ϕ for subsonic free-stream flows to subroutine GUESSP at mesh points which lie outside the range of the previous mesh. The formulation is based on the subsonic far-field solution for free air and for various tunnel simulation boundaries (free jet, solid wall, ideal slotted wall, ideal porous/perforated wall). For free air the formulation used is

$$\phi(x,\tilde{y}) = -\frac{\Gamma_{ff}}{2\pi} \cdot \tan^{-1}\left(\frac{\sqrt{K}\tilde{y}}{x}\right) + \frac{D}{2\pi\sqrt{K}} \frac{x - \frac{1}{2}}{\left(x - \frac{1}{2}\right)^2 + K\tilde{y}^2}$$

and for tunnel wall boundaries

$$\phi(x,\tilde{y})_{x\to+\infty} = -\frac{\Gamma_{ff}}{2}\left[1 - \operatorname{sgn}(\eta) + (1 - J)\psi_o \frac{\sin(\eta\beta_o)}{\beta_o} e^{-\beta_o\xi}\right] + \frac{D}{2K\tilde{H}}\left[B + \Omega_o\cos(\alpha_o\eta)e^{-\alpha_o\xi}\right]$$

$$\phi(x,\tilde{y})_{x\to-\infty} = -\frac{\Gamma_{ff}}{2}\left[1 - \frac{J\tilde{y}}{H(1+F)} - \psi_2 \frac{\sin[\eta(\pi - \beta_2)]}{\pi - \beta_2} e^{(\pi-\beta_2)\xi}\right] + \frac{D}{2K\tilde{H}}\left[(1 - B)\Omega_1\cos[(\pi - \alpha_1)\eta]e^{(\pi-\alpha_1)\xi}\right]$$

where

$$\xi = \frac{x - \frac{1}{2}}{H\cdot\sqrt{K}}$$

$$\eta = \frac{\tilde{y}}{\tilde{H}}$$

and the other parameters are defined according to the following table.

	B	α_0	α_1	Ω_0	Ω_1	Ω_2	J	β_0	β_1	ψ_0	ψ_2
Solid Wall	$\frac{1}{2}$	π	π	1	1	1	0	$\frac{\pi}{2}$	$\frac{\pi}{2}$	1	1
Free Jet	0	$\frac{\pi}{2}$	$\frac{\pi}{2}$	1	1	1	$\frac{1}{2}$	0	0	1	1
Perforated Wall	0	θ_2	θ_2	1	1	1	0	θ_1	θ_1	1	1
Slotted Wall	0	*	*	*	*	*	$\frac{1}{2}$	*	*	*	*

*No simplication possible for ideal slotted wall--must use formulas below.

$$\cot \alpha_o = F\alpha_o - \theta \qquad 0 \leq \alpha_o \leq \pi$$

$$\cot \alpha_1 = F(\alpha_1 - \pi) - \theta \qquad 0 \leq \alpha_1 \leq \pi$$

$$\Omega_o = \left(1 + \frac{F}{1 + \cot^2 \alpha_1}\right)^{-1}$$

$$\Omega_1 = \left(1 + \frac{F}{1 + \cot^2 \alpha_1}\right)^{-1}$$

$$\tan \beta_o = -F\beta_o + \theta \qquad 0 \leq \beta_o \leq \frac{\pi}{2}$$

$$\tan \beta_2 = -F(\beta_2 - \pi) + \theta \qquad -\frac{\pi}{2} \leq \beta_2 \leq \frac{\pi}{2}$$

$$\psi_o = \left(1 + \frac{F}{1 + \tan^2 \beta_2}\right)^{-1}$$

$$\psi_2 = \left(1 + \frac{F}{1 + \tan^2 \beta_o}\right)^{-1}$$

$$\theta = \frac{\sqrt{K}}{\tilde{P}}$$

$$\theta_1 = \tan^{-1}(\theta)$$

$$\theta_2 = \cot^{-1}(\theta)$$

5.2.17 Subroutine FARFLD.- Subroutine FARFLD computes the appropriate boundary data for the outer boundaries of the computational mesh. In the case of a supersonic free stream ($K \leq 0.0$), the upstream boundary conditions correspond to uniform undisturbed flow, the downstream boundary is required to be supersonic, and for the top and bottom boundaries the simple wave solution is employed. In this case, the subroutine simply defines the variable FHINV = 1/F*H and returns.

For a subsonic free stream, the functional form of the potential on the outer boundaries is prescribed and calculated. These forms represent the asymptotic far-field behavior of the potential solution, and are given by a concentrated unit strength doublet and vortex in free air or various wind-tunnel environments, with the doublet and vortex located at $x = 0.5$, $y = 0$. For an ideal slotted wind tunnel (BCTYPE = 4), subroutines DROOTS and VROOTS are called to compute the constants needed in the doublet and vortex solutions; otherwise, the various constants are calculated within the subroutine. We note that the actual boundary values for ϕ are set in subroutines RECIRC and REDUB, where the functional forms determined here are multiplied by the appropriate vortex and doublet strengths.

5.2.18 Subroutine FINDSK(ISTART,IEND,J,ISK).- Subroutine FINDSK identifies the presence of a shock wave on a specified row (J) of the computation mesh between x-points ISTART and IEND. Pairs of ϕ_x values are checked along the row until the condition

$$\text{PX(ISK,J)} \leq \text{SONVEL} \leq \text{PX(ISK-1,J)}$$

is satisfied, where SONVEL is the sonic point streamwise perturbation velocity. If such a pair is found, the subroutine is immediately exited with that value of ISK. If no shock is found, ISK is set equal to -IEND and the subroutine exited.

5.2.19 Subroutine FIXPLT.- Subroutine FIXPLT uses the airfoil surface pressure distribution arrays CPL and CPU to set up the arrays XP, CPUP, CPLO, and CPS for use in subroutine CPPLOT.

5.2.20 Subroutine GUESSP.- Subroutine GUESSP initializes the small-disturbance potential ϕ array as follows:

PSTART = 1, ϕ is set to zero

PSTART = 2, ϕ, X, and Y arrays are read from unit 7 in subroutine READIN together with other flow information about the old solution

PSTART = 3, the arrays from the previous case are already in ϕ, XOLD, YOLD

If PSTART = 2 or 3, the old ϕ array on the XOLD,YOLD mesh must be interpolated onto the current X,Y mesh. A check is made to see if the XOLD mesh is the same as the XIN mesh. If XIN and XOLD are the same mesh, the ϕ array may be interpolated by simple deletion of values at mesh points which have been deleted in subroutine CUTOUT. If the old and new X meshes are not the same, then a simple linear interpolation is made from the old ϕ's providing that each new x-point lies within the range of the old X mesh. If a new x-point lies outside the old X mesh, then for a supersonic free stream ϕ is set to zero,while for a subsonic free stream subroutine EXTRAP is called to extrapolate a new ϕ value using the far-field solution.

The same steps are followed to interpolate ϕ in the y-direction with the following slight difference. If the new y-point lies outside the range of the old Y mesh, then ϕ is set equal to either $\phi_{JMINO,i}$ if the new y value is less than the minimum old y value, or to $\phi_{JMAXO,i}$ if the new y value is greater than the maximum old y value. Only in the case of subsonic free air flow (K > 0., BCTYPE = 1) is subroutine EXTRAP called to extrapolate for ϕ using the far-field formula.

5.2.21 Subroutine INPERR(I).- Subroutine INPERR writes the appropriate error message associated with an error in input and stops the program. There are eight input error messages:

Error Number	Message
1	IMAX or JMAX is greater than 100, not allowed
2	X mesh points not monotonic increasing
3	Y mesh points not monotonic increasing
4	Mach number not in permitted range (0.5,2.0)

Error Number	Message
5	Alpha not in permitted range (-9.0,9.0)
6	Delta not in permitted range (0.0,1.0)
7	AK = 0. Value of AK must be input since PHYS = .F.
8	Mach number too close to 1, not allowed

5.2.22 Subroutine ISLIT(X).- For a given x-mesh array X, subroutine ISLIT computes the I indices associated with the mesh points on the airfoil surface ($0. \leq x \leq 1.$) at or just behind the leading edge (I = ILE) and at or just ahead of the trailing edge (I = ITE).

5.2.23 Subroutine JSLIT(Y).- For a given y-mesh array Y, subroutine JSLIT computes the J indices associated with the rows of mesh points immediately below (J = JLOW) and above (J = JUP) the airfoil (y = 0.).

5.2.24 Function LIFT (CLFACT).- The real function LIFT computes the lift coefficient from the jump in potential $\Delta\phi$ at the trailing edge. The lift coefficient is defined as

$$C_L = -\int_0^1 (C_{p_u} - C_{p_\ell})\,dx = +2\delta^{2/3}M_\infty^{-n}\int_0^1 [(\phi_x)_u - (\phi_{x_\ell})]\,dx$$

or, equivalent, from an integration by parts

$$C_L = 2 \cdot \text{CLFACT} \cdot \Delta\phi_{te}$$

where CLFACT $(=\delta^{2/3}M_\infty^{-n})$ is the appropriate transonic scaling factor for the lift coefficient.

5.2.25 Subroutine MACHMP.- Subroutine MACHMP produces a print map of the local Mach numbers, rounded to the nearest 0.1, throughout the flow field. The row of points immediately above the airfoil are designated by (+), the row immediately below by (-), the leading edge by (L), and the trailing edge by (T). Supersonic points are designated by an asterisk (*).

5.2.26 Subroutine MILINE.- Subroutine MILINE determines the coordinates where sonic velocity occurs and outputs them. Beginning with row J = JMAX, pairs of ϕ_x values are checked along the row to determine whether either of the two conditions

$$PX(I,J) \leq SONVEL \leq PX(I-1,J)$$

$$PX(I,J) \geq SONVEL \geq PX(I-1,J)$$

is satisfied, where SONVEL is the streamwise perturbation velocity at a sonic point. If either of these conditions are met, a linear interpolation is made between X(I,J) and X(I - 1,J), that computed x-coordinate stored temporarily in array XSONIC and permanently in array XSLPRT, and the y-coordinate loaded into array YSLPRT. After each row is scanned, the XSONIC array and the J index of the row are printed. When the row immediately under the airfoil is reached, the heading "BODY LOCATION" is printed if at least one sonic point has been found.

If more than 200 sonic points are found, a message to this effect is printed and the subroutine is exited. After the entire grid has been checked for sonic points and if at least one has been found, the subroutine checks whether any of the sonic points lie on the outer boundaries. If one does and if the case under study is either a subsonic free-stream calculation or a free air (BCTYPE = 1) supersonic free-stream calculation, the following message is printed out:

```
                    * * * * * CAUTION * * * * *

     SONIC LINE HAS REACHED A BOUNDARY
     THIS VIOLATES ASSUMPTIONS USED TO DERIVE BOUNDARY CONDITIONS
     SOLUTION IS PROBABLY INVALID
```

Finally, the subroutine defines the boundaries and step increments for the printer plot of the sonic line and passes these constants along with the arrays XSLPRT and YSLPRT and the number NPTS of sonic points into a call to the subroutine PLTSON, which plots the sonic line.

5.2.27 Subroutine NEWISK (ISKOLD,J,ISKNEW).- Subroutine NEWISK locates an updated x-position (I = ISKNEW) of the shock wave on a specified row J given an initial guess for the location (I = ISKOLD). The subroutine searches the range $ISKOLD - 3 \leq I \leq ISKOLD + 2$ testing the condition $PX(ISKNEW - 1,J) \geq SONVEL \geq PX(ISKNEW,J)$. If the condition is met, the subroutine returns with the current value of ISKNEW. Otherwise, with no shock being found, ISKNEW is set negative and the subroutine exited.

5.2.28 Function PITCH (CMFACT).- Function PITCH computes the airfoil pitching moment (positive nose-up) about $x = x_m$, $y = 0$. Pitching moment is defined as

$$C_m = \int_0^1 (x - x_m)\,(C_{p_u} - C_{p_\ell})\,dx$$

or, equivalently

$$C_m = -2 \cdot \text{CMFACT} \cdot (1 - x_m) \cdot \Delta\phi_{te} - \int_0^1 \Delta\phi \; dx$$

where CMFACT (= $\delta^{2/3} M_\infty^{-n}$) is the appropriate transonic scaling for the moment coefficient. The subroutine uses the latter form for C_m and computes the second integral by trapezoidal rule integration through subroutine TRAP. We note that the subroutine sets $x_m = 0.25$, so that the pitching moment is calculated about the quarter chord.

5.2.29 Subroutine PLTSON (X,Y,XAXMIN,XMAX,XINCR,YAXMIN,YMAX,YINCR, NPTS).- Subroutine PLTSON is a modified version of a printer plot routine developed by M. S. Itzkowitz, May 1967. The subroutine provides a printer plot of the sonic lines that are present in the flow field. The plot is provided on a 51 × 101 point rectangular grid with $-1.0 \leq y \leq 1.5$ and $0.75 \leq x \leq 1.75$, and uses 56 printer lines. The argument list is all input and is defined as follows:

X	array of x-ordinates to be plotted
Y	array of y-ordinates to be plotted
XAXMIN	minimum x (left) grid boundary
XMAX	maximum x (right) grid boundary
XINCR	increment between x-grid marks
YAXMIN	minimum y (lower) grid boundary
YMAX	maximum y (upper) grid boundary
YINCR	increment between y-grid marks
NPTS	dimension of (X,Y) arrays

If either of the incremental step sizes is zero, the program will exit with no plot produced. The input arrays are not destroyed during the calculation.

5.2.30 Subroutine PRBODY.- Subroutine PRBODY prints out the airfoil geometrical characteristics. If logical variable PHYS = .T., all dimensions are normalized by the airfoil chord; otherwise, all dimensions except x are normalized by chord length times thickness ratio. Quantities printed are maximum thickness, volume of airfoil per unit span, maximum camber, and for each input x-mesh point along the airfoil, the y-ordinates of the upper and lower surfaces of the airfoil, the thickness distribution, and camberline.

5.2.31 Subroutine PRINT.- Subroutine PRINT is the main print control of program output. The subroutine prints header information regarding:

(i) choice of printout in similarity on physical variables

(ii) definition of transonic scaling (Cole, Spreiter, Krupp, or user)

(iii) boundary condition type (free air, free jet, solid wall, slotted wall, or porous wall)

(iv) choice of differencing (fully conservative or not conservative) at shock

(v) choice of Kutta condition or lift specification

and also outputs the Mach number, thickness ratio, angle of attack, transonic similarity parameter, far-field doublet strength, airfoil volume (per unit span), and the values of the transonic scaling parameters used for scaling the coefficients of pressure, lift, drag, and moment, the y-coordinate, and the vertical velocity. The rest of the print output is performed by calling the following subroutines: PRINT1, FIXPLT, PRTWAL, MILINE, PRTFLD, and CDCOLE.

5.2.32 Subroutine PRINT1.- Subroutine PRINT1 outputs the pressure coefficient and local Mach number (or local similarity parameter if PHYS = .F.) on the airfoil and dividing streamline ($y = 0.\underline{+}$) at each x-point of the current mesh, and also provides a printer plot of the pressure coefficient along side the tabulated values. In addition, the y-coordinate array Y is printed as well as the lift, moment, and sonic pressure coefficients. Since PRINT1 is used to putput these quantities on each grid (coarse, medium, and fine), a header is written to identify the current grid. If the local Mach number exceeds 1.3, a warning message is printed indicating that the predicted shock jumps may be in error. Also, if a detached bow shock wave is between IMIN and IMIN + 1, a message is printed indicating that the detached shock will lie upstream of the current x mesh, the ABORT parameter set equal to true and the calculation terminated.

5.2.33 Subroutine PRTFLD.- Subroutine PRTFLD outputs the pressure coefficient, flow angle, and Mach number in the flow field. The number of rows (J lines) printed is set by the user-input value of PRTFLO as follows:

PRTFLO = 1, no J lines are printed

PRTFLO = 2, all J lines are printed

PRTFLO = 3, three J lines around the row where the maximum iteration error in ϕ occurs (i.e., J = JERROR) are printed

5.2.34 Subroutine PRTMC.- Subroutine PRTMC produces a local flow character map of the flow field by ascribing to each point in the input mesh a letter designating whether the flow at that point is elliptic (subsonic), parabolic (sonic), hyperbolic (supersonic), or shock (shock point) according to the convention:

-	Elliptic	(Subsonic)
P	Parabolic	(Sonic)
H	Hyperbolic	(Supersonic)
S	Shock Point	(Shock)

5.2.35 Subroutine PRTSK (Z,ARG,L,NSHOCK,CDSK,LPRT1).- Subroutine PRTSK provides an inviscid wake profile for all of the shock waves contained within the momentum contour used to calculate the drag. The wave drag contribution CD(y) and total pressure loss $P_o(y)/P_\infty$ along each shock wave is given as a function of the transonically scaled y-coordinate. In addition, the total wave drag for each shock is also provided. If a shock wave extends outside the contour, a message to that effect is printed indicating that shock losses are not available for that portion of the shock.

5.2.36 Subroutine PRTWAL.- Subroutine PRTWAL determines the pressure coefficient and the flow angle on the wind-tunnel walls ($y = \pm H$) according to the particular type of wall, prints that information, and also provides a printer plot of the pressure distribution along side the tabulated printout. Information regarding the wall type, tunnel half height, wall porosity factor (if applicable), tunnel slot parameter (if applicable), and critical pressure coefficient are also provided.

5.2.37 Function PX(I,J).- Function PX computes the streamwise perturbation velocity ϕ_x at the point (I,J). Different differencing forms are used depending whether the point is on the upstream or downstream boundaries or is an interior point. For the interior points, ϕ_x is given by

$$\phi_x = \frac{1}{2}\left[\frac{\phi_{j,i+1} - \phi_{j,i}}{x_{i+1} - x_i} + \frac{\phi_{j,i} - \phi_{j,i-1}}{x_i - x_{i-1}}\right]$$

while on the upstream boundary (I = IMIN)

$$\phi_x = \frac{3}{2}\left[\frac{\phi_{j,i+1} - \phi_{j,i}}{x_{i+1} - x_i}\right] - \frac{1}{2}\left[\frac{\phi_{j,i+2} - \phi_{j,i+1}}{x_{i+2} - x_{i+1}}\right]$$

and on the downstream boundary (I = IMAX)

$$\phi_x = \frac{3}{2}\left[\frac{\phi_{j,i} - \phi_{j,i-1}}{x_i - x_{i-1}}\right] - \frac{1}{2}\left[\frac{\phi_{j,i-1} - \phi_{j,i-2}}{x_{i-1} - x_{i-2}}\right]$$

5.2.38 Function PY (I,J).- Function PY computes the vertical perturbation velocity ϕ_y at the point (I,J). Different differencing formulas are employed depending whether the point is on the upper or lower boundaries or on the rows immediately above or below the airfoil. In the latter case, separate formulations are involved depending upon whether the point is ahead, over or under, or behind the airfoil. For all of the other points,

$$\phi_y = \frac{1}{2}\left[\frac{\phi_{j+1,i} - \phi_{j,i}}{y_{j+1} - y_j} + \frac{\phi_{j,i} - \phi_{j-1,i}}{y_j - y_{j-1}}\right]$$

The exceptional cases are:

Lower Boundary (j = JBOT)

$$\phi_y = \frac{3}{2}\left[\frac{\phi_{j+1,i} - \phi_{j,i}}{y_{j+1} - y_j}\right] - \frac{1}{2}\left[\frac{\phi_{j+2,i} - \phi_{j+1,i}}{y_{j+2} - y_{j+1}}\right]$$

Upper Boundary (j = JTOP)

$$\phi_y = \frac{3}{2}\left[\frac{\phi_{j,i} - \phi_{j-1,i}}{y_j - y_{j-1}}\right] - \frac{1}{2}\left[\frac{\phi_{j-1,i} - \phi_{j-2,i}}{y_{j-1} - y_{j-2}}\right]$$

Row below airfoil (j = JLOW)

(a) Ahead

$$\phi_y = \frac{1}{2}\left[\frac{\phi_{JUP,i} - \phi_{JLOW,i}}{y_{JUP} - y_{JLOW}} + \frac{\phi_{JLOW,i} - \phi_{JLOW-1,i}}{y_{JLOW} - y_{JLOW-1}}\right]$$

(b) Under

$$\phi_y = \frac{1}{2}\left[\left(\frac{dF_\ell}{dx}\right)_i - \alpha + \frac{\phi_{JLOW,i} - \phi_{JLOW-1,i}}{y_{JLOW} - y_{JLOW-1}}\right]$$

(c) Behind

$$\phi_y = \frac{1}{2}\left[\frac{\phi_{JUP,i} - \Delta\phi_i - \phi_{JLOW,i}}{y_{JUP} - y_{JLOW}} + \frac{\phi_{JLOW,i} - \phi_{JLOW-1,i}}{y_{JLOW} - y_{JLOW-1}}\right]$$

Row above airfoil (j = JUP)

(a) Ahead

$$\phi_y = \frac{1}{2}\left[\frac{\phi_{JUP,i} - \phi_{JLOW,i}}{y_{JUP} - y_{JLOW}} + \frac{\phi_{JUP+1,i} - \phi_{JUP,i}}{y_{JUP+1} - y_{JUP}}\right]$$

(b) Over

$$\phi_y = \frac{1}{2}\left[\left(\frac{dF_u}{dx}\right)_i - \alpha + \frac{\phi_{JUP+1,i} - \phi_{JUP,i}}{y_{JUP+1} - y_{JUP}}\right]$$

(c) Behind

$$\phi_y = \frac{1}{2}\left[\frac{\phi_{JUP,i} - \Delta\phi_i - \phi_{JLOW,i}}{y_{JUP} - y_{JLOW}} + \frac{\phi_{JUP+1,i} - \phi_{JUP}}{y_{JUP+1} - y_{JUP}}\right]$$

5.2.39 Subroutine READIN.- All user-option input to the program is read in subroutine READIN. The subroutine first calculates and prints the elapsed time in seconds that the previous case took to run, or for the first case sets the start time. Next, a check is made to determine if any test cases are left. If there are and if the user has opted to use the previous result for ϕ as a first guess for the current case (PSTART = 3), then a test is made to determine if the ϕ array in core from the previous case is usable (i.e., if the previous calculation was not aborted). Next, if the default grids for either subsonic free air (XKRUPP,YFREE) or tunnel (XKRUPP,YTUN), or the analytic default mesh (AYMESH = TRUE) are to be used, the subroutine loads those grids into the XIN, YIN arrays and then prints out all of the user-option input parameters, including those having default values. A check is then made to insure that the input mesh does not exceed 100 points in either direction and that the mesh ordinates are monotonic increasing. Next, checks are made on M_∞, α, and δ to insure they are within the permitted range, and then the indices of the leading

(I = ILE) and trailing (I = ITE) edges and the rows immediately above (J = JUP) and below (J = JLOW) the airfoil are determined. Subroutine CKMESH is then called to insure that certain grid areas have an appropriate (odd or even) number of points. If the case underway is a tunnel simulation calculation, the bounds of the grid are checked and adjusted if necessary. Finally, if the initial guess for the ϕ array is to be read from unit 7 (PSTART = 2), the necessary input from that calculation is read and then printed.

5.2.40 Subroutine RECIRC.- Subroutine RECIRC computes the jump in ϕ at the trailing edge, $\Delta\phi_{te}$, the updated far-field circulation, Γ_{ff}^{n+1}, and the jump in ϕ, $\Delta\phi(x)$, along the slit $y = 0.$, $x > 1.$, according to the following formulas.

For KUTTA = .T.,

$$\Delta\phi_{te} = \phi_{te}^{+} - \phi_{te}^{-} = \frac{\phi_{JUP,ITE} \cdot y_{JUP+1} - \phi_{JUP+1,ITE} \cdot y_{JUP}}{y_{JUP+1} - y_{JUP}}$$

$$- \frac{\phi_{JLOW-1,ITE} \cdot y_{JLOW} - \phi_{JLOW,ITE} \cdot y_{JLOW-1}}{y_{JLOW} - y_{JLOW-1}}$$

$$\Gamma_{ff}^{n+1} = (1. - \omega_{\Gamma}) \cdot \Gamma_{ff}^{n} + \omega_{\Gamma} \Delta\phi_{te}$$

$$\Delta\phi(x) = \Delta\phi_{te} + \frac{x - 1}{x_{max} - 1} \left(\Gamma_{ff}^{n+1} - \Delta\phi_{te} \right)$$

where ω_{Γ} is the relaxation factor for circulation, while for KUTTA = .F.,

$$\Delta\phi_{te} = \frac{CLSET}{2}$$

$$\Gamma_{ff} = \frac{CLSET}{2}$$

$$\Delta\phi(x) = \frac{CLSET}{2}$$

where CLSET is the specified lift coefficient.

5.2.41 Subroutine REDUB.- Subroutine REDUB computes the far-field doublet strength. For lifting free air flows (BCTYPE = 1 and ABS(CIRCFF) $> 10^{-4}$), the doublet strength is set equal to the model volume. For other flows the nonlinear contribution (DBLSUM = $((\gamma + 1)/4) \cdot \iint \phi_x^2 dx\, dy$) is added to the volume. The double integral is computed by considering ϕ_x to be centered midway between mesh points; that is,

$$\text{DBLSUM} = \frac{\gamma + 1}{4} \sum_{i=\text{IMIN}}^{\text{IMAX}} \Delta x_{i+1/2} \int_{y_{\text{JMIN}}}^{y_{\text{JMAX}}} (\phi_x^2)_{i+1/2} dy$$

so that

$$\text{DBLSUM} = \frac{\gamma + 1}{4} \sum_{i=\text{IMIN}}^{\text{IMAX}} \frac{1}{x_{i+1} - x_i} \int_{y_{\text{JMIN}}}^{y_{\text{JMAX}}} (\phi_{j,i+1} - \phi_{j,i})^2 dy$$

and the y-integration is performed using a modified trapezoidal rule.

We note that the doublet strength is required only for $M_\infty < 1$. For subsonic free air lifting flows, the doublet integral DBLSUM is not convergent since $\phi \sim \Gamma_{ff} \tan^{-1}(y/x)$; in this case, a more complicated integral applies (see Krupp, ref. 3). This program neglects that contribution, and while this procedure introduces an error, numerical experimentation has shown it not to be significant.

5.2.42 Subroutine REFINE.- Subroutine REFINE doubles the number of mesh points in both the x- and y-meshes by inserting new mesh points halfway between the old mesh points. The subroutine also linearly interpolates the ϕ array to the new points, determines the new (I,J) indices of the leading (ILE) and trailing (ITE) edges, and the rows immediately above (JUP) and below (JLOW) the airfoil by calls to subroutines ISLIT and JSLIT, respectively, and uses a linear extrapolation to calculate ϕ on the new JLOW and JUP rows.

5.2.43 Subroutine RESET.- Subroutine RESET updates the far-field boundary conditions for subsonic free-stream flows. The potential ϕ is recalculated on the upstream (IMIN) and downstream (IMAX) boundaries for both free air or wind-tunnel simulations. The update is accomplished at the end of each iteration sweep through the flow field. For free air flows (BCTYPE = 1), new boundary values are also calculated on the top (JMAX) and bottom (JMIN) boundaries; while for wind-tunnel simulations, this calculation is omitted.

5.2.44 Subroutine SAVEP.- Subroutine SAVEP automatically stores restart data from the currently completed calculation in an "old data" block. The subroutine first rescales the parameters back into the input format and then stores the following parameters and arrays: TITLE(I), IMIN, JMIN, IMAX, JMAX, CL, EMACH, ALPHA, DELTA, VOL, DUB, X(I), and YIN(J). If the user has opted to save the restart block (PSAVE = .T.), then the subroutine also writes the above information on Tape 3.

5.2.45 Subroutine SCALE.- Subroutine SCALE scales physical variables that are required for program computation. The option to scale or not is controlled by the logical input variable PHYS. For PHYS = .T., all input and output quantities are in physical units normalized by free-stream values and airfoil chord, and SCALE reduces them to transonic variables according to the following convention:

SIMDEF = 1, Cole scaling
SIMDEF = 2, Spreiter scaling
SIMDEF = 3, Krupp scaling
SIMDEF = 4, User-option scaling; if this option is used, the definition of local Mach number must also be adjusted in EMACH1

For PHYS = .F., input is already in scaled variables and no further scaling is done. In this case, the user must input the value of the transonic similarity parameter AK = $(1 - M_\infty^2)/M_\infty^{2m}\delta^{2/3}$ where the exponent m is now user-specified.

Subroutine SCALE then checks to determine that AK has an appropriate value for the case being considered, computes the square root of AK(RTK), the sonic velocity (SONVEL), and the critical pressure coefficient (CPSTAR) and then exits.

5.2.46 Subroutine SETBC.- Subroutine SETBC sets the limits on the range of the I and J indices for solution of the difference equations according to the following schedule:

$M_\infty < 1$				
BCTYPE	IUP	IDOWN	JTOP	JBOT
1	IMIN+1	IMAX-1	JMAX-1	JMIN+1
2	IMIN+1	IMAX-1	JMAX	JMIN
3	IMIN+1	IMAX-1	JMAX-1	JMIN+1
4	IMIN+1	IMAX-1	JMAX	JMIN
5(POR ≤ 1.5)	IMIN+1	IMAX-1	JMAX	JMIN
5(POR > 1.5)	IMIN+1	IMAX-1	JMAX-1	JMIN+1

$M_\infty > 1$				
BCTYPE	IUP	IDOWN	JTOP	JBOT
1	IMIN+2	IMAX	JMAX	JMIN
2	IMIN+2	IMAX	JMAX	JMIN
3	IMIN+2	IMAX	JMAX-1	JMIN+1
4	IMIN+2	IMAX	JMAX	JMIN
5(POR ≤ 1.5)	IMIN+2	IMAX	JMAX	JMIN
5(POR > 1.5)	IMIN+2	IMAX	JMAX-1	JMIN+1

The subroutine also computes the body slope boundary conditions at the current x-mesh points on the body, multiplies them by the appropriate mesh spacing constants and stores them into arrays FXUBC(J), FXLBC(I) for use in solving the finite-difference equations at points on the rows immediately above and below the airfoil

5.2.47 Subroutine SIMP (R,X,Y,N,IER).- Subroutine SIMP calculates the integral $\int y\,dx$ by using Simpson's rule integration. The subroutine argument list is defined as follows:

R resultant value of the integral

X vector array of x points

Y vector array of y values

N length of vector arrays (X,Y)

IER error control index; equal to 1 for satisfactory result; equal to 2 when only one point is in the interval (N = 1); equal to 4 when X array not monotonic

Equal point spacing is not required and the number of points N can be either odd or even. In the latter case, a polynomial fit through the first three points is used and an analytical integration performed from X(1) to X(2) in order to obtain an odd number of points for the remaining interval, X(2) to X(N).

5.2.48 Subroutine SOLVE.- Subroutine SOLVE controls the sequence of calculations involved in the finite-difference solution for ϕ. The potential is calculated by using a successive line over-relaxation (SLOR) algorithm and sweeping the flow field from upstream to downstream limits one column at a time. At the start of each sweep, subroutine RECIRC is called to compute the jump in potential at the trailing edge, the circulation for the far-field boundary, and the jump in potential along the slit $y = 0, x > 1$. Next, subroutine SYOR is called to compute a new value of the potential at all the grid points. For subsonic flows, after the program has completed an iteration sweep, and if the current calculation is a free air case, the potential is updated throughout the flow field by adding the increment in potential due to the change in circulation multiplied by the far-field vortex behavior. Then subroutine REDUB is called (but only at every NDUBth iteration sweep) to recompute the far-field doublet strength, and then subroutine RESET is called (at each iteration) to update the far-field boundary conditions. At every IPRTERth iteration, the iteration count (ITERATION), lift coefficient (CL), moment coefficient (CM), I and J locations (IERR,JERR) where the maximum iteration error in ϕ occurs, the absolute magnitude of the maximum iteration error in ϕ (ERROR), the I and J locations (IRL,JRL) of the maximum residual, the absolute magnitude of the maximum residual (BIGRL), the absolute magnitude of the iteration error in circulation (ERCIRC), the I location (ICPU) of the point on the airfoil where the maximum iteration error in upper surface pressure coefficient occurs, the absolute magnitude of the maximum iteration error in upper surface pressure coefficient (CPERRU), and the corresponding results (ICPL,CPERRL) for the maximum iteration error in surface pressure coefficient. The results are then checked for convergence of potential. If the test is met, the message "SOLUTION CONVERGED" is printed and the subroutine exited. If the convergence criteria is not met, a divergence test on ϕ is performed. If the maximum iteration error in ϕ has become greater than the divergence control (DVERGE), the error message "SOLUTION DIVERGED" is printed and the calculation aborted. If the solution has neither converged nor diverged, the iteration sweeps are continued up to the limit, MAXIT, at which point the message "ITERATION LIMIT REACHED" is printed and the subroutine exited.

5.2.49 Subroutine SPLN1 (X,Y,N).- Subroutine SPLN1 is a cubic spline interpolation subroutine which determines both the ordinate and slope of a function using a cubic spline fit. The argument list consists of a table of (X,Y) ordinates and is defined as follows:

X	array of independent variable
Y	array of dependent variable
N	dimension of (X,Y) arrays

There are two entry points to this subroutine. A call to SPLN1 initializes the cubic spline coefficient arrays, while a call to SPLN1X will determine the spline-fit ordinate (YP) and slope (DYP) at the specified point XP. We note that XP,YP, and DXP are passed through a name common block (SPLN) rather than an argument list.

To use SPLN1 it is necessary to specify a derivative of Y at the end points X(1),X(N). Either the first or second derivative at these points may be given. Control for this option is through the parameters (K1,K2) according to the following:

K1 = 1, DY1 = first derivative of Y at X(1)
K1 = 2, DY1 = second derivative of Y at X(1)
K2 = 1, DY2 = first derivative of Y at X(N)
K2 = 2, DY2 = second derivative of Y at X(N)

Values for (K1,K2,DY1,DY2) must be specified prior to the call to SPLN1.

5.2.50 Subroutine SYOR.- Subroutine SYOR determines the potential ϕ at the interior grid points throught the flow field; that is, JBOT $\leq$ J $\leq$ JTOP, IUP $\leq$ I $\leq$ IDOWN. This is accomplished by solving the tridiagonal matrix equation $A\overline{C}_i = f_i$ where $\overline{C}_i$ represents the correction potential and the N dimensional column vector (with N = JTOP - JBOT + 1) defined by

$$\overline{c}_i = \begin{pmatrix} c_{JBOT,i} \\ \vdots \\ c_{JTOP,i} \end{pmatrix}$$

and where A is an NXN dimensional, diagonally-dominant, tridiagonal matrix, and f_i is an N dimensional column vector.

The following solution sequence is repeated for each x-station from IUP to IDOWN. The coefficient $1/(x_i - x_{i-1})^2$ of the ϕ_{xt} term is calculated. Then the array VC_j representing the coefficient of ϕ_{xx} in the partial differential equation; that is, $(K - (\gamma + 1)\phi_x)/2\Delta x$, is computed at each J station. Next, the arrays representing the diagonal ($DIAG_j$), subdiagonal (SUB_j), and superdiagonal (SUP_j) elements of the tridiagonal matrix A are determined, where account is taken in calculating $DIAG_j$ of whether VC_j is greater or less than zero. The array RHS which is equal to the negative of the residual $(-R_{ij})$, and which represents the right-hand side f_i of the matrix equation is then computed. If the iteration sweep in x has proceeded to the airfoil; that is, ILE $\leq$ I $\leq$ ITE, the $DIAG_j$, SUB_j, SUP_j, and RHS_j arrays are modified at the points immediately below (j = JLOW) and above (j = JUP) the x axis to account for the airfoil boundary condition. A similar procedure is used at (j = JLOW,JUP) at locations behind the trailing edge to account for the Kutta condition jump in potential along the cut extending from the trailing edge to the downstream boundary. Next subroutine BCEND is called to modify the diagonal ($DIAG_j$) and right-hand-side (RHS_j) arrays to account for the appropriate boundary conditions at JBOT and JTOP. The current column is then scanned to see whether the maximum residual $|R_{ij}|_{max} = |RHS_j|$ is contained within it. If it is, that value (BIGRL) and the I,J) locations (IRL,JRL) are stored. Finally, modifications are made to $DIAG_j$ and RHS_j to add the $\epsilon \, \Delta t \, \phi_{xt}/\Delta x$ term according to

$$DIAG_j = DIAG_j - \frac{\epsilon}{(x_i - x_{i-1})^2}$$

$$RHS_j = RHS_j - \epsilon \frac{\left(\phi^{(n+1)}_{j,i-1} - \phi^{(n)}_{j,i-1}\right)}{(x_i - x_{i-1})^2}$$

The tridiagonal matrix equation $A \overline{C}_i = f_i$ is then solved by using the method of triangular decomposition. The NXN dimensional, tridiagonal matrix A is factored into the product A = LU, where L is a lower triangular matrix containing only subdiagonal and diagonal elements and U is a special upper triangular matrix containing only superdiagonal elements and unit diagonal elements. Thus, the original equation

$$A\overline{C}_i = L\ U\ \overline{C}_i = f_i$$

is factored into two equations

$$U\ \overline{C}_i = Z$$

$$L\ Z = f_i$$

The latter equation is solved first for Z and then the former equation is solved for $\overline{C}_i$ by back-substitution.

Finally, the new potential is computed by adding the correction to the old potential, and the correction potential $\overline{C}_i$ vector is scanned to determine whether the maximum correction is contained within it. If it is, that value (ERROR) and the (I,J) location (IERROR, JERROR) are stored for output.

5.2.51 Subroutine TRAP (X,Y,N,SUM).- Subroutine TRAP performs an integration of the vector array Y with respect to the ordinates in the vector array X by using the trapezoidal rule. Here, N is the length of the X,Y arrays and SUM is the resultant integral. The formula used is

$$\text{SUM} = \frac{1}{2} \sum_{i=1}^{N-1} (x_{i+1} - x_i)(y_{i+1} + y_i)$$

5.2.52 Main program TSFOIL (INPUT, OUTPUT, TAPE5 = INPUT, TAPE6 = OUTPUT, TAPE3, TAPE7).- TSFOIL is the main program. No calculations are performed within this routine, which acts only to call the necessary subroutines to read input, perform the required calculations, and print the output. Two tests are made within the routine that determine: (1) when the final computation mesh has been reached; and (2) whether the current calculation has been aborted. If either of these tests are positive, the program prints the final output for the current case, resets the mesh parameters back to those for the input mesh, terminates the current calculation, and goes on to read the input for the following case.

5.2.53 Subroutine VROOTS.- Subroutine VROOTS computes the constants BETA0, BETA1, BETA2, PSI0, PSI1, and PSI2 which are required for the subsonic far-field vortex in an ideal slotted wind tunnel (BCTYPE = 4). The BETA's are computed in an iterative fashion as follows:

$$\mathrm{BETA0}^{n} = \tan^{-1}\left[-F\cdot \mathrm{BETA0}^{n-1} + \frac{\sqrt{K}}{\tilde{P}}\right]$$

$$\mathrm{BETA1}^{n} = \tan^{-1}\left[-F\cdot (\mathrm{BETA1}^{n-1} + \pi) + \frac{\sqrt{K}}{\tilde{P}}\right]$$

$$\mathrm{BETA2}^{n} = \tan^{-1}\left[-F\cdot (\mathrm{BETA2}^{n-1} - \pi) + \frac{\sqrt{K}}{\tilde{P}}\right]$$

where F is the tunnel slot parameter, K the transonic similarity parameter, and $\tilde{P}$ the transonically scaled wall porosity factor. One hundred iterations are allowed for convergence with the error criteria

$$|\mathrm{BETA}^{n} - \mathrm{BETA}^{n-1}| < 10^{-5}$$

If any BETA fails to converge within 100 iterations, an error message is printed and the program stops. If all three BETA's converge, then the PSI's are computed as follows:

$$\mathrm{PSI0} = 1 + \frac{F}{1 + \tan^{2}(\mathrm{BETA0})}$$

with analogous formulas for PSI1 and PSI2.

APPENDIX
LISTING OF COMPUTER PROGRAM TSFOIL

```
      PROGRAM TSFOIL(INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT,TAPE3,TAPE7)
C*************************************************************************
C
C                   MAIN PROGRAM FOR TSFOIL
C                   PROGRAM COMPUTES TRANSONIC FLOW PAST A TWODIMENSIONAL
C                   LIFTING AIRFOIL USING TRANSONIC SMALL DISTURBANCE THEORY
C
C                   PROGRAM WRITTEN BY
C                       EARLL M. MURMAN AND FRANK R. BAILEY
C                       NASA-AMES RESEARCH CENTER
C                           AND
C                       MARGARET L. JOHNSON
C                       COMPUTER SCIENCES CORPORATION
C                  DOCUMENTED BY
C                       STEPHEN S. STAHARA
C                       NIELSEN ENGINEERING AND RESEARCH, INC.
C*************************************************************************
      LOGICAL          ABORT
      COMMON / COM3/ IREF     , ABORT   , ICUT    , KSTEP
C
C                   WRITE HEADER PAGE INFORMATION
C
      WRITE (6,1000)
      WRITE (6,1001)
      WRITE (6,1002)
      WRITE (6,1003)
      WRITE (6,1002)
      WRITE (6,1004)
      WRITE (6,1002)
      WRITE (6,1005)
      WRITE (6,1002)
      WRITE(6,1006)
      WRITE(6,1002)
      WRITE(6,1007)
      WRITE(6,1002)
      WRITE (6,1001)
 1000 FORMAT(1H1///////////////////)
 1001 FORMAT(24X,69(1H*))
 1002 FORMAT(24X,1H*,67X,1H*)
 1003 FORMAT(24X,1H*,25X,15H PROGRAM TSFOIL,27X,1H*/
     1  24X,1H*,29X, 7H SOLVES,31X,1H*/
     2  24X,1H*, 5X,56H INVISCID FLOW PAST THIN TWO DIMENSIONAL LIFTING
     3AIRFOIL,6X,1H*/
     4  24X,1H*,29X, 6H USING,32X,1H*/
     5  24X,1H*,15X,35H TRANSONIC SMALL DISTURBANCE THEORY,17X,1H*/
     6  24X,1H*, 9X,47H FULLY CONSERVATIVE FINITE DIFFERENCE EQUATIONS,
     7  11X,1H*/
     8  24X,1H*,17X,31H SUCCESSIVE LINE OVERRELAXATION,19X,1H*)
 1004 FORMAT(24X,1H*,27X,11H WRITTEN BY,29X,1H*)
 1005 FORMAT(24X,1H*,15X,36H EARLL M. MURMAN AND FRANK R. BAILEY,16X,1H*
     1         24X,1H*,19X,26H NASA-AMES RESEARCH CENTER,22X,1H*/
     2         24X,1H*,19X,26H MOFFETT FIELD, CALIFORNIA,22X,1H*/
     3         24X,1H*,31X, 4H AND,32X,1H*/
     4         24X,1H*,23X,20H MARGARET L. JOHNSON,24X,1H*/
     5         24X,1H*,18X,30H COMPUTER SCIENCES CORPORATION,19X,1H*/
     6         24X,1H*,20X,26H MOUNTAIN VIEW, CALIFORNIA,21X,1H*)
 1006 FORMAT(24X,1H*,25X,14H DOCUMENTED BY,28X,1H*)
 1007 FORMAT(24X,1H*,23X,19H STEPHEN S. STAHARA,25X,1H*/
     1   24X,1H*,14X,39H NIELSEN ENGINEERING AND RESEARCH, INC.,14X,1H*/
     2   24X,1H*,20X,26H MOUNTAIN VIEW, CALIFORNIA,21X,1H*)
C
C                   THE MAIN PROGRAM DOES NO COMPUTATIONS
C                   ALL COMPUTATIONS ARE DONE IN SUBROUTINES CALLED BY
C                   TSFOIL.
C                   SUBROUTINE ECHINP PROVIDES A LISTING OF ALL DATA
C                   CARDS FOR ENTIRE JOB.
      CALL ECHINP
C                   SUBROUTINE READIN READS ALL INPUT AND CHECKS IT
    1 CONTINUE
      CALL READIN
C
C                   SUBROUTINE SCALE RESCALES ALL PHYSICAL VARIABLES TO
C                   TRANSONIC SIMILARITY FORM
      CALL SCALE
C
C                   SUBROUTINE FARFLD SETS FAR FIELD BOUNDARY CONDITIONS.
      CALL FARFLD
C
C                   SUBROUTINE BODY COMPUTES AIRFOIL GEOMETRY AND PRINTS
C                   OUT GEOMETRICAL INFORMATION
      CALL BODY
C
C                   SUBROUTINE CUTOUT REMOVES MESH POINTS FROM THE INPUT
C                   MESH. CALCULATIONS ARE DONE FIRST ON COARSE MESH,
C                   AND THEN ON PROGRESSIVELY REFINED MESHES UNTIL
C                   INPUT MESH IS ACHIEVED.
      CALL CUTOUT
C
C                   SUBROUTINE GUESSP INITIALIZES P ARRAY
      CALL GUESSP
C
C                   SUBROUTINE DIFCOE CALCULATES FINITE DIFFERENCE
C                   EQUATION COEFFICIENTS WHICH DEPEND ON MESH SIZE.
      CALL DIFCOE
C
C                   SUBROUTINE SETBC  ADJUSTS THE AIRFOIL SLOPE BOUNDARY
C                   CONDITION FOR THE CURRENT X Y MESH. ALSO, THE LIMITS
C                   ON I AND J INDICIES FOR SOLVING THE DIFFERENCE
C                   EQUATIONS ARE SET.
      CALL SETBC
C
C                   SUBROUTINE SOLVE EXECUTES THE MAIN RELAXATION
C                   SOLUTION OF THE DIFFERENCE EQUATIONS
      CALL SOLVE
C
C                   IF FINAL MESH HAS BEEN REACHED, RESULTS ARE PRINTED
C                   OUT IN FINAL FORM.  IF NOT, INTERMEDIATE RESULTS
C                   ARE PRINTED OUT AND THE MESH IS REFINED.  THE ABOVE
C                   SEQUENCE OF CALCULATIONS ARE THEN REPEATED
      IF(IREF .LE. 0) GO TO 5
      IF (ABORT) GO TO 5
C
C                   SUBROUTINE PRINT1 PRINTS OUT BODY PRESSURE
C                   DISTRIBUTION.
      CALL PRINT1
C
C                   SUBROUTINE REFINE  ADDS MESH POINTS
      CALL REFINE
C
C                   REPEAT SEQUENCE OF RELAXATION CALCULATIONS
      CALL DIFCOE
      CALL SETBC
      CALL SOLVE
C
C                   IF FINAL MESH HAS BEEN REACHED, RESULTS ARE PRINTED
C                   OUT IN FINAL FORM.  IF NOT, INTERMEDIATE RESULTS
C                   ARE PRINTED OUT AND THE MESH IS REFINED.  THE ABOVE
C                   SEQUENCE OF CALCULATIONS ARE THEN REPEATED
      IF(IREF .LE. 0) GO TO 5
      IF (ABORT) GO TO 5
      CALL PRINT1
      CALL REFINE
      CALL DIFCOE
      CALL SETBC
      CALL SOLVE
C
C                   RELAXATION SOLUTION IS COMPLETED
    5 CONTINUE
C
C                   PRINTOUT FINAL INFORMATION
      CALL PRINT
      IF (IREF .GT. 0 ) CALL REFINE
      IF (IREF .GT. 0 ) CALL REFINE
C
C                   STORE SOLUTION FOR NEXT CASE OR ON TAPE 3
      CALL SAVEP
C
C                   RETURN TO READIN TO COMPUTE NEXT CASE OR TERMINATE
C                   CALCULATIONS.
      GO TO 1
      END
```

```
      SUBROUTINE ANGLE
C                   COMPUTES THETA AT EVERY MESH POINT.
C                   CALLED BY - FARFLD.
      COMMON / COM1/ IMIN     , IMAX    , IUP     , IDOWN   , ILE     ,
     1               ITE      , JMIN    , JMAX    , JUP     , JLOW    ,
     2               JTOP     , JBOT
      COMMON / COM2/ AK       , ALPHA   , DUB     , GAM1    , RTK
      LOGICAL        AMESH
      COMMON / COM4/ XIN(100) , YIN(100), AMESH
      COMMON /COM12/ F        , H       , HALFPI  , PI      , RTKPOR  ,
     1               TWOPI
```

```
      REAL JET
      COMMON /COM16/ ALPHAO   , ALPHA1  , ALPHA2  , XSING   ,
     1               OMEGAO   , OMEGA1  , OMEGA2  , JET
      COMMON /COM33/ THETA(100,100)

C                         SUBROUTINE TO COMPUTE THE ANGLE  THETA AT
C                         EACH MESH POINT.

      R2PI = 1.0 / TWOPI
      DO 20 I=IMIN,IMAX
      XX = XIN(I) - XSING
      DO 10 J=JMIN,JMAX
      YY = YIN(J) * RTK
      R = SQRT(YIN(J)**2 + XX*XX)
      ATN = ATAN2(YY,XX)
      Q = PI - SIGN(PI,YY)
      THETA(J,I) = -(ATN + Q) * R2PI
      IF ( R .LE. 1.0 ) THETA(J,I) = THETA(J,I) * R
   10 CONTINUE
   20 CONTINUE
      RETURN
      END
```

```
      FUNCTION ARF (X)

C               EVALUATES ERF WITH AN ERROR .LT. 1.5E-7 BY RATIONAL
C               APPROXIMATION 7.1.26 OF HANDBOOK OF MATH. FUNCTIONS
C               U. S. DEPT. OF COMMERCE.  NBS APPL MATH SER 55.
C               CALLED BY - AYMESH.

      DIMENSION C(5)
      DATA C /1.061405429,-1.453152027,1.421413741, -.284496736,
     1         .254829592/

      Y = X
      IF ( X .LT. 0.0 ) Y = -Y
      IF ( Y .LT. 10. ) GO TO 10
      ARF = 1.0
      GO TO 30
   10 CONTINUE
      T   = 1.0 / (1.0 + .3275911*Y)
      POLY = 0.0
      DO 20 I=1,5
      POLY = (POLY + C(I)) * T
   2J CONTINUE
      ARF = 1.0 - POLY * EXP(-Y*Y)
   30 CONTINUE
      IF (X .LT. 0.0) ARF = -ARF
      PETURN
      END
```

```
      SUBROUTINE AYMESH
C                    COMPUTES ANALYTICAL X AND Y MESH POINTS.
C                    CALLED BY - READIN.
      COMMON / COM1/ IMIN     , IMAX    , IUP     , IDOWN   , ILE     ,
     1               ITE      , JMIN    ,` JMAX   , JUP     , JLOW    ,
     2               JTOP     , JBOT
      LOGICAL        AMESH
      COMMON / COM4/ XIN(100) , YIN(100), AMESH
      INTEGER        PSTART
      LOGICAL        PSAVE
      COMMON /COM11/ ALPHAO   , CLOLD . , DELTAO  , DUBO    , EMACHO  ,
     1               IMINO    , IMAXO   , IMAXI   , JMINO   , JMAXO   ,
     2               JMAXI    , PSAVE   , PSTART  , TITLE(8), TITLEO(8),
     3               VOLO     , XOLD(100),YOLD(100)
      COMMON /COM12/ F        , H       , HALFPI  , PI      , RTKPOR  ,
     1               TWOPI
      INTEGER        BCTYPE
      COMMON /COM28/ BCTYPE   , CIRCFF  , FHINV   , POR     , CIRCTE
      COMMON /COM30/ BXH(401) , REST(3)

      DIMENSION  XH(401) , BX(100)
      DATA  AO/.225/, A1/1.4/, A2/1.6/, A3/.6188/, A4/.75/, A5/30./,
     1      A6/.603/, A7/2.0/
      DATA CT1/2.0/, CT2/2.0/, CT3/1.0/, CF1/1.0/, CF2/1.0/, CF3/5.2/

      IMAXI=81
      JMAXI=64
      IMA = (IMAXI - 1) / 2
      A22 = A2 * A2
      A72 = A7 * A7
      FACT = HALFPI * .005
      DO 10 I=201,401
      EX     = TAN(FACT * (I-201) )
      XH(I)  = EX
      EX2    = EX * EX
      BXH(I) = A1 * EX * EXP(-A22*EX2) + (1.0-EXP(-A72*EX2))*ARF(A4*EX)
   10 CONTINUE
      DO 20 I=1,200
      XH(I)  = - XH(402-I)
      BXH(I) = -BXH(402-I)
   20 CONTINUE
      TOOPI = 2.0 / PI

C                        ADD 2/PI ATAN(AK(X+A6)) TO BXH TO GIVE MORE
C                        POINTS NEAR THE LEADING EDGE.

      DO 30 I=1,401
      BXH(I) = BXH(I) * (1.-AO) + TOOPI*AO*ATAN(A5*(XH(I)+A6))
   30 CONTINUE

      DX    = 1.0 / IMA
      IM2   = IMA * 2
      IM2P1= IM2 + 1

      DO 42 I=1,IM2P1
      IF (I .EQ. 1 .OR. I .EQ. IM2P1) GO TO 31
      BX(I) = (I-1) * DX - 1.0
      GO TO 32
   31 CONTINUE
      IF (I .EQ. 1) BX(I) = -.999
      IF (I .EQ. IM2P1) Bx(I) = .999
   32 CONTINUE
      J     = 0
   33 CONTINUE
      J     = J + 1
      IF (BX(I) .GT. BXH(J)) GO TO 33
      IF (BX(I) .LT. BXH(J)) GO TO 34
      XI    = XH(J)
      GO TO 40

   34 CONTINUE
      BT1  = BX(I)   - BXH(J-1)
      BHT1 = BXH(J) - BXH(J-1)
      XHT1 = XH(J)   - XH(J-1)
      T1   = XHT1 / BHT1
      XI    = XH(J-1) + BT1 * T1
      IF (J .EQ. 2) GO TO 40

      BT2  = BX(I)     - BXH(J)
      BHT2 = BXH(J)    - BXH(J-2)
      BHT3 = BXH(J-1) - BXH(J-2)
      XHT2 = XH(J-1)   - XH(J-2)
      T2   = XHT2 / BHT3
      T12  = T1 - T2
      BT12 = BT1 + BT2
      TBT2 = T12 / BHT2
      XI    = XI + BT12 * TBT2
      IF (J .GE. 400) GO TO 40

      BT3  = BX(I)     - BXH(J-2)
      BHT4 = BXH(J+1) - BXH(J-2)
      BHT5 = BXH(J+1) - BXH(J)
      BHT6 = BXH(J+1) - BXH(J-1)
      XHT3 = XH(J+1)   - XH(J)
      T3   = XHT3 / BHT5
      XI    = XI + BT12 * BT3/BHT4 * ((T3-T1)/BHT6 - TBT2)
   40 CONTINUE
      XIN(I) = XI + A3
   42 CONTINUE
      CALL ISLIT(XIN)
      XFACT=1.0/XIN(ITE)
      DO 43 I=1,IMAXI
      XIN(I)=XIN(I)*XFACT
   43 CONTINUE
      XIN(ITE)=1.0
      IMAXI = IM2P1
      JM2   = JMAXI
      JMA = JM2 / 2                                                     AYMESH  99
      FJ = JMA                                                          AYMESH 100
      IF (BCTYPE .NE. 1) GO TO 44                                       AYMESH 101
      C1    = CF1                                                       AYMESH 102
      C2    = CF2                                                       AYMESH 103
      C3    = CF3                                                       AYMESH 104
      GO TO 45                                                          AYMESH 105
   44 CONTINUE                                                          AYMESH 106
      C1    = CT1                                                       AYMESH 107
      C2    = CT2                                                       AYMESH 108
      C3    = CT3                                                       AYMESH 109
   45 CONTINUE                                                          AYMESH 110
      DETA = 1.0 / (FJ*C1)                                              AYMESH 111
      IF (BCTYPE .EQ. 1) DETA = 1.0 / ((FJ+1.0)*C1)                     AYMESH 112
      C     = C3 / (TAN(HALFPI*DETA*FJ))**C2                            AYMESH 113
      DO 50 I=1,JMA                                                     AYMESH 114
      J     = JMA + I                                                   AYMESH 115
      ETAI = I * DETA                                                   AYMESH 116
      YIN(J) = C * (TAN(HALFPI*ETAI))**C2                               AYMESH 117
      YIN(J-2*I+1)   = -YIN(J)                                          AYMESH 118
   50 CONTINUE                                                          AYMESH 119
      RETURN                                                            AYMESH 120
      END                                                               AYMESH 121
```

```
      BLOCK DATA                                                        BLKDT    2
                                                                        BLKDT    3
                                                                        BLKDT    4
      COMMON          P(102,101),X(100)  , Y(100)                       BLANK    2
      COMMON / COM1/ IMIN      , IMAX    , IUP     , IDOWN   , ILE     , COM1     2
     1               ITE       , JMIN    , JMAX    , JUP     , JLOW    , COM1     3
     2               JTOP      , JBOT                                   COM1     4
      COMMON / COM2/ AK        , ALPHA   , DUB     , GAM1    , RTK      COM2     2
      LOGICAL        ABORT                                              COM3     2
      COMMON / COM3/ IREF      , ABORT   , ICUT    , KSTEP              COM3     3
      LOGICAL        AMESH                                              COM4     2
      COMMON / COM4/ XIN(100) , YIN(100), AMESH                         COM4     3
      COMMON / COM5/ XDIFF(100),YDIFF(100)                              COM5     2
      COMMON / COM6/ FL(100)   , FXL(100), FU(100) , FXU(100),          COM6     2
     1            CAMBER(100), THICK(100),VOL    , XFOIL(100), IFOIL    COM6     3
      COMMON / COM7/ CJUP      , CJUP1   , CJLOW   , CJLOW1             COM7     2
      COMMON / COM8/ CVERGE    , DVERGE  , IPRTER  , MAXIT   ,          COM8     2
     1               WE(3)     , EPS                                    COM8     3
      INTEGER        BCFOIL                                             COM9     2
      COMMON / COM9/ BCFOIL    , NL      , NU      , XL(100) , XU(100) , COM9     3
     1               YL(100)   , YU(100) , RIGF                         COM9     4
      LOGICAL XGRDIN,YGRDIN                                             COM10    2
      COMMON /COM10/ YFREE(100) , YTUN(100)  , XKRUPP(100) , GAM      , COM10    3
     1               JMXF     , JMXT     , XGRDIN  , YGRDIN             COM10    4
      INTEGER        PSTART                                             COM11    2
      LOGICAL        PSAVE                                              COM11    3
      COMMON /COM11/ ALPHAO    , CLOLD   , DELTAO  , DUBO    , EMACHO  , COM11    4
     1               IMINO     , IMAXO   , IMAXI   , JMINO   , JMAXO   , COM11    5
     2               JMAXI     , PSAVE   , PSTART  , TITLE(8), TITLEO(8), COM11    6
     3               VOLD      , XOLD(100),YOLD(100)                    COM11    7
      COMMON /COM12/ F         , H       , HALFPI  , PI      , RTKPOR  , COM12    2
     1               TWOPI                                              COM12    3
      COMMON /COM13/ CDFACT    , CLFACT  , CMFACT  , CPFACT  , CPSTAR   COM13    2
      LOGICAL        FCR       , KUTTA                                  COM14    2
      COMMON /COM14/ CLSET     , FCR     , KUTTA   , WCIRC              COM14    3
      COMMON /COM15/ B         , BETA0   , BETA1   , BETA2   , PSI0    , COM15    2
     1               PSI1      , PSI2                                   COM15    3
      REAL JET                                                          COM16    2
      COMMON /COM16/ ALPHA0    , ALPHA1  , ALPHA2  , XSING   ,          COM16    3
     1               OMEGA0    , OMEGA1  , OMEGA2  , JET                COM16    4
      COMMON /COM17/ CYYBLC    , CYYBLD  , CYYBLU  , CYYBUC  , CYYBUD  , COM17    2
     1               CYYBUU    ,FXLBC(100),FXUBC(100)                   COM17    3
      LOGICAL        OUTERR                                             COM18    2
      COMMON /COM18/ ERROR     , I1      , I2      , IERROR  , JERROR  , COM18    3
     1               OUTERR    , EMU(100,2)        , VC(100) ,          COM18    4
     2               WI        , DCIRC   , POLD(100,2)                  COM18    5
      COMMON /COM19/ DIAG(100), RHS(100), SUB(100), SUP(100)            COM19    2
      COMMON /COM20/ XMID(100), YMID(100)                               COM20    2
      COMMON /COM22/ CXC(100) , CXL(100), CXR(100), CXXC(100),CXXL(100), COM22    2
     1               CXXR(100), C1(100)                                 COM22    3
      COMMON /COM23/ CYYC(100), CYYD(100),CYYU(100), IVAL               COM23    2
      COMMON /COM24/ DTOP(100), DBOT(100),DUP(100), DDOWN(100),         COM24    2
     1               VTOP(100), VBOT(100),VUP(100), VDOWN(100)          COM24    3
      COMMON /COM25/ CPL(100) , CPU(100)                                COM25    2
```

```
      COMMON /COM26/ PJUMP(100)                                         COM26    2
      LOGICAL        PHYS                                               COM27    2
      INTEGER        PRTFLO    , SIMDEF                                 COM27    3
      COMMON /COM27/ CL        , DELTA   , DELRT2  , EMACH   , EMROOT  , COM27    4
     1               PHYS      , PRTFLO  , SIMDEF  , SONVEL  , VFACT   , COM27    5
     2               YFACT                                              COM27    6
      INTEGER        BCTYPE                                             COM28    2
      COMMON /COM28/ BCTYPE    , CIRCFF  , FHINV   , POR     , CIRCTE   COM28    3
      COMMON /COM32/ BIGRL     , IRL     , JRL                          COM32    2
      COMMON /COM33/ THETA(100,100)                                     COM33    2
                                                                        BLKDT   35
      DATA      BCFOIL / 3 / , BCTYPE / 1 /  , PSTART / 1 / ,           BLKDT   36
     1          PRTFLO / 1 / , SIMDEF / 3 /                             BLKDT   37
      DATA      PHYS /.T. /  , PSAVE / .F. / , FCR  / .T. / ,           BLKDT   38
     1          KUTTA / .T. /, ABORT / .T. /,  AMESH / .F. /            BLKDT   39
      DATA      EMACH  /.75/ , DELTA /.115/ , ALPHA   /.12/ ,           BLKDT   40
     1          AK      /0.0/,  GAM/1.4/, RIGF/0.0/, EPS/.2/            BLKDT   41
      DATA      CLSET /0.0/,  CVERGE/.00001/,  DVERGE/10./,             BLKDT   42
     1          F      / 0.0 /, H     / 0.0 /  , POR     / 0.0/,        BLKDT   43
     1          WCIRC/1.0/,  WE/1.8,1.9,1.95/                           BLKDT   44
      DATA      XGRDIN /.F./, YGRDIN /.F./                              BLKDT   45
      DATA      IMAXI/77/,  JMXF/56/,  MAXIT/500/,                      BLKDT   46
     1          NL     / 75  /, NU    / 100 /  , IPRTER / 10 /          BLKDT   47
      DATA      PI /3.14159265/ , HALFPI /1.570796325/ ,                BLKDT   48
     1          TWOPI/ 6.28318531/                                      BLKDT   49
      DATA     IMIN /1/       , JMIN /1/       , ICUT /2/               BLKDT   50
      DATA CPU/100*0.0/,CPL/100*0.0/                                    BLKDT   51
      DATA   YIN /100*0.0  /, JMAXI /100 /  , JMXT    /48 /             BLKDT   52
      DATA XKRUPP / -1.075    , -.950    ,                              BLKDT   53
     1             -.825    , -.7      , -.575    , -.45     , -.35     , BLKDT   54
     2             -.25     , -.175    , -.125    , -.075    , -.0525   , BLKDT   55
     3             -.035    , -.0225   , -.015    , -.0075   , -.0025   , BLKDT   56
     4              .0025   ,  .0075   ,  .0125   ,  .0175   ,  .0225   , BLKDT   57
     5              .0275   ,  .0325   ,  .0375   ,  .045    ,  .055    , BLKDT   58
     6              .065    ,  .075    ,  .085    ,  .0975   ,  .115    , BLKDT   59
     7              .140625 ,  .171875,  .203125,  .234375,  .265625,   BLKDT   60
     8              .296875 ,  .328125,  .359375,  .390625,  .421875,   BLKDT   61
     9              .453125 ,  .484375,  .515625,  .546875,  .578125,   BLKDT   62
     1              .609375 ,  .640625,  .671875,  .703125,  .734375,   BLKDT   63
     2              .765625 ,  .796875,  .828125,  .859375,  .885    ,  BLKDT   64
     3              .9      , .915     , .93      , .945     , .96      , BLKDT   65
     4              .975    , .99      , 1.0      , 1.01     , 1.025    , BLKDT   66
     5              1.05    , 1.09     , 1.15     , 1.225    , 1.3      , BLKDT   67
     6              1.4     , 1.5      , 1.625    , 1.75     , 1.875    , BLKDT   68
     7              23*0.0 /                                            BLKDT   69
      DATA YFREE /  -5.2     , -4.4     , -3.6     , -3.0     , -2.4     , BLKDT   70
     1              -1.95    , -1.6     , -1.35    , -1.15    , -.95     , BLKDT   71
     2              -.80     , -.65     , -.55     , -.45     , -.39     , BLKDT   72
     3              -.34     , -.30     , -.27     , -.24     , -.21     , BLKDT   73
     4              -.18     , -.15     , -.125    , -.1      , -.075    , BLKDT   74
     5               - .05   ,  - .03   ,  - .01   ,     .01  ,     .03  , BLKDT   75
     6                 .05   ,    .075  ,    .1    ,    .125  ,    .15   , BLKDT   76
     7                 .18   ,    .21   ,    .24   ,    .27   ,    .30   , BLKDT   77
     8                 .34   ,    .39   ,    .45   ,    .55   ,    .65   , BLKDT   78
     9                 .8    ,    .95   ,   1.15   ,   1.35   ,   1.60   , BLKDT   79
     1                1.95   ,   2.4    ,   3.0    ,   3.6    ,   4.4    , BLKDT   80
     2                5.2    , 44*0.0  /                                BLKDT   81
      DATA    YTUN /  -2.0    ,  -1.8   ,  -1.6   ,  -1.4    ,  -1.2    , BLKDT   82
     1               -1.0    ,   -.8   ,   -.65   ,   -.55   ,  -.45    , BLKDT   83
     2                -.39   ,   -.34   ,   -.30   ,   -.27   ,  -.24    , BLKDT   84
     3                -.21   ,   -.18   ,   -.15   ,   -.125  ,  -.1     , BLKDT   85
     4               - .075  ,  - .05   ,  - .03   ,  - .01   ,    .01   , BLKDT   86
     5                 .03   ,    .05   ,    .075  ,    .1    ,    .125  , BLKDT   87
     6                 .15   ,    .18   ,    .21   ,    .24   ,    .27   , BLKDT   88
     7                 .3    ,    .34   ,    .39   ,    .45   ,    .55   , BLKDT   89
     8                 .65   ,    .8    ,   1.0    ,   1.2    ,   1.4    , BLKDT   90
     9                1.6    ,   1.8    ,   2.0    , 52*0.0  /            BLKDT   91
      DATA   XU   /   0.000008, 0.000167, 0.000391, 0.000799, 0.001407, BLKDT   92
     1              0.002153, 0.003331, 0.005336, 0.008648, 0.014583,   BLKDT   93
     2              0.023481, 0.033891, 0.040887, 0.053973, 0.056921,   BLKDT   94
     3              0.058456, 0.059966, 0.061445, 0.062909, 0.065925,   BLKDT   95
     4              0.068785, 0.071482, 0.074007, 0.075322, 0.076603,   BLKDT   96
     5              0.077862, 0.079112, 0.080445, 0.081819, 0.083269,   BLKDT   97
     6              0.084841, 0.086702, 0.088848, 0.091378, 0.094413,   BLKDT   98
     7              0.098308, 0.103104, 0.109010, 0.116244, 0.125452,   BLKDT   99
     8              0.136635, 0.150037, 0.165853, 0.184699, 0.195177,   BLKDT  100
     9              0.206361, 0.218244, 0.230813, 0.244047, 0.257917,   BLKDT  101
     1              0.272371, 0.287410, 0.302990, 0.319057, 0.335555,   BLKDT  102
     2              0.352421, 0.369591, 0.386995, 0.404133, 0.421391,   BLKDT  103
     3              0.438708, 0.456013, 0.473246, 0.490343, 0.507242,   BLKDT  104
     4              0.523881, 0.539536, 0.554867, 0.569823, 0.584351,   BLKDT  105
     5              0.598405, 0.611936, 0.624904, 0.637273, 0.648435,   BLKDT  106
     6              0.659016, 0.668987, 0.678321, 0.687012, 0.695090,   BLKDT  107
     7              0.706936, 0.728406, 0.738649, 0.761390, 0.777010,   BLKDT  108
     8              0.792241, 0.809068, 0.824992, 0.836953, 0.857188,   BLKDT  109
     9            0.875621, 0.898268, 0.913686, 0.927686, 0.939804,
     1            0.952002, 0.971789, 0.989100, 0.997860, 1.000000/
      DATA  YU  / 0.000787, 0.003092, 0.004538, 0.006137, 0.007683,
     1            0.009056, 0.010675, 0.012803, 0.015607, 0.019624,
     2            0.024441, 0.029035, 0.031698, 0.035966, 0.036837,
     3            0.037277, 0.037700, 0.038103, 0.038497, 0.039276,
     4            0.039986, 0.040625, 0.041195, 0.041483, 0.041756,
     5            0.042019, 0.042274, 0.042539, 0.042804, 0.043079,
     6            0.043368, 0.043700, 0.044072, 0.044497, 0.044989,
     7            0.045595, 0.046312, 0.047154, 0.048132, 0.049301,
     8            0.050626, 0.052089, 0.053663, 0.055351, 0.056210,
     9            0.057068, 0.057918, 0.058751, 0.059559, 0.060335,
     1            0.061068, 0.061751, 0.062381, 0.062947, 0.063445,
     2            0.063867, 0.064213, 0.064473, 0.064646, 0.064733,
     3            0.064735, 0.064651, 0.064477, 0.064218, 0.063871,
     4            0.063438, 0.062945, 0.062376, 0.061731, 0.061014,
     5            0.060232, 0.059389, 0.058496, 0.057562, 0.056650,
     6            0.055721, 0.054791, 0.053867, 0.052965, 0.052086,
     7            0.050722, 0.048045, 0.046680, 0.043441, 0.041053,
     8            0.038606, 0.035768, 0.032958, 0.030775, 0.026954,
     9            0.023361, 0.018848, 0.015750, 0.012954, 0.010567,
     1            0.008213, 0.004559, 0.001620, 0.000293, 0.000000/
      DATA  XL  / 0.000000, 0.000012, 0.000043, 0.000183, 0.000249,
     1            0.000348, 0.000455, 0.000680, 0.001011, 0.001481,
     2            0.001875, 0.002316, 0.003055, 0.004201, 0.004747,
     3            0.005779, 0.007035, 0.008265, 0.009969, 0.012286,
     4            0.015346, 0.019276, 0.025335, 0.029379, 0.039095,
     5            0.052516, 0.062469, 0.073329, 0.085290, 0.099822,
     6            0.118563, 0.140987, 0.167184, 0.202933, 0.228511,
     7            0.247895, 0.263995, 0.282047, 0.297045, 0.310147,
     8            0.324075, 0.344872, 0.363502, 0.387644, 0.404492,
     9            0.426308, 0.450016, 0.475378, 0.521837, 0.549843,
     1            0.578612, 0.605305, 0.623479, 0.642152, 0.657543,
     2            0.671212, 0.690340, 0.708891, 0.726684, 0.746683,
     3            0.768502, 0.784892, 0.801149, 0.819187, 0.838546,
     4            0.858817, 0.879431, 0.903723, 0.926504, 0.943652,
     5            0.958668, 0.973623, 0.986187, 0.996582, 1.000000,
     6            25*0.0/
      DATA  YL  / 0.000000,-0.000700,-0.001385,-0.002868,-0.003330,
     1           -0.003880,-0.004379,-0.005199,-0.006133,-0.007183,
     2           -0.007933,-0.008676,-0.009776,-0.011204,-0.011815,
     3           -0.012861,-0.013983,-0.014962,-0.016175,-0.017636,
     4           -0.019336,-0.021258,-0.023836,-0.025373,-0.028634,
     5           -0.032423,-0.034840,-0.037182,-0.039456,-0.041862,
     6           -0.044483,-0.047017,-0.049298,-0.051443,-0.052406,
     7           -0.052859,-0.053062,-0.053117,-0.053027,-0.052849,
     8           -0.052562,-0.051951,-0.051218,-0.050013,-0.049004,
     9           -0.047495,-0.045601,-0.043288,-0.038336,-0.034916,
     1           -0.031104,-0.027333,-0.024661,-0.021854,-0.019517,
     2           -0.017429,-0.014527,-0.011771,-0.009228,-0.006537,
     3           -0.003868,-0.002086,-0.000524, 0.000950, 0.002227,
     4            0.003224, 0.003865, 0.004212, 0.004067, 0.003657,
     5            0.003067, 0.002242, 0.001329, 0.000376, 0.000000,
     6            25*0.0/
      END
```

```
      SUBROUTINE BCEND
C                  SUBROUTINE BCEND MODIFIES THE DIAG AND RHS VECTORS
C                  ON EACH I LINE IN THE APPROPRIATE WAY TO INCLUDE THE
C                  BOUNDARY CONDITIONS AT JBOT AND JTOP.
C                  CALLED BY - SYOR.

      COMMON          P(102,101),X(100)  , Y(100)
      COMMON / COM1/ IMIN     , IMAX    , IUP     , IDOWN   , ILE     ,
     1               ITE      , JMIN    , JMAX    , JUP     , JLOW    ,
     2               JTOP     , JBOT
      COMMON / COM2/ AK       , ALPHA   , DUB     , GAM1    , RTK
      COMMON / COM5/ XDIFF(100),YDIFF(100)
      COMMON /COM19/ DIAG(100), RHS(100), SUB(100), SUP(100)
      COMMON /COM23/ CYYC(100), CYYD(100),CYYU(100), IVAL
      INTEGER         BCTYPE
      COMMON /COM28/ BCTYPE   , CIRCFF  , FHINV   , POR     , CIRCTE

      I = IVAL
C                  BRANCH TO APPROPRIATE ADDRESS FOR BCTYPE
      GO TO (10,20,30,40,50,60) , BCTYPE
C                  BCTYPE = 1, FREE AIR
 10   CONTINUE
C
C                  DIRICHLET BOUNDARY CONDITION FOR SUBSONIC FREESTREAM
      IF (AK .GT. 0.0) RETURN
C                  NEUMAN BOUNDARY CONDITION FOR SUPERSONIC FREESTREAM
      DFACL = -CYYD(JBOT) * RTK * XDIFF(I)
      DFACU = -CYYU(JTOP) * RTK * XDIFF(I)
      RFACL = DFACL * (P(JMIN,I) - P(JMIN,I-1))
      RFACU = DFACU * (P(JMAX,I) - P(JMAX,I-1))
      GO TO 95
C                  BCTYPE = 2, SOLID WALL
 20   CONTINUE
C                  NEUMAN BOUNDARY CONDITION = 0.
C                  NO MODIFICATION NECESSARY TO DIAG OR RHS
      DFACL=0.
      DFACU=0.
      RFACL=0.
      RFACU=0.
      GO TO 95
C                  BCTYPE = 3, FREE JET
 30   CONTINUE
C                  DIRICHLET BOUNDARY CONDITION
      IF (AK .LT. 0.0) GO TO 31
      PJMIN = -.75 * CIRCFF
      PJMAX = -.25 * CIRCFF
      GO TO 32
   31 CONTINUE
      PJMIN = 0.0
      PJMAX = 0.0
   32 CONTINUE
      GO TO 90
C                  BCTYPE = 4, IDEAL SLOTTED WALL
 40   CONTINUE
C                  NEUMAN BOUNDARY CONDITION
      DFACL =-FHINV * CYYD(JBOT)
      DFACU =-FHINV * CYYU(JTOP)
      IF (AK .LT. 0.0) GO TO 41
      RFACL =  DFACL * ( .75 * CIRCFF + P(JBOT,I))
      RFACU =  DFACU * ( .25 * CIRCFF + P(JTOP,I))
      GO TO 42
   41 CONTINUE
      RFACL = DFACL * P(JBOT,I)
      RFACU = DFACU * P(JTOP,I)
   42 CONTINUE
      GO TO 95
C                  BCTYPE = 5,  POROUS/PERFORATED WALL
 50   CONTINUE
      IF(POR .GT. 1.5) GO TO 55
C                  NEUMAN BOUNDARY CONDITION FOR POR .LT. 1.5
      DFACL = -CYYD(JBOT) * POR * XDIFF(I)
      DFACU = -CYYU(JTOP) * POR * XDIFF(I)
      RFACL = DFACL * (P(JMIN,I) - P(JMIN,I-1))
      RFACU = DFACU * (P(JMAX,I) - P(JMAX,I-1))
      GO TO 95
 55   CONTINUE
C                  DIRCHLET BOUNDARY CONDITION FOR POR .GT. 1.5
      IF (I .NE. IUP) RETURN
C                  SET VALUES OF P ON BOUNDARY BY INTEGRATING PX USING
C                  OLD VALUES OF POTENTIAL
      PJMIN = P(JMIN,IUP)
      TERM = -.5 / (POR * (Y(JMIN) - Y(JMIN+1)))
      DO 57 II=IUP,IDOWN
      P(JMIN,II) = P(JMIN,II-1) - TERM * (X(II)-X(II-1)) *
     1             (P(JMIN,II)+P(JMIN,II-1)-P(JMIN+1,II)-P(JMIN+1,II-1))
   57 CONTINUE
      PJMAX = P(JMAX,IUP)
      TERM = .5 / (POR * (Y(JMAX) - Y(JMAX-1)))
      DO 58 II=IUP,IDOWN
      P(JMAX,II) = P(JMAX,II-1) - TERM*(X(II) - X(II-1)) *
     1             (P(JMAX,II)+P(JMAX,II-1)-P(JMAX-1,II)-P(JMAX-1,II-1))
   58 CONTINUE
      RHS(JBOT) = RHS(JBOT) -(CYYD(JBOT)*(P(JBOT-1,I)-PJMIN))
      RHS(JTOP) = RHS( JTOP) - (CYYU(JTOP)*(P(JTOP+1,I)-PJMAX))
      RETURN
C                  BCTYPE = 6,  GENERAL WALL BOUNDARY CONDITION
C                  DIFFERENCE EQUATIONS FOR THIS BOUNDARY CONDITION
C                  HAVE NOT YET BEEN WORKED OUT.  USER MUST INSERT
C                  INFORMATION NEEDED FOR CALCULATION
 60   CONTINUE
      WRITE(6,1000)
 1000 FORMAT(34H1ABNORMAL STOP IN SUBROUTINE BCEND/
     1       24H BCTYPE=6 IS NOT USEABLE)
      STOP
C
C                  DIRICHLET BOUNDARY CONDITIONS
 90   CONTINUE
```

```
      RHS(JBOT) = RHS(JBOT) - (CYYD(JBOT)*(PJMIN-P(JBOT-1,I)))
      RHS(JTOP) = RHS(JTOP) - (CYYU(JTOP)*(PJMAX-P(JTOP+1,I)))
      RETURN
C
C                   NEUMAN BOUNDARY CONDITIONS
   95 CONTINUE
      DIAG(JBOT) = DIAG(JBOT) + DFACL
      DIAG(JTOP) = DIAG(JTOP) + DFACU
      RHS(JBOT) = RHS(JBOT) - RFACL + CYYD(JBOT)*P(JBOT-1,I)
      RHS(JTOP) = RHS(JTOP) - RFACU + CYYU(JTCP)*P(JTOP+1,I)
      RETURN
      END
```

```
      SUBROUTINE BODY
C                 COMPUTES BODY GEOMETRY INFORMATION FOR BOUNDARY
C                 CONDITIONS AND OUTPUT INFORMATION.  FOUR CHOICES OF
C                 BODY DESCRIPTION ARE AVAILABLE AS FOLLOWS
C                      BCFOIL = 1  NACA 00XX AIRFOIL
C                      BCFOIL = 2  PARABOLIC ARC AIRFOIL
C                      BCFOIL = 3  AIRFOIL ORDINATES READ IN
C                      BCFOIL = 4  EXTRA ADDRESS FOR USERS CHOICE
C                 BODY ORDINATES AND SLOPES ARE COMPUTED AT THE INPUT
C                 X MESH LOCATIONS AND ARE DIVIDED BY THE THICKNESS
C                 RATIO DELTA.  THE BODY VOLUME, CAMBER, AND THICKNESS
C                 ARE ALSO COMPUTED.
C                 ACTUAL BOUNDARY CONDITION IS SET IN SUBROUTINE SETBC
C                 CALLED BY - TSFOIL.

      COMMON / COM1/ IMIN      , IMAX    , IUP     , IDOWN   , ILE     ,
     1               ITE       , JMIN    , JMAX    , JUP     , JLOW    ,
     2               JTOP      , JBOT
      COMMON / COM2/ AK        , ALPHA   , DUB     , GAM1    , RTK
      LOGICAL        AMESH
      COMMON / COM4/ XIN(100) , YIN(100), AMESH
      COMMON / COM6/ FL(100)   , FXL(100), FU(100) , FXU(100),
     1              CAMBER(100), THICK(100),VOL    , XFOIL(100), IFOIL
      INTEGER        BCFOIL
      COMMON / COM9/ BCFOIL    , NL      , NU      , XL(100) , XU(100) ,
     1               YL(100)   , YU(100) , RIGF
      LOGICAL        PHYS
      INTEGER        PRTFLC    , SIMDEF
      COMMON /COM27/ CL        , DELTA   , DELRT2  , EMACH   , EMROOT  ,
     1               PHYS      , PRTFLO  , SIMDEF  , SONVEL  , VFACT   ,
     2               YFACT
      COMMON /SPLN/ A(200)     , B(200)  , DY1     , DY2     , K1      ,
     1              K2         , XP      , YP      ,DYP

C                 SET NUMBER OF POINTS ON AIRFOIL
      IFOIL = ITE - ILE + 1
C                 ZERO ALL THICKNESSES AND SLOPES
      DO 10 I=IMIN,IMAX
      FU(I) = 0.
      FL(I) = 0.
      FXU(I) = 0.
      FXL(I) = 0.
   10 CONTINUE
C                 BRANCH TO APPROPRIATE AIRFOIL SPECIFICATION
      GO TO (100,200,300,400), BCFOIL
  100  CONTINUE
C                 BCFOIL = 1
C                 FORMULA FOR NACA 00XX SHAPE
      IC = 0
      DO 125 I = ILE,ITE
      IC = IC + 1
      Z = XIN(I)
      XFOIL(IC) = Z
      RTZ = SQRT(Z)
      Z2 = Z*Z
      Z3 = Z*Z2
      Z4 = Z*Z3
      FU(IC) = 1.4845*RTZ - .63*Z - 1.758*Z2 + 1.4215*Z3 - .5075*Z4
      FL(IC) = -FU(IC)
      FXU(IC) = .74225/RTZ - .63 - 3.516*Z + 4.2645*Z2 - 2.03*Z3
      FXL(IC) = -FXU(IC)
  125 CONTINUE
      GO TO 500
  200 CONTINUE
C                 BCFOIL = 2
C                 PARABOLIC ARC AIRFOIL*******BI-CONVEX.
      IC = 0
      DO 225 I=ILE,ITE
      IC = IC + 1
      Z = XIN(I)
      XFOIL(IC) = Z
      Z2 = Z*Z
      FU(IC) = 2.*(Z - Z2)
      FL(IC) =  -FU(IC)
      FXU(IC) = 2. - 4.*Z
      FXL(IC) = -FXU(IC)
  225 CONTINUE
      GO TO 500
  300 CONTINUE
C                 BCFOIL = 3
C                 BODY ORDINATES READ IN NAMELIST
      DELINV = 1.
      IF(PHYS) DELINV = 1./DELTA
C                 COMPUTE ORDINATES AND SLOPES AT X MESH LOCATION ON
C                 AIRFOIL BY CUBIC SPLINE INTERPOLATION.
C                 DERIVATIVE END CONDITIONS ARE SPECIFIED AT X=0
C                 AND X=1
      K1 = 1
      K2 = 1
C                                  UPPER SURFACE
C                 CALCULATE DY/DX AT END POINTS BY FINITE DIFFERENCE
C                 FORMULA.
      DY1 = (YU(2) - YU(1)) / (XU(2) - XU(1))
      DY2 = (YU(NU) - YU(NU-1)) / (XU(NU) - XU(NU-1))
C                 INITIALIZE CUBIC SPLINE INTERPOLATION
      CALL SPLN1(XU,YU,NU)
C                 CALCULATE ORDINATES AND SLOPES
      IC = 0
      DO 320 I=ILE,ITE
      IC = IC + 1
      XP = XIN(I)
      XFOIL(IC) = XP
      CALL SPLN1X(XU,YU,NU)
C                 SET ORDINATE AND SLOPE OF AIRFOIL TO INTERPOLATED
C                 VALUE DIVIDED BY THICKNESS RATIO
      FU(IC) = YP*DELINV
      FXU(IC) = DYP*DELINV
  320 CONTINUE
C                                  LOWER SURFACE
C                 CALCULATE DY/DX AT END POINTS BY FINITE DIFFERENCE
C                 FORMULA.
      DY1 = (YL(2) - YL(1)) / (XL(2) - XL(1))
      DY2 = (YL(NL) - YL(NL-1)) / (XL(NL) - XL(NL-1))
C                 INITIALIZE CUBIC SPLINE INTERPOLATION
      CALL SPLN1(XL,YL,NL)
C                 CALCULATE ORDINATES AND SLOPES
      IC = 0
      DO 330 I=ILE,ITE
      IC = IC + 1
      XP = XIN(I)
      CALL SPLN1X(XL,YL,NL)
C                 SET ORDINATE AND SLOPE OF AIRFOIL TO INTERPOLATED
C                 VALUE DIVIDED BY THICKNESS RATIO
      FL(IC) = YP* DELINV
      FXL(IC) = DYP*DELINV
  330 CONTINUE
      GO TO 500
  400 CONTINUE
C                 BCFOIL = 4
C                 THIS ADDRESS LEFT FOR USER TO INSERT OWN AIRFOIL
C                 DESCRIPTION.
      WRITE(6,1000)
 1000 FORMAT(33H0ABNORMAL STOP IN SUBROUTINE BODY/
     1      24H BCTYPE=4 IS NOT USEABLE)
      STOP
  500 CONTINUE
C                 EXECUTE  CALCULATIONS COMMON TO ALL AIRFOILS
C
C                 COMPUTE AIRFOIL VOLUMNE
      CALL SIMP(VOLU,XFOIL,FU,IFOIL,IERR)
      CALL SIMP(VOLL,XFOIL,FL,IFOIL,IERR)
      VOL = VOLU - VOLL
C                 COMPUTE CAMBER AND THICKNESS
      DO 525 I=1,IFOIL
      CAMBER(I) = .5*(FU(I) + FL(I))
      THICK(I) = .5*(FU(I) - FL(I))
  525 CONTINUE
      DO 530 I=1,IFOIL
      FXU(I) = FXU(I) / SQRT(1.0 + RIGF *(DELTA*FXU(I))**2 )
      FXL(I) = FXL(I) / SQRT(1.0 + RIGF *(DELTA*FXL(I))**2 )
  530 CONTINUE
      CALL PRBODY
      RETURN
      END




      SUBROUTINE CDCOLE
C                COMPUTES THE DRAG BY MOMENTUM INTEGRAL METHOD.
C                INTEGRATES AROUND A CONTOUR ENCLOSING THE BODY AND
C                ALONG ALL SHOCKS INSIDE THE CONTOUR
C                CALLED BY - PRINT.

      COMMON          P(102,101),X(100)  , Y(100)
      COMMON / COM1/ IMIN      , IMAX    , IUP      , IDOWN   , ILE     ,
     1               ITE       , JMIN    , JMAX     , JUP     , JLOW    ,
     2               JTOP      , JBOT
      COMMON / COM2/ AK        , ALPHA   , DUB      , GAM1    , RTK
      COMMON / COM6/ FL(100)   , FXL(100), FU(100)  , FXU(100),
     1              CAMBER(100), THICK(100),VOL     , XFOIL(100), IFOIL
      COMMON / COM7/ CJUP      , CJUP1   , CJLOW    , CJLOW1
      COMMON /COM13/ CDFACT    , CLFACT  , CMFACT   , CPFACT  , CPSTAR
      LOGICAL        PHYS
      INTEGER        PRTFLO    , SIMDEF
      COMMON /COM27/ CL        , DELTA   , DELRT2   , EMACH   , EMROOT  ,
     1               PHYS      , PRTFLO  , SIMDEF   , SONVEL  , VFACT   ,
     2               YFACT
      COMMON/COM30/ Z(100), ARG(100), REST(204)
      GAM123 = GAM1*2./3.
C                SET LOCATIONS OF CONTOUR BOUNDARIES
C
C                UPSTREAM BOUNDARY
C                           IF AK = 0.0 CDCOLE WILL NOT BE CALLED.
C                              AMACH MAY NOT BE = 1.0  .
      IF(AK .GT. 0.) IU = (ILE + IMIN)*.5
      IF(AK .LT. 0.) IU = IUP
C                TOP AND BOTTOM BOUNDARIES
C                SUBSONIC FREESTREAM
C                SET JB,JT TO INCLUDE AS MUCH OF SHOCKS AS POSSIBLE
      JT = JMAX - 1
      JB = JMIN + 1
      IF (AK .GT. 0.) GO TO 30
C                SUPERSONIC FREESTREAM
C                SET JB,JT TO INCLUDE ONLY SUBSONIC PART OF
C                DETACHED BOW WAVE
C
C                FIND BOW SHOCK WAVE
      ISTOP = ILE - 3
      CALL FINDSK(IUP,ISTOP,JUP,IBOW)
      IF(IBOW .LT. 0) GO TO 325
      IF (IBOW .LT. 4) GO TO 350
C                SEARCH UP SHOCK TO FIND TIP OF SUBSONIC REGION
      ISK = IBOW
      JSTART = JUP + 1
      JT = JUP - 1
      DO 10 J = JSTART,JMAX
      JT = JT + 1
      ISKOLD = ISK
      CALL NEWISK(ISKOLD,J, ISK)
      IF(ISK  .LT. 0) GO TO 15
   10 CONTINUE
   15 CONTINUE
C                SEARCH DOWN SHOCK TO FIND TIP OF SUBSONIC REGION
      ISK = IBOW
      JB = JLOW + 2
      DO 20 J = JMIN,JLOW
      JJ = JLOW - J + JMIN
      JB = JB - 1
      ISKOLD = ISK
      CALL NEWISK(ISKOLD,JJ,ISK)
      IF(ISK .LT. G) GO TO 25
   20 CONTINUE
   25 CONTINUE
C                SAVE I LOCATION OF BOW SHOCK WAVE ON LOWER BOUNDARY
      IBOW = ISKOLD
   30 CONTINUE
C                DOWNSTREAM BOUNDARY
      ID = (ITE + IMAX) * .5
      IF(PX(ITE+1,JUP) .LT. SONVEL)  GO TO 40
C                TRAILING EDGE IS SUPERSONIC.  PLACE DOWNSTREAM
C                BOUNDARY AHEAD OF TRAILING EDGE TO AVOID TAIL SHOCK
      I = ITE
   35 CONTINUE
      I = I-1
      IF(X(I) .GT. .75) GO TO 35
      ID = I
   40 CONTINUE
C
C                ALL BOUNDARIES ARE FIXED
C
C                COMPUTE INTEGRALS ALONG BOUNDARIES
C
C                INTEGRAL ON UPSTREAM BOUNDARY
      CDUP = 0.
      IF(AK .LT. 0.) GO TO 120
      L = 0
      DO 110 J = JB,JT
      L = L+1
      Z(L) = Y(J)
      U = PX(IU,J)
      V = PY(IU,J)
      ARG(L) =((AK - GAM123*U)*U*U - V*V)*.5
  110 CONTINUE
      CALL TRAP(Z,ARG,L,SUM)
      CDUP = 2.*CDFACT*SUM
  120 CONTINUE
C                INTEGRAL ON TOP BOUNDARY
      L = 0
      DO 130 I = IU,ID
      L = L + 1
      Z(L) = X(I)
      ARG(L) = -PX(I,JT)*PY(I,JT)
  130 CONTINUE
      CALL TRAP(Z,ARG,L,SUM)
      CDTOP = 2.*CDFACT*SUM
C                INTEGRAL ON BOTTOM BOUNDARY
      L = 0
       DO 140 I = IU,ID
      L = L +  1
      ARG(L) = PX(I,JB)*PY(I,JB)
  140 CONTINUE
      CALL TRAP(Z,ARG,L,SUM)
      CDBOT = 2.*CDFACT*SUM
C                INTEGRAL ON DOWNSTREAM BOUNDARY
      L = 0
      DO 150 J = JB,JT
      L = L + 1
      Z(L) = Y(J)
      U = PX(ID,J)
C                IF FLOW SUPERSONIC, USE BACKWARD DIFFERENCE FORMULA
      IF(U .GT. SONVEL) U = PX(ID-1,J)
      V = PY(ID,J)
      ARG(L) = ((GAM123*U - AK)*U*U + V*V)*.5
  150 CONTINUE
      CALL TRAP(Z,ARG,L,SUM)
      CDDOWN = 2.*CDFACT*SUM
C                INTEGRAL ON BODY BOUNDARY
      CDBODY = 0.
      IF(ID .GT. ITE) GO TO 200
      ILIM = ITE + 1
      L = 0
      DO 160 I=ID,ILIM
      IB = I-ILE + 1
      L = L + 1
      Z(L) = X(I)
      UU = CJUP*PX(I,JUP) - CJUP1*PX(I,JUP+1)
      UL = CJLOW*PX(I,JLOW) - CJLOW1*PX(I,JLOW-1)
      ARG(L) = -UU*FXU(IB) + UL*FXL(IB)
  160 CONTINUE
      CALL TRAP(Z,ARG,L,SUM)
      CDBODY = 2.*CDFACT*SUM
  200 CONTINUE
C
C                INTEGRATION ALONG SHOCK WAVES
      CDWAVE = 0.
      LPRT1 = 0
      LPRT2 = 0
      NSHOCK = 0
      IF(AK .GT. 0.) GO TO 220
C                INTEGRATE ALONG DETACHED BOW WAVE
      NSHOCK = NSHOCK + 1
      LPRT1 = 1
      LPRT2 = 1
      L = 0
      ISK = IBOW
      DO 210 J = JB,JT
      L = L + 1
      ISKOLD = ISK
      CALL NEWISK(ISKOLD,J,ISK)
      Z(L) = Y(J)
      ARG(L) = (PX(ISK+1,J) - PX(ISK-2,J))**3
  210 CONTINUE
      CALL TRAP(Z,ARG,L,SUM)
      CDSK = -GAM1/6.*CDFACT*SUM
      CDWAVE = CDWAVE + CDSK
      CALL PRTSK(Z,ARG,L,NSHOCK, CDSK,LPRT1)
  220 CONTINUE
C                    INTEGRATE ALONG SHOCKS ABOVE AIRFOIL
      ISTART = ILE
  225 CONTINUE
      CALL FINDSK(ISTART,ITE,JUP,ISK)
      IF(ISK .LT. 0) GO TO 250
C                    SHOCK WAVE FOUND
      ISTART = ISK + 1
      NSHOCK = NSHOCK + 1
      LPRT1 = 0
      L = 1
      Z(L) = 0.
      ARG(L) = (CJUP*(PX(ISK+1,JUP) - PX(ISK-2,JUP))
     *      - CJUP1*(PX(ISK+1,JUP+1) - PX(ISK-2,JUP+1)))**3
      DO 230 J = JUP , JT
      L = L+1
      Z(L) = Y(J)
      ARG(L) = (PX(ISK+1,J) - PX(ISK-2,J))**3
      ISKOLD = ISK
      JSK = J + 1
      CALL NEWISK(ISKOLD,JSK,ISK)
      IF(ISK .LT. 0) GO TO 240
      IF(ISK .GT. ID) GO TO 235
  230 CONTINUE
  235 CONTINUE
      LPRT1 = 1
  240 CONTINUE
      CALL TRAP(Z,ARG,L,SUM)
      CDSK = -GAM1/6.*CDFACT*SUM
      CDWAVE = CDWAVE + CDSK
      CALL PRTSK(Z,ARG,L,NSHOCK,CDSK,LPRT1)
      IF(LPRT1 .EQ. 1) LPRT2 = 1
C                    RETURN TO FIND NEXT SHOCK
      GO TO 225
C                    INTEGRATE ALONG SHOCKS BELOW AIRFOIL
  250 CONTINUE
      ISTART = ILE
  260 CONTINUE
      CALL FINDSK(ISTART,ITE,JLOW,ISK)
      IF(ISK .LT. 0) GO TO 300
C                    SHOCK WAVE FOUND
      ISTART = ISK + 1
      NSHOCK = NSHOCK + 1
      LPRT1 = 0
      L = 1
      Z(L) = 0.
      ARG(L) = (CJLOW*(PX(ISK+1,JLOW) - PX(ISK-2,JLOW))
     *      - CJLOW1*(PX(ISK+1,JLOW-1) - PX(ISK-2,JLOW-1)))**3
      DO 270 JJ = JB,JLOW
      J = JLOW + JB - JJ
      L = L+1
      Z(L) = Y(J)
      ARG(L) = (PX(ISK+1,J) - PX(ISK-2,J))**3
      ISKOLD = ISK
      JSK = J - 1
      CALL NEWISK(ISKOLD,JSK,ISK)
      IF(ISK .LT. 0) GO TO 280
      IF(ISK .GT. ID) GO TO 275
  270  CONTINUE
  275 CONTINUE
      LPRT1 = 1
  280 CONTINUE
      CALL TRAP(Z,ARG,L,SUM)
      CDSK = -GAM1/6.*CDFACT*(-SUM)
      CDWAVE = CDWAVE + CDSK
      CALL PRTSK(Z,ARG,L,NSHOCK,CDSK,LPRT1)
      IF(LPRT1 .EQ. 1) LPRT2 = 1
C                    RETURN TO FIND NEXT SHOCK
      GO TO 260
  300  CONTINUE
C
C                    INTEGRATION ALONG SHOCKS IS COMPLETE
C
C                    PRINTOUT CD INFORMATION
      XU = X(IU)
      XD = X(ID)
      YT = Y(JT)*YFACT
      YB = Y(JB)*YFACT
      CDC = CDUP + CDTOP + CDBOT + CDDOWN + CDBODY
      CD = CDC + CDWAVE
      WRITE(6,1001)
      WRITE(6,1002) XU,CDUP,  XD,CDDOWN,  YT,CDTOP,  YB,CDBOT
      IF(XD .LT. 1.)  WRITE(6,1003)  XD,CDBODY
      WRITE(6,1004) CDC
      WRITE(6,1005) NSHOCK,CDWAVE
      IF(NSHOCK .GT. 0 .AND. LPRT2 .EQ. 0)  WRITE(6,1007)
      IF(NSHOCK .GT. 0 .AND. LPRT2 .EQ. 1)  WRITE(6,1008)
      WRITE(6,1006) CD
      RETURN
  325 CONTINUE
C                    SHOCK IS TOO CLOSE TO BODY TO DO CONTOUR INTEGRAL.
C                    WRITE MESSAGE AND RETURN
      ULE = PX(ILE,JUP)
      IF(ULE .GT. SONVEL)  WRITE(6,1011)
      IF(ULE .LE. SONVEL)  WRITE(6,1012)
      CD = DRAG(CDFACT)
      WRITE(6,1013) CD
      RETURN
  350 WRITE (6,1014)
      CD=DRAG(CDFACT)
      WRITE(6,1013) CD
      RETURN
 1001 FORMAT(1H1,55X,23HDRAG COEFFICIENT OUTPUT/ 56X,23(1H*)//,
     1 60H CALCULATION OF DRAG COEFFICIENT BY MOMENTUM INTEGRAL METHOD)
 1002 FORMAT(27H0BOUNDARIES OF CONTOUR USED,15X,18HCONTRIBUTION TO CD/
     * 16H UPSTREAM    X =,F12.6,15X,8HCDUP   =,F12.6/
     * 16H DOWNSTREAM  X =,F12.6,15X,8HCDDOWN =,F12.6/
     * 16H TOP         Y =,F12.6,15X,8HCDTOP  =,F12.6/
     * 16H BOTTOM      Y =,F12.6,15X,8HCDBOT  =,F12.6)
 1003 FORMAT(16H BODY AFT OF X =,F12.6,15X,8HCDBODY =,F12.6)
 1004 FORMAT(15X,36HTOTAL CONTRIBUTIONS AROUND CONTOUR =,F12.6)
 1005 FORMAT(10H0THERE ARE,I3,38H SHOCKS INSIDE CONTOUR. TOTAL CDWAVE =,
     *   F12.6)
 1006 FORMAT(51H0DRAG CALCULATED FROM MOMENTUM INTEGRAL    CD     =,
     *  F12.6)
 1007 FORMAT(43H0NOTE - ALL SHOCKS CONTAINED WITHIN CONTOUR/
     *  30H CDWAVE EQUALS TOTAL WAVE DRAG)
 1008 FORMAT(52H0NOTE - ONE OR MORE SHOCKS EXTEND OUTSIDE OF CONTOUR/
     *   38H CDWAVE DOES NOT EQUAL TOTAL WAVE DRAG)
 1011 FORMAT(31H1SHOCK WAVE IS ATTACHED TO BODY/
     *   33H MOMENTUM INTEGRAL CANNOT BE DONE/
     *   45H DRAG OBTAINED FROM SURFACE PRESSURE INTEGRAL/)
 1012 FORMAT(41H1DETACHED SHOCK WAVE IS TOO CLOSE TO BODY/
     *   33H MOMENTUM INTEGRAL CANNOT BE DONE/
     *   45H DRAG OBTAINED FROM SURFACE PRESSURE INTEGRAL/)
 1013 FORMAT(4H0CD=,F12.6)
 1014 FORMAT(1H1,17X,19H***** CAUTION *****/16X,16HSOLUTION MAY BE ,
     1 7HINVALID//46H DETACHED SHOCK WAVE IS TOO CLOSE TO UPSTREAM ,
     2 8HBOUNDARY/11X,32HMOMENTUM INTEGRAL CANNOT BE DONE/5X,
     3 44HDRAG OBTAINED FROM SURFACE PRESSURE INTEGRAL)
      END
```

```
      SUBROUTINE CKMESH
C                    CHECK X MESH AND ADJUST TO CONTAIN ODD NO. OF
C                    POINTS BEFORE TAIL AND ODD NO. AFTER TAIL.
C                    ITE IS INCLUDED IN BOTH COUNTS.
C                    CKMESH IS CALLED ONCE BY READIN.
      COMMON / COM1/ IMIN      , IMAX    , IUP     , IDOWN   , ILE     ,
     1               ITE       , JMIN    , JMAX    , JUP     , JLOW    ,
     2               JTOP      , JBOT
      LOGICAL        ABORT
      COMMON / COM3/ IREF      , ABORT   , ICUT    , KSTEP
      LOGICAL        AMESH
      COMMON / COM4/ XIN(100) , YIN(100), AMESH
      IF (ICUT .GT. 0) GO TO 4
      IREF = -1
      RETURN
    4 CONTINUE
C                    TEST TO BE SURE THAT ADJUSTING THE NO. OF
C                    POINTS WONT MAKE IMAX OR JMAX LARGER THAN 100.
      IF (IMAX .LE. 98 .AND. JMAX .LE. 98) GO TO 8
      WRITE (6,100)
      IREF = -1
      RETURN
    8 CONTINUE
      IF (MOD(ITE-IMIN+1, 2) .NE. 0) GO TO 20
C                           ADD EXTRA MESH POINT AHEAD OF AIRFOIL.
      LP = IMAX + IMIN + 1
      DO 10 I=IMIN,IMAX
      L = LP - I
      XIN(L) = XIN(L-1)
   10 CONTINUE
      IMAX = IMAX + 1
      XIN(IMIN) = 2. * XIN(IMIN+1) - XIN(IMIN+2)
      CALL ISLIT ( XIN )
   20 CONTINUE
C                           ADD EXTRA MESH POINT AFTER AIRFOIL.
      IF (MOD(IMAX-ITE+1, 2) .NE. 0) GO TO 30
      IMAX = IMAX + 1
      XIN(IMAX) = 2. * XIN(IMAX-1) - XIN(IMAX-2)
   30 CONTINUE
C                           CHECK Y MESH AND ADJUST TO CONTAIN EVEN NO. OF
C                           POINTS ABOVE AND BELOW SLIT.
      IF (MOD(JLOW-JMIN ,2) .NE. 0) GO TO 50
C                           ADD EXTRA MESH POINT BELOW SLIT.
      LP = JMAX + JMIN + 1
      DO 40 J=JMIN,JMAX
      L = LP - J
      YIN(L) = YIN(L-1)
   40 CONTINUE
      JMAX = JMAX + 1
      YIN(JMIN) = 2. * YIN(JMIN+1) - YIN(JMIN+2)
      CALL JSLIT ( YIN )
   50 CONTINUE
C                           ADD EXTRA MESH POINT ABOVE SLIT.
      IF (MOD(JMAX-JUP  ,2) .NE. 0) GO TO 60
      JMAX = JMAX + 1
      YIN(JMAX) = 2.0 * YIN(JMAX-1) - YIN(JMAX-2)
   60 CONTINUE
      RETURN

  100 FORMAT(96H0 THE MESH CANNOT BE ADJUSTED FOR CUTOUT, BECAUSE IMAX O
     1R JMAX IS TOO CLOSE TO THE LIMIT OF 100./
     25X,19HIREF WAS SET TO  0 )

      END
```

```
      SUBROUTINE CPPLOT (X, Y, Z, W, NP)

C                           SUBROUTINE CPPLOT PRODUCES A PRINTER PLOT
C                           OF CRITICAL PRESSURE VS X .
C                           CALLED BY - FIXPLT.
      LOGICAL         AMESH
      COMMON / COM4/ XIN(100) , YIN(100), AMESH

      DIMENSION  X(101) , Y(101) , Z(101) , W(101) , M(120), ISYM(8)
      DIMENSION  A(3) , IC(3)
      DATA  IC/ 1, 1024, 1048576/
      DATA ISYM/1H ,1HU,1HL,1HB,1H-,1HU,1HL,1HB/
C                           NC IS THE NUMBER OF COLUMNS.
C                           NR IS THE NUMBER OF ROWS.
      DATA  NC /120/ , NR /50/
C     INITIALIZE RANGES
      IF ( AMESH ) GO TO 3
      NPL = 1
      NPR = NP - 1
      NL5 = 2
      GO TO 4
    3 CONTINUE
      NPL = 2
      NPR = NP - 2
      NL5 = 3
    4 CONTINUE
      HL = X(NPL)
      HR = X(NPL)
      VB=AMIN1(Y(1),Z(1),W(1))
      VT=AMAX1(Y(1),Z(1),W(1))
C     DETERMINE RANGES
      DO 5 I = NL5,NPR
      HL=AMIN1(HL,X(I))
      HR=AMAX1(HR,X(I))
      VB=AMIN1(VB,Y(I),Z(I),W(I))
      VT=AMAX1(VT,Y(I),Z(I),W(I))
  5   CONTINUE
C                           SKIP TO NEW PAGE AND WRITE PLOT HEADING.

      WRITE(6,900)
      VDEL=(VT-VB)/FLOAT(NR)
      HDEL=(HR-HL)/FLOAT(NC)
      HDELM = 1.0 / HDEL
      VL=VT


      DO 100 IROW = 1,NR
      VH=VL
      VL=FLOAT(NR-IROW)*VDEL+VB
      DO 15 I=1,NC
 15   M(I)=0

      DO 30 I =NPL,NPR
      J      = MAX0(1,MIN0(NC,1+INT((X(I)-HL) * HDELM)))
      A(1) = Y(I)
      A(2) = Z(I)
      A(3) = W(I)
      DO 20 K=1,3
      IF (A(K) .GT. VH) GO TO 20
      IF (A(K) .GT. VL .OR. (A(K) .LE. VB .AND. IROW .EQ. NR))
     1           M(J) = M(J) + IC(K)
   20 CONTINUE
   30 CONTINUE

      DO 90 I=1,NC
      J = 1
      IF (M(I) .LT. IC(3)) GO TO 70
      J = J + 4
      M(I) = MOD(M(I),IC(3))
   70 CONTINUE
      IF (M(I) .LT. IC(2)) GO TO 75
      J = J + 2
      M(I) = MOD(M(I),IC(2))
   75 CONTINUE
      IF (M(I) .LE. 0) GO TO 80
      J = J + 1
   80 CONTINUE
      M(I) = ISYM(J)
   90 CONTINUE

      WRITE(6,901)   (M(I),I=1,NC)
 100  CONTINUE

      RETURN

  900 FORMAT(1H1,34X,46HPRINTER PLOT OF CP ON BODY AND DIVIDING STREAM,
     1 4HLINE,15X,13HU = CP(UPPER)/35X,50(1H*),15X,13HL = CP(LOWER)/
     2 100X,25HB = CP(UPPER) = CP(LOWER)/98X,17H--- = CRITICAL CP)
  901 FORMAT(1X,120A1)

      END
```

```
      SUBROUTINE CUTOUT

C                           SUBROUTINE TO REDUCE THE NUMBER OF MESH POINTS
C                           FOR THE FIRST CUT AT SOLUTION. THE X-MESH AND
C                           Y-MESH WILL BE HALVED. AND IF POSSIBLE BE
C                           HALVED AGAIN.
C                                IREF =-1, CUTOUT SHOULDNT HAVE BEEN CALLED
C                                IREF = 0, IF NOT HALVED AT ALL.
C                                IREF = 1, IF HALVED ONCE.
C                                IREF = 2, IF HALVED TWICE.
C                           CALLED BY - TSFOIL.

      COMMON         P(102,101),X(100)  , Y(100)
      COMMON / COM1/ IMIN     , IMAX    , IUP     , IDOWN   , ILE     ,
     1               ITE      , JMIN    , JMAX    , JUP     , JLOW    ,
     2               JTOP     , JBOT
      LOGICAL        ABORT
      COMMON / COM3/ IREF     , ABORT   , ICUT    , KSTEP
      LOGICAL        AMESH
      COMMON / COM4/ XIN(100) , YIN(100), AMESH
      COMMON /COM20/ XMID(100), YMID(100)
      IF(IREF .NE. -1) GO TO 5
C                    MESH CANNOT BE REFINED, LOAD XIN,YIN INTO X,Y
      DO 1 I = IMIN,IMAX
      X(I) = XIN(I)
 1    CONTINUE
      DO 2 J = JMIN,JMAX
      Y(J) = YIN(J)
 2    CONTINUE
      IREF = 0
      RETURN
5     CONTINUE
      K = IMIN - 1
      DO 10 I=IMIN,IMAX,2
      K = K + 1
      XMID(K) = XIN(I)
   10 CONTINUE
      IMAX = (IMAX-IMIN) * .5 + IMIN
      CALL ISLIT ( XMID )
      K = JMIN - 1
      JE = JLOW - 1
      DO 15 J=JMIN,JE,2
      K = K + 1
      YMID(K) = YIN(J)
   15 CONTINUE
      JST = JUP + 1
      DO 20 J=JST,JMAX,2
      K = K + 1
      YMID(K) = YIN(J)
   20 CONTINUE
      JMAX = (JMAX-JMIN) * .5 + JMIN
      CALL JSLIT ( YMID )
      IREF = 1
C                           FIRST HALVING COMPLETE. CHECK IF NO. OF POINTS
C                           IS ODD.
      IF (ICUT .EQ. 1) GO TO 30
      IF (MOD(ITE-IMIN+1, 2) .EQ. 0) GO TO 30
      IF (MOD(IMAX-ITE+1,2) .EQ. 0) GO TO 30
      IF (MOD(JLOW-JMIN ,2) .EQ. 0) GO TO 30
      IF (MOD(JMAX-JUP  ,2) .NE. 0) GO TO 60
   30 CONTINUE
C                           ONLY ONE MESH REFINEMENT POSSIBLE.
      DO 40 I=IMIN,IMAX
      X(I) = XMID(I)
   40 CONTINUE
      DO 50 J=JMIN,JMAX
      Y(J) = YMID(J)
   50 CONTINUE
      RETURN
C                           ALL POINTS ARE ODD SO CUT AGAIN.
   60 CONTINUE
      K = IMIN - 1
      DO 70 I=IMIN,IMAX,2
      K = K + 1
      X(K) = XMID(I)
   70 CONTINUE
      IMAX = (IMAX-IMIN) * .5 + IMIN
      CALL ISLIT ( X )
      K = JMIN - 1
      JE = JLOW - 1
      DO 75 J=JMIN,JE,2
      K = K + 1
      Y(K) = YMID(J)
   75 CONTINUE
      JST = JUP + 1
      DO 80 J=JST,JMAX,2
      K = K + 1
      Y(K) = YMID(J)
   80 CONTINUE
      JMAX = (JMAX-JMIN) * .5 + JMIN
      CALL JSLIT ( Y )
      IREF = 2
      RETURN

      END
```

```
      SUBROUTINE DIFCOE
C
C  COMPUTE DIFFERENCE COEFFICIENTS IN FIELD
C                    CALLED BY - TSFOIL.
C
      COMMON          P(102,101),X(100)  , Y(100)
      COMMON / COM1/ IMIN      , IMAX    , IUP     , IDOWN   , ILE     ,
     1               ITE       , JMIN    , JMAX    , JUP     , JLOW    ,
     2               JTOP      , JBOT
      COMMON / COM2/ AK        , ALPHA   , DUB     , GAM1    , RTK
      COMMON / COM5/ XDIFF(100),YDIFF(100)
      COMMON / COM7/ CJUP      , CJUP1   , CJLOW   , CJLOW1
      COMMON /COM17/ CYYBLC    , CYYBLD  , CYYBLU  , CYYBUC  , CYYBUD  ,
     1               CYYBUU    ,FXLBC(100),FXUBC(100)
      COMMON /COM22/ CXC(100) , CXL(100), CXR(100), CXXC(100),CXXL(100),
     1               CXXR(100), C1(100)
      COMMON /COM23/ CYYC(100), CYYD(100),CYYU(100), IVAL
C
C                            COEFFICIENTS FOR (P)X AND (P)XX AT IMIN
      CXXL(IMIN) = 0.0
      CXXR(IMIN) = 0.0
      CXXC(IMIN) = 0.0
      CXL (IMIN) = 0.0
      CXR (IMIN) = 0.0
      CXC (IMIN) = 0.0
C  COEFFICIENTS FOR (P)X AND (P)XX FROM I=IMIN+1 TO I=IMAX-1
      C2 = GAM1*.5
      ISTART = IMIN+1
      IEND=IMAX-1
      DO 1 I=ISTART,IEND
      DXL=X(I)-X(I-1)
      DXR=X(I+1)-X(I)
      DXC = .5 * (X(I+1) - X(I-1))
C  FOR VC
      C1(I)=   AK/DXC
C  FOR (P)X
      CXL(I) = -C2 / (DXL*DXC)
      CXR(I) =  C2 / (DXR*DXC)
      CXC(I) = -CXL(I) - CXR(I)
C  FOR (P)XX
      CXXL(I) = 1.0 / DXL
      CXXR(I) = I.0 / DXR
      CXXC(I) = CXXL(I) + CXXR(I)
 1    CONTINUE
C                   COEFFICIENTS FOR (P)X AND (P)XX AT IMAX
      DX              = X(IMAX) - X(IMAX-1)
      Q = 1.0 / (DX*DX)
      C1(IMAX) = AK / DX
      CXL(IMAX)  = -C2 * Q
      CXR(IMAX)  =  C2 * Q
      CXC(IMAX) = 0.0
      CXXL(IMAX) =  1.0 / DX
      CXXR(IMAX) =  1.0 / DX
      CXXC(IMAX) =  CXXL(IMAX) + CXXR(IMAX)
C                                      COEFFICIENTS FOR (P)YY AT JMIN.
C
      DYU = Y(JMIN+1) - Y(JMIN)
      CYYD(JMIN) = 2.0 / DYU
      CYYU(JMIN) = 2./(DYU*DYU)
      CYYC(JMIN) = CYYU(JMIN)
C  COEFICIENTS FOR (P)YY FROM J=JMIN+1 TO J=JMAX-1
      JSTART = JMIN + 1
      JEND=JMAX-1
      DO 2 J=JSTART,JEND
      DYD=Y(J)-Y(J-1)
      DYU=Y(J+1)-Y(J)
      DYC=Y(J+1)-Y(J-1)
      CYYD(J)=2./(DYD*DYC)
      CYYU(J)=2./(DYU*DYC)
      CYYC(J) = CYYD(J) + CYYU(J)
 2    CONTINUE
C                                      COEFFICIENTS FOR (P)YY AT JMAX.
      DYD = Y(JMAX) - Y(JMAX-1)
      CYYD(JMAX) = 2./(DYD*DYD)
      CYYU(JMAX) = 2./DYD
      CYYC(JMAX) = CYYD(JMAX)

C  COEFFICIENTS FOR VELOCITY FORMULAS

      ISTART = IMIN + 1
      DO 3 I = ISTART,IMAX
      XDIFF(I) = 1./(X(I) - X(I-1))
 3    CONTINUE
      JSTART = JMIN +1
      DO 5 J = JSTART , JMAX
      YDIFF(J) = 1./(Y(J) - Y(J-1))
 5    CONTINUE

C COEFFICIENTS FOR EXTRAPOLATION FORMULAS FOR AIRFOIL SURFACE PROPERTIES

      CJLOW  = -Y(JLOW-1) / (Y(JLOW) - Y(JLOW-1))
      CJLOW1 = -Y(JLOW)   / (Y(JLOW) - Y(JLOW-2))
      CJUP   = Y(JUP+1) / (Y(JUP+1) - Y(JUP))
      CJUP1  = Y(JUP)   / (Y(JUP+1) - Y(JUP))
C                  COMPUTE SPECIAL DIFFERENCE COEFFICIENTS FOR PYY
C                  TO USE FOR AIRFOIL BOUNDARY CONDITION
C                  DIFFERENCE COEFFICIENTS FOR UPPER SURFACE
      CYYBUD = -2./(Y(JUP+1) + Y(JUP))
      CYYBUC = -CYYBUD / (Y(JUP+1) - Y(JUP))
      CYYBUU =  CYYBUC
C                  DIFFERENCE COEFFICIENTS FOR LOWER SURFACE
      CYYBLU=-2.0/(Y(JLOW) + Y(JLOW-1))
      CYYBLC = CYYBLU / (Y(JLOW) - Y(JLOW-1))
      CYYBLD = CYYBLC
      RETURN
      END
```

```
      FUNCTION DRAG(CDFACT)
C                 COMPUTES PRESSURE DRAG BY INTEGRATING U*V AROUND
C                 AIRFOIL USING TRAPEZOOIAL RULE.
C                 CALLED BY - CDCOLE.

      COMMON          P(102,101),X(100)   , Y(100)
      COMMON / COM1/ IMIN      , IMAX     , IUP      , IDOWN    , ILE      ,
     1               ITE       , JMIN     , JMAX     , JUP      , JLOW     ,
     2               JTOP      , JBOT
      COMMON / COM6/ FL(100)   , FXL(100), FU(100) , FXU(100),
     1              CAMBER(100), THICK(100),VOL    , XFOIL(100), IFOIL
      COMMON / COM7/ CJUP      , CJUP1    , CJLOW    , CJLOW1
      COMMON /COM30/ XI(100)   , ARG(100)  , REST(204)

      K = 1
      ARG(1) = 0.
      XI(1) = X(ILE-1)
      DO 10 I = ILE,ITE
      K = K+1
      PXUP = CJUP*PX(I,JUP) - CJUP1*PX(I,JUP+1)
      PXLOW = CJLOW*PX(I,JLOW) - CJLOW1*PX(I,JLOW-1)
      ARG(K) = FXU(K-1)*PXUP - FXL(K-1)*PXLOW
      XI(K) = X(I)
 10   CONTINUE
      K = K + 1
      ARG(K) = 0.
      XI(K) = X(ITE+1)
      CALL TRAP(XI,ARG,K,SUM)
      DRAG = - SUM*CDFACT*2.
      RETURN
      END
```

```
      SUBROUTINE DROOTS
C                 COMPUTE CONSTANTS ALPHAO,APLHA1,ALPHA2,OMEGAO,OMEGA1
C                 OMEGA2 USED IN FORMULA FOR DOUBLET IN SLOTTED WIND
C                 TUNNEL WITH SUBSONIC FREESTREAM
C                 CALLED BY - FARFLD.

      COMMON /COM12/ F         , H        , HALFPI  , PI       , RTKPOR  ,
     1               TWOPI
      REAL JET
      COMMON /COM16/ ALPHAO    , ALPHA1   ,.ALPHA2  , XSING    ,
     1               OMEGAO    , OMEGA1   , OMEGA2  , JET

      ERROR = .00001
C                 COMPUTE ALPHAO
      ALPHAO = 0.
      DO 10 I = 1,100
      TEMP = ALPHAO
      Q = F*TEMP - RTKPOR
      ALPHAO = HALFPI - ATAN(Q)
      DALPHA = ABS(ALPHAO - TEMP)
      IF(DALPHA .LT. ERROR) GO TO 15
 10   CONTINUE
      N = 0
      GO TO 9999
 15   CONTINUE
C                 COMPUTE ALPHA1
      ALPHA1 = 0.
      DO 20 I = 1,100
      TEMP = ALPHA1
      Q = F*(TEMP - PI) - RTKPOR
      ALPHA1 = HALFPI - ATAN(Q)
      DALPHA = ABS(ALPHA1 - TEMP)
      IF(DALPHA .LT. ERROR) GO TO 25
 20   CONTINUE
      N = 1
      GO TO 9999
 25   CONTINUE
C                 COMPUTE ALPHA2
      ALPHA2 = 0.
      DO 30 I=1,100
      TEMP = ALPHA2
      Q = F*(TEMP - TWOPI) - RTKPOR
      ALPHA2 = HALFPI - ATAN(Q)
      DALPHA = ABS(ALPHA2 - TEMP)
      IF(DALPHA .LT. ERROR) GO TO  35
 30   CONTINUE
      N = 2
      GO TO 9999
 35   CONTINUE
C                 COMPUTE OMEGAO,OMEGA1,OMEGA2
      TEMP = 1.0 / TAN(ALPHAO)
      OMEGAO = 1./(1. + F/(1.+ TEMP*TEMP))
      TEMP = 1.0 / TAN(ALPHA1)
      OMEGA1 = 1./(1. + F/(1. + TEMP*TEMP))
      TEMP = 1.0 / TAN(ALPHA2)
      OMEGA2 = 1./(1. + F/(1. + TEMP*TEMP))
      RETURN
C                 ABNORMAL STOP IF ITERATION FOR ALPHAS NOT CONVERGED
 9999 CONTINUE
      WRITE(6,1000) N
 1000 FORMAT(35H1ABNORMAL STOP IN SUBROUTINE DROOTS/
     1  38HONONCONVERGENCE OF ITERATION FOR ALPHA, I1)
      STOP
      END
```

```
      SUBROUTINE ECHINP
C                 PRINTS INPUT CARDS USED FOR RUN.
C                 CALLED BY - TSFOIL.
      DIMENSION   CRD(8)
      WRITE (6,110)
   10 CONTINUE
      READ (5,100) CRD
C               YES, NO
      IF (EOF(5)) 30,20
   20 CONTINUE
      WRITE (6,101) CRD
      GO TO 10
   30 CONTINUE
      REWIND 5
      RETURN

  100 FORMAT(8A10)
  101 FORMAT(1X,8A10)
  110 FORMAT(1H1,48X,35HLISTING OF INPUT CARDS FOR THIS RUN/49X,35(1H*)
     1  ///)

      END
      FUNCTION EMACH1(U)
C                 FUNCTION EMACH1 COMPUTES LOCAL SIMILARTY PARAMETER
C                 OR LOCAL MACH NUMBER
C                 CALLED BY - MACHMP, PRINT1, PRTFLO.

      COMMON / COM2/ AK       , ALPHA   , DUB     , GAM1    , RTK
      LOGICAL        PHYS
      INTEGER        PRTFLO   , SIMDEF
      COMMON /COM27/ CL       , DELTA   , DELRT2  , EMACH   , EMROOT  ,
     1               PHYS     , PRTFLO  , SIMDEF  , SONVEL  , VFACT   ,
     2               YFACT

C                 COMPUTE SIMILARITY PARAMETER BASED ON LOCAL VELOCITY
      AK1 = AK - GAM1*U
      IF(PHYS) GO TO 5
C                 RETURN VALUE OF LOCAL SIMILARITY PARAMETER
      EMACH1 = AK1
      RETURN
    5 CONTINUE
C                 COMPUTE VALUE OF LOCAL MACH NUMBER AND RETURN
C                 COLE SCALING
      ARG = DELRT2*AK1
C                 SPREITER SCALING
      IF(SIMDEF .EQ. 2) ARG = ARG*EMROOT*EMROOT
C                 KRUPP SCALING
      IF(SIMDEF .EQ. 3)  ARG = ARG*EMACH
      ARG = 1. - ARG
      EMACH1 = 0.
      IF(ARG .GT. 0.)EMACH1 = SQRT(ARG)
      RETURN
      END
```

```
      SUBROUTINE EXTRAP(XP,YP,PNEW)
C                 COMPUTE P AT X, YP USING FAR FIELD SOLUTION
C                 FOR SUBSONIC FLOW
C                 CALLED BY - GUESSP.

      COMMON / COM2/ AK       , ALPHA   , DUB     , GAM1    , RTK
      COMMON /COM12/ F        , H       , HALFPI  , PI      , RTKPOR  ,
     1               TWOPI
      COMMON /COM15/ B        , BETAO   , BETA1   , BETA2   , PSIO    ,
     1               PSI1     , PSI2
      REAL JET
      COMMON /COM16/ ALPHAO   , ALPHA1  , ALPHA2  , XSING   ,
     1               OMEGAO   , OMEGA1  , OMEGA2  , JET
      INTEGER        BCTYPE
      COMMON /COM28/ BCTYPE   , CIRCFF  , FHINV   , POR     , CIRCTE

      IF(BCTYPE .NE. 1) GO TO 100
C                 FREE AIR BOUNDARY CONDITION
      IF(ABS(YP) .LT. 1.E-6)  YP = -1.E-6
      XI = XP - XSING
      ETA = YP*RTK
      PNEW = - CIRCFF/TWOPI*(ATAN2(ETA,XI) + PI - SIGN(PI,ETA))
     1        + DUB /TWOPI/RTK*(XI/(XI*XI + ETA*ETA))
      RETURN
  100 CONTINUE
C                 TUNNEL WALL BOUNDARY CONDITION
      ETA = YP/H
      XI = (XP - XSING)/(H*RTK)
      IF(XI .LT. 0.) GO TO 200
C                 XP IS DOWNSTREAM OF AIRFOIL
      TERM = ETA
      IF(BCTYPE .NE. 3)  TERM = SIN(ETA*BETAO)/BETAO
      PNEW = - .5*CIRCFF*(1. - SIGN(1.,ETA)
     1                  + (1.-JET)*PSIO*TERM*EXP(-BETAO*XI))
     2        + DUB *.5/(AK*H)*(B + OMEGAO*COS(ETA*ALPHAO)
     3                  *EXP(-ALPHAO*XI))
      RETURN
  200 CONTINUE
C                 XP IS UPSTREAM OF AIRFOIL
      TERM = 0.
      IF(JET .NE. 0.) TERM = JET*ETA/(1.+F)
      ARG1 = PI - ALPHA1
      ARG2 = PI - BETA2
      PNEW = -.5*CIRCFF*(1.-TERM-PSI2*SIN(ETA*ARG2)/ARG2*EXP(ARG2*XI))
     1        -.5*DUB /(AK*H)*((1.-B)*OMEGA1*COS(ETA*ARG1)*EXP(XI*ARG1))
      RETURN
      END
```

```
      SUBROUTINE FARFLD
C                 SUBROUTINE COMPUTES BOUNDARY DATA FOR OUTER
C                 BOUNDARIES.
C                 CALLED BY - TSFOIL.

      COMMON / COM1/ IMIN     , IMAX    , IUP     , IDOWN   , ILE     ,
     1               ITE      , JMIN    , JMAX    , JUP     , JLOW    ,
     2               JTOP     , JBOT
      COMMON / COM2/ AK       , ALPHA   , DUB     , GAM1    , RTK
      LOGICAL        AMESH
      COMMON / COM4/ XIN(100) , YIN(100), AMESH
      COMMON /COM12/ F        , H       , HALFPI  , PI      , RTKPOR  ,
     1               TWOPI
      COMMON /COM15/ B        , BETAO   , BETA1   , BETA2   , PSIO    ,
     1               PSI1     , PSI2
      REAL JET
      COMMON /COM16/ ALPHAO   , ALPHA1  , ALPHA2  , XSING   ,
     1               OMEGAO   , OMEGA1  , OMEGA2  , JET
      COMMON /COM24/ DTOP(100), DBOT(100),DUP(100), DDOWN(100),
     1               VTOP(100), VBOT(100),VUP(100), VDOWN(100)
      INTEGER        BCTYPE
      COMMON /COM28/ BCTYPE   , CIRCFF  , FHINV   , POR     , CIRCTE
C
C                 TEST FOR SUPERSONIC OR SUBSONIC FREESTREAM
      IF(AK .GT. 0.) GO TO 99
      IF (F .NE. 0.0 .AND. H .NE. 0.0) GO TO 10
      FHINV = 1.0
      RETURN
   10 CONTINUE
      FHINV = 1.0 / (F * H)
C                 SUPERSONIC FREESTREAM
C                 UPSTREAM BOUNDARY CONDITIONS CORRESPOND TO UNIFORM
C                 UNDISTURBED FLOW
C                 DOWNSTREAM BOUNDARY REQUIRED TO BE SUPERSONIC
C                 TOP AND BOTTOM BOUNDARIES USE SIMPLE WAVE SOLUTION.
      RETURN
C
   99 CONTINUE
C
C                 SUBSONIC FREESTREAM
C
C                 FUNCTIONAL FORM OF THE POTENTIAL ON OUTER BOUNDARIES
C                 IS PRESCRIBED. EQUATIONS REPRESENT ASYMPTOTIC FORM
C                 FOR DOUBLET AND VORTEX IN FREE AIR AND WIND TUNNEL
C                 ENVIRONMENT. DOUBLET AND VORTEX ARE LOCATED AT
C                 X=XSING, Y=0.
C                 ACTUAL BOUNDARY VALUES ARE SET IN SUBROUTINES RECIRC
C                 AND REDUB WHERE THE FUNCTIONAL FORMS ARE MULTIPLIED
C                 BY THE VORTEX AND DOUBLET STRENGTHS.  THE BOUNDARY
C                 CONDITIONS ARE CALCULATED HERIN FOR THE INPUT X AND
C                 Y MESH AND VALUES ARE DELETED FOR THE COARSE MESH IN
C                 SUBROUTINE SETBC.

C                 SET LOCATION OF SINGLULAR VORTEX AND DOUBLET
      XSING = .5
C                 SET DEFAULT VALUES FOR TUNNEL WALL PARAMETERS
      B = 0.
      OMEGAO = 1.
      OMEGA1 = 1.
      OMEGA2 = 1.
      JET = 0.
      PSIO = 1.
      PSI1 = 1.
      PSI2 = 1.
C                 BRANCH TO APPROPRIATE FORMULAS DEPENDING ON BCTYPE
      GO  TO (100,200,300,400,500,600), BCTYPE
  10C CONTINUE
C                 BCTYPE = 1
C                 FREE AIR BOUNDARY CONDITION
C                 SET BOUNDARY ORDINATES
      YT = YIN(JMAX)*RTK
      YB = YIN(JMIN)*RTK
      XU = XIN(IMIN) - XSING
      XD = XIN(IMAX) - XSING
      YT2 = YT*YT
      YB2 = YB*YB
      XU2 = XU*XU
      XD2 = XD*XD
      COEF1 = 1./TWOPI
      COEF2 = 1.0/(TWOPI*RTK)
C                 COMPUTE DOUBLET AND VORTEX TERMS ON TOP AND BOTTOM
C                 BOUNDARIES.
      DO 110 I=IMIN,IMAX
      XP = XIN(I) - XSING
      XP2 = XP*XP
      DTOP(I) = XP/(XP2 + YT2)*COEF2
      DBOT(I) = XP/(XP2 + YB2)*COEF2
      VTOP(I) = -ATAN2(YT,XP)*COEF1
      VBOT(I)  = -(ATAN2(YB,XP) + TWOPI)*COEF1
  110 CONTINUE
C                   COMPUTE DOUBLET AND VORTEX TERMS ON UPSTREAM
C                   AND DOWNSTREAM BOUNDARIES
      DO 120 J=JMIN,JMAX
      YJ = YIN(J)*RTK
      YJ2 = YJ*YJ
      DUP(J) = XU/(XU2 + YJ2)*COEF2
      DDOWN(J) = XD/(XD2 + YJ2)*COEF2
      Q = PI - SIGN(PI,YJ)
      VUP(J) = -(ATAN2(YJ,XU) + Q)*COEF1
      VDOWN(J) = -(ATAN2(YJ,XD) + Q)*COEF1
  120 CONTINUE
      IF (AK .GT. 0.0) CALL ANGLE
      RETURN
C                   COMPUTE WALL CONSTANTS FOR VARIOUS WIND TUNNEL
C                   CONDITIONS.
  200 CONTINUE
C                   BCTYPE = 2
C                   SOLID WALL TUNNEL
      POR = 0.
C                   SET CONSTANTS FOR DOUBLET SOLUTION
      B = .5
      ALPHA0 = PI
      ALPHA1 = PI
      ALPHA2 = PI
C                   SET CONSTANTS FOR VORTEX SOLUTION
      BETA0 = HALFPI
      BETA1 = HALFPI
      BETA2 = HALFPI
      GO TO 700
  300 CONTINUE
C                   BCTYPE = 3
C                   FREE JET
      F = 0.
      RTKPOR = 0.
C                   SET CONSTANTS FOR DOUBLET SOLUTION
      ALPHA0 = HALFPI
      ALPHA1 = HALFPI
      ALPHA2 = HALFPI
C                   SET CONSTANTS FOR VORTEX SOLUTION
      JET = .5
      BETA0 = 0.
      BETA1 = 0.
      BETA2 = 0.
      GO TO 700
  400 CONTINUE
C                   BCTYPE = 4
C                   IDEAL SLOTTED WALL
      RTKPOR = 0.
      FHINV = 1.0 / ( F * H )
C                   SET CONSTANTS FOR DOUBLET SOLUTION
      CALL DROOTS
C                   SET CONSTANTS FOR VORTEX SOLUTION
      JET = .5
      CALL VROOTS
      GO TO 700
  500 CONTINUE
C                   BCTYPE = 5
C                   IDEAL PERFORATED/POROUS WALL
      F = 0.
      RTKPOR = RTK/POR
C                   SET CONSTANTS FOR DOUBLET SOLUTION
      ALPHA0 = HALFPI - ATAN(-RTKPOR)
      ALPHA1 = ALPHA0
      ALPHA2 = ALPHA0
C                   SET CONSTANTS FOR VORTEX SOLUTION
      BETA0 = ATAN(RTKPOR)
      BETA1 = BETA0
      BETA2 = BETA1
      GO TO 700
  600 CONTINUE
C                   BCTYPE = 6
C                   GENERAL HOMOGENEOUS WALL BOUNDARY CONDITION
C                   BOUNDARY CONDITION IS NOT OPERABLE YET IN FINITE
C                   DIFFERENCE SUBROUTINES.
C                   FAR FIELD SOLUTION HAS BEEN DERIVED AND IS INCLUDED
C                   HERE  FOR FUTURE USE
      RTKPOR = RTK/POR
      CALL DROOTS
      CALL VROOTS
      WRITE(6,1000)
 1000 FORMAT(35H1ABNORMAL STOP IN SUBROUTINE FARFLD/
     1        24H BCTYPE=6 IS NOT USEABLE)
      STOP
  700 CONTINUE
C                   COMPUTE FUNCTIONAL FORMS FOR UPSTREAM AND DOWNSTREAM
C                   BOUNDARY CONDITIONS  FOR DOUBLET AND VORTEX
      XU = (XIN(IMIN) - XSING)/(RTK*H)
      XD = (XIN(IMAX) - XSING)/(RTK*H)
C                   DOUBLET TERMS
      COEF1 = .5/AK/H
      ARG0 = ALPHA0
      ARG1 = PI - ALPHA1
      ARG2 = TWOPI - ALPHA2
      EXARG0 = EXP(-ARG0*XD)
      EXARG1 * EXP(ARG1*XU)
      EXARG2 = EXP(ARG2*XU)
      DO 720 J = JMIN,JMAX
      YJ = YIN(J) / H
      DDOWN(J) = COEF1*(B + OMEGA0*COS(YJ*ARG0)*EXARG0)
      DUP(J) = -COEF1*((1.-B)*OMEGA1*COS(YJ*ARG1)*EXARG1 +
     1  OMEGA2*COS(YJ*ARG2)*EXARG2)
  720 CONTINUE
C                   VORTEX TERMS
      ARG0 = BETA0
      ARG1 = PI + BETA1
      ARG2 = PI - BETA2
      EXARG0 = EXP(-ARG0*XD)
      EXARG1 = EXP(-ARG1*XD)
      EXARG2 = EXP(ARG2*XU)
      DO 740 J = JMIN,JMAX
      YJ = YIN(J) / H
      TERM = YJ
      IF (JET .EQ. 0.0) TERM = SIN(YJ*ARG0) / ARG0
      VDOWN(J) = -.5*(1. - SIGN(1.,YJ) + (1. - JET)*PSI0*TERM*EXARG0 +
     1  PSI1*SIN(YJ*ARG1)*EXARG1/ARG1)
      TERM = 0.
      IF (JET .NE. 0.0) TERM = JET * YJ / (1.0 + F)
      VUP(J) = -.5*(1. - TERM - PSI2*SIN(YJ*ARG2)*EXARG2/ARG2)
  740 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE FINDSK(ISTART,IEND,J, ISK)
C                   SUBROUTINE LOCATES SHOCK WAVE ON LINE J BETWEEN
C                   ISTART AND IEND.  SHOCK IS LOCATED AT SHOCK POINT.
C                   IF NO SHOCK FOUND, ISK IS SET NEGATIVE.
C                   CALLED BY - COCOLE.
      LOGICAL         PHYS
      INTEGER         PRTFLO   , SIMDEF
      COMMON /COM27/  CL       , DELTA    , DELRT2   , EMACH    , EMROOT   ,
     1                PHYS     , PRTFLO   , SIMDEF   , SONVEL   , VFACT    ,
     2                YFACT
      ISK = ISTART - 1
      U2 = PX(ISK,J)
    5 ISK = ISK + 1
      U1 = U2
      U2 = PX(ISK,J)
      IF(U1 .GT. SONVEL .AND. U2 .LE. SONVEL) GO TO 10
      IF (ISK .LE. IEND) GO TO 5
      ISK = - IEND
   10  CONTINUE
      RETURN
      END
```

```
      SUBROUTINE FIXPLT

C                       SETS UP ARRAYS FOR SUBROUTINE CPPLOT.
C                       CALLED BY - PRINT.

      COMMON          P(102,101),X(100)  , Y(100)
      COMMON / COM1/  IMIN     , IMAX     , IUP      , IDOWN    , ILE      ,
     1                ITE      , JMIN     , JMAX     , JUP      , JLOW     ,
     2                JTOP     , JBOT
      COMMON /COM13/  CDFACT   , CLFACT   , CMFACT   , CPFACT   , CPSTAR
      COMMON /COM25/  CPL(100) , CPU(100)
      COMMON /COM30/ CPUP(101), CPLO(101) , CPS(101) , XP(101)
      YMX = 5.*CPFACT
      YMN = -5.*CPFACT
      K = 0
      DO 150 I = IMIN,IMAX
      K = K + 1
      QCP = -CPU(I)
      QCP = AMAX1(QCP,YMN)
      QCP = AMIN1(QCP,YMX)
      CPUP(K) = QCP
      QC1 = -CPL(I)
      QC1 = AMAX1(QC1,YMN)
      QC1 = AMIN1(QC1,YMX)
       CPLO(K) = QC1
      QC2 = -CPSTAR
      QC2 = AMAX1(QC2,YMN)
      QC2 = AMIN1(QC2,YMX)
      CPS(K) = QC2
      XP(K) = X(I)
  150 CONTINUE
      IMP = K + 1
      CPUP(IMP) = YMX
      CPLO(IMP) = YMN
      CPS(IMP)  = 0.0
      XP(IMP) = X(IMAX) + .001
      CALL CPPLOT (XP, CPUP, CPLO, CPS, IMP)
      RETURN
      END
```

```
      SUBROUTINE GUESSP
C                    SUBROUTINE INITIALIZES P ARRAY AS FOLLOWS
C                         PSTART = 1  P SET TO ZERO
C                         PSTART = 2  P READ FROM UNIT 7
C                         PSTART = 3  P SET TO VALUES IN CORE
C                    IF PSTART = 2 OR 3, SOLUTION IS INTERPOLATED FROM
C                    XOLD, YOLD TO X,Y
C                    BOUNDARY CONDITIONS FOR P ON OUTER BOUNDARIES ARE
C                    AUTOMATICALLY SET DURING INITIALIZATION
C                    CALLED BY - TSFOIL.
C
      COMMON          P(102,101),X(100)  , Y(100)
      COMMON / COM1/ IMIN      , IMAX    , IUP      , IDOWN    , ILE      ,
     1               ITE       , JMIN    , JMAX     , JUP      , JLOW     ,
     2               JTOP      , JBOT
      COMMON / COM2/ AK        , ALPHA   , DUB      , GAM1     , RTK
      LOGICAL        ABORT
      COMMON / COM3/ IREF      , ABORT   , ICUT     , KSTEP
      LOGICAL        AMESH
      COMMON / COM4/ XIN(100) , YIN(100), AMESH
      INTEGER        PSTART
      LOGICAL        PSAVE
      COMMON /COM11/ ALPHAO    , CLOLD   , DELTAO   , DUBO     , EMACHO   ,
     1               IMINO     , IMAXO   , IMAXI    , JMINO    , JMAXO    ,
     2               JMAXI     , PSAVE   , PSTART   , TITLE(8), TITLEO(8),
     3               VOLO      , XOLD(100),YOLD(100)
      COMMON /COM13/ CDFACT    , CLFACT  , CMFACT   , CPFACT   , CPSTAR
      INTEGER        BCTYPE
      COMMON /COM28/ BCTYPE    , CIRCFF  , FHINV    , POR      , CIRCTE
      COMMON /COM30/ PT(100)   , REST(304)
C
C                   BRANCH TO APPROPRIATE LOCATION
      GO TO ( 200, 300, 400) , PSTART
  200 CONTINUE
C                   PSTART = 1
C                   P SET TO ZERO
      DO 205 I=1,101
      DO 205 J=1,102
      P(J,I) = 0.
 205  CONTINUE
      DUB = 0.
      CIRCFF = 0.
      CIRCTE=0.0
      RETURN
 300  CONTINUE
C                   PSTART = 2
C                   P, X, Y ARRAYS READ FROM UNIT 7 IN SUBROUTINE READIN
C                   TOGETHER WITH INFORMATION ABOUT OLD SOLUTION
 400  CONTINUE
C                   PSTART = 3
C                   ARRAYS FROM PREVIOUS CASE ARE ALREADY IN P,XOLD,YOLD
      DUB = DUBO
      CIRCFF = CLOLD/CLFACT
      CIRCTE=CIRCFF
C
C                   FOR PSTART = 2 OR 3, OLD P ARRAY ON XOLD, YOLD MESH
C                   MUST BE INTERPOLATED ONTO NEW X Y MESH.
C
C                   INTERPOLATE P FROM XOLD,YOLD TO X,YOLD
C                   CHECK TO SEE IF XOLD AND XIN ARE THE SAME MESH
      IF(IMAXI .NE. IMAXO) GO TO 450
      DO 410 I=IMIN, IMAXI
      TEST = ABS(XIN(I) - XOLD(I))
      IF(TEST .GT. .0001) GO TO 450
 410  CONTINUE
C                   XIN AND XOLD ARE SAME MESH.
C                   P ARRAY MAY BE INTERPOLATED BY SIMPLE DELETION OF
C                   VALUES AT MESH POINTS DELETED IN SUBROUTINE CUTOUT
C                   IF IREF .LE. ZERO, NO INTERPOLATION IS NEEDED
      IF(IREF .LE. 0) GO TO 500
      ISTEP = 2*IREF
      DO 430 J = JMINO,JMAXO
      INEW = 0
      DO 420 I = IMINO,IMAXO,ISTEP
      INEW = INEW + 1
      P(J,INEW) = P(J,I)
 420  CONTINUE
 430  CONTINUE
C                   INTERPOLATION IN X DIRECTION COMPLETE IF XIN AND
C                   XOLD ARE THE SAME.
      GO TO 500
 450  CONTINUE
C                   INTERPOLATE FROM XOLD TO X FOR ARBITRARY CASE
      DO 490 J = JMINO, JMAXO
      YP = YOLD(J)
      DO 475 I = IMIN, IMAX
      XP = X(I)
      IF(XP .LT. XOLD(IMINO)) GO TO 470
      IF(XP .GT. XOLD(IMAXO)) GO TO 470
C                   NEW X MESH POINT WITHIN RANGE OF OLD X MESH
C                   FIND VALUE OF XOLD .GT. XP
      X2 = XOLD(I)
      K = 0
 455  K = K +1
      X1 = X2
      X2 = XOLD(K)
      IF (X2 .LT. XP) GO TO 455
      IF (X2 .GT. XP) GO TO 460
      PT(I) = P(J,K)
      GO TO 475
  460 CONTINUE
      P1 = P(J,K-1)
      P2 = P(J,K)
      PT(I) = P1 + (P2 - P1)/(X2 - X1) * (XP - X1)
      GO TO 475
 470  CONTINUE
C                   NEW X MESH POINT IS OUTSIDE RANGE OF OLD X MESH
C                   FOR SUPERSONIC FREESTREAM SET P=0, FOR SUBSONIC
C                   FREESTREAM, EXTRAPOLATE USING FAR FIELD SOLUTION
      PT(I) = 0.
      IF(AK .GT. 0.) CALL EXTRAP(XP,YP,PT(I))
 475  CONTINUE
C                   WRITE NEW VALUES FOR P INTO P ARRAY
      DO 480 I = IMIN, IMAX
      P(J,I) = PT(I)
 480  CONTINUE
 490  CONTINUE
 500  CONTINUE
C                   INTERPOLATE FROM X,YOLD TO X,Y
C                   CHECK TO SEE IF YIN AND YOLD ARE THE SAME MESH
C
      IF(JMAXI .NE. JMAXO) GO TO  550
      DO 510 J = JMIN, JMAXI
      TEST = ABS(YIN(J) - YOLD(J))
      IF(TEST .GT. .0001) GO TO 550
 510  CONTINUE
C                   YIN AND YOLD ARE THE SAME MESH
C                   P ARRAY MAY BE INTERPOLATED BY SIMPLE DELETION OF
C                   VALUES AT MESH POINTS DELETED IN SUBROUTINE CUTOUT
C                   IF IREF .LE. ZERO, NO INTERPOLATION IS NEEDED
      IF(IREF .LE. 0) GO TO 600
      JSTEP = 2*IREF
      DO 530 I= IMIN, IMAX
      JNEW = 0
      DO 520 J = JMINO, JMAXO, JSTEP
      JNEW = JNEW + 1
      P(JNEW,I) = P(J,I)
  520 CONTINUE
  530 CONTINUE
C                   INTERPOLATION IN Y DIRECTION COMPLETE IF YIN AND
C                   YOLD ARE THE SAME.
      GO TO 600
  550 CONTINUE
C                   INTERPOLATE YOLD TO Y FOR ARBITRARY CASE
      DO 590 I = IMIN,IMAX
      XP = X(I)
      K = 2
      Y1 = YOLD(1)
      DO 575 J = JMIN,JMAX
      YP = Y(J)
      IF(YP .LT. YOLD(JMINO)) GO TO 570
      IF(YP .GT. YOLD(JMAXO)) GO TO 571
C                   NEW Y MESH POINT WITHIN RANGE OF OLD Y MESH
C                   FIND VALUE OF YOLD .GT. YP
      Y2 = Y1
      K = K - 1
  555 K = K + 1
      Y1 = Y2
      Y2 = YOLD(K)
      IF(Y2 .LE. YP) GO TO 555
      P1 = P(K-1,I)
      P2 = P(K,I)
      PT(J) = P1 + (P2 - P1) / (Y2 - Y1) * (YP - Y1)
      GO TO 575
C                   NEW Y MESH POINT OUTSIDE RANGE OF OLD Y MESH.
C                   SET P(J,I) = P(JMINO,I) OR, IF SUBSONIC FREESTREAM
C                   FREE AIRFLOW, EXTRAPOLATE FOR P(J,I) USING FARFLD
C                   FORMULA.
  570 CONTINUE
      PT(J) = P(JMINO,I)
      GO TO 572
  571 PT(J) = P(JMAXO,I)
  572 CONTINUE
      IF(AK .GT. 0. .AND. BCTYPE .EQ. 1) CALL EXTRAP(XP,YP,PT(J))
  575 CONTINUE
C                   PUT NEW P VALUES INTO P ARRAY
      DO 580 J = JMIN,JMAX
      P(J,I) = PT(J)
  580 CONTINUE
  590 CONTINUE
  600 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE INPERR (I)

C                          FATAL ERROR IN INPUT. WRITE MESSAGE AND STOP.
C                          CALLED BY - READIN, SCALE.

      IF (I .EQ. 1) WRITE (6,901)
      IF (I .EQ. 2) WRITE (6,902)
      IF (I .EQ. 3) WRITE (6,903)
      IF (I .EQ. 4) WRITE (6,904)
      IF (I .EQ. 5) WRITE (6,905)
      IF (I .EQ. 6) WRITE (6,906)
      IF (I .EQ. 7) WRITE (6,907)
      STOP
  901 FORMAT(1H0,5X,45HIMAX OR JMAX IS GREATER THAN 100,NOT ALLOWED.)
  902 FORMAT(1H0,5X,39HX MESH POINTS NOT MONOTONIC INCREASING.)
  903 FORMAT(1H0,5X,39HY MESH POINTS NOT MONOTONIC INCREASING.)
  904 FORMAT(1H0,5X,44HMACH NUMBER NOT IN PERMITTED RANGE. (.5,2.0))
  905 FORMAT(1H0,5X,41HALPHA NOT IN PERMITTED RANGE. (-9.0, 9.0))
  906 FORMAT(1H0,5X,41HDELTA NOT IN PERMITTED RANGE. ( 0.0, 1.0))
  907 FORMAT(1H0,5X,45HAK=0. VALUE OF AK MUST BE INPUT SINCE PHYS=F.)
      END
```

```
      SUBROUTINE ISLIT ( X )

C                          ISLIT COMPUTES ILE AND ITE FOR ANY XMESH ARRAY.
C                          CALLED BY - CKMESH, CUTOUT, READIN, REFINE.

      COMMON / COM1/ IMIN     , IMAX    , IUP     , IDOWN   , ILE     ,
     1               ITE      , JMIN    , JMAX    , JUP     , JLOW    ,
     2               JTOP     , JBOT

      DIMENSION X(100)
      I = IMIN - 1
   10 CONTINUE
      I = I + 1
      IF (X(I) .LT. 0.0) GO TO 10
      ILE = I
   20 CONTINUE
      I = I + 1
      IF (X(I) .LE. 1.0) GO TO 20
      ITE = I - 1
      RETURN
      END
```

```
      SUBROUTINE JSLIT ( Y )

C                          JSLIT COMPUTES JLOW AND JUP FROM Y ARRAY.
C                          CALLED BY - CKMESH, CUTOUT, READIN, REFINE.

      COMMON / COM1/ IMIN     , IMAX    , IUP     , IDOWN   , ILE     ,
     1               ITE      , JMIN    , JMAX    , JUP     , JLOW    ,
     2               JTOP     , JBOT

      DIMENSION  Y(100)
      J = JMIN - 1
   10 CONTINUE
      J = J + 1
      IF (Y(J) .LT. 0.0) GO TO 10
      JLOW = J - 1
      JUP  = J
      RETURN
      END
```

```
      REAL FUNCTION LIFT (CLFACT)
C                   COMPUTE LIFT COEFFICIENT FROM JUMP IN P AT TRAILING
C                   EDGE OF AIRFOIL
C                   CALLED BY - PRINT1, SOLVE.

      COMMON         P(102,101),X(100)  , Y(100)
      COMMON / COM1/ IMIN     , IMAX    , IUP     , IDOWN   , ILE     ,
     1               ITE      , JMIN    , JMAX    , JUP     , JLOW    ,
     2               JTOP     , JBOT
      COMMON / COM7/ CJUP     , CJUP1   , CJLOW   , CJLOW1

      PTOP = CJUP*P(JUP,ITE) - CJUP1*P(JUP + 1 , ITE)
      PBOT = CJLOW*P(JLOW,ITE) - CJLOW1*P(JLOW-1,ITE)
      LIFT = 2.*CLFACT*(PTOP-PBOT)
      RETURN
      END
      SUBROUTINE MACHMP
C
C                          SUBROUTINE TO PRINT MAP OF MACH NO. ROUNDED
C                          TO NEAREST .1. CALLED BY - PRINT.
C
      COMMON / COM1/ IMIN      , IMAX    , IUP     , IDOWN   , ILE     ,
     1               ITE       , JMIN    , JMAX    , JUP     , JLOW    ,
     2               JTOP      , JBOT
      COMMON /COM30/ MM(100) , REST(304)
C
      INTEGER CHAR
      DIMENSION CHAR(37)
      DATA CHAR/1H0,1H1,1H2,1H3,1H4,1H5,1H6,1H7,1H8,1H9,1HA,1HB,1HC,1HD,
     1 1HE,1HF,1HG,1HH,1HI,1HJ,1HK,1HL,1HM,1HN,1HO,1HP,1HQ,1HR,1HS,1HT,
     2 1HU,1HV,1HW,1HX,1HY,1HZ,1H*/
      DATA IB/1H / , IP/1H+/ , IM/1H-/ , IL/1HL/ , IT/1HT/
C
      WRITE (6,400)
      DO 60 K=2,JMAX
      J          = JMAX - K + 2
      IJC = IB
      IF ( J .EQ. JUP) IJC = IP
      IF ( J .EQ. JLOW ) IJC = IM
      DO 10 I=1,IMAX
      MM(I)      = IB
   10 CONTINUE
      DO 50 I=2,IMAX
      U          = PX(I,J)
      EM         = EMACH1 (U)
      IF (EM .GT. 0.0) GO TO 20
      MM(I) = CHAR(1)
      GO TO 50
   20 CONTINUE
      KAR=INT(10.*EM+1.5)
      IF (KAR .GT. 37) KAR=37
      MM(I)=CHAR(KAR)
   50 CONTINUE
      WRITE (6,410) IJC, (MM(I),I=2,IMAX)
   60 CONTINUE
      DO 70 I=1,IMAX
      MM(I) = IB
      IF (I .EQ. ILE) MM(I) = IL
      IF (I .EQ. ITE) MM(I) = IT
   70 CONTINUE
      WRITE (6,420) (MM(I),I=2,IMAX)
      RETURN

  400 FORMAT(1H1,58X,15HMACH NUMBER MAP/59X,15(1H*)///3X,4(6HSYMBOL,5X,
     1 5HRANGE,14X)/5X,1H0,10X,9HM.LE.0.05,10X,20HA  0.95.LT.M.LE.1.05,
     2 10X,20HK  1.95.LT.M.LE.2.05,10X,20HU  2.95.LT.M.LE.3.05/5X,
     3 20H1  0.05.LT.M.LE.0.15,10X,20HB  1.05.LT.M.LE.1.15,10X,
     4 20HL  2.05.LT.M.LE.2.15,10X,20HV  3.05.LT.M.LE.3.15/5X,
     5 20H2  0.15.LT.M.LE.0.25,10X,20HC  1.15.LT.M.LE.1.25,10X,
     6 20HM  2.15.LT.M.LE.2.25,10X,20HW  3.15.LT.M.LE.3.25/5X,
     7 20H3  0.25.LT.M.LE.0.35,10X,20HD  1.25.LT.M.LE.1.35,10X,
     8 20HN  2.25.LT.M.LE.2.35,10X,20HX  3.25.LT.M.LE.3.35/5X,
     9 20H4  0.35.LT.M.LE.0.45,10X,20HE  1.35.LT.M.LE.1.45,10X,
     A 20HO  2.35.LT.M.LE.2.45,10X,20HY  3.35.LT.M.LE.3.45/5X,
     B 20H5  0.45.LT.M.LE.0.55,10X,20HF  1.45.LT.M.LE.1.55,10X,
     C 20HP  2.45.LT.M.LE.2.55,10X,20HZ  3.45.LT.M.LE.3.55/5X,
     D 20H6  0.55.LT.M.LE.0.65,10X,20HG  1.55.LT.M.LE.1.65,10X,
     E 20HQ  2.55.LT.M.LE.2.65,10X,1H*,10X,9HM.GT.3.55/5X,
     F 20H7  0.65.LT.M.LE.0.75,10X,20HH  1.65.LT.M.LE.1.75,10X,
     G 20HR  2.65.LT.M.LE.2.75/5X,20H8  0.75.LT.M.LE.0.85,10X,
     H 20HI  1.75.LT.M.LE.1.85,10X,20HS  2.75.LT.M.LE.2.85/5X,
     I 20H9  0.85.LT.M.LE.0.95,10X,20HJ  1.85.LT.M.LE.1.95,10X,
     J 20HT  2.85.LT.M.LE.2.95//)
  410 FORMAT(11X,100A1)
  420 FORMAT (12X,99A1)

      END
```

```
      SUBROUTINE M1LINE
C                    PRINTS COORDINATES WHERE SONIC VELOCITY IS COMPUTED
C                    LINEAR INTERPOLATION BETWEEN MESH POINTS IS USED
C                    CALLED BY - PRINT.
C **********************************************************************

      COMMON         P(102,101),X(100)   , Y(100)
      COMMON / COM1/ IMIN      , IMAX    , IUP     , IDOWN   , ILE     ,
     1               ITE       , JMIN    , JMAX    , JUP     , JLOW    ,
     2               JTOP      , JBOT
      COMMON / COM2/ AK        , ALPHA   , DUB     , GAM1    , RTK
      LOGICAL        PHYS
      INTEGER        PRTFLO    , SIMDEF
      COMMON /COM27/ CL        , DELTA   , DELRT2  , EMACH   , EMROOT  ,
     1               PHYS      , PRTFLO  , SIMDEF  , SONVEL  , VFACT   ,
     2               YFACT
      INTEGER        BCTYPE
      COMMON /COM28/ BCTYPE    , CIRCFF  , FHINV   , POR     , CIRCTE
      COMMON /COM30/ XSLPRT(200) , YSLPRT(200) , REST(4)

      DIMENSION  XSONIC(10)
      NPTS = 0
      KMIN = JMIN
      KMAX = JMAX
      JP = JMAX + JMIN
      DO 200 K=KMIN,KMAX
      J = JP - K
      YPR = YFACT*Y(J)
      PX2 = PX(IMIN,J)
      M = 0
      IF (J .NE. JLOW) GO TO 170
      IF (NPTS .NE. 0) WRITE (6,2070)
  170 CONTINUE
      IMM = IMIN + 1
      DO 180 I=IMM,IMAX
      PX1 = PX2
      PX2 = PX(I,J)
      IF(PX1 .GT. SONVEL .AND. PX2 .GT. SONVEL) GO TO 180
      IF(PX1 .LT. SONVEL .AND. PX2 .LT. SONVEL) GO TO 180
      IF (NPTS .EQ. 0) WRITE (6,2000)
      M = M+1
      RATIO = (SONVEL-PX1)/(PX2-PX1)
      XSONIC(M) = X(I-1) + (X(I)-X(I-1))*RATIO
      NPTS = NPTS  + 1
      XSLPRT(NPTS) = XSONIC(M)
      YSLPRT(NPTS) = YPR
      IF(NPTS .GE. 200) GO TO 250
  180 CONTINUE
      IF(M .EQ. 0) GO TO 200
      WRITE(6,2040) YPR,(XSONIC(L),L=1,M)
 200  CONTINUE
      GO TO 300
 250  CONTINUE
      WRITE(6,2060)
      GO TO 400
 300  CONTINUE
      IF(NPTS .EQ.0) GO TO 400
      YM = Y(JMIN)
      YX = Y(JMAX)
      DO 320 N=1,NPTS
      IF (YSLPRT(N) .NE. YM .AND. YSLPRT(N) .NE. YX) GO TO 320
      IF ( AK .GT. 0.0 ) WPITE (6,2050)
      IF ( AK .LT. 0.0 .AND. BCTYPE .EQ. 1 ) WRITE (6,2050)
  320 CONTINUE
      XMIN  = -.75
      XMAX  = 1.75
      XINCR =  .25
      YMIN  = -1.0
      YMAX  =  1.5
      YINCR =   .5
      CALL PLTSON(XSLPRT,YSLPRT,XMIN,XMAX,XINCR,YMIN,YMAX,YINCR,NPTS)
 400  CONTINUE
      RETURN

 2000 FORMAT(1H1,58X,17HSONIC LINE OUTPUT/59X,17(1H*)/
     1 23H SONIC LINE COORDINATES//6X,1HY,10X,7HX-SONIC/)
 2040 FORMAT(11F10.5)
 2050 FORMAT(20H0***** CAUTION *****/
     *  34H SONIC LINE HAS REACHED A BOUNDARY/
     1 61H THIS VIOLATES ASSUMPTIONS USED TO DERIVE BOUNDARY CONDITIONS/
     2 29H SOLUTION IS PROBABLY INVALID)
 2060 FORMAT(20H0***** CAUTION *****/36H NUMBER OF SONIC POINTS EXDEEDED
     1 200/25H ARRAY DIMENSION EXCEEDED/42H EXECUTION OF SUBROUTINE M1LI
     2NE TERMINATED)
 2070 FORMAT(2X,13HBODY LOCATION)

      END
      SUBROUTINE NEWISK(ISKOLD,J,ISKNEW)
C                   FIND NEW LOCATION OF SHOCKWAVE (ISKNEW) ON LINE J
C                   GIVEN AN INITIAL GUESS FOR LOCATION (ISKOLD).
C                   SHOCK LOCATION IS DEFINED AS LOCATION OF SHOCK POINT.
C                   IF NO SHOCK IS FOUND, ISKNEW IS SET NEGATIVE.
C                   CALLED BY - CDCOLE.

      LOGICAL         PHYS
      INTEGER         PRTFLO   , SIMDEF
      COMMON /COM27/  CL       , DELTA   , DELRT2  , EMACH   , EMROOT  ,
     1                PHYS     , PRTFLO  , SIMDEF  , SONVEL  , VFACT   ,
     2                YFACT
      I2 = ISKOLD + 2
      ISKNEW = ISKOLD - 3
      U2 = PX(ISKNEW,J)
    5 ISKNEW = ISKNEW + 1
      U1 = U2
      U2 = PX(ISKNEW,J)
      IF(U1 .GT. SONVEL .AND. U2 .LE. SONVEL) GO TO 10
      IF(ISKNEW .LT. I2) GO TO 5
C                   NO SHOCK POINT FOUND, TIP OF SHOCK REACHED.
      ISKNEW = - ISKNEW
   10 RETURN
      END
```

```
      FUNCTION PITCH(CMFACT)
C                   COMPUTE AIRFOIL PITCHING MOMENT ABOUT X = XM, Y=0
C                   THE INTEGRAL OF(X-XM)(CPUPPER-CPLOWER) IS INTEGRATED
C                   BY PARTS TO GIVE AN INTEGRAL IN THE JUMP IN P PLUS A
C                   CONSTANT EQUAL TO THE JUMP IN P AT X = 1. TIMES THE
C                   MOMENT ARM AT THE TRAILING EDGE
C                   CALLED BY - PRINT1, SOLVE.

      COMMON          P(102,101),X(100)  , Y(100)
      COMMON / COM1/  IMIN     , IMAX    , IUP     , IDOWN   , ILE     ,
     1                ITE      , JMIN    , JMAX    , JUP     , JLOW    ,
     2                JTOP     , JBOT
      COMMON / COM7/  CJUP     , CJUP1   , CJLOW   , CJLOW1
      COMMON /COM30/  XI(100)  , ARG(100)  , REST(204)

C                   SET XM TO QUARTER CHORD
      XM = .25
      K = 0
      DO 10 I=ILE,ITE
      K = K + 1
      PTOP = CJUP*P(JUP,I) - CJUP1*P(JUP+1,I)
      PBOT = CJLOW*P(JLOW,I) - CJLOW1*P(JLOW-1,I)
      ARG(K) = PTOP - PBOT
      XI(K) = X(I)
   10 CONTINUE
      CALL TRAP(XI,ARG,K,SUM)
      PITCH = CMFACT*((1.-XM)*ARG(K) - SUM) * (-2.)
      RETURN
      END
```

```
      SUBROUTINE PLTSON (X,Y,XAXMIN,XMAX,XINCR,YAXMIN,YMAX,YINCR,NPTS)

C                              THIS IS A MODIFIED VERSION OF PRNPLT AND
C                              XMAX, XINCR, YMAX, YINCR MUST BE SUPPLIED.
C                              XMIN, AND YMIN MUST ALSO BE SUPPLIED.
C                        PRINTER PLOT ROUTINE M. S. ITZKOWITZ  MAY,1967
C                        PLOTS THE ≤NPTS≤ POINTS GIVEN BY, X(I),Y(I)
C                        ON A 51 X 101 GRID USING A TOTAL OF 56 LINES ON
C                        THE PRINTER.
C                        IF EITHER INCREMENTAL STEP SIZE IS ZERO, THE
C                        PROGRAM EXITS.
C                        NEITHER OF THE INPUT ARRAYS ARE DESTROYED.
C                         CALLED BY - M1LINE.

      DIMENSION  X(NPTS),  Y(NPTS),  IGRID(105),  XAXIS(11)
      DIMENSION IBS(9)
```

```
      INTEGER  BLANK , DOT , STAR , DASH
      DATA     BLANK , DOT , STAR , DASH / 1H , 1H., 1H*, 1H-/
      DATA      IBS/1HB,1HO,1HD,1HY,1H ,1HS,1HL,1HI,1HT/

      WRITE(6,900)
      WRITE(6,910)
      IF (XINCR .EQ. 0. .OR. YINCR .EQ. 0.) GO TO 800
      YRNGE  = YMAX - YAXMIN
      XRNGE  = XMAX - XAXMIN
      YVAL = YRNGE * .02
      XVAL = XRNGE * .01
      JSLT = IFIX( 51.*(YMAX/YRNGE) ) + 1
      DXV = 1.0 / XVAL
      DYV = 1.0 / YVAL
      IZERO  = YMAX * DYV  + 1.5
      JZERO = 103.5 - XMAX * DXV
      IF (JZERO .GT. 103 .OR. JZERO .LT. 4) JZERO = 2
      FIZERO = IZERO
      FJZERO = JZERO
      IGRID(1)      = BLANK
      IGRID(2)      = DOT
      IGRID(104)    = DOT
      IGRID(105)    = BLANK
      FIZER5 = FIZERO + .5
      FJZER5 = FJZERO + .5
C                        NOPW IS THE NUMBER OF PRINT WHEELS USED TO
C                                      SPAN THE BODY LENGTH.
      NOPW = DXV
C                        JS - THE NUMBER OF PRT WHEEL POSITIONS TO BE
C                             FILLED AT EACH END OF THE WORD +BODY SLIT+
      JS = 0
      IF (NOPW .GT. 9) JS = (NOPW-9) / 2

      WRITE (6,905)
      WRITE (6,903)
C                        LOOP TO SET UP ONE LINE EACH TIME THRU.
      DO 30 I=1,51
C                        BLANK THE LINE TO BE PRINTED.
      DO 2 J=3,103
      IGRID(J) = BLANK
    2 CONTINUE

C                        SEARCH ARRAY FOR POINTS ON THIS LINE.

      DO 10 K=1,NPTS
      ITEST = FIZER5 - Y(K) * DYV
      IF (ITEST .NE. I) GO TO 7
      J = FJZER5 + X(K) * DXV
      IF (J .GT. 103) J = 103
      IF (J .LT.   3) J = 3
      IGRID(J) = STAR
    7 CONTINUE
      IF (JSLT .EQ. I) GO TO 9
      GO TO 10
    9 CONTINUE
C                        WRITE +BODY SLIT+ IF THIS IS THE J0 LINE.
      J = JZERO + 1
      IF (JS .EQ. 0) GO TO 4
      DO 3 L=1,JS
      IF (IGRID(J) .NE. STAR) IGRID(J) = DASH
      J = J + 1
    3 CONTINUE
    4 CONTINUE
      DO 5 L=1,9
      IF (IGRID(J) .NE. STAR) IGRID(J) = IBS(L)
      J = J + 1
    5 CONTINUE
      IF (JS .EQ. 0) GO TO 10
      DO 6 L=1,JS
      IF (IGRID(J) .NE. STAR) IGRID(J) = DASH
      J = J + 1
    6 CONTINUE
   10 CONTINUE
      IF (MOD(I,10) .EQ. 1) GO TO 13
      WRITE (6,901) IGRID
      GO TO 30
   13 CONTINUE
      FI = I - 1
      YAXIS = YMAX - FI * YINCR * .1
      IF (ABS(YAXIS) .LT. YAXMIN) YAXIS = 0.
      WRITE (6,902) YAXIS, (IGRID(J),J=1,105)
   30 CONTINUE
      WRITE (6,903)
      WRITE (6,905)
      DO 40 M=1,11
      FM = 11 - M                                                       PLTSON 104
      XAXIS(M) = XMAX - XINCR * FM                                      PLTSON 105
      IF (XAXIS(M) .LT. XAXMIN) XAXIS(M) = XAXMIN                       PLTSON 106
   40 CONTINUE                                                          PLTSON 107
      WRITE (6,904) XAXIS, NPTS                                         PLTSON 108
      RETURN                                                            PLTSON 109
                                                                        PLTSON 110
  800 WRITE (6,9800)                                                    PLTSON 111
      CALL EXIT                                                         PLTSON 112
                                                                        PLTSON 113
  900 FORMAT(1H1,58X,17HSONIC LINE OUTPUT/59X,17(1H*)/)                 PLTSON 114
  901 FORMAT(14X,105A1)                                                 PLTSON 115
  902 FORMAT(1X,F10.1,2X,1H+,105A1,1H+)                                 PLTSON 116
  903 FORMAT(15X,103(1H.))                                              PLTSON 117
  904 FORMAT(7X,11(F10.2),2H (,I4,5H PTS) )                             PLTSON 118
  905 FORMAT(16X,11(1H+,9X))                                            PLTSON 119
  910 FORMAT(35X,15HSONIC LINE PLOT,10X,6HY VS X,10X,                   PLTSON 120
     1 16H * = SONIC POINT/)                                            PLTSON 121
 9600 FORMAT(46H1SCALING ERROR IN PRNPLT, EXECUTION TERMINATED )        PLTSON 122
                                                                        PLTSON 123
      END                                                               PLTSON 124
```

```
      SUBROUTINE PRBODY                                                 PRBODY   2
C                   PRINTS OUT BODY GEOMETRY                            PRBODY   3
C                   IF PHYS = .TRUE.  ALL DIMENSIONS ARE NORMALIZED BY  PRBODY   4
C                                     AIRFOIL CHORD                     PRBODY   5
C                   IF PHYS = .FALSE. ALL DIMENSIONS EXCEPT X ARE       PRBODY   6
C                                     NORMALIZED BY CHORD LENGTH AND    PRBODY   7
C                                     THICKNESS RATIO.                  PRBODY   8
C                   CALLED BY - BODY.                                   PRBODY   9
                                                                        PRBODY  10
      COMMON / COM6/ FL(100)  , FXL(100), FU(100) , FXU(100),           COM6     2
     1              CAMBER(100), THICK(100),VOL    , XFOIL(100), IFOIL  COM6     3
      LOGICAL         PHYS                                              COM27    2
      INTEGER         PRTFLO   , SIMDEF                                 COM27    3
      COMMON /COM27/ CL        , DELTA   , DELRT2  , EMACH   , EMROOT   , COM27    4
     1                PHYS     , PRTFLO  , SIMDEF  , SONVEL  , VFACT    , COM27    5
     2                YFACT                                             COM27    6
                                                                        PRBODY  13
      WRITE(6,1000)                                                     PRBODY  14
C                   FIND MAXIMUM THICKNESS AND CAMBER                   PRBODY  15
      THMAX = 0.                                                        PRBODY  16
      CAMAX = 0.                                                        PRBODY  17
      DO 10 I = 1,IFOIL                                                 PRBODY  18
      THMAX = AMAX1(THMAX,THICK(I))                                     PRBODY  19
      CAMAX = AMAX1(CAMAX,CAMBER(I))                                    PRBODY  20
 10   CONTINUE                                                          PRBODY  21
      THMAX = 2.*THMAX                                                  PRBODY  22
      IF(PHYS) GO TO 100                                                PRBODY  23
C                   PRINTOUT IN SIMILARITY VARIABLES                    PRBODY  24
      WRITE(6,1001) THMAX                                               PRBODY  25
      WRITE(6,1002) VOL,CAMAX                                           PRBODY  26
      WRITE(6,1003)                                                     PRBODY  27
      DO 40 I=1,IFOIL                                                   PRBODY  28
      WRITE (6,1005) XFOIL(I),FU(I),FXU(I),FL(I),FXL(I),THICK(I),       PRBODY  29
     1                CAMBER(I)                                         PRBODY  30
   40 CONTINUE                                                          PRBODY  31
      RETURN                                                            PRBODY  32
 100  CONTINUE                                                          PRBODY  33
C                   PRINTOUT IN PHYSICAL VARIALBES                      PRBODY  34
      THMAX = DELTA*THMAX                                               PRBODY  35
      CAMAX = DELTA*CAMAX                                               PRBODY  36
      WRITE(6,1006) THMAX                                               PRBODY  37
      VOLUME = VOL*DELTA                                                PRBODY  38
      WRITE(6,1002) VOLUME,CAMAX                                        PRBODY  39
      WRITE(6,1004)                                                     PRBODY  40
      DO 110 I=1,IFOIL                                                  PRBODY  41
      YUP = DELTA*FU(I)                                                 PRBODY  42
      YXUP = DELTA*FXU(I)                                               PRBODY  43
      YLO = DELTA*FL(I)                                                 PRBODY  44
      YXLO = DELTA*FXL(I)                                               PRBODY  45
      TH = DELTA*THICK(I)                                               PRBODY  46
      CA = DELTA*CAMBER(I)                                              PRBODY  47
      WRITE(6,1005) (XFOIL(I),YUP,YXUP,YLO,YXLO,TH,CA)                  PRBODY  48
 110  CONTINUE                                                          PRBODY  49
      RETURN                                                            PRBODY  50
 1000 FORMAT(1H1,55X,23HAIRFOIL GEOMETRY OUTPUT/56X,23(1H*)///)         PRBODY  51
 1001 FORMAT(33H PRINTOUT IN SIMILARITY VARIABLES,                      PRBODY  52
     *  48X, 15HMAX THICKNESS =,F12.8)                                  PRBODY  53
 1002 FORMAT(16H AIRFOIL VOLUME=,F12.8,53X,15HMAX CAMBER    =,F12.8//   PRBODY  54
     1 2X,11HINPUT  GRID,10X,14HUPPER  SURFACE,17X,14HLOWER  SURFACE)   PRBODY  55
 1003 FORMAT(8X,1HX,1X,2(15X,1HF,9X,5HDF/DX),11X,9HTHICKNESS,4X,        PRBODY  56
     1    6HCAMBER/)                                                    PRBODY  57
 1004 FORMAT(8X,1HX,1X,2(15X,1HY,9X,5HDY/DX),11X,9HTHICKNESS,4X,        PRBODY  58
     1    6HCAMBER/)                                                    PRBODY  59
 1005 FORMAT(1X,F12.8,5X,2F12.8,2(6X,2F12.8))                           PRBODY  60
 1006 FORMAT(56H PRINTOUT IN PHYSICAL VARIABLES NORMALIZED BY CHORD LENG PRBODY  61
     1TH, 23X, 15HMAX THICKNESS =,F12.8)                                PRBODY  62
      END                                                               PRBODY  63
```

```
      SUBROUTINE PRINT                                                  PRINT    2
                                                                        PRINT    3
C                        SUBROUTINE FOR MAIN OUTPUT PRINT CONTROL.      PRINT    4
C                        PRINTS RELATIVE PARAMETERS AND CALLS           PRINT    5
C                        SPECIALIZED PRINT/PLOT SUBROUTINES AS REQUIRED. PRINT   6
                                                                        PRINT    7
C                             PRINTOUT DESCRIPTION                      PRINT    8
C                 IF PHYS IS .TRUE. THE FOLLOWING INFORMATION IS        PRINT    9
C                 PRINTED IN PHYSICALLY SCALED VARIABLES (I.E. USUAL    PRINT   10
C                 AERODYNAMIC TERMS)                                    PRINT   11
C                      X,Y ARE COORDINATES NON-DIMENSIONALIZED BY       PRINT   12
C                          AIRFOIL CHORD.                               PRINT   13
C                      CP = (P - P(INF))/Q(INF) = -2.*(DP/DX)           PRINT   14
C                      CD = DRAG COEFF = D/Q(INF)*AIRFOIL CHORD         PRINT   15
C                      CPSTAR = CRITICAL PRESSURE COEFFICIENT           PRINT   16
C                 IF PHYS IS .FALSE. THE ABOVE INFORMATION IS PRINTED   PRINT   17
C                 IN TRANSONIC SIMILARITY VARIABLES.                    PRINT   18
C                                                                       PRINT   19
C                 PRINTOUT OF SONIC LINE ORDINATES IN SUBR. M1LINE      PRINT   20
C                 INCLUDING PRINTPLOT OF SONIC LINE ORDINATES           PRINT   21
C                 CALLED BY - TSFOIL.                                   PRINT   22
C **********************************************************************PRINT   23
                                                                        PRINT   24
      COMMON / COM2/ AK        , ALPHA   , DUB     , GAM1    , RTK      COM2     2
      LOGICAL        ABORT                                              COM3     2
      COMMON / COM3/ IREF      , ABORT   , ICUT    , KSTEP              COM3     3
      COMMON / COM6/ FL(100)   , FXL(100), FU(100) , FXU(100),          COM6     2
     1              CAMBER(100), THICK(100),VOL    , XFOIL(100), IFOIL  COM6     3
      INTEGER        PSTART                                             COM11    2
      LOGICAL        PSAVE                                              COM11    3
      COMMON /COM11/ ALPHAO    , CLOLD   , DELTAO  , DUBO    , EMACHO   , COM11    4
     1               IMINO     , IMAXO   , IMAXI   , JMINO   , JMAXO    , COM11    5
     2               JMAXI     , PSAVE   , PSTART  , TITLE(8), TITLEO(8), COM11    6
     3               VOLO      , XOLD(100),YOLD(100)                    COM11    7
      COMMON /COM13/ CDFACT    , CLFACT  , CMFACT  , CPFACT  , CPSTAR   COM13    2
      LOGICAL        FCR       , KUTTA                                  COM14    2
      COMMON /COM14/ CLSET     , FCR     , KUTTA   , WCIRC              COM14    3
      LOGICAL        PHYS                                               COM27    2
      INTEGER        PRTFLO    , SIMDEF                                 COM27    3
      COMMON /COM27/ CL        , DELTA   , DELRT2  , EMACH   , EMROOT   , COM27    4
     1               PHYS      , PRTFLO  , SIMDEF  , SONVEL  , VFACT    , COM27    5
     2               YFACT                                              COM27    6
      INTEGER        BCTYPE                                             COM28    2
      COMMON /COM28/ BCTYPE    , CIRCFF  , FHINV   , POR     , CIRCTE   COM28    3
                                                                        PRINT   33
      DIMENSION  TPH(6)  , SIM(8) , BCT(15) , FCP(14)                   PRINT   34
                                                                        PRINT   35
      DATA  TPH /4HSIMI,4HLARI,2HTY,4H PHY,4HSICA,2HL /                 PRINT   36
      DATA  SIM /4HCOLE,4H    ,4HSPRE,4HITER,4HKRUP,4HP   ,             PRINT   37
     1          4HUSER,4H    /                                          PRINT   38
      DATA  BCT /4HFREE,4H AIR,4H    ,4HSOLI,4HD WA,4HLL  ,4HFREE,      PRINT   39
     1    4H JET,4H    ,4HSLOT,4HTED ,4HWALL,4HPORO,4HUS W,4HALL /      PRINT   40
      DATA  FCP /4HFULL,4HY CO,4HNSER,4HVATI,4HVE. ,4H    ,4H    ,      PRINT   41
     1          4HNOT ,4HCONS,4HERVA,4HTIVE,4H AT ,4HSHOC,4HK.  /       PRINT   42
                                                                        PRINT   43
      WRITE (6,900)                                                     PRINT   44
      IS = 1                                                            PRINT   45
      IF (PHYS) IS = 4                                                  PRINT   46
      IE = IS + 2                                                       PRINT   47
      WRITE (6,901) (TPH(I),I=IS,IE)                                    PRINT   48
      IE = 2 * SIMDEF                                                   PRINT   49
      IS = IE - 1                                                       PRINT   50
      WRITE (6,902) (SIM(I),I=IS,IE)                                    PRINT   51
      IE = 3 * BCTYPE                                                   PRINT   52
      IS = IE - 2                                                       PRINT   53
      WRITE (6,903) (BCT(I),I=IS,IE)                                    PRINT   54
      IS = 8                                                            PRINT   55
      IF (FCR) IS = 1                                                   PRINT   56
      IE = IS + 6
      WRITE (6,9C4) (FCP(I),I=IS,IE)
      IF (KUTTA) GO TO 10
      WRITE (6,905)
      GO TO 20
   10 CONTINUE
      WRITE (6,906)
   20 CONTINUE
      ALPHVF = ALPHA * VFACT
      WRITE (6,911)
      IF ( PHYS ) WRITE (6,909) EMACH, DELTA
      WRITE (6,907) ALPHVF, AK
      DUBDEL=DUB*DELTA
      VOLDEL=VOL*DELTA
      IF (AK .GT. 0.0) WRITE(6,909) DUBDEL,VOLDEL
      IF ( PHYS ) WRITE(6,910)CPFACT,CDFACT,CMFACT,CLFACT,YFACT,VFACT
      CALL PRINT1
      CALL PRTMC
      CALL MACHMP
      IF ( ABORT ) GO TO 60
      CALL FIXPLT
      IF (BCTYPE .EQ. 1) GO TO 40
      IF (BCTYPE .EQ. 3) GO TO 40
      CALL PRTWAL
   40 CONTINUE
      CALL M1LINE
      IF (PRTFLO .EQ. 1) GO TO 50
      CALL PRTFLO
   50 CONTINUE
      CALL CDCOLE
   60 CONTINUE
      RETURN
C
  900 FORMAT(1H1,58X,18(1H*)/59X,1H*,16X,1H*/59X,18H*  FINAL OUTPUT  */
     1 59X,1H*,16X,1H*/59X,18(1H*))
  901 FORMAT(14H0 PRINTOUT IN ,2A4,A2,11H VARIABLES.)
  902 FORMAT(41H0 DEFINITION OF SIMILARITY PARAMETERS BY ,2A4)
  903 FORMAT(25H0 BOUNDARY CONDITION FOR ,3A4)
  904 FORMAT(27H0 DIFFERENCE EQUATIONS ARE ,7A4)
  905 FORMAT(37H0 LIFT COEFFICIENT SPECIFIED BY USER.)
  906 FORMAT(30H0 KUTTA CONDITION IS ENFORCED.)
  907 FORMAT(13X,7HALPHA =,F12.7/17X,3HK =,F12.7)
  908 FORMAT(2X,18HDOUBLET STRENGTH =,F12.7/4X,16HAIRFOIL VOLUME =,
     1 F12.7)
  909 FORMAT(14X,6HMACH =,F12.7/13X,7HDELTA =,F12.7)
  910 FORMAT(1H0,8X,38HPARAMETERS USED TO TRANSFORM VARIABLES/
     1     18X,20HTO TRANSONIC SCALING//12X,8HCPFACT =F12.7/
     2     12X,8HCDFACT =,F12.7/12X,8HCMFACT =,F12.7/12X,8HCLFACT =,F12.7
     3    /13X,7HYFACT =,F12.7/ 13X,7HVFACT =F12.7)
  911 FORMAT(1H0)

      END
```

```
      SUBROUTINE PRINT1
C                        PRINTS PRESSURE COEFFICIENT AND MACH NUMBER
C                        ON Y=0 LINE, AND PLOTS CP ALONG SIDE OF PRINT.
C                        CALLED BY - TSFOIL, PRINT.

      COMMON          P(102,101),X(100)  , Y(100)
      COMMON / COM1/  IMIN     , IMAX     , IUP      , IDOWN    , ILE     ,
     1                ITE      , JMIN     , JMAX     , JUP      , JLOW    ,
     2                JTOP     , JBOT
      LOGICAL         ABORT
      COMMON / COM3/  IREF     , ABORT    , ICUT     , KSTEP
      COMMON / COM7/  CJUP     , CJUP1    , CJLOW    , CJLOW1
      COMMON /COM13/  CDFACT   , CLFACT   , CMFACT   , CPFACT   , CPSTAR
      COMMON /COM25/  CPL(100) , CPU(100)
      LOGICAL         PHYS
      INTEGER         PRTFLO   , SIMDEF
      COMMON /COM27/  CL       , DELTA    , DELRT2   , EMACH    , EMROOT  ,
     1                PHYS     , PRTFLO   , SIMDEF   , SONVEL   , VFACT   ,
     2                YFACT
      COMMON /COM30/  EM1L(100), EM1U(100), YM(100), REST(104)

      REAL LIFT
      DIMENSION  LINE1(60)  , TMAC(2)

      DATA  TMAC / 2HM1, 2HK1/ , IB /1H /, IL / 1HL/,IU /1HU/, IS/1H*/
      DATA  IBB/ 1HB/
```

```
      CL = LIFT (CLFACT)
      CM = PITCH (CMFACT)
      CPMIN =  1.0E37
      CPMAX = -CPMIN
      IEM = 0
      CJ01 = -Y(JLOW)/(Y(JUP)-Y(JLOW))
      CJ02 = Y(JUP)/(Y(JUP)-Y(JLOW))

      DO 10 I=IMIN,IMAX
      UL       = CJLOW*PX(I,JLOW) - CJLOW1*PX(I,JLOW-1)
      IF(I .GT. ITE)  UL=CJ01*PX(I,JUP) + CJ02*PX(I,JLOW)
      IF(I .LT. ILE)  UL=CJ01*PX(I,JUP) + CJ02*PX(I,JLOW)
      CPL(I)   = -2.0 * UL * CPFACT
      EM1L(I) = EMACH1(UL)
      IF (EM1L(I) .GT. 1.3) IEM = 1
      UU       = CJUP *PX(I,JUP)  - CJUP1 *PX(I,JUP+1)
      IF (I .GT. ITE) UU = UL
      IF (I .LT. ILE) UU = UL
      CPU(I)   = -2.0 * UU * CPFACT
      EM1U(I) = EMACH1(UU)
      IF (EM1U(I) .GT. 1.3) IEM = 1
      CPMAX    = AMAX1(CPMAX,CPU(I), CPL(I))
      CPMIN    = AMIN1(CPMIN,CPU(I), CPL(I))
   10 CONTINUE

      CPLARG   = AMAX1(CPMAX,ABS(CPMIN))
      UNPCOL   = CPLARG / 29.

C                             LOCATE CP* FOR PRINTER PLOT

      COL            = -CPSTAR / UNPCOL
      NCOL           = SIGN((ABS(COL)+.5), COL)
      NCOLS          = NCOL + 30

C                             PRINT SINGLE VARIABLES

      IF (IREF .EQ. 2) WRITE (6,270)
      IF (IREF .EQ. 1) WRITE (6,280)
      IF (IREF .EQ. 0) WRITE (6,290)
      WRITE (6,260)
      WRITE (6,200) CL, CM, CPSTAR
      IF (CPL(IMIN) .LT. CPSTAR .AND. CPL(IMIN+1) .GT. CPSTAR) GO TO 70
      WRITE (6,210)
      KT = 2
      IF ( PHYS ) KT = 1

C                             PRINT COLUMN HEADERS.

      WRITE (6,220) TMAC(KT) , TMAC(KT)

      DO 40 I=IMIN,IMAX

      DO 30 K=1,60
      LINE1(K) = IB
   30 CONTINUE

      COL            = -CPU(I) / UNPCOL
      NCOL           =  SIGN((ABS(COL) + .5) , COL)
      NCOLU          =  NCOL + 30
      LINE1(NCOLU) =  IU

      COL            = -CPL(I) / UNPCOL
      NCOL           =  SIGN((ABS(COL) + .5) , COL)
      NCOLL          =  NCOL + 30
      LINE1(NCOLL) =  IL
      IF (NCOLL .EQ. NCOLU) LINE1(NCOLL) = IBB
      IF (IABS(NCOLS) .LT. 61) LINE1(NCOLS) = IS

      IF (I .EQ. ILE) WRITE (6,230)
      WRITE (6,250) I, X(I), CPL(I), EM1L(I), CPU(I), EM1U(I), LINE1
      IF (I .EQ. ITE) WRITE (6,240)

   40 CONTINUE
      IF ( IEM .EQ. 0 ) GO TO 50
      IF ( PHYS ) WRITE (6,300)
   50 CONTINUE
      DO 60 J=JMIN,JMAX
      YM(J) = Y(J) * YFACT
   60 CONTINUE
      WRITE (6,310) JMIN,JMAX,(YM(J),J=JMIN,JMAX)
      RETURN
   70 CONTINUE
      WRITE (6,320)
      ABORT = .TRUE.
      RETURN
```

```
  200 FORMAT(85X,28HB = BEFORE OR BEHIND AIRFOIL/10X,4HCL =,F10.6,61X,
     1 25HU = UPPER AIRFOIL SURFACE/10X,4HCM =,F10.6,61X,
     2 25HL = LOWER AIRFOIL SURFACE/9X,5HCP* =,F10.6,61X,
     3 21H* = CRITICAL PRESSURE)
  210 FORMAT(1H0,27X,5HLOWER,23X,5HUPPER/28X,4HY=0-,24X,4HY=0+)
  220 FORMAT(3X,1HI,8X,1HX,10X,2HCP,10X,A2,14X,2HCP,10X,A2/)
  230 FORMAT(25X,20HAIRFOIL LEADING EDGE,45X,20HAIRFOIL LEADING EDGE)
  240 FORMAT(25X,21HAIRFOIL TRAILING EDGE,44X,21HAIRFOIL TRAILING EDGE)
  250 FORMAT(1H ,I3,3F12.6,4X,2F12.6,2X,60A1)
  260 FORMAT(60H  FORCE COEFFICIENTS, PRESSURE COEFFICIENT, AND MACH NUM
     1BER /2X,59H(OR SIMILARITY PARAMETER) ON BODY AND DIVIDING STREAM L
     2INE.)
  270 FORMAT(1H1,52X,28HFINAL OUTPUT FOR COARSE MESH//)
  280 FORMAT(1H1,52X,28HFINAL OUTPUT FOR MEDIUM MESH//)
  290 FORMAT(1H1,53X,26HFINAL OUTPUT FOR FINE MESH//)
  300 FORMAT(20H0***** CAUTION *****/
     1 32H MAXIMUM MACH NUMBER EXCEEDS 1.3/
     2 69H SHOCK JUMPS IN ERROR IF UPSTREAM NORMAL MACH NUMBER GREATER T
     3HAN 1.3)
  310 FORMAT(///16X,13HY-GRID VALUES,5X,7HY(J) J=,I4,3H TO,I4/
     1 (10X,8F12.6))
  320 FORMAT(1H0,//,60H DETACHED SHOCK WAVE UPSTREAM OF X-MESH,SOLUTION
     1TERMINATED.)

        END
```

```
        SUBROUTINE PRTFLD
C
C                        PRINTS PRESSURE COEFFICIENT, FLOW ANGLE AND
C                        MACH NUMBER IN FLOW FIELD. NUMBER OF J LINES
C                        PRINTED IS DETERMINED FROM THE INPUT VALUE OF
C                        PRTFLO.
C                             PRTFLO = 1 , NONE.
C                             PRTFLO = 2 , ALL J LINES EXCEPT J0.
C                             PRTFLO = 3 , THREE J LINES AROUND JERROR.
C                       CALLED BY - PRINT.

      COMMON          P(102,101),X(100)   , Y(100)
      COMMON / COM1/  IMIN     , IMAX     , IUP      , IDOWN    , ILE     ,
     1                ITE      , JMIN     , JMAX     , JUP      , JLOW    ,
     2                JTOP     , JBOT
      COMMON /COM13/  CDFACT   , CLFACT   , CMFACT   , CPFACT   , CPSTAR
      LOGICAL         OUTERR
      COMMON /COM18/  ERROR    , I1       , I2       , IERROR   , JERROR  ,
     1                OUTERR   , EMU(100,2)          , VC(100) ,
     2                WI       , DCIRC    , POLD(100,2)
      LOGICAL         PHYS
      INTEGER         PRTFLO   , SIMDEF
      COMMON /COM27/  CL       , DELTA    , DELRT2   , EMACH    , EMROOT  ,
     1                PHYS     , PRTFLO   , SIMDEF   , SONVEL   , VFACT   ,
     2                YFACT
      COMMON /COM30/  JLIN(100), REST(304)

      DIMENSION  TMAC(2), CPPR(3), PYPR(3), YPRINT(3), PRT(10), EM1(3)
      DATA  TMAC / 2HM1, 2HK1/
      DATA  PRT  / 4HMACH,4H NUM,4HBERS,4H    ,4H    ,
     1            4HSIMI,4HLARI,4HTY P,4HARAM,4HETER/
      IF (PRTFLO.EQ. 2) GO TO 25
C                        LOCATE LINES AROUND JERROR.
      JL = 3
      IF (JERROR .EQ. JMIN) GO TO 10
      IF (JERROR .EQ. JLOW) GO TO 20
      IF (JERROR .EQ. JUP ) GO TO 10
      IF (JERROR .EQ. JMAX) GO TO 20
      JLIN(1) = JERROR - 1
      JLIN(2) = JERROR
      JLIN(3) = JERROR + 1
      GO TO 30
   10 CONTINUE
      JLIN(1) = JERROR
      JLIN(2) = JERROR + 1
      JLIN(3) = JERROR + 2
      GO TO 30
   20 CONTINUE
      JLIN(1) = JERROR - 2
      JLIN(2) = JERROR - 1
      JLIN(3) = JERROR
      GO TO 30
   25 CONTINUE
      JL = JMAX - JMIN + 1
C                        FILL JLIN ARRAY WITH VALUES OF J.
      K = 1
      DO 28 J=JMIN,JMAX
      JLIN(K) = J
      K = K + 1
   28 CONTINUE
   30 CONTINUE
C
C                        PRINT FLOW FIELD IN 3 J LINES PER PAGE.
      DO 100 MPR = 1,JL,3
      MPREND = MIN0(MPR+2,JL)
      DO  40 M=MPR,MPREND
      MQ = M-MPR+1
      JQ = JLIN(M)
      YPRINT(MQ) = Y(JQ)*YFACT
   40 CONTINUE
C                        WRITE PAGE HEADER.
      IS = 1
      IF ( PHYS ) IS = 6
      IE = IS + 4
      WRITE (6,900) (PRT(I),I=IS,IE) , CPSTAR
      WRITE(6, 901) (JLIN(M),M=MPR,MPREND)
      WRITE(6, 902)(YPRINT(M),M=1,MQ)
      KT = 2
      IF ( PHYS ) KT = 1
      WRITE (6,903) TMAC(KT), TMAC(KT), TMAC(KT)
      DO  60 I=IMIN,IMAX
      DO  50 M=MPR,MPREND
      MQ = M-MPR+1
      J = JLIN(M)
      U = PX(I,J)
      CPPR(MQ) = -2.0 * CPFACT * U
      PYPR(MQ) =  VFACT*PY(I,J)
      EM1(MQ)  = EMACH1(U)
   50 CONTINUE
      WRITE (6,904) (I,X(I),((CPPR(M),PYPR(M),EM1(M)),M=1,MQ))
   60 CONTINUE
  100 CONTINUE
      RETURN

  900 FORMAT(47H1PRESSURE COEFFICIENTS, FLOW ANGLES, AND LOCAL ,5A4/
     1        20H ON Y=CONSTANT LINES/9H CPSTAR =,F12.7//)
  901 FORMAT(13X,3(15X,2HJ=,I4,15X))
  902 FORMAT(13X,3(12X,2HY=,F10.6,12X))
  903 FORMAT(4H0  I,8X,1HX,5X,3(6X,2HCP,8X,5HTHETA,7X,A2,6X)//)
  904 FORMAT(1X,I3,2X,F10.6,1X,3(2X,3F11.6,1X))

      END
```

```
      SUBROUTINE PRTMC
C                        SUBROUTINE TO PRINT A CHARACTER FOR EACH
C                        POINT IN THE GRID DESCRIBING THE TYPE OF
C                        FLOW.   S , SHOCK POINT
C                                H , HYPERBOLIC POINT
C                                P , PARABOLIC POINT
C                                - , ELLIPTIC POINT
C                        CALLED BY - PRINT.

      COMMON          P(102,101),X(100)   , Y(100)
      COMMON / COM1/  IMIN     , IMAX     , IUP      , IDOWN    , ILE     ,
     1                ITE      , JMIN     , JMAX     , JUP      , JLOW    ,
     2                JTOP     , JBOT
      COMMON / COM2/  AK       , ALPHA    , DUB      , GAM1     , RTK
      COMMON /COM22/  CXC(100) , CXL(100), CXR(100), CXXC(100),CXXL(100),
     1                CXXR(100), C1(100)

      COMMON  /COM30/ IPC(100) , VT(100,2), REST(104)
      DATA  IHP/1HP/, IHH/1HH/, IHS/1HS/, IHD/1H-/, IB/1H /

      WRITE (6,100)
      DO 5 I=1,50,2
      IPC(I)   = IB
      IPC(I+1) = IB
    5 CONTINUE
      DO 10 J=JMIN,JMAX
      VT(J,1) = C1(2)
   10 CONTINUE
```

```
      DO 60 K=JMIN,JMAX
      J = JMAX - K + 1
      DO 50 I=IUP,IDOWN
      VT(J,2) = VT(J,1)
      VT(J,1) = C1(I)-(CXL(I)*P(J,I-1)+CXC(I)*P(J,I)+CXR(I)*P(J,I+1))
      IF (VT(J,1) .GT. 0.0) GO TO 30
      IF (VT(J,2) .LT. 0.0) GO TO 20
C                         PARABOLIC POINT   (SONIC)
      IPC(I) = IHP
      GO TO 50
   20 CONTINUE
C                         HYPERBOLIC POINT   (SUPERSONIC)
      IPC(I) = IHH
      GO TO 50
   30 CONTINUE
      IF (VT(J,2) .LT. 0.0) GO TO 40
C                         ELLIPTIC POINT  (SUBSONIC)
      IPC(I) = IHO
      GO TO 50
   40 CONTINUE
C                         SHOCK POINT
      IPC(I) = IHS
   50 CONTINUE
      WRITE (6,110) J, (IPC(I),I=IUP,IDOWN)
   60 CONTINUE
      RETURN

  100 FORMAT(1H1,56X,18HFLOW CHARACTER MAP/57X,18(1H*)//28X,
     1 13HP = PARABOLIC/28X,14HH = HYPERBOLIC/28X,9HS = SHOCK/28X,
     2 12H- = ELLIPTIC//)
  110 FORMAT(10X,I3,5X,100A1)

      END
```

```
      SUBROUTINE PRTSK(Z,ARG,L,NSHOCK,CDSK,LPRT1)
C                  PRINTOUT WAVE DRAG CONTRIBUTION AND TOTAL PRESSURE
C                  LOSS ALONG SHOCK WAVE
C                  CALLED BY - CDCOLE.

      COMMON / COM2/ AK        , ALPHA    , DUB      , GAM1     , RTK
      COMMON /COM13/ CDFACT    , CLFACT   , CMFACT   , CPFACT   , CPSTAR
      LOGICAL        PHYS
      INTEGER        PRTFLO    , SIMDEF
      COMMON /COM27/ CL        , DELTA    , DELRT2   , EMACH    , EMROOT   ,
     1               PHYS      , PRTFLO   , SIMDEF   , SONVEL   , VFACT    ,
     2               YFACT
      DIMENSION Z(1), ARG(1)
      CDYCOF = -CDFACT*GAM1/(6.*YFACT)
      POYCOF = DELTA*DELTA*GAM1*(GAM1-1.)/12.
      IF(NSHOCK .EQ.1) WRITE(6,1001)
      WRITE(6,1002) NSHOCK, CDSK
      DO 10 K = 1,L
      YY = Z(K)*YFACT
      CDY = CDYCOF*ARG(K)
      POY = 1. + POYCOF*ARG(K)
      WRITE(6,1003) YY,CDY,POY
 10   CONTINUE
      IF(LPRT1 .EQ. 1) WRITE(6,1004)
      RETURN
 1001 FORMAT(1H1,35X,43HSHOCK WAVE DRAG AND TOTAL PRESSURE PROFILE ,
     1 6HOUTPUT/36X,49(1H*)//39H INVISCID WAKE PROFILES FOR INDIVIDUAL ,
     2 35HSHOCK WAVES WITHIN MOMENTUM CONTOUR)
 1002 FORMAT(6HOSHOCK,I3/26H WAVE DRAG FOR THIS SHOCK=,F12.6/
     *   6X,1HY,9X,5HCD(Y),8X,8HPO/POINF/)
 1003 FORMAT(1X,3F12.8)
 1004 FORMAT(35HOSHOCK WAVE EXTENDS OUTSIDE CONTOUR/
     * 61H PRINTOUT OF SHOCK LOSSES ARE NOT AVAILABLE FOR REST OF SHOCK)
      END
```

```
      SUBROUTINE PRTWAL

C                        PRINTS PRESSURE COEFFICIENT AND FLOW ANGLE
C                        ON Y=-H AND Y=+H, AND PLOTS CP ALONG SIDE OF
C                        TABULATION.
C                        CALLED BY - PRINT.

      COMMON         P(102,101),X(100)  , Y(100)
      COMMON / COM1/ IMIN      , IMAX     , IUP      , IDOWN    , ILE      ,
     1               ITE       , JMIN     , JMAX     , JUP      , JLOW     ,
     2               JTOP      , JBOT
      COMMON / COM5/ XDIFF(100),YDIFF(100)
      COMMON /COM12/ F         , H        , HALFPI   , PI       , RTKPOR   ,
     1               TWOPI
      COMMON /COM13/ CDFACT    , CLFACT   , CMFACT   , CPFACT   , CPSTAR
      LOGICAL        PHYS
      INTEGER        PRTFLO    , SIMDEF
      COMMON /COM27/ CL        , DELTA    , DELRT2   , EMACH    , EMROOT   ,
     1               PHYS      , PRTFLO   , SIMDEF   , SONVEL   , VFACT    ,
     2               YFACT
      INTEGER        BCTYPE
      COMMON /COM28/ BCTYPE    , CIRCFF   , FHINV    , POR      , CIRCTE
      COMMON /COM30/ CPLW(100), CPUW(100), VLW(100), VUW(100), REST(4)

      DIMENSION  BCT(15) , LINE1(60)

      DATA   IB /1H /, IL / 1HL/, IU /1HU/, IS / 1H*/, IBB /1HB/
      DATA  BCT /4H    ,4HFREE,4H AIR,4H  SO,4HLID ,4HWALL,4H    ,
     1    4HFREE,4H JET,4HSLOT,4HTED ,4HWALL,4H POR,4HOUS ,4HWALL/

C                              PRINT SINGLE VARIABLES

      I2 = 3 * BCTYPE
      I1 = I2 - 2
      WRITE (6,903) (BCT(I),I=I1,I2)
      THH = H * YFACT
      WRITE(6,904) THH,H
      IF( BCTYPE .LT. 5 )  GO TO 4
      PORF = POR / YFACT
      WRITE(6,905) PORF,POR
    4 CONTINUE
      IF(  BCTYPE .NE. 4  .AND.  BCTYPE .NE. 6 )  GO TO 6
      WRITE (6,906) F
    6 CONTINUE
      WRITE (6,907) CPSTAR

      CPMIN =  1.0E37
      CPMAX = -CPMIN

      CPT = -2.0 * CPFACT
      DO 10 I=IUP,IDOWN
      CPLW(I) = CPT   * PX(I,JMIN)
      CPUW(I) = CPT   * PX(I,JMAX)
      CPMAX   = AMAX1(CPMAX,CPUW(I), CPLW(I))
      CPMIN   = AMIN1(CPMIN,CPUW(I), CPLW(I))
   10 CONTINUE
      DO 20 I=IUP,IDOWN
      IF (BCTYPE .NE. 2) GO TO 11
C                                     SOLID WALL
      VLW(I) = 0.0
      VUW(I) = 0.0
      GO TO 20
   11 CONTINUE
      IF (BCTYPE .NE. 3) GO TO 12
C                                     FREE JET
      VLW(I) = VFACT * PY(I,JMIN)
      VUW(I) = VFACT * PY(I,JMAX)
      GO TO 20
   12 CONTINUE
      IF (BCTYPE .NE. 4) GO TO 13
C                                     SLOTTED WALL
      VLW(I) =  VFACT * FHINV * (P(JBOT,I) + .75 * CIRCFF)
      VUW(I) = -VFACT * FHINV * (P(JTOP,I) - .25 * CIRCFF)
      GO TO 20
   13 CONTINUE
C                                     POROUS WALL
      IF (POR .GT. 1.5) GO TO 14
      VLW(I) =  VFACT * POR * XDIFF(I)*(P(JMIN,I)-P(JMIN,I-1))
      VUW(I) = -VFACT * POR * XDIFF(I)*(P(JMAX,I)-P(JMAX,I-1))
      GO TO 20
   14 CONTINUE
      VLW(I) = VFACT *.25*(P(JMIN+1,I+1)+2.*P(JMIN+1,I)+P(JMIN+1,I-1)
     1                    - P(JMIN  ,I+1)-2.*P(JMIN  ,I)-P(JMIN  ,I-1))
     2                    / (Y(JMIN+1)-Y(JMIN))
      VUW(I) = VFACT *.25*(P(JMAX,I+1)  +2.*P(JMAX,I)  +P(JMAX,I-1)
     1                    - P(JMAX-1,I+1)-2.*P(JMAX-1,I)-P(JMAX-1,I-1))
     2                    / (Y(JMAX)-Y(JMAX-1))
   20 CONTINUE

      CPLARG   = AMAX1(CPMAX,ABS(CPMIN))
      UNPCOL   = CPLARG / 29.

C                               LOCATE CP* FOR PRINTER PLOT

      COL             = -CPSTAR / UNPCOL
      NCOL            = SIGN((ABS(COL)+.5), COL)
      NCOLS           = NCOL + 30

      WRITE (6,210)

C                               PRINT COLUMN HEADERS.

      WRITE (6,220)

      DO 40 I=IUP,IDOWN

      DO 30 K=1,60
      LINE1(K) = IB
   30 CONTINUE

      COL             = -CPUW(I) / UNPCOL
      NCOL            =  SIGN((ABS(COL) + .5) , COL)
      NCOLU           =  NCUL + 30
      LINE1(NCOLU) =  IU

      COL             = -CPLW(I) / UNPCOL
      NCOL            =  SIGN((ABS(COL) + .5) , COL)
      NCOLL           =  NCOL + 30
      LINE1(NCOLL) =  IL
      IF ( NCOLL .EQ. NCOLU ) LINE1(NCOLL) = IBB
      IF (IABS(NCULS) .LT. 61) LINE1(NCOLS) = IS

      WRITE (6,250) I, X(I), CPLW(I), VLW(I), CPUW(I), VUW(I), LINE1
   40 CONTINUE
      RETURN

  210 FORMAT(1H0,27X,5HLOWER,23X,5HUPPER/28X,4HY=-H,24X,4HY=+H)
  220 FORMAT(3X,1HI,8X,1HX,10X,2HCP,9X,5HTHETA,12X,2HCP,9X,5HTHETA/)
  250 FORMAT(1H ,I3,3F12.6,4X,2F12.5,2X,60A1)
  903 FORMAT(2H1 ,3A4,20H BOUNDARY CONDITION.)
  904 FORMAT(1H0,10X,24HH (TUNNEL HALF HEIGHT) =,F9.6,15X,
     1 10HSCALED H =,F9.6)
  905 FORMAT(1H0,11X,23HPOR (POROSITY FACTOR) =,F9.6,13X,
     1 12HSCALED POR =,F9.6)
  906 FORMAT(1H0,14X,20HF (SLOT PARAMETER) =,F9.6)
  907 FORMAT(1H0,29X,5HCP* =,F9.6)

      END
```

```
      FUNCTION PX(I,J)
C                     FUNCTION PX COMPUTES U = DP/DX AT POINT I,J
C                     CALLED BY - CDCOLE, DRAG, FINDSK, MACHMP, M1LINE,
C                                 NEWSK,  PRINT1, PRTFLD, PRTWAL.

      COMMON          P(102,101),X(100)   , Y(100)
      COMMON / COM1/ IMIN      , IMAX     , IUP      , IDOWN    , ILE      ,
     1               ITE       , JMIN     , JMAX     , JUP      , JLOW     ,
     2               JTOP      , JBOT
      COMMON / COM5/ XDIFF(100),YDIFF(100)

C                     TEST TO LOCATE END POINTS
      IF(I .EQ. IMIN) GO TO 10
      IF(I .EQ. IMAX) GO TO 20
C                     INTERIOR MESH POINT
      PJI = P(J,I)
      PX = .5*(XDIFF(I+1)*(P(J,I+1)-PJI)  + XDIFF(I)*(PJI-P(J,I-1)))
      RETURN
 10   CONTINUE
C                     UPSTREAM BOUNDARY
      PX = 1.5*XDIFF(I+1)*(P(J,I+1)-P(J,I)) -
     1     0.5*XDIFF(I+2)*(P(J,I+2) - P(J,I+1))
      RETURN
 20   CONTINUE
C                     DOWNSTREAM BOUNDARY
      PX = 1.5*XDIFF(I)*(P(J,I) - P(J,I-1))
     1  -0.5*XDIFF(I-1)*(P(J,I-1) - P(J,I-2))
      RETURN
      END
```

```
      FUNCTION PY(I,J)
C                     FUNCTION PY COMPUTES V = DP/DY AT POINT I,J
C                     CALLED BY - CDCOLE, PRTFLD, PRTWAL.

      COMMON          P(102,101),X(100)   , Y(100)
      COMMON / COM1/ IMIN      , IMAX     , IUP      , IDOWN    , ILE      ,
     1               ITE       , JMIN     , JMAX     , JUP      , JLOW     ,
     2               JTOP      , JBOT
      COMMON / COM2/ AK        , ALPHA    , DUB      , GAM1     , RTK
      COMMON / COM5/ XDIFF(100),YDIFF(100)
      COMMON / COM6/ FL(100)   , FXL(100), FU(100) , FXU(100),
     1              CAMBER(100), THICK(100),VOL     , XFOIL(100), IFOIL
      COMMON /COM26/ PJUMP(100)
      INTEGER         BCTYPE
      COMMON /COM28/ BCTYPE    , CIRCFF   , FHINV    , POR      , CIRCTE

C                     TEST FOR END POINTS OR POINTS NEAR AIRFOIL SLIT
      IF(J .EQ. JMIN) GO TO 10
      IF(J .EQ. JLOW) GO TO 20
      IF(J .EQ. JUP ) GO TO 40
      IF(J .EQ. JMAX) GO TO 50
C                     I,J IS AN INTERIOR POINT
      PJI = P(J,I)
      PY = .5*(YDIFF(J+1)*(P(J+1,I)-PJI) + YDIFF(J)*(PJI-P(J-1,I)))
      RETURN
 10   CONTINUE
C                     I,J IS ON LOWER BOUNDARY. USE ONE SIDED DERIVATIVE
      PY = 1.5* YDIFF(J+1)*(P(J+1,I) - P(J,I)) -
     1     0.5* YDIFF(J+2)*(P(J+2,I) - P(J+1,I))
      RETURN
 20   CONTINUE
C                     I,J IS ON ROW OF MESH PIINTS BELOW AIRFOIL.

      VMINUS = YDIFF(J)*(P(J,I) - P(J-1,I))

C                     TEST TO SEE IF I,J IS AHEAD, UNDER, OR BEHIND SLIT.
      IF(I .LT. ILE) GO TO 21
      IF(I .GT. ITE) GO TO 22
C                     I,J IS UNDER AIRFOIL.  USE DERIVATIVE BOUNDARY
C                     CONDITION.
      IC = I - ILE + 1
      PY = .5 * (FXL(IC) - ALPHA + VMINUS)
      RETURN
 21   CONTINUE
C                            I,J IS AHEAD OF AIRFOIL.
      PY = .5*((P(JUP,I) - P(JLOW,I)) * YDIFF(JUP) + VMINUS)
      RETURN
 22   CONTINUE
C                       I,J IS BEHIND AIRFOIL
      PY = .5*((P(JUP,I) - PJUMP(I) - P(JLOW,I)) * YDIFF(JUP) + VMINUS)
      RETURN
 40   CONTINUE
C                     I,J IS ON ROW OF MESH POINTS ABOVE AIRFOIL
      VPLUS = YDIFF(J+1)*(P(J+1,I) - P(J,I))
C                     TEST TO SEE IF I IS AHEAD OF, OVER, OR BEHIND
C                     AIRFOIL SLIT.
      IF(I .LT. ILE) GO TO 41
      IF(I .GT. ITE) GO TO 42
      IC = I - ILE + 1
      PY = .5 * (VPLUS + FXU(IC) - ALPHA)
      RETURN
 41   CONTINUE
C                            I,J IS AHEAD OF AIRFOIL.
      PY = .5*((P(JUP,I) - P(JLOW,I)) * YDIFF(JUP) + VPLUS)
      RETURN
 42   CONTINUE
C                     I,J IS BEHIND AIRFOIL
      PY = .5*((P(JUP,I) - PJUMP(I) - P(JLOW,I)) * YDIFF(JUP) + VPLUS)
      RETURN
 50   CONTINUE
C                     I,J IS ON TOP ROW OF MESH POINTS. USE ONE SIDED
C                     FORMULA.
      PY = 1.5*YDIFF(J)*(P(J,I) - P(J-1,I))
     1  -  0.5*YDIFF(J-1)*(P(J-1,I) - P(J-2,I))

      RETURN
      END
      SUBROUTINE READIN

C                  CALLED BY - TSFOIL.

C                                INPUT EXPLANATION
C*************************************************************************
C
C         ALL INPUT IS READ IN THIS SUBROUTINE. THE ORDER IS AS DESCRIBED
C         BELOW.
C         1.) ONE CARD OF TITLE INFORMATION. AN +A+ (ALPHANUMERIC) FORMAT
C             IS USED TO READ AND WRITE THIS INFORMATION. MULTIPLE CASES
C             MAY BE RUN WITH THIS PROGRAM AND THE DATA FOR EACH CASE
C             MUST START WITH THIS CARD. THE LAST CARD OF THE INPUT MUST
C             BE A CARD WITH THE WORD +FINISHED+ IN THE FIRST 8 COLUMNS.
C
C         2.) NAMELIST CONTAINING THESE PARAMETERS IS NOW READ. (SEE
C             FORTRAN MANUAL FOR DESCRIPTION OF NAMELIST INPUT). THE
C             BLOCK DATA SUBROUTINE SETS A DEFAULT VALUE, AS NOTED BELOW,
C             FOR ALL OF THESE PARAMETERS.
C             ONLY THE VALUES WHICH ARE DIFFERENT FROM THE PREVIOUS CASE
C             (OR DEFAULT) MUST BE INCLUDED, ALTHOUGH AT LEAST ONE VALUE
C             MUST BE INPUT BY NAMELIST FOR EACH CASE.
C                              * (F) = FLOATING POINT *
C                              * (I) = INTEGER        *
C                              * (L) = LOGICAL        *
C                                                              DEFAULT
C                                                               VALUE
C                  AMESH  (L) OPTION FOR ANALYTICAL MESH CALC.      .F.
C                             .TRUE. X AND Y MESH VALUES ARE COMPUTED
C                                 ACCORDING TO AN ANALYTIC
C                                 FORMULATION. THE GRID USED IS
C                                 IMAX1=31,JMAX1=64, AND ALLOWS
C                                 FOR 1 MESH CUTS.
C                             .FALSE. X AND Y POINTS ARE THE DEFAULT
C                                    VALUES OR THE VALUES SUPPLIED
C                                    BY THE USER THRU NAMELIST.
C                  EMACH  (F) FREESTREAM MACH NUMBER.               .75
C                             NOTE****EMACH MAY NOT BE = 1.0
C                  DELTA  (F) BODY THICKNESS RATIO.                 .115
C                  ALPHA  (F) ANGLE OF ATTACK (DEGREES IF PHYS=T)   .12
C                  AK     (F) TRANSONIC SIMILARITY PARAMETER.       0.0
C                             (INPUT REQUIRED ONLY IF PHYS = .F. )
C                  GAM    (F) RATIO OF SPECIFIC HEATS.              1.4
C                  SIMDEF (I) SIMILARITY DEFINITION.                  3
C                             =1 COLE
C                             =2 SPREITER
C                             =3 KRUPP
C                             =4 USER
C                  PRTFLO (I)  OPTION FOR PRINT OF FINAL FLOW FIELD.  1
C                             =1  NO FLOW FIELD PRINT.
C                             =2  ALL J LINES PRINTED.
C                             =3 PRINT 3 J LINES AROUND MAXIMUM ERROR
C                  PSTART (I) OPTION FOR INITIALIZING P ARRAY.        1
C                             =1 SET TO ZERO.
C                             =2 READ P FROM UNIT 7
C                             =3 USE P IN CORE (PREVIOUS CASE).
C                  PSAVE  (L) OPTION FOR SAVING RESTART BLOCK OF    .F.
C                               VALUES ON UNIT 3.
C                             =.TRUE. SAVE FOR RESTART.
C                             =.FALSE. DO NOT SAVE.
C                  FCR    (L) FULLY CONSERVATIVE RELAXATION OPTION  .T.
C                             =.TRUE. DIFFERENCE EQUATIONS ARE
C                                     FULLY CONSERVATIVE FORM.
C                             =.FALSE. DIFFERENCE EQUATIONS NOT
C                                     CONSERVATIVE AT SHOCK WAVES.
C                  KUTTA  (L) KUTTA CONDITION OPTION.               .T.
C                             =.TRUE. KUTTA CONDITION IS ENFORCED
C                             =.FALSE. LIFT COEFFICIENT SPECIFIED
C                                     BY USER.
C                  CLSET  (F) LIFT COEFFICIENT, USED IF KUTTA       .0
C                             IS FALSE.
C                  BCFOIL (I) OPTION FOR FOIL OR BODY GEOMETRY.       3
C                             =1 NACA00XX
C                             =2 PARABOLIC ARC.
C                             =3 ORDINATES (READ LATER IN NAMELIST
C                                IF DIFFERENT FROM DEFAULT VALUES WHICH
C                                ARE FOR THE KORN AIRFOIL).
C                             =4 USER OPTION.
C                  BCTYPE (I) DESCRIBES THE TYPE OF FLOW TO BE        1
C                             COMPUTED.
C                             =1 FREE AIR.
C                             =2 SOLID WALL.
C                             =3 FREE JET.
C                             =4 SLOTTED WALL.
C                             =5 POROUS WALL.
C                  F      (F) TUNNEL SLOT PARAMETER.                0.
C                  H      (F) TUNNEL HALF HEIGHT/CHORD RATIO.       0.
C                  POR    (F) WALL POROSITY FACTOR.                 .0
C                  PHYS   (L) TYPE OF SCALING TO USE FOR I/O.       .T.
C                             =.TRUE. PHYSICALLY SCALED VALUES.
C                             =.FALSE. TRANSONICALLY SCALED VALUES
C                             FOR PHYS = .F. , ALSO INPUT VALUE FOR AK.
C                  IMAXI  (I) NUMBER OF X-MESH POINTS(.LE. 100)     77
C                  JMAXI  (I) NUMBER OF Y-MESH POINTS(.LE. 100)     56
C                  IMIN   (I) X MESH POINT WHERE CALC IS TO START     1
C                  JMIN   (I) Y MESH POINT WHERE'CALC IS TO START     1
C                  ICUT   (I) CONTROL FOR MESH CUT AND REFINEMENT.    2
C                             = 0  INPUT MESH IS USED TO CONVERGENCE.
C                             = 1  INPUT MESH MAY BE CUT ONCE.
C                             = 2  INPUT MESH MAY BE CUT TWICE.
C                  WE      (F)  3 VALUES FOR RELAXATION FACTOR FOR 1.8
C                               ELIPTIC PTS. 1-ST FOR COARSE MESH, 1.9
C                               2-ND FOR MED. MESH AND 3-RD FOR    1.95
C                               FINE MESH. DEFAULT VALUES ARE SUGGESTED
C                              VALUES, IN ORDER. IF SPECIFIED IN INPUT
C                              ALL THREE VALUES MUST BE GIVEN.
C                  WCIRC  (F) RELAXATION FACTOR FOR CIRCULATION.    1.0
C                  MAXIT   (I) MAXIMUM NUMBER OF ITERATION CYCLES  500
C                             ALLOWED.
C                  CVERGE (F) CONVERGENCE CRITERION FOR RESIDUALS .00001
C                             OF P.
C                  DVERGE (F) DIVERGENCE CRITERION FOR RESIDUALS    10.
C                             OF P.
C                  RIGF   (F) REIGLES RULE FOR BODY SLOPE.          0.0
C                  EPS     (F) COEFFICIENT OF PXT                   .2
C                  IPRTER (I) CONTROL FOR FREQUENCY OF PRINT OF      10
C                             LINE IN MESH WHERE ERROR IS LARGEST.
C                             I.E. IPRTER=10 , LINE WILL BE PRINTED
C                                  EVERY 10-TH ITERATION.
C
C NOTE***** WHEN ARRAYS ARE READ BY NAMELIST THE FULL ARRAY MUST BE
C           SET, I.E. IF ALL VALUES ARE NOT REQUIRED THE ARRAY MAY
C           BE FILLED USING MULTIPLE ZEROS. (N*0.0)
C                  XU      (F) ARRAY - X VALUES FOR UPPER BODY. USED
C                              IF BCFOIL = 3. KORN AIRFOIL USING ALL
C                              100 PTS.(UPPER) AND 75 (LOWER) IS DEFAULT.
C                  XL      (F) ARRAY - X VALUES FOR LOWER BODY.
C                  YU      (F) ARRAY - Y VALUES FOR UPPER BODY.
C                  YL      (F) ARRAY - Y VALUES FOR LOWER BODY.
C                  NU      (I) NUMBER OF POINTS TO USE FOR UPPER BODY 100
C                  NL      (I) NUMBER OF POINTS TO USE FOR LOWER BODY  75

C****** NOTE THIS PROGRAM USES A MESH REFINEMENT METHOD FOR DECREASING
C           COMPUTER TIME. FOLLOW THE RULES BELOW FOR CONSTRUCTING THE
C           X AND Y MESH TO TAKE FULL ADVANTAGE OF THIS FEATURE.
C                   IMAXI - ITE    SHOULD BE A MULTIPLE OF 4.
C                   ITE   - IMIN   SHOULD BE A MULTIPLE OF 4.
C                   JMAXI - JUP  + 1 SHOULD BE A MULTIPLE OF 4
C                   JLOW  - JMIN + 1 SHOULD BE A MULTIPLE OF 4
C                          (WHERE JLOW IS LAST POINT BELOW SLIT AND
C                                 JUP IS FIRST POINT ABOVE SLIT.)
C             WHERE ITE = I FOR X = 1.0 (OR POINT ON BODY CLOSEST TO
C                                     X = 1.0).
C           SUBROUTINE CKMESH INSPECTS THE X AND Y MESHES TO SEE IF
C           THIS IS TRUE AND, IF NOT, WILL MODIFY INPUT MESH IN SOME
C           CASES.

C                  XIN     (F) ARRAY - X MESH POINTS. LIMIT 100 PTS.
C                  YIN     (F) ARRAY - Y MESH POINTS. LIMIT 100 PTS.
C                              X AND Y MESH DEFAULT VALUES ARE KRUPP
C                                     BASIC GRID.
      COMMON          P(102,101),X(100)  , Y(100)
      COMMON / COM1/  IMIN     , IMAX    , IUP     , IDOWN   , ILE     ,
     1                ITE      , JMIN    , JMAX    , JUP     , JLOW    ,
     2                JTOP     , JBOT
      COMMON / COM2/  AK       , ALPHA   , DUB     , GAM1    , RTK
      LOGICAL         ABORT
      COMMON / COM3/  IREF     , ABORT   , ICUT    , KSTEP
      LOGICAL         AMESH
      COMMON / COM4/  XIN(100) , YIN(100), AMESH
      COMMON / COM8/  CVERGE   , DVERGE  , IPRTER  , MAXIT   ,
     1                WE(3)    , EPS
      INTEGER         BCFOIL
      COMMON / COM9/  BCFOIL   , NL      , NU      , XL(100) , XU(100) ,
     1                YL(100)  , YU(100) , RIGF
      LOGICAL XGRDIN,YGRDIN
      COMMON /COM10/  YFREE(100) , YTUN(100)  , XKRUPP(100) , GAM      ,
     1                JMXF     , JMXT    , XGRDIN  , YGRDIN
      INTEGER         PSTART
      LOGICAL         PSAVE
      COMMON /COM11/ ALPHAO   , CLOLD   , DELTAO  , DUBO    , EMACHO  ,
     1               IMINO    , IMAXO   , IMAXI   , JMINO   , JMAXO   ,
     2               JMAXI    , PSAVE   , PSTART  , TITLE(8), TITLEO(8),
     3               VOLO     , XOLD(100),YOLD(100)
      COMMON /COM12/ F        , H       , HALFPI  , PI      , RTKPOR  ,
     1               TWOPI
      LOGICAL        FCR      , KUTTA
      COMMON /COM14/ CLSET    , FCR     , KUTTA   , WCIRC
      LOGICAL        PHYS
      INTEGER        PRTFLO   , SIMDEF
      COMMON /COM27/ CL       , DELTA   , DELRT2  , EMACH   , EMROOT  ,
     1               PHYS     , PRTFLO  , SIMDEF  , SONVEL  , VFACT   ,
     2               YFACT
      INTEGER        BCTYPE
      COMMON /COM28/ BCTYPE   , CIRCFF  , FHINV   , POR     , CIRCTE

      DATA  DONE /8HFINISHED  /
      DATA   IFIRST /0/
      NAMELIST /INP/ AK     , ALPHA  , AMESH  , BCFOIL , BCTYPE , CLSET,
     1               CVERGE , DELTA  , DVERGE , EMACH  , EPS    , F     ,
     2               FCR    , GAM    , H      , ICUT   , IMAXI  , IMIN  ,
     3               IPRTER , JMAXI  , JMIN   , KUTTA  , MAXIT  , NL    ,
     4               NU     , PHYS   , POR    , PRTFLO , PSAVE  ,
     5               PSTART , RIGF   , SIMDEF , WCIRC  , WE     ,
     6               XIN    , YIN    , XL     , YL     , XU     , YU    ,
     7               XGRDIN , YGRDIN
    5 CONTINUE
      IF (IFIRST .NE. 0) GO TO 2
      IFIRST = 1
      CALL SECOND (TIME2)
    2 CONTINUE
      TIME1 = TIME2
      CALL SECOND (TIME2)
      ELPTM = TIME2 - TIME1
      IF (ELPTM .LT. .01) GO TO 3
     .WRITE (6,930) ELPTM
    3 CONTINUE
      READ (5,900) TITLE
      WRITE(6,901) TITLE
      IF (TITLE(1) .NE. DONE) GO TO 10
      WRITE(6,904)
      STOP
   10 CONTINUE
      READ (5,INP)
      IF (PSTART .NE. 3) GO TO 13
C                           TEST TO SEE IF P ARRAY IN CORE IS USEABLE.
      IF ( .NOT. ABORT) GO TO 13
      WRITE (6,905)
      GO TO 5
   13 CONTINUE
      IF ( PHYS ) AK = 0.0
      IF ( .NOT. AMESH ) GO TO 14
      CALL AYMESH
      GO TO 22
   14 CONTINUE
      IF (YGRDIN) GO TO 18
C                           IF YIN NOT READ IN NAMELIST, FILL YIN BY
C                           DEFAULT VALUE FOR TUNNEL OR FREE AIR CASE.
      IF (BCTYPE .NE. 1) GO TO 16
      JMAXI = JMXF
      DO 15 J=JMIN,JMAXI
      YIN(J) = YFREE(J)
   15 CONTINUE
      GO TO 18
   16 CONTINUE
      JMAXI = JMXT
      DO 17 J=JMIN,JMAXI
      YIN(J) = YTUN(J)
   17 CONTINUE
   18 CONTINUE
      IF (XGRDIN) GO TO 22
      DO 21 I=IMIN,IMAXI
   21 XIN(I)=XKRUPP(I)
   22 CONTINUE
      WRITE (6,921)
C
      WRITE (6,906) EMACH, POR, IMIN, BCTYPE, AMESH
      WRITE (6,907) DELTA, CLSET, IMAXI, BCFOIL, PHYS
      WRITE (6,908) ALPHA, EPS  , JMIN , PSTART, PSAVE
      WRITE (6,909) AK   , RIGF , JMAXI, PRTFLO, KUTTA
      WRITE (6,910) GAM, WCIRC, MAXIT, IPRTER, FCR
      WRITE (6,911) F, CVERGE, NU, SIMDEF
      WRITE (6,912) H, DVERGE, NL, ICUT
      WRITE (6,920) WE
      WRITE (6,913)
      WRITE (6,919) (XIN(I),I=IMIN,IMAXI)
```

```
      WRITE (6,914)
      WRITE (6,919) (YIN(J),J=JMIN,JMAXI)
      IF (BCFOIL .LE. 2) GO TO 19
      WRITE (6,915)
      WRITE (6,919) (XU(I),I=1,NU)
      WRITE (6,916)
      WRITE (6,919) (YU(I),I=1,NU)
      WRITE (6,917)
      WRITE (6,919) (XL(I),I=1,NL)
      WRITE (6,918)
      WRITE (6,919) (YL(I),I=1,NL)
   19 CONTINUE
      GAM1 = GAM + 1.0
      IREF = 0
      IMAX = IMAXI
      JMAX = JMAXI
      IM1  = IMAX - 1
      JM1  = JMAX - 1
      IF (IMAXI .GT. 100 .OR.  JMAXI .GT. 100) CALL INPERR (1)
C                           ANY CALL TO INPERR CAUSES A MESSAGE TO BE
C                           PRINTED AND EXECUTION IS STOPPED.

C                           CHECK INPUT MESH FOR MONOTONICALLY INCREASING
C                           VALUES.
      DO 20 I=IMIN,IM1
      IF (XIN(I) .GE. XIN(I+1)) CALL INPERR (2)
   20 CONTINUE

      DO 30 J=JMIN,JM1
      IF (YIN(J) .GE. YIN(J+1)) CALL INPERR (3)
   30 CONTINUE

      IF (EMACH .LT.    .5 .OR. EMACH .GT.  2.0) CALL INPERR (4)
      IF (ALPHA .LT. -9.0  .OR. ALPHA .GT. 9.0 ) CALL INPERR (5)
      IF (DELTA .LT.   0.0 .OR. DELTA .GT.  1.0) CALL INPERR (6)


C                           COMPUTE ILE AND ITE (LEADING AND TRAILING EDGE)

      CALL ISLIT ( XIN )

C                           COMPUTE JLOW AND JUP (LOCATION OF BODY SLIT)

      CALL JSLIT ( YIN )

C
C                           CHECK NUMBER OF MESH POINTS, IF NOT ODD ADD
C                           POINTS TO APPROPRIATE AREAS TO MAKE ODD NO.
C
      CALL CKMESH

C                           CHECK BOUNDS OF YMESH FOR TUNNEL CALCULATIONS.
      IF (BCTYPE .EQ. 1) GO TO 90
      HTM = H - .00001
      HTP = H + .00001
      YS  = ABS(YIN(JMIN))
      YE  = ABS(YIN(JMAX))
      IF (YS .LT. HTM .OR. YS .GT. HTP) GO TO 40
      IF (YE .GE. HTM .AND. YE .LE. HTP) GO TO 90
   40 CONTINUE
C                           RESCALE Y MESH TO -H,+H BOUNDS.
      TERM = -H / YIN(JMIN)
      DO 45 J=JMIN,JLOW
      YIN(J) = TERM * YIN(J)
   45 CONTINUE
      TERM = H / YIN(JMAX)
      DO 50 J=JUP,JMAX
      YIN(J) = TERM * YIN(J)
   50 CONTINUE

   90 CONTINUE
C                           IF PSTART = 2 READ OLD VALUES FROM TAPE 7.
      IF (PSTART .NE. 2) GO TO 100

      REWIND 7
      READ (7,900) TITLEO
      READ  (7,902) IMAXO, JMAXO, IMINO, JMINO
      READ  (7,903) CLOLD, EMACHO, ALPHAO, DELTAO, VOLO, DUBO
      READ (7,903) (XOLD(I),I=IMINO,IMAXO)
      READ (7,903) (YOLD(J),J=JMINO,JMAXO)
      DO 60 I=IMINO,IMAXO
      READ (7,903) (P(J,I), J=JMINO,JMAXO)
   60 CONTINUE
      WRITE(6,1000) TITLEO, IMINO,IMAXO,JMINO,JMAXO,CLOLD,EMACHO,
     1               ALPHAO,DELTAO,VOLO, DUBO
```

```
100 CONTINUE
    RETURN

900 FORMAT(8A10)
901 FORMAT(1H1,23X,8A10)
902 FORMAT(4I5)
903 FORMAT(8F10.6)
904 FORMAT(1H1)
905 FORMAT(21H0 CALCULATION ABORTED//
   1  43H OUTPUT OF PREVIOUS SOLUTION NOT AVAILABLE.)
906 FORMAT(1H0,12X,7HEMACH =,F9.5,8X,5HPOR =,F9.5,7X,6HIMIN =,I5,
   1     5X,8HBCTYPE =,I3,9X,8HAMESH = ,L1)
907 FORMAT(1HG,12X,7HDELTA =,F9.5,6X,7HCLSET =,F9.5,6X,7HIMAXI =,I5,
   1     5X,8HBCFOIL =,I3,10X,7HPHYS = ,L1)
908 FORMAT(1H0,12X,7HALPHA =,F9.5,8X,5HEPS =,F9.5,7X,6HJMIN =,I5,
   1     5X,8HPSTART =,I3,9X,8HPSAVE = ,L1)
909 FORMAT(1H0,15X,4HAK =,F9.5,7X,6HRIGF =,F9.5,6X,7HJMAXI =,I5,
   1     5X,8HPRTFLO =,I3,9X,8HKUTTA = ,L1)
910 FORMAT(1H0,14X,5HGAM =,F9.5,6X,7HWCIRC =,F9.5,6X,7HMAXIT =,I5,
   1     5X,8HIPRTER =,I3,11X,6HFCR = ,L1)
911 FORMAT(1HC,16X,3HF =,F9.5,5X,8HCVERGE =,F9.5,9X,4HNU =,I5,
   1     5X,6HSIMDEF =,I3)
912 FORMAT(1H0,16X,3HH =,F9.5,5X,8HDVERGE =,F9.1,9X,4HNL =,I5,
   1     7X,6HICUT =,I3)
913 FORMAT(1H0,14X,3HXIN)
914 FORMAT(1HC,14X,3HYIN)
915 FORMAT(1HG,15X,2HXU)
916 FORMAT(1H0,15X,2HYU)
917 FORMAT(1H0,15X,2HXL)
918 FORMAT(1H0,15X,2HYL)
919 FORMAT(10X,8F13.6)
920 FORMAT(1H0,15X,5HWE = ,F4.2,2(1H,F4.2))
921 FORMAT(/////58X,16HINPUT PARAMETERS/58X,16(1H*)/)
930 FORMAT(22H1TIME TO RUN CASE WAS ,F6.2,9H SECONDS.)
1000 FORMAT(39H1P INITIALIZED FROM PREVIOUS RUN TITLED/
   1        1X,8A10/31H WHICH HAD THE FOLLOWING VALUES/
   1        8H IMIN  =,I4/8H IMAX  =,I4/8H JMIN  =,I4/8H JMAX  =,I4/
   1        8H CL    =,F12.8/8H EMACH =,F12.8/8H ALPHA =,F12.8/
   1        8H DELTA =,F12.8/8H VOL   =,F12.8/8H DUB   =,F12.8/)

     END
```

```
      SUBROUTINE RECIRC
C                 SUBROUTINE RECIRC COMPUTES THE FOLLOWING
C                 1.) JUMP IN P AT TRAILING EDGE = CIRCTE
C                 2.) CIRCULATION FOR FARFIELD BOUNDARY = CIRCFF
C                 3.) JUMP IN P ALONG SLIT Y=0, X .GT.1 BY LINEAR
C                     INTERPOLATION BETWEEN CIRCTE AND CIRCFF
C                 4.) P(JO,ITE) AND P(JO, ITE-1)
C                 CALLED BY - SOLVE.

      COMMON          P(102,101),X(100)  , Y(100)
      COMMON / COM1/ IMIN     , IMAX    , IUP     , IDOWN   , ILE     ,
     1               ITE      , JMIN    , JMAX    , JUP     , JLOW    ,
     2               JTOP     , JBOT
      COMMON / COM2/ AK       , ALPHA   , DUB     , GAM1    , RTK
      COMMON / COM7/ CJUP     , CJUP1   , CJLOW   , CJLOW1
      COMMON /COM13/ CDFACT   , CLFACT  , CMFACT  , CPFACT  , CPSTAR
      LOGICAL        FCR      , KUTTA
      COMMON /COM14/ CLSET    , FCR     , KUTTA   , WCIRC
      LOGICAL        OUTERR
      COMMON /COM18/ ERROR    , I1      , I2      , IERROR  , JERROR  ,
     1               OUTERR   , EMU(100,2)        , VC(100) ,
     2               WI       , DCIRC   , POLD(100,2)
      COMMON /COM22/ CXC(100) , CXL(100), CXR(100), CXXC(100),CXXL(100),
     1               CXXR(100), C1(100)
      COMMON /COM26/ PJUMP(100)
      INTEGER        BCTYPE
      COMMON /COM28/ BCTYPE   , CIRCFF  , FHINV   , POR     , CIRCTE

C                 COMPUTE JUMP IN POTENTIAL AT TRAILING EDGE

      CTEOLD=CIRCTE
      PUP = CJUP*P(JUP,ITE) - CJUP1*P(JUP+1,ITE)
      PLOW = CJLOW*P(JLOW,ITE) - CJLOW1*P(JLOW-1,ITE)
      CIRCTE = PUP - PLOW
C                 COMPUTE FAR FIELD CIRCULATION
      CIRCO = CIRCFF
      IF(KUTTA) CIRCFF = (1.-WCIRC)*CIRCO + CIRCTE*WCIRC
      IF(.NOT. KUTTA) CIRCFF = .5*CLSET/CLFACT
C                 FIX JUMP IN P AT AIRFOIL TRAILING EDGE IF KUTTA=.F.
C                 AND LIFT OF AIRFOIL EXCEEDS CLSET.  THIS TREATMENT
C                 ASSUMES  THAT CL IS INCREASING FROM BELOW CLSET OR
C                 IS NOT TOU MUCH ABOVE CLSET TO START CALCULATION.

      IF ( .NOT. KUTTA) CIRCTE = CIRCFF
      DCIRC=CIRCTE-CTEOLD

C                 SET JUMP IN P ALONG Y = 0, X .OT. 1
      FACTOR = (CIRCFF - CIRCTE)/(X(IMAX) - 1.)
      DO 35 I = ITE,IMAX
      PJUMP(I) = CIRCTE + (X(I) - 1.) * FACTOR
 35   CONTINUE

      RETURN
      END
```

```
      SUBROUTINE REDUB
C                 SUBROUTINE REDUB COMPUTES DOUBLET STRENGTH
C                 FOR LIFTING FREE AIR FLOWS, DOUBLET STRENGTH IS SET
C                 EQUAL TO MODEL VOLUME.  FOR OTHER FLOWS, THE NON
C                 LINEAR CONTRIBUTION IS ADDED.
C                 CALLED BY - SOLVE.

      COMMON          P(102,101),X(100)  , Y(100)
      COMMON / COM1/ IMIN     , IMAX    , IUP     , IDOWN   , ILE     ,
     1               ITE      , JMIN    , JMAX    , JUP     , JLOW    ,
     2               JTOP     , JBOT
      COMMON / COM2/ AK       , ALPHA   , DUB     , GAM1    , RTK
      COMMON / COM5/ XDIFF(100),YDIFF(100)
      COMMON / COM6/ FL(100)  , FXL(100), FU(100) , FXU(100),
     1              CAMBER(100), THICK(100),VOL   , XFOIL(100), IFOIL
      INTEGER        BCTYPE
      COMMON /COM28/ BCTYPE   , CIRCFF  , FHINV   , POR     , CIRCTE
      COMMON /COM30/ XI(100)  , ARG(100)  , REST(204)

      IF(BCTYPE .NE. 1) GO TO 10
      IF(BCTYPE .EQ. 1 .AND. ABS(CIRCFF) .LT. .0001) GO TO 10
      DUB = VOL
      RETURN
 10   CONTINUE
C
C                 COMPUTE  DOUBLE INTEGRAL OF U*U OVER MESH DOMAIN FOR
C                 DOUBLET STRENGTH
C                 U = PX IS CENTERED MIDWAY BETWEEN X MESH POINTS.
C                 FIRST THE INTEGRAL (PX**2)DY IS CALCULATED FOR X
C                 HELD CONSTANT. THUS 1./(X(I+1)-X(I))**2 MAY BE
C                 PULLED OUT OF THE INTEGRAL WHICH IS CALCULATED BY
C                 THE TRAPEZOIDAL RULE. THE X INTEGRATION CORRESPONDS
C                 TO SUMMING THESE INTEGRALS, WHICH LIE MIDWAY BETWEEN
C                 X MESH POINTS, USING A MODIFIED TRAPEZODIAL RULE.
C
      IEND = IMAX - 1
      DBLSUM = 0.
      DO 50 I=IMIN,IEND
      NARG = 0
      DO 30 J = JMIN, JMAX
      NARG = NARG + 1
      TEMP = P(J,I+1) - P(J,I)
      ARG(NARG) = TEMP * TEMP
      XI(NARG) = Y(J)
 30   CONTINUE
      CALL TRAP(XI,ARG,NARG,SUM)
      DBLSUM = DBLSUM + SUM * XDIFF(I+1)
 50   CONTINUE
      DBLSUM = GAM1*.25*DBLSUM
      DUB = VOL + DBLSUM
      RETURN
      END
      SUBROUTINE REFINE
C                        ROUTINE TO EXPAND THE X-MESH AND Y-MESH TO
C                        DOUBLE THE NUMBER OF POINTS IN EACH. WILL HAVE
C                        TO BE CALLED TWICE IF MESH WAS HALVED TWICE.
C                        THE P(J,I) MESH IS ALSO FILLED BY
C                        INTERPOLATION.
C                        CALLED BY - TSFOIL.

      COMMON          P(102,101),X(100)  , Y(100)
      COMMON / COM1/ IMIN     , IMAX    , IUP     , IDOWN   , ILE     ,
     1               ITE      , JMIN    , JMAX    , JUP     , JLOW    ,
     2               JTOP     , JBOT
      LOGICAL        ABORT
      COMMON / COM3/ IREF     , ABORT   , ICUT    , KSTEP
      LOGICAL        AMESH
      COMMON / COM4/ XIN(100) , YIN(100), AMESH
      COMMON /COM20/ XMID(100), YMID(100)
      INTEGER        BCTYPE
      COMMON /COM28/ BCTYPE   , CIRCFF  , FHINV   , POR     , CIRCTE
      COMMON /COM30/ PT(100)  , REST(304)

      JMAXO = JMAX
      IMAX = 2 * (IMAX - IMIN) + IMIN
      JMAX = 2 * (JMAX - JMIN) + JMIN + 1
      IM2  = IMAX - 2
      JM2  = JMAX - 2
      IF (IREF .GT. 1) GO TO 30
      DO 10 I=IMIN,IMAX
      X(I) = XIN(I)
   10 CONTINUE
      DO 20 J=JMIN,JMAX
      Y(J) = YIN(J)
   20 CONTINUE
      IREF = 0
      GO TO 60
   30 CONTINUE
      DO 40 I=IMIN,IMAX
      X(I) = XMID(I)
   40 CONTINUE
      DO 50 J=JMIN,JMAX
      Y(J) = YMID(J)
   50 CONTINUE
      IREF = 1
   60 CONTINUE
      CALL ISLIT ( X )
      CALL JSLIT ( Y )
C                        SPREAD P(J,I) TO ALTERNATE I(X-MESH) POINTS.
      DO 90 J=JMIN,JMAXO
      K = IMIN - 1
      DO 70 I=IMIN,IMAX,2
      K = K + 1
      PT(I) = P(J,K)
   70 CONTINUE
      DO 80 I=IMIN,IMAX,2
      P(J,I) = PT(I)
   80 CONTINUE
   90 CONTINUE
C                        SPREAD P(J,I) TO ALTERNATE J (Y-MESH) POINTS.
      DO 130 I=IMIN,IMAX,2
      K = JMIN - 1
      JE = JLOW - 1
      JL = JLOW - 2
      DO 95 J=JMIN,JE, 2
      K = K + 1
      PT(J) = P(K,I)
   95 CONTINUE
      JST = JUP + 1
      DO 100 J=JST,JMAX,2
      K = K + 1
      PT(J) = P(K,I)
  100 CONTINUE
      DO 110 J=JMIN,JE,2
      P(J,I) = PT(J)
  110 CONTINUE
      DO 120 J=JST,JMAX,2
      P(J,I) = PT(J)
  120 CONTINUE
  130 CONTINUE
C                        INTERPOLATE TO FILL IN THE MISSING P VALUES.
      DO 140 I=IMIN,IM2
      PT(I) = (X(I+1)-X(I)) / (X(I+2)-X(I))
  140 CONTINUE
      DO 150 J=JMIN,JE,2
      DO 145 I=IMIN,IM2,2
      P(J,I+1) = P(J,I) + PT(I) * (P(J,I+2) - P(J,I))
  145 CONTINUE
  150 CONTINUE
      DO 160 J=JST,JMAX,2
      DO 155 I=IMIN,IM2,2
      P(J,I+1) = P(J,I) + PT(I) * (P(J,I+2) - P(J,I))
  155 CONTINUE
  160 CONTINUE
      DO 170 J=JMIN,JM2
      PT(J) = (Y(J+1)-Y(J)) / (Y(J+2)-Y(J))
  170 CONTINUE
      DO 190 I=IMIN,IMAX
      DO 175 J=JMIN,JL,2
      P(J+1,I) = P(J,I) + PT(J) * (P(J+2,I) - P(J,I))
  175 CONTINUE
      DO 180 J=JST,JM2,2
      P(J+1,I) = P(J,I) + PT(J) * (P(J+2,I) - P(J,I))
  180 CONTINUE
  190 CONTINUE
C                  USE EXTRAPOLATION FOR JLOW,JUP
      D1 = Y(JLOW) - Y(JLOW-1)
      D2 = Y(JLOW-1) - Y(JLOW-2)
      CL1 = (D1 + D2) / D2
      CL2 = D1/D2
      D1 = Y(JUP+1) - Y(JUP)
      D2 = Y(JUP+2) - Y(JUP+1)
      CU1 = (D1 + D2) / D2
      CU2 = D1 / D2
      DO 200 I = IMIN,IMAX
      P(JUP,I) = CU1*P(JUP+1,I) - CU2*P(JUP+2,I)
      P(JLOW,I) = CL1*P(JLOW-1,I) - CL2*P(JLOW-2,I)
 200  CONTINUE
      RETURN
      END
```

```
      SUBROUTINE RESET
C                  SUBROUTINE RESET  UPDATES FAR FIELD BOUNDARY
C                  CONDITIONS FOR SUBSONIC FREESTREAM FLOWS.
C                  CALLED BY - SOLVE.

      COMMON          P(102,101),X(100)  , Y(100)
      COMMON / COM1/ IMIN     , IMAX    , IUP     , IDOWN   , ILE     ,
     1               ITE      , JMIN    , JMAX    , JUP     , JLOW    ,
     2               JTOP     , JBOT
      COMMON / COM2/ AK       , ALPHA   , DUB     , GAM1    , RTK
      LOGICAL        ABORT
      COMMON / COM3/ IREF     , ABORT   , ICUT    , KSTEP
      COMMON /COM24/ DTOP(100), DBOT(100),DUP(100), DDOWN(100),
     1               VTOP(100), VBOT(100),VUP(100), VDOWN(100)
      INTEGER        BCTYPE
      COMMON /COM28/ BCTYPE   , CIRCFF  , FHINV   , POR     , CIRCTE

C                  SET BOUNDARY CONDITIONS AT UPSTREAM AND DOWNSTREAM
C                  ENDS.
      K = JMIN - KSTEP
      DO 10 J = JMIN,JMAX
      K = K + KSTEP
      IF (J .EQ. JUP) K = K + KSTEP - 1
      P(J,IMIN) = CIRCFF*VUP(K) + DUB*DUP(K)
      P(J,IMAX) = CIRCFF*VDOWN(K) + DUB*DDOWN(K)
 10   CONTINUE
      IF(BCTYPE .NE. 1) GO TO 25
C                  UPDATE BOUNDARY CONDITIONS ON TOP AND BOTTOM
      K = IMIN - KSTEP
      DO 20 I = IMIN,IMAX
      K = K + KSTEP
      P(JMIN,I) = CIRCFF*VBOT(K) + DUB*DBOT(K)
      P(JMAX,I) = CIRCFF*VTOP(K) + DUB*DTOP(K)
 20   CONTINUE
 25   RETURN
      END
      SUBROUTINE SAVEP
C                           SAVEP MOVES DATA INTO OLD DATA LOCATIONS AND
C                           WRITES IT ON TAPE3 IF REQUESTED.
C                           CALLED BY - TSFOIL.
      COMMON          P(102,101),X(100)   , Y(100)
      COMMON / COM1/ IMIN      , IMAX     , IUP      , IDOWN    , ILE      ,
     1               ITE       , JMIN     , JMAX     , JUP      , JLOW     ,
     2               JTOP      , JBOT
      COMMON / COM2/ AK        , ALPHA    , DUB      , GAM1     , RTK
      LOGICAL        ABORT
      COMMON / COM3/ IREF      , ABORT    , ICUT     , KSTEP
      LOGICAL        AMESH
      COMMON / COM4/ XIN(100) , YIN(100), AMESH
      COMMON / COM6/ FL(100)  , FXL(100), FU(100) , FXU(100),
     1            CAMBER(100), THICK(100),VOL     , XFOIL(100), IFOIL
      INTEGER        PSTART
      LOGICAL        PSAVE
      COMMON /COM11/ ALPHAO    , CLOLD    , DELTAO   , DUBO     , EMACHO   ,
     1               IMINO     , IMAXO    , IMAXI    , JMINO    , JMAXO    ,
     2               JMAXI     , PSAVE    , PSTART   , TITLE(8), TITLEO(8),
     3               VOLO      , XOLD(100),YOLD(100)
      COMMON /COM12/ F         , H        , HALFPI   , PI       , RTKPOR   ,
     1               TWOPI
      LOGICAL        PHYS
      INTEGER        PRTFLO    , SIMDEF
      COMMON /COM27/ CL        , DELTA    , DELRT2   , EMACH    , EMROOT   ,
     1               PHYS      , PRTFLO   , SIMDEF   , SONVEL   , VFACT    ,
     2               YFACT
      INTEGER        BCTYPE
      COMMON /COM28/ BCTYPE    , CIRCFF   , FHINV    , POR      , CIRCTE
C                           RESET PARAMETERS SCALED IN SUBROUTINE SCALE.
      ALPHA = ALPHA * VFACT
      H = H * YFACT
      POR = POR / YFACT
      DO 6 J=JMIN,JMAX
      YIN(J) = YIN(J) * YFACT
    6 CONTINUE
      IF (ABORT) RETURN
C                           MOVE RESTART DATA TO OLD BLOCK.
      DO 10 I=1,8
      TITLEO(I) = TITLE(I)
   10 CONTINUE
      IMINO = IMIN
      JMINO = JMIN
      IMAXO  = IMAX
      JMAXO  = JMAX
      CLOLD  = CL
      EMACHO = EMACH
      ALPHAO = ALPHA
      DELTAO = DELTA
      VOLO   = VOL
      DUBO = DUB

      DO 20 I=IMINO,IMAXO
      XOLD(I) = X(I)
   20 CONTINUE

      DO 30 J=JMINO,JMAXO
      YOLD(J) = YIN(J)
   30 CONTINUE
C                           CHECK TO SEE IF RESTART IS TO BE WRITTEN ON
C                                  TAPE3.
      IF ( .NOT. PSAVE) GO TO 100
   40 CONTINUE
      WRITE (3,900) TITLEO
      WRITE (3,901) IMAXO, JMAXO, IMINO, JMINO
      WRITE (3,902) CLOLD , EMACHO, ALPHAO, DELTAO, VOLO, DUBO
      WRITE (3,902) (XOLD(I),I=IMINO,IMAXO)
      WRITE (3, 902) (YOLD(J),J=JMINO, JMAXO)
      DO 50 I=IMINO,IMAXO
      WRITE (3,902) (P(J,I),J=JMINO,JMAXO)
   50 CONTINUE
  100 CONTINUE
      RETURN
  900 FORMAT(8A10)
  901 FORMAT(4I5)
  902 FORMAT(8F10.6)

      END
```

```
      SUBROUTINE SCALE
C                     SUBROUTINE SCALES PHYSICAL VARIABLES TO TRANSONIC
C                     VARIABLES.
C                     IF PHYS = .TRUE., ALL INPUT/OUTPUT QUANTITIES ARE IN
C                     PHYSICAL UNITS NORMALIZED BY FREESTREAM VALUES AND
C                     AIRFOIL CHORD. THIS SUBROUTINE THEN SCALES THE
C                     QUANTITIES TO TRANSONIC VARIABLES BY THE FOLLOWING
C                     CONVENTION
C                          SIMDEF = 1  COLE SCALING
C                          SIMDEF = 2  SPREITER SCALING
C                          SIMDEF = 3  KRUPP SCALING
C                          SIMDEF = 4  USER CHOICE
C                     IF PHYS = .FALSE., INPUT IS ALREADY IN SCALED
C                     VARIABLES AND NO FURTHER SCALING IS DONE.
C                     CALLED BY - TSFOIL.
      COMMON          P(102,101),X(100)   , Y(100)
      COMMON / COM1/ IMIN      , IMAX     , IUP      , IDOWN    , ILE      ,
     1               ITE       , JMIN     , JMAX     , JUP      , JLOW     ,
     2               JTOP      , JBOT
      COMMON / COM2/ AK        , ALPHA    , DUB      , GAM1     , RTK
      LOGICAL        AMESH
      COMMON / COM4/ XIN(100) , YIN(100), AMESH
      INTEGER        PSTART
      LOGICAL        PSAVE
      COMMON /COM11/ ALPHAO    , CLOLD    , DELTAO   , DUBO     , EMACHO   ,
     1               IMINO     , IMAXO    , IMAXI    , JMINO    , JMAXO    ,
     2               JMAXI     , PSAVE    , PSTART   , TITLE(8), TITLEO(8),
     3               VOLO      , XOLD(100),YOLD(100)
      COMMON /COM12/ F         , H        , HALFPI   , PI       , RTKPOR   ,
     1               TWOPI
      COMMON /COM13/ CDFACT    , CLFACT   , CMFACT   , CPFACT   , CPSTAR
      LOGICAL        PHYS
      INTEGER        PRTFLO    , SIMDEF
      COMMON /COM27/ CL        , DELTA    , DELRT2   , EMACH    , EMROOT   ,
     1               PHYS      , PRTFLO   , SIMDEF   , SONVEL   , VFACT    ,
     2               YFACT
      INTEGER        BCTYPE
      COMMON /COM28/ BCTYPE    , CIRCFF   , FHINV    , POR      , CIRCTE

      IF(PHYS) GO TO 50
C                     PHYS = .FALSE.  NO SCALING
      CPFACT = 1.
      CDFACT = 1.
      CLFACT = 1.
      CMFACT = 1.
      YFACT = 1.
      VFACT = 1.
      GO TO 600
C                     PHYS = .TRUE.  COMPUTE CONSTANTS
   50 CONTINUE
      EMACH2 = EMACH*EMACH
      BETA  = 1. - EMACH2
      DELRT1 = DELTA**(1./3.)
      DELRT2 = DELTA**(2./3.)
C
C                     BRANCH TO APPROPRIATE SCALING
      GO TO (100,200,300,400), SIMDEF
C
C                     SIMDEF = 1
C                     COLE SCALING
  100  CONTINUE
      AK = BETA/DELRT2
      YFACT = 1./DELRT1
      CPFACT = DELRT2
      CLFACT = DELRT2
      CDFACT = DELRT2*DELTA
      CMFACT = DELRT2
      VFACT = DELTA*57.295779
      GO TO 500
C                     SIMDEF = 2
C                     SPREITER SCALING
  200  CONTINUE
      EMROOT = EMACH**(2./3.)
      AK = BETA/(DELRT2*EMROOT*EMROOT)
      YFACT = 1./(DELRT1*EMROOT)
      CPFACT = DELRT2/EMROOT
      CLFACT = CPFACT
      CMFACT = CPFACT
      CDFACT = CPFACT*DELTA
      VFACT = DELTA*57.295779
      GO TO 500
C                     SIMDEF = 3
C                     KRUPP SCALING
```

```
  300   CONTINUE
      AK = BETA/(DELRT2*EMACH)
      YFACT = 1./(DELRT1*EMACH**.5)
      CPFACT = DELRT2/(EMACH**.75)
      CLFACT = CPFACT
      CMFACT = CPFACT
      CDFACT = CPFACT*DELTA
      VFACT = DELTA*57.295779
      GO TO 500
  400   CONTINUE
C                    SIMDEF = 4
C                    THIS ADDRESS IS INACTIVE
C                    USER MAY INSERT SCALING OF OWN CHOICE
C                    DEFINITION FOR LOCAL MACH NUMBER MUST BE ADJUSTED
C                    IN EMACH1.
      WRITE(6,1000)
 1000 FORMAT(34H1ABNORMAL STOP IN SUBROUTINE SCALE/
     1        24H SIMDEF=4 IS NOT USEABLE)
      STOP
  500   CONTINUE
C                    SCALE Y MESH
      YFACIV = 1.0 / YFACT
      DO 502 J=JMIN,JMAX
      YIN(J)  = YIN(J)  * YFACIV
  502 CONTINUE
      IF (PSTART .EQ. 1) GO TO 505
      DO 504 J=JMINO,JMAXO
      YOLD(J) = YOLD(J) * YFACIV
  504 CONTINUE
  505 CONTINUE
C                    SCALE TUNNEL PARAMETERS
      H = H/YFACT
      POR = POR*YFACT

C                    SCALE ANGLE OF ATTACK
      ALPHA = ALPHA/VFACT

  600   CONTINUE
C                    CHECK VALUE OF AK FOR DEFAULT.
      IF (AK .EQ. 0.0) CALL INPERR (7)
C                    COMPUTE SQUARE ROOT OF AK
      RTK = SQRT(ABS(AK))
C                    COMPUTE SONIC VELOCITY
      IF (ABS(GAM1).GT..0001) GO TO 999
      SONVEL=1.
      CPSTAR=0.
      RETURN
  999 CONTINUE
      SONVEL = AK / GAM1
      CPSTAR = -2.0 * SONVEL * CPFACT
      RETURN
      END
```

```
      SUBROUTINE SETBC
C                    SUBROUTINE SETBC SETS THE LIMITS ON RANGE OF I AND J
C                    FOR SOLUTION OF THE DIFFERENCE EQUATIONS.
C                    THE BODY SLOPE BOUNDARY CONDITION  AT THE CURRENT
C                    X MESH POINTS ON THE BODY ARE MULTIPLIED BY MESH
C                    SPACING CONSTANTS AND ENTERED INTO ARRAYS FXUBC AND
C                    FXLBC FOR USE IN SUBROUTINE SYOR.
C                    CALLED BY - TSFOIL.

      COMMON          P(102,101),X(100)   , Y(100)
      COMMON / COM1/ IMIN      , IMAX     , IUP      , IDOWN    , ILE      ,
     1               ITE       , JMIN     , JMAX     , JUP      , JLOW     ,
     2               JTOP      , JBOT
      COMMON / COM2/ AK        , ALPHA    , DUB      , GAM1     , RTK
      LOGICAL        ABORT
      COMMON / COM3/ IREF      , ABORT    , ICUT     , KSTEP
      COMMON / COM6/ FL(100)   , FXL(100), FU(100) , FXU(100),
     1             CAMBER(100), THICK(100),VOL     , XFOIL(100), IFOIL
      COMMON /COM17/ CYYBLC    , CYYBLD   , CYYBLU   , CYYBUC   , CYYBUD   ,
     1               CYYBUU    ,FXLBC(100),FXUBC(100)
      INTEGER        BCTYPE
      COMMON /COM28/ BCTYPE    , CIRCFF   , FHINV    , POR      , CIRCTE

C                    SET LIMITS ON I AND J INDICIES
      INT = 0
      IF(AK .LT. 0.) INT = 1
      IUP = IMIN + 1 + INT
      IDOWN = IMAX - 1 + INT
      JINT = 0
      IF(BCTYPE .EQ. 1 .AND. AK .GT. 0.) JINT = 1
      IF(BCTYPE .EQ. 3) JINT = 1
      IF(BCTYPE .EQ. 5 .AND. POR .GT. 1.5) JINT = 1
      JBOT = JMIN + JINT
      JTOP = JMAX - JINT
C                    AIRFOIL BODY BOUNDARY CONDITION
C                    ZERO ELEMENTS IN ARRAYS FOR UPPER AND LOWER BODY
C                    BOUNDARY CONDITIONS
      DO 30 I = IMIN,IMAX
      FXLBC(I) = 0.
      FXUBC(I) = 0.
   30 CONTINUE
C                    ENTER BODY SLOPES AT MESH POINTS ON AIRFOIL
C                    INTO ARRAYS FOR BODY BOUNDARY CONDITIONS
      IF(IREF .LE. 0) KSTEP = 1
      IF(IREF .EQ. 1)  KSTEP = 2
      IF(IREF .EQ. 2)  KSTEP = 4
      NFOIL = ITE - ILE + 1
      IF = IFOIL + KSTEP
      I = ITE + 1
      DO 50 N = 1,NFOIL
      I = I-1
      IF = IF - KSTEP
      FXLBC(I) = CYYBLU*(FXL(IF) - ALPHA)
      FXUBC(I) = CYYBUD*(FXU(IF) - ALPHA)
   50 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE SIMP(R,X,Y,N,IER)
C                    SUBROUTINE TO INTEGRATE BY SIMPSONS RULE.
C                    CALLED BY BODY.
      DIMENSION X(N),Y(N)
      R=0.0
      IF(N.GT.1) GO TO 1
      IER=2
      RETURN
    1 IF(X(1).EQ.X(2)) GO TO 12
      NM1=N-1
      IF(N.EQ.2) GO TO 13
      IF(X(1).LT.X(2)) GO TO 3
C   TEST FOR X TO BE MONOTONICALLY DECREASING
      DO 2 I=2,NM1
      IF(X(I+1).GE.X(I)) GO TO 12
    2 CONTINUE
      GO TO 5
C   TEST FOR X TO BE MONOTONICALLY INCREASING
    3 DO 4 I=2,NM1
      IF(X(I+1).LE.X(I)) GO TO 12
    4 CONTINUE
    5 NM2=N-2
      IF(MOD(N,2).EQ.0) GO TO 14
      P=0.0
      N1=1
    6 S1=X(N1+1)-X(N1)
      S2=X(N1+2)-X(N1+1)
      S3=X(NM1)-X(NM2)
      S4=X(N)-X(NM1)
      P=(2.*S1**2+S1*S2-S2**2)/S1*Y(N1)+(2.*S4**2+S3*S4-S3**2)/S4*Y(N)
      N1=N1+1
      DO 7 I=N1,NM1,2
      S1=X(I)-X(I-1)
      S2=X(I+1)-X(I)
    7 R=R+(S1+S2)**3/(S1*S2)*Y(I)
      IF(N.LT.5) GO TO 9
      N1=N1+1
      DO 8 I=N1,NM2,2
      S1=X(I-1)-X(I-2)
      S2=X(I)-X(I-1)
      S3=X(I+1)-X(I)
      S4=X(I+2)-X(I+1)
    8 R=R+((2.*S2**2+S1*S2-S1**2)/S2+(2.*S3**2+S3*S4-S4**2)/S3)*Y(I)
    9 R=R/6.+P
   10 CONTINUE
      IER=1
      RETURN
   12 IER=4
      RETURN
C     TRAPEZOIDAL RULE FOR N=2
   13 R=(X(2)-X(1))*(Y(1)+Y(2))/2.0
      GO TO 10
C     FIT POLYNOMIAL THRU FIRST 3 POINTS AND INTEGRATE FROM X(1) TO X(2).
   14 S1=X(2)-X(1)
      S2=X(3)-X(1)
      S3=Y(2)-Y(1)
      S4=Y(3)-Y(1)
      P=S1/6.*(2.*S3+6.*Y(1)+(S2**2*S3-S1**2*S4)/(S2*(S2-S1)))
      N1=2
      GO TO 6
      END
```

```
      SUBROUTINE SOLVE
C                   SOLVE CONTROLS THE MAIN ITERATION LOOP.
C                   CALLED BY - TSFOIL.
      COMMON         P(102,101),X(100)  , Y(100)
      COMMON / COM1/ IMIN     , IMAX    , IUP     , IDOWN   , ILE     ,
     1               ITE      , JMIN    , JMAX    , JUP     , JLOW    ,
     2               JTOP     , JBOT
      COMMON / COM2/ AK       , ALPHA   , DUB     , GAM1    , RTK
      LOGICAL        ABORT
      COMMON / COM3/ IREF     , ABORT   , ICUT    , KSTEP
      COMMON / COM7/ CJUP     , CJUP1   , CJLOW   , CJLOW1
      COMMON / COM8/ CVERGE   , DVERGE  , IPRTER  , MAXIT   ,
     1               WE(3)    , EPS
      COMMON /COM13/ CDFACT   , CLFACT  , CMFACT  , CPFACT  , CPSTAR
      LOGICAL        OUTERR
      COMMON /COM18/ ERROR    , I1      , I2      , IERROR  , JERROR  ,
     1               OUTERR   , EMU(100,2)        , VC(100) ,
     2               WI       , DCIRC   , POLD(100,2)
      COMMON /COM22/ CXC(100) , CXL(100), CXR(100), CXXC(100),CXXL(100),
     1               CXXR(100), C1(100)
      COMMON /COM25/ CPL(100) , CPU(100)
      INTEGER        BCTYPE
      COMMON /COM28/ BCTYPE   , CIRCFF  , FHINV   , POR     , CIRCTE
      COMMON /COM32/ BIGRL    , IRL     , JRL
      COMMON /COM33/ THETA(100,100)

      REAL LIFT
      DATA   NDUB / 25 /
C
C
      ABORT = .FALSE.
      WRITE(6,600)
C
      IF (IREF .EQ. 2) MAXITM = MAXIT / 4
      IF (IREF .EQ. 1) MAXITM = MAXIT / 2
      IF (IREF .EQ. 0) MAXITM = MAXIT
      KK = 3 - IREF
      IF (KK .EQ. 1) WRITE(6,607)
      IF (KK .EQ. 2) WRITE(6,608)
      IF (KK .EQ. 3) WRITE(6,609)
      WEP = WE(KK)
      WI = 1.0 / WEP
      WRITE (6,606) WEP, EPS, MAXITM
C
      WRITE(6,601)

      DO 1 ITER = 1,MAXITM
C
C                    INITIALIZE EMU
      I1=1
      I2=2
      DO 5 J=JMIN,JMAX
      POLD(J,I2) = P(J,IUP-1)
      EMU(J,I2) = 0.0
    5 CONTINUE

      IF ( AK .GT. 0.0 ) GO TO 7
      DO 6 J=JMIN,JMAX
      EMU(J,I2) = C1(2)
    6 CONTINUE
    7 CONTINUE
      OUTERR=.FALSE.
      IF(MOD(ITER,IPRTER) .EQ. 0)  OUTERR=.TRUE.
      ERROR=0.0
      BIGRL = 0.0
C                        UPDATE PJUMP.
      CALL RECIRC

      CALL SYOR

C                       UPDATE CIRCULATION FOR SUBSONIC FREESTREAM FLOW

      IF ( AK .LT. 0.0 ) GO TO 10
      IF (BCTYPE .NE. 1) GO TO 9
      IK = IUP - IMIN
      DO 8 I=IUP,IDOWN
      IK = IK + KSTEP
      JK = JBOT - JMIN
      DO 82 J=JBOT,JTOP
      JINC = KSTEP
      IF (Y(J) .LT. 0.0 .AND. Y(J+1) .GT. 0.0) JINC = 2 * KSTEP - 1
      JK = JK + JINC
      P(J,I) = P(J,I) + DCIRC * THETA(JK,IK)
   82 CONTINUE
    8 CONTINUE
    9 CONTINUE
C******
      IF (MOD(ITER,NDUB) .EQ. 0) CALL REDUB
C******
      CALL RESET
   10 CONTINUE
      IF(OUTERR)  GO TO 2
      GO TO 1
 2    CONTINUE
      CL = LIFT (CLFACT)
      CM = PITCH (CMFACT)
      ERCIRC=ABS(DCIRC)
      CPMAXL=0.0
      CPMAXU=0.0
      DO 14 I=ILE,ITE
      UL=CJLOW*PX(I,JLOW)-CJLOW1*PX(I,JLOW-1)
      CPOLD=CPL(1)
      CPL(I)=-2.0*UL*CPFACT
      CPERR=ABS(CPL(I)-CPOLD)
      IF (CPERR .LE. CPMAXL) GO TO 12
      CPMAXL=CPERR
      IERRL=I
   12 UU=CJUP*PX(I,JUP)-CJUP1*PX(I,JUP+1)
       CPOLD=CPU(I)
      CPU(I)=-2.0*UU*CPFACT
      CPERR=ABS(CPU(I)-CPOLD)
      IF (CPERR .LE. CPMAXU) GO TO 14
      CPMAXU=CPERR

      IERRU=I
   14 CONTINUE
      WRITE (6,602) ITER, CL, CM, IERROR, JERROR, ERROR, IRL, JRL,
     1 BIGRL,ERCIRC,IERRU,CPMAXU,IERRL,CPMAXL
      IF (ERROR .LE. CVERGE) GO TO 3
      IF (ERROR .GE. DVERGE) GO TO 4
 1    CONTINUE
      WRITE(6,605)
      RETURN
 3    CONTINUE
      WRITE(6,603)
      RETURN
 4    CONTINUE
      ABORT = .TRUE.
      WRITE(6,604)
      RETURN

 600  FORMAT(1H1)
  601 FORMAT(11H0 ITERATION,4X,2HCL,9X,2HCM,5X,4HIERR,2X,4HJERR,5X,
     1   5HERROR,5X,3HIRL,3X,3HJRL,6X,5HBIGRL,8X,6HERCIRC,4X,4HICPU,
     2   5X,6HCPERRU,4X,4HICPL,5X,6HCPERRL/)
  602 FORMAT(3X,I4,1X,2F11.5,2I6,E13.4,2I6,2E13.4,2(I6,E13.4))
  603 FORMAT(//20X,34H******  SOLUTION CONVERGED  ******)
 604  FORMAT(//20X,33H******  SOLUTION DIVERGED  ******)
 605  FORMAT(//20X,39H******  ITERATION LIMIT REACHED  ******)
  606 FORMAT(10X,5HWE = F8.4,5X,6HEPS = F8.4,5X,
     1    22HMAXIT FOR THIS MESH = I4)
  607 FORMAT(48X,35HINTERMEDIATE OUTPUT FOR COARSE MESH//)
  608 FORMAT(48X,35HINTERMEDIATE OUTPUT FOR MEDIUM MESH//)
  609 FORMAT(49X,33HINTERMEDIATE OUTPUT FOR FINE MESH//)

      END
      SUBROUTINE SPLN1 (X,Y,N)
C                    CALLED BY - BODY.
      COMMON /SPLN/ A(200)    , B(200)  , DY1     , DY2     , K1
     1              K2        , XP      , YP      ,DYP

CONTINUOUS DERIVATIVE INTERPOLATION SUBROUTINES
CURFIT COMPUTES COEFFICIENTS OF CUBICS  --  A(I)...I=1,2*N-2
C.....FOR THE WHOLE TABULATED TABLE
C     X(I) = INDEPENDENT VARIABLE.....I=1,N  (GIVEN)
C     Y(I) = DEPENDENT VARIABLE.....I=1,N  (GIVEN)
C     N = LENGTH OF Y-VS-X TABLE  (GIVEN)
C     DY1 = 1ST OR 2ND DERIVATIVE AT LOWER END OF TABLE
C     DY2 = 1ST OR 2ND DERIVATIVE AT UPPER END OF TABLE
C     K1 = 1 ......DY1 = 1ST DERIVATIVE  (GIVEN)
C     K1 = 2 ......DY1 = 2ND DERIVATIVE  (GIVEN)
C     K2 = 1 ......DY2 = 1ST DERIVATIVE  (GIVEN)
C     K2 = 2 ......DY2 = 2ND DERIVATIVE  (GIVEN)

      DIMENSION  X(1),  Y(1)

      N1=N-2
      C1=X(2)-X(1)
      IF (K1 .EQ. 2) GO TO 4
      B(1) = 0.
      A(1)=(DY1-(Y(2)-Y(1))/C1)/C1
      GO TO 5
    4 B(1)=-C1
      A(1)=-DY1/2.
5     J=1
      IF(N.EQ.2)GO TO 42
      DO 10 I=1,N1
      J=J+1
      C1=X(I+1)-X(1)
      C2=X(I+2)-X(I+1)
      C3=Y(I+1)-Y(I)
      C4=Y(I+2)-Y(I+1)
      C5=C3/C1-C4/C2
      C6=C1/C2
      C7=C1*C2
      B(J)=1.0/(C6*(C1-B(J-1)))
      A(J)=(C5/C2-C6*A(J-1))*B(J)
      J=J+1
      B(J)=1.0/((-C1-C2)/C7-C6*B(J-1))
      A(J) =(-C5/C7-C6*A(J-1))*B(J)
10    CONTINUE
      IF(K2.EQ.2)GJ TO 30
      A(J+1) = (DY2-C4/C2+C2*A(J))/(C2*(B(J)-C2))
      GO TO 45
30    A(J+1)=(DY2/2.+A(J))/(-2.*C2+B(J))
      GO TO 45
C     STATEMENTS 42 TO 44 ARE FOR N=2 ONLY
42    C3=K1
      C2=1.0/C3
      IF(K2.EQ.2)GO TO 44
      A(J+1) = ((Y(2)-Y(1))/C1-A(J)*C1-DY2)/(C1*C1)*C2
      GO TO 45
44    A(J+1)=C3*((DY2+2.0*A(1))/(4.0*C1))
45    J=2*(N-1)
50    J=J-1
      IF(J.LE.0)RETURN
      A(J) = A(J)-B(J)*A(J+1)
      GO TO 50
C

C   ENTRY POINT FOR INTERPOLATION
      ENTRY SPLN1X

      IF(XP.GT.X(1)) GO TO 11
C     SPECIAL CASE FOR EXTRAPOLATION BEYOND LOWER END OF X-TABLE
      C=X(2)-X(1)
      DYP=(Y(2)-Y(1))/C+A(1)*C
      YP=Y(1)+DYP*(XP-X(1))
      RETURN
   11 IF(XP.LT.X(N)) GO TO 13
C     SPECIAL CASE FOR EXTRAPOLATION BEYOND UPPER END OF Y-TABLE
      C=X(N)-X(N-1)
      DYP=(Y(N)-Y(N-1))/C-A(2*N-3)*C-A(2*N-2)*C*C
      YP=Y(N)+DYP*(XP-X(N))
      RETURN
   13 I=1
   14 I=I+1
      IF(X(I).LT.XP) GO TO 14
C     NOW XP HAS BEEN BRACKETED SO THAT X(I-1).LT.XP.LE.X(I)
      C=XP-X(I-1)
      D=X(I)-XP
      K=2*I-3
      SLOPE=(Y(I)-Y(I-1))/(X(I)-X(I-1))
      YP=Y(I-1)+(SLOPE+(A(K)+A(K+1)*C)*D)*C
                    DYP=SLOPE+A(K)*(D-C)+A(K+1)*(2.*D-C)*C
       RETURN
      END
```

```
      SUBROUTINE SYOR

C                    SYOR COMPUTES NEW P AT ALL MESH POINTS.
C                    CALLED BY - SOLVE.
      COMMON         P(102,101),X(100)  , Y(100)
      COMMON / COM1/ IMIN     , IMAX    , IUP     , IDOWN   , ILE     ,
     1               ITE      , JMIN    , JMAX    , JUP     , JLOW    ,
     2               JTOP     , JBOT
      COMMON / COM2/ AK       , ALPHA   , DUB     , GAM1    , RTK
      COMMON / COM8/ CVERGE   , DVERGE  , IPRTER  , MAXIT   ,
     1               WE(3)    , EPS
      LOGICAL        FCR      , KUTTA
      COMMON /COM14/ CLSET    , FCR     , KUTTA   , WCIRC
      COMMON /COM17/ CYYBLC   , CYYBLD  , CYYBLU  , CYYBUC  , CYYBUD  ,
     1               CYYBUU   ,FXLBC(100),FXUBC(100)
      LOGICAL        OUTERR
      COMMON /COM18/ ERROR    , I1      , I2      , IERROR  , JERROR  ,
     1               OUTERR   , EMU(100,2)        , VC(100) ,
     2               WI       , DCIRC   , POLD(100,2)
      COMMON /COM19/ DIAG(100), RHS(100), SUB(100), SUP(100)
      COMMON /COM22/ CXC(100) , CXL(100), CXR(100), CXXC(100),CXXL(100),
     1               CXXR(100), C1(100)
      COMMON /COM23/ CYYC(100), CYYD(1C0),CYYU(100), IVAL
      COMMON /COM26/ PJUMP(100)
      COMMON /COM32/ BIGRL    , IRL     , JRL
      DIMENSION     SAVE(100)

      IM2=IUP-1
      IF( AK .LT. 0.0 )  IM2=IUP-2


      J1 = JBOT + 1
      J2 = JTOP - JBOT

      DO 200 I=IUP,IDOWN
      EPSX = EPS/((X(I)-X(I-1))**2)

C                          COMPUTE VC = 1 - M**2

      DO 1C J=JBOT,JTOP
      VC(J) = C1(I) - (CXL(I)*POLD(J,I2) + CXC(I)*P(J,I)
     1                + CXR(I)*P(J,I+1))
      EMU(J,I1) = 0.0
      POLD(J,I1) = P(J,I)
   10 CONTINUE
      DO 20 J=JBCT,JTOP
      IF (VC(J) .LT. 0.0) EMU(J,I1) = VC(J)
   20 CONTINUE
      IF ( FCR ) GO TO 22
      DO 21 J=JBOT,JTOP
      EMU(J,I2) = EMU(J,I1)
   21 CONTINUE
   22 CONTINUE

C                          COMPUTE ELEMENTS OF MATRIX

      DO 30 J=JBOT,JTOP
      DIAG(J) = (EMU(J,I1) - VC(J)) * CXXC(I) * WI
     1          + EMU(J,I2) * CXXR(I-1) - CYYC(J)
      SUP(J)=CYYD(J)
      SUB(J)=CYYU(J)
   30 CONTINUE

C                          COMPUTE RESIDUAL

      DO 40 J=JBOT,JTOP
      RHS(J)   = -(VC(J)-EMU(J,I1))*
     1         (CXXL(I)*P(J,I-1) - CXXC(I)*P(J,I) + CXXR(I)*P(J,I+1))
   40 CONTINUE
      DO 50 J=JBOT,JTOP
      RHS(J)  = RHS(J) - (EMU(J,I2) * (CXXL(I-1)*P(J,IM2)
     1              - CXXC(I-1)*P(J,I-1) + CXXR(I-1)*P(J,I)))
   50 CONTINUE
      JA = JBOT + 1
      JB = JTOP - 1
      DO 60 J=JA,JB
      RHS(J)   = RHS(J) - (CYYD(J)*P(J-1,I) - CYYC(J)*P(J,I)
     1                                      + CYYU(J)*P(J+1,I))
   60 CONTINUE
      RHS(JBOT) = RHS(JBOT) - (-CYYC(JBOT)*P(JBOT,I)
     1                        + CYYU(JBOT)*P(JBOT+1,I))
      IF (JBOT .EQ. JMIN) GO TO 61
      RHS(JBOT) = RHS(JBOT) -CYYD(JBOT)*P(JBOT-1,I)
   61 CONTINUE
      RHS(JTOP) = RHS(JTOP) - (CYYD(JTOP)*P(JTOP-1,I)
     1                        - CYYC(JTOP)*P(JTOP,I))
      IF (JTOP .EQ. JMAX) GO TO 62
      RHS(JTOP) = RHS(JTOP) - CYYU(JTOP)*P(JTOP+1,I)
   62 CONTINUE

C                          CHECK FOR AIRFOIL B.C. AND KUTTA SLICE.

      IF (I .LT. ILE) GO TO 80
      IF (I .GT. ITE) GO TO 70

C                          AIRFOIL B. C.

      J=JUP
      DIAG(J)=DIAG(J)+CYYC(J)-CYYBUC
      SUP(J)=0.0
      SUB(J)=CYYBUU
      RHS(J)=RHS(J)+CYYD(J)*P(J-1,I)-CYYC(J)*P(J,I)+CYYU(J)*P(J+1,I)
     1              -(-CYYBUC*P(J,I)+CYYBUU*P(J+1,I)+FXUBC(I))
      J=JLOW
      DIAG(J)=DIAG(J)+CYYC(J)-CYYBLC
      SUP(J)=CYYBLD
      SUB(J)=0.0
      RHS(J)=RHS(J)+CYYD(J)*P(J-1,I)-CYYC(J)*P(J,I)+CYYU(J)*P(J+1,I)
     1              -(-CYYBLC*P(J,I)+CYYBLD*P(J-1,I)+FXLBC(I))
      GO TO 80

C                          KUTTA SLICE CHANGE.
   70 CONTINUE
      RHS(JLOW) = RHS(JLOW) + CYYU(JLOW)*PJUMP(I)
      RHS(JUP)  = RHS(JUP)  - CYYD(JUP )*PJUMP(I)
   80 CONTINUE

C                          INSERT WALL B. C.

      IVAL = 1
      CALL BCEND

C                          COMPUTE MAX RESIDUAL.

      IF ( .NOT. OUTERR) GO TO 110
      DO 100  J=JBOT,JTOP
      ARHS = ABS(RHS(J))
      IF (ARHS .GT. BIGRL) GO TU 90
      GO TO 100
   90 CONTINUE
      BIGRL = ARHS
      IRL   = I
      JRL   = J
  100 CONTINUE
  110 CONTINUE
C
C***********   ADD PXT
C
      DO 300 J = JBOT,JTOP
      DIAG(J) = DIAG(J) - EPSX
 300  RHS(J) = RHS(J) - EPSX*(P(J,I-1)-POLD(J,I2))

C                          SOLVE TRIDIAGONAL MATRIX EQUATION.

      DNOM       = 1.0 / DIAG(JBOT)
      SAVE(JBOT)=SUB(JBOT)*DNOM
      RHS(JBOT)  = RHS(JBOT) * DNOM
      DO 120 J=J1,JTOP
      DNOM=1./(DIAG(J)-SUP(J)*SAVE(J-1))
      SAVE(J)=SUB(J)*DNOM
      RHS(J)=(RHS(J)-SUP(J)*RHS(J-1))*DNOM
  120 CONTINUE
      DO 130 K=1,J2
      J      = JTOP - K
      RHS(J) = RHS(J) - SAVE(J) * RHS(J+1)
  130 CONTINUE
```

```
C                          COMPUTE NEW P.

      DO 140 J=JBOT,JTOP
      P(J,I) = P(J,I) + RHS(J)
  140 CONTINUE

C                          COMPUTE MAX ERROR

      IF ( .NOT. OUTERR) GO TO 180
      DO 170  J = JBOT,JTOP
      ARHS = ABS(RHS(J))
      IF (ARHS .GT. ERROR) GO TO 160
      GO TO 170
  160 CONTINUE
      ERROR = ARHS
      IERROR = I
      JERROR = J
  170 CONTINUE
  180 CONTINUE
      IF (AK .GT. 0.0) GO TO 195
      IF (I .NE. IDOWN-1) GO TO 195

C                          SET P(IDOWN+1) = P(IDOWN-1) TO OBTAIN
C                          CENTERED VELOCITY AT IDOWN FOR SUPERSINIC
C                          FREESTREAM FLOW.

      DO 190 J=JMIN,JMAX
      P(J,IDOWN+1) = P(J,IDOWN-1)
  190 CONTINUE
  195 CONTINUE
      ISAVE = I2
      I2    = I1
      I1    = ISAVE
      IM2=I-1
  200 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE TRAP(X,Y,N,SUM)
C                INTEGRATE Y DX BY TRAPEZODIAL RULE
C                N IS THE NUMBER OF (X,Y) POINTS AND SUM IS THE
C                RESULTING INTEGRAL.
C                CALLED BY - CDCOLE, DRAG, PITCH, REDUB.
C                INTEGRAL
      DIMENSION X(1),Y(1)
      SUM = C.
      NM1 = N-1
      DO 10 I=1,NM1
      Z = X(I+1) - X(I)
      W = Y(I+1) + Y(I)
      SUM = SUM + Z*W
 1C   CONTINUE
      SUM = .5*SUM
      RETURN
      END
```

```
      SUBROUTINE VROOTS
C                COMPUTE CONSTANTS BETA0,BETA1,BETA2,PSI0,PSI1,PSI2,
C                USED IN FORMULA FOR VORTEX IN SLOTTED WIND TUNNEL
C                WITH SUBSONIC FREESTREAM
C                CALLED BY - FARFLD.

      COMMON /COM12/ F       , H       , HALFPI  , PI      , RTKPOR  ,
     1               TWOPI
      COMMON /COM15/ B       , BETA0   , BETA1   , BETA2   , PSI0    ,
     1               PSI1    , PSI2

      ERROR = .00001
C                CALCULATE BETA0
      BETA0 = 0.
      DO 10 I = 1,100
      TEMP = BETA0
      Q = -F*TEMP + RTKPOR
      BETA0 = ATAN(Q)
      DBETA = ABS(TEMP - BETA0)
      IF(DBETA .LT. ERROR) GO TO 15
 10   CONTINUE
      N = 0
      GO TO 9999
 15   CONTINUE
C                    CALCULATE BETA1
      BETA1 = 0.
      DO 20 I=1,100
      TEMP = BETA1
      Q = -F*(TEMP + PI) + RTKPOR
      BETA1 = ATAN(Q)
      DBETA  = ABS(BETA1 - TEMP)
      IF(DBETA .LT. ERROR) GO TO 25
 20   CONTINUE
      N = 1
      GO TO 9999
 25   CONTINUE
C                    CALCULATE BETA2
      BETA2 = 0.
      DO 30 I=1,100
      TEMP = BETA2
      Q = -F*(TEMP - PI) + RTKPOR
      BETA2 = ATAN(Q)
      DBETA  = ABS(BETA2 - TEMP)
      IF(DBETA  .LT. ERROR) GO TO 35
 30   CONTINUE
      N = 2
      GO TO 9999
 35   CONTINUE
C                    COMPUTE PSI0,PSI1,PSI2
      TEMP = TAN(BETA0)
      PSI0 = (1. + F/(1. + TEMP*TEMP))
      PSI0 = 1.0 / PSI0
      TEMP = TAN(BETA1)
      PSI1 = (1. + F/(1.+ TEMP*TEMP))
      PSI1 = 1.0 / PSI1
      TEMP = TAN(BETA2)
      PSI2 = (1. + F/(1. + TEMP*TEMP))
      PSI2=1.0/PSI2
      RETURN
C                    ABNORMAL STOP  IF ITERATIONS FOR BETAS DID NOT CONVERGE
 9999 CONTINUE
      WRITE(6,1000) N
 1000 FORMAT(35H1ABNORMAL STOP IN SUBROUTINE VROOTS/
     1  37H0NONCONVERGENCE OF ITERATION FOR BETA,  I1)
      STOP
      END
```

REFERENCES

1. Murman, E. M., Bailey, F. R., and Johnson, M. H.: TSFOIL - A Computer Code for 2-D Transonic Calculations, Including Wind-Tunnel Wall Effects and Wave-Drag Evaluation. NASA SP-347, Part II, 1975, pp. 769-788.

2. Krupp, J. A.: The Numerical Calculation of Plane Steady Transonic Flows Past Thin Lifting Airfoils. Ph.D. Dissertation, University of Washington, 1971.

3. Krupp, J. A. and Murman, E. M.: Computation of Transonic Flows Past Lifting Airfoils and Slender Bodies. AIAA Journal, vol. 10, no. 7, July 1972, pp. 880-886.

4. Bailey, F. R. and Ballhaus, W. F.: Relaxation Methods for Transonic Flow About Wing-Cylinder Combinations and Lifting Swept Wings. Lecture Notes in Physics, vol. 19, Springer-Verlag, 1972, pp. 2-9.

5. Ballhaus, W. F. and Bailey, F. R.: Numerical Calculation of Transonic Flow About Swept Wings. AIAA Paper No. 72-677, June 1972.

6. Murman, E. M.: Analysis of Embedded Shock Waves Calculated by Relaxation Methods. AIAA Journal, vol. 12, no. 5, May 1974, pp. 626-632.

7. Murman, E. M. and Cole, J. D.: Inviscid Drag at Transonic Speeds. AIAA Paper No. 74-540, June 1974.

8. Murman, E. M.: Computation of Wall Effects in Ventilated Transonic Wind Tunnels. AIAA Paper No. 72-1007, Sept. 1972.

9. Murman, E. M.: A Relaxation Method for Calculating Transonic Flows with Detached Bow Shocks. Proceedings of the Third International Conference on Numerical Methods in Fluid Mechanics. Lecture Notes in Physics, vol. 19, July 1972, pp. 201-206.

10. Lock, R. C.: Research in the UK on Finite Difference Methods for Computing Steady Transonic Flows. RAE Tech. Memo. Aero. 1644, July 1975.

11. Albone, C. M., Catherall, D., Hall, M. G., and Joyce, G.: An Improved Numerical Method for Solving the Transonic Small-Perturbation Equation for the Flow Past a Lifting Airfoil, RAE Tech. Rept. 74056, August 1974.

12. Jameson, A.: Transonic Flow Calculation, Lecture Series 87 von Karman Institute for Fluid Dynamics Computational Fluid Dynamics

14. Olsen, J.: Subsonic and Transonic Flow Over Sharp and Round Nosed Nonlifting Airfoils. Ohio State Univ. Ph.D. Thesis, 1976.

15. Kacprzynski, J. J., Ohman, L., Garabedian, P., and Korn, D.: Analysis of the Flow Past a Shockless Lifting Airfoil in Design and Off Design Conditions. Aeronautical Report LR-554, National Research Council of Canada, Nov. 1971.

16. Baldwin, B., Turner, J., and Knechtel, E.: Wall Interference in Wind Tunnels with Slotted and Porous Boundaries at Subsonic Speeds. NACA TN 3176, 1954.

17. Collins, D. J. and Krupp, J. A.: Experimental and Theoretical Investigations in Two-Dimensional Transonic Flow. AIAA Journal, vol. 12, no. 6, June 1974, pp. 771-778.

18. Bailey, F. R. and Ballhaus, W. F.: Comparisons of Computed and Experimental Pressures for Transonic Flows About Isolated Wings and Wing-Fuselage Configurations. NASA SP-347, Part I, 1975, pp. 1213-1232.

19. Murman, E. M.: Analysis of Embedded Shock Waves Calculated by Relaxation Methods. Proceedings of AIAA Computational Fluid Dynamics Conference, Palm Springs, CA, July 1973, pp. 27-40.

20. Murman, E. M. and Cole, J. D.: Calculation of Plane Steady Transonic Flows. AIAA Journal, vol. 9, no. 1, Jan. 1971, pp. 114-121.

21. Bailey, F. R.: On the Computation of Two- and Three-Dimensional Steady Transonic Flows by Relaxation Methods. VKI Lecture Series "Progress in Numerical Fluid Dynamics," Von Karman Institute for Fluid Dynamics, Rhode-St-Genese, Belgium, Feb. 11-15, 1974.

22. Lock, R. C.: Test Cases for Numerical Methods in Two-Dimensional Transonic Flow. AGARD Rept. No. 575, Nov. 1970.

23. Steger, J. L. and Lomax, H.: Transonic Flow About Two-Dimensional Airfoils by Relaxation Procedures. AIAA Journal, vol. 10, no. 1, 1972, pp. 49-54.

24. Garabedian, P. R. and Korn, D. G.: Analysis of Transonic Airfoils. Comm. Pure Applied Math., vol. XXIV, 1971, pp. 841-851.

25. Sells, C. C. L.: Plane Subcritical Flow Past a Lifting Airfoil. RAE TR 67146, June 1967.

26. Jameson, A.: Iterative Solution of Transonic Flows Over Airfoils and Wings, Including Flows at Mach 1. Comm, Pure Applied Math., vol. 27, 1974, pp. 283-309.

27. Yoshihara, H.: A Survey of Computational Methods for 2D and 3D Transonic Flows with Shocks. Advances in Fluid Dynamics, AGARD Lecture Series No. 64, 1973, pp. 6-1 to 6-35.

28. Magnus, R. M.: The Direct Comparison of the Relaxation Method and the Pseudo-Unsteady Finite Difference Method for Calculating Steady Planar Transonic Flow. TN-73-SP03, General Dynamics-Convair Aerospace Division, 1973.

29. Melnik, R. E. and Ives, D. C.: On Viscous and Wind-Tunnel Wall Effects in Transonic Flows Over Airfoils. AIAA Paper No. 73-660, July 1973.

30. Osborne, J.: A Selection of Measured Transonic Flow Pressure Distributions for the NACA 0012 Airfoil: Provisional Data from an NPL Tunnel. Aero. Dept., RAE, June 1971.

31. Hafez, M. M. and Cheng, H. K.: Convergence Acceleration and Shock Fitting for Transonic Aerodynamic Computations. AIAA Paper No. 75-51, Jan. 1975.

32. Lomax, H. and Martin, E. D.: Fast Direct Numerical Solution of the Nonhomogeneous Cauchy-Riemann Equations. Journal Comp. Phys., vol. 15, 1974, pp. 55-80.

33. Martin, E. D.: A Fast Semidirect Method for Computing Transonic Aerodynamic Flows. AIAA 2nd Computational Fluid Dynamics Conference (Proceedings), Hartford, CT, June 19-20, 1975, pp. 162-174.

34. Hafez, M. M. and Cheng, H. K.: Shock-Fitting Applied to Relaxation Solutions of Transonic Small-Disturbance Equations. AIAA Jour. vol. 15, no. 6, June 1977, pp. 786-793.

1. Report No. NASA CR-3064	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Operational Manual for Two-Dimensional Transonic Code TSFOIL		5. Report Date December 1978 6. Performing Organization Code
7. Author(s) Stephen S. Stahara		8. Performing Organization Report No. NEAR TR 94
9. Performing Organization Name and Address Nielsen Engineering & Research, Inc. 510 Clyde Avenue Mountain View, California 94043		10. Work Unit No. 11. Contract or Grant No. NAS2-8648
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration Washington, D. C. 20546		13. Type of Report and Period Covered Contractor Report 14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

A detailed operating manual is presented for the computer code TSFOIL recently developed by Murman, Bailey, and Johnson at NASA/Ames Research Center. This code solves the two-dimensional, transonic, small-disturbance equations for flow past lifting airfoils in both free air and various wind-tunnel environments by using a variant of the finite-difference method initially proposed by Murman and Cole. A description of the theoretical and numerical basis of the code is provided, together with complete operating instructions and sample cases for the general user. In addition, a programmer's manual is also presented to assist the user interested in modifying the code. Included in the programmer's manual are a dictionary of subroutine variables in common and a detailed description of each subroutine.

17. Key Words (Suggested by Author(s)) Transonic Theory Steady Flow Airfoils Wind Tunnel Flows Finite-Difference Relaxation	18. Distribution Statement UNCLASSIFIED-UNLIMITED Cat. 02

19. Security Classif. (of this report) UNCLASSIFIED	20. Security Classif. (of this page) UNCLASSIFIED	21. No. of Pages 179	22. Price* $9.00

*For sale by the National Technical Information Service, Springfield, Virginia 22161

NASA-Langley, 1978