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# Development of a Three-Dimensional Supersonic Inlet Flow Analysis

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# SUMMARY

A method for computing three-dimensional flow in supersonic inlets is described. An approximate set of governing equations is given for viscous flows which have a primary flow direction. The governing equations are written in general orthogonal coordinates. These equations are modified in the subsonic region of the flow to prevent the phenomenon of branching. Results are presented for the two sample cases, a Mach number equals 2.5 flow in a square duct, and a Mach number equals 3.0 flow in a research jet engine inlet. In the latter case the computed results are compared with the experimental data. A users' manual is included.

# INTRODUCTION

The design of an inlet for a supersonic aircraft is a difficult task in view of the wide operating range over which good performance is desired. On supersonic airplanes the inlet design is compromised by the requirement that the plane operate at all speeds from zero to the supersonic design point, including the low speed, high angle of attack regime encountered during take-off and landing. In addition most supersonic aircraft must have a subsonic cruise capability where fuel economy often becomes a significant factor. As a result of these varied and sometimes conflicting requirements, the design of a supersonic inlet is a compromise. The optimum geometry at one operating point must be modified to be acceptable at other operating conditions. Even variable geometry inlets, which are required at high speeds, are limited by the system penalties associated with their added weight.

There are two basic aspects of inlets which greatly influence the net thrust of a propulsion system: (1) pressure recovery, and (2) distortion. The net, or useful, thrust of an engine is the gross thrust out of the nozzle minus the inlet ram drag. At high Mach numbers the inlet ram drag is large and the net thrust thus becomes the small (relatively) difference between two large numbers. At a gross-to-net thrust ratio of 5, a 1% loss in gross thrust, therefore becomes a 5% loss in net thrust. Since inlet pressure recovery factors directly into the gross thrust, the pressure recovery is especially important. Distortion is also important, but in another way. When the level of distortion at the engine-inlet interface is smaller than the engine distortion tolerance, the effects of distortion are seen only in the pressure recovery. However, when the inlet distortion becomes higher than the engine tolerance level, the engine can no longer operate at that flight condition. Consequently, either the power setting must be reduced or the angle of attack or yaw must be reduced. Thus pressure recovery in the inlet is related to overall losses in the propulsion system while distortion is related to the necessity of operating at other than the desired flight condition.

Viscous effects in the inlet are important in determining both the pressure recovery and the distortion. Three categories of viscous effects in the inlet are of interest: (1) the simple boundary layer growth along walls, (2) bleed of the boundary layer air, and (3) shock-boundary layer interaction. The simple boundary layer growth along the walls of the inlet (ramp, cowl and sidewalls) contributes to the pressure loss in the system (as well as modifies the flow within the duct) by the blockage caused by the displacement effect of the boundary layers. Boundary layer bleed is used to control shock wave boundary layer interactions such that losses are kept to an acceptable level. Since the bleed air comes form the boundary layer, viscous effects are important in determining how the flow field responds to the bleed.

The shock wave boundary layer interactions within an inlet can cause both pressure losses and distortion. There are typically three types of shock wave boundary layer interactions within rectangular inlets. The first type, called incident shock interactions, occurs on the cowl and ramp surfaces. These incident interactions are characterized by an incident shock hitting the wall boundary layer and generating a reflected shock. Under certain conditions, boundary layer spearation can occur thus giving rise to a streamwise recirculation zone and large loss levels. The second type, which could be termed a glancing shock interaction, takes place along the sidewalls where the shock wave travels across the sidewall. The boundary layer in this type of interaction does not usually lead to a streamwise recirculation but rather contributes to the cross flow. The third type of interaction takes place in the corners. In this case, the incident and glancing interactions coalesce along with the merged floor and sidewall boundary layers.

The foregoing considerations suggest that inlet design technology would benefit from a detailed and accurate flow field calculation procedure which would include the effects of the boundary layer. In addition, since the glancing shock wave boundary layer interactions along the sidewalls as well as corner effects give rise to highly three-dimensional flow fields, the calculation procedure should be three-dimensional. Calculation procedures which are either two-dimensional or do not account for boundary layer effects have a more limited applicability. The matching of the three-dimensional inviscid 'core' flow with a three-dimensional boundary layer is difficult to do in a consistent manner particularly with a rotational core region. In addition the glancing interactions along the sidewalls and the flow in the corners do not fall within the concept of conventional three-dimensional boundary layer theory.

Although a full three-dimensional Navier-Stokes procedure would provide the necessary generality to predict the flow in an inlet, the required computer time and storage (Ref. 1) indicate that such a procedure should be used only if no suitable alternative exists. An optimum analysis would possess the general three-dimensional viscous nature of the Navier-Stokes equations, but would take advantage of realistic physical approximations to limit the computer running time and storage requirements associated with the solution of the complete three-dimensional Navier-Stokes equations. In this study, such a simplifying approximation was used to reduce the complete three-dimensional Navier-Stokes equations to a form which could be treated as an initial-boundary value problem and solved by forward marching in space. The assumption made is that a 'primary flow' direction exists and that diffusion arising from the rate of change of flow in this 'primary flow' direction can be neglected. In this manner a set of steady state equations is produced for entirely supersonic flows which can be solved by an efficient spatial marching procedure. In any embedded subsonic regions, such as at no-slip walls, further approximations are required to allow solution by spatial marching.

The remainder of this report will discuss the application of a three-dimensional forward marching procedure to calculate the flow fields in rectangular supersonic inlets, including viscous effects. The report is divided into five major sections. In the first section the basic set of coupled nonlinear partial differential equations which are derived from the Navier-Stokes equations will be presented. The second section will discuss the phenomenon of branching, which can occur in spatial marching procedures when embedded subsonic regions are present in the flow, and show how that problem is treated in the present study. In the third section the linearizations and numerical technique used to solve the governing equations will be discussed. This will include the application of boundary conditions. The fourth section will discuss the results of sample cases, and the fifth section will be a users' guide for the computer code used to obtain the solutions.

# LIST OF SYMBOLS

## Symbols

| | |
|---|---|
| $a$ | Parameter in Roberts' transformation, Eq. (A-1) |
| $A$ | Matrix containing marching direction coefficients |
| $b$ | Parameter in Roberts' transformation, Eq. (A-1) |
| $B$ | Constant in logarithmic law of the wall, nominal value 5.0 |
| $c$ | Parameter in Roberts' transformation, Eq. (A-1) |
| $D$ | Matrix containing cross plane coefficients |
| $\mathcal{D}$ | Damping factor |
| $h$ | Metric coefficient |
| $h_o$ | Stagnation enthalpy |
| $\ell_m$ | Mixing length |
| $L$ | Reference length |
| $M$ | Mach number |
| $\vec{n}_m$ | Unit vector in direction of Mach line |
| $N$ | Number of grid points |
| $P$ | Static pressure; normal probability function |
| $S$ | Column vector containing source terms |
| $u$ | x-direction (or primary direction) velocity |
| $\tilde{u}$ | Velocity parallel to a wall |
| $u_\tau$ | Wall shear velocity |
| $v$ | y-direction velocity |
| $w$ | z-direction velocity |
| $x$ | Streamwise or primary direction in orthogonal coordinates |
| $y$ | Transverse direction in orthogonal coordinates |
| $\tilde{y}$ | Distance from a wall |
| $y^+$ | Nondimensional distance from a wall (Eq. 12) |
| $\bar{y}^+$ | Constant in damping factor (Eq. 11) |
| $z$ | Spanwise direction in orthogonal coordinates |

## Greek Symbols

| | |
|---|---|
| $\beta$ | Crank-Nicolson factor; Roberts' transformation estimate of boundary layer |

| | |
|---|---|
| $\gamma$ | Ratio of specific heats; angle of coordinate relative to the horiztonal |
| $\Delta$ | Change |
| $\delta$ | Finite difference operator; change; thickness |
| $\kappa$ | von Karman constant (nominal value 0.43) |
| $\phi$ | Column vector of dependent variables |
| $\mu$ | Viscosity |
| $\rho$ | Density |
| $\sigma_1$ | Constant in damping factor (Eq. 11) |
| $\tau$ | Shear stress |
| $\psi$ | Mach angle relative to coordinate system |

Subscripts

| | |
|---|---|
| b | Boundary layer |
| lam | Laminar or molecular |
| T | Turbulent; transformation |
| w | Wall |
| x | Associated with the x-direction |
| y | Associated with the y-direction |
| z | Associated with the z-direction |
| 1 | Associated with the x-direction |
| 2 | Associated with the y-direction |
| 3 | Associated with the z-direction |
| $\infty$ | Free stream conditions |

Superscripts

| | |
|---|---|
| n | Evaluated at the $n^{th}$ axial location |
| * | Value after the first sweep |
| ** | Value after the second sweep |
| $\overline{\quad\quad}$ | Ensemble average |

## GOVERNING EQUATIONS

In this study, calculation of the flow in inlets of rectangular cross section is obtained by spatial marching of the equations for conservation of mass, momentum and energy. For the class of geometries considered in this study (Fig. 1), the equations are cast in a curvilinear orthogonal coordinate system which is aligned with the flow in such a manner that one coordinate direction can be identified as the 'primary flow' direction (Ref. 2). The remaining two coordinate directions are used to define the secondary flow. The coordinates are chosen as x, y and z with corresponding metric coefficients $h_1$, $h_2$ and $h_3$ such that the incremental distance $\delta s$ is defined as

$$(\delta s)^2 = (h_1 \delta x)^2 + (h_2 \delta y)^2 + (h_3 \delta z)^2 \tag{1}$$

The x-direction is defined as the primary flow or streamwise direction while y and z define the coordinates in the secondary flow plane at a given streamwise location. The class of geometries considered in this study (rectangular inlets) yields metric coefficients which are function of x and y only.

The governing equations are derived from the Navier-Stokes equations for a viscous, heat conducting perfect gas. All variables are ensemble averaged and thus the equations apply to both laminar and turbulent flow. Viscous terms are simplified by assuming thin boundary layers and all primary flow direction (x) diffusion terms are neglected. The equations are as follows:

Continuity Equation

$$\frac{\partial}{\partial x}(h_2 h_3 \rho u) + \frac{\partial}{\partial y}(h_1 h_3 \rho v) + \frac{\partial}{\partial z}(h_1 h_2 \rho w) = 0 \tag{2}$$

Primary Flow (x) Direction Momentum Equation

$$\begin{aligned}
&\frac{\partial}{\partial x}(h_2 h_3 \rho u^2) + \left[\frac{\partial}{\partial y} + \frac{1}{h_1}\frac{\partial h_1}{\partial y}\right](h_1 h_3 \rho u v) \\
&+ \left[\frac{\partial}{\partial z} + \frac{1}{h_1}\frac{\partial h_1}{\partial z}\right](h_1 h_2 \rho u w) - h_3 \frac{\partial h_2}{\partial x}\rho v^2 \\
&- h_2 \frac{\partial h_3}{\partial x}\rho w^2 + h_2 h_3 \frac{\partial p}{\partial x} \\
&= \frac{\partial}{\partial y}\left(\frac{h_1 h_3}{h_2}\mu \frac{\partial u}{\partial y}\right) + \frac{\partial}{\partial z}\left(\frac{h_1 h_2}{h_3}\mu \frac{\partial u}{\partial z}\right)
\end{aligned} \qquad (3)$$

First Cross Flow (y) Direction Momentum Equation

$$\begin{aligned}
&\left[\frac{\partial}{\partial x} + \frac{1}{h_2}\frac{\partial h_2}{\partial x}\right](h_2 h_3 \rho u v) + \frac{\partial}{\partial y}(h_1 h_3 \rho v^2) \\
&+ \left[\frac{\partial}{\partial z} + \frac{1}{h_2}\frac{\partial h_2}{\partial z}\right](h_1 h_2 \rho v w) - h_3 \frac{\partial h_1}{\partial y}\rho u^2 \\
&- h_1 \frac{\partial h_3}{\partial y}\rho w^2 + h_1 h_3 \frac{\partial p}{\partial y} \\
&= \frac{4}{3}\frac{\partial}{\partial y}\left(\frac{h_1 h_3}{h_2}\mu \frac{\partial v}{\partial y}\right) + \frac{\partial}{\partial z}\left(\frac{h_1 h_2}{h_3}\mu \frac{\partial v}{\partial z}\right)
\end{aligned} \qquad (4)$$

Second Cross Flow (z) Direction Momentum Equation

$$\left[\frac{\partial}{\partial x} + \frac{1}{h_3}\frac{\partial h_3}{\partial x}\right](h_2 h_3 \rho u w) + \left[\frac{\partial}{\partial y} + \frac{1}{h_3}\frac{\partial h_3}{\partial y}\right](h_1 h_3 \rho v w)$$
$$+ \frac{\partial}{\partial z}(h_1 h_2 \rho w^2) - h_2 \frac{\partial h_1}{\partial z}\rho u^2 - h_1 \frac{\partial h_2}{\partial z}\rho v^2 \quad (5)$$
$$+ h_1 h_2 \frac{\partial p}{\partial z} = \frac{\partial}{\partial y}\left(\frac{h_1 h_3}{h_2}\mu\frac{\partial w}{\partial y}\right) + \frac{4}{3}\frac{\partial}{\partial z}\left(\frac{h_1 h_2}{h_3}\mu\frac{\partial w}{\partial z}\right)$$

It is assumed that the energy equation is represented by the equation

$$h_o = \text{constant} \quad (6)$$

In the above u, v and w represent the mass weighted mean velocity components in the x, y and z directions, respectively, e.g.,

$$u = \frac{\overline{\rho u}}{\rho} \quad (7)$$

where the bar denotes an ensemble average. Also $\rho$ and p are the ensemble-averaged density and static pressure, respectively, $\mu$ is the effective viscosity (defined as the sum of the molecular viscosity and the turbulent Boussinesq viscosity, i.e., $\mu = \mu_{lam} + \mu_T$), and $h_o$ is the stagnation enthalpy. The pressure, density, velocities and stagnation enthalpy are related to each other through the perfect gas equation of state, viz.,

$$p = \frac{\gamma - 1}{\gamma}\rho\left[h_o - \frac{1}{2}(u^2 + v^2 + w^2)\right] \quad (8)$$

where $\gamma$ is the ratio of specific heats (assumed to be constant). The turbulent viscosity, $\mu_T$, is calculated from a mixing length (algebraic) formulation, i.e.,

$$\mu_T = \rho \ell_m^2 \left[ \left( \frac{1}{h_2} \frac{\partial u}{\partial y} \right)^2 + \left( \frac{1}{h_2} \frac{\partial w}{\partial y} \right)^2 + \left( \frac{1}{h_3} \frac{\partial u}{\partial z} \right)^2 + \left( \frac{1}{h_3} \frac{\partial v}{\partial z} \right)^2 \right]^{1/2} \tag{9}$$

where $\ell_m$ is an a priori specified mixing length distribution. In this study the mixing length of McDonald and Camarata (Ref. 3) was utilized.

$$\ell_m(\tilde{y}) = 0.09 \delta_b \tanh \left[ \kappa \tilde{y} / (0.09 \delta_b) \right] \mathcal{D} \tag{10}$$

where $\delta_b$ is the local boundary layer thickness, $\kappa$ is the von Karman constant (= 0.43), $\tilde{y}$ is the distance from the nearest wall, and $\mathcal{D}$, the sublayer damping factor, is defined by

$$\mathcal{D} = \left[ p(y^+ - \bar{y}^+) \right]^{1/2} / \sigma_1 \tag{11}$$

where $p(y^+ - \bar{y}^+)$ is the normal probability function,

$$y^+ = \tilde{y} (\tau / \rho)^{1/2} / (\mu_{lam} / \rho) \tag{12}$$

where $\tau$ is the local wall shear stress, $\bar{y}^+ = 23$ and $\sigma_1 = 8$.

The partial differential equations (Eqs. (2) through (5)) along with the auxiliary relationships (Eqs. (6) and (8) through (10)) represent the set of equations which are supposed to describe the flow phenomena inside a rectangular supersonic inlet. These equations, along with the solution initial values at the first streamwise station and the appropriate boundary conditions, will be used as the base set of equations which are to be solved in the remainder of this report. However, before proceeding further, it is important to emphasize that the numerical procedure used in the present work can treat more general or alternate forms of the specified auxiliary relationships and governing equations. For instance the form of the mixing length or the perfect gas equation of state could be changed. Additional curvature or stress terms (as long as they are not in the primary flow direction) could easily be incorporated.

# BRANCHING SOLUTIONS TO THE GOVERNING EQUATIONS

At high speed operating conditions the flow upstream of the inlet throat is supersonic except for the regions near the walls and thus the governing equations in the supersonic core region are essentially spatially hyperbolic in nature. In typical supersonic inlets, boundary layer bleed is used to minimize distortion and pressure loss generated at incident shock wave boundary interactions. The bleed also has the effect of suppressing the extent of the subsonic region in the boundary layers, where the differential equations are essentially elliptic in nature and downstream influences can effect the upstream flow. With sufficient bleed the elliptic (subsonic) regions can be kept negligibly small, and if modifications are made to the solution procedure in the subsonic region, the governing equations in the supersonic inlet can still be solved by a forward marching procedure.

If the initial value approximations to the Navier-Stokes equations are used directly, i.e., without modification, for the case of the rectangular supersonic inlet a phenomenon known as 'branching' generally occurs. Basically this phenomenon occurs because of the interaction of the subsonic portion of the flow with the supersonic portion of the flow. When an adverse pressure gradient occurs (as would happen with the shock boundary layer interaction), the subsonic region reacts to this by expanding (see e.g., Shapiro, Ref. 4). This in turn causes the supersonic portion of the flow to also turn which, of course, causes a further rise in pressure. Since there is no damping mechanism for this phenomenon (since streamwise diffusion terms have been removed to create the initial value approximations to the Navier-Stokes equations) the result can be an unstable situation. An excellent review and interpretation of the branching phenomenon is given by Weinbaum and Garvine (Ref. 5).

Typically the problem of branching with initial value approximations to the Navier-Stokes equations has been avoided by explicitly specifying the pressure, as for instance is done in classical boundary layer theory. Previous work aimed at eliminating this branching problem is largely based on the early work of Rudman and Rubin (Ref. 6). Rudman and Rubin solved the equations for hypersonic viscous flow over slender bodies with sharp leading edges. In this work the streamwise pressure gradient was neglected and thus the branching phenomenon was suppressed. Based on this two-dimensional work a series of three-dimensional problems have been attacked (Refs. 7 to 15). All of these three-dimensional solution procedures use iterative techniques and in each case the streamwise pressure gradient was neglected. Lubard and Helliwell (Ref. 12) also tried setting the streamwise pressure gradient to the explicitly computed value but because of the small streamwise pressure gradient associated with the geometry, no significant difference was noted over the case with the zero pressure gradient assumption. The neglecting of the streamwise pressure gradient to suppress branching therefore limited these earlier works to flow situations where little streamwise pressure gradient is generated, e.g., flow over a cone. Since the purpose of an inlet is to efficiently diffuse the external flow for use by the engine by generating a streamwise pressure gradient, numerical techniques which neglect the streamwise pressure gradient are not sufficient for the analysis of flow in an inlet. The remainder of this section will discuss a technique for suppressing branching without neglecting the streamwise pressure gradient.

The technique for implicitly including the effect of the streamwise pressure gradient in the initial value approximations to the Navier-Stokes equations can be divided into three parts. First, the equations are assumed to reduce to the more conventional boundary layer equations in the subsonic regions of the flow. Second, the wall tangency condition is enforced at the interface between a supersonic and subsonic region. Finally, the subsonic region is kept from directly influencing the supersonic regions by the use of 'type dependent' finite difference operators. The first two parts will now be discussed in detail; discussion of the 'type dependent' differencing will be deferred until the next section.

Figure 2 shows the division of a planar cross section (at a given streamwise station) into supersonic and subsonic regions for a typical rectangular inlet. In this study the initial value approximations to the Navier-Stokes equations, represented by Eqs. (2) through (5), were used directly for the supersonic region. Since these equations are essentially spatially hyperbolic in behavior in the supersonic region, these equations can be replaced by their finite difference analogues without further modification and then solved by a forward marching procedure. In the (thin) subsonic region Eqs. (2) through (5) are modified. First it is assumed that in the entire (thin) subsonic region the momentum equation normal to the nearest wall is replaced by the conventional boundary layer approximation that the pressure gradient normal to the wall is balanced by the curvature terms. In a region close to a 'y wall' the cross flow y-momentum equation is replaced by

$$h_1 h_3 \frac{\partial p}{\partial y} = h_1 \frac{\partial h_3}{\partial y} \rho w^2 + h_3 \frac{\partial h_1}{\partial y} \rho u^2 \tag{13}$$

while near a 'z wall' the cross flow z-momentum equation is replaced by

$$h_1 h_2 \frac{\partial p}{\partial z} = h_2 \frac{\partial h_1}{\partial z} \rho u^2 + h_1 \frac{\partial h_2}{\partial z} \rho v^2 \tag{14}$$

For the case of rectangular inlets $h_3$ is equal to unity and the metrics are functions of x and y only. Hence Eqs. (13) and (14) can be reduced to their familiar boundary layer form

$$\frac{\partial p}{\partial y} = \frac{1}{h_1} \frac{\partial h_1}{\partial y} \rho u^2 \tag{15}$$

and

$$\frac{\partial p}{\partial z} = 0 \tag{16}$$

The second approximation is termed the wall tangency condition and this condition is used to replace the continuity equation on the sonic line by the approximation that the flow is parallel to the nearest wall. The tangency condition thus becomes a problem of geometry only (Fig. 3). In a region close to a 'y wall' (with no bleed) this becomes

$$\frac{v}{u} = \tan(\gamma_w - \gamma) \tag{17}$$

and in a region close to a 'z wall' (with no bleed) this becomes (since the $\gamma$'s are a function of y only)

$$w = 0 \tag{18}$$

It is to be noted that the normal pressure gradient-curvature relationship replaces the cross flow momentum equation everywhere in the subsonic region while the wall tangency condition is applied only at the sonic line. In the subsonic region the forms of the primary flow or x-momentum equation and the continuity equation (below the sonic point) remain unchanged. In addition the remaining momentum equation, i.e., the z-momentum equation near a 'y wall' or the y-momentum equation near a 'z wall', is also unchanged. This last feature allows for the existence of y-direction pressure gradients near a 'z wall' and z-direction pressure gradients near a 'y wall'. Thus, for instance, glancing shocks on the sidewalls are allowed to generate subsonic cross flows as a result of the cross flow pressure gradient generated in the supersonic region. The above formulation allows the streamwise pressure gradient term to be included without causing the initial value approximate form of the Navier-Stokes to exhibit branching. The pressure gradient-curvature relationship, along with the wall tangency condition and the appropriate differencing, has the effect of allowing the supersonic region to impress its pressure on the subsonic region while preventing the subsonic region from directly interacting with the supersonic region. The effect of the subsonic region on the supersonic region is indirect and occurs only as a result of stream tube expansion, not as the result of rate of change of stream tube expansion which it would if the normal velocity were not constrained by the wall tangency approximation. This limited interaction between the subsonic and supersonic regions is carried over into the numerical difference molecule which is 'type-dependent' in the manner in widespread use for transonic inviscid calculations (Jameson, Ref. 16). The type-dependent differencing of the dependent variables will be discussed in the latter part of the next section.

## NUMERICAL TECHNIQUE

In this section a brief discussion of the numerical procedure will be presented. For more details, the reader is referred to Refs. 2 and 17. The general approach is to take the governing system of equations which describe the flow in a supersonic inlet (Eqs. (2) through (5) and (15) through (18) as previously described) and replace them with finite difference analogues. The result of the replacement is a set of coupled nonlinear algebraic equations. These equations are linearized by Taylor series expansions about the solution at the most recent streamwise station. This results in a series of coupled implicit linear equations for the unknown dependent variables at the next streamwise station. The terms are then grouped by the coordinate direction and then solved by a consistently split, block implicit technique. The splitting technique is used to reduce the multidimensional (in this case two-dimensional) linearized difference equations to a sequence of one-dimensional matrix equations. For three point or less difference formulations, these linear one-dimensional difference equations can be written in a block-tridiagonal matrix form and solved efficiently and without iteration by standard block elimination techniques. To demonstrate how the above formation is used, the method will be applied to the continuity equation, Eq. (2). The first step is to replace the partial differential equation by its finite difference analogue. This results in, for variable centering in the streamwise direction,

$$\frac{(h_2h_3\rho u)^{n+1} - (h_2h_3\rho u)^{n}}{\Delta x} + \beta\left[\delta_y(h_1h_3\rho v) + \delta_z(h_1h_2\rho w)\right]^{n+1} + (1-\beta)\left[\delta_y(h_1h_3\rho v) + \delta_z(h_1h_2\rho w)\right]^{n} \tag{19}$$

where $\Delta x$ is the grid spacing in the marching (x) direction, $\delta_y$ and $\delta_z$ are the difference operators in the y and z cross plane directions, respectively, and the parameter $\beta$ has been introduced to permit a variable centering of the scheme in the x marching direction. If $\beta = 1$, a fully implicit scheme results and $\beta = 1/2$ yields the Crank-Nicolson formulation. n refers to the streamwise (x) station where the values of the dependent variables are known while n + 1 refers to the next streamwise station where the values of the dependent variables are unknown. Equation (19) is written at each grid point in the plane perpendicular to the streamwise direction, i.e., the y-z plane at x station n + 1. Equation (19) is nonlinear in the unknown dependent variables and is obviously coupled to the other governing equations through u, v, w and $\rho$. Linearizing Eq. (19) about the $n^{th}$ streamwise station by Taylor series expansion yields

$$\begin{aligned} h_2^{n+1} h_3^{n+1} \frac{(\rho^n u^{n+1} + u^n \rho^{n+1} - 2\rho^n u^n)}{\Delta x} &+ \rho^n u^n \frac{(h_2^{n+1} h_3^{n+1} - h_2^n h_3^n)}{\Delta x} \\ + \beta \delta_y \left[ h_1^{n+1} h_3^{n+1} (\rho^n v^{n+1} + v^n \rho^{n+1} - \rho^n v^n) \right] & \\ + (1-\beta) \delta_y (h_1^n h_3^n \rho^n v^n) & \\ + \beta \delta_z \left[ h_1^{n+1} h_2^{n+1} (\rho^n w^{n+1} + w^n \rho^{n+1} - \rho^n w^n) \right] & \\ + (1-\beta) \delta_z (h_1^n h_2^n \rho^n w^n) = 0 & \end{aligned} \tag{20}$$

Equation (20) is a <u>linear</u> equation in $u^{n+1}$, $v^{n+1}$, $w^{n+1}$ and $\rho^{n+1}$. This procedure can be utilized to derive linear implicit difference approximations to the momentum equations (or to the subsonic approximations to these equations). Pressure terms are easily linearized using the equation of state and the perfect gas law, for example

$$\left( \frac{\partial p}{\partial y} \right)^{n+1} \cong \delta_y \left\{ \frac{\gamma - 1}{\gamma} \rho \left[ h_o - \frac{1}{2} (u^2 + v^2 + w^2) \right] \right\}^{n+1} \tag{21}$$

becomes (with constant $\gamma$ and $h_o$)

$$\begin{aligned} \left( \frac{\partial p}{\partial y} \right)^{n+1} \cong \frac{\gamma - 1}{\gamma} \delta_y \Big\{ & -\rho^n \left[ u^n u^{n+1} + v^n v^{n+1} + w^n w^{n+1} \right] \\ & + \left[ h_o - \frac{1}{2} (u^2 + v^2 + w^2)^n \right] \rho^{n+1} + \rho^n \left[ u^2 + v^2 + w^2 \right]^n \Big\} \end{aligned} \tag{22}$$

When each of the governing equations is linearized as above, the resulting difference approximations can be grouped by coordinate direction and written in compact linear matrix difference operator notation as

$$\frac{A}{\Delta x}(\Phi^{n+1} - \Phi^{n}) = D_y\Phi^{n+1} + D_z\Phi^{n+1} + S \tag{23}$$

where $\Phi$ is a column vector containing the dependent variables u, v, w and $\rho$ at each grid point in the y-z plane and A is a square 4x4 submatrix. The $D_y$ and $D_z$ are square 4x4 submatrices (written at each grid point in the y-z plane) containing elements which are themselves spatial difference operators for the y and z directions, respectively. S is a column vector reserved for any source terms present. The matrices A, $D_y$, $D_z$ and the column vector S contain only quantities which are known, hence Eq. (23) is linear in $\Phi^{n+1}$.

Equation (23) could be solved by a direct method but only at considerable cost considering the number of grid points required for acceptable accuracy. In this study to reduce the computational labor of solving the system of equations the Douglas-Gunn splitting technique was utilized. For the case considered this results in the equations

$$\frac{A}{\Delta x}(\Phi^{*} - \Phi^{n}) = D_y\Phi^{*} + D_z\Phi^{n} + S \tag{24}$$

for the first sweep and

$$\frac{A}{\Delta x}(\Phi^{**} - \Phi^{n}) = D_y\Phi^{*} + D_z\Phi^{**} + S \tag{25}$$

for the second sweep, where $\Phi^{**}$ is the approximation to $\Phi^{n+1}$ to order $\Delta x^2$. Rather than solve Eq. (25) directly, some computational labor can be saved by subracting Eq. (24) from Eq. (25) and solving for the difference across a step, i.e.,

$$\frac{A}{\Delta x}(\Phi^{**} - \Phi^{*}) = D_z(\Phi^{**} - \Phi^{n}) \tag{26}$$

Additional computational labor can also be saved by observing that during the first sweep the implicit coupling between the z-momentum equation and the remaining equations is weak and that during the second sweep the implicit coupling between the y-momentum equation and the remaining equations is also weak. This uncoupling allows one to solve Eqs. (24) and (26) in two parts, the first with 3x3 submatrices and the second with 1x1 submatrices rather than in one part with 4x4 submatrices. For this system of equations this results in approximately 50% savings in computer time in the block elimination procedure. This concept is termed reducible sub-blocks and is discussed in more detail in Ref. 18.

Before proceeding to a discussion of the forms of the cross plane difference operators ($\delta_y$ and $\delta_z$) as applied to the case of the rectangular inlet, two further areas must be covered, initial conditions and boundary conditions. In order to apply Eqs. (24) and (26) it is necessary that all values of the dependent variables, viz., u, v, w and $\rho$ be provided at each grid point in the initial y-z plane. Once this is done Eqs. (24) and (26) can be marched in the primary flow direction (x) if appropriate boundary conditions are specified at the four boundaries corresponding to the boundaries of the y-z computational domain. Boundary conditions must be specified for each of the four partial differential equations. However because of use of the block matrix technique of solving all equations simultaneously (rather than the use of a sequential iterative solution technique) coupled boundary conditions can be specified. For instance, one possible boundary condition could be to specify that the pressure normal to the cowl is zero, i.e.,

$$\frac{\partial p}{\partial y} = 0 \tag{27}$$

However the pressure has been eliminated from the system by use of the perfect gas law and the assumption of constant stagnation enthalpy. Thus Eq. (27) becomes after linearization, a coupled relationship, Eq. (22) between the dependent variables. However the virtue of the block implicit approach is that this coupled but linearized relationship is easily implemented as a boundary condition.

Turning to the problem of 'type dependent' differencing, the form of the difference operators utilized in the present study is a necessary part of the technique of prohibiting the subsonic flow from causing the solution to branch. In the supersonic portion of the flow all cross plane derivatives are represented by means of standard three point central difference formulae. In the subsonic portion of the flow all pressure derivatives in the direction normal to the nearest wall are taken as two point one-sided away from the wall. This allows the subsonic pressure to be implicitly set by the supersonic flow. In addition, in the subsonic region the convective derivatives normal to the nearest wall are differenced as two point one-sided towards the wall. Finally on the sonic line, the convective derivatives normal to the nearest wall are differenced as two point one-sided away from the wall.

# TEST CASES

In order to evaluate the computational procedure described in the previous sections, two test cases were run with the PEPSIS computer code. The first case considered was that of a Mach number 2.5 flow entering a square duct. At some point downstream of the entrance air was blown into the duct through both the bottom and top walls. Further downstream the blowing was terminated. The intent of this test case was to determine if the PEPSIS computer code would correctly predict the expansion and compression waves produced by the initiation and termination of blowing. The second case considered was the flow in a Mach number 3.0 high-performance, "two-dimensional" mixed-compression, inlet system (Refs. 19 to 21). Although termed "two-dimensional" the inlet had a rectangular cross-section and the computations reflected this three-dimensionality. For the inlet case experimental data were available and hence comparisons were made between the predicted and measured results. Details of the two test cases run, the results of the theoretical predictions, and (for the inlet case) comparisons between theory and measurements will next be discussed in detail.

The first test considered was a uniform flow entering a square duct (Figure 4). The free stream Mach number was 2.5, while the Reynolds number based on free stream properties and the duct height was 5000. The viscosity was assumed to be constant. The primary direction of the flow was parallel to the walls of the duct. From 0.36 to 0.44 duct heights downstream of the duct entrance, air was normally injected into the oncoming flow from both the floor and top surface of the duct. The injection rate was varied in the spanwise plane as is shown in Figure 5. For this case a 10 x 10 uniform finite difference grid was utilized. Because of the uniform nature of the flow entering the square duct and the geometry of the duct two planes of symmetry can be associated with this problem, and hence the flow need only be solved in the quarter plane. On the planes of symmetry, symmetry boundary conditions were utilized, while on the walls the three no-slip conditions were used for the velocity components and the normal momentum equation was used as the fourth condition. Figures 6 through 8 show the transverse pressure coefficient distributions (at four spanwise stations each) at three selected streamwise stations, i.e., at streamwise locations 0.522, 0.810, and 2.213 duct heights from the duct entrance.

In Figure 5, which is slightly downstream of the cessation of blowing, the compression disturbance can be seen propagating across the duct. Since the amount of blowing decreases as the sidewall is approached, the strength of the disturbance is smaller in the region of the sidewall. In Fig. 6 the effect of the expansion (caused by the cessation of blowing) can be seen to have somewhat cancelled the effect of the compression in the region of the wall, and by the time the flow has reached the last streamwise station (Fig. 6) the interaction effects of the compression and expansion have to a great degree cancelled each other out. Figure 9 shows the streamwise variation of the pressure coefficient at selected transverse locations on the vertical plane of symmetry (curves (1), (2) and (3) correspond to transverse locations of 0.05, 0.22 and 0.45 duct heights respectively). From careful examination of this plot it can be deduced that over the streamwise domain of this calculation the compression wave has reflected off the horizontal plane of symmetry and has propagated back down to the bottom wall. On the other hand, the expansion wave has propagated upward, reflected off the plane of symmetry, but not yet reached the bottom wall.

For the second test case, the PEPSIS computer code was used to calculate the flow field for the NASA Ames Research Center large-scale variable-geometry inlet system operating at a design Mach number of 3.0 with a Reynolds number per foot of $2.2 \times 10^6$. A schematic of the inlet system is shown in Fig. 10. For more details of this experimental apparatus the reader is referred to Refs. 19 to 21. The inlet capture area is 14 inches square with the ramp initially inclined 7° to the horizontal. A variable-ramp drive mechanism allows the second portion of the ramp to pivot around a point 28 inches from the ramp leading edge. The design condition (and that used for the computations) was a second ramp angle inclined at 14° to the horizontal while the cowl surface is parallel to the horizontal. The coordinate system used for the computation of the flow field is shown in Fig. 11. This coordinate system was generated by Charles Towne of NASA Lewis Research Center with the ADD computer code (Ref. 22). The ADD code uses a Schwartz-Cristoffel transformation technique to calculate the conformal coordinate system ($h_1 = h_2$)

associated with a given geometry. The ADD code will not generate a coordinate system that allows for a step discontinuity in curvature (as happens when the ramp angle discontinuously changes from 7° to 14°, but instead generates a smooth curve rather than a discontinuity. For instance, inspection of Fig. 11 shown that the initial ramp angle is not 7°, but instead transitions from 0° to 7° gradually. The second ramp angle, 14°, also does not occur discontinuously.

The coordinate system shown in Fig. 11 was used by the PEPSIS computer code to calculate the flow field inside the NASA Ames inlet. It was assumed that the initial flow was at uniform free stream conditions. For the first runs on the NASA Lewis Research Center's UNIVAC 1100 a 20 x 20 nonuniform mesh was used in the cross-sectional plane with (as can be seen in Fig. 11) packing of grid points in the region of the ramp and cowl. The PEPSIS computer code was marched 181 streamwise steps, the computation terminating just upstream of the inlet throat. For the first 10 streamwise stations a marching step size, $\Delta x$, of 0.025 was used. From streamwise station 10 to 20, the marching step size was increased from 0.025 to 0.04. After station 20 the step size remained constant at 0.04. The cowl was encountered at streamwise station 70. (It is to be noted that the streamwise grid of Fig. 11 only plots every other marching station.) $\Delta x$ is the computational step size and not the physical step size, which is given by $h_1(x)\Delta x$, thus accounting for the varying physical step size when $\Delta x$ is a constant.

The boundary conditions utilized for the computation in the inlet can be divided into three categories: (1) boundary conditions on walls, (2) boundary conditions on the computational surface upstream of cowl, and (3) boundary conditions on the plane of symmetry. The wall boundary conditions require that the two components of the velocity parallel to a wall obey the wall function boundary condition (see Appendix B) and that the velocity component normal to the wall be zero (or equal to the bleed rate). In addition the momentum equation in the direction normal to a wall is presumed to be satisfied. On the computational surface upstream of the cowl Mach line extrapolation was utilized (see Appendix B). Initially some difficulty was encountered with these boundary conditions. Preliminary analysis indicates that this problem was associated mainly with the poor accuracy of the metric information in the vicinity of the boundaries. The last category of boundary conditions was applied on the transverse plane of symmetry. This computational plane of symmetry exists only because of the geometry of the inlet considered and because a 0° yaw case was considered. The symmetry conditions require that the transverse derivatives of the streamwise velocity, u, transverse velocity, v, and the density, $\rho$, be zero at the plane of symmetry. In addition, the spanwise velocity, w, must be zero. Because of the magnitude of the Reynolds number of the flow inside the inlet, the entire flow was presumed to be turbulent. For the case considered the previously discussed mixing length model of McDonald and Camarata (Ref. 3) was utilized. Finally, for this calculation the effect of bleed was neglected.

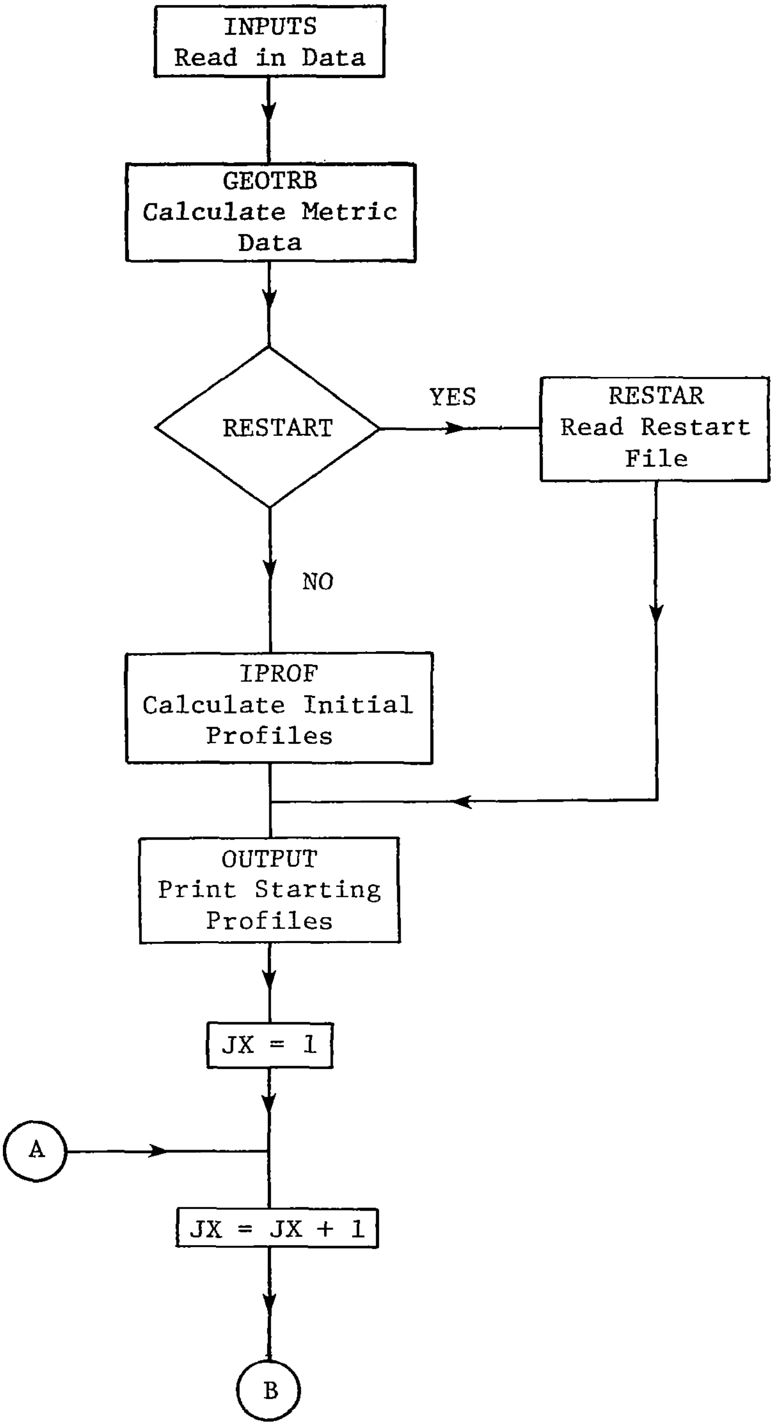
Results of the computation are presented in Figs. 12 to 17. Figure 12 shows the inviscid shock pattern. The pattern for the above case was computed by two-dimensional method of characteristics (Ref. 19). Figure 13 shows the "shock" pattern as calculated by the PEPSIS computer code. Except for the shock produced by the discontinuous 7°-14° bend in the ramp all of the inviscid shock waves are reproduced by the PEPSIS calculation. It is likely that the absence of the shock due to the ramp discontinuity is caused by the previously discussed smoothing produced by the ADD code coordinate system. This smoothing causes the PEPSIS code to produce a series of compression waves rather than an easily identifiable shock wave. Figures 14 and 15 show the streamwise distribution of pressure along both the ramp and cowl at the plane of symmetry. It is evident that the PEPSIS computations agree very well with the experimental results, both in the positioning of and the strength of the shock waves. Figures 16 and 17 compare the two-dimensional method of characteristics ramp and cowl pressure distributions with those produced by the PEPSIS computer code. The PEPSIS results compare favorably with the method of characteristics solution. The only difference is that the PEPSIS results are slightly more diffuse than the method of characteristics solution.

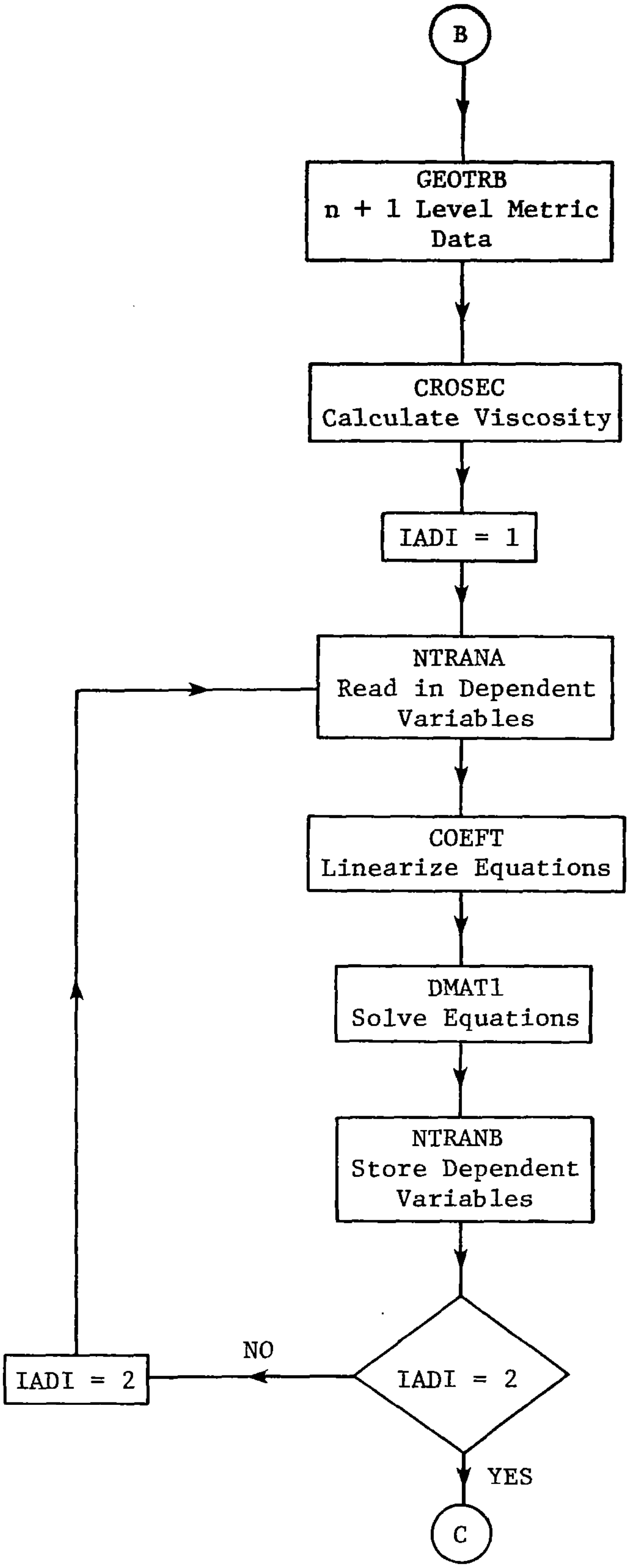
# USERS' MANUAL

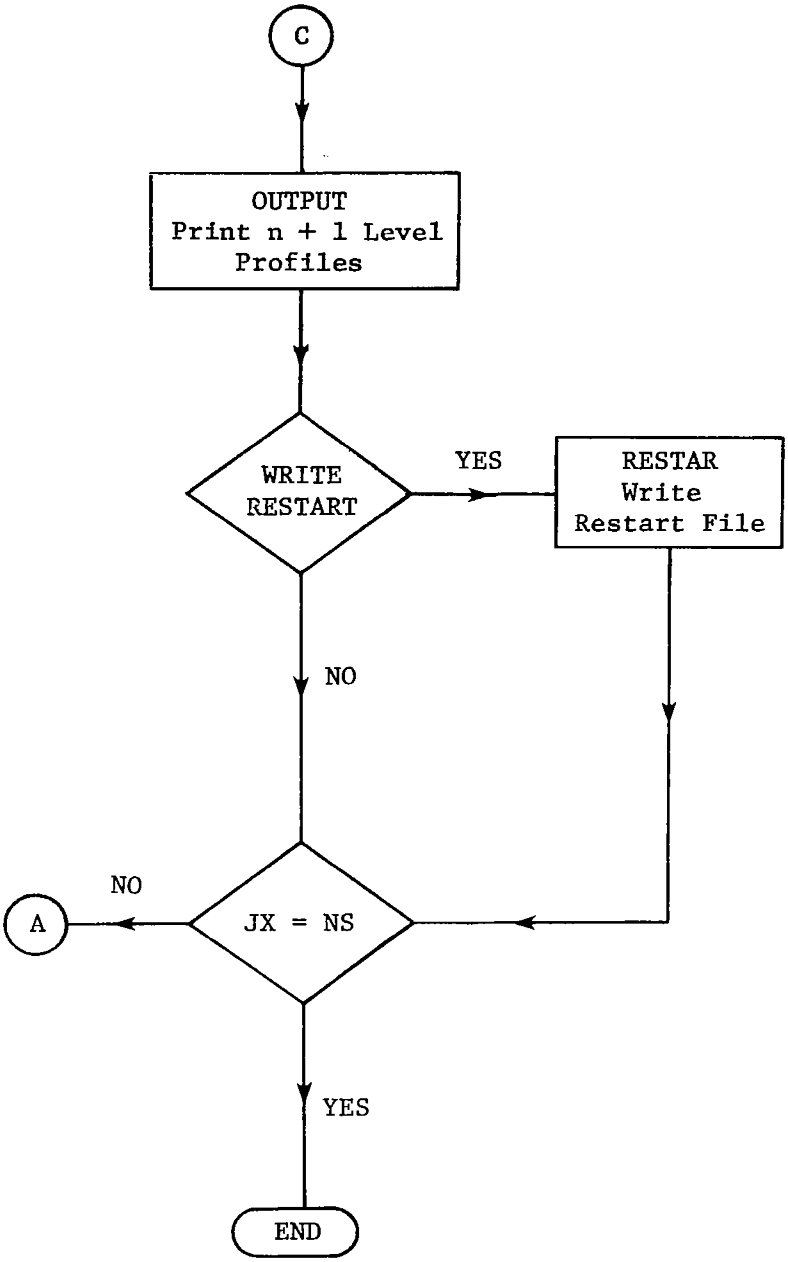
The PEPSIS users' manual is meant to serve as a guide in helping the user perform successful runs with the PEPSIS computer program. The manual is divided into six parts. The first part is a flow diagram to help the user understand the basic flow of the program. Because of the size of the code, a detailed flow diagram would be rather cumbersome to use and would probably by of little use to the user. Therefore the flow diagram provides only the 'big picture' of the code. If a user is interested in the details, it is suggested that he consult the program listing. The second part describes in detail the input required to run a case with the PEPSIS computer code. The vast majority of the input is input via the NAMELIST format. There are two advantages to the NAMELIST format, viz., that if the default values are acceptable, the user need not input that variable and that, within a given NAMELIST, the order in which the variables are entered is irrelevant. The third part of the users' manual describes the error conditions which can occur in PEPSIS and the corrective action which should be taken if they occur. The fourth part describes the PEPSIS FORTRAN variables. The FORTRAN variable (with dimensions for dimensional variables), their COMMON block for the variable, and the description of the variable is presented for the variables in alphabetical order. The fifth part describes the storage devices which are required to make a run with PEPSIS. If general orthogonal coordinates are used, the present version of PEPSIS reads data off unit 10 by means of binary reads. The main reason that this was done was to economize on computer run time as formatted reads take considerably more time than binary reads. However if the metric data generated on unit 10 is done on say a UNIVAC computer and the PEPSIS run is to be made on say a CDC computer, the binary reads must be changed to formatted reads because of the incompatability between UNIVAC binary and CDC binary. The required changes must be made in SUBROUTINE GEOTRB. Finally, the sixth part of the users' manual gives the input and output for a typical PEPSIS run.

Before proceeding to the first part, it is perhaps wise to give some general background that will help in interpreting that which follows. Figure 18 is a schematic of a typical cross flow section at a given axial station. In the PEPSIS computer code, the transverse direction is denoted as the y-direction while the spanwise direction is denoted as the z-direction. The lower boundary is called the 1 surface, the upper boundary the 2 surface, the left boundary the 3 surface and the right boundary is called the 4 surface. The PEPSIS logic assumes that the ramp is on a 1 surface and that the cowl is on a 2 surface. The 3 surface is assumed to be a plane of symmetry while the sidewall must be on a 4 surface.

Flow Diagram for PEPSIS Code




B
GEOTRB
n + 1 Level Metric Data
CROSEC
Calculate Viscosity
IADI = 1
NTRANA
Read in Dependent Variables
COEFT
Linearize Equations
DMAT1
Solve Equations
NTRANB
Store Dependent Variables
IADI = 2
NO
IADI = 2
YES
C


C
OUTPUT
Print n + 1 Level
Profiles
WRITE
RESTART
YES
RESTAR
Write
Restart File
NO
NO
A
JX = NS
YES
END

## PEPSIS Input

Except for a title card and two input variables which are needed by the plot file, all PEPSIS input is input through NAMELISTS $LIST2 through $LIST8. The input variables in each of the NAMELISTS will be described and if a default value exists, its value will be given.

### Plot File Input

Card 1

| Columns | Format | Variable | Function |
|---|---|---|---|
| 1-32 | 5A6,A2 | TITLE(I) | Title Card |

Card 2

| Columns | Format | Variable | Function |
|---|---|---|---|
| 1-2 | I2 | ISYM | Reciprical of Symmetry |
| 3-12 | F10.0 | SYSTEM | SYSTEM=1 - Quasi-Cartesian Coordinates<br>SYSTEM=2 - Quasi-Cylindrical Coordinates |

### Namelist Input Description

| Namelist or variable name | Description |
|---|---|
| $LIST2 | Reference Variables |
| UZERO | Reference value of velocity (ft/sec). |
| YZERO | Reference length (ft). |
| TZERO | Reference temperature ($^{o}$R), Default 416.0 $^{o}$R. |
| VISCOS | Reference kinematic viscosity (ft$^2$/sec). |
| RG | Gas constant (ft-lbf/slug-$^{o}$R), Default 1716.3 |
| USCALE | Scale factor for metric information from ADD code. |
| IWR | Flag to print out namelists. Default value is 1.<br>IWR=1. Print namelists.<br>IWR=0. Do not print namelists. |

| Namelist or variable name | Description |
|---|---|
| $LIST3 | Geometry Options |
| IAXI | Axisymmetric geometry sentinel. Default value is 0.<br>IAXI = 0. No axisymmetric option.<br>IAXI = 1. Axisymmetric option used. |
| ICAR | Cartesian geometry sentinel. Default value is 1.<br>ICAR = 0. No Cartesian option.<br>ICAR = 1. Cartesian geometry used.<br>If ICAR = 0 and IAXI = 0, general orthogonal coordinates are used. For this option storage unit 10 must be generated from the ADD code (or equivalent). (Ref. 22). |
| $LIST4 | Geometry and Restart Options |
| YS(1,1) | Nondimensional value of y at the number 1 surface. |
| YS(2,1) | Nondimensional value of y at the number 2 surface. |
| YS(1,2) | Nondimensional value of z at the number 3 surface. |
| YS(2,2) | Nondimensional value of z at the number 4 surface. |
| NE(IADI) | Number of grid points in the y(IADI = 1) and z(IADI = 2) directions. |
| IGRID(IADI) | Roberts' grid transformation sentinel for y and z directions, respectively. Default values are 1. (See Appendix A).<br>IGRID(IADI) = 0. Equally spaced grid points.<br>IGRID(IADI) = 1. One boundary layer grid at surface number 1 (IADI = 1) or 3 (IADI = 2).<br>IGRID(IADI) = 2. Boundary layers at both surface numbers 1 and 2 (IADI = 1) or surface numbers 3 and 4 (IADI = 2).<br>IGRID(IADI) = 3. One boundary layer grid at surface number 2 (IADI = 1) or 4 (IADI = 2). |

| Namelist or variable name | Description |
|---|---|
| EPS(IADI) | Estimate of boundary layer thickness for use with Roberts' grid transformation. If IGRID(IADI) = 2, the value of EPS(IADI) is the same on both surfaces. EPS(IADI) equals the percentage of the distance YS(2,IADI) - YS(1,IADI). EPS corresponds to the $\beta$ used in Appendix A. |
| NS | Number of stations to be marched during a run. |
| X1,X2,XENTR,AP | X2-X1 is the nominal value of $\Delta X$ in the equation<br>X(I) = X(I-1) + AP*(X(I-1) - X(I-2))<br>where X(ISTART) = XENTR<br>and X(ISTART+1) = X(ISTART) + $\Delta X$<br>and I varies from ISTART+2 to NS. For a restart ISTART=IRSTIN while for a new case ISTART=1, AP represents the rate at which the marching step size grows (AP > 1) or diminishes (AP < 1). Default values of XENTR and AP are 0.0 and 1.0, respectively. The value of XENTR must be input during each restart run and must equal the value of X at the restart station. |
| IRSTIN | Marching station number where data is to be read in for restart case. Default value is 0.<br>IRSTIN = 0. Not a restart case.<br>IRSTIN $\neq$ 0. Restart case started from data at station IRSTIN. |
| IRSTOT | Interval for saving restart information. Default value is 0.<br>IRSTOT = 0. No restart information is saved.<br>IRSTOT $\neq$ 0. Information is saved at each IRSTOT$^{th}$ station. |
| JRSTIN | Logical file name from which restart information is to be read. Default value is 11. |
| JRSTOT | Logical file name onto which restart information is to be written. Default value is 11. |
| NFILE | Sequence number in JRSTIN of the desired restart information. |

| Namelist or variable name | Description |
|---|---|
| NSAVED | Number of restart stations saved on JRSTOT. Default value is 0. On a restart by setting JRSTOT = JRSTIN and NFILE = NSAVED one file can be used for both read and write without destroying the information previously saved. |
| AMDOTD(I,JX,N) | Distribution of nondimensional bleed velocity at marching station JX and surface N. The index I represents the spanwise (for N = 1 and 2) or transverse (for N = 3 and 4) grid locations for the distributions. Default values are 0.0 AMDOTD(20,200,4). |
| XJXTW | Marching direction location at which the cowl begins. Default value is 0.0. |
| $LIST5 | Turbulent Option |
| ILAM | Sentinel for laminar flow. Default value is 1.<br>ILAM = 0. Turbulent flow.<br>ILAM = 1. Laminar flow. |
| $LIST6 | Mixing Length Constant |
| YSLOT(IADI) | Representative location of outer edge of boundary layer, $\delta_B$ of Eq. (10). |
| $LIST7 | Boundary Conditions |
| NBCON(IVAR,N,1) | Boundary condition of the IVAR$^{th}$ variable on the N$^{th}$ surface.<br>X-Momentum Equation (NV1 = 1)<br>NBCON(NV1,N,1) = 0. U set equal to 0.0.<br>NBCON(NV1,N,1) = 1. First derivative of u set equal to 0.0 when N $\neq$ 2. For N = 2, u is set by Mach line extrapolation in region upstream of the cowl. (See Appendix B). Downstream of the cowl appropriate wall boundary condition is set automatically by code.<br>NBCON(NV1,N,1) = 2. Second derivative of u set equal to zero.<br>NBCON(NV1,N,1) = 3. Not used. |

Namelist or variable name

Description

NBCON(NV1,N,1) = 4. Value of u set by wall functions. See write-up on NBCON(NV2,N,1) = 4 and NBCON(NV3,N,1) = 4. (See Appendix B).

Y-Momentum Equation (NV2 = 2)

NBCON(NV2,N,1) = 0. V set equal to AMDOTD(IZ,JX,N) where IZ is the spanwise grid location, JX is the marching location and N is 1 or 2. For N equal to 3 or 4, V set equal to 0.0.

NBCON(NV2,N,1) = 1. First derivative of V set equal to 0.0 when N ≠ 2. If N = 2, V is set by Mach line extrapolation upstream of the cowl. Downstream of the cowl appropriate wall boundary condition set automatically by code.

NBCON(NV2,N,1) = 2. Second derivative of V set equal to zero.

NBCON(NV2,N,1) = 3. Not used.

NBCON(NV2,N,1) = 4. Value of V set by wall functions. Cannot be used for N = 1 or 2. If used for N = 3 or 4, values of NBCON(NV1,N,1) must be set equal to 4.

Z-Momentum Equation (NV3 = 4)

NBCON(NV3,N,1) = 0. W set equal to AMDTOD(IY,JX,N) where IY is the transverse grid location, JX is the marching location and N is 3 or 4. For N equal to 1 or 2, W is set equal to 0.0.

NBCON(NV3,N,1) = 1. First derivative of W set equal to 0.0.

NBCON(NV3,N,1) = 2. Second derivative of W set equal to 0.0.

NBCON(NV3,N,1) = 3. Not used.

NBCON(NV3,N,1) = 4. Value of W set by wall functions. Cannot be used for N = 3 or 4. If used for N = 1 or 2, values of NBCON(NV1,N,1) must be set equal to 4.

| Namelist or variable name | Description |
|---|---|
| | Continuity Equation (NRHO = 3) |
| | NBCON(NRHO,N,1) = 0. Pressure specified to be that of pressure at previous station. |
| | NBCON(NRHO,N,1) = 1. Apply normal momentum equation boundary condition when $N \neq 2$. If $N = 2$, $\rho$ is set by Mach line extrapolation upstream of the cowl. Downstream of the cowl appropriate wall boundary condition set automatically by the code. |
| | NBCON(NRHO,N,1) = 2. Second derivative of density set equal to 0.0. |
| $LIST8 | Plot Information |
| IPLOT | Plot option sentinel. Default value is 0. |
| | IPLOT = 0. No plots. |
| | IPLOT = 1. Plot file created. |

# Error Conditions in PEPSIS

## SUBROUTINE GEOTRB

In SUBROUTINE GEOTRB there are three modes of failure when using the general orthogonal geometry capability. All failure modes indicate that an attempt is being made to calculate metric information in a region where the ADD computer code (or its equivalent) did not generate data. The error message is printed in the dayfile.

| | |
|---|---|
| 'STOP GEOTRB' | Indicates that an attempt is being made to obtain metric information at a value of x less than that at the first x-station for which data was generated by the ADD code. |
| 'STOP GEOTRB1' | Indicates that an attempt is being made to obtain metric information at a value of y less than that of the first y-station for which data was generated by the ADD code. |
| 'STOP GEOTRB2' | Indicates that an attempt is being made to obtain metric information at a value of y greater than that at the last y-station for which data was generated by the ADD code. |

## SUBROUTINE RESTAR

There are several modes by which SUBROUTINE RESTAR can fail. All involve improper use of the restart file. A message, 'STOP RESTAR', will be printed in the dayfile and a message 'RESTART REQUESTED AT STATION (Station Number) BUT STORED INFORMATION AT SEQUENCE (File Number) IS AT STATION' (Station Number). This message appears because the value of JX (marching station number) does not match the value of IRSTIN (see input). This can be caused by either an incorrect value of NFILE (see input) and a proper value of IRSTIN or an incorrect value of IRSTIN and a proper value of NFILE or incorrect values of both variables. Another failure mode would be for the file JRSTIN to be null or for the value of IRSTIN to be incorrect. These failure modes will cause the program to cease while in the NTRAN routine.

## SUBROUTINE MINVRS

The mode of failure in this routine indicates that a matrix is singular and thus cannot be inverted. A message, 'STOP MINVRS', is printed in the dayfile and a message 'MATRIX SINGULARITY' followed by four integers is printed out. This usually indicates that an incorrect boundary condition(s) has been chosen. It is suggested that the values of NBCON be re-evaluated.

## FAILURE IN SQRT

If an attempt is made to take the square root of a negative number, a failure will occur. Usually this is due to a breakdown of the solution procedure when the flow wants to recirculate (an impossibility with a paramobilized method). The case to be run should be re-evaluated to determine if more bleed should be added to prevent the recirculation.

## PEPSIS FORTRAN Variables

| FORTRAN SYMBOL | COMMON BLOCK | DESCRIPTION |
|---|---|---|
| A(5,16,20) | | STORAGE FOR LINEARIZATION BLOCK MATRIX COEFFICIENTS - EQUIVALENCED TO BLK |
| AB | INPUT | GAS CONSTANT / SCECIFIC HEAT |
| ABENG | INPUT | ABENG = (GAMMA-1) * CMACH |
| AG(20,9,2) | WEIGHT | DIFFERENCE WEIGHTS |
| AG7 | WEIGHT | INVERSE OF STREAMWISE STEP SIZE |
| AMDOTD(20,200,4) | CET | BLEED RATES |
| ATS(19,20) | STORE | STORAGE ARRAY FOR LINEARIZATION COEFFICIENTS |
| B | INPUT | B = -0.5 * AB |
| BLK(2500) | BLKMM | GENERAL PURPOSE STORAGE ARRAY |
| BLK1(2500) | BLKMM | GENERAL PURPOSE STORAGE ARRAY |
| BWD | BWDIF | CRANK-NICHOLSON FACTOR |
| BWDP1 | BWDIF | BWDP1 = BWD + 1 |
| CMACH | INPUT | MACH NUMBER |
| COORD(20,4) | COORD | GEOMETRIC INFORMATION NEEDED FOR PLOT FILE |
| DW | BCONW | SOURCE TERM - USED BY BOUNDARY CONDITION SUBROUTINE |
| DWT(5,4) | BCONW | STORAGE FOR LINEARIZATION COEFFICIENTS IN BOUNDARY CONDITION SUBROUTINE |
| EPS(2) | INPUTA | MESH DISTRIBUTION FACTOR |
| FF(2,20,3) | DFNCTN | GENERAL STORAGE ARRAY - USED MAINLY FOR GEOMETRY |
| FG(8,2,20) | GEOMV | STORAGE FOR METRIC COEFFICIENTS AND DERIVATIVES |
| F(14,1) | | STORAGE FOR PLOT INFORMATION - EQUIVALENCED TO BLK |
| GAMM(20,2) | CANG | ANGLE OF COORDINATE LINES RELATIVE TO THE HORIZONTAL |
| GAMMA | INPUTA | RATIO OF SPECIFIC HEATS |
| GAMMR | INPUTA | PRODUCT OF GAMMA TIMES GAS CONSTANT |
| IADI | NTRANZ | ADI SWEEP DIRECTION |
| IADSHF(2) | GENDIM | SHIFT INDEX |
| IJ | INDEX | LINES ON WHICH ADI IS BEING PERFORMED |
| IJM | NTRANZ | COUNTER FOR NTRANNING SUBROUTINES |
| IAXI | PCOR | SENTINEL FOR AXISYMMTRIC COORDINATES |
| ICAR | PCOR | SENTINEL FOR CARTESIAN COORDINATES |
| ILAM | INPUT | SENTINEL FOR LAMINAR AND TURBULENT FLOW |
| IO | RESTRT | SENTINEL FOR READING AND WRITING |

## PEPSIS FORTRAN Variables

| FORTRAN SYMBOL | COMMON BLOCK | DESCRIPTION |
|---|---|---|
| IPLOT | INPUTA | SENTINEL FOR PLOT OPTION |
| IRSTIN | RESTRT | AXIAL STATION NUMBER FOR RESTART |
| IRSTOT | RESTRT | INTERVAL FOR RESTART INFORMATION |
| ISS(20,2) | CISS | LOCATION OF SONIC LINE |
| ISSD(20,2) | CISS | LOCATION OF SONIC LINE |
| ISYM | BPLOT | RECIPORICAL OF SYMMETRY |
| IWALLF | BCONW | SENTINEL WHICH DETERMINES IF WALL FUNCTION LOGIC IS NEEDED |
| JRSTIN | RESTRT | LOGICAL FILE FROM WHICH RESTART INFORMATION IS READ |
| JRSTOT | RESTRT | LOGICAL FILE ON WHICH RESTART INFORMATION IS WRITTEN |
| JX | INDEX | MARCHING STATION INDEX |
| K9 | NTRANZ | STATUS CHECK |
| LGP(I,J) | | LGP(I,J) = I + (J-1) * NPOINT - STATEMENT FUNCTION DEFINING GRID POINT ADDRESS |
| LZ | PARAM1 | LZ = MZVAR * MLEVEL * NPOINT * NZ |
| MEZ | NTRANZ | MEZ = NOUTER + 1 |
| MLEVEL | PARAM1 | MAXIMIUM LEVELS OF STORAGE |
| MU | VARNUM | INDEX FOR LAMINAR VISCOSITY |
| MUT | VARNUM | INDEX FOR TURBULENT VISCOSITY |
| MZ | PARAM1 | MZ = LZ + 1 |
| MZVAR | PARAM1 | MAXIMIUN NUMBER OF STORAGE VARIABLES |
| N(7) | BCONW | INDICIES USED BY BOUNDARY CONDITION ROUTINE |
| NBCON(5,4,2) | BCONW | INDEX WHICH SPECIFIES TYPE OF BOUNDARY CONDITION |
| NCAP | BCONW | FLAG WHICH TELLS WHEN END CAP LOGIC IS TO BE USED |
| NFILE | RESTRT | SEQUENCE NUMBER OF RESTART INFORMATION |
| NCOL | GENDIM | NCOL = 3 * NROW + 1 |
| NCOLS(2) | GENDIM | NCOL(I) = 3 * NROWS(I) + 1 |
| NENG | VARNUM | INDEX FOR ENTHALPY |
| NEZ | NTRANZ | NEZ = NUPPER + 1 |
| NH1 | VARNUM | INDEX FOR METRIC COEFFICIENT IN X - DIRECTION |
| NH12 | VARNUM | INDEX FOR DERIVATIVE OF X METRIC IN Y DIRECTION |
| NH2 | VARNUM | INDEX FOR METRIC COEFFICIENT IN Y - DIRECTION |
| NH21 | VARNUM | INDEX FOR DERIVATIVE OF Y METRIC IN X DIRECTION |

## PEPSIS FORTRAN Variables

| FORTRAN SYMBOL | COMMON BLOCK | DESCRIPTION |
|---|---|---|
| NH3 | VARNUM | INDEX FOR METRIC COEFFICIENT IN Z - DIRECTION |
| NH31 | VARNUM | INDEX FOR DERIVATIVE OF Z METRIC IN X DIRECTION |
| NH32 | VARNUM | INDEX FOR DERIVATIVE OF Z METRIC IN Y DIRECTION |
| NIM | NTRANZ | COUNTER FOR NTRANNING SUBROUTINES |
| NIN | PARAM1 | MAXIMIUM LINES OF STORAGE IN CORE AT ONE TIME |
| NLEN | VARNUM | INDEX FOR MIXING LENGTH |
| NE(2) | GRID | NUMBER OF GRID POINTS IN Y AND Z DIRECTIONS |
| NOUTER | NTRANZ | NOUTER = NE(3-IADI) - 1 |
| NPOINT | PARAM1 | MAXIMIUM NUMBER OF GRID POINTS IN Y OR Z DIRECTION |
| NREAD | NTRANZ | COUNTER FOR NTRANNING SUBROUTINES |
| NRHO | VARNUM | INDEX FOR DENSITY |
| NROW | GENDIM | NUMBER OF ROWS IN COEFFICIENT MATRIX |
| NROWS(2) | GENDIM | NUMBER OF EQUATIONS SOLVED SIMULTANEOUSLY IN A SET |
| NS | GRID | NUMBER OF STATIONS TO BE MARCHED |
| NSAVED | RESTRT | NUMBER OF RESTART STATIONS SAVED |
| NSETA | GENDIM | SENTINEL FOR INDICATING WHICH SET OF EQUATIONS BEING SOLVED |
| NSLAB | NTRANZ | NSLAB = MLEVEL * MZVAR * NPOINT |
| NTAU | VARNUM | INDEX FOR STRAIN TENSOR CONTRACTION |
| NUPPER | OUTA | NUPPER = NE(IADI) - 1 |
| NV1 | VARNUM | INDEX FOR X - DIRECTION VELOCITY |
| NV2 | VARNUM | INDEX FOR Y - DIRECTION VELOCITY |
| NV3 | VARNUM | INDEX FOR Z - DIRECTION VELOCITY |
| NZ | PARAM1 | MAXIMIUM NUMBER OF GRID POINTS IN Z DIRECTION |
| PZERO | BPLOT | REFERENCE PRESSURE |
| RG | INPUTA | GAS CONSTANT |
| RM1 | INPUT | INVERSE OF THE REYNOLDS NUMBER |
| RZERO | INPUT | REFERENCE DENSITY |
| SYSTEM | BPLOT | PLOT OPTION |
| TITLE(6) | BPLOT | TITLE INFORMATION |
| TZERO | INPUT | REFERENCE TEMPERATURE |
| USTAR(20,4) | USTARR | FRICTION VELOCITY |
| UZERO | INPUT | REFERENCE VELOCITY |

# PEPSIS FORTRAN Variables

| FORTRAN SYMBOL | COMMON BLOCK | DESCRIPTION |
|---|---|---|
| VKC | TURA | VON KARMAN CONSTANT |
| VISCOS | INPUTA | LAMINAR KINEMATIC VISCOSITY |
| X(50) | GRID | MARCHING STATION LOCATIONS |
| XENTR | INPUT | MARCHING STATION LOCATION AT BEGINNING OF A CALCULATION |
| XJXTW | CWALL | AXIAL LOCATION OF COWL |
| Y(20,2) | GRID | PHYSICAL DISTANCE IN COMPUTATIONAL DIRECTION |
| YS(2,2) | GRID | NONDIMENSIONAL EXTENTS OF COMPUTATIONAL DOMAIN |
| YSLOT(2) | IPROFF | BOUNDARY LAYER THICKNESSES |
| YSAVE(20,2) | GRID | COMPUTATIONAL COORDINATES |
| YZERO | INPUT | REFERENCE LENGTH |
| Z(M,N,I,J) | | EQUIVALENT OF ZZ - STATEMENT FUNCTION |
| ZBLK(2500) | BLKM | GENERAL PURPOSE STORAGE ARRAY |
| ZZ(17,3,80) | VARIAB | GENERAL PURPOSE STORAGF FOR DEPENDENT VARIABLES |
| ZZZ(M,N,LGP(I,J)) | | EQUIVALENT OF ZZ - STATEMENT FUNCTION |

## Storage Devices Needed to Run PEPSIS

The following storage devices are needed to successfully run the PEPSIS computer program.

| Unit Number | Use |
|---|---|
| 8 | Plot tape, needed only when input value of IPLOT=1. This file must be saved after a run. |
| 9 | General purpose NTRAN mass storage device. Assumes word addressable device. No need to save this file. |
| 10 | Storage device for metric data generated by the ADD computer code. Only needed when IAXI=0 and ICAR=0, i.e., for general orthogonal coordinates. |
| JRSTIN | Logical file from which restart information is to be read. Default value is 11. |
| JRSTOT | Logical file onto which restart information is to be written. Default value is 11. This file must be saved after a run. |

## Input and Results for a Sample Case

Table I presents the input for a sample case the results of which are presented in the following pages. This run is taken from one of the first runs made on the inlet test case previously reported. The first part of the input is associated with the title and options for the plot option. Input in $LIST2 requires that no NAMELIST information will be printed (IWR=0) and inputs the reference values that yield a Mach number equals 3.0 flow. The $LIST3 data yields the general orthogonal geometry option and thus requires that the ADD computer geometry be generated on unit 10. $LIST4 data sets up the computational domain, the bleed schedule and restart information. This case was run three streamwise stations (to keep the printout manageable for the report). The value of IRSTOT requires that restart information be stored each three stations. A value of IRSTIN=0 indicates that this is the first run of the computation, i.e., not a restart. $LIST5 datum tells that this case is for a turbulent run. The input for $LIST6 contains the estimate of the boundary layer thickness while the $LIST7 contains the boundary conditions. These boundary conditions are typical of those required for turbulent inlet calculations. It is to be noted that the 2 surface boundary conditions are not those required for a cowl. Rather they are the boundary conditions associated with Mach line extrapolation. The code will automatically generate the cowl boundary conditions when the marching direction distance exceeds XJXTW. The final NAMELIST, $LIST8, is void because the default value of IPLOT is zero and this is the value desired. It is to be noted that even though no values are input in $LIST8 the cards $LIST8 and $END are required.

The output from PEPSIS for the above input is presented in Table II. The first two pages consist of the central difference operators for the cross flow directions. Next the metric information at the starting station is displayed. The BETA on the far right is the streamwise coordinate angle. Next the initial conditions are printed. For turbulent flow this consists of the cross flow plane distribution of x-velocity, y-velocity, z-velocity, density, stagnation enthalpy, turbulent viscosity, turbulence kinetic energy, dissipation, mixing length, shear, pressure coefficient divided by 2, Mach number and finally temperature. All of these variables are in nondimensional form, e.g., velocities are nondimensionalized by UZERO. The IZ across the top of the distributions refers to z grid point location and z refers to the actual z location. The integers on the left-hand side refer to the transverse grid point location while the numbers to their immediate right are the corresponding values of the physical distances (corresponding to the FORTRAN variable Y) and are actually the integral of the computational y times $h_2$. Above each distribution is the axial marching station JX and the marching distance X(JX). After the temperature distribution are two groupings which describe the extent of the supersonic and subsonic domains. In the first grouping the IJ refers to the z-grid location. The value of ISS is the y-grid location of the first supersonic grid point relative to surface 1 while ISSD is the y-grid location of the first supersonic grid point relative to surface 2. In the second grouping IJ refers to the y-grid location. ISS is the z-grid location of the first supersonic grid point relative to the 3 surface while ISSD is the z-grid location of the first supersonic grid point relative to the 4 surface. A value of ISS or ISSD of 999 refer to a row or column of all subsonic points and a value of ISS or ISSD of 1000 means that the corresponding surface value of the Mach number is supersonic unless that surface happens to have a wall function boundary condition. Following the initial conditions, the above procedure is repeated at each marching station until the NS$^{th}$ station is reached. At each station where a restart is written, a message is written. The message tells the file name, the marching station number and the sequence number. The only difference between the above output and that for a laminar case is the lack of printout associated with the turbulence related variables.

# APPENDIX A

# THE ROBERTS' TRANSFORMATION

An analytical coordinate transformation, developed by Roberts (Ref. 23), is a very effective means of concentrating grid points in the region of the computational boundaries. If, for instance, the region near a computational boundary corresponds to a boundary layer, the concentration of grid points in the physical plane will help in resolving the large gradients. Suppose that N grid points are used in the range $y_1 \leq y \leq y_2$ (the same applies to the z-direction), and that the steep gradients are anticipated in a region $\beta(y_2 - y_1)$ near $y_1$. Then Roberts' transformation $y_T(y)$ is given by

$$y_T(y) = N + (N-1)\ln\left(\frac{b+y-c}{b-y+c}\right) \Big/ \ln\left(\frac{b+a}{b-a}\right) \tag{A-1}$$

where $a = y_2 - y_1$, $b^2 = a^2/(1-\beta)$ and $c = y_2$. The use of equally-spaced points in the transformed coordinate, $y_T$, ensures a concentration in the region $y_1 \leq y < y_1+\beta(y_2 - y_1)$. Derivatives with respect to the physical coordinate, y, are obtained from the chain rule formulae:

$$\frac{\partial}{\partial y} = \frac{\partial y_T}{\partial y}\frac{\partial}{\partial y_T} \tag{A-2}$$

and

$$\frac{\partial^2}{\partial y^2} = \left(\frac{\partial y_T}{\partial y}\right)^2 \frac{\partial^2}{\partial y_T^2} + \frac{\partial^2 y_T}{\partial y^2}\frac{\partial}{\partial y_T} \tag{A-3}$$

The relationships for $dy_T/dy$ and $d^2y_T/dy^2$ are easily calculated from Eq. (A-1).

# APPENDIX B

## SPECIAL BOUNDARY CONDITIONS

Most of the boundary conditions utilized in the PEPSIS computer code are fairly straightforward and have been included in the users' manual portion of this report without comment. Three types of boundary conditions not in common usage are also available to the PEPSIS user. They are (1) Mach line extrapolation, (2) wall functions and (3) the momentum equation as a boundary condition.

Mach line extrapolation is predicated on the concept that in a simple wave region, the flow properties remain constant along Mach lines. For a scalar quantity, $\phi$, this results in the equation

$$\vec{n}_M \cdot \nabla \phi = 0 \tag{B-1}$$

while for the velocity, $\vec{V}$, this results in the equation

$$\vec{n}_M \cdot \nabla \vec{V} = 0 \tag{B-2}$$

where $\vec{n}_m$ is the unit vector in the direction of the Mach line. In two dimensions, the Mach angle relative to the coordinate system, $\psi$, is given by the sum of the flow angle relative to the coordinate system and the Mach angle relative to the flow; viz,

$$\psi = \tan^{-1}\left(\frac{v}{u}\right) + \sin^{-1}\left(\frac{1}{M}\right) \tag{B-3}$$

Thus in general orthogonal coordinates Eq. (B-1) becomes

$$\frac{\partial \phi}{\partial x} + \frac{h_1}{h_2} \tan \psi \frac{\partial \phi}{\partial y} = 0 \tag{B-4}$$

while Eq. (B-2), a vector equation, yields two scalar equations

$$\frac{\partial u}{\partial x} + \frac{1}{h_2}\frac{\partial h_1}{\partial y} v + \frac{h_1}{h_2}\tan\psi\left(\frac{\partial u}{\partial y} - \frac{1}{h_1}\frac{\partial h_2}{\partial x} v\right) = 0 \qquad \text{(B-5)}$$

and

$$\frac{\partial v}{\partial x} - \frac{1}{h_2}\frac{\partial h_1}{\partial y} u + \frac{h_1}{h_2}\tan\psi\left(\frac{\partial v}{\partial y} + \frac{1}{h_1}\frac{\partial h_2}{\partial x} u\right) = 0 \qquad \text{(B-6)}$$

The Mach line extrapolation boundary conditions Eq. (B-4) through (B-6) are typically applied on the boundary upstream of the cowl lip. Eq. (B-4) is associated with the continuity equation (with $\phi = \rho$) while Eq. (B-5) and Eq. (B-6) are associated with the x- and y-momentum equations, respectively.

In the PEPSIS computer code, wall functions may be used for the wall boundary conditions in lieu of the no-slip condition. Wall functions (as utilized in PEPSIS) are valid only for turbulent flow and are typically used when it is not possible to have enough grid points in the wall boundary layers to adequately resolve the large gradients normal to the wall. The wall function concept assumes that the velocity parallel to a wall, $\tilde{u}$, obeys the logarithmic law of the wall profile

$$\tilde{u} = u_\tau\left(\frac{\ln y^+}{\kappa} + B\right) \qquad \text{(B-7)}$$

where

$$y^+ = \frac{\rho u_\tau \tilde{y}}{\mu_{lam}} \qquad \text{(B-8)}$$

$u_\tau$ is the wall shear velocity and $\tilde{y}$ is the normal distance from a wall. Taking the derivative of Eq. (B-7) with respect to, say y (for a 1 surface), yields

$$\frac{\partial \tilde{u}}{\partial y} = \frac{u_\tau}{\kappa \tilde{y}} \qquad \text{(B-9)}$$

For a 1 surface, $\tilde{u}$ is given by the relationship

$$\tilde{u} = \sqrt{u^2 + w^2} \tag{B-10}$$

and by assuming that the ratio of u/w does not vary (as a function of y) in the region of a wall, the relationships for ∂u/∂y and ∂w/∂y can be derived. They are

$$\frac{\partial u}{\partial y} = \frac{u}{\sqrt{u^2+w^2}} \frac{u_\tau}{\kappa \tilde{y}} \tag{B-11}$$

and

$$\frac{\partial w}{\partial y} = \frac{w}{\sqrt{u^2+w^2}} \frac{u_\tau}{\kappa \tilde{y}} \tag{B-12}$$

The boundary conditions represented by Eqs. (B-11) and (B-12) are applied at the first grid point away from a wall rather than at a wall grid point since the logarithm law of the wall is not valid at the wall. Solution of Eqs. (B-11) and (B-12) in conjunction with the governing partial differential equations results in nonzero wall slip values for u and w. These slip values represent the values of u and w required to satisfy the derivative conditions, Eqs. (B-11) and (B-12). Equations analogous to Eqs. (B-11) and (B-12) can easily be derived for surfaces 2, 3 and 4.

The last category of boundary condition considered in this appendix is the normal momentum boundary condition. This boundary condition is typically applied as one of the wall boundary conditions (the other wall boundary conditions, for instance, might be u = v = w = 0). If a 1 or 2 surface is considered, Eq. (4) can be utilized, except that in this case several of the terms can be dropped. In the zero bleed case (v = 0), Eq. (4) becomes

$$\frac{\partial}{\partial y}(h_1 h_3 \rho v^2) - h_3 \frac{\partial h_1}{\partial y} \rho u^2 - h_1 \frac{\partial h_3}{\partial y} \rho w^2 + h_1 h_3 \frac{\partial p}{\partial y} = \frac{4}{3} \frac{\partial}{\partial y}\left(\frac{h_1 h_3}{h_2} \mu \frac{\partial v}{\partial y}\right) \tag{B-13}$$

For the case of u, v, w and their derivatives small, Eq. (B-13) becomes the boundary layer approximation

$$\frac{\partial p}{\partial y} = 0 \tag{B-14}$$

An equation analogous to Eq. (B-13) can easily be derived for a 3 or 4 surface except that in this case Eq. (5) is used as the starting point.

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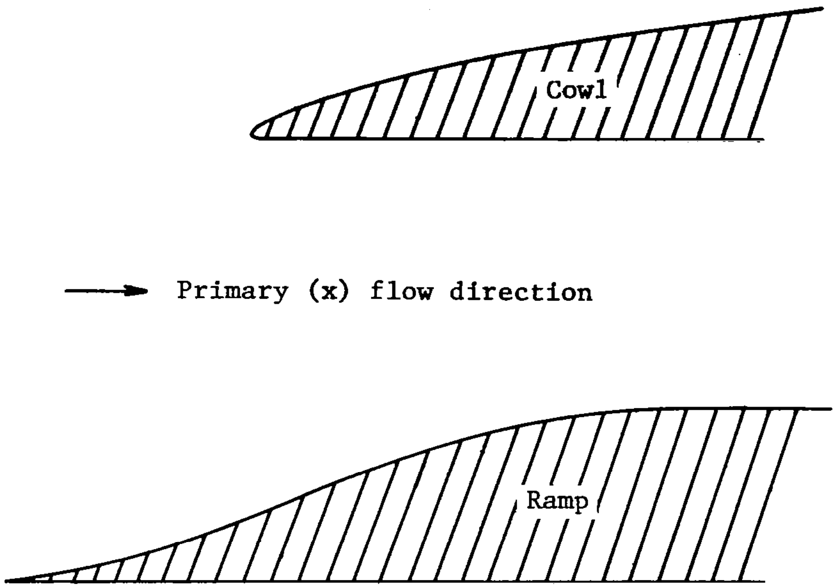
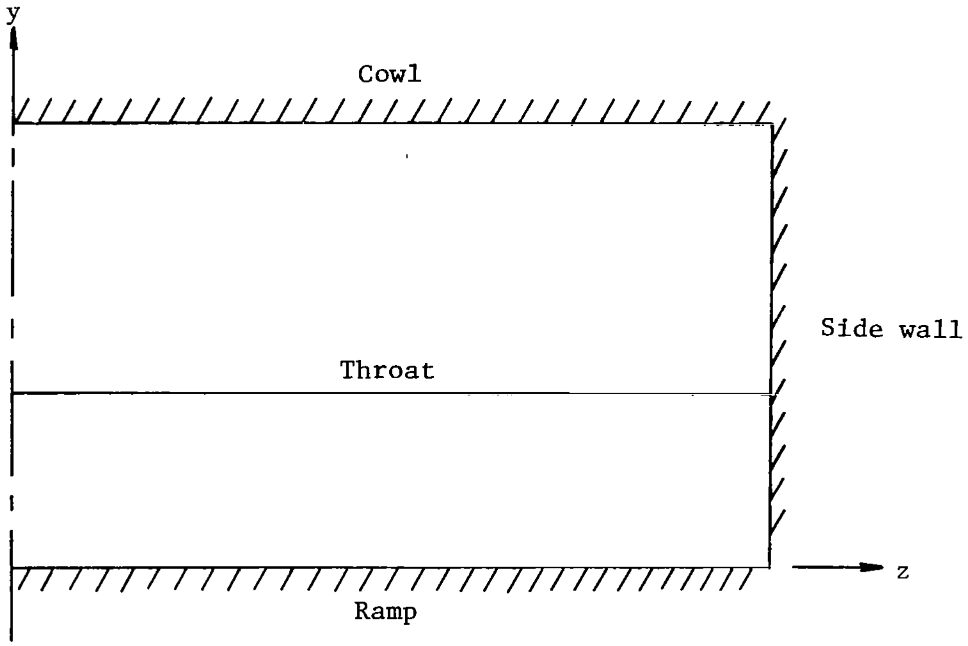


Side view



Front view

Figure 1. - Typical supersonic inlet geometry.

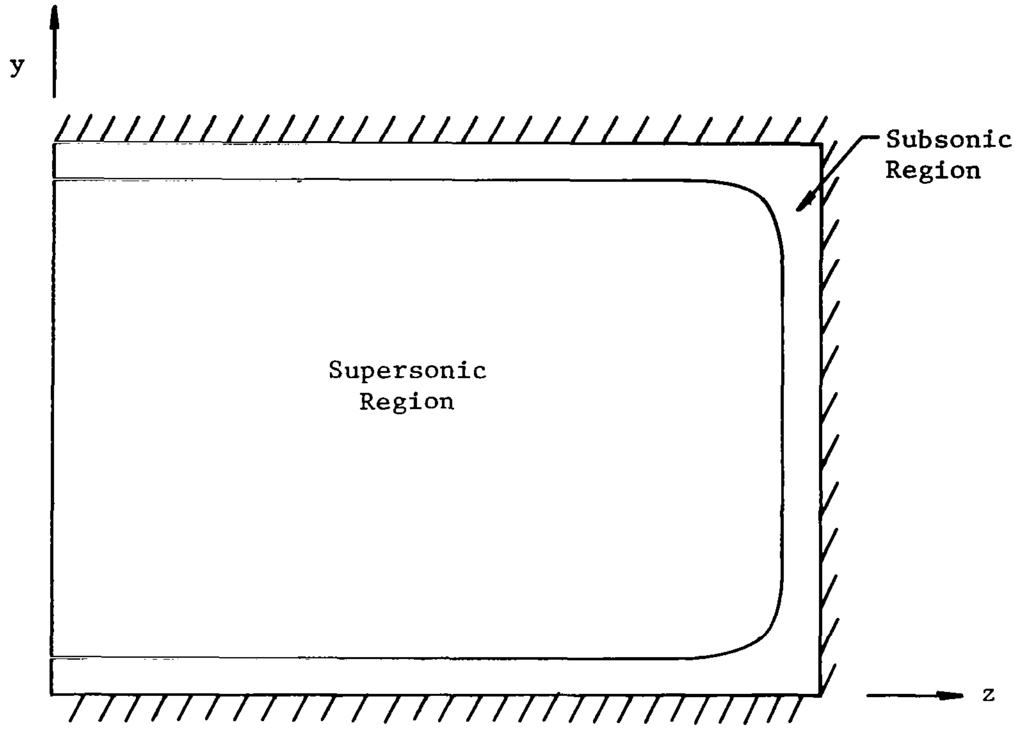


Figure 2. - Supersonic-subsonic regions of a typical cross flow section.

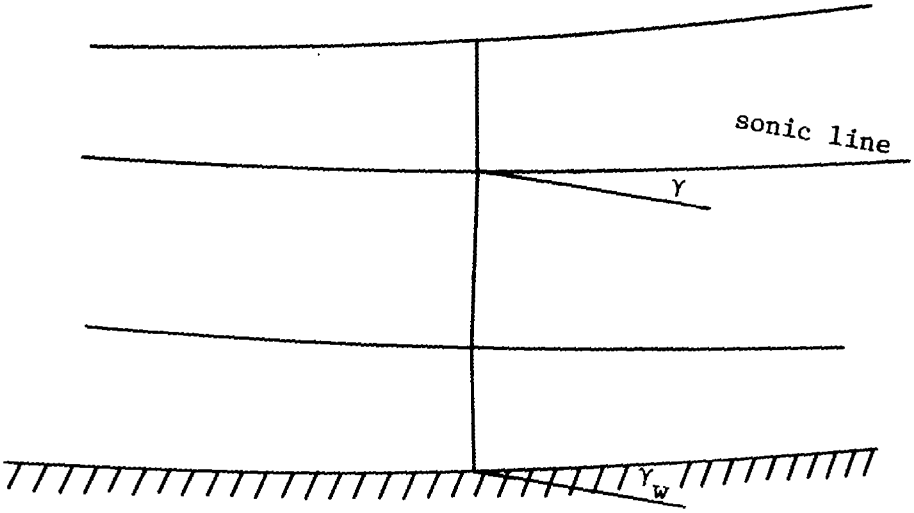


Figure 3. - Geometry for wall tangency condition.

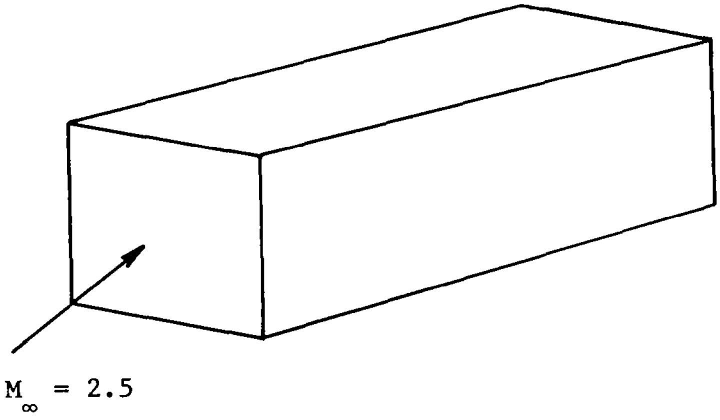


Figure 4. - Flow into a square duct.

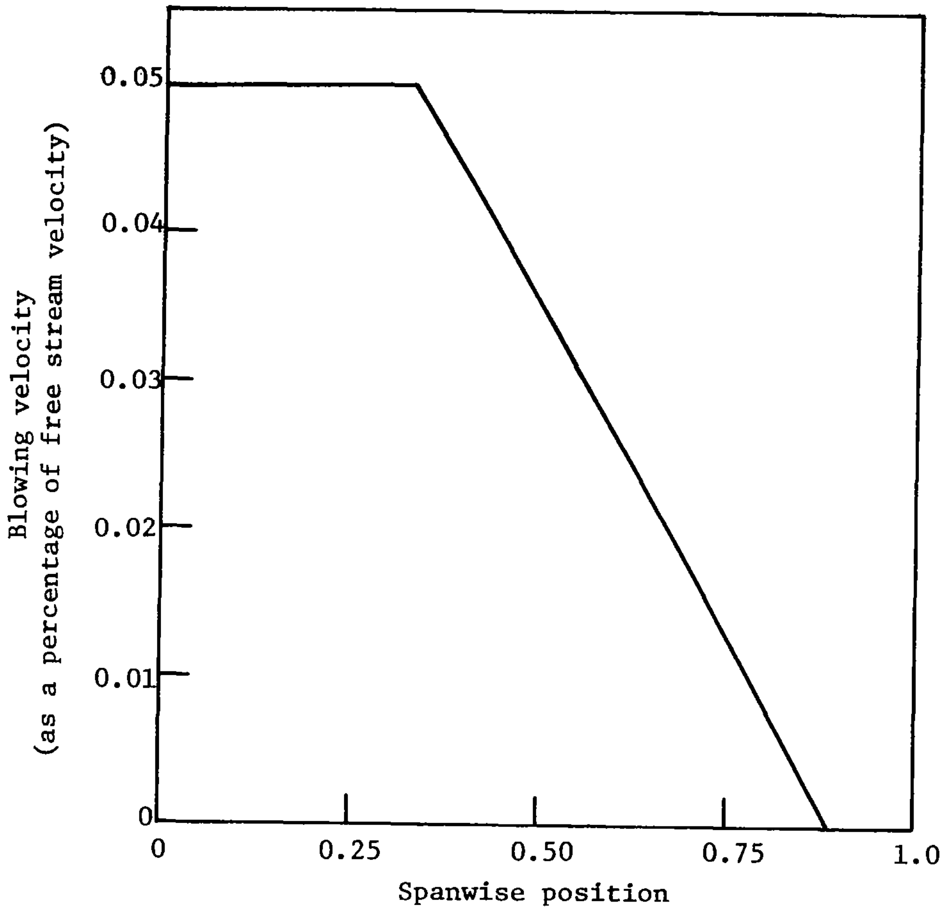
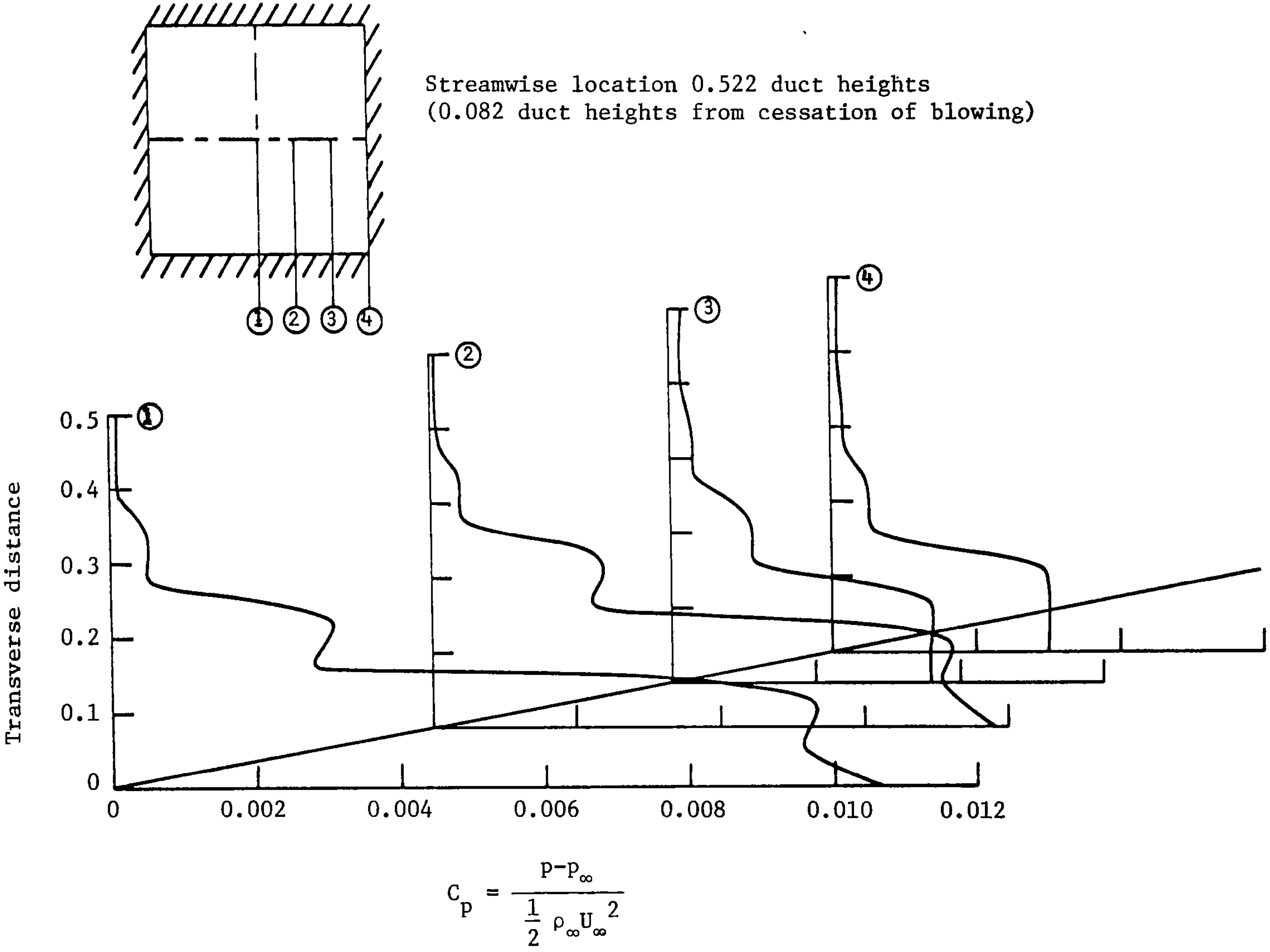
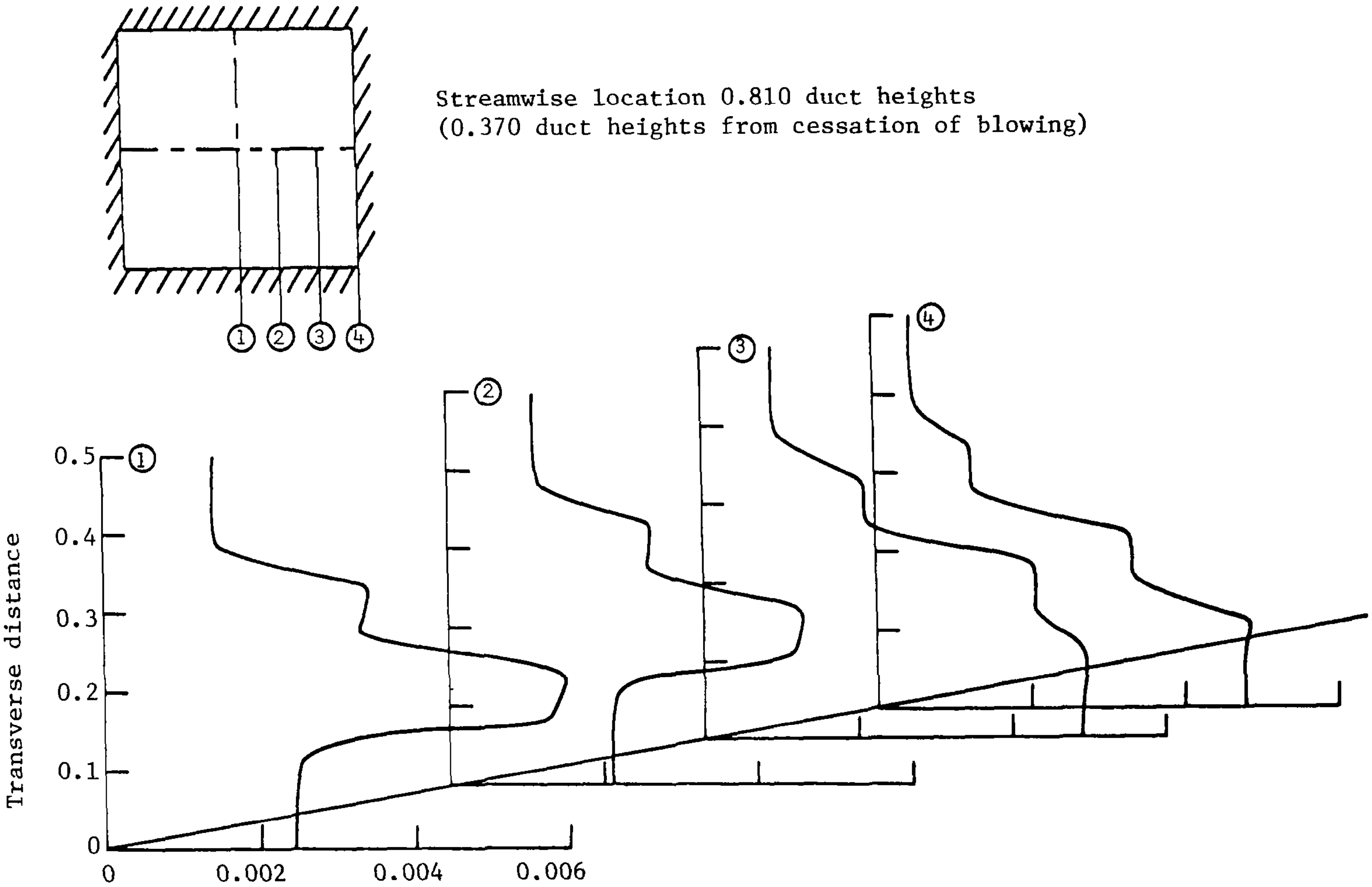


Figure 5. - Spanwise blowing distribution.



$$C_p = \frac{p - p_\infty}{\frac{1}{2}\rho_\infty U_\infty^2}$$

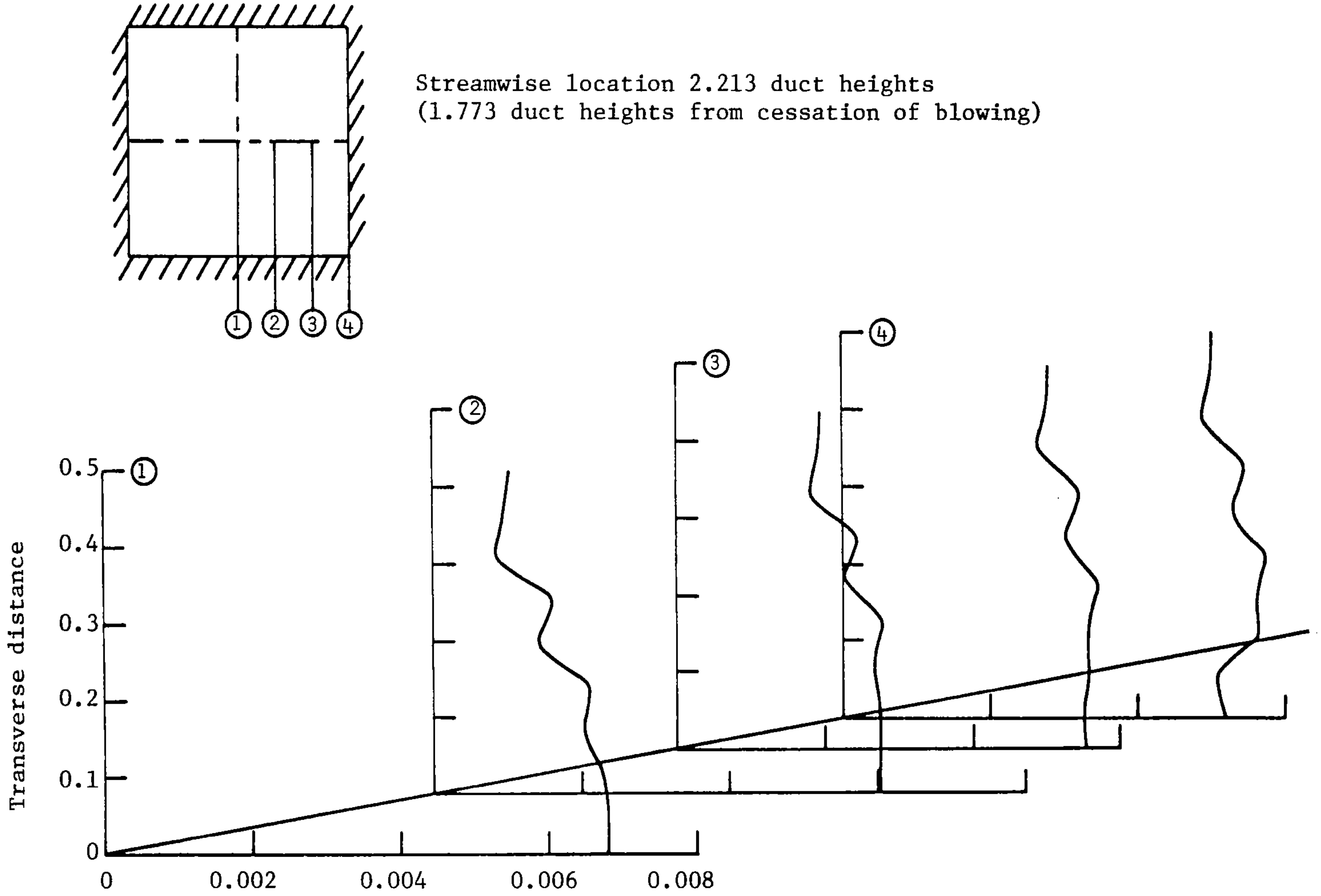
Figure 6. - Variation of pressure coefficient at selected spanwise locations.



Streamwise location 0.810 duct heights
(0.370 duct heights from cessation of blowing)

$$C_p = \frac{p - p_\infty}{\frac{1}{2}\rho_\infty U_\infty^2}$$

Figure 7. - Variation of pressure coefficient at selected spanwise locations.



Streamwise location 2.213 duct heights
(1.773 duct heights from cessation of blowing)

$$C_p = \frac{p - p_\infty}{\frac{1}{2}\rho_\infty U_\infty^2}$$

Figure 8. - Variation of pressure coefficient at selected spanwise locations.

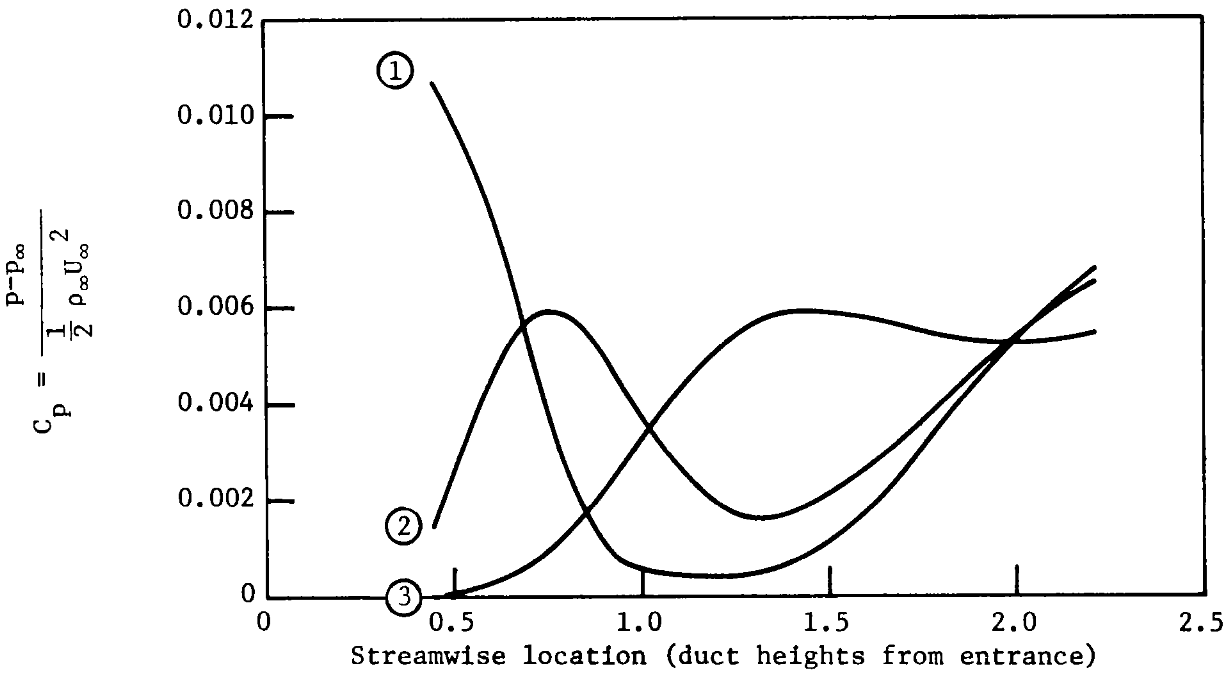


Figure 9. - Streamwise variation of pressure coefficient at selected transverse locations on the spanwise plane of symmetry.

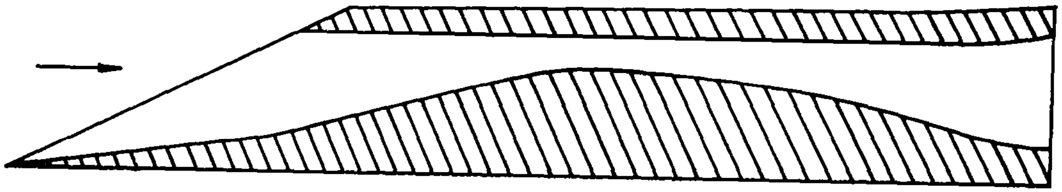


Figure 10. - Cross-section of NASA Ames inlet.

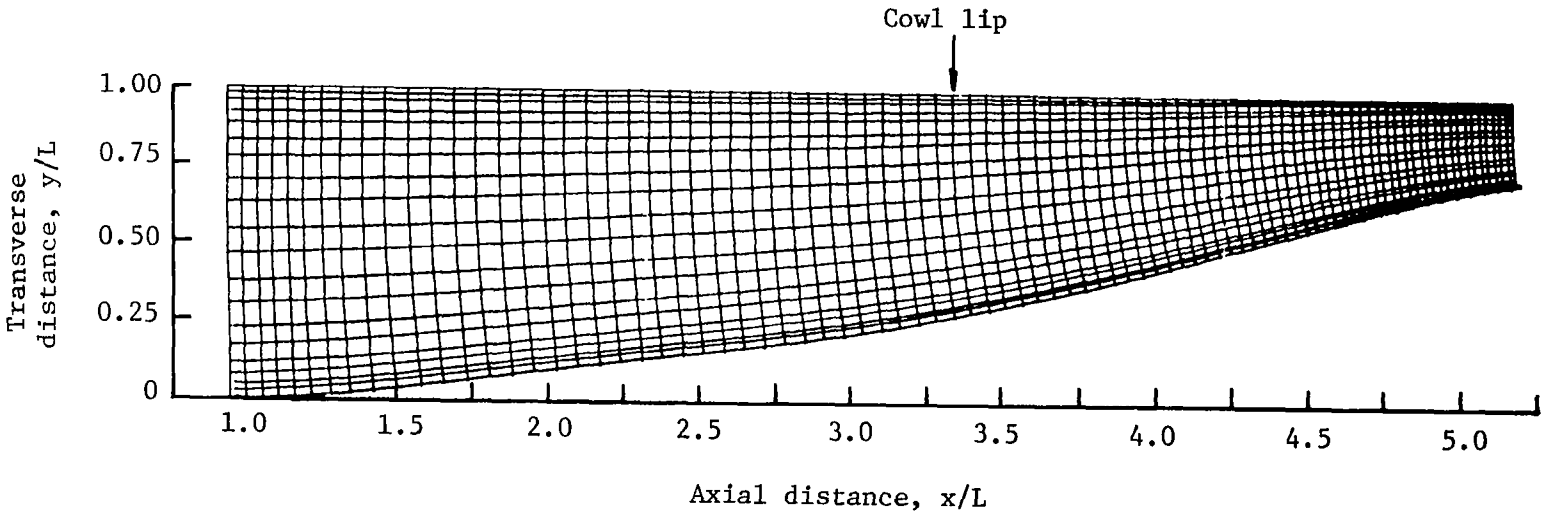


Figure 11. - The computational mesh.

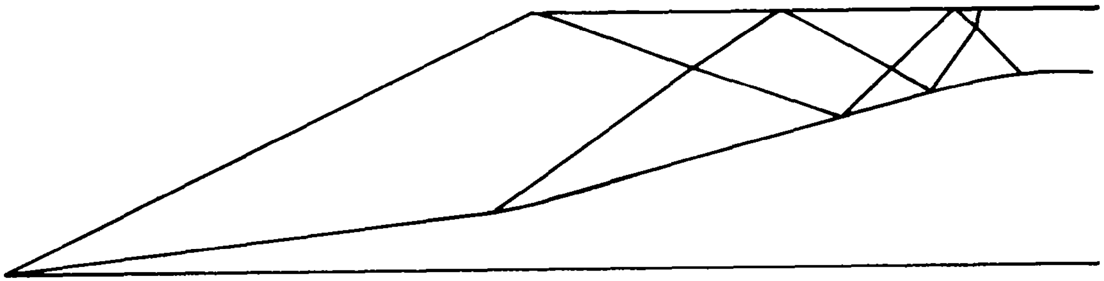


Figure 12. - Inviscid shock pattern.

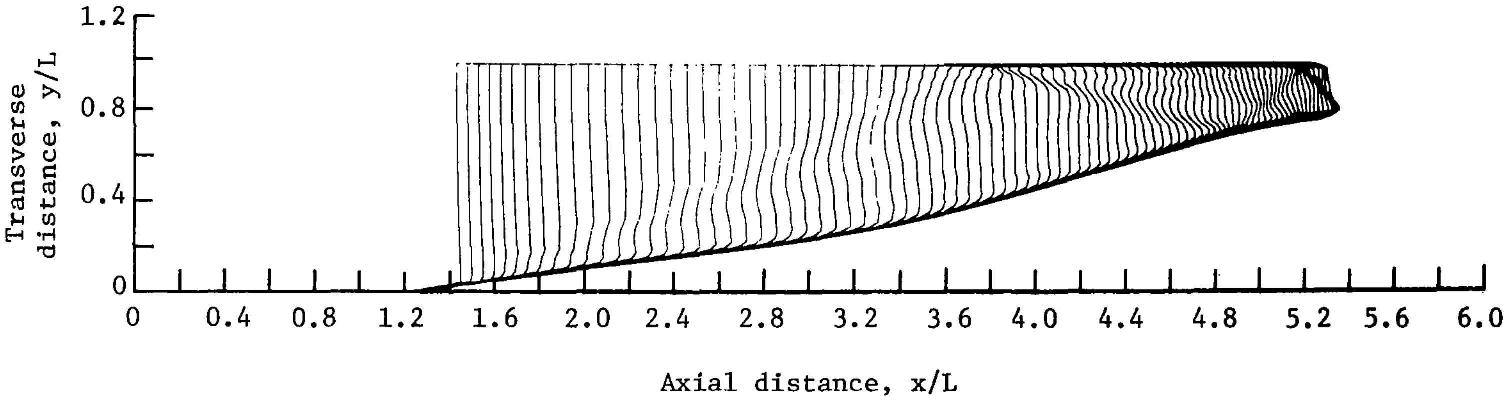


Figure 13. - Mach number profiles in center plane of inlet.

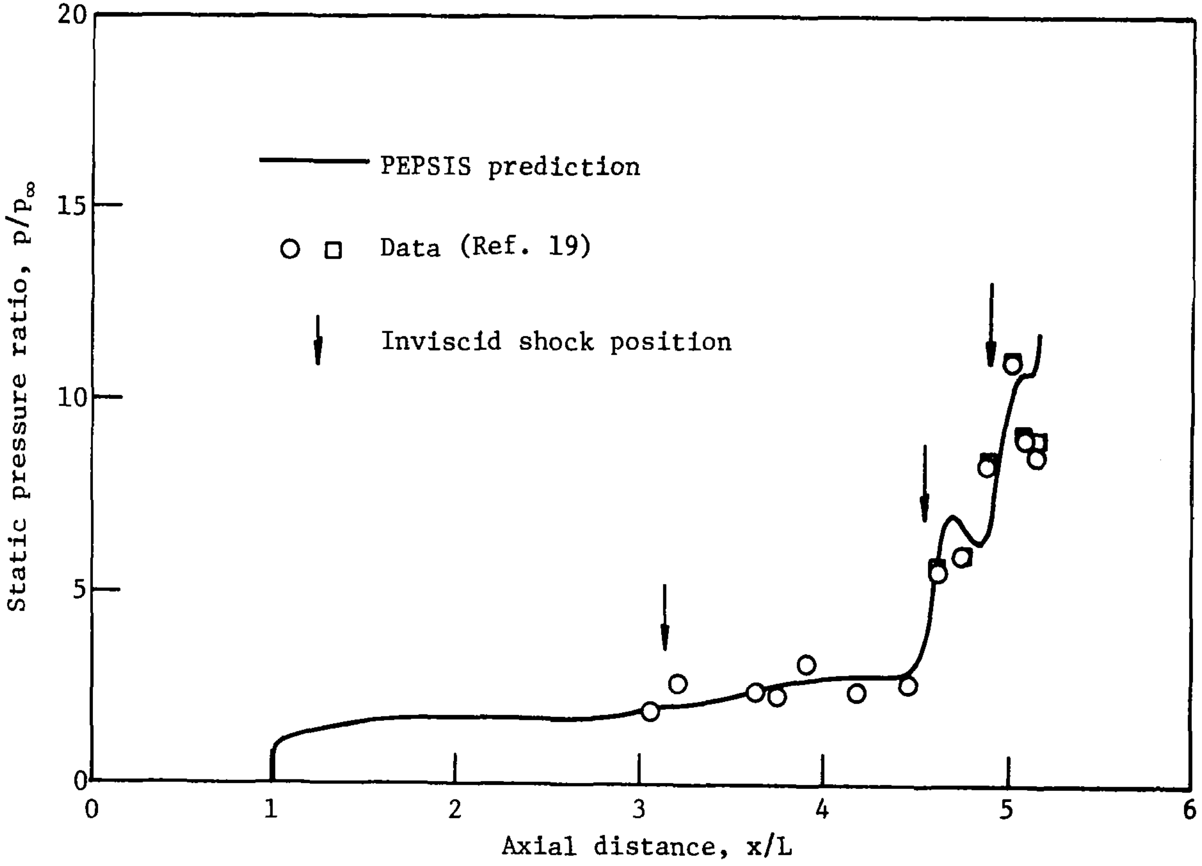


Figure 14. - Comparison of computed pressure distribution with data along ramp.

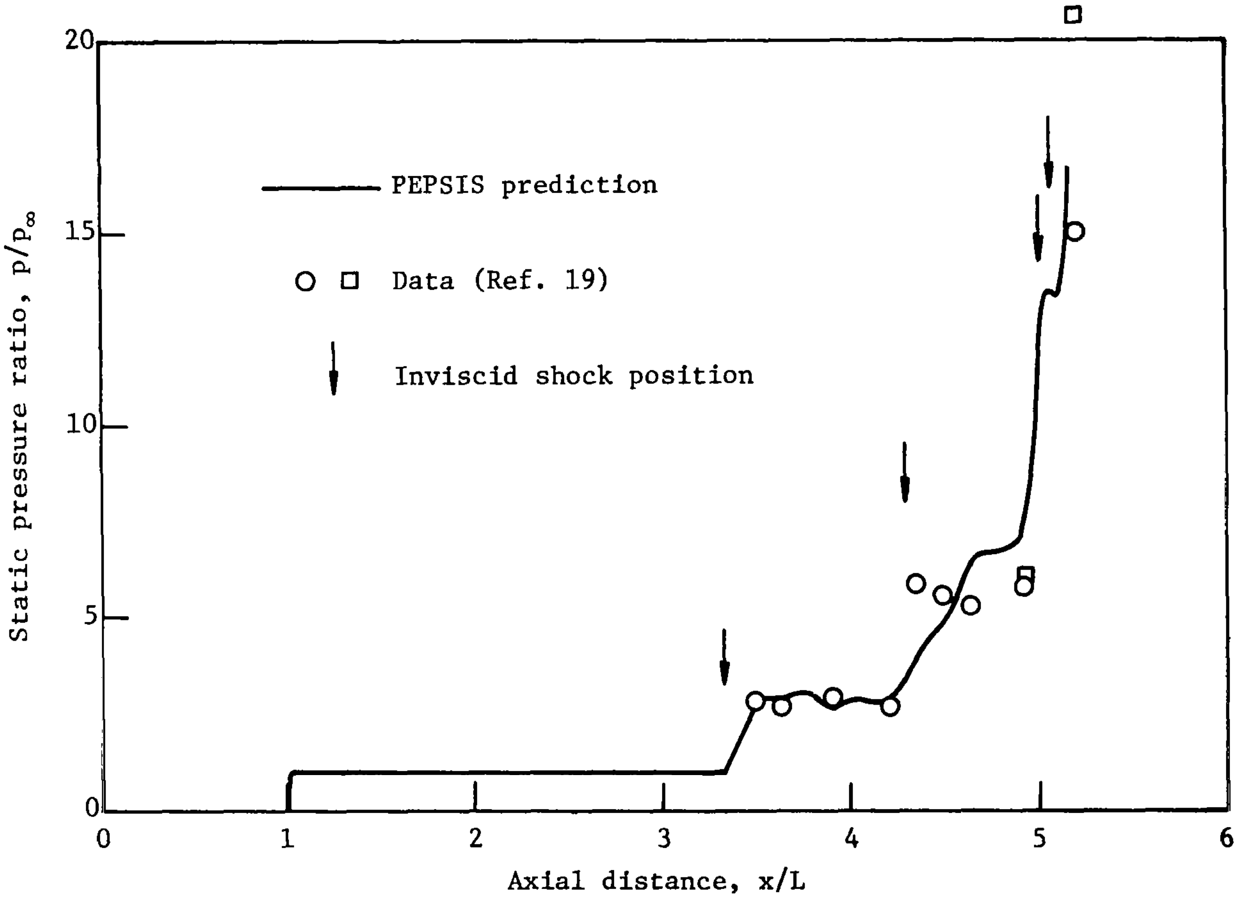


Figure 15. - Comparison of computed pressure distribution with data along cowl.

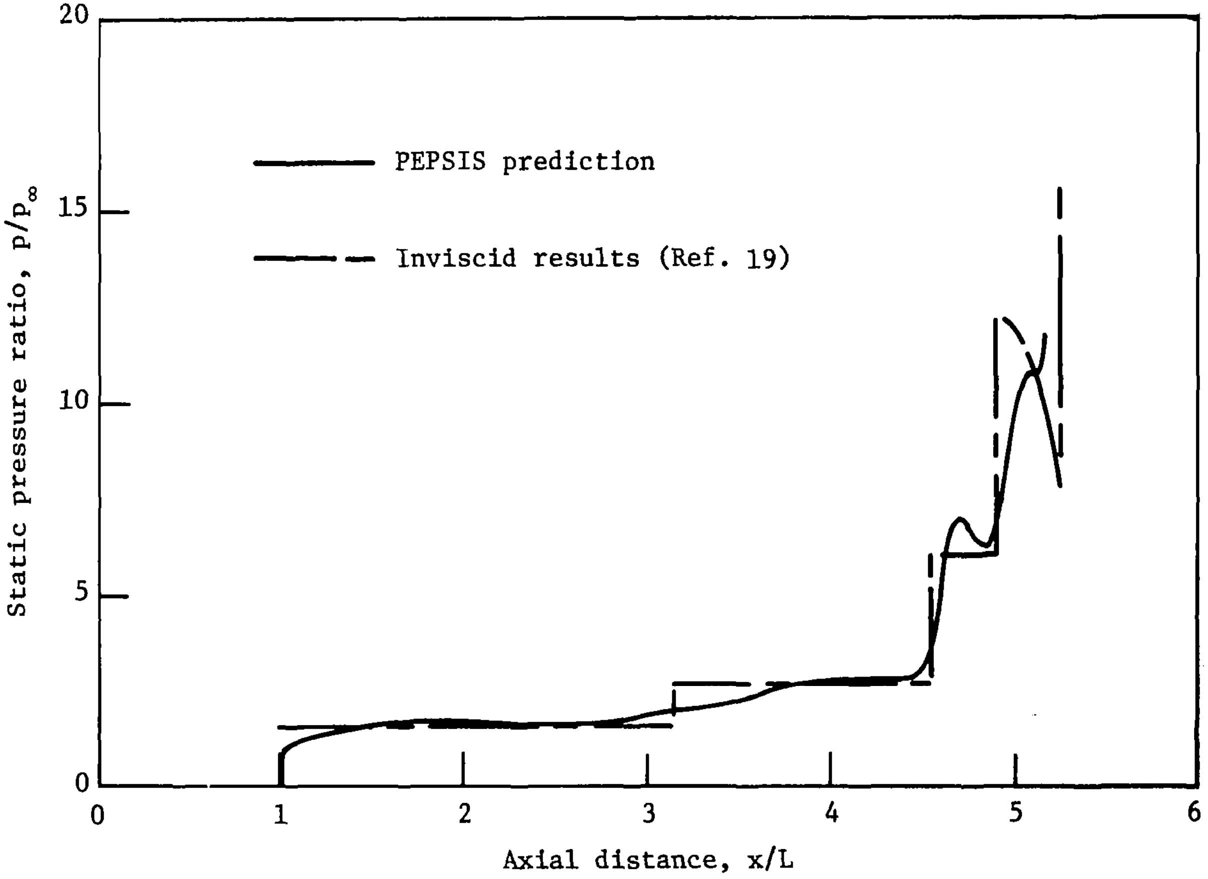


Figure 16. - Comparison of computed pressure distribution with inviscid results along ramp.

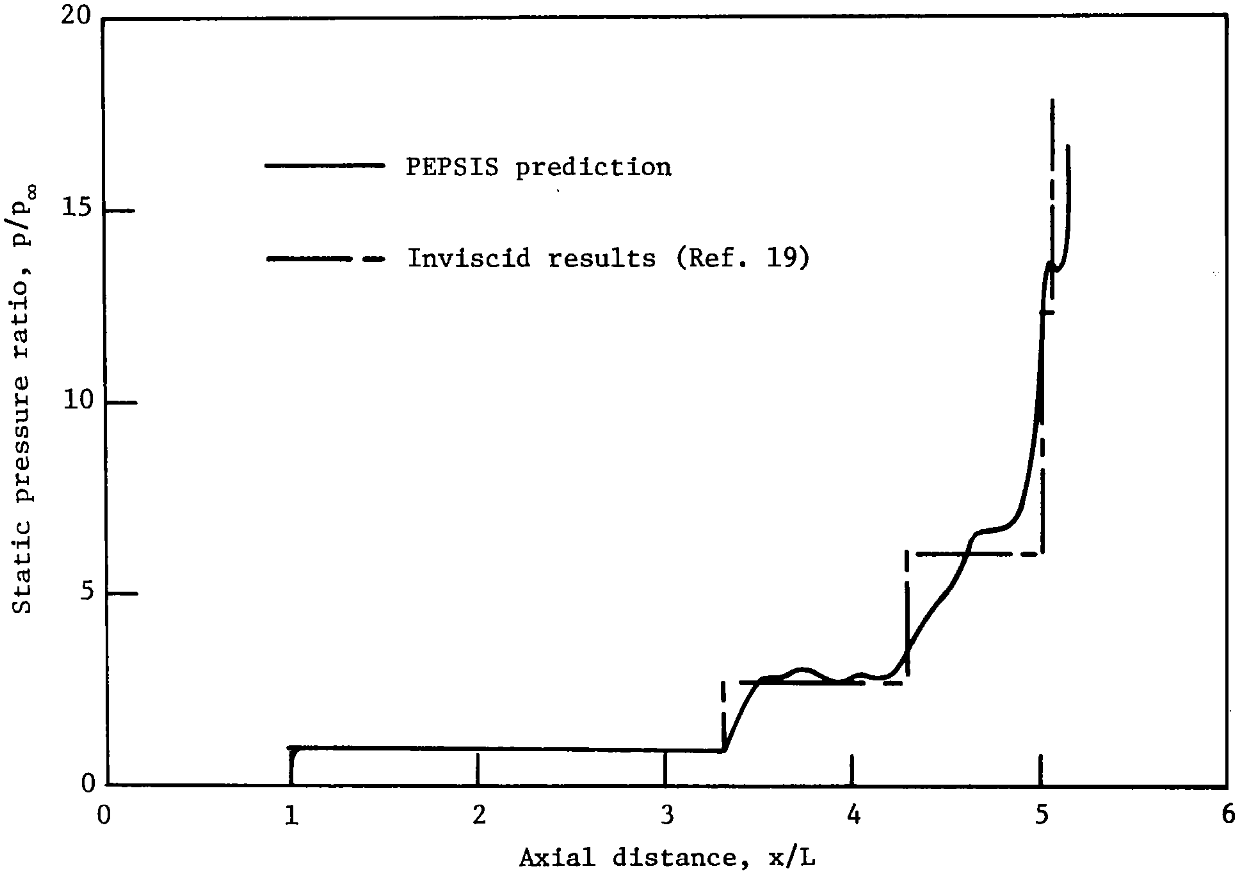


Figure 17. - Comparison of computed pressure distribution with inviscid results along cowl.

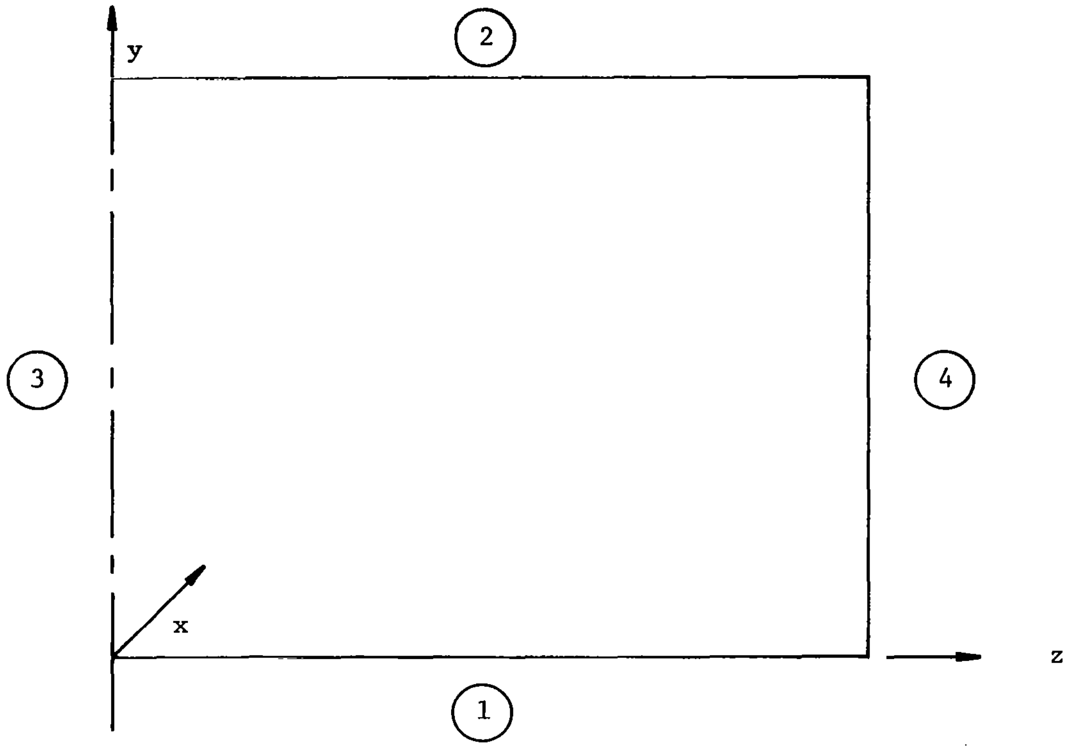


Figure 18. - Typical cross flow section.

## TABLE I. - PEPSIS SAMPLE INPUT

```
NASA - LEWIS TEST CASE
021.0
 $LIST2
 IWR = 0,
 USCALE = 1.0,
 TZERO = 416.0,
 UZERO = 3000.0,
 YZERO = 1.16666667,
 VISCOS = 0.01,
 $END
 $LIST3
 ICAR = 0,
 IAXI = 0,
 $END
 $LIST4
 XJXTW = 3.72463,
 AMDOTD = 16000*0.0,
 YS(1,1) = 0.0,
 YS(2,1) = 1.0,
 YS(1,2) = 0.0,
 YS(2,2) = 0.5,
 NE(1) = 20,
 NE(2) = 6,
 IGRID(1) = 2,
 IGRID(2) = 0,
 EPS(1) = 0.10,
 XENTR = 0.91821,
 X1 = 0.0,
 X2 = 0.025,
```

```
AP = 1.0,
NS = 3,
IRSTOT = 3,
IRSTIN = 0,
NFILE=0,
NSAVED=0,
$END
$LIST5
ILAM = 0,
$END
$LIST6
YSLOT(2) = 0.05,
$END
$LIST7
NBCON(1,1,1)=4,
NBCON(1,2,1)=1,
NBCON(1,3,1)=1,
NBCON(1,4,1)=1,
NBCON(2,1,1)=0,
NBCON(2,2,1)=1,
NBCON(2,3,1)=1,
NBCON(2,4,1)=1,
NBCON(3,1,1)=1,
NBCON(3,2,1)=1,
NBCON(3,3,1)=1,
NBCON(3,4,1)=1,
NBCON(4,1,1)=4,
NBCON(4,2,1)=1,
NBCON(4,3,1)=0,
NBCON(4,4,1)=1,
$END
$LIST8
$END
```

# TABLE II. - PEPSIS SAMPLE OUTPUT

```
                                    DIFFERENCE OPERATORS DIRECTION-2

  I      Y(I)        AG(I,1)      AG(I,2)      AG(I,3)      AG(I,4)      AG(I,5)      AG(I,6)

  1   0.0000       -2.9429+01   1.1772+02   -8.8288+01   3.9352+03   -8.8122+03   4.8770+03
  2   1.9489-02     2.2538+01   0.0000      -2.2538+01   1.7665+03   -4.0638+03   2.2973+03
  3   4.4783-02     1.7471+01   0.0000      -1.7471+01   1.0699+03   -2.4420+03   1.3721+03
  4   7.7159-02     1.3757+01   0.0000      -1.3757+01   6.6997+02   -1.5140+03   8.4399+02
  5   1.1787-01     1.1049+01   0.0000      -1.1049+01   4.3756+02   -9.7656+02   5.3900+02
  6   1.6794-01     9.0949+00   0.0000      -9.0949+00   3.0100+02   -6.6174+02   3.6074+02
  7   2.2787-01     7.7139+00   0.0000      -7.7139+00   2.2041+02   -4.7604+02   2.5563+02
  8   2.9729-01     6.7770+00   0.0000      -6.7770+00   1.7359+02   -3.6743+02   1.9384+02
  9   3.7474-01     6.1970+00   0.0000      -6.1970+00   1.4838+02   -3.0722+02   1.5884+02
 10   4.5761-01     5.9199+00   0.0000      -5.9199+00   1.3857+02   -2.8036+02   1.4180+02
 11   5.4239-01     5.9199+00   0.0000      -5.9199+00   1.4180+02   -2.8036+02   1.3857+02
 12   6.2526-01     6.1970+00   0.0000      -6.1970+00   1.5884+02   -3.0722+02   1.4838+02
 13   7.0271-01     6.7770+00   0.0000      -6.7770+00   1.9384+02   -3.6743+02   1.7359+02
 14   7.7213-01     7.7139+00   0.0000      -7.7139+00   2.5563+02   -4.7604+02   2.2041+02
 15   8.3206-01     9.0949+00   0.0000      -9.0949+00   3.6074+02   -6.6174+02   3.0100+02
 16   8.8213-01     1.1049+01   0.0000      -1.1049+01   5.3900+02   -9.7656+02   4.3756+02
 17   9.2284-01     1.3757+01   0.0000      -1.3757+01   8.4399+02   -1.5140+03   6.6997+02
 18   9.5522-01     1.7471+01   0.0000      -1.7471+01   1.3721+03   -2.4420+03   1.0699+03
 19   9.8051-01     2.2538+01   0.0000      -2.2538+01   2.2973+03   -4.0638+03   1.7665+03
 20   1.0000+00     8.8288+01  -1.1772+02    2.9429+01   4.8770+03   -8.8122+03   3.9352+03
```

```
                              DIFFERENCE OPERATORS DIRECTION-3

 I      Y(I)        AG(I,1)      AG(I,2)      AG(I,3)      AG(I,4)      AG(I,5)      AG(I,6)

 1   0.0000       -5.0000+00    2.0000+01   -1.5000+01    1.0000+02   -2.0000+02    1.0000+02
 2   1.0000-01     5.0000+00    0.0000      -5.0000+00    1.0000+02   -2.0000+02    1.0000+02
 3   2.0000-01     5.0000+00    0.0000      -5.0000+00    1.0000+02   -2.0000+02    1.0000+02
 4   3.0000-01     5.0000+00    0.0000      -5.0000+00    1.0000+02   -2.0000+02    1.0000+02
 5   4.0000-01     5.0000+00    0.0000      -5.0000+00    1.0000+02   -2.0000+02    1.0000+02
 6   5.0000-01     1.5000+01   -2.0000+01    5.0000+00    1.0000+02   -2.0000+02    1.0000+02
```

METRIC DATA

| I | X | Y | FG(NH1) | FG(NH2) | FG(NH3) | FG(NH12) | FG(NH21) | FG(NH31) | FG(NH32) | BETA |
|---|---|---|---|---|---|---|---|---|---|---|
| 20 | 9.182-01 | 1.000+00 | 9.831-01 | 9.831-01 | 1.000+00 | -6.426-04 | -3.628-02 | 0.000 | 0.000 | 3.669-06 |
| 19 | 9.182-01 | 9.805-01 | 9.831-01 | 9.831-01 | 1.000+00 | -1.620-03 | -3.626-02 | 0.000 | 0.000 | 4.793-02 |
| 18 | 9.182-01 | 9.552-01 | 9.832-01 | 9.832-01 | 1.000+00 | -3.726-03 | -3.619-02 | 0.000 | 0.000 | 1.101-01 |
| 17 | 9.182-01 | 9.228-01 | 9.833-01 | 9.833-01 | 1.000+00 | -6.441-03 | -3.604-02 | 0.000 | 0.000 | 1.895-01 |
| 16 | 9.182-01 | 8.821-01 | 9.837-01 | 9.837-01 | 1.000+00 | -9.889-03 | -3.571-02 | 0.000 | 0.000 | 2.888-01 |
| 15 | 9.182-01 | 8.321-01 | 9.843-01 | 9.843-01 | 1.000+00 | -1.420-02 | -3.512-02 | 0.000 | 0.000 | 4.099-01 |
| 14 | 9.182-01 | 7.721-01 | 9.853-01 | 9.853-01 | 1.000+00 | -1.954-02 | -3.409-02 | 0.000 | 0.000 | 5.525-01 |
| 13 | 9.182-01 | 7.027-01 | 9.869-01 | 9.869-01 | 1.000+00 | -2.604-02 | -3.243-02 | 0.000 | 0.000 | 7.131-01 |
| 12 | 9.182-01 | 6.253-01 | 9.892-01 | 9.892-01 | 1.000+00 | -3.387-02 | -2.985-02 | 0.000 | 0.000 | 8.844-01 |
| 11 | 9.182-01 | 5.424-01 | 9.924-01 | 9.924-01 | 1.000+00 | -4.314-02 | -2.603-02 | 0.000 | 0.000 | 1.055+00 |
| 10 | 9.182-01 | 4.576-01 | 9.965-01 | 9.965-01 | 1.000+00 | -5.397-02 | -2.061-02 | 0.000 | 0.000 | 1.210+00 |
| 9 | 9.182-01 | 3.747-01 | 1.001+00 | 1.001+00 | 1.000+00 | -6.633-02 | -1.329-02 | 0.000 | 0.000 | 1.337+00 |
| 8 | 9.182-01 | 2.973-01 | 1.007+00 | 1.007+00 | 1.000+00 | -8.001-02 | -3.980-03 | 0.000 | 0.000 | 1.425+00 |
| 7 | 9.182-01 | 2.279-01 | 1.013+00 | 1.013+00 | 1.000+00 | -9.459-02 | 7.144-03 | 0.000 | 0.000 | 1.469+00 |
| 6 | 9.182-01 | 1.679-01 | 1.019+00 | 1.019+00 | 1.000+00 | -1.094-01 | 1.954-02 | 0.000 | 0.000 | 1.475+00 |
| 5 | 9.182-01 | 1.179-01 | 1.025+00 | 1.025+00 | 1.000+00 | -1.238-01 | 3.249-02 | 0.000 | 0.000 | 1.449+00 |
| 4 | 9.182-01 | 7.716-02 | 1.030+00 | 1.030+00 | 1.000+00 | -1.371-01 | 4.518-02 | 0.000 | 0.000 | 1.404+00 |
| 3 | 9.182-01 | 4.478-02 | 1.035+00 | 1.035+00 | 1.000+00 | -1.492-01 | 5.710-02 | 0.000 | 0.000 | 1.347+00 |
| 2 | 9.182-01 | 1.949-02 | 1.039+00 | 1.039+00 | 1.000+00 | -1.550-01 | 6.906-02 | 0.000 | 0.000 | 1.266+00 |
| 1 | 9.182-01 | 0.000 | 1.041+00 | 1.041+00 | 1.000+00 | -1.148-01 | 7.972-02 | 0.000 | 0.000 | 1.086+00 |

```
JX=  1, VARIABLE AT X( 1)=    .91821+00


                                  LEVEL  3   *****        U-VEL    *****


       IZ=            1           2           3           4           5           6
       Z =         .0000      .1000+00    .2000+00    .3000+00    .4000+00    .5000+00
 20    .1000+01    .1000+01    .1000+01    .1000+01    .1000+01    .1000+01    .1000+01
 19    .9810+00    .1000+01    .1000+01    .1000+01    .1000+01    .1000+01    .1000+01
 18    .9561+00    .1000+01    .1000+01    .1000+01    .1000+01    .1000+01    .1000+01
 17    .9243+00    .1000+01    .1000+01    .1000+01    .1000+01    .1000+01    .1000+01
 16    .8842+00    .1000+01    .1000+01    .1000+01    .1000+01    .1000+01    .1000+01
 15    .8349+00    .1000+01    .1000+01    .1000+01    .1000+01    .1000+01    .1000+01
 14    .7759+00    .1000+01    .1000+01    .1000+01    .1000+01    .1000+01    .1000+01
 13    .7075+00    .9999+00    .9999+00    .9999+00    .9999+00    .9999+00    .9999+00
 12    .6310+00    .9999+00    .9999+00    .9999+00    .9999+00    .9999+00    .9999+00
 11    .5489+00    .9998+00    .9998+00    .9998+00    .9998+00    .9998+00    .9998+00
 10    .4645+00    .9998+00    .9998+00    .9998+00    .9998+00    .9998+00    .9998+00
  9    .3818+00    .9997+00    .9997+00    .9997+00    .9997+00    .9997+00    .9997+00
  8    .3040+00    .9997+00    .9997+00    .9997+00    .9997+00    .9997+00    .9997+00
  7    .2339+00    .9997+00    .9997+00    .9997+00    .9997+00    .9997+00    .9997+00
  6    .1730+00    .9997+00    .9997+00    .9997+00    .9997+00    .9997+00    .9997+00
  5    .1218+00    .9997+00    .9997+00    .9997+00    .9997+00    .9997+00    .9997+00
  4    .7993-01    .9997+00    .9997+00    .9997+00    .9997+00    .9997+00    .9997+00
  3    .4650-01    .9997+00    .9997+00    .9997+00    .9997+00    .9997+00    .9997+00
  2    .2027-01    .9998+00    .9998+00    .9998+00    .9998+00    .9998+00    .9998+00
  1    .0000       .9998+00    .9998+00    .9998+00    .9998+00    .9998+00    .9998+00
```

```
JX=  1, VARIABLE AT X( 1)=    .91821+00

                          LEVEL  3   *****     V-VEL   *****

        IZ=          1          2          3          4          5          6
        Z =        .0000     .1000+00   .2000+00   .3000+00   .4000+00   .5000+00
20   .1000+01  -.6394-07  -.6394-07  -.6394-07  -.6394-07  -.6394-07  -.6394-07
19   .9810+00  -.8366-03  -.8366-03  -.8366-03  -.8366-03  -.8366-03  -.8366-03
18   .9561+00  -.1921-02  -.1921-02  -.1921-02  -.1921-02  -.1921-02  -.1921-02
17   .9243+00  -.3307-02  -.3307-02  -.3307-02  -.3307-02  -.3307-02  -.3307-02
16   .8842+00  -.5041-02  -.5041-02  -.5041-02  -.5041-02  -.5041-02  -.5041-02
15   .8349+00  -.7154-02  -.7154-02  -.7154-02  -.7154-02  -.7154-02  -.7154-02
14   .7759+00  -.9642-02  -.9642-02  -.9642-02  -.9642-02  -.9642-02  -.9642-02
13   .7075+00  -.1245-01  -.1245-01  -.1245-01  -.1245-01  -.1245-01  -.1245-01
12   .6310+00  -.1543-01  -.1543-01  -.1543-01  -.1543-01  -.1543-01  -.1543-01
11   .5489+00  -.1841-01  -.1841-01  -.1841-01  -.1841-01  -.1841-01  -.1841-01
10   .4645+00  -.2112-01  -.2112-01  -.2112-01  -.2112-01  -.2112-01  -.2112-01
 9   .3818+00  -.2333-01  -.2333-01  -.2333-01  -.2333-01  -.2333-01  -.2333-01
 8   .3040+00  -.2486-01  -.2486-01  -.2486-01  -.2486-01  -.2486-01  -.2486-01
 7   .2339+00  -.2564-01  -.2564-01  -.2564-01  -.2564-01  -.2564-01  -.2564-01
 6   .1730+00  -.2574-01  -.2574-01  -.2574-01  -.2574-01  -.2574-01  -.2574-01
 5   .1218+00  -.2529-01  -.2529-01  -.2529-01  -.2529-01  -.2529-01  -.2529-01
 4   .7993-01  -.2450-01  -.2450-01  -.2450-01  -.2450-01  -.2450-01  -.2450-01
 3   .4650-01  -.2350-01  -.2350-01  -.2350-01  -.2350-01  -.2350-01  -.2350-01
 2   .2027-01  -.2209-01  -.2209-01  -.2209-01  -.2209-01  -.2209-01  -.2209-01
 1   .0000     -.1895-01  -.1895-01  -.1895-01  -.1895-01  -.1895-01  -.1895-01
```

```
JX=  1, VARIABLE AT X( 1)=    .91821+00

                              LEVEL  3   *****      W-VEL    *****

       IZ=           1          2            3            4            5            6
       Z =         .0000      .1000+00     .2000+00     .3000+00     .4000+00     .5000+00
 20   .1000+01     .0000      .0000        .0000        .0000        .0000        .0000
 19   .9810+00     .0000      .0000        .0000        .0000        .0000        .0000
 18   .9561+00     .0000      .0000        .0000        .0000        .0000        .0000
 17   .9243+00     .0000      .0000        .0000        .0000        .0000        .0000
 16   .8842+00     .0000      .0000        .0000        .0000        .0000        .0000
 15   .8349+00     .0000      .0000        .0000        .0000        .0000        .0000
 14   .7759+00     .0000      .0000        .0000        .0000        .0000        .0000
 13   .7075+00     .0000      .0000        .0000        .0000        .0000        .0000
 12   .6310+00     .0000      .0000        .0000        .0000        .0000        .0000
 11   .5489+00     .0000      .0000        .0000        .0000        .0000        .0000
 10   .4645+00     .0000      .0000        .0000        .0000        .0000        .0000
  9   .3818+00     .0000      .0000        .0000        .0000        .0000        .0000
  8   .3040+00     .0000      .0000        .0000        .0000        .0000        .0000
  7   .2339+00     .0000      .0000        .0000        .0000        .0000        .0000
  6   .1730+00     .0000      .0000        .0000        .0000        .0000        .0000
  5   .1218+00     .0000      .0000        .0000        .0000        .0000        .0000
  4   .7993-01     .0000      .0000        .0000        .0000        .0000        .0000
  3   .4650-01     .0000      .0000        .0000        .0000        .0000        .0000
  2   .2027-01     .0000      .0000        .0000        .0000        .0000        .0000
  1   .0000        .0000      .0000        .0000        .0000        .0000        .0000
```

```
JX=  1, VARIABLE AT X( 1)=   .91821+00

                                LEVEL  3   *****        RHO     *****

      IZ=           1          2          3          4          5          6
      Z =        .0000     .1000+00   .2000+00   .3000+00   .4000+00   .5000+00
20  .1000+01   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01
19  .9810+00   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01
18  .9561+00   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01
17  .9243+00   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01
16  .8842+00   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01
15  .8349+00   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01
14  .7759+00   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01
13  .7075+00   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01
12  .6310+00   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01
11  .5489+00   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01
10  .4645+00   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01
 9  .3818+00   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01
 8  .3040+00   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01
 7  .2339+00   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01
 6  .1730+00   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01
 5  .1218+00   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01
 4  .7993-01   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01
 3  .4650-01   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01
 2  .2027-01   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01
 1  .0000      .1000+01   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01
```

```
  JX=  1, VARIABLE AT X( 1)=    .91821+00

                               LEVEL  3   *****     ENERGY  *****

        IZ=          1          2          3          4          5          6
        Z =        .0000     .1000+00   .2000+00   .3000+00   .4000+00   .5000+00
  20   .1000+01    .0000     .0000      .0000      .0000      .0000      .0000
  19   .9810+00    .0000     .0000      .0000      .0000      .0000      .0000
  18   .9561+00    .0000     .0000      .0000      .0000      .0000      .0000
  17   .9243+00    .0000     .0000      .0000      .0000      .0000      .0000
  16   .8842+00    .0000     .0000      .0000      .0000      .0000      .0000
  15   .8349+00    .0000     .0000      .0000      .0000      .0000      .0000
  14   .7759+00    .0000     .0000      .0000      .0000      .0000      .0000
  13   .7075+00    .0000     .0000      .0000      .0000      .0000      .0000
  12   .6310+00    .0000     .0000      .0000      .0000      .0000      .0000
  11   .5489+00    .0000     .0000      .0000      .0000      .0000      .0000
  10   .4645+00    .0000     .0000      .0000      .0000      .0000      .0000
   9   .3818+00    .0000     .0000      .0000      .0000      .0000      .0000
   8   .3040+00    .0000     .0000      .0000      .0000      .0000      .0000
   7   .2339+00    .0000     .0000      .0000      .0000      .0000      .0000
   6   .1730+00    .0000     .0000      .0000      .0000      .0000      .0000
   5   .1218+00    .0000     .0000      .0000      .0000      .0000      .0000
   4   .7993-01    .0000     .0000      .0000      .0000      .0000      .0000
   3   .4650-01    .0000     .0000      .0000      .0000      .0000      .0000
   2   .2027-01    .0000     .0000      .0000      .0000      .0000      .0000
   1   .0000       .0000     .0000      .0000      .0000      .0000      .0000
```

```
JX=  1, VARIABLE AT X( 1)=    .91821+00

                                   LEVEL  3    *****          MU     *****

          IZ=          1          2          3          4          5          6
          Z =        .0000      .1000+00   .2000+00   .3000+00   .4000+00   .5000+00
   20     .1000+01   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01
   19     .9810+00   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01
   18     .9561+00   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01
   17     .9243+00   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01
   16     .8842+00   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01
   15     .8349+00   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01
   14     .7759+00   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01
   13     .7075+00   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01
   12     .6310+00   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01
   11     .5489+00   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01
   10     .4645+00   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01
    9     .3818+00   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01
    8     .3040+00   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01
    7     .2339+00   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01
    6     .1730+00   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01
    5     .1218+00   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01
    4     .7993-01   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01
    3     .4650-01   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01
    2     .2027-01   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01
    1     .0000      .1000+01   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01
```

```
JX=  1, VARIABLE AT X( 1)=    .91821+00


                              LEVEL  3   *****        MUT     *****

        IZ=          1          2          3          4          5          6
        Z =      .0000      .1000+00   .2000+00   .3000+00   .4000+00   .5000+00
 20  .1000+01   .3122+00   .3122+00   .3122+00   .3122+00   .3122+00   .3122+00
 19  .9810+00   .3122+00   .3122+00   .3122+00   .3122+00   .3122+00   .3122+00
 18  .9561+00   .3111+00   .3111+00   .3111+00   .3111+00   .3111+00   .3111+00
 17  .9243+00   .3093+00   .3093+00   .3093+00   .3093+00   .3093+00   .3093+00
 16  .8842+00   .3063+00   .3063+00   .3063+00   .3063+00   .3063+00   .3063+00
 15  .8349+00   .3013+00   .3013+00   .3013+00   .3013+00   .3013+00   .3013+00
 14  .7759+00   .2936+00   .2936+00   .2936+00   .2936+00   .2936+00   .2936+00
 13  .7075+00   .2820+00   .2820+00   .2820+00   .2820+00   .2820+00   .2820+00
 12  .6310+00   .2648+00   .2648+00   .2648+00   .2648+00   .2648+00   .2648+00
 11  .5489+00   .2406+00   .2406+00   .2406+00   .2406+00   .2406+00   .2406+00
 10  .4645+00   .2074+00   .2074+00   .2074+00   .2074+00   .2074+00   .2074+00
  9  .3818+00   .1640+00   .1640+00   .1640+00   .1640+00   .1640+00   .1640+00
  8  .3040+00   .1101+00   .1101+00   .1101+00   .1101+00   .1101+00   .1101+00
  7  .2339+00   .4718-01   .4718-01   .4718-01   .4718-01   .4718-01   .4718-01
  6  .1730+00   .2223-01   .2223-01   .2223-01   .2223-01   .2223-01   .2223-01
  5  .1218+00   .9468-01   .9468-01   .9468-01   .9468-01   .9468-01   .9468-01
  4  .7993-01   .1693+00   .1693+00   .1693+00   .1693+00   .1693+00   .1693+00
  3  .4650-01   .2879+00   .2879+00   .2879+00   .2879+00   .2879+00   .2879+00
  2  .2027-01   .6445+00   .6445+00   .6445+00   .6445+00   .6445+00   .6445+00
  1  .0000     -.1178+01  -.1178+01  -.1178+01  -.1178+01  -.1178+01  -.1178+01
```

```
JX=  1, VARIABLE AT X( 1)=    .91821+00

                              LEVEL  3    *****        TKE      *****

       IZ=        1          2          3          4          5          6
       Z =      .0000      .1000+00   .2000+00   .3000+00   .4000+00   .5000+00
  20   .1000+01  .1501-03    .1501-03   .1501-03   .1501-03   .1501-03   .1501-03
  19   .9810+00  .1501-03    .1501-03   .1501-03   .1501-03   .1501-03   .1501-03
  18   .9561+00  .1501-03    .1501-03   .1501-03   .1501-03   .1501-03   .1501-03
  17   .9243+00  .1501-03    .1501-03   .1501-03   .1501-03   .1501-03   .1501-03
  16   .8842+00  .1501-03    .1501-03   .1501-03   .1501-03   .1501-03   .1501-03
  15   .8349+00  .1501-03    .1501-03   .1501-03   .1501-03   .1501-03   .1501-03
  14   .7759+00  .1501-03    .1501-03   .1501-03   .1501-03   .1501-03   .1501-03
  13   .7075+00  .1501-03    .1501-03   .1501-03   .1501-03   .1501-03   .1501-03
  12   .6310+00  .1501-03    .1501-03   .1501-03   .1501-03   .1501-03   .1501-03
  11   .5489+00  .1501-03    .1501-03   .1501-03   .1501-03   .1501-03   .1501-03
  10   .4645+00  .1501-03    .1501-03   .1501-03   .1501-03   .1501-03   .1501-03
   9   .3818+00  .1500-03    .1500-03   .1500-03   .1500-03   .1500-03   .1500-03
   8   .3040+00  .1500-03    .1500-03   .1500-03   .1500-03   .1500-03   .1500-03
   7   .2339+00  .1500-03    .1500-03   .1500-03   .1500-03   .1500-03   .1500-03
   6   .1730+00  .1500-03    .1500-03   .1500-03   .1500-03   .1500-03   .1500-03
   5   .1218+00  .1500-03    .1500-03   .1500-03   .1500-03   .1500-03   .1500-03
   4   .7993-01  .1500-03    .1500-03   .1500-03   .1500-03   .1500-03   .1500-03
   3   .4650-01  .1483-03    .1483-03   .1483-03   .1483-03   .1483-03   .1483-03
   2   .2027-01  .5365-04    .5365-04   .5365-04   .5365-04   .5365-04   .5365-04
   1   .0000     .5365-04    .5365-04   .5365-04   .5365-04   .5365-04   .5365-04
```

```
JX=  1, VARIABLE AT X( 1)=   .91821+00

                         LEVEL  3   *****       DIS    *****

      IZ=          1           2           3           4           5           6
      Z =        .0000     .1000+00    .2000+00    .3000+00    .4000+00    .5000+00
 20   .1000+01   .6717-04    .6717-04    .6717-04    .6717-04    .6717-04    .6717-04
 19   .9810+00   .6717-04    .6717-04    .6717-04    .6717-04    .6717-04    .6717-04
 18   .9561+00   .6717-04    .6717-04    .6717-04    .6717-04    .6717-04    .6717-04
 17   .9243+00   .6717-04    .6717-04    .6717-04    .6717-04    .6717-04    .6717-04
 16   .8842+00   .6717-04    .6717-04    .6717-04    .6717-04    .6717-04    .6717-04
 15   .8349+00   .6716-04    .6716-04    .6716-04    .6716-04    .6716-04    .6716-04
 14   .7759+00   .6716-04    .6716-04    .6716-04    .6716-04    .6716-04    .6716-04
 13   .7075+00   .6715-04    .6715-04    .6715-04    .6715-04    .6715-04    .6715-04
 12   .6310+00   .6715-04    .6715-04    .6715-04    .6715-04    .6715-04    .6715-04
 11   .5489+00   .6713-04    .6713-04    .6713-04    .6713-04    .6713-04    .6713-04
 10   .4645+00   .6712-04    .6712-04    .6712-04    .6712-04    .6712-04    .6712-04
  9   .3818+00   .6711-04    .6711-04    .6711-04    .6711-04    .6711-04    .6711-04
  8   .3040+00   .6709-04    .6709-04    .6709-04    .6709-04    .6709-04    .6709-04
  7   .2339+00   .6708-04    .6708-04    .6708-04    .6708-04    .6708-04    .6708-04
  6   .1730+00   .6708-04    .6708-04    .6708-04    .6708-04    .6708-04    .6708-04
  5   .1218+00   .6709-04    .6709-04    .6709-04    .6709-04    .6709-04    .6709-04
  4   .7993-01   .6711-04    .6711-04    .6711-04    .6711-04    .6711-04    .6711-04
  3   .4650-01   .6597-04    .6597-04    .6597-04    .6597-04    .6597-04    .6597-04
  2   .2027-01   .1496-04    .1496-04    .1496-04    .1496-04    .1496-04    .1496-04
  1   .0000      .2991-04    .2991-04    .2991-04    .2991-04    .2991-04    .2991-04
```

```
JX=  1, VARIABLE AT X( 1)=    .91821+00


                        LEVEL  3  *****        CP/2   *****


       IZ=            1          2          3          4          5          6
       Z =         .0000   .1000+00   .2000+00   .3000+00   .4000+00   .5000+00
20   .1000+01      .0000      .0000      .0000      .0000      .0000      .0000
19   .9810+00  -.1863-08  -.1863-08  -.1863-08  -.1863-08  -.1863-08  -.1863-08
18   .9561+00  -.1863-08  -.1863-08  -.1863-08  -.1863-08  -.1863-08  -.1863-08
17   .9243+00  -.1863-08  -.1863-08  -.1863-08  -.1863-08  -.1863-08  -.1863-08
16   .8842+00      .0000      .0000      .0000      .0000      .0000      .0000
15   .8349+00  -.1863-08  -.1863-08  -.1863-08  -.1863-08  -.1863-08  -.1863-08
14   .7759+00      .0000      .0000      .0000      .0000      .0000      .0000
13   .7075+00  -.1863-08  -.1863-08  -.1863-08  -.1863-08  -.1863-08  -.1863-08
12   .6310+00  -.1863-08  -.1863-08  -.1863-08  -.1863-08  -.1863-08  -.1863-08
11   .5489+00  -.1863-08  -.1863-08  -.1863-08  -.1863-08  -.1863-08  -.1863-08
10   .4645+00  -.1863-08  -.1863-08  -.1863-08  -.1863-08  -.1863-08  -.1863-08
 9   .3816+00  -.1863-08  -.1863-08  -.1863-08  -.1863-08  -.1863-08  -.1863-08
 8   .3040+00  -.1863-08  -.1863-08  -.1863-08  -.1863-08  -.1863-08  -.1863-08
 7   .2339+00  -.1863-08  -.1863-08  -.1863-08  -.1863-08  -.1863-08  -.1863-08
 6   .1730+00  -.1863-08  -.1863-08  -.1863-08  -.1863-08  -.1863-08  -.1863-08
 5   .1218+00  -.1863-08  -.1863-08  -.1863-08  -.1863-08  -.1863-08  -.1863-08
 4   .7993-01  -.1863-08  -.1863-08  -.1863-08  -.1863-08  -.1863-08  -.1863-08
 3   .4650-01  -.1863-08  -.1863-08  -.1863-08  -.1863-08  -.1863-08  -.1863-08
 2   .2027-01  -.1863-08  -.1863-08  -.1863-08  -.1863-08  -.1863-08  -.1863-08
 1   .0000     -.1863-08  -.1863-08  -.1863-08  -.1863-08  -.1863-08  -.1863-08
```

```
JX=  1, VARIABLE AT X( 1)=    .91821+00

                                   LEVEL  3    *****        MACH    *****

        IZ=          1          2          3          4          5          6
        Z =        .0000      .1000+00   .2000+00   .3000+00   .4000+00   .5000+00
  20    .1000+01   .3001+01   .3001+01   .3001+01   .3001+01   .3001+01   .3001+01
  19    .9810+00   .3001+01   .3001+01   .3001+01   .3001+01   .3001+01   .3001+01
  18    .9561+00   .3001+01   .3001+01   .3001+01   .3001+01   .3001+01   .3001+01
  17    .9243+00   .3001+01   .3001+01   .3001+01   .3001+01   .3001+01   .3001+01
  16    .8842+00   .3001+01   .3001+01   .3001+01   .3001+01   .3001+01   .3001+01
  15    .8349+00   .3001+01   .3001+01   .3001+01   .3001+01   .3001+01   .3001+01
  14    .7759+00   .3001+01   .3001+01   .3001+01   .3001+01   .3001+01   .3001+01
  13    .7075+00   .3001+01   .3001+01   .3001+01   .3001+01   .3001+01   .3001+01
  12    .5310+00   .3001+01   .3001+01   .3001+01   .3001+01   .3001+01   .3001+01
  11    .5489+00   .3001+01   .3001+01   .3001+01   .3001+01   .3001+01   .3001+01
  10    .4645+00   .3001+01   .3001+01   .3001+01   .3001+01   .3001+01   .3001+01
   9    .3818+00   .3001+01   .3001+01   .3001+01   .3001+01   .3001+01   .3001+01
   8    .3043+00   .3001+01   .3001+01   .3001+01   .3001+01   .3001+01   .3001+01
   7    .2339+00   .3001+01   .3001+01   .3001+01   .3001+01   .3001+01   .3001+01
   6    .1730+00   .3001+01   .3001+01   .3001+01   .3001+01   .3001+01   .3001+01
   5    .1218+00   .3001+01   .3001+01   .3001+01   .3001+01   .3001+01   .3001+01
   4    .7993-01   .3001+01   .3001+01   .3001+01   .3001+01   .3001+01   .3001+01
   3    .4650-01   .3001+01   .3001+01   .3001+01   .3001+01   .3001+01   .3001+01
   2    .2027-01   .3001+01   .3001+01   .3001+01   .3001+01   .3001+01   .3001+01
   1    .0000      .3001+01   .3001+01   .3001+01   .3001+01   .3001+01   .3001+01
```

```
JX=  1, VARIABLE AT X( 1)=    .91821+00

                         LEVEL  3    *****        TSTAT   *****

       IZ=          1          2          3          4          5          6
       Z =      .0000     .1000+00   .2000+00   .3000+00   .4000+00   .5000+00
20  .1000+01   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01
19  .9810+00   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01
18  .9561+00   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01
17  .9243+00   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01
16  .8842+00   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01
15  .8349+00   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01
14  .7759+00   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01
13  .7075+00   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01
12  .6310+00   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01
11  .5489+00   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01
10  .4645+00   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01
 9  .3818+00   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01
 8  .3040+00   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01
 7  .2339+00   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01
 6  .1730+00   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01
 5  .1218+00   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01
 4  .7993-01   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01
 3  .4650-01   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01
 2  .2027-01   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01
 1  .0000      .1000+01   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01
```

```
IADI=1   IJ= 2   ISS=1000   ISSD=1000
IADI=1   IJ= 3   ISS=1000   ISSD=1000
IADI=1   IJ= 4   ISS=1000   ISSD=1000
IADI=1   IJ= 5   ISS=1000   ISSD=1000



IADI=2   IJ= 2   ISS=1000   ISSD=1000
IADI=2   IJ= 3   ISS=1000   ISSD=1000
IADI=2   IJ= 4   ISS=1000   ISSD=1000
IADI=2   IJ= 5   ISS=1000   ISSD=1000
IADI=2   IJ= 6   ISS=1000   ISSD=1000
IADI=2   IJ= 7   ISS=1000   ISSD=1000
IADI=2   IJ= 8   ISS=1000   ISSD=1000
IADI=2   IJ= 9   ISS=1000   ISSD=1000
IADI=2   IJ=10   ISS=1000   ISSD=1000
IADI=2   IJ=11   ISS=1000   ISSD=1000
IADI=2   IJ=12   ISS=1000   ISSD=1000
IADI=2   IJ=13   ISS=1000   ISSD=1000
IADI=2   IJ=14   ISS=1000   ISSD=1000
IADI=2   IJ=15   ISS=1000   ISSD=1000
IADI=2   IJ=16   ISS=1000   ISSD=1000
IADI=2   IJ=17   ISS=1000   ISSD=1000
IADI=2   IJ=18   ISS=1000   ISSD=1000
IADI=2   IJ=19   ISS=1000   ISSD=1000
```

```
                                                  METRIC DATA
  I      X          Y         FG(NH1)    FG(NH2)    FG(NH3)    FG(NH12)   FG(NH21)   FS(NH31)   FG(NH32)    BETA
 20   9.432-01   1.000+00   9.820-01   9.820-01   1.000+00   -6.555-04  -3.821-02   0.000      0.000      3.417-06
 19   9.432-01   9.805-01   9.820-01   9.820-01   1.000+00   -1.649-03  -3.820-02   0.000      0.000      5.035-02
 18   9.432-01   9.552-01   9.821-01   9.821-01   1.000+00   -3.788-03  -3.814-02   0.000      0.000      1.156-01
 17   9.432-01   9.228-01   9.822-01   9.822-01   1.000+00   -6.554-03  -3.799-02   0.000      0.000      1.991-01
 16   9.432-01   8.821-01   9.826-01   9.826-01   1.000+00   -1.006-02  -3.769-02   0.000      0.000      3.035-01
 15   9.432-01   8.321-01   9.832-01   9.832-01   1.000+00   -1.446-02  -3.714-02   0.000      0.000      4.310-01
 14   9.432-01   7.721-01   9.842-01   9.842-01   1.000+00   -1.991-02  -3.619-02   0.000      0.000      5.815-01
 13   9.432-01   7.027-01   9.858-01   9.858-01   1.000+00   -2.655-02  -3.465-02   0.000      0.000      7.518-01
 12   9.432-01   6.253-01   9.882-01   9.882-01   1.000+00   -3.458-02  -3.225-02   0.000      0.000      9.347-01
 11   9.432-01   5.424-01   9.914-01   9.914-01   1.000+00   -4.414-02  -2.869-02   0.000      0.000      1.119+00
 10   9.432-01   4.576-01   9.957-01   9.957-01   1.000+00   -5.536-02  -2.364-02   0.000      0.000      1.290+00
  9   9.432-01   3.747-01   1.001+00   1.001+00   1.000+00   -6.827-02  -1.681-02   0.000      0.000      1.435+00
  8   9.432-01   2.973-01   1.007+00   1.007+00   1.000+00   -8.267-02  -8.076-03   0.000      0.000      1.543+00
  7   9.432-01   2.279-01   1.013+00   1.013+00   1.000+00   -9.813-02   2.384-03   0.000      0.000      1.609+00
  6   9.432-01   1.679-01   1.019+00   1.019+00   1.000+00   -1.140-01   1.409-02   0.000      0.000      1.637+00
  5   9.432-01   1.179-01   1.025+00   1.025+00   1.000+00   -1.294-01   2.635-02   0.000      0.000      1.632+00
  4   9.432-01   7.716-02   1.031+00   1.031+00   1.000+00   -1.439-01   3.841-02   0.000      0.000      1.606+00
  3   9.432-01   4.478-02   1.036+00   1.036+00   1.000+00   -1.581-01   4.983-02   0.000      0.000      1.566+00
  2   9.432-01   1.949-02   1.040+00   1.040+00   1.000+00   -1.760-01   6.207-02   0.000      0.000      1.498+00
  1   9.432-01   0.000      1.043+00   1.043+00   1.000+00   -1.419-01   7.517-02   0.000      0.000      1.302+00
```

```
JX=  2, VARIABLE AT X( 2)=    .94321+00

                              LEVEL  1   *****        U-VEL    *****

        IZ=         1          2          3          4          5          6
        Z =       .0000     .1000+00   .2000+00   .3000+00   .4000+00   .5000+00
  20  .1000+01  .1000+01   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01
  19  .9810+00  .1000+01   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01
  18  .9561+00  .1000+01   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01
  17  .9243+00  .1000+01   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01
  16  .8842+00  .1000+01   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01
  15  .8349+00  .1000+01   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01
  14  .7759+00  .9999+00   .9999+00   .9999+00   .9999+00   .9999+00   .9999+00
  13  .7075+00  .9999+00   .9999+00   .9999+00   .9999+00   .9999+00   .9999+00
  12  .6310+00  .9999+00   .9999+00   .9999+00   .9999+00   .9999+00   .9999+00
  11  .5489+00  .9998+00   .9998+00   .9998+00   .9998+00   .9998+00   .9998+00
  10  .4645+00  .9997+00   .9997+00   .9997+00   .9997+00   .9997+00   .9997+00
   9  .3818+00  .9997+00   .9997+00   .9997+00   .9997+00   .9997+00   .9997+00
   8  .3040+00  .9996+00   .9996+00   .9996+00   .9996+00   .9996+00   .9996+00
   7  .2339+00  .9996+00   .9996+00   .9996+00   .9996+00   .9996+00   .9996+00
   6  .1730+00  .9996+00   .9996+00   .9996+00   .9996+00   .9996+00   .9996+00
   5  .1218+00  .9996+00   .9996+00   .9996+00   .9996+00   .9996+00   .9996+00
   4  .7993-01  .9996+00   .9996+00   .9996+00   .9996+00   .9996+00   .9996+00
   3  .4650-01  .9996+00   .9996+00   .9996+00   .9996+00   .9996+00   .9996+00
   2  .2027-01  .1001+01   .1001+01   .1001+01   .1001+01   .1001+01   .1001+01
   1  .0000     .7181+00   .7181+00   .7181+00   .7181+00   .7181+00   .7181+00
```

```
JX=  2, VARIABLE AT X( 2)=    .94321+00

                                   LEVEL  1    *****       V-VEL    *****

     IZ=           1          2          3          4          5          6
     Z =         .0000      .1000+00   .2000+00   .3000+00   .4000+00   .5000+00
20   .1000+01  -.4918-04  -.4918-04  -.4918-04  -.4918-04  -.4918-04  -.4918-04
19   .9810+00  -.8791-03  -.8791-03  -.8791-03  -.8791-03  -.8791-03  -.8791-03
18   .9561+00  -.2018-02  -.2018-02  -.2018-02  -.2018-02  -.2018-02  -.2018-02
17   .9243+00  -.3473-02  -.3473-02  -.3473-02  -.3473-02  -.3473-02  -.3473-02
16   .8842+00  -.5296-02  -.5296-02  -.5296-02  -.5296-02  -.5296-02  -.5296-02
15   .8349+00  -.7520-02  -.7520-02  -.7520-02  -.7520-02  -.7520-02  -.7520-02
14   .7759+00  -.1015-01  -.1015-01  -.1015-01  -.1015-01  -.1015-01  -.1015-01
13   .7075+00  -.1312-01  -.1312-01  -.1312-01  -.1312-01  -.1312-01  -.1312-01
12   .6310+00  -.1631-01  -.1631-01  -.1631-01  -.1631-01  -.1631-01  -.1631-01
11   .5489+00  -.1952-01  -.1952-01  -.1952-01  -.1952-01  -.1952-01  -.1952-01
10   .4645+00  -.2251-01  -.2251-01  -.2251-01  -.2251-01  -.2251-01  -.2251-01
 9   .3816+00  -.2503-01  -.2503-01  -.2503-01  -.2503-01  -.2503-01  -.2503-01
 8   .3040+00  -.2691-01  -.2691-01  -.2691-01  -.2691-01  -.2691-01  -.2691-01
 7   .2339+00  -.2805-01  -.2805-01  -.2805-01  -.2805-01  -.2805-01  -.2805-01
 6   .1730+00  -.2852-01  -.2852-01  -.2852-01  -.2852-01  -.2852-01  -.2852-01
 5   .1218+00  -.2842-01  -.2842-01  -.2842-01  -.2842-01  -.2842-01  -.2842-01
 4   .7993-01  -.2797-01  -.2797-01  -.2797-01  -.2797-01  -.2797-01  -.2797-01
 3   .4650-01  -.2670-01  -.2670-01  -.2670-01  -.2670-01  -.2670-01  -.2670-01
 2   .2027-01  -.2589-01  -.2589-01  -.2589-01  -.2589-01  -.2589-01  -.2589-01
 1   .0000      .0000      .0000      .0000      .0000      .0000      .0000
```

```
JX=  2, VARIABLE AT X( 2)=    .94321+00

                              LEVEL  1    *****       W-VEL    *****

        IZ=           1           2           3           4           5           6
        Z =        .0000     .1000+00    .2000+00    .3000+00    .4000+00    .5000+00
 20  .1000+01      .0000     .2018-08    .1346-08   -.3616-08   -.5541-08   -.6183-08
 19  .9810+00      .0000     .1397-08    .9728-09   -.2746-08   -.4653-08   -.5588-08
 18  .9561+00      .0000    -.4657-09   -.1475-09   -.1359-09   -.1990-08   -.4191-08
 17  .9243+00      .0000    -.2328-08    .6250-09   -.2995-08   -.3719-09    .1397-08
 16  .8842+00      .0000     .7916-08   -.2569-08   -.1109-08    .1386-08    .1863-08
 15  .8349+00      .0000     .4191-08    .7366-08   -.2434-08   -.1001-08   -.4657-09
 14  .7759+00      .0000     .4191-08    .2428-08   -.3775-08   -.3095-08   -.2794-08
 13  .7075+00      .0000     .5122-08   -.2030-08   -.3910-09    .3529-09    .1397-08
 12  .6310+00      .0000     .0000      -.5303-08    .6443-09    .5412-08    .6985-08
 11  .5489+00      .0000     .8848-08   -.9947-09   -.1722-08    .5486-08    .6985-08
 10  .4645+00      .0000    -.5586-08   -.4476-08   -.1827-08    .7322-09    .9313-09
  9  .3818+00      .0000    -.1397-08   -.1360-08    .4873-09   -.2653-08   -.2328-08
  8  .3040+00      .0000     .2794-08    .4980-09   -.2063-08    .1847-09   -.1397-08
  7  .2334+00      .0000    -.1164-07    .3338-08    .5206-08   -.5836-08   -.9779-08
  6  .1730+00      .0000    -.5122-08   -.9750-09   -.1453-08    .3042-08    .3725-08
  5  .1218+00      .0000    -.3725-08    .4893-08    .2582-08   -.1252-08   -.1863-08
  4  .7993-01      .0000     .4657-09    .2311-08   -.7713-08   -.5051-08   -.6985-08
  3  .4650-01      .0000    -.9313-09    .2706-08    .2355-08    .3589-08    .5588-08
  2  .2027-01      .0000     .5588-08    .1377-09   -.5465-08   -.9592-09    .4657-09
  1  .0000         .0000    -.9313-09    .2706-08    .2355-08    .3589-08    .4000-08
```

```
JX=  2, VARIABLE AT X( 2)=    .94321+00

                         LEVEL  1    *****       RHO    *****

      IZ=          1          2          3          4          5          6
      Z =        .0000     .1000+00   .2000+00   .3000+00   .4000+00   .5000+00
 20 .1000+01   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01
 19 .9810+00   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01
 18 .9561+00   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01
 17 .9243+00   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01
 16 .8842+00   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01
 15 .8349+00   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01
 14 .7759+00   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01
 13 .7075+00   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01
 12 .6310+00   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01
 11 .5489+00   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01
 10 .4645+00   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01
  9 .3818+00   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01
  8 .3040+00   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01
  7 .2339+00   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01
  6 .1730+00   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01
  5 .1218+00   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01
  4 .7993-01   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01
  3 .4650-01   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01
  2 .2027-01   .1023+01   .1023+01   .1023+01   .1023+01   .1023+01   .1023+01
  1 .0000      .1309-02   .1309-02   .1309-02   .1309-02   .1310-02   .1310-02
```

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JX=  2, VARIABLE AT X( 2)=    .94321+00

                          LEVEL  1   *****      ENERGY  *****

      IZ=          1          2          3          4          5          6
      Z =        .0000      .1000+00   .2000+00   .3000+00   .4000+00   .5000+00
 20  .1000+01    .0000      .0000      .0000      .0000      .0000      .0000
 19  .9810+00    .0000      .0000      .0000      .0000      .0000      .0000
 18  .9561+00    .0000      .0000      .0000      .0000      .0000      .0000
 17  .9243+00    .0000      .0000      .0000      .0000      .0000      .0000
 16  .8842+00    .0000      .0000      .0000      .0000      .0000      .0000
 15  .8349+00    .0000      .0000      .0000      .0000      .0000      .0000
 14  .7759+00    .0000      .0000      .0000      .0000      .0000      .0000
 13  .7075+00    .0000      .0000      .0000      .0000      .0000      .0000
 12  .6310+00    .0000      .0000      .0000      .0000      .0000      .0000
 11  .5489+00    .0000      .0000      .0000      .0000      .0000      .0000
 10  .4645+00    .0000      .0000      .0000      .0000      .0000      .0000
  9  .3818+00    .0000      .0000      .0000      .0000      .0000      .0000
  8  .3040+00    .0000      .0000      .0000      .0000      .0000      .0000
  7  .2339+00    .0000      .0000      .0000      .0000      .0000      .0000
  6  .1730+00    .0000      .0000      .0000      .0000      .0000      .0000
  5  .1218+00    .0000      .0000      .0000      .0000      .0000      .0000
  4  .7993-01    .0000      .0000      .0000      .0000      .0000      .0000
  3  .4650-01    .0000      .0000      .0000      .0000      .0000      .0000
  2  .2027-01    .0000      .0000      .0000      .0000      .0000      .0000
  1  .0000       .0000      .0000      .0000      .0000      .0000      .0000
```

```
JX=  2, VARIABLE AT X( 2)=    .94321+00

                               LEVEL  1    *****          MUT     *****

        IZ=            1           2           3           4           5           6
        Z =          .0000     .1000+00    .2000+00    .3000+00    .4000+00    .5000+00
 20   .1000+01    .3122+00    .3122+00    .3122+00    .3122+00    .3122+00    .3122+00
 19   .9810+00    .3122+00    .3122+00    .3122+00    .3122+00    .3122+00    .3122+00
 18   .9561+00    .3111+00    .3111+00    .3111+00    .3111+00    .3111+00    .3111+00
 17   .9243+00    .3093+00    .3093+00    .3093+00    .3093+00    .3093+00    .3093+00
 16   .8842+00    .3063+00    .3063+00    .3063+00    .3063+00    .3063+00    .3063+00
 15   .8349+00    .3013+00    .3013+00    .3013+00    .3013+00    .3013+00    .3013+00
 14   .7759+00    .2936+00    .2936+00    .2936+00    .2936+00    .2936+00    .2936+00
 13   .7075+00    .2820+00    .2820+00    .2820+00    .2820+00    .2820+00    .2820+00
 12   .6310+00    .2648+00    .2648+00    .2648+00    .2648+00    .2648+00    .2648+00
 11   .5489+00    .2406+00    .2406+00    .2406+00    .2406+00    .2406+00    .2406+00
 10   .4645+00    .2074+00    .2074+00    .2074+00    .2074+00    .2074+00    .2074+00
  9   .3818+00    .1640+00    .1640+00    .1640+00    .1640+00    .1640+00    .1640+00
  8   .3040+00    .1101+00    .1101+00    .1101+00    .1101+00    .1101+00    .1101+00
  7   .2339+00    .4718-01    .4718-01    .4718-01    .4718-01    .4718-01    .4718-01
  6   .1730+00    .2223-01    .2223-01    .2223-01    .2223-01    .2223-01    .2223-01
  5   .1218+00    .9468-01    .9468-01    .9468-01    .9468-01    .9468-01    .9468-01
  4   .7993-01    .1693+00    .1693+00    .1693+00    .1693+00    .1693+00    .1693+00
  3   .4650-01    .2879+00    .2879+00    .2879+00    .2879+00    .2879+00    .2879+00
  2   .2027-01    .6445+00    .6445+00    .6445+00    .6445+00    .6445+00    .6445+00
  1   .0000      -.1178+01   -.1178+01   -.1178+01   -.1178+01   -.1178+01   -.1178+01
```

```
JX=  2, VARIABLE AT X( 2)=    .94321+00

                         LEVEL  1    *****        TKE      *****

      IZ=           1           2           3           4           5           6
      Z =        .0000     .1000+00    .2000+00    .3000+00    .4000+00    .5000+00
 20   .1000+01   .1501-03    .1501-03    .1501-03    .1501-03    .1501-03    .1501-03
 19   .9810+00   .1501-03    .1501-03    .1501-03    .1501-03    .1501-03    .1501-03
 18   .9561+00   .1501-03    .1501-03    .1501-03    .1501-03    .1501-03    .1501-03
 17   .9243+00   .1501-03    .1501-03    .1501-03    .1501-03    .1501-03    .1501-03
 16   .8842+00   .1501-03    .1501-03    .1501-03    .1501-03    .1501-03    .1501-03
 15   .8349+00   .1501-03    .1501-03    .1501-03    .1501-03    .1501-03    .1501-03
 14   .7759+00   .1501-03    .1501-03    .1501-03    .1501-03    .1501-03    .1501-03
 13   .7075+00   .1501-03    .1501-03    .1501-03    .1501-03    .1501-03    .1501-03
 12   .6310+00   .1501-03    .1501-03    .1501-03    .1501-03    .1501-03    .1501-03
 11   .5489+00   .1501-03    .1501-03    .1501-03    .1501-03    .1501-03    .1501-03
 10   .4645+00   .1501-03    .1501-03    .1501-03    .1501-03    .1501-03    .1501-03
  9   .3816+00   .1500-03    .1500-03    .1500-03    .1500-03    .1500-03    .1500-03
  8   .3040+00   .1500-03    .1500-03    .1500-03    .1500-03    .1500-03    .1500-03
  7   .2339+00   .1500-03    .1500-03    .1500-03    .1500-03    .1500-03    .1500-03
  6   .1730+00   .1500-03    .1500-03    .1500-03    .1500-03    .1500-03    .1500-03
  5   .1218+00   .1500-03    .1500-03    .1500-03    .1500-03    .1500-03    .1500-03
  4   .7993-01   .1500-03    .1500-03    .1500-03    .1500-03    .1500-03    .1500-03
  3   .4650-01   .1483-03    .1483-03    .1483-03    .1483-03    .1483-03    .1483-03
  2   .2027-01   .5365-04    .5365-04    .5365-04    .5365-04    .5365-04    .5365-04
  1   .0000      .5365-04    .5365-04    .5365-04    .5365-04    .5365-04    .5365-04
```

```
JX=  2, VARIABLE AT X( 2)=   .94321+00

                              LEVEL  1   *****       DIS     *****

       IZ=           1          2          3          4          5          6
       Z =         .0000    .1000+00   .2000+00   .3000+00   .4000+00   .5000+00
20    .1000+01   .6717-04   .6717-04   .6717-04   .6717-04   .6717-04   .6717-04
19    .9810+00   .6717-04   .6717-04   .6717-04   .6717-04   .6717-04   .6717-04
18    .9561+00   .6717-04   .6717-04   .6717-04   .6717-04   .6717-04   .6717-04
17    .9243+00   .6717-04   .6717-04   .6717-04   .6717-04   .6717-04   .6717-04
16    .8842+00   .6717-04   .6717-04   .6717-04   .6717-04   .6717-04   .6717-04
15    .8349+00   .6716-04   .6716-04   .6716-04   .6716-04   .6716-04   .6716-04
14    .7759+00   .6716-04   .6716-04   .6716-04   .6716-04   .6716-04   .6716-04
13    .7075+00   .6715-04   .6715-04   .6715-04   .6715-04   .6715-04   .6715-04
12    .6310+00   .6715-04   .6715-04   .6715-04   .6715-04   .6715-04   .6715-04
11    .5489+00   .6713-04   .6713-04   .6713-04   .6713-04   .6713-04   .6713-04
10    .4645+00   .6712-04   .6712-04   .6712-04   .6712-04   .6712-04   .6712-04
 9    .3818+00   .6711-04   .6711-04   .6711-04   .6711-04   .6711-04   .6711-04
 8    .3340+00   .6709-04   .6709-04   .6709-04   .6709-04   .6709-04   .6709-04
 7    .2339+00   .6708-04   .6708-04   .6708-04   .6708-04   .6708-04   .6708-04
 6    .1730+00   .6708-04   .6708-04   .6708-04   .6708-04   .6708-04   .6708-04
 5    .1218+00   .6709-04   .6709-04   .6709-04   .6709-04   .6709-04   .6709-04
 4    .7993-01   .6711-04   .6711-04   .6711-04   .6711-04   .6711-04   .6711-04
 3    .4650-01   .6597-04   .6597-04   .6597-04   .6597-04   .6597-04   .6597-04
 2    .2027-01   .1496-04   .1496-04   .1496-04   .1496-04   .1496-04   .1496-04
 1    .0000      .2991-04   .2991-04   .2991-04   .2991-04   .2991-04   .2991-04
```

```
JX=  2, VARIABLE AT X( 2)=    .94321+00

                              LEVEL  1   *****          LEN    *****

       IZ=           1          2          3          4          5          6
       Z =        .0000     .1000+00   .2000+00   .3000+00   .4000+00   .5000+00
 20  .1000+01   .4500-02   .4500-02   .4500-02   .4500-02   .4500-02   .4500-02
 19  .9810+00   .4500-02   .4500-02   .4500-02   .4500-02   .4500-02   .4500-02
 18  .9561+00   .4500-02   .4500-02   .4500-02   .4500-02   .4500-02   .4500-02
 17  .9243+00   .4500-02   .4500-02   .4500-02   .4500-02   .4500-02   .4500-02
 16  .8842+00   .4500-02   .4500-02   .4500-02   .4500-02   .4500-02   .4500-02
 15  .8349+00   .4500-02   .4500-02   .4500-02   .4500-02   .4500-02   .4500-02
 14  .7759+00   .4500-02   .4500-02   .4500-02   .4500-02   .4500-02   .4500-02
 13  .7075+00   .4500-02   .4500-02   .4500-02   .4500-02   .4500-02   .4500-02
 12  .6310+00   .4500-02   .4500-02   .4500-02   .4500-02   .4500-02   .4500-02
 11  .5489+00   .4500-02   .4500-02   .4500-02   .4500-02   .4500-02   .4500-02
 10  .4645+00   .4500-02   .4500-02   .4500-02   .4500-02   .4500-02   .4500-02
  9  .3818+00   .4500-02   .4500-02   .4500-02   .4500-02   .4500-02   .4500-02
  8  .3040+00   .4500-02   .4500-02   .4500-02   .4500-02   .4500-02   .4500-02
  7  .2339+00   .4500-02   .4500-02   .4500-02   .4500-02   .4500-02   .4500-02
  6  .1730+00   .4500-02   .4500-02   .4500-02   .4500-02   .4500-02   .4500-02
  5  .1218+00   .4500-02   .4500-02   .4500-02   .4500-02   .4500-02   .4500-02
  4  .7993-01   .4500-02   .4500-02   .4500-02   .4500-02   .4500-02   .4500-02
  3  .4650-01   .4499-02   .4499-02   .4499-02   .4499-02   .4499-02   .4499-02
  2  .2027-01   .4317-02   .4317-02   .4317-02   .4317-02   .4317-02   .4317-02
  1  .0000      .0000      .0000      .0000      .0000      .0000      .0000
```

```
JX=  2, VARIABLE AT X( 2)=   .94321+00

                              LEVEL  1    *****          TAU    *****

      IZ=          1          2          3          4          5          6
      Z =       .0000      .1000+00   .2000+00   .3000+00   .4000+00   .5000+00
 20  .1000+01   .4265-01   .4265-01   .4265-01   .4265-01   .4265-01   .4265-01
 19  .9810+00   .4405-01   .4405-01   .4405-01   .4405-01   .4405-01   .4405-01
 18  .9561+00   .4390-01   .4390-01   .4390-01   .4390-01   .4390-01   .4390-01
 17  .9243+00   .4364-01   .4364-01   .4364-01   .4364-01   .4364-01   .4364-01
 16  .8842+00   .4321-01   .4321-01   .4321-01   .4321-01   .4321-01   .4321-01
 15  .8349+00   .4251-01   .4251-01   .4251-01   .4251-01   .4251-01   .4251-01
 14  .7759+00   .4143-01   .4143-01   .4143-01   .4143-01   .4143-01   .4143-01
 13  .7075+00   .3978-01   .3978-01   .3978-01   .3978-01   .3978-01   .3978-01
 12  .6310+00   .3737-01   .3737-01   .3737-01   .3737-01   .3737-01   .3737-01
 11  .5489+00   .3394-01   .3394-01   .3394-01   .3394-01   .3394-01   .3394-01
 10  .4645+00   .2926-01   .2926-01   .2926-01   .2926-01   .2926-01   .2926-01
  9  .3818+00   .2314-01   .2314-01   .2314-01   .2314-01   .2314-01   .2314-01
  8  .3040+00   .1554-01   .1554-01   .1554-01   .1554-01   .1554-01   .1554-01
  7  .2339+00   .6656-02   .6656-02   .6656-02   .6656-02   .6656-02   .6656-02
  6  .1730+00   .3136-02   .3136-02   .3136-02   .3136-02   .3136-02   .3136-02
  5  .1218+00   .1336-01   .1336-01   .1336-01   .1336-01   .1336-01   .1336-01
  4  .7993-01   .2389-01   .2389-01   .2389-01   .2389-01   .2389-01   .2389-01
  3  .4650-01   .4065-01   .4065-01   .4065-01   .4065-01   .4065-01   .4065-01
  2  .2027-01   .9882-01   .9882-01   .9882-01   .9882-01   .9882-01   .9882-01
  1  .0000      .2265+00   .2265+00   .2265+00   .2265+00   .2265+00   .2265+00
```

```
JX=  2, VARIABLE AT X( 2)=   .94321+00

                               LEVEL  1   *****        CP/2    *****

        IZ=            1          2          3          4          5          6
        Z =        .0000     .1000+00   .2000+00   .3000+00   .4000+00   .5000+00
 20   .1000+01   .6352-06   .6352-06   .6352-06   .6352-06   .6352-06   .6333-06
 19   .9810+00   .1946-05   .1946-05   .1946-05   .1943-05   .1946-05   .1960-05
 18   .9561+00  -.1056-05  -.1054-05  -.1051-05  -.1060-05  -.1060-05  -.1069-05
 17   .9243+00  -.8065-06  -.7991-06  -.7804-06  -.8047-06  -.7804-06  -.7953-06
 16   .8842+00  -.3781-06  -.3837-06  -.4061-06  -.4061-06  -.4061-06  -.4303-06
 15   .8349+00   .1825-06   .1766-06   .1565-06   .1173-06   .1565-06   .1304-06
 14   .7759+00   .6352-06   .6277-06   .6109-06   .5942-06   .6277-06   .6203-06
 13   .7075+00   .9313-06   .9313-06   .9313-06   .9537-06   .9369-06   .9388-06
 12   .6310+00   .1118-05   .1119-05   .1123-05   .1140-05   .1119-05   .1090-05
 11   .5489+00   .1486-05   .1473-05   .1431-05   .1490-05   .1447-05   .1423-05
 10   .4645+00   .1209-05   .1213-05   .1222-05   .1235-05   .1222-05   .1211-05
  9   .3816+00   .9127-06   .9146-06   .9201-06   .8978-06   .9146-06   .9146-06
  8   .3040+00   .6892-07   .6892-07   .6892-07   .6892-07   .4843-07   .5029-07
  7   .2339+00  -.1075-05  -.1052-05  -.9372-06  -.1052-05  -.1032-05  -.1015-05
  6   .1730+00  -.1850-05  -.1848-05  -.1842-05  -.1848-05  -.1853-05  -.1866-05
  5   .1218+00  -.2889-05  -.2876-05  -.2850-05  -.2898-05  -.2872-05  -.2867-05
  4   .7993-01   .2212-04   .2212-04   .2210-04   .2207-04   .2214-04   .2215-04
  3   .4650-01   .1925-04   .1925-04   .1923-04   .1923-04   .1921-04   .1921-04
  2   .2027-01   .1398-02   .1398-02   .1398-02   .1398-02   .1398-02   .1398-02
  1   .0000     -.7914-01  -.7914-01  -.7914-01  -.7914-01  -.7914-01  -.7914-01
```

```
JX=  2, VARIABLE AT X( 2)=    .94321+00

                          LEVEL  1    *****         MACH    *****

         IZ=         1          2          3          4          5          6
         Z =       .0000    .1000+00   .2000+00   .3000+00   .4000+00   .5000+00
   20   .1000+01  .3001+01  .3001+01   .3001+01   .3001+01   .3001+01   .3001+01
   19   .9810+00  .3001+01  .3001+01   .3001+01   .3001+01   .3001+01   .3001+01
   18   .9561+00  .3001+01  .3001+01   .3001+01   .3001+01   .3001+01   .3001+01
   17   .9243+00  .3001+01  .3001+01   .3001+01   .3001+01   .3001+01   .3001+01
   16   .8842+00  .3001+01  .3001+01   .3001+01   .3001+01   .3001+01   .3001+01
   15   .8349+00  .3001+01  .3001+01   .3001+01   .3001+01   .3001+01   .3001+01
   14   .7759+00  .3001+01  .3001+01   .3001+01   .3001+01   .3001+01   .3001+01
   13   .7075+00  .3001+01  .3001+01   .3001+01   .3001+01   .3001+01   .3001+01
   12   .6310+00  .3001+01  .3001+01   .3001+01   .3001+01   .3001+01   .3001+01
   11   .5489+00  .3001+01  .3001+01   .3001+01   .3001+01   .3001+01   .3001+01
   10   .4645+00  .3001+01  .3001+01   .3001+01   .3001+01   .3001+01   .3001+01
    9   .3818+00  .3001+01  .3001+01   .3001+01   .3001+01   .3001+01   .3001+01
    8   .3040+00  .3001+01  .3001+01   .3001+01   .3001+01   .3001+01   .3001+01
    7   .2339+00  .3001+01  .3001+01   .3001+01   .3001+01   .3001+01   .3001+01
    6   .1730+00  .3001+01  .3001+01   .3001+01   .3001+01   .3001+01   .3001+01
    5   .1218+00  .3001+01  .3001+01   .3001+01   .3001+01   .3001+01   .3001+01
    4   .7993-01  .3001+01  .3001+01   .3001+01   .3001+01   .3001+01   .3001+01
    3   .4650-01  .3001+01  .3001+01   .3001+01   .3001+01   .3001+01   .3001+01
    2   .2027-01  .3014+01  .3014+01   .3014+01   .3014+01   .3014+01   .3014+01
    1   .0000     .1575+01  .1575+01   .1575+01   .1575+01   .1575+01   .1575+01
```

```
JX=  2, VARIABLE AT X( 2)=    .94321+00


                          LEVEL  1    *****        TSTAT   *****


     IZ=          1          2          3          4          5          6
     Z =       .0000   .1000+00   .2000+00   .3000+00   .4000+00   .5000+00
20   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01
19   .9810+00   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01
18   .9561+00   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01
17   .9243+00   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01
16   .8842+00   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01
15   .8349+00   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01
14   .7759+00   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01
13   .7075+00   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01
12   .6310+00   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01
11   .5489+00   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01
10   .4645+00   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01
 9   .3818+00   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01
 8   .3040+00   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01
 7   .2339+00   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01
 6   .1730+00   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01
 5   .1218+00   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01
 4   .7993-01   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01
 3   .4650-01   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01
 2   .2027-01   .9945+00   .9945+00   .9945+00   .9945+00   .9945+00   .9945+00
 1   .0000      .1872+01   .1872+01   .1872+01   .1872+01   .1872+01   .1872+01
```

```
IADI=1   IJ= 2   ISS=1000   ISSD=1000
IADI=1   IJ= 3   ISS=1000   ISSD=1000
IADI=1   IJ= 4   ISS=1000   ISSD=1000
IADI=1   IJ= 5   ISS=1000   ISSD=1000
```

```
IADI=2   IJ= 2   ISS=1000   ISSD=1000
IADI=2   IJ= 3   ISS=1000   ISSD=1000
IADI=2   IJ= 4   ISS=1000   ISSD=1000
IADI=2   IJ= 5   ISS=1000   ISSD=1000
IADI=2   IJ= 6   ISS=1000   ISSD=1000
IADI=2   IJ= 7   ISS=1000   ISSD=1000
IADI=2   IJ= 8   ISS=1000   ISSD=1000
IADI=2   IJ= 9   ISS=1000   ISSD=1000
IADI=2   IJ=10   ISS=1000   ISSD=1000
IADI=2   IJ=11   ISS=1000   ISSD=1000
IADI=2   IJ=12   ISS=1000   ISSD=1000
IADI=2   IJ=13   ISS=1000   ISSD=1000
IADI=2   IJ=14   ISS=1000   ISSD=1000
IADI=2   IJ=15   ISS=1000   ISSD=1000
IADI=2   IJ=16   ISS=1000   ISSD=1000
IADI=2   IJ=17   ISS=1000   ISSD=1000
IADI=2   IJ=18   ISS=1000   ISSD=1000
IADI=2   IJ=19   ISS=1000   ISSD=1000
```

### METRIC DATA

| I | X | Y | FG(NH1) | FG(NH2) | FG(NH3) | FG(NH12) | FG(NH21) | FG(NH31) | FG(NH32) | BETA |
|---|---|---|---|---|---|---|---|---|---|---|
| 20 | 9.682-01 | 1.000+00 | 9.809-01 | 9.809-01 | 1.000+00 | -6.684-04 | -4.014-02 | 0.000 | 0.000 | 3.170-06 |
| 19 | 9.682-01 | 9.805-01 | 9.809-01 | 9.809-01 | 1.000+00 | -1.677-03 | -4.013-02 | 0.000 | 0.000 | 5.277-02 |
| 18 | 9.682-01 | 9.552-01 | 9.810-01 | 9.810-01 | 1.000+00 | -3.851-03 | -4.007-02 | 0.000 | 0.000 | 1.212-01 |
| 17 | 9.682-01 | 9.228-01 | 9.811-01 | 9.811-01 | 1.000+00 | -6.667-03 | -3.993-02 | 0.000 | 0.000 | 2.087-01 |
| 16 | 9.682-01 | 8.821-01 | 9.815-01 | 9.815-01 | 1.000+00 | -1.024-02 | -3.966-02 | 0.000 | 0.000 | 3.183-01 |
| 15 | 9.682-01 | 8.321-01 | 9.821-01 | 9.821-01 | 1.000+00 | -1.471-02 | -3.915-02 | 0.000 | 0.000 | 4.522-01 |
| 14 | 9.682-01 | 7.721-01 | 9.832-01 | 9.832-01 | 1.000+00 | -2.027-02 | -3.828-02 | 0.000 | 0.000 | 6.106-01 |
| 13 | 9.682-01 | 7.027-01 | 9.848-01 | 9.848-01 | 1.000+00 | -2.706-02 | -3.686-02 | 0.000 | 0.000 | 7.906-01 |
| 12 | 9.682-01 | 6.253-01 | 9.872-01 | 9.872-01 | 1.000+00 | -3.529-02 | -3.464-02 | 0.000 | 0.000 | 9.851-01 |
| 11 | 9.682-01 | 5.424-01 | 9.905-01 | 9.905-01 | 1.000+00 | -4.513-02 | -3.135-02 | 0.000 | 0.000 | 1.183+00 |
| 10 | 9.682-01 | 4.576-01 | 9.948-01 | 9.948-01 | 1.000+00 | -5.675-02 | -2.667-02 | 0.000 | 0.000 | 1.371+00 |
| 9 | 9.682-01 | 3.747-01 | 1.000+00 | 1.000+00 | 1.000+00 | -7.021-02 | -2.031-02 | 0.000 | 0.000 | 1.534+00 |
| 8 | 9.682-01 | 2.973-01 | 1.006+00 | 1.006+00 | 1.000+00 | -8.532-02 | -1.216-02 | 0.000 | 0.000 | 1.662+00 |
| 7 | 9.682-01 | 2.279-01 | 1.013+00 | 1.013+00 | 1.000+00 | -1.017-01 | -2.369-03 | 0.000 | 0.000 | 1.749+00 |
| 6 | 9.682-01 | 1.679-01 | 1.019+00 | 1.019+00 | 1.000+00 | -1.185-01 | 8.630-03 | 0.000 | 0.000 | 1.798+00 |
| 5 | 9.682-01 | 1.179-01 | 1.025+00 | 1.025+00 | 1.000+00 | -1.351-01 | 2.020-02 | 0.000 | 0.000 | 1.815+00 |
| 4 | 9.682-01 | 7.716-02 | 1.031+00 | 1.031+00 | 1.000+00 | -1.507-01 | 3.162-02 | 0.000 | 0.000 | 1.808+00 |
| 3 | 9.682-01 | 4.478-02 | 1.036+00 | 1.036+00 | 1.000+00 | -1.671-01 | 4.254-02 | 0.000 | 0.000 | 1.785+00 |
| 2 | 9.682-01 | 1.949-02 | 1.041+00 | 1.041+00 | 1.000+00 | -1.971-01 | 5.504-02 | 0.000 | 0.000 | 1.731+00 |
| 1 | 9.682-01 | 0.000 | 1.044+00 | 1.044+00 | 1.000+00 | -1.693-01 | 7.060-02 | 0.000 | 0.000 | 1.518+00 |

```
JX=  3, VARIABLE AT X( 3)=   .96821+00

                         LEVEL  1    *****      U-VEL    *****

        IZ=          1          2          3          4          5          6
        Z =        .0000      .1000+00   .2000+00   .3000+00   .4000+00   .5000+00
 20   .9995+00   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01
 19   .9804+00   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01
 18   .9555+00   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01
 17   .9237+00   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01
 16   .8837+00   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01
 15   .8345+00   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01   .1000+01
 14   .7756+00   .9999+00   .9999+00   .9999+00   .9999+00   .9999+00   .9999+00
 13   .7072+00   .9999+00   .9999+00   .9999+00   .9999+00   .9999+00   .9999+00
 12   .6307+00   .9999+00   .9999+00   .9999+00   .9999+00   .9999+00   .9999+00
 11   .5487+00   .9998+00   .9998+00   .9998+00   .9998+00   .9998+00   .9998+00
 10   .4645+00   .9997+00   .9997+00   .9997+00   .9997+00   .9997+00   .9997+00
  9   .3816+00   .9996+00   .9996+00   .9996+00   .9996+00   .9996+00   .9996+00
  8   .3040+00   .9996+00   .9996+00   .9996+00   .9996+00   .9996+00   .9996+00
  7   .2339+00   .9995+00   .9995+00   .9995+00   .9995+00   .9995+00   .9995+00
  6   .1730+00   .9995+00   .9995+00   .9995+00   .9995+00   .9995+00   .9995+00
  5   .1219+00   .9995+00   .9995+00   .9995+00   .9995+00   .9995+00   .9995+00
  4   .8000-01   .9994+00   .9994+00   .9994+00   .9994+00   .9994+00   .9994+00
  3   .4655-01   .9994+00   .9994+00   .9994+00   .9994+00   .9994+00   .9994+00
  2   .2030-01   .9977+00   .9977+00   .9977+00   .9977+00   .9977+00   .9977+00
  1   .0000      .7183+00   .7183+00   .7183+00   .7183+00   .7183+00   .7183+00
```

```
JX=  3, VARIABLE AT X( 3)=    .96821+00

                                   LEVEL  1    *****      V-VEL    *****

          IZ=          1           2           3           4           5           6
          Z =       .0000      .1000+00    .2000+00    .3000+00    .4000+00    .5000+00
   20  .9995+00  -.8579-04   -.8579-04   -.8578-04   -.8579-04   -.8579-04   -.8579-04
   19  .9804+00  -.9265-03   -.9265-03   -.9265-03   -.9265-03   -.9265-03   -.9265-03
   18  .9555+00  -.2119-02   -.2119-02   -.2119-02   -.2119-02   -.2119-02   -.2119-02
   17  .9237+00  -.3641-02   -.3641-02   -.3641-02   -.3641-02   -.3641-02   -.3641-02
   16  .8837+00  -.5555-02   -.5555-02   -.5555-02   -.5555-02   -.5555-02   -.5555-02
   15  .8345+00  -.7892-02   -.7892-02   -.7892-02   -.7892-02   -.7892-02   -.7892-02
   14  .7756+00  -.1066-01   -.1066-01   -.1066-01   -.1066-01   -.1066-01   -.1066-01
   13  .7072+00  -.1380-01   -.1380-01   -.1380-01   -.1380-01   -.1380-01   -.1380-01
   12  .6307+00  -.1720-01   -.1720-01   -.1720-01   -.1720-01   -.1720-01   -.1720-01
   11  .5487+00  -.2065-01   -.2065-01   -.2065-01   -.2065-01   -.2065-01   -.2065-01
   10  .4645+00  -.2393-01   -.2393-01   -.2393-01   -.2393-01   -.2393-01   -.2393-01
    9  .3818+00  -.2678-01   -.2678-01   -.2678-01   -.2678-01   -.2678-01   -.2678-01
    8  .3040+00  -.2902-01   -.2902-01   -.2902-01   -.2902-01   -.2902-01   -.2902-01
    7  .2339+00  -.3055-01   -.3055-01   -.3055-01   -.3055-01   -.3055-01   -.3055-01
    6  .1730+00  -.3141-01   -.3141-01   -.3141-01   -.3141-01   -.3141-01   -.3141-01
    5  .1219+00  -.3167-01   -.3167-01   -.3167-01   -.3167-01   -.3167-01   -.3167-01
    4  .8000-01  -.3158-01   -.3158-01   -.3158-01   -.3158-01   -.3158-01   -.3158-01
    3  .4655-01  -.2909-01   -.2909-01   -.2909-01   -.2909-01   -.2909-01   -.2909-01
    2  .2030-01  -.2757-01   -.2757-01   -.2757-01   -.2757-01   -.2757-01   -.2757-01
    1  .0000      .0000       .0000       .0000       .0000       .0000       .0000
```

```
JX=  3, VARIABLE AT X( 3)=   .96821+00

                                   LEVEL  1   *****      W-VEL    *****

         IZ=             1             2             3             4             5             6
         Z =          .0000       .1000+00      .2000+00      .3000+00      .4000+00      .5000+00
   20    .9995+00     .0000       .1226-07      .7259-08     -.1235-07     -.1429-07     -.1494-07
   19    .9834+00     .0000       .7451-08      .5253-08     -.9003-08     -.1115-07     -.1164-07
   18    .9555+00     .0000      -.6985-08     -.7643-09      .1036-08     -.1719-08     -.2794-08
   17    .9237+00     .0000      -.4657-08      .5390-08      .4180-09     -.4313-08     -.6985-08
   16    .8837+00     .0000       .1956-07     -.7870-09     -.7050-08      .2202-08      .4657-08
   15    .8345+00     .0000       .1537-07      .2522-07     -.1092-07     -.1563-07     -.1863-07
   14    .7756+00     .0000       .1723-07      .5395-08     -.1681-07     -.6370-08     -.5122-08
   13    .7072+00     .0000       .9779-08     -.2873-08     -.1028-08      .1457-08      .1863-08
   12    .6307+00     .0000       .6519-08     -.6555-08     -.4840-08      .1057-08      .1397-08
   11    .5487+00     .0000       .2654-07     -.1345-08     -.3974-08      .7372-08      .1071-07
   10    .4645+00     .0000       .7916-08     -.6391-08     -.3437-08      .7275-08      .1211-07
    9    .3818+00     .0000      -.1071-07     -.1155-08     -.1531-08     -.9333-08     -.1211-07
    8    .3040+00     .0000      -.4657-08     -.6117-08     -.3747-08     -.4361-09      .9313-09
    7    .2339+00     .0000      -.2142-07      .9165-10     -.1560-09     -.1441-07     -.2142-07
    6    .1730+00     .0000      -.1583-07     -.8927-08      .3267-08      .1031-08      .4657-09
    5    .1219+00     .0000      -.1909-07     -.1500-08      .8104-08     -.2360-08     -.7916-08
    4    .8000-01     .0000       .7451-08     -.1958-08     -.1390-07     -.1004-07     -.8848-08
    3    .4655-01     .0000       .1816-07      .1385-07      .2653-08      .3576-08      .3260-08
    2    .2030-01     .0000       .2049-07      .1406-07     -.2309-08     -.6921-08     -.9313-08
    1    .0000        .0000       .1659-07      .1381-07      .4187-08      .3845-08      .3731-08
```

```
JX=  3, VARIABLE AT X( 3)=    .96821+00


                              LEVEL  1    *****        RHO    *****


      IZ=           1           2           3           4           5           6
      Z =        .0000      .1000+00    .2000+00    .3000+00    .4000+00    .5000+00
20    .9995+00   .1000+01    .1000+01    .1000+01    .1000+01    .1000+01    .1000+01
19    .9804+00   .1000+01    .1000+01    .1000+01    .1000+01    .1000+01    .1000+01
18    .9555+00   .9999+00    .9999+00    .9999+00    .9999+00    .9999+00    .9999+00
17    .9237+00   .9999+00    .9999+00    .9999+00    .9999+00    .9999+00    .9999+00
16    .8837+00   .9999+00    .9999+00    .9999+00    .9999+00    .9999+00    .9999+00
15    .8345+00   .9999+00    .9999+00    .9999+00    .9999+00    .9999+00    .9999+00
14    .7756+00   .9999+00    .9999+00    .9999+00    .9999+00    .9999+00    .9999+00
13    .7072+00   .9999+00    .9999+00    .9999+00    .9999+00    .9999+00    .9999+00
12    .6307+00   .9999+00    .9999+00    .9999+00    .9999+00    .9999+00    .9999+00
11    .5487+00   .9999+00    .9999+00    .9999+00    .9999+00    .9999+00    .9999+00
10    .4645+00   .9999+00    .9999+00    .9999+00    .9999+00    .9999+00    .9999+00
 9    .3618+00   .9999+00    .9999+00    .9999+00    .9999+00    .9999+00    .9999+00
 8    .3040+00   .9998+00    .9998+00    .9998+00    .9998+00    .9998+00    .9998+00
 7    .2339+00   .9998+00    .9998+00    .9998+00    .9998+00    .9998+00    .9998+00
 6    .1730+00   .9997+00    .9997+00    .9997+00    .9997+00    .9997+00    .9997+00
 5    .1219+00   .9997+00    .9997+00    .9997+00    .9997+00    .9997+00    .9997+00
 4    .8000-01   .1001+01    .1001+01    .1001+01    .1001+01    .1001+01    .1001+01
 3    .4655-01   .1001+01    .1001+01    .1001+01    .1001+01    .1001+01    .1001+01
 2    .2030-01   .1042+01    .1042+01    .1042+01    .1042+01    .1042+01    .1042+01
 1    .0000      .5721+00    .5721+00    .5721+00    .5721+00    .5721+00    .5721+00
```

```
JX=  3, VARIABLE AT X( 3)=    .96821+00

                               LEVEL  1   *****      ENERGY  *****

       IZ=            1            2            3            4            5            6
       Z =        .0000     .1000+00     .2000+00     .3000+00     .4000+00     .5000+00
  20   .9995+00   .0000        .0000        .0000        .0000        .0000        .0000
  19   .9804+00   .0000        .0000        .0000        .0000        .0000        .0000
  18   .9555+00   .0000        .0000        .0000        .0000        .0000        .0000
  17   .9237+00   .0000        .0000        .0000        .0000        .0000        .0000
  16   .8837+00   .0000        .0000        .0000        .0000        .0000        .0000
  15   .8345+00   .0000        .0000        .0000        .0000        .0000        .0000
  14   .7756+00   .0000        .0000        .0000        .0000        .0000        .0000
  13   .7072+00   .0000        .0000        .0000        .0000        .0000        .0000
  12   .6307+00   .0000        .0000        .0000        .0000        .0000        .0000
  11   .5487+00   .0000        .0000        .0000        .0000        .0000        .0000
  10   .4645+00   .0000        .0000        .0000        .0000        .0000        .0000
   9   .3818+00   .0000        .0000        .0000        .0000        .0000        .0000
   8   .3040+00   .0000        .0000        .0000        .0000        .0000        .0000
   7   .2339+00   .0000        .0000        .0000        .0000        .0000        .0000
   6   .1730+00   .0000        .0000        .0000        .0000        .0000        .0000
   5   .1219+00   .0000        .0000        .0000        .0000        .0000        .0000
   4   .8000-01   .0000        .0000        .0000        .0000        .0000        .0000
   3   .4655-01   .0000        .0000        .0000        .0000        .0000        .0000
   2   .2030-01   .0000        .0000        .0000        .0000        .0000        .0000
   1   .0000      .0000        .0000        .0000        .0000        .0000        .0000
```

```
 JX=  3, VARIABLE AT X( 3)=   .96821+00

                                   LEVEL  1   *****        MUT    *****

         IZ=         1           2           3           4           5           6
         Z =      .0000     .1000+00    .2000+00    .3000+00    .4000+00    .5000+00
   20  .9995+00  .3203+00   .3203+00    .3203+00    .3203+00    .3203+00    .3203+00
   19  .9804+00  .3203+00   .3203+00    .3203+00    .3203+00    .3203+00    .3203+00
   18  .9555+00  .3270+00   .3270+00    .3270+00    .3270+00    .3270+00    .3270+00
   17  .9237+00  .3253+00   .3253+00    .3253+00    .3253+00    .3253+00    .3253+00
   16  .8837+00  .3226+00   .3226+00    .3226+00    .3226+00    .3226+00    .3226+00
   15  .8345+00  .3180+00   .3180+00    .3180+00    .3180+00    .3180+00    .3180+00
   14  .7756+00  .3109+00   .3109+00    .3109+00    .3109+00    .3109+00    .3109+00
   13  .7072+00  .3002+00   .3002+00    .3002+00    .3002+00    .3002+00    .3002+00
   12  .6307+00  .2846+00   .2846+00    .2846+00    .2846+00    .2846+00    .2846+00
   11  .5487+00  .2625+00   .2625+00    .2625+00    .2625+00    .2625+00    .2625+00
   10  .4645+00  .2324+00   .2324+00    .2324+00    .2324+00    .2324+00    .2324+00
    9  .3818+00  .1931+00   .1931+00    .1931+00    .1931+00    .1931+00    .1931+00
    8  .3040+00  .1442+00   .1442+00    .1442+00    .1442+00    .1442+00    .1442+00
    7  .2339+00  .8705-01   .8705-01    .8705-01    .8705-01    .8705-01    .8705-01
    6  .1730+00  .2352-01   .2352-01    .2352-01    .2352-01    .2352-01    .2352-01
    5  .1219+00  .4207-01   .4207-01    .4207-01    .4207-01    .4207-01    .4207-01
    4  .8000-01  .1627+00   .1627+00    .1627+00    .1627+00    .1627+00    .1627+00
    3  .4655-01  .3136+00   .3136+00    .3136+00    .3136+00    .3137+00    .3137+00
    2  .2030-01  .4092+02   .4092+02    .4092+02    .4092+02    .4092+02    .4092+02
    1  .0000    -.9272+02  -.9272+02   -.9272+02   -.9272+02   -.9272+02   -.9272+02
```

```
JX=  3, VARIABLE AT X( 3)=    .96821+00

                          LEVEL  1   *****        TKE     *****

         IZ=          1          2          3          4          5          6
         Z =      .0000    .1000+00   .2000+00   .3000+00   .4000+00   .5000+00
  20  .9995+00   .1501-03   .1501-03   .1501-03   .1501-03   .1501-03   .1501-03
  19  .9804+00   .1501-03   .1501-03   .1501-03   .1501-03   .1501-03   .1501-03
  18  .9555+00   .1501-03   .1501-03   .1501-03   .1501-03   .1501-03   .1501-03
  17  .9237+00   .1501-03   .1501-03   .1501-03   .1501-03   .1501-03   .1501-03
  16  .8837+00   .1501-03   .1501-03   .1501-03   .1501-03   .1501-03   .1501-03
  15  .8345+00   .1501-03   .1501-03   .1501-03   .1501-03   .1501-03   .1501-03
  14  .7756+00   .1501-03   .1501-03   .1501-03   .1501-03   .1501-03   .1501-03
  13  .7372+00   .1501-03   .1501-03   .1501-03   .1501-03   .1501-03   .1501-03
  12  .6307+00   .1501-03   .1501-03   .1501-03   .1501-03   .1501-03   .1501-03
  11  .5487+00   .1501-03   .1501-03   .1501-03   .1501-03   .1501-03   .1501-03
  10  .4645+00   .1501-03   .1501-03   .1501-03   .1501-03   .1501-03   .1501-03
   9  .3818+00   .1501-03   .1501-03   .1501-03   .1501-03   .1501-03   .1501-03
   8  .3040+00   .1500-03   .1500-03   .1500-03   .1500-03   .1500-03   .1500-03
   7  .2339+00   .1500-03   .1500-03   .1500-03   .1500-03   .1500-03   .1500-03
   6  .1730+00   .1500-03   .1500-03   .1500-03   .1500-03   .1500-03   .1500-03
   5  .1219+00   .1500-03   .1500-03   .1500-03   .1500-03   .1500-03   .1500-03
   4  .8000-01   .1500-03   .1500-03   .1500-03   .1500-03   .1500-03   .1500-03
   3  .4655-01   .1484-03   .1484-03   .1484-03   .1484-03   .1484-03   .1484-03
   2  .2030-01   .2388-02   .2388-02   .2388-02   .2388-02   .2388-02   .2388-02
   1  .0000      .2388-02   .2388-02   .2388-02   .2388-02   .2388-02   .2388-02
```

```
JX=  3, VARIABLE AT X( 3)=    .9621+00

                              LEVEL  1   *****        DIS   *****

        IZ=          1          2          3          4          5          6
        Z =       .0000     .1000+00   .2000+00   .3000+00   .4000+00   .5000+00
  20  .9995+00   .6717-04   .6717-04   .6717-04   .6717-04   .6717-04   .6717-04
  19  .9804+00   .6717-04   .6717-04   .6717-04   .6717-04   .6717-04   .6717-04
  18  .9555+00   .6718-04   .6718-04   .6718-04   .6718-04   .6718-04   .6718-04
  17  .9237+00   .6718-04   .6718-04   .6718-04   .6718-04   .6718-04   .6718-04
  16  .8837+00   .6718-04   .6718-04   .6718-04   .6718-04   .6718-04   .6718-04
  15  .8345+00   .6717-04   .6717-04   .6717-04   .6717-04   .6717-04   .6717-04
  14  .7756+00   .6717-04   .6717-04   .6717-04   .6717-04   .6717-04   .6717-04
  13  .7072+00   .6716-04   .6716-04   .6716-04   .6716-04   .6716-04   .6716-04
  12  .6307+00   .6716-04   .6716-04   .6716-04   .6716-04   .6716-04   .6716-04
  11  .5487+00   .6714-04   .6714-04   .6714-04   .6714-04   .6714-04   .6714-04
  10  .4645+00   .6713-04   .6713-04   .6713-04   .6713-04   .6713-04   .6713-04
   9  .3818+00   .6712-04   .6712-04   .6712-04   .6712-04   .6712-04   .6712-04
   8  .3040+00   .6710-04   .6710-04   .6710-04   .6710-04   .6710-04   .6710-04
   7  .2339+00   .6709-04   .6709-04   .6709-04   .6709-04   .6709-04   .6709-04
   6  .1730+00   .6708-04   .6708-04   .6708-04   .6708-04   .6708-04   .6708-04
   5  .1219+00   .6708-04   .6708-04   .6708-04   .6708-04   .6708-04   .6708-04
   4  .8000-01   .6711-04   .6711-04   .6711-04   .6711-04   .6711-04   .6711-04
   3  .4655-01   .6601-04   .6601-04   .6601-04   .6601-04   .6601-04   .6601-04
   2  .2030-01   .4440-02   .4440-02   .4440-02   .4440-02   .4440-02   .4440-02
   1  .0000      .8879-02   .8879-02   .8879-02   .8879-02   .8879-02   .8879-02
```

```
JX=  3, VARIABLE AT X( 3)=    .96821+00

                         LEVEL  1    *****         LEN    *****

      IZ=          1          2          3          4          5          6
      Z =      .0000      .1000+00   .2000+00   .3000+00   .4000+00   .5000+00
  20  .9995+00  .4500-02   .4500-02   .4500-02   .4500-02   .4500-02   .4500-02
  19  .9804+00  .4500-02   .4500-02   .4500-02   .4500-02   .4500-02   .4500-02
  18  .9555+00  .4500-02   .4500-02   .4500-02   .4500-02   .4500-02   .4500-02
  17  .9237+00  .4500-02   .4500-02   .4500-02   .4500-02   .4500-02   .4500-02
  16  .8837+00  .4500-02   .4500-02   .4500-02   .4500-02   .4500-02   .4500-02
  15  .8345+00  .4500-02   .4500-02   .4500-02   .4500-02   .4500-02   .4500-02
  14  .7756+00  .4500-02   .4500-02   .4500-02   .4500-02   .4500-02   .4500-02
  13  .7072+00  .4500-02   .4500-02   .4500-02   .4500-02   .4500-02   .4500-02
  12  .6307+00  .4500-02   .4500-02   .4500-02   .4500-02   .4500-02   .4500-02
  11  .5487+00  .4500-02   .4500-02   .4500-02   .4500-02   .4500-02   .4500-02
  10  .4645+00  .4500-02   .4500-02   .4500-02   .4500-02   .4500-02   .4500-02
   9  .3818+00  .4500-02   .4500-02   .4500-02   .4500-02   .4500-02   .4500-02
   8  .3040+00  .4500-02   .4500-02   .4500-02   .4500-02   .4500-02   .4500-02
   7  .2339+00  .4500-02   .4500-02   .4500-02   .4500-02   .4500-02   .4500-02
   6  .1730+00  .4500-02   .4500-02   .4500-02   .4500-02   .4500-02   .4500-02
   5  .1219+00  .4500-02   .4500-02   .4500-02   .4500-02   .4500-02   .4500-02
   4  .8000-01  .4500-02   .4500-02   .4500-02   .4500-02   .4500-02   .4500-02
   3  .4655-01  .4499-02   .4499-02   .4499-02   .4499-02   .4499-02   .4499-02
   2  .2330-01  .4318-02   .4318-02   .4318-02   .4318-02   .4318-02   .4318-02
   1  .0000     .0000      .0000      .0000      .0000      .0000      .0000
```

```
JX=  3, VARIABLE AT X( 3)=    .96821+00

                                LEVEL  1   *****          TAU    *****

          IZ=          1          2          3          4          5          6
          Z =     .0000     .1000+00   .2000+00   .3000+00   .4000+00   .5000+00
 20  .9995+00   .4047-01   .4047-01   .4047-01   .4047-01   .4047-01   .4047-01
 19  .9804+00   .4520-01   .4520-01   .4520-01   .4520-01   .4520-01   .4520-01
 18  .9555+00   .4614-01   .4614-01   .4614-01   .4614-01   .4614-01   .4614-01
 17  .9237+00   .4590-01   .4590-01   .4590-01   .4590-01   .4590-01   .4590-01
 16  .8837+00   .4551-01   .4551-01   .4551-01   .4551-01   .4551-01   .4551-01
 15  .8345+00   .4486-01   .4486-01   .4486-01   .4486-01   .4486-01   .4486-01
 14  .7756+00   .4386-01   .4386-01   .4386-01   .4386-01   .4386-01   .4386-01
 13  .7072+00   .4236-01   .4236-01   .4236-01   .4236-01   .4236-01   .4236-01
 12  .6307+00   .4015-01   .4015-01   .4015-01   .4015-01   .4015-01   .4015-01
 11  .5487+00   .3704-01   .3704-01   .3704-01   .3704-01   .3704-01   .3704-01
 10  .4645+00   .3279-01   .3279-01   .3279-01   .3279-01   .3279-01   .3279-01
  9  .3818+00   .2724-01   .2724-01   .2724-01   .2724-01   .2724-01   .2724-01
  8  .3040+00   .2034-01   .2034-01   .2034-01   .2034-01   .2034-01   .2034-01
  7  .2339+00   .1228-01   .1228-01   .1228-01   .1228-01   .1228-01   .1228-01
  6  .1730+00   .3319-02   .3319-02   .3319-02   .3319-02   .3319-02   .3319-02
  5  .1219+00   .5936-02   .5936-02   .5936-02   .5936-02   .5936-02   .5936-02
  4  .8000-01   .2295-01   .2295-01   .2295-01   .2295-01   .2295-01   .2295-01
  3  .4655-01   .4428-01   .4428-01   .4428-01   .4428-01   .4428-01   .4428-01
  2  .2030-01   .6129+01   .6129+01   .6129+01   .6129+01   .6129+01   .6129+01
  1  .0000      .2411+02   .2411+02   .2411+02   .2411+02   .2411+02   .2411+02
```

```
JX=  3, VARIABLE AT X( 3)=    .96821+00

                                          LEVEL  1    *****        CP/2    *****

       IZ=           1           2           3           4           5           6
       Z =        .0000     .1000+00    .2000+00    .3000+00    .4000+00    .5000+00
 20  .9995+00   .2198-06    .2217-06    .2198-06    .2105-06    .2272-06    .2272-06
 19  .9804+00  -.7916-06   -.7991-06   -.8084-06   -.8326-06   -.7823-06   -.7935-06
 18  .9555+00  -.8909-05   -.8894-05   -.8848-05   -.8866-05   -.8883-05   -.8883-05
 17  .9237+00  -.8466-05   -.8464-05   -.8451-05   -.8533-05   -.8494-05   -.8494-05
 16  .8837+00  -.7970-05   -.7989-05   -.8045-05   -.8017-05   -.8000-05   -.8034-05
 15  .8345+00  -.6979-05   -.6991-05   -.7017-05   -.7121-05   -.6983-05   -.7002-05
 14  .7756+00  -.6398-05   -.6419-05   -.6486-05   -.6448-05   -.6402-05   -.6426-05
 13  .7072+00  -.6270-05   -.6275-05   -.6296-05   -.6296-05   -.6296-05   -.6298-05
 12  .6307+00  -.6586-05   -.6586-05   -.6581-05   -.6545-05   -.6545-05   -.6542-05
 11  .5487+00  -.6888-05   -.6914-05   -.7000-05   -.6920-05   -.6979-05   -.6963-05
 10  .4645+00  -.8913-05   -.8937-05   -.9013-05   -.8937-05   -.9008-05   -.9008-05
  9  .3818+00  -.1160-04   -.1159-04   -.1156-04   -.1160-04   -.1157-04   -.1156-04
  8  .3040+00  -.1570-04   -.1568-04   -.1564-04   -.1562-04   -.1564-04   -.1565-04
  7  .2339+00  -.2077-04   -.2074-04   -.2066-04   -.2073-04   -.2065-04   -.2066-04
  6  .1730+00  -.2468-04   -.2466-04   -.2460-04   -.2464-04   -.2466-04   -.2464-04
  5  .1219+00  -.3115-04   -.3112-04   -.3103-04   -.3109-04   -.3107-04   -.3107-04
  4  .8300-01   .8065-04    .8065-04    .8062-04    .8067-04    .8066-04    .8065-04
  3  .4655-01   .1052-03    .1052-03    .1051-03    .1051-03    .1051-03    .1051-03
  2  .2030-01   .3913-02    .3913-02    .3913-02    .3913-02    .3913-02    .3913-02
  1  .0000      .5576-02    .5575-02    .5575-02    .5575-02    .5575-02    .5575-02
```

```
JX=  3, VARIABLE AT X( 3)=    .96821+00


                                      LEVEL  1    *****        MACH    *****


          IZ=            1          2          3          4          5          6
          Z =          .0000      .1000+00   .2000+00   .3000+00   .4000+00   .5000+00
    20    .9995+00     .3001+01   .3001+01   .3001+01   .3001+01   .3001+01   .3001+01
    19    .9804+00     .3001+01   .3001+01   .3001+01   .3001+01   .3001+01   .3001+01
    18    .9555+00     .3001+01   .3001+01   .3001+01   .3001+01   .3001+01   .3001+01
    17    .9237+00     .3001+01   .3001+01   .3001+01   .3001+01   .3001+01   .3001+01
    16    .8837+00     .3001+01   .3001+01   .3001+01   .3001+01   .3001+01   .3001+01
    15    .8345+00     .3001+01   .3001+01   .3001+01   .3001+01   .3001+01   .3001+01
    14    .7756+00     .3001+01   .3001+01   .3001+01   .3001+01   .3001+01   .3001+01
    13    .7072+00     .3001+01   .3001+01   .3001+01   .3001+01   .3001+01   .3001+01
    12    .6307+00     .3001+01   .3001+01   .3001+01   .3001+01   .3001+01   .3001+01
    11    .5487+00     .3001+01   .3001+01   .3001+01   .3001+01   .3001+01   .3001+01
    10    .4645+00     .3001+01   .3001+01   .3001+01   .3001+01   .3001+01   .3001+01
     9    .3818+00     .3001+01   .3001+01   .3001+01   .3001+01   .3001+01   .3001+01
     8    .3040+00     .3001+01   .3001+01   .3001+01   .3001+01   .3001+01   .3001+01
     7    .2339+00     .3001+01   .3001+01   .3001+01   .3001+01   .3001+01   .3001+01
     6    .1730+00     .3001+01   .3001+01   .3001+01   .3001+01   .3001+01   .3001+01
     5    .1219+00     .3001+01   .3001+01   .3001+01   .3001+01   .3001+01   .3001+01
     4    .8000-01     .3000+01   .3000+01   .3000+01   .3000+01   .3000+01   .3000+01
     3    .4655-01     .3000+01   .3000+01   .3000+01   .3000+01   .3000+01   .3000+01
     2    .2030-01     .2985+01   .2985+01   .2985+01   .2985+01   .2985+01   .2985+01
     1    .0000        .1576+01   .1576+01   .1576+01   .1576+01   .1576+01   .1576+01
```

```
JX=  3, VARIABLE AT X( 3)=    .96821+00

                                    LEVEL  1    *****        TSTAT   *****

           IZ=          1            2            3            4            5            6
           Z =       .0000       .1000+00     .2000+00     .3000+00     .4000+00     .5000+00
  20    .9995+00    .1000+01     .1000+01     .1000+01     .1000+01     .1000+01     .1000+01
  19    .9804+00    .1000+01     .1000+01     .1000+01     .1000+01     .1000+01     .1000+01
  18    .9555+00    .1000+01     .1000+01     .1000+01     .1000+01     .1000+01     .1000+01
  17    .9237+00    .1000+01     .1000+01     .1000+01     .1000+01     .1000+01     .1000+01
  16    .8837+00    .1000+01     .1000+01     .1000+01     .1000+01     .1000+01     .1000+01
  15    .8345+00    .1000+01     .1000+01     .1000+01     .1000+01     .1000+01     .1000+01
  14    .7756+00    .1000+01     .1000+01     .1000+01     .1000+01     .1000+01     .1000+01
  13    .7072+00    .1000+01     .1000+01     .1000+01     .1000+01     .1000+01     .1000+01
  12    .6307+00    .1000+01     .1000+01     .1000+01     .1000+01     .1000+01     .1000+01
  11    .5487+00    .1000+01     .1000+01     .1000+01     .1000+01     .1000+01     .1000+01
  10    .4645+00    .1000+01     .1000+01     .1000+01     .1000+01     .1000+01     .1000+01
   9    .3818+00    .1000+01     .1000+01     .1000+01     .1000+01     .1000+01     .1000+01
   8    .3040+00    .1000+01     .1000+01     .1000+01     .1000+01     .1000+01     .1000+01
   7    .2339+00    .1000+01     .1000+01     .1000+01     .1000+01     .1000+01     .1000+01
   6    .1730+00    .9999+00     .9999+00     .9999+00     .9999+00     .9999+00     .9999+00
   5    .1219+00    .9999+00     .9999+00     .9999+00     .9999+00     .9999+00     .9999+00
   4    .8000-01    .1000+01     .1000+01     .1000+01     .1000+01     .1000+01     .1000+01
   3    .4655-01    .1001+01     .1001+01     .1001+01     .1001+01     .1001+01     .1001+01
   2    .2030-01    .1007+01     .1007+01     .1007+01     .1007+01     .1007+01     .1007+01
   1    .0000       .1871+01     .1871+01     .1871+01     .1871+01     .1871+01     .1871+01
```

```
IADI=1   IJ= 2   ISS=1000   ISSD=1000
IADI=1   IJ= 3   ISS=1000   ISSD=1000
IADI=1   IJ= 4   ISS=1000   ISSD=1000
IADI=1   IJ= 5   ISS=1000   ISSD=1000
```

```
IADI=2   IJ= 2   ISS=1000   ISSD=1000
IADI=2   IJ= 3   ISS=1000   ISSD=1000
IADI=2   IJ= 4   ISS=1000   ISSD=1000
IADI=2   IJ= 5   ISS=1000   ISSD=1000
IADI=2   IJ= 6   ISS=1000   ISSD=1000
IADI=2   IJ= 7   ISS=1000   ISSD=1000
IADI=2   IJ= 8   ISS=1000   ISSD=1000
IADI=2   IJ= 9   ISS=1000   ISSD=1000
IADI=2   IJ=10   ISS=1000   ISSD=1000
IADI=2   IJ=11   ISS=1000   ISSD=1000
IADI=2   IJ=12   ISS=1000   ISSD=1000
IADI=2   IJ=13   ISS=1000   ISSD=1000
IADI=2   IJ=14   ISS=1000   ISSD=1000
IADI=2   IJ=15   ISS=1000   ISSD=1000
IADI=2   IJ=16   ISS=1000   ISSD=1000
IADI=2   IJ=17   ISS=1000   ISSD=1000
IADI=2   IJ=18   ISS=1000   ISSD=1000
IADI=2   IJ=19   ISS=1000   ISSD=1000
```

```
     RESTART INFORMATION WRITTEN IN FILE 11 AT STATION  3 IN SEQUENCE NUMBER  1
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| | | |
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15. Supplementary Notes

Final report. Project Manager, Charles Towne, Wind Tunnel and Flight Division, NASA Lewis Research Center, Cleveland, Ohio 44135.

16. Abstract

A method for computing three-dimensional flow in supersonic inlets is described. An approximate set of governing equations is given for viscous flows which have a primary flow direction. The governing equations are written in general orthogonal coordinates. These equations are modified in the subsonic region of the flow to prevent the phenomenon of branching. Results are presented for the two sample cases, a Mach number equals 2.5 flow in a square duct, and a Mach number equals 3.0 flow in a research jet engine inlet. In the latter case the computed results are compared with the experimental data. A users' manual is included.

| | |
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