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COOLANT SIDE HEAT TRANSFER WITH ROTATION
USER MANUAL FOR 3D-TEACH WITH ROTATION

by

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1.0 INTRODUCTION

This manual is written for users of the three-dimensional version of the TEACH computer program as developed at P&WA.

This program solves the governing transport equations in Reynolds average form for the flow of a three-dimensional, steady state, viscous, heat conducting, multiple species, single phase, Newtonian fluid with combustion. The governing partial differential equations are solved in physical variables in either a Cartesian or cylindrical coordinate system. The effects of rotation on the momentum and enthalpy calculations are modeled in cartesian coordinates. The flow of the fluid should be confined and subsonic with a maximum Mach number no larger than 0.5.

The program is flexible and is written in a modular form. By simply turning the calculation of various transport equations in the input on or off, several types of flow can be solved. For example; either laminar or turbulent, reacting or nonreacting, single or multiple specie, and isothermal or nonisothermal flows can be solved. The fluid may contain up to four distinct species, which may be inert or undergoing turbulent combustion.

In order to demonstrate the range of fluid flow problems that can be solved by the above procedure, several sample cases are included. These cases range from simple laminar pipe flow to the flow field generated by a JT9D cooling louver.

The program has been made quite versatile by adding a useful feature which allows blockage inside the flow field to be defined by the input. This feature enables the flow inside almost any geometry, within the constraints of the coordinate system, to be computed.

An effort has been made to include 'warnings' etc., so that the solution obtained is the numerically correct representation of the flow field. However, Computational Fluid Mechanics is, in spite of the advances made, a black art and the user has to rely on his experience to ensure that an accurate solution has been obtained. The following criteria should be helpful in this respect.

1) The input is properly defined. Close inspection of geometry plots and careful examination of every variable field in the printout is necessary to make this determination.

2) The solution has converged. All the residuals are smaller than the error determined to be acceptable for the case. Determination of an acceptable error is usually done from experience, and generally varies from 0.5% to 5%.

3) The solution has stabilized. Flow properties in sensitive regions of the computational domain have stopped changing from one iteration to another. This criterion, in conjunction with the convegence criterion, is necessary to ensure that a numerically correct solution has been obtained. However, in some cases, where the convergence criterion is difficult to satisfy, acute monitoring of the variable fields during the iteration process can be relied on for an acceptable solution.

4) A grid independent solution is obtained. Grid independence is attained when the use of a finer mesh does not change the results significantly. In a 3D code, the number of nodes available is often not adequate to go to a finer mesh. In such situations, some idea of mesh independence can be obtained by going to a coarser mesh.

5) Mesh Reynolds numbers and Peclet numbers are within limits. The wall Reynolds numbers and Peclet numbers are printed in the output. Wall Reynolds numbers should be between 30 and 400. Peclet numbers should be between -5 and +5 in regions where any field variable has a high gradient.

6) Cell aspect ratio is acceptable. The aspect ratio of computational cells should be unity to ensure accuracy, rapid convergence and to avoid numerical instability. However, in most cases this criterion may not be satisfied and under relaxation factors may have to be reduced significantly to achieve convergence.

Since proper definition of the computational grid is essential for smooth convergence and accurate solution of the flow field, the user is advised to make a preliminary run with a coarse grid. The flow field obtained should then be inspected carefully to ensure that the boundary conditions are properly specified and to ascertain regions of steep gradients which will require a denser grid. The problem should then be run again with a fine grid using a denser grid in the regions of steep gradients. An option is provided for the inspection of the grid before running the program to facilitate the selection of optimum grid spacing.

In the initial running of TEACH, it is often difficult to obtain stability in the simulation of turbulent reacting flow. Guidelines to aid the use are given in Appendix F.

The program can be run interactively or submitted to batch from any CMS terminal. Running interactively allows the user to check the geometry and boundary conditions and make a short run to see if a case will start properly and examine intermediate calculations to determine if it is going to solve the problem intended. Because it is not always practical for the user to run all cases to completion on CMS, a version of TEACH is available to execute these cases as a batch job. The decision to run batch or CMS is made at the beginning of a CMS terminal session.

The user will require some basic experience before he is able to employ all the capabilities of the program. It is strongly advised that a few simple problems be solved before attempting to solve a complicated problem. In this regard reproducing at least a few of the sample cases solved in this manual might prove useful.

In the next section the theoretical foundations of the computer program, which include the governing transport equations, the discretized equations, the solution procedure, and models of combustion and turbulence, are described briefly. See reference 1 for details.

In Section 3 the mechanical structure and operation of the program are described. This includes a functional diagram, a flow diagram, line by line description of the input and a sample of the output options available. A typical CMS session is also included.

The final section contains the sample cases. Each case includes a copy of the input, grid plot, sample output, and streak line plots in the planes of interest.

2.0 ENGINEERING DESCRIPTION

This section presents the theoretical foundations of TEACH to familiarize potential users with the TEACH model, and includes the coordinate system, the basic differential equations being solved, and the finite difference versions of those equations used in the model.

2.1 Grid and Coordinate System

TEACH uses a 3-dimensional orthogonal coordinate system (Cartesian or cylindrical). The grid formed by the intersection of coordinate lines is used in the modeling of fluid flow systems. The intersection of the grid lines form the grid nodes at which all flow properties except the velocities u, v, and w are calculated. The axial velocity, u, is calculated midway between grid nodes in the axial direction, the radial velocity, v, is calculated midway between grid nodes in the radial direction, and the tangential velocity, w, is calculated midway between grid nodes in the tangential direction (figures 1 and 2). Directions in the grid are identified as north, south, east, west, front and back.

A breakup results in defining an array of rectangular cells, each bounded to its west and east by X-gridlines, to its north and south by Y-gridlines and to its front and back by Z-gridlines. The u, y, and w velocities lie in such a manner that normal velocities lie on scalar cell boundaries (Figure 3).

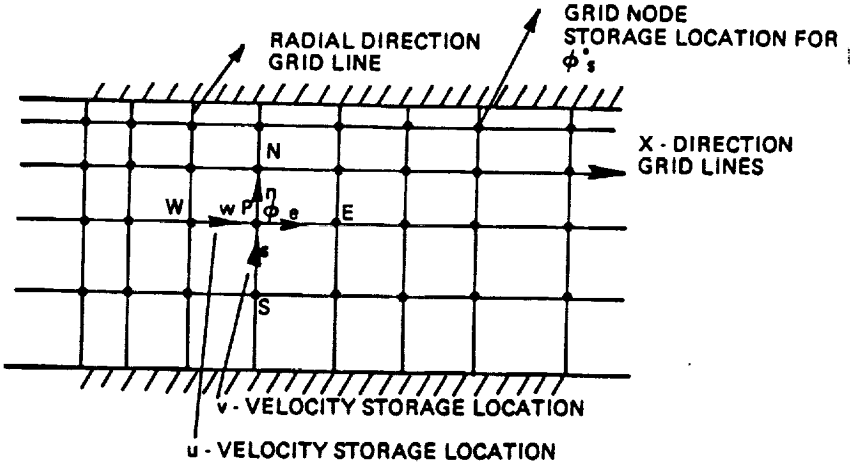


FIGURE 1   GRID ARRANGEMENT

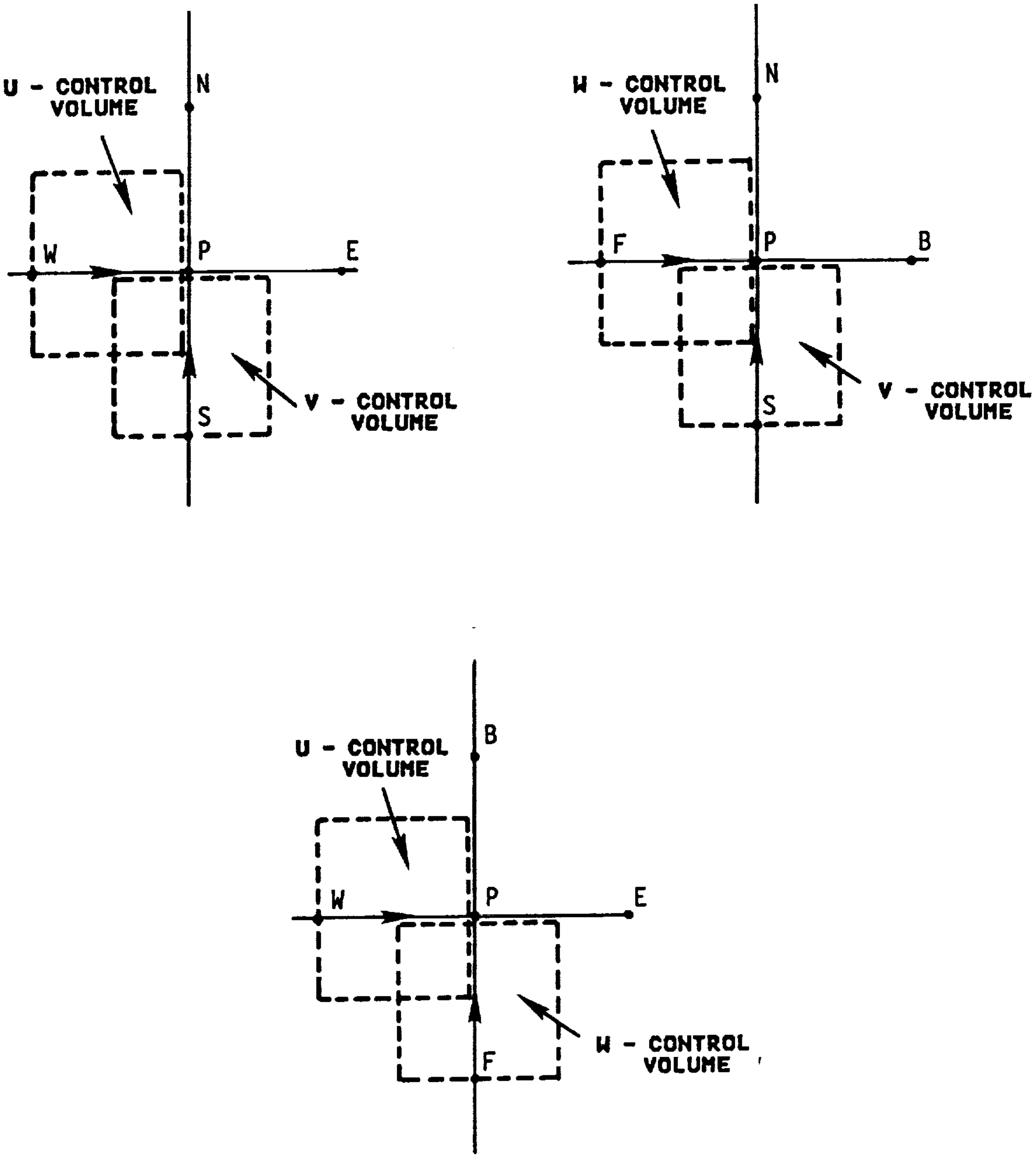
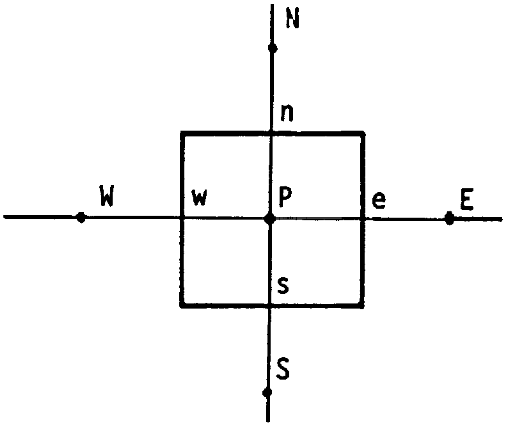
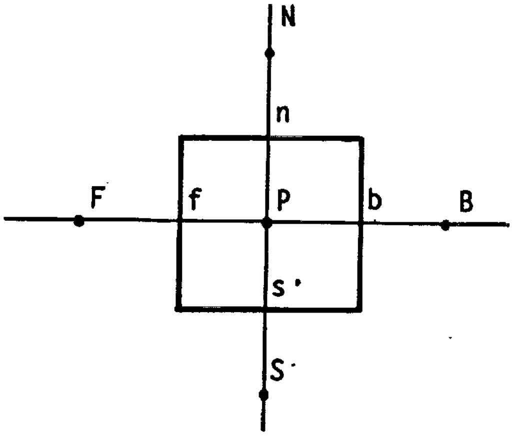


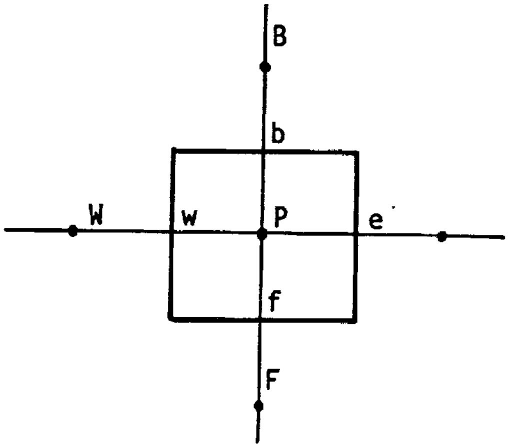
FIGURE 2 U, V, AND W CONTROL VOLUMES



φ - CONTROL VOLUME
looking forward



φ - CONTROL VOLUME
looking eastward



φ - CONTROL VOLUME
looking northward

FIGURE 3 φ - CONTROL VOLUME

2.2 Governing Differential Equations

Solution of a flow problem in TEACH consists of solving a set of equations including, the continuity equation (conservation of mass), the three equations of motion (conservation of momentum), the energy equation, the thermodynamic equation of state (relating pressure, density, and temperature), and a suitable set of scalar equations such as the species transport equations. These equations are derived for nonreacting, compressible, multiple species, laminar flow. For an explanation of the turbulence model, the combustion model, and their inclusion in the equations developed here, see reference (1).

Laminar flow problems can be solved with the Navier-Stokes equations and a suitable set of scalar transport equations. The transport equation in its general form states that the net amount of a scalar such as species or energy carried into a control volume by the mass entering it (the convection term) plus the amount entering through diffusion or conduction (the diffusion term) plus the amount generated within the control volume, such as through a chemical reaction (the source term), must equal zero. Turbulent flow equations are similar to the laminar flow equations except that viscosity is replaced by an effective viscosity which includes the "turbulent" viscosity caused by the turbulent eddies, and an effective pressure term due to the turbulence kinetic energy.

2.2.1 The Continuity Equation

The continuity equation is a special case of the transport equation in which the mass itself is being balanced; there is no diffusion term and no generation term. The continuity equation expresses the fact that for any control volume under steady state conditions the mass flowing into the volume must equal the mass flowing out. The flow field is specified by the velocity vector

$$V = iu + jv + kw \tag{1}$$

where i, j and k are the unit vectors, and u, v, and w are the components of velocity in the X-, Y-, and Z-directions respectively.

The mass flowing out of the two faces of the control volume perpendicular to the X-axis having area dydz are given by

$$\rho u dydz \text{ and } (\rho u + \frac{\partial \rho u}{\partial x} dx)\, dydz \tag{2}$$

Similiar expressions can be written for the front and the back faces. Subtracting the mass flowing into one face from the mass flowing out of the other gives the net mass flowing into the element in the X-direction

$$\frac{\partial \rho u}{\partial x} dxdydz \tag{3}$$

A similar expression can be written for the mass flowing into the element in the Y-, and Z-direction.

$$\frac{\partial \rho v}{\partial y} dydxdz \tag{4}$$

$$\frac{\partial \rho w}{\partial z} dzdxdy \tag{5}$$

Addition of equation 3, 4 and 5 gives the equation of continuity which states that the mass flowing into the volume must equal the mass flowing out for a steady state system

$$\frac{\partial \rho U}{\partial x} + \frac{\partial \rho V}{\partial y} + \frac{\partial \rho W}{\partial z} = 0 \qquad (6)$$

2.2.2 Momentum Transport Equations

The equations of motion are derived from Newton's Second Law, which states that the summation of forces acting on a body is equal to the time rate of change of its momentum (i.e. mass times velocity)

$$\Sigma F = \frac{1}{gc}\frac{d(mv)}{dt} \qquad (7)$$

considering the right hand side of the equation first, the mass of fluid entering the west face is ρ udydz. The velocity of this fluid is u and therefore the momentum per unit time entering the west face is

$$(\rho udydz)u = \rho u^2 dydz \qquad (8)$$

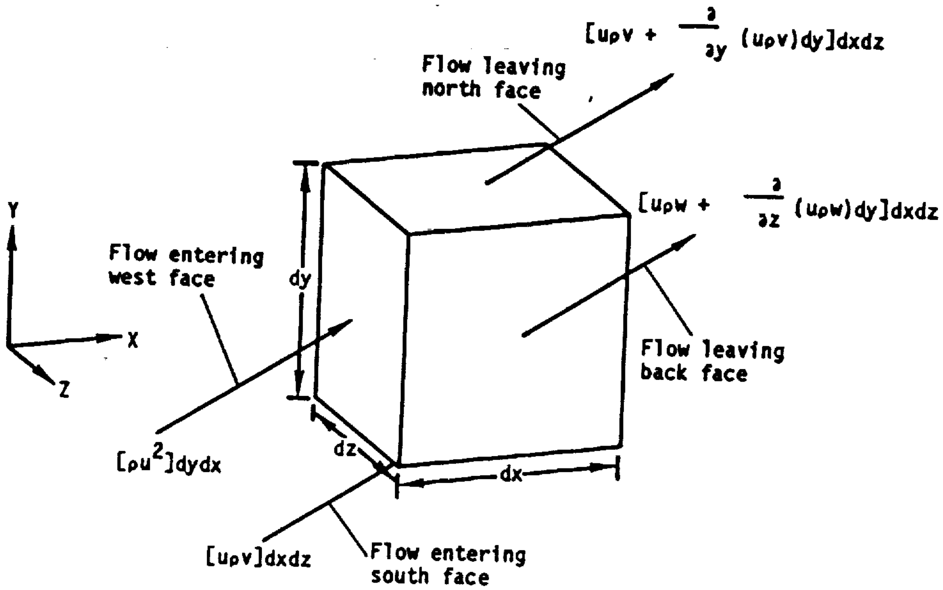


FIGURE 4
U-MOMENTUM TRANSPORT INTO A FLUID CELL
(For clarity, not all flows are shown)

Figure 4 shows the expressions for the U-momentum crossing the faces of the Control Volume.

Fluid flows into the control volume through the south face at the rate vdxdz with a velocity component in the X-direction of u, so the contribution to the X-momentum per unit volume is

(9) $$(\rho vdxdz)u = \rho uvdxdz$$

The momentum per unit time leaving the east face is

(10) $$[\rho u^2 + \frac{\partial}{\partial x}(\rho u^2)\, dx]\, dydz$$

Similarly, the momentum per unit time leaving through the north face is

(11) $$[\rho uv + \frac{\partial}{\partial y}(\rho uv)\, dy]\, dxdz$$

Similar expressions can be written for the front and the back faces. Subtracting the momentum per unit time entering from that leaving, gives the net increase in X-momentum per unit time of the fluid in the control volume

(12) $$[\frac{\partial}{\partial x}(\rho u^2)\, dx]\, dydz + [\frac{\partial}{\partial y}(\rho uv)\, dy]\, dxdz + [\frac{\partial}{\partial z}(\rho uw)\, dz].dxdy$$

Any increase in momentum of the fluid in the X-direction is produced by forces acting in the X-direction on the control volume. In general there are two types of forces to be considered: Body forces such as gravity and surface forces such as pressure and viscous shear.

When a control volume having dimensions dx, dy, and dz is isolated from a fluid, the forces acting on it while in the fluid can be represented as shown in figure 5.

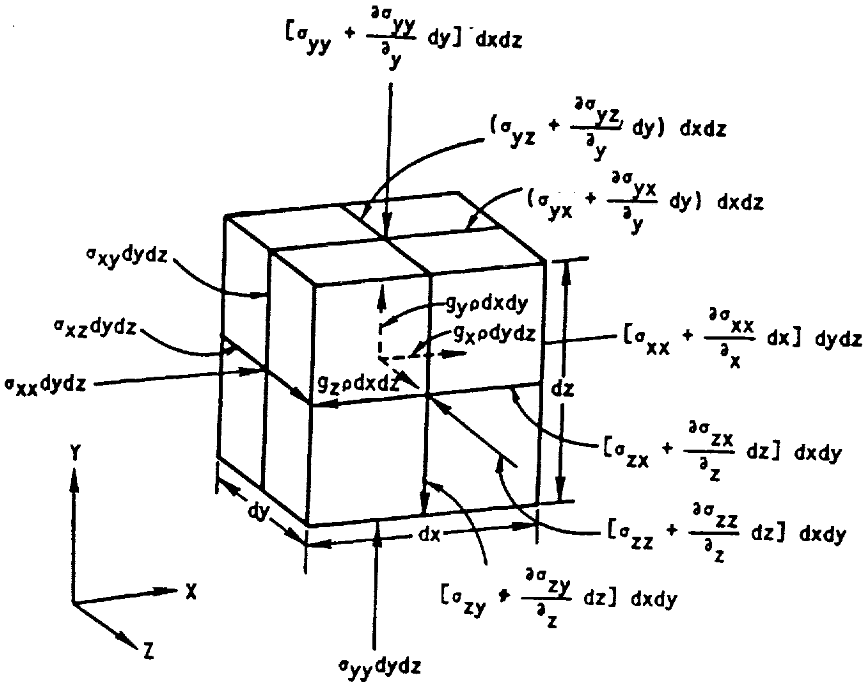


FIGURE 5
EXTERNAL FORCES ACTING ON A FLUID CELL
(For clarity, not all forces are shown)

Gravity is a body force acting on every particle in the control volume. Its contribution to the external forces acting on the control volume is

(13) $g_x \rho dxdydz$

where g is a vector denoting the gravitational force per unit volume. If the coordinate system is rotating, centrifugal and Coriolis forces must be added as body forces.

(13.1) $\rho\,[2\,\bar{\omega} \times \bar{V} + \bar{\omega} \times (\bar{\omega} \times \bar{r})\,]$

Where $\bar{\omega}$ is the vector representing the angular velocity of rotations, $\bar{V}$ is the vector representing the velocity of the fluid and $\bar{r}$ is the vector representing the location of the center of the fluid cell.

$$\bar{\omega} = \bar{i}\omega_x + \bar{j}\omega_y + \bar{k}\omega_z$$
$$\bar{V} = \bar{i}u + \bar{j}v + \bar{k}w$$
$$\bar{r} = \bar{i}x + \bar{j}y + \bar{k}z$$

See reference (4) for the development of (13.1). The other components shown in the figure are pressure and shear forces which act only on the surface of the control volume. The x-momentum enters and leaves the control volume as a result of normal stress σ_{xx} and shear stress σ_{yx} and σ_{zx}. These stresses can be expressed in terms of strain rates in the following manner.

(14) $\sigma_{xx} = -P + 2\mu \frac{\partial u}{\partial x} + \lambda \left(\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} \right)$

(15) $\sigma_{yx} = \mu \left(\frac{\partial v}{\partial x} + \frac{\partial u}{\partial y} \right)$

and

(16) $\sigma_{zx} = \mu \left(\frac{\partial w}{\partial x} + \frac{\partial u}{\partial z} \right)$

where μ is the viscosity of the fluid and λ is the second coefficient of viscosity which has an empirically determined value of $-(2/3)\,\mu$.

The x-momentum entering and leaving the control volume by the action of these stresses can be treated in a manner similar to the x-momentum entering and leaving the control volume by convection. Hence summing all the forces in the X-direction and dropping terms that cancel yields

(17) $\left(g_x \rho + \frac{\partial \sigma_{xx}}{\partial x} + \frac{\partial \sigma_{yx}}{\partial y} + \frac{\partial \sigma_{zx}}{\partial z} \right) dxdydz$

Putting equations 14, 15, and 16 in equation 17 yields

(18) $$\left\{ g_x \rho - \frac{\partial P}{\partial x} + \frac{\partial}{\partial x} \left[2\mu \frac{\partial u}{\partial x} - \frac{2}{3} \left(\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} \right) \right] + \frac{\partial}{\partial y} \left(\mu \left(\frac{\partial u}{\partial y} + \frac{\partial v}{\partial x} \right) \right) + \frac{\partial}{\partial z} \left[\mu \left(\frac{\partial w}{\partial x} + \frac{\partial u}{\partial z} \right) \right] \right\} dxdydz$$

Equating the rate of change of momentum to the forces acting on the control volume (expressions 12 and 18 respectively) and dividing throughout by dx dy dz we have the following x-direction equation of motion

$$(19)\quad \frac{\partial(\rho uu)}{\partial x} + \frac{\partial(\rho uv)}{\partial y} + \frac{\partial(\rho uw)}{\partial z} = \rho g_x - \frac{\partial P}{\partial x} + \frac{\partial}{\partial x}\left[2\mu \frac{\partial u}{\partial x} - \frac{2}{3}\left(\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} \right)\right] + \frac{\partial}{\partial y}\left(\mu\left(\frac{\partial u}{\partial y} + \frac{\partial v}{\partial x} \right)\right) + \frac{\partial}{\partial z}\left(\mu\left(\frac{\partial w}{\partial x} + \frac{\partial u}{\partial z} \right)\right)$$

2.2.3 Thermodynamic Equation of State

Density at every point in the control volume is calculated using the equation of state

$$(20)\quad \rho = \frac{P}{RT\Sigma \frac{m_\ell}{Mw_\ell}}$$

where m_ℓ is the mass fraction and $M_w\ell$ is the molecular weight of species ℓ .

2.2.4 Scalar Transport Equations

An example of a scalar transport equation is the energy equation which has a convection term, a diffusion term, and heat generation terms. The convection term represents the net heat carried into the control volume by the mass flowing across its boundaries at a rate proportional to the velocity normal to the boundary.

$$(21)\quad \frac{\partial}{\partial x}(\rho uH) + \frac{\partial}{\partial y}(\rho vH) + \frac{\partial}{\partial z}(\rho wH)$$

The diffusion term represents the net heat entering the control volume through conduction at a rate proportional to the thermal conductivity of the fluid

$$(22)\quad \frac{\partial}{\partial x}\left(K \frac{\partial T}{\partial x}\right) + \frac{\partial}{\partial y}\left(K \frac{\partial T}{\partial y}\right) + \frac{\partial}{\partial z}\left(K\frac{\partial T}{\partial z}\right)$$

and heat carried in by mass diffusion

$$(23)\quad \frac{\partial}{\partial x}\left(\Sigma h_\ell \Gamma_\ell \frac{\partial m_\ell}{\partial x}\right) + \frac{\partial}{\partial y}\left(\Sigma h_\ell \Gamma_\ell \frac{\partial m_\ell}{\partial y}\right) + \frac{\partial}{\partial z}\left(\Sigma h_\ell \Gamma_\ell \frac{\partial m_\ell}{\partial z}\right)$$

The generation term S(H) consists of radiation and shear work, and when the corrdinate system is rotating, S(R) consists of work done on the fluid by centrifugal and Coriolis forces. The terms due to centrifugal and Coriolis forces are:

$$(23.5)\quad S(R) = -\rho\nabla .\ [\ \bar{\omega}\ (\bar{\omega}\ .\ \bar{r}) - \bar{r}\ (\bar{\omega}\ .\ \bar{\omega})\ ]$$

See reference (4) for the development of S(R). See reference (1) for the development of the shear work terms and reference (2) for development of the radiation terms. The final energy equations becomes:

$$(24)\quad \frac{\partial}{\partial x}(\rho uH) + \frac{\partial}{\partial y}(\rho vH) + \frac{\partial}{\partial z}(\rho wH) = \frac{\partial}{\partial x}\left(K\frac{\partial T}{\partial x}\right) + \frac{\partial}{\partial y}\left(K\frac{\partial T}{\partial y}\right) + \frac{\partial}{\partial z}\left(K\frac{\partial T}{\partial z}\right) + \frac{\partial}{\partial x}\left(\Sigma \Gamma_\ell h_\ell \frac{\partial m_\ell}{\partial x}\right) + \frac{\partial}{\partial y}\left(\Sigma \Gamma_\ell h_\ell \frac{\partial m_\ell}{\partial y}\right) + \frac{\partial}{\partial z}\left(\Sigma \Gamma_\ell h_\ell \frac{\partial m_\ell}{\partial z}\right) + S(H) + S(R)$$

The specie transport equation must be solved for each species present in the control volume. The convection term represents the mass fraction flowing into a control volume

(25) $$\frac{\partial}{\partial x}(\rho u m_\ell) + \frac{\partial}{\partial y}(\rho v m_\ell) + \frac{\partial}{\partial z}(\rho w m_\ell)$$

The diffusion term represents molecular diffusion of the species into the control volume

(26) $$\frac{\partial}{\partial x}\left(\Gamma_\ell \frac{\partial m_\ell}{\partial x}\right) + \frac{\partial}{\partial y}\left(\Gamma_\ell \frac{\partial m_\ell}{\partial y}\right) + \frac{\partial}{\partial z}\left(\Gamma_\ell \frac{\partial m_\ell}{\partial z}\right)$$

where Γ_ℓ is the mass diffusion coefficient of species l. The source term

(27) $$S_\ell\,(T,\ m_\ell)$$

represents the time averaged reaction rate of species m_ℓ which is a function of temperature and mass fraction of the species. The final species equation becomes:

(28) $$\frac{\partial}{\partial x}(\rho u m_\ell) + \frac{\partial}{\partial y}(\rho v m_\ell) + \frac{\partial}{\partial z}(\rho w m_\ell) = \frac{\partial}{\partial x}\Gamma_\ell \frac{\partial m_\ell}{\partial x} + \frac{\partial}{\partial y}\Gamma_\ell \frac{\partial m_\ell}{\partial y} + \frac{\partial}{\partial z}\Gamma_\ell \frac{\partial m_\ell}{\partial z} + S_\ell\,(T,\ m_\ell)$$

2.2.5 The Modeled Equations

To summarize the equations being solved and the flexibility afforded by the program, assume that a very basic problem is to be solved. Such as a constant density, constant temperature, single species liquid flow field. The unknowns in this example are u, v, w, and p. The three equations needed are:

the continuity equation

(29) $$\frac{\partial}{\partial x}(\rho u) + \frac{\partial}{\partial y}(\rho v) + \frac{\partial}{\partial z}(\rho w) = 0$$

the X-momentum equation

$$\begin{aligned}
&\frac{\partial(\rho uu)}{\partial x} + \frac{\partial(\rho uv)}{\partial y} + \frac{\partial(\rho uw)}{\partial z} = \rho g_x - \frac{\partial P}{\partial x} + \frac{\partial}{\partial x}\left(2\mu \frac{\partial u}{\partial x}\right) \\
&+ \frac{\partial}{\partial y}\left(\mu\left(\frac{\partial u}{\partial y} + \frac{\partial v}{\partial x}\right)\right) + \frac{\partial}{\partial z}\left(\mu\left(\frac{\partial w}{\partial x} + \frac{\partial u}{\partial z}\right)\right) \\
&+ \rho[(v - z\,\omega_x + x\omega_z)\,\omega_z - (w - x\omega_y + y\omega_x)\,\omega_y + v\omega_z - w\,\omega_y]
\end{aligned} \tag{30}$$

the Y-momentum equation is

$$\begin{aligned}
&\frac{\partial(\rho uv)}{\partial x} + \frac{\partial(\rho vv)}{\partial y} + \frac{\partial(\rho vw)}{\partial z} = \rho g_y - \frac{\partial P}{\partial y} + \frac{\partial}{\partial x}\left(\mu\left(\frac{\partial u}{\partial y} + \frac{\partial v}{\partial x}\right)\right) \\
&+ \frac{\partial}{\partial y}\left(2\mu \frac{\partial v}{\partial y}\right) + \frac{\partial}{\partial z}\left(\mu\left(\frac{\partial w}{\partial y} + \frac{\partial v}{\partial z}\right)\right) \\
&+ \rho[(w - x\omega_y + y\omega_x)\,\omega_x - (u - y\omega_z + z\omega_y)\,\omega_z + w\omega_x - u\omega_z]
\end{aligned} \tag{31}$$

the z-momentum equation is

$$\begin{aligned}
&\frac{\partial(\rho uw)}{\partial x} + \frac{\partial(\rho vw)}{\partial y} + \frac{\partial(\rho ww)}{\partial z} = \rho g_z - \frac{\partial P}{\partial z} + \frac{\partial}{\partial x}\left(\mu\left(\frac{\partial w}{\partial x} + \frac{\partial u}{\partial z}\right)\right) + \frac{\partial}{\partial y}\left(\mu\left(\frac{\partial v}{\partial z} + \frac{\partial w}{\partial y}\right)\right) \\
&+ \frac{\partial}{\partial z}\left(2\mu \frac{\partial w}{\partial z}\right) \\
&+ \rho\,[(u - y\omega_z + z\omega_y)\,\omega_y - (v - z\omega_x + x\omega_z)\,\omega_x + u\omega_y - v\omega_x]
\end{aligned} \tag{32}$$

If the problem is changed to a non isothermal gaseous flow extra unknowns, P and T are to be calculated. The equation of state and the energy equation must also be solved.

$$P = \rho R T \tag{33}$$

Energy equation

$$\frac{\partial}{\partial x}(\rho u H) + \frac{\partial}{\partial y}(\rho v H) + \frac{\partial}{\partial z}(\rho w H) = \frac{\partial}{\partial x}\left(K \frac{\partial T}{\partial x}\right) + \frac{\partial}{\partial y}\left(K \frac{\partial T}{\partial y}\right) + \frac{\partial}{\partial z}\left(K \frac{\partial T}{\partial z}\right) + S \tag{34}$$

If the flow field involves different specie undergoing mixing, the energy equation has more terms added to account for the heat carried by the diffusion of the individual specie.

Energy equation

$$\begin{aligned}
&\frac{\partial}{\partial x}(\rho u H) + \frac{\partial}{\partial y}(\rho v H) + \frac{\partial}{\partial z}(\rho w H) = \frac{\partial}{\partial x}\left(K \frac{\partial T}{\partial x}\right) + \frac{\partial}{\partial y}\left(K \frac{\partial T}{\partial y}\right) + \frac{\partial}{\partial z}\left(K \frac{\partial T}{\partial z}\right) \\
&+ \frac{\partial}{\partial x}\left(\Sigma \Gamma_\ell h_\ell \frac{\partial m_\ell}{\partial x}\right) + \frac{\partial}{\partial y}\left(\Sigma \Gamma_\ell h_\ell \frac{\partial m_\ell}{\partial y}\right) + \frac{\partial}{\partial z}\left(\Sigma \Gamma_\ell h_\ell \frac{\partial m_\ell}{\partial z}\right) + S
\end{aligned} \tag{35}$$

where a species transport equation must be solved for each species, ℓ.

Specie transport equation

$$\frac{\partial}{\partial x}(\rho u m_\ell) + \frac{\partial}{\partial y}(\rho v m_\ell) + \frac{\partial}{\partial z}(\rho w m_\ell) = \frac{\partial}{\partial x}\left(\Gamma_\ell \frac{\partial m_\ell}{\partial x}\right) + \frac{\partial}{\partial y}\left(\Gamma_\ell \frac{\partial m_\ell}{\partial y}\right) + \frac{\partial}{\partial z}\left(\Gamma_\ell \frac{\partial m_\ell}{\partial z}\right) \tag{36}$$

For turbulent flow, two more equations must be solved; one for K, the turbulence energy, and one for ϵ, the energy dissipation. The turbulence model replaces the laminar viscosity μ_l with the eddy viscosity μ_{eff} in the momentum equations. It also adds extra terms to the momentum equations, the species transport equations, and the energy equation. For reacting flows, a reaction rate term which determines the rate at which the fuels and oxidants react to form products is added to the specie transport equations, equation 36, as a source term.

All of the transport equations can be algebraically manipulated into the form:

$$\frac{\partial}{\partial x}(\rho u \phi) + \frac{\partial}{\partial y}(\rho v \phi) + \frac{\partial}{\partial z}(\rho w \phi) = \frac{\partial}{\partial x}\Gamma\frac{\partial \phi}{\partial x} + \frac{\partial}{\partial y}\Gamma\frac{\partial \phi}{\partial y} + \frac{\partial}{\partial z}\Gamma\frac{\partial \phi}{\partial z} + S_\phi \tag{37}$$

where the left hand side contains the convection terms and the right hand side comprises the diffusion terms and the source terms (S). Any term that is not a diffusion term or a convection term is added to the source terms. Table 1 contains a tabulation of the terms in ϕ, Γ and S.

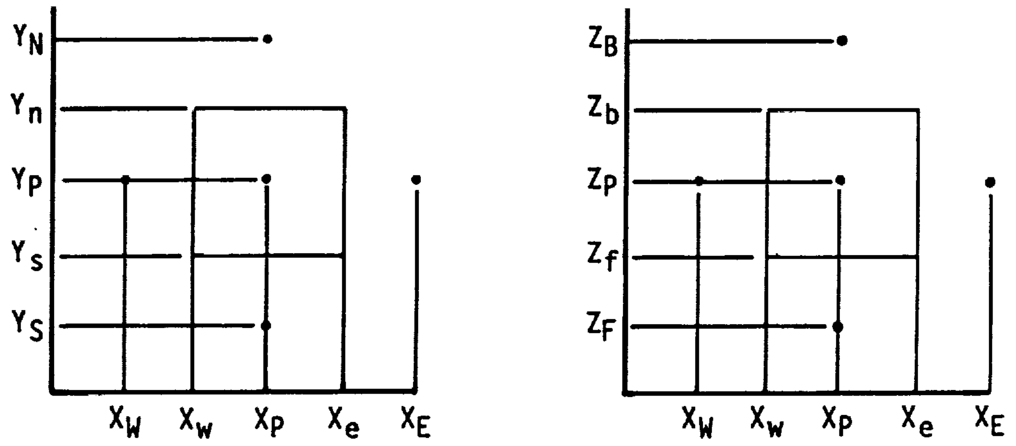
	ϕ	Γ	S_ϕ
Continuity	1	0	0
x-momentum	u	μ	$\frac{\partial}{\partial x} \mu \frac{\partial u}{\partial x} - \frac{2}{3} \mu \frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} + \frac{\partial}{\partial y} \mu \frac{\partial v}{\partial x} + \frac{\partial}{\partial z} \mu \frac{\partial w}{\partial x} - \frac{\partial P}{\partial x} + \rho g_x$ $+ \rho\, [(v - z\omega_x + x\omega_z)\, \omega_z - (w - x\omega_y + y\omega_x)\, \omega_y + v\omega_z - w\omega_y]$
y-momentum	v	μ	$\frac{\partial}{\partial y} \mu \frac{\partial v}{\partial y} - \frac{2}{3} \mu \frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} + \frac{\partial}{\partial x} \mu \frac{\partial u}{\partial y} + \frac{\partial}{\partial z} \mu \frac{\partial w}{\partial y} - \frac{\partial P}{\partial v} + \rho g_y$ $+ \rho\, [(w - x\omega_y + y\omega_x)\, \omega_x - (u - y\omega_z + z\omega_y)\, \omega_z + w\omega_x - u\omega_z]$
z-momentum	w	μ	$\frac{\partial}{\partial z} \mu \frac{\partial w}{\partial z} - \frac{2}{3} \mu \frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} + \frac{\partial}{\partial x} \mu \frac{\partial u}{\partial z} + \frac{\partial}{\partial y} \mu \frac{\partial v}{\partial z} - \frac{\partial P}{\partial z} + \rho g_z$ $+ \rho\, [(u - y\omega_z + z\omega_y)\, \omega_y - (y - z\omega_x + x\omega_z)\, \omega_x + u\omega_y - y\omega_x]$
Energy	H	K	$\frac{\partial}{\partial x}\left(h \frac{\partial m}{\partial x}\right) + \frac{\partial}{\partial y}\left(h \frac{\partial m}{\partial y}\right) + \frac{\partial}{\partial z}\left(h \frac{\partial m}{\partial z}\right) + S_T$ $- \rho \left\{ u\, [\omega_y(y\omega_x - x\omega_y) + \omega_z\, (z\omega_x - x\omega_z)] + v\, [\omega_x\, (x\omega_y - y\omega_x)\right.$ $\left. + \omega_z\, (z\omega_y - y\omega_z)] + w\, [\omega_x\, (x\omega_z - z\omega_x) + \omega_y\, (y\omega_z - z\omega_y)] \right\}$
Specie transport	m_ℓ	Γ_ℓ	S_ϕ

Table 1

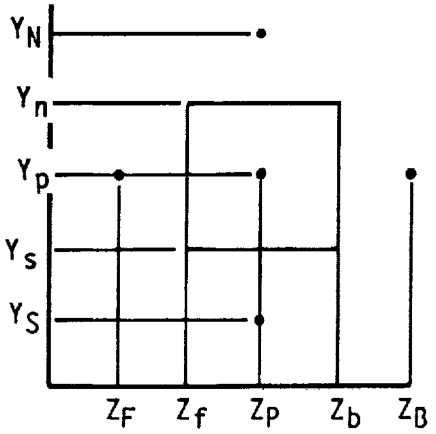
2.3 Discretizing the Equations

This section contains a presentation of the technique used by TEACH to solve the general transport equations, given in section 2.2.5. The goal is to describe the approximations that are made in derving the finite difference form of the equations from the differential equations. This knowledge will allow the user to recognize the errors that could arise and enable him to avoid them. There are several techniques that can be used to discretize the differential equations all of which produce essentially the same difference equations (see reference 3). The technique used here is the integral method. In this method the differential equation is integrated over the volume of a cell. The cell geometry given below will be used throughout this section.

FIGURE 6
SUBSCRIPT NOTATION FOR A FLUID CELL



(Looking Backward) (Looking Northward)



(Looking Eastward)

Integrating the convection terms over the cell volume:

(38) $$\int_{z_f}^{z_b} \int_{y_s}^{y_n} \int_{x_w}^{x_e} \frac{\partial}{\partial x} (\rho u \phi)\, dxdydz$$

yields

(39) $$\int_{z_f}^{z_b} \int_{y_s}^{y_n} \left\{ (\rho u \phi)_{x_e} - (\rho u \phi)_{x_w} \right\} dydz$$

separating

(40) $$\int_{z_f}^{z_b} \int_{y_s}^{y_n} (\rho u \phi)_{x_e}\, dydz - \int_{z_f}^{z_b} \int_{y_s}^{y_n} (\rho u \phi)_{x_w}\, dydz$$

At this point we make our first approximation; ρ, u, and ϕ are all functions of x, y, and z, but using the mean value theorem, which states

(41) $$\int_{z - \frac{\Delta z}{2}}^{z + \frac{\Delta z}{2}} f(z)dz \sim f(z)\Delta z$$

where

(42) $$z - \frac{\Delta z}{2} \leq \bar{z} \leq z + \frac{\Delta z}{2}$$

yields

(43) $$(\rho u \phi)_{x_e, y_p z_p} \quad (y_n - y_s)\ (zb\text{-}zf) - (\rho u \phi)_{x_w, p_p z_p} \ (y_n - y_s) * (zb\text{-}zf)$$

but

(44) $$(y_n - y_s)_{x_e}^{*} (z_b - z_f)_{x_e} = a_e \quad \text{and} \quad (y_n - y_s)_{x_w}^{*} (z_b - z_f)_{x_w} = a_w$$

where a_e and a_w are the surface areas of the east and west cell walls respectively, yielding

(45) $$(\rho u \phi)_{x_e, y_p, z_p}\ a_e - (\rho v \phi)_{x_w, y_p, z_p}\ a_w$$

Similarly the other convection term works out to be

(46) $$(\rho v \phi)_{x_p, y_n, z_p}\ a_n - (\rho v \phi)_{x_p, y_s, z_p}\ a_s$$

(47) $$(\rho w \phi)_{x_p, y_p, z_b}\ a_b - (\rho w \phi)_{x_p, y_p, z_f}\ a_f$$

Integrating the diffusion terms over the cell volume

(48) $$\int_{z_f}^{z_b} \int_{y_s}^{y_n} \int_{x_w}^{x_e} \frac{\partial}{\partial x} \Gamma \frac{\partial \phi}{\partial x} \, dxdydz$$

yields

(49) $$\int_{z_f}^{z_b} \int_{y_s}^{y_n} \left(\Gamma \frac{\partial \phi}{\partial x}\right)_{x_e} dydz - \int_{z_f}^{z_b} \int_{y_s}^{y_n} \left(\Gamma \frac{\partial \phi}{\partial x}\right) dydz$$

Using the mean value theorem again gives

(50) $$\left(\Gamma \frac{\partial \phi}{\partial x}\right)_{x_e, y_p, z_p} a_e - \left(\Gamma \frac{\partial \phi}{\partial x}\right)_{x_w, x_p, z_p} a_w$$

by using the midpoint rule (see reference 3) we can approximate $\partial \phi / \partial x$ and get

(51) $$\frac{(\phi_N - \phi_P)}{\Delta y} \Gamma_n \, a_n - \frac{(\phi_P - \phi_S)}{\Delta y} \Gamma_s \, a_s$$

Similarly

(52) $$\frac{(\phi_E - \phi_P)}{\Delta x} \Gamma_e \, a_e - \frac{(\phi_P - \phi_W)}{\Delta x} \Gamma_w \, a_w$$

and

(53) $$\frac{(\phi_B - \phi_P)}{\Delta z} \Gamma_b \, a_b - \frac{(\phi_P - \phi_F)}{\Delta z} \Gamma_f \, a_f$$

The source term is linearized as:

$$S_\phi = A\phi_p + B$$

where A and B are assumed contstant. Integrating the linearized source term over the control volume as,

$$\int_{z_f}^{z_b} \int_{y_o}^{y_x} \int_{x_w}^{x_e} (A\phi_p+B)\, dxdydz = A\phi_p .\ \mathrm{vol} + B\ .\ \mathrm{vol}\ .$$

Defining A Vol=Sp and B Vol=Su we have

$$\int_{z_f}^{z_b} \int_{y_s}^{y_n} \int_{x_w}^{x_e} S_\phi\ dxdydz = S_p\phi_p + S_u$$

The transport equation can now be written out

$$\begin{aligned} C_E\phi_e - C_W\phi_w + C_N\phi_n - C_S\phi_s + C_B\phi_B - C_F\phi_F &= D_E(\phi_E - \phi_P) - D_W(\phi_P - \phi_W) \\ &+ D_N(\phi_N - \phi_P) - D_S(\phi_P - \phi_S) + D_B(\phi_B - \phi_P) - D_F(\phi_P - \phi_F) + S_U + S_P\phi_P \end{aligned} \tag{54}$$

where C_E, C_N, etc. are the convection coefficients

$$C_E = (\rho u)_e\, a_e\ ,\quad C_N = (\rho u)_n\, a_n\ ,\ \mathrm{etc.} \tag{55}$$

D_E , D_N , etc. are the diffusion coefficients

$$D_E = \frac{\Gamma_e}{\Delta x}\, a_e\ ,\quad D_N = \frac{\Gamma_n}{\Delta y}\, a_n\ ,\ \mathrm{etc.} \tag{56}$$

and SU comprises all the source terms which do not contain ϕ_P and $S_P\phi_P$ comprises all the source terms containing ϕ_P.

Note that in equation 54, ϕ_w, ϕ_e, ϕ_f, ϕ_b, ϕ_s, and ϕ_n are unknown.

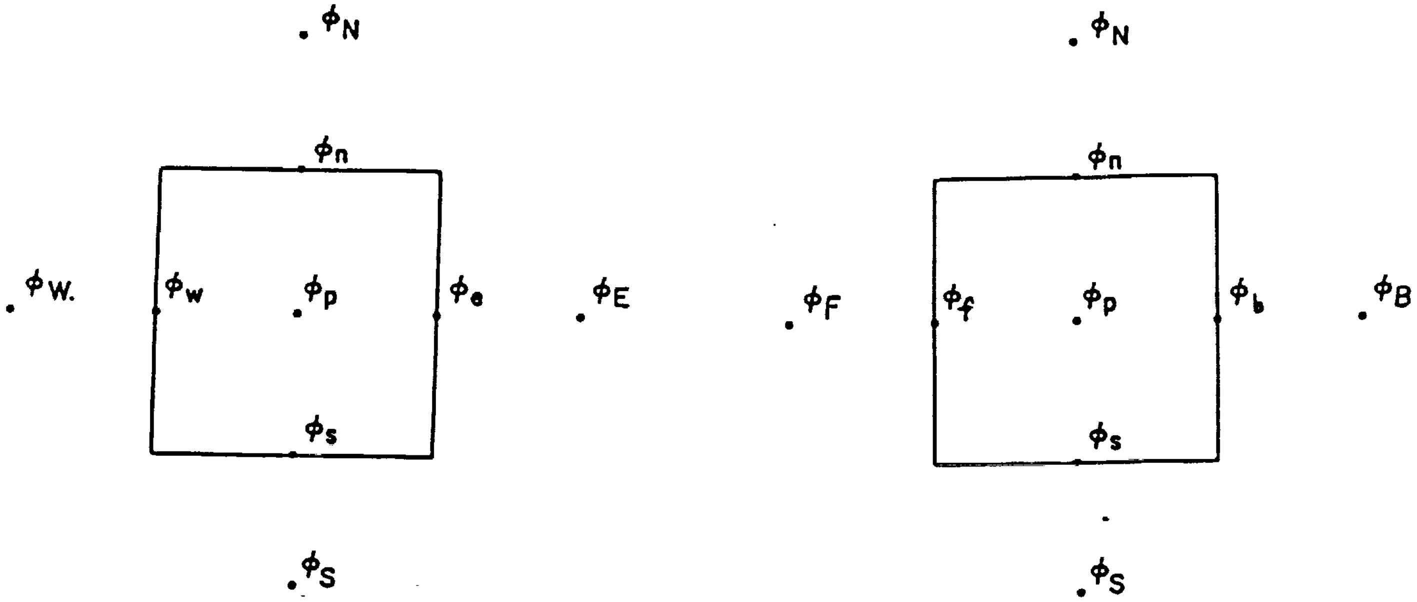


FIGURE 7

LOCATION OF Φs USED IN TRANSPORT EQUATIONS

ϕ is assumed to vary according to the following relation between cell centers, so the unknown ϕ s can be calculated from the known ϕ s according to

(57) $$\phi_e = g_E \phi_E + (1 - g_E) \phi_p$$

where g is a weighting factor defined as:
g = 1/2 $\quad -2 \le Pe \le 2.$
g = 0 $\quad Pe > 2$
g = 1 $\quad Pe < -2.$ where Pe = CE/DE

The transport equation can be rewritten now

(58) $$C_E(f_e\phi_P + (1 - f_e)\phi_E) - C_W(f_w\phi_W + (1 - f_w)\phi_P) + C_N(f_n\phi_P + (1 - f_n))\phi_N$$
$$- C_S(f_s\phi_S + (1 - f_s)\phi_p) + C_B(f_b\phi_P + (1 - f_b)\phi_B) - C_F(f_f\phi_B + (1 - f_f)\phi_p) = S_P\phi_P + S_U$$

where

(59) $$f_e = 1 - g_E \frac{D_E}{C_E}$$

with algebraic manipulation and subtracting ϕ times the continuity equation

(60) $$(C_E - C_W + C_N - C_S + C_B - C_F)\ \phi_p = 0$$

the transport equation reduces to

$$(61)\quad A_N(\phi_N - \phi_P) + A_S(\phi_S - \phi_P) + A_E(\phi_E - \phi_P) + A_W(\phi_W - \phi_P) + A_B(\phi_B - \phi_P) + A_F(\phi_F - \phi_P) + S_P\phi_P + S_U = 0$$

where

$$(62)\quad A_N = C_N\,(f_n - 1)\ ,\quad A_S = C_S f_s\ , \text{ etc.}$$

which can be further simplified to the finite difference equation for 0:

$$(63)\quad A_P\phi_P = A_N\phi_N + A_S\phi_S + A_E\phi_E + A_W\phi_W + A_B\phi_B + A_F\phi_F + S_U$$

where

$$(64)\quad A_P = A_N + A_S + A_W + A_E + A_B + A_F - S_P$$

To solve the above equation, the weighting factors fe, fw, fn, fs, fb, and ff have to be calculated based on the values calculated for g , g_n, g_s, g_b, g_f, and g_w for each cell. The method.used to calculate weighting factors is given in reference 1.

2.4 Solution Procedure

2.4.1 Boundary Conditions

If the cells are numbered from 1 to NI in the X-direction, from 1 to NJ in the Y-direction, and from 1 to NK in the Z-direction, the equations will be solved in the field from 2 to NI-1, from 2 to NJ-1, and from 2 to NK-1. The values lying on the border of the domain are set by the input boundary conditions. There are three types of boundary conditions which can be applied. One type is where the value of ϕ is specified, such as the velocity in an inlet. Another is where the gradient of ϕ is zero, such as the zero temperature gradient at an adiabatic wall. The last is where ϕ is unspecified such as at an outlet. On an axis of symmetry, v-velocity and the gradients of all ϕs except v-velocity are set to zero. The values of field variables in the boundary cells adjacent to a periodic boundary are adjusted every iteration by making them equal to the corresponding cell next to the periodic boundary on the opposite end of the control volume.

The handling of wall effects on heat transfer, turbulence energy, and energy dissipation rate is beyond the scope of this manual. Refer to reference 1 for details.

2.4.2 Description of the Solution Algorithm

The finite difference equation to be solved is the transport equation

(65) $$A_P\phi_P = A_N\phi_N + A_S\phi_S + A_W\phi_W + A_E\phi_E + A_B\phi_B + A_F\phi_F + S_U$$

where ϕ can be u, v, w, P, k, e, M_ℓ, or H. The equation gives the value of ϕ at a point P as a function of its neighbors to the north, south, east, west, front, and back and must be solved for each cell in the flow field. The method used to solve all the equations is to solve for values of ϕ in a given plane one row or one column at a time. If the fields are solved row by row then the values in the neighboring columns and planes are assumed as constant. Once one plane is solved, then the neighboring plane is solved until the whole block matrix is updated.

(66) $$A_P\phi_P = A_N\phi_N + A_S\phi_S + C'$$

or

(67) $$A_P\phi_j = A_N\phi_{j+1} + A_S\phi_{j-1} + C'$$

where

(68) $$C' = A_W\phi_W + A_E\phi_E + A_B\phi_B + A_F\phi_F + S_U$$

In this case all the ϕs in one column are calculated at once using a Tri-Diagonal Matrix Algorithm (TDMA), and solution of the whole field proceeds by solving each column sequentially in this manner.

2.4.3 Underrelaxation

Because the finite difference equations being solved are all non-linear, allowing the program to calculate and assign new values of ϕ in one set of finite difference equations can have a drastic effect on other variables being solved, leading to convergence problems. To prevent this, the values of ϕ calculated are under-relaxed before they are used in other equations.

(69) $$\phi_{P_{new}} = F\phi_{P_{calculated}} - (1-F)\phi_{P_{old}}$$

where F is an under-relaxation factor usually between .3 and .7 depending on the variable ϕ.

2.4.4 Pressure Correction

At this point it should be noted that none of the transport equations can be used to calculate pressure, yet the momentum equations use it. Another equation is needed to solve for pressure. The extra equation added is the pressure correction equation and the algorithm setting it up and using it is called SIMPLE (Semi Implicit Method for Pressure Linked Equations). Briefly, this method does not calculate a pressure field but corrects a pressure field from an initial guess or from the previous iteration.

At the start of an analysis, the pressure field is assumed to be constant and the velocity fields are solved using the momentum transport equations. Because the pressures used in the momentum equations are guesses, there will be errors in the velocities calculated and continuity is not conserved. Using the new velocity fields the continuity equation is applied to each cell and the error in the net mass flow into the cell is saved as a "source" term.

$$(70)\quad M_p = (\rho u^*)_e\, \alpha_e - (\rho u^*)_w\, \alpha_w + (\rho v^*)_n\, \alpha_n - (\rho v^*)_s\, \alpha_s + (\rho w^*)_b\, \alpha_b - (\rho w^*)_f\, \alpha_f$$

If we subtract this from the continuity equation

$$(71)\quad (\rho u)_e\, \alpha_e - (\rho u)_w\, \alpha_w + (\rho v)_n\, \alpha_n - (\rho v)_s\, \alpha_s + (\rho w)_b\, \alpha_b - (\rho w)_f\, \alpha_f = 0$$

we get

$$(72)\quad -M_P = (\rho u')_e\, \alpha_e - (\rho u')_w\, \alpha_w + (\rho v')_n\, \alpha_n - (\rho v')_s\, \alpha_s + (\rho w')_b\, \alpha_b - (\rho w')_f\, \alpha_f$$

where

$$(73)\quad u' = u - u^*$$

u' is the velocity error, u is the exact velocity, and u^* is the velocity obtained from the solution of the momentum equation.

Similarly v' and w' can also be found.

If we assume that the velocity errors between two cells is proportional only to the difference in pressure errors between those cells, we can substitute those pressures and a constant of proportionality for the velocities in the continuity equation and get the pressure correction equation:

$$(74)\quad A_P P_P = A_N P_N + A_S P_S + A_W P_W + A_E P_E + A_B P_B + A_F P_F + S_U$$

where

$$(75)\quad A_P = A_N + A_S + A_W + A_E + A_B + A_F$$

A_n, A_s, A_w, A_e, A_f, and A_b are the constants of proportionality which come from the momentum equations, and

$$(76)\quad S_U = -M_P$$

The pressure correction equations are solved and the pressure corrections are added to the pressure field. The velocity fields are also corrected using the assumed proportionality between pressure difference and velocity. For more information about SIMPLE see reference 1.

2.4.5 Convergence Criteria

Convergence is determined at the end of each iteration on the basis of the 'residual source' criterion. The residual source R_{ϕ} is defined as

(77) $$R_{\phi} = A_P\phi_P - A_N\phi_N - A_S\phi_S - A_E\phi_E - A_W\phi_W - A_B\phi_B - A_F\phi_F - S_U$$

For convergence, R_{ϕ} is summed over the entire flow field:

(78) $$\frac{\Sigma |R\phi|}{R_{\phi ref}} < \epsilon$$

where $R_{\phi ref}$ is a reference flux based on the total fixed flux of Φ into the domain and the error is of the order of .001.

When mixing calculations are involved an additional requirement that the sum of the mass fractions at each node be less than ($1 \pm \epsilon$) must be satisfied. When variable density flows are being calculated there is an additional requirement that the change in density at each node in one iteration must be less than ϵ.

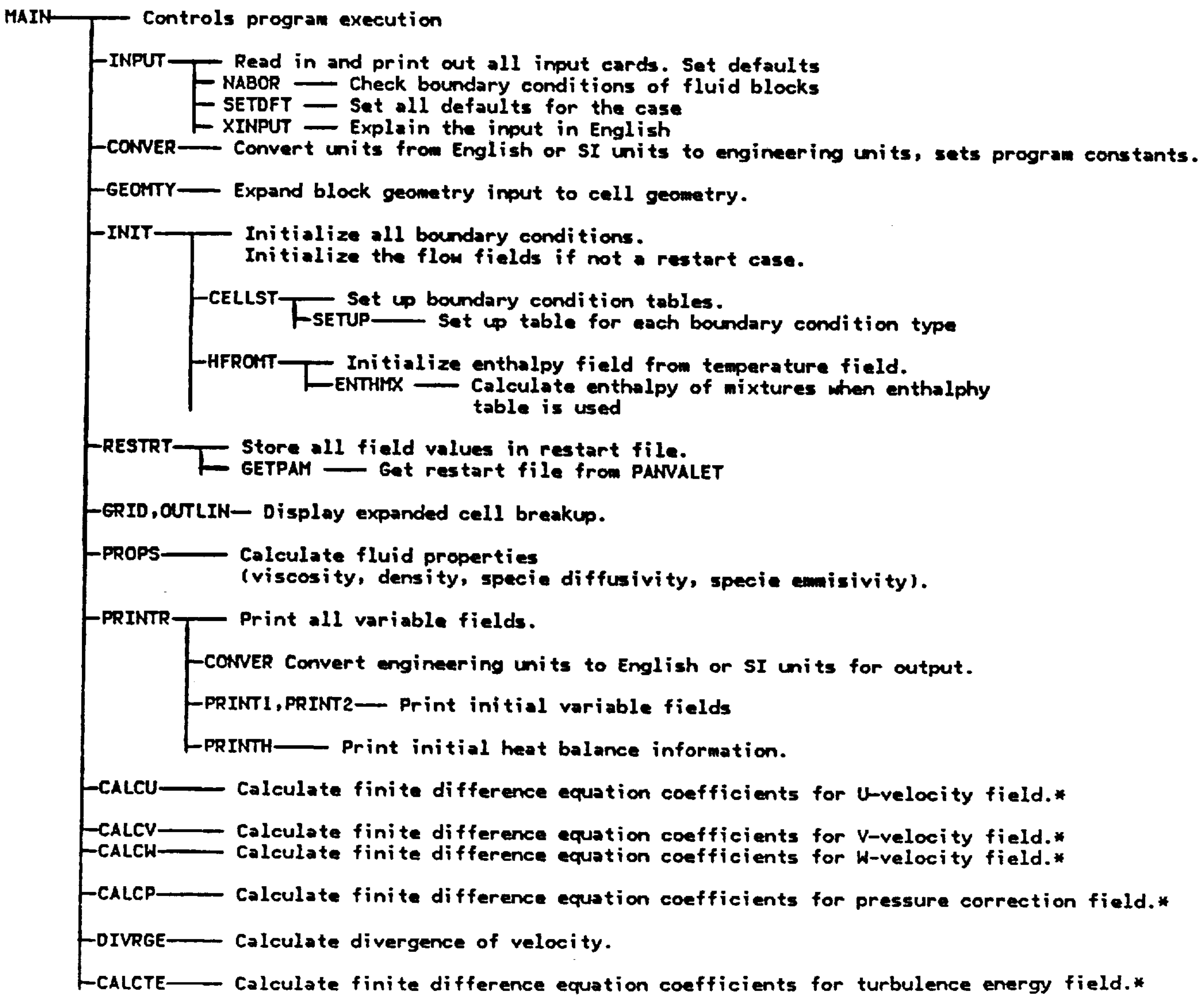
2.4.6 Solution Procedure

1. Guess fields for all variables.
2. Solve for u*, v*, and w* using prevailing pressure field.
3. Solve pressure correction equation and correct pressure and velocity fields.
4. Solve equations for all other variables.
5. Update fluid properties such as density and viscosity.
6. Test for convergence. If not converged, use prevailing fields as guesses and repeat from (2).

3.0 PROGRAM DESCRIPTION

3.1 Functional Diagram

This section contains a functional description of each major subroutine in the program. Following each subroutine name (given in capitals) is a brief description of the subroutine's purpose in the program. Branches emanating from the subroutine name denote routines which are called by that subroutine.



```
MAIN──┬── Controls program execution
      │
      ├INPUT──┬─ Read in and print out all input cards. Set defaults
      │       ├─ NABOR ── Check boundary conditions of fluid blocks
      │       ├─ SETDFT ── Set all defaults for the case
      │       └─ XINPUT ── Explain the input in English
      ├CONVER── Convert units from English or SI units to engineering units, sets program constants.
      │
      ├GEOMTY── Expand block geometry input to cell geometry.
      │
      ├INIT──────┬── Initialize all boundary conditions.
      │          │   Initialize the flow fields if not a restart case.
      │          │
      │          ├CELLST──┬── Set up boundary condition tables.
      │          │        └SETUP──── Set up table for each boundary condition type
      │          │
      │          ├HFROMT──┬── Initialize enthalpy field from temperature field.
      │          │        └ENTHMX ─── Calculate enthalpy of mixtures when enthalphy
      │          │                    table is used
      │
      ├RESTRT──┬── Store all field values in restart file.
      │        └── GETPAM ─── Get restart file from PANVALET
      │
      ├GRID,OUTLIN── Display expanded cell breakup.
      │
      ├PROPS────── Calculate fluid properties
      │            (viscosity, density, specie diffusivity, specie emmisivity).
      │
      ├PRINTR──┬── Print all variable fields.
      │        │
      │        ├CONVER Convert engineering units to English or SI units for output.
      │        │
      │        ├PRINT1,PRINT2─── Print initial variable fields
      │        │
      │        └PRINTH───── Print initial heat balance information.
      │
      ├CALCU────── Calculate finite difference equation coefficients for U-velocity field.*
      │
      ├CALCV────── Calculate finite difference equation coefficients for V-velocity field.*
      ├CALCW────── Calculate finite difference equation coefficients for W-velocity field.*
      │
      ├CALCP────── Calculate finite difference equation coefficients for pressure correction field.*
      │
      ├DIVRGE───── Calculate divergence of velocity.
      │
      └CALCTE───── Calculate finite difference equation coefficients for turbulence energy field.*
```

FIGURE 8
TEACH Functional Diagram

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* Refer to Figure 8a

- -CALCED—— Calculate finite difference equation coefficients for energy dissipation field.*
- -CALCF—— Calculate finite difference equation coefficients for species mass fraction fields.
  - -FSORCE—— Calculate extra source terms in the species mass fractions equations.
  - -MODF—— Modify coefficients for species mass fraction boundary conditions.
  - -TDMAIJ—— Solve the field using tridiagonal matrix algorithm.
- -CALCH—— Calculate finite difference equation coefficients for enthalpy field.
  - -HSORCE—— Calculate extra source terms in the enthalpy equations.
  - -MODT—— Modify coefficients for enthalpy boundary conditions.
  - -TDMAIJ—— Solve the field using tridiagonal matrix algorithm.
  - -TFROMH—— Calculate temperature field from enthalpy field.
    - ENTHMX —— Calculate enthalpy of mixtures when enthalpy table is used.
- -CALCFM—— Calculate finite difference equation coefficients for mixture fraction field.*
- -CALCFL—— Calculate finite difference equation coefficients for mixture fraction fluctuation field.
  - -MODFL—— Modify coefficients for mixture fraction fluctuation boundary conditions.
  - -TDMAIJ—— Solve the field using tridiagonal matrix algorithm.
- -CALCRD—— Calculate finite difference equation coefficients for radiation field.
  - -MODRD—— Modify coefficients for radiation boundary conditions.
  - -TDMAIJ—— Solve the field using tridiagonal matrix algorithm.
- -PROPS—— Calculate fluid properties (viscosity, density, specie diffusivity, specie emmisivity).
- -SEEIT—— Display convergence plot on Tektronix.
- -SEEIT2—— Display convergence plot on A/N terminal.
- -PRINTR——
  - -PRINT1,PRINT2—— Print variable fields
  - -PRINTH—— Print heat balance information.
- -RESTRT—— Save field variables in restart file.
- -SSOUTP—— User subroutine for special outputs.
- -PRINTN—— Print Peclet numbers and wall Reynold's numbers and wall shear stresses
- -FURATE—— Calculate reaction rates.
- -PLANES—— Select plane for streak line plot.
  - -STREAK—— plot streak lines.

FIGURE 8 (continued)
TEACH Functional Diagram

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* Refer to Figure 8a.

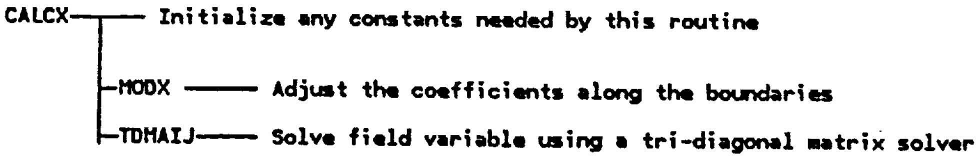

CALCX — Initialize any constants needed by this routine
-MODX — Adjust the coefficients along the boundaries
-TDMAIJ — Solve field variable using a tri-diagonal matrix solver

FIGURE 8a (continued)
TEACH Functional Diagram

3.2 Flow Diagram

This section contains a flow diagram which shows the logical ordering of the functions described in the previous section. A basic understanding of program flow will be helpful to users of TEACH in the interactive mode.

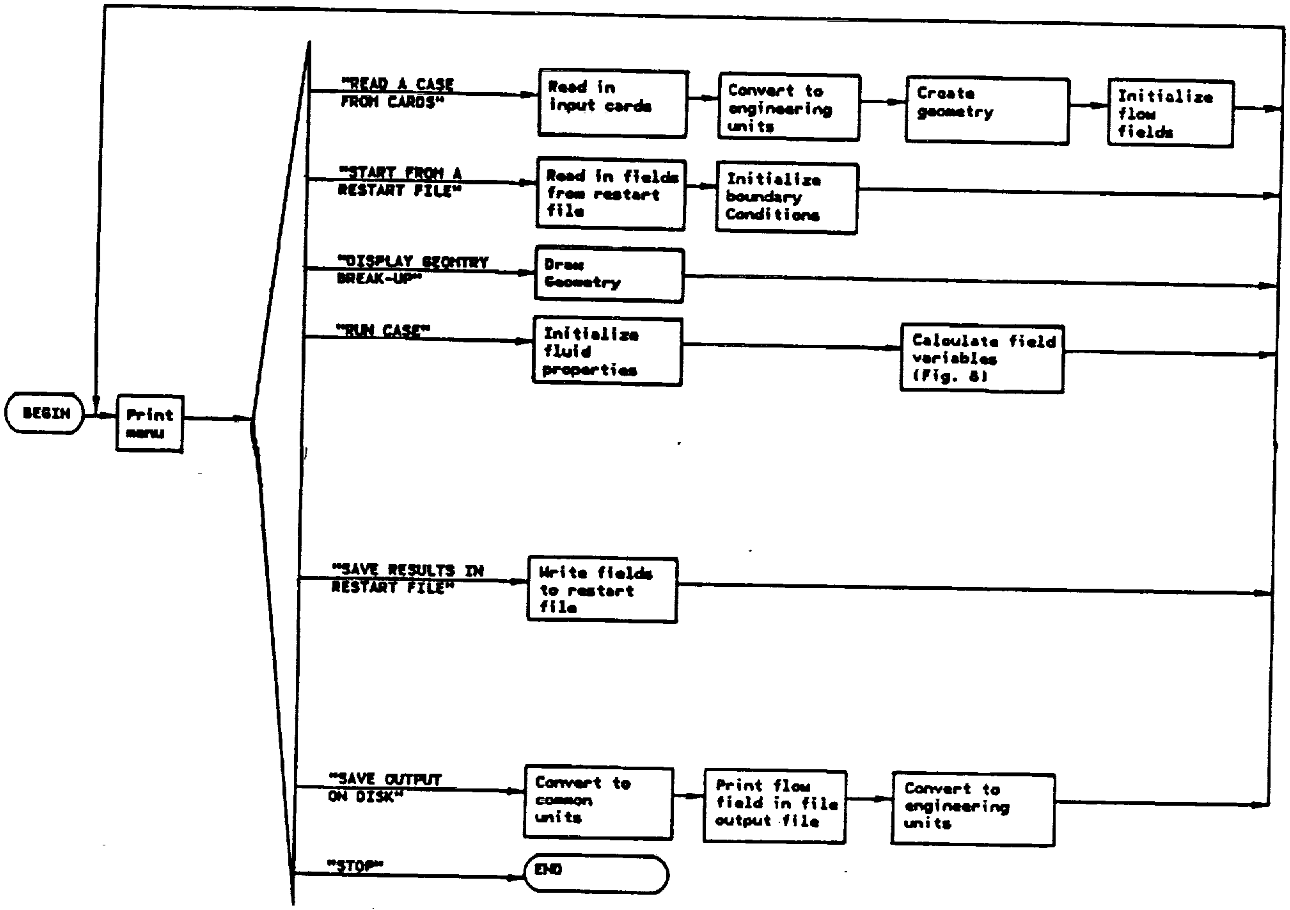


FIGURE 9
TEACH Flow Diagram

Calculate Field Variables

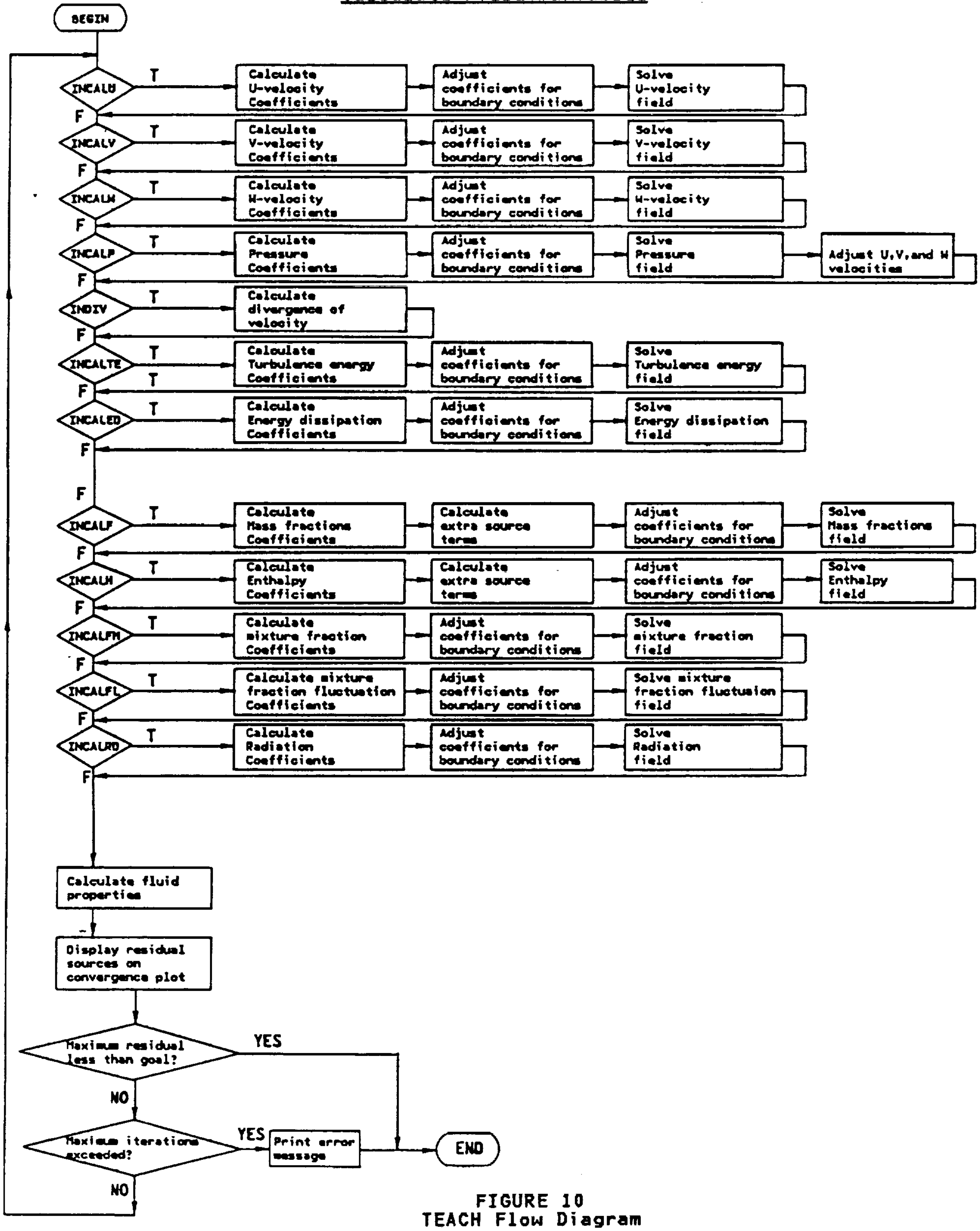


FIGURE 10
TEACH Flow Diagram

3.3 Input

This section contains a detailed description of the card image input. Although the description is complete it may be difficult to fully understand without an example to follow. Therefore referring to the sample geometry input in Appendix B may prove helpful.

One of the most difficult decisions a user has to make while setting up the input to TEACH concerns the grid breakup. The user must trade numerical accuracy for CPU time, and obtain an acceptable solution in the minimum amount of CPU time. While the ultimate decision can only be made after a process of trial and error, a few guidelines which apply to all cases are given here.

CPU Time

1) Solution time increases proportionally to the square of the number of grid nodes.

2) Given two similar cases with the same number of grid nodes but different grid spacings, the one with the most evenly spaced grid lines will converge sooner.

Numerical Accuracy

1) The most evenly spaced grid will give the most accurate solution.

2) The finer grid spacings should be located near the walls, near the shear layers between coaxial jets, and near the interface between a jet and the surrounding fluid.

3) Finer grid spacings should be located in regions where fluid variables have a high gradient, such as near an inlet and at a flame front.

4) Wall Reynolds number (printed at the end of the output) should be between 30 and 400.

5) Cell Reynolds number (printed at the end of the output) in any direction having high diffusion should be less than 5.

For variables requiring units, either the English or SI system may be used. A summary is shown below.

	English Units	SI Units
Temperature	°F	°C
Length	ft	m
Velocity	ft/sec	m/sec
Pressure	lb/in^2	N/m^2
Turbulence Energy	ft^2/sec^2	m^2/sec^2
Turbulence Energy Disipation Rate	ft^2/sec^3	m^2/sec^3
Viscosity	lbm/(ft-sec)	kg/(m-sec)
Density	lbm/ft^3	kg/m^3
Enthalpy (Enthalpy File)	BTU/lb-mole	Cal/kg-mole
Enthalpy (Output file)	ft^2/sec^2	m^2/sec^2

The input to TEACH consists of one or two card image files. The main file comprises everything required to solve a case if temperatures are not being calculated. If temperatures are being calculated and if specific heat is not constant, an enthalpy file must also be supplied. The enthalpy file has to be supplied if combustion is being calculated. The following is a description of the input for these two files. The enthalpy file is kept separate because one enthalpy file can be applicable to many cases.

3.3.1 Card Image Input

TEACH uses a 3-dimensional orthogonal coordinate system (cartesian or cylindrical). The grid formed by the intersection of coordinate lines is used in the modeling of fluid flow systems. Directions in the grid are identified as north, south, east, west, front and back, with the origin located at the southwest front corner unless an offset is input. With axisymmetry, an annulus is modeled by adding a radial offset to the Y coordinate so that the origin lies on the axis of symmetry, and the south wall of the breakup lies on the ID of the annulus. All blocks within the fluid volume must have the conditions on all boundaries (n, s, e, w, f, and b) described.

Boundary conditions are input and stored as a table (see section 3.4). Each entry in the table is assigned a unique identifying integer label and a three letter mnemonic indicating the type of boundary. A boundary can be one of six types:

Boundary Conditions	Mnemonic	Numeric
1. Axis of symmetry	SYM	1
2. Unspecified wall	UWL	2
3. Specified wall	SWL	3
4. Unspecified opening	UOP (Note 1)	4
5. Specified opening	SOP	5
6. Periodic Boundary	PER	6

Note 1: An unspecified opening can not be used in conjunction with an adjoining blockage. Only one unspecified opening can be used in a setup.

A specified boundary is one for which the user supplies all boundary values such as velocities, temperatures, etc. An unspecified boundary is one for which the boundary values are calculated by the program. The specified boundary can be a wall or an opening. High shear forces are present near a wall, but not near an opening. To account for these shear forces, a "wall function" is used by the program when a specified wall is called for. Most walls would be input as specified walls with all velocities set to zero. A moving wall could be modeled by specifying non-zero velocities in the plane of the wall. A symmetric boundary is a plane having no gradients across it. A periodic boundary is a boundary shared by both ends of the computational domain to simulate repeating geometries and flow patterns. Symmetric boundaries and periodic boundaries can be specified only for the outermost boundaries of the computational domain and must be specified identically for every block bounding the symmetric or periodic plane.

Section 3.4 gives a step by step procedure for specifying geometry input and the user is strongly advised to read it carefully before attempting to model his or her case.

The following is a description of the card image input file. Note that any field which has a default value may be left blank. Caution should be observed when using default values, however, because the default value may not be correct for the problem being solved. Also note that although English units are shown, SI units may be substituted by setting IUNIT (card 7) to the appropriate value.

The format of each input item is identified by type.

TYPE	EXAMPLE	DESCRIPTION
A	TEST☐CASE☐	**ALPHANUMERIC**: Any keyboard characters are specified within the given field.
F	☐☐-23.64☐☐	**FLOATING POINT**: Decimal fractions including decimal point are specified anywhere within the given field. Positive values are assumed unless the value is preceded by a minus sign.
	-.2364☐☐E2	Scientific notation may be substituted by specifying a decimal mantissa (as above) and a right adjusted base 10 multiplier preceded by a symbol E.
I	☐☐☐☐☐☐☐☐46	**INTEGER**: Right adjusted whole numbers (no decimal point) are specified within the given field.
L	☐☐☐☐☐☐☐☐☐T	**LOGICAL**: T-true, F-false; right adjusted in the field.

Blanks in an F or I field are interpreted as zeros, blanks in an A field are interpreted as blank characters, and a blank L field is interpreted as false.

Card Type: 1

Title: Title Card

General Description:

Name	Type	Columns	Default	Units	Description
TITLE	A	1-80			Descriptive title for case which will appear on printout and all plots.

Card Type: 2

Title: Origin and Counters

General Description:

Name	Type	Columns	Default	Units	Description
NXBLK	I	1-5		Note 1	Number of blocks used in the block breakup in the X-direction.
NYBLK	I	6-10		Note 1	Number of blocks used in the block breakup in the Y-direction.
NZBLK	I	11-15		Note 1	Number of blocks used in the block breakup in the Z-direction.
NFBLK	I	16-20		Note 1	Number of fluid block description cards (card type 4).
NBC	I	21-25		Note 1	Number of boundary condition description cards (card type 5A and 5B).
IPAPER	I	26-30	20		Paper code for plots, See Note 2.
XBEGIN	F	31-40		ft	Axial location of the south-west corner of the geometry.
YBEGIN	F	41-50		ft	Radial location of the south-west corner of the geometry.
ZBEGIN	F	51-60		ft	Tangential location of the front south-west corner of the geometry.
IROT	I	66-70			Rotation Indicator IROT = 0 No rotation IROT = 1 Rotation in component vector form (card type 7C must be supplied) IROT = 2 Rotation in magnitude and direction form (card type 7D must be supplied)

Notes:
1. There is a limit on the maximum number of these cards. See Appendix E.
2. Appendix B has a listing of available paper codes.

Card Type: 3A

Title: West to East Block Break-Up

General Description:

This card repeated NXBLK times.

Name	Type	Columns	Default	Units	Description
XEND	F	1-10		ft	The X-direction coordinate of the east end of a plane of blocks.
NX	I	11-15			The number of cells the block is to be broken up into in the west to east direction. Note 1.
EPSX	F	16-20	1.0	Note 4	The expansion factor to be used in this block. Expansion factor is the ratio of the width of a given cell to the width of its neighbor on the side closest to the origin.

Card Type: 3B

Title: South to North Block Break-Up

General Description:

This card repeated NYBLK times.

Name	Type	Columns	Default	Units	Description
YEND	F	1-10		ft	The Y-direction coordinate of the north end of a plane of blocks.
NY	I	11-15			The number of cells the block is to be broken up into in the south to north direction. Note 2.
EPSY	F	16-20	1.0	Note 4	The expansion factor to be used in this block.

Card Type: 3C

Title: Front to Back Block Break-Up

General Description:

This card repeated NZBLK times.

Name	Type	Columns	Default	Units	Description
ZEND	F	1-10		ft	The Z-direction coordinate of the back end of a plane of blocks.
NZ	I	11-15			The number of cells the block is to be broken up into in the front to back direction. Note 3.
EPSZ	F	16-20	1.0	Note 4	The expansion factor to be used in this block.

Notes:

1. The sum of the NX's must not exceed a maximum. See Appendix E.
2. The sum of the NY's must not exceed a maximum.
3. The sum of the NZ's must not exceed a maximum.
4. Inaccuracies and instabilities can occur for values different than 1.0. Values greater than 1.25 or less than 0.8 should be avoided whenever possible.

ISSUED: 11/16/84
REVISED: 03/04/86

Card Type: 4

Title: Fluid Block Description

General Description:

This card repeated NFBLK times.

Name	Type	Columns	Default	Units	Description
MFBI	I	1-5			Considered fluid block number in the X-direction.
MFBJ	I	6-10			Consider fluid block number in the Y-direction.
MFBK	I	11-15			Considered fluid block number in the Z-direction.
MBCW	I	16-20	Note 1		Integer name of boundary condition description cards used to describe the boundary conditions on the west boundary of this block (cards 5A and 5B).
MBCE	I	21-25	Note 1		Integer name of boundary condition description cards used to describe the boundary conditions on the east boundary of this block (cards 5A and 5B).
MBCS	I	26-30	Note 1		Integer name of boundary condition description cards used to describe the boundary conditions on the south boundary of this block (cards 5A and 5B).
MBCN	I	31-35	Note 1		Integer name of boundary condition description cards used to describe the boundary conditions on the north boundary of this block (cards 5A and 5B).
MBCF	I	36-40	Note 1		Integer name of boundary condition description cards used to describe the boundary conditions on the front boundary of this block (cards 5A and 5B)
MBCB	I	41-45	Note 1		Integer name of boundary condition description cards used to describe the boundary conditions on the back boundary of this block (cards 5A and 5B)

Note 1: These integers can be anything between 1 and the maximum for NBC (Card Type 2) and are given in the first five columns of the Card Type 5A. Please see Appendix B, Sample Input, for further clarification.

Card Type: 5A

Title: Boundary Condition Description Card

General Description:

There is one card 5A followed by one card 5B for each boundary condition. There are NBC card pairs to be input.

Name	Type	Columns	Default	Units	Description
LBC	I	1-5			Unique integer "name" assigned to this boundary condition card pair.
IBC	A	8-10			Boundary condition type: IBC = SYM : axis of symmetry or plane of symmetry IBC = UWL : unspecified wall IBC = SWL : specified wall IBC = UOP : unspecified opening IBC = SOP : specified opening IBC = PER : periodic boundary Note 1
UBC	F	11-20		ft/sec	Velocity in X-direction at this boundary.
VBC	F	21-30		ft/sec	Velocity in Y-direction at this boundary.
WBC	F	31-40		ft/sec	Velocity in Z-direction at this boundary.
PSBC	F	41-50		lb/in^2	Static pressure at this boundary.
TBC	F	51-60		°F	Temperature at this boundary. Note 2.
TEBC	F	61-70			Turbulence energy coefficient at this boundary. Note 3.
IWUNIT	I	71-75			Swirl indicator at this boundary. Note 4. IWUNIT = 0 No conversion of WBC. WBC in ft/sec IWUNIT > 0 Solid body rotation. WBC input in rev/min
EMISSW	F	76-80	1.		Emissivity of this boundary.

Notes:

1. The boundary condition types can also be input as right adjusted integers; 1 = SYM, 2 = UWL, 3 = SWL, 4 = UOP, 5 = SOP, 6 = PER. Also note that periodic and symmetry conditions can only be applied to the outer most boundaries and must be specified for every block bounding the symmetric or periodic plane.

2. A value of -10,000. for temperature indicates to the program that the wall is adiabatic.

3. The coefficient is the constant of proportionality in the equation: $K = TEBC * U^2$ where $TEBC = 3/2 * (\text{turbulence intensity})^2$

4. The units depend on the swirl indicator IWUNIT.

Card Type: 5B

Title: Boundary Condition Description Card

General Description:

There is one card 5A followed by one card 5B for each boundary condition. There are NBC card pairs to be input.

Name	Type	Columns	Default	Units	Description
FBC(1)	F	1-10			Mass fraction of species 1. Note 1.
FBC(2)	F	11-20			Mass fraction of species 2. Note 1
FBC(3)	F	21-30			Mass fraction of species 3. Note 1
FBC(4)	F	31-40			Mass fraction of species 4. Note 1.
EDBC	F	71-80		ft^2/sec^3	Energy disipation at this boundary. Note 2.

Notes:

1. A value of -10,000. for any mass fraction indicates to the program that there is no diffusion of the species across the boundary.

2. The energy dissipation at all specified openings 'SOP' must be specified. In the absence of a better value, the following formula can be used EDBC = 3.0 * (TEBC) ** 1.5 U^3 /L where TEBC was specified on card type 5A and L is the height of the passage.

Card Type: 6

Title: Case Indicators

General Description:

Name	Type	Columns	Default	Units	Description
INDCOS	I	1-5	2		Problem type indicator INDCOS = 1 : Cartesian coordinates INDCOS = 2 : Cylindrical coordinates
IPREF	I	6-10	1		Number of cells in the X-direction of the reference cell used for initial temperature and pressure guess.
JPREF	I	11-15	1		Number of cells in the Y-direction of the reference cell used for initial temperature and pressure guess.
KPREF	I	16-20	1		Number of cells in the Z-direction of the reference cell used for initial temperature and pressure guess.
IMON	I	21-25	2		Number of cells in the X-direction of cell to be monitored in the output file.
JMON	I	26-30	2		Number of cells in the Y-direction of cell to be monitored in the output file.
KMON	I	31-35	2		Number of cells in the Z-direction of cell to be monitored in the output file.
DAMPW	F	41-50	100.	Note 1	Swirl damping factor.
DAMPR	F	51-60	100.	Note 1	Radiation damping factor.
TBMN	F	61-70	1.	°R	Minimum temperature limit for temperature prediction.
TBMX	F	71-80	1.E6	°R	Maximum temperature limit for temperature prediction.

Note

1. These damping factors have been optimized to give optimum performance over a wide range of flow conditions and should be adjusted if a number of parametric studies are to be conducted.

Card Type: 7

Title: Case Indicators

General Description:

Name	Type	Columns	Default	Units	Description
INLAM	I	1-5	0		Laminar flow indicator INLAM = 0 : laminar flow INLAM = 1 : turbulent flow
IDENS	I	6-10	0		Density calculation indicator IDENS < 0 : Density calculations proceed every iteration starting with the -IDENSth iteration IDENS = 0 : Constant density case IDENS > 0 : Density calculations performed every IDENSth iteration
INPRO	L	11-15	F Note 1		Fluid Property calculation switch INPRO = F : properties calculated every iteration INPRO = T : VISCOS (card 8) used for viscosity DENSIT (card 8) used for density
INDPRI	I	16-20	1000		All variable fields printed every INDPRI iteration.
IUNIT	I	21-25	1		Input and output units indicator IUNIT = 1 : SI units IUNIT = 2 : English units (lengths in feet) IUNIT = 3 : English units (lengths in inches)
MAXIT	I	26-30	200		Maximum number of iterations allowed to converge before stopping.
SORMAX	F	31-40	.005		The maximum non dimensionalized value each residual source may have, to consider the case converged.
ITEMP	I	41-45	0		Temperature calculation indicator ITEMP < 0 : Temperature calculations proceed every iteration starting with the -ITEMPth iteration ITEMP = 0 : Constant temperature case ITEMP > 0 : Temperature calculations performed every ITEMPth iteration

Notes:

1. Fluid properties include eddy viscosity which has to be calculated every iteration if turbulent flow is being calculated. Hence enter (INPRO=F) if INLAM>0. Also for variable density flows enter (INPRO=F). As a rule, if in doubt set (INPRO=F).

Card Type: 7 (continued)

Name	Type	Columns	Default	Units	Description
KMBUST	I	46-50			Combustion model indicator KMBUST = 0 : No combustion KMBUST = 1 : Eddy breakup model
IRAD	I	51-55	-50		Radiation calculation indicator IRAD < 0 : Radiation calculations proceed every iteration starting with the -IRADth iteration IRAD > 0 : Radiation calculations performed every IRADth iteration
EGAS	F	61-70			Emmisivity of the gas. Overrides the emmisivity calculated by the program.
DH	F	71-80			Hydraulic diameter used for radiation calculation.

Card Type: 7C

Title: Rotation in Component Vector Form

General Description:

This card describes the rotation of the control volume about the origin of the axes by giving the component vectors along the principal axes of the coordinate system. It is input when IROT=1 (Card Type 2).

Name	Type	Columns	Default	Units	Description
OMEGAX	F	1-10		Rad/sec	Component of the rotation vector along the X-axis.
OMEGAY	F	11-20		Rad/sec	Component of the rotation vector along the Y-axis.
OMEGAZ	F	21-30		Rad/sec	Component of the rotation vector along the Z-axis.

Card Type: 7D

Title: Rotation in Magnitude and Direction

General Description:

This card describes the rotation of the control volume about the origin of the axes by giving the magnitude direction of the rotation vector relative to the principal axes. It is input only when IROT=2.

Name	Type	Columns	Default	Units	Description
OMGROT	F	1-10		Rad/sec	Magnitude of the rotation of the control volume about the origin.
THTROT	F	11-20		Radians	The angle between a projection of the roation vector on the XY-plane and the X-axis.
PHIROT	F	21-30		Radians	The angle between the rotation vector and the Z-axis.

Card Type: 8

Title: Fluid Properties

General Description:

Name	Type	Columns	Default	Units	Description
ALAMDA	F	1-10	.005		Length scale factor used to normalize energy dissipation residuals.
VISCOS	F	11-20		lbm/ ft-sec	Fluid viscosity.
DENSIT	F	21-30		lbm/ft^3	Density for constant density cases.
FW	F	31-40	29.		Molecular weight of fluid for non-mixing cases.
PRANDL	F	41-50	.7		Prandtl number for laminar flow cases.
C3	F	51-60	Note 1	Constan	of the turbulence model.
DECLIN	F	61-70	0.0	Deg	Angle of declination measured from the vertical. Used only when INBUOY = T (card 9).
CPDUM	F	71-80	.25	Btu/ (lbm°F)	Constant pressure specific heat of fluid. Note 2.

Notes:

1. Defaults to the value of C1 on card type 12.

2. Any negative value indicates to the program the enthalpy cards are to be read in.

Card Type: 9

Title: Calculation Switches

General Description:

All switches turn calculation on if T is input, and off if F is input.

Name	Type	Columns	Default	Units	Description
INCALU	L	1-5	F		U-velocity calculation switch.
INCALV	L	6-10	F		V-velocity calculation switch.
INCALW	L	11-15	F		W-velocity calculation switch.
INCALP	L	16-20	F	Note 1	Pressure calculation switch.
INCALK	L	21-25	F	Note 2	Turbulence kinetic energy calculation switch.
INCALD	L	26-30	F	Note 2	Energy dissipation calculation switch.
INCALT	L	31-35	F		Temperature calculation switch.
INCALF	L	36-40	F		Mixing calculation switch.
INVD	L	41-45	F		Divergence of velocity calculation switch.
INBUOY	L	46-50	F		Buoyancy calculation switch.
INRAD	L	51-55	F		Radiation calculation switch.
ISKEW	I	56-60	F	Note 3	Difference scheme selector: 0-hydrid, 1-SUDS, 2-BSUDS2.
DBSKEW	I	61-65			DBSKEW>0 bounding variables printed.

Notes:

1. This switch in addition to calculating pressure, solves the continuity equation as well and must be turned on even if constant pressure or constant density calculations are being made. As a rule, if in doubt turn this switch on.

2. Turbulence energy and dissipation must be calculated if turbulent flow is being computed. Hence these two switches must be turned on if INLAM>0 on card type 7.

3. BSUDS2 and SUDS are differencing schemes that are more accurate than hybrid but these can become unstable for some flows. If instability occurs, starting with a converged hybrid solution helps sometimes. But in some cases, it may not be possible to obtain a converged solution with BSUDS2 or SUDS.

Card Type: 10

Title: Under-relaxation Factors

General Description:

Unless there is a very unusual circumstance these variables should be allowed to assume their default values.

Name	Type	Columns	Default	Units	Description
URFU	F	1-5	.5	Note 1	U-velocity calculation under-relaxation factor.
URFV	F	6-10	.5	Note 1	V-velocity calculation under-relaxation factor.
URFW	F	11-15	.5	Note 1	W-velocity calculation under-relaxation factor.
URFP	F	6-20	1.0	Note 2	Pressure calculation under-relaxation factor.
URFK	F	21-25	.7		Kinetic energy calculation under-relaxation factor.
URFE	F	26-30	.7		Energy dissipation calculation under-relaxation factor.
URFT	F	31-35	1.0		Temperature calculation under-relaxation factor.
URFVIS	F	36-40	.7		Viscosity calculation under-relaxation factor.
URFDEN	F	41-45	.3	Note 3	Density calculation under-relaxation factor.
URFF	F	46-50	.7		Mixing calculation under-relaxation factor.
URFDIV	F	51-55	.8		Divergence calculation under-relaxation factor.
URFR	F	56-60	1.0		Radiation calculation under-relaxation factor.

Notes:

1. It is not advisable to increase these under-relaxation factors beyond the default value. Reducing these to 0.3 usually helps to converge cases which are unstable during the iteration process.
2. The default value should be reduced to achieve convergence. However, a large penalty in convergence rate is incurred if this value is reduced by a large amount, below 0.8 for example.
3. For combustion cases and where large density gradients exist, this value may be reduced to 0.1.

Card Type: 11

Title: Number of Sweeps

General Description:

Number of times each field variable is swept by the tridiagonal matrix solver. Unless there is a very unusual circumstance these variables should be allowed to assume their default values.

Name	Type	Columns	Default	Units	Description
NSWPU	I	1-5	3		Number of U-velocity calculation sweeps.
NSWPV	I	6-10	3		Number of V-velocity calculation sweeps.
NSWPW	I	11-15	3		Number of W-velocity calculation sweeps.
NSWPP	I	16-20	5		Number of Pressure calculation sweeps.
NSWPK	I	21-25	3		Number of Kinetic energy calculation sweeps.
NSWPD	I	26-30	3		Number of Energy dissipation calculation sweeps.
NSWPT	I	31-35	3		Number of Temperature calculation sweeps.
NSWPF	I	46-50	3		Number of Mixing calculation sweeps.
NSWPR	I	56-60	10		Number of Radiation calculation sweeps.

Card Type: 12

Title: Turbulent Air Properties

General Description:

Unless there is a very unusual circumstance these variables should be allowed to assume their default values.

Name	Type	Columns	Default	Units	Description
CMU	F	1-10	.09		Constants of the turbulence model.
CD	F	11-20	1.0		
C1	F	21-30	1.44		
C2	F	31-40	1.92		
CAPPA	F	41-50	.4187		
ELOG	F	51-60	9.793		
PRTE	F	61-70	1.		
PRANDT	F	71-80	.5		

Card Type: 13A

Title: Specie Names

General Description:

Name	Type	Columns	Default	Units	Description
SPENAM(1)	A	3-10	'H2'		Name associated with specie 1.
SPENAM(2)	A	13-20	'02'		Name associated with specie 2.
SPENAM(3)	A	23-30	'C02'		Name associated with specie 3.
SPENAM(4)	A	33-40	'H20'		Name associated with specie 4.

Card Type: 13B

Title: Specie Switches

General Description:

Specie "L" will be included in the mixture calculation if ICOMP(L) is T. It will be excluded if ICOMP(L) = F.

Name	Type	Columns	Default	Units	Description
ICOMP(1)	L	1-10	F		Calculation switch for specie 1.
ICOMP(2)	L	11-20	F		Calculation switch for specie 2.
ICOMP(3)	L	21-30	F		Calculation switch for specie 3.
ICOMP(4)	L	31-40	F		Calculation switch for specie 4.
MIXTYP	I	71-75	1		Mixture calculation type indicator
					MIXTYP = 1 : Assumes no specie fluctuations. Note 1.

Note:

1. For the present, only one mixture calculation is available so 1 must be specified.

Card Type: 13C

Title: Specie Molecular Weights

General Description:

Specify the molecular weight for each specie selected on card type 13B.

Name	Type	Columns	Default	Units	Description
XMOLWT(1)	F	1-10	2.016		Molecular weight of specie 1.
XMOLWT(2)	F	11-20	32.		Molecular weight of specie 2.
XMOLWT(3)	F	21-30	44.01		Molecular weight of specie 3.
XMOLWT(4)	F	31-40	18.016		Molecular weight of specie 4.

Card Type: 13D

Title: Specie Laminar Flow Prandtl Number

General Description:

Specify the laminar flow Prandtl number for each specie selected on card 13B.

Name	Type	Columns	Default	Units	Description
PRANML(1)	F	1-10	1.		Laminar flow Prandtl number of specie 1.
PRANML(2)	F	11-20	1.		Laminar flow Prandtl number of specie 2.
PRANML(3)	F	21-30	1.		Laminar flow Prandtl number of specie 3.
PRANML(4)	F	31-40	1.		Laminar flow Prandtl number of specie 4.

Card Type: 13E

Title: Specie Turbulent Flow Prandtl Number

General Description:

Specify the turbulent flow Prandtl number for each specie selected on card 13B.

Name	Type	Columns	Default	Units	Description
PRANMT(1)	F	1-10	0.5		Turbulent flow Prandtl number of specie 1. Note 1.
PRANMT(2)	F	11-20	0.5		Turbulent flow Prandtl number of specie 2.
PRANMT(3)	F	21-30	0.5		Turbulent flow Prandtl number of specie 3.
PRANMT(4)	F	31-40	0.5		Turbulent flow Prandtl number of specie 4.

Note:

1. Turbulent Prandtl numbers for all species should be equal to these values and should also be equal to PRANDT on card type 12.

Card Type: 14

Title: Combustion

General Description:

This card is input only if MIXTYP > 0 (card 13B).

Name	Type	Columns	Default	Units	Description
IFUEL	I	1-5	1		The number of the fuel species.
IOX	I	6-10	2		The number of oxidant species.
IPROD1	I	11-15	3		The number of the first product species.
IPROD2	I	16-20	4		The number of the species to be the second product.
STOIC	F	31-40	7.937		Stoichiometric oxidant/fuel ratio. The default value is for hydrogen and oxygen.
FPROD1	F	41-50	1.		Fraction of first product in total products.
A1MAG	F	51-60	4.		Combustion model constant.
A2MAG	F	61-70	2.		Combustion model constant.

Card Type: 15

Title: Mixture Fraction

General Description:

This card is input only if MIXTYP > 1 (card 13B). This card is used at present to define the value of the mixture fraction at the boundary.

Name	Type	Columns	Default	Units	Description
IFUELS	I	1-5			Cell number x-direction for the fuel stream.
JFUELS	I	6-10			Cell number y-direction for the fuel stream.
KFUELS	I	11-15			Cell number z-direction for the fuel stream.
IOXS	I	16-20			Cell number x-direction for the oxidant stream.
JOXS	F	21-25			Cell number y-direction for the oxidant stream.
KOXS	F	26-30			Cell number z-direction for the oxidant stream.
PRFML	F	31-40			Laminar Prandtl number.
PRFMT	F	41-50			Turbulent Prandtl number.
PRFLUC	F	51-60			Prandtl number for fluctuation.
CG1	F	61-70			Constant for mixture fraction fluctuation equation.
CG2	F	71-80			Constant for mixture fraction fluctuation equation.

3.3.2 Enthalpy Card Input

The following is a description of the enthalpy card file. This file is used to set up a table of enthalpies vs. temperatures for each species involved in the case. These cards are required only if temperatures are being calculated and if CPDUM (card type 8) is negative. The mixing calculation switch, INCALF (card type 9) must be turned on.

Card Type: H1

Title: Enthalpy Input - Species Names

General Description:

Name	Type	Columns	Default	Units	Description
IUNTAB	I	1-5	1		Input units indicator for enthalpies IUNTAB = 1 : SI units IUNTAB = 2 : English units
HNAMES(1)	A	11-18			Name of specie 1 for which enthalpy is being supplied.
HNAMES(2)	A	21-28			Name of specie 2 for which enthalpy is being supplied.
HNAMES(3)	A	31-38			Name of specie 3 for which enthalpy is being supplied.
HNAMES(4)	A	41-48			Name of specie 4 for which enthalpy is being supplied.

Card Type: H2

Title: Enthalpy Input - Temperature and Enthalpies

General Description:

This card must be repeated as many times (up to 20) as are required to adequately describe the enthalpies of each specie as a function of temperature over the range of temperatures calculated for the case.

Name	Type	Columns	Default	Units	Description
TTABLE	F	1-10		°R	Temperature for which enthalpies are being input.
HTABLE(1)	F	11-20		BTU/(lb-mole)	Enthalpy for species 1.
HTABLE(2)	F	21-30		BTU/(lb-mole)	Enthalpy for species 2.
HTABLE(3)	F	31-40		BTU/(lb-mole)	Enthalpy for species 3.
HTABLE(4)	F	41-50		BTU/(lb-mole)	Enthalpy for species 4.

3.4 A Sample Input

A step-by-step procedure for geometry input is presented. For this purpose, a simple geometry is chosen (Figure 11).

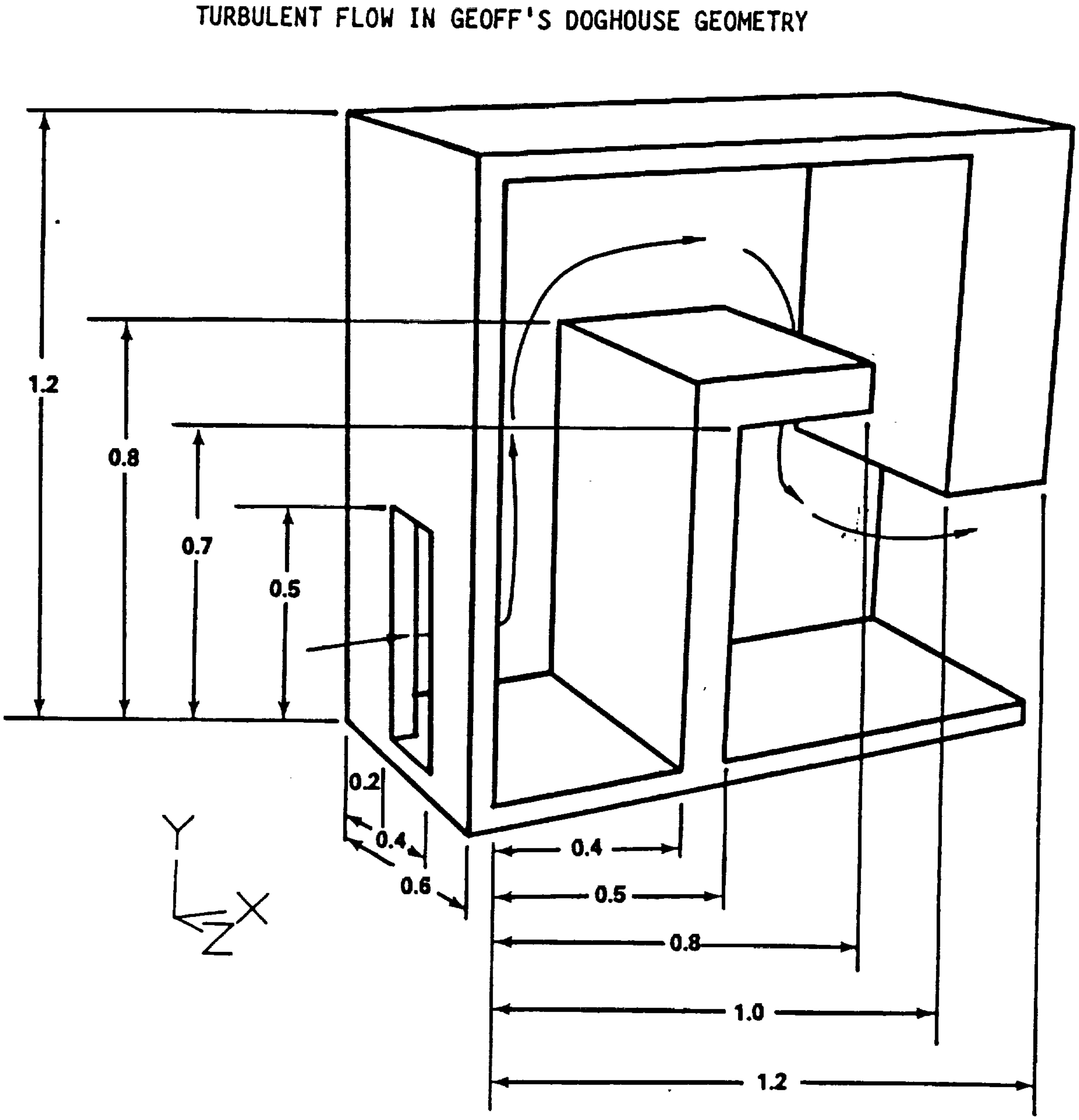


FIGURE 11

Cut Away Of Sample Geometry

It should be noted that TEACH models the fluid volume contained by the geometry shown in the previous figure. If the fluid volume is modeled with a coarse breakup, Figure 12 will result. It is clear from the modeling of this simple geometry that a preprocessor is required to provide input to 3D-TEACH. In the absence of such a processor, a number of hand drawings and a lot of imagination will be needed to model even simple geometries in TEACH. From Figure 12 it is clear that five blocks are needed in the X-direction, four blocks are required in the y direction and three block are necessary in the Z-direction.

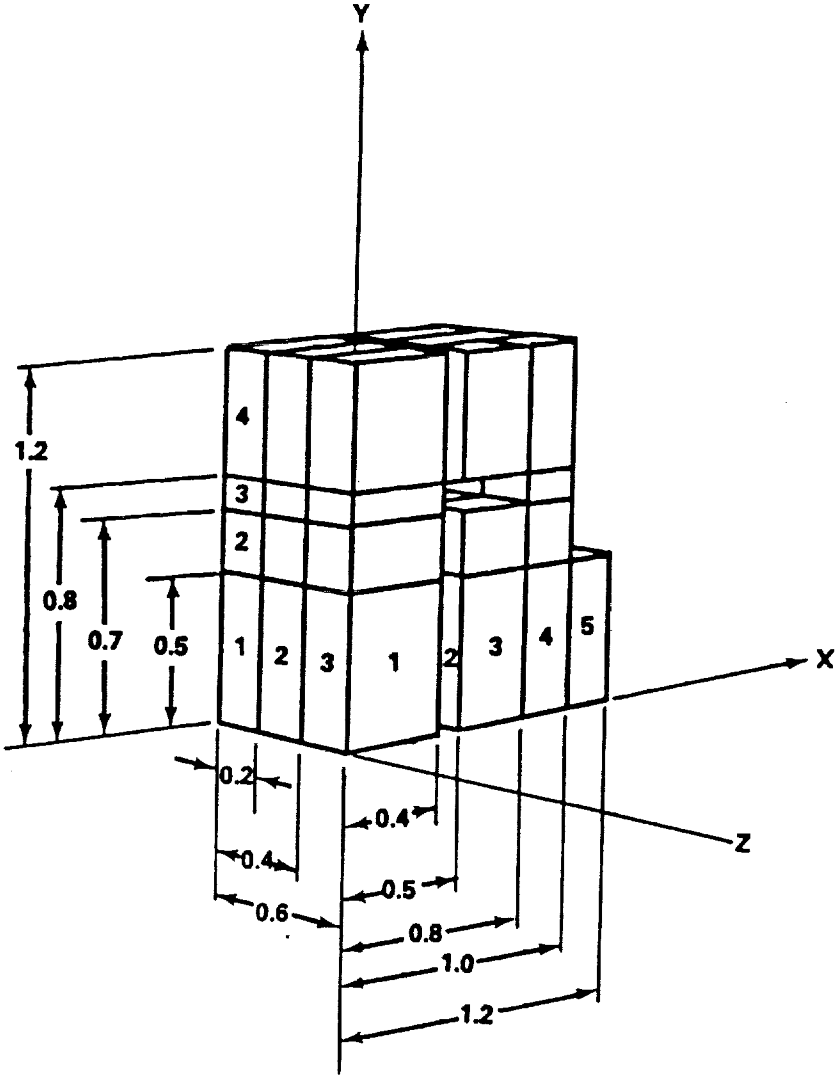


FIGURE 12

Block Breakup of Sample Geometry

Once the geometry shown in Figure 12 is visualized using the preprocessor or otherwise, the process of filling cards begins.

Card No 1 is simple, we write TURBULENT FLOW IN GEOFFS DOGHOUSE.

Card No 2 can only be filled in after cards up to 5 have been filled.

Card 3A describes the cell break up. From Figure 12 we know the number of blocks in the X-direction, which gives us the number of cards of type 3A. Knowing the X-cordinate at which each of these blocks ends, also from Figure 12, XEND for all cards can be filled in. Now, the number of cells in each fluid block and the expansion factor associated with them have to be provided. This is done by trail and error to give a smooth over-all break-up. For the present geometry, a uniform break-up is provided.

	XEND	NX	EPSX
(3A)	.4	4	1.0
(3A)	.5	1	1.0
(3A)	.8	3	1.0
(3A)	1.0	2	1.0
(3A)	1.2	2	1.0

Cards 3B and 3C can be filled similarly.

	YEND	NY	EPSY
(3B)	.5	5	1.0
(3B)	.7	2	1.0
(3B)	.8	3	1.0
(3B)	1.2	4	1.0

	ZEND	NZ	EPSZ
(3C)	.2	2	1.0
(3C)	.4	2	1.0
(3C)	.6	2	1.0

Card type 4 should be filled in next; however, inspection of card type 4 description, shows that it requires the integer names of the boundary condition cards which are provided in card type 5. Hence card type 5 will be filled in first.

Figure 11 shows that there are only three different boundary conditions for this case, namely specified opening, wall, and unspecified openings. So three boundary condition card pairs (cards 5A and 5B, listed alternately) will be needed. The integer names (LBC) given to each card pair is arbitrary:

	LBC	IBC	UBC	VBC	WBC	PSBC	TBC	TEBC
(5A)	5	SOP	93.	0.	0.	15.	70.	.01
*(5A)	4	UOP	0.	0.	0.	0.	0.	0.
(5A)	3	SWL	0.	0.	0.	0.	0.	0.

	FBC(1)	FBC(2)	FBC(3)	FBC(4)	EDBC
(5B)	0	0	0	0	24131.0.
(5B)	0	0	0	0	0
(5B)	0	0	0	0	0

*Note: An unspecified opening can not be used in conjunction with an adjoining blockage.

For card 4, the number of fluid blocks that need to have boundary conditions applied has to be determined. This number can only be determined by filling in the card type 4 cards until the complete geometry is defined and then counting the number of cards filled. Filling these cards without the help of a pre-processor requires the geometry being modeled to be visualized in ones mind. Making several 2D sketches at different planes helps, but some trial and error is involved. In the absence of a pre-processor two tools are provided in the code. 1) The code checks these cards for consistent boundary conditions and flags the cards that are not consistent. This feature of the code is extremely useful in ensuring that the proper geometry is being specified. 2) Once the inconsistencies are corrected, the cell break up at different planes can be plotted to further check out the geometry. However these tools can only be used after the complete input file is set up. The recommendation at this point will be to fill these cards as best as one can, fill out other cards required for the INPUT, and proceed to run the case. Then using the two debugging tools described above, a complete and accurate specification of the desired geometry and mesh can be achieved.

Once the iteration process described above is completed, it is found that the total number of cards required to specify the geometry is 39. For clarity, all the fluid blocks are shown in an exploded view in Figure 13. In this figure, block numbers are in parentheses and boundary condition numbers are circled.

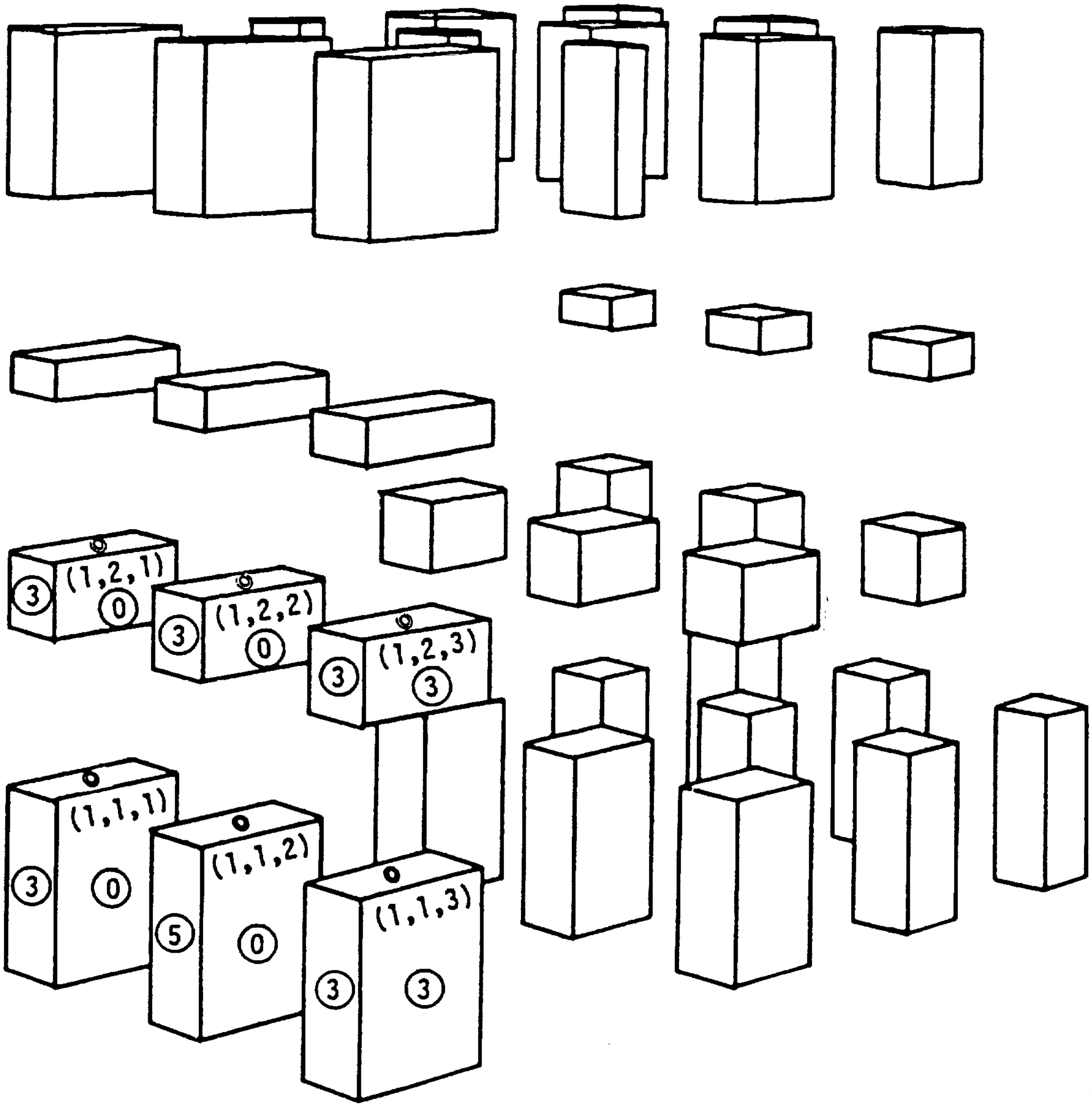


FIGURE 13

Block and Boundary Condition Numbering
(Numbers in parentheses refer to X-direction, Y-direction, and Z-direction respectively)

This is an exploded view of the fluid blocks shown in figure 12.

The "names" of the boundary condition description cards appear at all block boundaries. The boundary condition description cards for the six blocks annotated in Figure 13 are then completed:

X-index MFBI	Y-index MFBJ	Z-index MFBK	west MBCW	east MBCE	south MBCS	north MBCN	front MBCF	back MBCB
1	1	1	3	3	3	0	3	0
1	1	2	5	3	3	0	0	0
1	1	3	3	3	3	0	0	3
1	2	1	3	3	0	0	3	0
1	2	2	3	3	0	0	0	0
1	2	3	3	3	0	0	0	3

For example, block (1,1,2) has boundary description cards number 5 describing its west boundary and 3 describing its east and south boundaries. A 0 on its north, front, and back boundaries indicates a boundary common with another fluid block. This process is repeated until all 39 cards are filled in.

This input is further explained in Figure 14 which illustrates the completed geometry input showing how boundary condition number 3 is applied to the west face of cell (1,1,1) from the breakup of Figure 12.

Card Type 2 can now be filled.

NXBLK	NYBLK	NZBLK	NFBLK	NBC	IPAPER	XBEGIN	YBEGIN	ZBEGIN
5	4	3	39	3				

The paper code for Calcomp plots can be left blank to assume default value. The coordinates of lower south-west-front corner of the geometry can also be omitted, therby assuming default values; XBEGIN=0.0, YBEGIN=0.0, and ZBEGIN=0.0.

Card Type 6: On this card, certain indicators and damping factors can be specified, but for the present problem, only the first four are needed. Since the geometry is cartesian, INDCOS=1. It should be noted that IPREF, JPREF and KPREF should define the <u>cell,</u> not block, which is located in the specified inflow boundary. Hence Card 6 can be filled in as follows:

INCOS	IPREF	JPREF	KPREF	IMON	JMON	KMON	DAMPW	DAMPR	TBMN	TBMX
1	1	2	3							

Card Type 7: This card allows one to run either a laminar or turbulent flow case and provides the ability to use SI or English units. Maximum number of iterations, and the convergence level can also be specified. We would be running a turbulent case using English units for 200 iteration and the convergence level is 0.005. Hence card type 7 can be filled as follows.

INLAM	IDENS	INPRO	INDPRI	IUNIT	MAXIT	SORMAX	ITEMP
F		F		2	200	0.005	

```
SSDOG   TURBULENT FLOW IN GEOFS DOGHOUSE
    5     4     3   39     5    10   0.0         0.0         0.0         0
   0.4000     4 1.00
   0.5000     1 1.00
   0.8000     3 1.00
   1.0000     2 1.00
   1.2000     2 1.00
   0.5000     5 1.00
   0.7000     2 1.00
   0.8000     1 1.00
   1.2000     4 1.00
   0.2000     2 1.00
   0.4000     2 1.00
   0.6000     2 1.00
    1     1     1     3     3     3     0     3     0
    1     2     1     3     3     0     0     3     0
    1     3     1     3     3     0     0     3     0
    1     4     1     3     0     0     3     3     0
    2     4     1     0     0     3     3     3     0
    3     4     1     0     0     3     3     3     0
    4     4     1     0     3     0     3     3     0
    4     3     1     3     3     0     0     3     0
    4     2     1     0     3     0     0     3     0
    3     2     1     3     0     0     3     3     0
    3     1     1     3     0     3     0     3     0
    4     1     1     0     0     3     0     3     0
    5     1     1     0     4     3     3     3     0
    1     1     2     5     3     3     0     0     0
    1     2     2     3     3     0     0     0     0
    1     3     2     3     3     0     0     0     0
    1     4     2     3     0     0     3     0     0
    2     4     2     0     0     3     3     0     0
    3     4     2     0     0     3     3     0     0
    4     4     2     0     3     0     3     0     0
    4     3     2     3     3     0     0     0     0
    4     2     2     0     3     0     0     0     0
    3     2     2     3     0     0     3     0     0
    3     1     2     3     0     3     0     0     0
    4     1     2     0     0     3     0     0     0
    5     1     2     0     4     3     3     0     0
    1     1     3     3     3     3     0     0     3
    1     2     3     3     3     0     0     0     3
    1     3     3     3     3     0     0     0     3
    1     4     3     3     0     0     3     0     3
    2     4     3     0     0     3     3     0     3
    3     4     3     0     0     3     3     0     3
    4     4     3     0     3     0     3     0     3
    4     3     3     3     3     0     0     0     3
    4     2     3     0     3     0     0     0     3
    3     2     3     3     0     0     3     0     3
    3     1     3     3     0     3     0     0     3
    4     1     3     0     0     3     0     0     3
    5     1     3     0     4     3     3     0     3
    1   SYM        0.0         0.0         0.0         0.0         0.0         0.0       0 0.0
      0.0          0.0         0.0         0.0                                            0.
    3   SWL        0.0         0.0         0.0         0.0         0.0         0.0       0 1.00
      0.0          0.0         0.0         0.0                                            0.
    4   UOP        0.0         0.0         0.0         0.0       70.00         0.0       0 1.00
      0.0          0.0         0.0         0.0                                            0.
    6   PER        0.0         0.0         0.0         0.0         0.0         0.0       0 1.00
      0.0          0.0         0.0         0.0                                            0.
    5   SOP       93.00        0.0         0.0       15.00       70.00         0.01      0 1.00
      0.0          0.0         0.0         0.0                                       24131.
```

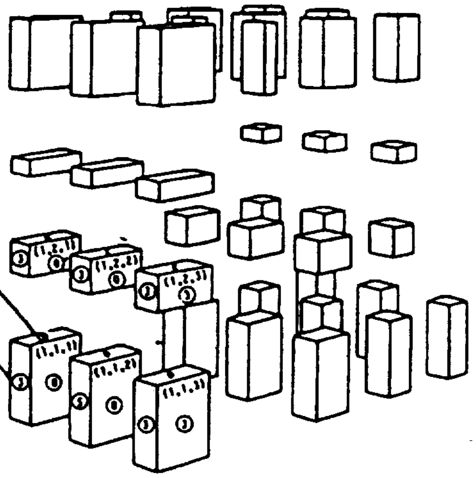


Figure 14

INDPRI, which specifies the number of iterations after which variable fields have to be printed, can be left to its default value. IDENS and ITEMP are not required for the present problem.

Card Type 8: On this card, fluid properties are specified. For the present case, viscosity, density, molecular weight, and Prandtl number need to be specified. Other variables assume default values.

ALAMDA	VISCOS	DENSIT	FW	PRANDL	C3	DECLN	CPDUM
	1.11E-5	0.0805	29	0.7			

Card Type 9: This card is used to specify the variable fields that need to be calculated. Since we are solving a case with turbulent flow, turbulence kinetic energy and its dissipation rate have to be calculated in addition to the three momentum equations and the continuity equation. All other variables can be left to assume default values.

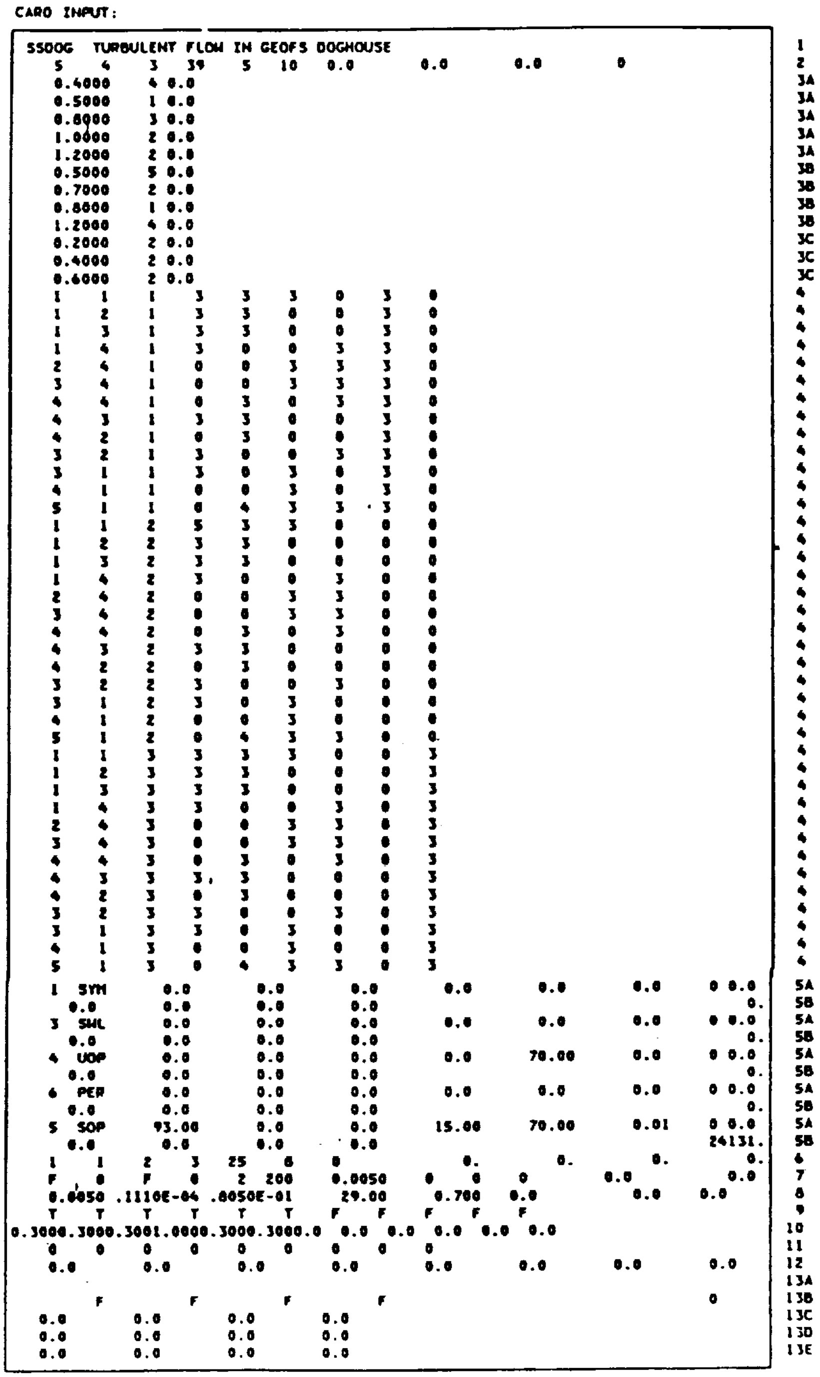
INCALU	INCALV	INCALW	INCALP	INCALK	INCALD
T	T	T	T	T	T

Card Type 10: This card specifies the under-relaxation factors. It was found by trail and error that the following under-relaxation factors worked best for the present configuration.

URFU	URFV	URFW	URFP	URFK	URFE
0.3	0.3	0.3	1.0	0.5	0.5

This completes the number of INPUT cards that have to be filled. All the remaining cards can be left to assume default values and can be left blank.

Figure 15 shows the complete INPUT file.



```
CARO INPUT:
 55OOG   TURBULENT FLOW IN GEOFS DOGHOUSE                                         1
    5     4     3   39     5    10   0.0         0.0         0.0         0        2
     0.4000      4 0.0                                                            3A
     0.5000      1 0.0                                                            3A
     0.8000      3 0.0                                                            3A
     1.0000      2 0.0                                                            3A
     1.2000      2 0.0                                                            3A
     0.5000      5 0.0                                                            3B
     0.7000      2 0.0                                                            3B
     0.8000      1 0.0                                                            3B
     1.2000      4 0.0                                                            3B
     0.2000      2 0.0                                                            3C
     0.4000      2 0.0                                                            3C
     0.6000      2 0.0                                                            3C
    1     1     1     3     3     3     0     3     0                             4
    1     2     1     3     3     0     0     3     0                             4
    1     3     1     3     3     0     0     3     0                             4
    1     4     1     3     0     0     3     3     0                             4
    2     4     1     0     0     3     3     3     0                             4
    3     4     1     0     0     3     3     3     0                             4
    4     4     1     0     3     0     3     3     0                             4
    4     3     1     3     3     0     0     3     0                             4
    4     2     1     0     3     0     0     3     0                             4
    3     2     1     3     0     0     3     3     0                             4
    3     1     1     3     0     3     0     3     0                             4
    4     1     1     0     0     3     0     3     0                             4
    5     1     1     0     4     3     3     3     0                             4
    1     1     2     5     3     3     0     0     0                             4
    1     2     2     3     3     0     0     0     0                             4
    1     3     2     3     3     0     0     0     0                             4
    1     4     2     3     0     0     3     0     0                             4
    2     4     2     0     0     3     3     0     0                             4
    3     4     2     0     0     3     3     0     0                             4
    4     4     2     0     3     0     3     0     0                             4
    4     3     2     3     3     0     0     0     0                             4
    4     2     2     0     3     0     0     0     0                             4
    3     2     2     3     0     0     3     0     0                             4
    3     1     2     3     0     3     0     0     0                             4
    4     1     2     0     0     3     0     0     0                             4
    5     1     2     0     4     3     3     0     0                             4
    1     1     3     3     3     3     0     0     3                             4
    1     2     3     3     3     0     0     0     3                             4
    1     3     3     3     3     0     0     0     3                             4
    1     4     3     3     0     0     3     0     3                             4
    2     4     3     0     0     3     3     0     3                             4
    3     4     3     0     0     3     3     0     3                             4
    4     4     3     0     3     0     3     0     3                             4
    4     3     3     3     3     0     0     0     3                             4
    4     2     3     0     3     0     0     0     3                             4
    3     2     3     3     0     0     3     0     3                             4
    3     1     3     3     0     3     0     0     3                             4
    4     1     3     0     0     3     0     0     3                             4
    5     1     3     0     4     3     3     0     3                             4
    1  SYM       0.0         0.0         0.0        0.0        0.0        0.0      0 0.0   5A
      0.0        0.0         0.0         0.0                                          0.   5B
    3  SWL       0.0         0.0         0.0        0.0        0.0        0.0      0 0.0   5A
      0.0        0.0         0.0         0.0                                          0.   5B
    4  UOP       0.0         0.0         0.0        0.0      70.00        0.0      0 0.0   5A
      0.0        0.0         0.0         0.0                                          0.   5B
    6  PER       0.0         0.0         0.0        0.0        0.0        0.0      0 0.0   5A
      0.0        0.0         0.0         0.0                                          0.   5B
    5  SOP     93.00         0.0         0.0      15.00      70.00       0.01      0 0.0   5A
      0.0        0.0         0.0         0.0                                      24131.   5B
    1     1     2     3    25     6     0           0.         0.         0.        0.   6
    F     0     F     0     2   200   0.0050    0     0     0        0.0          0.0    7
    0.0050 .1110E-04 .6050E-01     29.00     0.700   0.0         0.0       0.0          8
    T     T     T     T     T     T     F     F     F     F     F                        9
0.3000.3000.3001.0000.3000.3000.0  0.0  0.0  0.0  0.0  0.0                             10
    0     0     0     0     0     0     0     0     0                                  11
    0.0        0.0        0.0        0.0        0.0        0.0        0.0        0.0   12
                                                                                       13A
         F          F          F          F                                 0          13B
   0.0        0.0        0.0        0.0                                                13C
   0.0        0.0        0.0        0.0                                                13D
   0.0        0.0        0.0        0.0                                                13E
```

Figure 15
Complete Input File

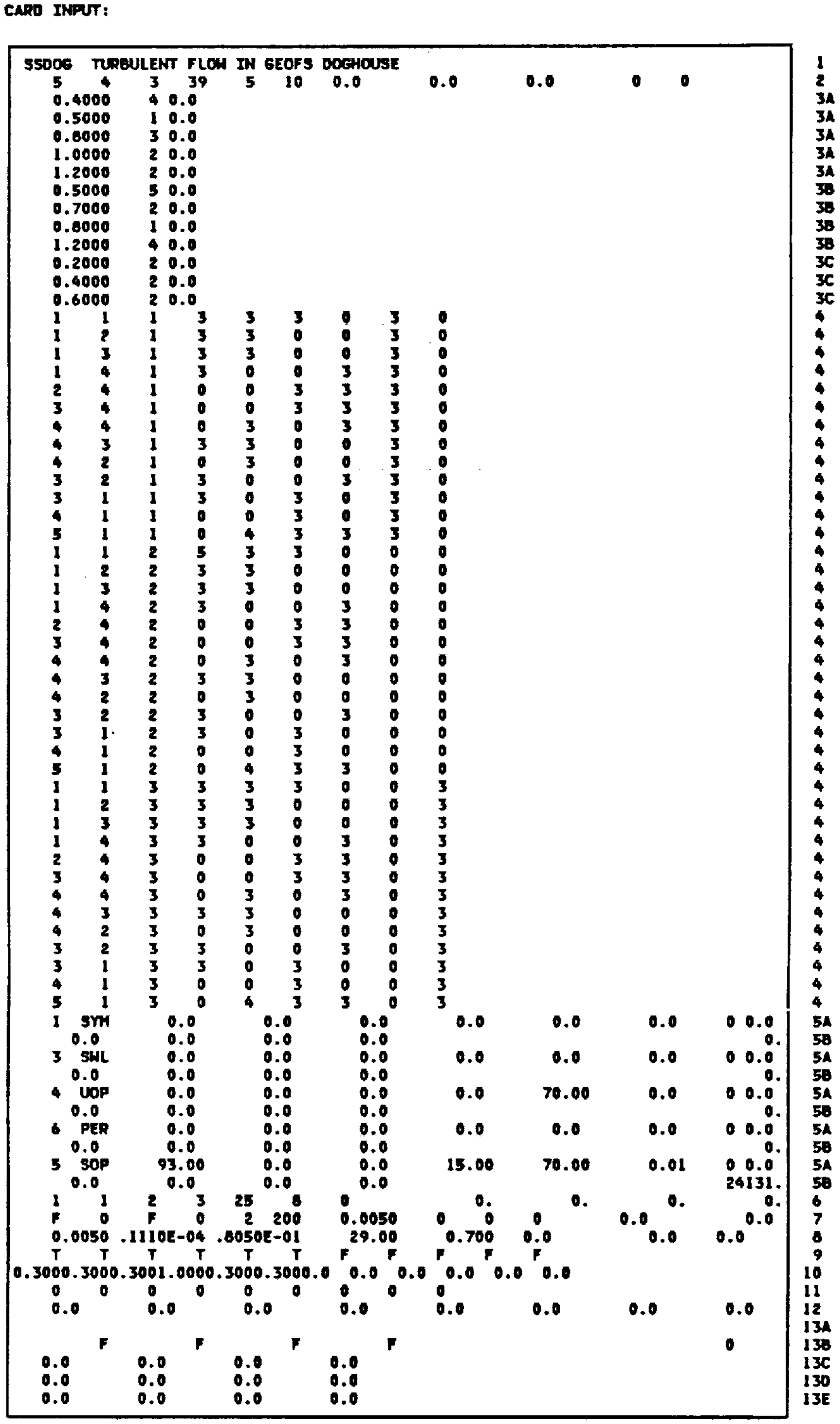
3.5 A Sample Output

This section provides and explains a sample output. This output is a result of a TEACH run from the input given in the proceeding section.

VERSION 1.0

(05/05/83)

The first page of the output is the input given in Figure 15 but since the write format used is not identical to the read format of the INPUT this figure is not identical to Figure 15.

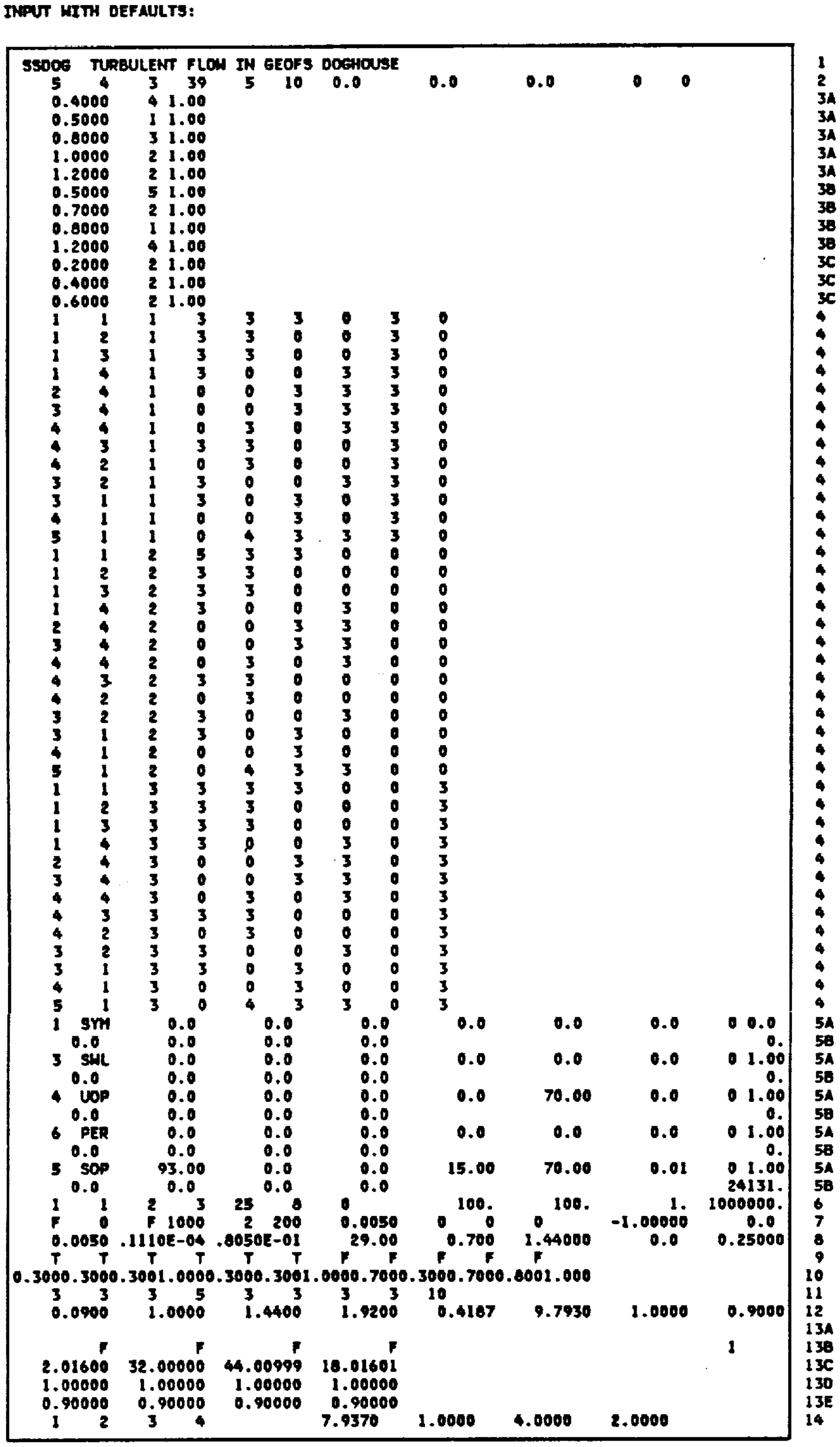


```
CARD INPUT:

 SSDOG  TURBULENT FLOW IN GEOFS DOGHOUSE                                      1
    5     4     3    39     5    10   0.0        0.0        0.0        0    0  2
    0.4000     4 0.0                                                          3A
    0.5000     1 0.0                                                          3A
    0.6000     3 0.0                                                          3A
    1.0000     2 0.0                                                          3A
    1.2000     2 0.0                                                          3A
    0.5000     5 0.0                                                          3B
    0.7000     2 0.0                                                          3B
    0.8000     1 0.0                                                          3B
    1.2000     4 0.0                                                          3B
    0.2000     2 0.0                                                          3C
    0.4000     2 0.0                                                          3C
    0.6000     2 0.0                                                          3C
    1    1    1    3    3    3    0    3    0                                 4
    1    2    1    3    3    0    0    3    0                                 4
    1    3    1    3    3    0    0    3    0                                 4
    1    4    1    3    0    0    3    3    0                                 4
    2    4    1    0    0    3    3    3    0                                 4
    3    4    1    0    0    3    3    3    0                                 4
    4    4    1    0    3    0    3    3    0                                 4
    4    3    1    3    3    0    0    3    0                                 4
    4    2    1    0    3    0    0    3    0                                 4
    3    2    1    3    0    0    3    3    0                                 4
    3    1    1    3    0    3    0    3    0                                 4
    4    1    1    0    0    3    0    3    0                                 4
    5    1    1    0    4    3    3    3    0                                 4
    1    1    2    5    3    3    0    0    0                                 4
    1    2    2    3    3    0    0    0    0                                 4
    1    3    2    3    3    0    0    0    0                                 4
    1    4    2    3    0    0    3    0    0                                 4
    2    4    2    0    0    3    3    0    0                                 4
    3    4    2    0    0    3    3    0    0                                 4
    4    4    2    0    3    0    3    0    0                                 4
    4    3    2    3    3    0    0    0    0                                 4
    4    2    2    0    3    0    0    0    0                                 4
    3    2    2    3    0    0    3    0    0                                 4
    3    1    2    3    0    3    0    0    0                                 4
    4    1    2    0    0    3    0    0    0                                 4
    5    1    2    0    4    3    3    0    0                                 4
    1    1    3    3    3    3    0    0    3                                 4
    1    2    3    3    3    0    0    0    3                                 4
    1    3    3    3    3    0    0    0    3                                 4
    1    4    3    3    0    0    3    0    3                                 4
    2    4    3    0    0    3    3    0    3                                 4
    3    4    3    0    0    3    3    0    3                                 4
    4    4    3    0    3    0    3    0    3                                 4
    4    3    3    3    3    0    0    0    3                                 4
    4    2    3    0    3    0    0    0    3                                 4
    3    2    3    3    0    0    3    0    3                                 4
    3    1    3    3    0    3    0    0    3                                 4
    4    1    3    0    0    3    0    0    3                                 4
    5    1    3    0    4    3    3    0    3                                 4
    1  SYM       0.0       0.0       0.0       0.0       0.0       0.0     0 0.0  5A
     0.0         0.0       0.0       0.0                                    0.  5B
    3  SWL       0.0       0.0       0.0       0.0       0.0       0.0     0 0.0  5A
     0.0         0.0       0.0       0.0                                    0.  5B
    4  UOP       0.0       0.0       0.0       0.0     70.00       0.0     0 0.0  5A
     0.0         0.0       0.0       0.0                                    0.  5B
    6  PER       0.0       0.0       0.0       0.0       0.0       0.0     0 0.0  5A
     0.0         0.0       0.0       0.0                                    0.  5B
    5  SOP     93.00       0.0       0.0     15.00     70.00      0.01     0 0.0  5A
     0.0         0.0       0.0       0.0                                24131.  5B
    1    1    2    3   25    8    0             0.        0.        0.      0.  6
    F    0    F    0    2  200   0.0050    0    0    0       0.0         0.0    7
    0.0050 .1110E-04 .8050E-01   29.00    0.700   0.0        0.0     0.0        8
    T    T    T    T    T    T    F    F    F    F    F                       9
0.3000.3000.3001.0000.3000.3000.0  0.0  0.0  0.0  0.0  0.0                   10
    0    0    0    0    0    0    0    0    0                                11
    0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0  12
                                                                             13A
         F         F         F         F                               0     13B
   0.0       0.0       0.0       0.0                                         13C
   0.0       0.0       0.0       0.0                                         13D
   0.0       0.0       0.0       0.0                                         13E
```

Figure 16
Input File

The second page of the file is the input file with the default set by the program, as given in Figure 17 below.



```
INPUT WITH DEFAULTS:

  SSDOG  TURBULENT FLOW IN GEOFS DOGHOUSE                                           1
    5    4    3   39    5   10  0.0       0.0       0.0         0    0              2
    0.4000    4 1.00                                                                3A
    0.5000    1 1.00                                                                3A
    0.8000    3 1.00                                                                3A
    1.0000    2 1.00                                                                3A
    1.2000    2 1.00                                                                3A
    0.5000    5 1.00                                                                3B
    0.7000    2 1.00                                                                3B
    0.8000    1 1.00                                                                3B
    1.2000    4 1.00                                                                3B
    0.2000    2 1.00                                                                3C
    0.4000    2 1.00                                                                3C
    0.6000    2 1.00                                                                3C
    1    1    1    3    3    3    0    3    0                                         4
    1    2    1    3    3    0    0    3    0                                         4
    1    3    1    3    3    0    0    3    0                                         4
    1    4    1    3    0    0    3    3    0                                         4
    2    4    1    0    0    3    3    3    0                                         4
    3    4    1    0    0    3    3    3    0                                         4
    4    4    1    0    3    0    3    3    0                                         4
    4    3    1    3    3    0    0    3    0                                         4
    4    2    1    0    3    0    0    3    0                                         4
    3    2    1    3    0    0    3    3    0                                         4
    3    1    1    3    0    3    0    3    0                                         4
    4    1    1    0    0    3    0    3    0                                         4
    5    1    1    0    4    3    3    3    0                                         4
    1    1    2    5    3    3    0    0    0                                         4
    1    2    2    3    3    0    0    0    0                                         4
    1    3    2    3    3    0    0    0    0                                         4
    1    4    2    3    0    0    3    0    0                                         4
    2    4    2    0    0    3    3    0    0                                         4
    3    4    2    0    0    3    3    0    0                                         4
    4    4    2    0    3    0    3    0    0                                         4
    4    3    2    3    3    0    0    0    0                                         4
    4    2    2    0    3    0    0    0    0                                         4
    3    2    2    3    0    0    3    0    0                                         4
    3    1    2    3    0    3    0    0    0                                         4
    4    1    2    0    0    3    0    0    0                                         4
    5    1    2    0    4    3    3    0    0                                         4
    1    1    3    3    3    3    0    0    3                                         4
    1    2    3    3    3    0    0    0    3                                         4
    1    3    3    3    3    0    0    0    3                                         4
    1    4    3    3    0    0    3    0    3                                         4
    2    4    3    0    0    3    3    0    3                                         4
    3    4    3    0    0    3    3    0    3                                         4
    4    4    3    0    3    0    3    0    3                                         4
    4    3    3    3    3    0    0    0    3                                         4
    4    2    3    0    3    0    0    0    3                                         4
    3    2    3    3    0    0    3    0    3                                         4
    3    1    3    3    0    3    0    0    3                                         4
    4    1    3    0    0    3    0    0    3                                         4
    5    1    3    0    4    3    3    0    3                                         4
    1  SYM       0.0       0.0       0.0       0.0       0.0       0.0     0 0.0     5A
      0.0       0.0       0.0       0.0                                      0.     5B
    3  SWL       0.0       0.0       0.0       0.0       0.0       0.0    0 1.00     5A
      0.0       0.0       0.0       0.0                                      0.     5B
    4  UOP       0.0       0.0       0.0       0.0     70.00       0.0    0 1.00     5A
      0.0       0.0       0.0       0.0                                      0.     5B
    6  PER       0.0       0.0       0.0       0.0       0.0       0.0    0 1.00     5A
      0.0       0.0       0.0       0.0                                      0.     5B
    5  SOP     93.00       0.0       0.0     15.00     70.00      0.01    0 1.00     5A
      0.0       0.0       0.0       0.0                                  24131.     5B
    1    1    2    3   25    8    0         100.      100.        1.  1000000.     6
    F    0    F 1000    2  200   0.0050   0    0    0      -1.00000       0.0     7
    0.0050 .1110E-04 .8050E-01     29.00     0.700   1.44000       0.0   0.25000     8
    T    T    T    T    T    T    F    F    F    F    F                             9
0.3000.3000.3001.0000.3000.3001.0000.7000.3000.7000.8001.000                        10
    3    3    3    5    3    3    3    3   10                                        11
    0.0900    1.0000    1.4400    1.9200    0.4187    9.7930    1.0000    0.9000     12
                                                                                    13A
         F         F         F         F                                  1         13B
   2.01600  32.00000  44.00999  18.01601                                            13C
   1.00000   1.00000   1.00000   1.00000                                            13D
   0.90000   0.90000   0.90000   0.90000                                            13E
    1    2    3    4             7.9370    1.0000    4.0000    2.0000               14
```

Figure 17
Input File (with default)

The next few pages of the output give information on the type of case being run. An example of this is given in Figure 18.

```
Turbulent.

Constant density.

Viscosity is being calculated every iteration.

All variable fields are being printed every 1000 iterations.

All input in English units (lengths in

All calculations will stop after  200 iterations or when all residual sources fall below .50000E-02.

No combustion.

Emmisivity of the gas =-1.0000    overides the emmisivity   calculation by the program.

Rectangular coordinates.

Calculations turned on:

   U-Velocity
   V-Velocity
   W-Velocity
   Pressure
   Kinetic Energy
   Energy Disipation

THOMAS" ALGORITHM IS USED TO SOLVE MATRIX EQUATIONS.

*ERROR: IPREF=  1, JPREF=  2, KPREF=  3, IS NOT A SPECIFIED FLUID CELL.


ERROR: IPREF=  1, JPREF=  2, KPREF=  4, WILL BE USED.

    At X = .0          from Y = .0          to Y = .5000       and from Z = .2000      to Z = .4000

    Mass flow in                     .74865      (LBM/SEC)
    Inlet fluid velocity             93.000      (FT/S)
    Inlet fluid temperature          70.000      (DEG F)
    Reynolds number                  .26978E+06
    Fluid density                    .80500E-01 (LB/FT**3)

 AT X =     0.0       FROM Y=    0.0      TO Y =     0.50000 AND FROM Z =     0.20000 TO Z =     0.40000
               THE SUM OF THE FLOWS FOR WEST      WALL    IS        0.74865

                Prandtl number                                 =     7.000E-01


    Total mass flow in               .74865      (LBM/SEC)
Cards have been read in

    At X = .0          from Y = .0          to Y = .5000       and from Z = .2000      to Z = .4000

    Mass flow in                     .74865      (LBM/SEC)
    Inlet fluid velocity             93.000      (FT/S)
    Inlet fluid temperature          70.000      (DEG F)
    Reynolds number                  .26978E+06
    Fluid density                    .80500E-01 (LB/FT**3)

 AT X =     0.0       FROM Y=    0.0      TO Y =     0.50000 AND FROM Z =     0.20000 TO Z =     0.40000
               THE SUM OF THE FLOWS FOR WEST      WALL    IS        0.74865

                Prandtl number                                 =     7.000E-01


    Total mass flow in               .74865      (LBM/SEC)

USER1 CALLED.
```

Figure 18
Case Information

Note the error, *, in the center of the page. TEACH checks your boundary condition and if possible corrects small errors. All errors of this type will be noted here in the output.

Figure 19 below gives the next section of the output. Here the residuals of each field variable for each iteration are printed out.

```
ITER  I---------------ABSOLUTE RESIDUAL SOURCE SUMS---------------I
 NO.  UMOM      VMOM      MASS      TKIN      TEMP      DISP      FLUC      FRAC      DENS      WMOM      TR4
   1 .500      .335E-05  2.00      .102E-01  .0        .177E-03  .0        .0        .0        .154E-04  .0
   2 1.11      .549      2.30      .213E-01  .0        .113E-03  .0        .0        .0        .792      .0
   3 1.62      2.22      2.57      .245E-01  .0        .940E-04  .0        .0        .0        .601      .0
   4 2.16      1.95      1.60      .239E-01  .0        .835E-04  .0        .0        .0        .418      .0
   5 1.74      2.03      .875      .280E-01  .0        .767E-04  .0        .0        .0        .365      .0
   6 1.57      1.99      .527      .340E-01  .0        .722E-04  .0        .0        .0        .278      .0
   7 1.36      1.75      .513      .389E-01  .0        .695E-04  .0        .0        .0        .259      .0
   8 1.19      1.55      .528      .403E-01  .0        .678E-04  .0        .0        .0        .243      .0
   9 .997      1.30      .608      .391E-01  .0        .664E-04  .0        .0        .0        .236      .0
  10 .820      1.02      .595      .357E-01  .0        .648E-04  .0        .0        .0        .231      .0
  11 .750      .926      .557      .323E-01  .0        .630E-04  .0        .0        .0        .218      .0
  12 .863      1.00      .499      .291E-01  .0        .610E-04  .0        .0        .0        .206      .0
  13 .923      1.14      .474      .270E-01  .0        .601E-04  .0        .0        .0        .194      .0
  14 .947      1.18      .324      .252E-01  .0        .588E-04  .0        .0        .0        .182      .0
  15 .901      1.13      .257      .237E-01  .0        .574E-04  .0        .0        .0        .171      .0
  16 .793      1.01      .273      .223E-01  .0        .556E-04  .0        .0        .0        .164      .0
  17 .646      .854      .334      .210E-01  .0        .533E-04  .0        .0        .0        .158      .0
  18 .500      .659      .314      .194E-01  .0        .508E-04  .0        .0        .0        .152      .0
  19 .392      .502      .272      .177E-01  .0        .483E-04  .0        .0        .0        .147      .0
  20 .402      .471      .230      .162E-01  .0        .468E-04  .0        .0        .0        .142      .0
  21 .447      .498      .192      .151E-01  .0        .462E-04  .0        .0        .0        .138      .0
  22 .470      .510      .153      .143E-01  .0        .459E-04  .0        .0        .0        .133      .0
  23 .457      .495      .127      .145E-01  .0        .457E-04  .0        .0        .0        .127      .0
  24 .406      .439      .116      .148E-01  .0        .457E-04  .0        .0        .0        .120      .0
  25 .328      .369      .115      .148E-01  .0        .456E-04  .0        .0        .0        .112      .0
  26 .242      .299      .113      .144E-01  .0        .449E-04  .0        .0        .0        .104      .0
  27 .180      .237      .105      .136E-01  .0        .437E-04  .0        .0        .0        .952E-01  .0
  28 .162      .218      .902E-01  .125E-01  .0        .418E-04  .0        .0        .0        .869E-01  .0
  29 .170      .228      .712E-01  .112E-01  .0        .394E-04  .0        .0        .0        .792E-01  .0
  30 .178      .238      .525E-01  .997E-02  .0        .370E-04  .0        .0        .0        .715E-01  .0
  31 .176      .240      .395E-01  .894E-02  .0        .344E-04  .0        .0        .0        .641E-01  .0
  32 .160      .226      .396E-01  .817E-02  .0        .317E-04  .0        .0        .0        .571E-01  .0
  33 .135      .200      .444E-01  .752E-02  .0        .289E-04  .0        .0        .0        .510E-01  .0
  34 .106      .166      .471E-01  .692E-02  .0        .262E-04  .0        .0        .0        .455E-01  .0
  35 .835E-01  .134      .461E-01  .635E-02  .0        .238E-04  .0        .0        .0        .411E-01  .0
  36 .787E-01  .113      .421E-01  .583E-02  .0        .218E-04  .0        .0        .0        .376E-01  .0
  37 .841E-01  .109      .358E-01  .541E-02  .0        .202E-04  .0        .0        .0        .348E-01  .0
  38 .911E-01  .110      .285E-01  .509E-02  .0        .190E-04  .0        .0        .0        .325E-01  .0
  39 .916E-01  .111      .222E-01  .483E-02  .0        .182E-04  .0        .0        .0        .303E-01  .0
  40 .849E-01  .105      .206E-01  .464E-02  .0        .175E-04  .0        .0        .0        .284E-01  .0
  41 .737E-01  .945E-01  .218E-01  .450E-02  .0        .172E-04  .0        .0        .0        .265E-01  .0
  42 .603E-01  .811E-01  .227E-01  .435E-02  .0        .168E-04  .0        .0        .0        .249E-01  .0
  43 .490E-01  .675E-01  .218E-01  .416E-02  .0        .164E-04  .0        .0        .0        .234E-01  .0
  44 .424E-01  .595E-01  .193E-01  .394E-02  .0        .159E-04  .0        .0        .0        .221E-01  .0
  45 .406E-01  .589E-01  .164E-01  .369E-02  .0        .153E-04  .0        .0        .0        .209E-01  .0
  46 .416E-01  .594E-01  .134E-01  .344E-02  .0        .146E-04  .0        .0        .0        .198E-01  .0
  47 .405E-01  .588E-01  .114E-01  .323E-02  .0        .138E-04  .0        .0        .0        .188E-01  .0
  48 .374E-01  .550E-01  .107E-01  .308E-02  .0        .130E-04  .0        .0        .0        .179E-01  .0
  49 .330E-01  .494E-01  .110E-01  .293E-02  .0        .122E-04  .0        .0        .0        .174E-01  .0
  50 .274E-01  .422E-01  .113E-01  .278E-02  .0        .114E-04  .0        .0        .0        .167E-01  .0
```

Figure 19
Table of Residuals

ORIGINAL PAGE IS
OF POOR QUALITY

```
ITER  I---------------ABSOLUTE RESIDUAL SOURCE SUMS---------------I
 NO.  UMOM     VMOM     MASS     TKIN     TEMP      DISP     FLUC      FRAC      DENS      WMOM     TR4
 51 .219E-01 .348E-01 .108E-01 .263E-02 .0        .107E-04 .0        .0        .0        .162E-01 .0
 52 .188E-01 .308E-01 .992E-02 .248E-02 .0        .101E-04 .0        .0        .0        .157E-01 .0
 53 .178E-01 .305E-01 .860E-02 .234E-02 .0        .963E-05 .0        .0        .0        .152E-01 .0
 54 .179E-01 .315E-01 .719E-02 .222E-02 .0        .920E-05 .0        .0        .0        .148E-01 .0
 55 .180E-01 .318E-01 .591E-02 .211E-02 .0        .882E-05 .0        .0        .0        .143E-01 .0
 56 .169E-01 .309E-01 .549E-02 .203E-02 .0        .846E-05 .0        .0        .0        .137E-01 .0
 57 .151E-01 .286E-01 .557E-02 .195E-02 .0        .813E-05 .0        .0        .0        .132E-01 .0
 58 .133E-01 .255E-01 .570E-02 .187E-02 .0        .779E-05 .0        .0        .0        .128E-01 .0
 59 .123E-01 .223E-01 .557E-02 .178E-02 .0        .743E-05 .0        .0        .0        .122E-01 .0
 60 .122E-01 .198E-01 .527E-02 .169E-02 .0        .707E-05 .0        .0        .0        .117E-01 .0
 61 .123E-01 .187E-01 .483E-02 .160E-02 .0        .669E-05 .0        .0        .0        .112E-01 .0
 62 .125E-01 .182E-01 .429E-02 .150E-02 .0        .630E-05 .0        .0        .0        .107E-01 .0
 63 .123E-01 .173E-01 .379E-02 .142E-02 .0        .591E-05 .0        .0        .0        .101E-01 .0
 64 .117E-01 .160E-01 .350E-02 .133E-02 .0        .553E-05 .0        .0        .0        .963E-02 .0
 65 .109E-01 .143E-01 .341E-02 .125E-02 .0        .517E-05 .0        .0        .0        .914E-02 .0
 66 .986E-02 .124E-01 .330E-02 .118E-02 .0        .485E-05 .0        .0        .0        .865E-02 .0
 67 .881E-02 .109E-01 .308E-02 .111E-02 .0        .455E-05 .0        .0        .0        .814E-02 .0
 68 .788E-02 .101E-01 .280E-02 .105E-02 .0        .429E-05 .0        .0        .0        .764E-02 .0
 69 .723E-02 .988E-02 .250E-02 .100E-02 .0        .406E-05 .0        .0        .0        .715E-02 .0
 70 .678E-02 .975E-02 .217E-02 .961E-03 .0        .387E-05 .0        .0        .0        .668E-02 .0
 71 .645E-02 .956E-02 .190E-02 .927E-03 .0        .371E-05 .0        .0        .0        .626E-02 .0
 72 .607E-02 .928E-02 .177E-02 .898E-03 .0        .357E-05 .0        .0        .0        .588E-02 .0
 73 .563E-02 .890E-02 .176E-02 .870E-03 .0        .344E-05 .0        .0        .0        .553E-02 .0
 74 .521E-02 .852E-02 .176E-02 .842E-03 .0        .332E-05 .0        .0        .0        .524E-02 .0
 75 .490E-02 .816E-02 .174E-02 .814E-03 .0        .322E-05 .0        .0        .0        .498E-02 .0
 76 .473E-02 .791E-02 .170E-02 .785E-03 .0        .312E-05 .0        .0        .0        .476E-02 .0
 77 .463E-02 .780E-02 .163E-02 .756E-03 .0        .302E-05 .0        .0        .0        .457E-02 .0
 78 .454E-02 .776E-02 .153E-02 .728E-03 .0        .293E-05 .0        .0        .0        .441E-02 .0
 79 .440E-02 .769E-02 .146E-02 .701E-03 .0        .285E-05 .0        .0        .0        .427E-02 .0
 80 .419E-02 .755E-02 .145E-02 .677E-03 .0        .277E-05 .0        .0        .0        .413E-02 .0
 81 .394E-02 .732E-02 .146E-02 .656E-03 .0        .270E-05 .0        .0        .0        .400E-02 .0
 82 .367E-02 .704E-02 .147E-02 .637E-03 .0        .264E-05 .0        .0        .0        .388E-02 .0
 83 .342E-02 .678E-02 .145E-02 .621E-03 .0        .258E-05 .0        .0        .0        .375E-02 .0
 84 .322E-02 .658E-02 .143E-02 .607E-03 .0        .253E-05 .0        .0        .0        .364E-02 .0
 85 .306E-02 .642E-02 .139E-02 .595E-03 .0        .249E-05 .0        .0        .0        .353E-02 .0
 86 .294E-02 .624E-02 .134E-02 .584E-03 .0        .245E-05 .0        .0        .0        .343E-02 .0
 87 .282E-02 .604E-02 .129E-02 .574E-03 .0        .241E-05 .0        .0        .0        .332E-02 .0
 88 .269E-02 .578E-02 .125E-02 .565E-03 .0        .238E-05 .0        .0        .0        .320E-02 .0
 89 .254E-02 .549E-02 .122E-02 .555E-03 .0        .234E-05 .0        .0        .0        .308E-02 .0
 90 .239E-02 .516E-02 .120E-02 .544E-03 .0        .230E-05 .0        .0        .0        .296E-02 .0
 91 .224E-02 .484E-02 .117E-02 .533E-03 .0        .227E-05 .0        .0        .0        .284E-02 .0
```

Figure 19 (continued)

The rest of the output file consists of a listing of all field variables on all planes. The entire U-Velocity is given in Figure 20. The orginal output would also contain the following field variables: V-Velocity, W-Velocity, Static Pressure, Turbulence Energy, Energy Dissipation Rate, Viscosity, Density, East-West Peclet Number, North-South Peclet Number, Front-Back Peclet Number, Wall Reynolds Number, West and East Wall Shear Stress, South and North Wall Stress, and Front and Back Wall Stress.

```
*-*-*-*-*-*-*-*-*-*-*-*-      U VELOCITY                              AT Z( 1)=-.50000E-01       -*-*-*-*-*-*-*-*-*-*-*-*
  J    Y              2             3             4             5             6             7             8             9
 14   1.25000  0.0           0.0           0.0           0.0           0.0           0.0           0.0           0.0
 13   1.15000  0.0           0.0           0.0           0.0           0.0           0.0           0.0           0.0
 12   1.05000  0.0           0.0           0.0           0.0           0.0           0.0           0.0           0.0
 11   0.95000  0.0           0.0           0.0           0.0           0.0           0.0           0.0           0.0
 10   0.85000  0.0           0.0           0.0           0.0           0.0           0.0           0.0           0.0
  9   0.75000  0.0           0.0           0.0           0.0           0.0           0.0           0.0           0.0
  8   0.65000  0.0           0.0           0.0           0.0           0.0           0.0           0.0           0.0
  7   0.55000  0.0           0.0           0.0           0.0           0.0           0.0           0.0           0.0
  6   0.45000  0.0           0.0           0.0           0.0           0.0           0.0           0.0           0.0
  5   0.35000  0.0           0.0           0.0           0.0           0.0           0.0           0.0           0.0
  4   0.25000  0.0           0.0           0.0           0.0           0.0           0.0           0.0           0.0
  3   0.15000  0.0           0.0           0.0           0.0           0.0           0.0           0.0           0.0
  2   0.05000  0.0           0.0           0.0           0.0           0.0           0.0           0.0           0.0
  1  -0.05000  0.0           0.0           0.0           0.0           0.0           0.0           0.0           0.0
X=               0.0         0.10000       0.20000       0.30000       0.40000       0.50000       0.60000       0.70000
  J    Y             10            11            12            13            14
 14   1.25000  0.0           0.0           0.0           0.0           0.0
 13   1.15000  0.0           0.0           0.0           0.0           0.0
 12   1.05000  0.0           0.0           0.0           0.0           0.0
 11   0.95000  0.0           0.0           0.0           0.0           0.0
 10   0.85000  0.0           0.0           0.0           0.0           0.0
  9   0.75000  0.0           0.0           0.0           0.0           0.0
  8   0.65000  0.0           0.0           0.0           0.0           0.0
  7   0.55000  0.0           0.0           0.0           0.0           0.0
  6   0.45000  0.0           0.0           0.0           0.0           0.0
  5   0.35000  0.0           0.0           0.0           0.0           0.0
  4   0.25000  0.0           0.0           0.0           0.0           0.0
  3   0.15000  0.0           0.0           0.0           0.0           0.0
  2   0.05000  0.0           0.0           0.0           0.0           0.0
  1  -0.05000  0.0           0.0           0.0           0.0           0.0
X=             0.80000       0.90000       1.00000       1.10000       1.20000

*-*-*-*-*-*-*-*-*-*-*-*-      U VELOCITY                              AT Z( 2)= .50000E-01       -*-*-*-*-*-*-*-*-*-*-*-*
  J    Y              2             3             4             5             6             7             8             9
 14   1.25000  0.0           0.0           0.0           0.0           0.0           0.0           0.0           0.0
 13   1.15000  0.0           4.33500E+00   1.06777E+01   1.80508E+01   3.16725E+01   3.85558E+01   3.99304E+01   3.70363E+01
 12   1.05000  0.0          -1.17946E-01   2.87567E+00   1.24696E+01   2.92490E+01   3.53083E+01   3.62420E+01   3.39066E+01
 11   0.95000  0.0          -5.59304E+00  -5.39041E+00   7.14951E+00   3.06896E+01   3.39939E+01   3.50799E+01   3.60582E+01
 10   0.85000  0.0          -1.13273E+01  -1.35052E+01  -4.76053E-02   3.28802E+01   2.42321E+01   2.55091E+01   3.44220E+01
  9   0.75000  0.0          -1.69191E+01  -2.20286E+01  -1.41953E+01   0.0           0.0           0.0           0.0
  8   0.65000  0.0          -2.11813E+01  -2.78967E+01  -1.99235E+01   0.0           0.0           1.02818E+01   1.06476E+01
  7   0.55000  0.0          -2.42204E+01  -3.17203E+01  -2.27382E+01   0.0           0.0           8.14431E+00   1.02752E+01
  6   0.45000  0.0          -2.63003E+01  -3.37121E+01  -2.38429E+01   0.0           0.0           6.83557E+00   1.23152E+01
  5   0.35000  0.0          -2.83989E+01  -3.41046E+01  -2.38246E+01   0.0           0.0           4.84790E+00   1.06192E+01
  4   0.25000  0.0          -3.09010E+01  -3.46254E+01  -2.41161E+01   0.0           0.0           5.73944E-01   1.90141E+00
  3   0.15000  0.0          -3.26551E+01  -3.53937E+01  -2.44054E+01   0.0           0.0          -7.02472E+00  -1.19310E+01
  2   0.05000  0.0          -3.33523E+01  -3.55047E+01  -2.42988E+01   0.0           0.0          -2.06610E+01  -3.26692E+01
  1  -0.05000  0.0           0.0           0.0           0.0           0.0           0.0           0.0           0.0
X=               0.0         0.10000       0.20000       0.30000       0.40000       0.50000       0.60000       0.70000
  J    Y             10            11            12            13            14
 14   1.25000  0.0           0.0           0.0           0.0           0.0
 13   1.15000  2.99216E+01   1.73914E+01   0.0           0.0           0.0
 12   1.05000  2.72814E+01   1.44641E+01   0.0           0.0           0.0
 11   0.95000  3.45219E+01   1.80422E+01   0.0           0.0           0.0
 10   0.85000  5.33483E+01   2.28507E+01   0.0           0.0           0.0
  9   0.75000  0.0           6.20654E+00   0.0           0.0           0.0
  8   0.65000  2.84275E+00   4.49058E+00   0.0           0.0           0.0
  7   0.55000  5.90830E+00   8.78106E+00   0.0           0.0           0.0
  6   0.45000  1.32985E+01   2.50802E+01   4.84201E+01   2.15368E+01   2.15499E+01
  5   0.35000  1.40931E+01   2.54901E+01   4.25045E+01   4.06003E+01   4.06096E+01
  4   0.25000  6.83776E+00   1.68913E+01   3.13830E+01   3.73842E+01   3.73855E+01
  3   0.15000 -1.33304E+01   2.68159E+00   1.83610E+01   2.84088E+01   2.83969E+01
  2   0.05000 -3.43213E+01  -1.96481E+01   1.21426E+01   2.55433E+01   2.55137E+01
  1  -0.05000  0.0           0.0           0.0           0.0           0.0
X=             0.80000       0.90000       1.00000       1.10000       1.20000
```

Figure 20
Complete Listing of U-Velocity Field Variable Calculated On All Planes

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#-#-#-#-#-#-#-#-#-#-#-         U VELOCITY                                          AT Z( 3)= .15000           -#-#-#-#-#-#-#-#-#-#-#
  J    Y            2           3            4            5            6            7            8            9
 14  1.25000  0.0          0.0          0.0          0.0          0.0          0.0          0.0          0.0
 13  1.15000  0.0          1.15953E+01  2.16614E+01  2.89699E+01  3.60596E+01  3.98642E+01  3.99324E+01  3.64402E+01
 12  1.05000  0.0          1.08592E+01  2.16622E+01  2.99862E+01  3.87508E+01  4.19948E+01  4.15380E+01  3.80956E+01
 11  0.95000  0.0          8.67430E+00  1.81884E+01  2.61668E+01  4.02754E+01  4.22825E+01  4.25530E+01  4.18451E+01
 10  0.85000  0.0          5.62081E+00  1.20856E+01  2.04107E+01  4.17029E+01  3.16948E+01  3.22371E+01  3.99011E+01
  9  0.75000  0.0          2.38451E+00  4.41471E+00  5.42568E+00  0.0          0.0          0.0          0.0
  8  0.65000  0.0          5.36769E-01  1.35622E+00  2.00146E+00  0.0          0.0          1.06313E+01  1.13631E+01
  7  0.55000  0.0          1.56484E+00  3.06605E+00  3.20885E+00  0.0          0.0          8.09369E+00  1.08122E+01
  6  0.45000  0.0          7.06035E+00  8.83290E+00  6.61122E+00  0.0          0.0          6.34466E+00  1.25249E+01
  5  0.35000  0.0          1.36416E+01  1.47877E+01  8.36398E+00  0.0          0.0          3.79970E+00  1.01050E+01
  4  0.25000  0.0          1.69720E+01  1.48685E+01  7.25144E+00  0.0          0.0         -8.55672E-01  5.11394E-01
  3  0.15000  0.0          1.68152E+01  1.34447E+01  6.14137E+00  0.0          0.0         -8.37230E+00 -1.31159E+01
  2  0.05000  0.0          1.71299E+01  1.28696E+01  5.77797E+00  0.0          0.0         -2.14083E+01 -3.32612E+01
  1 -0.05000  0.0          0.0          0.0          0.0          0.0          0.0          0.0          0.0
X=                0.0         0.10000      0.20000      0.30000      0.40000      0.50000      0.60000      0.70000
  J    Y           10           11           12           13           14
 14  1.25000  0.0          0.0          0.0          0.0          0.0
 13  1.15000  2.88178E+01  1.61531E+01  0.0          0.0          0.0
 12  1.05000  3.06148E+01  1.66340E+01  0.0          0.0          0.0
 11  0.95000  3.86100E+01  2.07317E+01  0.0          0.0          0.0
 10  0.85000  5.76574E+01  2.53776E+01  0.0          0.0          0.0
  9  0.75000  0.0          7.49570E+00  0.0          0.0          0.0
  8  0.65000  4.30370E+00  5.95773E+00  0.0          0.0          0.0
  7  0.55000  7.39085E+00  1.02001E+01  0.0          0.0          0.0
  6  0.45000  1.47046E+01  2.65574E+01  4.93815E+01  2.20722E+01  2.20729E+01
  5  0.35000  1.51167E+01  2.67779E+01  4.34138E+01  4.11508E+01  4.11513E+01
  4  0.25000  7.51281E+00  1.78936E+01  3.20216E+01  3.78182E+01  3.78193E+01
  3  0.15000 -1.35884E+01  2.96076E+00  1.85893E+01  2.86920E+01  2.86927E+01
  2  0.05000 -3.49962E+01 -2.03963E+01  1.17987E+01  2.56504E+01  2.56492E+01
  1 -0.05000  0.0          0.0          0.0          0.0          0.0
X=                0.80000      0.90000      1.00000      1.10000      1.20000

#-#-#-#-#-#-#-#-#-#-#-         U VELOCITY                                          AT Z( 4)= .25000           -#-#-#-#-#-#-#-#-#-#-#
  J    Y            2           3            4            5            6            7            8            9
 14  1.25000  0.0          0.0          0.0          0.0          0.0          0.0          0.0          0.0
 13  1.15000  0.0          1.54224E+01  2.67840E+01  3.47051E+01  4.01345E+01  4.24669E+01  4.16866E+01  3.77548E+01
 12  1.05000  0.0          1.75852E+01  3.00624E+01  3.80219E+01  4.41330E+01  4.56466E+01  4.41652E+01  4.01609E+01
 11  0.95000  0.0          1.79807E+01  2.94825E+01  3.73078E+01  4.83620E+01  4.86626E+01  4.69922E+01  4.48568E+01
 10  0.85000  0.0          1.75492E+01  2.77377E+01  3.55387E+01  5.12165E+01  4.04551E+01  3.93238E+01  4.47394E+01
  9  0.75000  0.0          1.70541E+01  2.48222E+01  2.19953E+01  0.0          0.0          0.0          0.0
  8  0.65000  0.0          1.96380E+01  2.87527E+01  2.35937E+01  0.0          0.0          1.08449E+01  1.20197E+01
  7  0.55000  0.0          3.37111E+01  4.34829E+01  3.31018E+01  0.0          0.0          8.15232E+00  1.12914E+01
  6  0.45000  9.30000E+01  8.51881E+01  7.38007E+01  4.84401E+01  0.0          0.0          6.36435E+00  1.27677E+01
  5  0.35000  9.30000E+01  9.09460E+01  7.69591E+01  4.89282E+01  0.0          0.0          3.75713E+00  9.75690E+00
  4  0.25000  9.30000E+01  8.90009E+01  7.37108E+01  4.56177E+01  0.0          0.0         -8.51929E-01  4.17339E-01
  3  0.15000  9.30000E+01  8.78090E+01  7.18857E+01  4.40037E+01  0.0          0.0         -8.33587E+00 -1.32406E+01
  2  0.05000  9.30000E+01  8.69308E+01  7.06779E+01  4.32527E+01  0.0          0.0         -2.11514E+01 -3.31489E+01
  1 -0.05000  0.0          0.0          0.0          0.0          0.0          0.0          0.0          0.0
X=                0.0         0.10000      0.20000      0.30000      0.40000      0.50000      0.60000      0.70000
  J    Y           10           11           12           13           14
 14  1.25000  0.0          0.0          0.0          0.0          0.0
 13  1.15000  3.00539E+01  1.76638E+01  0.0          0.0          0.0
 12  1.05000  3.25688E+01  1.86583E+01  0.0          0.0          0.0
 11  0.95000  4.07674E+01  2.22845E+01  0.0          0.0          0.0
 10  0.85000  6.10444E+01  2.67587E+01  0.0          0.0          0.0
  9  0.75000  0.0          7.94020E+00  0.0          0.0          0.0
  8  0.65000  5.48068E+00  6.59963E+00  0.0          0.0          0.0
  7  0.55000  8.45137E+00  1.08101E+01  0.0          0.0          0.0
  6  0.45000  1.55811E+01  2.72258E+01  4.98268E+01  2.17382E+01  2.17156E+01
  5  0.35000  1.56638E+01  2.73585E+01  4.38447E+01  4.11644E+01  4.11486E+01
  4  0.25000  7.66607E+00  1.83690E+01  3.24165E+01  3.80526E+01  3.80515E+01
  3  0.15000 -1.35691E+01  3.18424E+00  1.88738E+01  2.90542E+01  2.90721E+01
  2  0.05000 -3.50876E+01 -2.08146E+01  1.19904E+01  2.61205E+01  2.61579E+01
  1 -0.05000  0.0          0.0          0.0          0.0          0.0
X=                0.80000      0.90000      1.00000      1.10000      1.20000
```

Figure 20 (continued)

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*-*-*-*-*-*-*-*-*-*-*-       U VELOCITY                                AT Z( 5)= .35000        -*-*-*-*-*-*-*-*-*-*-*
  J     Y           2            3            4            5            6            7            8            9
 14  1.25000  0.0          0.0          0.0          0.0          0.0          0.0          0.0          0.0
 13  1.15000  0.0          1.54108E+01  2.67648E+01  3.46810E+01  4.01089E+01  4.24417E+01  4.16644E+01  3.77402E+01
 12  1.05000  0.0          1.75723E+01  3.00402E+01  3.79891E+01  4.40904E+01  4.55941E+01  4.41069E+01  4.01058E+01
 11  0.95000  0.0          1.79726E+01  2.94680E+01  3.72868E+01  4.83354E+01  4.86205E+01  4.69311E+01  4.47819E+01
 10  0.85000  0.0          1.75479E+01  2.77349E+01  3.55325E+01  5.12025E+01  4.04316E+01  3.92937E+01  4.46936E+01
  9  0.75000  0.0          1.70574E+01  2.48247E+01  2.19971E+01  0.0          0.0          0.0          0.0
  8  0.65000  0.0          1.96423E+01  2.87550E+01  2.35952E+01  0.0          0.0          1.08433E+01  1.20026E+01
  7  0.55000  0.0          3.37135E+01  4.34837E+01  3.31021E+01  0.0          0.0          8.14175E+00  1.12765E+01
  6  0.45000  9.30000E+01  8.51906E+01  7.38020E+01  4.84402E+01  0.0          0.0          6.33735E+00  1.27540E+01
  5  0.35000  9.30000E+01  9.09436E+01  7.69554E+01  4.89244E+01  0.0          0.0          3.72302E+00  9.77886E+00
  4  0.25000  9.30000E+01  8.89992E+01  7.37081E+01  4.56146E+01  0.0          0.0         -8.81172E-01  4.26851E-01
  3  0.15000  9.30000E+01  8.78079E+01  7.18838E+01  4.40014E+01  0.0          0.0         -8.35750E+00 -1.32407E+01
  2  0.05000  9.30000E+01  8.69303E+01  7.06768E+01  4.32513E+01  0.0          0.0         -2.11604E+01 -3.31445E+01
  1 -0.05000  0.0          0.0          0.0          0.0          0.0          0.0          0.0          0.0
X=               0.0        0.10000      0.20000      0.30000      0.40000      0.50000      0.60000      0.70000
  J     Y          10           11           12           13           14
 14  1.25000  0.0          0.0          0.0          0.0          0.0
 13  1.15000  3.00562E+01  1.76988E+01  0.0          0.0          0.0
 12  1.05000  3.25333E+01  1.86679E+01  0.0          0.0          0.0
 11  0.95000  4.06995E+01  2.22599E+01  0.0          0.0          0.0
 10  0.85000  6.09912E+01  2.67207E+01  0.0          0.0          0.0
  9  0.75000  0.0          7.93195E+00  0.0          0.0          0.0
  8  0.65000  5.47257E+00  6.60564E+00  0.0          0.0          0.0
  7  0.55000  8.44180E+00  1.08255E+01  0.0          0.0          0.0
  6  0.45000  1.55657E+01  2.72418E+01  4.98447E+01  2.17708E+01  2.17549E+01
  5  0.35000  1.56587E+01  2.73768E+01  4.38672E+01  4.11951E+01  4.11841E+01
  4  0.25000  7.67462E+00  1.83903E+01  3.24364E+01  3.80729E+01  3.80727E+01
  3  0.15000 -1.35410E+01  3.21191E+00  1.88758E+01  2.90409E+01  2.90546E+01
  2  0.05000 -3.50740E+01 -2.07829E+01  1.19617E+01  2.60706E+01  2.60981E+01
  1 -0.05000  0.0          0.0          0.0          0.0          0.0
X=             0.80000      0.90000      1.00000      1.10000      1.20000

*-*-*-*-*-*-*-*-*-*-*-       U VELOCITY                                AT Z( 6)= .45000        -*-*-*-*-*-*-*-*-*-*-*
  J     Y           2            3            4            5            6            7            8            9
 14  1.25000  0.0          0.0          0.0          0.0          0.0          0.0          0.0          0.0
 13  1.15000  0.0          1.15842E+01  2.16434E+01  2.89487E+01  3.60396E+01  3.98448E+01  3.99126E+01  3.64197E+01
 12  1.05000  0.0          1.08500E+01  2.16466E+01  2.99678E+01  3.87319E+01  4.19709E+01  4.15066E+01  3.80551E+01
 11  0.95000  0.0          8.66817E+00  1.81773E+01  2.61525E+01  4.02586E+01  4.22594E+01  4.25183E+01  4.17959E+01
 10  0.85000  0.0          5.61888E+00  1.20834E+01  2.04060E+01  4.16883E+01  3.16688E+01  3.22040E+01  3.98629E+01
  9  0.75000  0.0          2.38621E+00  4.42007E+00  5.42868E+00  0.0          0.0          0.0          0.0
  8  0.65000  0.0          5.40286E-01  1.36290E+00  2.00500E+00  0.0          0.0          1.06303E+01  1.13587E+01
  7  0.55000  0.0          1.56889E+00  3.07146E+00  3.21166E+00  0.0          0.0          8.09100E+00  1.08086E+01
  6  0.45000  0.0          7.06524E+00  8.83701E+00  6.61342E+00  0.0          0.0          6.34212E+00  1.25239E+01
  5  0.35000  0.0          1.36494E+01  1.47902E+01  8.36465E+00  0.0          0.0          3.80086E+00  1.01198E+01
  4  0.25000  0.0          1.69755E+01  1.48690E+01  7.25146E+00  0.0          0.0         -8.47255E-01  5.30938E-01
  3  0.15000  0.0          1.68160E+01  1.34437E+01  6.14073E+00  0.0          0.0         -8.35803E+00 -1.31017E+01
  2  0.05000  0.0          1.71293E+01  1.28681E+01  5.77734E+00  0.0          0.0         -2.13837E+01 -3.32387E+01
  1 -0.05000  0.0          0.0          0.0          0.0          0.0          0.0          0.0          0.0
X=               0.0        0.10000      0.20000      0.30000      0.40000      0.50000      0.60000      0.70000
```

Figure 20 (continued)

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  J    Y            10           11           12           13           14
 14  1.25000  0.0          0.0          0.0          0.0          0.0
 13  1.15000  2.87958E+01  1.61308E+01  0.0          0.0          0.0
 12  1.05000  3.05693E+01  1.65930E+01  0.0          0.0          0.0
 11  0.95000  3.85508E+01  2.06727E+01  0.0          0.0          0.0
 10  0.85000  5.76190E+01  2.53261E+01  0.0          0.0          0.0
  9  0.75000  0.0          7.46544E+00  0.0          0.0          0.0
  8  0.65000  4.30380E+00  5.93686E+00  0.0          0.0          0.0
  7  0.55000  7.39128E+00  1.01869E+01  0.0          0.0          0.0
  6  0.45000  1.47044E+01  2.65520E+01  4.93891E+01  2.20762E+01  2.20799E+01
  5  0.35000  1.51195E+01  2.67783E+01  4.34245E+01  4.11648E+01  4.11679E+01
  4  0.25000  7.51882E+00  1.78979E+01  3.20318E+01  3.78295E+01  3.78311E+01
  3  0.15000 -1.35737E+01  2.97246E+00  1.85932E+01  2.86860E+01  2.86840E+01
  2  0.05000 -3.49787E+01 -2.03751E+01  1.17926E+01  2.56258E+01  2.56181E+01
  1 -0.05000  0.0          0.0          0.0          0.0          0.0
X=               0.80000      0.90000      1.00000      1.10000      1.20000

*-*-*-*-*-*-*-*-*-*-*-        U VELOCITY                          AT Z( 7)= .55000     -*-*-*-*-*-*-*-*-*-*-*
  J    Y             2           3            4            5            6            7            8            9
 14  1.25000  0.0          0.0          0.0          0.0          0.0          0.0          0.0          0.0
 13  1.15000  0.0          4.32355E+00  1.06596E+01  1.80329E+01  3.16630E+01  3.85492E+01  3.99235E+01  3.70269E+01
 12  1.05000  0.0         -1.25778E-01  2.86158E+00  1.24551E+01  2.92390E+01  3.52986E+01  3.62311E+01  3.38949E+01
 11  0.95000  0.0         -5.59882E+00 -5.39973E+00  7.13870E+00  3.06791E+01  3.39810E+01  3.50625E+01  3.60360E+01
 10  0.85000  0.0         -1.13309E+01 -1.35100E+01 -5.34015E-02  3.28691E+01  2.42153E+01  2.54897E+01  3.44049E+01
  9  0.75000  0.0         -1.69208E+01 -2.20297E+01 -1.41953E+01  0.0          0.0          0.0          0.0
  8  0.65000  0.0         -2.11822E+01 -2.78960E+01 -1.99218E+01  0.0          0.0          1.02796E+01  1.06595E+01
  7  0.55000  0.0         -2.42214E+01 -3.17185E+01 -2.27358E+01  0.0          0.0          8.14635E+00  1.02941E+01
  6  0.45000  0.0         -2.63018E+01 -3.37092E+01 -2.38403E+01  0.0          0.0          6.85176E+00  1.23405E+01
  5  0.35000  0.0         -2.84008E+01 -3.41010E+01 -2.38221E+01  0.0          0.0          4.86512E+00  1.05999E+01
  4  0.25000  0.0         -3.09025E+01 -3.46226E+01 -2.41141E+01  0.0          0.0          5.86673E-01  1.87173E+00
  3  0.15000  0.0         -3.26558E+01 -3.53920E+01 -2.44041E+01  0.0          0.0         -7.01729E+00 -1.19336E+01
  2  0.05000  0.0         -3.33526E+01 -3.55036E+01 -2.42979E+01  0.0          0.0         -2.06504E+01 -3.26633E+01
  1 -0.05000  0.0          0.0          0.0          0.0          0.0          0.0          0.0          0.0
X=               0.0          0.10000      0.20000      0.30000      0.40000      0.50000      0.60000      0.70000
  J    Y            10           11           12           13           14
 14  1.25000  0.0          0.0          0.0          0.0          0.0
 13  1.15000  2.99095E+01  1.73776E+01  0.0          0.0          0.0
 12  1.05000  2.72692E+01  1.44531E+01  0.0          0.0          0.0
 11  0.95000  3.44973E+01  1.80193E+01  0.0          0.0          0.0
 10  0.85000  5.33360E+01  2.28351E+01  0.0          0.0          0.0
  9  0.75000  0.0          6.19935E+00  0.0          0.0          0.0
  8  0.65000  2.85052E+00  4.48762E+00  0.0          0.0          0.0
  7  0.55000  5.92037E+00  8.78084E+00  0.0          0.0          0.0
  6  0.45000  1.33194E+01  2.50878E+01  4.84321E+01  2.15396E+01  2.15516E+01
  5  0.35000  1.41025E+01  2.54960E+01  4.25131E+01  4.06068E+01  4.06155E+01
  4  0.25000  6.83671E+00  1.68895E+01  3.13839E+01  3.73858E+01  3.73871E+01
  3  0.15000 -1.33641E+01  2.66574E+00  1.83560E+01  2.84083E+01  2.83977E+01
  2  0.05000 -3.43314E+01 -1.96733E+01  1.21338E+01  2.55423E+01  2.55156E+01
  1 -0.05000  0.0          0.0          0.0          0.0          0.0
X=               0.80000      0.90000      1.00000      1.10000      1.20000

*-*-*-*-*-*-*-*-*-*-*-        U VELOCITY                          AT Z( 8)= .65000     -*-*-*-*-*-*-*-*-*-*-*
  J    Y             2           3            4            5            6            7            8            9
 14  1.25000  0.0          0.0          0.0          0.0          0.0          0.0          0.0          0.0
 13  1.15000  0.0          0.0          0.0          0.0          0.0          0.0          0.0          0.0
 12  1.05000  0.0          0.0          0.0          0.0          0.0          0.0          0.0          0.0
 11  0.95000  0.0          0.0          0.0          0.0          0.0          0.0          0.0          0.0
 10  0.85000  0.0          0.0          0.0          0.0          0.0          0.0          0.0          0.0
  9  0.75000  0.0          0.0          0.0          0.0          0.0          0.0          0.0          0.0
  8  0.65000  0.0          0.0          0.0          0.0          0.0          0.0          0.0          0.0
  7  0.55000  0.0          0.0          0.0          0.0          0.0          0.0          0.0          0.0
  6  0.45000  0.0          0.0          0.0          0.0          0.0          0.0          0.0          0.0
  5  0.35000  0.0          0.0          0.0          0.0          0.0          0.0          0.0          0.0
  4  0.25000  0.0          0.0          0.0          0.0          0.0          0.0          0.0          0.0
  3  0.15000  0.0          0.0          0.0          0.0          0.0          0.0          0.0          0.0
  2  0.05000  0.0          0.0          0.0          0.0          0.0          0.0          0.0          0.0
  1 -0.05000  0.0          0.0          0.0          0.0          0.0          0.0          0.0          0.0
X=               0.0          0.10000      0.20000      0.30000      0.40000      0.50000      0.60000      0.70000
```

Figure 20 (continued)

```
  J     Y            10          11          12          13          14
 14   1.25000  0.0         0.0         0.0         0.0         0.0
 13   1.15000  0.0         0.0         0.0         0.0         0.0
 12   1.05000  0.0         0.0         0.0         0.0         0.0
 11   0.95000  0.0         0.0         0.0         0.0         0.0
 10   0.85000  0.0         0.0         0.0         0.0         0.0
  9   0.75000  0.0         0.0         0.0         0.0         0.0
  8   0.65000  0.0         0.0         0.0         0.0         0.0
  7   0.55000  0.0         0.0         0.0         0.0         0.0
  6   0.45000  0.0         0.0         0.0         0.0         0.0
  5   0.35000  0.0         0.0         0.0         0.0         0.0
  4   0.25000  0.0         0.0         0.0         0.0         0.0
  3   0.15000  0.0         0.0         0.0         0.0         0.0
  2   0.05000  0.0         0.0         0.0         0.0         0.0
  1  -0.05000  0.0         0.0         0.0         0.0         0.0
X=                0.80000     0.90000     1.00000     1.10000     1.20000
```

Figure 20 (continued)

Pages 71 and 72 intentionally omitted

3.6 A Sample Terminal Session

TEACH can be run from any virtual machine that has 4.0 Megabytes of storage and is linked to disk CMB1-F by typing "U57103". If a Tektronix terminal is used, the CalComp preview package displays all plots on the screen making any CalComp plots optional. On any other terminal, all plots, except the convergence plot, are plotted by the CalComp.

The menu that first appears will be a subset of the one shown below. Options will appear in the menu as they become relevant. For example, the "RC" option is not relevant until the input files have been identified (option "II") and is not displayed initially.

A second filename and filetype (U57103 ENTHALPY in this case) is not required unless temperatures are being calculated.

```
                                 3-D TEACH
                                SYSTEM MENU

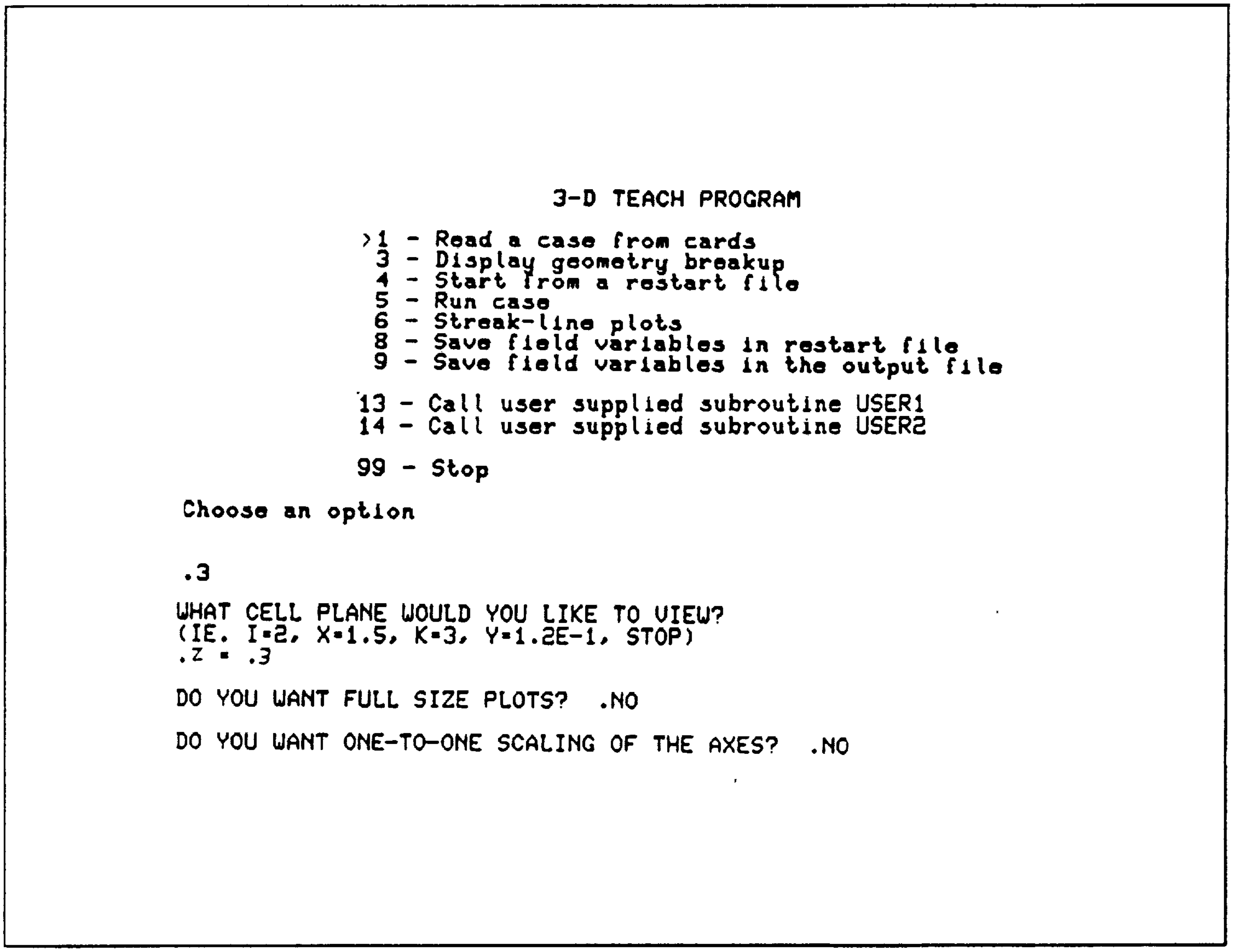
                 II  IDENTIFY THE INPUT FILES
                 EI  EDIT THE MAIN INPUT FILE
                 RR  READ RESTART FILE FROM PANVALET
                 RC  RUN ON CMS
                 RB  RUN ON BATCH
                 EO  EDIT THE OUTPUT
                 PO  PRINT THE OUTPUT
                 FO  FICHE THE OUTPUT
                 RI  RENAME THE MAIN INPUT FILE
                 MI  PUT INPUT CARDS ON MINIDISK
                 PR  PUT RESTART FILE ON PANVALET
                 DS  DISPLAY STATUS OF FILES BEING USED
                 ST  STOP

   CHOOSE AN OPTION:
    RC
```

If the option to make temporary input revisions is chosen, a dummy file is created and the user is put into the edit mode to make modifications while the original file is left undisturbed.

If the option to put restart file on PANVALET is chosen, a batch job is submitted. Therefore the file will not immediately be put on PANVALET. This delay should be taken into consideration when using this option so that files are not temporarily irretrievable.

The menu appears on the screen whenever a new option is to be selected. Option 1 must be selected first. If the same case had been run earlier and the results saved in a restart file, those results could be loaded back into the program by selecting option 4. In this example option 3 was selected allowing the user to check his breakup before proceeding with the analysis.



```
                        3-D TEACH PROGRAM

            >1 - Read a case from cards
             3 - Display geometry breakup
             4 - Start from a restart file
             5 - Run case
             6 - Streak-line plots
             8 - Save field variables in restart file
             9 - Save field variables in the output file

            13 - Call user supplied subroutine USER1
            14 - Call user supplied subroutine USER2

            99 - Stop

Choose an option

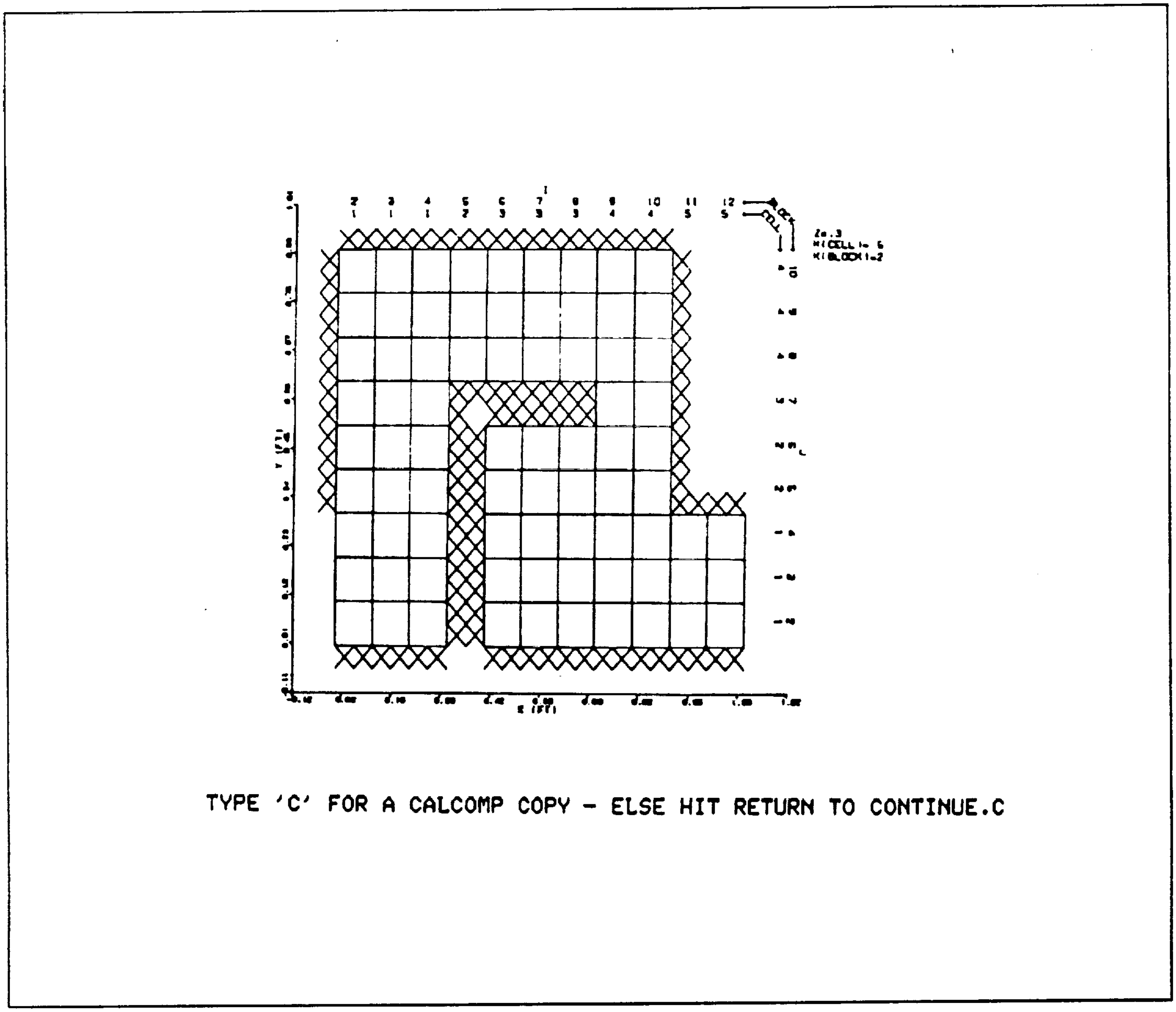

.3

WHAT CELL PLANE WOULD YOU LIKE TO VIEW?
(IE. I=2, X=1.5, K=3, Y=1.2E-1, STOP)
.Z = .3

DO YOU WANT FULL SIZE PLOTS?  .NO

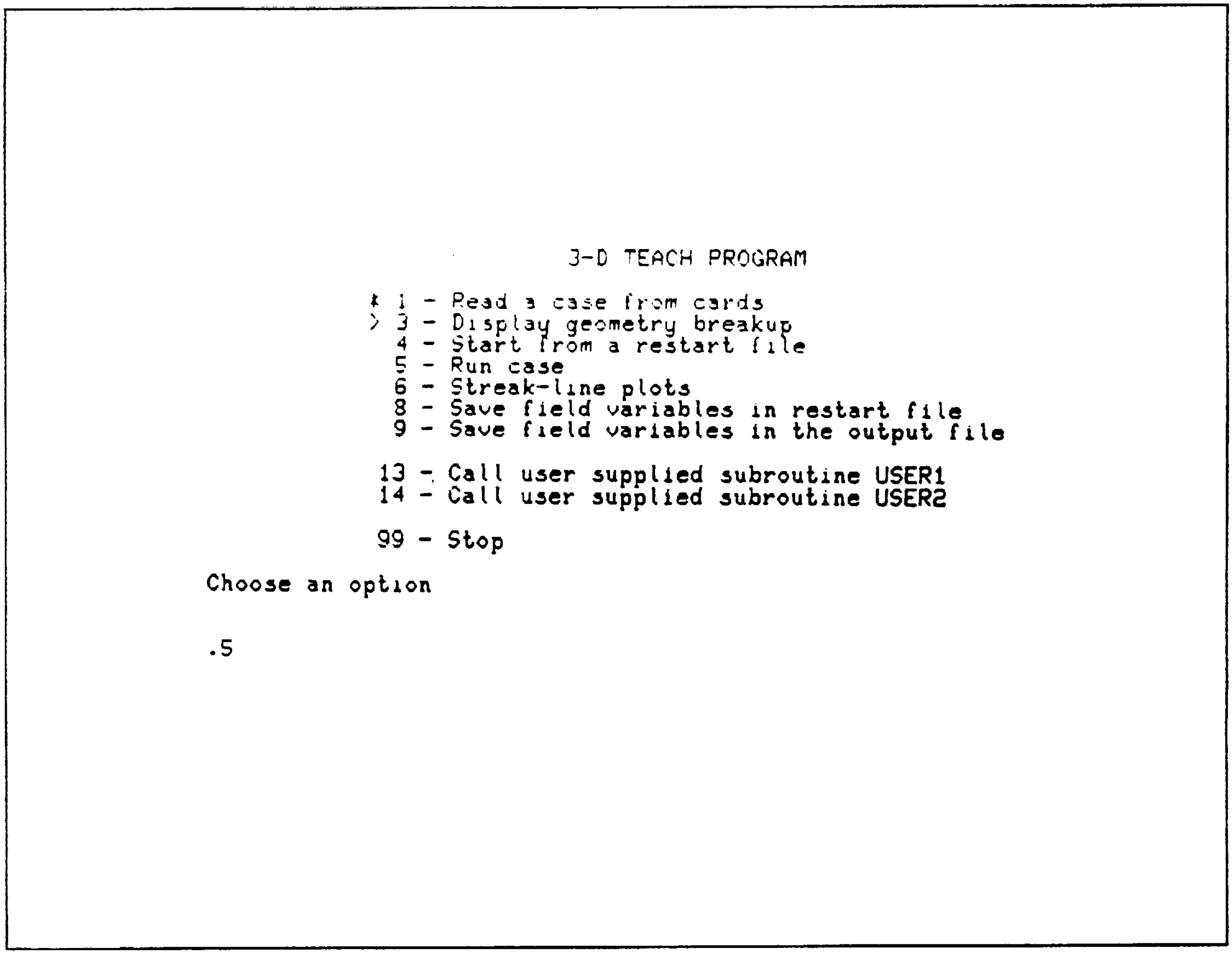
DO YOU WANT ONE-TO-ONE SCALING OF THE AXES?  .NO
```

ORIGINAL PAGE IS
OF POOR QUALITY



```
TYPE 'C' FOR A CALCOMP COPY - ELSE HIT RETURN TO CONTINUE.C
```

It was determined that the geometry breakup is acceptable so option 5 is selected to run the case.



```
                    3-D TEACH PROGRAM

             * 1 - Read a case from cards
             > 3 - Display geometry breakup
               4 - Start from a restart file
               5 - Run case
               6 - Streak-line plots
               8 - Save field variables in restart file
               9 - Save field variables in the output file

              13 - Call user supplied subroutine USER1
              14 - Call user supplied subroutine USER2

              99 - Stop

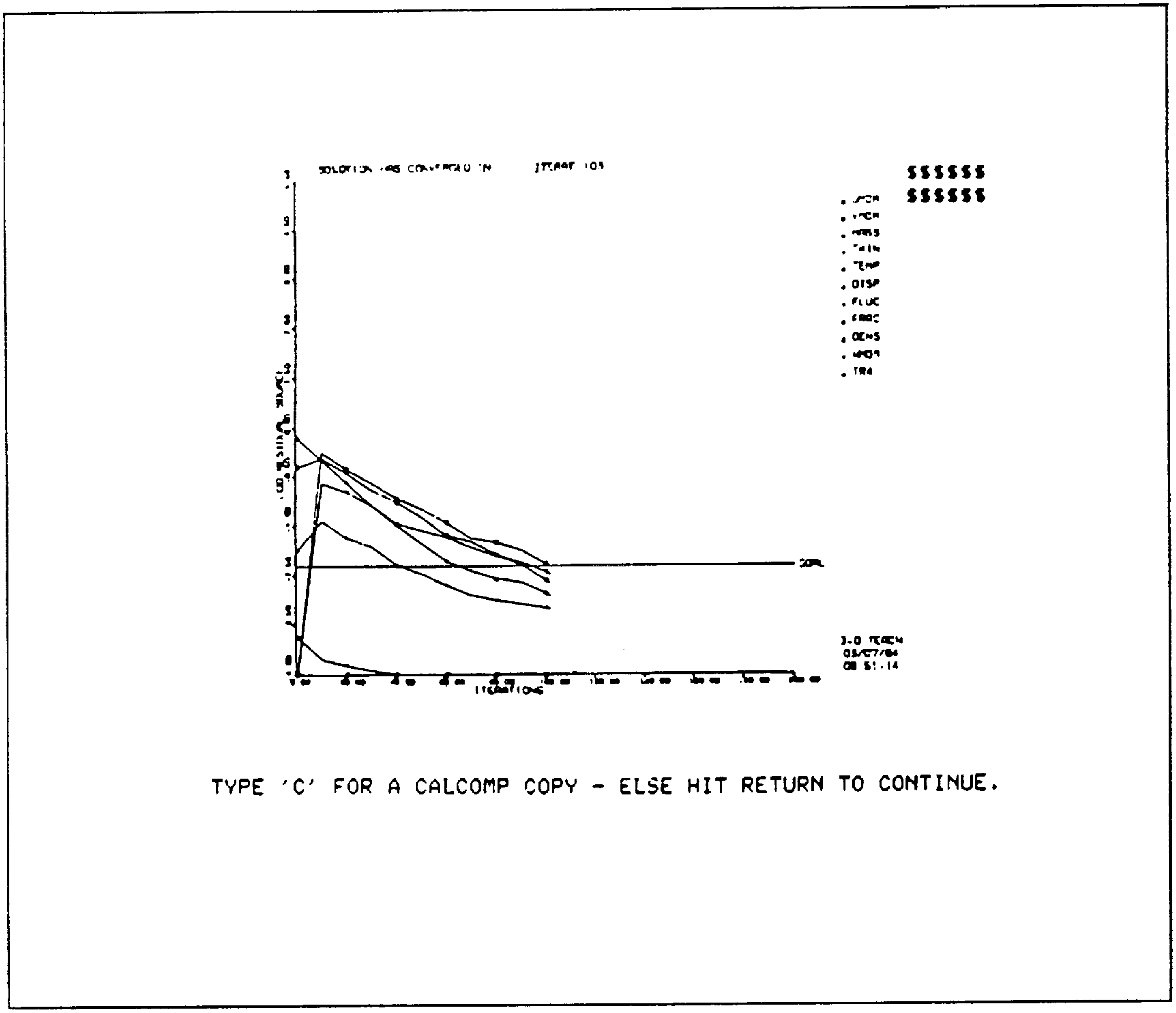
   Choose an option

   .5
```

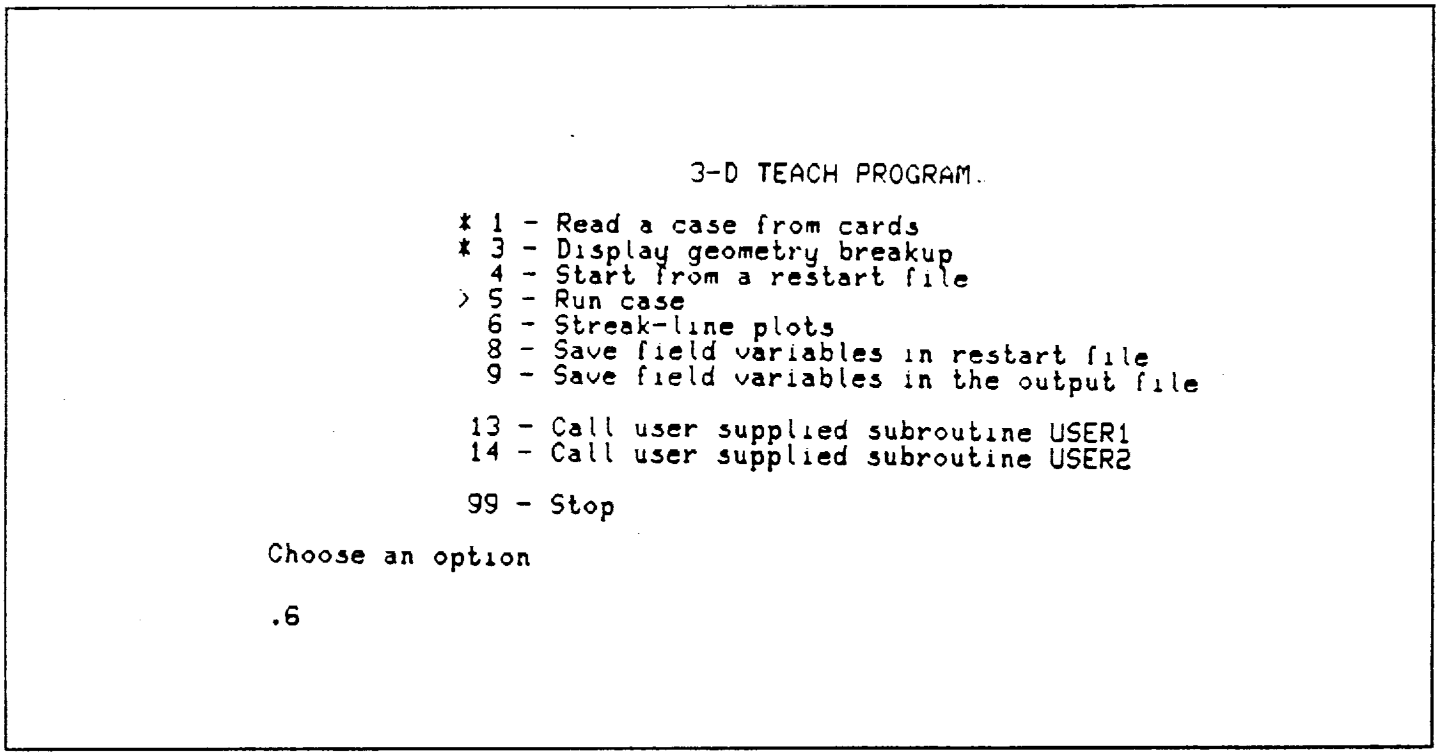
ORIGINAL PAGE IS
OF POOR QUALITY

ORIGINAL PAGE IS
OF POOR QUALITY

The convergence plot is drawn as the case proceeds showing the values of each residual source as they approach the goal (SORMAX). If after several iterations it does not look as though the case will converge the iteration loop may be exited by hitting carriage return to put the terminal into CMS and typing "HALT". In this case computation will stop after the next set of residual sources are plotted. In any case, after the iterations are complete, the menu will reappear.



TYPE 'C' FOR A CALCOMP COPY - ELSE HIT RETURN TO CONTINUE.



```
                  3-D TEACH PROGRAM.

        * 1 - Read a case from cards
        * 3 - Display geometry breakup
          4 - Start from a restart file
        > 5 - Run case
          6 - Streak-line plots
          8 - Save field variables in restart file
          9 - Save field variables in the output file

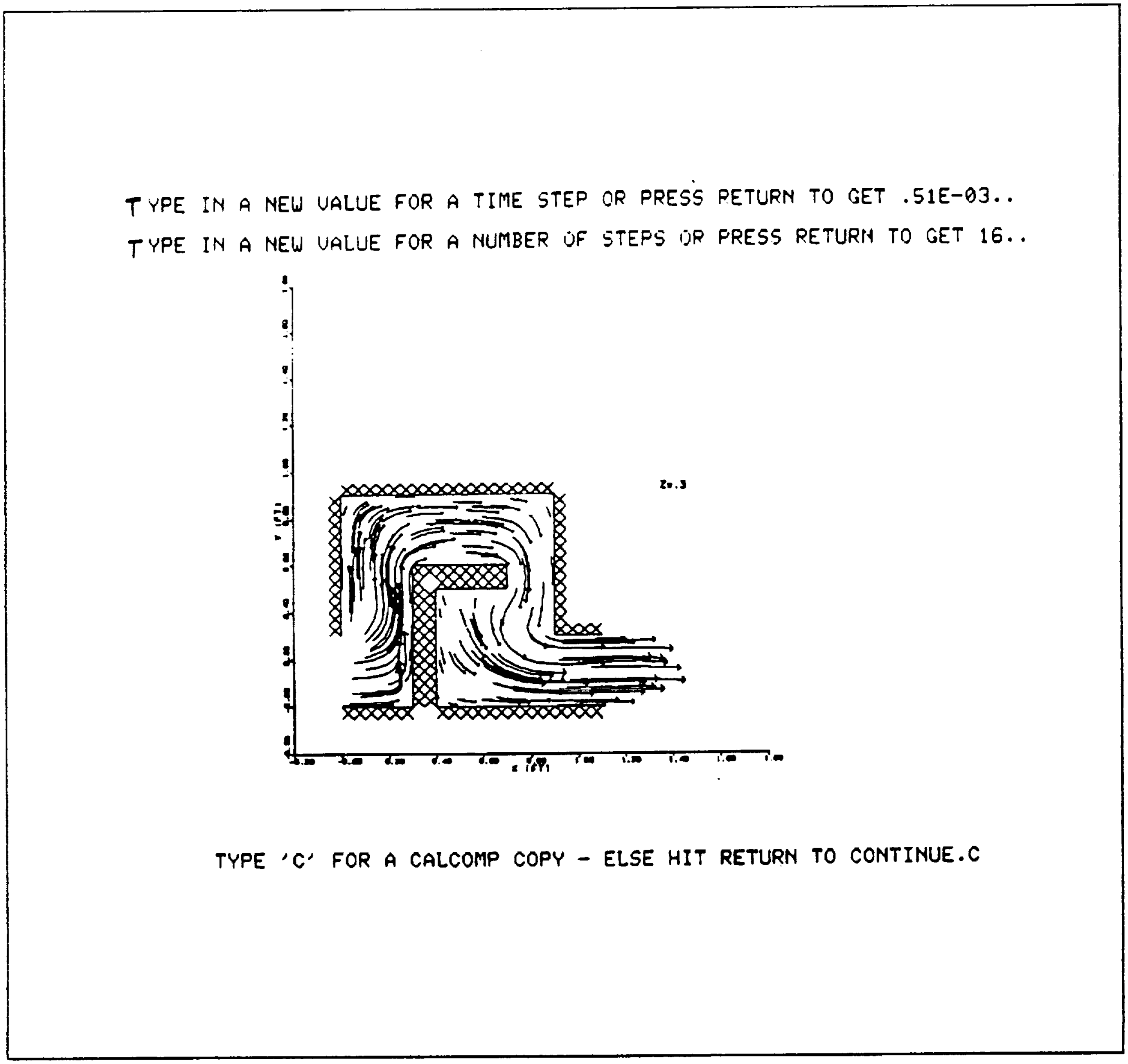
         13 - Call user supplied subroutine USER1
         14 - Call user supplied subroutine USER2

         99 - Stop

Choose an option

.6
```

The streakline plot is an approximate graphic representation of what might be seen in a water tunnel when particles in the fluid are illuminated as they pass through a fixed plane. A plane perpendicular to any of the coordinate axes and located anywhere in the flow field is selected by the user. One hundred massless particles are injected into the flow field from random locations in the plane and their path is approximated using the Runge-Kutta prediction-corrector method. The number of time steps and the time interval of each step can be selected by the user. If not, the number of time steps defaults to twenty and the time interval defaults to a value based on the highest velocity in the field and diagonal length of the control volume. Care should be exercised in choosing the number of time steps and the time interval. Too many time steps and/or too large a time interval will have the effect of making the 'laser beam' quite thick and the streak line plot will not be representative of the flow in a plane but rather flow in a block. One has to be especially careful at the exit. In interpreting the streaklines it should be kept in mind, that at best, this is a qualitative picture. Quantitative information should never be extracted from this plot.

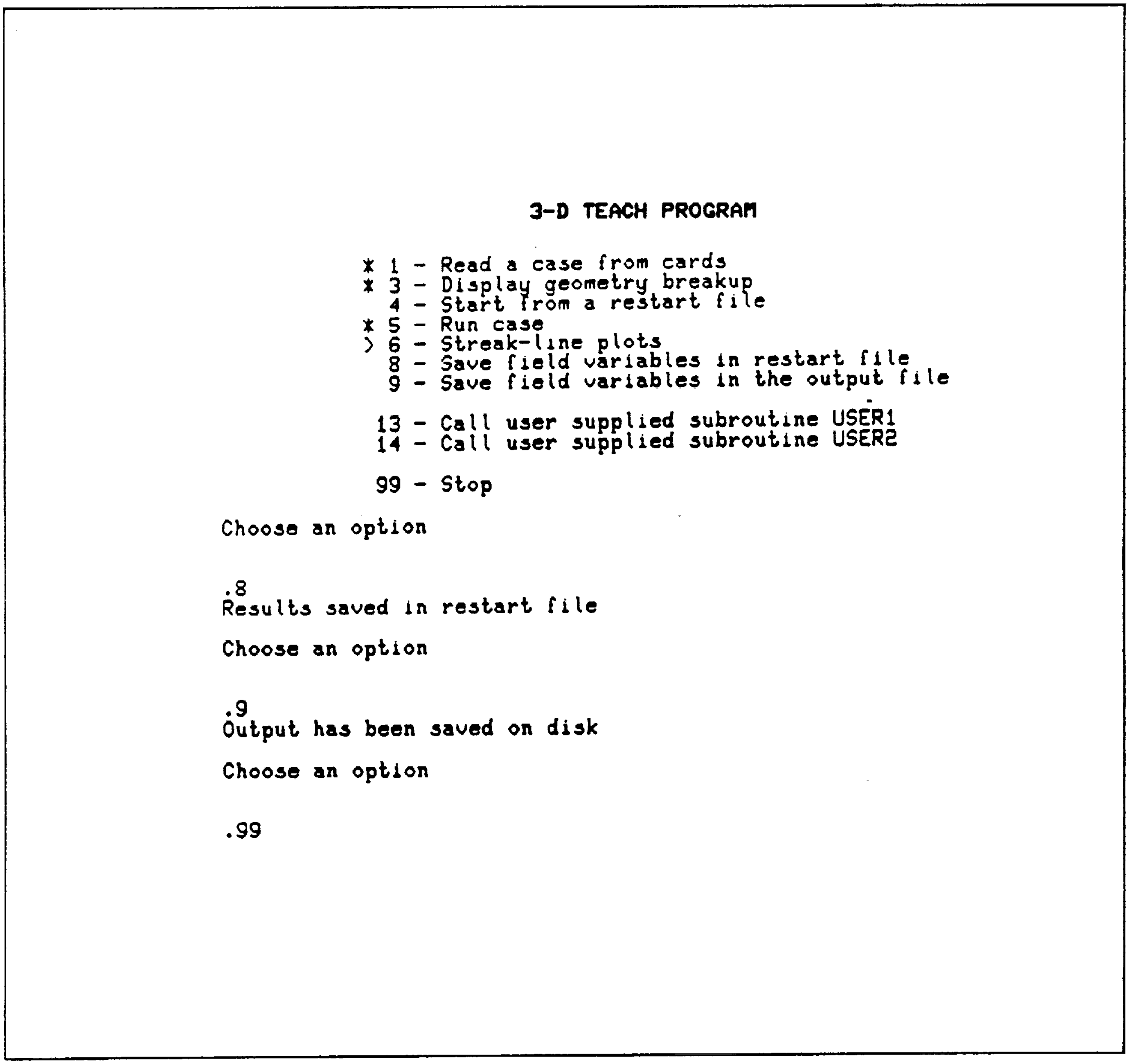


```
TYPE IN A NEW VALUE FOR A TIME STEP OR PRESS RETURN TO GET .51E-03..
TYPE IN A NEW VALUE FOR A NUMBER OF STEPS OR PRESS RETURN TO GET 16..
```

```
TYPE 'C' FOR A CALCOMP COPY - ELSE HIT RETURN TO CONTINUE.C
```

Option 9 places all field variables in the output file for printing later.

Option 8 is used to save all the field variables calculated by the program for restarting at a later time. This allows the user to continue running a case that had not converged yet, to plot the results in a later session, or to change the boundary conditions and start using the restart file as initial guesses thereby saving CPU time. Option 99 takes the user out of the 3D-TEACH program menu and returns to the system menu. In this menu the saved output file can be edited and printed if need be by using options EO and PO respectively. Sometimes the output file becomes too large to be edited inside the menu. In that case, it can usually be edited by coming out of the menu by typing ST and typing XE U571 OUTPUT D.



```
                      3-D TEACH PROGRAM

             * 1 - Read a case from cards
             * 3 - Display geometry breakup
               4 - Start from a restart file
             * 5 - Run case
             > 6 - Streak-line plots
               8 - Save field variables in restart file
               9 - Save field variables in the output file

              13 - Call user supplied subroutine USER1
              14 - Call user supplied subroutine USER2

              99 - Stop

Choose an option

.8
Results saved in restart file

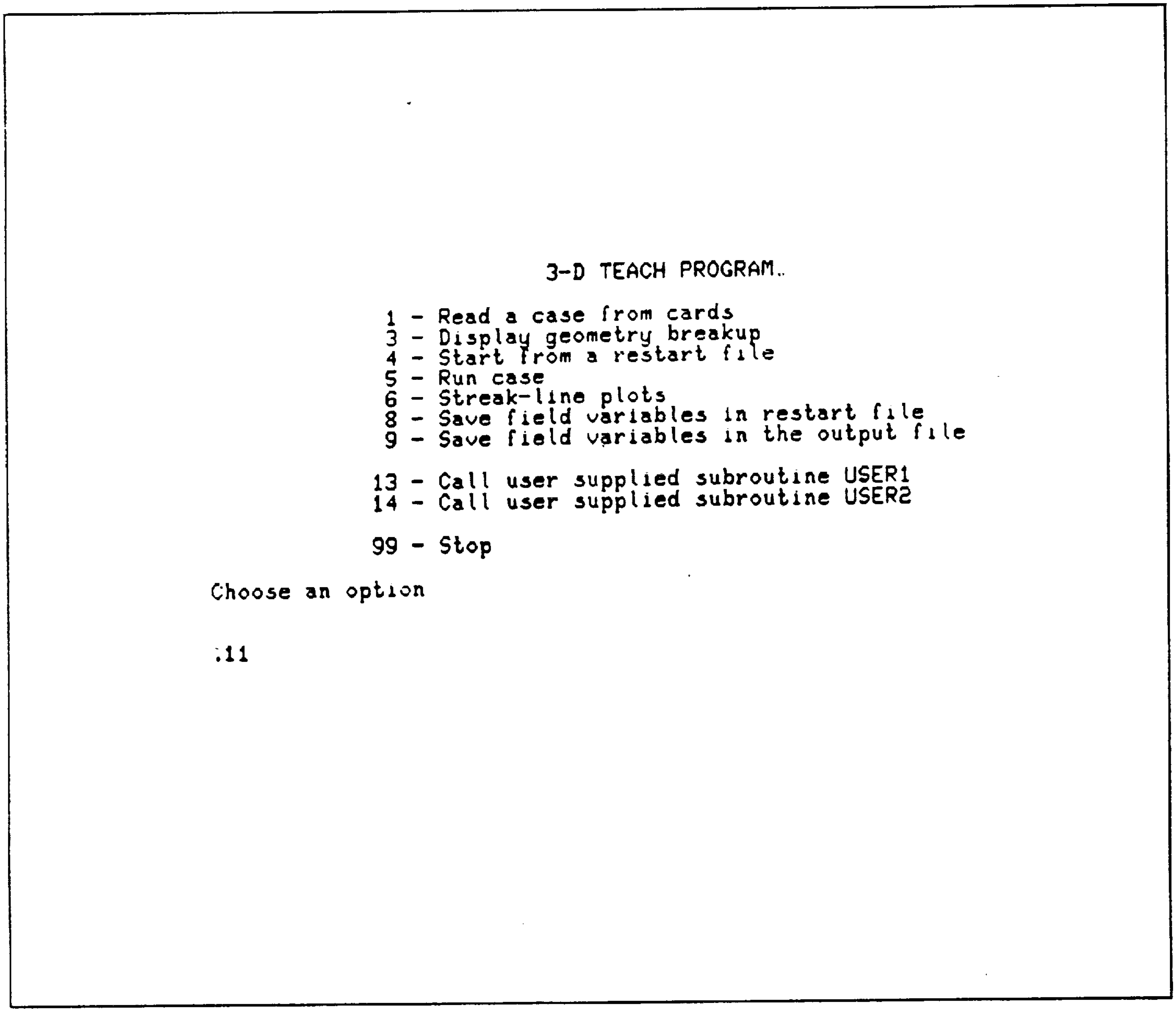
Choose an option

.9
Output has been saved on disk

Choose an option

.99
```

Occasionally a user is interested in printing or plotting parameters which are not calculated by the production version of TEACH. Two dummy subroutines in the prodcution version, called USER1 and USER2, have been provided as "place holders" to give users access to all the TEACH variables for calculation of special parameters. Either or both of these subroutines can be replaced by subroutines written by the user and invoked by selecting option 13 or 14 from the MAIN Menu ("Call user supplied subroutine USER1" or "call user supplied subroutine USER2" respectively). Because individual needs may vary, no explanation of how to write a user supplied subroutine will be given in the manual. The aid of a programmer familiar with TEACH should be solicited.



```
                  3-D TEACH PROGRAM..

          1 - Read a case from cards
          3 - Display geometry breakup
          4 - Start from a restart file
          5 - Run case
          6 - Streak-line plots
          8 - Save field variables in restart file
          9 - Save field variables in the output file

         13 - Call user supplied subroutine USER1
         14 - Call user supplied subroutine USER2

         99 - Stop

 Choose an option

 :11
```

4.0 SAMPLE CASES

Three cases are given in this section to give the user an idea of the range of problems that can be solved by TEACH. Much effort has been expended to make the input structured and logical. After setting up a few cases the user should be able to set up and modify new cases with little help from the manual. The three cases are arranged in order of complexity starting with a very simple case (Laminar Flow in a Pipe, case 17) to one having complex boundary conditions (JT9D Louver, case 23). The user should go through each case in order before attempting to set up a case on his own. Each sample case is chosen because of its similarities to and differences from the previous case so that an understanding of the philosophy behind the input can be gained a step at a time.

4.1 Laminar Flow in a Pipe

4.1.1 Problem

To model laminar airflow in a .1 ft diameter by 3.2 ft long pipe. The air at 15 psia and 70°F is entering the pipe with a uniform velocity profile of .1 ft/sec.

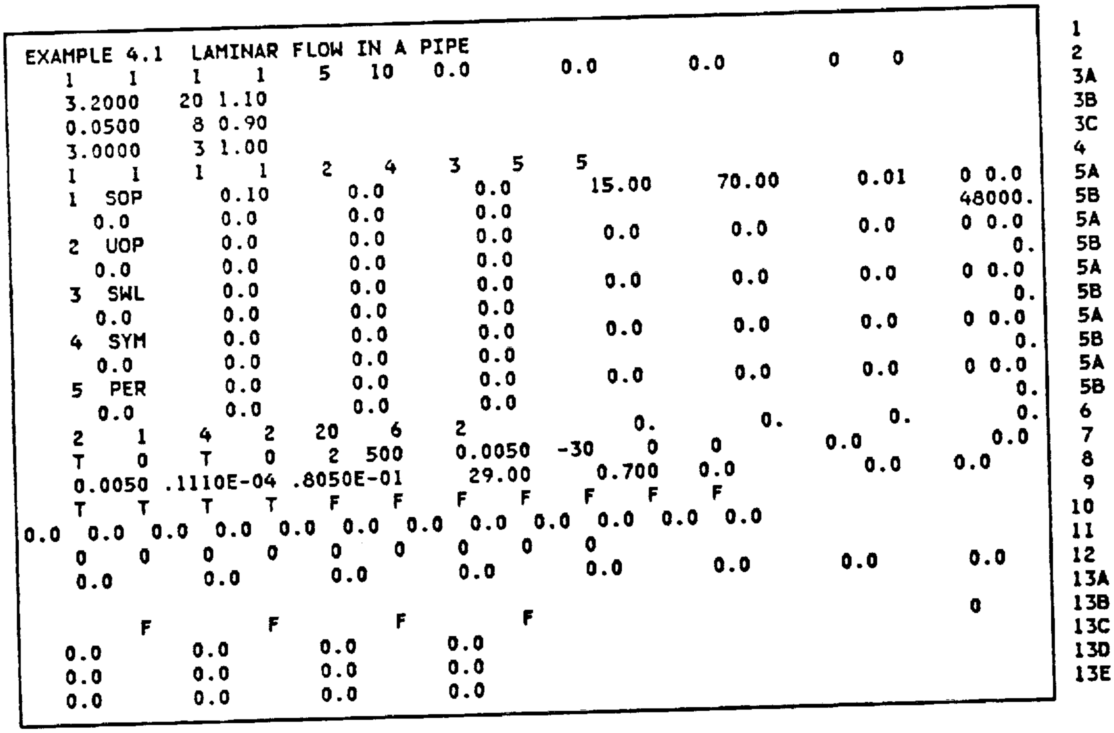
4.1.2 Input

This is a simple problem which can be modeled with one block. As a first pass, 20 cells are desired in the X-direction and 8 cells in the Y-direction. Because the velocity will be changing more rapidly in the vicinity of the inlet and more slowly downstream of the inlet, a finer grid has to be used in the inlet region. An expansion factor of 1.1 will provide this adequately (card 3A). As the boundary layer builds up with increasing distance from the inlet, some high velocity gradients will be present near the wall, requiring a fine breakup near the pipe wall. An expansion factor of .9 in the Y-direction will give the extra resolution needed near the wall (card 3B). There are no variations in properties in the Z-direction so making the section of the pipe being modeled three radians thick is arbitrary. One block has five boundary condition card pairs so five boundary condition card pairs (cards 5A and 5B) are needed. The first card pair describes the velocity, temperature, pressure, and the coefficient of turbulent kinetic energy for the inlet. The second card pair makes the east wall of the block an outlet in which fluid properties must be calculated by the program. The next card pair places a wall having a temperature of 70°F at the north boundary, the fourth pair makes the south boundary an axis of symmetry, and the last pair makes the front and back walls periodic.

The case indicator card (card 6) is set up to treat the problem as a body of revolution. All the field variables will be initialized to the value of cell (1,4,2) in the inlet and cell (20,6,4) will be monitored in the output. None of the other variables on the card require values for the case. Case indicator card 7 states that the flow is laminar, density is constant, the viscosity to be used is input, all input and output units are English, and temperature is constant. The card also sets a maximum residual source of .005 and maximum iterations to 100.

The fluid properties card (card 8) gives some of the constants required by the program. The calculation switches card (card 9) has turned on U-velocity, V-velocity, W-velocity, and pressure calculations. All the other cards in the input are left blank allowing the default values to be set by the program.

CARD INPUT:



```
EXAMPLE 4.1  LAMINAR FLOW IN A PIPE                                                        1
   1    1    1    1    5   10   0.0       0.0       0.0        0    0                    2
   3.2000   20 1.10                                                                      3A
   0.0500    8 0.90                                                                      3B
   3.0000    3 1.00                                                                      3C
   1    1    1    1    2    4    3    5    5                                              4
   1  SOP      0.10       0.0       0.0     15.00     70.00      0.01     0 0.0          5A
    0.0        0.0        0.0       0.0                                  48000.          5B
   2  UOP      0.0        0.0       0.0      0.0       0.0       0.0      0 0.0          5A
    0.0        0.0        0.0       0.0                                      0.          5B
   3  SWL      0.0        0.0       0.0      0.0       0.0       0.0      0 0.0          5A
    0.0        0.0        0.0       0.0                                      0.          5B
   4  SYM      0.0        0.0       0.0      0.0       0.0       0.0      0 0.0          5A
    0.0        0.0        0.0       0.0                                      0.          5B
   5  PER      0.0        0.0       0.0      0.0       0.0       0.0      0 0.0          5A
    0.0        0.0        0.0       0.0                                      0.          5B
   2    1    4    2   20    6    2           0.        0.        0.        0.          6
   T    0    T    0    2  500   0.0050  -30    0    0          0.0          0.0          7
   0.0050 .1110E-04 .8050E-01   29.00     0.700    0.0          0.0      0.0            8
   T    T    T    T    F    F    F    F    F    F    F                                   9
0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0                              10
   0    0    0    0    0    0    0    0    0                                            11
   0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0            12
                                                                         0              13A
        F         F         F         F                                                 13B
  0.0       0.0       0.0       0.0                                                     13C
  0.0       0.0       0.0       0.0                                                     13D
  0.0       0.0       0.0       0.0                                                     13E
```

Figure 21

Input for Laminar Flow in a Pipe

4.1.3 Output

Figures 21 and 22 show the card input before and after the program has added the defaults, respectively. Figure 23 shows the geometry plot. This case has an exact solution which TEACH can approach, with a sufficiently fine breakup, to a point which could, for all intents and purposes, be considered exact. In this case, even a coarse grid gives very good results. The exact solution is a parabolic velocity field having a velocity of 0.0 at the walls and a velocity of twice the average on the centerline (Figure 24).

```
INPUT WITH DEFAULTS:

 EXAMPLE 4.1  LAMINAR FLOW IN A PIPE                                             1
    1    1    1    1    5   10   0.0       0.0       0.0         0    0          2
    3.2000   20 1.10                                                             3A
    0.0500    8 0.90                                                             3B
    3.0000    3 1.00                                                             3C
    1    1    1    1    2    4    3    5    5                                    4
    1  SOP      0.10      0.0       0.0      15.00     70.00      0.01    0 1.00 5A
      0.0       0.0       0.0       0.0                                   48000. 5B
    2  UOP      0.0       0.0       0.0       0.0       0.0       0.0     0 1.00 5A
      0.0       0.0       0.0       0.0                                       0. 5B
    3  SWL      0.0       0.0       0.0       0.0       0.0       0.0     0 1.00 5A
      0.0       0.0       0.0       0.0                                       0. 5B
    4  SYM      0.0       0.0       0.0       0.0       0.0       0.0     0 0.0  5A
      0.0       0.0       0.0       0.0                                       0. 5B
    5  PER      0.0       0.0       0.0       0.0       0.0       0.0     0 1.00 5A
      0.0       0.0       0.0       0.0                                       0. 5B
    2    1    4    2   20    6    2           100.      100.        1. 1000000. 6
    T    0    T 1000    2  500    0.0050  -30    0    0       -1.00000       0.0 7
    0.0050 .1110E-04 .8050E-01     29.00     0.700   1.44000      0.0   0.25000 8
    T    T    T    T    F    F    F    F    F    F    F                          9
0.5000.5000.5001.0000.7000.7001.0000.7000.3000.7000.8001.000                     10
    3    3    3    5    3    3    3    3   10                                    11
    0.0900    1.0000    1.4400    1.9200    0.4187    9.7930    1.0000    0.9000 12
                                                                                 13A
         F         F         F         F                                  I      13B
   2.01600  32.00000  44.00999  18.01601                                         13C
   1.00000   1.00000   1.00000   1.00000                                         13D
   0.90000   0.90000   0.90000   0.90000                                         13E
    1    2    3    4            7.9370    1.0000    4.0000    2.0000             14
```

FIGURE 22

Input with Defaults for Laminar Flow in a Pipe

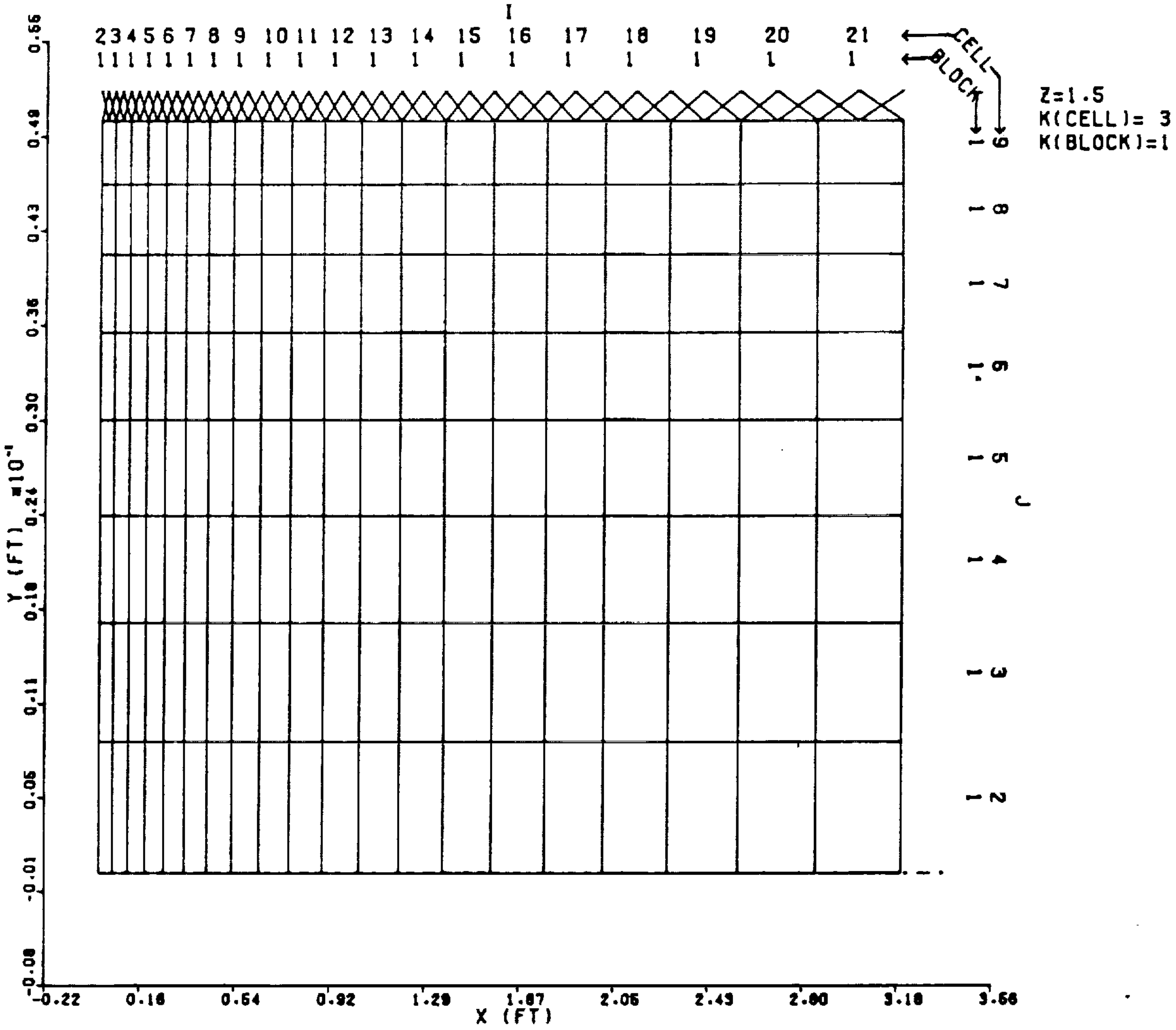


FIGURE 23

Grid Breakup for Laminar Flow in a Pipe

```
*-*-*-*-*-*-*-*-*-*-*-          U VELOCITY                                  AT Z( 3)= 1.5000              -*-*-*-*-*-*-*-*-*-*-*
  J     Y           2             3             4             5             6             7             8             9
 10   0.05199  0.0           0.0           0.0           0.0           0.0           0.0           0.0           0.0
  9   0.04801  1.00000E-01   2.78490E-02   1.92902E-02   1.74976E-02   1.67397E-02   1.63474E-02   1.61328E-02   1.60150E-02
  8   0.04359  1.00000E-01   6.97924E-02   5.68768E-02   5.24394E-02   5.04624E-02   4.94334E-02   4.88696E-02   4.85601E-02
  7   0.03868  1.00000E-01   9.95799E-02   9.07978E-02   8.59612E-02   8.34661E-02   8.21116E-02   8.13586E-02   8.09430E-02
  6   0.03322  1.00000E-01   1.19471E-01   1.18696E-01   1.16157E-01   1.14348E-01   1.13238E-01   1.12589E-01   1.12223E-01
  5   0.02716  1.00000E-01   1.31826E-01   1.39513E-01   1.41173E-01   1.41405E-01   1.41324E-01   1.41216E-01   1.41141E-01
  4   0.02042  1.00000E-01   1.38823E-01   1.53521E-01   1.59882E-01   1.63037E-01   1.64697E-01   1.65599E-01   1.66095E-01
  3   0.01294  1.00000E-01   1.42305E-01   1.61821E-01   1.72109E-01   1.78158E-01   1.81779E-01   1.83921E-01   1.85161E-01
  2   0.00462  1.00000E-01   1.43669E-01   1.65664E-01   1.78233E-01   1.86160E-01   1.91173E-01   1.94258E-01   1.96091E-01
  1  -0.00462  1.00000E-01   1.43669E-01   1.65664E-01   1.78234E-01   1.86160E-01   1.91173E-01   1.94258E-01   1.96091E-01
X=                0.0         0.05587       0.11733       0.18493       0.25930       0.34110       0.43108       0.53006
  J     Y          10            11            12            13            14            15            16            17
 10   0.05199  0.0           0.0           0.0           0.0           0.0           0.0           0.0           0.0
  9   0.04801  1.59520E-02   1.59200E-02   1.59048E-02   1.58985E-02   1.58964E-02   1.58959E-02   1.58958E-02   1.58951E-02
  8   0.04359  4.83948E-02   4.83109E-02   4.82716E-02   4.82558E-02   4.82510E-02   4.82507E-02   4.82509E-02   4.82492E-02
  7   0.03868  8.07210E-02   8.06091E-02   8.05575E-02   8.05379E-02   8.05334E-02   8.05345E-02   8.05359E-02   8.05340E-02
  6   0.03322  1.12027E-01   1.11931E-01   1.11889E-01   1.11876E-01   1.11876E-01   1.11881E-01   1.11885E-01   1.11883E-01
  5   0.02716  1.41102E-01   1.41089E-01   1.41090E-01   1.41100E-01   1.41113E-01   1.41125E-01   1.41133E-01   1.41134E-01
  4   0.02042  1.66371E-01   1.66525E-01   1.66614E-01   1.66668E-01   1.66703E-01   1.66726E-01   1.66740E-01   1.66743E-01
  3   0.01294  1.85859E-01   1.86243E-01   1.86451E-01   1.86564E-01   1.86628E-01   1.86665E-01   1.86686E-01   1.86693E-01
  2   0.00462  1.97137E-01   1.97714E-01   1.98023E-01   1.98186E-01   1.98274E-01   1.98323E-01   1.98349E-01   1.98359E-01
  1  -0.00462  1.97137E-01   1.97714E-01   1.98023E-01   1.98187E-01   1.98275E-01   1.98324E-01   1.98350E-01   1.98359E-01
X=              0.63894       0.75870       0.89044       1.03536       1.19476       1.37011       1.56299       1.77516
  J     Y          18            19            20            21            22
 10   0.05199  0.0           0.0           0.0           0.0           0.0
  9   0.04801  1.58931E-02   1.58895E-02   1.58841E-02   1.58768E-02   1.58256E-02
  8   0.04359  4.82439E-02   4.82339E-02   4.82182E-02   4.81966E-02   4.81456E-02
  7   0.03868  8.05262E-02   8.05107E-02   8.04858E-02   8.04508E-02   8.03998E-02
  6   0.03322  1.11874E-01   1.11854E-01   1.11821E-01   1.11774E-01   1.11723E-01
  5   0.02716  1.41124E-01   1.41100E-01   1.41061E-01   1.41004E-01   1.40952E-01
  4   0.02042  1.66734E-01   1.66708E-01   1.66663E-01   1.66599E-01   1.66547E-01
  3   0.01294  1.86684E-01   1.86657E-01   1.86609E-01   1.86539E-01   1.86487E-01
  2   0.00462  1.98351E-01   1.98324E-01   1.98274E-01   1.98201E-01   1.98149E-01
  1  -0.00462  1.98352E-01   1.98324E-01   1.98275E-01   1.98202E-01   1.98149E-01
X=              2.00855       2.26528       2.54767       2.85831       3.20001
```

FIGURE 24

Axial Velocity Field for Laminar Pipe Flow

4.2 Turbulent Flow in a Channel

4.2.1 Problem

To model turbulent flow in a .05 ft wide by 4. ft long channel. The air at 15 psia and 70°F is entering the channel with a uniform velocity profile of 93. ft/sec and an energy dissipation of 48261 ft^2/sec^2. The air at the inlet has a Re = 67446, which means that the flow is turbulent.

4.2.2 Input

The block breakup is the same as the previous sample case with the exception that a finer grid (25X16) is being used and there is no axis of symmetry, so the boundary condition description cards for that are eliminated. The north and south wall use the same boundary condition description card pair (cards 5A and 5B). The case indicator cards have been changed to indicate turbulent flow, with viscosity calculated every iteration. The maximum number of iterations allowed has been increased to 200 because of the finer breakup being used. The fluid properties (card 8) are the same as the previous case, so no change is made to this card. The calculation switches card (card 9) has been changed to turn on the calculation of kinetic energy and energy dissipation. The rest of the input is left blank allowing default values to be set by the program.

Figures 25 and 26 show the input without and then with defaults.

4.2.3 Output

Figure 27 shows the geometry breakup. All goemetry breakup plots show the boundaries of the scalar cells which are bounded on the west and east by u-velocity gridlines and on the south and north by v-velocity gridlines. Figures 28 and 29 show the U-velocity and pressure fields respectively (only the values near the inlet and exit are reproduced here). Note that the maximum velocity (103 ft/sec) is only 10% higher than the the average velocity (93 ft/sec) when the flow is turbulent.

CARD INPUT:

```
 EXAMPLE 4.2  TURBULENT FLOW IN A HALF PLANE CHANNEL  2-D                           1
    1    2    1    2    4   10   0.0       0.0       0.0        0    0              2
    4.0000   25 1.10                                                                3A
    0.0250    8 1.10                                                                3B
    0.0500    8 0.91                                                                3B
    3.0000    3 1.00                                                                3C
    1    1    1    1    2    3    0    6    6                                       4
    1    2    1    1    2    0    3    6    6                                       4
    1  SOP     93.00      0.0       0.0      15.00     70.00      0.01    0 0.0     5A
      0.0       0.0       0.0       0.0                                   48261.    5B
    2  UOP      0.0       0.0       0.0       0.0       0.0       0.0     0 0.0     5A
      0.0       0.0       0.0       0.0                                       0.    5B
    3  SWL      0.0       0.0       0.0       0.0       0.0       0.0     0 0.0     5A
      0.0       0.0       0.0       0.0                                       0.    5B
    6  PER      0.0       0.0       0.0       0.0       0.0       0.0     0 0.0     5A
      0.0       0.0       0.0       0.0                                       0.    5B
    1    1    4    2   25    8   20             0.        0.        0.        0.    6
    F    0    F    0    2  200    0.0050    0    0    0        0.0          0.0     7
    0.0050 .1110E-04 .8050E-01     29.00     0.700   0.0          0.0    0.0        8
    T    T    T    T    T    T    F    F    F    F    F                             9
0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0                          10
    0    0    0    0    0    0    0    0    0                                       11
    0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0       12
                                                                                    13A
         F         F         F         F                                  0         13B
   0.0       0.0       0.0       0.0                                                13C
   0.0       0.0       0.0       0.0                                                13D
   0.0       0.0       0.0       0.0                                                13E
```

FIGURE 25
Input for Turbulent Flow in a Channel

INPUT WITH DEFAULTS:

```
 EXAMPLE 4.2  TURBULENT FLOW IN A HALF PLANE CHANNEL  2-D                          1
    1    2    1    2    4   10   0.0       0.0       0.0        0    0             2
    4.0000   25 1.10                                                               3A
    0.0250    8 1.10                                                               3B
    0.0500    8 0.91                                                               3B
    3.0000    3 1.00                                                               3C
    1    1    1    1    2    3    0    6    6                                      4
    1    2    1    1    2    0    3    6    6                                      4
    1  SOP     93.00      0.0       0.0      15.00     70.00      0.01    0 1.00   5A
      0.0       0.0       0.0       0.0                                   48261.   5B
    2  UOP      0.0       0.0       0.0       0.0       0.0       0.0     0 1.00   5A
      0.0       0.0       0.0       0.0                                       0.   5B
    3  SWL      0.0       0.0       0.0       0.0       0.0       0.0     0 1.00   5A
      0.0       0.0       0.0       0.0                                       0.   5B
    6  PER      0.0       0.0       0.0       0.0       0.0       0.0     0 1.00   5A
      0.0       0.0       0.0       0.0                                       0.   5B
    1    1    4    2   25    8   20           100.      100.        1.  1000000.   6
    F    0    F 1000    2  200    0.0050    0    0    0       -1.00000       0.0   7
    0.0050 .1110E-04 .8050E-01     29.00     0.700   1.44000       0.0   0.25000   8
    T    T    T    T    T    T    F    F    F    F    F                            9
0.5000.5000.5001.0000.7000.7001.0000.7000.3000.7000.8001.000                       10
    3    3    3    5    3    3    3    3   10                                      11
    0.0900    1.0000    1.4400    1.9200    0.4187    9.7930    1.0000    0.9000   12
                                                                                   13A
         F         F         F         F                                  1        13B
   2.01600  32.00000  44.00999  18.01601                                           13C
   1.00000   1.00000   1.00000   1.00000                                           13D
   0.90000   0.90000   0.90000   0.90000                                           13E
    1    2    3    4              7.9370   1.0000    4.0000    2.0000              14
```

FIGURE 26
Input with Defaults for Turbulent Flow in a Channel

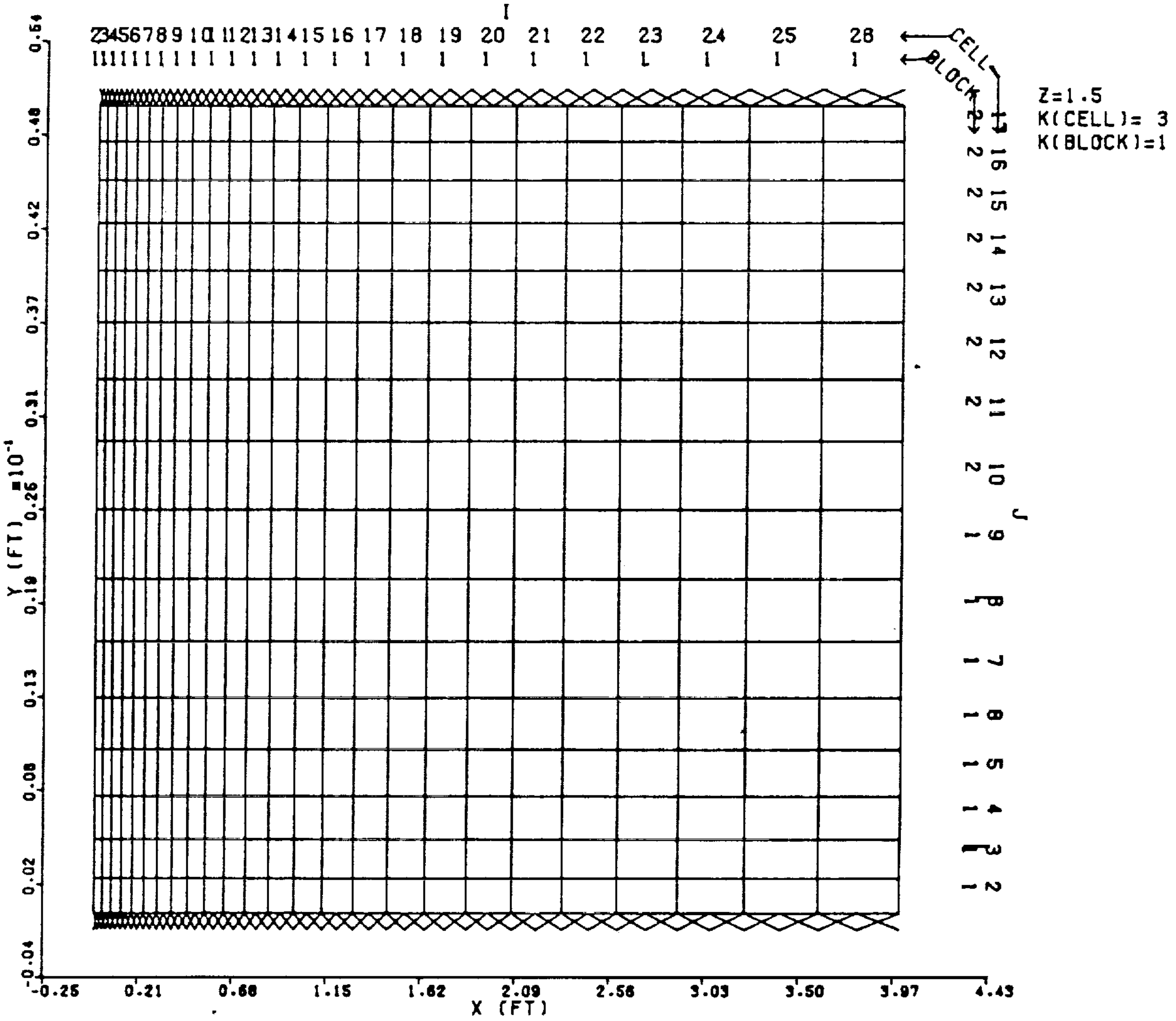


FIGURE 27

Grid Breakup for Turbulent Flow in a Channel

```
*-*-*-*-*-*-*-*-*-*-*-        U VELOCITY                                       AT Z( 3)= 1.5000          -*-*-*-*-*-*-*-*-*-*-*
  J    Y          2            3            4            5            6            7            8            9
 18  0.05104  0.0          0.0          0.0          0.0          0.0          0.0          0.0          0.0
 17  0.04896  9.30000E+01  8.76636E+01  8.29661E+01  7.89335E+01  7.55771E+01  7.29136E+01  7.09049E+01  6.94431E+01
 16  0.04667  9.30000E+01  9.25358E+01  9.15180E+01  9.01807E+01  8.86250E+01  8.69535E+01  8.52922E+01  8.37659E+01
 15  0.04415  9.30000E+01  9.34102E+01  9.35747E+01  9.35454E+01  9.33141E+01  9.28605E+01  9.21779E+01  9.13042E+01
 14  0.04138  9.30000E+01  9.36149E+01  9.41426E+01  9.45829E+01  9.49206E+01  9.51353E+01  9.52020E+01  9.50989E+01
 13  0.03833  9.30000E+01  9.36665E+01  9.43297E+01  9.49637E+01  9.55507E+01  9.60761E+01  9.65257E+01  9.68844E+01
 12  0.03498  9.30000E+01  9.36728E+01  9.43886E+01  9.51088E+01  9.58151E+01  9.64950E+01  9.71395E+01  9.77410E+01
 11  0.03129  9.30000E+01  9.36673E+01  9.44015E+01  9.51582E+01  9.59203E+01  9.66774E+01  9.74226E+01  9.81519E+01
 10  0.02723  9.30000E+01  9.36621E+01  9.44016E+01  9.51709E+01  9.59547E+01  9.67440E+01  9.75334E+01  9.83204E+01
  9  0.02277  9.30000E+01  9.36621E+01  9.44016E+01  9.51709E+01  9.59547E+01  9.67441E+01  9.75334E+01  9.83204E+01
  8  0.01871  9.30000E+01  9.36673E+01  9.44016E+01  9.51582E+01  9.59203E+01  9.66774E+01  9.74226E+01  9.81519E+01
  7  0.01502  9.30000E+01  9.36728E+01  9.43886E+01  9.51089E+01  9.58151E+01  9.64950E+01  9.71395E+01  9.77410E+01
  6  0.01167  9.30000E+01  9.36665E+01  9.43297E+01  9.49637E+01  9.55507E+01  9.60761E+01  9.65257E+01  9.68844E+01
  5  0.00862  9.30000E+01  9.36149E+01  9.41426E+01  9.45829E+01  9.49206E+01  9.51352E+01  9.52020E+01  9.50989E+01
  4  0.00585  9.30000E+01  9.34102E+01  9.35747E+01  9.35453E+01  9.33141E+01  9.28605E+01  9.21778E+01  9.13040E+01
  3  0.00333  9.30000E+01  9.25357E+01  9.15179E+01  9.01805E+01  8.86248E+01  8.69534E+01  8.52920E+01  8.37657E+01
  2  0.00104  9.30000E+01  8.76634E+01  8.29659E+01  7.89332E+01  7.55768E+01  7.29135E+01  7.09048E+01  6.94429E+01
  1 -0.00104  0.0          0.0          0.0          0.0          0.0          0.0          0.0          0.0
X=                0.0        0.04067      0.08541      0.13463      0.18876      0.24831      0.31381      0.38587
  J    Y          10           11           12           13           14           15           16           17
 18  0.05104  0.0          0.0          0.0          0.0          0.0          0.0          0.0          0.0
 17  0.04896  6.83888E+01  6.76195E+01  6.70513E+01  6.66348E+01  6.63417E+01  6.61546E+01  6.60589E+01  6.60402E+01
 16  0.04667  8.24576E+01  8.13918E+01  8.05542E+01  7.99164E+01  7.94502E+01  7.91315E+01  7.89391E+01  7.88530E+01
 15  0.04415  9.03289E+01  8.93619E+01  8.84904E+01  8.77610E+01  8.71878E+01  8.67662E+01  8.64837E+01  8.63231E+01
 14  0.04138  9.48196E+01  9.43873E+01  9.38586E+01  9.33067E+01  9.27968E+01  9.23721E+01  9.20528E+01  9.18417E+01
 13  0.03833  9.71345E+01  9.72589E+01  9.72496E+01  9.71185E+01  9.69019E+01  9.66513E+01  9.64148E+01  9.62258E+01
 12  0.03498  9.82905E+01  9.87750E+01  9.91765E+01  9.94762E+01  9.96626E+01  9.97411E+01  9.97362E+01  9.96835E+01
 11  0.03129  9.88613E+01  9.95435E+01  1.00186E+02  1.00772E+02  1.01278E+02  1.01682E+02  1.01969E+02  1.02138E+02
 10  0.02723  9.91031E+01  9.98765E+01  1.00631E+02  1.01353E+02  1.02021E+02  1.02608E+02  1.03085E+02  1.03427E+02
  9  0.02277  9.91031E+01  9.98764E+01  1.00631E+02  1.01353E+02  1.02021E+02  1.02608E+02  1.03085E+02  1.03427E+02
  8  0.01871  9.88614E+01  9.95435E+01  1.00186E+02  1.00772E+02  1.01278E+02  1.01682E+02  1.01968E+02  1.02137E+02
  7  0.01502  9.82905E+01  9.87751E+01  9.91765E+01  9.94762E+01  9.96626E+01  9.97410E+01  9.97356E+01  9.96818E+01
  6  0.01167  9.71344E+01  9.72589E+01  9.72495E+01  9.71184E+01  9.69018E+01  9.66510E+01  9.64140E+01  9.62239E+01
  5  0.00862  9.48195E+01  9.43872E+01  9.38585E+01  9.33066E+01  9.27966E+01  9.23717E+01  9.20519E+01  9.18397E+01
  4  0.00585  9.03287E+01  8.93617E+01  8.84902E+01  8.77608E+01  8.71875E+01  8.67658E+01  8.64828E+01  8.63210E+01
  3  0.00333  8.24574E+01  8.13916E+01  8.05540E+01  7.99162E+01  7.94500E+01  7.91311E+01  7.89383E+01  7.88512E+01
  2  0.00104  6.83886E+01  6.76193E+01  6.70512E+01  6.66346E+01  6.63415E+01  6.61542E+01  6.60582E+01  6.60388E+01
  1 -0.00104  0.0          0.0          0.0          0.0          0.0          0.0          0.0          0.0
X=                0.46513      0.55231      0.64822      0.75371      0.86975      0.99740      1.13781      1.29227
  J    Y          18           19           20           21           22           23           24           25
 18  0.05104  0.0          0.0          0.0          0.0          0.0          0.0          0.0          0.0
 17  0.04896  6.60817E+01  6.61635E+01  6.62630E+01  6.63583E+01  6.64328E+01  6.64778E+01  6.64935E+01  6.64870E+01
 16  0.04667  7.88516E+01  7.89105E+01  7.90028E+01  7.91018E+01  7.91857E+01  7.92418E+01  7.92666E+01  7.92656E+01
 15  0.04415  8.62632E+01  8.62794E+01  8.63441E+01  8.64284E+01  8.65083E+01  8.65676E+01  8.65992E+01  8.66053E+01
 14  0.04138  9.17294E+01  9.16976E+01  9.17225E+01  9.17778E+01  9.18402E+01  9.18922E+01  9.19245E+01  9.19357E+01
 13  0.03833  9.60993E+01  9.60339E+01  9.60178E+01  9.60338E+01  9.60645E+01  9.60958E+01  9.61183E+01  9.61285E+01
 12  0.03498  9.96159E+01  9.95545E+01  9.95087E+01  9.94796E+01  9.94646E+01  9.94591E+01  9.94582E+01  9.94580E+01
 11  0.03129  1.02206E+02  1.02199E+02  1.02146E+02  1.02075E+02  1.02006E+02  1.01952E+02  1.01916E+02  1.01897E+02
 10  0.02723  1.03622E+02  1.03681E+02  1.03640E+02  1.03544E+02  1.03435E+02  1.03342E+02  1.03277E+02  1.03241E+02
  9  0.02277  1.03621E+02  1.03679E+02  1.03636E+02  1.03538E+02  1.03427E+02  1.03333E+02  1.03268E+02  1.03232E+02
  8  0.01871  1.02203E+02  1.02193E+02  1.02136E+02  1.02060E+02  1.01986E+02  1.01929E+02  1.01893E+02  1.01876E+02
  7  0.01502  9.96119E+01  9.95468E+01  9.94952E+01  9.94595E+01  9.94382E+01  9.94288E+01  9.94276E+01  9.94303E+01
  6  0.01167  9.60948E+01  9.60254E+01  9.60032E+01  9.60122E+01  9.60364E+01  9.60638E+01  9.60864E+01  9.60999E+01
  5  0.00862  9.17249E+01  9.16890E+01  9.17082E+01  9.17569E+01  9.18133E+01  9.18618E+01  9.18943E+01  9.19090E+01
  4  0.00585  8.62590E+01  8.62716E+01  8.63310E+01  8.64095E+01  8.64842E+01  8.65404E+01  8.65724E+01  8.65816E+01
  3  0.00333  7.88479E+01  7.89037E+01  7.89917E+01  7.90857E+01  7.91652E+01  7.92186E+01  7.92437E+01  7.92453E+01
  2  0.00104  6.60789E+01  6.61583E+01  6.62545E+01  6.63461E+01  6.64170E+01  6.64599E+01  6.64756E+01  6.64710E+01
  1 -0.00104  0.0          0.0          0.0          0.0          0.0          0.0          0.0          0.0

X=                1.46217      1.64906      1.85463      2.08077      2.32952      2.60314      2.90413      3.23522
  J    Y          26           27
 18  0.05104  0.0          0.0
 17  0.04896  6.64645E+01  6.64541E+01
 16  0.04667  7.92464E+01  7.92397E+01
 15  0.04415  8.65934E+01  8.65910E+01
 14  0.04138  9.19316E+01  9.19329E+01
 13  0.03833  9.61296E+01  9.61328E+01
 12  0.03498  9.94586E+01  9.94618E+01
 11  0.03129  1.01891E+02  1.01893E+02
 10  0.02723  1.03228E+02  1.03229E+02
  9  0.02277  1.03221E+02  1.03221E+02
  8  0.01871  1.01874E+02  1.01875E+02
  7  0.01502  9.94359E+01  9.94385E+01
  6  0.01167  9.61064E+01  9.61091E+01
  5  0.00862  9.19100E+01  9.19109E+01
  4  0.00585  8.65743E+01  8.65715E+01
  3  0.00333  7.92299E+01  7.92228E+01
  2  0.00104  6.64514E+01  6.64406E+01
  1 -0.00104  0.0          0.0
X=                3.59941      4.00003
```

FIGURE 28

Axial Velocity Field for Turbulent Channel Flow

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```
*-*-*-*-*-*-*-*-*-*-*-*-    STATIC PRESSURE    (LB/IN**2)    AT Z( 3)= 1.5000    -*-*-*-*-*-*-*-*-*-*-*-*

 J     Y          1             2             3             4             5             6             7             8
18  0.05104  0.0           0.0           0.0           0.0           0.0           0.0           0.0           0.0
17  0.04896  1.50001E+01   1.49817E+01   1.49806E+01   1.49794E+01   1.49783E+01   1.49770E+01   1.49757E+01   1.49743E+01
16  0.04667  1.50001E+01   1.49823E+01   1.49812E+01   1.49801E+01   1.49788E+01   1.49775E+01   1.49761E+01   1.49746E+01
15  0.04415  1.50001E+01   1.49823E+01   1.49812E+01   1.49801E+01   1.49789E+01   1.49777E+01   1.49763E+01   1.49749E+01
14  0.04138  1.50001E+01   1.49822E+01   1.49812E+01   1.49801E+01   1.49789E+01   1.49777E+01   1.49763E+01   1.49749E+01
13  0.03833  1.50001E+01   1.49822E+01   1.49812E+01   1.49801E+01   1.49789E+01   1.49777E+01   1.49763E+01   1.49750E+01
12  0.03498  1.50001E+01   1.49822E+01   1.49812E+01   1.49801E+01   1.49789E+01   1.49777E+01   1.49763E+01   1.49750E+01
11  0.03129  1.50001E+01   1.49821E+01   1.49812E+01   1.49801E+01   1.49789E+01   1.49776E+01   1.49763E+01   1.49750E+01
10  0.02723  1.50001E+01   1.49821E+01   1.49812E+01   1.49801E+01   1.49789E+01   1.49776E+01   1.49763E+01   1.49750E+01
 9  0.02277  1.50001E+01   1.49821E+01   1.49812E+01   1.49801E+01   1.49789E+01   1.49776E+01   1.49763E+01   1.49750E+01
 8  0.01871  1.50001E+01   1.49821E+01   1.49812E+01   1.49801E+01   1.49787E+01   1.49776E+01   1.49763E+01   1.49750E+01
 7  0.01502  1.50001E+01   1.49822E+01   1.49812E+01   1.49801E+01   1.49789E+01   1.49777E+01   1.49763E+01   1.49750E+01
 6  0.01167  1.50001E+01   1.49822E+01   1.49812E+01   1.49801E+01   1.49789E+01   1.49777E+01   1.49763E+01   1.49750E+01
 5  0.00862  1.50001E+01   1.49822E+01   1.49812E+01   1.49801E+01   1.49789E+01   1.49777E+01   1.49763E+01   1.49749E+01
 4  0.00585  1.50001E+01   1.49823E+01   1.49812E+01   1.49801E+01   1.49787E+01   1.49777E+01   1.49763E+01   1.49749E+01
 3  0.00333  1.50001E+01   1.49823E+01   1.49812E+01   1.49801E+01   1.49788E+01   1.49775E+01   1.49761E+01   1.49746E+01
 2  0.00104  1.50001E+01   1.49817E+01   1.49806E+01   1.49794E+01   1.49783E+01   1.49770E+01   1.49757E+01   1.49743E+01
 1 -0.00104  0.0           0.0           0.0           0.0           0.0           0.0           0.0           0.0
X=              -0.01937       0.01937       0.06198       0.10885       0.16040       0.21712       0.27950       0.34812
```

```
 J     Y          25             26             27
18  0.05104  0.0           0.0           0.0
17  0.04896  1.49255E+01   1.49195E+01   0.0
16  0.04667  1.49256E+01   1.49196E+01   0.0
15  0.04415  1.49257E+01   1.49197E+01   0.0
14  0.04138  1.49258E+01   1.49198E+01   0.0
13  0.03833  1.49259E+01   1.49199E+01   0.0
12  0.03498  1.49260E+01   1.49200E+01   0.0
11  0.03129  1.49261E+01   1.49201E+01   0.0
10  0.02723  1.49262E+01   1.49202E+01   0.0
 9  0.02277  1.49262E+01   1.49202E+01   0.0
 8  0.01871  1.49261E+01   1.49201E+01   0.0
 7  0.01502  1.49260E+01   1.49200E+01   0.0
 6  0.01167  1.49259E+01   1.49199E+01   0.0
 5  0.00862  1.49258E+01   1.49198E+01   0.0
 4  0.00585  1.49257E+01   1.49197E+01   0.0
 3  0.00333  1.49256E+01   1.49196E+01   0.0
 2  0.00104  1.49255E+01   1.49195E+01   0.0
 1 -0.00104  0.0           0.0           0.0
X=                3.40864       3.79018        4.20987
```

FIGURE 29

Pressure Field for Turbulent Channel Flow

.3 John Moore's Rotating Duct

.3.1 Problem

he case is a model of the experiment conducted by John Moore (Ref. 5). In this experment, a duct 72" x 3" x .75" was rotated at 175 RPM about an axis passing through the enter parallel to the 3" axis. A blower was used to flow the air through the duct. See igure 30.

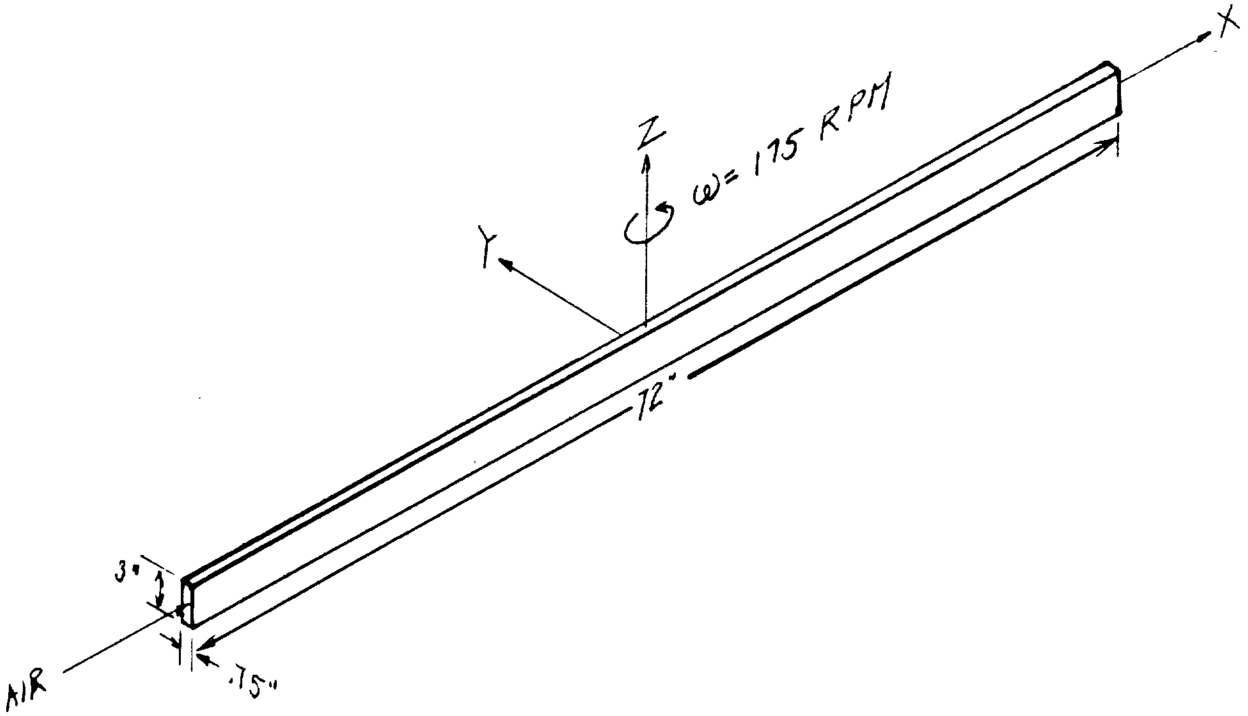

FIGURE 30
John Moore's Rotating Duct

4.3.2 Input

Figure 31 gives the cell breakup in the plane perpendicular to the flow. In order to accurately calculate the boundary layers, a finer breakup was used near the south and north walls (y=-.03125 ft and y=.03125 ft). Uniform breakups were used in the X and Z directions. Cross-sections of other directions are not shown because of the high aspect ratio of the length to height and length to width. Figure 32 shows the input for this case.

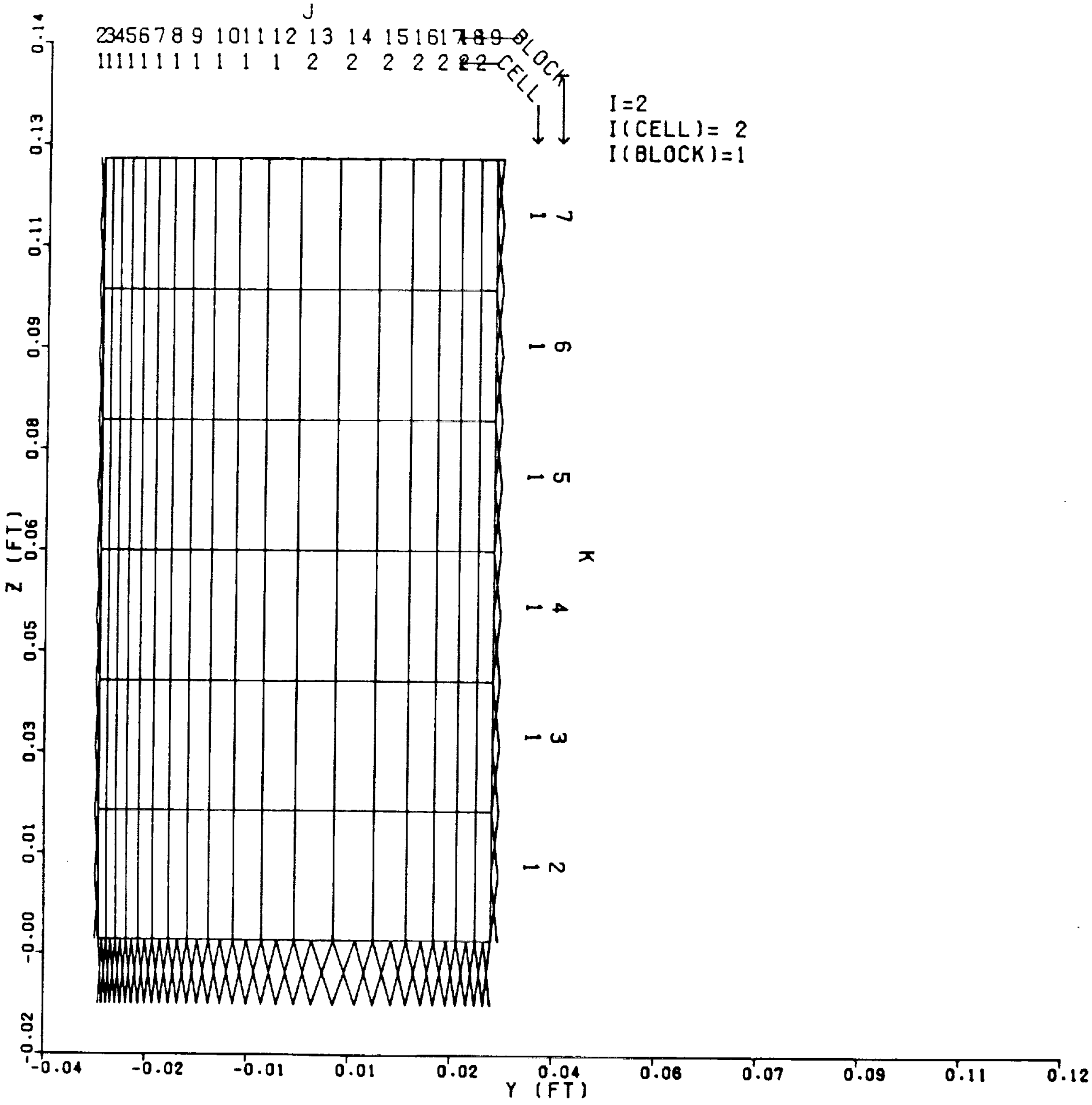

FIGURE 31

Cross Section of John Moore's Rotating Duct

CARD INPUT:

```
3-D TEACH  EXPERIMENTAL DUCT(J.MOORE) / AR = 4. / BELOW PLANE OF SYMMETRY         1
    2    2    1    4    4   10  -3.00000  -0.03125   0.0        0    1             2
    0.0       6 1.00                                                               3A
    3.0000    6 1.00                                                               3A
    0.0      11 1.15                                                               3B
    0.0312    7 0.83                                                               3B
    0.1250    6 1.00                                                               3C
    1    1    1   16    0    1    0    1    5                                      4
    2    1    1    0   13    1    0    1    5                                      4
    1    2    1   16    0    0    1    1    5                                      4
    2    2    1    0   13    0    1    1    5                                      4
    1  SWL      0.0       0.0       0.0       0.0     167.00      0.01    0 0.0    5A
      0.0       0.0       0.0       0.0                                       0.   5B
    5  SYM      0.0       0.0       0.0       0.0       0.0       0.0    0 0.0    5A
      0.0       0.0       0.0       0.0                                       0.   5B
   13  UOP      0.0       0.0       0.0       0.0       0.0       0.0    0 0.0    5A
      0.0       0.0       0.0       0.0                                       0.   5B
   16  SOP     55.00      0.0       0.0      14.70     60.00      0.01    0 0.0    5A
      0.0       0.0       0.0       0.0                                     453.   5B
    1    1    2    2    0    0    0           100.      100.        1. 1000000.   6
    F    0    F    0    2  800    0.0200  -10    0    0        0.0          0.10   7
 .0        .0        18.21                                                         7C
    0.0050 .1200E-04 .7700E-01     29.00     0.700   1.00000      0.0    0.24000   8
   0T  -1T  -1T  -1T  -1T  -1T   0F   0F   0F   0F   0F                            9
0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0  0.0                         10
    0    0    0    0    0    0    0    0    0                                      11
    0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0      12
                                                                                   13A
         F         F         F         F                                  0        13B
   0.0       0.0       0.0       0.0                                               13C
   0.0       0.0       0.0       0.0                                               13D
   0.0       0.0       0.0       0.0                                               13E
```

FIGURE 32

Input File for John Moore's Experiment

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3.3 Output

gure 33 shows the axial velocities in the duct at the plane of symmetry. The numbers in column represent the velocities as they vary from the south wall to the north wall. Be- use of Coriollis forces acting on the gas. The velocity is peaking off center as can be een by locating the highest velocity at each axial station.

```
*-*-*-*-*-*-*-*-*-*-*-*-          U VELOCITY                                       AT Z( 8)= .13542             -*-*-*-*-*-*-*-*-*-*-*
  J    Y           2            3            4            5            6            7            8            9
 20  0.03238  0.0          0.0          0.0          0.0          0.0          0.0          0.0          0.0
 19  0.03012  5.50000E+01  4.32019E+01  4.13195E+01  4.11653E+01  4.11568E+01  4.11620E+01  4.11452E+01  4.11089E+01
 18  0.02740  5.50000E+01  5.17081E+01  4.97293E+01  4.91673E+01  4.90435E+01  4.90056E+01  4.89620E+01  4.89042E+01
 17  0.02412  5.50000E+01  5.52985E+01  5.42788E+01  5.36673E+01  5.34635E+01  5.33810E+01  5.33106E+01  5.32346E+01
 16  0.02017  5.50000E+01  5.68128E+01  5.70555E+01  5.68285E+01  5.66634E+01  5.65621E+01  5.64710E+01  5.63791E+01
 15  0.01542  5.50000E+01  5.75324E+01  5.86898E+01  5.90711E+01  5.91265E+01  5.90802E+01  5.89962E+01  5.89014E+01
 14  0.00968  5.50000E+01  5.78945E+01  5.95838E+01  6.05106E+01  6.09127E+01  6.10263E+01  6.10089E+01  6.09450E+01
 13  0.00278  5.50000E+01  5.80447E+01  5.99751E+01  6.12158E+01  6.19154E+01  6.22444E+01  6.23672E+01  6.23967E+01
 12 -0.00278  5.50000E+01  5.80341E+01  5.99758E+01  6.12563E+01  6.20367E+01  6.24760E+01  6.27142E+01  6.28474E+01
 11 -0.00761  5.50000E+01  5.79317E+01  5.97571E+01  6.09227E+01  6.16513E+01  6.21223E+01  6.24444E+01  6.26762E+01
 10 -0.01181  5.50000E+01  5.77452E+01  5.93351E+01  6.02629E+01  6.08589E+01  6.13157E+01  6.16935E+01  6.20074E+01
  9 -0.01546  5.50000E+01  5.74610E+01  5.86807E+01  5.92803E+01  5.97202E+01  6.01499E+01  6.05618E+01  6.09329E+01
  8 -0.01863  5.50000E+01  5.70457E+01  5.77391E+01  5.79766E+01  5.82881E+01  5.86987E+01  5.91302E+01  5.95340E+01
  7 -0.02140  5.50000E+01  5.64373E+01  5.64383E+01  5.63545E+01  5.65912E+01  5.69951E+01  5.74366E+01  5.78544E+01
  6 -0.02380  5.50000E+01  5.55199E+01  5.46937E+01  5.43987E+01  5.46133E+01  5.50190E+01  5.54624E+01  5.58812E+01
  5 -0.02589  5.50000E+01  5.40665E+01  5.23976E+01  5.20399E+01  5.22698E+01  5.26783E+01  5.31158E+01  5.35255E+01
  4 -0.02770  5.50000E+01  5.15946E+01  4.93638E+01  4.90822E+01  4.93419E+01  4.97471E+01  5.01692E+01  5.05604E+01
  3 -0.02928  5.50000E+01  4.70677E+01  4.51052E+01  4.49705E+01  4.52489E+01  4.56359E+01  4.60291E+01  4.63898E+01
  2 -0.03065  5.50000E+01  3.83904E+01  3.75139E+01  3.75125E+01  3.77687E+01  3.81014E+01  3.84331E+01  3.87344E+01
  1 -0.03185  0.0          0.0          0.0          0.0          0.0          0.0          0.0          0.0
X=                -3.00000     -2.50000     -2.00000     -1.50000     -1.00000     -0.50000      0.0          0.50000
  J    Y          10           11           12           13           14
 20  0.03238  0.0          0.0          0.0          0.0          0.0
 19  0.03012  4.10718E+01  4.10515E+01  4.10582E+01  4.10856E+01  4.11888E+01
 18  0.02740  4.88502E+01  4.88193E+01  4.88217E+01  4.88548E+01  4.89581E+01
 17  0.02412  5.31678E+01  5.31287E+01  5.31273E+01  5.31626E+01  5.32659E+01
 16  0.02017  5.63011E+01  5.62547E+01  5.62496E+01  5.62850E+01  5.63884E+01
 15  0.01542  5.88197E+01  5.87709E+01  5.87648E+01  5.88013E+01  5.89047E+01
 14  0.00968  6.08812E+01  6.08443E+01  6.08466E+01  6.08894E+01  6.09929E+01
 13  0.00278  6.23982E+01  6.24071E+01  6.24407E+01  6.25038E+01  6.26074E+01
 12 -0.00278  6.29334E+01  6.30063E+01  6.30847E+01  6.31763E+01  6.32800E+01
 11 -0.00761  6.28531E+01  6.29992E+01  6.31310E+01  6.32571E+01  6.33607E+01
 10 -0.01181  6.22670E+01  6.24838E+01  6.26694E+01  6.28310E+01  6.29344E+01
  9 -0.01546  6.12534E+01  6.15248E+01  6.17531E+01  6.19442E+01  6.20475E+01
  8 -0.01863  5.98897E+01  6.01930E+01  6.04468E+01  6.06557E+01  6.07590E+01
  7 -0.02140  5.82248E+01  5.85411E+01  5.88047E+01  5.90204E+01  5.91237E+01
  6 -0.02380  5.62520E+01  5.65683E+01  5.68310E+01  5.70455E+01  5.71490E+01
  5 -0.02589  5.38866E+01  5.41940E+01  5.44487E+01  5.46567E+01  5.47602E+01
  4 -0.02770  5.09035E+01  5.11949E+01  5.14359E+01  5.16327E+01  5.17362E+01
  3 -0.02928  4.67045E+01  4.69714E+01  4.71922E+01  4.73711E+01  4.74746E+01
  2 -0.03065  3.89961E+01  3.92175E+01  3.94013E+01  3.95472E+01  3.96506E+01
  1 -0.03185  0.0          0.0          0.0          0.0          0.0
X=                 1.00000      1.50000      2.00000      2.50000      3.00000
```

FIGURE 33

Axial Velocities in the Plane of Symmetry

5.0 REFERENCES

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3. Roach, P. (1979), Computational Fluid Dynamics, Hermosa Publishers, Albuquerque.

4. Strugess, G. J., Datta P., (1984), PWA-5930-29, 'Task Report: Application of Computational Fluid Dynamics: Baseline CFD Code and modification for rotation with verification testing'.

5. Moore, J., "Effects of Coriolis on Turbulent Flow in Rotating Rectangular Channels," Gas Turbine Lab. Report No.89, Massachusettes Institute of Technology, May 1968.

.0 APPENDICES

.1 Appendix A - Nomenclature

Variables

Coefficient of the finite difference equation
Area of a cell face
Convection coefficient
Diffusion coefficient
Weighting factor in the finite difference equation
Weighting factor in the finite difference equation
Total energy
Specific enthalpy of the species
Thermal conductivity
Mass source
Mass fraction
Static pressure
Universal gas constant
Source term in the differential equation
Temperature
Time
Velocity in the x-direction
Velocity vector
Velocity in the y-direction
Velocity in the w-direction
Axial distance
Radial distance
Tangential distance
Exchange coefficient
Kinematic viscosity
Density
Stress

Subscripts

B	Back node
b	Back face
E	East node
e	East face
F	Front node
f	Front face
eff	Effective
i	Cell X-direction index number
j	Cell Y-direction index number
k	Cell Z-direction index number
l	Specie
N	North node
n	North face
P	Node being computed
S	South node
s	South face
W	West node
w	West face
x	Axial direction
y	Radial direction
z	Tangential direction

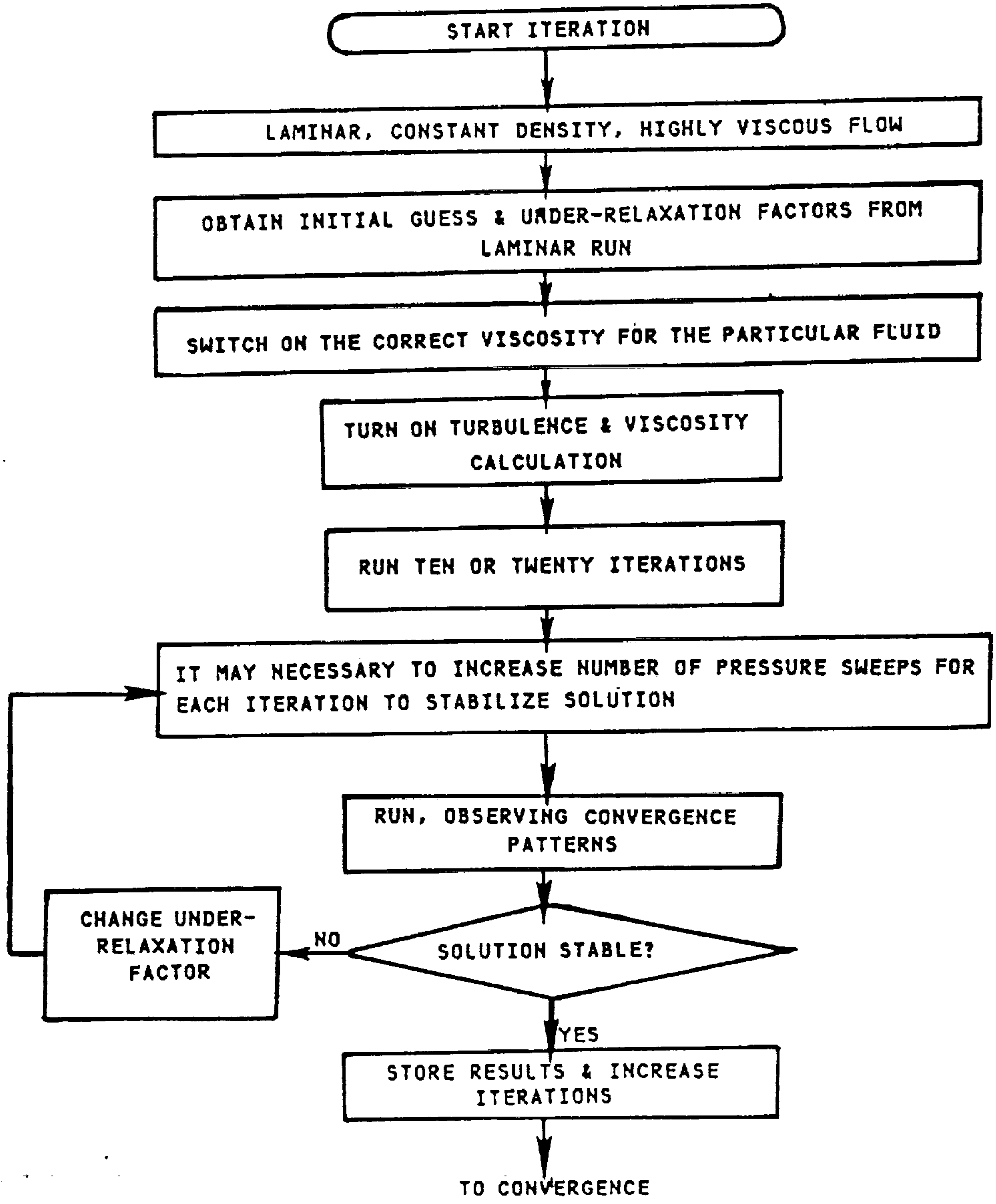
2 Appendix B - Graph Paper Codes

ode	No.	Description	Width
1	605	10 x 10 to the centimeter	11"
2	602	10 x 10 to the half inch	11"
3	500	Plain White	34"
4	505	10 x 10 to the centimeter	34"
5	502	10 x 10 to the half inch	34"
6	501	10 x 10 to the inch	34"
7	GC13813	Probability Paper-perforated	11"
8	605B	Centimeter - perforated	11"
9	500	Mylar	34"
0	600	Plain White	11"
1	GC13809-10817	A size half inch - perforated	11"
2	600	Mylar	11"
3	GC13812-10818	A size centimeter - perforated	11"
4	622	2-cycle full log	11"
5	640	4-log cycles x 10 div.	11"
6	GC13807	3 cycles - perforated	11"
7	GC13808	5 cycles - perforated	11"
8	601	10 x 10 to the inch	11"
9	600	With ballpoint pens	11"
1	10819	Weibull Prob. - perforated	11"
2	600	Mylar with Ballpoint pens	11"
9	500	Mylar with Ballpoint pens	34"
0	500	With ballpoint pens	34"
3	500	Vellum34"	

OTE: Should this parameter be omitted or invalid, graph paper code Number 02 (10 x 10 to the half inch, 11" wide) will be used when making the plot.

6.3 Appendix C - Flow Diagram For Calculating Potentially Unstable Problems

For complex problems the computer program may be unstable if all the flow complexities are 'turned on' at once. The following guidelines are meant to guide the user in obtaining a stable solution. The Flow Diagram provided below is only a guide and does not guarantee a stable solution.



.4 Appendix D - Warnings and Remedies

he following list of warnings and/or corresponding remedies have been collected as a reult of extensive use of 3D TEACH. Their appearance here is to help the user with common ccuring user solvable problems.

) Because initial guesses for enthalpies may not be consistent with the initial guesses or specie mass fractions, temperatures and densities calculated based on these could ause divergence of the solution procedure. To avoid this problem, density and temperture calculations are not turned on for at least 10 iterations.

) If, during the iterative process, a divide check occurs in LISOLV, it is possible that ll flow is going into or coming out of a single cell. If this is the case the user hould try perturbing the solution process by one of the following: a) put a contraction t the exit b) change the number of sweeps or the under-relaxation factor on the velocity alculations c) temporarily change the velocities on specified boundaries.

) Any blockage at an inlet must be at least two cells thick.

) An unspecified opening can not be used in conjunction with an adjoining blockage.

) No flow should be entering the calculation domain from an unspecified opening and the low should be parabolic. If negative flow is generated block part of the opening to acelerate the flow and make all flow positive.

) Stability and accuracy of the flow field depends on cell aspect ratios and the expanion ratio. Cell aspect-ratios greater than 10.0 will give rise to instabilities. Any alue greater than 1.0 will give rise to inaccuracy. This error will increase as the asect ratio is increased. Expansion ratios greater than 1.25 and less than 0.8 should also e avoided.

7) When using streakline plots it should be kept in mind that the combination of the size f the time step and the number of time steps should not be very large. A rule of thumb o follow would be that this time should not be more than one tenth of the time required or a particle to travel from one end of the geometry to the other. Special care should e taken when plotting streaklines near an outlet. In that case the time step should be less than the time required for the particle to exit the geometry.

6.5 Appendix E - Program Maximums

Variable	Card it appears on	Current Maximum Value
NXBLK	(Card Type 2)	58
NYBLK	(Card Type 2)	58
NZBLK	(Card Type 2)	16
NFBLK	(Card Type 2)	1500
NBC	(Card Type 2)	120
Sum of NX	(Card Type 3A)	58
Sum of NY	(Card Type 3B)	58
Sum of NZ	(Card Type 3C)	16

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16. ABSTRACT

This program solves the governing transport equations in Reynolds average form for the flow of a three-dimensional, steady state, viscous, heat conducting, multiple species, single phase, Newtonian fluid with combustion. The governing partial differential equations are solved in physical variables in either a Cartesian or cylindrical coordinate system. The effects of rotation on the momentum and enthalpy calculations modeled in Cartesian coordinates. The flow of the fluid should be confined and subsonic with a maximum Mach number no larger than 0.5. This manual describes the operating procedures and input details for executing a 3D-TEACH computation.

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