Space Shuttle Main Engine
High Pressure Fuel Pump
Aft Platform Seal Cavity
Flow Analysis

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I. INTRODUCTION

In working to improve the performance of the Space Shuttle Main Engine (SSME), the engineer is confronted with the difficult task of analyzing a complex engine system running under extreme operating conditions. The temperatures in the Shuttle's engines range from 37°C up to 5000°C, pressure vary from 20 to 8000 psi, and the engines' pumps rotate at speeds up to 37,000 rpm. Direct measurement of the engine environment is often impractical. Indeed, the particular area under consideration may be virtually inaccessible to instrumentation. Fortunately, the capability of modeling heat and mass transfer using computers has advanced to the point where computational fluid dynamics (CFD) can provide an alternate method of analyzing the engine. When used to model the various components and processes in the engine, numerical analysis can provide the engineer with valuable insight by allowing him or her to examine a wide range of operating conditions. The effect of a change in geometry, of a change in flowrate, or of a change in any parameter can be examined. Even a simple numerical model can demonstrate the sensitivity of the engine system to such changes, and a sophisticated numerical model, especially when used in conjunction with measured data, is a highly effective analytical tool.

In the current application, a general-purpose CFD code named PHOENICS, developed by CHAM Inc., is used to model the temperatures, pressures, and velocities in the SSME's High Pressure Fuel Turbopump (HPFTP) aft-platform seal cavity for a variety of boundary conditions and geometries. This cavity is located downstream of the fuel pump’s second turbine disk, between the disk and the aft platform seal (Figs. 1 to 4). It is an annular cavity where 1400°C combustion products and 150°C coolant hydrogen mix in a complex flow pattern and then are vented into the pump’s turbine exhaust. An understanding of the flow field in this cavity is critical since there are at least two known problems in the High Pressure Fuel Pump which may be linked to the environment in this region. Specifically, these problems are (1) cracking of the second stage turbine blade shanks, and (2) hot gas leakage into the stack behind the aft platform seal (Fig. 4). The first problem, blade cracking, can severely limit the time a pump can operate before it must be rebuilt. The second problem, that of hot gas leakage, is potentially more severe since, in the extreme, it may cause the pump to shut down prematurely if the temperatures or pressures in the coolant liner behind the aft-platform seal exceed certain redlines.

Accordingly, the primary purpose of the present analysis is to investigate the two problem areas mentioned above. In doing so, the study addresses the following questions:

1) How severe is the temperature gradient in the region where the turbine blades are cracking?

2) What would be the temperature of any fluid which leaked from the cavity into the coolant liner?

The analysis addresses these questions, not only for the pump operating under normal conditions, but also for a range of off-design conditions since even a slight departure from the norm might have a radical effect on the flow pattern and temperatures in the aft-platform seal cavity. As such, the broad objective of this study is to develop a model flexible enough that it can examine the effect that boundary parameters such as clearances, pressures, and flowrates have on the flow pattern and temperatures in the cavity. Such a model must be general enough that it can support future analytical and experimental investigations of the HPFTP aft-platform seal cavity.
SSME POWERHEAD

- Oxidizer Preburner
- Fuel Preburner
- Fuel Turbopump
- Oxidizer Turbopump
- Preburner Boost Pump
- Main Combustion Chamber
- Nozzle Forward Manifold

Figure 1. The Space Shuttle Main Engine.
Figure 3. HPFTP turbine flow paths.

Figure 4. Aft-platform seal cavity.
II. PROBLEM DESCRIPTION

The region being modeled is the aft-platform seal cavity downstream of the second-stage turbine in the Space Shuttle's HPFTP. A close-up of the aft-platform seal cavity is provided in Figure 4. General views of the shuttle engine, the fuel pump, and the fuel pump turbine section are given in Figures 1 to 3. The dashed lines in the close-up view, Figure 4, represent the limits of the problem as specified in the model. The fluid properties and either the pressures or the flowrates at the boundaries must be input into the program. Unfortunately, the only available measurements of these parameters (i.e., temperature and pressure) are far removed from the inlets and exits of the aft-platform seal cavity. As such, the boundary conditions chosen as inputs rely heavily on an existing one-dimensional analysis of the HPFTP and must be used with caution [1].

Inspection of Figure 2, the HPFTP, will show that the aft-platform seal cavity is an axisymmetric annular cavity defined by stationary walls on one side and a rotating disk on the other. Flow enters the cavity through two inlets, one at the inner radius of the cavity and one near the outer radius of the disk. The flow leaves the region via the gap between the outer radius of the aft-platform seal and the blade lips. At high rpm (up to 37,000) the flow is a turbulent mixture of hydrogen and water at temperatures ranging from approximately 140°R to possibly as high as the turbine exhaust at 1700°R. Flowrates are on the order of 1 lbm/sec and pressures are in the range of 4000 psi.

The inlets and exits of the aft-platform seal cavity are described qualitatively below. The specific numbers used in this study, e.g., flowrates, pressures, etc., and the assumptions used in defining these numbers, can be found in the section on numerical model set-up.

A. Inlets

1. Coolant Inlets

At the inner radius of the cavity, approximately 0.3 lbm/sec of liquid hydrogen flows into the aft-platform seal cavity through a labyrinth seal. The source of this hydrogen is the coolant circuit which is fed by the discharge of the HPFTP (Fig. 3). In the two-dimensional model, this flowrate is calculated implicitly based on the pressure drop through the labyrinth seal. In the three-dimensional model, in the interest of computational economy, the coolant flowrate through the labyrinth seal is not calculated internally, but is simply set to the value predicted by the two-dimensional model operating with the same average clearances and flowrate through the blade shanks.

2. Hot Gas Inlet at the Blade Shanks

One wall of the aft-platform seal cavity is formed by the rotating disk upon which are mounted the second stage turbine blades. At the periphery of this disk, a mixture of coolant hydrogen and combustion products enters the cavity through the gap between the shank of one turbine blade and the next (Fig. 5). Since there are 58 blades in the second stage disk, there are, accordingly, 58 holes available for this hot gas mixture to flow through into the aft platform seal cavity from the high pressure side of the turbine disk. The flow pattern of the fluid entering through these holes is complex since the shanks of the blades are curved and the disk itself is rotating at up to 37,000 rpm.

In modeling this inlet, the 58 separate streams entering through the disk have been "smeared" in the circumferential direction into a single, continuous axisymmetric source. The flowrate and fluid properties at this inlet are prescribed based on predicted values, and the angular velocity of the fluid entering the cavity through these passages is assumed to have the same angular velocity as the disk.
Figure 5: HPFTP second-stage turbine disk with blades.
B. Exits

1. Exit Gap Between the Outer Diameter of the Aft-Platform Seal and the Blades

In this study, the single most important parameter which affects the flow pattern in the aft-platform seal cavity is the gap between the outer diameter of the aft platform seal and the lip of the turbine blades. This gap is very small, on the order of one hundredth of an inch, and it supports a high pressure drop of over 500 psi between the aft-platform seal cavity and the turbine exhaust. Any slight variation in this gap clearance will have a strong effect on the total flow and overall flow pattern in the cavity. In general, the actual flow exiting through this gap at a given location will respond to changes in the overall turbine discharge pressure, the circumferential variation in turbine discharge pressure, and any changes in the width of the gap. The latter could be due to a number of different causes, including: sideloads, dynamics, machining tolerances, eccentricity, or thermal expansion.

In the model, the exit pressure outside the gap is fixed at the best estimate for the turbine discharge pressure. The pressure drop across this exit is then related to the flowrate based on a loss coefficient times the local dynamic head.

2. Secondary Exit Hole

In one of the test runs discussed in this report, the aft-platform seal is modeled with a second exit in order to simulate a postulated leak. The leak was assumed to be around the bolts which secure the aft-platform seal to the lift-off seal stack (Fig. 4). The hole size, loss coefficient, and exit pressure of this second exit were chosen such that the resulting calculated flowrate would be approximately 0.2 lbm/sec. The leak rate of 0.2 lbm/sec was chosen because it is the maximum flowrate which could be leaking past the bolts. This last conclusion is based on experimental measurements of the pressure drops in the coolant liner cavity which is downstream of the postulated leak.

III. NUMERICAL MODEL SET-UP

CHAM Inc.'s general purpose computational fluid dynamics code, PHOENICS [2], has been employed for all the numerical studies described herein. To use PHOENICS, special purpose “satellite” and “ground station” sub-programs must be formulated whereby the built-in features can either be turned on or off or modified, as necessary. One set of the sub-programs adapted specifically for the HPFTP aft-platform seal cavity three-dimensional studies is listed, in full, in Appendix A. Full listings of the other adapted sub-programs used in this study are given in a separate CHAM report [3]. All of these sets of sub-programs are extensively annotated (via built-in “COMMENT” statements) so as to make then self-explanatory when read in conjunction with the PHOENICS User's Manual [4]. Consequently, no detailed line-by-line description is given here; however, the most relevant features are described below.

The two-dimensional calculations described herein have been performed by using the two-dimensional y/z, polar coordinate option of the code. Figure 6 shows the selected two-dimensional grid distribution. There are 1120 control cells, with 40 and 28 cells in the radial (IY) and (IZ) directions, respectively. Due to the (initially) assumed cyclic symmetry of the problem, only one control cell is required in the circumferential (IX) direction. However, to enable correct account to be taken of the wall shear stresses acting on the fluid entering between the blade shanks, the circumferential extent of the calculation domain is taken to be equal to the space between 2 consecutive blades (i.e., an angle of $1/58 \times 2 \pi \text{ deg}$, where $58 = \text{total number of blades}$).

In the three-dimensional calculation, the full three-dimensional x/y/z coordinate capabilities of PHOENICS were employed. The identical y/z grid distribution of the 2-dimensional calculations was retained with, in addition, 8 cells in the circumferential (IX) direction, such that a total of $8 \times 40 \times 28 = 8960$ control cells is used.
As depicted in Figure 3, the "cold" liquid hydrogen coolant enters axially, through the labyrinth seal, at the inner radius of the cavity. This "cold" hydrogen then joins with the mixture of "hot" hydrogen and water that flows into the cavity from between the blade shanks located at the outer radius of the rotating disk. The combined streams of fluid then exit beneath the blade lips, as also shown in Figure 3.

A. Assumptions/Model Details

The major assumptions and salient features of the physical models and the boundary conditions employed are described below.

1) All boundary surfaces (both stationary and rotating) have been assumed to be adiabatic.

2) The hydrogen and water mixture are treated as a single homogeneous fluid with mixture properties (density and laminar viscosity) and temperature deduced from the calculated mixture enthalpy and specified hydrogen and water property curve fit data as described in Appendix B.

3) The turbulence effects are presented by way of the two-equation (k-ε) model of turbulence. In this model, two parameters, viz: the turbulence kinetic energy, k, and its dissipation rate, ε, are computed from differential transport equations. Thus, it has the capability of representing both the local and history effects. The effective viscosity is expressed as:

\[ \mu_{\text{eff}} = \mu_{\nu} + C_{\mu} \rho \frac{k^2}{\epsilon} \]
where \( \mu_e \) is the laminar viscosity, \( C_\mu \) is an empirical constant and \( \rho \) is the local mixture density. In addition, four other empirical constants are assigned the values as recommended in original publications [4].

4) All boundary surfaces of irregular shape are accommodated in the present calculations by use of “cell porosities.” In this approach, each control cell is characterized by a set of fractions, in the range from 0 to 1. These fractions determine the proportion of the cell volume which is available for flow from the cell to its neighbor in a given direction. This practice is much more rigorous and accurate than the practice of using rectangular steps.

5) The wall shear stress is calculated by using the conventional wall functions which are based on the assumption of the logarithmic law of the wall. For partially blocked control cells, the wall stress is calculated for the projected surfaces parallel to the velocity components.

It should be noted that the PHOENICS (1981 version) built-in process for determining wall shear stress is restricted to a finite number of special regions, to be set via the satellite subroutine. For the complex aft-platform seal geometry, many such special regions would be necessary, in excess of the built-in maximum, and a special PHOENICS user subroutine program was written for the current problem to overcome this restriction. This user sub-program (GWALL) performs the identical job as the built-in PHOENICS “WALL” subroutine but is used via the PHOENICS ground station. A listing of GWALL is included in Appendix A.

6) In PHOENICS, an iterative finite-difference solution procedure is employed to solve the governing differential equations together with the above mentioned relations. The method is based on a fully implicit, conservative formulation. As a result there is no restriction on the selection of the grid and the magnitude of the time steps.

The variables calculated and/or solved for (and printed) in the seal cavity flow calculation include the following:

a. The fluid velocities in the 3 coordinate directions
b. The mixture enthalpy and deduced temperature
c. The (mass) concentration of water vapor
d. The turbulent kinetic energy and its dissipation rate
e. The static and total pressures
f. The mixture density and separate densities of both the hydrogen and water
g. The effective viscosity.

7) Boundary conditions are:

a. Prescribed mass flowrate, velocities, enthalpy, mixture ratio, and turbulence parameters at all inlets except for the two-dimensional solutions, in which case the flowrate through the labyrinth seal was computed based on a prescribed inlet pressure.

b. Prescribed exit pressure at all outlets, with the pressure drop related to the flowrate based on a specified loss coefficient times the dynamic head.
c. The incoming fluid enclosed between the blade shanks is assumed to rotate at the same speed as the adjacent disk surface.

8) The (phase change) freezing of the water is not accounted for; any water at temperatures below freezing is given the properties (density, etc.) of liquid water at freezing.

9) The effects of viscous heating have been ignored.

IV. TWO-DIMENSIONAL TEST RUNS

Three different two-dimensional test cases were run. The first of these was considered to be the basecase using the best estimate of the average conditions for the pump operating at the full power level (FPL). A second test run was made with a reduced amount of coolant entering through the labyrinth seal in order to determine the sensitivity of the solution to the ratio of hot gas flowing in at the blades relative to the hydrogen entering at the labyrinth seal. Finally, a third two-dimensional test run was made in order to see what effect a postulated leak through the stack bolts would have on the calculated cavity temperatures and flows. These three test runs and results are described in more detail below.

A. Two-Dimensional Test Runs: Boundary Conditions

1. Basecase 2-D

The basecase two-dimensional run uses boundary conditions and operating clearances taken from a one-dimensional flow analysis provided by Lockheed, Inc. [1]. These boundary conditions are tabulated in Table 1. It should be noted that for this particular run, the boundary condition specified at the labyrinth seal is that of a prescribed pressure boundary from which the flowrate is then deduced based on the following relationship [5]:

\[
\text{MASSFLOW} = FC \times \text{AREA} \times \text{SQRT}\left(\frac{\text{RHO} \times \text{PO} (1 - (\text{PN} / \text{PO})^2))}{(\text{NUMBER OF TEETH} + \text{ALOG} (\text{PO} / \text{PN}))}\right)
\]

**WHERE** \(\text{PO} = \text{UPSTREAM PRESSURE}; \text{PN} = \text{DOWNSTREAM PRESSURE}; \text{FC} = \text{FLOW COEFF}.\)

(Note that for the basecase test run, the above equation when coupled with the PHOENICS two-dimensional model predicts a slightly lower flowrate through the labyrinth seal (0.26 lbm/sec versus 0.36 lbm/sec) as compared to the Lockheed one-dimensional model predictions.)

2. Reduced Coolant (Labyrinth) Flow

In the second run, the basecase two-dimensional model was modified by reducing the clearance at the outer diameter of the aft-platform seal while leaving all the other boundary conditions, including the hot gas flowrate, the same. When the gap size is reduced, the pressure in the cavity goes up and the coolant through the labyrinth seal decreases. The purpose here was to determine the effect that a reduction in coolant flow would have on the temperature field in the cavity.
3. Leak Through the Stack Bolts

The final two-dimensional run of the current study simulated a 0.2 lbm/sec leak through the stack bolts. The boundary conditions for this run were the same as the basecase but with a "hole" at the location shown in Figure 4. The loss coefficient at this hole and the hole size were chosen such that they dictated a leak rate of approximately 0.2 lbm/sec.

**TABLE 1. TWO-DIMENSIONAL BOUNDARY CONDITIONS**

<table>
<thead>
<tr>
<th>Variable</th>
<th>Basecase</th>
<th>Reduced Coolant</th>
<th>Leak</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rotational speed of the disk (RPM)</td>
<td>37,000</td>
<td>37,000</td>
<td>37,000</td>
</tr>
<tr>
<td>Gap size at the labyrinth seal (in.)</td>
<td>0.1069</td>
<td>0.1069</td>
<td>0.1069</td>
</tr>
<tr>
<td>Total flow area (360°) between the blade shanks (in.²)</td>
<td>3.877</td>
<td>3.877</td>
<td>3.877</td>
</tr>
<tr>
<td>Clearance between the aft-platform seal and blades (in.)</td>
<td>0.0108</td>
<td>0.0102</td>
<td>0.0108</td>
</tr>
<tr>
<td>Loss coefficient at the exit near the blade shanks</td>
<td>1.5</td>
<td>1.5</td>
<td>1.5</td>
</tr>
<tr>
<td>Enthalpy of the H₂ upstream of the labyrinth seal (Btu/lbm) (Resultant calculated temperature – degrees Rankine)</td>
<td>278.3 (145°R)</td>
<td>278.3 (145°R)</td>
<td>278.3 (145°R)</td>
</tr>
<tr>
<td>Enthalpy of H₂ and H₂O entering through the blades (Btu/lbm) (Resultant calculated temperature – degrees Rankine)</td>
<td>3558 (1466°R)</td>
<td>3558 (1466°R)</td>
<td>3558 (1466°R)</td>
</tr>
<tr>
<td>Density of the H₂ upstream of the labyrinth seal (lbm/ft³)</td>
<td>3.574</td>
<td>3.574</td>
<td>3.574</td>
</tr>
<tr>
<td>Density of H₂ and H₂O entering through the blades (lbm/ft³)</td>
<td>0.931</td>
<td>0.931</td>
<td>0.931</td>
</tr>
<tr>
<td>Mass flowrate of H₂ and H₂O entering past the blades (lbm/s)</td>
<td>3.649</td>
<td>3.649</td>
<td>3.649</td>
</tr>
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<td>Mass fraction of H₂O entering through the blades</td>
<td>0.474</td>
<td>0.474</td>
<td>0.474</td>
</tr>
<tr>
<td>Pressure at the turbine discharge (psi)</td>
<td>3582</td>
<td>3582</td>
<td>3582</td>
</tr>
<tr>
<td>Pressure at the labyrinth seal inlet (psi)</td>
<td>4254</td>
<td>4254</td>
<td>4254</td>
</tr>
<tr>
<td>Loss coefficient for the second (leak) exit</td>
<td>1.5</td>
<td>1.5</td>
<td>1.5</td>
</tr>
<tr>
<td>Total flow area at the second (leak) exit (in.²)</td>
<td>0</td>
<td>0</td>
<td>0.00019</td>
</tr>
</tbody>
</table>
B. Two-Dimensional Test Runs: Results and Observations

1. Basecase

According to the model, when the HPFTP is operating at full power, centrifugal force dominates the flow field and pressure field in the aft-platform seal cavity. This is not surprising when one considers that at 37,000 rpm and a radius of 4.5 in., the hot gas exits the blade shanks with a centrifugal force equal to approximately 175,000 g’s. Figures 7 and 8 show that there is virtually no penetration of the hot gas down into the aft-platform seal cavity and, as a result, the temperature in the cavity remains cold, at approximately 375°F. The flow pattern in the main cavity consists of two large co-rotating vortices which maintain the cavity at a relatively uniform temperature. The liquid hydrogen which enters through the labyrinth seal at the inner radius of the cavity flows radially outward along the face of the disk and then abruptly merges with the hot fluid stream exiting from between the shanks. While it appears from the drawing that the cold flow then recirculates, in fact all of the coolant which enters through the labyrinth seal must, by continuity, mix and then exit with the hot stream, resulting in the sharp temperature gradient at the blade shanks especially evident in the close-up view provided in Figure 8. The actual local gradients that the blade shanks would see would be more severe than predicted here since, in the model, the hot gas flow is treated as an axisymmetric source which would tend to smooth out the temperature gradients at the trailing edge of the blade shanks. In reality, there are 58 blade shanks between which the hot gas flows into the cavity. The cold fluid which is slung off the disk, up behind the trailing edge of the blade shanks, will be sheltered from the hot flow entering from between the blade shanks. As a result, the local mixing of hot and cold fluid will be delayed, and the local temperature gradient will be even more severe than shown here.

2. Reduced Coolant (Labyrinth) Flow

During the course of the study the question was raised as to what would happen if the proportion of coolant to hot gas flow were different that that predicted by the one-dimensional model used to define the boundary conditions [1]. In order to answer this question, the boundary conditions in the model are manipulated in a somewhat contrived manner in order to change the proportion of hot gas flow to coolant flow, viz: the coolant flowrate is reduced by slightly reducing the clearance between the aft-platform seal and the blade lips. The result is that a reduction of only six ten-thousandths of an inch (6 percent) of this clearance reduces the coolant flow by over half. This change, however, has little effect on the flow field in the cavity. As with the basecase, the flow in the cavity remains dominated by the centrifugal force. As shown in Figures 9 and 10, the temperature in the cavity has risen by only approximately 150 deg, up to 525°F, which is a moderate increase when compared with the hot gas inlet temperature of 1466°F. The conclusion is that the flow field and temperature field of the aft-platform seal cavity is relatively insensitive to the amount of coolant entering at the labyrinth seal relative to the amount of hot gas mixture entering through the blade shanks. However, the pressure and coolant flowrate are extremely sensitive to the exit clearance at the outer diameter of the aft-platform seal for a fixed hot gas inlet flow.

3. Leak Through the Stack Bolts

For the third two-dimensional test run, a “hole” is simulated underneath the bolts which secure the lift-off stack. The rationale behind such a study is that a flow leaking past these bolts into the coolant liner might be one explanation for the erratic temperatures and pressures sometimes recorded in the coolant liner. The exit area and loss coefficient at this hole are adjusted so that the calculated leakage rate is 0.2 lbm/sec. The flowrate of 0.2 lbm/sec comes from the best estimate of the upper limit of what the leak rate could be, based on the known temperature and pressure measurements in the liner [6]. Figures 11 and 12 show that a leak of 0.2 lbm/sec through the stack bolts does not dramatically change the flow field or temperature field as compared with the no-leak, baseline case. The temperature of the main cavity and the fluid leaking out past the bolts remains relatively unchanged at around 375°F (-85°F).
BASECASE
DSK 2D BC
O.D. GAP = .0109"
2-D SOLUTION

EXIT PRESSURE = 3558 PSI
FLOWRATE THROUGH THE BLADE SHANKS = 3.65 lbm/s
RESULTANT LABYRINTH FLOWRATE = .26 lbm/s

Figure 7. Two-dimensional basecase results.
BASECASE
DSK 2D BC
2D SOLUTION

EXIT PRESSURE = 3558 PSI
FLOWRATE THROUGH THE BLADE SHANKS = 3.65 lbm/s
RESULTANT LABYRINTH FLOWRATE = .26 lbm/s

Figure 8. Two-dimensional basecase results, expanded view.
Figure 9. Two-dimensional reduced coolant flow results.
EXIT PRESSURE = 3558 PSI

FLOWRATE THROUGH THE BLADE SHANKS = 3.65 lbm/s

RESULTANT LABYRINTH FLOWRATE = .12 lbm/s

Figure 10. Two-dimensional reduced coolant flow, expanded view.
SECOND EXIT

DSK 2D 2H

2-D SOLUTION

EXIT PRESSURE = 3558 PSI
FLOWRATE THROUGH THE BLADE SHANKS = 3.65 lbm/s
RESULTANT LABYRINTH FLOWRATE = .34 lbm/s
SECOND EXIT HOLE FLOWRATE = .20 lbm/s

Figure 11. Two-dimensional 0.2 lbm/s leak flow results.
SECOND EXIT
DSK 2D 2H
O.D. GAP = 0.0158" 
2-D SOLUTION

EXIT PRESSURE = 3558 PSI
FLOWRATE THROUGH THE BLADE SHANKS = 3.66 lbm/s
RESULTANT LABYRINTH FLOWRATE = 0.34 lbm/s
SECOND EXIT HOLE FLOWRATE = 0.20 lbm/s

Figure 12. Two-dimensional 0.2 lbm/s leak flow, expanded view.
C. Convergence Characteristics and Computer Time

Numerical solutions of flows involving rotating boundaries are notoriously slow to converge for a variety of reasons (not to be discussed here) and so it was deemed essential that careful checks be made to ensure that the PHOENICS solutions being obtained were meaningful. Thus, before the two-dimensional production runs described above were fully completed, a series of test calculations were performed to ensure that the solutions were converged to an acceptable degree. To this end, various runs were made for the basecase setup with different initial guess/starting solutions that were quite extensive. The results of these investigations are presented and discussed in Appendix C. As shown in the latter, the PHOENICS solutions are clearly converging to an identical solution in each case, as should (and must) be expected.

As depicted in Appendix C, the two-dimensional basecase was run for a total of 500 sweeps, at which time all calculated monitor flow variables had settled to an acceptable degree (Figs. C-1 to C-8). All the other 2-dimensional runs reported here were restarted from this basecase solution (i.e., the initial fields for the starting of the iterative calculation procedure were taken to be the basecase solution, rather than some simple initial guess) and then run on until, again, the solution monitor values were suitably settled. This usually required another 150 to 200 sweeps, at most. Computer times for these restart runs were approximately 35 CPU minutes on CHAM's Perkin Elmer 3251 mini-computer.

All the 3-dimensional calculations described in the next section were also restarted from the 2-dimensional basecase solution which was symmetrically duplicated in the circumferential IX-direction. Again, converged solutions then took approximately 150 to 200 more sweeps and required approximately 5 CPU hours of computer time on the Perkin-Elmer 3251 machine.

V. THREE-DIMENSIONAL TEST RUNS

The disadvantage of the preceding axisymmetric analysis is that, by definition, it does not include the three-dimensional effects either known or suspected to exist in the pump. One of the most important of these asymmetries left unaccounted for by the two-dimensional analysis is the circumferential variation in pressure which has been measured downstream of the exit of the fuel turbine. This exit pressure serves as one of the boundary pressures which regulates the flow in the aft-platform seal cavity. In addition to this known pressure variation, there may be variations in clearances or other parameters which could radically alter the flow pattern in the cavity. As such, a three-dimensional model is an essential tool for a proper study of this cavity. As a starting point, three different three-dimensional cases were run and are presented here. The first is the basecase which uses the same set of flowrates, fluid properties, and clearances as used in the two-dimensional basecase. The only difference between the two is that the three-dimensional basecase also includes a prescribed asymmetrical turbine exit pressure based on pressure measurements taken during a full scale test of the shuttle engine. The second three-dimensional case was set-up to simulate a 0.003 in. shift in the rotor position with a corresponding change in the clearance at the labyrinth seal and at the exit gap between the aft-platform seal and the blade lip. This shift is relative to the average labyrinth seal clearance of 0.003 in. and the average exit gap of 0.0108 in. The last three-dimensional run presented here simulates a relatively large eccentricity of the aft-platform seal alone, such that the exit clearance is skewed to one side by 0.0081 in., which is 75 percent of its average clearance.

A. Three-Dimensional Test Runs: Boundary Conditions

1. Basecase (Geometrically Axisymmetric with Asymmetric Exit Pressures)

As its boundary conditions, the basecase three-dimensional run uses the same operating clearances, flowrates, pressures, mixture ratios, and enthalpies, etc., as used by the two-dimensional basecase analysis. The
only exception is that the exit pressure of the turbine is no longer uniform but varies circumferentially based on data taken during Rocketdyne’s engine test 902-279 [7]. These boundary conditions are the best estimate of the operating conditions in the fuel pump at full power (109 percent). The specific numbers used for this run, and for the subsequent three-dimensional runs, are listed in Table 2.

2. Eccentric Rotor (Rotor Shift of 0.003 in.)

The Eccentric Rotor (0.003 in.) case was set up to simulate the effect that a rotor shift of 0.003 in. would have on the flow field in the cavity. The shift of 0.003 in. was chosen because it is an upper limit on the distance the rotor can shift before the shaft starts rubbing against the labyrinth seal. Such a rotor shift in a given direction would open up the exit clearance between the aft-platform seal and the blade lips, while at the same time it would close down the clearance at the labyrinth seal. This effect is simulated in the model by, on the one hand, directly adjusting the clearances at the outer diameter of the aft-platform seal and, on the other, by adjusting the flow rate at the labyrinth seal. All the other inputs remain the same as for the three-dimensional basecase.

**TABLE 2. THREE-DIMENSIONAL BOUNDARY CONDITIONS**

<table>
<thead>
<tr>
<th>Variable</th>
<th>Basecase</th>
<th>Rotor Eccentricity = 0.003 in.</th>
<th>Aft-Platform Eccentricity = 0.0081 in.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rotational speed of the disk (RPM)</td>
<td>37,000</td>
<td>37,000</td>
<td>37,000</td>
</tr>
<tr>
<td>Flowrate at the labyrinth seal (Ibm/sec)</td>
<td>0.0323</td>
<td>0.0095</td>
<td>0.0323</td>
</tr>
<tr>
<td>1:00</td>
<td>0.0323</td>
<td>0.0323</td>
<td>0.0323</td>
</tr>
<tr>
<td>2:30</td>
<td>0.0323</td>
<td>0.0551</td>
<td>0.0323</td>
</tr>
<tr>
<td>4:00</td>
<td>0.0323</td>
<td>0.0646</td>
<td>0.0323</td>
</tr>
<tr>
<td>5:30</td>
<td>0.0323</td>
<td>0.0551</td>
<td>0.0323</td>
</tr>
<tr>
<td>7:00</td>
<td>0.0323</td>
<td>0.0323</td>
<td>0.0323</td>
</tr>
<tr>
<td>8:30</td>
<td>0.0323</td>
<td>0.0095</td>
<td>0.0323</td>
</tr>
<tr>
<td>10:00</td>
<td>0.0323</td>
<td>0.0000</td>
<td>0.0323</td>
</tr>
<tr>
<td>11:30</td>
<td>0.0323</td>
<td>0.258</td>
<td>0.0323</td>
</tr>
<tr>
<td>Total Mass Flowrate</td>
<td>0.258</td>
<td>0.258</td>
<td>0.258</td>
</tr>
<tr>
<td>Total flow area (360°) between the blade shanks (in.²)</td>
<td>3.877</td>
<td>3.877</td>
<td>3.877</td>
</tr>
<tr>
<td>Clearance between the aft-platform seal and blades (in.)</td>
<td>0.0108</td>
<td>0.0129</td>
<td>0.0165</td>
</tr>
<tr>
<td>1:00</td>
<td>0.0108</td>
<td>0.0108</td>
<td>0.0108</td>
</tr>
<tr>
<td>2:30</td>
<td>0.0108</td>
<td>0.0087</td>
<td>0.0051</td>
</tr>
<tr>
<td>4:00</td>
<td>0.0108</td>
<td>0.0087</td>
<td>0.0051</td>
</tr>
<tr>
<td>5:30</td>
<td>0.0108</td>
<td>0.0108</td>
<td>0.0108</td>
</tr>
<tr>
<td>7:00</td>
<td>0.0108</td>
<td>0.0129</td>
<td>0.0165</td>
</tr>
<tr>
<td>8:30</td>
<td>0.0108</td>
<td>0.0138</td>
<td>0.1800</td>
</tr>
<tr>
<td>10:00</td>
<td>0.0108</td>
<td>0.0313</td>
<td>0.1800</td>
</tr>
<tr>
<td>11:30</td>
<td>0.307</td>
<td>0.307</td>
<td>0.307</td>
</tr>
<tr>
<td>Total Area</td>
<td>1.5</td>
<td>1.5</td>
<td>1.5</td>
</tr>
<tr>
<td>Loss coefficient at the exit near the blade shanks</td>
<td>278.3</td>
<td>278.3</td>
<td>278.3</td>
</tr>
<tr>
<td>(Resultant calculated temperature – degrees Rankine)</td>
<td>(145°R)</td>
<td>(145°R)</td>
<td>(145°R)</td>
</tr>
<tr>
<td>Enthalpy of H₂ entering at the labyrinth seal (Btu/Ibm)</td>
<td>3380</td>
<td>3380</td>
<td>2280</td>
</tr>
<tr>
<td>(Resultant calculated temperature – degrees Rankine)</td>
<td>(1466°R)</td>
<td>(1466°R)</td>
<td>(1466°R)</td>
</tr>
<tr>
<td>Enthalpy of H₂ and H₂O entering through the blades (Btu/Ibm)</td>
<td>3.574</td>
<td>3.574</td>
<td>3.574</td>
</tr>
<tr>
<td>Density of the H₂ entering at the labyrinth seal (lbm/ft³)</td>
<td>0.931</td>
<td>0.931</td>
<td>0.931</td>
</tr>
<tr>
<td>Density of H₂ and H₂O entering through the blades (lbm/ft³)</td>
<td>3.649</td>
<td>3.649</td>
<td>3.649</td>
</tr>
<tr>
<td>Mass flowrate of H₂ and H₂O entering past the blades (Ibm/s)</td>
<td>0.474</td>
<td>0.474</td>
<td>0.474</td>
</tr>
<tr>
<td>Mass fraction of H₂O entering through the blades</td>
<td>3451</td>
<td>3451</td>
<td>3451</td>
</tr>
<tr>
<td>Pressure at the turbine discharge (psi)</td>
<td>3451</td>
<td>3451</td>
<td>3451</td>
</tr>
<tr>
<td>1:00</td>
<td>3541</td>
<td>3541</td>
<td>3541</td>
</tr>
<tr>
<td>2:30</td>
<td>3697</td>
<td>3697</td>
<td>3697</td>
</tr>
<tr>
<td>4:00</td>
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<td>3622</td>
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<tr>
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<td>3606</td>
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<td>7:00</td>
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<td>3592</td>
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<tr>
<td>8:30</td>
<td>3476</td>
<td>3476</td>
<td>3476</td>
</tr>
<tr>
<td>10:00</td>
<td>3481</td>
<td>3481</td>
<td>3481</td>
</tr>
<tr>
<td>11:30</td>
<td>3558</td>
<td>3558</td>
<td>3558</td>
</tr>
<tr>
<td>Average Exit Pressure</td>
<td>20</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
3. Eccentric Aft-Platform Seal (Aft-Platform Seal Shift of 0.0081 in.)

The third three-dimensional test run models the flow field for a highly eccentric (75 percent) aft-platform seal. In this run the clearance at the gap between the aft-platform seal and the blade lips is adjusted so that it models what the gap would be if the aft-platform seal had moved laterally 0.0081 in. in the 11:30 direction. Note that the rotor itself has not moved but is still concentric with the labyrinth seal so that the gap between the labyrinth seal and the rotor axle remains at a uniform 0.003 in. (In general, the clocking positions used in this report correspond to the convention adopted by Rocketdyne in Reference 7, however, in this particular test run the decision to move the aft-platform seal in the 11:30 direction is arbitrary, and is based on convenience rather than any physical justification.) The choice of the magnitude of the eccentricity is also somewhat arbitrary but the reasoning behind the shift of 0.0081 in. was the desire to choose a large aft-platform eccentricity in order to observe extreme effects. An aft-platform shift of 0.0081 in. is 75 percent of the total aft-platform seal clearance.

B. Three-Dimensional Test Runs: Results and Observations

1. Basecase

A comparison of the three-dimensional basecase results (Figs. 13 to 21) with the two-dimensional basecase results (Figs. 7 and 8) shows that the addition of an asymmetric pressure distribution at the exit of the turbine has had little effect on the flow pattern in the aft-platform seal cavity. While some evidence of the influence of the external pressure distribution can be seen at the outer diameter of the disk near the blade shanks (e.g., Fig. 16), this effect is small; toward the center of the cavity the results are nearly identical to the two-dimensional solution. At the flowrates and small clearances of the aft-platform seal cavity running at full power, a circumferential pressure difference of 220 psi as modeled here represents only a fraction of the over 600 psi pressure drop between the aft-platform seal cavity and the turbine exhaust. As a result, the 220 psi circumferential variation on the outside of the cavity has little effect on the flow pattern inside. In addition, even with the circumferential variation in turbine exhaust pressure, the centrifugal force in the aft-platform seal cavity still dominates the flow such that the influence that is felt due to the pressure variation is confined to the periphery of the cavity. For an example of this effect, examine the lines of constant temperature given in the close-up view in Figure 17.

2. Eccentric Rotor (Rotor Shift of 0.003 in.)

Perhaps the most notable feature of the aft-platform seal cavity flow field (Figs. 22 to 30) with a 0.003 in. eccentric rotor is the small change as compared to the three-dimensional basecase with its centered rotor. Even with an eccentric rotor, the temperatures in the cavity have risen just 75°F, indicating only a slight increase in the heat transferred down into the cavity. Again, the only significant effect is felt at the outer diameter of the turbine disk where, at the 5:30 clock position, the hot gas actually flows down into the cavity causing a local hot spot. This hot spot will be felt by the blade shanks once per revolution, with a corresponding cooling in between. In general, therefore, a rotor shift of 0.003 in. results in a slight warming of the average cavity temperature, and a cyclical variation of temperature at the outer diameter of the disk of approximately 600°F.

3. Eccentric Aft-Platform Seal (Aft-Platform Seal Shift of 0.0081 in.)

Of the six different two-dimensional and three-dimensional test runs investigated during this study, the most dramatic results (Figs. 31 to 39) come from running the model with an aft-platform seal that has been shifted to one side by 3/4 of the exit clearance (i.e., by 0.0081 in.). With the exit gap substantially closed down on one side, the hot gas which would normally exit through that gap must, instead, exit at a different location. The centrifugal force
Figure 13. Three-dimensional basecase results: vectors.
Figure 14. Three-dimensional basecase results: vectors (close-up).
Figure 15. Three-dimensional basecase results: vectors (end view).
Figure 16. Three-dimensional basecase results: temperature.
Figure 17. Three-dimensional basecase results: temperature (close-up).
Figure 18. Three-dimensional basecase results: temperature (end view).
Figure 19. Three-dimensional basecase results: mass concentration.
Figure 20. Three-dimensional basecase results: static pressure.
BASECASE

DSK 32 BC

3-D SOLUTION

ASYMMETRICAL

EXIT PRESSURE

TOTAL PRESSURE (PSI)

SYMMETRICAL

SIDE VIEW

GAP (".010")

EXIT PRESSURE =
3505 PSI

11:30

4260 PSI

4230 PSI

EXIT PRESSURE =
3565 PSI

2:30

4260 PSI

4230 PSI

EXIT PRESSURE =
3615 PSI

8:30

4260 PSI

4230 PSI

EXIT PRESSURE =
3645 PSI

5:30

4260 PSI

4230 PSI

Figure 21. Three-dimensional basecase results: total pressure.
Figure 22. Three-dimensional eccentric (0.003 in.) rotor: vectors.
Figure 23. Three-dimensional eccentric (0.003 in.) rotor: vectors (close-up).
Figure 24. Three-dimensional eccentric (0.003 in.) rotor: vectors (end view).
Figure 25. Three-dimensional eccentric (0.003 in.) rotor: temperature.
Figure 26. Three-dimensional eccentric (0.003 in.) rotor; temperature (close-up).
Figure 27. Three-dimensional eccentric (0.003 in.) rotor: temperature (end view).
Figure 28. Three-dimensional eccentric (0.003 in.) rotor: Mass concentration.
Figure 29. Three dimensional eccentric (0.003 in.) rotor: static pressure.
Figure 30. Three-dimensional eccentric (0.003 in.) rotor: total pressure.
Figure 31. Three-dimensional eccentric (0.0081 in.) aft-platform seal: vectors.
Figure 32. Three-dimensional eccentric (0.0081 in.) aft-platform seal: vectors (close-up).
Figure 33. Three-dimensional eccentric (0.0081 in.) aft-platform seal: vectors (end view).
Figure 34. Three-dimensional eccentric (0.0081 in.) aft-platform seal: temperature.
Figure 35. Three-dimensional eccentric (0.0081 in.) aft-platform seal: temperature (close-up).
Figure 36. Three-dimensional eccentric (0.0081 in.) aft-platform seal: temperature (end view).
Figure 37. Three-dimensional eccentric (0.0081 in.) aft-platform seal: mass concentration.
Figure 38. Three-dimensional eccentric (0.0081 in.) aft-platform seal: static pressure.
Figure 39. Three-dimensional eccentric (0.0081 in.) aft-platform seal: total pressure.
on this hot gas still works to confine it to the outer radius of the cavity. However, the pressure differences in the radial direction are, in this case, becoming large enough that they are forcing more and more hot gas down into the cavity. This is clearly evident in the velocity diagrams (Figs. 31 and 32) where, at the 5:30 clock position, there is a strong inward flow of hot gas down into the cavity. The temperature profiles also indicate a dramatic increase in hot gas in the cavity. The temperatures at the center of the cavity are now up to 675°R (215°) which is 300° warmer than for the basecase. As with the other three-dimensional runs, the most pronounced effects can still be seen at the outer radius of the cavity. Here at the outer radius of the disk near the blade shanks, there is a large circumferential variation in both temperature and pressure with the temperature cycling 600°R and the pressure varying by 20 psi.

One further observation on the results from this test run has to do with the static pressure. The observation is that for a 0.0081 in. eccentric aft-platform seal, the pressure in the cavity has gone up by 80 psi relative to the three-dimensional basecase. The implications of this pressure rise are not simple to determine. The difficulty lies in the fact that such a pressure in the cavity would reduce the flow rate through the labyrinth seal, which, for the three-dimensional model is (numerically) fixed based on the flowrates calculated earlier in the two-dimensional basecase. Since the total exit areas and average turbine discharge pressure for all the three-dimensional runs are the same as for the two-dimensional basecase, this is a reasonable assumption. In this final three-dimensional case, however, the assumption leads to a contradiction. For the eccentric aft-platform seal case, using the flowrates from the two-dimensional basecase, the pressure at the exit of the labyrinth seal is calculated as being higher than the pressure at the labyrinth inlet. In other words, if in the three-dimensional model this boundary had been specified as a fixed pressure instead of a fixed flowrate, the model would have predicted reverse flow through the labyrinth seal. That there could actually be reverse flow through the labyrinth seal is considered extremely unlikely. What would more likely occur is that an eccentricity in the aft-platform seal would raise the pressure in the aft-platform seal cavity, reducing both the hot gas flow past the blade shanks and the labyrinth seal flow.

VI. SUMMARY OF THE CURRENT TEST RUN RESULTS AND OBSERVATIONS

The axisymmetric computer model of the aft-platform seal cavity indicates that at 37,000 rpm the flow in the aft-platform seal cavity is dominated by the centrifugal force caused by the rotating turbine disk. The disk drives a recirculating flow in the central region of the cavity, creating a core of nearly uniform temperature. In general, the temperature field throughout the aft-platform seal cavity is dictated primarily by convection (as opposed to conduction) as indicated by the fact that little heat from the hot gas at the periphery of the cavity is conducted down into the isothermal core. As a result, the core stays relatively cold, even when the coolant flowrate is reduced by over 50 percent.

The most severe temperature gradient in the aft-platform seal cavity occurs at the outer diameter of the turbine disk, near the blade shanks. At this location, the hot gas entering from between the blade shanks mixes with the coolant flow that is being slung off the face of the disk. The temperature difference between the two streams is over 1000°R.

The three-dimensional computer model of the aft-platform seal cavity shows that, for normal clearances and operating conditions, the flow field in the cavity is relatively insensitive to the circumferential pressure variation known to exist in the turbine discharge. The flow field is shown to be sensitive, however, to eccentricities of the exit gap between the aft-platform seal and the blade shanks. But in both cases, it is the centrifugal force which still dominates the flow pattern, such that any perturbation of the flow field or temperature field which results from either pressure changes or geometrical changes are, for the most part, confined by centrifugal force to the outer diameter of the cavity.
In addition to the above, the study also reveals that, for fixed flow through the blade shanks, the labyrinth flowrate is extremely sensitive to the exit area at the outer diameter of the aft-platform seal. While this result is somewhat misleading, since it is based on the unrealistic boundary condition of a fixed flowrate through the blade shanks, it nevertheless merits further consideration especially with regard to transient phenomena. Finally, as a related observation, the flowrate through the labyrinth seal is also sensitive to the eccentricity of the aft-platform seal clearance, even for a constant exit area. This sensitivity is something which has yet to be included in the current one-dimensional models of the flow through the pump’s turbine section.

VII. CONCLUSIONS

The results of the study summarized above provide the following insight into the specific problems which initiated the study, i.e., (1) the cracking of the HPFTP second stage blades, and (2) the suspected hot gas leakage into the coolant cavity behind the aft-platform seal bolts.

As far as the blade cracking is concerned, the model has shown that the second stage blade shanks are subjected to varying degrees of thermal stress, both steady state and once per revolution. The severity of this gradient has been shown to be sensitive to asymmetries in the external pressure and to variations in the geometrical clearances. At the time of this writing, however, it is believed that the primary cause of cracking is not due to thermal effects but is the result of a very high mean mechanical stress coupled with the moderate thermal stress. The proposed solution to alleviate the cracking is to recontour the shank in the high stress area, to shot-peen the surface to reduce the surface mean operating stress, and to coat the shanks to reduce the thermal stress [8].

As for the variations in coolant liner pressure and temperature thought to be indicative of a leak into the coolant liner, they remain an enigma. In order to gain a clearer understanding of this problem, the fluid temperatures calculated in the current study will be used as an input to the thermal stress analysis of the hardware. Prior to this study it was believed that the temperatures in the cavity were on the order of 900°F hotter than predicted here [8]. With a better estimate of the fluid temperature, the thermal stress analysis will be better able to predict the deformation of the aft-platform seal and the other components neighboring the aft-platform seal cavity. This will, in turn, generate improved estimates of the clearances and flowrates in the region.

The new flowrates estimated from the above will be fed back into the PHOENICS model for an improved analysis of the flow and temperature field in the cavity. Other changes which could be incorporated into the model would be to include the effect of heat transfer into the cavity and the viscous heating of the fluid itself, both of which will result in increases in the cavity temperature.

In addition to further analytical studies and improvements, there are plans to build a fuel pump that has pressure and temperature measurements built into the aft-platform seal, the labyrinth seal, the lift-off seal stack, and the coolant liner [8]. The test data from this instrumented pump, in conjunction with the computer model predictions should greatly increase the level of understanding of the operating environment of the high pressure fuel pump aft-platform seal cavity.
REFERENCES


APPENDIX A: PHOENICS COMPUTER CODE
SATELLITE AND GROUND ADAPTATIONS
FOR THE SPACE SHUTTLE MAIN ENGINE HPFTP
AFT-PLATFORM SEAL CAVITY 3-D MODEL
$BATCH
C$DIRECTIVE**SATLIT
C ***
C *FILE NAME: DSK32SAT.FTN
C ***
C *ABSTRACT: SATELLITE FOR SSME AFT-PLATFORM SEAL 3-D MODEL (2 EXITS)
C ***
C *DOCUMENTATION: PHOENICS INSTRUCTION MANUAL (SPRING 1983).
C *AUXILIARY SUBROUTINES (TAPEs, ETC.) ARE IN SATLITLITE LIBRARY
C SERVICE, WHICH MUST BE INCLUDED IN LINK EDIT TO RUN.
CXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX STANDARD SECTION 1 STARTS:
C--------------------------
CCHAPTER 1 COMMON BLOCKS AND USER'S DATA.
C--------------------------
C$INCLUDE 9,CMNUSSI.FTN/G
$INCLUDE 9,GSSEQUI.FTN/G
$INCLUDE 9,CMNFRIC.FTN/G
C
COMMON/CPI/IPWRIT.IDUM(243)
DIMENSION GDTRAPE(3),DFALT(4)
DIMENSION ARRAY1(309),ARRAY2(194),ARRAY3(421)
LOGICAL LSPDA,WRD,NDLST
INTEGER ARRAY2,XPLANE,YPLANE,ZPLANE
INTEGER PA,PPP,UT,UT2,VL,V2,WH,W1,WH1,WH2,WH3,WH4,WHC
C3,C4
REAL NORTH,LLOW
EQUIVALENCE (ARRAY1(1),CARTES),(ARRAY2(1),NX)
EQUIVALENCE (ARRAY3(1),SPARE1(1)),(M1,R1),(M2,R2)
EQUIVALENCE (LISTUN,INTGR(12)),(NDLST,LOGIC(88))
CXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX STANDARD SECTION 1 ENDS.
CXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX USER SECTION 1 STARTS:
C
GRAFIC ARRAYS DIMENSIONED AS NEEDED...
C ***
C
COMMON/GRAF1/PHI(134500)/GRAF2/PHI2(239500)
COMMON/GRAF1/PHI(1)/GRAF2/PHI2(1)
C ***
POROSITY & SPECIAL DATA ARRAYS DIMENSIONED AS NEEDED...
C ***
DIMENSION PE(8,40,28),PN(8,40,28),PH(8,40,28),PC(8,40,28)
DIMENSION LSPDA(1),ISPDA(1),RSPDA(37)
DIMENSION PEIX(8),GEXIT(8)
C ***
C USER PLACES HIS VARIABLES, ARRAYS, EQUIVALENCES ETC. HERE.
C ***
DATA NLSP,NISP,NSP/1,1,37/
EQUIVALENCE (RSPDA(17),PEIX(1)),(RSPDA(30),GEXIT(1))
C ***
C USER PLACES HIS DATA STATEMENTS HERE.
C ***
DATA PI,G,TINY/3.1416,32.174,1.E-10/
C ***
CXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX USER SECTION 1 ENDS.
CXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX STANDARD SECTION 2 STARTS:
C
CHAPTER 2 SET CONSTANTS, AND ARRANGE FILE MANIPULATIONS.
C--------------------------
C
PLEASE DO NOT ALTER, OR RE-SET, ANY OF THE REMAINING
C STATEMENTS OF THIS CHAPTER.
C
DATA CELL,EAST,WEST,NORTH,SOUTH,HIGH,LOW,VOLUME/1
& 0.1,2,3,4,5,6,7/
DATA P1,PP,U1,U2,V1,V2,W1,W2,R1,R2,RS,KE,EP,H1,H2,H3,C1,C2,
&3,34/1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20/
DATA FIXFLU,FIXVAL,ONLYMS,WALL/1.E-10,1.E10,0.0,-10.0/
DATA IPLACE,XPLACE,YPLACE,ZPLACE/0,1,2,3/
DATA WRD,WRD,FALUT/.TRUE.,.FALSE.,4HEFAL,4HALUT,4HTFA/.1HG/
DATA GDTAPE/4HQUI,4HE1.0,2HTA/
DATA NLDATA,NIDATA,NRDATA/309,194,421/
DATA NLREG,NCTVG/60,350/
CALL TAPES(10,GDTAPE,3,1,4,NRDATA)
C------------------------------------READ DEFAULT FILE IF BLOCKDATA ABSENT
C IF(INTGR1(29).NE.10) GO TO 2
C CALL WRIT4(4OHDATA ESTABLISHED IN BLOCK DATA. )
C GO TO 3
C 2 CALL TAPES(1,DFLUNT,4,2,4,NRDATA)
C CALL DATA(40,1)
C CALL WRIT4(4OHDATA TAKEN FROM DEFAULT,DYT DATA GROUP A/C)
C 3 CALL WRIT4(4OHFILE MODSTL.FTN IS THE SATLIT USED. )
C -------------------------------------------------------------
C CHAPTER 3  DEFINE DATA FOR NRUN RUNS
C -------------------------------------------------------------
C CXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX STANDARD SECTION 2 ENDS.
C CXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX USER SECTION 2 STARTS:
C C LOGIC(89)=.TRUE.
C DO 410 II=1,1
C 410 RUN(II)=.TRUE.
C C CC ************************************
C C CC ** SET GINC1 TO THE (LARGE) GAP HT (IN) AT THE COLD INLET
C GINC1 = .10693
C CC ** SET GEXIT1 * THE AVERAGE GAP CLEARANCE AT THE EXIT (INCHES)
C NB. SHOULD NOT BE LARGER THAN CELL WIDTH (=0.03333)
C GEXIT1 = .0108
C CC ** SET ECCENT * THE RADIAL ECCENTRICITY (INCHES) OF THE ROTOR IN
C THE CELL 1 (11:30) DIRECTION. THIS ECCENTRICITY WOULD NORMALY
C BE LIMITED BY THE CLEARANCE OF THE LABYRINTH SEAL (GINC1) AT
C ITS NARROWEST (IE WHERE "FEET" MEET SHAFT).
C THE ECCENTRICITY EFFECTS BOTH THE EXIT GAP AT THE HOT GAS EXIT
C AND THE DISTRIBUTION OF FLOW AT THE LABYRINTH SEAL INLET.
C GINC1=0.003
C C ECCENT = GINC1
C C CC ** SET GEXIT ARRAY TO ACTUAL REQUIRED GAP CLEARANCE AT EXIT (FEET)
C (SEE DESCRIPTION OF PEXIT ARRAY BELOW FOR CLOCKING CONVENTION)
C C NB. GEXIT ARRAY CALCULATIONS BELOW ARE GRID DEPENDENT!!!
C C CC SET GEXIT(1) TO AVERAGE GAP CLEARANCE AT 11:30
C GEXIT1=(&GEXIT1+GEXIT1+COS(0.)*ECCENT)/12.
C CC SET GEXIT(2) TO AVERAGE GAP CLEARANCE AT 10:00
C GEXIT2=(&GEXIT1+GEXIT1+COS(2.*PI/8.)*ECCENT)/12.
SET GEXIT(3) TO AVERAGE GAP CLEARANCE AT 8:30
GEXIT(3) = (GEXIT1 + COS(2. * PI/4.) * ECCENT) / 12.

SET GEXIT(4) TO AVERAGE GAP CLEARANCE AT 7:00
GEXIT(4) = (GEXIT1 + COS(2. * PI/3.) * ECCENT) / 12.

SET GEXIT(5) TO AVERAGE GAP CLEARANCE AT 5:30
GEXIT(5) = (GEXIT1 + COS(PI) * ECCENT) / 12.

SET GEXIT(6) TO AVERAGE GAP CLEARANCE AT 4:00
GEXIT(6) = (GEXIT1 + COS(2. * PI/5.) * ECCENT) / 12.

SET GEXIT(7) TO AVERAGE GAP CLEARANCE AT 2:30
GEXIT(7) = (GEXIT1 + COS(2. * PI/3.) * ECCENT) / 12.

SET GEXIT(8) TO AVERAGE GAP CLEARANCE AT 1:00
GEXIT(8) = (GEXIT1 + COS(2. * PI/7.) * ECCENT) / 12.

** SET AINH1 TO THE AREA (SQ IN) AT THE HOT INLET
AINH1 = 3.877

** SET ARGRD1 = THE HIGH FACE GRID AREA (SQ IN) AT THE HOT INLET
ARGRD1 = 8.143

** 1/SLICES = THE FRACTION OF 360 DEGREES BEING MODELLED
SLICES = 1.0

** PROPERTIES

** SET HIINC1 TO THE ENTHALPY (BTU/LBM) AT THE COLD INLET
HIINC1 = 278.3

** SET HIINH1 TO THE ENTHALPY (BTU/LBM) AT THE HOT INLET
HIINH1 = 3380.

** SET HEXIT1 TO THE ENTHALPY (BTU/LBM) OF THE TURBINE EXIT
HEXIT1 = 3895.4

** SET ROINC1 TO THE DENSITY (LBM / CU FT) AT THE COLD INLET
ROINC1 = 3.574

** SET ROINH1 TO THE DENSITY (LBM / CU FT) AT THE HOT INLET
ROINH1 = 0.931

** NOTE. THE DIRECTION OF ROTATION OF THE TURBINE IS
COUNTERCLOCKWISE ACCORDING TO THE CLOCKING CONVENTION

USED IN ROCKEDEYNE HPFTP INSTRUMENTED TURBINE TEST

DATA REPORT P9-17-82

THE PRESSURE OF 3562 IS AN AVERAGE OF

THE 3D DATA (3505, 3500, 3615, 3630, 3645, 3720, 3565, 3475) WHICH
COMES FROM TEST 902-279 FPL DATA - IT CORRESPONDS TO AN
AVERAGE COOLANT LINER PRESSURE OF 3800 PSI

!!! NB. VALUES BELOW INCREMENTED IN ACCORDANCE WITH NEW DATA

** SET PEXIT(1) TO THE PRESSURE (PSF) AT 11:30
PEXIT(1) = 144.0 * 3481.4

** SET PEXIT(2) TO THE PRESSURE (PSF) AT 10:00
PEXIT(2) = 144.0 * 3476.4

** SET PEXIT(3) TO THE PRESSURE (PSF) AT 8:30
PEXIT(3) = 144.0 * 3591.4

** SET PEXIT(4) TO THE PRESSURE (PSF) AT 7:00
PEXIT(4) = 144.0 * 3606.4

** SET PEXIT(5) TO THE PRESSURE (PSF) AT 6:30
PEXIT(5) = 144.0 * 3621.4

** SET PEXIT(6) TO THE PRESSURE (PSF) AT 5:30
PEXIT(6) = 144.0 * 3696.4

** SET PEXIT(7) TO THE PRESSURE (PSF) AT 2:30
PEXIT(7) = 144.0 * 3541.4

** SET PEXIT(8) TO THE PRESSURE (PSF) AT 1:00
PEXIT(8) = 144.0 * 3451.4

** SET PEXITA TO THE AVERAGE TURBINE DISCHARGE PRESSURE (PSF)
PEXITA = 144.0 + 3558.4

C**************************************************************
C SET UP EXIT PRESSURES AS UNIFORM
PEXIT(1) = PEXITA
PEXIT(2) = PEXITA
PEXIT(3) = PEXITA
PEXIT(4) = PEXITA
PEXIT(5) = PEXITA
PEXIT(6) = PEXITA
PEXIT(7) = PEXITA
PEXIT(8) = PEXITA
C**************************************************************
CC **** BOUNDARY CONDITIONS
CC
CC ** INPUT RPM
RPM = 37000.
CC ** SET FEEDC1 TO THE TOTAL MASS FLOWRATE (LM/B/S)
FEEDC1 = .2582
CC
CC ** SET FEEDH1 TO THE TOTAL MASS FLOWRATE (LM/B/S)
CC
FEEDH1 = .3649
CC
CC ** SET H20INH TO THE H2O MASS FRACTION AT THE HOT INLET
H20INH = .474
CC
CC ** SET H20XIT TO THE H2O MASS FRACTION AT THE TURBINE EXIT
H20XIT = .5
CC
CC ** SET GLOSS1 TO LOSS COEFFICIENT FOR LOSSES AT EXIT
CC
GLOSS1 = 1.5 + TINY
CC
C
CXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX USER SECTION 2 ENDS.
CXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX STANDARD SECTION 3 STARTS:
DO 10 IRUN = 1, 30
10 IF (.NOT. RUN(IRUN)) GO TO 10
IRUN = IRUN + 1
LSTRUN = IRUN
10 CONTINUE
DO 999 IRUN = 1, LSTRUN
999 IF (.NOT. RUN(IRUN)) GO TO 999
IRUN = IRUN + 1
C
CXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX STANDARD SECTION 3 ENDS.
CXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX USER SECTION 3 STARTS:
C-- ALL INTEGER VARIABLES ARE DEFAULTED TO 0, AND REAL VARIABLES
C TO 0.0, UNLESS OTHERWISE INDICATED.
C E.G. VARIABLE<10>, OR <10:0> AS APPROPRIATE.
C THE DEFAULT SETTINGS OF ALL LOGICAL VARIABLES ARE FALSE.
C INDICATED, E.G. VARIABLE<.T.>, OR VARIABLE<.F.>.
C
C C-- RUN1
C-- GROUP 1. FLOW TYPE:
C PARAB<.F.>, PARAB<.T.>, CARTES<.T.>, CARTES<.F.>
C CARTES = .FALSE.
C--
C-- GROUP 2. TRANSIENSE:
C STEADY<.T.>, ATIME<.T.>, FSTEP<1>
C TLAST<1.E10>, TFRACT<1.30> <30.1.>
C SERVICE SUBROUTINE FOR 'N' POWER-LAW TIME STEPS:
C CALL GRDPWR0,NT,TLAST,POWER

C---------------------
C--- GROUP 3. X-DIRECTION:
C  NX<1>,XULAST<1.0>,XFRAC(1-30)
C  SERVICE SUBROUTINE FOR POWER-LAW GRID:
C CALL GRDPWR1,NX,XULAST,POWER)
C  NX = 8
C  XFRAC(1) = -8.0
C  XFRAC(2) = 1.8/8.0
C  XULAST = 2.*PI/SLICES

C---------------------
C--- GROUP 4. Y-DIRECTION:
C  NY<1>,YULAST<1.0>,YFRAC(1-30),RINNER,SNALFA
C  SERVICE SUBROUTINE FOR POWER-LAW GRID:
C CALL GRDPWR2,2,NY,YULAST,POWER)
C  NY = 40

CC *** 2.6 = DISTANCE FROM THE INNER CAVITY RADIUS
C  TO THE OUTER RADIUS (INCHES)
C  YVLAST = 2.6/12.
C  YFRAC(1) = -14.0
C  YFRAC(2) = 1./26.0
C  YFRAC(3) = 5.0
C  YFRAC(4) = 1./2.0+26.0)
C  YFRAC(5) = 2.0
C  YFRAC(6) = 1./26.0
C  YFRAC(7) = 5.0
C  YFRAC(8) = 1.0/(2.0+26.0)
C  YFRAC(9) = 12.0
C  YFRAC(10) = 1.0/(3.0+26.0)
C  RINNER = 1.87/12.

C---------------------
C--- GROUP 5. Z-DIRECTION:
C  N2<1>,ZWLAST<1.0>,ZFRAC(1-30)
C  SERVICE SUBROUTINE FOR POWER-LAW GRID:
C CALL GRDPWR3,NZ,ZWLAST,POWER)
C  NZ = 28

CC *** 2.5 = DISTANCE FROM THE LEFT WALL OF THE CAVITY
C  TO THE RIGHT SIDE OF THE GRID (INCHES)
C  ZWLAST = 2.5/12.
C  ZFRAC(1) = -14.0
C  ZFRAC(2) = 2.+1./50.0
C  ZFRAC(3) = 2.0
C  ZFRAC(4) = 1.0/50.0
C  ZFRAC(5) = 8.0
C  ZFRAC(6) = 1.0/(2.0+50.0)
C  ZFRAC(7) = 1.0
C  ZFRAC(8) = 1.0/50.0
C  ZFRAC(9) = 3.0
C  ZFRAC(10) = 5.0+1./50.0

C---------------------
C--- GROUP 6. MOVING GRID:
C  MGRID,IZW1,IZW2,AZW2,BZW2,CZW2,PINT,ZW2MT

C---------------------
C--- GROUP 7. BLOCKAGE: BLOCK<.F.>,IPLANE,IPWRIT
C  SET CONSTANT POROSITIES OVER SUB-DOMAINS USING:
C  CALL CONPDR0(IR,TYPE,VALUE,IIF,IIY,FZL,IIYF,IIYFZL)
C  IR=RUN SECTION NUMBER, E.G. 1 FOR RUN1 SECTION
C  TYPE = EAST, WEST, NORTH, SOUTH, HIGH, LOW & CELL. 'VALUE' = WANDFD POROSITY
C  OVER REGION IIF,...,IZL.
C  DIMENSION ARRAYS PE(NX,NY,NZ), PN(NX,NY,NZ), PI(NX,NY,NZ). &
C PC(NX,NY,NZ) ABOVE.
C FOR FULLY-BLOCKED CELLS (IE. 'VALUE' = 0.0) USER NEED SET ONLY
C THE 'CELL' POROSITY (TO ZERO). AS CELL-FACE AREAS ARE THEN
C AUTOMATICALLY ZERODED.
C 'FOR SATELLITE PRINTOUT OF ALL POROSITIES IN DOMAIN. 'IPlane'=
C XPLANE YPLANE OR ZPLANE. FOR DESIRED CROSS-SECTION DIRECTION.
C 'FOR EACH 'TYPE' A MAXIMUM OF 10 CALLS TO CONPOR IS ALLOWED.
C BUT IF REQUIREMENTS EXCEED THIS PROVISION SET BLOCK=.T. &
C IPWRIT=-1, AND SET POROSITY ARRAYS EXPLICITLY HERE AS WANTED.
C IN THIS CASE, THE USER M U S T SET ALL ELEMENTS OF
C ARRAYS PE, PN, PH, PC (MANY MAY BE 0.0 OR 1.0). HE MAY USE:
C CALL CR(PARRAY,VALUE,IXF,IYL,IZF,IYL,IZF,IXL,NX,NY,NZ)
C ANY NUMBER OF TIMES, TO SET 'PARRAY' (= PE, ETC.) TO
C 'VALUE' OVER RANGE IXF TO IYL, IYL TO IYL, IYL TO 1ZL.
C CONPOR M U S T NOT BE USED IN CONJUNCTION WITH EXPLICIT
C SETTINGS OF THE ARRAYS (INCLUDING SETTINGS VIA CR).
C BLOCK=.T.
C IPWRIT=-1
C *** INITIALIZE ALL POROSITIES TO 1.0 (OPEN)
DO 70 IX = 1,NX
DO 70 IY = 1,NY
DO 70 IZ = 1,NZ
PE(IX,IY,IZ)= 1.0
PN(IX,IY,IZ)= 1.0
PH(IX,IY,IZ)= 1.0
TO 70 PC(IX,IY,IZ)= 1.0
C *** ROW 1 (BOTTOM)
C CALL CR(PC,0.0,1,NX,1,1,12,NX,NY,NZ)
C CALL CR(PN,0.0,1,NX,1,1,13,NX,NY,NZ)
C CALL CR(PE,0.0,1,NX,1,1,12,NX,NY,NZ)
C CALL CR(PH,0.0,1,NX,1,1,12,NX,NY,NZ)
C CALL CR(PC,0.0,1,NX,1,1,12,NX,NY,NZ)
C CALL CR(PN,0.0,1,NX,1,1,12,NX,NY,NZ)
C CALL CR(PE,0.0,1,NX,1,1,12,NX,NY,NZ)
C CALL CR(PH,0.0,1,NX,1,1,12,NX,NY,NZ)
C *** ROW 2
C CALL CR(PC,0.0,1,NX,2,2,13,NX,NY,NZ)
C CALL CR(PN,0.0,1,NX,2,2,13,NX,NY,NZ)
C CALL CR(PE,0.0,1,NX,2,2,13,NX,NY,NZ)
C CALL CR(PH,0.0,1,NX,2,2,13,NX,NY,NZ)
C *** ROW 3
C CALL CR(PC,0.0,1,NX,3,3,1,4,NX,NY,NZ)
C CALL CR(PN,0.0,1,NX,3,3,1,4,NX,NY,NZ)
C CALL CR(PE,0.0,1,NX,3,3,1,4,NX,NY,NZ)
C CALL CR(PH,0.0,1,NX,3,3,1,4,NX,NY,NZ)
C CALL CR(PC,0.5,1,NX,3,3,5,5,NX,NY,NZ)
C CALL CR(PN,1.0,1,NX,3,3,5,5,NX,NY,NZ)
C CALL CR(PE,0.5,1,NX,3,3,5,5,NX,NY,NZ)
C CALL CR(PH,1.0,1,NX,3,3,5,5,NX,NY,NZ)
C CALL CR(PC,0.5,1,NX,3,3,12,12,NX,NY,NZ)
CALL CR(PN, 1.0, 1, NX, 3, 3, 12, 12, NX, NY, NZ)
CALL CR(PE, 0.5, 1, NX, 3, 3, 12, 12, NX, NY, NZ)
CALL CR(PH, 0.0, 1, NX, 3, 3, 12, 12, NX, NY, NZ)
CALL CR(PG, 0.0, 1, NX, 3, 3, 13, 13, NX, NY, NZ)
CALL CR(PN, 0.0, 1, NX, 3, 3, 13, 13, NX, NY, NZ)
CALL CR(PE, 0.0, 1, NX, 3, 3, 13, 13, NX, NY, NZ)
CALL CR(PH, 0.0, 1, NX, 3, 3, 13, 13, NX, NY, NZ)
CALL CR(PG, 0.0, 1, NX, 3, 3, 22, 28, NX, NY, NZ)
CALL CR(PN, 0.0, 1, NX, 3, 3, 22, 28, NX, NY, NZ)
CALL CR(PE, 0.0, 1, NX, 3, 3, 22, 28, NX, NY, NZ)
CALL CR(PH, 0.0, 1, NX, 3, 3, 21, 28, NX, NY, NZ)

C *** ROW 4
CALL CR(PC, 0.0, 1, NX, 4, 4, 1, 3, NX, NY, NZ)
CALL CR(PN, 0.0, 1, NX, 4, 4, 1, 3, NX, NY, NZ)
CALL CR(PE, 0.0, 1, NX, 4, 4, 1, 3, NX, NY, NZ)
CALL CR(PH, 0.0, 1, NX, 4, 4, 1, 3, NX, NY, NZ)
CALL CR(PC, 15.1, NX, 4, 4, 4, 4, NX, NY, NZ)
CALL CR(PN, 5.1, NX, 4, 4, 4, 4, NX, NY, NZ)
CALL CR(PE, 15.1, NX, 4, 4, 4, 4, NX, NY, NZ)
CALL CR(PH, 75.1, NX, 4, 4, 4, 4, NX, NY, NZ)
CALL CR(PC, 0.0, 1, NX, 4, 4, 13, 13, NX, NY, NZ)
CALL CR(PN, 0.0, 1, NX, 4, 4, 13, 13, NX, NY, NZ)
CALL CR(PE, 0.0, 1, NX, 4, 4, 13, 13, NX, NY, NZ)
CALL CR(PH, 0.0, 1, NX, 4, 4, 12, 13, NX, NY, NZ)
CALL CR(PC, 0.0, 1, NX, 4, 4, 17, 28, NX, NY, NZ)
CALL CR(PN, 0.0, 1, NX, 4, 4, 17, 28, NX, NY, NZ)
CALL CR(PE, 0.0, 1, NX, 4, 4, 17, 28, NX, NY, NZ)
CALL CR(PH, 0.0, 1, NX, 4, 4, 16, 28, NX, NY, NZ)

C *** ROW 5
CALL CR(PC, 0.0, 1, NX, 5, 5, 1, 3, NX, NY, NZ)
CALL CR(PN, 0.0, 1, NX, 5, 5, 1, 3, NX, NY, NZ)
CALL CR(PE, 0.0, 1, NX, 5, 5, 1, 3, NX, NY, NZ)
CALL CR(PH, 0.0, 1, NX, 5, 5, 1, 3, NX, NY, NZ)
CALL CR(PC, 75.1, NX, 5, 5, 4, 4, NX, NY, NZ)
CALL CR(PN, 10.1, NX, 5, 5, 4, 4, NX, NY, NZ)
CALL CR(PE, 75.1, NX, 5, 5, 4, 4, NX, NY, NZ)
CALL CR(PH, 10.1, NX, 5, 5, 4, 4, NX, NY, NZ)
CALL CR(PC, 30.1, NX, 5, 5, 13, 13, NX, NY, NZ)
CALL CR(PN, 10.1, NX, 5, 5, 13, 13, NX, NY, NZ)
CALL CR(PE, 30.1, NX, 5, 5, 13, 13, NX, NY, NZ)
CALL CR(PH, 30.1, NX, 5, 5, 12, 13, NX, NY, NZ)
CALL CR(PC, 0.0, 1, NX, 5, 5, 21, 28, NX, NY, NZ)
CALL CR(PN, 0.0, 1, NX, 5, 5, 21, 28, NX, NY, NZ)
CALL CR(PE, 0.0, 1, NX, 5, 5, 21, 28, NX, NY, NZ)
CALL CR(PH, 0.0, 1, NX, 5, 5, 20, 28, NX, NY, NZ)

C *** ROW 6
CALL CR(PC, 0.0, 1, NX, 6, 6, 1, 2, NX, NY, NZ)
CALL CR(PN, 0.0, 1, NX, 6, 6, 1, 2, NX, NY, NZ)
CALL CR(PE, 0.0, 1, NX, 6, 6, 1, 2, NX, NY, NZ)
CALL CR(PH,0,0,1,NX, 6, 6, 1, 2,NX,NY,NZ)
CALL CR(PC,.25,1,NX, 6, 6, 3, 3,NX,NY,NZ)
CALL CR(PN,0.5,1,NX, 6, 6, 3, 3,NX,NY,NZ)
CALL CR(PE,.25,1,NX, 6, 6, 3, 3,NX,NY,NZ)
CALL CR(PH,1.0,1,NX, 6, 6, 3, 3,NX,NY,NZ)
CALL CR(PC,0.0,1,NX, 6, 6,21,28,NX,NY,NZ)
CALL CR(PN,0.0,1,NX, 6, 6,21,28,NX,NY,NZ)
CALL CR(PE,0.0,1,NX, 6, 6,21,28,NX,NY,NZ)
CALL CR(PH,0.0,1,NX, 6, 6,20,28,NX,NY,NZ)
C *** ROW 7
CALL CR(PC,0.0,1,NX, 7, 7, 1, 2,NX,NY,NZ)
CALL CR(PN,0.0,1,NX, 7, 7, 1, 2,NX,NY,NZ)
CALL CR(PE,0.0,1,NX, 7, 7, 1, 2,NX,NY,NZ)
CALL CR(PH,0.0,1,NX, 7, 7, 1, 2,NX,NY,NZ)
CALL CR(PC,.85,1,NX, 7, 7, 3, 3,NX,NY,NZ)
CALL CR(PN,1.0,1,NX, 7, 7, 3, 3,NX,NY,NZ)
CALL CR(PE,.85,1,NX, 7, 7, 3, 3,NX,NY,NZ)
CALL CR(PH,1.0,1,NX, 7, 7, 3, 3,NX,NY,NZ)
CALL CR(PC,0.0,1,NX, 7, 7,21,28,NX,NY,NZ)
CALL CR(PN,0.0,1,NX, 7, 7,21,28,NX,NY,NZ)
CALL CR(PE,0.0,1,NX, 7, 7,21,28,NX,NY,NZ)
CALL CR(PH,0.0,1,NX, 7, 7,20,28,NX,NY,NZ)
C *** ROW 8
CALL CR(PC,0.0,1,NX, 8, 8, 1, 1,NX,NY,NZ)
CALL CR(PN,0.0,1,NX, 8, 8, 1, 1,NX,NY,NZ)
CALL CR(PE,0.0,1,NX, 8, 8, 1, 1,NX,NY,NZ)
CALL CR(PH,0.0,1,NX, 8, 8, 1, 1,NX,NY,NZ)
CALL CR(PC,.85,1,NX, 8, 8, 2, 2,NX,NY,NZ)
CALL CR(PN,.75,1,NX, 8, 8, 2, 2,NX,NY,NZ)
CALL CR(PE,.85,1,NX, 8, 8, 2, 2,NX,NY,NZ)
CALL CR(PH,1.0,1,NX, 8, 8, 2, 2,NX,NY,NZ)
CALL CR(PC,0.0,1,NX, 8, 8,21,28,NX,NY,NZ)
CALL CR(PN,0.0,1,NX, 8, 8,21,28,NX,NY,NZ)
CALL CR(PE,0.0,1,NX, 8, 8,21,28,NX,NY,NZ)
CALL CR(PH,0.0,1,NX, 8, 8,20,28,NX,NY,NZ)
C *** ROW 9
CALL CR(PC,0.0,1,NX, 9, 9, 1, 1,NX,NY,NZ)
CALL CR(PN,0.0,1,NX, 9, 9, 1, 1,NX,NY,NZ)
CALL CR(PE,0.0,1,NX, 9, 9, 1, 1,NX,NY,NZ)
CALL CR(PH,0.0,1,NX, 9, 9, 1, 1,NX,NY,NZ)
CALL CR(PC,.99,1,NX, 9, 9,21,28,NX,NY,NZ)
CALL CR(PN,1.0,1,NX, 9, 9,22,28,NX,NY,NZ)
CALL CR(PE,.99,1,NX, 9, 9,22,28,NX,NY,NZ)
CALL CR(PH,1.0,1,NX, 9, 9,22,28,NX,NY,NZ)
CALL CR(PC, .40, 1, NX, 10, 10, 2, 2, NX, NY, NZ)
CALL CR(PN, O.O, 1, NX, 10, 10, 1, 2, NX, NY, NZ)
CALL CR(PE, .40, 1, NX, 10, 10, 2, 2, NX, NY, NZ)
CALL CR(PH, .20, 1, NX, 10, 10, 2, 2, NX, NY, NZ)

CALL CR(PC, .20, 1, NX, 10, 10, 3, 3, NX, NY, NZ)
CALL CR(PN, O.O, 1, NX, 10, 10, 3, 3, NX, NY, NZ)
CALL CR(PE, .20, 1, NX, 10, 10, 3, 3, NX, NY, NZ)
CALL CR(PH, .30, 1, NX, 10, 10, 3, 3, NX, NY, NZ)

CALL CR(PC, .80, 1, NX, 10, 10, 4, 4, NX, NY, NZ)
CALL CR(PN, .35, 1, NX, 10, 10, 4, 4, NX, NY, NZ)
CALL CR(PE, .80, 1, NX, 10, 10, 4, 4, NX, NY, NZ)
CALL CR(PH, 1.0, 1, NX, 10, 10, 4, 4, NX, NY, NZ)

CALL CR(PC, 1.0, 1, NX, 10, 10, 20, 20, NX, NY, NZ)
CALL CR(PN, 1.0, 1, NX, 10, 10, 20, 20, NX, NY, NZ)
CALL CR(PE, 1.0, 1, NX, 10, 10, 20, 20, NX, NY, NZ)
CALL CR(PH, 2.0, 1, NX, 10, 10, 20, 20, NX, NY, NZ)

CALL CR(PC, 2.0, 1, NX, 10, 10, 21, 21, NX, NY, NZ)
CALL CR(PN, 1.0, 1, NX, 10, 10, 21, 21, NX, NY, NZ)
CALL CR(PE, 2.0, 1, NX, 10, 10, 21, 21, NX, NY, NZ)
CALL CR(PH, 1.5, 1, NX, 10, 10, 21, 21, NX, NY, NZ)

CALL CR(PC, 1.0, 1, NX, 10, 10, 22, 22, NX, NY, NZ)
CALL CR(PN, 1.0, 1, NX, 10, 10, 22, 22, NX, NY, NZ)
CALL CR(PE, 1.0, 1, NX, 10, 10, 22, 22, NX, NY, NZ)
CALL CR(PH, 0.0, 1, NX, 10, 10, 22, 22, NX, NY, NZ)

CALL CR(PC, .0, 1, NX, 10, 10, 23, 28, NX, NY, NZ)
CALL CR(PN, .0, 1, NX, 10, 10, 23, 28, NX, NY, NZ)
CALL CR(PE, .0, 1, NX, 10, 10, 23, 28, NX, NY, NZ)
CALL CR(PH, .0, 1, NX, 10, 10, 23, 28, NX, NY, NZ)

CALL CR(PC, .0, 1, NX, 11, 11, 1, 2, NX, NY, NZ)
CALL CR(PN, .0, 1, NX, 11, 11, 1, 2, NX, NY, NZ)
CALL CR(PE, .0, 1, NX, 11, 11, 1, 2, NX, NY, NZ)
CALL CR(PH, .0, 1, NX, 11, 11, 1, 2, NX, NY, NZ)

CALL CR(PC, .5, 1, NX, 11, 11, 3, 3, NX, NY, NZ)
CALL CR(PN, .90, 1, NX, 11, 11, 3, 3, NX, NY, NZ)
CALL CR(PE, .5, 1, NX, 11, 11, 3, 3, NX, NY, NZ)
CALL CR(PH, .0, 1, NX, 11, 11, 3, 3, NX, NY, NZ)

CALL CR(PC, .75, 1, NX, 11, 11, 4, 4, NX, NY, NZ)
CALL CR(PN, 1.0, 1, NX, 11, 11, 4, 4, NX, NY, NZ)
CALL CR(PE, .75, 1, NX, 11, 11, 4, 4, NX, NY, NZ)
CALL CR(PH, 1.0, 1, NX, 11, 11, 4, 4, NX, NY, NZ)

CALL CR(PC, .95, 1, NX, 11, 11, 23, 23, NX, NY, NZ)
CALL CR(PN, 1.0, 1, NX, 11, 11, 23, 23, NX, NY, NZ)
CALL CR(PE, .95, 1, NX, 11, 11, 23, 23, NX, NY, NZ)
CALL CR(PH, .80, 1, NX, 11, 11, 23, 23, NX, NY, NZ)

CALL CR(PC, .5, 1, NX, 11, 11, 24, 24, NX, NY, NZ)
CALL CR(PN, 1.0, 1, NX, 11, 11, 24, 24, NX, NY, NZ)
CALL CR(PE, .5, 1, NX, 11, 11, 24, 24, NX, NY, NZ)
CALL CR(PH,0.2,1,NX,21,21,4,4,NK,NY,NZ)

CALL CR(PC,.45,1,NX,21,21,5,5,NX,NY,NZ)

CALL CR(PN,0.0,1,NX,21,21,5,5,NX,NY,NZ)

CALL CR(PE,.45,1,NX,21,21,5,5,NX,NY,NZ)

CALL CR(PH,0.7,1,NX,21,21,5,5,NX,NY,NZ)

CALL CR(PC,.9,1,NX,21,21,6,6,NX,NY,NZ)

CALL CR(PN,0.4,1,NX,21,21,6,6,NX,NY,NZ)

CALL CR(PE,.9,1,NX,21,21,6,6,NX,NY,NZ)

CALL CR(PH,1.0,1,NX,21,21,6,6,NX,NY,NZ)

CALL CR(PC,0.8,1,NX,21,21,23,23,NX,NY,NZ)

CALL CR(PN,0.0,1,NX,21,21,23,23,NX,NY,NZ)

CALL CR(PE,0.8,1,NX,21,21,23,23,NX,NY,NZ)

CALL CR(PH,0.9,1,NX,21,21,23,23,NX,NY,NZ)

CALL CR(PC,0.6,1,NX,21,21,24,24,NX,NY,NZ)

CALL CR(PN,0.0,1,NX,21,21,24,24,NX,NY,NZ)

CALL CR(PE,0.6,1,NX,21,21,24,24,NX,NY,NZ)

CALL CR(PH,0.4,1,NX,21,21,24,24,NX,NY,NZ)

CALL CR(PC,.05,1,NX,21,21,25,25,NX,NY,NZ)

CALL CR(PN,0.0,1,NX,21,21,25,25,NX,NY,NZ)

CALL CR(PE,.05,1,NX,21,21,25,25,NX,NY,NZ)

CALL CR(PH,.0,1,NX,21,21,25,25,NX,NY,NZ)

CALL CR(PC,0.0,1,NX,21,21,26,28,NX,NY,NZ)

CALL CR(PN,0.0,1,NX,21,21,26,28,NX,NY,NZ)

CALL CR(PE,0.0,1,NX,21,21,26,28,NX,NY,NZ)

CALL CR(PH,0.0,1,NX,21,21,26,28,NX,NY,NZ)

C ... ROW 22

CALL CR(PC,0.0,1,NX,22,22,1,5,NX,NY,NZ)

CALL CR(PN,0.0,1,NX,22,22,1,5,NX,NY,NZ)

CALL CR(PE,0.0,1,NX,22,22,1,5,NX,NY,NZ)

CALL CR(PH,0.0,1,NX,22,22,1,5,NX,NY,NZ)

CALL CR(PC,.05,4,NX,22,22,6,6,NX,NY,NZ)

CALL CR(PN,0.0,1,NX,22,22,6,6,NX,NY,NZ)

CALL CR(PE,.05,1,NX,22,22,6,6,NX,NY,NZ)

CALL CR(PH,20,1,NX,22,22,6,6,NX,NY,NZ)

CALL CR(PC,0.4,1,NX,22,22,7,7,NX,NY,NZ)

CALL CR(PN,0.0,1,NX,22,22,7,7,NX,NY,NZ)

CALL CR(PE,0.4,1,NX,22,22,7,7,NX,NY,NZ)

CALL CR(PH,0.6,1,NX,22,22,7,7,NX,NY,NZ)

CALL CR(PC,0.7,1,NX,22,22,8,8,NX,NY,NZ)

CALL CR(PN,0.0,1,NX,22,22,8,8,NX,NY,NZ)

CALL CR(PE,0.7,1,NX,22,22,8,8,NX,NY,NZ)

CALL CR(PH,1.0,1,NX,22,22,8,8,NX,NY,NZ)

CALL CR(PC,1.0,1,NX,22,22,20,20,NX,NY,NZ)

CALL CR(PN,1.0,1,NX,22,22,20,20,NX,NY,NZ)

CALL CR(PE,1.0,1,NX,22,22,20,20,NX,NY,NZ)

CALL CR(PH,0.3,1,NX,22,22,20,20,NX,NY,NZ)

CALL CR(PC,0.2,1,NX,22,22,21,21,NX,NY,NZ)

CALL CR(PN,0.0,1,NX,22,22,21,21,NX,NY,NZ)
CALL CR(PE, 0, 0, 1, NX, 25, 25, 21, 28, NX, NY, NZ)
CALL CR(PH, 0, 0, 1, NX, 25, 25, 20, 28, NX, NY, NZ)
C
C *** ROW 26
CALL CR(PC, 0, 0, 1, NX, 26, 26, 11, NX, NY, NZ)
CALL CR(PN, 0, 0, 1, NX, 26, 26, 11, NX, NY, NZ)
CALL CR(PE, 0, 0, 1, NX, 26, 26, 11, NX, NY, NZ)
CALL CR(PH, 0, 0, 1, NX, 26, 26, 11, NX, NY, NZ)
C
CALL CR(PC, 0, 5, 1, NX, 26, 26, 12, 12, NX, NY, NZ)
CALL CR(PN, 0, 0, 1, NX, 26, 26, 12, 12, NX, NY, NZ)
CALL CR(PE, 0, 5, 1, NX, 26, 26, 12, 12, NX, NY, NZ)
CALL CR(PH, 1, 0, 1, NX, 26, 26, 12, 12, NX, NY, NZ)
C
CALL CR(PC, 0, 0, 1, NX, 26, 26, 21, 28, NX, NY, NZ)
CALL CR(PN, 0, 0, 1, NX, 26, 26, 21, 28, NX, NY, NZ)
CALL CR(PE, 0, 0, 1, NX, 26, 26, 21, 28, NX, NY, NZ)
CALL CR(PH, 0, 0, 1, NX, 26, 26, 20, 28, NX, NY, NZ)
C
C *** ROW 27
CALL CR(PC, 0, 0, 1, NX, 27, 27, 1, 12, NX, NY, NZ)
CALL CR(PN, 0, 0, 1, NX, 27, 27, 1, 12, NX, NY, NZ)
CALL CR(PE, 0, 0, 1, NX, 27, 27, 1, 12, NX, NY, NZ)
CALL CR(PH, 0, 0, 1, NX, 27, 27, 1, 12, NX, NY, NZ)
C
CALL CR(PC, 0, 5, 1, NX, 27, 27, 13, 13, NX, NY, NZ)
CALL CR(PN, 0, 0, 1, NX, 27, 27, 13, 13, NX, NY, NZ)
CALL CR(PE, 0, 5, 1, NX, 27, 27, 13, 13, NX, NY, NZ)
CALL CR(PH, 1, 0, 1, NX, 27, 27, 13, 13, NX, NY, NZ)
C
CALL CR(PC, 0, 0, 1, NX, 27, 27, 21, 28, NX, NY, NZ)
CALL CR(PN, 0, 0, 1, NX, 27, 27, 21, 28, NX, NY, NZ)
CALL CR(PE, 0, 0, 1, NX, 27, 27, 21, 28, NX, NY, NZ)
CALL CR(PH, 0, 0, 1, NX, 27, 27, 20, 28, NX, NY, NZ)
C
C *** ROW 28
CALL CR(PC, 0, 0, 1, NX, 28, 28, 1, 13, NX, NY, NZ)
CALL CR(PN, 0, 0, 1, NX, 28, 28, 1, 13, NX, NY, NZ)
CALL CR(PE, 0, 0, 1, NX, 28, 28, 1, 13, NX, NY, NZ)
CALL CR(PH, 0, 0, 1, NX, 28, 28, 1, 13, NX, NY, NZ)
C
CALL CR(PC, 0, 5, 1, NX, 28, 28, 14, 14, NX, NY, NZ)
CALL CR(PN, 0, 0, 1, NX, 28, 28, 14, 14, NX, NY, NZ)
CALL CR(PE, 0, 5, 1, NX, 28, 28, 14, 14, NX, NY, NZ)
CALL CR(PH, 1, 0, 1, NX, 28, 28, 14, 14, NX, NY, NZ)
C
CALL CR(PC, 0, 0, 1, NX, 28, 28, 21, 28, NX, NY, NZ)
CALL CR(PN, 0, 0, 1, NX, 28, 28, 21, 28, NX, NY, NZ)
CALL CR(PE, 0, 0, 1, NX, 28, 28, 21, 28, NX, NY, NZ)
CALL CR(PH, 0, 0, 1, NX, 28, 28, 20, 28, NX, NY, NZ)
C
C *** ROW 29
CALL CR(PC, 0, 0, 1, NX, 29, 29, 1, 14, NX, NY, NZ)
CALL CR(PN, 0, 0, 1, NX, 29, 29, 1, 14, NX, NY, NZ)
CALL CR(PE, 0, 0, 1, NX, 29, 29, 1, 14, NX, NY, NZ)
CALL CR(PH, 0, 0, 1, NX, 29, 29, 1, 14, NX, NY, NZ)
C
CALL CR(PC, 25, 1, NX, 29, 29, 15, 15, NX, NY, NZ)
CALL CR(PN, 0, 0, 1, NX, 29, 29, 15, 15, NX, NY, NZ)
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<tr>
<th>Line</th>
<th>Code</th>
<th>Description</th>
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<tr>
<td>1020</td>
<td>C</td>
<td>CALL CR(PC,RAT,1,NX,36,36,21,28,NX,NY,NZ)</td>
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<td>1021</td>
<td>C</td>
<td>CALL CR(PN,RAT,1,NX,36,36,21,28,NX,NY,NZ)</td>
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<td>C</td>
<td>CALL CR(PE,1.0,1,NX,36,36,21,28,NX,NY,NZ)</td>
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<td>1023</td>
<td>C</td>
<td>CALL CR(PH,RAT,1,NX,36,36,20,28,NX,NY,NZ)</td>
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<td>1024</td>
<td>C</td>
<td>CALL CR(PC,RAT,1,NX,37,37,1,16,NX,NY,NZ)</td>
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<td>1025</td>
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<td>CALL CR(PN,RAT,1,NX,37,37,1,16,NX,NY,NZ)</td>
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<td>1026</td>
<td>C</td>
<td>CALL CR(PE,0.0,1,NX,37,37,1,16,NX,NY,NZ)</td>
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<tr>
<td>1027</td>
<td>C</td>
<td>CALL CR(PH,RAT,1,NX,37,37,1,16,NX,NY,NZ)</td>
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<td>1028</td>
<td>C</td>
<td>CALL CR(PC,RAT,1,NX,37,37,17,17,NX,NY,NZ)</td>
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<td>1029</td>
<td>C</td>
<td>CALL CR(PN,RAT,1,NX,37,37,17,17,NX,NY,NZ)</td>
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<td>C</td>
<td>CALL CR(PE,0.2,1,NX,37,37,17,17,NX,NY,NZ)</td>
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<tr>
<td>1031</td>
<td>C</td>
<td>CALL CR(PH,1.0,1,NX,37,37,17,17,NX,NY,NZ)</td>
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<tr>
<td>1032</td>
<td>C</td>
<td>CALL CR(PC,RAT,1,NX,37,37,21,28,NX,NY,NZ)</td>
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<td>1033</td>
<td>C</td>
<td>CALL CR(PN,RAT,1,NX,37,37,21,28,NX,NY,NZ)</td>
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<td>1034</td>
<td>C</td>
<td>CALL CR(PE,1.0,1,NX,37,37,21,28,NX,NY,NZ)</td>
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<td>1035</td>
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<td>CALL CR(PH,RAT,1,NX,37,37,20,28,NX,NY,NZ)</td>
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<td>1036</td>
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<td>CALL CR(PC,RAT,1,NX,38,38,1,17,NX,NY,NZ)</td>
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<td>1037</td>
<td>C</td>
<td>CALL CR(PN,RAT,1,NX,38,38,1,17,NX,NY,NZ)</td>
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<td>1038</td>
<td>C</td>
<td>CALL CR(PE,0.0,1,NX,38,38,1,17,NX,NY,NZ)</td>
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<td>1039</td>
<td>C</td>
<td>CALL CR(PH,RAT,1,NX,38,38,1,17,NX,NY,NZ)</td>
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<td>1040</td>
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<td>CALL CR(PC,RAT,1,NX,38,38,21,28,NX,NY,NZ)</td>
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<td>1041</td>
<td>C</td>
<td>CALL CR(PN,RAT,1,NX,38,38,21,28,NX,NY,NZ)</td>
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<td>1042</td>
<td>C</td>
<td>CALL CR(PE,1.0,1,NX,38,38,21,28,NX,NY,NZ)</td>
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<td>1043</td>
<td>C</td>
<td>CALL CR(PH,RAT,1,NX,38,38,20,28,NX,NY,NZ)</td>
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<td>1044</td>
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<td>CALL CR(PC,RAT,1,NX,39,39,1,17,NX,NY,NZ)</td>
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<td>1045</td>
<td>C</td>
<td>CALL CR(PN,RAT,1,NX,39,39,1,17,NX,NY,NZ)</td>
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<td>1046</td>
<td>C</td>
<td>CALL CR(PE,0.0,1,NX,39,39,1,17,NX,NY,NZ)</td>
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<td>1047</td>
<td>C</td>
<td>CALL CR(PH,RAT,1,NX,39,39,1,17,NX,NY,NZ)</td>
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<tr>
<td>1048</td>
<td>C</td>
<td>CALL CR(PC,RAT,1,NX,39,39,21,28,NX,NY,NZ)</td>
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<td>1049</td>
<td>C</td>
<td>CALL CR(PN,RAT,1,NX,39,39,21,28,NX,NY,NZ)</td>
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<td>1050</td>
<td>C</td>
<td>CALL CR(PE,1.0,1,NX,39,39,21,28,NX,NY,NZ)</td>
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<td>1051</td>
<td>C</td>
<td>CALL CR(PH,RAT,1,NX,39,39,20,28,NX,NY,NZ)</td>
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<td>CALL CR(PC,RAT,1,NX,40,40,1,16,NX,NY,NZ)</td>
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<td>C</td>
<td>CALL CR(PN,RAT,1,NX,40,40,1,16,NX,NY,NZ)</td>
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<td>1054</td>
<td>C</td>
<td>CALL CR(PE,0.0,1,NX,40,40,1,16,NX,NY,NZ)</td>
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<td>1055</td>
<td>C</td>
<td>CALL CR(PH,RAT,1,NX,40,40,1,16,NX,NY,NZ)</td>
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<tr>
<td>1056</td>
<td>C</td>
<td>CALL CR(PC,RAT,1,NX,40,40,17,17,NX,NY,NZ)</td>
</tr>
<tr>
<td>1057</td>
<td>C</td>
<td>CALL CR(PN,RAT,1,NX,40,40,17,17,NX,NY,NZ)</td>
</tr>
<tr>
<td>1058</td>
<td>C</td>
<td>CALL CR(PE,1.0,1,NX,40,40,17,17,NX,NY,NZ)</td>
</tr>
<tr>
<td>1059</td>
<td>C</td>
<td>CALL CR(PH,RAT,1,NX,40,40,16,16,NX,NY,NZ)</td>
</tr>
<tr>
<td>1060</td>
<td>C</td>
<td>CALL CR(PC,RAT,1,NX,40,40,21,28,NX,NY,NZ)</td>
</tr>
<tr>
<td>1061</td>
<td>C</td>
<td>CALL CR(PN,RAT,1,NX,40,40,21,28,NX,NY,NZ)</td>
</tr>
<tr>
<td>1062</td>
<td>C</td>
<td>CALL CR(PE,1.0,1,NX,40,40,21,28,NX,NY,NZ)</td>
</tr>
<tr>
<td>1063</td>
<td>C</td>
<td>CALL CR(PH,RAT,1,NX,40,40,20,28,NX,NY,NZ)</td>
</tr>
<tr>
<td>1064</td>
<td>C</td>
<td>CALL CR(PC,RAT,1,NX,40,40,18,18,NX,NY,NZ)</td>
</tr>
<tr>
<td>1065</td>
<td>C</td>
<td>CALL CR(PN,RAT,1,NX,40,40,18,18,NX,NY,NZ)</td>
</tr>
<tr>
<td>1066</td>
<td>C</td>
<td>CALL CR(PE,0.0,1,NX,40,40,18,18,NX,NY,NZ)</td>
</tr>
<tr>
<td>1067</td>
<td>C</td>
<td>CALL CR(PH,RAT,1,NX,40,40,17,17,NX,NY,NZ)</td>
</tr>
<tr>
<td>1068</td>
<td>C</td>
<td>CALL CR(PC,RAT,1,NX,40,40,20,28,NX,NY,NZ)</td>
</tr>
<tr>
<td>1069</td>
<td>C</td>
<td>CALL CR(PN,RAT,1,NX,40,40,20,28,NX,NY,NZ)</td>
</tr>
<tr>
<td>1070</td>
<td>C</td>
<td>CALL CR(PE,1.0,1,NX,40,40,20,28,NX,NY,NZ)</td>
</tr>
<tr>
<td>1071</td>
<td>C</td>
<td>CALL CR(PH,RAT,1,NX,40,40,20,28,NX,NY,NZ)</td>
</tr>
<tr>
<td>1072</td>
<td>C</td>
<td>CALL CR(PC,RAT,1,NX,40,40,21,28,NX,NY,NZ)</td>
</tr>
<tr>
<td>1073</td>
<td>C</td>
<td>CALL CR(PN,RAT,1,NX,40,40,21,28,NX,NY,NZ)</td>
</tr>
<tr>
<td>1074</td>
<td>C</td>
<td>CALL CR(PE,1.0,1,NX,40,40,21,28,NX,NY,NZ)</td>
</tr>
<tr>
<td>1075</td>
<td>C</td>
<td>CALL CR(PH,RAT,1,NX,40,40,20,28,NX,NY,NZ)</td>
</tr>
</tbody>
</table>
GROUP 8. DEPENDENT VARIABLES TO BE SOLVED FOR OR STORED:

- SOLVAR(1-25), SOLVAR(26), ... , SOLVAR(1-40), SOLVAR(41-4).

GROUP 9. VARIABLE LABELS:

- TITLE(1-25): Water Mass Flow
- TITLE(26): Temperature of the Mixture
- TITLE(27): Total Pressure
- TITLE(28): Density of the Mixture
- TITLE(29): Density of the Water
- TITLE(30): Density of the Hydrogen
- TITLE(31): Effective Viscosity
- TITLE(32): Pressure Correction
- TITLE(33): Continuity Error

GROUP 10 PROPERTIES:

- rho1: 1.0, rho2: 1.0, rhd1: 1.0, rhd2: 1.0, var(1-20)
- iem1: 1.0, emu1: 1.0, emulam: 1.0, iem2: 1.0, emu2: 1.0
- ihsat: 1.0, h2sat: 1.0, psat: 1.0
- sigma(1-25): 1.0, 2.0, 1.1, 1.0, 1.1, 1.0
- 1.1, 1.3, 1.0, 1.5, 1.5, 1.0

**UNITS ARE IN LBF, SLUGS, FEET, AND DEGREES RANKINE**

**THE DENSITY IS CALCULATED IN GROUND CH. 10**

**SETTING IEMU1 = 2 IMPLIES THE K-ECTILON MODEL IS ACTIVE**
CC *** SIGMA = TURB. PRANDTL OR SCHMIDT NO.
C FOR H1 AND C1 THEY ARE .9 BASED ON CHAM TR/75, PAGE 3.2-26
C
CC *** LAM VISCOITY FOR WALL FRICTION IS CALCULATED IN GROUND CH. 10
EMULAM= 1.
C
C -- GROUP 11 INTER-PHASE TRANSFER PROCESSES:
C
1GFIP.CFIPS,MDT,CAT1<1.E6>,CAT2<1.E6>
C
C
C -- GROUP 12 SPECIAL SOURCES:
C
IFICSO(1-25),AGRSA,AGRAVY,AGRAVZ,ABUDY,HERF
C
C
C -- GROUP 13 INITIAL FIELDS:
C
FIINIT(1-25)<25+1.E-10>
C
C
OMEGA = RPM*2.*PI/60.
C
C
FIINIT(U1)=0.4*OMEGA
C
FIINIT(V1)=0.0
C
FIINIT(W1)=0.0
C
FIINIT(C1)=0.1
C
C
C *** SET TEMP AT INTERMEDIATE VALUE (LMSC-HREC TR D697954)
C
FIINIT(18) = 400.
C
C *** FIINIT (P1), (H1), (KE) & (EP) ARE SET BELOW TN GROUP 15
C
C -- GROUP 14 BOUNDARY/INTERNAL CONDITIONS
C
ILOOP1.ILOOPN,XCYCLE<F,.>,PBAR,REGION(1-10)<10...>
C
C *N.B. ALL 10 REGIONS ARE DEFAULTED *TRUE*, THE USER SHOULD
C
SET REGION(I).=.FALSE. FOR UNUSED REGIONS *"I".
DO 140 I=1,10
140
C
REGION(I)=.FALSE.
XCYCLE = .TRUE.
C
C -- GROUP 15 TO 24 REGIONS 1 TO 10
C
C -- ONLY THOSE REGIONS ARE ACTIVE WHICH ARE SPECIFIED BY THE
C USER, PREFERABLY BY WAY OF:
C
CALL PLACE(IREGN,TYPE,IXF,IXL,IYF,IYL,IZF,IZL)
C
C CALL COVAL(IREGN,VARBLE,COEFF,VALUE)
C
C
C *** 'COLD' H2, INLET ***
C
C
C *** FEEDC1 IS SET TO THE TOTAL MASS FLOWRATE (LBM/S)
C
C AT THE COLD INLET. (SEE LMSC-HREC TR D697954).
C
C THEN CONVERTED TO SLUGS/SEC OVER SOLUTION SEGMENT
C
FEEDC = FEEDC1/GSLICES
C
C AS OF 3/85 THE FLOW THROUGH THE LABY SEAL IS VARIED AS
C
C AS A FUNCTION OF THE ECCENTRICITY OF THE ROTOR:
C
C WEIGHTED FLOWRATE (PER SEGMENT) = (TOTAL FLOWRATE/NX)*
C ((SM GAP HT)*COS(ANGLE)*(ECCENTRICITY))/(SM GAP HT)
C
C
C FOR EIGHT CELLS IN THE X DIRECTION:
C
FEEDC1 = FEEDC*(GINC1S*COS(0.)*ECCENT)/GINC1S
C
FEEDC2 = FEEDC*(GINC1S*COS(2.*PI/8.)*ECCENT)/GINC1S
C
FEEDC3 = FEEDC*(GINC1S*COS(2.*PI/4.)*ECCENT)/GINC1S
C
FEEDC4 = FEEDC*(GINC1S*COS(2.*PI/3.)*ECCENT)/GINC1S
C
FEEDC5 = FEEDC*(GINC1S*COS(1.)*ECCENT)/GINC1S
C
FEEDC6 = FEEDC*(GINC1S*COS(2.*PI/5.)*ECCENT)/GINC1S
CALL COVAL(5,H1,ONLYMS,H1INC)
CALL COVAL(5,C1,ONLYMS,0.0)

CALL PLACE(6,CELL,6,6,1,1,13,13)
CALL COVAL(6,M1,FIXFLU,FEEDC/50AT(NX))
CALL COVAL(6,U1,ONLYMS,0.5*Omega*(RADINC*2))
CALL COVAL(6,W1,ONLYMS,W1INC)
CALL COVAL(6,KE,ONLYMS,01+VELSO)
CALL COVAL(6,EP,ONLYMS,0.16433*(0.01+VELSO)*1.5/1.1*GINC1/12.)
CALL COVAL(6,H1,ONLYMS,H1INC)
CALL COVAL(6,C1,ONLYMS,0.0)

CALL PLACE(7,CELL,7,7,1,1,13,13)
CALL COVAL(7,M1,FIXFLU,FEEDC/50AT(NX))
CALL COVAL(7,U1,ONLYMS,0.5*Omega*(RADINC*2))
CALL COVAL(7,W1,ONLYMS,W1INC)
CALL COVAL(7,KE,ONLYMS,0.01+VELSO)
CALL COVAL(7,EP,ONLYMS,0.16433*(0.01+VELSO)*1.5/1.1*GINC1/12.)
CALL COVAL(7,H1,ONLYMS,H1INC)
CALL COVAL(7,C1,ONLYMS,0.0)

CALL PLACE(8,CELL,8,8,1,1,13,13)
CALL COVAL(8,M1,FIXFLU,FEEDC/50AT(NX))
CALL COVAL(8,U1,ONLYMS,0.5*Omega*(RADINC*2))
CALL COVAL(8,W1,ONLYMS,W1INC)
CALL COVAL(8,KE,ONLYMS,0.01+VELSO)
CALL COVAL(8,EP,ONLYMS,0.16433*(0.01+VELSO)*1.5/1.1*GINC1/12.)
CALL COVAL(8,H1,ONLYMS,H1INC)
CALL COVAL(8,C1,ONLYMS,0.0)

C
CC *** 'HOT' H2 & H2O INLET ****
CC
CC *** FEEDH IS SET TO THE TOTAL MASS FLOWRATE (lbm/s)
CC AT THE HOT INLET. (SEE LMSC-HREC TR D697954),
CC THEN CONVERTED TO SLUGS/SEC OVER SOLUTION SEGMENT
CC FEEDH = FEEDH/(G*SLICES)
CC
CC *** HIINH IS SET TO THE ENTHALPY (BTU/LBM) AT THE HOT
CC INLET (TR D697954) THEN CONVERTED TO FT-LBF/SLUGS
CC H1INH = H1INH*778.16*G
CC
CC *** ROWNH IS THE DENSITY (SLUG/CU FT) AT THE HOT INLET
CC ROWNH = ROWNH/G
CC
CC *** RADNH IS THE AVERAGE RADIUS (FT) OF THE HOT INLET
CC RADNH = RINNER + 2.45/12.
CC
CC *** AINH1 IS SET TO THE AREA (SO IN) AT THE HOT INLET
CC THEN CONVERTED TO THE INLET AREA (SQ FT) PER SEGMENT
CC AINH = AINH1/(144.0*SLICES)
CC
CC *** CALCULATE THE FEED VELOCITY AT THE HOT INLET
CC W1INH = FEEDH/(ROWNH*AINH)
CC
CC *** TOTAL NOMINAL GRID AREA PER SEGMENT AT HOT INLET
CC ARGGRID = ARGGRID/(144.0*SLICES)
CC
C
CALL PLACE(9,HIGH,1,NX,32.40,28.28)
CALL COVAL(9,M1,FIXFLU,FEEDH/ARGGRID)
CALL COVAL(9,W1,ONLYMS,W1INH)

C
CC *** INITIALIZE ENTHALPY, TURBULENCE, AND DISSIPATION
CC FICINIT(H1)*3.67
CC FICINIT(KE)*.01*(OMEGA*RADNH*2+W1INH*2)
CC FICINIT(EP)*.16433*(FICINIT(KE))*1.5/(1.1*AINH/(RADNH*XULAST))
C *** OUTLERS ***

C *** THE EXIT PressURES AROUND THE PERIPHERY OF THE
C AFT-PLATFORM SEAL ARE SPECIFIED IN SATELLITE. BUT
C ARE APPLIED AS A BOUNDARY CONDITION IN GROUND.
C *** BELOW THE VALUES OF U1,KE,...AT THE EXIT ARE CALCULATED
C BEFORE THEY ARE TRANSFERRED TO GROUND. THESE VALUES MUST
C BE SPECIFIED IN CASE THERE IS IN-FLOW AT THE PERIPHERY
C OF THE SEAL (EITHER TEMPORARY OR STEADY), OR NEAR BOLTS.
C *** CALCULATE THE RADIUS AND AREA AT THE PRIMARY EXIT
C RADIT = RINNER + YLAST
C AEXIT=(GEXIT/12.)+RADIT*XULAST

C *** ESTIMATE THE VELOCITIES AT PRIMARY EXIT
C FEED=FEEDC + FEEDH
C WEXIT=-FEEDT/(ROINH+AEXIT)
C UEXIT=OMEGA+RADIT+2

C
C VELS=WEXIT**2*(UEXIT/RADIT)**2
C VALX=0.01*VELS
C VAEX=16.433*VALX**1.5/(1.4*GEXIT/12.)
C HEXIT=HEXIT+778.16#G

C *** INITIALIZE PRESSURE (PEXIT+HALF EXPECTED LOSS AT PRIMARY EXIT)
C FINIT(1)= PEXIT+0.5*GOSKL*ROINH+WEXIT**2/2.
C
C
C*** ROTATING WALL AND WALL FRICTION ***

C ALL ROTATION AND WALL FRICTION EFFECTS SET UP IN GROUND CH. 5

C-----------------------------------------------
C--- GROUP 25 GROUND STATION :
C  GROSTA<.F.>,NAMLIST<.F.>
C  NAMLIST ACTIVATES NAMELIST IN GROUND.
C  GROSTA=.TRUE.
C-----------------------------------------------
C--- GROUP 26 SOLUTION TYPE AND RELATED PARAMETERS :
C  WHOLEP<.F.>,SUBPST<.F.>,DONACC<.F.>
C  WHOLEP=.TRUE.
C-----------------------------------------------
C--- GROUP 27 SWEEP AND ITERATION NUMBERS :
C  IH01F<.I.>=.NRHO1<.I.>=.NRHO1L<.I.>=10000.
C  IH02F<.I.>=.NRHO2<.I.>=.NRHO2L<.I.>=10000.
C  LSweep= 200
C  LITER<.I.>= 15
C-----------------------------------------------
C--- GROUP 28 TERMINATION CRITERIA :
C-----------------------------------------------
--- GROUP 29 RELAXATION
C RLXP<1,> ,RLXPXY<1,> ,RLXPY<1,> ,RLXRD<1,> ,RLXMTD<1,> ,
C DTFALS(3-25)<23+1.E10> 
C UI MAX = ABS(U1EXIT) 
C W1 MAX = ABS(W1INH) 
C V1 MAX = W1 MAX 
C DT FALS(V1) = YVLAST/(FLOAT(NY)+V1 MAX+TINY) 
C DT FALS(W1) = ZVLAST/(FLOAT(NZ)+W1 MAX+TINY) 
C DT FALS(KE) = 1.05*MAX1(DTFALS(V1),DT FALS(W1)) 
C DTFA L(S) = DT FALS(KE) 
---
---
--- GROUP 30 LIMITS: 
C VEL MAX<1. E10>, VELMIN<1. E10>, RHOMAX<1. E10>, RHOMIN<1. E-10>, 
C TKEMAX<1. E10>, TKEMIN<1. E-10>, EMUMAX<1. E10>, EMUMIN<1. E-10>, 
C EPS MAX<1. E10>, EPSMIN<1. E-10>, AMDTMX<1. E10>, AMDTMX<1. E-10> 
C EMUMAX<1.00+0. 5E-5/G 
C EMUMAX<1. E4*1.2E-3/G 
C EPS MAX<1. E20 
---
--- GROUP 31 SLOWINGVICES: SLOHI<1,> ,SLOEMU<1,> 
---
--- GROUP 32 PRINT-OUT OF VARIABLES: 
C PRINT(1-25)<T, ,. ., . .> ,SUBWGR< . ,.> 
C PRINT(2)*.TRUE. 
---
--- GROUP 33 MONITOR PRINT-OUT: 
C IXMON<1,> ,IYMON<1,> ,IZMON<1,> ,NPRMON<1,> ,NPRMT<1> 
C IZMON<9> 
C IYMON<13> 
C IXMON<1> 
---
--- GROUP 34 FIELD PRINT-OUT CONTROL: 
C NPRINT<100,> ,NTPRIN<100,> ,NPRINN<1,> ,NYPRIN<1,> ,NZPRN<1,> , 
C IZPRF<1,> ,ISTPRF<1,> ,IZPRL<10000> ,ISTPRL<10000> 
C NUMCLS<10>,KOUTPT 
C NPRINT = LSWEEP 
---
--- GROUP 35 TABLE CONTROL: 
C TABLES<.F.,> ,NATBLR, NTABVR, LINTAB, NPRTAB, NMON, 
C ITAB<1-8>,MTABVR<1-8> 
---
--- GROUP 36-38 ARE NOT DOCUMENTED IN THE INSTRUCTION 
---
--- MANUAL AND ARE INTENDED FOR MAINTENANCE PURPOSES ONLY 
---
--- GROUP 36 DEBUG PRINT-OUT SLAB AND TIME-STEP: 
C IZPR1<1,> ,IZPR2<1,> ,ISTPR1<1,> ,ISTPR2<1,> 
---
--- GROUP 37 DEBUG SWEEP AND SUBROUTINES: 
C KEMU, KMAIN, KINDEX, KGEOM, KINPUT, KSOOT, KCOMPF, KSDRCE, 
C KSOOLV1, KSOOLV2, KSOOLV3, KCOMMP, KADJST, KFLUX, KSHIFT, KDF, 
C KCOMPU, KCOMPV, KCOMPW, KCOMPP, KAWALL, KDBRHO<1-1>, KDBEXP, KDBMDT 
C KDBGEN 
---
--- GROUP 38 MONITOR, TEST, AND FLAG: 
C MONTIN<.F.,> ,FLAG<.F.,> ,TEST<T, ,. ,. ,. ,. ,.> ,KFLAG<.F.,> 
---
--- END OF MAINTENANCE-ONLY SECTION 
---
--- GROUP 39 ERROR AND RESIDUAL PRINT-OUT: 
C IERRP<1000>, RESREF<1-24><25+1,>, RESMAP<.F.,> , 
C RESID(1-25)<2+.F.,> ,KOUPT 
C IERRP=25
RESREF(P1) = FEED/R0INH
RESREF(U1) = FEED/U1MAX
RESREF(V1) = FEED/V1MAX
RESREF(W1) = FEED/W1MAX
RESREF(K1) = FEED/FINIT(K1)
RESREF(E1) = FEED/FINIT(E1)
RESREF(H1) = FEED/FINIT(H1)
RESREF(C1) = FEED/H2OINH

C-----------------------------
C --- GROUP 40 SPECIAL DATA : LOGIC(1...10), INTRG(1...10), REF(21...30),
C NLSP<1>, NISP<1>, NRSIP<1>, SPDATA<1>, LSPDA(1), LSPDA(1), RSPDA(1)
C USE FIRST 10 ELEMENTS OF ARRAYS LOGIC & INTRG AND 21ST
C TO 30TH OF ARRAY RE FOR TRANSFERRING SPECIAL DATA FROM
C SATELLITE TO GROUND. BUT IF REQUIREMENTS EXCEED THIS
C PROVISION SET SPDARA = .T., AND DIMENSION ARRAYS LSPDA, C
C RSPDA, RSPDA ABOVE AND IN GROUND AS NEEDED, AND SET HERE
C NLSP, NISP, NRSIP TO DIMENSION VALUES.

C CC ** PASS THE FOLLOWING INPUT GEOMETRIES, PROPERTIES, AND BOUNDARY
C CC CONDITIONS TO GROUND VIA RSPDA (FOR PRINTING ETC.)
C SADATA = .TRUE.
C RSPDA(1) = GINCC1
C RSPDA(2) = GEXIT1
C RSPDA(3) = AINH1
C RSPDA(4) = RINNER
C RSPDA(5) = H1INC1
C RSPDA(6) = H1NH1
C RSPDA(7) = ROIINC1
C RSPDA(8) = ROINH1
C RSPDA(9) = ECNCC1
C RSPDA(10) = RPM
C RSPDA(11) = FEEDC1
C RSPDA(12) = FEEDH1
C RSPDA(13) = H2OINH
C RSPDA(14) = WIINC
C RSPDA(15) = WIWH1

C + VARIABLES FOR EX11 AT O.D. OF AFT-PLATFORM SEAL
C RSPDA(16) = GLOS1
C RSPDA(17) = PEXIT(B) ARRAY IS EQUIVALENTED TO RSPDA(17)
C RSPDA(25) = VALKE
C RSPDA(26) = VALEP
C RSPDA(27) = HEXIT1
C RSPDA(28) = SLICES
C RSPDA(29) = H2OEXIT1

C +.GEXIT(B) ARRAY IS EQUIVALENTED TO RSPDA(30)

C-----------------------------
C --- GROUP 42 RESTARTS AND DUMPS : SAVEM<.F.>, RESIRI<.F.>, KINPUT
C SAVEM = .TRUE.
C RESTAR = .TRUE.

C-----------------------------
C --- GROUP 43 GRAFFIC :
C GRAPHS<.F.>, ORTHOG<.T.>, ANSYM, NIPRT<1>, ITT<5...4H+++>
C FOR A GRAFFIC RUN, DIMENSION PHI1 & PHI2 AS FOLLOWS:
C PHI1(NX+NY+N2+N4)
C PHI2((NX+2)*(NY+2)+(N2+1)*(N4+1)) WHERE
C N2, N4: NO. OF VARIABLES STORED + DENSITY(IES)
C IBLK = 0 IF BLOCK=.FALSE.*4 IF A 3D RUN.
C = 3 IF A 2D YZ RUN.
C = 4 GRAPH5 = .TRUE.

C-----------------------------
1500 IF(IRUN.EQ.1) GO TO 900
1501 C--- RUN2
1502 IF(IRUN.EQ.2) GO TO 900
1503 C--- RUN3
1504 IF(IRUN.EQ.3) GO TO 900
1505 C--- RUN4
1506 IF(IRUN.EQ.4) GO TO 900
1507 C--- RUN5
1508 IF(IRUN.EQ.5) GO TO 900
1509 C--- RUN6
1510 IF(IRUN.EQ.6) GO TO 900
1511 C--- RUN7
1512 IF(IRUN.EQ.7) GO TO 900
1513 C--- RUN8
1514 IF(IRUN.EQ.8) GO TO 900
1515 C--- RUN9
1516 IF(IRUN.EQ.9) GO TO 900
1517 C--- RUN10
1518 IF(IRUN.EQ.10) GO TO 900
1519 C--- RUN11
1520 IF(IRUN.EQ.11) GO TO 900
1521 C--- RUN12
1522 IF(IRUN.EQ.12) GO TO 900
1523 C--- RUN13
1524 IF(IRUN.EQ.13) GO TO 900
1525 C--- RUN14
1526 IF(IRUN.EQ.14) GO TO 900
1527 C--- RUN15
1528 IF(IRUN.EQ.15) GO TO 900
1529 C--- RUN16
1530 IF(IRUN.EQ.16) GO TO 900
1531 C--- RUN17
1532 IF(IRUN.EQ.17) GO TO 900
1533 C--- RUN18
1534 IF(IRUN.EQ.18) GO TO 900
1535 C--- RUN19
1536 IF(IRUN.EQ.19) GO TO 900
1537 C--- RUN20
1538 IF(IRUN.EQ.20) GO TO 900
1539 C--- RUN21
1540 IF(IRUN.EQ.21) GO TO 900
1541 C--- RUN22
1542 IF(IRUN.EQ.22) GO TO 900
1543 C--- RUN23
1544 IF(IRUN.EQ.23) GO TO 900
1545 C--- RUN24
1546 IF(IRUN.EQ.24) GO TO 900
1547 C--- RUN25
1548 IF(IRUN.EQ.25) GO TO 900
1549 C--- RUN26
1550 IF(IRUN.EQ.26) GO TO 900
1551 C--- RUN27
1552 IF(IRUN.EQ.27) GO TO 900
1553 C--- RUN28
1554 IF(IRUN.EQ.28) GO TO 900
1555 C--- RUN29
1556 IF(IRUN.EQ.29) GO TO 900
1557 C--- RUN30
1558 IF(IRUN.EQ.30) GO TO 900
1559 900 CONTINUE
C--- ALL RUNS
CXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX USER SECTION 3 ENDS.
CXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX STANDARD SECTION 4 STARTS:
C------------------------------------------------
C WRITE GENERAL DATA ON TO THE GUSIE1.DTA TAPE, ETC...
1565 IF(SPDATA) CALL WRTSPC(LSPDA,NLSP,ISPDA,NISP,RSPDA,NRSP)
1566 IF(BLOCK) CALL WRTPOR(PE,PN,PH,PC,NX,NY,NZ,IPLANE)
1567 C OLD PRACTICES RETAINED FOR REFERENCE:
1568 C IF(SPDATA) CALL SPCDAT(IRUN)
1569 C IF(BLOCK) CALL PORDAT(IRUN)
1570 IF(GRAPHS) CALL SORT(IRUN)
1571 IF(RESTR) GO TO 902
1572 C DO 901 INDX=1,25
1573 IF(IFIX(FIINIT(INDVAR)+0.1).NE.10101) GO TO 901
1574 CALL FLDAT(IRUN)
1575 GO TO 902
1576 901 CONTINUE
1577 902 CALL DATAO(WRT,10)
1578 IF(MONITR) CALL DATAO(WRT,-6)
1579 999 CONTINUE
1580 STOP
1581 END
1582 P1

@BRKPT PRINTS
RUNKLEBIN197+TPFS(0).SLPRT
1 $BATCH
2 C$DIRECTIVE**MAIN
3 C ***
4 C *FILE NAME: DSK32GR0.FTN
5 C ***
6 C *ABSTRACT: GROUND STATION FOR SSME HPFTP APS 3-D MODEL (2 EXITS)
7 C ***
8 C *INCLUDED SUBROUTINES: THE MODELS OF MAIN, GROUND
9 C *DOCUMENTATION: PHOENICS INSTRUCTION MANUAL (SPRING 1983).
10 C *SATELLITE FILE NAME: DSKSAT.FTN
11 COMMON/ISHTF/I1/I(57),NFMAX
12 C SET F-ARRAY DIMENSION AS NEEDED, & SET NFMAX ACCORDINGLY.
13 COMMON F(324000)
14 NFMAX=324000
15 CALL MAIN
16 STOP
17 END
18 C$DIRECTIVE**GROUND
19 SUBROUTINE GROUND(IRN,ICHAP,ISTP,ISWP,IZED,INDVAR)
20 $INCLUDE 9,CMMGUISI.FTN/G
21 $INCLUDE 9,CMMGUISI.FTN/G
22 C$INCLUDE 9,CMMGLIST.FTN/G
23 CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC STANDARD SECTION 1 STARTS:
24 C----------------------------------------
25 C### MEANING OF SUBROUTINE ARGUMENTS:
26 C IRN=RUN NUMBER  ICHAP=CHAPTER CALLED
27 C ISWP=SOLUTION SWEEP  IZED-Z-SLAB
28 C### USER-INTRODUCED VARIABLES & ARRAYS:
29 C TO AVOID CONFLICT WITH VARIABLE NAMES USED IN COMMON, ALL
30 C VARIABLES INTRODUCED BY THE USER SHOULD HAVE NAMES STARTING
31 C WITH 'G' IF REAL, 'I' IF INTEGER, AND 'S' OR 'J' IF LOGICAL.
32 C THUS GDZ(IJ) MIGHT BE A 2- INTERVAL ARRAY
33 C GW(IX,Y) A 2-D ARRAY FOR AXIAL VELOCITY
34 C USER-GENERATED SUBROUTINES SHOULD BE NAMED CORRESPONDINGLY, EG
35 C GSUBR GVISCON(TEMP, GCNC, GVSC), FOR COMPUTING VISCOSITY
36 C FROM CONCENTRATION & TEMPERATURE.
37 C### GROUND-TO-EARTH CONNECTING SUBROUTINES:
38 C USE GET(NAME,GARRAY,NY,NX) TO PUT VALUES OF VARIABLE NAMED
39 C 'NAME' INTO ARRAY 'GARRAY' DIMENSIONED GARRAY(NY,NX).
40 C USE GET(NAME,IX,IXL,IXF,YL,YL,GARRAY,NX,NX) TO SET VARIABLE
41 C 'NAME' TO GARRAY(IX,IXL) OVER THE REGION: IXL-IXL & IYLE-YLE.
42 C USE PRNLSB(NAME) TO PRINT VARIABLE 'NAME' OVER X-Y PLANE.
43 C USE ADD(NAME,IX,IXL,IXF,YL,YL,TYPE,CM,VM,CVAR,VVAR,NX,NX)
44 C TO ADD SOURCE TO VARIABLE NAMED 'NAME' (SEE CHAPTER 5).
45 C USE READIZ(IZED) IN CHAPTERS 1, 2, 8, 9, TO ACCESS P1,...DM
46 C & VOL....AHLDZ. (SEE FOOTNOTE TO LEGALITY TABLE)
47 C USE GT1D(NAME,GARRAY,NDIM) TO PUT VARIABLE NAMED 'NAME' IN
48 C ONE-D ARRAY 'GARRAY' DIMENSIONED NDIM. THUS:
49 C CALL GT1D(NAME,GNX,NX) FOR XG,...,NX & DIMENSION GNX(NX)
50 C CALL GT1D(NAME,GNY,NY) FORYG,...,NY & DIMENSION GNY(NY)
51 C CALL GT1D(NAME,GNZ,NZ) FOR ZG,...,NZ & DIMENSION GNZ(NZ).
52 C### LEGALITY TABLE FOR USE OF EARTH-CONNECTING SUBROUTINES:
53 C ENTRIES IN TABLE GIVE CHAPTERS IN WHICH SUBROUTINES CAN BE
54 C USED FOR VARIABLES IN LEFT-HAND COLUMN. (SUBROUTINE
55 C STRIDE IS REGARDED AS BEING IN CHAPTER 3)
56 C V... V... V... V... V...
57 C : VARIABLE:: GET & SET : ADD : READIZ : GT1D :
C  *IN CHAPTERS 1, 2, 6, 8, & 9 VARIABLES P1...DM & GEOMETRY
C  VOL...AH0Z CAN BE ACCESSED BUT ONLY IN CONJUNCTION WITH
C  USE OF READIZ, THUS:
C  DO 1 IZED=1,NZ
C  CALL READIZ(Ized)
C  1 CALL GET(... AS REQUIRED...) C  *GEOMETRY ACCESSED BY READIZ IS THAT AT INITIAL TIME
C  *D1DP & D2DP ONLY ACCESSIBLE IN UNEASY FLOWS.
C+++++GROUND SERVICE SUBROUTINES:
C  *USE CONTRNAME,IPLANE,ILOC,NINT,11,12,J1,J2,GARRAY,NDIM) FOR
C  LINE-PRINTER PLOTS OF CONTOURS. 'NAME' = U1,...C4
C  'IPLANE'= XPLANE, YPLANE, OR ZPLANE
C  IZ LOCATION OF PLANE
C  IZ, J1, J2 SET FIRST & LAST
C  CELLS IN HORIZ. & VERT. ON PLOT GARRAY IS 1-D WORKING ARRAY
C  OF DIMENSION NX*NY. NX*NY, OR NY*NX DICTATED BY IPLANE
C  NDIM SETS VALUE OF DIMENSION OF GARRAY
C  *USE FLD2D(A(TITLE,GARRAY,NX,NX) TO PRINT ANY ARRAY DIMENSIONED
C  GARRAY(NX,NX) SET 'TITLE' TO REQUIRED NAME ( 4 HOLLETH
C  CHARACTERS ONLY)
C  *USE FLD3D(A(TITLE,GARRAY,NX,NY,NZ,IPLANE,ILOC) TO PRINT ANY
C  ARRAY DIMENSIONED GARRAY(NX,NY,NZ) IN PLANE SPECIFIED BY
C  'IPLANE' & 'ILOC' AS FOR CONTUR ABOVE
C  FLD2DA.
C  VARIABLE NAMES FOR USE IN GROUND:
C  COMMON/TYPE/COLL, EAST, WEST, NORTH, SOUTH, HIGH, LOW, VOLUME, WALL
C  COMMON/VAR/P1,PP, U1, U2, V1, V2, W1, W2, R1, R2, RS.
C  &KE, EP, H1, H2, H3, C1, C2, C3, C4, RX, RY, RZ, S1, S2
C  COMMON/VAROLO/P10, PPO, U10, U20, V10, V20, W10, W20, R10, R20, RS0.
C  &KEO, EPO, H10, H20, H30, C10, C20, C30, C40, RADO, RYO, RYD, R70, S10, S20
C  COMMON/VAROLO/P11, PPL, U11, U21, V11, V21, W11, W21, R11, R21, RSL.
C  &KEL, EPL, H1L, H2L, H3L, CI1, C2L, C3L, C4L, RXL, RYL, RZL, S1L, S2L
C  COMMON/VARSH/P1H, PPI, U1H, U2H, V1H, V2H, W1H, W2H, R1H, R2H, RSH
C  &KEH, EPH, H1H, H2H, H3H, C1H, C2H, C3H, C4H, RHX, RHY, RHZ, SHH, S2H
C  COMMON/GMTRY/VOL, VOLO, AEAST, ANORTH, AHIGH, AEON, ANY, AH0Z
C  COMMON/PBDP/D1, D2, D1DP, D2DP, MU1, MU1LAM, EXCD, CFR, MD, HST1, HST2
C  COMMON/PBPDLO/PD0, D20
C  COMMON/PBPLLOW/PD1, D2L, EXCD
C  COMMON/PBPHI/D1H, D12H, MU1H, EXCDH
C  COMMON/VARNX/XG, XU, DXU, DXG
C  COMMON/VARNY/YG, YV, DYV, DYG, RY
C  COMMON/VARNZ/ZG, ZW1, DZW, DZG, WGRD
C  COMMON/GDMSCL/XPLANE, YPLANE, ZPLANE, XNO
C  COMMON/GDMSCL/LSLAB, MSLAB, HSLAB, LAMMU
C  REAL NORTH, LOW
C  INTEGER P1, PP, U1, U2, V1, V2, W1, W2, R1, R2, RS.
C  &EP, H1, H2, H3, C1, C2, C3, C4, RX, RY, RZ, S1, S2
C  INTEGER P10, PPO, U10, U20, V10, V20, W10, W20, R10, R20, RS0.
C ** DATA FOR SECOND EXIT
C = TOTAL EXIT AREA (SQ IN) FIRST, LAST IX-LOCATION
C NB. MAKE SURE EXIT AREA IS PERTINENT TO CHOSEN CALCULATION DOMAIN
C DATA GL&K2,GAXI2,GJXIEF,GJXIE2/L/1.5,0.0, 0.0/
C
C CXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX USER SECTION 1 ENDS
C CXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX STANDARD SECTION 2 STARTS:
C PLEASE DO NOT ALTER, OR RE-SET, ANY OF THE REMAINING
C STATEMENTS OF THIS SECTION.
C IF(SPDATA)
C &CALL RDSPC(1RN,INTGR(12),LSPDA,NLSP,I&SPDA,NSPDA,RSPDA,NRSP)
C CALL GROUTY(1RN,ICHAP,IZED,INDVAR)
C IF(ICHAP.EQ.-5) GO TO 10
C IF(ICHAP.LE.0.OR.ICHAP.GT.16) RETURN
C GO TO (100,200,300,400,500,600,700,800,900,1000,1100,1200,
C 1300,1400,1500,1600).ICHAP
C RETURN
C CXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX STANDARD SECTION 2 ENDS;
C CXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX USER SECTION 2 STARTS:
C----------------------------------------------------------------------
C----------------------------------------------------------------------
C IF(.NOT.NAMLST) RETURN
C IF(IRN.EQ.NRUN) DATFILE.FALSE.
C-- READ SATLIT DATA NAMELIST HERE
C CALL WRIT40(40HENTER NAMELIST DATA FOR GROUPS 1 TO 24 )
C READ(20,G1G24)
C CALL WRIT40(40HENTER NAMELIST DATA FOR GROUPS 25 TO 42 )
C READ(20,G2SG42)
C----------------------------------------------------------------------
CC ** SUMMARY PRINTOUT OF INPUT DATA
C WRITE(6,21)
C WRITE(6,22) RSPDA(10),RSPDA(1),RSPDA(9),RSPDA(3),RSPDA(2),
C $RSPDA(16)
C WRITE(6,23) RSPDA(5),RSPDA(6),RSPDA(27)/(178.16+G),RSPDA(11),
C $RSPDA(12)
C WRITE(6,24) RSPDA(7),RSPDA(8),RSPDA(14),RSPDA(15),
C $RSPDA(13),RSPDA(29)
C WRITE(6,28) RSPDA(37),RSPDA(36),RSPDA(35),RSPDA(34),RSPDA(33),
C $RSPDA(32),RSPDA(31),RSPDA(30)
C WRITE(6,25) RSPDA(24),RSPDA(23),RSPDA(22),RSPDA(21)
C WRITE(6,26) RSPDA(20),RSPDA(19),RSPDA(18),RSPDA(17)
C WRITE(6,27) GL&K2,GAXI2,GJXIEF,GJXIE2L
C----------------------------------------------------------------------
C FORMAT(////5X,21HSUMMARY OF INPUT DATA,5X,21(IH-))
C FORMAT(1X,1PE12.3,2X,36HRATIONAL SPEED OF THE DISC. (RPM),
C $1X,1PE12.3,2X,4HGAP SIZE AT THE Labyrinth SEAL. (INCHES),
C $1X,1PE12.3,2X,46HECCENTRICITY IN THE 11:30 DIRECTION, (INCHES),
C $1X,1PE12.3,2X,70TOTAL FLOW AREA (OVER 360 DEG) BETWEEN TURBINE B
C $LAGE SHANKS. (SQ INS).
C $1X,1PE12.3,2X,B5H(AVERAGE) CLEARANCE BETWEEN AFI-PLATFORM SEAL OD
C $ AND THE TURBINE BLADE LIP. (INCHES).
C $1X,1PE12.3,2X,64HLoss COEFFICIENT FOR ADDITIONAL LOSSES AT EXIT N
C $EAR BLADE ROOTS.)
C FORMAT(1X,1PE12.3,2X,53HENTHALPY OF H2 ENTERING AT LABYRINTH SEAL. (BTU/
C $LB)).
420 $/X,E12.3,2X,78HENTHALPY OF H2 + H2O MIXTURE ENTERING BETWEEN TURB
421 $INE BLADE SHANKS, (BTU/LBM).
422 $/X,E12.3,2X,40HENTHALPY OF TURBINE DISCHARGE (BTU/LBM).
423 $/X,E12.3,2X,74HTOTAL MASS FLOWRATE OF THE H2 ENTERING THROUGH L
424 $ABYRINTH SEAL (LBM/CU FT).
425 $/X,E12.3,2X,63TOTAL MASS FLOWRATE OF H2 + H2O MIXTURE ENTERING
426 $ BETWEEN BLADE SHANKS, (LBM/CU FT).)
427 44. FORMAT(
428 $/X,E12.3,2X,63HDENSITY OF THE H2 ENTERING THROUGH LABYRINTH SEA
429 $L, (LBM/CU FT).
430 $/X,E12.3,2X,75HDENSITY OF THE H2 + H2O MIXTURE ENTERING BETWEEN
431 $ BLADE SHANKS, (LBM/CU FT).
432 $/X,E12.3,2X,68HCALCULATED INLET VELOCITY OF THE H2 AT THE LABYR
433 $NTH SEAL. (FT/SEC).
434 $/X,E12.3,2X,60HCALCULATED INLET VELOCITY OF THE H2 + H2O MIXTURE
435 ENTERING BETWEEN BLADE SHANKS. (FT/SEC).
436 $/X,E12.3,2X,51HMASS FRACTION OF H2 ENTERING BETWEEN BLADE SHAN
437 $/X,E12.3,2X,36HMASS FRACTION OF H2 EXITING TURBINE.}
438 28. FORMAT(
439 $/X,E12.3,2X,33HEXIT GAP CLEARANCE (FEET) AT 1:00.
441 $/X,E12.3,2X,33HEXIT GAP CLEARANCE (FEET) AT 4:00.
443 $/X,E12.3,2X,33HEXIT GAP CLEARANCE (FEET) AT 7:00.
444 $/X,E12.3,2X,33HEXIT GAP CLEARANCE (FEET) AT 8:30.
446 $/X,E12.3,2X,34HEXIT GAP CLEARANCE (FEET) AT 10:00.
447 $/X,E12.3,2X,34HEXIT GAP CLEARANCE (FEET) AT 11:30.)
448 25. FORMAT(
449 $/X,E12.3,2X,23TEXIT PRESSURE (PSF) AT 1:00.
451 $/X,E12.3,2X,23TEXIT PRESSURE (PSF) AT 4:00.
452 $/X,E12.3,2X,24TEXIT PRESSURE (PSF) AT 5:30)
453 24. FORMAT(
454 $1X,E12.3,2X,24TEXIT PRESSURE (PSF) AT 7:00.
455 $/X,E12.3,2X,24TEXIT PRESSURE (PSF) AT 8:30.
456 $/X,E12.3,2X,28TEXIT PRESSURE (PSF) AT 10:00.
457 $/X,E12.3,2X,28TEXIT PRESSURE (PSF) AT 11:30.)
458 26. FORMAT(
459 $/X,E12.3,2X,232LOSS COEFFICIENT AT SECOND EXIT.
461 $/X,E12.4H TO .12.2X,40HIX-CELLS OVER WHICH SECOND EXIT LOCATED.
462 $/`)}
463 27. FORMAT(
464 $/X,E12.3,2X,32LOSS COEFFICIENT AT SECOND EXIT.
466 $/X,E12.4H TO .12.2X,40HIX-CELLS OVER WHICH SECOND EXIT LOCATED.
467 $/`)}
468 28. C
469 29. C ***
470 30. C CALCULATE ANY REQUIRED QUANTITIES FOR USE IN CH.5
471 GRPM=RSPDA(10)
472 GOMEGA=GRPM*2.*GPI/60.
473 GLOSS1=RSPDA(16)
474 SLICES=RSPDA(28)
475 GCELL=RBLADE/FLOAT(NX)/SLICES
476 GONB=2*GPI/GBLADE
477 31. C ** GET THE PROPERTIES OF THE TURBINE EXHAUST GASES FROM SATELLITE
478 C THESE VALUES ARE ASSIGNED TO ANY INFLOW AT THE 'EXIT'.
479 C BETWEEN THE O.D. OF THE AFT-PLATFORM SEAL AND THE BLADE LIPS
480 GEXIT=RSPDA(2)
300 GVALE = RSPDA(25)
301 GVALEP = RSPDA(26)
302 GMEXIT = RSPDA(27)
303 H2EXIT = RSPDA(29)
304 CC *** NEED TO CHECK ON VALUE OF H AND H20
305 C GVAL = 0.01 * MWEXIT ** 2
306 CWM = SQRT(100. * GVAL) / 10.
307 RETURN
308 C----------------------------------------
309 C CHAPTER 1: CALLED AT THE START OF EACH TIME STEP.
310 C SET 'DT' HERE WHEN TLAST SET NEGATIVE IN BLOCK DATA.
311 C 'ATIME + DT' GIVES THE END TIME OF THE CURRENT TIME STEP.
312 C NOT ACCESSED IF STEADY, OR PARABOLIC.
313 C----------------------------------------
314 100 CONTINUE
315 RETURN
316 C----------------------------------------
317 C CHAPTER 2: CALLED AT THE START OF EACH SWEEP
318 C----------------------------------------
319 200 CONTINUE
320 RETURN
321 C----------------------------------------
322 C CHAPTER 3: CALLED AT THE START OF EACH SLAB
323 C NOT ACCESSED IF PARABOLIC, BUT 'STRIDE' IS.
324 C----------------------------------------
325 300 CONTINUE
326 C *** IF (.NOT. (RESTART .AND. ISWP .EQ. FSWEEP)) RETURN
327 CALL GET(C1,GC1,NY,NX)
328 CALL GET(T1,GT1,NY,NX)
329 CALL GVISC(GT1,GC1,GMUL,NY,NX)
330 C ***
331 RETURN
332 C----------------------------------------
333 C CHAPTER 4: CALLED AT THE START OF EACH RE-CALCULATION OF
334 C VARIABLES P1,...,C4 AT CURRENT SLAB. ITNO = ITERATION NUMBER.
335 C----------------------------------------
336 400 CONTINUE
337 RETURN
338 C----------------------------------------
339 C CHAPTER 5: GROUND CALLED WHEN SOURCE TERM IS COMPUTED.
340 C INDVAR GIVES DEPENDENT VARIABLE IN QUESTION (E. U1,...,C4).
341 C TO ADD SOURCE TO DEPENDENT VARIABLE CT (SAY) FOR IX-IXF, IXL
342 C AND IY-IYF, IYL INSERT STATEMENT:
343 C IF (INDVAR .EQ. CI)
344 C & CALL ADD (INDVAR, I1X, I1X, I1Y, I1Y, TYPE, CM, VM, CVAR, VVAR, NY, NX)
345 C NOTES ON 'ADD':
346 C *SOURCE* = (CVAR(IX,IX)+AMAX1(0.0,MASFLD))+(VVAR(IX,IX)-PHI).
347 C WHERE PHI IS THE IN-CELL VALUE OF VARIABLE IN QUESTION.
348 C **MASFLD** * CM(IX,IX)+VM(IX,IX)-P).
349 C WHERE P IS THE IN-CCELL PRESSURE.
350 C *FOR INDVAR = M1, OR = M2, SOURCE ADDED IS 'MASFLD' ONLY.
351 C EXCEPT FOR ONEPHS .EQ. F .& MASFLD < 0.0 (IE. OUTFLOW) WHEN
352 C CM(IX,IX) IS MULTIPLIED BY R1*D1 (FOR M1) & R2*D2 (FOR M2).
353 C *BOTH 'CVAR' & 'CM' ARE MULTIPLIED BY CELL-GEOMETRY QUANTITY
354 C DICTATED BY SETTING OF 'TYPE' (=CELL, EAST AREA,...VOLUME).
355 C 'TYPE-SPECIFIED AREAS ARE CALCULATED AS IF BLOCKAGE ABSENT,
356 C BUT 'VOLUME' WITH ACCOUNT FOR ITS PRESENCE.
357 C *FOR ALL SOLVED VARIABLES, INCLUDING M1 ( & M2 WHEN ONEPHS=F).
358 C IF 'CM' > 0.0 CALL 'ADD' FOR M1 & M2 ALTHOUGH 'CVAR' & 'VVAR'
359 C
C HAVE NO SIGNIFICANCE THEY MUST BE ENTERED AS ARGUMENTS.
C *'CVAR', 'VVAR', 'CM' & 'VM' MUST BE DIMENSIONED NY,NX.
C
C 500 CONTINUE
C *** IF(INRVAR NE.U1) GO TO 502
C FIX ANGULAR MOMENTUM IN CELL(S) COMPLETELY ENFRAMED BY BLADES
C IF(IZED.I.GT.21) GO TO 502
C CALL GET1D(R,GR,NY)
C JIYF = 32
C JIYL = 40
C DO 501 JIY=1,NX
C DO 501 JIY=JIYF,JIYL
C CVAR(JIY,JIY)=FIXVAL
C CALL ADD(U1,1,NX,JIYF,JIYL,CELL,CM,VM,CVAR,VVAR,NY,NX)
C 501
C 502 IF(INRVAR NE.C1) GO TO 503
C C GET ADDITIONAL VARIABLES REQUIRED FOR TOTAL PRESSURE CALCULATIONS
C CALL GET(P1,GPT,NY,NX)
C CALL GET(W1,GW1,NY,NX)
C C SAVE CALCULATED EFFECTIVE VISCOSITIES FOR PRINTOUT
C CALL GET(MU1,GMU1,NY,NX)
C C GET VARIABLES REQUIRED FOR SUBROUTINE GWALL (IN COMMON/WALLG/)
C CALL GET(U1,GU1,NX,NX)
C CALL GET(W1,GV1,NX,NX)
C CALL GET(U1,GW1,NY,NX)
C CALL GET(D1,GD1,NX,NX)
C C!!! NB. THE "GET" COMMAND CANNOT BE USED FOR MULAM IN CH. 5 AND
C!!! SO THE LOCAL LAMINAR VISCOSITY ARRAY (GMLAM) MUST BE SET-UP
C!!! ELSEWHERE IN GND. FOR THE CURRENT PROBLEM IT IS CALCULATED (FOR
C!!! CONVENIENCE) IN CH. 10, AND THEN "SET" IN CH. 12 (FOR PASSING
C!!! BACK TO EARTH).
C
C CALL GET1D(DUX,GDXU,NX)
C CALL GET1D(DVY,GDVY,NY)
C CALL GET1D(DZ, GDZW,NX)
C CALL GET1D(R,GR,NY)
C
C *** CALCULATE WALL FRICTION EFFECTS ***
C 503 GVELW=INDVAR.EQ.U1.OR.INDVAR.EQ.W1
C GVELV=INDVAR.EQ.V1.OR.INDVAR.EQ.W1
C GVELUV=INDVAR.EQ.U1.OR.INDVAR.EQ.V1
C GKEEP=INDVAR.EQ.K.E.OR.INDVAR.EQ.EP
C 504
C C *** ROTATING WALL(S) ***
C 505
C *** ROW 1
C IF(.NOT.(IZED.GE.13.AND.IZED.LE.19)) GO TO 504
C IF(.NOT.GVELU) GO TO 5040
C CALL GWALL(INDVAR,1,NX,1,1,IZED,SOUTH,GOMEGA,0.,0,0.,-1.)
C CALL ADD(INDVAR,1,NX,1,1,SOUTH,CM,VM,CVAR,VVAR,NY,NX)
C 5040 IF(.NOT.GKEEP) GO TO 504
C CALL GWALL(INDVAR,1,NX,1,1,IZED,SOUTH,GOMEGA,0.,0,0.,-1.)
C CALL ADD(INDVAR,1,NX,1,1,CELL,CM,VM,CVAR,VVAR,NY,NX)
504 IF(.NOT. (IZED.EQ.19)) GO TO 505
505 IF(.NOT. GVELUV) GO TO 506
506 CALL GWALL(INDVAR, 1, NX, 1, 1, IZED, HIGH, GOMEGA, 0, 0, 0)
507 CALL ADD(INDVAR, 1, NX, 1, 1, HIGH, CM, VM, CVAR, VVAR, NY, NX)
508 IF(.NOT. GKEEP) GO TO 509
509 CALL GWALL(INDVAR, 1, NX, 1, 1, IZED, HIGH, GOMEGA, 0, 0, 0)
510 CALL ADD(INDVAR, 1, NX, 1, 1, CELL, CM, VM, CVAR, VVAR, NY, NX)
511 IF(.NOT. GVELUV) GO TO 512
512 C *** ROWS 2 TO 3
513 IF(.NOT. (IZED.EQ.21)) GO TO 506
514 CALL GWALL(INDVAR, 1, NX, 2, 3, IZED, HIGH, GOMEGA, 0, 0, 0)
515 CALL ADD(INDVAR, 1, NX, 2, 3, HIGH, CM, VM, CVAR, VVAR, NY, NX)
516 IF(.NOT. GKEEP) GO TO 506
517 CALL GWALL(INDVAR, 1, NX, 2, 3, IZED, HIGH, GOMEGA, 0, 0, 0)
518 CALL ADD(INDVAR, 1, NX, 2, 3, CELL, CM, VM, CVAR, VVAR, NY, NX)
519 C *** ROWS 4 TO 5
520 IF(.NOT. (IZED.EQ.16)) GO TO 509
521 CALL GWALL(INDVAR, 1, NX, 4, 4, IZED, HIGH, GOMEGA, 0, 0, 0)
522 CALL ADD(INDVAR, 1, NX, 4, 4, HIGH, CM, VM, CVAR, VVAR, NY, NX)
523 IF(.NOT. GKEEP) GO TO 509
524 CALL GWALL(INDVAR, 1, NX, 4, 4, IZED, HIGH, GOMEGA, 0, 0, 0)
525 CALL ADD(INDVAR, 1, NX, 4, 4, CELL, CM, VM, CVAR, VVAR, NY, NX)
526 C *** ROW 4
527 528 IF(.NOT. (IZED.EQ.17 AND IZED.EQ.21)) GO TO 508
529 IF(.NOT. GVELUV) GO TO 508
530 CALL GWALL(INDVAR, 1, NX, 3, 3, IZED, NORTH, GOMEGA, 0, 0, 0)
531 CALL ADD(INDVAR, 1, NX, 3, 3, NORTH, CM, VM, CVAR, VVAR, NY, NX)
532 IF(.NOT. GKEEP) GO TO 508
533 CALL GWALL(INDVAR, 1, NX, 3, 3, IZED, NORTH, GOMEGA, 0, 0, 0)
534 CALL ADD(INDVAR, 1, NX, 3, 3, CELL, CM, VM, CVAR, VVAR, NY, NX)
535 C *** ROWS 5 TO 10
536 537 IF(.NOT. (IZED.EQ.17 AND IZED.EQ.20)) GO TO 510
538 IF(.NOT. GVELUV) GO TO 510
539 CALL GWALL(INDVAR, 1, NX, 5, 5, IZED, SOUTH, GOMEGA, 0, 0, 0)
540 CALL ADD(INDVAR, 1, NX, 5, 5, SOUTH, CM, VM, CVAR, VVAR, NY, NX)
541 IF(.NOT. GKEEP) GO TO 510
542 CALL GWALL(INDVAR, 1, NX, 5, 5, IZED, SOUTH, GOMEGA, 0, 0, 0)
543 CALL ADD(INDVAR, 1, NX, 5, 5, CELL, CM, VM, CVAR, VVAR, NY, NX)
544 C *** ROW 5
545 546 IF(.NOT. (IZED.EQ.20)) GO TO 511
547 IF(.NOT. GVELUV) GO TO 511
548 CALL GWALL(INDVAR, 1, NX, 5, 10, IZED, HIGH, GOMEGA, 0, 0, 0)
549 CALL ADD(INDVAR, 1, NX, 5, 10, HIGH, CM, VM, CVAR, VVAR, NY, NX)
550 IF(.NOT. GKEEP) GO TO 511
551 CALL GWALL(INDVAR, 1, NX, 5, 10, IZED, HIGH, GOMEGA, 0, 0, 0)
552 CALL ADD(INDVAR, 1, NX, 5, 10, CELL, CM, VM, CVAR, VVAR, NY, NX)
IF (.NOT. GVELW) GO TO 5120
CALL GWALL (INDVAR, 1, NX, 10, 10, IZED, SOUTH, GOMEGA, 0, 0, 0, -1)
CALL ADD (INDVAR, 1, NX, 10, SOUTH, VM, CVAR, VVAR, NY, NX)
IF (.NOT. GKEEP) GO TO 512
CALL GWALL (INDVAR, 1, NX, 10, 10, IZED, SOUTH, GOMEGA, 0, 0, 0, -1)
CALL ADD (INDVAR, 1, NX, 10, CELL, CM, VM, CVAR, VVAR, NY, NX)
C
512 IF (.NOT. (IZED.EQ.22)) GO TO 513
IF (.NOT. GVELUV) GO TO 5130
CALL GWALL (INDVAR, 1, NX, 10, 10, IZED, HIGH, GOMEGA, 0, 0, 0, -1)
CALL ADD (INDVAR, 1, NX, 10, 10, HIGH, CM, VM, CVAR, VVAR, NY, NX)
5130 IF (.NOT. GKEEP) GO TO 513
CALL GWALL (INDVAR, 1, NX, 10, 10, IZED, HIGH, GOMEGA, 0, 0, 0, -1)
CALL ADD (INDVAR, 1, NX, 10, 10, CELL, CM, VM, CVAR, VVAR, NY, NX)
C
C *** ROW 11
513 IF (.NOT. (IZED.EQ.23)) GO TO 514
IF (.NOT. GVELW) GO TO 5140
CALL GWALL (INDVAR, 1, NX, 11, 11, IZED, SOUTH, GOMEGA, 0, 0, 0, -1)
CALL ADD (INDVAR, 1, NX, 11, 11, SOUTH, CM, VM, CVAR, VVAR, NY, NX)
5140 IF (.NOT. GKEEP) GO TO 514
CALL GWALL (INDVAR, 1, NX, 11, 11, IZED, SOUTH, GOMEGA, 0, 0, 0, -1)
CALL ADD (INDVAR, 1, NX, 11, 11, CELL, CM, VM, CVAR, VVAR, NY, NX)
514 C
514 IF (.NOT. (IZED.EQ.24)) GO TO 515
IF (.NOT. GVELW) GO TO 5150
CALL GWALL (INDVAR, 1, NX, 11, 11, IZED, HIGH, GOMEGA, 0, 0, 0, -1)
CALL ADD (INDVAR, 1, NX, 11, 11, HIGH, CM, VM, CVAR, VVAR, NY, NX)
5150 IF (.NOT. GKEEP) GO TO 515
CALL GWALL (INDVAR, 1, NX, 11, 11, IZED, HIGH, GOMEGA, 0, 0, 0, -1)
CALL ADD (INDVAR, 1, NX, 11, 11, CELL, CM, VM, CVAR, VVAR, NY, NX)
515 C
C *** ROWS 12 TO 13
515 IF (.NOT. (IZED.EQ.24)) GO TO 516
IF (.NOT. GVELW) GO TO 5160
CALL GWALL (INDVAR, 1, NX, 12, 13, IZED, HIGH, GOMEGA, 0, 0, 0, -1)
CALL ADD (INDVAR, 1, NX, 12, 13, HIGH, CM, VM, CVAR, VVAR, NY, NX)
5160 IF (.NOT. GKEEP) GO TO 516
CALL GWALL (INDVAR, 1, NX, 12, 13, IZED, HIGH, GOMEGA, 0, 0, 0, -1)
CALL ADD (INDVAR, 1, NX, 12, 13, CELL, CM, VM, CVAR, VVAR, NY, NX)
516 C
516 IF (.NOT. (IZED.GE.21. AND. IZED.LE.24)) GO TO 517
IF (.NOT. GVELW) GO TO 5170
CALL GWALL (INDVAR, 1, NX, 13, 13, IZED, NORTH, GOMEGA, 0, 0, 0, -1)
CALL ADD (INDVAR, 1, NX, 13, 13, NORTH, CM, VM, CVAR, VVAR, NY, NX)
5170 IF (.NOT. GKEEP) GO TO 517
CALL GWALL (INDVAR, 1, NX, 13, 13, IZED, NORTH, GOMEGA, 0, 0, 0, -1)
CALL ADD (INDVAR, 1, NX, 13, 13, CELL, CM, VM, CVAR, VVAR, NY, NX)
517 C
C *** ROW 14
517 IF (.NOT. (IZED.EQ.20)) GO TO 518
IF (.NOT. GVELW) GO TO 5180
CALL GWALL (INDVAR, 1, NX, 14, 14, IZED, HIGH, GOMEGA, 0, 0, 0, -1)
CALL ADD (INDVAR, 1, NX, 14, 14, HIGH, CM, VM, CVAR, VVAR, NY, NX)
5180 IF (.NOT. GKEEP) GO TO 518
CALL GWALL (INDVAR, 1, NX, 14, 14, IZED, HIGH, GOMEGA, 0, 0, 0, -1)
CALL ADD (INDVAR, 1, NX, 14, 14, CELL, CM, VM, CVAR, VVAR, NY, NX)
518 C
C *** ROW 15
518 IF (.NOT. (IZED.GE.21. AND. IZED.LE.23)) GO TO 519
IF(.NOT.GVELUW) Go To 5190
CALL GWALL(INVAR, 1, NX, 15, 15, IZED, SOUTH, GOMEGA, O., O., O., -1.)
CALL ADD(INVAR, 1, NX, 15, 15, SOUTH, CM, VM, CVAR, VVAR, NY, NX)
5190 IF(.NOT.GKEEP) Go To 519
CALL GWALL(INVAR, 1, NX, 15, 15, IZED, SOUTH, GOMEGA, O., O., O., -1.)
CALL ADD(INVAR, 1, NX, 15, 15, CELL, CM, VM, CVAR, VVAR, NY, NX)
C
519 IF(.NOT.(IZED.EQ.24)) Go To 520
IF(.NOT.GVELUW) Go To 5200
CALL GWALL(INVAR, 1, NX, 15, 15, IZED, HIGH, GOMEGA, O., O., O., -1.)
CALL ADD(INVAR, 1, NX, 15, 15, HIGH, CM, VM, CVAR, VVAR, NY, NX)
5200 IF(.NOT.GKEEP) Go To 520
CALL GWALL(INVAR, 1, NX, 15, 15, IZED, HIGH, GOMEGA, O., O., O., -1.)
CALL ADD(INVAR, 1, NX, 15, 15, CELL, CM, VM, CVAR, VVAR, NY, NX)
C
*** ROWS 16 TO 21
520 IF(.NOT.(IZED.EQ.25)) Go To 521
IF(.NOT.GVELUW) Go To 5210
CALL GWALL(INVAR, 1, NX, 16, 21, IZED, HIGH, GOMEGA, O., O., O., -1.)
CALL ADD(INVAR, 1, NX, 16, 21, HIGH, CM, VM, CVAR, VVAR, NY, NX)
5210 IF(.NOT.GKEEP) Go To 521
CALL GWALL(INVAR, 1, NX, 16, 21, IZED, HIGH, GOMEGA, O., O., O., -1.)
CALL ADD(INVAR, 1, NX, 16, 21, CELL, CM, VM, CVAR, VVAR, NY, NX)
C
521 IF(.NOT.(IZED.GE.23 .AND. IZED.LE.24)) Go To 522
IF(.NOT.GVELUW) Go To 5220
CALL GWALL(INVAR, 1, NX, 21, 21, IZED, NORTH, GOMEGA, O., O., O., -1.)
CALL ADD(INVAR, 1, NX, 21, 21, NORTH, CM, VM, CVAR, VVAR, NY, NX)
5220 IF(.NOT.GKEEP) Go To 522
CALL GWALL(INVAR, 1, NX, 21, 21, IZED, NORTH, GOMEGA, O., O., O., -1.)
CALL ADD(INVAR, 1, NX, 21, 21, CELL, CM, VM, CVAR, VVAR, NY, NX)
C
*** ROWS 22 TO 31
522 IF(.NOT.(IZED.GE.21 .AND. IZED.LE.22)) Go To 523
IF(.NOT.GVELUW) Go To 5230
CALL GWALL(INVAR, 1, NX, 22, 22, IZED, NORTH, GOMEGA, O., O., O., -1.)
CALL ADD(INVAR, 1, NX, 22, 22, NORTH, CM, VM, CVAR, VVAR, NY, NX)
5230 IF(.NOT.GKEEP) Go To 523
CALL GWALL(INVAR, 1, NX, 22, 22, IZED, NORTH, GOMEGA, O., O., O., -1.)
CALL ADD(INVAR, 1, NX, 22, 22, CELL, CM, VM, CVAR, VVAR, NY, NX)
C
523 IF(.NOT.(IZED.EQ.20)) Go To 524
IF(.NOT.GVELUW) Go To 5240
CALL GWALL(INVAR, 1, NX, 22, 31, IZED, HIGH, GOMEGA, O., O., O., -1.)
CALL ADD(INVAR, 1, NX, 22, 31, HIGH, CM, VM, CVAR, VVAR, NY, NX)
5240 IF(.NOT.GKEEP) Go To 524
CALL GWALL(INVAR, 1, NX, 22, 31, IZED, HIGH, GOMEGA, O., O., O., -1.)
CALL ADD(INVAR, 1, NX, 22, 31, CELL, CM, VM, CVAR, VVAR, NY, NX)
C
*** ROWS 32 TO 40
524 IF(.NOT.(IZED.GE.21 .AND. IZED.LE.28)) Go To 5251
C
NOTE THAT GDELT A IS SPECIFIED AS 0.5*( ANGLE BETWEEN EACH BLADE ) SO
THAT FRICTION AND KE AND EP VALUES CALCULATED AS FOR BETWEEN BLADES
5251 IF(.NOT.GVELUW) Go To 5250
C
CALL GWALL(INVAR, 1, NX, 32, 40, IZED, EAST, GOMEGA, O., O., O., GONEBL)
C ACCOUNT FOR THERE BEING MORE THAN ONE BLADE IN EACH CELL BY
C INCREASING FRICTION LOSS ES PROPORTIONATELY (IE: *NO. BLADES/NX)}
532 IF (.NOT.(IZED.EQ.12)) GO TO 533
533 IF (.NOT.(GVELU)) GO TO 5330
CALL GWALL(INDOVAR, 1, NX, 3, 5, IZED, HIGH, O, O, O, O, . . ., 1.)
CALL ADD(INDOVAR, 1, NX, 3, 5, HIGH, CM, VM, CVAR, VVAR, NY, NX)
5330 IF (.NOT.(GKEEP)) GO TO 533
CALL GWALL(INDOVAR, 1, NX, 3, 5, IZED, HIGH, O, O, O, O, . . ., 1.)
CALL ADD(INDOVAR, 1, NX, 3, 5, CELL, CM, VM, CVAR, VVAR, NY, NX)
534 IF (.NOT.(IZED.EQ.5) AND (IZED.LE.12)) GO TO 534
535 IF (.NOT.(GVELU)) GO TO 5350
CALL GWALL(INDOVAR, 1, NX, 3, 3, IZED, SOUTH, O, O, O, O, . . ., 1.)
CALL ADD(INDOVAR, 1, NX, 3, 3, SOUTH, CM, VM, CVAR, VVAR, NY, NX)
5350 IF (.NOT.(GKEEP)) GO TO 535
CALL GWALL(INDOVAR, 1, NX, 3, 3, IZED, SOUTH, O, O, O, O, . . ., 1.)
CALL ADD(INDOVAR, 1, NX, 3, 3, CELL, CM, VM, CVAR, VVAR, NY, NX)
536 IF (.NOT.(IZED.EQ.4)) GO TO 537
537 IF (.NOT.(GVELU)) GO TO 5380
CALL GWALL(INDOVAR, 1, NX, 4, 5, IZED, SOUTH, O, O, O, O, . . ., 1.)
CALL ADD(INDOVAR, 1, NX, 4, 5, SOUTH, CM, VM, CVAR, VVAR, NY, NX)
538 IF (.NOT.(GKEEP)) GO TO 536
CALL GWALL(INDOVAR, 1, NX, 4, 5, IZED, SOUTH, O, O, O, O, . . ., 1.)
CALL ADD(INDOVAR, 1, NX, 4, 5, CELL, CM, VM, CVAR, VVAR, NY, NX)
5380 IF (.NOT.(GVELU)) GO TO 5390
CALL GWALL(INDOVAR, 1, NX, 4, 4, IZED, LOW, O, O, O, O, . . ., 1.)
CALL ADD(INDOVAR, 1, NX, 4, 4, LOW, CM, VM, CVAR, VVAR, NY, NX)
539 IF (.NOT.(GKEEP)) GO TO 537
CALL GWALL(INDOVAR, 1, NX, 4, 4, IZED, LOW, O, O, O, O, . . ., 1.)
CALL ADD(INDOVAR, 1, NX, 4, 4, CELL, CM, VM, CVAR, VVAR, NY, NX)
5390 IF (.NOT.(ORIZED.EQ.0) AND (ORIZED.LE.0)) GO TO 539
540 IF (.NOT.(GVELU)) GO TO 5400
CALL GWALL(INDOVAR, 1, NX, 8, 8, IZED, SOUTH, O, O, O, O, . . ., 1.)
CALL ADD(INDOVAR, 1, NX, 8, 8, SOUTH, CM, VM, CVAR, VVAR, NY, NX)
5400 IF (.NOT.(GKEEP)) GO TO 540
CALL GWALL(INDOVAR, 1, NX, 8, 8, IZED, SOUTH, O, O, O, O, . . ., 1.)
CALL ADD(INDOVAR, 1, NX, 8, 8, CELL, CM, VM, CVAR, VVAR, NY, NX)
540 IF (.NOT. GVELUV) GO TO 5410
   CALL GWALL (INODVAR, 1, NX, 8, 8, IZED, LOW, O,, O,, O,, O,,...1)
   CALL ADD (INODVAR, 1, NX, 8, 8, LOW, CM, CVAR, VVAR, NY, NX)
5410 IF (.NOT. GKEEP) GO TO 5411
   CALL GWALL (INODVAR, 1, NX, 8, 8, IZED, LOW, O,, O,, O,, O,,...1)
   CALL ADD (INODVAR, 1, NX, 8, 8, CELL, CM, CVAR, VVAR, NY, NX)

C
541 IF (.NOT. (IZED EQ. 0)) GO TO 541
541 IF (.NOT. GVELUV) GO TO 5414
   CALL GWALL (INODVAR, 1, NX, 9, 9, IZED, LOW, O,, O,, O,, O,,...1)
   CALL ADD (INODVAR, 1, NX, 9, 9, LOW, CM, CVAR, VVAR, NY, NX)
5414 IF (.NOT. GKEEP) GO TO 541
   CALL GWALL (INODVAR, 1, NX, 9, 9, IZED, LOW, O,, O,, O,, O,,...1)
   CALL ADD (INODVAR, 1, NX, 9, 9, CELL, CM, CVAR, VVAR, NY, NX)

C
C *** ROW 10
541 IF (.NOT. (IZED EQ. 0)) GO TO 545
541 IF (.NOT. GVELUV) GO TO 5450
   CALL GWALL (INODVAR, 1, NX, 10, 10, IZED, SOUTH, O,, O,, O,,...1)
   CALL ADD (INODVAR, 1, NX, 10, 10, SOUTH, CM, CVAR, VVAR, NY, NX)
5450 IF (.NOT. GKEEP) GO TO 545
   CALL GWALL (INODVAR, 1, NX, 10, 10, IZED, SOUTH, O,, O,, O,,...1)
   CALL ADD (INODVAR, 1, NX, 10, 10, CELL, CM, CVAR, VVAR, NY, NX)

C
545 IF (.NOT. (IZED EQ. 2 AND IZED EQ. 4)) GO TO 546
545 IF (.NOT. GVELUV) GO TO 5460
   CALL GWALL (INODVAR, 1, NX, 10, 10, IZED, NORTH, O,, O,, O,,...1)
   CALL ADD (INODVAR, 1, NX, 10, 10, NORTH, CM, CVAR, VVAR, NY, NX)
5460 IF (.NOT. GKEEP) GO TO 546
   CALL GWALL (INODVAR, 1, NX, 10, 10, IZED, NORTH, O,, O,, O,,...1)
   CALL ADD (INODVAR, 1, NX, 10, 10, CELL, CM, CVAR, VVAR, NY, NX)
546 IF (.NOT. GVELUV) GO TO 5470
548 IF (.NOT. (IZED EQ. 2 AND IZED EQ. 4)) GO TO 549
548 IF (.NOT. GVELUV) GO TO 5490
   CALL GWALL (INODVAR, 1, NX, 11, 11, IZED, LOW, O,, O,, O,,...1)
   CALL ADD (INODVAR, 1, NX, 11, 11, LOW, CM, CVAR, VVAR, NY, NX)
5490 IF (.NOT. GKEEP) GO TO 549
5490 IF (.NOT. GKEEP) GO TO 549
   CALL GWALL (INODVAR, 1, NX, 11, 11, IZED, SOUTH, O,, O,, O,,...1)
   CALL ADD (INODVAR, 1, NX, 11, 11, SOUTH, CM, CVAR, VVAR, NY, NX)
549 IF (.NOT. GVELUV) GO TO 5500

C
C *** ROW 11
547 IF (.NOT. (IZED GE. 2 AND IZED LE. 4)) GO TO 549
547 IF (.NOT. GVELUV) GO TO 5480
   CALL GWALL (INODVAR, 1, NX, 11, 11, IZED, LOW, O,, O,, O,,...1)
   CALL ADD (INODVAR, 1, NX, 11, 11, LOW, CM, CVAR, VVAR, NY, NX)
5480 IF (.NOT. GKEEP) GO TO 548
5480 IF (.NOT. GKEEP) GO TO 548
   CALL GWALL (INODVAR, 1, NX, 11, 11, IZED, LOW, O,, O,, O,,...1)
   CALL ADD (INODVAR, 1, NX, 11, 11, CELL, CM, CVAR, VVAR, NY, NX)
548 IF (.NOT. GVELUV) GO TO 5490
548 IF (.NOT. GVELUV) GO TO 5490
   CALL GWALL (INODVAR, 1, NX, 11, 11, IZED, SOUTH, O,, O,, O,,...1)
   CALL ADD (INODVAR, 1, NX, 11, 11, SOUTH, CM, CVAR, VVAR, NY, NX)
5490 IF (.NOT. GKEEP) GO TO 549
5490 IF (.NOT. GKEEP) GO TO 549
   CALL GWALL (INODVAR, 1, NX, 11, 11, IZED, SOUTH, O,, O,, O,,...1)
   CALL ADD (INODVAR, 1, NX, 11, 11, CELL, CM, CVAR, VVAR, NY, NX)

C
C *** ROWS 12 TO 17
549 IF (.NOT. (IZED EQ. 3)) GO TO 550
549 IF (.NOT. GVELUV) GO TO 5500
   CALL GWALL (INODVAR, 1, NX, 12, 17, IZED, LOW, O,, O,, O,,...1)
   CALL ADD (INODVAR, 1, NX, 12, 17, LOW, CM, CVAR, VVAR, NY, NX)
550 IF (.NOT. GKEEP) GO TO 551
550 IF (.NOT. GKEEP) GO TO 551
   CALL GWALL (INODVAR, 1, NX, 12, 17, IZED, SOUTH, O,, O,, O,,...1)
   CALL ADD (INODVAR, 1, NX, 12, 17, SOUTH, CM, CVAR, VVAR, NY, NX)
551 IF (.NOT. GVELUV) GO TO 5520
551 IF (.NOT. GVELUV) GO TO 5520
   CALL GWALL (INODVAR, 1, NX, 12, 17, IZED, SOUTH, O,, O,, O,,...1)
   CALL ADD (INODVAR, 1, NX, 12, 17, CELL, CM, CVAR, VVAR, NY, NX)
5500 IF(.NOT.GKEEP) GO TO 550
5501 CALL GWALL(INDBAR,1,NX,12,17,IZED,LOW,O,O,O,O,-1.)
5502 CALL ADD(INDBAR,1,NX,12,17,CELL,CM,VM,CVAR,VVAR,NY,NX)
5503 C
5504 IF(.NOT.(IZED.GE.3.AND.IZED.LE.4)) GO TO 551
5505 IF(.NOT.GVELUV) GO TO 5510
5506 CALL GWALL(INDBAR,1,NX,17,17,IZED,NORTH,O,O,O,O,-1.)
5507 CALL ADD(INDBAR,1,NX,17,17,NORTH,CM,VM,CVAR,VVAR,NY,NX)
5510 IF(.NOT.GKEEP) GO TO 551
5511 CALL GWALL(INDBAR,1,NX,17,17,IZED,NORTH,O,O,O,O,-1.)
5512 CALL ADD(INDBAR,1,NX,17,17,CELL,CM,VM,CVAR,VVAR,NY,NX)
5513 C
5514 *** ROWS 18 TO 21
5515 IF(.NOT.(IZED.EQ.4)) GO TO 552
5516 IF(.NOT.GVELUV) GO TO 5520
5517 CALL GWALL(INDBAR,1,NX,18,20,IZED,LOW,O,O,O,O,-1.)
5518 CALL ADD(INDBAR,1,NX,18,20,LOW,CM,VM,CVAR,VVAR,NY,NX)
5520 IF(.NOT.GKEEP) GO TO 552
5521 CALL GWALL(INDBAR,1,NX,18,20,IZED,LOW,O,O,O,O,-1.)
5522 CALL ADD(INDBAR,1,NX,18,20,CELL,CM,VM,CVAR,VVAR,NY,NX)
5523 C
5524 IF(.NOT.(IZED.EQ.4)) GO TO 553
5525 IF(.NOT.GVELUV) GO TO 5530
5526 CALL GWALL(INDBAR,1,NX,21,21,IZED,NORTH,O,O,O,O,-1.)
5527 CALL ADD(INDBAR,1,NX,21,21,NORTH,CM,VM,CVAR,VVAR,NY,NX)
5530 IF(.NOT.GKEEP) GO TO 553
5531 CALL GWALL(INDBAR,1,NX,21,21,IZED,NORTH,O,O,O,O,-1.)
5532 CALL ADD(INDBAR,1,NX,21,21,CELL,CM,VM,CVAR,VVAR,NY,NX)
5533 C
5534 *** ROWS 22 TO 29
5535 IF(.NOT.(IZED.GE.5.AND.IZED.LE.6)) GO TO 555
5536 IF(.NOT.GVELUV) GO TO 5540
5537 CALL GWALL(INDBAR,1,NX,21,21,IZED,NORTH,O,O,O,O,-1.)
5538 CALL ADD(INDBAR,1,NX,21,21,NORTH,CM,VM,CVAR,VVAR,NY,NX)
5540 IF(.NOT.GKEEP) GO TO 555
5541 CALL GWALL(INDBAR,1,NX,21,21,IZED,NORTH,O,O,O,O,-1.)
5542 CALL ADD(INDBAR,1,NX,21,21,CELL,CM,VM,CVAR,VVAR,NY,NX)
5543 C
5544 *** ROWS 22 TO 29
5545 IF(.NOT.(IZED.GE.6.AND.IZED.LE.8)) GO TO 556
5546 IF(.NOT.GVELUV) GO TO 5560
5547 CALL GWALL(INDBAR,1,NX,22,22,IZED,NORTH,O,O,O,O,-1.)
5548 CALL ADD(INDBAR,1,NX,22,22,NORTH,CM,VM,CVAR,VVAR,NY,NX)
5550 IF(.NOT.GKEEP) GO TO 556
5551 CALL GWALL(INDBAR,1,NX,22,22,IZED,NORTH,O,O,O,O,-1.)
5552 CALL ADD(INDBAR,1,NX,22,22,CELL,CM,VM,CVAR,VVAR,NY,NX)
5553 C
5554 IF(.NOT.(IZED.EQ.9)) GO TO 557
5555 IF(.NOT.GVELUV) GO TO 5570
5556 CALL GWALL(INDBAR,1,NX,23,23,IZED,NORTH,O,O,O,O,-1.)
5557 CALL ADD(INDBAR,1,NX,23,23,NORTH,CM,VM,CVAR,VVAR,NY,NX)
5559 IF(.NOT.GKEEP) GO TO 557
5560 CALL GWALL(INDBAR,1,NX,23,23,IZED,NORTH,O,O,O,O,-1.)
5561 CALL ADD(INDBAR,1,NX,23,23,CELL,CM,VM,CVAR,VVAR,NY,NX)
5562 C
5563 IF(.NOT.(IZED.EQ.10)) GO TO 558
5564 IF(.NOT.GVELUV) GO TO 5580
5565 CALL GWALL(INDBAR,1,NX,24,24,IZED,NORTH,O,O,O,O,-1.)
5566 CALL ADD(INDBAR,1,NX,24,24,NORTH,CM,VM,CVAR,VVAR,NY,NX)
5569 IF(.NOT.GKEEP) GO TO 558
5570 CALL GWALL(INDBAR,1,NX,24,24,IZED,NORTH,O,O,O,O,-1.)
CALL GWALL(INDVAR, 1, NX, 32, 37, IZED, LOW, 0, 0, 0, 0, -1.)
CALL ADD(INDVAR, 1, NX, 32, 37, LOW, CM, VM, CVAR, VVAR, NY, NX)

5670 IF(.NOT. GKEEP) GO TO 567
CALL GWALL(INDVAR, 1, NX, 32, 37, IZED, LOW, 0, 0, 0, 0, -1.)
CALL ADD(INDVAR, 1, NX, 32, 37, CELL, CM, VM, CVAR, VVAR, NY, NX)

C

C *** ROWS 38 TO 39
567 IF(.NOT. (IZED.EQ.18)) GO TO 568
IF(.NOT. GVELU) GO TO 5680
CALL GWALL(INDVAR, 1, NX, 38, 39, IZED, LOW, 0, 0, 0, 0, -1.)
CALL ADD(INDVAR, 1, NX, 38, 39, LOW, CM, VM, CVAR, VVAR, NY, NX)

5680 IF(.NOT. GKEEP) GO TO 568
CALL GWALL(INDVAR, 1, NX, 38, 39, IZED, LOW, 0, 0, 0, 0, -1.)
CALL ADD(INDVAR, 1, NX, 38, 39, CELL, CM, VM, CVAR, VVAR, NY, NX)

C

C *** ROW 40
568 IF(.NOT. (IZED.EQ.17)) GO TO 575
IF(.NOT. GVELU) GO TO 5690
CALL GWALL(INDVAR, 1, NX, 40, 40, IZED, SOUTH, 0, 0, 0, 0, -1.)
CALL ADD(INDVAR, 1, NX, 40, 40, SOUTH, CM, VM, CVAR, VVAR, NY, NX)

5690 IF(.NOT. GKEEP) GO TO 575
CALL GWALL(INDVAR, 1, NX, 40, 40, IZED, SOUTH, 0, 0, 0, 0, -1.)
CALL ADD(INDVAR, 1, NX, 40, 40, CELL, CM, VM, CVAR, VVAR, NY, NX)

C

C ACCOUNT FOR MOMENTUM LOSSES AT EXIT(S) ***

C

C *** EXIT NEAR BLADE ROOTS (O.D. OF AFT-PLATFORM SEAL)
575 IF(.NOT. (IZED.EQ.17)) GO TO 582
J1I = NY
CALL GET(AHIGH, GAHIGH, NY, NX)
CALL GET1(DYV, G DyV, NY)
CALL GET(W1, GW1, NY, NX)

C

C USE A LOSS COEFFICIENT (GLOS1) TO COMPUTE THE PRESSURE
C LOSS ACROSS THE EXIT AT THE O.D. OF THE AFT-PLATFORM SEAL
C MASSFLOW = CM (EXIT PRESS - CELL PRESS)
CM = 2 * (EXIT AREA)/(GLOS1*EXIT VELOCITY)
NOTE: SUB. FOR VELOCITY, VELOCITY = W1(FULL CELL AXIAL VELOCITY) + (CELL HEIGHT/GAP SIZE)
SUB. FOR EXIT AREA, EXIT AREA = GAHIGH(FULL CELL AREA) + (GAP SIZE/CELL HEIGHT)
DO 580 JIX = 1, NX
C PREVENT LARGE CM BY LIMITING SMALLEST W1 (= .1*Nominal Exit W1)
ABSGW1 = MAX(W1, 10, ABSGW1(J1I, JIX)))
(CALCULATE THE LOSS COEFFICIENT CM)
CM(J1I, JIX) = 2.0 + GAHIGH(J1I, JIX)/(GLOS1 + ABSGW1(GTINV))
T(GDGE1(GLY1)/DYV(J1I, JIX)) + 2.
C PREVENT CM FROM BEHAVING ERRATICALLY IN FIRST FEW (5) SWEEPS
C NB. THE .0025 IS A 'LARGE' VALUE SUFFICIENT TO FIX P-PEXIT
IF(ISWP.LE.5) CM(J1I, JIX) = 0.0025 + GAHIGH(J1I, JIX)
C GIVE SAVED CM A FINITE VALUE AT EXIT
IF(ISWP.LE.1) CM(J1I, JIX) = 0.0025
C UNDER-RELAX CM TO PREVENT INSTABILITY
CM(J1I, JIX) = CMRLX1 + CM(J1I, JIX) + (1. - CMRLX1) * CM(J1I, JIX)
C SAVE CM VALUE FOR RELAXATION
CM1S(J1I) = CM(J1I, JIX)
C (ASSIGN VM THE CIRCUMFERENTIAL EXIT PRESSURES)
VM(JIY,JIX)=GPEXIT(JIX)
C
C *** SET THE VALUES OF U1,V1,W1,H1,KE,AND EP AT THE O.D. OF
C THE AFT-PLATFORM SEAL IN CASE OF INFLOW.
C *** CM & VM HAVE BEEN SET ABOVE FOR PRESCRIBED MASS FLOW
C CVAR IS SET TO ZERO FOR ZERO DIFFUSION FLUX
C CVAR(JIY,JIX)=0.0
C
C SET VVAR TO EXTERNAL VALUE APPROPRIATE FOR THE VARIABLE
C VVAR(JIY,JIX)=0.0
C IF (INDVAR.EQ.H1) VVAR(JIY,JIX) = GHEXIT
C IF (INDVAR.EQ.C1) VVAR(JIY,JIX) = H2OXIT
C IF (INDVAR.EQ.KE) VVAR(JIY,JIX) = GVALKE
C IF (INDVAR.EQ.EP) VVAR(JIY,JIX) = GVAEP
C
C *** NOTE: THE VALUES OF CVAR AND VVAR NEED NOT BE DEFINED FOR W1
C AS THEY DO FOR OTHER VARIABLES (REF. CHAM TR/75 SEC.4.2-9)

580 CONTINUE
C
C **** ADD SOURCE TERM ****
C CALL ADD(INDVAR,1,NI,JY,JIY,CELL,CM,VM,CM,CAJAR,CAJAR,NY,NX)

C
C SUM THE MASSFLOW OUT EXIT1
C IF(.NOT.(ISWP.EQ.LSWEET.AND.INDVAR.EQ.W1)) GO TO 582
C EMOUT1=0.0
C DO 581 JIX=1,NI
C EMOUT1=EMOUT1+GD1(JIY,JIX)+GW1(JIY,JIX)+GHIGH(JIY,JIX)+G
C 581 CONTINUE
C IF(NX.EQ.1) EMOUT1=EMOUT1+2.*GPI/XULAST

C
C
C
C *** SECOND EXIT ***
C 582 IF(.NOT.(JIXE2F.GE.1.AND.JIXE2FL.EQ.NX)) GO TO 587
C IF(IZED.NE.1) GO TO 587
C JIY=10
C CALL GET(GHIGH,GAHIGH,NY,NX)
C CALL GET(W1,GW1,NY,NX)

C
C *** SUM UP THE TOTAL HIGH FACE AREA BEING CONSIDERED
C GAHSUM=0.0
C DO 583 JIX=JIXE2F,JIXE2L
C GAHSUM=GAHSUM+GHIGH(JIY,JIX)
C 583 GAHSUM=GAHSUM+GAHIGH(JIY,JIX)

C
C *** USE A LOSS COEFFICIENT (GLSK2) TO COMPUTE THE PRESSURE
C LOSS ACROSS THE EXIT
C MASSFLOW = CM (EXIT PRESS - CELL PRESS)
C CM = 2 * (EXIT AREA)/(GLSK2*EXIT VELOCITY)
C NOTE: SUBSTITUTE VEL. W1 (FULL CELL AXIAL VELOCITY)
C + (FULL CELL AREA/EXIT AREA)
C DO 584 JIX=JIXE2F,JIXE2L
C (CALCULATE THE LOSS COEFFICIENT CM)
C (FIRST NEED TO CALCULATE EXIT AREA PER CELL (GAREAC))
C GAREAC= (GAXI2/144.0)+(GAHIGH(JIY,JIX))/GAHSUM)
C PREVENT LARGE CM BY LIMITING SMALLEST W1 (>0.1*NOMINAL EXIT W1)
C AREA RATIO
C
C ABUSW1=MAX1(W1XIM*GAREAC/GAHIGH(JIY,JIX),ABG(GW1(JIY,JIX)))
C CM(JIY,JIX)=(2.0*GAREAC/GLSK2*ABS(W1))
C *(GAREAC/GAHIGH(JIY,JIX))
C C PREVENT CM FROM BEHAVING ERRATICALLY IN FIRST FFW 5 SWEEPS
C NB: THE .02 IS A 'LARGE' VALUE SUFFICIENT TO FIX P-PEXIT
C IF(ISWP.LE.5) CM(JIY,JIX)=0.02*GAHIGH(JIY,JIX)
C GIVE SAVED CM A FINITE VALUE AT SWEEP 1
C IF(ISWP.LE.1) CM25(JIY)=CM(JIY,JIX)
C UNDER-RELAX CM TO PREVENT INSTABILITY
CM(JIY,JIX)=CMRLX2+CM(JIY,JIX)*(1.-CMRLX2)*CM2S(JIX)
C SAVE CM VALUE FOR RELAXATION
CM2S(JIX)=CM(JIY,JIX)
C (ASSIGN VM THE SPECIFIED EXIT PRESSURE (SAME AS EXIT 1))
VM(JIY,JIX)=GPEXIT(JIX)
C ** SET THE VALUES OF U1,V1,W1,H1,KE,AND EP AT THE EXIT
C IN CASE OF INFLOW.
C ** CM & VM HAVE BEEN SET ABOVE FOR PRESCRIBED MASS FLOW
C CVAR IS SET TO ZERO FOR ZERO DIFFUSION FLUX
CVAR(JIY,JIX) = 0.0
C SET VVAR TO EXTERNAL VALUE APPROPRIATE FOR THE VARIABLE
C OUT OF LAZINESS AND FOR WANT OF ANYTHING BETTER, THE
C VALUES BELOW ARE THE SAME AS FOR EXIT 1
VVAR(JIY,JIX) = 0.0
IF (INDVAR.EQ.H1) VVAR(JIY,JIX) = GHEXIT
IF (INDVAR.EQ.C1) VVAR(JIY,JIX) = H2OXIT
C ** IF (INDVAR.EQ.KE) VVAR(JIY,JIX) = GVALKE
IF (INDVAR.EQ.EP) VVAR(JIY,JIX) = GWALEP
C 584 CONTINUE
C **** ADD SOURCE TERM ****
CALL ADD(INDVAR,JIXE2F,JIXE2L,JIY,JIY,CELL,CM,VM,CMVAR,VVAR,NY,NX)
C ** SUM THE MASSFLOW OUT EXIT2
IF (.NOT. (ISWP.EQ.LSWEAP.AND.INDVAR.EQ.W1)) GO TO 587
EMOUT2=0.0
DO 585 JIY=JIXE2F,JIXE2L
EMOUT2=EMOUT2+GK(JIY,JIX)*G(1+G(JIY,JIX))*GAHIGH(JIY,JIX)*G
585 CONTINUE
IF (NX.EQ.1) EMOUT2=EMOUT2*2.*GPI/XULAST
C 587 DO 590 JIX=1,NX
DO 590 JIY=1,NY
CM(JIY,JIX)=0.0
VM(JIY,JIX)=0.0
590 CONTINUE
C 591 C
C **** RESET CM AND VM SO THAT THEY DON'T INTERFERE WITH 'GWALL'
C 592 DO 597 JIX=1,NX
DO 597 JIY=1,NY
CM(JIY,JIX)=1.0
VM(JIY,JIX)=1.0
597 CONTINUE
C 598 C
C **** CALCULATE TOTAL PRESSURES
IF (INDVAR.NE.C1) GO TO 599
DO 595 JIY=1,NX
DO 595 JIX=1,NY
UVEL=GV1(JIY,JIX)/GR(JIY)
VVEL=GV1(JIY,JIX)
IF (JY.GT.1) UVEL=0.5*(UVEL+GV1(JIY-1,JIX))
WVEL=GV1(JIY,JIX)
IF ((IZEF.EQ.17.AND.JIY.EQ.40).OR.(IZEF.EQ.13.AND.JIY.EQ.1))
701 GO TO 594
701 IF (IZEF.GT.1) WVEL=0.5*(WVEL+GV1(JIY,JIX))
702 VELSO=UVEL+UVEL+VVEL+VVEL+WVEL+WVEL
703 GPT(JIY,JIX)=GPT(JIY,JIX)+0.5*GD1(JIY,JIX)+VELSO
704 C
705 C
706 C
707 C
708 599 RETURN
C
CHAPTER 6: CALLED AT THE END OF EACH VARIABLE-RECALCULATION

CYCLE COMMENCED AT CHAPTER 4. ITNO = ITERATION NUMBER.

---

600 CONTINUE

RETURN

---

CHAPTER 7: CALLED AT END OF EACH SLAB-WISE CALCULATION.

---

700 CONTINUE

---

C ***

C PASS CALCULATED AUXILIARY VARIABLES BACK TO EARTH

CALL SET(JM1,1,NX,1,NY,GM1,NX)

CALL SET(JPT,1,NX,1,NY,GM1,NX)

IF(MOT.(IRH01,EQ,-1)) RETURN

CALL SET(JM2,1,NX,1,NY,GM2,NX)

CALL SET(JRH20,1,NX,1,NY,GRH20,NX)

---

C ***

C AUTOPTION FILE

IF(MOD(ISWP,NPRMON).EQ.0.AND.IZED.EQ.1ZMON) THEN

JSTP=JSTP

JSWP=JSWP

CALL AUTOPTION(JSTP,JSWP)

ENDIF

---

RETURN

---

C ***

C CHAPTER 8: CALLED AT THE END OF EACH SWEEP

C NOT ACCESSED IF PARABOLIC.

---

800 CONTINUE

RETURN

---

C ***

C CHAPTER 9: CALLED AT THE END OF EACH TIME STEP

C NOT ACCESSED IF PARABOLIC.

---

900 CONTINUE

---

C ***

WRITE(6,991) EMOUT1,EMOUT2

991 FORMAT('///1X,1PE12.3,2X,72HCALCULATED (TOTAL) MASS OUTFLOW RATE

.AT EXIT NEAR BLADE ROOTS (LBM/SEC.)///.

.///1X,E12.3,2X,62HCALCULATED (TOTAL) MASS OUTFLOW RATE AT SECOND EXI

.T (LBM/SEC.)///')

---

RETURN

---

C ***

C CHAPTER 10: SET PHASE 1 DENSITY HERE WHEN IRH01=-1 IN DATA.

C SET CURRENT-Z 'SLAB' DENSITY. D1, IF MLSLAB=1...

C EG. IF(MSLAB) CALL SET(D1,1,NX,1,NY,GM1,NX).

C SET NEXT LARGER-Z 'SLAB' DENSITY. D1H, IF HSLAB=1. & PARAB-F

C EG. IF(HSLAB) CALL SET(D1H,1,NX,1,NY,GD1H,NX).

C SET D(D(D1))/DP (IE. D1DP) FOR UNSTEADY FLOW.

C EG. IF(MSLAB) CALL SET(D1DP,1,NX,1,NY,GD1DP,NX).

---

1000 CONTINUE

---

C ***

C CALCULATE TEMP., DENSITY AND VISCOcosity OF HYDROGEN/WATER MIXTURE

C IF(MSLAB) GO TO 1001

JH1=H1H

JC1=CH
102

1140 JD1=D1H
1141 JT1=TIH
1142 GO TO 1002
1143 1001 JH1=H1
1144 JC1=C1
1145 JD1=D1
1146 JT1=T1
1147 C
1148 1002 CALL GET(JH1,GH1,NY,NX)
1149 CALL GET(JT1,GT1,NY,NX)
1150 CALL GET(JC1,GC1,NY,NX)
1151 C
1152 C DEDUCE TEMPERATURE OF MIXTURE FROM CALCULATED MIXTURE ENTHALPY
1153 CALL GTEMP(GH1,GC1,GT1,NY,NX,MSLAB)
1154 C
1155 C CALCULATE DENSITIES FROM DEDUCED MIXTURE TEMPERATURE
1156 CALL GRHD(GT1,GC1,GT1,GRH20,GRH2,NY,NX,MSLAB)
1157 C
1158 C PASS CALCULATED MIXTURE DENSITY BACK TO EARTH
1159 CALL SET(JD1,1,NY,1,NY,GT1,1,NY,GT1,NY,1)
1160 C
1161 IF(.NOT.MSLAB) RETURN
1162 C
1163 C CALCULATE THE LAMINAR VISCOSITY OF THE MIXTURE ("SET" IN CH. 12)
1164 CALL GVISC(GT1,GC1,GMUL,NY,NX)
1165 C
1166 C SAVE MSLAB TEMPERATURES
1167 DO 1010 IX=1,NX
1168 DO 1010 IY=1,NY
1169 1010 GTIM(IY,IX)=GT1(IY,IX)
1170 C ***
1171 RETURN
1172 C
1173 C CHAPTER 11: SET PHASE 2 DENSITY HERE WHEN IRH02=1 IN DATA.
1174 C SET CURRENT-Z SLAB DENSITY, 02, IF MSLAB=1.
1175 C EG. IF(MSLAB) CALL SET(D2,1,IX,1,NX,1,NY,1,ND2,NX)
1176 C SET NEXT LARGER-Z SLAB DENSITY, 02H, IF HSLAB=1. & PARAB=F
1177 C EG. IF(HSLAB) CALL SET(D2H,1,IX,1,NX,1,ND2H,NX)
1178 C SET D(LN(D2))/DP FOR UNSTEADY FLOW.
1179 C EG. IF(MSLAB) CALL SET(D2DP,1,IX,1,NX,1,ND2DP,NX)
1180 C ***
1181 1100 CONTINUE
1182 RETURN
1183 C
1184 C CHAPTER 12: SET PHASE 1 VISCOSITY HERE WHEN IEMU=1 IN DATA.
1185 C SET CURRENT-Z SLAB VISCOSITY (MU1), IF MSLAB=1.
1186 C EG. IF(MSLAB) CALL SET(MU1,1,IX,1,NX,1,GMUL,NX)
1187 C SET NEXT LARGER-Z SLAB VISC. (MU1H), IF HSLAB=1. & PARAB=F
1188 C EG. IF(HSLAB) CALL SET(MU1H,1,IX,1,NX,1,GMUL,NX)
1189 C
1190 C CHAPTER ALSO ACCESSED WHEN EMULAM=1.0 IN DATA, SO THAT THE
1191 C LAMINAR VISCOSITY WHICH APPEARS IN WALL FUNCTIONS & IN THE
1192 C KE-EP TURBULENCE MODEL (IEMU=2) MAY BE SET NON-CONSTANT.
1193 C SET CURRENT-Z SLAB VALUE (MU1LAM) WHEN LAMMU=1.
1194 C EG. IF(LAMMU) CALL SET(MU1LAM,1,IX,1,NX,1,GMUL,NX)
1195 C
1196 1200 CONTINUE
1197 C ***
1198 C PASS CALCULATED MIXTURE VISCOSITY BACK TO EARTH
1199 IF(LAMMU) CALL SET(MU1LAM,1,IX,1,NX,1,GMUL,NX)
C **
C ---------------------
C 1000 CONTINUE
C ---------------------
C 1001 RETURN
C ---------------------
C 1002 C CHAPTER 13: SET EXCHANGE COEFFICIENT (E.C.) FOR VARIABLE
C 1003 C INDOVAR WHEN SIGMA(INDOVAR)= 1.0 IN DATA.
C 1004 C SET CURRENT-Z 'SLAB' E.C. (EXCO) IF MLSLAB= T..
C 1005 C EG. IF(MSLAB) CALL SET(EXCO,1,NX,1,NY,GEXCO,NX,NX).
C 1006 C SET NEXT SMALLER-Z 'SLAB' E.C. (EXCOL) IF MLSLAB= T..
C 1007 C EG. IF(MSLAB) CALL SET(EXCOL,1,NX,1,NY,GEXCOL,NX,NX).
C 1008 C SET NEXT LARGER-Z 'SLAB' E.C. (EXCOH) IF HLSLAB= T..
C 1009 C EG. IF(HSLAB) CALL SET(EXCOH,1,NX,1,NY,GEXCOH,NX,NX).
C 1010 C NOTE: FOR MLSLAB, INDOVAR=U1...C4 FOR HLSLAB, INDOVAR=U1L...C4L
C 1011 C & FOR HLSLAB, INDOVAR=U1H...C4H. IF PARAB= T. SET MLSLAB ONLY.
C ---------------------
C 1012 C ---------------------
C 1013 C 1300 CONTINUE
C 1014 RETURN
C ---------------------
C 1015 C CHAPTER 14: SET INTER-PHASE FRICTION COEFFICIENT (CFP) HERE
C 1016 C WHEN ICFP = -1 IN DATA ITS UNITS = FORCE / (CELL * RELATIVE
C 1017 C SPEED OF PHASES).
C 1018 C ---------------------
C 1019 C 1400 CONTINUE
C 1020 RETURN
C ---------------------
C 1021 C CHAPTER 15: SET INTER-PHASE MASS-TRANSFER RATE PER CELL (MDT)
C 1022 C HERE WHEN IMDT = -1 IN DATA.
C 1023 C ---------------------
C 1024 C 1500 CONTINUE
C 1025 RETURN
C ---------------------
C 1026 C CHAPTER 16: SET HERE PHASE 1 & 2 SATURATION ENTHALPIES
C 1027 C (HST1 & HST2) WHEN IHSAT = -1 IN DATA.
C 1028 C ---------------------
C 1029 C 1600 CONTINUE
C 1030 RETURN
C ---------------------
C 1031 C SUBROUTINE GTEMP(GH1,GC1,GT1,NX,NX,MSLAB)
C 1032 C PURPOSE: - TO DETERMINE THE TEMPERATURE OF THE HYDROGEN/WATER MIXTURE
C 1033 C FROM THE CALCULATED MIXTURE ENTHALPY
C 1034 C ---------------------
C 1035 C CURVE FITS OF THE ANALYTICAL FORM:-
C 1036 C HH2=CH2+BH2*T+AH2*T**2
C 1037 C HH20=CH20+BH20*T+AH20*T**2
C 1038 C C REFERENCES:-
C 1039 C H2:
C 1040 C H20:
C 1041 C C RANGES OF VALIDITY:-
C 1042 C H2:  T=170 TO 2000 DEG R
C 1043 C H20:  T=490 TO 2060 DEG R (BUJ EXTRAPOLATION BELOW THIS O.K.)
C 1044 C C UNITS:-
C 1045 C H IN BTU/LBM AND T IN DEG R
C 1046 C H'S CONVERTED TO FT-LBF/S Lug BEFORE RETURN TO GROUND
C 1047 C ---------------------
C 1048 C DIMENSION GH1(NX,NX),GC1(NX,NX),GT1(NX,NX),CH2(6),BH2(6),
C 1049 C AH2(6),CH2(2),BH2(2),AH2(2)
LOGICAL MSLAB

C HYDROGEN ENTHALPY CURVE FIT DATA
C DATA CH2/ -357.6903/ .4588960/
C DATA BH2/ 4.468995. .357702/
C DATA AH2/ -.92706E-4/ .7.15694E-6/
C WATER ENTHALPY CURVE FIT DATA
C DATA CH2.
C .424.5538.2289.552.-.7363.69.599.5881.-.307.5449. .96.3053/
C DATA BH2.
C .0.82414.-.4.577089.6.913.-.1.27177.1.190721.1.285063/
C DATA AH2.
C .1.3067E-4.2.815249E-3.0.0.1.369267E-3.0.0.-.1.75707E-4/
C UNIT CONVERSION FACTOR
C DATA CONVH/25036.52/
C CONVH = CONVERSION FACTOR FROM BTU/LBM TO FT.LBF/SLUG = 778.16+G
C DATA TINY/1.E-10/
C
D 50 IX=1,NX
D 50 IY=1,NY
ENTH=GH1(IY,IX)/CONVH
IF(ENTH.LE.TINY) GO TO 35
TEMP=GT(IY,IX)
XH2O=GC1(IY,IX)
C DETERMINE WHICH OF THE SIX WATER ENTHALPY/TEMP CURVE FITS TO USE
IF(TEMP.GE.10. .AND. TEMP.LT.975.) GO TO 12
IF(TEMP.GE.975. .AND. TEMP.LT.1184.6) GO TO 13
IF(TEMP.GE.1184.6 .AND. TEMP.LT.1223.3) GO TO 14
IF(TEMP.GE.1223.3 .AND. TEMP.LT.1281.4) GO TO 15
IF(TEMP.GE.1281.4 .AND. TEMP.LT.1400.) GO TO 16
IF(TEMP.GE.1400. .AND. TEMP.LT.2000.) GO TO 161
GO TO 90
12 IHW=1
GO TO 17
13 IHW=2
GO TO 17
14 IHW=3
GO TO 17
15 IHW=4
GO TO 17
16 IHW=5
GO TO 17
161 IHW=6
C DETERMINE WHICH OF THE TWO HYDROGEN ENTHALPY/TEMP CURVE FITS TO USE
17 IF(TEMP.GE.10. .AND. TEMP.LT.508.) GO TO 18
11 IHW=1
18 IHW=1
GO TO 20
19 IHW=2
C SOLVE QUADRATIC IN 1 TO DETERMINE LOCAL MIXTURE TEMPERATURE (DEG R)
CC=CH2(IHW)*(1.-XH2O)*XH2O+CH2O(IHW)-ENTH
BB=BH2(IHW)*(1.-XH2O)*XH2O+BH2O(IHW)
AA=AH2(IHW)*(1.-XH2O)*XH2O+AH2O(IHW)
C IF(ABS(AA).LE.TINY) GO TO 28
1322 ROOT=SQRT(BB-BB-4.*AA*CC)
1323 T1=(-BB+ROOT)/(2.*AA)
1324 T2=(-BB-ROOT)/(2.*AA)
1325 IF(AA.LT.0.) GO TO 27
1326 C AA POSITIVE
1327 TEMP=MAX1(T1,T2)
1328 GO TO 40
1329 C AA NEGATIVE
1330 27 TEMP=MIN1(T1,T2)
1331 GO TO 40
1332 C AA ZERO
1333 28 TEMP=CC/BB
1334 GO TO 40
1335 C
1336 C SET TEMP TO ZERO IN FULLY BLOCKED CELLS
1337 35 TEMP=0.0
1338 C
1339 40 GT1(IY,IX)=TEMP
1340 C
1341 50 CONTINUE
1342 C
1343 RETURN
1344 C--------------------------------- DE-BUG ---------------------------------
1345 C-------------------------------------------------------
1346 WRITE(6,91) IY,IX,TEMP,ENTH,MSLAB
1347 WRITE(6,92) FORMAT(//,I2,214,IPE12.3,1LI)
1348 91 FORMAT(///IX,88H*** TEMPERATURE OUT OF RANGE OF CURVE FITS IN SUBR
1349 OUTLINE GTEMP, EXECUTION TERMINATED *** )
1350 STOP
1351 END
1352 SUBROUTINE GRH0(GT1,GC1,GO1,GRH2,GRH2,NX,NX,MSLAB)
1353 C---------------------------------- TO CALCULATE THE DENSITIES OF THE MIXTURE, HYDROGEN AND
1354 C WATER AT THE MIXTURE TEMPERATURE DERIVED FROM THE
1355 C CALCULATED MIXTURE ENTHALPY (IN SUBROUTINE GTEMP)
1356 C----------------------------------
1357 C
1358 C C CURVE FITS OF THE ANALYTICAL FORM:
1359 C RH2=EXP(CH2+BH2*LN(T)+AH2+LN(T)**2)
1360 C RH2=H20+EH20*T+DH20*T**2+CH20*T**3+BH20*T**4+AH20*T**5
1361 C
1362 C REFERENCES:
1363 C H2:
1364 C H20:
1365 C
c
1366 C RANGES OF VALIDITY:
1367 C H2: T=170 TO 2000 DEG R (BUT EXTRAPOLATION DOWN TO 150 O.K.)
1368 C H2O: T=490 TO 2060 DEG R
1369 C (NB. H2O AT T BELOW 490 GIVEN DENSITY OF H2O AT FREEZING)
1370 C
c
1371 C UNITS:
1372 C RH2 IN LBM/FT**3 AND T IN DEG R
1373 C RH2'S CONVERTED TO SLUG/CU FT BEFORE RETURNING TO GROUND
1374 C----------------------------------
1375 C
1376 C DIMENSION GT1(NY,NX),GRH20(NY,NX),GRH2(NY,NX),GC1(NY,NX),
1378 C LOGICAL MLSLAB
1379 C----------------------------------
C HYDROGEN DENSITY CURVE FIT DATA
DATA CH2,BH2,AH2/4.579578,-.5199177,-2.86885E-2/
C WATER DENSITY CURVE FITS DATA
DATA FH20/-82.117,-2177.783,119.1372,30.17724/
DATA EH20/0.623537,1.2733,-.770357E-2,-.2573409E-2/
DATA DH20/-6.77963E-4,-.54395E-3,-1.00694E-4,.195174E-6/
DATA CH2O/-3.41207E-7,-.91391E-6,.516186E-8,.000/
DATA BH20/9.23406E-10,1.686E-9,.000/.000/
DATA AH20/-3.9688E-13,.000/.000/.000/
C UNIT CONVERSION FACTOR
DATA CONVR/32.174/
C CONVR = CONV = 32.174, TO CONVERT LB/FT**3 TO SLUG/FT**3
C DATA RH2OF/62.578/
C RH2OF = WATER DENSITY AT FREEZING (APPROX 490 DEG R), IN LB/FT**3
C DATA TINY/1.E-10/
C-------------------------------------------------------------
DO 20 IX=1,NX
DO 20 IY=1,NY
TEMPT=GT1(IY,IX)
CONC=GC1(IY,IX)
IF(TEMPT.LE.TINY) GO TO 18
TEMLN=ALOG(TEMPT)
C DETERMINE WHICH OF THE 4 WATER DENSITY/TEMPERATURE CURVE FITS TO USE
IF(TEMPT.GE.100..AND..TEMP.LT.1180.) GO TO 12
IF(TEMPT.GE.1180..AND..TEMP.LT.1250.) GO TO 13
IF(TEMPT.GE.1250..AND..TEMP.LT.1380.) GO TO 14
IF(TEMPT.GE.1380..AND..TEMP.LT.2000.) GO TO 141
GO TO 50
12 IT=1
13 IT=2
14 IT=3
15 IT=4
IF(TEMPT.LT.190.) GO TO 16
C DENSITY OF WATER (IN SLUG/FT**3)
RH2=-(FH20(IT)+EH20(IT)+TEMP+DH20(IT)+TEMP**2
+CH2O(IT)+TEMP**3+EH20(IT)+TEMP**4+AH20(IT)+TEMP**5)/CONVR
GO TO 17
C TRAP WATER DENSITY TO ITS VALUE AT FREEZING FOR TEMPS BELOW FREEZING
16 RH2=RH2OF/CONVR
C DENSITY OF HYDROGEN (IN SLUG/FT**3)
17 RH2=(EXP(CH2+BH2+TEMLN+AH2+TEMLN**2))/CONVR
GO TO 19
C SET DENSITIES TO TINY IN FULLY BLOCKED CELLS
18 RH2=TINY
C CALCULATE THE MIXTURE DENSITY
19 GD1(IY,IX)=1./((CONC+RH2*(1.-CONC))/RH2)
IF (.NOT. MSLAB) GO TO 20
C SAVE MSLAB DENSITIES FOR PRINTOUT FROM EARTH
GRH2D(IY,IX)=RH2
C
20 CONTINUE
C
RETURN
C--------------------------------- DE-BUG ---------------------------------
C
50 WRITE(6,51)
WRITE(6,52) IY,IX,TEMP,CONC,MSLAB
C
51 FORMAT(//,IX,8(2H+*** TEMPERATURE OUT OF RANGE OF CURVE FITS IN SUBR
OUTINE GRH2, EXECUTION TERMINATED *** )
52 FORMAT(//,IX,2I4,1PE12.3,1L1)
C
STOP
END
SUBROUTINE GVISC(GT1,GCS,GMUL,NY,NX)
C
C PURPOSE: TO CALCULATE THE LAMINAR VISCOSITY OF THE MIXTURE
C
C
C CURVE FITS OF THE ANALYTICAL FORM:
C
C EMUH2=DH2+CH2*TEMP+BH2*TEMP**2+AH2*TEMP**3
C EMUH2=EXP(FH2O+EH2O*TEMP+DI2O*TEMP**2+CH2O*TEMP**3+BH2O*TEMP**4
C +AH2D*TEMP**5)
C
C REFERENCES:
C H2:
C H2O:
C
C RANGES OF VALIDITY:
C H2: T=170 TO 2000 DEG R (BUT EXTRAPOLATION DOWN TO 150 O.K.)
C H2O: T=490 TO 1752 DEG R
C (NB. H2O AT T BELOW 490 GIVEN VISCOSITY OF H2O AT FREEZING)
C
C UNITS:
C EMU IN LBM/FT.SEC AND T IN DEG R
C EMU'S CONVERTED TO SLUG/FT.SEC BEFORE RETURNING TO GROUND
C
C DIMENSION GT1(NY,NX),GCS(NY,NX),GMUL(NY,NX)
C
C
C HYDROGEN VISCOSITY CURVE FIT DATA
C DATA DH2,CH2,BH2,AH2/0.4989,-5.4575E-5,5.1824E-7,1.4948E-10/
C WATER VISCOSITY CURVE FIT DATA
C .3.2726E-5,6.6687E-8,8.3627E-11,2.6237E-14/
C DATA FH2O,AH2O/6.5334525E-3,1.11E-5/
C
C UNIT CONVERSION FACTOR
C DATA CONVM/32.174/
C CONVM = G = 32.174, TO CONVERT LBM TO SLUG
C DATA EMULWF/1.2446E-3/
C EMULWF=LAM VISCOSITY OF WATER AT FREEZING (490 DEG R) IN LBM/FT.SEC
C
C DO 20 IX=1,NX
C DO 20 IY=1,NY
C TEMP=GT1(IY,IX)
C CONC=GC1(IY,IX)
C VISCOSITY OF HYDROGEN (IN LB/FT^2SEC)
  EMUH2=(DH2+CH2+TEMP+BH2+TEMP*2+AH2+TEMP*3)+1.E-5
C IF(TEMP.LE.490.) GO TO 17
C IF(TEMP.GE.1392.) GO TO 16
C VISCOSITY OF WATER (IN LB/FT^2SEC)
  EMUH2O=EXP(5.275+EMUH2+TEMP+2*CH2+TEMP*3+BH2+TEMP*4
      +AH2+TEMP*5)+1.E-5
C GO TO 18
16 EMUH2O=EMUH2O+EMUH2A+EMUH2O+TEMP
C TRAP WATER VISCOSITY TO ITS VALUE AT FREEZING FOR TEMPS BELOW FREEZING
  17 EMUH2O=EMULWF
C C CALCULATE THE MIXTURE VISCOSITY (IN SLUGS/FT^2SEC)
18 GML1L(IY,IX)=I1/(CONC/EMUH2O+(1.-CONC)/EMUH2)/(CONV)
C 20 CONTINUE
C RETURN
END
C--- OCTOBER 1984, CHAM (NA) GROUND SUBPROGRAM "GWALL". TO FACILITATE
C THE SETTING OF AN UNLIMITED NUMBER OF WALL SURFACES IN THE SPRING
C 1983 VERSION OF PHOENICS.
C SUBROUTINE GWALL(JVAR,JX,JY,JZ,GWALL,GWALL,GWALL,GWALL,GDELTA)
C------------------------
$INCLUDE 9.CMNQUSI.FTN/G (NLIST)
$INCLUDE 9.CMNQUSI.FTN/G (NLIST)
C------------------------
C PURPOSE: TO COMPUTE CVAR (=GCVAR) AND VVAR (=GVVVAR) FOR TURBULENT
AND LAMINAR WALL FUNCTIONS
C------------------------
C ANY QUESTIONS (OR PROBLEMS) ON THE USE OF THIS SUBPROGRAM SHOULD BE
C ADDRESSED TO:
C L.W. KEeton, CHAM (NA) INC.
C 1525-A SPARKMAN DRIVE,
C HUNTSVILLE, AL 35802. U.S.A.
C TEL: (205) 830-2620
C------------------------
C RESTRICTIONS:-
C 1: GWALL IS NOT VALID FOR 2-FIUID MODEL CALCuLATIONS.
C 2: PROVISION FOR A MOVING GRID HAS NOT YET BEEN INCLUDED.
C------------------------
C NOTES:-
C 1: THIS GROUND SUBPROGRAM IS INTENDED TO FACILITATE THE SETTING OF
APPROPRIATE WALL BOUNDARY CONDITIONS VIA GROUND FOR THOSE CASES
WHEN THE 10 REGIONS OF THE SATELLITE ARE INSUFFICIENT. INSTEAD,
OF USING A SPECIAL REGION TO SPECIFY THE PRESENCE OF A WALL THE
GROUND USER SUBPROGRAM GWALL CAN NOW BE USED INSTEAD. THE MODELS
EMPLOYED ARE IDENTICAL TO THOSE CURRENTLY INCORPORATED IN EARTH
SUBPROGRAM "WALL" (SEE NOTE 3 BELOW).
C 2: TO FACILITATE CROSS-CHECKING, WHERE FEASIBLE, ALL VARIABLE NAMES
AND CODING IN GWALL ARE SIMILAR TO THOSE USED IN EARTH SUBPROGRAM
3. THE WALL BOUNDARY CONDITION TREATMENT USED HEREIN IS EXACTLY AS DESCRIBED IN THE SPRING 1983 PHOENICS USER'S MANUAL (CHAM TR/75), ON PAGES 3.2-47 TO 49. ITS MAIN FEATURES ARE OUTLINED BELOW.

4. THE QUANTITIES GCVAR (+GCoeff) AND GVVAR (+GVALUE) COMPUTED IN GWALL ARE EQUIVALENT TO THE "COEFFICIENT" AND "VALUE" QUANTITIES (CPIR, VPIR ETC.) DISCUSSED IN THE USER'S MANUAL ON PAGES 3.2-41 TO 49. THE GWALL ARRAYS GCVAR AND GVVAR ARE IDENTICALLY EQUIVALENT TO THE GROUND ARRAYS CVAR AND VVAR, RESPECTIVELY, AND MUST BE EQUIVALENCED TO EACH OTHER IN GROUND (SEE NOTES 5 AND 6 BELOW).

5. TO USE GWALL, THE USER MUST PROVIDE, IN GROUND CH. 5:

   B. VIA "CALL GET" STATEMENTS IN GROUND CH. 5: THE 3 COMPONENTS OF FLUID VELOCITIES, GUI,GV1,GW1 AND THE DENSITIES, GD1.
   C. VIA "CALL GETIO" STATEMENTS IN GROUND CH. 5: THE CELL WIDTHS IN THE 3 COORDINATE DIRECTIONS, GDUX, GDVY, GDZW AND THE RADIUS AT EACH CELL GRID NODE, GR AND GM.
   D. VIA LOCAL CALCULATION IN GROUND CH. 5 (SEE NOTES 9 AND 10): THE CURRENT IZ-SLAB LAMINAR VISCOSITIES, GMIUL.

THE REQUIRED CVAR AND VVAR VALUES ARE THEN RETURNED TO GROUND FOR EACH VARIABLE, THROUGH COMMON/WALLG/, VIA THE GCVAR AND GVVAR ARRAYS (WHICH ARE EQUIVALENCED TO CVAR AND VVAR), RESPECTIVELY.

6. SUBROUTINE GWALL SHOULD BE CALLED, SEPARATELY, FOR EACH CONTINUOUS REGION OF CELLS AT THE CURRENT SLAB CONTAINING (OR NEIGHBOURING) A WALL. CONSEQUENTLY, THE QUANTITIES IN GROUP A ABOVE MUST BE PROVIDED ON A REGION-BY-REGION BASIS. THE VARIABLES IN GROUPS B, C AND D, HOWEVER, SHOULD BE OBTAINED ONCE ONLY FOR EACH IZ-SLAB VIA "CALL GET" OR "CALL GETIO" STATEMENTS (SEE USER'S MANUAL, PAGE 4.2-26) OR LOCAL CALCULATION, RESPECTIVELY, AS DESCRIBED IN NOTE 5 ABOVE. THESE VARIABLES ARE STORED IN GROUND IN THE LOCAL ARRAYS NAMES GIVEN AND ARE THEN PASSED TO SUBROUTINE GWALL VIA THE GROUND/WALL COMMON BLOCK "WALLG", THE NAMES AND SEQUENCE OF THE ELEVEN ARRAYS IN COMMON/WALLG/ MUST NOT BE ALTERED BY THE USER. FURTHERMORE, THEY MUST BE APPROPRIATELY AND CONSISTENTLY DIMENSIONED IN BOTH GROUND AND GWALL, VIZ.: GUI,GV1,GW1,GR1,GMIUL, GDUX, GDVY, GR(NY) AND GDZW(NZ), IN GROUND/WALL COMMON BLOCK "WALLG".

ADDITION, THE GCVAR AND GVVAR ARRAYS MUST BE EQUIVALENCED IN GROUND TO CVAR AND VVAR, RESPECTIVELY, SO THAT THEIR VALUES AS CALCULATED IN GWALL CAN BE PASSED BACK TO GROUND (VIA COMMON/WALLG/) FOR USE IN THE CORRESPONDING CALLS TO "ADD".

7. GROUND SUBPROGRAM GWALL MUST BE CALLED FOR EACH CELL OR REGION OF CELLS WHERE A SPECIAL WALL BOUNDARY TREATMENT IS REQUIRED.
THE WALL, i.e. for U1, V1, W1, H1, KE and EP as necessary, followed by
A CALL TO ADD TO INCLUDE THE APPROPRIATE CVAR AND VVAR SOURCE
MODIFICATION TO THE RELEVANT F.D. EQUATIONS. IT SHOULD BE STRESSED
THAT EVERY CALL TO Gwall IN GAS FOR ANY VARIABLE MUST BE
FOLLOWED IMMEDIATELY BY A CORRESPONDING CALL TO ADD, I.E. WITH
SAME VARIABLE INDEX, REGION OF CELLS AND CELL TYPE (UNLESS EITHER:
A. AREAS CALCULATED LOCALLY - SEE NOTE 9 BELOW
B. THE VARIABLE INDEX (VVAR) IS EITHER KE OR EP, IN WHICH CASE THE CALL TO ADD
TYPE MUST ALWAYS BE "CELL" (DUE TO THEIR VALUES BEING FIXED)
NOTE ALSO THAT GWALL MUST BE CALLED SEPARATELY (AND REPEATEDLY)
FOR EACH DIFFERENT WALL TYPE (E.G. NORTH, HIGH...) THAT MIGHT
OCCUR IN ANY CELL OR CELLS.

8. FOR POLAR COORDINATES (WHEN UR IS SOLVED-FOR RATHER THAN U) THE
GWALL AND QUANTITIES ARE ASSUMED (IN GWALL) TO BE
ANGULAR VELOCITY (OMEGA = U/R) AND UR-AT-THE-CELL, RESPECTIVELY.
THE GWALL (=OMEGA) IS THEN MULTIPLIED (WITHIN GWALL, WHENEVER
CARTESIAN F.) BY THE LOCAL RADIUS*2 TO GIVE THE REQUIRED LOCAL
UR-AT-THE-WALL VALUE. IF THIS IS NOT APPROPRIATE FOR ANY
PARTICULAR PROBLEM THEN THE MULTIPLICATION BY R**2 SHOULD BE
SUPPRESSED BY THE USER IN GWALL AND THE DESIRED GWALL VALUE
RATHER THAN OMEGA, SHOULD THEN BE FED VIA THE GWALL ARGUMENT.

9. GCVAR IS NOT MULTIPLIED BY THE APPROPRIATE AREAS OF CONTACT WITHIN
GWALL. THIS MUST BE DONE BY THE USER WITHIN GROUND CH. 5 ITSELF.
FOR EACH PARTICULAR VARIABLE, AS NECESSARY, AFTER CVAR
HAS BEEN RETURNED FROM GWALL. THIS CAN BE DONE EITHER BY
EXPLICITLY CALCULATING THE APPROPRIATE AREAS OR VIA THE "TYPE"
SPECIFICATION IN THE CALL TO ADD. IF THE AREAS ARE CALCULATED
LOCALLY (AND THEN MULTIPLIED TO CVAR) THEN THE CALL TO ADD "TYPE"
SHOULD BE PER "CELL" FOR EVERY VARIABLE (AND REGION) SO TREATED.

10. THE LAMINAR VISCOSITIES AT EACH 12-SLAB WHERE GWALL IS TO BE CALLED
MUST BE SET-UP AND STORED IN THE LOCAL ARRAY GMULI, WITHIN GROUND
CH.5 (SEE NOTE 5 ABOVE). THESE CAN BE SET EITHER: A. TO A CONSTANT
VALUE EVERYWHERE (E.G. EMULAM) OR B. DETERMINED LOCALLY (BASED
ON LOCAL CONDITIONS) AS DESCRIBED IN NOTE 11 BELOW.

11. THE LAMINAR VISCOSITIES USED IN THE WALL FUNCTIONS WITHIN THE
PHOENICS SUBPROGRAM WALL CAN BE SET TO A NON-CONSTANT VALUE BY
SETTING EMULAM = -1. IN THE SATELLITE, AND INSERTING APPROPRIATE
CODING IN GROUND CH.12, AS DESCRIBED ON PAGE 4.3-14 OF THE USER'S
MANUAL. IF GWALL IS TO BE USED, HOWEVER, THE CODING FOR VARYING
LAMINAR VISCOSITY (LOCAL ARRAY: GMULI) MUST BE INCLUDED IN CH.5
AND NOT CH. 12). THIS IS BECAUSE THE CALL TO CH. 12 ORIGINATES
FROM WITHIN THE PHOENICS WALL SUBPROGRAM, WHICH WILL NOT BE
ACCESSED IF GWALL IS USED INSTEAD. THE CALCULATED GMULI VALUES
MUST, HOWEVER, STILL BE "SET" IN CH. 12.

12. FOR THOSE CASES WHEN THE WALLS ARE ALIGNED WITH CELL FACES, THE
PERPENDICULAR DISTANCES FROM THE WALL (GDELA) ARE NORMALLY
EXACTLY EQUAL TO ONE HALF THE APPROPRIATE CELL WIDTH (I.E. DX/2
ETC.). WHEN SUCH A TREATMENT IS APPROPRIATE THE USER OF GWALL
NEEDS SIMPLY TO SET GDELA TO ANY NEGATIVE VALUE (E.G. -.1) AND
THE APPROPRIATE HALF-CELL WIDTH(S) WILL THEN BE AUTOMATICALLY
USED INSIDE GWALL. IF THIS TREATMENT IS NOT DESIRED, HOWEVER,
THE APPROPRIATE NORMAL DISTANCES MUST BE SPECIFIED AS AN
ARGUMENT (CELL-BY-CELL OR REGION-BY-REGION) IN THE GWALL CALL
STATEMENT. HOWEVER, IT SHOULD BE NOTED THAT, IN POLAR GEOMETRIES
WHEN THE NORMAL DISTANCE FROM AN EAST OR WEST WALL IS BEING
C SPECIFIED EXPLICITLY ONLY THE ANGLE (I.E. DX/2) BETWEEN THE GRID
C NODE AND WALL SURFACE NEEDS TO BE SPECIFIED AS THE CORRESPONDING
C NORMAL DISTANCE IS DEDUCED FROM WITHIN GWALL ITSELF BY MULTIPLYING
C THE SPECIFIED ANGLE BY THE LOCAL RADIUS.

C DESCRIPTION OF THE WALL BOUNDARY TREATMENT EMPLOYED:

A. THE TURBULENT WALL SHEAR STRESS IS CALCULATED FROM A WALL FUNCTION
B. BASED ON THE LOGARITHMIC LAW OF THE WALL (REF. LAUNDER AND
C. SPALDING (1972), "MATHEMATICAL MODELS OF TURBULENCE"), THE
D. SO-CALLED "LOG LAW OF THE WALL" IS GIVEN BY:

\[ \text{UPLUS} = \left( \frac{1}{\text{AK}} \right) \log(\text{Ewall} \times \text{YPLUS}) \]

WHERE

\[ \text{UPLUS} = \frac{\text{UGRID}}{\text{USTAR}} \]
\[ \text{YPLUS} = \frac{\text{RHO}}{\text{USTAR}} \] \times \text{DELTA} / \text{EMUL} \]
\[ \text{AK} = \text{VON KARMAAN CONSTANT} \times 0.435 \]
\[ \text{Ewall} = \text{EMPirical CONSTANT} \times 0.3 \]
\[ \text{UGRID} = \text{VELOCITY AT THE NEAR-WALL GRID NODE} \]
\[ \text{USTAR} = \text{WALL SHEAR VELOCITY} \times \text{Sqrt(TAUW/RHO)} \]
\[ \text{RHO} = \text{DENSITY} \]
\[ \text{DELTA} = \text{PERPENDICULAR DISTANCE OF NEAR-WALL NODE FROM WALL} \]
\[ \text{EMUL} = \text{LAMINAR VISCOITY} \]

THE TURBULENT WALL SHEAR STRESS IS THEN GIVEN BY:

\[ \text{TAUW} = \text{EMUL} \times \text{UPLUS} / \text{UPLUS} \]
\[ \text{VTAU} = \text{EMUL} \times \text{YPLUS} / \text{UPLUS} \]

THE QUANTITIES YPLUS AND UPLUS ARE COMMONLY REFERRED TO AS
C. THE NORMALISED DISTANCE AND VELOCITY, RESPECTIVELY, IN THE
D. CODING OF GWall BELOW UPLUS AND YPLUS ARE NOT SEEN EXPLICITLY,
E. HOWEVER, THEY CAN BE DEDUCED AS FOLLOWS:

\[ \text{UPLUS} = 1 / \text{Sqrt(GS)} \]
\[ \text{YPLUS} = \text{REYNOLDS} \times \text{Sqrt(GS)} / \text{REYNOLDS} \times \text{YPLUS} \]

WHERE

\[ \text{Sqrt(GS)} = \text{USTAR} / \text{UGRID} \]
\[ \text{TAUW} = \text{RHO} / \text{UGRID} \]
\[ \text{REYNOLDS} = \text{RHO} \times \text{UGRID} / \text{DELTA} / \text{EMUL} \]

B. DUE TO THE IMPLICIT RELATIONSHIP BETWEEN UPLUS AND YPLUS THEIR

VALUES ARE OBTAINED ITERATIVELY. THE ITERATIVE PROCEDURE'S

INITIAL GUESS FOR GS (WHERE UPLUS = 1 / Sqrt(GS)) IS TAKEN FROM

KUTATELADEZ AND LEONTIEV "TURBULENT BOUNDARY LAYERS", VIZ:

\[ \text{GS} = a \times \text{(REYNOLDS NO)}^{**b} \]
\[ \text{WHERE } a = 0.74 \text{ AND } b = 0.142857 \] \text{ARE TAKEN FROM TABLE 3-1 OF
THE ABOVE REFERENCE.}

C. THE TURBULENT KINETIC ENERGY AND DISSIPATION RATE VALUES ARE THEN

FIXED AT THE VALUES WHICH WOULD PREVAIL AT THE NEAR-WALL GRID
C. NODES IF THE SUPPOSED UNIVERSAL LOGARITHMIC VELOCITY PROFILE
D. PREVAILED.
D. FOR LAMINAR WALL SHEAR STRESS (REYNOLDS NO. LE. 132.25) A
LINEAR VELOCITY PROFILE IS ASSUMED NEAR TO THE WALL.
E. THE WALL HEAT TRANSFER RATE IS EVALUATED FROM THE CHILTON-
COLBURN FORM OF THE REYNOLDS'S ANALOGY, AS DESCRIBED IN THE
PHOENICS USER'S MANUAL, PAGE 3.2-48.

CHAPTER 0 PRELIMINARIES

IF(JVISIT.GT.0) GO TO 10
JVISIT=JVISIT+1
GACON=1./GAFRIC**(2./((1.+GAFRIC))
GBCON=1.-GAFRIC/(1.+GAFRIC)
GAKRA=1./SIGMA(24)**0.666667
GWALC=0.18439/GAK

DO 390 JIX=JIXF,JIXL
DO 390 JIY=JIYF,JIYL

RWRDP2=1.
GRGRID=GR(JIY)
JWTYPE=IFIX(JWTYPE)
GDEL=GDELTAL
GWALL=GWALL
FOLLOWING STATEMENT SHOULD BE SUPPRESSED (IE. "COMMENTED OUT") IF
NOT APPROPRIATE (SEE NOTE 8 ABOVE)
IF(.NOT.CARTES) GWALL=GWALL+GRGRID**2
GOTO (13,13,12,12,11,11), JWTYPE
DETERMINE DISTANCE FROM WALL AND RELATIVE VELOCITY PARALLEL TO WALL
HIGH OR LOW WALL
11 IF(GDELTAL.LE.Q.) GDEL=0.5*GDZW(JI2)
GV1WAL=GWALL
GV2WAL=GWALL+GRGRID
GV1CEL=GV1(JIY,JIX)
GV2CEL=GV1(JIY,JIX)/GRGRID
GO TO 17

NORTH OR SOUTH WALL
12 IF(GDELTAL.LE.Q.) GDEL=0.5*GDYW(JIY)
GV1WAL=GWALL
GV2WAL=GWALL+GRGRID
GV1CEL=GV1(JIY,JIX)
GV2CEL=GV1(JIY,JIX)/GRGRID
IF(.NOT.(.NOT.CARTES.AND.JVAR.EQ.JU1)) GO TO 17
WHEN SOLVING FOR UR, MODIFY U SO THAT NEAR-WALL U IS Employed
GFAC=0.5
IF(JWTYPE.EQ.JSOUTH) GFAC=-0.5
RWRDP2=(1.+GFAC*GDYW(JIY)/GRGRID)**2
GO TO 17

C

13 IF(GDELTA.LT.0.) GDELM+0.5*GDXH(JIX)

14 IF(.NOT.CARTES) GDELM=GDELM+GRGRID

15 GVIW=GVIWAL

16 GV2W=GVIW

17 GV1CEL=GV1(JIY,JIX)

18 GV2CEL=GV1(JIY,JIX)

C

19 C CALCULATE RELATIVE VELOCITY OF FLUID PARALLEL TO WALL

20 17 CONTINUE

21 GSPEED=SQRT((GVI1CEL-GVIWAL)**2+(GV2CEL-GV2W)**2)

C

22 C SET APPROPRIATE WALL VALUE (I.E. ITS VELOCITY OR ENTHALPY)

23 GVPHI=0.0

24 IF(JVAR.EQ.JKE.OR.JVAR.EQ.JEP) GO TO 18

25 IF(JVAR.EQ.JU1) GVPHI=GVIWAL/WRDP2

26 IF(JVAR.EQ.JV1) GVPHI=GVIW

27 IF(JVAR.EQ.JW1) GVPHI=GVIW

28 IF(JVAR.EQ.JH1) GVPHI=GVIW

C

29 18 GRHO=GD1(JIY,JIX)

30 GDELMU=GDELM/GMUL(JIY,JIX)

31 GREYNO=GRHO*GSPEED+GDELMU

32 GVALUE=0.0

33 GCOEFF=0.0

C

34 IF(JVAR.EQ.JKE.OR.JVAR.EQ.JEP) GO TO 100

35 IF(JVAR.EQ.JU1.OR.JVAR.EQ.JV1.OR.JVAR.EQ.JW1) GO TO 300

36 IF(JVAR.EQ.JH1) GO TO 301

37 GO TO 350

C

38 C----------------------------------------

39 C CHAPTER 1  FIX TURBULENT KINETIC ENERGY (KE)

40 C----------------------------------------

41 100 GS=GACON+AMAX1(GREYNO,1.0)**(GBCON-1.)

42 DO 101 JITS=1,3

43 101 GSHF=SQRT(GS)

44 101 GS=(GAK/ALOG(1.01+GEWALL*GREYNO*GSHF)**2

45 GSHF=GS*GREYNO*GSPEED/GDELMU+GEWALL*GREYNO*GSHF/GDELMU

46 GSHF=AMAX1(GSHF/(GRHO+GIADUK),TKEMIN),TKEMAX)

C

47 IF(JVAR.EQ.JEP) GO TO 200

C

48 C GVALUE=GKE

49 GCOEFF=GREAT

C

50 C GO TO 350

C

51 C----------------------------------------

52 C CHAPTER 2  FIX KE DISSIPATION RATE (EP)

53 C----------------------------------------

54 200 GVALUE=GWALC*SQRT(GTKE)+GTKE/GDELM

55 GCOEFF=GREAT

C

56 C GO TO 350

C

57 C----------------------------------------

58 C CHAPTER 3  WALL FRICTION (U1,V1,W1) AND HEAT TRANSFER (HI)

59 C----------------------------------------

60 C LAMINAR

61 C WALL FRICTION
300 GDEFF=RWDRP2/GDELMU
301 GDEFF=GAKRA+RWDRP2/GDELMU
C HEAT TRANSFER
302 IF(GREYN0,LE.132.25) GO TO 310
C TURBULENT
303 GS=GACon+GREYN0*(GBCON-1.)
DO 303 JTS=1,3
304 GSHALF=SORT(GS)
305 GS=(GAK/ALOG(1.01+GEWALL+GREYN0+GSHALF))**2
306 GDEFF=GDEFF+GS*GREYN0
310 GVALUE=GVPHI
C SET UP GCVAR (=CVAR) AND GVVAR (=VVAR) ARRAYS
350 GCVAR(JIY,JIX)=GDEFF
370 GVVAR(JIY,JIX)=GVALUE
C CONTINUE
390 C
391 C
392 C
393 C END
394 SUBROUTINE AUTMON(ISTP,ISWP)
395 INCLUDE CMGUSSI.FTN/G (NLIST)
396 INCLUDE GUSSEQUI.FTN/G (NLIST)
397 DIMENSION ISOLV(25)
398 LOGICAL FIRST
399 DATA FIRST/.TRUE./
400 DATA KSTP/0/
401 C USER DIMENSIONED (NY X NX) ARRAY FOR GETTING VARIABLES
402 DIMENSION GDUM(40,8)
C IF( First ) THEN
403 OPEN(20,FILE="AUTMON.DTA",STATUS="RENEW",RECL=20,FORM="
404 +"FORMATTED")
405 NUMSOL = 0
406 DO 10 I = 1,25
407 IF(SOLVAR(I).OR.STOVAR(I)) THEN
408 ISOLV(NUMSOL+1) = I
409 NUMSOL = NUMSOL+1
410 END IF
411 C CONTINUE
412 FIRST=.FALSE.
413 C
414 C IF(KSTP.NE.ISTP) THEN
415 IF(.NOT.STEADY) WRITE(20,('TIME STEP NO. "",13)) ISTP
416 WRITE(20,('I2')) NUMSOL
417 DO 15 I = 1,NUMSOL
418 WRITE(20,('A44')) TITLE(ISOLV(I))
419 KSTP = ISTP
420 END IF
421 C WRITE(20,('I3')) ISWP
422 DO 20 II = 1,NUMSOL
423 CALL GET(ISOLV(II),GDUM,NY,NX)
424 WRITE(20,('IPE10.3')) GDUM(IYMON,IXMON)
425 20 CONTINUE
APPENDIX B: PROPERTY CURVE FITS

The individual enthalpy curves for water and hydrogen have been combined in order to calculate a mixture enthalpy, \( \text{Enthalpy}_{\text{mix}} \), defined as:

\[
\text{Enthalpy}_{\text{mix}}(T) = (\text{Mass Ratio } \text{H}_2\text{O}) \times \text{Enthalpy Water (T)} + (1-\text{Mass Ratio } \text{H}_2\text{O}) \times \text{Enthalpy Hydrogen (T)}
\]

This combined property curve is needed to be able to calculate the temperature of any given mixture of water and hydrogen in the aft-platform seal cavity, based on the mixture ratio and enthalpy calculated by the model. From the temperature are then calculated other fluid properties, such as density and viscosity. The curve fits used to compute these properties are depicted in Figures B-1 to B-6.
ENTHALPY OF WATER

**CURVE FIT I**  
\[ H (\text{Btu/lbm}) = -424.5938 + 0.82414T + 1.3067 \times 10^{-4}T^2 \]  
\((492 < T < 975^\circ R)\)

**CURVE FIT II**  
\[ H = 2289.552 - 4.577089T + 2.815249 \times 10^{-3}T^2 \]  
\((975 < T < 1184.6^\circ R)\)

**CURVE FIT III**  
\[ H = -7363.69 + 6.913T \]  
\((1184.6 < T < 1223.3^\circ R)\)

**CURVE FIT IV**  
\[ H = 599.5881 - 1.27177T + 1.369267 \times 10^{-3}T^2 \]  
\((1223.3 < T < 1281.4^\circ R)\)

**CURVE FIT V**  
\[ H = -307.5449 + 1.190721T \]  
\((1281.4 < T < 1400^\circ R)\)

STANDARD ERROR = 4.08 Btu/lbm

These curves were fit to data taken from *Thermodynamic Properties of Steam*, Joseph Keenan and Frederick Keyes, (New York: Wiley and Sons, 1936) pp. 72-75.
DENSITY OF WATER

CURVE FIT I

(490°F ≤ T ≤ 1180°F)

\[ \text{density (lbm/ft}^3\text{)} = -82.117 + .62353T - 6.77693 \times 10^{-4}T^2 \\
-3.41207 \times 10^{-7}T^3 + 9.23406 \times 10^{-10}T^4 \\
-3.9688 \times 10^{-13}T^5 \]

CURVE FIT II

(1180°F ≤ T ≤ 1250°F)

\[ \text{density} = -2177.783 + 7.12733T - 4.54395 \times 10^{-3}T^2 \\
-1.91391 \times 10^{-6}T^3 + 1.686 \times 10^{-9}T^4 \]

CURVE FIT III

(1250°F ≤ T ≤ 1400°F)

\[ \text{density} = 119.1372 - 4.770357 \times 10^{-2}T - 1.00694 \times 10^{-4}T^2 \\
+ 5.516186 \times 10^{-6}T^3 \]

STANDARD ERROR = 0.61 lbm/ft\(^3\)

\(^2\)These curves are fit to data taken from Keenan, pp. 72-75.
VISCOSITY OF WATER

\[ VISC (x10^3) = \left[ 20.5532 - 6.52199 \times 10^{-2} T + 3.2726 \times 10^{-5} T^2 \\
+ 6.6687 \times 10^{-8} T^3 - 8.3627 \times 10^{-11} T^4 + 2.6237 \times 10^{-14} T^5 \right] \]

\[ e \]

STANDARD ERROR \((x10^3) = 0.0066 \text{ lb/ft-sec} \)

\(^3\)This curve is fit to data taken from Steam Tables, Joseph Keenan, et al., (New York: Wiley and Sons, Inc., 1969) p. 113.

Figure B-3.
ENTHALPY OF HYDROGEN

CURVE FIT I
(170R<T<508R)
H (Btu/1bm) = -5.92706x10⁻⁴T² + 4.468995T - 357.6903

CURVE FIT II
(508R<T<2000R)
H = -7.15694x10⁻⁶T² + 3.557702T - 45.88906

STANDARD ERROR = 4.39 Btu/1bm

DENSITY OF HYDROGEN

\[
density (\text{lbm/ft}^3) = \left[ -5.26685 + 3.049183(\ln H) - 0.41497(\ln H)^2 \\
+ 1.40759 \times 10^{-2}(\ln H)^3 \right] e
\]

where \( H \) is the enthalpy of hydrogen.

STANDARD ERROR = .0189 lbm/ft\(^3\)

\(^5\)This curve is fit to data taken from McCarty, p. 472.

Figure B-5.
VISCOSITY OF HYDROGEN

VISC. (lbm/ft-sec \times 10^5) = 0.4989 - 5.4575 \times 10^{-5} T
+ 5.1824 \times 10^{-7} T^2 - 1.4948 \times 10^{-10} T^3

STANDARD ERROR (x10^5) = 0.00047 lbm/ft-sec

APPENDIX C: CONVERGENCE CHARACTERISTICS

The insensitivity of the model to the initial values chosen for temperature and velocity is demonstrated by the solution sets given below. There were four different test cases run using identical boundary conditions but with the different guesses of velocity and temperature listed in the following table. Cases 1 to 3 were run to test the sensitivity of the solution to the initial temperature guess, and case 4 was run to check the sensitivity of the solution to the initial choice of the velocity field.

INITIAL FIELD VALUES

<table>
<thead>
<tr>
<th></th>
<th>Temperature</th>
<th>Velocity</th>
</tr>
</thead>
<tbody>
<tr>
<td>CASE 1</td>
<td>Hot Guess</td>
<td>Omega = 0.4 Disk Omega</td>
</tr>
<tr>
<td>CASE 2</td>
<td>Best Guess</td>
<td>Same as above</td>
</tr>
<tr>
<td>CASE 3</td>
<td>Cold Guess</td>
<td>Same as above</td>
</tr>
<tr>
<td>CASE 4</td>
<td>Best Guess</td>
<td>Omega = 0</td>
</tr>
</tbody>
</table>

(Omega in radians/sec)

After 500 sweeps, the values of velocity, temperature, and pressure, at a reference point in the middle of the cavity, have converged to the extent shown in Figures C-1 to C-8. By 500 sweeps the constant pressure lines (Fig. C-2) for all four cases are very similar, as are the streamlines (Fig. C-8), and to a lesser extent the temperature profiles (Figs. C-1 and C-7). Of the three, temperature is the slowest to recover from a poor initial guess. However, even with an initial temperature estimate 1000°F off the final values, the temperature at the monitoring point has converged to within 200°F of the final value after 200 sweeps, and to within 75°F of the final value after 400 sweeps. This is an acceptable convergence rate for our application, especially since the magnitude of the error is readily apparent from the slope of the temperature convergence curve (Fig. C-1). In the event that greater accuracy were required, the solution could be bracketed or else extended the necessary number of sweeps.
Figure C-1. Temperature convergence, cases 1 to 3.
Figure C-2. Pressure convergence, cases 1 to 3.
Figure C-3. Circumferential velocity convergence, cases 1 to 3.
Figure C-4. Radial velocity convergence, cases 1 to 3.
Figure C-5. Pressure and temperature convergence, case 4.
Figure C-6. Temperature fields, cases 1 to 3.
Figure C-7. Velocity field and streamlines, cases 1 to 4.
A general purpose, three-dimensional computational fluid dynamics code named PHOENICS, developed by CHAM Inc., is used to model the flow in the aft-platform seal cavity in the high pressure fuel pump of the space shuttle main engine. The model is used to predict the temperatures, velocities, and pressures in the cavity for six different sets of boundary conditions. The results are presented as input for further analysis of two known problems in the region, specifically: erratic pressures and temperatures in the adjacent coolant liner cavity and cracks in the blade shanks near the outer diameter of the aft-platform seal.