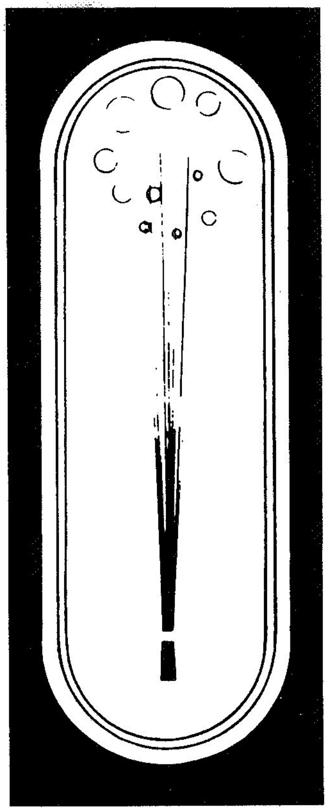
FZA-450-3

15 SEPTEMBER 1970



STUDY OF CRYOGENIC FLUID MIXING TECHNIQUES

Final Report

(JULY 1969-JULY 1970)

Volume III - Computer Procedure for the Prediction of Stratification in Supercritical Oxygen Tanks

GENERAL DYNAMICS

Fort Worth Division

GENERAL DYNAMICS
Fort Worth Division

FZA-450-3
15 September 1970

STUDY OF CRYOGENIC FLUID MIXING TECHNIQUES

FINAL REPORT

(July 1969 - July 1970)

Volume III: Computer Procedure for the Prediction of Stratification in Supercritical Oxygen Tanks

L. J. Poth

Prepared for the
George C. Marshall Space Flight Center
National Aeronautics and Space Administration
Huntsville, Alabama

Under

Contract No. NAS8-24882

Approved by:

J R Van Hook

J. R. Van Hook
Project Manager

Approved by:

D. M. Goodwin

R. A. Stevens
Aerothermodynamics Group Engineer

F O R E W O R D

This document is Volume III of the final report on NASA Contract NAS8-24882, "Study of Cryogenic Propellant Stratification Reduction Techniques." The study was performed by the Fort Worth Division of General Dynamics Corporation for the George C. Marshall Space Flight Center of the National Aeronautics and Space Administration. The program was conducted under the technical direction of Mr. T. W. Winstead of the MSFC Astronautics Laboratory. His assistance in the performance of this study is gratefully acknowledged.

The final reports consists of three volumes:

Volume I. Large-Scale Experimental Mixing Investigations and Liquid-Oxygen Mixer Design

Volume II. Large-Scale Mixing Data

Volume III. Computer Procedure for the Prediction of Stratification in Supercritical Oxygen Tanks

Volume I contains a presentation of the large-scale experimental investigation and liquid-oxygen mixer design study together with a summary of the important findings of the study. Volume II contains a presentation of the experimental data utilized in this study. Volume III describes the computer procedure developed during the study for the prediction of stratification development in supercritical oxygen tanks.

TABLE OF CONTENTS

SECTION 1

INTRODUCTION AND SUMMARY

The computer procedure described herein was developed and used during this study to predict the thermodynamic state of supercritical oxygen. This procedure, designated as General Dynamics Procedure SW6, is used to predict the transient pressure, density, temperature, and mass of supercritical oxygen stored under a "zero-gravity" environment in a spherical tank. Both temperature-stratified and -mixed cases have been analyzed. In the stratified case, only radial variations in the thermodynamic state are considered. The fluid is withdrawn from the center region of the tank. Environmental heating occurs at the outer tank wall. An internal electrical heater is used to control the fluid pressure in the tank.

For the mixed case (thermodynamic equilibrium), the thermodynamic state of the stored oxygen is established by overall mass and energy conservation along with an appropriate equation of state. In a similar manner, the thermodynamic state of the radially stratified case is defined by the laws of spacial conservation of mass, and energy, along with an equation of state. These governing equations have been solved in an approximate fashion by the use of a finite-element, numerical solution. Although the results are valid for a compressible fluid, the stable time increment used is orders-of-magnitude greater than that usually required for the finite-difference solution of compressible flow. The large time step that can be used for this solution is a direct consequence of an assumption that the pressure is uniform throughout tank. Typically, the fluid behavior during a mission of 10 hours can be analyzed by the use of a few minutes of computer time.

The description of the computer program includes such information as typical error diagnosis, sample problem input and output data, and the computer program listing.

The equations solved by the computer program described herein are similar to those solved by Kamat (Reference 1) although the numerical procedure used differed appreciably from that of Kamat.

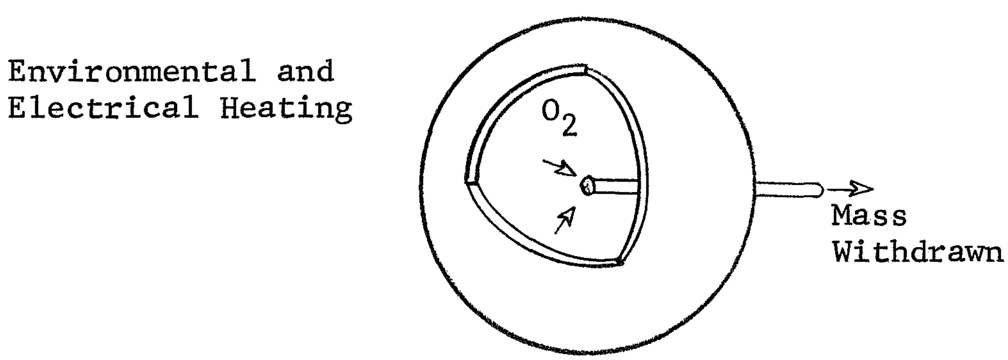
SECTION 2

PROGRAM DESCRIPTION

In this section, the program applications, the governing equations, which were numerically integrated, along with the appropriate boundary conditions are described. In addition, the finite-difference approximations resulting from the governing equations and the corresponding numerical procedure are discussed.

2.1 PROGRAM APPLICATION

Computer program SW6 was written to predict the transient thermodynamic state (i.e., pressure, density, temperature) of a single-phase cryogen stored in a spherical tank under a zero-gravity environment with simultaneous environmental/electrical heating and fluid withdrawal (including venting). A sketch of the supercritical storage tank is shown below



Supercritical Storage Tank

Energy due to the environment or electrical heaters is assumed to be added at the outer tank boundaries. Mass withdrawal is assumed to take place at the center of the tank. The mass withdrawal rate due to venting is included if the tank pressure rises above a specified vent pressure.

Temperature, internal energy, enthalpy, and density gradients are assumed to exist only in the radial direction. The velocities developed in the tank due to heating and mass outflow are also considered to occur in the radial direction only.

The predictions of this program include:

1. Tank pressure history
2. Radial temperature distribution as a function of time
3. Radial density distribution as a function of time
4. Radial velocity distribution as a function of time
5. Stored mass history
6. Mass flow-rate history.

Other quantities that can be easily obtained from the computer output include:

7. Vented mass as a function of time
8. Electrical heater duty cycle, power requirements history, and total accumulated electrical heater power requirements
9. Mixer duty cycle
10. Energy added to the tank by the mixer operation.

The program has the capability of plotting the first six items mentioned as a function of time and the second and third items as a function of radial position in the tank.

Some of the other capabilities and options of the program include

1. An option to use one of two different finite-difference equations of energy and mass

2. An option to use one of three different methods of defining the velocity at the boundary of each node,

3. An option to consider either an ideal gas with constant specific heats or a real fluid, with variable properties defined by thermodynamic tables.

Limitations of the program include:

1. One-dimensional (radial) property variations (temperature, density, and velocity)

2. Mass withdrawal at the tank center region

3. Heating at the tank wall.

2.2 GOVERNING EQUATIONS

The governing equations used as the basis for this program include the one-dimensional compressible form of the

- continuity,
- energy,
- r-momentum, and
- thermodynamic state equations or thermodynamic tables.

The continuity equation is

$$\frac{\partial(\rho)}{\partial t} + \frac{1}{r^2}\frac{\partial}{\partial r}(\rho u r^2) = 0$$

where ρ is the density

u is the radial velocity

r is the radial coordinate

t is the time.

The energy equation is

$$\frac{\partial}{\partial t}(\rho e) = -\frac{1}{r^2}\frac{\partial}{\partial r}(\rho h u r^2) + \frac{1}{r^2}\frac{\partial}{\partial r}\left(k r^2 \frac{\partial T}{\partial r}\right)$$

where e is the specific internal energy

h is the specific enthalpy

T is the temperature

k is the thermal conductivity.

The r momentum equation is

$$\rho\left[\frac{\partial u}{\partial t} + u\frac{\partial u}{\partial r}\right] = \frac{4}{3}\mu\left[\frac{\partial^2 u}{\partial r^2} + \frac{2}{r}\frac{\partial u}{\partial r} - \frac{2u}{r^2}\right] - \frac{\partial P}{\partial r}$$

where μ is the dynamic viscosity

P is the pressure.

In addition to the above equations, an equation of state or thermodynamic property table relating the internal energy and enthalpy to two independent properties (i.e., ρ and P) is required. The equation of state is

$$\rho = P/ZRT$$

where Z is the compressibility

R is the gas constant.

For very low compressible flow (Mach number on the order of 10^{-7}), convective and viscous terms of the momentum equation can be neglected as can be shown by an order-of-magnitude analysis. The momentum equation reduces to

$$\rho \frac{\partial u}{\partial t} + \frac{\partial P}{\partial r} = 0$$

The above equation is coupled with the continuity equation to form a wave equation. Any sizeable pressure fluctuation propagates at the speed of sound and equalizes the tank pressure. Consequently, the pressure gradients are essentially zero. For the long storage times in which this prediction is applicable, the momentum equation reduces to a quasi-steady condition in which

$$\frac{\partial P}{\partial r} = 0$$

This condition along with the continuity and energy equations and thermodynamic property tables serve as the basis for the numerical solution.

2.3 BOUNDARY CONDITIONS

The boundary conditions associated with this solution establishes the energy and mass fluxes across the inner and outer tank boundaries. On the inner surface three boundary conditions are applied:

1. The velocity, $u(r_1, t)$, is

$$u(r_1,t) = \dot{m}_o/4\pi r_1^2 \rho_1(r_1,t)$$

where $\dot{m}_o$ is the mass utilization or venting rate

r_1 is the inner radius

ρ_1 is the outflow density

2. The heat transfer by conduction, q_1, is assumed to be zero; hence,

$$\frac{\partial T}{\partial r}(r_1,t) = 0$$

3. The energy transfer, E', by convection at (r_1,t) is

$$E' = h(r_1,t)u(r_1,t)\rho(r_1,t)4\pi r_1^2$$

Three boundary conditions are also applied to the outer tank surface at (r_t,t):

1. The velocity, $u(r_t,t)$, is zero

2. The heat transfer by conduction is

$$Q = 4\pi r_t^2 \frac{k\partial T}{\partial r}(r_t,t)$$

where Q is the total electrical and/or environmental heating, k is the thermal conductivity.

Thus the transient behavior of the fluid in the tank is completely defined by (1) the equations of continuity, energy and momentum (uniform pressure within the fluid at a given time) and equation of state (thermodynamic tables), (2) the initial conditions in terms of density and pressure, and (3) the boundary conditions defined in terms of the mass flow at the tank center and heat transfer at the tank walls.

2.4 FINITE-DIFFERENCE EQUATIONS

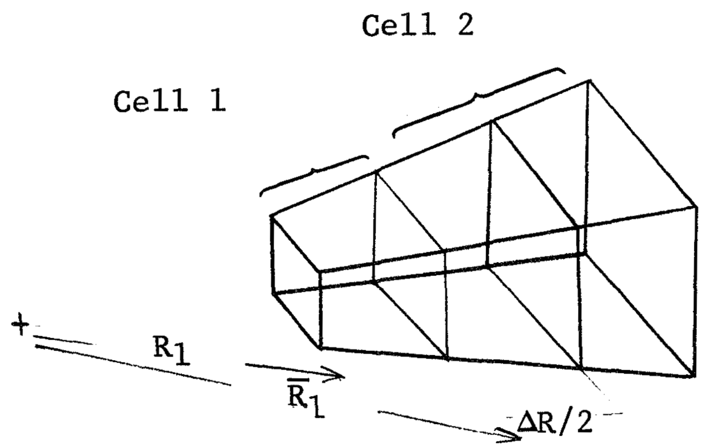
The finite-difference equations derived in this subsection satisfy energy and mass conservation on a finite-size element. As a result, the form of the difference equations differs somewhat from those that are conventionally obtained from use of a Taylor series-type expansion of the governing equations.

2.4.1 Cell Description

In order to facilitate the derivation of the finite element equations, a description of the cells and the corresponding mass and energy storage in each cell along with energy and mass flow across the cell boundaries is presented. In the description of the elemental cells, the cell geometry and flow areas are also defined. A description of three means of defining the cell boundary velocities is presented. Finally, conservation of mass and energy is applied to establish the finite element equations.

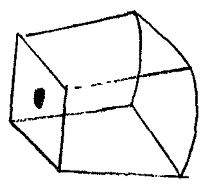
2.4.1.1 Cell Geometry

The cell geometry used in the finite-element solution is shown in the sketch below. The element or cell is described in spherical coordinates for a unit solid angle or steradian. The energy and mass flow is assumed to take place in the radial direction only. The inner tank boundary consists of the spherical surface of radius R_1. The last cell, n, is bounded on the outer edge by a spherical surface which consists of the tank wall. The first cell, of thickness $\Delta R/2$, is bounded by the outer spherical surface of radius $R = \bar{R}_1$. The interior cells, 2 to n-1, are of thickness ΔR and each cell, i, is bounded on the inner spherical surface by $\bar{R}_{i-1}$ and on the outer surface by $\bar{R}_i$.

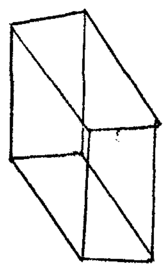


Cell Flow Area

The cell flow area per unit solid angle is defined at the inner radius, R_1, and the outer tank radius, R_n, for the first and last cells, respectively. The outer boundary area of the first cell is defined at $\bar{R}_1$ and the inner boundary of the last cell is defined at $\bar{R}_{n-1}$ as shown below.



First Cell



Last Cell

The inner and outer flow area at the first cell boundaries are

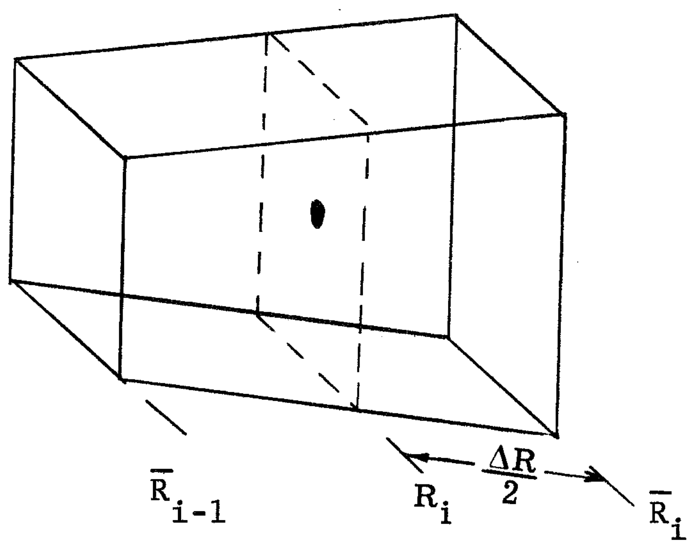
$$\bar{A}_1 = R_1^2 \quad \text{and} \quad \bar{A}_1 = \bar{R}_1^2$$

respectively. The inner and outer flow areas at the boundaries of the last cell are

$$\bar{A}_{n-1} = \bar{R}_{n-1}^2 \quad \text{and} \quad \bar{A}_n = R_n^2$$

respectively.

For an interior cell, sketched below, the inner area is



given by

$$\bar{A}_{i-1} = \bar{R}_{i-1}^2$$

and the outer area by

$$\bar{A}_i = \bar{R}_i^2$$

where

$$\bar{R}_i = R_i + \Delta R/2$$

<u>Cell Volume</u>

The volume per unit solid angle (4π steradians for the sphere) of the first cell is given by

$$VOL(1) = \frac{1}{3} \left(\bar{R}_1^3 - R_1^3 \right)$$

and for the last cell by

$$VOL(n) = \frac{1}{3} \left(R_{n-1}^3 - R_n^3 \right)$$

The volume of each interior cell is also defined per steradian as

$$VOL(i) = \frac{1}{3} \left(\bar{R}_i^3 - \bar{R}_{i-1}^3 \right)$$

where

$$\bar{R}_i = R_i + \Delta R/2$$

The tank volume, V_t, is given by

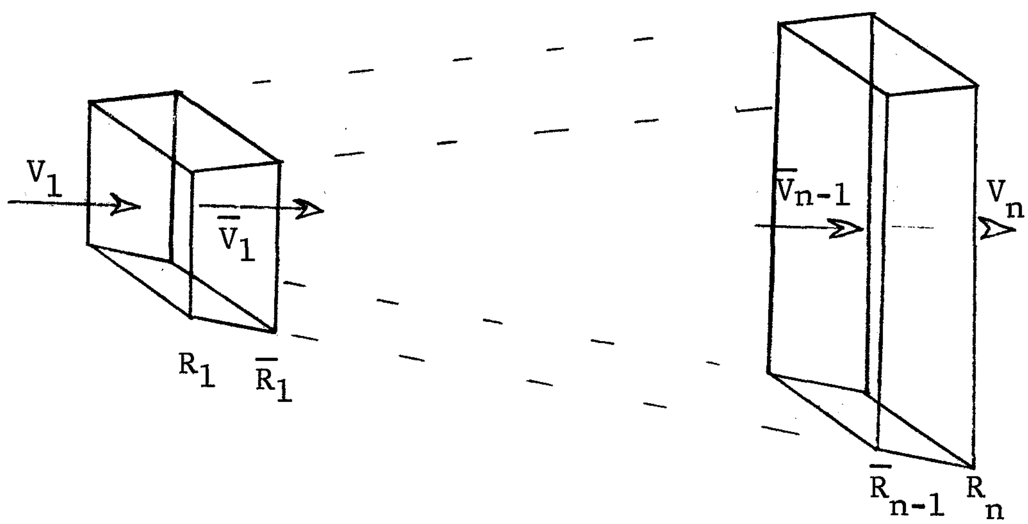
$$V_t = \frac{4\pi}{3} \left(R_n^3 - R_1^3 \right)$$

It can be easily shown from the above equations that the summation of the cell volumes equals the tank volume since each $\bar{R}_i^3$ cancels in the summation.

Another representation of the cell volumes and areas is used as an option in the computer procedure. The volume representation, however, does not sum to the exact tank volume. Hence this option, which is derived from the finite-difference equation, is not recommended.

2.4.1.2 Velocities at Cell Boundaries

The velocity is defined at each cell boundary. For the first and last cells the velocities are shown in the sketch at the appropriate boundaries



The velocity at the inner boundary of the first cell is

$$V_1 = \dot{m}_o / (4 \pi \; R_1^2 \; \rho_1)$$

where $\dot{m}_o$, the mass flow rate into the tank and ρ_1, the inflow density, are computer input quantities representing either the utilization rate (negative $\dot{m}_o$) and/or the vent rate (also negative $\dot{m}_o$).

The velocity at the outer boundary of the first cell is established by one of three options:

1. The arithmetic average between cell 1 and 2

   $\bar{V}_1 = (V_1 + V_2)/2$

2. The area-weighted arithmetic average,

   $\bar{V}_1 = (R_1^2 V_1 + R_2^2 V_2)/2 \ (\bar{R}_1)^2$ or

3. A computer iteration process by which the boundary velocity is varied in such a manner that the pressure between the cells adjacent to the boundary is converged to within a specified pressure difference.

The velocity of the inner boundary of the last cell is given by a similar set of options:

1. $\bar{V}_{n-1} = (V_{n-1} + V_n)/2$
2. $\bar{V}_{n-1} = (\bar{R}_{n-1}^2 V_{n-1} + R_n^2 V_n)/2 \ \bar{R}_{n-1}^2$

3. A pressure relaxing iteration process.

The velocity at the outer boundary of the last cell is assumed equal to zero.

The velocity of the inner boundaries of the interior cells is similarly given by

1. $\bar{V}_{i-1} = (V_{i-1} + V_i)/2$
2. $\bar{V}_{i-1} = (\bar{R}_{i-1}^2 V_{i-1} + R_i^2 V_i)/2(\bar{R}_{i-1}^2)$
3. A pressure iteration process.

The velocity at the outer boundary of the interior cells is given by

1. $\overline{V}_i = (V_i + V_{i+1})/2$
2. $\overline{V}_i = (V_i R_i^2 + V_{i+1} R_{i+1}^2)/2 \overline{R}_i^2$
3. A pressure iteration process.

2.4.1.3 Cell Mass

The cell mass, M_i, of the two boundary and the interior cells is given by

$$M_i = VOL(i) \rho_i$$

where ρ_i is the density of the ith cell and VOL(i) is the cell volume.

The tank mass, M_t, may be calculated by

$$M_t = \sum_{i=1}^{n} VOL(i) \rho_i$$

or by

$$M_t = V_t \rho_m$$

where V_t is the tank volume, and

ρ_m is the mean density

The new mean density, ρ_m, is calculated after one time step, Δt, by

$$\rho_m = (M_t + \dot{m}\ \Delta t)/V_t$$

or by

$$\rho_m = \sum_{i=1}^{n} (\rho_i\ VOL(i))/V_t$$

2.4.1.4 Cell Energy

The energy, E_i, stored in the ith cell is given by

$$E_i = VOL(i)\ \rho_i\ e_i$$

where

e_i is the specific internal energy.

The specific internal energy, calculated initially by the computer procedure, is based on thermodynamic tables of temperature and enthalpy as dependent variables and pressure and density as independent variables. For an initial pressure and density, the enthalpy, h_i, at each cell is calculated. The internal energy, e_i, is then calculated by the equation

$$e_i = h_i - P_i/\ \rho_i$$

Thereafter, a new value of the specific internal energy, e_i, of each cell is calculated by the use of the finite-element form of the energy equation.

The total internal energy, E_t, is given by

$$E_t = \sum_{i=1}^{n} VOL(i)\ \rho_i\ e_i$$

and also by

$$E_t = V_t\ \rho_m\ e_m$$

where ρ_m and e_m are mean quantities.

The new mean internal energy, e'_m, is given by

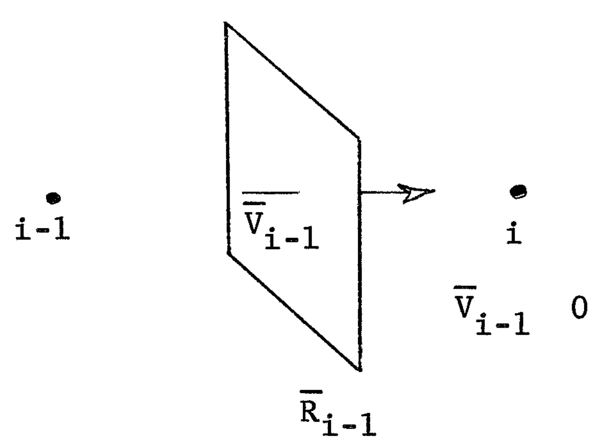
$$e'_m = (E_t + \dot{m}\ h_1\ \Delta t) / \rho_m\ V_t$$

where h_1 is the enthalpy of the first cell.

2.4.1.5 <u>Boundary Mass Flow Rate</u>

The mass flow rate across both cell boundaries is defined by use of a convention to ensure mass conservation and numerical stability.

For the inner boundary of the ith cell shown below,



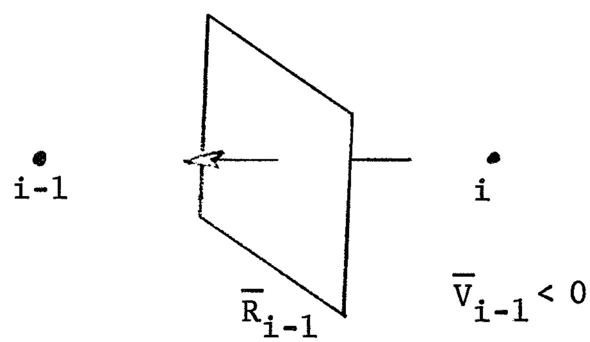
the mass flow rate per solid angle for $\bar{V}_{i-1} > 0$ is

$$\bar{\dot{m}}_{i-1} = (\rho_{i-1})\, \bar{V}_{i-1}\, \bar{A}_{i-1}$$

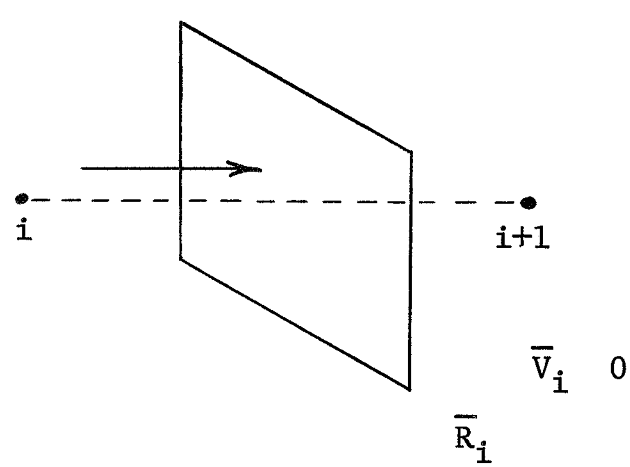
For $\bar{V}_{i-1} < 0$, the mass flow rate per solid angle is

$$\bar{\dot{m}}_{i-1} = (\rho_{i})\, \bar{V}_{i-1}\, \bar{A}_{i-1}$$

Note that the density used is evaluated at the "tail" side of the velocity arrow, as illustrated in the above and below sketches.



For the outer cell boundaries, the mass flow rate, $\bar{\dot{m}}_i$, is shown below for $\bar{V}_i > 0$



and is given by

$$\bar{\dot{m}}_i = \rho_i \bar{V}_i \bar{A}_i$$

For $\bar{V}_i < 0$, the mass flow rate, $\bar{\dot{m}}_i$, is given by

$$\bar{\dot{m}}_i = \rho_{i+1} \bar{V}_i \bar{A}_i$$

The mass flow rate across the inner boundary of the first cell is

$$\dot{m}_1 = \dot{m}_o / 4\pi$$

where $\dot{m}_o$ is the total mass flow rate into the tank.

The mass flow rate across the nth cell outer boundary (i.e., the tank wall) is zero.

2.4.1.6 Boundary Energy Flow

The flow of energy across the cell boundaries is in the form of convection and the conduction. The convection of energy across the inner boundary of the first cell is given by

$$\dot{E}_1 = V_1 A_1 (\rho_1 h_1) \text{ for } V_1 < 0,$$

where h_1 is the specific enthalpy of the first cell.

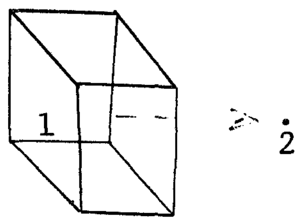
The convection of energy across the outer boundary of the first cell is given by

$$\bar{\dot{E}}_1 = \bar{V}_1 \bar{A}_1 (\rho_1 h_1) \text{ for } \bar{V}_1 > 0$$

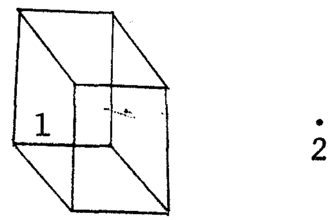
and

$$\bar{\dot{E}}_1 = \bar{V}_1 \bar{A}_1 \left(\rho_2 h_2 \right) \quad \text{for } \bar{V}_1 < 0$$

as illustrated in the sketch below:



$\bar{V}_i > 0$



$\bar{V}_i < 0$

Here again, the thermodynamic properties, ρh, being convected are evaluated at the cell upstream or at the "tail" of the velocity vector.

The energy convected across the outer boundary of the last cell is zero because of the presence of the tank wall. The energy convected across the inner boundary of the last cell is given by

$$\bar{\dot{E}}_{n-1} = \bar{V}_{n-1} \bar{A}_{n-1} \left(\rho_{n-1} h_{n-1} \right)$$

for $\bar{V}_{n-1} > 0$ and

$$\dot{\bar{E}}_{n-1} = \bar{V}_{n-1} \bar{A}_{n-1} (\rho_n h_n)$$

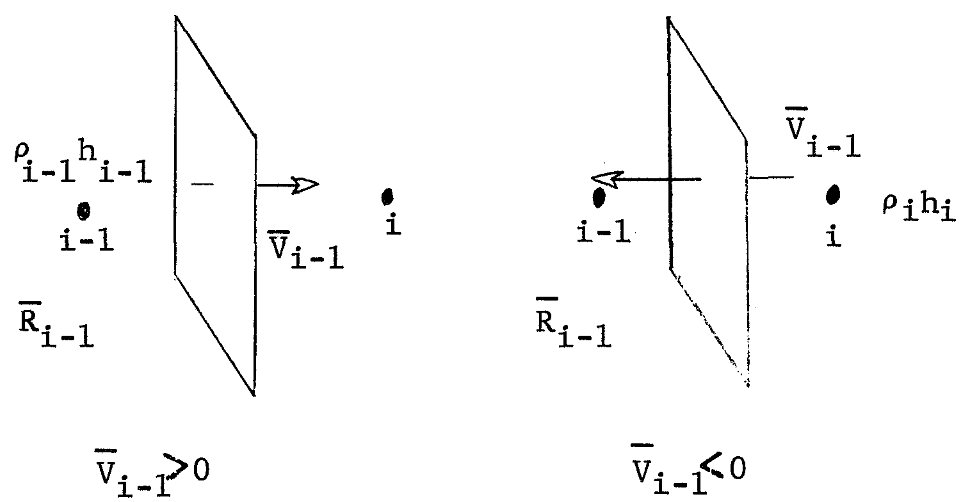
for $\bar{V}_{n-1} < 0$.

Similar equations for the convective energy across the inner boundary or each interior cell may be expressed as

$$\dot{\bar{E}}_{i-1} = V_{i-1} A_{i-1} (\rho_{i-1} h_i)$$

for $\bar{V}_{i-1} > 0$.

The sketch below shows the inner boundary for each interior cell, i:



For the outer boundary of each interior cell, the conductive energy flow is

$$\dot{\bar{E}}_i = \bar{V}_i \bar{A}_i (\rho_i h_i)$$

for $\bar{V}_i > 0$ and

$$\dot{\bar{E}}_i = \bar{V}_i \bar{A}_i (\rho_{i+1} h_{i+1})$$

for $\overline{V}_i < 0$.

In addition to the convective energy flow across each cell boundary, heat transfer by thermal conduction is present. The rate of energy conducted from the first cell across the boundary at the average radius, $\overline{R}_1$ is

$$\overline{Q}_1 = -K\,\overline{A}_1\,(T_2 - T_1)/\Delta R$$

where K is the thermal conductivity.

In this analysis, the energy conducted across the inner tank boundary is assumed to be zero. The rate of energy conducted into the last cell is

$$\overline{Q}_{n-1} = -K\,\overline{A}_{n-1}\,(T_n - T_{n-1})/\Delta R.$$

The rate of energy added to the last cell takes into account the rate of energy added along the tank boundaries by environmental and/or electrical heater sources. In a similar manner, the energy crossing the inner boundary of cell i is

$$\overline{Q}_{i-1} = -K\,\overline{A}_{i-1}\,(T_i - T_{i-1})/\Delta R$$

and the energy crossing the outer boundary of cell is

$$\overline{Q}_i = -K\,\overline{A}_i\,(T_{i+1} - T_i)/\Delta R$$

2.4.2 Conservation of Mass

The finite-element description of the cell properties given in Subsection 2.4.1 serve as the basis for the development of the conservation characteristics in space and time. For any cell, i, the change in the amount of mass stored is equal to the summation of the mass rate of flow at the boundaries multiplied by the time interval. In mathematical form, the conservation of mass for the interior cells is written as

$$\rho_i \; VOL(i) - \rho_i \; VOL(i) = \Delta t \; (\bar{\dot{m}}_i - \bar{\dot{m}}_{i-1})$$

For the first and last cells, similar equations may be written as

$$\rho_1 \; VOL(i) - \rho_1 \; VOL(i) = \Delta t \; (\bar{\dot{m}}_1 - \bar{\dot{m}}_2)$$

and

$$\rho_n \; VOL(n) - \rho_n \; VOL(n) = \Delta t \; \bar{\mathring{m}}_{n-1}$$

The primed densities are at the time, t+ Δt.

The new density may be determined, giving for the i<u>th</u> cell

$$\rho_i = \rho_i + \Delta t \; (\bar{\dot{m}}_i - \bar{\dot{m}}_{i+1})/VOL(i)$$

The mass flow rate across the boundaries have been defined previously for boundary velocities greater than and less than zero. In a similar manner, the densities at the new time, t+ Δt, for the first and last cells are

$$\rho_1 = \rho_1 + \Delta t \; (\dot{m}_1 - \bar{\dot{m}}_1)/VOL(i)$$

and

$$\rho_n = \rho_n + \Delta t\ (\bar{\dot{m}}_{n-1})/VOL(n)$$

The three above equations are used in the computer solution.

2.4.3 Conservation of Energy

The finite element form of the energy equation which is used in the computer solution for the internal energy and temperature of each cell is based upon the basic cell characteristics previously derived. The change in energy of the i<u>th</u> interior cell is equal to the net energy convected and conducted across the cell boundaries and is given by

$$(\ \rho'_i\ e'_i - \rho_i\ e_i)VOL(i) = \Delta t\ (\bar{\dot{E}}_{i-1} - \bar{\dot{E}}_i) + \Delta t(\bar{Q}_{i-1} - \bar{Q}_i)$$

where $\bar{\dot{E}}_i$ and $\bar{Q}_i$ are the energies convected and conducted across the boundary at $R = \bar{R}_i$. Similar expressions can be written for energy conservation for the first and last cells.

The new specific internal energy at the time t+ Δt for the i<u>th</u> interior cell is

$$e'_i = \rho_i e_i / \rho'_1 + \Delta t(\bar{\dot{E}}_{i-1} - \bar{\dot{E}}_i) / \rho'_i VOL(i) + \Delta t\left(Q_{i-1} - Q_i\right) / \rho'_i VOL(i)$$

The specific internal energies at the time t+ Δt for the first and last cells are, respectively,

$$e'_1 = \rho_1 e_1 / \rho'_1 + \Delta t(\bar{\dot{E}}_{i-1} - \dot{E}_1 + \bar{Q}_{i-1} - \bar{Q}_i) / \rho'_1 VOL(i)$$

and

$$e'_n = \rho_n e_n / \rho'_n + \Delta t(\bar{\dot{E}}_{n-1} + \bar{Q}_{i-1} - Q_i)/ \rho'_n \, VOL(i)$$

The new internal energy along with the new density at each cell defines the thermodynamic state of each cell. A thermodynamic table is nominally used (pressure and density as independent variables and temperature and enthalpy as dependent variables) along with an iteraction procedure to establish the pressure and temperature of each cell. The computer procedure possesses an option which permits the specific heat at constant volume to be used to calculate the new temperature for the case of an ideal gas. The ideal gas equation (corrected by use of a constant compressibility factor) is then used in this option to calculate a new pressure at each cell.

Once the new temperature and pressure is calculated at each cell an iteration process is initiated to relax the pressure gradients in the tank to zero or a very small value before the calculations for the next time step ($t+2\Delta t$) are initiated. In order to relax the nonuniformities in the tank pressure, cell boundary flow is assumed as described in Subsection 2.4.5.

2.4.4 Thermodynamic Tables/Equation of State

The thermodynamic tables provide a relation between any two thermodynamic variables (i.e., p and ρ) and any remaining variable, e,T, or h. The equation of state as used in this program calculates the compressibility factor, $Z(\rho\ P)$, by

$$Z(\rho,P) = P/\rho RT$$

where $T = T(\rho,P)$ is found by interpolating tabular values of a thermodynamic table. The compressibility factor in this program is used for the ideal gas case and is not varied with time.

2.5 STABILITY CONSIDERATIONS

A conventional stability criterion is used to establish the time increment. There is a characteristic stable time for each cell which is given by

$$\Delta t_{si} = \left[\frac{2\alpha}{\Delta R^2} + \left| \frac{V_i}{\Delta R} \right| \right]^{-1}$$

where

α is the thermal diffusivity

V_i is the node velocity

ΔR is the distance between cells.

The stable time increment used is the minimum value of Δt_{si} as calculated for each cell. The actual time step used is some fraction, TF, of the minimum stable time step,

$$\Delta t = TF\ (\text{Minimum}\ \Delta t_{si})$$

2.6 NUMERICAL PROCEDURE

The numerical procedure utilizes a forward marching technique in time to obtain the thermodynamic state history of the supercritical oxygen. The program consists of data input, problem initialization, new state calculations and a printout/plotting procedure.

After the data is read in the initialization technique includes

1. the calculation of the volume of the tank and of each cell,

2. the determination of the initial temperature, internal energy, enthalpy, and mass of the tank as a whole and of each cell, and

3. the initialization of the velocity distribution.

The new state calculations include

4. the calculation of the new densities at each cell by the use of the continuity equation,

5. the calculation of the new specific internal energy at each cell by the use of the energy equation,

6. the determination of the pressure and temperature of each cell by use of thermodynamic tables of the new densities and internal energies and

7. the relaxation of any pressure non-uniformities by allowing for mass flow in the direction opposite to the pressure gradient.

Steps 4 through 7 are repeated as often as necessary to reduce any pressure difference to less than a specified input value.

The results are printed out and the time is updated.

Various checks may be performed with the optional outputs from this program. The stored mass in the tank and total internal energy is evaluated in three ways to insure accurate predictions. It has been established that mass and energy is conserved at each cell in the tank and in the whole tank. In addition it has been established as described in the method of solution that the tabular thermodynamic state is satisfied at each node for the stratified case and for the complete tank in the case of thermal equilibrium.

The computer procedure consists of one main program and four subroutines. The subroutines include

DATCHK
INTERP
NEWQUA
SIMPLT
SC102

DATCHK checks the input data for errors and inconsistencies. The principle check is made on input data for the plot option.

INTERP uses the thermodynamic table to calculate values of the temperature and enthalpy from input values of density and pressure.

NEWQUA calculates the values of the pressure, velocity, temperature, internal energy, density, at a new time step from the old values.

SIMPLT permits a group of 8 curves to be plotted on the one graph.

SC102 permits each curve on a graph to be plotted by the use of the "scores package" for the Stromberg Carlson 4020 plotter.

2.7 OPTIONAL CONDITIONS

Various options in the computer procedure include

1. ideal gas assumption
2. conventional form of the finite difference equations
3. method by which velocity at boundaries are evaluated
4. plotting option

The use of these options are described in Section 3.

The option using the conventional form of the finite difference equation is not recommended since exact mass and energy conservation is not achieved, even though the finite difference equations are written in "conservative form" as described by Torrance in Reference 2.

Linear average of the velocity across the boundary is not recommended.

SECTION 3

INPUT DATA

The input data consist of thermodynamic property library data, physical property data and control numbers.

3.1 LIBRARY DATA

The library data consist of densities, temperatures, enthalpies, and pressures. J1 values of temperature, enthalpy, and pressure are read in for each density. In all, I1 values of density are read in. The library data are as follows:

I1, J1
$\rho(1)$
T(1,1), H(1,1), P(1,1), T(1,2), H(1,2), P(1,2)
T(1,3), H(1,3), P(1,3), T(1,4), H(1,4), P(1,4)
T(1,J1), H(1,J1), P(1,J1)

(2)
T(2,1), H(2,1), P(2,1), T(2,2), H(2,2), P(2,2)

T(2,I1), H(2,I1), P(2,I1)

⋮

$\rho(I1)$
T(I1,1), H(I1,1), P(I1,1), T(I1,2), H(I1,2), P(I1,2)
⋮
T(I1,J1), H(I1,J1), P(I1,J1)

where

T(I,J) is a library table temperature, ^{o}R

H(I,J) is a library table enthalpy, Btu/lb

P(I,J) is a library table pressure, psia

The two indices, I1 and J1, are read in on the first card and have a field width of five spaces (2I5) and must be right-adjusted.

The second library card is used to read in the first two sets of temperatures, enthalpies and pressures with a 6E10.0 format statement. The first temperature, including decimal, occupies the first 10 spaces, the first enthalpy occupies the next 10 spaces, etc., up to 60 spaces. The additional sets of T, H, P for the first density are read in on subsequent cards.

3.2 PROBLEM DATA

The problem data consist of the appropriate physical quantities for the problem along with required control numbers. Each problem data card is discussed below.

<u>First Card</u> Six values of the problem data are read in with a field width of 10 spaces (columns):

0	10	20	30	40	50	60
Qe		$\dot{m}_o$	ΔR	P	P_{max}	R_1

where Qe is the environment heating, Btu/sec

$\dot{m}_o$ is the main flow into the tank, lb/sec

ΔR is the radial distance between nodes, ft

ΔP is the pressure difference, psi, to which two adjacent cells are relaxed

P_{max} is the maximum tank pressure, psi

R_1 is the radius at the center of the tank (inner tank boundary), ft

<u>Second Card</u> Six values are read in with a 10 space field width:

10	20	30	40	50	60
R_M	μ	k	TF	t	

where R_M is the tank radius, ft

μ is the dynamic viscosity, lb_m/ft sec

k is the thermal conductivity, Btu/^oR-sec-ft

TF is the fraction of the stable time step

t is the initial time increment, sec

ρ is the initial density, lb_m/ft^3

<u>Third Card</u> Six values are read in:

10	20	30	40	50	60
P	R_G	c_p	c_v	t_i	$\dot{m}_v$

where P is the initial pressure, psia

R_G is the gas constant, lb_f ft/^oR lb_m

c_p is the specific heat at constant pressure, Btu/lb ^oR

c_v is the specific heat at constant volume, Btu/lb-^oR

t_i is the initial time, seconds

$\dot{m}_v$ is the initial vent rate, lbs/sec (negative for outflow)

Fourth Card The six values read in are

10	20	30	40	50	60
Q_h	Q_m	P_{vo}	P_{vc}	P_{ho}	P_{hf}

where Q_h is the electrical heating in Btu/sec

Q_m is the heat added to the tank by mixer operation in Btu/sec

P_{vo} is the pressure in psia at which the vent valve is open

P_{vc} is the pressure in psia at which the vent valve is closed

P_{ho} is the pressure in psia at which the heater is turned on

P_{hf} is the pressure in psia at which the heater is turned off

Fifth Card The four values read in are

10	20	30	40	50	60
DT_{mo}	DT_{mf}	CT	PC	-	-

where DT_{mo} is the temperature difference in the tank at which the mixer is turned on

DT_{mf} is the temperature difference in the tank at which the mixer is turned off

CT is the max computer time in one hundreds of a second

PC is a fraction increase in the pressure used for derivatives obtained from the thermodynamic tables

Sixth Card

5	10	15	20	25	30	35	40	45	50	55	60
IM	NCOUT	NC2	NC7	IDM	NTIMEM	IMIX	IHET	IVENT	NC3	NC4	NC6

where IM is the number of cells

NCOUT is a control number, if equal to 1 uses average velocities across cell boundaries

NC2 is a control number, if equal to 1 uses constant density at all nodes

NC7 is a control number, if equal to 1 uses the exact cell volumes.

IDM is the maximum number of pressure iterations per time step

NTIMEM is the maximum number of time steps

IMIX is set equal to 1 for initial mixing, 0 for no initial mixing

IHET is initially set to 1 for the heater on, 0 for heater off

IVENT is initially set to 1 for venting, 0 for nonventing

NC3 is a control number, if equal to 1, the initial densities are read in.

NC4 is a control number, if equal to 1 uses a constant specific heat and compressibility

NC6 is a control number, if equal to 1 uses boundary velocities rather than velocities at the center of the cell

<u>7th Card</u> The variables using a field width of 5 spaces each (12I5)

5	10	15	20	25	30	35	40	45	50	55	60
NFI	NWO	NW1	NW2	NW3	NW4	NPC1	INPRIN	NTT	NW5		

where NFI is a control number, if = 1, plots each curve of graph I on separate graph

NWO is a control number, if = 1, writes calculated values of specific heat

NW1 is a control number, if = 1, writes the mass flux across each cell boundary

NW2 is a control number, if = 1, writes the specific heat and compressibility

NW3 is a control number, if = 1, writes the mass flux across each boundary

NW4 is a control number, if = 1, writes the output of Subroutine Interp (Thermodynamic Table Interpolation subroutine)

NPC1 is a control number, if = 1, plots the results

INPRIN is the number of time steps between printing

NTT is the number of pair of points of the drain history

NW5 is a control number, which when set equal to 1, writes the input of quantities to Subroutine Simplt.

<u>Card 8 through 15</u> These cards are for plotting the results

5	10	15	20	25	30	35	40
KXI( )	KYI(1)	NUS(1)	NGR(1)	NCC(1)	JN(1)	JTN(1)	
KXI(2)	KYI(2)	NUS(2)	NGR(2)	NCC(2)	JN(2)	JTN(2)	
⋮	⋮	⋮	⋮	⋮	⋮	⋮	
KXI(8)	KYI(8)	NUS(8)	NGR(8)	NCC(8)	JN(8)	JTN(8)	

where KXI(I) = 0 for a linear abcissa scale and 1 for a logarithmic scale

KYI(I) = 0 for a linear ordinate and 1 for a logarithmic ordinate scale

NVS(I) = 1 for point plots, 2 for points connected with straight line

NGR(I) = is the graph number to be plotted

NCC(I) = the number of curves on each plot

JN(I) = the cell number to be plotted on the curves

JTN(I) = the time steps to be plotted.

<u>Card 16 through 19</u> History of mass flow into the tank can be specified by these cards. The field width is 10 spaces, with 6 quantities per card as shown below:

10	20	30	40	50	60
$\dot{m}_1$	t_1	$\dot{m}_2$	t_2	$\dot{m}_3$	t_3

⋮

10	20	30	40	50	60
				$\dot{m}_{NTT}$	t_{NTT}

where $\dot{m}$ is the mass flow rate in pounds/hr

t is the time in hours and

NTT is the number of $(\dot{m},t)$ pairs

SECTION 4

ERROR DIAGNOSIS

The two means of diagnosing input data and program errors are

1. Error messages and
2. Optional printout

The error messages are self-explanatory. For example, in Subroutine Newqua, if the absolute value of the pressure difference between two adjacent cells is not less than a specified input value, the following message is printed out:

'Iterations did not converge in IDM steps'.

IDM is the maximum number of iterations specified by the input data.

For the Subroutine Interp, if the value of either a given pressure or density cannot be found in the thermodynamic table, the following message is printed:

'Enthalpy is outside of density library data' or

'Enthalpy is outside of pressure library data'.

Almost all pertinent intermediate data may be obtained by the use of the proper input data control numbers described in Section 3.

SECTION 5

PROBLEM TIMING

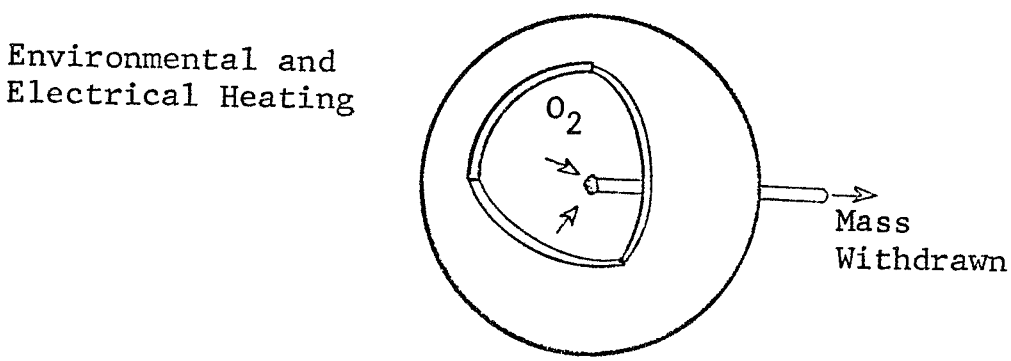
A typical SW6 computer run will calculate the transient thermodynamic state of supercritical oxygen for a period of real time of about 10 hours using about 1 minute of computer time with a distance between nodes of 0.1 ft and an outflow velocity of 10^{-1} ft/hour. Generally the computer time will increase as the inverse of the square of the distance between nodes and as the outflow velocity is increased.

SECTION 6

SAMPLE PROBLEM

6.1 PROBLEM DESCRIPTION

The following sample problem consists of environmental heating, mass withdrawal and electrical heating of supercritical oxygen stored in a low gravity space environment. The pressure history, temperature and density distributions are predicted. A sketch of the tank is shown below:



Some of the most pertinent parameters are

1. Environment heating, Q_e = 0.0 Btu/sec
2. Withdrawal rate, $\dot{m}_o$ = - 1.0 pounds/hr
3. Distance between nodes, R = 0.1 Ft
4. Minimum Radius, R_1 = 0.1 Ft
5. Maximum Radius, R_m = 1. ft
6. Initial density, ρ = 55 lb/ft^3

7. Initial Pressure, $P = 870$ psia

8. Electrical Heater Power, $P_h = 0.166$ Btu/sec

9. Vent Valves open pressure, $P_{vo} = 2500$ psia

10. Vent valve close pressure, $P_{vc} = 2400$ psia

11. Heater on pressure, $P_{ho} = 860$ psia

12. Heater off pressure, $P_{ho} = 1000$ psia

6.2 LIBRARY DATA

The sample library data is shown below.

18	12					003557L010001
0.3+00						003557L010002
1.64+02	9.175+01	1.575+01	2.068+02	1.0125+02	2.0+01	003557L010003
2.25+02	1.055+02	2.2+01	2.5+02	1.11+02	2.475+01	003557L010004
3.0+02	1.215+02	2.975+01	3.5+02	1.325+02	3.5+01	003557L010005
4.0+02	1.435+02	4.0+01	4.5+02	1.545+02	4.55+01	003557L010006
5.0+02	1.6575+02	5.05+01	5.5+02	1.7675+02	5.55+01	003557L010007
6.0+02	1.8775+02	6.05+01	6.5+02	1.99+02	6.55+01	003557L010008
0.6+00						003557L010009
1.775+02	9.45+01	3.45+01	2.0+02	9.9+01	3.75+01	003557L010010
2.25+02	1.045+02	4.3+01	2.5+02	1.1025+02	4.75+01	003557L010011
3.0+02	1.21+02	5.85+01	3.5+02	1.3175+02	6.85+01	003557L010012
4.0+02	1.43+02	7.9+01	4.5+02	1.54+02	8.95+01	003557L010013
5.0+02	1.655+02	10.0+01	5.5+02	1.765+02	11.1+01	003557L010014
6.0+02	1.875+02	12.1+01	6.5+02	1.985+02	13.1+01	003557L010015
1.0+00						003557L010016
1.895+02	0.92+02	6.0+01	2.0+02	0.98+02	6.35+01	003557L010017
2.25+02	1.035+02	7.15+01	2.5+02	1.0925+02	8.05+01	003557L010018
3.0+02	1.205+02	9.75+01	3.5+02	1.315+02	11.4+01	003557L010019
4.0+02	1.45+02	13.1+01	4.5+02	1.535+02	14.75+01	003557L010020
5.0+02	1.65+02	16.5+01	5.5+02	1.76+02	18.25+01	003557L010021
6.0+02	1.87+02	20.0+01	6.5+02	1.9825+02	22.0+01	003557L010022
1.5+00						003557L010023
2.0+02	0.975+02	0.915+02	2.25+02	1.025+02	1.05+02	003557L010024
2.5+02	1.0825+02	1.18+02	2.75+02	1.1375+02	1.325+02	003557L010025
3.0+02	1.195+02	1.45+02	3.5+02	1.305+02	1.72+02	003557L010026
4.0+02	1.44+02	2.0+02	4.5+02	1.53+02	2.25+02	003557L010027
5.0+02	1.6425+02	2.5+02	5.5+02	1.7525+02	2.8+02	003557L010028
6.0+02	1.86+02	3.05+02	6.5+02	1.95+02	3.3+02	003557L010029
3.0+00						003557L010030
2.21+02	0.985+02	1.85+02	2.25+02	0.99+02	1.375+02	003557L010031
2.5+02	1.0525+02	2.2+02	2.75+02	1.1075+02	2.48+02	003557L010032
3.0+02	1.165+02	2.75+02	3.5+02	1.28+02	3.3+02	003557L010033
4.0+02	1.3925+02	3.85+02	4.5+02	1.5075+02	4.37+02	003557L010034
5.0+02	1.62+02	4.95+02	5.5+02	1.7325+02	5.47+02	003557L010035
6.0+02	1.845+02	6.0+02	6.5+02	1.96+02	6.55+02	003557L010036
6.0+00						003557L010037
2.465+02	9.6+01	3.52+02	2.5+02	9.9+01	3.62+02	003557L010038
2.75+02	10.5+01	4.2+02	3.0+02	11.05+01	4.8+02	003557L010039
3.25+02	11.7+01	5.4+02	3.5+02	12.3+01	6.0+02	003557L010040
4.0+02	13.475+01	7.2+02	4.5+02	14.65+01	8.4+02	003557L010041
5.0+02	15.8+01	9.5+02	5.5+02	16.975+01	10.6+02	003557L010042
6.0+02	18.125+01	11.75+02	6.5+02	19.3+01	13.0+02	003557L010043

10.0+00							003557L010044
2.64+02	0.9425+02	5.25+02	2.75+02	0.975+02	5.8+02		003557L010045
3.0+02	1.04+02	6.85+02	3.25+02	1.105+02	7.95+02		003557L010046
3.5+02	1.17+02	9.05+02	3.75+02	1.23+02	10.10+02		003557L010047
4.0+02	1.2925+02	11.25+02	4.5+02	1.41+02	13.40+02		003557L010048
5.0+02	1.5325+02	15.50+02	5.5+02	1.65+02	17.50+02		003557L010049
6.0+02	1.7725+02	19.50+02	6.5+02	1.8925+02	21.50+02		003557L010050
14.0+00							003557L010051
2.719+02	8.9+01	6.38+02	2.75+02	9.025+01	6.7+02		003557L010052
3.0+02	9.725+01	8.35+02	3.25+02	10.425+01	10.1+02		003557L010053
3.5+02	11.075+01	11.75+02	4.0+02	12.350+01	15.0+02		003557L010054
4.5+02	13.65+01	18.25+02	5.0+02	14.85+01	21.4+02		003557L010055
5.5+02	16.1+01	24.5+02	6.0+02	17.4+01	27.75+02		003557L010056
6.5+02	18.65+01	30.75+02	7.0+02	19.85+01	33.75+02		003557L010057
18.0+00							003557L010058
2.75+02	0.85+02	7.0+02	3.0+02	0.9175+02	9.25+02		003557L010059
3.25+02	0.9875+02	11.75+02	3.5+02	1.0550+02	14.0+02		003557L010060
3.75+02	1.1225+02	16.4+02	4.0+02	1.19+02	18.5+02		003557L010061
4.25+02	1.2575+02	20.75+02	4.5+02	1.3225+02	23.0+02		003557L010062
5.0+02	1.4525+02	27.5+02	5.5+02	1.58+02	31.5+02		003557L010063
6.0+02	1.71+02	36.25+02	6.5+02	1.835+02	40.75+02		003557L010064
25.0+00							003557L010065
2.776+02	0.71+02	7.15+02	3.0+02	8.275+01	10.6+02		003557L010066
3.25+02	9.0+01	14.3+02	3.5+02	9.775+01	19.0+02		003557L010067
3.75+02	10.45+01	21.75+02	4.0+02	11.15+01	25.4+02		003557L010068
4.25+02	11.875+01	29.25+02	4.5+02	12.575+01	32.5+02		003557L010069
5.0+02	13.95+01	39.75+02	5.5+02	15.275+01	45.0+02		003557L010070
6.0+02	16.6+01	52.0+02	6.5+02	17.9+01	58.0+02		003557L010071
30.0+00							003557L010072
2.775+02	0.7+02	7.32+02	3.0+02	0.765+02	11.75+02		003557L010073
3.25+02	0.8425+02	16.6+02	3.5+02	0.9175+02	21.6+02		003557L010074
3.75+02	0.9925+02	26.5+02	4.0+02	1.07+02	31.75+02		003557L010075
4.25+02	1.1475+02	37.0+02	4.5+02	1.21+02	41.50+02		003557L010076
4.75+02	1.285+02	46.0+02	5.0+02	1.3525+02	50.5+02		003557L010077
5.25+02	1.42+02	55.0+02	5.5+02	1.485+02	59.0+02		003557L010078
35.0+00							003557L010079
2.76+02	0.6475+02	7.1+02	3.0+02	0.715+02	13.0+02		003557L010080
3.13+02	0.755+02	16.25+02	3.25+02	0.7975+02	19.5+02		003557L010081
3.38+02	0.835+02	22.5+02	3.5+02	0.875+02	25.0+02		003557L010082
3.63+02	0.915+02	29.2+02	3.75+02	0.955+02	32.25+02		003557L010083
4.0+02	1.0375+02	39.0+02	4.25+02	1.115+02	45.0+02		003557L010084
4.5+02	1.185+02	51.5+02	4.75+02	1.2525+02	58.0+02		003557L010085
40.0+00							003557L010086
2.725+02	0.59+02	6.6+02	2.75+02	0.595+02	7.3+02		003557L010087
2.88+02	0.625+02	10.75+02	3.0+02	0.67+02	15.5+02		003557L010088
3.13+02	0.71+02	19.25+02	3.25+02	0.75+02	23.75+02		003557L010089
3.38+02	0.8+02	28.5+02	3.5+02	0.84+02	32.75+02		003557L010090
3.63+02	0.885+02	36.75+02	3.75+02	0.93+02	40.50+02		003557L010091
4.0+02	1.0075+02	47.5+02	4.25+02	1.0875+02	55.5+02		003557L010092

45.0+00							003557L010093
2.65+02	0.51+02	5.6+02	2.7+02	0.525+02	7.2+02		003557L010094
2.75+02	0.545+02	9.25+02	2.88+02	0.57+02	13.6+02		003557L010095
3.0+02	0.635+02	20.0+02	3.13+02	0.6725+02	25.0+02		003557L010096
3.25+02	0.7175+02	30.75+02	3.38+02	0.765+02	35.0+02		003557L010097
3.5+02	0.815+02	41.50+02	3.63+02	0.8575+02	47.0+02		003557L010098
3.75+02	0.905+02	52.5+02	4.0+02	0.9775+02	61.0+02		003557L010099
50.0+00							003557L010100
2.535+02	4.2+01	4.3+02	2.556+02	4.275+01	4.85+02		003557L010101
2.6+02	4.375+01	6.25+02	2.643+02	4.55+01	8.0+02		003557L010102
2.686+02	4.7+01	10.25+02	2.729+02	4.925+01	13.0+02		003557L010103
2.75+02	5.075+01	14.90+02	2.8125+02	5.3+01	18.0+02		003557L010104
2.88+02	5.55+01	21.40+02	3.0+02	6.0+01	29.6+02		003557L010105
3.13+02	6.525+01	36.0+02	3.25+02	6.975+01	43.5+02		003557L010106
55.0+00							003557L010107
2.38+02	3.2+01	2.75+02	2.404+02	3.275+01	3.65+02		003557L010108
2.428+02	3.35+01	4.9+02	2.452+02	3.45+01	6.55+02		003557L010109
2.476+02	3.575+01	8.7+02	2.5+02	3.75+01	11.5+02		003557L010110
2.5625+02	4.0+01	15.0+02	2.625+02	4.3+01	19.0+02		003557L010111
2.6875+02	4.65+01	24.0+02	2.75+02	5.025+01	30.0+02		003557L010112
2.88+02	5.55+01	38.25+02	3.0+02	6.025+01	46.5+02		003557L010113
60.0+00							003557L010114
2.17+02	2.375+01	1.65+02	2.18+02	2.4+01	2.16+02		003557L010115
2.196+02	2.425+01	2.92+02	2.21+02	2.45+01	3.87+02		003557L010116
2.223+02	2.5+01	5.15+02	2.236+02	2.6+01	6.80+02		003557L010117
2.25+02	2.7+01	9.0+02	2.3+02	2.875+01	12.50+02		003557L010118
2.35+02	3.125+01	17.75+02	2.4+02	3.4+01	19.25+02		003557L010119
2.45+02	3.725+01	34.50+02	2.5+02	4.0+01	45.0+02		003557L010120
71.35							003557L010121
165.4	2.176	588.	166.9	2.5	700.		003557L010122
167.4	3.0	800.	168.2	3.4	900.		003557L010123
168.9	3.95	1000.	169.5	3.45	1100.		003557L010124
170.12	5.156	1176.	171.5	5.8	1350.		003557L010125
172.6	6.9	1500.	174.9	8.416	1754.		003557L010126
177.2	10.2	2000.	180.2	12.407	2352.		003557L010127

6.3 PROBLEM DATA

1st Card:

10	20	30	40	50	60
$Q_e = 0.0$	$\dot{m}_o = -.27\times10^{-3}$	$R = 0.1$	$P = 0.01$	$P_{max} = 3000.$	$R_1 = 0.1$

2nd Card:

10	20	30	40	50	60
$R_m = 1.0$	$\mu = 1\times10^{-6}$	$k = 1\times10^{-5}$	$TF = .25$	$t = 10^{-3}$	$\rho = 55.$

3rd Card:

10	20	30	40	50	60
$P = 870.$	$R_G = 48.3$	$C_p = .58$	$C_v = .337$	$t_1 = 0.0$	$\dot{m}_v = 0.0$

4th Card:

10	20	30	40	50	60
$Q_h = .166$	$Q_m = 0.0$	$P_{vo} = 2500.$	$P_{vc} = 2400.$	$P_{ho} = 860$	$P_{hf} = 1000.$

5th Card:

10	20	30	40	50	60
$DT_{mo} = 500.$	$DT_{mf} = 400.$	$CT = 6000.$	$PC = .05$		

The first five data cards are shown below:

```
0.0        -0.000277    0.1          0.01     3000.0         0.1 3733P010001
1.0          .000001   .00001        0.25      0.001         55. 3733P010002
 870.        48.3      0.58        0.3367       0.0          0.0 3733P010003
0.1667       0.0       2500.        2400.      860.        1000. 3733P010004
 500.        400.      6000.        0.05                         3733P010005
```

6th Card:

5	10	15	20	25	30	35	40	45	50	55	60
IM	NCOUT	NC2	NC7	IDM	NTIMEM	IMIX	IHET	IVENT	NC3	NC4	NC6
10	0	0	1	150	40	0	0	0	2	0	0

7th Card:

5	10	15	20	25	30	35	40	45	50	55	60
NFI	NWO	NW1	NW2	NW3	NW4	NPC1	INPRIN	NTT	NW5		
1	0	1	1	1	1	1	1	10	1		

The 6th and 7th cards are shown below:

10	0	0	1	150	40	0	0	0	2	0	0	3733P010006
0	1	0	1	1	1	1	1	10	1			3733P010007

The 8th through 15th problem data cards are shown below

0	0	2	1	2	1	1	3733P010008
0	0	2	2	6	2	10	3733P010009
0	0	2	3	6	3	20	3733P010010
0	0	2	4	6	4	50	3733P010011
0	0	2	5	1	5	100	3733P010012
0	0	2	6	1	0	140	3733P010013
0	0	1	7	8	0	160	3733P010014
0	0	1	8	8	0	200	3733P010015

The 16th through 19th problem data cards are shown below:

```
-1.0                  0.0-1.0                       10.0-1.0                        100.3733P010016
         0.0       101.0          0.0               120.           0.0              150.3733P010017
-10.                151. -10.0                      200.1.0                         250.3733P010018
 1.0              1000.                                                                3733P010019
```

6.4 PROBLEM OUTPUT

Typical problem data output is shown on the next page.

NODE NO ,	TIME ,	TEMPERATURE ,	PRESSURE ,	DENSITY ,	VELOCITY ,
1	0.0	0.247600E 03	0.870000E 03	0.550000E 02	-0.400780E-04
2	0.0	0.247600E 03	0.870000E 03	0.550000E 02	0.0
3	0.0	0.247600E 03	0.870000E 03	0.550000E 02	0.0
4	0.0	0.247600E 03	0.870000E 03	0.550000E 02	0.0
5	0.0	0.247600E 03	0.870000E 03	0.550000E 02	0.0
6	0.0	0.247600E 03	0.870000E 03	0.550000E 02	0.0

NODE NO ,	TIME ,	TEMPERATURE ,	PRESSURE ,	DENSITY ,	VELOCITY ,
1	0.372182E 03	0.247567E 03	0.865201E 03	0.549942E 02	-0.401906E-04
2	0.372182E 03	0.247567E 03	0.865202E 03	0.549942E 02	-0.171631E-05
3	0.372182E 03	0.247567E 03	0.865208E 03	0.549942E 02	-0.469997E-06
4	0.372182E 03	0.247567E 03	0.865202E 03	0.549942E 02	-0.152369E-06
5	0.372182E 03	0.247567E 03	0.865203E 03	0.549942E 02	-0.582942E-08
6	0.372182E 03	0.247567E 03	0.865215E 03	0.549942E 02	0.0

SECTION 7

PROGRAM LISTING

The program listing is shown on the following pages.

```
C**** SMOUTI IS THE DRAIN RATE , POUNDS/SEC                              SW6M002
C**** DELTAR IS THE DISTANCE BETWEEN NODES , FT                          SW6M003
C**** PMMI IS THE PRESSURE DIFFERENCE BETWEEN ADJACENT NODESFOR CONVERGESW6M004
C**** NCE ,PSI                                                           SW6M005
C**** TM IS THE MAX TANK PRESSURE                                        SW6M0060
C**** RADMIN IS THE MINIMUM TANK RADIUS , FT                             SW6M007
C**** RADMAX IS THE TANK RADIUS , FT                                     SW6M008
C**** VIDY IS THE DYNAMIC VISCOSITY                                      SW6M009
C**** COND IS THE THERMAL CONDUCTIVITY , BTU/HR-FT-DEG F                 SW6M010
C**** TF IS THE FRACTION OF THE STABLE TIME STEP USED                    SW6M011
C**** DELT IS THE INITIAL TIME STEP (SHOULD BE SMALL SAY 0.1 SEC )       SW6M012
C**** RHOI IS THE INITIAL DENSITY , POUNDS/FT CUBE                       SW6M013
C**** PRESI IS THE INITIAL PRESSURE , PSI                                SW6M014
C**** GASCON IS THE GAS CONSTANT                                         SW6M015
C**** SPHTP IS THE SPECIFIC HEAT (CON PRESS) BTU/POUNDS- DEG F           SW6M016
C**** SPHTV IS THE SPECIFIC HEAT (CON VOL  ) BTU/POUNDS- DEG F           SW6M017
C**** TIMEI IS THE INITIAL TIME ,SEC                                     SW6M018
C**** SMVENT IS THE VENT RATE , POUNDS/SEC                               SW6M019
C**** QHEATR IS THE HEATING RATE OF THE HEATER, BTU/HR                   SW6M020
C**** QMOTOR IS THE MOTOR HEAT DISSIPATION , BTU/HR                      SW6M021
C**** PVENTO IS THE PRESSURE AT WHICH VENT VALVE OPENS ,PSI              SW6M022
C**** PVENTC IS THE PRESSURE AT WHICH VENT VALVE CLOSES,PSI              SW6M023
C**** PHETON IS THE PRESSURE AT WHICH HEATER IS TURNED ON                SW6M024
C**** PHETOF IS THE PRESSURE AT WHICH HEATER IS TURNED OFF               SW6M025
C**** DTMIXN IS THE TEMP DIFFERENCE AT WHICH MIXER IS TURNED ON          SW6M026
C**** DTMIXF IS THE TEMP DIFFERENCE AT WHICH MIXER IS TURNED OFF         SW6M027
C**** COMFM IS THE MAX COMPUTER TIME IN ONE HUNDREDS OF A SECOND         SW6M028
C**** PC IS A FACTOR USUALLY MUCH LESS THAN 1 FOR SPECIFIC HEAT CALCUL.  SW6M029
C**** IM IS THE NUMBER OF NODES                                          SW6M030
C**** NCONT EQ 1 USE AVERAGE VELOCITY ACROSS CELL BOUNDARIES  (LINEAR)   SW6M031
C**** NC2 EQ 1 DENSITY OF ALL NODES REMAIN CONSTANT                      SW6M032
C**** IF NC3 EQ 1 READ IN INITIAL DENSITY AND MIXED DENSITY              SW6M0332
C**** NC4 EQ 1 USE CONSTANT SPECIFIC HEAT AND COMPRESSIBILITY            SW6M034
C**** NC6 EQ 1 USE VEL(I) AT THE CELL BOUNDARIES                         SW6M035
C**** NC7 EQ 1 USE EXACT EQUATION FOR VOLUME ELEMENTS                    SW6M036
C**** IOM IS MAXIMUM NUMBER OF ITERATIONS IN SUBROUTINE NEWQUA           SW6M037
C**** NTIMEM IS THE MAXIMUIM NUMBER OF TIME STEPS                        SW6M038
C**** IMIX IF IMIX = 1 , MIXER ON                                        SW6M039
C**** IHET IF = 1       , HEATER ON                                      SW6M040
C**** IVENT IF = 1      , VENT VALVE OPEN                                SW6M041
C**** NFI IF = 1 , PLOT EACH CURVE OF GRAPH 1 ON SEPARATE FRAME          SW6M042
C**** NWO IF = 1 , WRITE RESULTS OF SUB. INTERP FOR SPECIFIC HEAT- NODE2SW6M043
C**** NW1 IF = 1 , WRITE SMAS1 , SMAS2 , SMAS3  ETC                      SW6M044
C**** NW2 IF = 1 , WRITE SPHTVV(1), ZCOMP(1) ....   SPHTVV(IMM)....      SW6M045
C**** NW3 EQ 1 WRITE MASS FLUX CELL BOUNDARIES                           SW6M046
C**** NW4 EQ 1 WRITE INTERP OUTPUT - FR, TP1 ,TP2 ETC                    SW6M047
C**** IF NW5 EQ 1 WRITE INPUTS TO SUBROUTINE SIMPLT                      SW6M048
C**** NPC1 EQ1 PLOT RESULTS                                              SW6M049
C**** INPRIN IS THE NUMBER OF TIME STEPS BETWEEN PRINTING                SW6M050
C**** NTT IS THE NUMBER OF PAIR OF POINTS OF DRAIN HISTORY               SW6M051
C**** KXI(K) IS 0 FOR KTH GRAPH LINEAR SCALE, 1 FOR LOG SCALE OF X COOR  SW6M052
C**** KYI(K) IS 0 FOR LINEAR ORD SCALE, 1 FOR LOG                        SW6M053
```

```
C**** NVS(K) IS 1 FOR POINT PLOT , 2 FOR LINE PLOT FOR GRAPH               SW6M054
C**** NGRI(K) IS GRAPH NO., 1 FOR FIRST,2 FOR SECOND ETC FOR PLOTTING       SW6M055
C**** NCCI(K) IS THE NUMBER OF CURVES ON THE KTH GRAPH                      SW6M056
C**** JN(K) IS THE  NODE NUMBER TO BE PLOTTED ON THE KTH CURVE              SW6M057
C**** JTN(K)  IS THE  TIME STEP TO BE PLOTTED,   WHEN JTN=NTIME             SW6M058
C**** SMT(I) IS THE DRAIN RATE ,POUNDS/HOUR                                 SW6M059
C**** TIMT(I) IS THE TIME IN HOURS                                          SW6M060
C**** READ IN INITIAL DENSITY AND PRESSURE                                  SW6M061
C**** SMAS1 IS THE AVER DENSITY TIMES TANK VOLUME                           SW6M062
C**** SMAS2 IS THE DENSITY TIMES THE VOLUME ELEMENTS                        SW6M063
C**** SMAS3 IS THE INITIAL MASS MINUS MASS OUT                              SW6M064
C**** ENOUTT IS THE TOTAL ENERGY OUT                                        SW6M065
C**** ENINT  IS THE TOTAL ENERGY IN                                         SW6M066
C**** ENENT1 IS THE AVER INTERNAL ENERGY TIMES DENSITY TIMES TANK VOLUMESW6M067
C**** ENENT2 IS THE INTERNAL ENERGY TIMES DENSITY TIMES VOLUME ELEMENTS SW6M068
C**** ENENT3 IS THE INITIAL TOTAL INTERNAL ENERGY PLUS ENG. IN MINUS ENGSW6M069
C****  OUT                                                                  SW6M070
      COMMON/PROP/ENTHT(30,30),TEMT(30,30), PREST(30,30), RHOT(30) ,        SW6M071
     1IIMAX,  J1MAX                                                         SW6M072
      DIMENSION     TIT(108) , ABSA(108) , ORD(108) , LABLCU(320)           SW6M0731
      DIMENSION X(200,2), Y(200,8,8) , NVS(8) , NCS(8) , NGRI(8), KXI(8)SW6M0742
     1 ,KYI(8),  JN(8) , NCCI(8) ,  JTN(8) ,NPI(8)                          SW6M0753
      DIMENSION SMT(50), TIMT(50)                                           SW6M0764
      COMMON/CONTR/NW3,NW4                                                  SW6M0775
      DIMENSION PRESSP(100), TEMPNP(100) , TEMPNU(100),PRESSU(100)          SW6M078
      DATA TIT/'FIGURE        TANK PRESSURE HISTORY          ,FIGURE  SW6M0791
     1     TANK TEMPERATURE HISTORY          ,FIGURE       TANK DENSITYSW6M0802
     2 HISTORY              ,FIGURE      TANK VELOCITY HISTORY           SW6M0813
     X',                                                                   'SW6M0824
     3   ,FIGURE       STORAGE MASS HISTORY               ,FIGURE      HISW6M0835
     4STORY OF MASS FLOW              ,FIGURE       TEMPERATURE STRATIFSW6M0846
     5ICATION         ,FIGURE      DENSITY STRATIFICATION             , SW6M0857
     6                                                  ' /                 SW6M0868
      DIMENSION ENTHLP(100), ENTHLO(100)                                    SW6M087
      DATA ABSA/'            STORAGE TIME, HOURS              ,             SW6M0881
     1       STORAGE TIME, HOURS                 ,          STORAGE TIMESW6M0892
     2,HOURS                 ,               STORAGE TIME, HOURS            SW6M0903
     3,  ,', '          STORAGE TIME, HOURS                  ,            SSW6M0914
     4TORAGE TIME, HOURS                 ,               RADIAL DISTANCE, FSW6M0925
     5FEET             ,              RADIAL DISTANCE, FEET              , SW6M0936
     6                                                  '/                  SW6M0947
      DIMENSICN AO(100)                                                     SW6M095
      DATA ORD/'          PRESSURE, PSIA                     ,              SW6M0961
     1TEMPERATURE, DEGREES F                  ,            DENSITY, POUNDSSW6M0972
     2/CUBIC FT            ,              VELOCITY, FT/HOUR                 SW6M0983
     X',                                                                   'SW6M0994
     3  ,              STORAGE MASS, POUNDS                  ,          FLOWSW6M1005
     4 RATE  , POUNDS/ HOUR                ,             TEMPERATURE , DEGREES SW6M1016
     5 R              ,                 DENSITY , POUNDS/ CUBIC FT      ,  SW6M1027
     6                                                  '/                  SW6M1038
      DIMENSION XAR(200),YAR(200), PRESSR(4,200), TIMER(200), IS(12)       SW6M104
      DATA LABLCU/'NODE                  ,                       , STRATIFIED NSW6M1052
```

```
      1ODE    ,              HOURS'/                                          SW6M1063
       COMMON RHO(100), TEMP(100), RADIUS(100) , ENTHLY(100),                 SW6M107
      1VEL(100), VELN(100) , PRESS(100) , TEMPN(100) ,ENTHLN(100).,           SW6M108
      2SMFLUX(100), RHON(100) , TAU(100) , RHOO(100) , VELO(100),             SW6M109
      3ENVOL(100) , ENVOLN(100), ENVOLL(100) , ENVOLO(100),                   SW6M110
      4ILAST(100) , JLAST(100) , IMAX , DELT , DELR , DELTAR, IM,             SW6M111
      5NC1,NC2,NC3,NC4, NC5, NC6 ,NC7,NC8, QFLUX(100)., TF,RADMAX,QTAN       SW6M112
       COMMON/PROR/ZCOMP(100),SPHTVV(100)                                     SW6M113
       COMMON/V11/VOLE(50)  ,VOLTAN                                           SW6M114
       COMMON/NEW/ GASCON, A(100) , IDD , IDM ,PMM1                           SW6M115
       CALL GSTART ('SW6',MOVER)                                              SW6M116
       GO TO (10,20),MOVER                                                    SW6M117
   10 CALL LIB                                                                SW6M118
C**** I1MAX IS THE NUMBER OF LIB. DENSITIES                                   SW6M119
       READ(5,12) I1MAX ,J1MAX                                                SW6M120
   12 FORMAT (2I5)                                                            SW6M121
C**** J1MAX IS NUMBER OF LIB. PRESSURES                                       SW6M122
       DO 14 I=1,I1MAX                                                        SW6M123
       READ(5,16)RHOT(I)                                                      SW6M124
   13 FORMAT(1H ,1E16.8)                                                      SW6M125
   15 FORMAT(1H ,3E16.8)                                                      SW6M126
   16 FORMAT(1E10.0)                                                          SW6M127
       READ(5,17)(TEMT (I,J), ENTHT(I,J) , PREST(I,J) ,J=1,J1MAX )           SW6M128
   17 FORMAT(6E10.0)                                                          SW6M129
       WRITE(6, 9)                                                            SW6M130
    9 FORMAT('0',' DENSITY ' )                                                SW6M131
       WRITE(6,13) RHOT(I)                                                    SW6M132
       WRITE(6, 8)                                                            SW6M133
    8  FORMAT('0',' PRESSURE      , TEMPERATURE   ,   ENTHALPY ')            SW6M134
       WRITE(6,15)(PREST(I,J),TEMT(I,J),ENTHT(I,J),J=1,J1MAX)                SW6M135
   14 CONTINUE                                                                SW6M136
   20 CALL PROB                                                               SW6M137
       CALL STATUS(IS)                                                        SW6M138
       COMP1 = IS(8)                                                          SW6M139
       READ(5,71) QTANI, SMOUTI , DELTAR ,  PMM1, TM , RADMIN,               SW6M140
      1 RADMAX , VIDY , COND , TF , DELT , RHOI , PRESI  , GASCON,           SW6M141
      2 SPHTP , SPHTV , TIMEI, SMVENT , QHEATR , QMOTOR , PVENTO ,           SW6M142
      3 PVENTC , PHETON , PHETOF , DTMIXN , DTMIXF,COMPM,PC                  SW6M143
       READ(5,72) IM  , NCONT , NC2 ,  NC7      , IDM, NTIMEM, IMIX ,        SW6M144
      1 IHET , IVENT   ,NC3,NC4,NC6,NFI                                       SW6M145
      2,NW0, NW1, NW2, NW3 , NW4, NPC1, INPRIN,NTT ,NW5                       SW6M1461
       READ(5,771)(KXI(K), KYI(K), NVS(K), NGRI(K)          , NCCI(K),JN(KSW6M1472
      1 ), JTN(K), K=1 ,8)                                                    SW6M1483
  771 FORMAT( 7I5)                                                            SW6M1494
   71 FORMAT (6F10.0)                                                         SW6M150
   72 FORMAT(12I5)                                                            SW6M151
       READ(5, 21)(SMT(I), TIMT(I), I=1,NTT)                                  SW6M1521
   21 FORMAT( 6E10.0)                                                         SW6M1532
       WRITE(6,73)                                                            SW6M154
   73 FORMAT(1H ,' ENVON HEAT-B/S, DRAIN RATE-P/S  DELTA RADIUS-FT, PRESSW6M155
      1 DIF. PSI, MAX PRES PSI, MIN RADIUS - FT   ' )                         SW6M156
       WRITE(6,74)QTANI, SMOUTI , DELTAR , PMM1, TM , RADMIN                  SW6M157
```

```
   74 FORMAT(1H ,6E16.7)                                                    SW6M158
      WRITE(6,75)                                                           SW6M159
   75 FORMAT(1H ,'  RADMAX, FT     ,  DYN. VISC.    ,  THERMAL COND ,      SW6M160
     1TF        ,     DELT  SEC     ,  INIT DENSITY  ')                     SW6M161
      WRITE(6,74)RADMAX , VIDY , COND , TF , DELT , RHUI                    SW6M162
      WRITE(6,76)                                                           SW6M163
   76 FORMAT(1H ,'   PRESI PSI    ,    GASCON       ,  SPHTP B/P-F   , SPHTVSW6M164
     1B/P-F     ,   TIMEI  SEC      ,  VENT RATE P/S ')                     SW6M165
      WRITE(6,74) PRESI, GASCON , SPHTP , SPHTV , TIMEI , SMVENT            SW6M166
      WRITE(6,78)                                                           SW6M167
   78 FORMAT(1H ,' Q-HEATER B/S   , Q-MOTOR  B/S   ,  PVENT-O  PSI ,  PVENSW6M168
     1T-C  PSI ,  P-HET-ON  PSI ,  P-HET-OFF PSI ')                         SW6M169
      WRITE(6,74) QHEATR , QMOTOR, PVENTO, PVENTC , PHETON , PHETOF         SW6M170
      WRITE(6,79)                                                           SW6M171
   79 FORMAT(1H ,' DEL-TEMP-MIX-ON, DEL-TEMP-MIX-OF ,COMPM,PC         ')SW6M172
      WRITE(6,74) DTMIXN,  DTMIXF,COMPM,PC                                  SW6M173
      WRITE(6,82)                                                           SW6M174
   82 FORMAT(1H ,'  IM NCONT  NC2  NC7  IDM NTIMEN IMIX IHET IVENT    NCSW6M175
     13 NC4  NC6 NFI  NWO  NW1  NW2  NW3  NW4 NPC1 INPRIN NTT NW5')        SW6M1762
      WRITE(6,81) IM , NCONT , NC2 , NC7 ,       IDM, NTIMEM, IMIX, IHET,SW6M177
     1 IVENT     ,NC3,NC4,NC6,NFI                                           SW6M178
     2,NWO, NW1, NW2, NW3 , NW4, NPC1, INPRIN,NTT,NW5                       SW6M1791
      WRITE(6,773)(  KXI(K),KYI(K),NVS(K), NGRI(K) , NCCI(K) , JN(K),     SW6M1802
     1 JTN(K), K=1, 8 )                                                     SW6M1813
  773 FORMAT(1H ,'KXI=',I5,'  KYI=',I5,'  NVS=',I5,'  NGRI=',I5,'  NCCI=SW6M1824
     1',I5,'  JN=',I5,'  JTN=',I5 )                                         SW6M1835
   81 FORMAT(1H ,24I5)                                                      SW6M184
      WRITE(6, 22)                                                          SW6M1851
   22 FORMAT(1H ,'DRAIN RATE-POUNDS/HR , TIME HOURS ETC'    )               SW6M1862
      WRITE(6,26 )(SMT(I), TIMT(I), I=1,NTT)                                SW6M1873
   26 FORMAT(1H ,8E14.6)                                                    SW6M1884
      IMAX = IM - 1                                                         SW6M189
      CALL DATCHK(KXI, KYI, NVS, NGRI, NCCI, JN, JTN, ERR , IM, NTIMEM     SW6M1902
     1 , NPC1 )                                                             SW6M1913
      IF(ERR.EQ.1) GO TO 20                                                 SW6M1924
      IMM  = IM + 1                                                         SW6M193
      II = 1                                                                SW6M1941
      QTAN = QTANI                                                          SW6M195
      DIR = IM - 1                                                          SW6M1952
      IF(DIR. NE. 0.) DELTAR = (RADMAX - RADMIN)/DIR                        SW6M197
      ENINT=0.0                                                             SW6M203
      NPRNT  = 0                                                            SW6M2042
      RADIUS(1) = RADMIN                                                    SW6M205
      X(1,2) = RADIUS(1)                                                    SW6M2061
      X(IMM,2)= 0.0                                                         SW6M2073
      RADIUS(IMM)= 0.0                                                      SW6M208
      RADIUS(IM)= RADMAX                                                    SW6M209
      X(IM,2)= RADIUS(IM)                                                   SW6M2102
      DO 31 I= 2,IMAX                                                       SW6M211
      RADIUS(I) = RADIUS(I-1) + DELTAR                                      SW6M212
  311 X(I,2) = RADIUS(I)                                                    SW6M2132
   31 CONTINUE                                                              SW6M214
```

```
      SMFLUX(1) = SMOUTI/(4.*3.1416)                                    SW6M215
      DELR = 2.*DELTAR                                                  SW6M216
      VOLTAN = 3.1416*4.*(RADIUS(IM)**3.- RADIUS(1)**3.)/3.0            SW6M217
      AREOUT = 3.1416*(RADIUS(1)**2.) *4.                               SW6M218
      RATIO  = AREOUT/VOLTAN                                            SW6M219
      XL = 0.0                                                          SW6M220
      XU = 0.0                                                          SW6M221
      YL = 0.0                                                          SW6M222
      YU = 0.0                                                          SW6M223
      ENOUTT =0.0                                                       SW6M224
      NTQ = 0                                                           SW6M2251
      IND = 1                                                           SW6M226
      DO 251 I=2, IMAX                                                  SW6M227
      VOLE(I)= 4.*3.1416*((RADIUS(I)+DELTAR/2.)**3.-(RADIUS(I)-DELTAR/2.SW6M228
     1)**3 )/3.                                                         SW6M229
  251 CONTINUE                                                          SW6M230
      VOLE(1)= 4.*3.1416*((RADIUS(1)+DELTAR/2.)**3. - RADIUS(1)**3.)/3. SW6M231
      VOLE(IM)= 4.*3.1416*(RADIUS(IM)**3.-(RADIUS(IM)-DELTAR/2.)**3.)/3.SW6M232
      DO 27 I = 1 , IMM                                                 SW6M233
      PRESS(I) = PRESI                                                  SW6M234
      RHO(I) = RHOI                                                     SW6M235
   27 CONTINUE                                                          SW6M236
      IF(NC3. NE. 1) GO TO 34                                           SW6M2371
      READ(5, 28)(RHO(I), I=1, IMM)                                     SW6M2381
      READ(5  ,28)(PRESS(I), I=1,IMM )                                  SW6M2382
   28 FORMAT( 6E10.0)                                                   SW6M2393
      WRITE(6 ,29)                                                      SW6M2404
   29 FORMAT(1H ,'THE INITIAL DENSITIES ARE..... ' )                    SW6M2415
      WRITE(6, 32)( I, RHO(I), I=1 , IMM )                              SW6M2426
      WRITE(6, 32)( I, PRESS(I), I=1 , IMM )                            SW6M2427
   32 FORMAT(1H ,I5,8E14.6)                                             SW6M2437
   34 CONTINUE                                                          SW6M244
      CALL INTERP(IND, PRESS , RHO , ENTHLY , TEMP ,IMM)                SW6M245
      TIME = TIMEI                                                      SW6M2460
      NTIMES = 0                                                        SW6M2471
      NTIME = 0                                                         SW6M248
      DO 40 I=1 ,IMM                                                    SW6M249
      ENVOLI = ENTHLY(I)*RHO(I) - 0.185*PRESS(I)                        SW6M250
      VELN(I) = 0.0                                                     SW6M251
      PRESS(I) = PRESI                                                  SW6M252
      ENVOL(I) = ENVOLI                                                 SW6M253
      SPHTVV(I) = SPHTV                                                 SW6M254
      ZCOMP(I)=(PRESS(I)/(RHO(I)*GASCON*TEMP(I)))*144.                  SW6M255
   40 CONTINUE                                                          SW6M256
      ENENTI = VOLTAN*ENVOL(IMM)                                        SW6M257
      SMAS3 = VOLTAN*RHO(IMM)                                           SW6M258
      PPFIVE = PHETOF + 0.5                                             SW6M2581
      PMFIVE = PHETON - 0.5                                             SW6M2582
      PMFE = PHETOF - 0.5                                               SW6M2711
      PPFE = PHETON + 0.5                                               SW6M2712
      DO 60 I=2,IMM                                                     SW6M259
      VEL(I) = 0.0                                                      SW6M260
```

```
   60 CONTINUE                                                          SW6M261
      VEL(1 ) =SMFLUX(1)/(RHO(1)*(RADIUS(1)**2 ))                      SW6M262
      K52 = 0                                                           SW6M2621
      GO TO 90                                                          SW6M263
  100 CONTINUE                                                          SW6M264
      IDD = 1                                                           SW6M265
C**** IF IMIX = 1 , MIXER ON                                            SW6M266
C**** IF IHET = 1 , HEATER ON                                           SW6M267
C**** IF IVENT= 1 , VENT  VALVE OPEN                                    SW6M268
      DIT = ABS(TEMP(IM)- TEMP(1))                                      SW6M269
      IF(DIT.GT.DTMIXN) IMIX= 1                                         SW6M270
      IF(DIT.LE.DTMIXF) IMIX= 0                                         SW6M271
      IF(PRESS(2).GT. PVENTO) IVENT = 1                                 SW6M272
      IF(PRESS(2).LE. PVENTC) IVENT = 0                                 SW6M273
      IF(PRESS(2).LE. PPFE ) IHET = 1                                   SW6M274
      DELTO = DELT                                                      SW6M2742
      IF(PRESS(2).GE. PMFE ) IHET = 0                                   SW6M275
      KDLP = 0                                                          SW6M2752
      QTAN = QTANI + IHET*QHEATR +IMIX*QMOTOR                           SW6M276
      KONT1 = 0                                                         SW6M2761
      TIMM = TIMT(II)*3600.                                             SW6M2772
      IF(TIME.LT. TIMM) GO TO 121                                       SW6M2783
      SMOUTI =  SMT(II)/3600.                                           SW6M2790
      II = II + 1                                                       SW6M2792
  121 CONTINUE                                                          SW6M2794
      DO 122 I=1, IMM                                                   SW6M2795
  122 PRESSO(I) = PRESS(I)                                              SW6M2796
      KONT= 0                                                           SW6M2827
  124 CONTINUE                                                          SW6M2828
      SMFLUX(1) = (SMOUTI + SMVENT*IVENT)/(4.*3.1416)                   SW6M283
      DO 129 I=1,IMM                                                    SW6M2831
  129 PRESS(I) = PRESSO(I)                                              SW6M2832
      VEL(1)  =SMFLUX(1)/(RHO (1)*(RADIUS(1)**2))                       SW6M284
      DELTT = DELT                                                      SW6M285
      RHON(IMM) = RHO(IMM) + VEL(1)*DELT*RHO(1)*RATIO                   SW6M288
  123 CALL NEWQUA(NCONT,DELT, RHO, VEL, TEMP , ENVOL , ENVOLN ,         SW6M289
     1RHON , VELN , ENTHLY , ENTHLN , RADIUS , QFLUX , COND , PRESS,    SW6M290
     2DELTAR, NC2, SMFLUX, QTAN, VIDY, TF, IMAX ,NC6,NC7,SPHTV,SPHTP,   SW6M2901
     3  TEMPN , NC4  )                                                  SW6M2902
      DLP = ABS(PRESSO(2)- PRESS(2) )                                   SW6M2905
      KDLP = KDLP + 1                                                   SW6M2906
      IF(DLP.GT. 11.) DELT = DELTO*10./DLP                              SW6M2907
      IF(DLP.GT. 11..AND. KDLP.LT. 4 ) GO TO 124                        SW6M2909
      IF(KONT1.GT.0) GO TO 125                                          SW6M2913
      KONT1 = KONT1 + 1                                                 SW6M2914
      PHIG = 0.                                                         SW6M2915
      PLOW = 0.                                                         SW6M2916
      IF(PRESS(2).LE. PPFIVE)GO TO 127                                  SW6M2917
      IF(PRESSO(2).NE.PRESS(2)) PHIG =(PHETOF-PRESSO(2))/(PRESS(2)-PRESSSW6M2918
     1O(2))                                                             SW6M2919
      IF(PHIG.LE.0. OR. PHIG.GT..98) GO TO 127                          SW6M2920
      DELT = DELTO*PHIG                                                 SW6M2922
```

```
      GO TO 124                                                         SW6M2924
  127 IF(PRESS(2).GE. PMFIVE )GO TO 125                                 SW6M2926
      IF(PRESSO(2).NE. PRESS(2)) PLOW= (PRESSO(2)- PHETON)/(PRESSO(2) - SW6M2928
     1PRESS(2) )                                                        SW6M2929
      IF(PLOW .LE.0..OR.PLOW .GT.0.98 ) GO TO 125                       SW6M2931
      DELT = DELTO*PLOW                                                 SW6M2933
      GO TO 124                                                         SW6M2935
  125 CONTINUE                                                          SW6M2937
      DELTP = DELT                                                      SW6M2938
      IF ( IDD .EQ. -1 ) GO TO 20                                       SW6M294
      DELT = DELTT                                                      SW6M295
      SMOUTT = DELT*SMFLUX(1)*4.*3.1416                                 SW6M296
      ENEWAV= QTAN+SMFLUX(1)*4.*3.1416*ENTHLY(1)                        SW6M297
      ENOUTT = ENOUTT + DELT*SMFLUX(1)*4.*3.1416*ENTHLY(1)              SW6M298
      ENINT  = ENINT  + DELT*QTAN                                       SW6M300
      DELT  = DELTP                                                     SW6M301
      IF ( IDD .EQ. -1 ) GO TO 20                                       SW6M302
      IF(NC4.EQ.1) GO TO 220                                            SW6M303
      IND = 1                                                           SW6M304
      DO 215 I = 1, IMM                                                 SW6M305
      ZCOMP(I)=(PRESS(I)/(RHON(I)*GASCON*TEMPN(I)))*144.                SW6M306
  215 CONTINUE                                                          SW6M307
  220 CONTINUE                                                          SW6M308
      ENENT2 = ENVOLN(1)*VOLE(1) + ENVOLN(IM)*VOLE(IM)                  SW6M309
      ENENT1 = VOLTAN*ENVOLN(IMM)                                       SW6M310
      ENENT3 = ENENT1 + ENOUTT + ENINT                                  SW6M311
      DO 237 I=2,IMAX                                                   SW6M312
      ENENT2 = ENENT2 + ENVOLN(I)*VOLE(I)                               SW6M313
  237 CONTINUE                                                          SW6M314
      SMAS1  = VOLTAN*RHON(IMM)                                         SW6M315
      SMAS2  = VOLE(1)*RHON(1)                                          SW6M316
      DO 252 I=2, IM                                                    SW6M317
      SMAS2  = SMAS2 + RHON(I)*VOLE(I)                                  SW6M318
  252 CONTINUE                                                          SW6M319
      SMAS3 = SMAS3 + SMOUTT                                            SW6M320
      IF(NW1.NE. 1 ) GO TO 240                                          SW6M3212
      WRITE(6,238)                                                      SW6M322
  238 FORMAT(1H ,'SMAS1-POUNDS ,SMAS2-POUNDS ,SMAS3-POUNDS ,ENER.OUT-BTUSW6M323
     1 ,ENER.IN-BTU  ,ENENT1 -BTU  , ENENT2 -BTU , ENENT3-BTU  ,')      SW6M324
  239 FORMAT(1H ,8E14.5)                                                SW6M325
      WRITE(6,239)SMAS1,SMAS2,SMAS3,ENOUTT,ENINT,ENENT1,ENENT2,ENENT3   SW6M326
  240 CONTINUE                                                          SW6M3272
      SUMP =0.0                                                         SW6M328
      IF(IMIX.NE.1) GO TO 25                                            SW6M329
      DO 23 I=1, IM                                                     SW6M330
      RHO(I) = RHO(IMM)                                                 SW6M331
      TEMP(I)= TEMP(IMM)                                                SW6M332
      PRESS(I)= PRESS(IMM)                                              SW6M333
      ENVOL(I) = ENVOL(IMM)                                             SW6M334
   23 CONTINUE                                                          SW6M335
      IF(TM. LT. PRESS(1) ) NTIMES = NTIMEM                             SW6M3352
   25 CONTINUE                                                          SW6M336
```

```
      DO 80 I=1,IMM                                              SW6M337
      RHO(I) =RHON(I)                                            SW6M338
      TEMP(I) = TEMPN(I)                                         SW6M339
      ENTHLY(I) = ENTHLN(I)                                      SW6M340
      ENVOL(I) = ENVOLN(I)                                       SW6M341
      SUMP = SUMP + PRESS(I)                                     SW6M342
   80 CONTINUE                                                   SW6M343
      DO 83 I=1,8                                                SW6M3431
   83 IF(JTN(I).EQ. NTIMES) K52 = K52 +1                         SW6M3432
      X(NTIME,1) = TIME/3600.                                    SW6M3444
      DO 315 K1= 1,8                                             SW6M3456
      IF(K1.NE. NGRI(K1))GO TO 315                               SW6M3468
      NGR = NGRI(K1)                                             SW6M347
      NCC = NCCI(K1)                                             SW6M3482
      DO 316 J=1,NCC                                             SW6M3494
      NK = JN(J)                                                 SW6M3506
      IF(J.EQ.NCC)NK = IMM                                       SW6M3517
      IF(NK.EQ.0)GO TO 321                                       SW6M3528
      IF(NGR.EQ.1) Y(NTIME,J ,NGR) = PRESS(NK)                   SW6M3530
      IF(NGR.EQ.2) Y(NTIME,J ,NGR) = TEMP(NK)                    SW6M3542
      IF(NGR.EQ.3) Y(NTIME,J ,NGR) = RHO(NK)                     SW6M3554
      IF(NGR.EQ.4) Y(NTIME,J ,NGR) = VEL(NK)*3600.               SW6M3566
  321 CONTINUE                                                   SW6M3578
      K5 = 0                                                     SW6M3589
      NK1=JTN(J)                                                 SW6M3590
      IF(NGR.LT.7) GO TO 317                                     SW6M3601
      IF(NK1.NE. NTIMES ) GO TO 317                              SW6M3612
      DO 314 J2=1 , IM                                           SW6M3626
      IF(NGR.EQ.7) Y(J2, J  , NGR) = TEMP(J2)                    SW6M3637
  314 IF(NGR.EQ.8) Y(J2, J  , NGR) = RHO(J2)                     SW6M3648
  317 CONTINUE                                                   SW6M3659
  316 CONTINUE                                                   SW6M3660
      IF(NGR.EQ.5) Y(NTIME,1,5  )  = SMAS1                       SW6M3673
      IF(NGR.EQ.6) Y(NTIME,1,6  )  = 4*3.1416*SMFLUX(1)*3600.    SW6M3684
  315 CONTINUE                                                   SW6M3692
       NP = NTIME                                                SW6M3709
      CALL STATUS(IS)                                            SW6M371
      COMP2 = IS(8)                                              SW6M372
      COMP = COMP2 - COMP1                                       SW6M373
      NNN = 0                                                    SW6M374
      NNH = 0                                                    SW6M3751
      IF(COMP.GE.COMPM)NNN=1                                     SW6M376
      IF(COMP .GE. COMPM ) NTIMES = NTIMEM                       SW6M3762
      IF(NTIME.GE.200.OR .NTIMES.GE.NTIMEM)NNH=1                 SW6M377
      IF(NNN.EQ.0.AND. NNH.EQ.0 )GO TO 105                       SW6M378
      CALL STATUS(IS)                                            SW6M379
      COMPP1 = IS(8)                                             SW6M380
      IF(NPC1.NE.1) GO TO 371                                    SW6M3812
      WRITE(6,115)                                               SW6M382
  115 FORMAT(1H ,'COMPUTER TIME AT START OF PLOT,IN SECONDS')    SW6M383
      COMP = COMP/100                                            SW6M384
      WRITE(6,116) COMP                                          SW6M385
```

```
116 FORMAT(1H ,F14.5)                                                  SW6M386
    DO 772  J1 = 1, 8                                                  SW6M3871
    IF(NGRI(J1).NE. J1 ) GO TO 772                                     SW6M3883
    NGR = J1                                                           SW6M3895
    KX= KXI(J1)                                                        SW6M3907
    KY= KYI(J1)                                                        SW6M3919
    IF(NGR.EQ.7.OR.NGR.EQ.8) NP= IM                                    SW6M3920
    IF(NGR.NE.7.AND.NGR.NE.8)        NP= NTIME                         SW6M3932
    NCC= NCCI(J1)                                                      SW6M3944
    IF( NGR.EQ.7 .OR. NGR.EQ. 8) NCC = K52                             SW6M3945
    NV = NVS(J1)                                                       SW6M3956
    CALL SIMPLT(KX, KY, X       , Y        , NP       , NCC  , NV   , NGR SW6M3960
   1,TIT       , ABSA     , ORD   ,    LABLCU , NFI ,JN,JTN,IMM,NW5)   SW6M3971
772 CONTINUE                                                           SW6M3982
    CALL STATUS(IS)                                                    SW6M399
    COMPP2 = IS(8)                                                     SW6M400
    COMPTT =(COMPP2 -COMPP1)/100.                                      SW6M401
    WRITE(6,109)                                                       SW6M402
109 FORMAT(1H ,'COMPUTER TIME IN SECONDS FOR PLOT ')                   SW6M403
    WRITE(6,112) COMPTT                                                SW6M404
112 FORMAT(1H ,E14.5)                                                  SW6M405
371 CONTINUE                                                           SW6M4062
    IF(NNN.EQ.1 ) NTIMEM = NTIMES                                      SW6M407
    NTIME = 0                                                          SW6M4082
105 CONTINUE                                                           SW6M409
    IF(NPRNT.NE. NTIMES)GO TO 500                                      SW6M4102
 90 CONTINUE                                                           SW6M411
    WRITE(6,201)                                                       SW6M412
201 FORMAT('0','NODE NO ,    TIME    , TEMPERATURE   ,    PRESSURE    ,   SW6M413
   1DENSITY    ,    VELOCITY    , ENTHALPY     , DENSITY-INTEN , RADIUS' )SW6M414
    WRITE(6,205) (I, TIME, TEMP(I),PRESS(I),RHO(I), VEL(I), ENTHLY(I),SW6M415
   1ENVCL(I) , RADIUS(I) ,   I=1 ,  IMM)                               SW6M416
205 FORMAT(1H ,I5,8E15.6)                                              SW6M417
    NPRNT = NPRNT + INPRIN                                             SW6M4182
500 CONTINUE                                                           SW6M419
    IF(NW2.NE.1) GO TO 128                                             SW6M4202
    WRITE(6,222)                                                       SW6M421
222 FORMAT(1H ,'SPECIFIC HEAT AND COMP. OF NODE J1 AND IMM' )          SW6M422
    WRITE(6,221) SPHTVV(1),ZCOMP(1),SPHTVV(2),ZCOMP(2),SPHTVV(IM),     SW6M423
   1ZCOMP(IM), SPHTVV(IMM), ZCOMP(IMM)                                 SW6M424
221 FORMAT(1H ,8E14.6)                                                 SW6M425
128 CONTINUE                                                           SW6M426
    TIME = TIME + DELT                                                 SW6M427
    NTIME = NTIME + 1                                                  SW6M428
    NTIMES = NTIMES + 1                                                SW6M4291
    IF(NTIMES .LE.NTIMEM) GO TO 100                                    SW6M430
700 GO TO 20                                                           SW6M431
    END                                                                SW6M432
```

```
      SUBROUTINE NEWQUA (NCONT, DELT, RHO, VEL, TEMP, ENVOL,  ENVOLN,    SW6N001
     1RHON , VELN , ENTHLY , ENTHLN , RADIUS , QFLUX  ,COND , PRESS,     SW6N002
     2DELTAR, NC2, SMFLUX, QTAN, VIDY , TF , IMAX ,NC6,NC7,SPHTV,SPHTP ,SW6N003
     3 TEMPN ,NC4     )                                                  SW6N004
      COMMON/NEW/ GASCON, A(100) , IDD , IDM ,PMM1                       SW6N005
      COMMON/PROR/ZCOMP(100),SPHTVV(100)                                 SW6N006
      COMMON/V11/VOLE(50)   ,VOLTAN                                      SW6N007
      COMMON/CONTR/NW3,NW4                                               SW6N0072
      DIMENSION B(100),AA(100), PRESSO(100) , RHOA(100), ENN(100),       SW6N0073
     1ENNO(100),ENNA(100)                                                SW6N0074
      DATA AF/0.01/                                                      SW6N0075
      DIMENSION  RHO(100)   , VEL(100) , TEMP(100)                       SW6N008
      DIMENSION  ENVOL(100), ENVOLN(100), RHON(100)                      SW6N009
      DIMENSION  VELN (100), ENTHLY(100), ENTHLN(100)                    SW6N010
      DIMENSION  RADIUS(100), QFLUX(100), PRESS(100)                     SW6N011
      DIMENSION  TEMPN (100) ,SMFLUX(100)                                SW6N012
      DIMENSION RAVER(100) , RAVERP(100)                                 SW6N013
      DIMENSION DELV(100) ,  DELP(100) , DELPO(100)                      SW6N014
      DIMENSION NSAME(100)                                               SW6N015
      DIMENSION ISKIP(100)                                               SW6N016
      DIMENSION SMAS(100), SMASP(100), ENEG(100) , ENEGP(100)            SW6N017
      DIMENSION ENP(100) ,ENNP(100)                                      SW6N0171
      DATA TF2 /.03/                                                     SW6N0172
C**** SUBROUTINE NEWQUA CALCULATES NEW DENSITIES, VELCOTIES,AND INTERNALSW6N018
C**** IF NC6 EQUALS 1 USE VEL(I) AT BOUNDARIES                           SW6N019
C**** ENERGIES PER UNIT VOLUME                                           SW6N020
C**** IF NC7 EQUALS ONE USE EXACT RELATIONSHIP FOR VOLUME ELEMENTS       SW6N021
      IDD = 1                                                            SW6N022
       IND = 1                                                           SW6N0221
      IC = 1                                                             SW6N0222
      DPO =0.                                                            SW6N0223
   10 CONTINUE                                                           SW6N023
      IM = IMAX + 1                                                      SW6N024
      IMM = IM + 1                                                       SW6N0245
      SMASP(IM)= 0.0                                                     SW6N025
      CALL INTERP( IND,PRESS, RHO, ENTHLN, TEMPN , IMM)                  SW6N0252
      Q2 =.0.0                                                           SW6N0253
      IF( QTAN.LT.0.0) Q2 = 0.0995                                       SW6N0254
      ENEWAV = QTAN + SMFLUX(1)*4.*3.1416*ENTHLY(1) + Q2                 SW6N0282
      ENVOLN(IMM) =  ENVOL(IMM) + DELT*ENEWAV/VOLTAN                     SW6N0284
      DO 25 I= 1, IM                                                     SW6N026
      NSAME(I)= 1                                                        SW6N027
      ISKIP(I) = 1                                                       SW6N028
   25 CONTINUE                                                           SW6N029
      DO 5 I=1, IMM                                                      SW6N0252
      ENN(I) = ENTHLN(I) - 0.185* PRESS(I) /RHO(I)                       SW6N0294
      ENNP(I) = ENN(I)                                                   SW6N0295
      PRESSO(I) = PRESS(I)                                               SW6N0296
      PRESS(I) = PRESS(I) + 2.                                           SW6N0297
      ENNO(I) = ENN(I)                                                   SW6N0298
    5 RHOA(I) = RHO(I) - 0.5                                             SW6N0299
      DELVI = 0.000001                                                   SW6N030
```

```
      AB = 0.5                                                          SW6N031
      CALL INTERP( IND,PRESS, RHO, ENTHLN, TEMPN , IMM)                 SW6N0311
      DO 7 I=1,IMM                                                      SW6N0312
      ENN(I) = ENTHLN(I) - 0.185* PRESS(I)/RHO(I)                       SW6N0314
      AA(I) = 0.                                                        SW6N0315
    7 IF(ENN(I).NE. ENNO(I)) AA(I) = (PRESS(I)- PRESSO(I))/(ENN(I)- ENN SW6N0316
     1 O(I) )                                                           SW6N0317
      DELR = 2.*DELTAR                                                  SW6N032
      CALL INTERP( IND,PRESSO,RHOA,ENTHLN, TEMPN , IMM)                 SW6N0321
      DO 8 I=1, IMM                                                     SW6N0322
      ENN(I) = ENTHLN(I) - 0.185*PRESSO(I)/ RHOA(I)                     SW6N0323
      B(I) = 0.                                                         SW6N0324
      IF(RHOA(I).NE.RHO(I))B(I)=-AA(I)*(ENN(I)-ENNO(I))/(RHOA(I)-RHO(I))SW6N0325
      ENNO(I) = ENVOL(I)/RHO(I)                                         SW6N0326
      PRESS(I) = PRESSO(I)                                              SW6N0326
    8 RHOA(I) = RHO(I)                                                  SW6N0327
      QFIN = QTAN/(4.*3.1416*(RADIUS(IM)**2))                           SW6N033
      DO 51 I=2,IM                                                      SW6N 34
      RAVER(I) = RADIUS(I-1)  + DELTAR/2.                               SW6N035
      RAVERP(I)= RADIUS(I  )  + DELTAR/2.                               SW6N036
      DELV(I) =  VEL(1)*AB*(RADIUS(1)/(RAVER(I)))**2                    SW6N037
   51 IF(VEL(1). EQ. 0) DELV(I) = DELVI                                 SW6N 38
   50 CONTINUE                                                          SW6N039
      IF( IDU.EQ.1) GO TO 52                                            SW6N 391
      CALL INTERP(IND, PRESS ,RHO , ENTHLN, TEMPN, IMM )                SW6N 392
      DO 53 I=1, IMM                                                    SW6N 394
      ENP(I) = ENTHLN(I) - 0.185* PRESS(I)/RHO (I)                      SW6N 396
   53 IF(ENP(I).NE. ENNP(I)) AA(I) =(PRESS(I)- PRESSO(I))/(ENP(I)- ENNP(SW6N 398
     1 I))                                                              SW6N 399
      CALL INTERP(IND, PRESS  , RHON, ENTHLN, TEMPN , IMM )             SW6N 402
      DO 54 I=1, IMM                                                    SW6N 403
      ENN(I) = ENTHLN(I) - 0.185* PRESS (I)/ RHON(I)                    SW6N 404
   54 IF(RHON(I).NE.RHO(I) ) B(I)= -AA(I)*(ENN(I)- ENP (I))/(RHON(I) -  SW6N 405
     1 RHO(I) )                                                         SW6N 406
   52 CONTINUE                                                          SW6N 408
      IJK =2                                                            SW6N 409
      DO 43 I=2 , IM                                                    SW6N041
      QFLUX(I) = COND*(RAVER(I)**2). *(TEMP(I) - TEMP(I-1))/DELTAR      SW6N042
   43 CONTINUE                                                          SW6N043
      IJKM= IMAX                                                        SW6N044
  123 DO 100 I= IJK, IJKM                                               SW6N045
      RAVE     = RAVER(I)                                               SW6N046
      RAVEP    = RAVERP(I)                                              SW6N047
C**** IF NCONT EQUALS ONE USES LINEAR AVERAGE VELOCITY ACROSS BOUNDARIESSW6N048
      IF(NCONT .NE. 1 )  GO TO 320                                      SW6N049
C**** IF ISKIP(I) EQ 2 SKIPS NODE I                                     SW6N050
      VELB   =(VEL(I-1) + VEL(I))/2.                                    SW6N051
      IF(ISKIP(I).EQ. 2 ) GO TO 100                                     SW6N052
      VELBP   =(VEL(I+1)+ VEL(I))/2.                                    SW6N053
      GO TO 340                                                         SW6N054
  320 CONTINUE                                                          SW6N055
      VELB = (VEL(I-1)*(RADIUS(I-1)**2) +  VEL(I)*(RADIUS(I)**2))/((RAVESW6N056
```

```
     1**2)*2.)                                                         SW6N057
      VELBP= (VEL(I+1)*(RADIUS(I+1)**2) + VEL(I)*(RADIUS(I)**2))/((RAVEPSW6N058
     1**2)*2.)                                                         SW6N059
  340 CONTINUE                                                         SW6N060
      IF(NC6.EQ.1) VELB= VEL(I)                                        SW6N061
      IF(NC6.EQ.1) VELBP=VEL(I+1)                                      SW6N062
      IF(VELB   .LE. 0.0)GO TO 212                                     SW6N063
      CONDE  = (RAVE**2 )* ( RHO(I-1)* VELB )                          SW6N064
      CONEN = CONDE*ENTHLY(I-1)                                        SW6N065
      GO TO  225                                                       SW6N066
  212 CONDE  = (RAVE**2 )* ( RHO(I   )* VELB )                         SW6N067
      CONEN = CONDE*ENTHLY(I)                                          SW6N068
  225 IF(VELBP   .LE. 0.0) GO TO 250                                   SW6N069
      CONDEP = (RAVEP**2)* ( RHO(I   )* VELBP)                         SW6N070
      CONENP = CONDEP*ENTHLY(I)                                        SW6N071
      GO TO 255                                                        SW6N072
  250 CONDEP = (RAVEP**2)* ( RHO(I+1)* VELBP)                          SW6N073
      CONENP = (CONDEP)*ENTHLY(I+1)                                    SW6N074
  255 CONTINUE                                                         SW6N075
C**** DIFFU IS THE DIFFUSIVE TERM OF THE ENERGY EQUATION                SW6N076
      DIFFU=(QFLUX (I+1)-QFLUX(I))/(DELTAR*(RADIUS(I)**2))             SW6N077
      IF( NC2.EQ. 1 ) GO TO 286                                        SW6N078
      IF(NC7.NE.1)GO TO 385                                            SW6N079
      CONDT =(CONDEP - CONDE)*3.1416*4.                                SW6N080
      RHON(I) = RHO(I) - DELT*CONDT/VOLE(I)                            SW6N081
      GO TO 386                                                        SW6N082
  385 CONTINUE                                                         SW6N083
      RHON(I) = RHO(I) - DELT*(CONDEP - CONDE)/(DELTAR*(RADIUS(I))**2) SW6N084
  386 CONTINUE                                                         SW6N085
      SMAS(I) = CONDE                                                  SW6N086
      SMASP(I)= CONDEP                                                 SW6N087
  286 CONENG = DELT*( CONEN - CONENP)/((RADIUS(I)**2)*DELTAR)          SW6N088
      AFR = 1                                                          SW6N089
      Q1 = 0.0                                                         SW6N0892
      IF(I.EQ.2 .AND. QTAN.LT.0.0) Q1 =0.0995                          SW6N0894
      IF(NC7.EQ.1)AFR=4.*3.1416*(RADIUS(I)**2.)*DELTAR/VOLE(I)         SW6N090
      ENVOLN(I)=ENVOL(I)+ AFR*(CONENG + DELT*DIFFU)+Q1*DELT/VOLE(I)    SW6N091
  100 CONTINUE                                                         SW6N092
C**** AT I=1                                                           SW6N093
  101 CONTINUE                                                         SW6N094
      I= 1                                                             SW6N095
      RAVE    =  RADIUS(IMAX)  + DELTAR/2.                             SW6N096
      IF(ISKIP(1).EQ. 2 ) GO TO 482                                    SW6N097
      RAVEP   =  RADIUS(  1 )  + DELTAR/2.                             SW6N098
      IF(NCONT .NE. 1 ) GO TO 420                                      SW6N099
      VELB    =  (VEL(IM) + VEL(IMAX ))/2.                             SW6N100
      VELBP   =  (VEL(2 ) + VEL(1)     )/2.                            SW6N101
      GO TO 440                                                        SW6N102
  420 CONTINUE                                                         SW6N103
      VELBP= (VEL(2)*(RADIUS(2)**2) + VEL(1)*(RADIUS(1)**2))/((RAVEP**2)SW6N104
     1*2.)                                                             SW6N105
  440 CONTINUE                                                         SW6N106
```

```
      IF(NC6.EQ.1) VELBP=VEL(2)
      IF( VELBP.LE. 0.0) GO TO 351
      CONDEP = (RAVEP**2)* ( RHO(1   )* VELBP)
      CONENP = CONDEP* ENTHLY(1)
      GO TO 381
  351 CONDEP = (RAVEP**2)* ( RHO(2   )* VELBP)
      CONENP = (CONDEP)*ENTHLY( 2 )
  381 CONTINUE
      SMOUT  = SMFLUX(1)
      SMAS(1) = SMOUT
      ENGOUT = ENTHLY(1)*SMOUT
      SMASP(1)= CONDEP
      IF( NC2 .EQ. 1 ) GO TO 422
      CONDT =(CONDBP-SMOUT)*3.1416*4.
      RHON(1)=  RHO(1) - DELT*(CONDEP - SMOUT)*2./(DELTAR*(RADIUS(1))**
     1 2 )
      IF(NC7.EQ.1) RHON(1) = RHO(1) - DELT*CONDT/VOLE(1)
  422 CONENG = DELT*(CONENP - ENGOUT)/(DELTAR * RADIUS(1)**2 )
      DIFFU = (QFLUX(2))/(DELTAR*(RADIUS(1)**2))
      AFR =1
      IF(NC7.EQ.1)AFR=4.*3.1416*(RADIUS(1)**2.)*DELTAR/(VOLE(1)*2.)
      ENVOLN(1)= ENVOL(1) + 2.*AFR*(DELT*DIFFU - CONENG)
C**** AT I= IM
  482 CONTINUE
      I= IM
      IF(ISKIP(IM).EQ. 2 ) GO TO 511
      RAVE = RADIUS(IMAX) + DELTAR/2.
      VELB = (VEL(IM)*(RADIUS(IM)**2) + VEL(IMAX)*(RADIUS(IMAX)**2 )) /
     1((RAVE **2)*2.)
      IF(NC6.EQ.1) VELB =VEL(IM)
      IF( VELB .LE. 0.0) GO TO 451
      CONDE  = (RAVE **2)* ( RHO(IMAX)*VELB )
      CONEN = CONDE*ENTHLY(IMAX)
      GO TO 481
  451 CONDE  = (RAVE **2)* ( RHO(IM  )*VELB )
      CONEN = CONDE*ENTHLY(IM  )
  481 CONTINUE
      SMAS(IM)= CONDE
      IF( NC2.EQ. 1) GO TO 502
      CODENS  = DELT*CONDE/(DELTAR*(RADIUS(IM  ))**2)
      CONDT = CONDE*3.1416*4.
      RHON(IM)  = RHO( IM)  + 2.*CODENS
      IF(NC7.EQ.1) RHON(IM)= RHO(IM)+ DELT*CONDT/VOLE(IM)
  502 CONENG  = DELT*(CONEN)/((RADIUS(IM  )**2)*DELTAR)
      QTANR=((RADIUS(I))**2)*QFIN
      DIFFU =(QTANR-QFLUX(I))/(DELTAR*(RADIUS(I)**2))
      AFR =1
      IF(NC7.EQ.1)AFR=4.*3.1416*(RADIUS(IM)**2.)*DELTAR/(VOLE(IM)*2.)
      ENVOLN(IM) = ENVOL(IM) + AFR*2.*(CONENG + DELT*DIFFU )
  511 CONTINUE
      DELINM =0.0
      IF(RHON(I).LE. 0.) WRITE(  6,504)
```

```
  504 FORMAT(1H ,' NEW DENSITY IS LESS THAN OR EQUAL TO ZERO  ' )        SW6N1574
      IF(RHON(I).LE. 0.) GO TO 974                                        SW6N1576
      VIDA = VIDY                                                         SW6N158
      IF ( VIDY .LE. COND/SPHTV  ) VIDY = COND/SPHTV                      SW6N159
      DO 501 I= 1, IM                                                     SW6N160
      DELINV = 2.*VIDY/(RHON(I)*(DELTAR**2))  + ABS(VEL (I)/DELTAR)       SW6N161
      IF (DELINV. LE. DELINM ) GO TO 510                                  SW6N162
      DELINM = DELINV                                                     SW6N163
  510 CONTINUE                                                            SW6N164
  501 CONTINUE                                                            SW6N165
      VIDY = VIDA                                                         SW6N1651
      IF(NC4.NE.1) GO TO 80                                               SW6N1652
      DO 79 I=1, IMM                                                      SW6N1653
      ENENGO = ENVOL(I)/RHO(I)                                            SW6N1654
      ENENG  = ENVOLN(I)/RHON(I)                                          SW6N1655
      SPHTV = SPHTVV(I)                                                   SW6N1656
      TEMPN(I) = TEMP(I) + (ENENG - ENENGO)/SPHTV                         SW6N1657
      PRESS(I) = ZCOMP(I)*RHON(I)*GASCON *TEMPN(I)/144.                   SW6N1658
   79 ENTHLN(I)= ( ENVOLN(I) + 0.185*PRESS(I))/RHON(I)                    SW6N1659
      GO TO 78                                                            SW6N1660
   80 CONTINUE                                                            SW6N1661
      DPM = 0.0                                                           SW6N1661
      DO 65 I=1,IMM                                                       SW6N1662
      ENN(I)  = ENVOLN(I)/ RHON(I)                                        SW6N1661
      DRA = ABS(-AA(I)*(ENN(I)-ENNO(I)) + B(I)*(RHO(I)- RHON(I)))         SW6N1663
   65 IF( DRA.GT. DPM) DPM=DRA                                            SW6N1664
      AF = 1.0                                                            SW6N1665
      IF(DPM.GT.50.)AF= 50./DPM                                           SW6N1667
      IF(AF.GT. 1.) AF=1.                                                 SW6N1668
      IC=1                                                                SW6N1668
      IF(AF.LT..98) IC =0                                                 SW6N1669
      CALL INTERP( IND, PRESS ,RHON, ENTHLN, TEMPN, IMM )                 SW6N167
      ICC = 1                                                             SW6N1673
      DO 70 I=1, IMM                                                      SW6N1674
      AAA =-AA(I)                                                         SW6N1675
      ENNA(I) = ENTHLN(I) - 0.185*PRESS(I) /RHON(I)                       SW6N1678
      DP =-AF* (AAA  *(ENN(I)- ENNO(I)) + B(I)*(RHO (I)- RHON(I)))        SW6N1682
      RHOA(I) = RHON(I)                                                   SW6N1686
   70 PRESS(I) = DP + PRESSO(I)                                           SW6N1688
      IF(NW3.EQ.1) WRITE( 6,71)( AA(I), B(I), PRESSO(I), PRESS(I), RHOA(SW6N1710
     1I), RHO (I), VEL(I) , ENN(I) , ENNA(I), I=1,IMM)                    SW6N1714
   71 FORMAT(1H ,9E13.6 )                                                 SW6N1716
      IF(NW3.EQ.1) WRITE( 6, 72)  DPM, AF , IC                            SW6N1718
   72 FORMAT(1H ,'DPM=',E14.7,'AF= ',E14.7,'IC=', I5  )                   SW6N172
   78 CONTINUE                                                            SW6N1736
      PMAX1 = 0.0                                                         SW6N175
      DO 772 I=2 , IM                                                     SW6N176
      DELP(I)  = PRESS(I) - PRESS(I-1)                                    SW6N177
      IF(ABS(DELP(I)).LT.0.00000001) DELP(I)= 0.00000001                  SW6N178
      ABDELP = ABS(DELP(I))                                               SW6N179
      IF( ABDELP .LT. PMAX1 )GO TO 772                                    SW6N180
      PMAX1 = ABDELP                                                      SW6N181
```

```
  772 CONTINUE                                                          SW6N182
      IF(PMAX1.LT.PMM1) GO TO 996                                       SW6N183
      E = 0.0                                                           SW6N1832
      DO 702 I= 2 ,IM                                                   SW6N184
      IF(IDD.LT.2 ) GO TO 705                                           SW6N185
      E1 = ABS(ENNA(I) - ENN(I))                                        SW6N1842
      IF( E1.GT. E ) E = E1                                             SW6N1843
      IF( E1.EQ. E ) IG = I                                             SW6N1844
      ISKIP(I) = 2                                                      SW6N186
      IF(NC6.NE.1) ISKIP(I) =1                                          SW6N187
      IF(ABS(DELP(I)) .LT.0.5*PMAX1 )GO TO 701                          SW6N188
      ISKIP(I) = 1                                                      SW6N189
      IF(DELPO(I)*DELP(I).GT. 0 ) GO TO 710                             SW6N190
      NSAME(I)=1                                                        SW6N191
      IF(DELPO(I).NE.0)AFACTR=.5*ABS(DELP(I))/(ABS(DELP(I))+ ABS(DELPO( SW6N1922
     1 I)))                                                             SW6N1924
      DELV(I) = -AFACTR*DELV(I)                                         SW6N193
      GO TO 705                                                         SW6N194
  710 NSAME(I)=NSAME(I)+1                                               SW6N195
      SIGN = 0.0                                                        SW6N1948
      IF(DELP(I).NE.0.) SIGN =DELP(I)/ ABS(DELP(I))                     SW6N195
      IF(NSAME(I).LE. 4 )GO TO 704                                      SW6N197
      DELV(I) =-SIGN*ABS(DELV(I))*1.4                                   SW6N198
      GO TO 705                                                         SW6N199
  704 DELV(I) =-SIGN*ABS(DELV(I))                                       SW6N200
  705 VEL (I) = VEL(I) + DELV(I)                                        SW6N201
      DELPO(I) = DELP(I)                                                SW6N202
  701 CONTINUE                                                          SW6N203
  702 CONTINUE                                                          SW6N204
      IDD = IDD + 1                                                     SW6N205
      IF(NW3.EQ.1)WRITE(6  ,703)VEL(1),VEL(2),VEL(3), VEL(4)            SW6N2051
  703 FORMAT(1H ,'VEL(1)=',E14.7,'VEL(2)= ',E14.7,'VEL(3)=',E14.7,'VEL(4SW6N2052
     1)=',E14.7 )                                                       SW6N2053
      IF(IDD.GT.IDM)GO TO 998                                           SW6N206
      GO TO 50                                                          SW6N207
  998 WRITE(6  ,997) IDM, IG , E                                        SW6N2080
  997 FORMAT(1H ,'ITERATIONS DIDNT CONVERGE IN',I5,' ITERATIONS, ENERGY SW6N2090
     1ERROR AT NODE',I5,' IS ',E14.7,'BTU/POUND')                       SW6N2091
      GO TO 974                                                         SW6N2092
  996 IF(ICC.EQ.0 ) GO TO 50                                            SW6N210
  999 CONTINUE                                                          SW6N211
      IF(NW3.NE.1) GO TO 974                                            SW6N2112
      WRITE(6,971)                                                      SW6N212
  971 FORMAT(1H ,'SMAS(1)        , SMAS(2)      , SMAS(3)       , SMAS(4) SW6N213
     1    , SMAS(5)        ' )                                          SW6N214
      WRITE(6,972)(SMAS(I), I=1 , 5  )                                  SW6N215
  972 FORMAT(1H ,5E14.6 )                                               SW6N216
      WRITE(6,973)                                                      SW6N217
  973 FORMAT(1H ,'SMASP(1)       , SMASP(2)     , SMASP(3)      , SMASP(4) SW6N218
     1    , SMASP(5)     ')                                             SW6N219
      WRITE(6,972) (SMASP(I), I=1 , 5 )                                 SW6N220
  974 CONTINUE                                                          SW6N2202
```

```
      DPMN = ABS(DPM)                                                    SW6N2212
      IF(DPMN.GT. 0.1.AND. TF2.GT..0'01) TF2 = TF2*9.2 /DPMN             SW6N2214
      IF(TF2.GT. TF) TF2 = TF                                            SW6N2216
      DELT = TF2/DELINM                                                  SW6N2218
      RETURN                                                             SW6N222
      END                                                                SW6N223
```

```
      SUBROUTINE DATCHK(KXI, KYI, NVS, NGRI, NCCI, JN , JTN, ERR,IM,NTIMSW6D0001
     1EM ,NPC1)                                                          SW6D0002
      DIMENSION KXI(8) , KYI(8), NVS(8), NGRI(8), NCCI(8) ,             SW6D0004
     1 JN(8), JTN(8)                                                     SW6D0005
      ERR= 0                                                             SW6D001
      DO 10 K=1,8                                                        SW6D
      IF(KXI(K).EQ.0.OR.KXI(K).EQ.1) GO TO 12                            SW6D0016
      WRITE(6  ,13)                                                      SW6D0017
   13 FORMAT(1H ,'KXI(K) IS NOT 0 OR 1 ..... THEREFORE KXI(K) IS BEING SSW6D0018
     1ET EQUAL  TO 0 ' )                                                 SW6D0019
       KXI(K) = 0                                                        SW6D0020
   12 IF(KYI(K).EQ.0.OR. KYI(K).EQ.1) GO TO 10                           SW6D0021
      WRITE(6  ,14)                                                      SW6D0022
   14 FORMAT(1H ,'KYI(K) IS NOT 0 OR 1 ..... THEREFORE KYI(K) IS BEING  SW6D0023
     1SET EQUAL  TO 0 ' )                                                SW6D0024
   10 CONTINUE                                                           SW6D0025
      DO 20 K=1, 8                                                       SW6D0030
      IF(NVS(K). EQ. 1.OR. NVS(K).EQ.2 ) GO TO 20                        SW6D0031
      WRITE(6  , 21)                                                     SW6D0032
   21 FORMAT(1H ,'NVS(K) IS NOT 0 OR 1 ..... THEREFORE NVS(K) IS BEING SSW6D0033
     1ET EQUAL  TO 1 ')                                                  SW6D0034
      NVS(K) = 1                                                         SW6D0035
   20 CONTINUE                                                           SW6D0036
      NCTT = 0                                                           SW6D0040
      DO 30 K=1, 8                                                       SW6D0041
      IF(NGRI(K).EQ.K ) GO TO 30                                         SW6D0042
      NCTT = NCTT + 1                                                    SW6D0043
   30 CONTINUE                                                           SW6D0044
      IF(NCTT.NE.8) GO TO 34                                             SW6D0045
      IF(NPC1.EQ.1) NPC1 = 0                                             SW6D0046
      WRITE(  6, 35)                                                     SW6D0047
   35 FORMAT(1H ,'NO GRAPHS WILL BE PLOTTED BECAUSE NONE OF THE NGRI S  SW6D0048
     1ARE BETWEEN 1 AND 8 ' )                                            SW6D0049
   34 CONTINUE                                                           SW6D0050
      NJJ= 0                                                             SW6D0060
      IMM= IM+1                                                          SW6D0694
      DO 40 K=1,8                                                        SW6D0070
      IF( JN(K).LE.IMM)GO TO 44                                          SW6D0071
      JN(K) = IM                                                         SW6D0072
      WRITE(6  ,43)                                                      SW6D0073
   43 FORMAT(1H ,'JN(K) IS GREATER THAN IM.... JN(K) = IM ')             SW6D0074
   44 IF(JN(K). GE .0 ) GO TO 46                                         SW6D0075
      JN(K) = 1                                                          SW6D0076
      WRITE(  6,47)                                                      SW6D0077
   47 FORMAT(1H ,' JN(K) IS LESS THAN 1, JN(K) = 1 ' )                   SW6D0078
   46 IF( JN(K).NE.0 ) GO TO 40                                          SW6D0079
      NJJ = NJJ + 1                                                      SW6D0080
   40 CONTINUE                                                           SW6D0081
      NJK = 8- NJJ                                                       SW6D0082
      DO 50  K=1, 4                                                      SW6D0083
   50 IF(NCCI(K).GT. NJK) NCCI(K) = NJK                                  SW6D0084
      NCCI(5)=1                                                          SW6D0085
      NCCI(6)=1                                                          SW6D0086
      DO 70 K=1,8                                                        SW6D0087
   70 IF( JTN(K).GT. NTIMEM) JTN(K) = 0                                  SW6D0088
      NJTN = 0                                                           SW6D0089
```

```
      DO 72 K=1, 8                                                       SW6D0090
      IF(JTN(K).NE.0) GO TO 72                                           SW6D0091
      NJTN = 1 + NJTN                                                    SW6D0092
   72 CONTINUE                                                           SW6D0093
      NJTNT = 8 - NJTN                                                   SW6D0094
      IF(NJTNT.LT.NCCI(7)) NCCI(7) = NJTNT                               SW6D0095
      IF(NJTNT.LT.NCCI(8)) NCCI(8) = NJTNT                               SW6D0096
      RETURN                                                             SW6D0099
      END                                                                SW6D0100
```

```
      SUBROUTINE INTERP (IND ,PRESS , RHO ,ENTHLN ,TEMPN, NNODES)
      DIMENSION PRESS(100), RHO(100),ENTHLN(100) , TEMPN(100) ,
     1ILAST(100),JLAST(100)
      COMMON/CONTR/NW3,NW4
      DIMENSION JFOUND(2)
      DATA NCT/1/
      COMMON /PROP/ ENTHT(30,30), TEMT(30,30),PREST(30,30),RHOT(30) ,
     1I1MAX,  J1MAX
      DATA ILAST/100*1/,JLAST/100*1/
C**** IF IND EQUALS 4 ONLY ONE PASS IS MADE WITH I EQ IM+1(AVE PRESS)
   50 CONTINUE
      DO 120 I= 1,NNODES
      TP1 = 1.0
      TP2 = 1.0
      FP   = 1.0
      I1 = ILAST(I)
      J1 = JLAST(I)
      ICOUT = 1
       IF(IND.NE. 4 ) GO TO 130
       I = NNODES + 1
  130 CONTINUE
      IF(RHO(I) .NE. RHOT(I1)) GO TO 118
      ILAST(I) =I1
      FP = 0.0
      TP2 = 0.0
      GO TO 230
  118 IF(RHO(I) .LT. RHOT(I1)) GO TO 140
      IF(RHO(I) .GE. RHOT(I1+1)) GO TO 125
      ILAST(I)= I1
       FR =(RHO(I) - RHOT(I1))/(RHOT(I1+1) - RHOT(I1))
      IF( I1 .LT. 1.OR . I1.GT. I1MAX ) GO TO 300
      GO TO 230
  125 I1 = I1 +1
      GO TO 130
  140 I1 = I1 -1
      IF( I1 .LT. 1.OR . I1.GT. I1MAX ) GO TO 300
      GO TO 130
  300 WRITE( 6, 310)
  310 FORMAT('0','ENTHALPY IS OUTSIDE OF DENSITY LIBRARY DATA')
      GO TO 120
  230 CONTINUE
  202 IF(PRESS(I).NE. PREST(I1,J1))GO TO 218
      JLAST(I) = J1
      JFOUND(ICOUT) = J1
      IF( FP   .EQ. 0 ) GO TO 650
      IF(ICOUT.EQ.1)TP1=0.0
      IF( ICOUT   .EQ .  2 )  GO TO 430
      ICOUT   = 2
      J1 = J1 + 1
      GO   TO   230
  430 TP2 = 0.0
      GO TO 330
  650 TP1 = 0.0
      TP2 = 0.0
      GO TO 330
  218 IF( PRESS(I) .LT.  PREST(I1, J1) ) GO TO 240
```

```
      IF( PRESS(I) .GE.  PREST(I1, J1+1 ) ) GO TO  225
      JLAST(I) = J1
      JFOUND(ICOUT) = J1
      IF( ICOUT .EQ. 2 .OR. RHO(I).EQ. RHCT(I1).OR. FR.EQ. 0.0)GO TO 230
      ICOUT = 2
      I1 = I1 + 1
      GO TO 230
  225 J1 = J1+1
      IF(J1 .LT. 1.OR. J1 .GE. J1MAX ) GO TO 400
      GO TO 230
  400 WRITE(6,420)
  420 FORMAT('0','ENTHALPY IS OUTSIDE OF PRESS-LIB DATA' )
      GO TO 120
  240 J1 = J1 -1
      IF(J1 .LT. 1.OR. J1 .GT. J1MAX ) GO TO 400
      GO TO 230
  230 J11 = JFOUND(1)
      J12 = JFOUND(ICOUT)
      IF(ICOUT.NE.1       ) I1 = I1 - 1
      IF( TP1. EQ. 0.0) GO TO 450
      TP1 =(PRESS(I) - PREST(I1, J11))/(PREST(I1,J11+1) - PREST(I1,J11))
  450 CONTINUE
      IF( TP2 .EQ. 0.0) GO TO 550
      TP2 =(PRESS(I) - PREST(I1+1,J12))/(PREST(I1+1 ,J12 +1) - PREST(
     1 I1+1 , J12 ))
  550 CONTINUE
      TEMI1 =   TP1*(TEMT(I1,J11+1) - TEMT(I1,J11))
      ENTI1 =   TP1*(ENTHT(I1,J11+1) - ENTHT(I1, J11))
      TEMI11=   TP2*(TEMT(I1+1,J12+1) - TEMT(I1+1, J12))
      ENTI11=   TP2*(ENTHT(I1+1 ,J12+1) - ENTHT(I1+1, J12) )
      TEMPN(I) =(1.-FR)*(TEMT(I1, J11) + TEMI1 ) + FR*(TEMT(I1+1, J12
     1) + TEMI11)
      ENTHLN(I) =(1. - FR)*(ENTHT(I1, J11) + ENTI1 ) + FR*(ENTHT(I1+1 ,
     1 J12 )  + ENTI11 )
      IF(NW4.NE.1) GO TO 502
      IF(NW4.EQ.1.AND. I.EQ.1)WRITE(6  ,503) FR,TP1,TP2, ICOUT, I1, J1,
     1 J11, J12, ILAST(1), JLAST(1), JFOUND(1), JFOUND(2)
  503 FORMAT(1H ,'FR= ',F14.7,'TP1=',F14.7,'TP2=',F14.7,'NODE= 1',9I5)
      IF(NW4.EQ.1.AND. I.EQ.2)WRITE(6  ,504) FR,TP1,TP2, ICOUT, I1, J1,
     1 J11, J12, ILAST(2), JLAST(2), JFOUND(1), JFOUND(2)
  504 FORMAT(1H ,'FR=',F14.7,'TP1=',F14.7,'TP2=',F14.7,'NODE= 2 ',9I5)
  502 CONTINUE
  120 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE SIMPLT(KX, KY , X       , Y       ,NP, NCC,NV , NGR      SW6C001
     1,TIT       , ABSA     , ORD   ,    LABLCU  , NFI  ,JN,JTN,IMM,NW5)    SW6C0012
C**** KX IS 0 FOR LINEAR IN X , 1 FOR LOG                                   SW6C002
C**** KY IS 0 FOR LINEAR IN Y , 1 FOR LOG                                   SW6C003
C**** X IS SUBSCRIPTED     200,2 ABSCISSA                                   SW6C004
C**** Y IS SUBSCRIPTED  200,8,8   ORDINATE                                  SW6C005
C**** NP IS NUMBER OF POINTS FOR EACH CURVES                                SW6C006
C**** NCS IS CURVE SYMBOLS                                                  SW6C007
C**** NVS IS 2 FOR LINE PLOTTING                                            SW6C008
C**** NGR IS THE GRAPH NUMBER                                               SW6C009
C**** NCC IS THE NUMBER OF CURVES                                           SW6C010
C**** TIT IS GRAPH TITLE 12 LOCATIONS (108 TOTAL) 8 GRAPHS ,1BLANK          SW6C011
C**** ABSA IS ABSCISSA TITLE    12 LOCATIONS(48 CHAR) 8GRAPHS 1 BLANK 108SW6C012
C**** ORD IS  ORDINATE TITLE 12 LOCATIONS(48 CHAR) 8GRAPHS 1 BLANK 108  SW6C013
C**** LABLCU IS THE CURVE LABLES (PRINTED ON SEPARATE PAGE ) 20CHAR/CUR SW6C014
C****                                                                       SW6C015
C****                                                                       SW6C016
C****                                                                       SW6C017
C****                                                                       SW6C018
C****                                                                       SW6C019
C****                                                                       SW6C020
C****                                                                       SW6C021
C****                                                                       SW6C022
      DIMENSION X(200,2), Y(200,8,8)             , NCS(8) , NGPI(8)         SW6C040
     1             , JN(8) ,               JTN(8) ,NCP(8)                   SW6C044
C                                                                           SW6C048
      DIMENSION      TIT(108) ,  ABSA(108) , ORD(108) , LABLCU(320)         SW6C052
      IF(NW5.NE.1) GO TO 2                                                  SW6C053
C                                                                           SW6C058
      WRITE(6,105) ((X(I,J),I=1,NP),J=1,2)                                  SW6C0582
      WRITE(6,105)(((Y(I,J,K),I=1,NP),J=1,8),K=1,8)                         SW6C0584
      WRITE(6,108)                         ( JN(I),I=1,8) ,( JTN(I),I=1,8)  SW6C0586
      WRITE(6,109) (TIT(I),I=1,108)                                         SW6C0588
      WRITE(6,109) (ABSA(I),I=1,108)                                        SW6C0592
      WRITE(6,109) (ORD(I), I=1,108)                                        SW6C0594
      WRITE(6,109) (LABLCU(I), I=1,108)                                     SW6C0596
  105 FORMAT(1H , 8E14.7 )                                                  SW6C0602
  108 FORMAT(1H , 24I5    )                                                 SW6C0604
  109 FORMAT(1H , 27A4    )                                                 SW6C0606
    , WRITE(6,3) X(1,1), X(NP,1), Y(1,1,1) , Y(NP,1,1 ), NP, NCC, NV ,      SW6C 607
     1NCP , NFI, JN(1) , JTN(1), IMM , JN(NCC)                              SW6C 608
    3 FORMAT(1H ,4E14.7,9I5)                                                SW6C 61
    2 CONTINUE                                                              SW6C069
      NN = 1 + (NGR-1)*12                                                   SW6C070
      NX11 = 380                                                            SW6C071
      NX12 = 340                                                            SW6C072
      K1 =1                                                                 SW6C073
      IF(NGR.EQ.7.OR.NGR.EQ.8)K1 = 2                                        SW6C074
      YU = Y(1,1,NGR)*1.01                                                  SW6C081
      YL = Y(1,1,NGR)*0.9                                                   SW6C082
      XU = X(1,K1)*1.01                                                     SW6C083
      XL = X(1,K1)*.99                                                      SW6C084
      DO 20 J=1,NCC                                                         SW6C085
      DO 20 I=1, NP                                                         SW6C091
C                                                                           SW6C092
      IF(J.NE.1) GO TO 21                                                   SW6C093
```

```
      IF(X(I,K1).GT.XU)  XU= X(I,K1)                                        SW6C094
      IF(X(I,K1).LE.XL)  XL =X(I,K1)                                        SW6C095
   21 IF( Y(I,J,NGR).GE.  YU)  YU = Y(I,J,NGR)                              SW6C105
   20 IF( Y(I,J,NGR).LT.  YL)  YL  =  Y(I,J,NGR)                            SW6C110
      NCS(1)= 42                                                            SW6C120
      NCS(2)= 63                                                            SW6C121
      NCS(3)= 16                                                            SW6C122
      NCS(4)= 44                                                            SW6C123
      NCS(5)= 38                                                            SW6C124
      NCS(6)= 55                                                            SW6C125
      NCS(7)= 19                                                            SW6C126
      NCS(8)= 24                                                            SW6C127
      NCP(1)= 0                                                             SW6C130
      NCP(2)= 3                                                             SW6C131
      NCP(3)= 5                                                             SW6C132
      NCP(4)= 6                                                             SW6C133
      NCP(5)= 1                                                             SW6C134
      NCP(6)= 2                                                             SW6C135
      NCP(7)= 11                                                            SW6C136
      NCP(8)= 10                                                            SW6C137
      K2 =1                                                                 SW6C138
      IF(NGR.EQ.7.OR.NGR.EQ.8)K2=2                                          SW6C139
C                                                                           SW6C140
C                                                                           SW6C141
      CALL  BIGV                                                            SW6C150
      CALL  BRITEV                                                          SW6C151
      CALL  FRAMEV( 3)                                                      SW6C152
      DO  40 J=1, NCC                                                       SW6C170
      IF(NGR.LT.5) NLC  =  1                                                SW6C171
      IF(NLC.LT.5.AND.J.EQ.  NCC)NLC  =6                                    SW6C1712
      IF(NGR.EQ.7.OR.  NGR.EQ.8)  NLC =16                                   SW6C1714
      NY11  =   800  -  40*J                                                SW6C172
      NCP1  =   NCP(J)                                                      SW6C173
      DO  40 K=1,3                                                          SW6C174
      CALL  POINTV(NX12,  NY11,  NCP1  ,  ANY)                              SW6C175
      CALL  PRINTV(20  ,  LABLCU(NLC)  ,  NX11  ,  NY11  )                  SW6C176
      IF(NGR.EQ.7.OR.  NGR.EQ.8)  GO  TO  42                                SW6C1762
      NX2  =  NX11  +  40                                                   SW6C1772
      XJN  =  JN(J)                                                         SW6C1773
      IF(J.EQ.NCC)XJN   =IMM                                                SW6C1774
      CALL  LABLV(XJN,  NX2,  NY11  ,  4  ,  2,  2)                         SW6C1776
      GO  TO  41                                                            SW6C1778
   42 JL  =   JTN(J)                                                        SW6C178
      NX3  =  NX11                                                          SW6C1782
      XX  =  X(JL,1)                                                        SW6C1784
      CALL  LABLV(XX  ,  NX3  ,  NY11  ,  7  ,  2  ,  4  )                  SW6C1786
   41 CONTINUE                                                              SW6C1788
   40 CONTINUE                                                              SW6C179
      I= NGP                                                                SW6C1792
      DO  70  J=1  ,  NCC                                                   SW6C180
      IF(J.EQ.  1)  NF= 1                                                   SW6C181
      IF(J.NE.  1)  NF= 2                                                   SW6C182
      IF(NFI.EQ.1.AND.NGR.EQ.1)NF=1                                         SW6C1825
      IF(J.NE.  1)  NN= 97                                                  SW6C183
      NC  =  NCS(J)                                                         SW6C185
   70 CALL  SC102  (KX,  KY,X(1,K2),Y(1,J,I),NP,1,  NV  ,1,  NC  ,TIT(NN)  ,      SW6C186
```

```
148 , ABSA(NN) , 48 , ORD(NN) , 48 , NE,1, 16.0, 16.0, 2 , XL ,      SW6C187
2XU , 2  , YL , YU )                                                  SW6C188
 RETURN                                                               SW6C495
 END                                                                  SW6C500
```

R E F E R E N C E S

1. Kamat, D. V. and Abraham W. H., "Pressure Collapse in Oxygen Storage Under Zero-g" Journal of Spacecraft Vol. 2, No. 2, February 1968.

2. Torrance, K. E. "Comparison of Finite-Difference Computations of Natural Convection", J. Research of the National Bureau of Standards-B. Mathematical Sciences, 72B,281.

GENERAL DYNAMICS
Fort Worth Division
P. O. Box 748
Fort Worth, Texas 76101