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GENERALIZED FLUID SYSTEM SIMULATION PROGRAM (GFSSP) VERSION 3.0

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FOREWORD

The motivation to develop a general purpose computer program to compute pressure and flow distribution in a complex fluid network came from the need to calculate the axial load on the bearings in a turbopump. During the past several years, several specific purpose codes were developed to model the Space Shuttle Main Engine (SSME) turbopumps. However, it was difficult to use those codes for a new design without making extensive changes in the original code. Such efforts often turn out to be time consuming and inefficient. To satisfy the need to model these turbopumps in an efficient and timely manner, a subtask plan, entitled “Generalized Fluid System Simulation Program (GFSSP)” was prepared in March of 1994, under Task Directive 331-201 for Contract NAS8-37814, with Mr. Henry Stinson of the Turbomachinery Branch at Marshall Space Flight Center (MSFC) as the Task Initiator. The objective of this subtask was to develop a general fluid flow system solver capable of handling phase change, compressibility and mixture thermodynamics. Emphasis was given to construct a “user friendly” program using a modular structured code. The intent of this effort was that an engineer with an undergraduate background in fluid mechanics and thermodynamics should be able to rapidly develop a reliable model. The interest in modular code development was intended to facilitate future modifications to the program.

The code development was carried out in several phases. At the end of each phase, a workshop was held where the latest version of the code was released to MSFC engineers for testing, verification and feedback. After the release of Version 1.3, a request was made by the Propulsion System Branch to extend the code’s capability to analyze fluid transients. Therefore, a new subtask plan entitled “Development of Computer Models of Operational Transients in Flow Systems” was prepared in May of 1996, under Task Directive 341-204 with Ms. Susan Turner of the Propulsion System Branch as the Task Initiator. Under this task, GFSSP’s capability was extended to perform transient analysis for propellant feed systems. The capability to model propellant tank pressurization was developed under Task Directive 341-204 with Dr. Charles Schaffer as the Task Initiator. GFSSP’s capability to model non-circular ducts was extended under Task Directive 611-022 with Mr. Eric Earhart of the Structures and Dynamics Laboratory as the Task Initiator.

This document provides a detailed discussion of the mathematical formulation, solution procedure and computer program and it provides instructions for using the code through the inclusion of a number of example problems. Chapter 1 provides background information and discusses past and present work. The mathematical formulation used to develop GFSSP is described in detail in Chapter 2. All of the governing equations used in the code and the solution procedure implemented in GFSSP are described in this chapter. The program structure is discussed in Chapter 3. Chapter 4 describes how to use the code. Several example problems are given in Chapter 5. The new user, who is only interested in applying GFSSP to solve flow network problems, can skip the first three chapters of this document and go directly to Chapter 4 and Chapter 5. With some experience in applying GFSSP, the user will benefit from the first three chapters (in particular, Chapter 2).

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ABSTRACT

The Generalized Fluid System Simulation Program (GFSSP) is a general-purpose computer program for analyzing steady state and time-dependant flow rates, pressures, temperatures, and concentrations in a complex flow network. The program is capable of modeling phase changes, compressibility, mixture thermodynamics, pumps, compressors and external body forces such as gravity and centrifugal.

The program contains subroutines for computing “real fluid” thermodynamic and thermophysical properties for 12 fluids. The fluids are: helium, methane, neon, nitrogen, carbon monoxide, oxygen, argon, carbon dioxide, fluorine, hydrogen, water and kerosene (RP-1). The program also provides the options of using any incompressible fluid with constant density and viscosity or ideal gas. The program has the provision of integrating additional thermodynamic property programs to extend the fluid library.

Eighteen different resistance/source options are provided for modeling momentum sources or sinks in the branches. These options include: pipe flow, flow through a restriction, non-circular duct, pipe flow with entrance and/or exit losses, thin sharp orifice, thick orifice, square edge reduction, square edge expansion, rotating annular duct, rotating radial duct, labyrinth seal, parallel plates, common fittings and valves, pump characteristics, pump power, valve with a given loss coefficient, Joule-Thompson device, and control valve. The program has the provision of including additional resistance options through user subroutines.

GFSSP employs a finite volume formulation of mass, momentum, and energy conservation equations in conjunction with the thermodynamic equations of state for real fluids. Mass, energy and specie conservation equations are solved at the nodes; the momentum conservation equations are solved in the branches. The system of equations describing the fluid network is solved by a hybrid numerical method that is a combination of the Newton-Raphson and successive substitution methods.

This report illustrates the application and verification of the code through twelve demonstrated example problems. The examples are: 1) Simulation of a flow system containing a pump, valve and pipeline, 2) Flow network for a water distribution system, 3) Compressible flow in a converging-diverging nozzle, 4) Mixing of combustion gases and a cold gas stream, 5) Flow in a counter flow heat exchanger, 6) Radial flow in a rotating radial disk, 7) Flow in a squeeze film damper, 8) Blow down of a pressurized tank, 9) A reciprocating Piston-Cylinder, 10) Pressurization of a Propellant Tank, 11) Power Balancing of a Turbopump Assembly, and 12) Helium Pressurization of LOX and RP-1 propellant tanks.

Keywords: Flow, Network, Numerical, Simulation, Turbopump, Cryogenic, Thermodynamics, Mixture, Transient.

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NOMENCLATURE

Symbol	Description
A	Area (in^2)
a	Length (in)
A_0	Pump Characteristic Curve Coefficient
b	Length (in)
B_0	Pump Characteristic Curve Coefficient
C	Heat Capacity ($\text{Btu/sec} - {}^\circ \text{R}$)
C_L	Flow Coefficient
c	Clearance (in)
$c_{i,k}$	Mass Concentration of k^{th} Specie at i^{th} Node
c_p	Specific Heat ($\text{Btu/lb} \, {}^\circ\text{F}$)
C_v	Flow Coefficient for a Valve
D	Diameter (in)
f	Darcy Friction Factor
g	Gravitational Acceleration (ft/sec^2)
g_c	Conversion Constant ($= 32.174 \, \text{lb-ft/lb-f sec}^2$)
h	Enthalpy (Btu/lb)
J	Mechanical Equivalent of Heat ($778 \, \text{ft-lb/Btu}$)
K_f	Flow Resistance Coefficient ($\text{lb-f sec}^2 / (\text{lb-ft})^2$)
K_{rot}	Non-dimensional Rotating Flow Resistance Coefficient
K, K_1	Non-dimensional Head Loss Factor
K_i	Inlet Loss Coefficient
K_e	Exit Loss Coefficient
k_v	Empirical Factor
L	Length (in)
L_{ohm}	Resistance of the Joule Thompson Device
M	Molecular Weight
m	Resident Mass (lb)
\dot{m}	Mass Flow Rate (lb/sec)
m_p	Pitch (in)
N	Revolutions Per Minute (rpm), Number of Iterations
n	Number of Teeth
p	Pressure (lb/in^2)
P	Pump Power (hp)
P_o	Poiseuille Number
Q	Heat Source (Btu/sec)
Re	Reynolds Number ($Re = \rho u D / \mu$)
R	Gas Constant (lb-f ft/lb-R)
r	Radius (in)
S	Momentum Source (lb_f)
s	Entropy (Btu/lb-R)

NOMENCLATURE (Continued)

Symbol	Description
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T	Temperature ($^{\circ}$ F)
u	Velocity (ft/sec)
V	Volume (in 3)
V_f	Viscosity Correction Factor
v	Specific Volume (ft 3 /lb)
w	Joule Thompson Device Flow Rate (lbm/hr)
x	Quality and Mass Fraction
z	Compressibility Factor

Greek

ρ	Density (lb/ft 3)
θ	Angle Between Branch Flow Velocity Vector and Gravity Vector (deg), Angle Between Neighboring Branches for Computing Shear (deg)
q_T	Time required to drain pressurized propellant tank (sec)
ω	Angular Velocity (rad/sec)
ϵ	Absolute Roughness (in), Heat Exchanger Effectiveness, Labyrinth Seal Carry Over Factor
ϵ/D	Relative Roughness
α	Multiplier for Labyrinth Seal Resistance
η	Efficiency
Δh	Head Loss (ft)
μ	Viscosity (lb/ft-sec)
n	Kinematic Viscosity (ft 2 /sec)
\bar{r}	Molar Density (lb-mol/ft 3)
γ	Specific Heat Ratio
d	Distances between velocity locations (in)
$\Delta\tau$	Time Step (sec)
τ	Time (sec)

Subscript

B	Back
c	Cold
cr	Critical
Dis	Discharge
F	Front
h	Hot
Im	Impeller

NOMENCLATURE (Continued)

Symbol	Description
Subscript (Continued)	
i	Node
ij	Branch
trans	Transverse
gen	Generation
eff	Effective
or	Orifice
f	Liquid
g	Vapor
Turb	Turbine

1.0 INTRODUCTION

A fluid flow network consists of a group of flow branches, such as pipes and ducts, that are joined together at a number of nodes. They can range from simple systems consisting of a few nodes and branches to very complex networks containing many flow branches simulating valves, orifices, bends, pumps and turbines. In the analysis of existing or proposed networks, some node pressures and temperatures are specified or known. The problem is to determine all unknown nodal pressures, temperatures and branch flow rates.

An accurate prediction of axial thrust in a liquid rocket engine turbopump requires the modeling of fluid flow in a very complex network. Such a network involves the flow of cryogenic fluid through extremely narrow passages, flow between rotating and stationary surfaces, phase changes, mixing of fluids and heat transfer. Propellant feed system designers are often required to analyze pressurization or blow down processes in flow circuits consisting of many series and parallel flow branches containing various pipe fittings and valves using cryogenic fluids.

Available commercial codes are generally suitable for steady-state, single phase incompressible flow. Because of the proprietary nature of such codes, it is not possible to extend their capability to satisfy the above mentioned needs. In the past, specific purpose codes were developed to model the SSME turbopump. However, it was difficult to use those codes for a new design without making extensive changes in the original code. Such efforts often turn out to be time consuming and inefficient. Therefore, a Generalized Fluid System Simulation Program (GFSSP) has been developed as a general fluid flow system solver capable of handling phase changes, compressibility, mixture thermodynamics and transient operations. It also includes the capability to model external body forces such as gravity and centrifugal effects in a complex flow network.

This program requires that the flow network be resolved into nodes and branches. The program's preprocessor allows the user to interactively develop a fluid network simulation consisting of nodes and branches. In each branch, the momentum equation is solved to obtain the flow rate in that branch. At each node, the conservation of mass, energy and species equations are solved to obtain the pressures, temperatures and species concentrations at that node.

This report documents the mathematical formulation and solution procedure used by the code and it serves as a user's guide through the inclusion of a number of example problems. These examples include: 1) Simulation of a flow system containing a pump, valve and pipeline, 2) Flow network for a water distribution system, 3) Compressible flow in a converging-diverging nozzle, 4) Mixing of combustion gases and a cold gas stream, 5) Flow in a counter flow heat exchanger, 6) Radial flow in a rotating radial disk, 7) Flow in a squeeze film damper, 8) Blow down of a pressurized tank, 9) A Reciprocating-Piston Cylinder, 10) Pressurization of a

Propellant Tank, 11) Power Balancing of a Turbopump Assembly, and 12) Helium Pressurization of LOX and RP-1 Propellant Tanks.

1.1 PAST WORK

The oldest method for systematically solving a problem consisting of steady flow in a pipe network is the Hardy Cross method [1]. Not only is this method suited for hand calculations, but it has also been widely employed for use in computer generated solutions. But as computers allowed much larger networks to be analyzed, it became apparent that the convergence of the Hardy Cross method might be very slow or even fail to provide a solution in some cases. The main reason for this numerical difficulty is that the Hardy Cross method does not solve the system of equations simultaneously. It considers a portion of the flow network to determine the continuity and momentum errors. The head loss and the flow rates are corrected and then it proceeds to an adjacent portion of the circuit. This process is continued until the whole circuit is completed. This sequence of operations is repeated until the continuity and momentum errors are minimized. It is evident that the Hardy Cross method belongs in the category of successive substitution methods and it is likely that it may encounter convergence difficulties for large circuits. In later years, the Newton-Raphson method has been utilized [2] to solve large networks, and with improvements in algorithms based on the Newton-Raphson method, computer storage requirements are not much larger than those needed by the Hardy Cross method.

The flow of fluid in a rocket engine turbopump can be classified into two main categories. The flow through the impeller and turbine blade passages is designated as primary flow. Controlled leakage flow through bearings and seals for the purpose of axial thrust balance, bearing cooling and rotodynamic stability is referred to as secondary flow. Flows in the blade passages are modeled by solving Navier-Stokes equations of mass, momentum and energy conservation in three dimensions. Navier-Stokes methods, however, are not particularly suitable for modeling flow distribution in a complex network.

Most of the available commercial software for solving flow networks [3,4] are based on either the successive substitution method or on the Newton-Raphson method and they are only applicable for a single phase incompressible fluid. They are not suitable for modeling rocket engine turbopumps where mixing, phase change and rotational effects are present. Two public domain computer programs [5,6] have been developed in the aerospace industry to analyze the secondary flow in the SSME turbopumps. These programs use real gas properties to compute variable density in the flow passage. Mixing of fluids, phase changes and rotational effects, however, are not considered by these programs.

1.2 PRESENT WORK

The objective of the present effort is to develop: a) a robust and efficient numerical algorithm to solve a system of equations describing a flow network containing phase changes, mixing and rotation, and b) to implement the algorithm in a structured, easy-to-use computer program.

The earlier programs that were used to analyze the flow in the SSME turbomachinery used a very simplified form of the momentum equation. The momentum equations used in Reference 5 and Reference 6 only considered pressure and frictional forces. A more generalized form of the momentum equation is necessary to account for rotational effects. The momentum equation used in GFSSP includes inertia, pressure, friction, gravity, centrifugal and any external momentum sources. The frictional resistances are proportional to the square of mass flow rate in the branch. The proportionality constant was derived from empirical information available in the literature [7-12].

The thermodynamic and thermophysical properties required in the conservation equations are obtained from three thermodynamic property programs, GASP, WASP and GASPAK [13, 14, 28]. The thermodynamic property programs, GASP and WASP, provide thermodynamic and thermophysical properties for helium, methane, neon, nitrogen, carbon monoxide, oxygen, argon, carbon dioxide, fluorine, hydrogen, and water. GASPAK provides thermodynamic properties for helium, methane, neon, nitrogen, carbon monoxide, oxygen, argon, carbon dioxide, hydrogen, parahydrogen, water, isobutane, butane, deuterium, ethane, ethylene, hydrogen sulfide, krypton, propane, xenon, R-11, R-12, R-22, R-32, R-123, R-124, R-125, R-134A, R-152A, nitrogen trifluoride and ammonia. The properties of RP-1 fuel [15] have been provided as a look up table. A real gas formulation has been used to compute mixture properties. The code also includes the options of modeling any incompressible fluid of constant density and viscosity or an ideal gas.

GFSSP includes a preprocessor to facilitate the creation of the model. With the help of this preprocessor, a user without a substantial background in computational methods or the FORTRAN programming language can use the code to model complex flow circuits.

The task of the computational model is to obtain a simultaneous solution of the governing equations. This system of equations is solved by GFSSP utilizing a novel numerical procedure, which is a combination of Newton-Raphson and successive substitution methods.

The code development has been carried out in stages. At the end of each stage, a workshop was held to distribute the latest version of the code to MSFC engineers for testing, verification and feedback. In the first workshop, held in August of 1994, GFSSP Version 1.0 was released. This version of GFSSP contained the basic mathematical framework of the solver and the integration of the thermodynamic property program GASP.

The second workshop was held in December of 1994 to release GFSSP Version 1.1. This version included a preprocessor which allowed the user to create an input data file for GFSSP through an interactive process. The preprocessor eliminated the need for the user to modify and compile the source code. Additional features of GFSSP Version 1.1 included: a) the inclusion of the water property program WASP, and b) the introduction of a hybrid numerical technique for use in the solver.

GFSSP Version 1.2 was released in February of 1995. This version included the capability to model the thermodynamics of real gas mixtures and to calculate the axial thrust exerted on a rotating component in a flow circuit. The inter-propellant seal flow circuit for the SSME high pressure oxygen turbopump was modeled and the predictions were compared with the predictions from Pratt & Whitney's model. Excellent agreement [16] was obtained between these two models.

The third workshop was held in October of 1995 to release GFSSP Version 1.3. This version of GFSSP included four additional capabilities: a) a quasi-steady state option used for modeling dynamic environments, b) a thermodynamic property routine for RP-1 fuel that was needed for modeling different types of engines, c) provisions for heat sources or sinks to be used for modeling flows in low clearance rotating passages, and d) a generalized momentum equation that accounts for fluid inertial forces. This version was used to model the natural convection process in a cryogenic propellant conditioning system. Good agreement was obtained [17] between test data and GFSSP predictions.

Version 1.4 [18] was released in the fourth workshop held in October of 1996. The capability to include external body forces, such as a pump, as a momentum source was added into this version. This version also provided the user with the capability to model rotational flows in a turbo-machine. Another major feature of GFSSP Version 1.4 was its enhanced capability to model different types of resistances in a flow network. Fifteen different resistance/source options were provided for modeling momentum sources or sinks in the branches. These include: pipe flow, flow through a restriction, pipe flow with entrance and/or exit losses, thin sharp orifice, thick orifice, square edge reduction, square edge expansion, rotating annular duct, rotating radial duct, labyrinth seal, parallel plates, common fittings and valves, pump characteristics, pump power and a valve with a given loss coefficient. These additional features of the code were verified by comparing GFSSP's predictions with two other commercial codes [3, 4]. The GFSSP predictions compared [19] favorably with the other two codes.

Version 2.0 [20] was released in the fifth workshop. The code's capability was extended to model transient flow. This added capability allows the user to model pressurization and blow down processes. GFSSP's transient predictions of a blow down process was verified by comparing the predictions with an analytical solution [21]. This version was also capable of modeling a heat exchanger and turbopump in a given flow system. An additional resistance option was provided to model the Joule-Thompson effect that occurs in a Viscojet [22]. Comparing with experimental data [23] validated a secondary flow prediction in a turbopump.

Version 2.6 was released in the sixth workshop. One of the main highlights of this version was an alternate formulation of the energy equation by the second law of thermodynamics [24]. In this formulation, entropy was solved instead of enthalpy. There was a significant improvement in the performance of the numerical scheme by devising an alternate solution sequence of conservation equations. In addition, the pressurization and control valve options were added to the code. The pressurization option was verified by comparing with a published correlation [25].

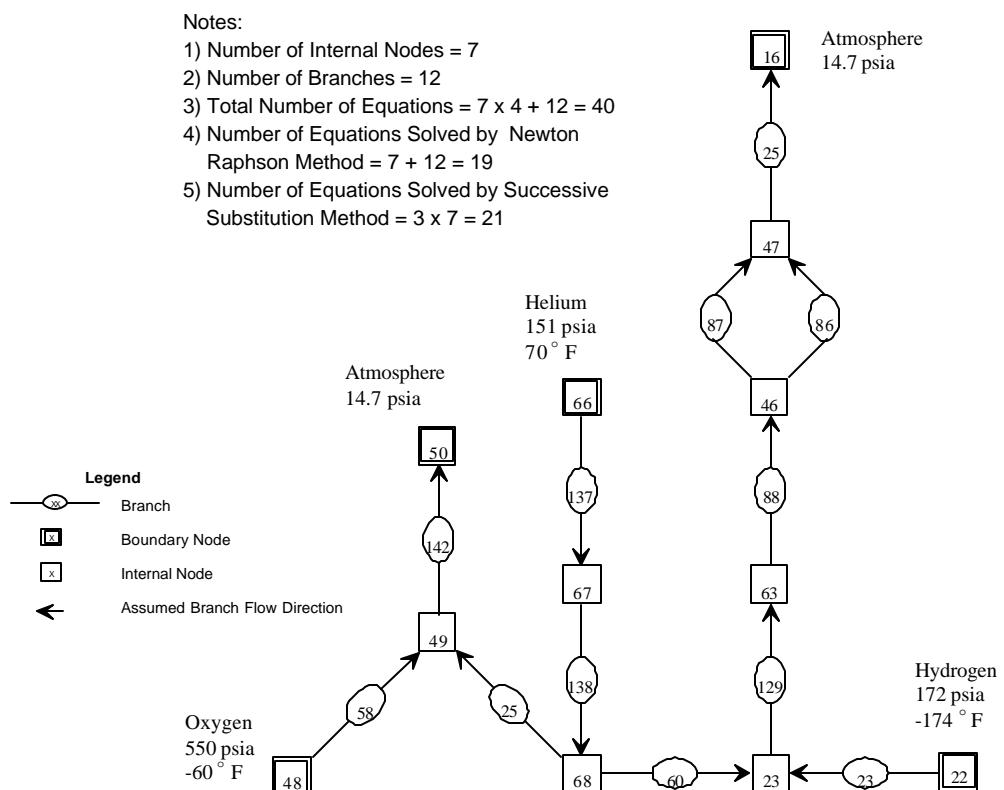
This report documents GFSSP Version 3.0. This version provides flexibility to add new capabilities. Additional capabilities, such as new resistance options, new fluids and non-linear boundary conditions can be added through the use of user subroutines. All capabilities of previous versions have been retained in this version.

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2.0 MATHEMATICAL FORMULATION

GFSSP assumes a Newtonian, non-reacting and one-dimensional flow in the flow circuit. The flow can be either laminar or turbulent, incompressible or compressible, with or without heat transfer, phase change and mixing. The analysis of the flow and pressure distribution in a complex fluid flow network requires resolution of the system into nodes and branches. Nodes can be either boundary nodes or internal nodes. Pressures, temperatures, and concentrations of fluid species are specified at the boundary nodes. At each internal node, scalar properties such as pressures, temperatures, enthalpies, and mixture concentrations are computed. The flow rates (vector properties) are computed at the branches.

The purpose of the mathematical model is to predict the conditions at the internal nodes and the flow rates in the branches. A sample flow circuit consisting of 12 nodes and 12 branches is shown in Figure 2.1. Figure 2.1 shows a portion of the propellant flow circuit in a Pratt & Whitney High Pressure Oxygen Turbopump Secondary Flow Circuit, where a helium buffer is used to prevent the mixing of hydrogen and oxygen leakage flow.



The nodes and branches shown in Figure 2.1 are numbered arbitrarily. There are five boundary nodes (48, 50, 66, 16, and 22) in the flow circuit. Oxygen, hydrogen, and helium enter into the circuit through nodes 48, 22, and 66 respectively. The pressures and temperatures are specified at these nodes and are shown in the figure. Nodes 50 and 16 are outflow boundaries where only pressures are specified. The mixtures of helium-oxygen and helium-hydrogen exit through these nodes. The computer code calculates pressures, temperatures, and fluid specie concentrations at all of the internal nodes and the flow rates in all of the branches.

2.1 GOVERNING EQUATIONS

Figure 2.1.1 displays a schematic showing adjacent nodes, their connecting branches, and the indexing system used by GFSSP. In order to solve for the unknown variables, mass, energy and fluid specie conservation equations are written for each internal node and flow rate equations are written for each branch.

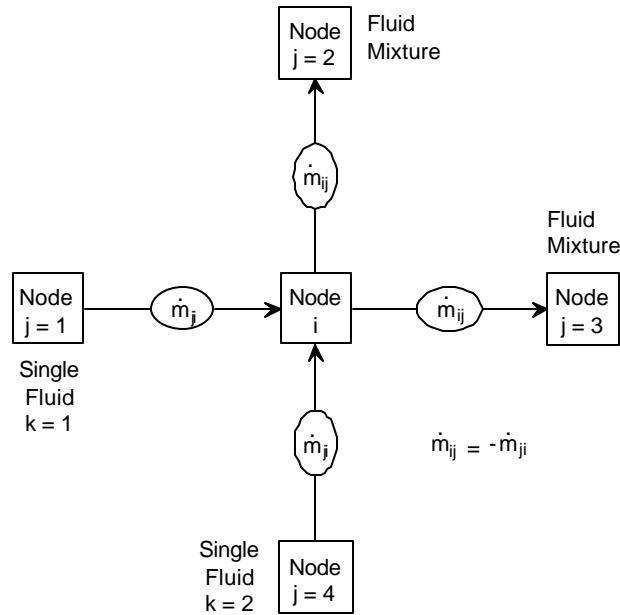


Figure 2.1.1 - Schematic of GFSSP Nodes, Branches and Indexing Practice

2.1.1 Mass Conservation Equation

$$\frac{m_{\tau+\Delta\tau} - m_\tau}{\Delta\tau} = \sum_{j=1}^{j=n} m_{ij} \quad (2.1.1)$$

Equation 2.1.1 requires that for the transient formulation, the net mass flow from a given node must equate to rate of change of mass in the control volume. In the steady state formulation, the left side of

the equation is zero. This implies that the total mass flow rate into a node is equal to the total mass flow rate out of the node.

2.1.2 Momentum Conservation Equation

The flow rate in a branch is calculated from the momentum conservation equation (Equation 2.1.2) which represents the balance of fluid forces acting on a given branch. A typical branch configuration is shown in Figure 2.1.2. Inertia, pressure, gravity, friction and centrifugal forces are considered in the conservation equation. In addition to these five forces, a source term S has been provided in the equation to input pump characteristics or to input power to a pump in a given branch. If a pump is located in a given branch, all other forces except pressure are set to zero. The source term, S , is set to zero in all branches without a pump.

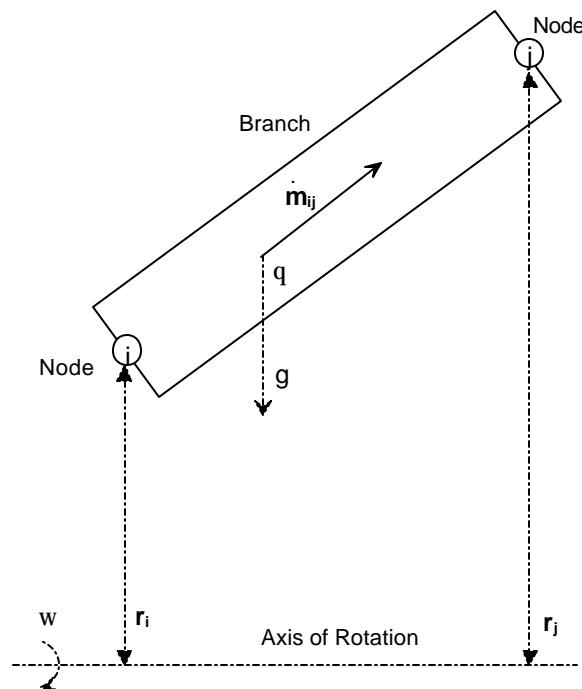


Figure 2.1.2 - Schematic of a Branch Showing Gravity and Rotation

$$\frac{(mu)_{t+\Delta t} - (mu)_t}{g_c \Delta t} + MAX\left[m_{ij}, 0\right](u_{ij} - u_u) - MAX\left[-m_{ij}, 0\right](u_{ij} - u_u)$$

-- -Unsteady --- ----- Longitudinal Inertia -----

$$+ MAX\left[m_{trans}, 0\right](u_{ij} - u_p) - MAX\left[-m_{trans}, 0\right](u_{ij} - u_p) =$$

----- Transverse Inertia -----

$$(p_i - p_j)A_{ij} + \frac{rgV\cos q}{g_c} - K_f m_{ij} \left| A_{ij} \right| + \frac{\mathbf{r} K_{rot}^2 \mathbf{W}^2 A}{g_c} + \mathbf{m} \frac{u_p - u_{ij}}{g_c d_{ij,p}} A_s$$

--Pressure-- -- Gravity -- -- Friction -- -- Centrifugal -- -- Shear --

$$- \mathbf{r} A_{norm} u_{norm} u_{ij} / g_c + \left(\mathbf{m}_d \frac{u_d - u_{ij}}{d_{ij,d}} - \mathbf{m}_u \frac{u_{ij} - u_u}{d_{ij,u}} \right) \frac{A_{ij}}{g_c} + S \quad (2.1.2)$$

-- Moving Boundary-- -- Normal Stress --- -- Source --

The momentum equation consists of eleven terms. There will be no occasion when all eleven terms will be present in a control volume. Users have the access to include or exclude all terms except the pressure term. The pressure term will be active under all circumstances. The left hand side of the momentum equation represents the inertia of the fluid. The surface and body forces applied in the control volume are assembled in the right hand side of the equation.

Unsteady

This term represents rate of change of momentum with time. For steady state flow, time step is set to an arbitrary large value and this term is reduced to zero.

Longitudinal Inertia

This term is important when there is a significant change in velocity in the longitudinal direction due to change in area and density. An upwind differencing scheme is used to compute the velocity differential.

Transverse Inertia

This term is important for multi-dimensional flow. It accounts for any longitudinal momentum being transported by a transverse velocity component. Once again an upwind differencing scheme is used to compute the velocity differential.

Pressure

This term represents the pressure gradient in the branch. The pressures are located at the upstream and downstream face of a branch.

Gravity

This term represents the effect of gravity. The gravity vector makes an angle (θ) with the assumed flow direction vector. At $\theta = 180^\circ$ fluid is flowing against gravity, at $\theta = 90^\circ$ fluid is flowing horizontally and gravity has no effect on the flow.

Friction

This term represents the frictional effect. Friction was modeled as a product of K_f and the square of the flow rate and area. K_f is a function of the fluid density in the branch and the nature of the flow passage

being modeled by the branch. The calculation of K_f for different types of flow passages has been described in detail later within this report.

Centrifugal

This term in the momentum equation represents the effect of the centrifugal force. This term will be present only when the branch is rotating as shown in Figure 2.1.2. K_{rot} is the factor representing the fluid rotation. K_{rot} is unity when the fluid and the surrounding solid surface rotate with the same speed. This term also requires knowledge of the distances from the axis of rotation between the upstream and downstream faces of the branch.

Shear

This term represents shear force exerted on the control volume by a neighboring branch. This term is active only for multi-dimensional flow. The friction term is deactivated when this term is present. This term requires knowledge of distances between branches to compute the shear stress.

Moving Boundary

This term represents force exerted on the control volume by a moving boundary. This term is not active for multi-dimensional calculations.

Normal Stress

This term represents normal viscous force. This term is important for highly viscous flows.

Source

This term represents a generic source term. Any additional force acting on the control volume can be modeled through the source term. In a system level model, a pump can be modeled by this term. A detailed description of modeling a pump by this source term, S , appears in Sections 2.1.7.14 and 2.1.7.15 of this report.

A simplified form of the momentum equation has also been provided to compute choked flowrate for compressible flow in an orifice. When the inertia term is not activated and the following criteria is satisfied:

$$\frac{p_j}{p_i} < p_{cr}, \quad (2.1.2.a)$$

where:

$$p_{cr} = \left(\frac{2}{g+1} \right)^{\frac{g}{g-1}}, \quad (2.1.2.b)$$

the flow rate in a branch is calculated from:

$$\dot{m}_j = C_{Lij} A \sqrt{p_i \rho_i g_c \frac{2\gamma}{\gamma-1} (p_{cr})^{2/\gamma} \left[1 - (p_{cr})^{(\gamma-1)/\gamma} \right]}. \quad (2.1.2.c)$$

2.1.3 Energy Conservation Equation

The energy conservation equation for node i, shown in Figure 2.1.1, can be expressed following first or second law of thermodynamics. The first law formulation uses enthalpy as the dependant variable while second law formulation uses entropy. The energy conservation equation based on enthalpy is shown in Equation 2.1.3a.

$$\frac{m \left(h - \frac{p}{rJ} \right)_{t+\Delta t} - m \left(h - \frac{p}{rJ} \right)_t}{\Delta t} = \sum_{j=1}^{j=n} \left\{ MAX \left[-\dot{m}_{ij}, 0 \right] h_j - MAX \left[\dot{m}_{ij}, 0 \right] h_i \right\} + \frac{MAX \left[-\dot{m}_{ij}, 0 \right]}{\left| \dot{m}_{ij} \right|} \left[(p_i - p_j) + K_{ij} \dot{m}_{ij}^2 \right] (\mathbf{u}_{ij} \cdot \mathbf{A}) + Q_i \quad (2.1.3a)$$

Equation 2.1.3a shows that for transient flow, the rate of increase of internal energy in the control volume is equal to the rate of energy transport into the control volume minus the rate of energy transport from the control volume plus the rate of work done on the fluid by the pressure force plus the rate of work done on the fluid by the viscous force plus the rate of heat transfer into the control volume.

For a steady state situation, the energy conservation equation, Equation 2.1.3, states that the net energy flow from a given node must equate to zero. In other words, the total energy leaving a node is equal to the total energy coming into the node from neighboring nodes and from any external heat sources (Q_i) coming into the node and work done on the fluid by pressure and viscous forces. The MAX operator used in Equation 2.1.3 is known as an upwind differencing scheme and has been extensively employed in the numerical solution of Navier-Stokes equations in convective heat transfer and fluid flow applications [26]. When the flow direction is not known, this operator allows the transport of energy only from its upstream neighbor. In other words, the upstream neighbor influences its downstream neighbor but not vice versa. The second term in the right hand side represents the work done on the fluid by the pressure and viscous force. The difference between the steady and unsteady formulation lies in the left side of the equation. For a steady state situation, the left side of Equation 2.1.3 is zero, where as in unsteady cases the left side of the equation must be evaluated.

The energy conservation equation based on entropy is shown in Equation 2.1.3b.

$$\frac{(ms)_{t+\Delta t} - (ms)_t}{\Delta t} = \sum_{j=1}^{j=n} \left\{ MAX[-\dot{m}_{ij}, 0] s_j - MAX[\dot{m}_{ij}, 0] s_i \right\} + \sum_{j=1}^{j=n} \left\{ \frac{MAX[-\dot{m}_{ij}, 0]}{\left| \dot{m}_{ij} \right|} \right\} \dot{s}_{ij, gen} + \frac{Q_i}{T_i} \quad (2.1.3b)$$

The entropy generation rate due to fluid friction in a branch is expressed as [27]

$$S_{ij,gen} = \frac{m_{ij} \Delta p_{ij,viscous}}{r_u T_u J} = \frac{K_f \left(\left| \dot{m}_{ij} \right| \right)^3}{r_u T_u J} \quad (2.1.3c)$$

Equation 2.1.3b shows that for unsteady flow, the rate of increase of entropy in the control volume is equal to the rate of entropy transport into the control volume plus the rate of entropy generation in all upstream branches due to fluid friction plus the rate of entropy added to the control volume due to heat transfer. The first term in the right hand side of the equation represents the convective transport of entropy from neighboring nodes. The second term represents the rate of entropy generation in branches connected to the i^{th} node. The third term represents entropy change due to heat transfer.

2.1.4 Fluid Specie Conservation Equation

The flow network shown in Figure 2.1.1 has a fluid mixture flowing in most of the branches. In order to calculate the density of the mixture, the concentration of the individual fluid species within the branch must be determined. The concentration for the k^{th} specie can be written as

$$\frac{(m_i c_{i,k})_{t + \Delta t} - (m_i c_{i,k})_t}{\Delta t} = \sum_{j=1}^n \left\{ MAX\left[-\dot{m}_{ij}, 0\right] c_{j,k} - MAX\left[\dot{m}_{ij}, 0\right] c_{i,k} \right\} + S_{i,k} \quad (2.1.4)$$

For a transient flow, Equation 2.1.4 states that the rate of increase of the concentration of k^{th} specie in the control volume equals the rate of transport of the k^{th} specie into the control volume minus the rate of transport of the k^{th} specie out of the control volume plus the generation rate of the k^{th} specie in the control volume.

Like Equation 2.1.3, for steady state conditions, Equation 2.1.4 requires that the net mass flow of the k^{th} specie from a given node must equate to zero. In other words, the total mass flow rate of the given specie into a node is equal to the total mass flow rate of the same specie out of that node. For steady state, the left side of Equation 2.1.4 is zero. For the unsteady formulation, the resident mass in the control volume is changing and therefore the left side must be computed.

2.1.5 Thermodynamic and Thermophysical Properties

The momentum conservation equation, Equation 2.1.2, requires knowledge of the density and the viscosity of the fluid within the branch. These properties are functions of the temperatures, pressures and concentrations of fluid species for a mixture. Three thermodynamic property routines have been integrated into the program to provide the required fluid property data. GASP [13] provides the

thermodynamic and transport properties for ten fluids. These fluids include Hydrogen, Oxygen, Helium, Nitrogen, Methane, Carbon Dioxide, Carbon Monoxide, Argon, Neon and Fluorine. WASP [14] provides the thermodynamic and transport properties for water and steam. GASPAK [28] provides thermodynamic properties for helium, methane, neon, nitrogen, carbon monoxide, oxygen, argon, carbon dioxide, hydrogen, parahydrogen, water, isobutane, butane, deuterium, ethane, ethylene, hydrogen sulfide, krypton, propane, xenon, R-11, R-12, R-22, R-32, R-123, R-124, R-125, R-134A, R-152A, nitrogen trifluoride and ammonia. For RP-1 fuel, a look up table of properties has been generated by a modified version of GASP. An interpolation routine has been developed to extract the required properties from the tabulated data.

2.1.6 Mixture Property Calculations

This section describes a procedure developed for GFSSP to estimate the density and temperature of mixtures of real fluids. Let us assume that n numbers of fluids are mixing in the i^{th} node. At node i , pressure, p_i , and molar concentrations, x_k , are known. The problem is to calculate the density, ρ_i , and temperature, T_i , specific heat, C_p , specific heat ratio, γ , and viscosity, μ , of the mixture at the i^{th} node.

During iterative calculations, GFSSP calculates the mixture properties using the following steps:

1. Calculate ρ_k , μ_k , $C_{p,k}$ and γ_k from p_i and T_i using the thermodynamic property routines of the program.
2. Calculate the compressibility of each component of the mixture, z_k , from the equation of state for a real gas (Equation 2.1.5).

$$z_k = \frac{p_i}{\rho_k R_k T_k} \quad (2.1.5)$$

Where R_k is the gas constant for k^{th} fluid.

3. Calculate compressibility of the mixture, z_i , as shown in Equation 2.1.6, by taking the molar average of the component compressibilities obtained in Step 2.

$$z_i = \sum_{k=1}^n x_k z_k \quad (2.1.6)$$

4. Calculate gas constant of the mixture, R_i , by taking the molar average of the component gas constants.

$$R_i = \sum_{k=1}^{k=n} x_k R_k \quad (2.1.7)$$

5. Calculate the density of the mixture, ρ_i , from the equation of state of a real fluid.

$$r_i = \frac{p_i}{z_i R_i T_i} \quad (2.1.8)$$

6. Calculate viscosity, specific heat and specific heat ratio of the mixture by taking the molar average of the component properties, μ_k , $C_{p,k}$ and γ_k as shown in equation (2.1.9), (2.1.10) and (2.1.11).

$$\mu_i = \sum_{k=1}^{k=n} x_k \mu_k \quad (2.1.9)$$

$$C_{p,i} = \sum_{k=1}^{k=n} \frac{C_{p,k} x_k M_k}{x_k M_k} \quad (2.1.10)$$

$$\gamma_i = \sum_{k=1}^{k=n} x_k \gamma_k \quad (2.1.11)$$

7. Calculate T_i from the energy conservation equation expressed in terms of a product of specific heat and temperature instead of enthalpy.

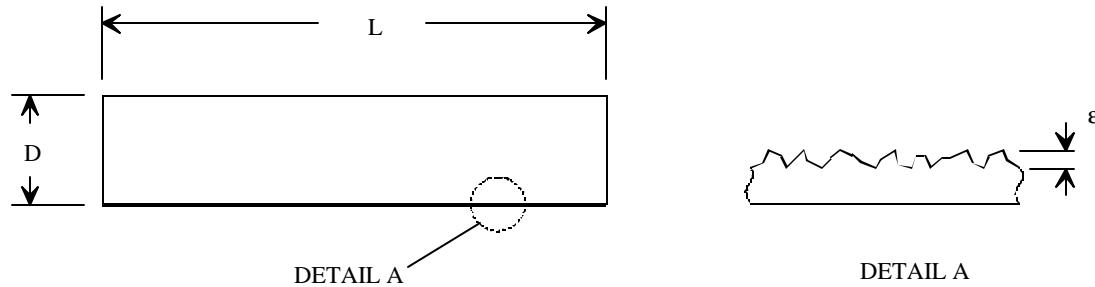
$$(T_i)_{t+\Delta t} = \frac{\sum_{j=1}^{j=n} \sum_{k=1}^{k=n_f} C_{p,k} x_k T_j \text{MAX}\left[-m_{ij}, 0\right] + (C_{p,i} m_i T_i)_t / \Delta t + Q_i}{\sum_{j=1}^{j=n} \sum_{k=1}^{k=n_f} C_{p,k} x_k \text{MAX}\left[m_{ij}, 0\right] + (C_{p,i} m_i)_t / \Delta t} \quad (2.1.12)$$

Where $C_{p,k}$ is the molar specific heat and x_k is the mole-fraction of the k^{th} specie. Note that an unsteady formulation of the energy equation (Equation 2.1.3) was used to compute T_i .

2.1.7 Friction Calculations

It was mentioned earlier in this document that the friction term in the momentum equation is expressed as a product of K_f , the square of the flow rate and the flow area. Empirical information is necessary to estimate K_f . Several options for flow passage resistance are listed in Table 2.1.1.

2.1.7.1 Branch Option 1 (Pipe Flow)



Where:

D = Pipe Diameter

L = Pipe Length

ϵ = Absolute Roughness

Figure 2.1.3 - Pipe Resistance Option Parameters

Figure 2.1.3 shows the pipe resistance option parameters that are required by GFSSP. This option considers that the branch is a pipe with length, L , diameter, D , and surface roughness, ϵ . For this option, K_f can be expressed as:

$$K_f = \frac{8fL}{\rho_u \pi^2 D^5 g_c} \quad (2.1.13)$$

Where ρ_u is the density of the fluid at the upstream node of a given branch. The derivation of K_f for pipe flow is covered in Appendix A.

The Darcy friction factor, f , is determined from the Colebrook Equation [7] which is expressed as:

$$\frac{1}{\sqrt{f}} = -2 \log \left[\frac{\epsilon}{3.7D} + \frac{2.51}{Re \sqrt{f}} \right] \quad (2.1.14)$$

Where ϵ/D and Re are the surface roughness factor and Reynolds number respectively.

2.1.7.2 Branch Option 2 (Flow Through a Restriction)

This option regards the branch as a flow restriction with a given flow coefficient, C_L , and area, A . For this option, K_f can be expressed as:

$$K_f = \frac{1}{2 g_c \rho_u C_L^2 A^2} \quad (2.1.15)$$

Table 2.1.1 - Resistance Options in GFSSP

Option	Type of Resistance	Input Parameters	Option	Type of Resistance	Input Parameters
1	Pipe Flow	L (in), D (in), ε/D	10	Rotating Radial Duct	L (in), D (in), N (rpm)
2	Flow Through Restriction	C _L , A (in ²)	11	Labyrinth Seal	r _i (in), c (in), m (in), n, α
3	Non-circular Duct	a (in), b (in)	12	Flow Between Parallel Plates	r _i (in), c (in), L (in)
4	Pipe with Entrance and Exit Loss	L (in), D (in), ε/D, K _i , K _e	13	Common Fittings and Valves (Two K Method)	D (in), K ₁ , K ₂
5	Thin, Sharp Orifice	D ₁ (in), D ₂ (in)	14	Pump Characteristics ¹	A ₀ , B ₀ , A (in ²)
6	Thick orifice	L (in), D ₁ (in), D ₂ (in)	15	Pump Power	P (hp), η, A (in ²)
7	Square Reduction	D ₁ (in), D ₂ (in)	16	Valve with Given C _v	C _v , A
8	Square Expansion	D ₁ (in), D ₂ (in)	17	Joule-Thompson Device	L _{ohm} , V _f , k _v , A
9	Rotating Annular Duct	L (in), r _o (in), r _i (in), N (rpm)	18	Control Valve	See Example 12 data file

¹ Pump characteristics are expressed as $\Delta p = A_0 + B_0 \dot{m}$
 Δp - Pressure rise, lbf/ft²
 \dot{m} - Flow rate, lbm/sec

In classical fluid mechanics, head loss is expressed in terms of a nondimensional “K factor”.

$$\Delta h = K \frac{u^2}{2g} \quad (2.1.16)$$

K and C_L are related as:

$$C_L = \frac{1}{\sqrt{K}} \quad (2.1.17)$$

2.1.7.3 Branch Option 3 (Non-circular Duct)

This option considers a duct with a non-circular cross-section. Four different types of cross-sections can be modeled as shown in Figure 2.1.4. These include 1) rectangle, 2) ellipse, 3) concentric cylinder and 4) circular sector.

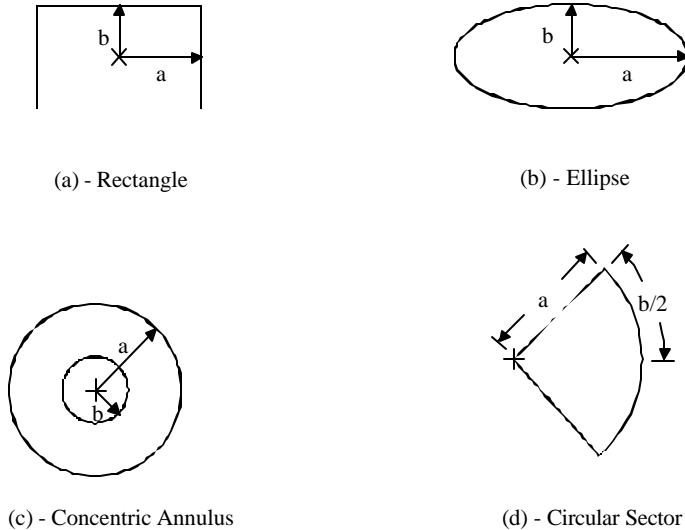


Figure 2.1.4 - Non-circular Duct Cross-section

White [29] described a procedure to estimate the friction factor in a non-circular duct. This procedure consists of the following steps:

1. Estimate the hydraulic diameter of the cross-section:

$$D_h = (4)(\text{Area}) / \text{Perimeter}$$

2. Estimate the Poiseuille Number for a particular cross-section. The Poiseuille Number can be expressed as a polynomial function of aspect ratio as shown in Equation 2.1.18. Table 2.1.2 provides the coefficients for different geometries.

$$Po = A_0 + A_1 \left(\frac{b}{a} \right) + A_2 \left(\frac{b}{a} \right)^2 + A_3 \left(\frac{b}{a} \right)^3 + A_4 \left(\frac{b}{a} \right)^4 \quad (2.1.18)$$

Table 2.1.2 - Poiseuille Number Coefficients for Non-circular Duct Cross-sections

Coefficients	Rectangle	Ellipse	Concentric * Cylinder	Circular Section
A ₀	23.9201	19.7669	22.0513	11.9852
A ₁	-29.436	-4.53458	6.44473	3.01553
A ₂	30.3872	-11.5239	-7.35451	-1.09712
A ₃	-10.7128	22.3709	2.78999	0.0
A ₄	0.0	-10.0874	0.0	0.0

* for b/a < 0.2508 $Po = A_0 \left(\frac{b}{a} \right)^{A_1}$, where, A₀ = 24.8272, A₁ = 0.0479888

- Calculate the friction factor for a non-circular pipe:

Laminar flow (Re<2300)

$$f = \frac{4Po}{Re} \quad (2.1.19)$$

Turbulent flow

- Compute the effective diameter:

$$D_{\text{eff}} = \frac{16D_h}{Po} \quad (2.1.20)$$

- Compute the effective Reynolds number:

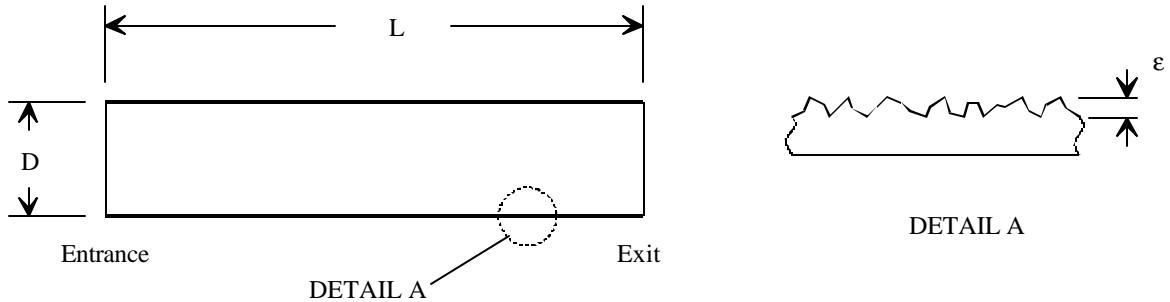
$$Re_{\text{eff}} = \frac{\dot{m}}{\mu} \frac{D_{\text{eff}}}{A} \quad (2.1.21)$$

- Compute the friction factor using the Colebrook equation (Equation 2.1.14).

- Compute K_f from the following expression:

$$K_f = \frac{8fL}{\rho_u \pi^2 D_h^5 g_c} \quad (2.1.22)$$

2.1.7.4 Branch Option 4 (Pipe with Entrance and Exit Loss)



Where:

D = Pipe Diameter

K_i = Entrance Loss Coefficient

L = Pipe Length

K_e = Exit Loss Coefficient

ϵ = Absolute Roughness

Figure 2.1.5 - Pipe With Entrance and/or Exit Loss Resistance Option Parameters

Figure 2.1.5 shows the pipe with entrance and/or exit loss resistance option parameters that are required by GFSSP. This option is an extension of Option 1. In addition to the frictional loss in the pipe, entrance and exit losses are also calculated. For this option, K_f can be expressed as:

$$K_f = \frac{8K_i}{\rho_u \pi^2 D^4 g_c} + \frac{8fL}{\rho_u \pi^2 D^5 g_c} + \frac{8K_e}{\rho_u \pi^2 D^4 g_c} \quad (2.1.23)$$

Where K_i and K_e are the entrance and exit loss coefficients respectively.

2.1.7.5 Branch Option 5 (Thin Sharp Orifice)

Figure 2.1.6 shows the thin sharp orifice resistance option parameters that are required by GFSSP. This option considers the branch as a thin sharp orifice with a pipe diameter of D_1 and an orifice diameter of D_2 . For this option, K_f can be expressed [8] as:

$$K_f = \frac{K_1}{2g_c \rho_u A^2} \quad (2.1.24)$$

$$\text{where, } A = \frac{\pi D_1^2}{4}$$

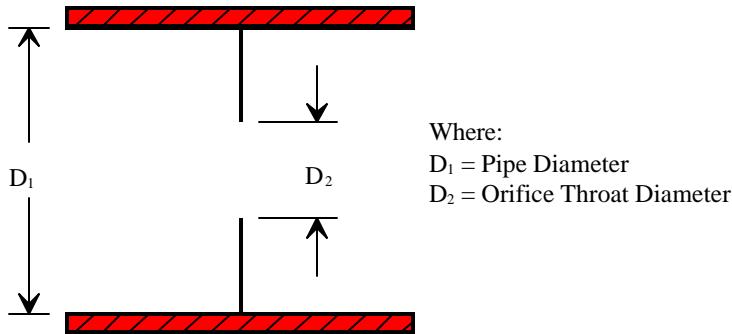


Figure 2.1.6 - Thin Sharp Orifice Resistance Option Parameters

Where, for upstream $Re \leq 2500$:

$$K_1 = \left[2.72 + \left(\frac{D_2}{D_1} \right)^2 \left(\frac{120}{Re} - 1 \right) \right] \left[1 - \left(\frac{D_2}{D_1} \right)^2 \right] \left[\left(\frac{D_1}{D_2} \right)^4 - 1 \right] \quad (2.1.25)$$

For upstream $Re > 2500$:

$$K_1 = \left[2.72 - \left(\frac{D_2}{D_1} \right)^2 \left(\frac{4000}{Re} \right) \right] \left[1 - \left(\frac{D_2}{D_1} \right)^2 \right] \left[\left(\frac{D_1}{D_2} \right)^4 - 1 \right] \quad (2.1.26)$$

2.1.7.6 Branch Option 6 (Thick Orifice)

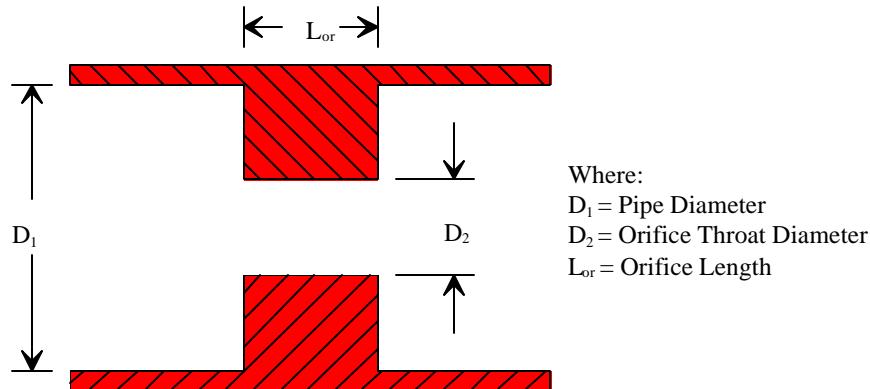


Figure 2.1.7 - Thick Orifice Resistance Option Parameters

Figure 2.1.7 shows the thick orifice resistance option parameters that are required by GFSSP. This option models the branch as a thick orifice with a pipe diameter of D_1 , an orifice diameter of D_2 and orifice length of L_{or} . This option should be used if $L_{or}/D_2 \leq 5$. If $L_{or}/D_2 > 5$ the user should use a square

expansion, Option 8, or a square reduction, Option 7. For Option 6, K_f can be expressed as in Equation 2.1.24. However, the K_1 in Equation 2.1.24 is calculated [8] from the following expressions.

For upstream $Re \leq 2500$:

$$K_1 = \left[2.72 + \left(\frac{D_2}{D_1} \right)^2 \left(\frac{120}{Re} - 1 \right) \right] \left[1 - \left(\frac{D_2}{D_1} \right)^2 \right] \left[\left(\frac{D_1}{D_2} \right)^4 - 1 \right] \left[0.584 + \frac{0.0936}{\left(L_{or} / D_2 \right)^{1.5} + 0.225} \right] \quad (2.1.27)$$

For upstream $Re > 2500$:

$$K_1 = \left[2.72 - \left(\frac{D_2}{D_1} \right)^2 \left(\frac{4000}{Re} \right) \right] \left[1 - \left(\frac{D_2}{D_1} \right)^2 \right] \left[\left(\frac{D_1}{D_2} \right)^4 - 1 \right] \left[0.584 + \frac{0.0936}{\left(L_{or} / D_2 \right)^{1.5} + 0.225} \right] \quad (2.1.28)$$

2.1.7.7 Branch Option 7 (Square Reduction)

Figure 2.1.8 shows the square reduction resistance option parameters that are required by GFSSP. This option considers the branch as a square reduction. The diameters of the upstream and downstream pipes are D_1 and D_2 respectively. For this option, K_f can be expressed as in Equation 2.1.24. However, the K_1 in Equation 2.1.24 is calculated from the following expressions [8]. The Reynolds number and friction factor that are utilized within these expressions are based on the upstream conditions. *The user must specify the correct flow direction through this branch. If the model determines that the flow direction is in the reverse direction, the user will have to replace the reduction with an expansion and rerun the model.*

For upstream $Re \leq 2500$:

$$K_1 = \left[1.2 + \frac{160}{Re} \right] \left[\left(\frac{D_1}{D_2} \right)^4 - 1 \right] \quad (2.1.29)$$

For upstream $Re > 2500$:

$$K_1 = \left[0.6 + 0.48f \right] \left(\frac{D_1}{D_2} \right)^2 \left[\left(\frac{D_1}{D_2} \right)^2 - 1 \right]^2 \quad (2.1.30)$$

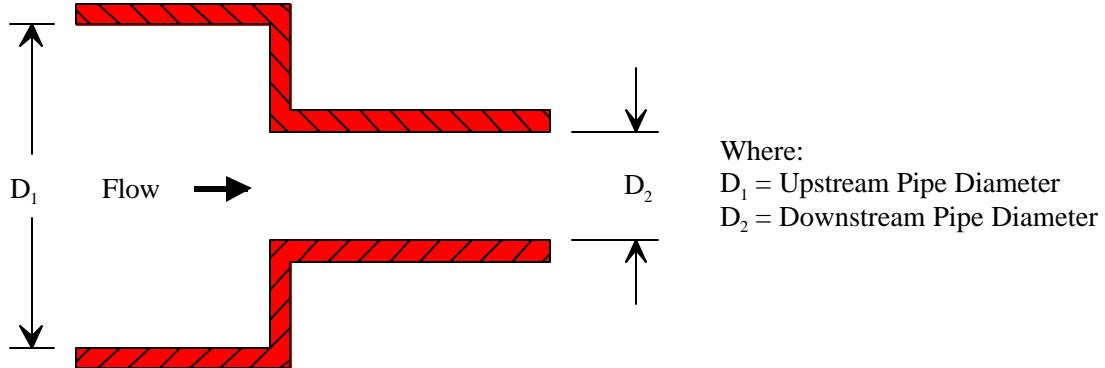


Figure 2.1.8 - Square Reduction Resistance Option Parameters

2.1.7.8 Branch Option 8 (Square Expansion)

Figure 2.1.9 shows the square expansion resistance option parameters that are required by GFSSP. This option considers the branch as a square expansion. The diameters of the upstream and downstream pipes are D_1 and D_2 respectively. For this option, K_f can be expressed as in Equation 2.1.24. However, the K_1 in Equation 2.1.24 is calculated from the following expressions [8]. The Reynolds number and friction factor that are utilized within these expressions are based on the upstream conditions. *The user must specify the correct flow direction through this branch. If the model determines that the flow direction is in the reverse direction, the user will have to replace the expansion with a reduction and rerun the model.*

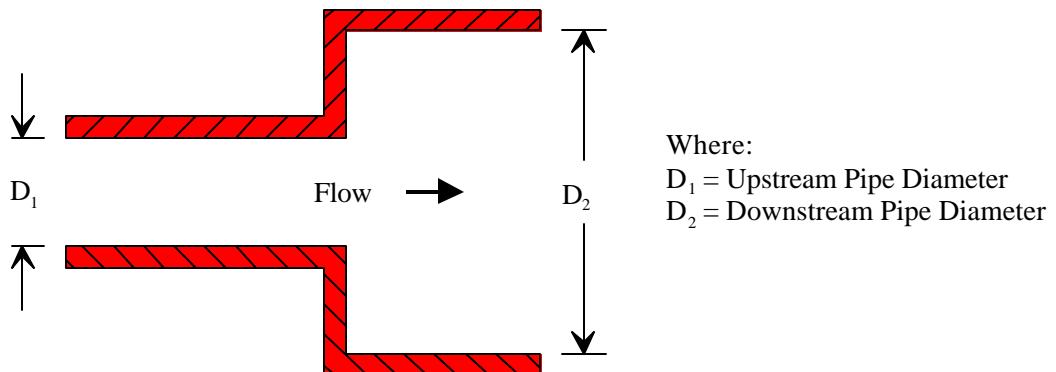


Figure 2.1.9 - Square Expansion Resistance Option Parameters

For upstream $Re \leq 4000$:

$$K_1 = 2 \left[1 - \left(\frac{D_1}{D_2} \right)^4 \right] \quad (2.1.31)$$

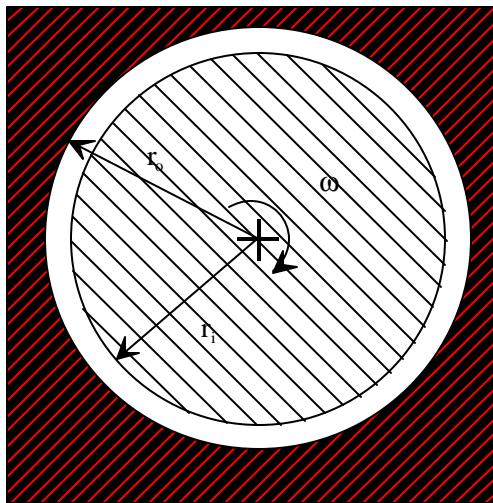
For upstream $Re > 4000$:

$$K_l = [1 + 0.8f] \left[1 - \left(\frac{D_1}{D_2} \right)^2 \right]^2 \quad (2.1.32)$$

2.1.7.9 Branch Option 9 (Rotating Annular Duct)

Figure 2.1.10 shows the rotating annular duct resistance option parameters that are required by GFSSP. This option considers the branch as a rotating annular duct. The length, outer and inner radius of the annular passage are L , r_o , and r_i respectively. The inner surface is rotating at N rpm ($N=30\omega/\pi$). For this option, K_f can be expressed as:

$$K_f = \frac{fL}{\rho_u \pi^2 A^2 g_c (r_o - r_i)} \quad (2.1.33)$$



Where:

L = Duct Length (Perpendicular to Page)

b = Duct Wall Thickness ($b = r_o - r_i$)

ω = Duct Rotational Velocity

r_i = Duct Inner Radius

r_o = Duct Outer Radius

Figure 2.1.10 - Rotating Annular Duct Resistance Option Parameters

The friction factor, f , in Equation 2.1.33 was calculated from the following expressions [12]:

$$f_{0T} = 0.077 (Ru)^{-0.24} \quad (2.1.34)$$

Where:

$$Ru = \frac{\rho_u u 2(r_o - r_i)}{\mu} \quad (2.1.35)$$

And u is the mean axial velocity, therefore:

$$\frac{f}{f_{0T}} = \left[1 + 0.7656 \left(\frac{\omega r_i}{2u} \right)^2 \right]^{0.38} \quad (2.1.36)$$

2.1.7.10 Branch Option 10 (Rotating Radial Duct)

Figure 2.1.11 shows the rotating radial duct resistance option parameters that are required by GFSSP. This option considers the branch as a rotating radial duct. This option accounts only for the frictional losses encountered with this type of flow. Since centrifugal effects are also important in a rotating radial duct, the user must select this option and activate the rotational term in the momentum conservation equation (Equation 2.1.2).

Where:
 L = Duct Length
 ω = Duct Rotational Velocity
 D = Duct Diameter

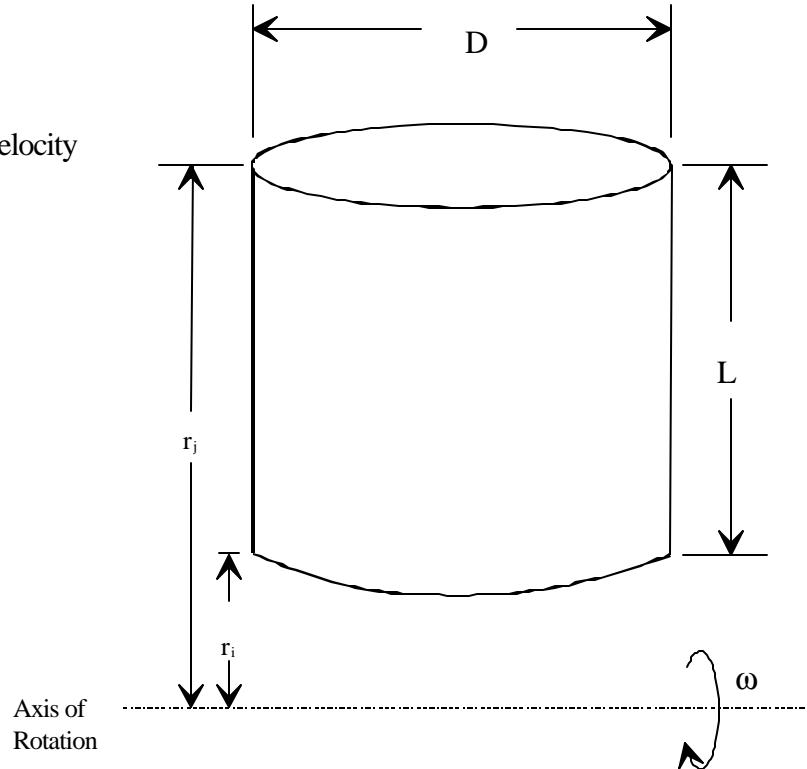


Figure 2.1.11 - Rotating Radial Duct Resistance Option Parameters

The length and diameter of the duct are L and D respectively. The rotational speed is ω radian/sec. For this option, K_f can be expressed as:

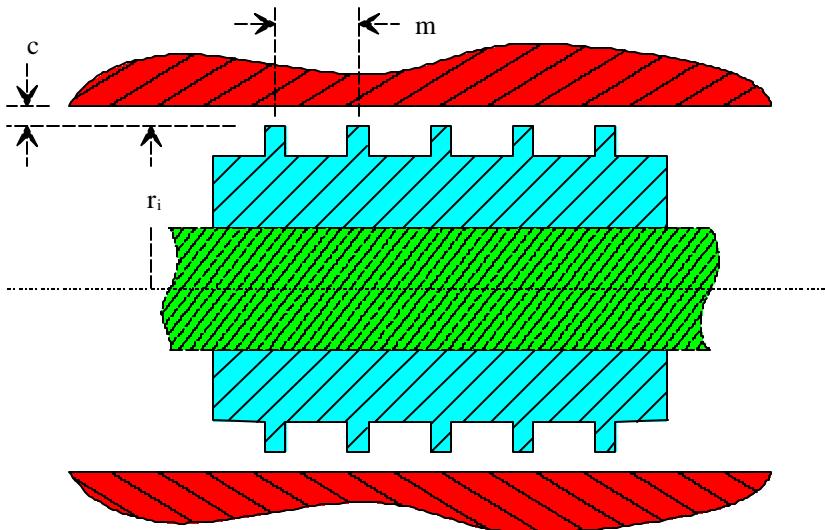
$$K_f = \frac{8fL}{\rho_u \pi^2 D^5 g_c} \quad (2.1.37)$$

The friction factor, f , in equation 2.1.37 was calculated from the following equations [11]:

$$f_{0T} = 0.0791(\text{Re})^{-0.25} \quad (2.1.38)$$

$$\frac{f}{f_{0T}} = 0.942 + 0.058 \left[\left(\frac{wD}{u} \right) \left(\frac{wD^2}{n} \right) \right]^{0.282} \quad (2.1.39)$$

2.1.7.11 Branch Option 11 (Labyrinth Seal)



Where:
 c = Clearance
 m = Gap Length (Pitch)
 r_i = Radius (Tooth Tip)
 n = Number of Teeth

Figure 2.1.12 - Labyrinth Seal Resistance Option Parameters

Figure 2.1.12 shows the labyrinth seal resistance option parameters that are required by GFSSP. This option considers the branch as a labyrinth seal. The number of teeth, clearance and pitch are n , c and m respectively. For this option, K_f can be expressed as:

$$K_f = \frac{(1/\varepsilon^2 + 0.5)n + 1.5}{2g_c \rho_u \alpha^2 A^2} \quad (2.1.40)$$

where the carry over factor, ε , is expressed as:

$$\epsilon = \sqrt{\frac{1}{1 - \frac{(n-1)c/m_p}{n(c/m + 0.02)}}} \quad (2.1.41)$$

For a straight labyrinth seal α should be set to unity. For a stepped labyrinth seal α should be less than unity. A value of 0.9 has been recommended for many rocket engine turbopump applications.

2.1.7.12 Branch Option 12 (Flow Between Parallel Plates)

Figure 2.1.13 shows the parallel flat plate resistance option parameters that are required by GFSSP. This option considers the branch as having laminar flow between parallel flat plates. A face seal can be modeled using this option. The flow is assumed to occur between two parallel plates separated by a distance equal to the clearance between the shaft and the housing. The effect of curvature is neglected. The length, inner diameter and clearance of the seal are L, D and c respectively. For this option, K_f can be expressed [10] as:

$$K_f = \frac{12\mu L \rho}{\pi g_c D c^3 |m|} \quad (2.1.42)$$

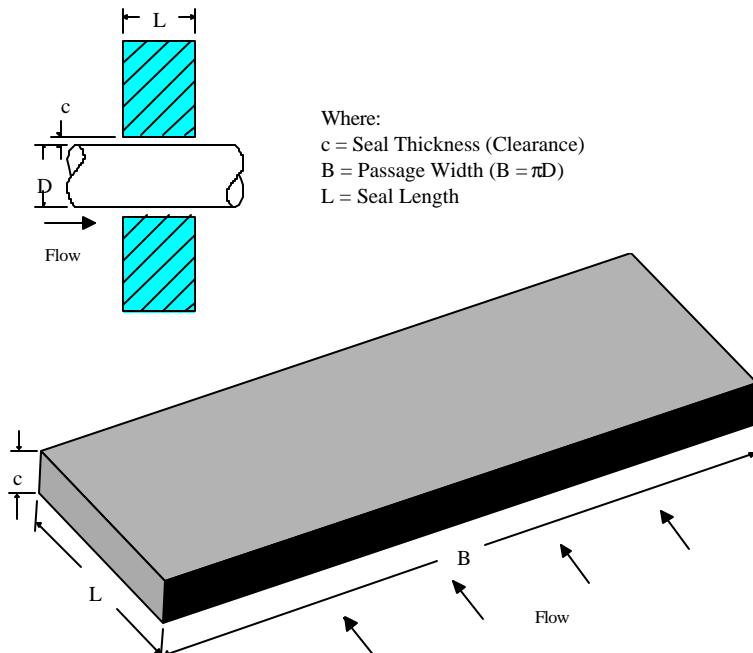


Figure 2.1.13 - Parallel Flat Plate Resistance Option Parameters

2.1.7.13 Branch Option 13 (Common Fittings and Valves)

This option considers the branch as a common fittings or valves. The resistance in common fittings and valves can be computed by the two-K method [9]. For this option, K_f can be expressed as:

$$K_f = \frac{K_1 / Re + K_\infty (1 + 1 / D)}{2 g_c \rho_u A^2} \quad (2.1.43)$$

Where:

- K_1 = K for the fitting at $Re = 1$;
- K_∞ = K for the fitting at $Re = \infty$;
- D = Internal diameter of attached pipe, in.

The constants K_1 and K_∞ for common fittings and valves are listed in Table 2.1.3.

2.1.7.14 Branch Option 14 (Pump Characteristics)

This option considers the branch as a pump with given characteristics. The pump characteristics must be expressed as:

$$\Delta p = A_0 + B_0 \dot{m}^2 \quad (2.1.44)$$

Where:

Δp = Pressure rise, lbf/ft²

\dot{m} = Flow rate, lbm/sec

The momentum source, S, in Equation 2.1.2 is then expressed as:

$$S = \Delta p A \quad (2.1.45)$$

2.1.7.15 Branch Option 15 (Pump Horsepower)

This option considers the branch as a pump with a given horsepower, P, and efficiency, η . The momentum source, S, in Equation 2.1.2 is then expressed as:

$$S = \frac{550 \rho_u P \eta A}{\dot{m}} \quad (2.1.46)$$

**Table 2.1.3 - Constants for Two K Method of Hooper (Reference 9) for Fittings/Valves
(GFSSP Resistance Option 13)**

Fitting Type		K_I	K_Y	
90° Elbows	Standard (R/D = 1), Screwed	800	0.40	
	Standard (R/D = 1), Flanged or Welded	800	0.25	
	Long Radius (R/D = 1.5), All Types	800	0.20	
	Mitered (R/D = 1.5)	1 Weld (90° Angle)	1000	1.15
		2 Welds (45° Angle)	800	0.35
		3 Welds (30° Angle)	800	0.30
		4 Welds (22.5° Angle)	800	0.27
		5 Welds (18° Angle)	800	0.25
45° Elbows	Standard (R/D = 1), All Types	500	0.20	
	Long Radius (R/D = 1.5), All Types	500	0.15	
	Mitered, 1 Weld, 45° Angle	500	0.25	
	Mitered, 2 Weld, 22.5° Angle	500	0.15	
180° Elbows	Standard (R/D = 1), Screwed	1000	0.60	
	Standard (R/D = 1), Flanged or Welded	1000	0.35	
	Long Radius (R/D = 1.5), All Types	1000	0.30	
Tee, Used as Elbow	Standard, Screwed	500	0.70	
	Long Radius, Screwed	800	0.40	
	Standard, Flanged or Welded	800	0.80	
	Stub-in-type Branch	1000	1.00	
Tee, Flow Through	Screwed	200	0.10	
	Flanged or Welded	150	0.50	
	Stub-in-type Branch	100	0.0	
Valves	Gate, Ball, Plug $(\beta = d_{\text{orifice}}/d_{\text{pipe}})$	Full Line Size, $\beta = 1.0$	300	0.10
		Reduced Trim, $\beta = 0.9$	500	0.15
		Reduced Trim, $\beta = 0.8$	1000	0.25
	Globe, Standard		1500	4.0
	Globe, Angle or Y-Type		1000	2.0
	Diaphragm, Dam Type		1000	2.0
	Butterfly		800	0.25
	Check	Lift	2000	10.0
		Swing	1500	1.5
		Tilting Disk	1000	0.5

2.1.7.16 Branch Option 16 (Valve with a Given Loss Coefficient)

This option considers the branch as a valve with a given flow coefficient, C_v . The flow coefficient is the volume (in gallons) of water at 60 °F that will flow per minute through a valve with a pressure drop of 1 psi across the valve. The recommended formula for C_v determination with water is:

$$C_v = Q \sqrt{\frac{1}{\Delta p}} \quad (2.1.47)$$

Where Q is the volumetric flow rate in GPM of water at 60° F and Δp is the pressure drop in psia. For this option, K_f can be expressed as:

$$K_f = \frac{4.68 \times 10^5}{\rho_u C_v^2} \quad (2.1.48)$$

2.1.7.17 Branch Option 17 (Joule-Thompson Device)

This option considers the branch as a Viscojet [30], which is a specific type of flow resistance with relatively large flow passages with very high-pressure drops. The flow rate through the Viscojet is given by:

$$w = 10000 k_v \frac{V_f}{L_{ohm}} \sqrt{\Delta p S} (1 - x) \quad (2.1.49)$$

Where w is the flow rate in lbm/hr, L_{ohm} is the resistance of the fluid device, k_v is an empirical factor and V_f is the viscosity correction factor.

For this option, K_f can be expressed as:

$$K_f = \frac{18.6624}{S} \left(\frac{L_{ohm}}{V_f k_v (1 - x)} \right)^2 \quad (2.1.50)$$

2.1.7.18 Branch Option 18 (Control Valve)

This is an exclusively transient option that considers the branch as a control valve that monitors the pressure at some arbitrary point downstream of the valve and opens and closes to maintain that pressure within a prescribed tolerance. This option was originally developed for use with the pressurization option to model on/off, or “bang-bang”, pressurization systems as shown in Figure 2.1.14. The valve is regarded as a flow restriction with a given flow coefficient, C_L , and area, A , and uses Equation 2.1.15 to calculate K_f for the valve.

The remaining inputs for the control valve option define its open/close characteristics. The sub-option determines the type of open/close response of the valve (instantaneous, linear or non-linear) and the valve initial position describes whether the valve is initially open or closed. The control node defines the location in the model where the control valve option is to monitor and maintain the pressure while the pressure tolerance file name provides the code with the name of the file containing the pressure tolerance data for the control valve. For a linear open/close response, the time to open/close and the number of time steps needed to complete that response are provided as additional inputs. Finally, for a non-linear open/close response, the file names for the open and close characteristics of the valve are required as additional inputs.

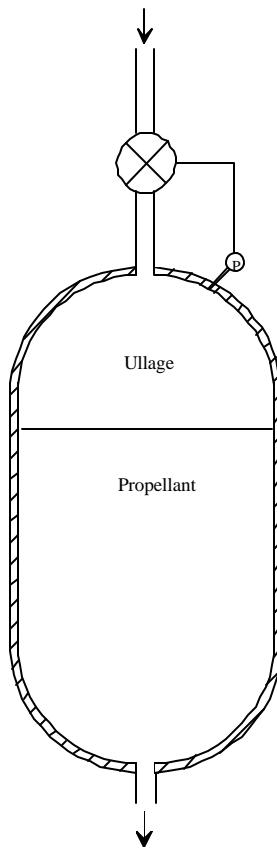


Figure 2.1.14 – Control Valve in a Pressurization System

2.2 SOLUTION PROCEDURE

In the sample circuit shown in Figure 2.1, pressures, temperatures, and concentrations of helium, hydrogen and oxygen are to be calculated for the 7 internal nodes; flow rates are to be calculated in the 12 branches. The total number of equations can be evaluated from the following relationship: Number of equations = Number of internal nodes * Number of scalar transport equations + Number of branches. Therefore, the total number of equations to be solved is 40 ($= 7 \times 4 + 12$). There is no explicit equation for pressure. The pressures are implicitly computed from the mass conservation equation (Equation 2.1.1). The flow rates are calculated from Equation 2.1.2. The inertia and friction

terms are nonlinear in Equation 2.1.2. The pressures and mass flow rates appear in the flow rate equations. The enthalpy and concentrations are solved using Equations 2.1.3 and 2.1.4 respectively. The flow rates also appear in the enthalpy and the concentration equations. The governing equations to be solved are strongly coupled and nonlinear and therefore they must be solved by an iterative method.

Stoecker [31] described two types of numerical methods available to solve a set of non-linear coupled algebraic equations: (1) the successive substitution method and (2) the Newton-Raphson method. In the successive substitution method, each equation is expressed explicitly to calculate one variable. The previously calculated variable is then substituted into the other equations to calculate another variable. In one iterative cycle each equation is visited. The iterative cycle is continued until the difference in the values of the variables in successive iterations becomes negligible. The advantages of the successive substitution method are its simplicity to program and its low code overhead. The main limitation, however, is finding an optimum order for visiting each equation in the model. This visiting order, which is called the information flow diagram, is crucial for convergence. Under-relaxation (partial substitution) of variables is often required to obtain numerical stability. Details of the successive substitution method appear in Appendix C.

In the Newton-Raphson method, the simultaneous solution of a set of non-linear equations is achieved through an iterative guess and correction procedure. Instead of solving for the variables directly, correction equations are constructed for all of the variables. The intent of the correction equations is to eliminate the error in each equation. The correction equations are constructed in two steps: (1) the residual errors in all of the equations are estimated and (2) the partial derivatives of all of the equations, with respect to each variable, are calculated. The correction equations are then solved by the Gaussian elimination method. These corrections are then applied to each variable, which completes one iteration cycle. These iterative cycles of calculations are repeated until the residual error in all of the equations is reduced to a specified limit. The Newton-Raphson method does not require an information flow diagram. Therefore, it has improved convergence characteristics. The main limitation to the Newton-Raphson method is its requirement for a large amount of computer memory. Details of the Newton-Raphson method appear in Appendix B.

In GFSSP, a combination of the successive substitution method and the Newton-Raphson method is used to solve the set of equations. This method is called SASS (Simultaneous Adjustment with Successive Substitution). In this scheme, the mass and momentum conservation equations are solved by the Newton-Raphson method. The energy and specie conservation equations are solved by the successive substitution method. The underlying principle for making such a division was that the equations that are more strongly coupled are solved by the Newton-Raphson method. The equations that are not strongly coupled with the other set of equations are solved by the successive substitution method. Thus, the computer memory requirement can be significantly reduced while maintaining superior numerical convergence characteristics.

SASS has two options available. In one option, there are two iterative loops: inner and outer. In the inner iterative loop, mass and momentum conservation equations are solved by the Newton-Raphson scheme. For unsteady formulation, the equation of state is also solved by the Newton-Raphson scheme

in addition to mass and momentum conservation equations. In the outer loop, the energy and specie conservation equations are solved by the successive substitution method. The outer loop also calculates the density and other thermodynamic and thermo-physical properties and the flow resistance coefficient, K_f , which is a function of density. The total number of iterations in this option can be expressed as:

$$N_{Total} = \sum_{i=1}^{n_0} n_i , \quad (2.2.1)$$

where n_0 is the number of outer iterations and n_i is the number of inner iterations. The inner iterative cycle is terminated when the normalized maximum correction, Δ_{max} , is less than the convergence criterion, C_c . Δ_{max} is determined from

$$\Delta_{max} = MAX \left| \sum_{i=1}^{N_E} \frac{\Phi_i^' - \Phi_i}{\Phi_i} \right| \quad (2.2.2)$$

where N_E is the total number of equations solved by the Newton-Raphson scheme

$(N_E = Number\ of\ Nodes + Number\ of\ Branches\ (Steady\ Flow))$

$= Number\ of\ Nodes \times 2 + Number\ of\ Branches\ (Unsteady\ Flow))$

The outer iteration is terminated when Δ_{max}^o is less than the convergence criterion, C_c . Δ_{max}^o is determined from

$$\Delta_{max}^o = MAX \left| \Delta_{K_f}, \Delta_r, \Delta_h \text{ or } \Delta_s \right| \quad (2.2.3)$$

where,

$$\begin{aligned} \Delta_{K_f} &= MAX \left| \sum_{i=1}^{N_B} \frac{K_f^i - K_f}{K_f} \right| \\ \Delta_r &= MAX \left| \sum_{i=1}^{N_N} \frac{\mathbf{r}^i - \mathbf{r}}{\mathbf{r}} \right| \\ \Delta_h &= MAX \left| \sum_{i=1}^{N_N} \frac{h^i - h}{h} \right| \\ \Delta_s &= MAX \left| \sum_{i=1}^{N_N} \frac{s^i - s}{s} \right| \end{aligned} \quad (2.2.4)$$

N_B and N_N are the number of branches and nodes respectively in a flow circuit.

In the second option, there is only one iterative loop. During the iterative cycle mass, momentum and the equation of state are first solved by the Newton-Raphson scheme. Then the energy and specie conservation equations are solved by the successive substitution method. The iterative cycle is terminated when the normalized maximum correction, Δ_{max} , is less than the convergence criterion, C_c . The second option is more efficient than the first one. The first option, however, is more numerically stable. With the help of the logical variable, SIMUL, the user can switch between the first and second options.

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3.0 COMPUTER PROGRAM

GFSSP was developed on an IBM compatible PC using the Lahey EM32 FORTRAN compiler. The same source code also runs on a Silicon Graphics workstation. The code was developed with a modular structure to achieve two objectives. First, the code's solver module was separated from the preprocessor module such that users are not required to write any code to develop their models. Secondly, the code can easily be extended to enhance its capability by adding new modules. The main routine controls all of the program operations and makes the decisions whether to continue or to stop the calculations.

The computer program has three major parts. The first part consists of the subroutines for the preprocessor. The preprocessor allows the user to interactively create the flow network model consisting of nodes and branches. All of the input specifications, including the boundary conditions, are specified through the preprocessor. The second major part of the program consists of the subroutines that provide the initial conditions and then develop and solve all of the conservation equations in the flow network. The third part of the program consists of the thermodynamic property programs, GASP [13] and WASP [14], which provide the necessary thermodynamic and thermophysical property data required for solving the resulting system of equations.

Figure 3.1 shows GFSSP's process flow diagram. The user runs the interactive preprocessor to generate the input data file. The input data file contains all the information necessary for the model. The solver module reads the input data file and produces the solution in conjunction with the thermodynamic property programs. It should be noted that the user interfaces with the program only through the input data file. The user is never required to modify the source program to develop the model. The user is also not required to understand the structure of the solver module in order to develop their model. However, for the completeness of the documentation, a flow chart showing the major activities of the code is described in Figure 3.2.

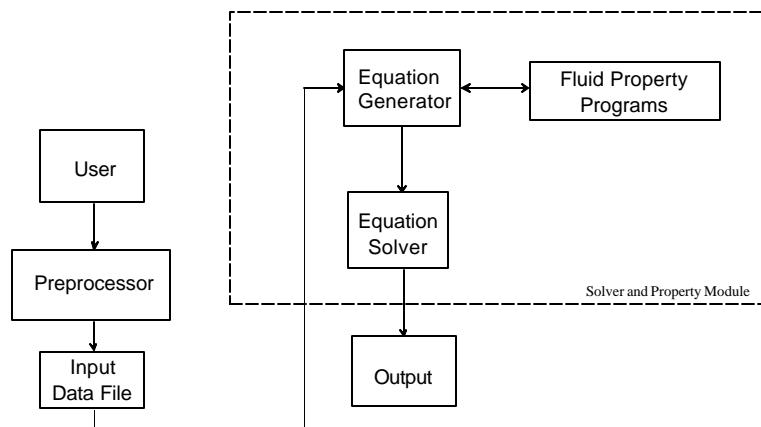


Figure 3.1 - GFSSP Process Flow Diagram

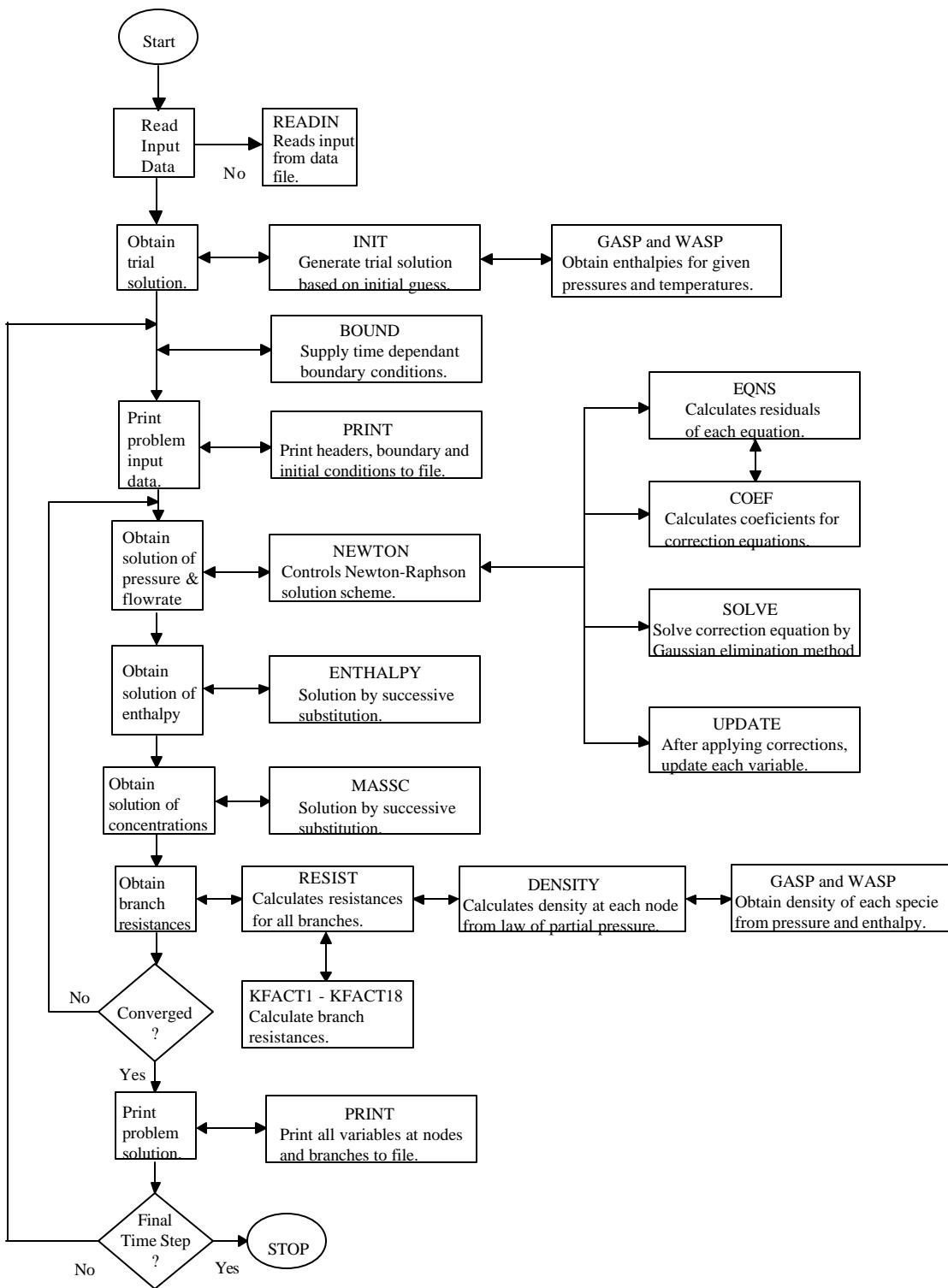


Figure 3.2 - Flowchart of Solver and Property Module

3.1 PREPROCESSOR

The preprocessor consists of one main routine and subroutine WRITEIN. This is an interactive routine that allows the user to select the necessary logical options required for their particular flow model. All of the flow network information required to define the model, including numbering and classification of nodes, the connecting branches, information to calculate branch resistance, the initial and boundary conditions, are provided through an interactive dialogue with the user. At the end of the interactive session, the input data is written by Subroutine WRITEIN to a text file.

3.2 SOLVER

The main routine and the associated set of subroutines perform seven major functions including: 1) the reading of the input data file generated by the preprocessor, 2) the generation of a trial solution based on the initial guess, 3) supply time-dependent boundary conditions, 4) Newton-Raphson solution of the conservation equations, 5) successive substitution method of solving the concentration equation, 6) the calculation of the flow resistance in the branches, and 7) prints input/output variables of the problem. The subroutine READIN reads the input data file. The subroutine INIT generates a trial solution by interacting with the thermodynamic property codes GASP, WASP and GASPAK, or the RP-1 tables. Subroutine BOUND reads any applicable time-dependent boundary conditions from the model history files. Subroutine NEWTON conducts the Newton-Raphson solution of the mass conservation, flow rate and energy conservation equations with the help of the subroutines EQNS, COEF, SOLVE and UPDATE. The subroutine EQNS generates the equations. The coefficients of the correction equations are calculated in COEF. The correction equations are solved by the Gaussian Elimination method in SOLVE. After applying the corrections, the variables are updated in subroutine UPDATE. The resistance for each branch is calculated in RESIST following the calculation of fluid densities at each node in the subroutine DENSITY. The flow resistance coefficients (K_f) for each branch are computed in subroutines KFACT1 through KFACT18 depending upon the resistance option selected for a particular branch. The solver module also calls twelve User Subroutines from various subroutines as described in Section 3.4.

3.3 THERMODYNAMIC PROPERTY PACKAGE

The thermodynamic property packages included in GFSSP consist of two separate programs, GASP [13] and WASP [14] and it also includes tabulated data for RP-1 [15]. The GASP and WASP programs consist of a number of subroutines. GASP provides the thermodynamic properties for ten fluids: helium, methane, neon, nitrogen, carbon monoxide, oxygen, argon, carbon dioxide, fluorine and hydrogen. WASP provides the thermodynamic properties of water. RP-1 properties are provided in the form of tables. Subroutine RP1 searches for the required property values from these tables.

The thermodynamic property subroutines are called from two GFSSP subroutines, INIT and DENSITY. In subroutine INIT, enthalpies and densities are computed from given pressures and temperatures at the boundary and internal nodes. In subroutine DENSITY, density, temperatures, specific heats and specific heat ratios are calculated from given pressures and enthalpies at each node.

3.4 USER SUBROUTINES

Experienced users have the ability to introduce additional capability in the code through User Subroutines. Twelve User Subroutines are called from various locations of the Solver module.

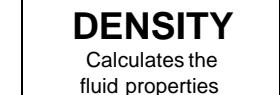
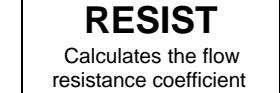
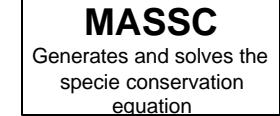
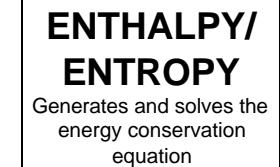
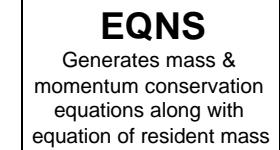
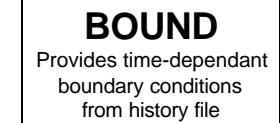
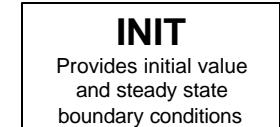
The caller and called subroutines are shown in Figure 3.3. All necessary GFSSP variables are available through COMMON BLOCK and subroutine arguments. Users can develop many additional capabilities by developing their own code in User Subroutines. These may include:

1. Heat or mass transfer model in any node of a circuit.
2. External forces applied on the fluid in any branch of the circuit. Users also have the ability to modify the existing formulation of various forces already existing in the code.
3. Variable time step, geometry and boundary conditions for a time-dependant problem.
4. New resistance or fluid option.
5. Develop customized output and/or plot file.

Appropriate use of User Subroutines requires some familiarity with GFSSP variables and indexing practice. Common block variables are explained in Appendix – D. GFSSP indexing practice and User subroutines are explained in Section 4.3 and 4.4 respectively. The use of User Subroutines has also been demonstrated in Examples 8 and 10.

In Example 8, an alternate thermodynamic property program, GASPAK [28], was integrated through User Subroutines. GASPAK provides thermodynamic properties for helium, methane, neon, nitrogen, carbon monoxide, oxygen, argon, carbon dioxide, hydrogen, parahydrogen, water, isobutane, butane, deuterium, ethane, ethylene, hydrogen sulfide, krypton, propane, xenon, R-11, R-12, R-22, R-32, R-123, R-124, R-125, R-134A, R-152A, nitrogen trifluoride and ammonia. In Example 10, User Subroutines are used to include the effects of mass transfer on a tank pressurization simulation.

Solver Module/function



User Subroutine/function

FILENUM

Defines input and output files numbers within the code

TSTEP

Allows user to overwrite the input deck defined time step

USRSET

Allows user to redefine input file to custom format

USRINT

Allows user to overwrite initial values and
steady state boundary conditions

BNDUSER

Allows user to define time-dependant boundary conditions

SORCEM

Allows user to provide an external mass source

SOURCEF

Allows user to provide an external momentum source

SOURCEQ

Allows user to provide an external heat source

SOURCEC

Allows user to provide an external specie source

KFUSER

Allows user to define new resistance options

PRPUSER

Allows user to define new fluid properties

PRNUSER

Allows user to provide any additional output file(s)

Figure 3.3 - Interaction of User Subroutine with Solver Module

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4. 0 USER'S GUIDE

In the previous chapter, we learned that GFSSP's interactive preprocessor generates the model input data file that is read by the solver module. The purpose of this chapter is to provide detailed instructions on how to create a data file for any given flow circuit with the help of the GFSSP interactive preprocessor. This chapter also includes a detailed description of the contents of the model input data file. An introduction to GFSSP's indexing system and User Subroutines has been included for the users to add additional capabilities in the code.

4.1 PREPROCESSOR

The GFSSP preprocessor prompts the user for all of the necessary information to create the model input data file. After prompting the user for all of the data required to define the model, the code writes this data into a file specified by the user at the end of the interactive session. As part of the model definition process, the user will provide a file name to be used by the program for the output file and the analyst's name, which is also recorded in the input and output files. Before building the desired model, the preprocessor will prompt the user to input a model title of less than or equal to 80 characters. After the preceding information has been input, the preprocessor will proceed to construct the model.

The sequence of inputs defining the model in the preprocessor are as follows:

1. Selection of model options
2. Node information
3. Branch information
4. Boundary conditions
5. Additional information

These steps will be discussed in detail in the following sections.

4.1.1 Selection of Model Options

GFSSP offers the capability to model various physical situations. These capabilities are made available through model logical options that are set by the model builder to either 'true' or 'false'. The user can select one or more of these options during the development of a flow model. A complete listing of the available logical variables and their significance appears in Table 4.1.1.

During a model building session, the preprocessor will ask the user to select between various modeling options available in the code. The user can select the option by typing either an upper or lower case 'y' to activate the current option or 'n' to leave the option deselected. The code sets the logical variables either to TRUE or FALSE depending upon the user's answer to the preprocessor's prompt.

The interactive session is sequential. This implies that the preprocessor will prompt the user to supply information based on the choices made previously during this session. The following sections provide additional details for each of the available logical options.

Table 4.1.1 - GFSSP Logical Variables

Variable	Meaning
DENCON	= T; The program utilizes a user supplied constant density and viscosity.
	= F; All thermodynamic and thermophysical properties are computed.
GRAVITY	= T; Gravitational force effects will be calculated for branches utilizing Resistance Option 1 or 4.
	= F; Gravitational force effects are not calculated.
ENERGY	= T; The energy equation is solved (for DENCON = F and/or with heat sources).
	= F; The energy equation is not solved.
MIXTURE	= T; Used when there is more than one fluid in the circuit.
	= F; Used when there is single fluid in the circuit.
THRUST	= T; Axial thrust is calculated by the program from node pressures and areas.
	= F; Axial thrust is not calculated by the program.
STEADY	= T; Calculates a steady state solution for the given flow circuit.
	= F; Performs quasi-steady and unsteady calculations for the flow circuit with a given time history for the boundary conditions.
TRANSV	= T; This option allows the program to perform unsteady calculations.
	= F; Unsteady effect is neglected
SAVER	= T; This option allows the program to save the solution in a restart data file.
	= F; The solution is not saved to a restart data file.
HEX	= T; This option indicates to the program that the user wants to include a heat exchanger in the model.
	= F; This option indicates to the program that the user does not want to include a heat exchanger in the model.
HCOEF	= T; This option sets the program to calculate the overall heat transfer coefficient for a heat exchanger.
	= F; This option requires the user to supply the overall heat transfer coefficient for a heat exchanger.
REACTING	= F; This option is currently inactive and must be set to FALSE.
INERTIA	= T; The inertial effects of the fluid are considered.
	= F; The inertial effects of the fluid are neglected.

Variable	Meaning
CONDX	= T; This option calculates heat conduction within the fluids. = F; Heat conduction within the fluids is neglected.
ADDPROP	= T; This option allows the user to access the thermophysical property package GASPAK which contains data for 33 fluids. = F; This option allows user to access the thermophysical property packages GASP and WASP which contains data for 12 fluids.
PRINTI	= T; This option prints out the initial flow field. = F; This option suppresses the print out of the initial flow field.
ROTATION	= T; This option allows the user to input branches with rotation. = F; Branch rotation is not activated.
BUOYANCY	= T; This option activates buoyancy when GRAVITY = .TRUE. = F; Buoyancy is not activated.
HRATE	= T; The applied heat load is in Btu/sec = F; The applied heat load is in Btu/lbm
INVAL	= T; This option allows the program to read the initial flow field from a named restart data file. = F; The initial flow field is not read from a data file.
MSORCE	= T; This option allows the user to specify a momentum source in a given branch. = F; The user does not want to specify a momentum source.
MOVBND	= T; This option allows the user to model a moving boundary in a node. = F; The moving boundary option is not activated.
TPA	= T; This option allows the user to include a turbopump assembly. = F; This choice indicates that the user does not want to include a turbopump assembly.
VARGEO	= T; This option allows the user to model a time dependent geometry. = F; The model geometry is considered to be invariant in time.
TVM	= F; ; This option is currently inactive and must be set to FALSE.
SHEAR	= F; ; This option is currently inactive and must be set to FALSE.
LAMINAR	=T; This option uses molecular viscosity to calculate momentum transport by shear =F; This option uses wall function to calculate momentum transport by shear
TRANSQ	=T; This option allows the user to a time dependent heat source =F; Heat source is invariant with time
PRESS	=T; This option allows the user to include a tank pressurization system =F; This choice indicates that the user does not include this option.
INSUC	= F; This option is currently inactive and must be set to FALSE.
VARROT	= T; This option allows the user to model a time dependent rotational speed. = F; The rotational speed is considered to be invariant in time.

Variable	Meaning
NORMAL	=T; This option allows the user to include normal stress in momentum equation. =F; Normal stress is neglected in momentum equation.
SIMUL	=T; This option activates simultaneous solution scheme. =F; Simultaneous solution scheme is not activated.
SECONDL	=T; This option allows users to solve energy conservation equation based on entropy. =F; This option allows users to solve energy conservation equation based on enthalpy.
PRINTIN	= T; This option prints the model input data file information into the output file. = F; Input data file information is not printed into the output file
PRNTADD	= T; This option prints additional thermodynamic and thermophysical property data into the output file. = F; Additional printout is not activated.

4.1.1.1 Compressibility Option

The preprocessor will set the compressibility option based on the users response to the following question:

“IS DENSITY CONSTANT IN THE CIRCUIT?”

If the user answers ‘yes’ to this question, the program will assume a constant density within the fluid circuit and the user will be prompted to supply the density and viscosity of the fluid. If user answers ‘no’ to this question, the program will assume that the density can vary and will prompt the user, later in the model building process, to select the appropriate fluid or fluids, in the case of a mixture, from the GFSSP library of fluids. These related questions will be asked at the end of the “model options” portion of the current preprocessor interactive session.

4.1.1.2 Transient Option

The preprocessor will set the transient option based on the users response to the following question:

“IS FLOW TRANSIENT?”

GFSSP has the capability to model steady, quasi-steady and unsteady flow in any given flow system. If the user answers ‘no’ to the preceding question, a steady state flow will be assumed. If the user selects the transient option by responding to the preceding question with a ‘yes’, the program will require the

user to distinguish between the quasi-steady and unsteady formulations. Therefore, to make the distinction, the program asks the following question:

“WILL NODE VOLUME BE SUPPLIED?”

The unsteady formulation requires node volume information. A ‘yes’ answer to this question will select an unsteady formulation, while a ‘no’ answer will lead to a quasi-steady formulation. For either the quasi-steady or the unsteady formulation, the user will be required to supply time step information by answering the following question:

“INPUT TIME STEP, START TIME, AND FINAL TIME IN SECONDS”

The numbers can either be separated by a comma or by a space. The ‘enter’ key must be pressed after the requested data has been input. If the user presses the enter key before supplying all of the data requested by the preprocessor, the program will not proceed until it receives the correct number of values.

For unsteady flow, the volume could be a function of time (e.g., positive displacement pump, squeeze film damper). The user can select that option by answering ‘yes’ to the following question:

WILL GEOMETRY BE FUNCTION OF TIME?

The user will be asked to provide the name of the data file containing the variable geometry information during the sequence of supplying boundary conditions.

For unsteady flow, the user may include a tank pressurization system in a flow circuit. The user can select that option by answering ‘yes’ to the following question:

IS THERE ANY PRESSURIZATION SYSTEM?

If this option is activated, the associated questions are asked in the ‘additional information’ portion of the current preprocessor interactive session.

4.1.1.3 Gravity Option

The next preprocessor question is:

“DO YOU WANT TO ACTIVATE GRAVITY?”

If the user answers ‘yes’ to this question, the program will account for gravity effects in determining a solution for the current model. In other words, the gravitational term in Equation 2.1.2 will be included. The user will be asked to supply the orientation of the flow direction in the branches with respect to the

gravitational force vector (angle θ in Figure 2.1.2) during the ‘branch information’ portion of the current preprocessor interactive session.

The next prompt the user must respond to is:

“DO YOU WANT TO ACTIVATE BUOYANCY?”

For a problem involving natural convection, the user must activate this option by responding with a ‘y’ at the prompt. In a situation where natural convection occurs, the fluid experiences a buoyancy force because of density differences in the presence of a gravitational field. Under the action of this force, the lighter fluid tends to move up. Therefore, the buoyancy force always acts in a direction opposite to the gravitational force. If this option is activated, the user must supply a reference point for calculating the density in the ‘additional information’ portion of the current preprocessor interactive session.

4.1.1.4 Fluid Inertia Option

For many flow situations involving incompressible flows, fluid inertia can be neglected. For such flows, the momentum equation (Equation 2.1.2) represents a balance between the pressure force, friction force and body force. When analyzing compressible flows, the inertia force must be accounted for in most flow simulations. However, there are situations when dealing with compressible flows that the user may want to use a simplified version of the flow rate equation (Equation 2.1.2.c) which implicitly accounts for the inertial effect. For an additional discussion of this topic the reader is encouraged to review Section 2.1.2. To accurately model the flow in a converging-diverging nozzle, the user must include the inertia force. To include the inertia force in the compressible flow formulation, the user must answer ‘yes’ to the following question:

“DO YOU WANT TO ACTIVATE INERTIA?”

If this option is selected, the user will also be required to provide the angle between the upstream and downstream branches.

In Figure 4.1.1(a), the fluid flowing in Branch 2 experiences no inertial effects from the fluid flowing in Branch 1, assuming that the flow is from Branch 1 to Branch 2 and the angle between Branch 1 and Branch 2 is 90 degrees. In Figure 4.1.1(b), the fluid flowing in Branch 2 experiences the total effect of the inertia force from Branch 1, assuming that the flow is from Branch 1 to Branch 2 and the angle between these branches is zero. In the data file, the angles between adjacent branches are set by default to zero. The user must update the data file, using a text editor, to supply the correct angles between the branches if this option is activated.

In many flow circuits, inertia force is not important in all branches. Therefore, the user will be asked to identify the branches where inertia force must be considered as described in Section 4.2.

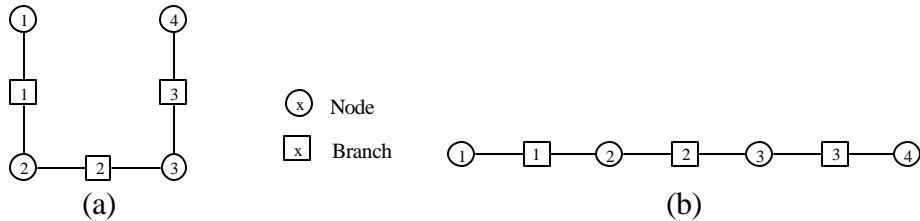


Figure 4.1.1 - Examples of Flow Circuit Arrangement to Demonstrate the Effect of Fluid Inertia.

4.1.1.5 Rotation Option

Rotating flow occurs in turbomachinery on the front and back sides of the impeller. In such flows, the axis of rotation is perpendicular to the flow direction and the flow is subjected to centrifugal force. Under these circumstances, the centrifugal force in Equation 2.1.2 must be activated by answering ‘yes’ to the following question:

“DO YOU WANT TO ACTIVATE ROTATION?”

GFSSP allows the user to model rotating flows in branches to account for the centrifugal forces on the fluid that occur in these branches due to the rotation. When the axis of rotation is not parallel to the main flow direction, the fluid experiences a centrifugal force. The magnitude of the centrifugal force depends on the radii of the axis of rotation and on the angular speed of the fluid. If this option is activated, the associated questions are asked in the ‘additional information’ portion of the current preprocessor interactive session.

If rotation is activated for unsteady flow, users will be asked the following question:

DOES ROTATIONAL SPEED VARY WITH TIME?

During start-up and shut down of the turbopump rotational speed varies with time. By answering ‘yes’ to this question, the user can activate this option and will be asked to provide a data file containing the history of rotational speed.

4.1.1.6 External Momentum Source Option

The user has an option to add external momentum sources in a particular branch. This external momentum source is included as the ‘S’ term in Equation 2.1.2 and could be due to any other body or

surface force that was not accounted for elsewhere. The user can activate this option by answering ‘yes’ to the following question:

“IS THERE ANY MOMENTUM SOURCE?”

If this option is activated, the associated questions are asked in the ‘additional information’ portion of the current preprocessor interactive session.

4.1.1.7 Axial Thrust Calculation Option

One of the main objectives for developing GFSSP was to provide a tool that could accurately calculate the axial thrust that occurs in a rocket engine turbopump. This option can be activated by answering ‘yes’ to the following question:

“IS AXIAL THRUST CALCULATION REQUIRED IN THE CIRCUIT?”

This axial thrust is created when a pressure differential exists between opposing faces of a mechanism, such as a turbine disk. If the GFSSP axial thrust calculation option is activated, the user must supply surface areas normal to the thrust vector. If a normal vector to the input surface area aligns with the thrust vector, the magnitude of the surface area, in square inches (in^2), is entered with a positive sign. The surface area must be entered with a negative sign if a normal vector to the given surface area is opposite to the direction of the thrust vector. The user may choose to update the data file, using a text editor, to supply the areas once the data file is created. The user must answer ‘n’ to this option to avoid answering questions on areas during the interactive session.

4.1.1.8 Moving Boundary Option

A moving boundary is encountered in reciprocating machines and rotodynamic applications. There are two ways the user can model a moving boundary. In a steady state flow situation, the user is required to provide the surface area and velocity of the moving node. In an unsteady flow situation, the user is required to choose the variable geometry option. In either case, to select the moving boundary option the user must say ‘yes’ to the following question:

“IS THERE ANY MOVING BOUNDARY?”

If this option is activated, the associated questions are asked in the ‘additional information’ portion of the current preprocessor interactive session.

4.1.1.9 External Heat Source Option

If the presence of heat sources or sinks in the flow circuit can affect the flow distribution, the user must activate this option by answering ‘y’ to the following question:

“ARE THERE ANY HEAT SOURCES?”

During the ‘additional information’ portion of the current preprocessor interactive session, the user will be required to identify the nodes where heat loads are applied and the magnitude of the heat loads in each of the identified nodes.

4.1.1.10 Heat Conduction Within Fluids Option

If the user wants to consider heat conduction within the fluid, the user can activate the heat conduction option between nodes by answering ‘y’ to the following question:

“DO YOU WANT TO ACTIVATE HEAT CONDUCTION?”

If this option is activated, the user must supply the distances between nodes and the cross sectional flow area normal to the heat conduction path during the ‘branch information’ portion of the current preprocessor interactive session.

4.1.1.11 Heat Exchanger Option

If the user wants to include any heat exchangers in the current model, the user must answer ‘y’ to the following question:

“IS THERE ANY HEAT EXCHANGER IN THE CIRCUIT?”

This option allows the user to include a heat exchanger, as shown in Figure 4.1.2, in a flow circuit. GFSSP has the capability to include ten heat exchangers in a flow system. If this option is activated, the user will be asked to provide the following information in the ‘additional information’ portion of the current preprocessor interactive session:

1. The number of heat exchangers to include in the circuit.
2. The branch names corresponding to the hot and cold branches of each heat exchanger.
3. User must select one of the following modeling methods:
 - a. Log Mean Temperature Difference Method
 - b. Effectiveness - NTU method.

- If the user chooses the Effectiveness - NTU method, the code will ask the user either to supply the effectiveness or to identify the type of heat exchanger so that the program can calculate the effectiveness from the built-in relationships. The code has built-in relationships for counter flow and parallel flow heat exchangers. For other types, such as cross flow or multipass, the effectiveness must be supplied by the user.

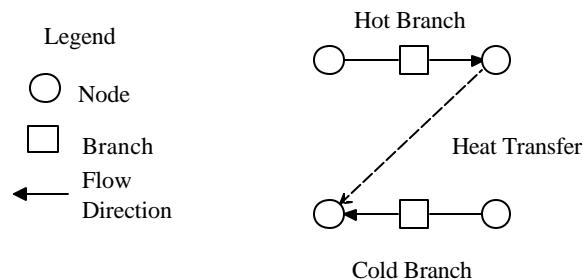


Figure 4.1.2 - Modeling of Heat Exchanger in a Flow System

4.1.1.12 Turbopump Option

If the user wants to include any turbopumps in the current model, the user must answer ‘y’ to the following question:

“IS THERE ANY TURBOPUMP ASSEMBLY IN THE CIRCUIT?”

This option allows the user to include a turbopump assembly (TPA) in a flow circuit as shown in Figure 4.1.3. GFSSP has the capability to include ten turbopump assemblies in a flow system. If this option is activated, the user will be asked to provide the following information in the ‘additional information’ portion of the current preprocessor interactive session:

- The number of turbopumps to include in the flow circuit.
- Which branches correspond to the pump and turbine branches for each turbopump assembly.
- The name of the file containing the pump performance characteristics.
- The speed and efficiency of the turbine.

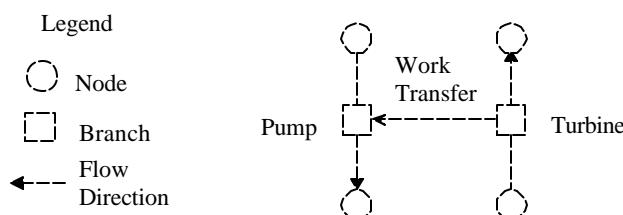


Figure 4.1.3 - Modeling of Turbopump in a Flow System

4.1.1.13 Fluid Selection

The next set of information the preprocessor will collect from the user concerns the fluid or fluids used in the flow circuit. The program will prompt the user to input whether or not multiple fluids are present in the system:

“IS THE FLUID A MIXTURE?”

Once the user answers this question, either ‘y’ or ‘n’, the code will print a list of fluids. This list will depend on which thermodynamic property package, either GASP or GASPAK, is being used. The following preprocessor screen output assumes that GASP has been selected. The only difference the user would observe if GASPAK was the selected property package would be a larger list of fluids. The fluids available with GASP are shown below and in Table 4.1.2 and the fluids available in GASPAK are shown in Table 4.1.3.

“GFSSP HAS A LIBRARY OF THE FOLLOWING FLUIDS:

- 1 - HELIUM
- 2 - METHANE
- 3 - NEON
- 4 - NITROGEN
- 5 - CARBON-MONOXIDE
- 6 - OXYGEN
- 7 - ARGON
- 8 - CARBON-DIOXIDE
- 9 - FLUORINE
- 10 - HYDROGEN
- 11 - WATER
- 12 - RP1

NOTE: RP1 PROPERTY RANGE HAS LIMITED VALIDITY;

PRESSURE RANGE:.01 TO 650 PSI

TEMPERATURE RANGE: 440 TO 600 R”

GFSSP can calculate the properties of the listed fluids. If the mixture option is not chosen, the user will need to identify only one fluid from the list. If the user answers ‘y’ to the previous question, the code will ask:

“HOW MANY OF THESE FLUIDS ARE PRESENT IN THE CIRCUIT?”

The user must provide the total number of fluids as well as identify the index number of each fluid that is present from the given list.

Table 4.1.2 - Fluids Available in GFSSP for ADDPROP = .FALSE.

Index	Fluid	Index	Fluid
1	HELIUM	7	ARGON
2	METHANE	8	CARBON DIOXIDE
3	NEON	9	FLUORINE
4	NITROGEN	10	HYDROGEN
5	CARBON MONOXIDE	11	WATER
6	OXYGEN	12	RP-1

Table 4.1.3 - Fluids Available in GFSSP for ADDPROP = .TRUE.

Index	Fluid	Index	Fluid
1	HELIUM	18	HYDROGEN SULFIDE
2	METHANE	19	KRYPTON
3	NEON	20	PROPANE
4	NITROGEN	21	XENON
5	CO	22	R-11
6	OXYGEN	23	R12
7	ARGON	24	R22
8	CO ₂	25	R32
9	PARAHYDROGEN	26	R123
10	HYDROGEN	27	R124
11	WATER	28	R125
12	RP-1	29	R134A
13	ISOBUTANE	30	R152A
14	BUTANE	31	NITROGEN TRIFLUORIDE
15	DEUTERIUM	32	AMMONIA
16	ETHANE	33	IDEAL GAS
17	ETHYLENE		

4.1.1.14 Print Control Option

The last of the program options that the user will be asked to set relates to the data that will be included in the output file. The user will be asked to select three print control options. First, the code will ask:

“DO YOU WANT PRINT OUT OF INITIAL FIELD VALUES?”

If the user does not need to see the initial solution, the user should respond with a ‘n’ to this question. This will be followed by a second question:

“DO YOU WANT TO SUPPRESS PRINT OUT OF INPUT DATA?”

By accepting this option, the user can suppress the inclusion of information in the output file that is already available in the input data file.

GFSSP also provides an additional print control option used to activate an extended print out. If the user is interested to see a print out of enthalpy, entropy and thermophysical properties, an affirmative answer to the following question is required:

“DO YOU WANT EXTENDED PRINT OUT?”

4.1.2 Node Information

Following the completion of the portion of the interactive session that sets the required program logical options, the preprocessor prompts the user to input information for the nodes that will be used for the current model. The user will first be required to supply the total number of nodes. The code will then ask the user to designate a number for each of the nodes. The numbering scheme is completely arbitrary. The user can devise any numbering scheme, using a maximum of four digits.

Next, the user is required to specify the type of each of the nodes. GFSSP allows two types of nodes. A node could be either an internal node or a boundary node. The code calculates pressures, temperatures and mixture concentrations at the internal nodes. The pressures, temperatures and concentrations must be supplied in the boundary nodes. GFSSP does not use the temperatures and concentrations at the outflow boundary nodes. However, the user must supply those values because GFSSP does not distinguish between inflow and outflow boundary nodes during problem setup. A boundary node can have either an inflow or outflow depending upon the specified boundary conditions.

The format of the questions in this portion of the current interactive session is as follows:

ENTER TOTAL NUMBER OF NODES

ENTER NUMBER ASSIGNED TO NODE 1

IS IT AN INTERNAL NODE?

The preprocessor will repeat the last two questions until the number of nodes input by the user has been reached.

4.1.3 Branch Information

After the user has completed the portion of the current interactive session that inputs the node information, the preprocessor prompts the user to input information for the branches that will be used for the current model. Every node in the circuit is connected to the circuit through at least one branch. The code will visit every internal node, identified by the user in the previous session, and ask the user to supply the number of branches connected with each internal node.

Next the preprocessor will prompt the user to supply the following information for each branch specified previously:

- a) A branch number within four digits.
- b) The assumed upstream and downstream nodes for the given branch.
- c) A branch type (resistance option) and all of the necessary information required for that resistance option.

If the gravity option is activated, the user must supply the angle that the branch makes with the gravity vector. If the heat conduction option is activated, the user must also supply the distances between the nodes and the cross sectional flow area normal to the heat conduction flux.

The format of the questions in this portion of the current interactive session is as follows (the responses to the prompts are in bold):

```
HOW MANY BRANCHES ARE CONNECTED WITH NODE    2?  
2  
ENTER BRANCH NUMBER( J = 1 OF 2 ) OF NODE    2  
12  
ENTER UPSTREAM NODE OF BRANCH NO.    12  
1  
ENTER DOWNSTREAM NODE OF BRANCH NO.    12  
2  
SELECT RESISTANCE OPTION FOR BRANCHES:  
OPTION - 1: PIPE FLOW  
OPTION - 2: FLOW THROUGH RESTRICTION  
OPTION - 3: NON-CIRCULAR DUCT  
OPTION - 4: PIPE FLOW WITH ENTRANCE & EXIT LOSS  
OPTION - 5: THIN SHARP ORIFICE  
OPTION - 6: THICK ORIFICE  
OPTION - 7: SQUARE REDUCTION
```

OPTION - 8: SQUARE EXPANSION
OPTION - 9: ROTATING ANNULAR DUCT
OPTION - 10: ROTATING RADIAL DUCT
OPTION - 11: LABY SEAL
OPTION - 12: FACE SEAL
OPTION - 13: COMMON FITTINGS & VALVES
OPTION - 14: PUMP CHARACTERISTICS
OPTION - 15: PUMP POWER PRESCRIPTION
OPTION - 16: VALVE WITH GIVEN CV
OPTION - 17: VISCOJET RESTRICTION
OPTION - 18: CONTROL VALVE
OPTION - 19: USER SPECIFIED

1

ENTER LENGTH (IN), DIAMETER (IN), & ROUGHNESS FACTOR(E/D) OF BRANCH
12

10,0.5,0.005

ENTER ANGLE WITH GRAVITY VECTOR (90 DEG FOR HORIZONTAL AXIS) FOR
BRANCH NO. **12**

100

The preceding screen prompts will be repeated until all of the branch information has been entered. One branch naming convention that has been found to be useful in modeling flow circuits is to give the branch a number that is a combination of the numbers assigned to the nodes that the branch connects. For example, if there are two nodes, Node 1 and Node 2, that are connected by one branch, the name for that branch would be 12 according to this convention. This technique has been found to be helpful in facilitating the comprehension of the model results.

4.1.4 Boundary Conditions

In this portion of the current interactive session, the user is required to supply pressures, temperatures and concentrations at all of the boundary nodes. For a steady state model, the format of the dialogue is as follows:

“ENTER PRESSURE (PSIA) & TEMPERATURE (DEG F) FOR NODE 1”

This screen prompt will be repeated for each boundary node that has been identified.

For transient calculations, the user is required to supply the filename containing the history data for each boundary node in the model. The user will be prompted to provide the following information:

“ENTER FILENAME (20 CHARACTERS) FOR READING DATA HISTORY FOR
NODE 1

The format of the file is described in Example 8 of Chapter 5.

4.1.5 Additional Information

The following subsections discuss additional information that is required by the preprocessor that is dependent on which program options the user has incorporated into the current model. If the option has not been selected the associated prompts will not be displayed by the program.

4.1.5.1 Mass Source

The user will be prompted to declare whether or not there are internal nodes that have specified flow rates entering or leaving the node, excluding what the program calculates in the connected branches, with the following question:

“HOW MANY INTERNAL NODES HAVE SPECIFIED FLOWRATES?”

GFSSP requires the specification of pressure at all of the boundary nodes. The code calculates the flow rates in all of the branches. The code, however, has been provided with the capability of accepting a mass source or sink in the internal nodes. The user will enter a ‘0’ if there is no such mass source in the circuit. Otherwise, the actual number of internal nodes with mass flowing into, or out of, must be typed. The code then will ask user to provide the following information for the supplied number of internal nodes:

- a) The internal node number.
- b) The mass source (a positive number) or mass sink (a negative number) in lb/sec.

The format of the questions will be as follows (the responses to the prompts are in bold):

HOW MANY INTERNAL NODES HAVE SPECIFIED FLOWRATES?

1

SPECIFY INTERNAL NODE NUMBER

2

SPECIFY FLOWRATE(LBM/S) FOR NODE **2**

1.0

Depending on the number entered by the user to the first question, the last two questions will be repeated until the necessary information has been entered.

4.1.5.2 Heat Source

The program will prompt the user to declare how many of the internal nodes have heat added to or removed from them with the following question:

“HOW MANY INTERNAL NODES HAVE SPECIFIED HEAT SOURCES?”

The user is prompted to supply the number of internal nodes where there are heat sources or sinks in the circuit. The user must enter a ‘0’ if there is no such source in the circuit. Otherwise, the actual number must be typed. The heat source can be specified in either BTU/lbm or in BTU/sec. The user must select the option (See Table 4.1, program option variable HRATE). The code then will ask the user to provide the following information for the input number of internal nodes:

- a) The internal node number.
- b) The heat source flux (a positive number) or sink flux (a negative number) in appropriate units.

The format of the questions will be as follows (the responses to the prompts are in bold):

HOW MANY INTERNAL NODES HAVE SPECIFIED HEAT SOURCES?

1

HEAT SOURCE SPECIFICATION HAS TWO OPTIONS

1. SOURCE IN BTU/SEC
2. SOURCE IN BTU/LBM

SELECT YOUR OPTION

2

SPECIFY INTERNAL NODE NUMBER

3

SPECIFY HEAT SOURCE (BTU/LBM) FOR NODE **3**

1.0

Depending on the number entered by the user to the first question, the last three questions will be repeated until the necessary information has been entered.

4.1.5.3 Buoyancy

If buoyancy was activated earlier in the current interactive session, the following question will be asked:

“SPECIFY REFERENCE NODE FOR DENSITY”

When buoyancy is activated, the gravitational term in Equation 2.1.2 is replaced by a buoyancy term that requires a density difference term instead of a density. The user must define the reference node for the density difference term. It is preferable to select a boundary node to be the reference node.

4.1.5.4 Rotation

If the rotational option was activated earlier in the current interactive session, the user will be prompted with the question:

"HOW MANY BRANCHES HAVE THE ROTATING FLOWS?"

Once the user answers this question, the code will ask the user to provide the following information for the user-supplied number of branches:

- a) The branch number.
- b) The upstream and downstream radius of the branch with respect to the axis of rotation.
- c) The rotational speed and the factor representing the extent of the rotation of fluid with respect to the solid boundary.

The format of the questions will be as follows (the responses to the prompts are in bold):

HOW MANY BRANCHES HAVE ROTATING FLOWS?

1

SPECIFY BRANCH NUMBER

12

INPUT UPSTREAM AND DOWNSTREAM RADIUS OF BRANCH 12

1.0,3.0

INPUT ROTATIONAL SPEED (RPM) AND KFACTOR OF BRANCH 12

30,000,0.25

Depending on the number entered by the user to the first question, the last three questions will be repeated until the necessary information has been entered.

4.1.5.5 Momentum Source

If the momentum source option was activated earlier in the current interactive session, the following questions will be asked (the responses to the prompts are in bold):

HOW MANY BRANCHES HAVE MOMENTUM SOURCES?

1

SPECIFY BRANCH NUMBER

34

INPUT MOMENTUM SOURCE IN LBF FOR BRANCH 34

1.0

Depending on the number entered by the user to the first question, the last two questions will be repeated until the necessary information has been entered.

4.1.5.6 Heat Exchanger

If the heat exchanger option was activated earlier in the current interactive session, the following questions will be asked (the responses to the prompts are in bold):

HOW MANY HEAT EXCHANGERS (HEX) ARE THERE?

1

SPECIFY HOT & COLD BRANCH FOR HEX 1

12,34

SELECT YOUR MODELING OPTION

1. LOG MEAN TEMP. DIF.(LMTD)

2. EFFECTIVENESS-NTU

SELECT 1 OR 2

2

SUPPLY EFFECTIVENESS OF HEAT EXCHANGER 1

EFFECTIVENESS BETWEEN 0 TO 1,GFSSP USES THE VALUE

EFFECTIVENESS GREATER THAN 1,GFSSP COMPUTES THE VALUE

1.5

SPECIFY TYPE OF HEAT EXCHANGER

1 : COUNTER FLOW

2 : PARALLEL FLOW

1

Depending on the number entered by the user to the first question, the last four questions will be repeated until the necessary information has been entered.

4.1.5.7 Moving Boundary

If the moving boundary option was activated earlier in the current interactive session, the following questions will be asked (the responses to the prompts are in bold):

' HOW MANY NODES HAVE MOVING BOUNDARY? '

1

'SPECIFY NODE NUMBER '

10

'SPECIFY AREA (IN**2) & VELOCITY (FPS) OF 10 '

1,10

Depending on the number entered by the user to the first question, the last two questions will be repeated until the necessary information has been entered.

4.1.5.8 Turbopump

If the turbopump option was activated earlier in the current interactive session, the following questions will be asked (the responses to the prompts are in bold):

HOW MANY TURBOPUMPS ARE IN THE CIRCUIT?

1

SPECIFY PUMP & TURBINE BRANCH FOR TPA 1

12,34

ENTER FILENAME (20 CHARACTERS) OF PUMP PERFORMANCE CURVE FOR
BRANCH 12

PCURVE.DAT

SPECIFY SPEED AND EFFICIENCY OF TURBINE FOR BRANCH 34
30000,0.85

Depending on the number entered by the user to the first question, the last three questions will be repeated until the necessary information has been entered.

4.1.5.9 Pressurization

If the pressurization option was activated earlier in the current interactive session, the following questions will be asked (the responses to the prompts are in bold):

HOW MANY TANKS ARE IN THE CIRCUIT?

1

SPECIFY TANK ULLAGE NODE & INTERFACE BOUNDARY NODE FOR TANK 1

2,3

SPECIFY INITIAL TANK TEMPERATURE (DEG F) FOR TANK 1

-264

SPECIFY TANK SURFACE AREA (IN**2),THICKNESS(IN) FOR TANK 1

6431.91,0.375

SPECIFY TANK DENSITY(LBM/FT**3) AND SPECIFIC HEAT (BTU/LBM-F) FOR
TANK 1

170.00,0.20

SPECIFY TANK CONDUCTIVITY(BTU/FT-SEC-R) FOR TANK 1

0.0362

SPECIFY AREA AND ADJUSTMENT FACTOR FOR HEAT TRANSFER
COEFFICIENT FOR TANK 1

4015.0,1.00

SPECIFY PROPELLANT NODE ADJACENT TO ULLAGE VOLUME FOR TANK 1

4

SPECIFY BRANCH FOR PROPELLANT DISCHARGE FOR TANK 1

34

Depending on the number entered by the user to the first question, the remaining questions will be repeated until the necessary information has been entered.

4.1.5.10 Interactive Session Completion

At the end of the current interactive session, the user will be asked to provide a filename for use in naming the input and output data files for the current model and the preprocessor will also request the analyst's name. The questions that will be asked in sequence are:

ENTER FILENAME FOR WRITING THE INPUT DATA

ENTER FILENAME FOR WRITING THE OUTPUT DATA

ENTER ANALYST NAME

An example of the complete interactive session of creating a data file is provided in Appendix R.

4.2 DESCRIPTION OF THE INPUT DATA FILE

The previous sections describe how to create a GFSSP model of a fluid flow network using the available GFSSP preprocessors. The following section describes the structure of the GFSSP input data file that is created by the preprocessors. The data in the GFSSP input data file can be classified into the following 18 sections. The data file from Example 1 was used as an example within this section to explain the content of the different sections of the input file:

1. Version Number:

The code prints a three digit version number:

```
GFSSP VERSION  
300
```

2. Analyst's Name:

The code prints the analyst's name with a limit of 40 characters:

ANALYST
ALOK MAJUMDAR

3. Input Data File Name:

The code prints the input data file name with a limit of 40 characters:

```
INPUT DATA FILE NAME
EX1.DAT
```

4. Output Data File Name:

The code prints output data file name with a limit of 40 characters:

```
OUTPUT FILE NAME
EX1.OUT
```

5. Title:

The user can specify a model title of 80 characters or less:

```
TITLE
PUMP-SYSTEM CHARACTERISTICS
```

6. Logical Variables:

The settings for the thirty-six program logical variables are provided in next four lines:

```
USEUP
F
DENCON GRAVITY ENERGY MIXTURE THRUST STEADY TRANSV SAVER
F T T F F T F F
HEX HCOEF REACTING INERTIA CONDX ADDPROP PRINTI ROTATION
F F F F F F F F
BUOYANCY HRATE INVAL MSORCE MOVBND TPA VARGEO TVM
F F F F F F F F
SHEAR PRNTIN PRNTADD LAMINAR TRANSQ
F F F T F
PRESS INSUC VARROT
F F F
NORMAL SIMUL SECONDL
F T T
```

Table 4.1.1 contains a listing of the GFSSP logical variables and their options.

7. Node, Branch and Fluid Information:

NNODES - Number of nodes.
NINT - Number of internal nodes.
NBR - Number of branches.
NF - Number of fluids.

NNODES	NINT	NBR	NF
4	2	3	1

8. Relaxation Parameters:

RELAXK - Under relaxation parameter for resistance (Recommended value = 1.0).
RELAXD - Under relaxation parameter for density (Recommended value = 0.5).
RELAXH - Under relaxation parameter for enthalpy (Recommended value = 1.0).

RELAXK	RELAXD	RELAXH	CC	NITER
1.000	0.500	1.000	0.100E-03	500

9. Index Number for Fluids:

The index number for each fluid is printed in this line. Table 4.1.2 and 4.1.3 show the fluids that are available in GFSSP.

NFLUID(I) , I= 1 , NF
11

10. Nodes and Indices:

In this section, the node numbers, NODE(I), and their indices, INDEX(I), are printed. INDEX(I) = 1 indicates internal node and INDEX(I) = 2 indicates a boundary node.

NODE	INDEX
1	2
2	1
3	1
4	2

11. Node Information:

In this section, pressure, temperature, mass source, heat source and node areas are printed sequentially. Node areas are required only when the axial thrust calculation option is activated. For transient

calculations, the code reads pressure, temperature and concentrations from a file defined in this part of the data file.

For STEADY = .TRUE.

NODE	PRES (PSI)	TEMP(DEGF)	MASS SOURC	HEAT SOURC	THRST AREA
1	0.1470E+02	0.6000E+02	0.0000E+00	0.0000E+00	0.0000E+00
2	0.1000E+02	0.6000E+02	0.0000E+00	0.0000E+00	0.0000E+00
3	0.4803E+02	0.6000E+02	0.0000E+00	0.0000E+00	0.0000E+00
4	0.1470E+02	0.6000E+02	0.0000E+00	0.0000E+00	0.0000E+00

For STEADY = .FALSE.

NODE	PRES (PSI)	TEMP(DEGF)	MASS SOURC	HEAT SOURC	THRST AREA
1	0.1000E+03	0.8000E+02	0.0000E+00	0.0000E+00	0.0000E+00
	hist2.dat				

12. Branch Connection:

The number of branches connected to every internal node is defined within this portion of the input file. Also included in this section are the names of the connected branches.

INODE(I) - Internal node number.

NUMBR(I) - Number of branches connected with the Ith internal node.

NAMEBR(I,J), J = 1, NUMBR(I) - Name of the branches connected with the Ith internal node.

INODE	NUMBR	BRANCH 1	BRANCH 2	BRANCH 3	BRANCH 4	BRANCH 5	BRANCH
6							
2	2	12		23			
3	2		23		34		

13. Branch Information:

Branch information is provided in this section. In the first part of this section, the branch number, upstream node, downstream node and selected resistance option are printed. In the second part, the required input parameters of every branch are printed in the same order as in the first part. A header is printed for every branch describing the required input parameters.

BRANCH	UPNODE	DNNODE	OPTION
12	1	2	14
23	2	3	13
34	3	4	1
BRANCH OPTION -14:	PUMP CONST1,	PUMP CONST2,	AREA
12	30888.00000	-0.00081	201.06177
BRANCH OPTION -13:	DIA, K1, K2,	AREA	
23	6.00000	1000.00000	0.10000 28.27431
BRANCH OPTION -1:	LENGTH, DIA,	EPSD, ANGLE,	AREA

```
34 18000.00000      6.00000      0.00500      95.74000      28.27431
```

14. Unsteady Information

When the option TRANSV is set to TRUE, initial flowrates in all branches must be provided in the input data file. This information is required after branch information. A portion of the data file from Example 10 is shown here to illustrate the format of these data.

```
INITIAL FLOWRATES IN BRANCHES FOR UNSTEADY FLOW
 12      1.00000
 34      0.01000
 45      0.01000
```

15. Inertia Information:

In order to account for the inertial effects in the fluid flow model, the velocity in the upstream branch is required along with the angle between the branches. During the course of the calculation, if the flow rate becomes negative, the designated downstream branch becomes the upstream branch. Therefore, in this section, all of the upstream and downstream branches, for each branch in the flow circuit, are defined. In the first part of this section, the number of upstream branches and their designated numbers are listed. In the second part, the number of downstream branches and their designated numbers are listed. Finally the information about the angle the branch makes with its upstream and downstream neighbors are printed. The default values of the angle are set to zero. If the user wants to modify these angles, the user must use a text editor to alter the data file.

```
BRANCH    NOUBR    NMUBR
 12          0
 23          1        12
 34          1        23
BRANCH    NODBR    NMDBR
 12          1        23
 23          1        34
 34          0
BRANCH
 12
UPSTRM BR.    ANGLE
DNSTRM BR.    ANGLE
 23          0.00
BRANCH
 23
UPSTRM BR.    ANGLE
 12          0.00
DNSTRM BR.    ANGLE
 34          0.00
BRANCH
 34
UPSTRM BR.    ANGLE
```

```
23      0.00
DNSTRM BR.    ANGLE
```

In many flow circuits the inertia term is required to be included in branches when there is a significant change in area in the direction of flow. Therefore, user must specify the branches where inertia must be activated. The following section of the data file is a sample from Example 3. Example 3 has sixteen branches and inertia is active in all sixteen branches.

```
NUMBER OF BRANCHES WITH INERTIA
16
12      - BRANCH NUMBERS
23
34
45
56
67
78
89
910
1011
1112
1213
1314
1415
1516
1617      - BRANCH NUMBERS
```

16. Rotation Information:

When the option ROTATION is set to TRUE, this section provides the related information. First, the number of rotating branches is printed. This is followed by a table of related data:

BRANCH: Designated branch number.

RADU: Radial distance to the upstream node from the axis of rotation, in units of inches.

RADD: Radial distance to the downstream node from the axis of rotation, in units of inches.

RPM: Rotational speed of the branch in units of rpm.

AKROT: Empirical factor representing the ratio of the fluid and the solid surface speeds.

A portion of the data file from Example 6 is shown here to illustrate the use of the rotation option.

```
NUMBER OF ROTATING BRANCHES
9
BRANCH    UPST RAD      DNST RAD      RPM          K ROT
23    0.125000E+01  0.225000E+01  0.500000E+04  0.867100E+00
34    0.225000E+01  0.362500E+01  0.500000E+04  0.815800E+00
45    0.362500E+01  0.468750E+01  0.500000E+04  0.763000E+00
56    0.468750E+01  0.537500E+01  0.500000E+04  0.725200E+00
67    0.537500E+01  0.550000E+01  0.500000E+04  0.707600E+00
```

89	0.550000E+01	0.537500E+01	0.500000E+04	0.712900E+00
910	0.537500E+01	0.468750E+01	0.500000E+04	0.734900E+00
1011	0.468750E+01	0.362500E+01	0.500000E+04	0.782400E+00
1112	0.362500E+01	0.265000E+01	0.500000E+04	0.837600E+00

17. Heat Exchanger

If the heat exchanger option is activated (HEX = .TRUE.), the data file contains the following variables:

NHEX: Number of heat exchangers in the circuit

IBRHOT: Branch carrying hot fluid

IBRCLD: Branch carrying cold fluid

ITYPHX: Type of heat exchanger

ARHOT: Heat transfer area on hot side

ARCOLD: Heat transfer area on cold side

UA: Product of overall heat transfer coefficient and area

HEXEFF: Heat exchanger effectiveness

A portion of the data file from Example 5 is shown here to illustrate the use of the heat exchanger option.

NUMBER OF HEAT EXCHANGERS						
1						
IBRHOT	IBRCLD	ITYPHX	ARHOT	ARCOLD	UA	HEXEFF
23	67	1	0.00000	0.00000	1.10375	1.50000

18. Moving Boundary

If the moving boundary option is activated (MOVBND = .TRUE.), the data file contains the following variables:

NMNODE: Number of nodes with moving boundary

AREAN: Surface area of the node moving in to or away from the field

VBOUND: Velocity of the moving boundary (positive when moving into, negative when moving away from)

A portion of the data file from Example 7 is shown here to illustrate the use of the moving boundary option.

NUMBER OF NODES WITH MOVING BOUNDARY		
18		
NODE	AREAN	VBOUND
2	0.777126E+00	0.256180E+00
3	0.777126E+00	0.484598E+00
4	0.777126E+00	0.660503E+00

```

5  0.777126E+00  0.764832E+00
6  0.777126E+00  0.786280E+00
7  0.777126E+00  0.722522E+00
8  0.777126E+00  0.580468E+00
9  0.777126E+00  0.375510E+00
10 0.777126E+00  0.129861E+00
11 0.777126E+00 -0.129861E+00
12 0.777126E+00 -0.375510E+00
13 0.777126E+00 -0.580468E+00
14 0.777126E+00 -0.722522E+00
15 0.777126E+00 -0.786280E+00
16 0.777126E+00 -0.764832E+00
17 0.777126E+00 -0.660503E+00
18 0.777126E+00 -0.484598E+00
19 0.777126E+00 -0.256180E+00

```

19. Pressurization

If the pressurization option is activated (PRESS = .TRUE.), the data file contains the following variables:

NTANK: Number of pressurization tanks in a model

NODUL: Node number representing ullage in a given tank

NODULB: Pseudo boundary node representing the interface between ullage and propellant

NODPRP: Node number representing propellant tank pressure and temperature

IBRPRP: Branch number representing propellant flow rate

TNKAR: Tank surface area (ft^2) for heat transfer with ullage gas

TNKTH: Tank thickness (ft) for heat conduction calculation in tank wall

TNKCP: Tank density (lb_m/ft^3) for heat conduction calculation in tank wall

TNKCON: Tank specific heat ($\text{Btu}/\text{lb}_m \cdot ^\circ\text{R}$) for heat conduction calculation in tank wall

ARHC: Surface area for heat transfer (ft^2) between ullage and propellant

FCTHC: Factor controlling the magnitude of heat transfer coefficient (Default value = 1)

TNKT_M: Initial Tank temperature ($^\circ\text{R}$)

A portion of the data file from Example 10 is shown here to illustrate the use of the pressurization option.

```

NUMBER OF TANKS IN THE CIRCUIT
1
NODUL NODULB NODPRP IBRPRP TNKAR TNKTH TNKRHO TNKCP TNKCON ARHC FCTHC TNKTM
2      3      4      34 6431.91  0.375 170.00  0.20 0.0362 4015.00  1.00 -264.00

```

20. Restart

Two additional data files are required if the user has activated the restart option. If SAVER = .TRUE., the code saves node and branch information in two files. One file contains the node data and the other file contains the branch information. The user can select any twenty character name for these two files. In the example listed below the names of these files are FNODE.DAT and FBANCH.DAT. If

`INVAL = .TRUE.`, the code reads node and branch information from these two data files for initial field values. This section of the data file appears as:

```
NODE DATA FILE  
FNODE.DAT  
BRANCH DATA FILE  
FBRANCH.DAT
```

4.3 GFSSP INDEXING PRACTICE

Users who will be using User Subroutines to add new features in the code need to understand the indexing practice. In order to develop the coding to incorporate new features, users need to access different variables at nodes and branches. All variables are stored in one-dimensional arrays. The description of all node variables appears in Sections 2 and 3 of Appendix D. Section 4 describes all branch variables.

4.3.1 Node Index

User defined node names are stored in NODE-array. NODE-array includes both internal and boundary nodes. The total number of elements in NODE-array is `NNODES`, which represents the total number of nodes in a given model. The internal nodes are stored in INODE-array. There are `NINT` elements in INODE-array. `NINT` represents the total number of internal nodes. Two coding examples are now given to find the address location for a given node (say node number 100).

```
NUMBER = 100  
DO II = 1, NNODES  
  IF (NUMBER .EQ. NODE(II)) IP = II  
ENDDO
```

Now pressure, temperature and density for node ‘100’ can be accessed at `P(IP)`, `TF(IP)` and `RHO(IP)` respectively.

If node ‘100’ is an internal node, `IP` can also be determined using the following coding:

```
NUMBER = 100  
DO II = 1, NINT  
  IF (NUMBER .EQ. INODE(II)) IP = II  
ENDDO
```

4.3.2 Branch Index

User defined branch numbers are stored in IBRANCH-array. The total number of elements in IBRANCH array is `NBR`, which represents the total number of branches in a given model. The following coding may be used to find address location of branch ‘500’.

```
NUMBER = 500
```

```

DO II = 1, NBR
  IF (NUMBER .EQ. IBRANCH(II)) IB = II
ENDDO

```

Now velocity and flowrate for branch ‘500’ can be accessed at VEL(IB) and FLOWR(IB) respectively. Values at the upstream and downstream node of branch ‘500’ can be accessed using the following coding:

```

NUMUP = IBRUN(IB)
NUMDN = IBRDN(IB)
DO II = 1, NNODES
  IF (NUMUP .EQ. NODE(II)) IPUP = II
  IF (NUMDN .EQ. NODE(II)) IPDN = II
ENDDO

```

Upstream and downstream pressure for branch ‘500’ can be accessed at P(IPUP) and P(IPDN) respectively.

4.4 DESCRIPTION OF USER SUBROUTINES

Additional capabilities can be added to the code by the utilization of User Subroutines. Twelve blank subroutines are provided with a Common Block of variables. They are called from various locations of the solver module as shown in Figure 3.3. A few subroutines also pass pertinent local variables through arguments. Users can develop their code to add new capabilities through use of these variables. A short description of each subroutine is now provided. A description of all common block variables appears in Appendix D and listing of blank User Subroutines are provided in Appendix E.

4.4.1 Subroutine USRINT

This subroutine is called from Subroutine INIT. This allows the user to develop initial and boundary values using an alternate thermodynamic package. GFSSP’s built-in thermodynamic package consists of GASP [13] and WASP [14]. An example of such use is shown in Example 8 of Chapter 5. In this example GASPAK [28] has been integrated with GFSSP through the User Subroutines.

4.4.2 Subroutine SORCEM

This subroutine is called from Subroutine EQNS. It has two arguments:

IPN – Address location of node

TERMU – Transient term of mass conservation equation

In this subroutine, the users can define any additional mass sources, EMS (IPN), at any internal node. An alternative form of the transient term in the mass conservation equation (Equation 2.1.1) can be used by overwriting the existing TERMU.

4.4.3 Subroutine SORCEF

This subroutine is called from Subroutine EQNS. This subroutine allows users access to each term in the momentum equation and provides an opportunity to add external momentum sources to any branch. It has thirteen arguments:

I – Address location of branch
TERM0 – Unsteady Term in Momentum Conservation Equation
TERM1 – Longitudinal Inertia
TERM2 – Pressure Gradient
TERM3 – Gravity Force
TERM4 – Friction Force
TERM5 – Centrifugal Force
TERM6 – External Momentum Source due to Pump
TERM7 – Momentum Source due to Transverse Flow (Multi-Dimensional Model)
TERM8 - Momentum Source due to Shear (Multi-Dimensional Model)
TERM9 – Variable Geometry Unsteady Term
TERM10 – Normal Stress
TERM100 – User Supplied Momentum Source

The first argument is the address location of the branch. The other twelve arguments represent the various terms of the momentum equation. The algebraic form of each term is described in Equation 2.1.2. However, GFSSP's Newton-Raphson scheme solves the equation in the following form:

$$F(x_1, x_2, x_{31}, \dots, x_{n1}) = 0$$

The momentum equation in Subroutine EQNS, therefore, appear as:

$$\text{TERM0} + \text{TERM1} - \text{TERM2} - \text{TERM3} + \text{TERM4} - \text{TERM5} - \text{TERM6} + \text{TERM7} - \text{TERM8} + \text{TERM9} - \text{TERM10} - \text{TERM100} = 0$$

4.4.4 Subroutine SOURCEQ

This subroutine is called from subroutine ENTHALPY (if SECONDL is false) or from subroutine ENTROPY (if SECONDL is true). It has two arguments:

IPN - Address location of node
TERMD – Component of linearized source term appearing in the denominator of the enthalpy or entropy equation.

This subroutine allows the user to introduce a heat source or sink at any internal node. In numerical calculation it is often necessary to linearize heat source to ensure numerical stability. Suppose we want to account for heat transfer from the wall at a given temperature (say T_{wall}) to the fluid at T_F in the energy conservation equation. The additional heat source can be expressed as:

$$\dot{Q}_{wall} = hA(T_{wall} - T_F)$$

In a linearized formulation of the energy conservation equation, $h_c A T_{wall}$ appears in the numerator and $h_c A / C_p$ appears in the denominator of the equation as shown below:

$$h_i = \frac{\sum_{j=1}^{j=n} a_j h_j + h_c A T_{wall}}{\sum_{j=1}^{j=n} a_j + h_c A / C_p}$$

Example of coding:

SOURCEF(IPN) = HC * HAREA * TWALL

TERMD = HC * HAREA / CPNODE(IPN)

Where HC = Heat transfer coefficient (Btu/ft²-sec-R)

HAREA = Heat transfer area (ft²)

TWALL = Wall Temperature (° R)

CPNODE(IPN) = Specific heat of fluid at IPN (Btu/lb_m -R)

An example of adding a heat source is shown in Example 8 of Chapter 5.

4.4.5 Subroutine SOURCEC

This subroutine is called from subroutine MASSC. This subroutine allows the user to introduce a source or sink of species at any internal node. An example of use of this subroutine appears in Example 10 of chapter 5.

4.4.6 Subroutine KFUSER

This subroutine is called from subroutine RESIST. In this subroutine, the user can introduce a new resistance option in any branch. It has four arguments:

I – Address location of branch

RHOU – Upstream node density

EMUU – Upstream node viscosity

AKNEW - K_f for the branch in consideration.

The user must provide all input data to calculate K_f for the branch in this subroutine.

4.4.7 Subroutine PRPUSER

This subroutine is called from subroutine DENSITY if GASPAK is set to true. This subroutine will be used when the user wants to integrate a separate thermodynamic property package instead of built-in thermodynamic property packages, GASP and WASP. Example 8 in Chapter 5 demonstrates the use of an alternative thermodynamic property package by use of this subroutine.

4.4.8 Subroutine TSTEP

This subroutine is called from the main program at the start of each time step. In this subroutine the user has the opportunity to overwrite and prescribe a new time step.

4.4.9 Subroutine BNDUSER

This subroutine is called from subroutine BOUND. In this subroutine the user can modify boundary conditions and geometry at each time step for an unsteady model. This subroutine must be used when the user wants to integrate a separate thermodynamic property package instead of the built-in thermodynamic property packages, GASP and WASP. In an unsteady model, boundary conditions are specified at each time step. The thermodynamic properties at the boundary node must be calculated at the start of new time step. Example 8 in chapter 5 demonstrates the use of this subroutine.

4.4.10 Subroutine PRNUSER

This subroutine is called from subroutine PRINT. In this subroutine the user can add additional information in GFSSP output files or can create new output files. Example 8 in chapter 5 demonstrates the use of this subroutine.

4.4.11 Subroutine FILNUM

This subroutine is called from the main program at the beginning of computation. All file numbers that are used by GFSSP are assigned integer variable names in this subroutine. It also includes 10 additional file numbers for possible use in user subroutines. Example 8 in chapter 5 demonstrates the use of this subroutine.

4.4.12 Subroutine USRSET

This subroutine is called from subroutine READIN if USETUP is set to true. This subroutine allows the user to set up their own model instead of using the GFSSP preprocessors. When this option is activated, GFSSP reads the title, input and output filenames from the data file. The user must provide other necessary information for the model. Only experienced users may have a need to use this subroutine.

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5.0 EXAMPLES

The purpose of this chapter is to demonstrate the major features of the code through twelve example problems. These example problems were selected to serve two purposes. First, these problems will instruct the user on how to use the various options available in the code to analyze different fluid engineering problems. The other purpose of the examples contained within this chapter is to verify the code's predictions. This verification was accomplished by comparing the GFSSP solutions with analytical solutions, other numerical solutions or with test data. The included demonstration problems are:

1. Simulation of a Flow System Consisting of a Pump, Valve and Pipe Line
2. Simulation of a Water Distribution Network
3. Simulation of Compressible Flow in a Converging-Diverging Nozzle.
4. Simulation of the Mixing of Combustion Gases and a Cold Gas Stream.
5. Simulation of a Flow System Involving a Heat Exchanger
6. Radial Flow on a Rotating Radial Disk
7. Flow in a Long Bearing Squeeze Film Damper
8. Simulation of the Blow Down of a Pressurized Tank
9. A Reciprocating Piston-Cylinder
10. Pressurization of a Propellant Tank
11. Power Balancing of a Turbopump Assembly
12. Helium Pressurization of LOX and RP-1 Propellant Tanks

The selection of the order for these problems is primarily determined by their complexities. The first seven problems consider steady state flows and use relatively simple flow networks. Each example demonstrates use of a special option. Example 8 is a 2-node model to demonstrate the use of the unsteady option. The application of a user subroutine to model heat transfer has been introduced in this example. More complex unsteady flow examples are illustrated in Examples 9,10, and 12. Options for time dependant geometry and moving boundary are shown in Example 9. Pressurization of a cryogenic propellant tank is described in Example 10. This example also illustrates the use of User subroutines to calculate evaporation and mass transfer. The application of the Turbopump and Heat Exchanger options in a typical gas turbine system is illustrated in Example 11. The use of a control valve in a pressurization system consisting of both fuel and oxidant tanks is the highlight of Example 12. Example 12 is the most complex example, using many options such as mixture and inertia in unsteady flow. Table 5.1 describes a matrix of the example problems and their use of various options to model the necessary physical processes. Several technical papers [16,23,32] also illustrate the application of GFSSP in computing secondary flow and axial thrust in rocket engine turbopumps for both steady and unsteady flow.

Table 5.1 – Use of Various Options in Example Problems

Examples→	1	2	3	4	5	6	7	8	9	10	11	12
Options												
Gravity	X											
Long. Inertia			X			X						X
Mixture				X						X		X
Unsteady								X	X	X		X
Rotation						X						
Heat Exchanger					X						X	
Variable Geometry									X			
Moving Boundary							X		X			
Pump	X											X
Turbopump											X	
Pressurization										X		X
Control Valve												X
Non-Circular Duct							X					
Constant Property		X					X					
Ideal gas								X				
User Subroutines								X				X

5.1 Example 1 - Simulation of a Flow System Consisting of a Pump, Valve and Pipe Line

Problem Considered:

A problem commonly encountered in fluid engineering is to match a pump's characteristics with the operating system's characteristics. The designer needs to know the flow rate in the system and the power consumed by the pump. The following example problem demonstrates how GFSSP can be used to predict this information.

The system considered for this example is shown in Figure 5.1.1. It consists of two reservoirs connected by 1500 feet of 6 inch diameter pipe with a roughness factor (ϵ/D) of 0.005. The receiving reservoir is located at an elevation that is 150 feet higher than the supply reservoir. The head-flow characteristics of the pump considered in this problem are shown in Figure 5.1.2. We want to use this pump to transport water, at 60 degree Fahrenheit, from the supply reservoir to the receiving reservoir. GFSSP will be used to determine the system flowrate and required pump horsepower.

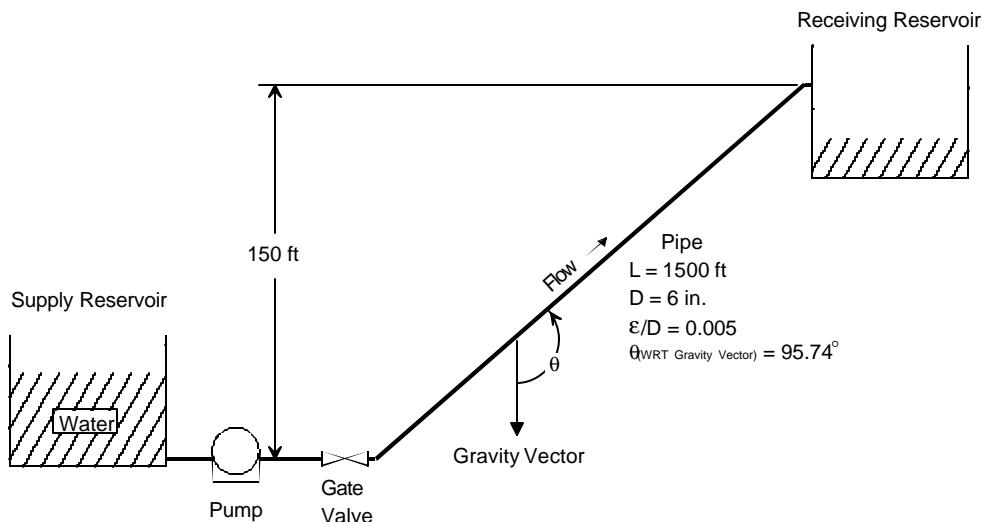


Figure 5.1.1 - Schematic of Pumping System and Reservoirs (Example 1)

GFSSP Model:

The fluid system shown in Figure 5.1.1 can be simulated with a GFSSP model consisting of four nodes and three branches as shown in Figure 5.1.3. Nodes 1 and 4 are the boundary nodes representing the supply and receiving reservoirs that are both at 14.7 psia and 60°F. Node 2 is an internal node representing the pump exit and the inlet to the gate valve. Node 3 is an internal node representing the exit from the gate valve and the inlet to the pipe line which connects the valve to the receiving reservoir. Branches 12, 23 and 34 represent the pump, gate valve and pipe line respectively.

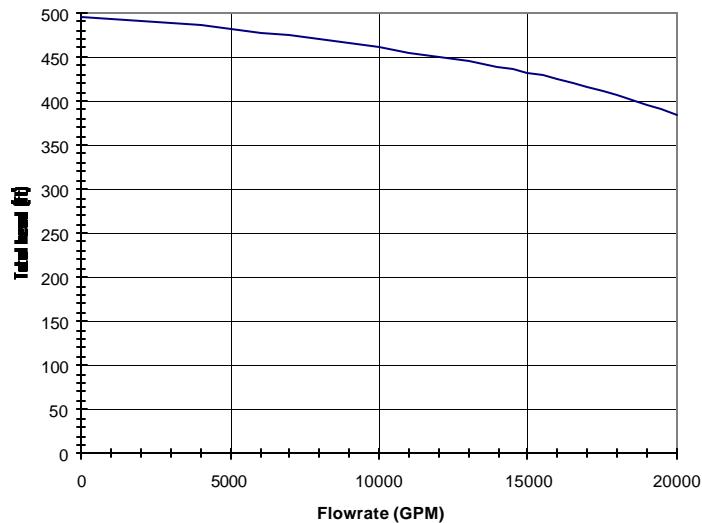


Figure 5.1.2 - Manufacturer Supplied Pump Head-Flow Characteristics

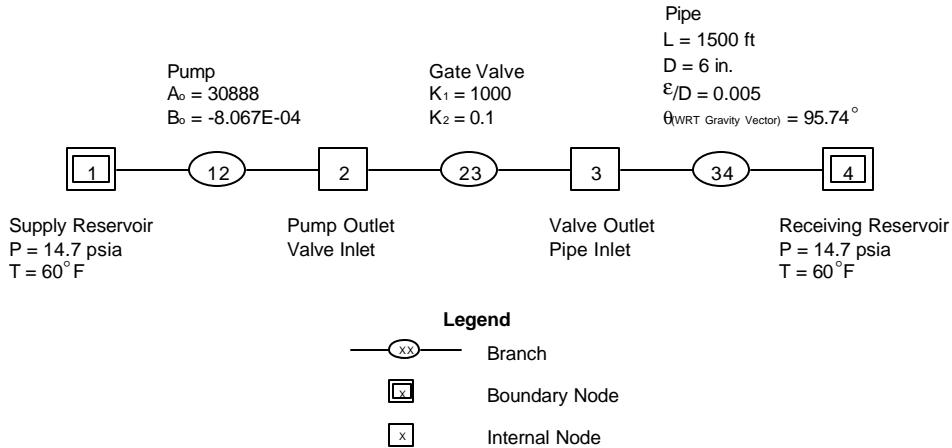


Figure 5.1.3 - GFSSP Model of Pumping System and Reservoirs

Once the boundary conditions have been established, the next step is to obtain the necessary information required to model the resistances and the momentum source located in the branches.

Branch 12 (Pump)

Option 14 was selected to represent the pump because this option allows the user to model a pump with a given characteristics curve. This option requires the input of two constants, A₀ and B₀, as well as the pump area (area is only required for the velocity calculation). These constants represent the slope and the intercept of the \dot{m}^2 vs. Δp curve. The following procedure is used to obtain these constants:

1. Construct a table, based on user selected points, from the pump characteristics curve shown in Figure 5.1.2 to develop a relationship between \dot{m}^2 and Δp. This data is shown in Table 5.1.1

$$\text{Where: } \dot{m} = \rho Q \quad \text{and} \quad \Delta p = \frac{\rho g}{g_c} H$$

Table 5.1.1 - Tabulated Pump Characteristics Data

Q (GPM)	\dot{m} (lb/s)	Head (ft)	Δp (psf)	\dot{m}^2 (lb/s) ²
0	0	495	30,888	0
4000	556.13	485	30,264	3.093e05
8000	1112.3	470	29,328	1.2372e06
12000	1668.4	450	28080	2.784e06
16000	2224.5	425	26520	4.9484e06
20000	2781	385	24024	7.734e06

2. Plot the Δp and \dot{m}^2 data from Table 5.1.1 as shown in Figure 5.1.4. Note that the relationship is linear (i.e. $\Delta p = A_0 + B_0 \dot{m}^2$). Therefore, the pump characteristic curve can be prescribed with two constants, A_0 and B_0 .

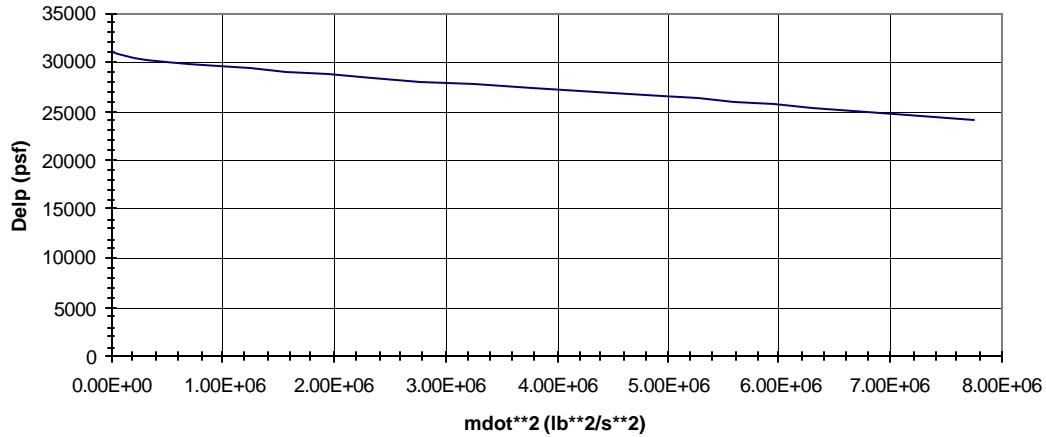


Figure 5.1.4 - Pump Characteristics Curve in GFSSP Format

3. Determine the constants A_0 and B_0 from Figure 5.1.4.

The intercept (Δp at $\dot{m}^2 = 0$) is:

$$A_0 = 30888$$

The slope (taken about $Q = 10,000$ GPM) is:

$$B_0 = \frac{28080 - 29328}{(2.784E + 6) - (1.2372E + 6)} = -(8.067E - 4)$$

Since the curve is linear, the slope can be determined at any point without sacrificing accuracy.

Branch 23 (Gate valve)

Option 13 was used to represent the gate valve. Option 13 requires two constants, K_1 and K_∞ (two K method), and the internal diameter to model various pipe fittings. The two required constants were obtained from Table 2.1.3 (see Chapter 2) assuming a reduced trim ($b = 0.8$) gate valve).

Branch 34 (Pipe line)

Option 1 was used to represent the pipe line. This branch resistance option requires the user to supply the length, diameter, roughness factor (ϵ/D) and the angle between the gravity vector and the pipe line.

Results

The Example 1 GFSSP input and output data files (ex1.dat and ex1.out) are included in APPENDIX F.

The Example 1 GFSSP model predicts a flowrate of 191 lb/sec and the pressure rise across the pump is 214 psi. Interpolation in the Table 5.1.1 data shows that the pump pressure rise for the GFSSP predicted flowrate is 213 psi, which indicates that the model is working as expected. This example demonstrates that GFSSP can accurately predict the operating point of a fluid system consisting of a pump and a pipeline with a valve.

When selecting a pump, the mass flow rate in the attached fluid system is generally unknown. By generating a system characteristic curve and plotting this curve against the pump characteristic curve the operating point of the system can be determined. Using the Example 1 GFSSP model, the system characteristic curve can be generated in the following manner:

1. Eliminate the pump by setting A_0 and B_0 to zero.
2. Set boundary pressures P_1 and P_4 to desired values.
3. Run the model.
4. Repeat steps 2 & 3 to cover the desired range.

Table 5.1.2 shows typical system characteristics generated by performing the parametric study described above. The inlet pressures were arbitrarily selected to cover the expected operating range. The GFSSP predicted mass flow rates are shown in the third column. The flow resistance coefficients for the valve and the pipe are shown in the next two columns. The method of calculating these values is discussed in Chapter 2. The next three columns of Table 5.1.2 show hand calculated pressure drops over the gate valve and the pipe and the pressure difference that is associated with the elevation change that exists in the Example 1 model. The sum of these three losses is tabulated in the next column. The last column shows the overall pressure drop for the system for the given mass flow rate. A comparison of the values contained in the last two columns shows good agreement.

To determine the operating point of the system with a given pump, the system characteristics can be plotted together with the pump characteristics. The system operating point will be determined by the intersection of these two curves. Figure 5.1.5 shows the Example 1 fluid system characteristics, generated previously, plotted along with the pump characteristics data that is shown in Table 5.1.1. As seen from this figure, the operating point predicted by this method occurs at a pressure drop of approximately 214 psid and a mass flow rate of 190 lbm/s which compares well with the predicted results from the GFSSP model containing the pump.

Finally, the power input to the pump can be calculated from the following relationship:

$$\text{Horse Power} = \frac{\dot{m}}{\rho} \Delta p = \frac{\left(191 \frac{\text{lbm}}{\text{sec}}\right) \left(214 \frac{\text{lbf}}{\text{in}^2}\right) \left(144 \frac{\text{in}^2}{\text{ft}^2}\right)}{\left(62.4 \frac{\text{lbm}}{\text{ft}^3}\right) \left(550 \frac{\text{ft-lbf}}{\text{hp}}\right)} = 171 \text{ hp}$$

Table 5.1.2 - Predicted System Characteristics

P ₁ (psia)	P ₄ (psia)	\dot{m} (lbm/s)	K _{f, gate} $\frac{\text{lbf} - \text{s}^2}{(\text{lb} - \text{ft})^2}$	K _{f, pipe} $\frac{\text{lbf} - \text{s}^2}{(\text{lb} - \text{ft})^2}$	$\Delta p, \text{gate}$ (psia)	$\Delta p, \text{pipe}$ (psia)	$\Delta p, \text{gravity}$ (psia)	$\Delta p, \text{cal}$ (psia)	$\Delta p, \text{pres}$ (psia)
150	14.7	131	0.0019	0.593	0.225	70.67	65.00	135.89	135.3
200	14.7	171	0.0019	0.592	0.385	120.21	65.00	185.59	185.3
250	14.7	203	0.0019	0.591	0.544	169.13	65.00	234.67	235.3
300	14.7	231	0.0019	0.591	0.704	219.00	65.00	284.71	285.3

$\Delta p, \text{cal}$ is the sum of three pressure drops listed in columns 6 through 8.

$\Delta p, \text{pres}$ is the prescribed pressure differential ($= P_1 - P_4$) across the circuit.

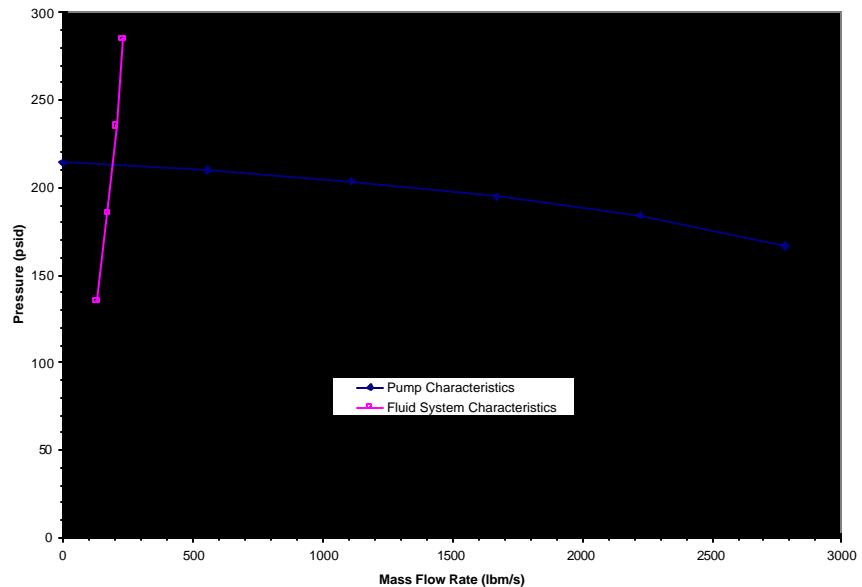


Figure 5.1.5 - Fluid System Operating Point

5.2 Example 2 - Simulation of a Water Distribution Network

Problem Considered:

In Example 1 we analyzed a single line pipe flow problem commonly encountered by pipeline designers. In this example, we consider an example associated with multipath systems which are commonly known

as flow networks. In general, water supply systems are considered as flow networks, since nearly all such systems consist of many interconnecting pipes. A ten pipe (commercial steel) distribution system is shown in Figure 5.2.1. Water at 50 psia enters the circuit at boundary node 1. Water is removed from the circuit at boundary nodes 3, 4 and 9 where pressures are also known. Use GFSSP to determine pressures at all of the remaining nodes and the flowrates in all of the pipes. The length, diameter and roughness factors for each pipe are given in Table 5.2.1. Note that pipes are designated as branches in the subsequent discussions.

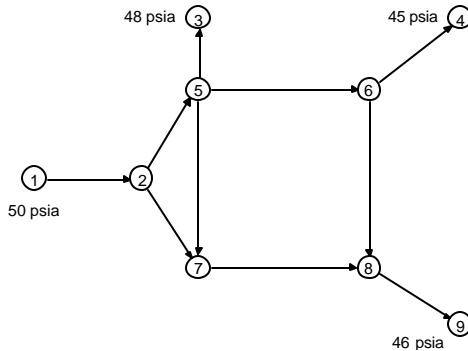


Figure 5.2.1 - Water Distribution Network Schematic (Example 2)

Table 5.2.1 - Water Distribution Network Branch Data

Branch	Length(inches)	Diameter(inches)	Roughness Factor
12	120	6	0.0018
25	2400	6	0.0018
27	2400	5	0.0018
57	1440	4	0.0018
53	120	5	0.0018
56	2400	4	0.0018
64	120	4	0.0018
68	1440	4	0.0018
78	2400	4	0.0018
89	120	5	0.0018

GFSSP Model

The system shown in Figure 5.2.1 is modeled by GFSSP using 9 nodes and 10 branches as shown in Figure 5.2.2. The fluid was assumed incompressible and therefore a constant density (DENCON = .TRUE.) option was used. Nodes 1, 3, 4 and 9 are boundary nodes where the pressures are

prescribed. Node 1 represents the inlet boundary node. Nodes 3, 4 and 9 are outlet boundary nodes. All of the remaining nodes (2, 5, 6, 8 and 7) are internal nodes where the pressures are calculated. All of the branches in this circuit simulate pipes. Therefore, each branch uses branch resistance option 1. The length, diameter and roughness factors of all branches are given in Table 5.2.1.

Results

The input and output data files (ex2.dat and ex2.out) are shown in APPENDIX G. The GFSSP predicted results are shown in Table 5.2.2 and 5.2.3. Table 5.2.2 lists the predicted pressures at the internal nodes in psia and feet of water. Table 5.2.3 lists the predicted flowrates in lbm/sec and ft³/sec. Table 5.2.3 also provides a comparison between the GFSSP predicted results and values predicted by the Hardy Cross [1,33] method.

Table 5.2.2 - GFSSP Predicted Pressure Distribution at the Internal Nodes

P ₂		P ₅		P ₆		P ₇		P ₈	
psia	feet								
49.80	114.92	48.11	111.02	45.34	104.63	48.35	111.58	46.01	106.18

Figure 5.2.3 shows a comparison between GFSSP and Hardy Cross predicted flowrates. The comparison appears reasonable considering the fact that Hardy Cross method assumes a constant friction factor in the branch while GFSSP computes the friction factor for all branches. Therefore, as the flowrates change the friction factor also changes.

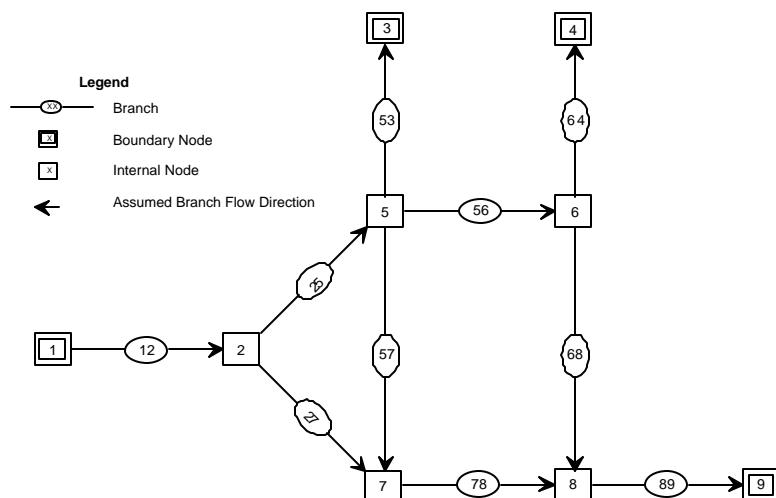


Figure 5.2.2 - GFSSP Model of the Water Distribution Network

Table 5.2.3 - GFSSP and Hardy Cross Method Predicted Branch Flow Rates

Flowrate	GFSSP		Hardy Cross	
	lb/sec	ft ³ /sec	lb/sec	ft ³ /sec
m_{12}	100.16	1.605	100.16*	1.605*
m_{25}	63.1	1.011	63.59	1.019
m_{27}	37.0	0.593	36.58	0.5862
m_{53}	44.43	0.7115	44.43*	0.7115*
m_{56}	29.1	0.466	29.11	0.4665
m_{57}	-10.4	-0.167	-9.93	-0.1592
m_{64}	47.07	0.7548	47.07*	0.7548*
m_{68}	-18.0	-0.288	-17.99	-0.2883
m_{78}	26.7	0.428	26.64	0.4270
m_{89}	8.66	0.1387	8.66*	0.1387*

* Boundary flow rates are prescribed from GFSSP predictions.

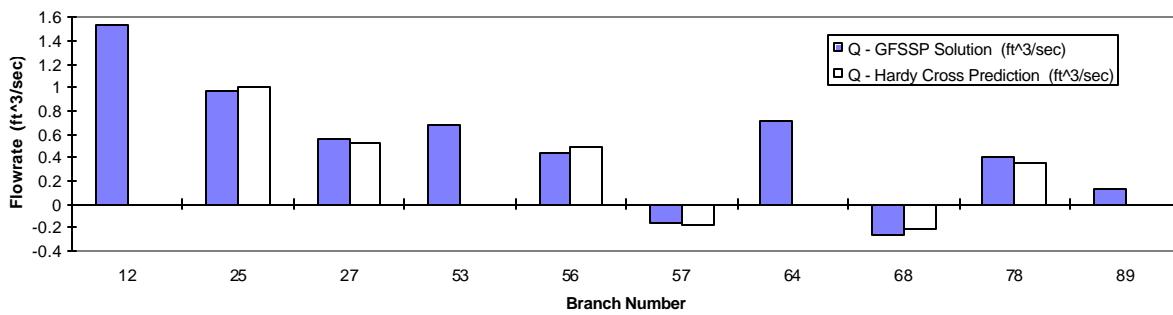


Figure 5.2.3 - A Flow Rate Comparison Between GFSSP and Hardy Cross Method Predictions

5.3 Example 3 - Simulation of Compressible Flow in a Converging-Diverging Nozzle

Problem Considered:

In the previous examples we considered incompressible flows in fluid systems. In this example we will consider compressible flow in a converging-diverging nozzle to demonstrate GFSSP's capability to handle compressibility. One of the characteristics of the compressible flow in a duct is that the flow rate becomes independent of exit pressure after reaching a threshold flowrate. This threshold value is known as the choked flow rate and it is a function of inlet pressure and temperature. Flow in a confined duct becomes choked when the flow velocity equals the local velocity of sound. The purpose of this example is to investigate how accurately GFSSP can predict the choked flow rate in a converging-diverging nozzle.

The converging-diverging nozzle considered for this example is shown in Figure 5.3.1. The nozzle is 6.3 inches long with a 0.492 inch diameter throat. The inlet diameter of the nozzle is 0.6758 inch and throat of the nozzle is located 0.158 inches downstream of the inlet. The fluid considered was steam at 150 psia and 1000 °F. The nozzle back pressure was varied from 134 psia to 15 psia. We want to use GFSSP to predict the flow rate and the pressure distribution for different exit pressures. The predicted flow rate will also be compared with the isentropic solution.

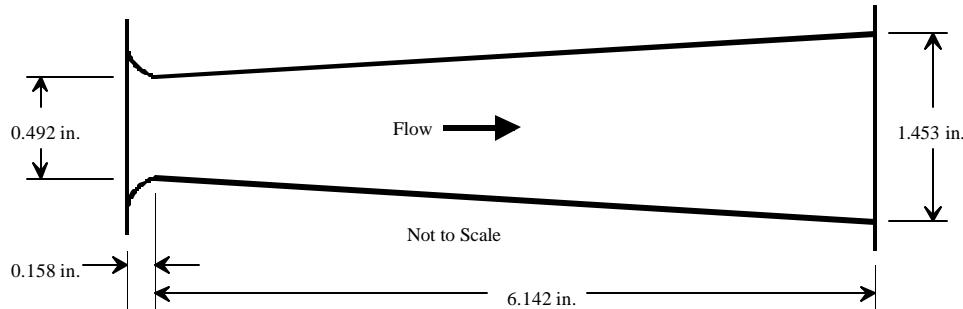


Figure 5.3.1 - Converging-Diverging Steam Nozzle Schematic (Example 3)

GFSSP Model:

The fluid system shown in Figure 5.3.1 can be simulated with a GFSSP model consisting of seventeen nodes and sixteen branches as shown in Figure 5.3.2. Nodes 1 and 17 are the boundary nodes representing the inlet and outlet of the nozzle. All of the remaining nodes are internal nodes connected in series. GFSSP can be used to construct an isentropic model by selecting branch resistance option 2 (flow through a restriction), using a flow coefficient, C_f , set equal to zero and by setting the logical flag INERTIA = .TRUE. This option eliminates friction from the momentum equation, which represents a balance between the inertia and pressure force with the inclusion of the inertia term. Each branch

assumes a constant flow area that was determined from the nozzle geometry at the mid point of the branch location. The branch information is listed in Table 5.3.1.

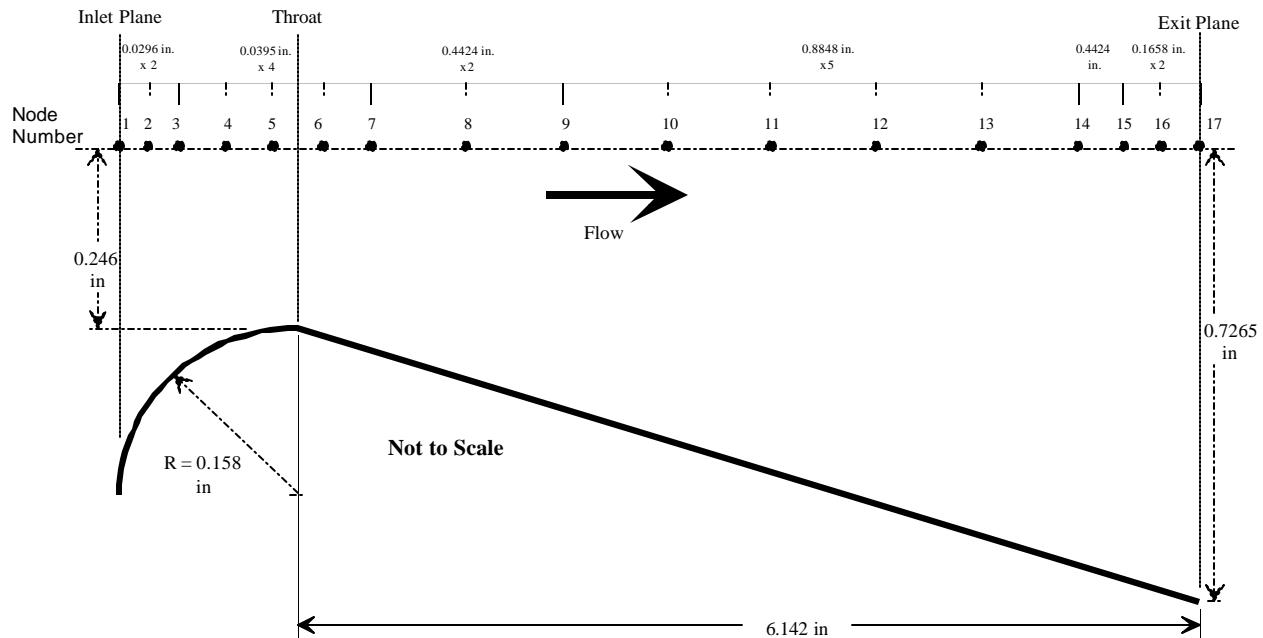


Figure 5.3.2 – Converging-Diverging Steam Nozzle Model

Table 5.3.1 – Converging-Diverging Nozzle Branch Information

Branches	Option	Area (in^2)	C_1
12	2	0.3587	0.0
23	2	0.2717	0.0
34	2	0.2243	0.0
45	2	0.2083	0.0
56	2	0.1901	0.0
67	2	0.1949	0.0
78	2	0.2255	0.0
89	2	0.2875	0.0
910	2	0.3948	0.0
1011	2	0.5640	0.0
1112	2	0.7633	0.0
1213	2	0.9927	0.0
1314	2	1.2520	0.0
1415	2	1.4668	0.0
1516	2	1.5703	0.0
1617	2	1.6286	0.0

It may be mentioned here that the temperature at the outlet boundary node has no influence on the solution. However, the code must be supplied with a value to satisfy the input requirements for a boundary node. In this example the temperature was specified arbitrarily to 1000 °F at node 17. The boundary conditions are specified in Table 5.3.2.

Table 5.3.2 – Converging-Diverging Nozzle Boundary Conditions

P ₁ (psia)	T ₁ (°F)	P ₁₇ (psia)	T ₁₇ (°F)
150	1000	134	1000
150	1000	100	1000
150	1000	60	1000
150	1000	30	1000
150	1000	15	1000

Results

The outlet boundary node pressures were varied to include 134, 100, 60, 30 and 15 psia. The input and output files (ex3.dat and ex3.out) from the example case using an exit pressure of 60 psia are included in Appendix H. The predicted pressure distributions for five test cases are shown in Figure 5.3.3. Figure 5.3.4 shows the predicted temperature distributions for the same cases.

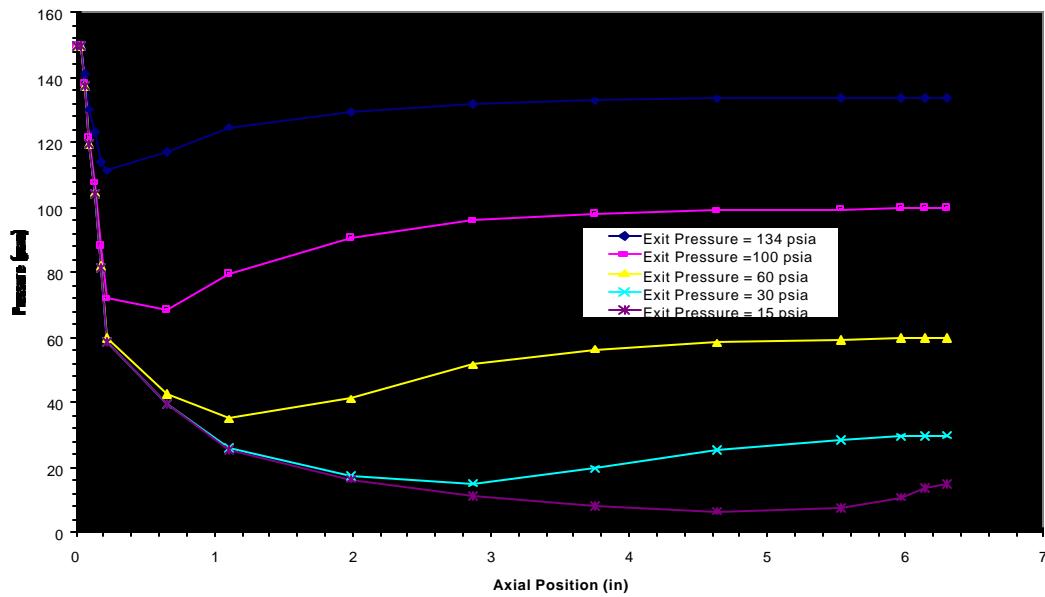


Figure 5.3.3 - Predicted Pressures for the Isentropic Steam Nozzle

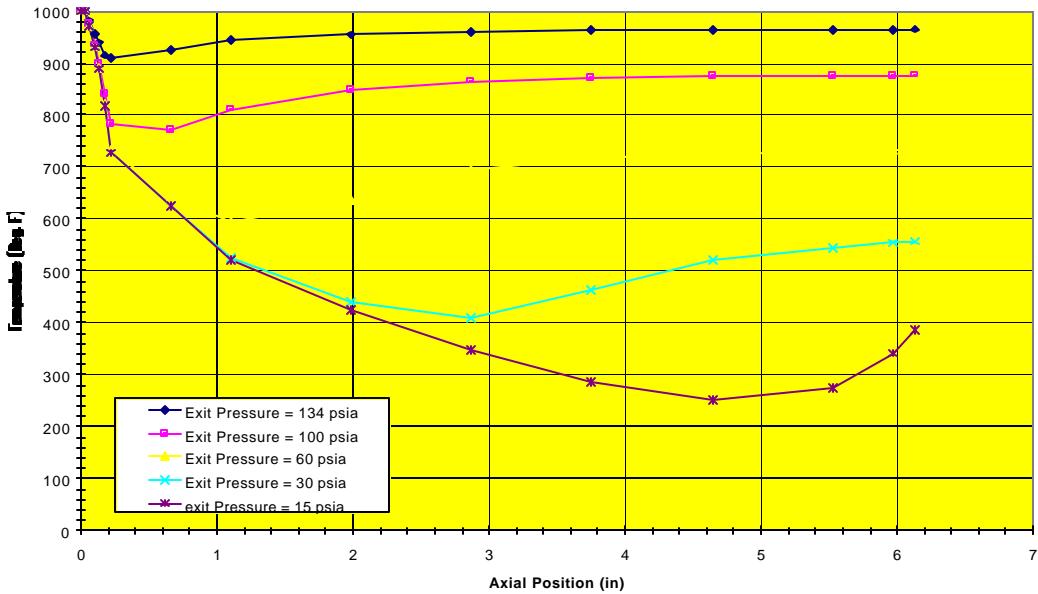


Figure 5.3.4 - Predicted Temperatures for the Isentropic Steam Nozzle

Table 5.3.3 lists the model predicted mass flow rates with varying exit pressures. As expected, the mass flow rate increased as the exit pressure was decreased until the pressure ratio decreased below the critical pressure ratio. At this point and below, the mass flow rate remained constant due to choking of the flow at the nozzle throat.

Table 5.3.3 - Predicted Mass Flow Rate with Varying Exit Pressure

P _{exit} (psia)	\dot{m} (lbm/s)
134	0.279
100	0.329
60	0.336
30	0.337
15	0.337

The isentropic flow rate was calculated from Equation 5.3.1. This equation assumes that the inlet pressure is a stagnation pressure. GFSSP's formulation assumes that the prescribed boundary conditions are taken at a static condition. The nozzle inlet velocity head component must be added to the GFSSP static inlet boundary pressure to obtain the correct nozzle inlet stagnation pressure to use in Equation 5.3.1 as shown in Equation 5.3.2.

$$\dot{m} = A_{\text{throat}} P_{\text{inlet}} \sqrt{\frac{g_c \gamma}{R T_{\text{inlet}}}} \left(\frac{2}{\gamma + 1} \right)^{\frac{\gamma+1}{\gamma-1}} \quad (5.3.1)$$

$$P_{\text{Inlet}} = P_{\text{Static}} \left(1 + \left(\frac{\gamma - 1}{2} \right) M^2 \right)^{\frac{\gamma}{\gamma-1}} \quad (5.3.2)$$

Obtaining a value of the specific heat ratio at the nozzle inlet boundary node from GASP, and the inlet Mach Number from the first branch connected to the inlet node in the model output data file contained in Appendix H, and substituting these values into Equation 5.3.2, gives the following total pressure at the nozzle inlet:

$$P_{\text{Inlet}} = (150 \text{ psia}) \left(1 + \left(\frac{1.2809 - 1}{2} \right) (0.342)^2 \right)^{\frac{1.2809}{1.2809-1}} = 161.6 \text{ psia} \quad (5.3.3)$$

Substituting the calculated total inlet pressure from Equation 5.3.3 into Equation 5.3.1 and solving for the choked mass flow rate gives a calculated isentropic choked mass flow rate of 0.326 lbm/s as shown below:

$$\dot{m} = (0.19012 \text{ in}^2) \left(161.6 \frac{\text{lbf}}{\text{in}^2} \right) \sqrt{\frac{32.174 \frac{\text{lbf} \cdot \text{ft}}{\text{lbf} \cdot \text{s}^2} (1.281)}{85.83 \frac{\text{lbf} \cdot \text{ft}}{\text{lbm} \cdot \text{ft}^2} 1460^\circ \text{R}}} \left(\frac{2}{1.281+1} \right)^{\frac{2.281}{0.281}} = 0.327 \frac{\text{lbm}}{\text{s}} \quad (5.3.4)$$

As the reader can see by comparing the results shown in Table 5.3.3 and Equation 5.3.4, there is good agreement (approximately a 3 percent difference) between the GFSSP predicted choked flow rate and the calculated isentropic choked flow rate. The prediction from first law based formulation has also been compared with the second law formulation. In the first law formulation, enthalpy was used as the dependant variable and Equation 2.1.3a was used instead of Equation 2.1.3b. Unlike the second law formulation where density is computed from pressure and entropy, the first law formulation calculates density from pressure and enthalpy. The comparison of choked mass flowrate for both formulations with the isentropic solution is shown in Table 5.3.4. It may be noted that the entropy based formulation more accurately predicts the mass flowrate than the enthalpy based formulation.

Table 5.3.4 - Comparison of Choked Mass Flow Rates

Parameter	GFSSP Version 2.6 (6 th Workshop Release)	GFSSP Version 2.0 (5 th Workshop Release)
GFSSP Predicted Isentropic Mass Flow Rate	0.337 lbm/s	.308 lbm/s
Calculated Stagnation Inlet Pressure	161.6 psia	159.71 psia
Calculated Isentropic Mass Flow Rate	0.327 lbm/s	0.323 lbm/s
% Difference Between GFSSP Predicted and Calculated Isentropic Mass Flow Rates	3.06 %	- 4.64 %

To validate GFSSP's ability to predict temperatures, the GFSSP predicted temperature at the nozzle throat was also compared with a hand calculated temperature using Equation 5.3.5. This equation assumes an isentropic process. In Equation 5.3.5, the pressure P_1 was assumed to be the total pressure at the nozzle inlet that was calculated from Equation 5.3.3 and the throat pressure was taken from the GFSSP output.

$$T_2 = T_1 \left(\frac{P_2}{P_1} \right)^{\frac{\gamma-1}{\gamma}} = (1460 \text{ } ^\circ\text{R}) \left(\frac{82.13 \text{ psia}}{161.6 \text{ psia}} \right)^{\frac{1.2809-1}{1.2809}} = 1258.6 \text{ } ^\circ\text{R} = 798.6 \text{ } ^\circ\text{F} \quad (5.3.5)$$

The GFSSP predicted nozzle throat temperature is 819.9 °F. This temperature compares well, within 3%, with the value calculated from Equation 5.3.5

The isentropic steam nozzle model represents a reversible process in which no entropy is generated. In an actual steam nozzle there will be frictional losses that result in an increase in entropy. To demonstrate GFSSP's ability to predict the irreversibility (entropy generation) of a process, the isentropic steam nozzle model was modified to allow for frictional losses. The branch resistance option for each model branch was changed from Option 2 with a $C_L = 0$, to Option 1 using the branch lengths and diameters shown in Figure 5.3.2 and assuming an absolute roughness of 0.01 inch.

Figure 5.3.5 shows a temperature/entropy comparison between the GFSSP isentropic steam nozzle model and the GFSSP steam nozzle model with frictional losses. As one can see in the referenced figure, the isentropic model predicts no change in entropy through the nozzle while the irreversible process predicts a increase in entropy of 0.032 btu/(lbm °R). As would be expected, the temperature change predicted by GFSSP in the irreversible process is greater than that observed in the isentropic process to account for the increase in entropy due to frictional losses.

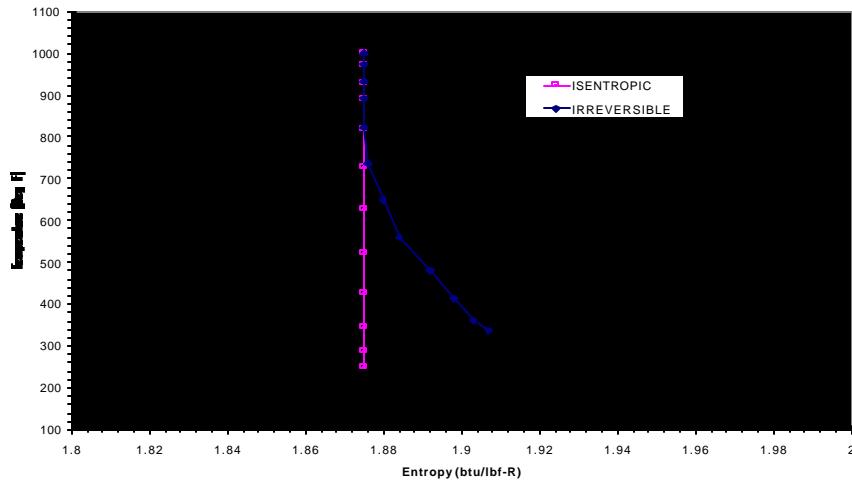


Figure 5.3.5 - Temperature/Entropy Plot Comparing the Isentropic Steam Nozzle with an Irreversible Process

5.4 Example 4 - Simulation of the Mixing of Combustion Gases and a Cold Gas Stream

Problem Considered:

In the previous examples, the fluid systems we considered employed a single fluid. In this example we will consider the simulation of multiple fluids in a mixing process. We will demonstrate how to use the MIXTURE logical option in the code to simulate the mixing of combustion gases and a cold gas stream by utilizing the flow system shown in Figure 5.4.1. A mixture of hot combustion products, consisting of water vapor and oxygen, is mixed with cooler oxygen gas. The mixture temperature and composition are required to be calculated.

A mixture consisting of 90 percent water vapor and 10 percent oxygen (by mass), at 500 psia and 1500 °F, mixes with pure oxygen at 500 psia and 80 °F. We want to use GFSSP to predict the flow rate, mixture temperature and composition of the mixture. We will also perform a hand calculation of the mixture temperature and the composition of the mixture to verify GFSSP's predictions.

GFSSP Model:

The mixing chamber shown in Figure 5.4.1 can be simulated with a GFSSP model consisting of four nodes and three branches as shown in Figure 5.4.2. Nodes 1, 2 and 4 are the boundary nodes representing the inlet and outlet of the mixing chamber and node 3 is the internal node representing the mixing chamber. All three branches connecting the nodes are represented by option 2 using a flow coefficient of 0.6 and area of 1 in².

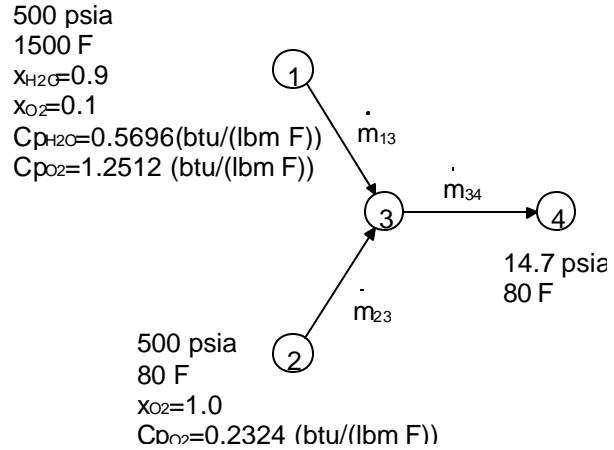


Figure 5.4.1 - Mixing Problem Schematic (Example 4)

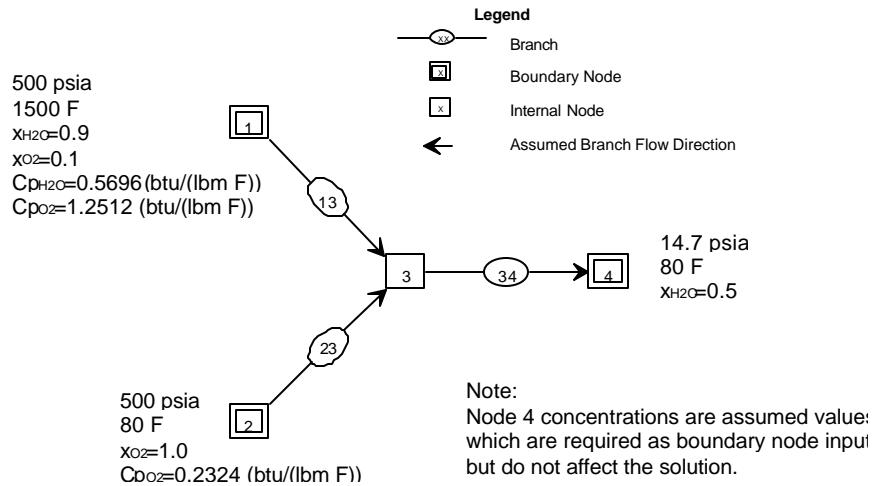


Figure 5.4.2 - GFSSP Model of Mixing Problem

Results:

The input and output files of this example are included in APPENDIX - I as ex4.dat and ex4.out. The predicted flowrates in branches 13, 23 and 34 are 1.06, 2.83 and 3.89 lbm/s respectively. The predicted temperature at the outlet of the mixing chamber, node 3, is 799 °F and the composition is 24.47 % water vapor and 75.53% oxygen. The mixture will not vary between node 3 and 4.

Now we would like to verify the predicted results by performing hand calculations of the mixing process. The temperature of the mixture can be calculated from the energy conservation equation written for the mixing chamber. The energy conservation equation for node 3 can be written as:

$$x_{H_2O} m_{13} c_{p,H_2O} T_1 + x_{O_2} m_{13} c_{p,o_2} T_1 + m_{23} c_{p,o_2} T_2 = m_{34} c_{p,mix} T_3 \quad (5.4.1)$$

The above equation can be rearranged to find T_3 .

$$T_3 = \frac{x_{H_2O} m_{13} c_{p,H_2O} T_1 + x_{O_2} m_{13} c_{p,o_2} T_1 + m_{23} c_{p,o_2} T_2}{m_{34} c_{p,mix}} \quad (5.4.2)$$

Where:

$$c_{p,mix} = \frac{x_{H_2O} m_{13} c_{p,H_2O} + x_{O_2} m_{13} c_{p,o_2} + m_{23} c_{p,o_2}}{m_{34}} \quad (5.4.3)$$

Substituting Equation 5.4.3 in Equation 5.4.2, T_3 can be expressed as:

$$\begin{aligned} T_3 &= \frac{x_{H_2O} m_{13} c_{p,H_2O} T_1 + x_{O_2} m_{13} c_{p,o_2} T_1 + m_{23} c_{p,o_2} T_2}{x_{H_2O} m_{13} c_{p,H_2O} + x_{O_2} m_{13} c_{p,o_2} + m_{23} c_{p,o_2}} \quad (5.4.4) \\ &= \frac{(0.9)(1.3 \frac{lb}{sec})(0.5696 \frac{Btu}{lb-R})(1960R) + (0.1)(1.3 \frac{lb}{sec})(1.2512 \frac{Btu}{lb-R})(1960R) + (3.49 \frac{lb}{sec})(0.2324 \frac{Btu}{lb-R})(540R)}{(0.9)(1.3 \frac{lb}{sec})(0.5696 \frac{Btu}{lb-R}) + (0.1)(1.3 \frac{lb}{sec})(1.2512 \frac{Btu}{lb-R}) + (3.49 \frac{lb}{sec})(0.2324 \frac{Btu}{lb-R})} \\ &= 1257.8 \text{ } ^\circ\text{R or } 797.8 \text{ } ^\circ\text{F} \end{aligned}$$

Equation 5.4.4 calculates the temperature to be $797.8 \text{ } ^\circ\text{F}$, which compares well with the GFSSP prediction of $799 \text{ } ^\circ\text{F}$.

The concentration of the specie can be calculated from the specie conservation equation for node 3. The concentration of water vapor and oxygen can be expressed as:

$$\begin{aligned} X_{3,H_2O} &= \frac{X_{1,H_2O} m_{13}}{m_{34}} \quad (5.4.5) \\ &= \frac{(0.9)(1.3 \frac{lb}{sec})}{4.79 \frac{lb}{sec}} = 0.2443 \end{aligned}$$

$$X_{3,O_2} = \frac{X_{1,O_2} m_{13} + m_{23}}{m_{34}} \quad (5.4.6)$$

$$= \frac{(0.1)(1.3 \frac{\text{lb}}{\text{sec}}) + 3.49 \frac{\text{lb}}{\text{sec}}}{4.79 \frac{\text{lb}}{\text{sec}}} = 0.7557$$

The concentration of water vapor and oxygen from the above equations are 0.2443 and 0.7557, which also compare well with the GFSSP predictions.

5.5 Example 5 - Simulation of a Flow System Involving a Heat Exchanger

Problem Considered:

In dealing with fluid system analysis, engineers often encounter systems that contain a heat exchanger. It is important that the thermal behavior of a heat exchanger is correctly accounted for in any system simulation. Otherwise, temperature discrepancies in the fluid property calculations will result in inaccurate system characteristics being predicted. The following example demonstrates GFSSP's ability to accurately predict fluid temperatures in a heat exchanger system using effectiveness calculations.

GFSSP has the ability to calculate temperatures downstream of a heat exchanger for three different cases. For the first case, a known heat exchanger effectiveness is used by GFSSP to calculate the flow temperatures downstream from the heat exchanger. The second case involves requiring GFSSP to calculate the effectiveness of the heat exchanger using the counter flow heat exchanger equations. That calculated effectiveness is then used to calculate the heat exchanger downstream temperatures. For the third case, the heat exchanger effectiveness is calculated using the parallel flow heat exchanger equations and the heat exchanger downstream temperatures are calculated from that effectiveness.

A simple counter flow heat exchanger system configuration, as shown in Figure 5.5.1, was chosen for this example. As shown in Figure 5.5.1, counter flow occurs when the hot branch of the heat exchanger has flow that is propagating in a direction opposite to the cold branch. This counter flow heat exchanger configuration consists of hot water, at 50 psi and 100 °F, flowing through 10 in. of 0.25 in. inner diameter pipe, through a 10 in. long heat exchanger and out through another 10 in. long section of 0.25 in. inner diameter pipe at 25 psi. Also, cold water, at 50 psi and 60 °F, flows through a 10 in. section of 0.5 in. inner diameter pipe, through the heat exchanger, and out through another 10 in. section of 0.5 in. inner diameter pipe at 25 psi. All of the pipes are assumed to have an absolute roughness of zero. At the conditions described above, $C_p=0.9978 \text{ Btu/lbm-R}$ is calculated for the hot water and $C_p=1.0014 \text{ Btu/lbm-R}$ is calculated for the cold water.

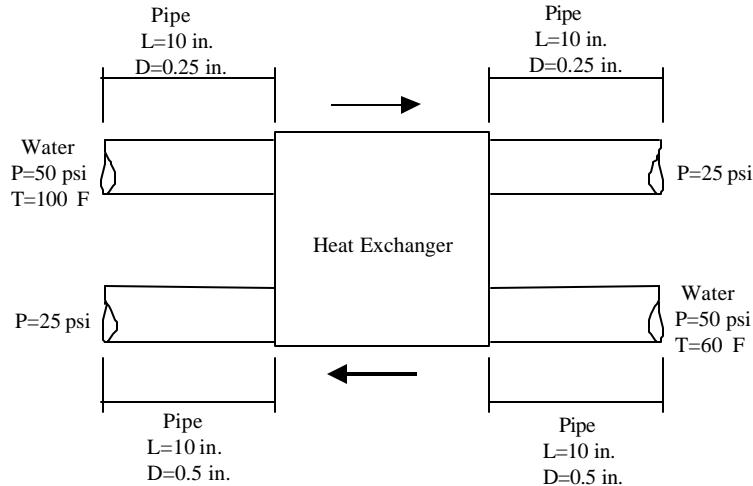


Figure 5.5.1 - Flow System Schematic of a Heat Exchanger (Example 5)

GFSSP Model:

A GFSSP model consisting of 8 nodes and 6 branches can represent the counter flow heat exchanger system shown in Figure 5.5.1. This model is shown in Figure 5.5.2. Nodes 1, 4, 5, and 8 are boundary nodes. Nodes 1 and 5, the inlet boundary nodes for the hot and cold flow respectively, both have a pressure of 50 psi. In addition, the boundary temperature at Node 1 is 100 °F while the boundary temperature at Node 5 is 60 °F. Nodes 4 and 8, which are the downstream boundary nodes for the hot and cold flow, both have a boundary pressure of 25 psi. Downstream boundary temperatures are not used in GFSSP calculations so “dummy” temperature values of 80 °F and 70 °F are used for the hot and cold flow downstream boundary nodes. Nodes 2 and 6 are internal nodes that represent the entrances to the heat exchanger for the hot and cold flow respectively. In the same manner, Nodes 3 and 7 are internal nodes that represent the hot and cold flow heat exchanger exits. Branches 12, 34, 56, and 78 represent the pipes leading into and out of the heat exchanger for both the hot and cold flows. Finally, branches 23 and 67 represent the hot and cold sides of the heat exchanger.

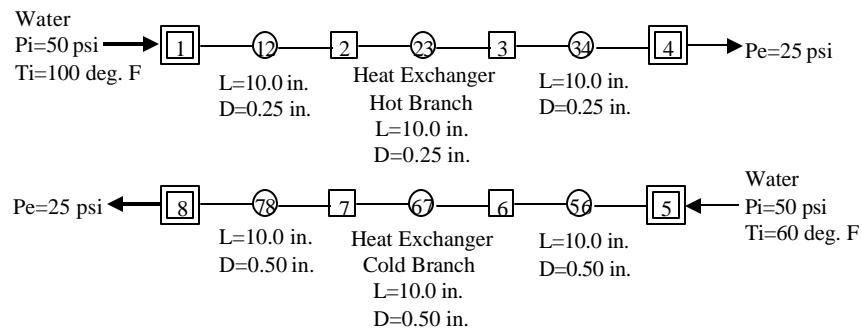


Figure 5.5.2 - GFSSP Model of the Heat Exchanger

Branches 12, 34, 56, and 78 (Pipe Lines)

Option 1 was used to represent each of the pipe sections in the heat exchanger model. The user is required to provide the length, inner diameter and relative roughness factor (ϵ/D) for this branch resistance option.

Branches 23 and 67 (Heat Exchanger)

Option 1 was also used to simulate the two heat exchanger branches. In addition to providing the length, inner diameter and ϵ/D for the two branches, the user must designate which branch represents the hot flow side of the exchanger and which branch represents the cold flow side of the exchanger. Also, the user must either designate an effectiveness or designate the type of heat exchanger in the system and a value for UA. UA is the product of the overall conductance for heat transfer and the surface area on which that conductance is based.

Results

The Example 5 GFSSP input and output data files (ex5.dat and ex5.out) are included in APPENDIX J. The output file includes all of the input data, the trial solution for the internal nodes, and the final model solution.

The first area of interest is the counter flow heat exchanger effectiveness calculations. During the GFSSP preprocessor input, a value for UA and an effectiveness are input to define the heat exchanger's characteristics. For these verifications a value for UA was assumed with the following process. It was assumed that the heat exchanger had an effectiveness of $\epsilon = 0.7$. Then a GFSSP model was run with that effectiveness to obtain the mass flow rates. The mass flow rate for the cold branch was calculated to be 5.41 lbm/s and the flow rate for the hot branch was calculated to be 0.885 lbm/s. Then, Equations 5.5.1 and 5.5.2 were used to calculate the hot and cold fluid capacity rates [34].

$$C_h = (\dot{m} C_p)_{\text{hot branch}} = (0.885 \frac{\text{lbm}}{\text{s}})(0.9978 \frac{\text{Btu}}{\text{lbm} \cdot {}^\circ\text{R}}) = 0.883 \frac{\text{Btu}}{\text{s} \cdot {}^\circ\text{R}} \quad (5.5.1)$$

$$C_c = (\dot{m} C_p)_{\text{cold branch}} = (5.41 \frac{\text{lbm}}{\text{s}})(1.0014 \frac{\text{Btu}}{\text{lbm} \cdot {}^\circ\text{R}}) = 5.418 \frac{\text{Btu}}{\text{s} \cdot {}^\circ\text{R}} \quad (5.5.2)$$

Based on the previously calculated values, $C_{\max} = C_c$ and $C_{\min} = C_h$. For the counter flow heat exchanger case, it was assumed that C_{\max} , C_{\min} and ϵ would remain the same as the values above. Next, a counter flow exchanger performance table was used, along with the previously calculated values, to estimate the number of heat transfer units, $N_u=1.25$, for the counter flow exchanger [29]. Then Eq. 5.5.3 was used to calculate UA [34].

$$N_{tu} = \frac{UA}{C_{\min}} \quad (5.5.3)$$

$$UA = N_{tu} C_{\min} = (1.25)(0.883 \frac{Btu}{s - ^\circ R}) = \underline{\underline{1.10375 \frac{Btu}{s - ^\circ R}}}$$

A value greater than 1.0 was used for the effectiveness, which instructed GFSSP to calculate the effectiveness instead of employing a user input value. For this case, the counter flow heat exchanger option was chosen. Table 5.5.1 lists the predicted temperatures and mass flow rates from this model.

Table 5.5.1 – Temperature and Flowrate Predictions in Heat Exchanger

	Temperature (°F)	Mass Flow Rate (lbm/s)
Node 3 (Hot Branch)	71.8	0.885
Node 7 (Cold Branch)	64.51	5.41

The mass flow rates predicted by this model were the same as predicted for the counter flow exchanger that was used for the assumed case. Therefore, C_c and C_h remained the same. The heat exchanger effectiveness is not included in the data written to the GFSSP output file so it was necessary to calculate the effectiveness that GFSSP used. GFSSP's effectiveness was calculated using Eq. 5.5.4 [34].

$$e = \frac{C_h (T_{h,in} - T_{h,out})}{C_{\min} (T_{h,in} - T_{c,in})} = \frac{C_c (T_{c,out} - T_{c,in})}{C_{\min} (T_{h,in} - T_{c,in})} \quad (5.5.4)$$

$$e = \frac{\left(0.883 \frac{lbm}{s}\right) (560^\circ R - 532.53^\circ R)}{\left(0.883 \frac{lbm}{s}\right) (560^\circ R - 520^\circ R)} = \underline{\underline{0.687}}$$

For comparison, a hand calculated counter flow effectiveness was determined using Equation. 5.5.5 [34].

$$e = \frac{1 - e^{-N_{tu} (1 - \frac{C_{\min}}{C_{\max}})}}{1 - (\frac{C_{\min}}{C_{\max}}) e^{-N_{tu} (1 - \frac{C_{\min}}{C_{\max}})}} \quad (5.5.5)$$

$$e = \frac{1 - e^{-1.25(1 - \frac{0.883 \frac{Btu}{s - R}}{5.418 \frac{Btu}{s - R}})}}{1 - \left(\frac{0.883 \frac{Btu}{s - R}}{5.418 \frac{Btu}{s - R}} \right)^e} = 0.688$$

Good agreement can be seen in a comparison between the hand calculated value and the GFSSP value.

The second area of interest is the accuracy of GFSSP's temperature predictions at the nodes downstream of the hot and cold heat exchanger branches. Equation 5.5.4 was manipulated to come up with Equations 5.5.6 and 5.5.7 which were used to hand calculate $T_{h,out}$ and $T_{c,out}$ [34].

$$T_{h,out} = T_{h,in} - \frac{C_{min}(T_{h,in} - T_{c,in})e}{C_h} \quad (5.5.6)$$

$$T_{h,out} = 560^{\circ}R - \frac{(0.883 \frac{Btu}{s - R})(560^{\circ}R - 520^{\circ}R)(0.688)}{(0.883 \frac{Btu}{s - R})} = 532.48^{\circ}R = 72.48^{\circ}F$$

$$T_{c,out} = T_{c,in} + \frac{C_{min}(T_{h,in} - T_{c,in})e}{C_c} \quad (5.5.7)$$

$$T_{c,out} = 520^{\circ}R + \frac{(0.883 \frac{Btu}{s - R})(560^{\circ}R - 520^{\circ}R)(0.688)}{(5.418 \frac{Btu}{s - R})} = 524.49^{\circ}R = 64.49^{\circ}F$$

Comparing the hand calculated values with GFSSP's temperature results in Table 5.5.1 shows very good agreement, verifying the heat exchanger temperature calculation process used by the GFSSP code.

5.6 Example 6 - Radial Flow on a Rotating Radial Disk

Problem Considered:

This example illustrates the rotational effect (centrifugal force contribution) capability of GFSSP by modeling the flow of water through a closed impeller [35]. The impeller is 11 inches in diameter, it uses water as the operating fluid and is running at 5,000 rpm. The "slip" of the fluid is described by the rotational K-factor ($K_{rotation}$). $K_{rotation}$ is defined as the ratio of the mean circumferential fluid speed divided by the impeller speed:
$$\left(K_{rotation} = \frac{u_\theta}{r\omega} \right)$$
.

(Higher $K_{rotation}$ -factors translates to a higher pressure rise for radially outward flow.) A $K_{rotation}$ for each side of the impeller has been proposed and it is the purpose of this example to validate these $K_{rotation}$ correlations. The proposed correlations are:

$$K_{front_face} = 0.8455 - 0.1403 \left(\frac{r - r_i}{r_o - r_i} \right) \quad K_{back_face} = 0.8857 - 0.1762 \left(\frac{r - r_i}{r_o - r_i} \right)$$

desired to compare the results with experimental data. The impeller is schematically shown in Figure 5.6.1. For this example the effects of friction will be neglected for the rotating branches.

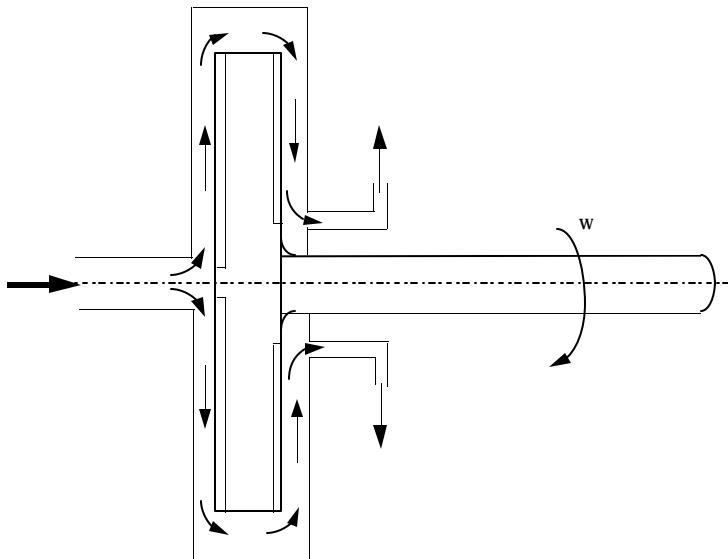


Figure 5.6.1 - Flow Schematic of a Rotating Radial Disk (Example 6)

GFSSP Model:

The GFSSP model circuit is shown in Figure 5.6.2. In the model, branches 23, 34, 45, 56, 67, 89, 910, 1011, and 1112 are rotating at 5000 rpm. The inlet and outlet radii are defined in the

preprocessor for each of the rotating branches. The area of each of the radial branches is calculated as the average cross sectional area for each branch $\left(A_{\text{branch ab}} = \frac{1}{r_b - r_a} \int_{r_a}^{r_b} 2\pi r dr \right)$.

Results

The Example 6 GFSSP input and output data files (ex6.dat and ex6.out) are included in APPENDIX K.

The pressure distribution predicted by GFSSP for the front and back faces of the impeller is shown in Figure 5.6.3. As is seen in Figure 5.6.3, the model results show excellent agreement with the experimental data.

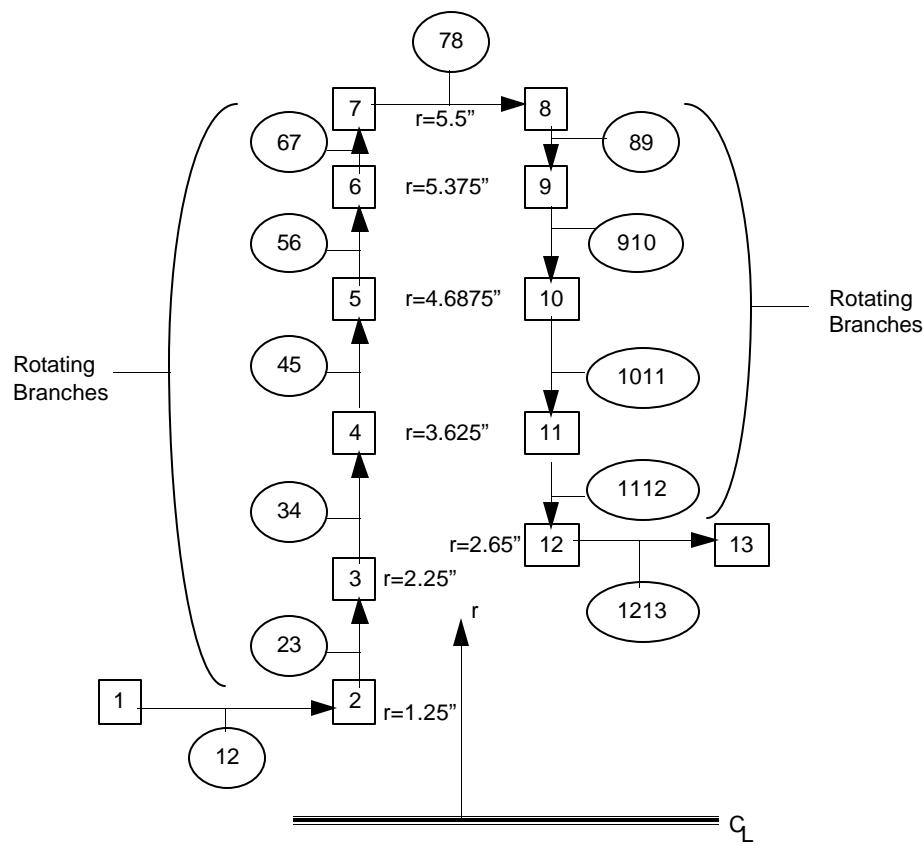


Figure 5.6.2 - GFSSP Model of the Rotating Radial Disk

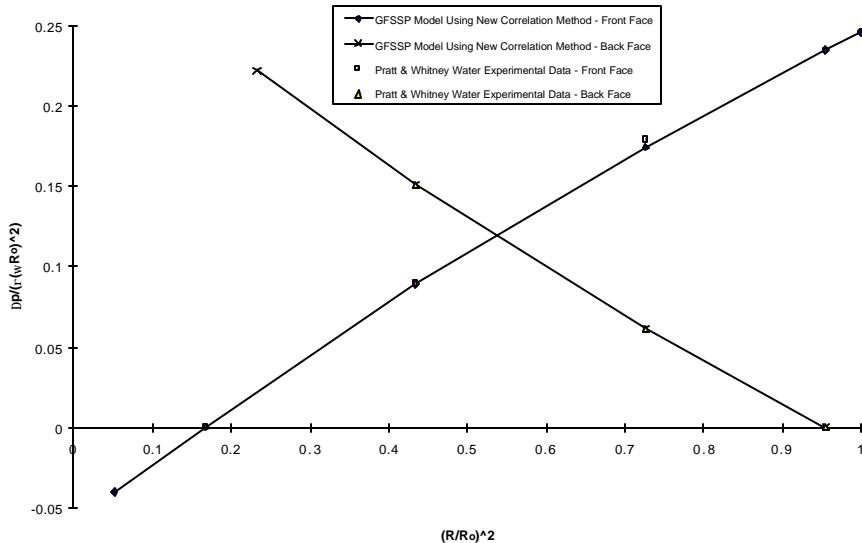


Figure 5.6.3 - Comparison of GFSSP Model Results with Experimental Data

5.7 Example 7 - Flow in a Long Bearing Squeeze Film Damper

Problem Considered:

Squeeze film dampers are used in turbomachinery to dampen out unstable behavior. The damper is installed at the bearing supports of a rotor-stator system on the outer race of a rolling-element bearing. The squeeze film damper consists of inner and outer elements separated by fluid (usually an oil). The inner element is mounted to the outer race of the rolling-element bearing, and the outer element is mounted to the bearing support. The arrangement is similar to a journal bearing except that the inner damper element does not rotate; it only translates. In order to calculate the effect of the squeeze film damper on the system, the forces generated by the squeeze film damper in the radial and tangential directions must be estimated. The forces are estimated by integrating the pressure distribution of the fluid in the damper. The difficulty for the designer/analyst is the estimation of the pressure distribution. The following example problem demonstrates how GFSSP can be used to predict this pressure distribution.

The squeeze film damper considered for this example is shown schematically in Figures 5.7.1 and 5.7.2. Since the damper has sealed ends the axial flow is neglected. The diameter (d) of the bearing is 5 inches, the width (w) of the bearing is 0.94 inches, the clearance (c) is 0.0625 inches, and the ratio of the dynamic eccentricity (ϵ , radius of orbit to the clearance) is 0.82. The fluid density (ρ) is 57.806 lbm/ft³. The fluid viscosity (μ) is 5.932×10^{-3} lbm/(ft•sec). The running speed (ω) is set at 1770 rpm ($\omega = 185.354$ radians/second). GFSSP will be used to determine the pressure distribution around the damper and the results will be compared with experimental data [36].

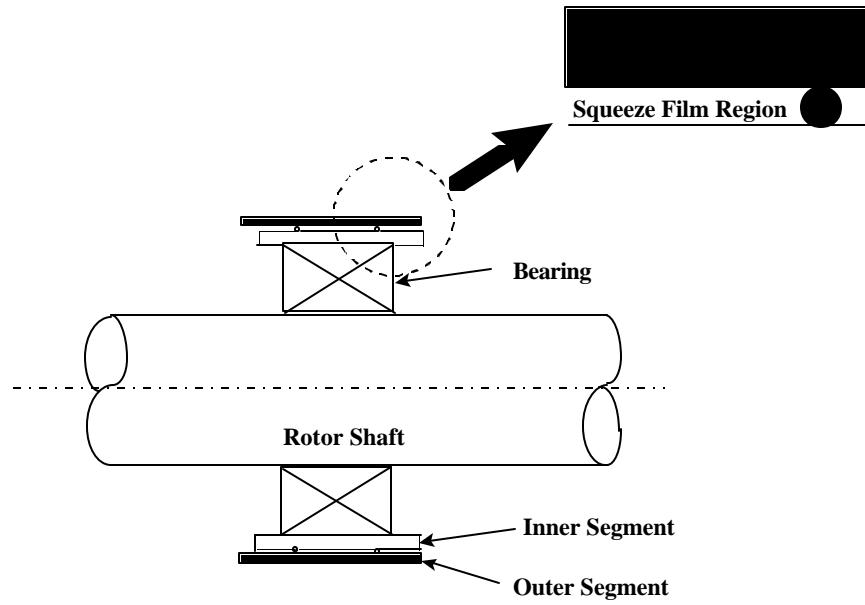


Figure 5.7.1 - Squeeze Film Damper Schematic (Example 7, View 1)

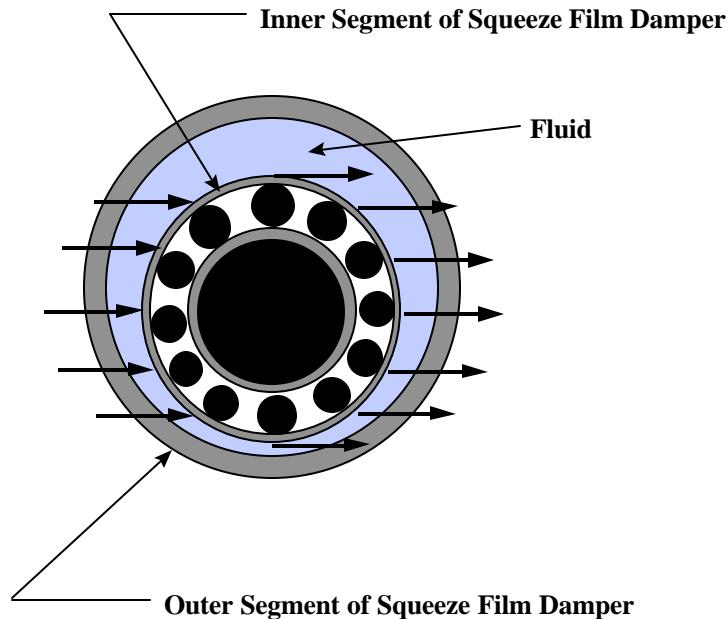


Figure 5.7.2 - Squeeze Film Damper Schematic (Example 7, View 2)

GFSSP Model:

A GFSSP model consisting of 20 nodes and 19 branches can approximate the fluid contained within the squeeze film damper system shown in Figures 5.7.1 and 5.7.2. The fluid to be used is not contained in

the standard library of fluids and is assumed to be incompressible, therefore, the constant density feature of GFSSP must be used. In order to model the squeeze film damper, the damper will be “unwrapped.” Figure 5.7.3 shows the unwrapping of the damper and the discretization of the flow region. The GFSSP model is shown in Figure 5.7.4. As is shown in Figure 5.7.4, nodes 1 and 20 are the boundary nodes. The branches will use branch resistance Option 3 - Non Circular Duct, Sub-option 1 - Rectangular Duct. The heights of the branches are given in Table 5.7.1. The motion of the inner element will be simulated using the moving boundary option in GFSSP (only the motion of the damper normal to the inner element is modeled in this technique). The velocity of the moving boundary is given in Table 5.7.2. Setting the boundary nodes at the same pressure will simulate the periodic behavior of the damper. The boundary pressure is set at 0.0 psi.

Results

The Example 7 GFSSP input and output data files (ex7.dat and ex7.out) are included in APPENDIX L.

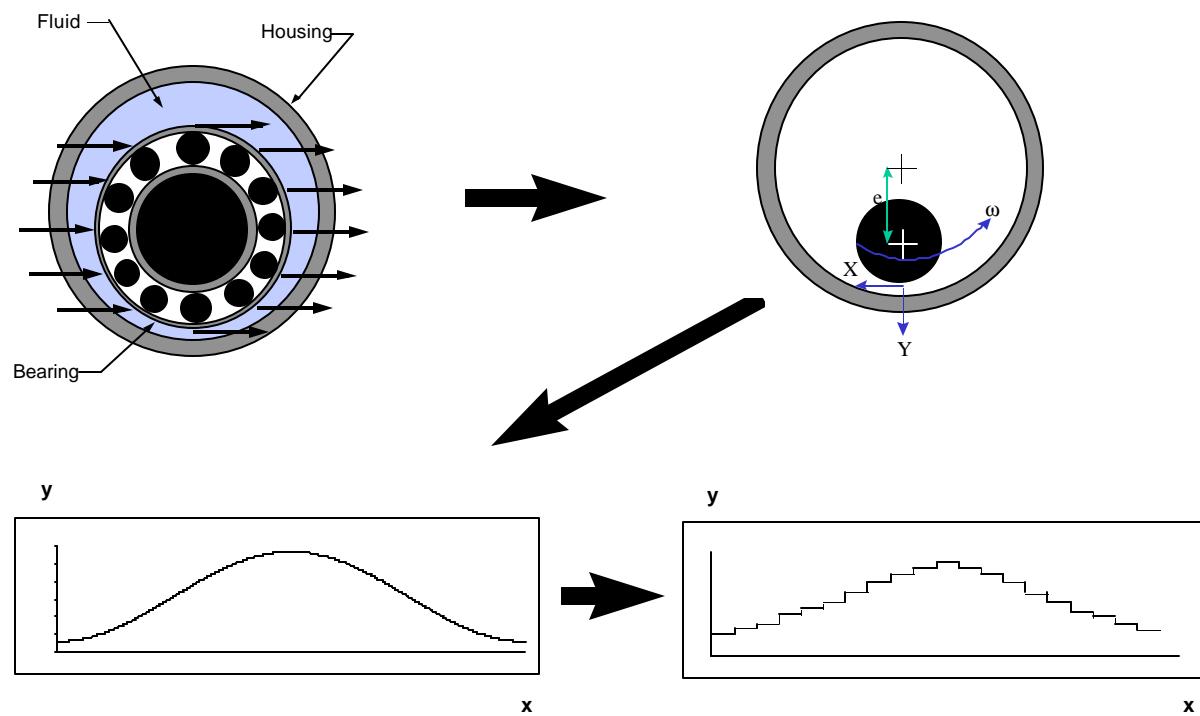


Figure 5.7.3 - Unwrapping and Discretization of Squeeze Film Damper

Table 5.7.1 - Branch Dimensions of Squeeze Film Damper

Branch Number	Width (inches)	Length (inches)	Height (inches)
12	0.94	0.82673	0.012578
23	0.94	0.82673	0.017987
34	0.94	0.82673	0.028221
45	0.94	0.82673	0.042169
56	0.94	0.82673	0.058320
67	0.94	0.82673	0.074925
78	0.94	0.82673	0.090183
89	0.94	0.82673	0.102441
910	0.94	0.82673	0.110370
1011	0.94	0.82673	0.113113
1112	0.94	0.82673	0.110370
1213	0.94	0.82673	0.102441
1314	0.94	0.82673	0.090183
1415	0.94	0.82673	0.074925
1516	0.94	0.82673	0.058320
1617	0.94	0.82673	0.042169
1718	0.94	0.82673	0.028221
1819	0.94	0.82673	0.017987
1920	0.94	0.82673	0.012578

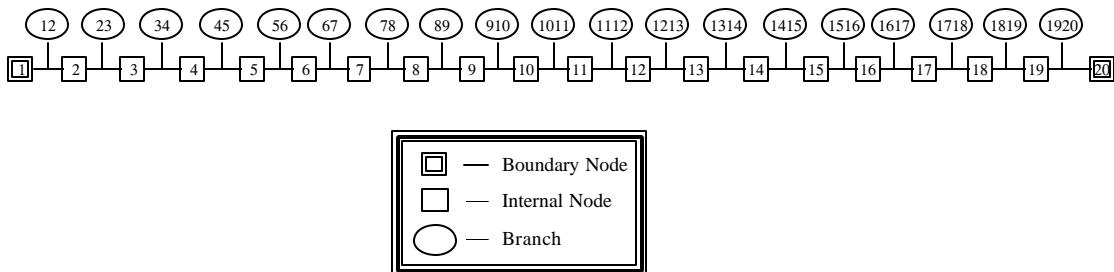


Figure 5.7.4 - GFSSP Model of Squeeze Film Damper

The pressure distribution predicted by GFSSP is shown in Figure 5.7.5. The plot of pressure vs. angle (i.e. node position) in Figure 5.7.5 shows that the pressure is symmetric about the boundary pressure of 0.0 psi. The model results are compared to experimental results in Figure 5.7.6. In Figure 5.7.6, the pressure is normalized with a characteristic pressure ($C_p Re$) and the angle has been converted to compare to a dimensionless time (ωt) for comparison with the experimental data. As seen in Figure 5.7.6, the pressure profile of the GFSSP model compares favorably with the experimental results in shape and magnitude, the only major difference between the two results is a phase shift.

Table 5.7.2 - Moving Boundary Information of Squeeze Film Damper

Node	Normal Area (in ²)	Velocity (ft/sec)
2	0.777126	0.256180
3	0.777126	0.484598
4	0.777126	0.660503
5	0.777126	0.764832
6	0.777126	0.786280
7	0.777126	0.722522
8	0.777126	0.580468
9	0.777126	0.375510
10	0.777126	0.129861
11	0.777126	-0.129861
12	0.777126	-0.375510
13	0.777126	-0.580468
14	0.777126	-0.722522
15	0.777126	-0.786280
16	0.777126	-0.764832
17	0.777126	-0.660503
18	0.777126	-0.484598
19	0.777126	-0.256180

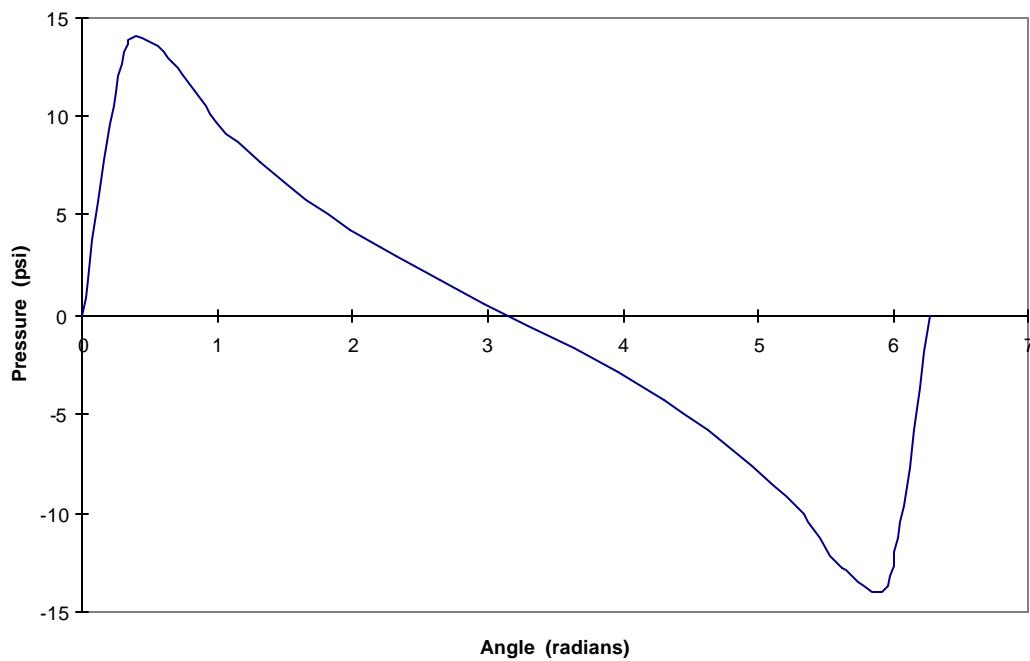


Figure 5.7.5 – Predicted Circumferential Pressure Distributions in the Squeeze Film Damper

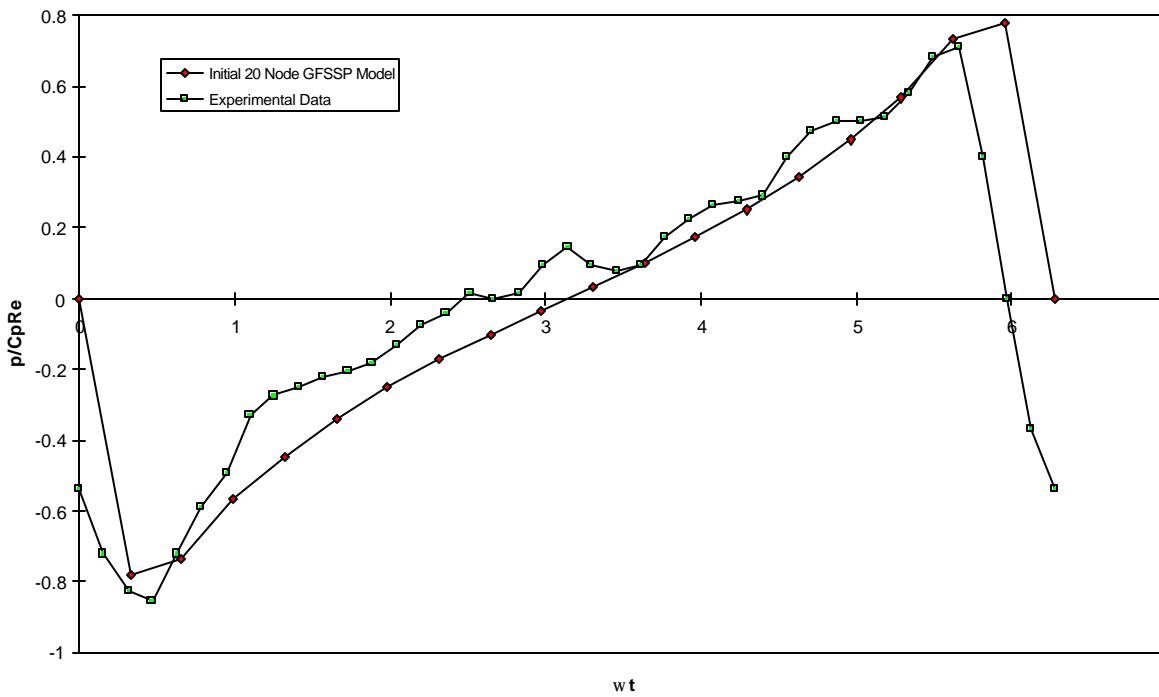


Figure 5.7.6 - Comparison of GFSSP Model Results with Experimental Data for Squeeze Film Damper

5.8 Example 8 - Simulation of the Blow Down of a Pressurized Tank

Problem Considered:

In the previous examples we considered the simulation of steady state flow in a given flow circuit. In this example we will employ the capabilities of the unsteady flow formulation of GFSSP to simulate the process of blowing down a pressurized tank. Another highlight of this example is the use of User Subroutines to integrate an alternate thermodynamic property package.

Consider a tank with an internal volume of 10 ft^3 , containing air at a pressure and temperature of 100 psia and 80°F respectively. Air is discharged into the atmosphere through an orifice of 0.1 inch diameter for a period of 200 seconds. GFSSP will be used to determine the pressure, mass flowrate and temperature history of the isentropic blow down process. These predicted values are then compared with the analytical solution.

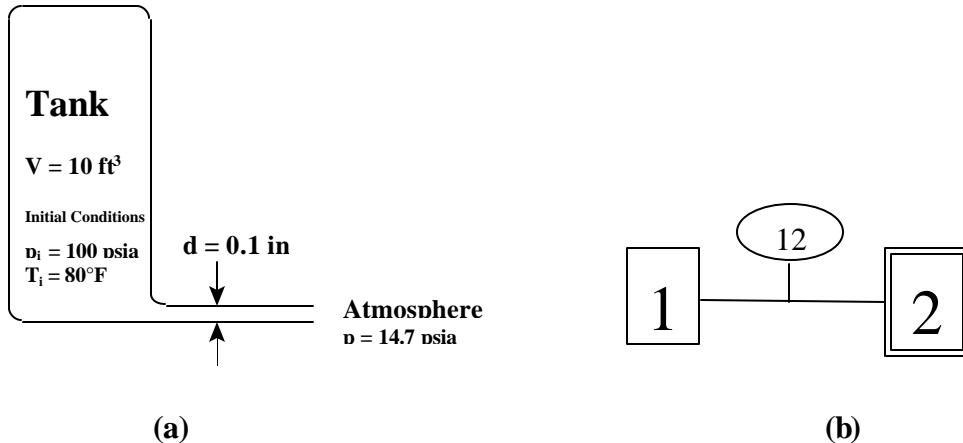


Figure 5.8.1 - Physical Schematic (a) and GFSSP Model (b) for Venting Air Tank

GFSSP Model:

The physical schematic for Example 8 is shown in Figure 5.8.1.a and a schematic of the corresponding GFSSP model is shown in Figure 5.8.1.b. The venting process can be modeled with two nodes and one branch. Node 1 is an internal node that represents the tank. For the unsteady formulation, the node volume and the initial conditions must be supplied for each internal node and a history file must be supplied for each boundary node. The history file contains the pressures, temperatures and concentrations at discrete times. At a minimum this file should include values at the process start time and at some time corresponding to the expected process stop time. Additional times can be included to account for non-linear variation in the values if required. The code interpolates in the history file data to determine the values for a particular instant. Shown below is a listing of HIST2.DAT, which is the history file of Example 8 used to provide the boundary conditions for node 2. The file listing has been annotated to explain the meaning of the entries.

HIST2.DAT

2 - Number of data points			
tau(sec)	p(psia)	T (°F)	Concentration
0	14.700	80.00	1.00
200	14.700	80.00	1.00

In addition to supplying the internal node volumes and history data files, the time step (DTAU), start time (TAUF), stop time (TAUL) and print interval (NPSTEP) must also be included within the model input data file when creating an unsteady flow (STEADY = .False.) model.

The initial pressure within the tank (node 1) was 100 psia. Resistance Option 2 was used for branch 12 with a flow coefficient of 1.0.

User Subroutine

Air is modeled as an ideal gas that is available under the property package GASPAK, which is integrated by User Subroutine. Integration of GASPAK with GFSSP requires the use of three User Subroutines: USRINT, PRPUSER, BNDUSER. Subroutine SORCEQ has been used to model isothermal flow. Listing of these subroutines is provided in Appendix M.

Subroutine USRINT

The purpose of this subroutine is to provide initial conditions. This subroutine calls subroutine INITGP if GASPAK is set to true. Subroutine INITGP performs following functions:

1. It calls several subroutines of GASPAK package to compute necessary thermodynamic and thermophysical properties at all internal and boundary nodes.
 2. It calls subroutine RP1 for obtaining RP-1 properties by table lookup.
 3. For ideal gas, it computes density by ideal gas law and assigns reference values to property-array.
- In addition, subroutine INITGP has two sections: one for a pure fluid and the other for a mixture.

Subroutine PRPUSER

The purpose of this subroutine is to calculate thermodynamic and thermophysical properties at all internal nodes during iterative cycle using an alternate thermodynamic property program. This particular User Subroutine uses GASPAK and a few other subroutines to calculate the necessary property data. This subroutine calls subroutine DENSTGP. Subroutine DENSTGP performs following functions:

1. It calls several subroutines of GASPAK package to compute necessary thermodynamic and thermophysical property at all internal nodes.
2. It calls subroutine RP1 for obtaining RP-1 properties by table lookup.
3. For ideal gas, it computes density by ideal gas law and assigns reference values to property-array.
4. For water, R11, R12, R22, R32, R123, R124, R125, R134a, R152a and ammonia, viscosity and conductivity are computed from ASHRAE correlation [37] coded in subroutine CONDCTV and VISCTY.

In addition, subroutine DENSTGP has two sections: one for a pure fluid and the other for a mixture.

Subroutine BNDUSER

For unsteady problems, this subroutine calculates thermodynamic and thermophysical properties at all boundary nodes at each time step using an alternate thermodynamic property program. This particular User Subroutine uses GASPAK and a few other subroutines to calculate the necessary property data. This subroutine calls subroutine BOUNDGP. Subroutine BOUNDGP performs the following functions:

1. It calls several subroutines of GASPAK package to compute necessary thermodynamic and thermophysical property at all boundary nodes.
2. For ideal gas, it computes density by ideal gas law and assigns reference values to property-array.
3. For water, R11, R12, R22, R32, R123, R124, R125, R134a, R152a and ammonia, viscosity and conductivity are computed from ASHRAE correlations [37] coded in subroutine CONDCTV and VISCTY.

Subroutine SORCEQ

The purpose of this subroutine is to introduce an additional heat source in any internal node. This subroutine has been used in this example to model an isothermal process. The temperature of the fluid remains constant in an isothermal process. In this example it is presumed that initially the air and tank wall are at the same temperature. During blow down, the air temperature tends to drop. With heat transfer from the wall, temperature drop would be less compared to an isentropic process. For an isothermal process, there will be no change in temperature. This particular situation (isothermal) can be modeled by setting an infinite heat transfer coefficient between the wall and fluid. The user can choose between isothermal and adiabatic process by setting a local logical variable ISOTHRM to true or false.

Results

The input and output files of this example are included in APPENDIX M as ex8.dat and ex8.out. It may be noted that for each time step, solutions for each node and branch are printed in the output file.

Analytical Solution:

The differential equation governing an isentropic blow down process can be written as:

$$\left(\frac{p}{p_i}\right)^{(1-3g)/2g} \frac{d(p/p_i)}{dt} = \frac{gA}{r_i V} \sqrt{g g_c p_i r_i} \left(\frac{2}{g+1}\right)^{(g+1)/2(g-1)} \quad (5.8.1)$$

This is an initial value problem and the initial conditions are:

$$t = 0, \frac{p}{p_i} = 1$$

The analytical solution for p / p_i is given by Moody [38] as:

$$\frac{p}{p_i} = \left[1 + \left(\frac{g-1}{2} \right) \left(\frac{2}{g+1} \right)^{(g+1)/2(g-1)} \sqrt{\frac{g g_c p_i}{r_i}} \frac{At}{V} \right]^{-2g/(g-1)} \quad (5.8.2)$$

The analytical and GFSSP solutions are compared in Figure 5.8.2. The figure shows a comparison between the GFSSP solution and the analytical solution of pressures. The difference in pressures is also shown plotted for three different time steps (1, 0.1 and 0.01 seconds). The discrepancies between analytical and numerical solutions are found to diminish with reduction in time step. This observation is in conformity with expectations.

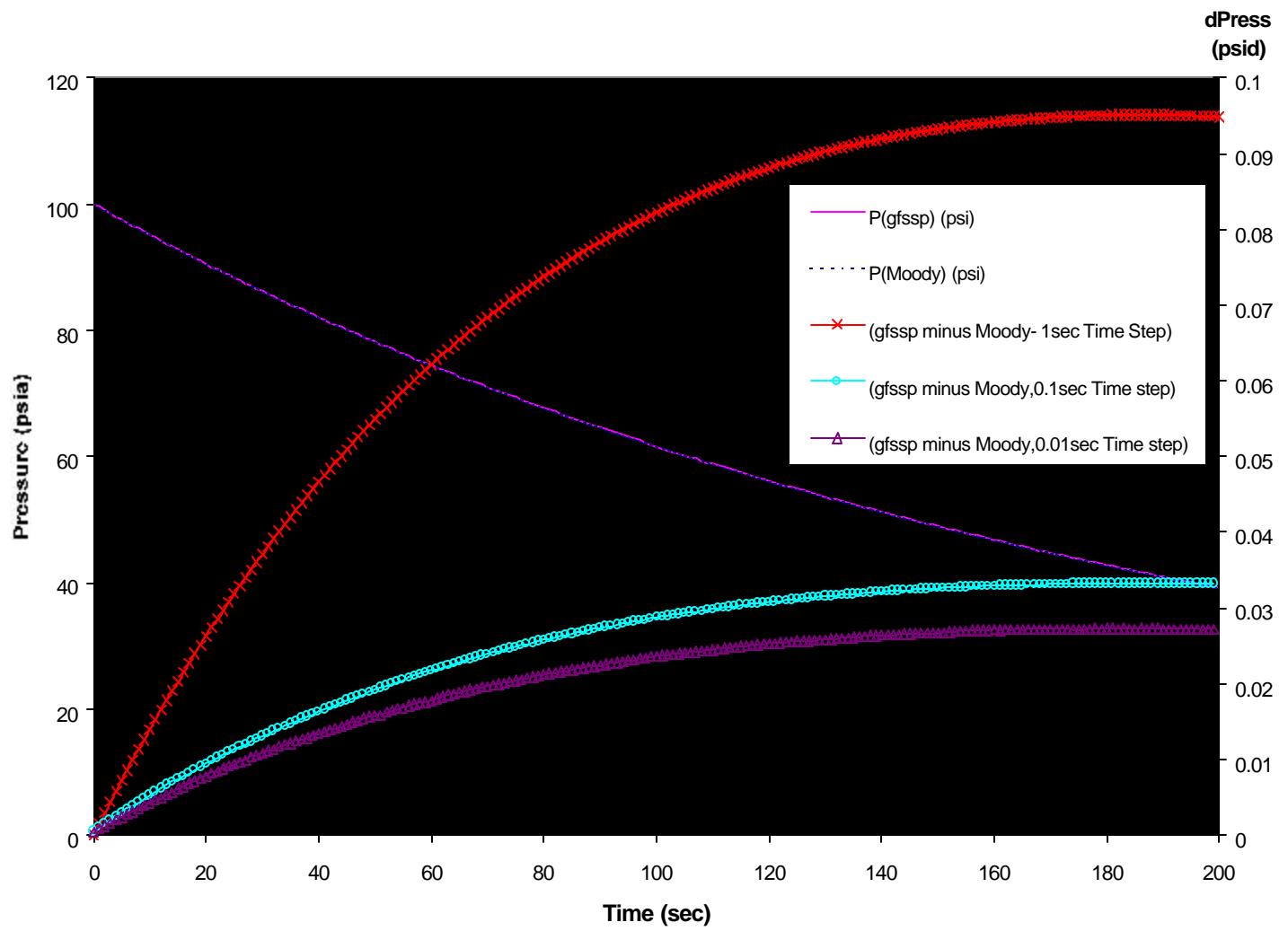


Figure 5.8.2 - Comparison of the Predicted Pressure History by GFSSP and the Analytical Solution

5.9 Example 9 - A Reciprocating Piston-Cylinder

Problem Considered:

This example further illustrates GFSSP's capability to model complex unsteady flow. Figure 5.9.1 shows the piston-cylinder configuration considered by this example problem. The cylinder has a diameter of 3.0 inches. Within the cylinder is nitrogen gas, sealed in by a piston moving at a rotational speed of 1200 rpm and a stroke of 3.0 inches. GFSSP will be used to predict the pressure and temperature within the system and the results will be compared with the isentropic solution.

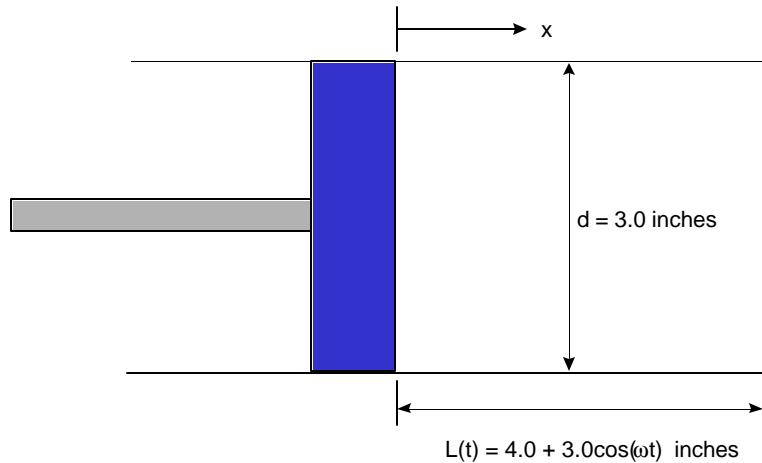


Figure 5.9.1 - Piston-Cylinder Configuration

GFSSP Model:

In order to model this configuration, a coordinate transformation is utilized. In this new coordinate system, the endplate of the cylinder is modeled as another piston and the origin of the coordinate system is at the midpoint between the two “pistons.” Figure 5.9.2 demonstrates the modified piston-cylinder arrangement.

The GFSSP model of the piston-cylinder arrangement consists of two internal nodes and one branch (Note: the model does not have any boundary nodes). Figure 5.9.3 shows the GFSSP piston-cylinder model. In order to model the motion of the piston, two special options are utilized: the moving boundary option and the variable geometry option. The moving boundary option is required to adequately model the work input by the motion of the pistons. The variable geometry option is required to model the variation of the geometry of branch 12. The initial condition of the nitrogen in the cylinder is: 14.7 psia and 75°F.

Results:

APPENDIX N contains the input, history and output files for this example. The results of the study are compared to an analytical solution (for constant ratio of specific heat, γ). Equations 5.9.1 and 5.9.2 are used to obtain the analytical solution assuming an isentropic process.

$$T(t) = \left\{ (T_0 + 459.6) \left[\frac{\rho(t)}{\rho_0} \right]^{\gamma-1} \right\} - 459.6 \quad (5.9.1)$$

$$p(t) = p_0 \left[\frac{\rho(t)}{\rho_0} \right]^\gamma \quad (5.9.2)$$

Where T_0 , p_0 and ρ_0 are temperature, pressure and density at time equal 0.

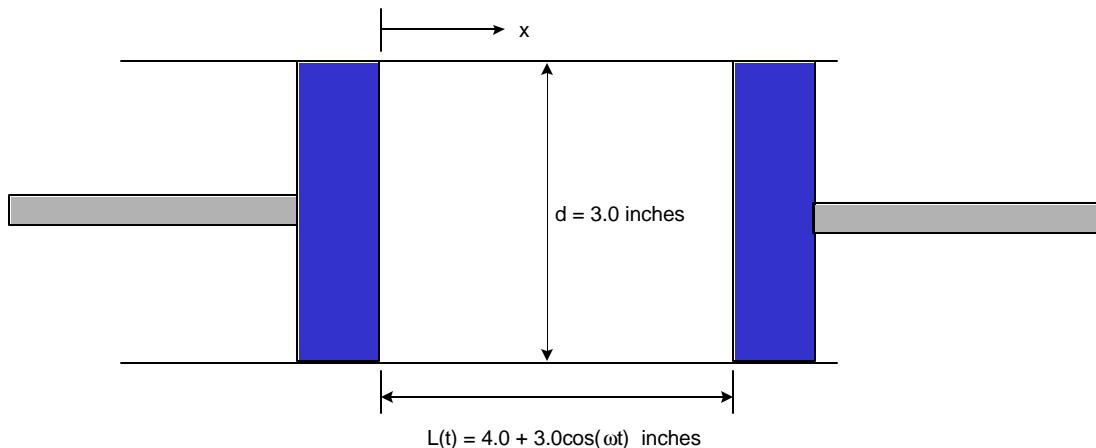


Figure 5.9.2 - Coordinate Transformed Piston-Cylinder Configuration

Figures 5.9.4 and 5.9.5 compare the results of the GFSSP piston-cylinder model with the analytical solution from Equations 5.9.1 and 5.9.2. As these figures illustrate, the GFSSP model compares favorably to the analytical solution. It should be noted that the isentropic solution uses a constant ratio of specific heats (γ), whereas GFSSP accounts for the variation of specific heat ratios with changes in temperature and pressure.

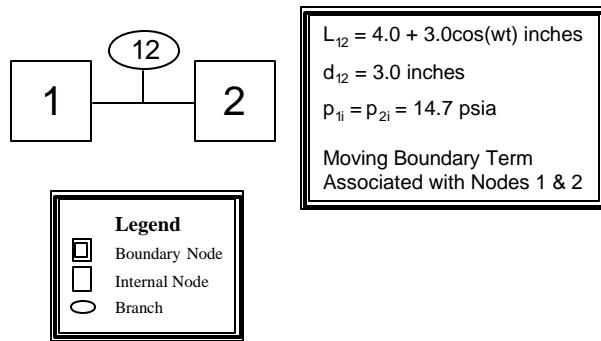


Figure 5.9.3 - GFSSP Model of the Piston-Cylinder

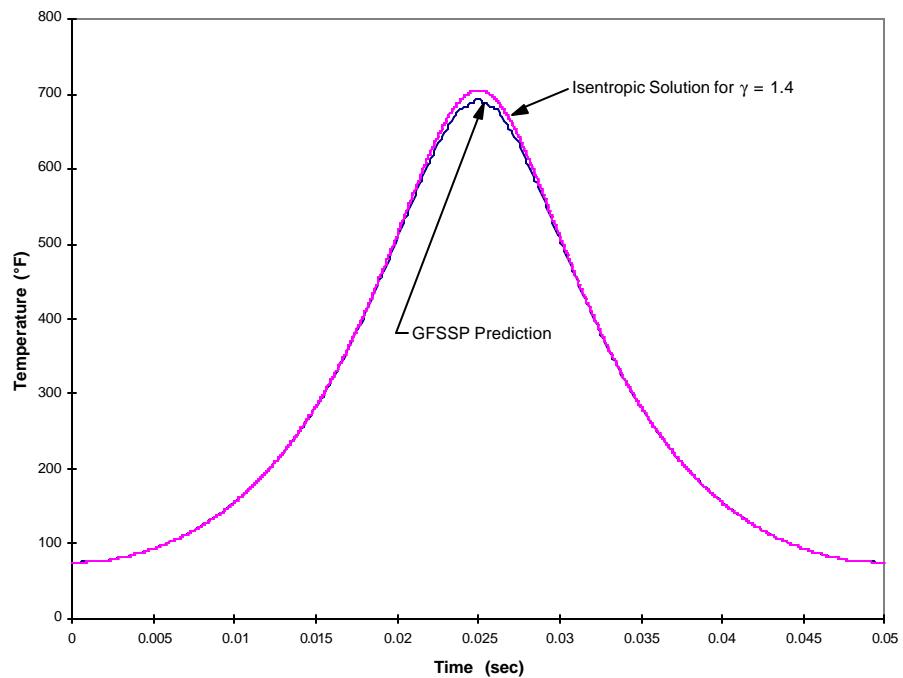


Figure 5.9.4 – Predicted Temperature History of Piston Cylinder Model

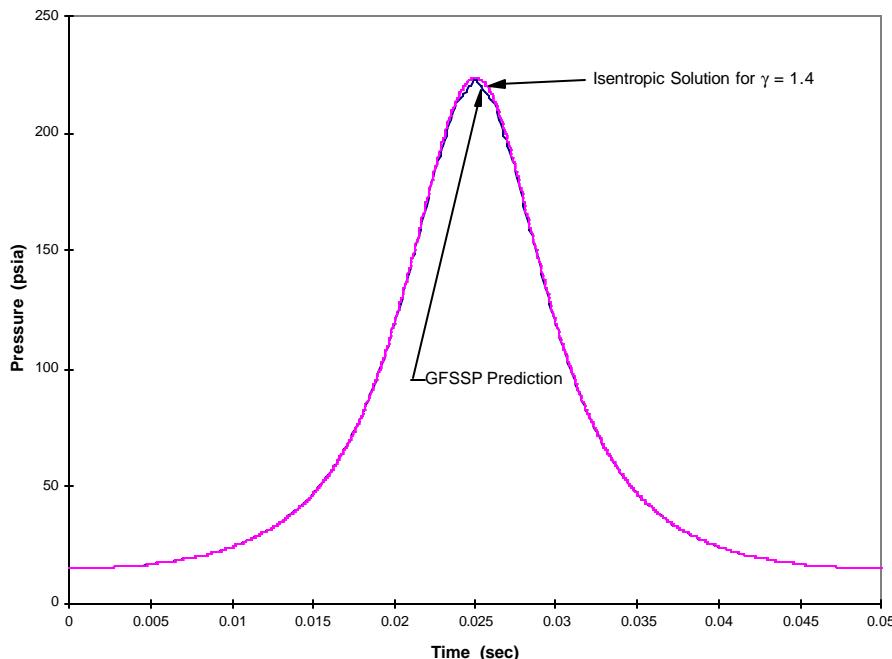


Figure 5.9.5 – Predicted Pressure History of Piston Cylinder Model

5.10 Example 10 - Pressurization of a Propellant Tank

Problem Considered:

In Example 8, we demonstrated the use of GFSSP's unsteady formulation by predicting the pressure and temperature history during the blow down of a pressurized tank. In this example, we will consider a more complex unsteady process, the pressurization of a propellant tank [25]. This example will also illustrate the use of User Subroutines to construct a model of mass transfer due to evaporation of propellant to the ullage space.

The tank pressurization option incorporated in GFSSP models the following physical processes:

- Change in ullage and propellant volume,
- Change in gravitational head in the tank,
- Heat transfer from pressurant to propellant,
- Heat transfer from pressurant to the tank wall,
- Heat conduction between the pressurant exposed tank surface and the propellant exposed tank surface,
- Mass transfer from propellant to ullage.

A schematic of a propellant pressurization system is shown in Figure 5.10.1. It is assumed that initially the ullage space is filled with pressurant at propellant temperature. As the warm pressurant enters the ullage space, it mixes with the cold ullage gas and the temperature of the ullage gas starts to increase due to mixing and compression. Initially, the walls of the tank are also at propellant temperature. Heat transfer from the ullage gas to the propellant and the tank wall and mass transfer from the propellant to the ullage start immediately after the

pressurant begins flowing into the tank. Propellant flows from the tank to the engine under the influence of ullage pressure and gravitational head in the tank. In the current model, condensation of propellant vapor has been neglected.

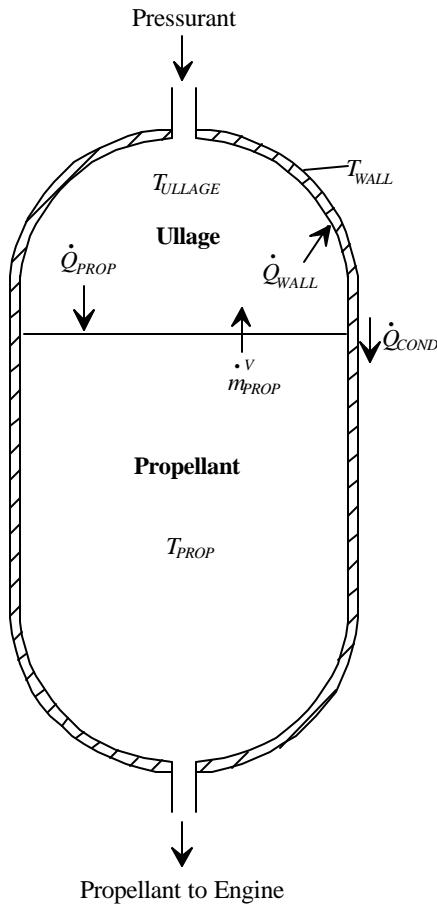


Figure 5.10.1 - Schematic of Propellant Tank Pressurization System

GFSSP Model:

A 5-node pressurization system GFSSP test model, as shown in Figure 5.10.2, was developed to test the implementation of the pressurization option. Helium at 95 psia and 120° F enters the ullage space, which is initially filled with helium at -264° F. Node 2 represents the ullage space. A pseudo boundary node (Node 3) has been introduced to exert ullage pressure on the propellant volume, which is represented by Node 4. The pressure at the pseudo boundary node is calculated from the ullage pressure and gravitational head and is the driving force to supply the propellant to the engine. This pressure is calculated at the beginning of each time step. Branch 12 models the tank inlet, Branch 34 represents the propellant surface and Branch 45 represents the line to the engine. All three branches were modeled using a Flow through a Restriction (Option 2). The flow coefficient of Branch 45 is adjusted to restrict the propellant flow such that all propellant is expelled from the tank over the course of the run. In this test model, the engine inlet pressure was set at 50 psia.

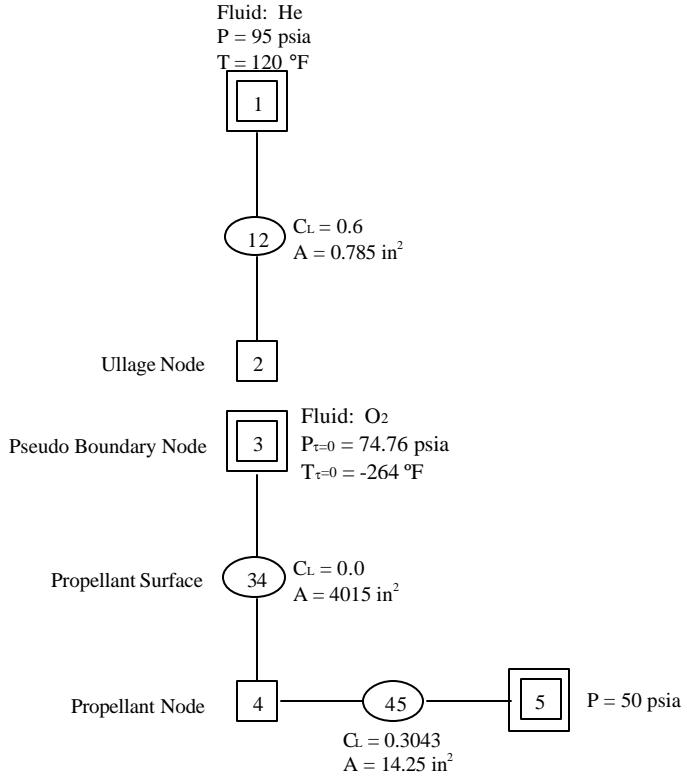


Figure 5.10.2 - Simple Pressurization System Test Model

User Subroutine

The calculation of mass transfer from propellant to ullage is not a capability that is available with the pressurization option so in the course of developing this test model separate coding was written to account for the mass transfer. This coding was included in the user routine SORCEC. This routine uses the heat transfer rate from the ullage to the propellant to calculate the mass transfer rate of vaporized propellant to the ullage. It is assumed that the propellant is vaporized from the surface and the heat transfer from the ullage only contributes to the vaporization of propellant. The mass transfer due to vaporization is expressed as:

$$\dot{m}_{prop}^v = \frac{\dot{Q}_{prop}}{h_{fg} + c_{pf}(T_{sat} - T_{prop})} \quad (5.10.1)$$

The saturation temperature in Equation 5.10.1 is calculated using the vapor pressure relation:

$$\ln p_{sat} = A + \frac{B}{T_{sat}} + C \ln T_{sat} + DT_{sat}, \quad (5.10.2)$$

where A, B, C and D are fluid specific vapor pressure relation constants. Table 5.10.1 lists the values of the vapor pressure relation constants for the propellants considered in these routines.

Table 5.10.1. - Vapor Pressure Relation Constants

Fluid	A	B	C	D
Oxygen	81.66	-2857.	-13.05	0.0310
Nitrogen	67.79	-2156.	-10.97	0.0327
Hydrogen	11.40	-211.9	-1.228	0.0405
RP-1	-3552.	888438.	68.05	2.732

The enthalpy of vaporization in Equation 5.10.1 is calculated using the Clapeyron Equation:

$$h_{fg} = T_{sat} \left(v_g - v_f \right) \frac{dP}{dT} \Big|_{sat} \quad (5.10.3)$$

where v_g is found using the Lee and Kesler modified BWR equation as described by Reid et al[39] with the exception of RP-1, where v_g is calculated using the ideal gas equation. v_f is determined from the following correlation:

$$v_f = C_0 + C_1 T + C_2 T^2 + C_3 T^3 + \dots \quad (5.10.4)$$

where C_0 , C_1 , C_2 etc. are curve fit constants. It should be noted that in the case of RP-1, v_f is assumed to be constant at a value of 0.01923 ft³/lbm. Table 5.10.2 lists the values of the correlation constants for the other propellants considered in these routines.

Table 5.10.2. - Liquid Specific Volume Correlation Constants

	Oxygen	Nitrogen	Hydrogen
C_0	-0.34614	-0.01204	-13.132
C_1	0.011286	0.00061	1.7962
C_2	-0.00013837	-4.23216E-06	-0.094964
C_3	8.2613E-07	1.06765E-08	0.002464
C_4	-2.4007E-09	---	-3.1377E-05
C_5	2.7247E-12	---	1.5712E-07

Subroutine SORCEC

This subroutine is called from subroutine MASSC. The purpose of this subroutine is to calculate the rate of mass transfer of propellant, m_{prop}^v , in the ullage space due to evaporation. This subroutine can handle four liquid propellants, namely nitrogen, oxygen, hydrogen and RP-1. For each fluid, the saturation temperature and enthalpy of evaporation were computed in subroutine SATPRP. SORCECON(IPUL,KFLU) is the source term of propellant specie in the ullage node and SORCEMAS is the mass source in the ullage node. The subroutine SATPRP calculates saturation temperature of the propellant at the prevailing ullage pressure. It employs a Newton-Raphson method to compute temperature from the vapor pressure relation shown in Equation 5.10.2. It also calls subroutine BWR to calculate specific volumes of liquid and vapor at a given pressure and temperature. Finally, it calculates enthalpy of evaporation as given in Equation 5.10.3.

Subroutine PRNUSEN

This subroutine is called from subroutine PRINT. The purpose of this subroutine is to write specific variables in a file for plotting purpose. The variables written in this subroutine include various heat and mass transfer rates, temperature and volumes. For description of each variable, the reader is referred to Appendix D.

Results

The User Subroutine, input and output files including history files of Example 10 have been attached in Appendix - O. The pressurization system transient test model was run for 200 seconds with 0.1-second time step. The model run time was approximately 85 seconds using a 200 MHz Pentium II with Windows NT and 32 megabytes of RAM.

Figure 5.10.3 shows both the ullage pressure and tank bottom pressure histories for the test model. After an initial pressure rise due to a “ramping up” transient effect, both pressures begin a slow but steady decline for the remainder of the run. It should be noted that tank bottom pressure was calculated by adding ullage pressure with pressure due to gravitational head. Figure 5.10.3 shows that as the gravitational head decreases, the ullage and tank bottom pressures slowly converge until all propellant is drained from the tank. The slow decline in ullage pressure is mainly due to the expanding ullage volume.

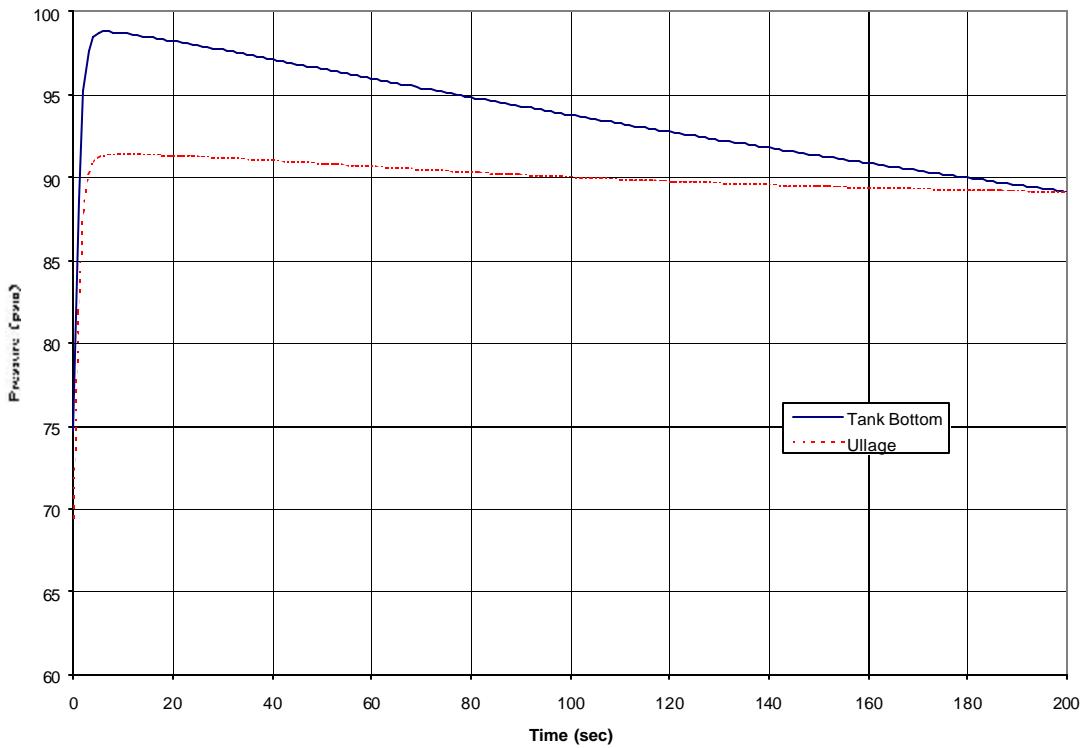


Figure 5.10.3 - Ullage and Tank Bottom Pressure History

Figure 5.10.4 shows the histories for the ullage temperature and the tank wall temperature. This figure shows that the tank wall temperature rises thirty-four degrees over the course of the model run. It reveals that the 120 °F helium gas entering the tank has an increasing effect on the tank wall as propellant is drained from the tank and the wall surface area exposed to the warmer ullage gas grows. This effect is somewhat dampened, however, because the heat gained by the wall is conducted to the portion of the tank that is submerged in LOX, which acts as a heat sink. The ullage temperature rises two hundred eight degrees during the first sixty seconds of tank pressurization before beginning a slow decline for the remainder of the simulation. This large initial temperature rise is primarily due to the mixing of hot helium gas with the relatively cold gas present in the ullage. The decline in temperature is a result of expansion due to continuous increase of the ullage volume.

Helium flow rate into the tank is shown in Figure 5.10.5. The helium flow rate was found to drop initially as the start transient takes place, which is consistent with the “ramp up” effect noted in Figure 5.10.3. Then the flow rate begins to gradually increase as ullage pressure drops due to the expanding ullage volume. LOX flow rate into the engine is shown in Figure 5.10.6. The LOX flow rate curve mirrors the ullage and tank bottom pressure curves, rising through an initial start transient to a peak value and then declining for the remainder of the run as tank pressure drops.

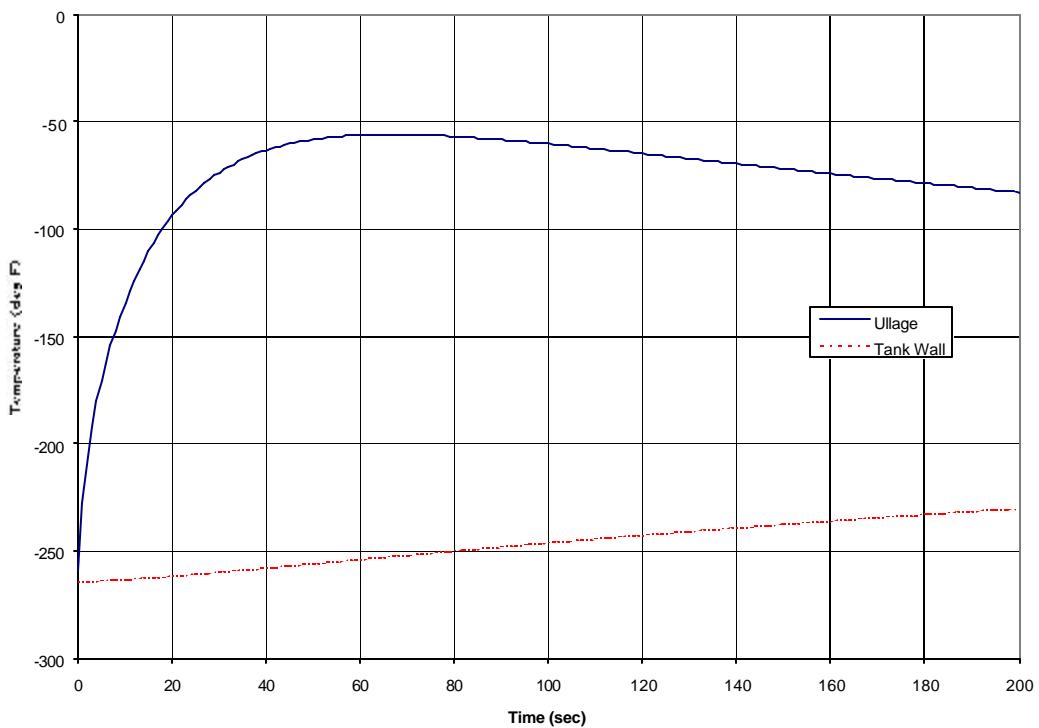


Figure 5.10.4 Ullage and Tank Wall Temperature History

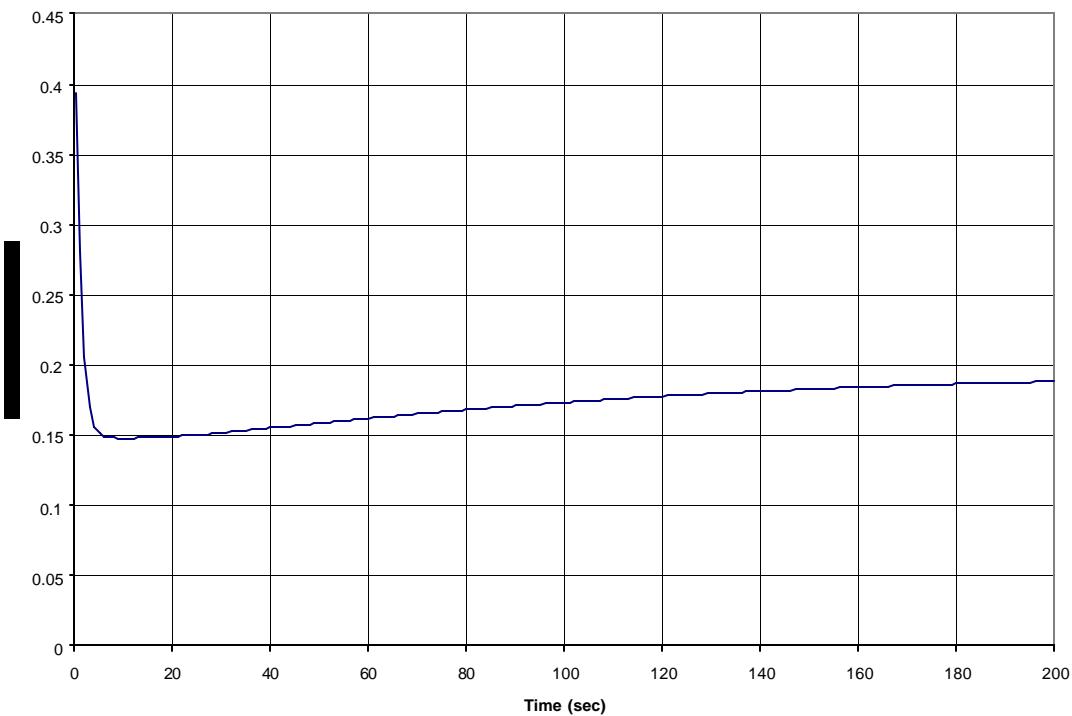


Figure 5.10.5. - Helium Mass Flow Rate History

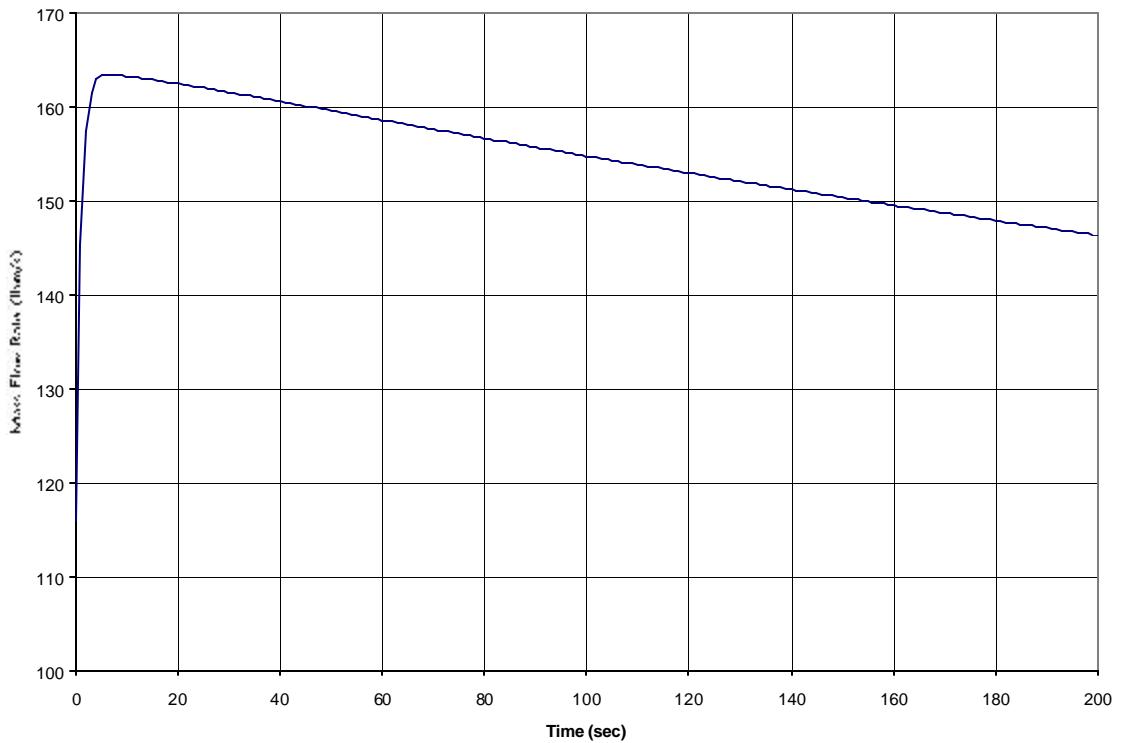


Figure 5.10.6. - LOX Mass Flow Rate History

Figure 5.10.7 shows the mass transfer rate of Gaseous Oxygen (GOX) into the ullage space over the duration of the run. The mass transfer rate curve mirrors the ullage temperature curve, which is what one expects since the mass transfer is based on the ullage to propellant heat transfer, which is based on ullage temperature. GFSSP predicts a final GOX mass concentration of 0.16 in the ullage.

As a validation, the model results were compared with a published correlation of pressurant requirements for a given displacement of propellant as published by Epstein and Anderson [40]. The correlation calculates the collapse factor, which is defined by Van Dresar [41] as a ratio of the actual pressurant consumption to an ideal pressurant consumption where no heat or mass transfer from the pressurant occurs. This correlation takes the form shown in equations 5.10.5 through 5.10.9.

$$\frac{w_p}{w_p^0} = \left\{ \left(\frac{T_0}{T_s} - 1 \right) \left[1 - \exp(-p_1 C^{p_2}) \right] \times \left[1 - \exp(-p_3 S^{p_4}) \right] + 1 \right\} \\ \times \exp \left[-p_5 \left(\frac{1}{1+C} \right)^{p_6} \left(\frac{S}{1+S} \right)^{p_7} Q^{p_8} \right] \quad (5.10.5)$$

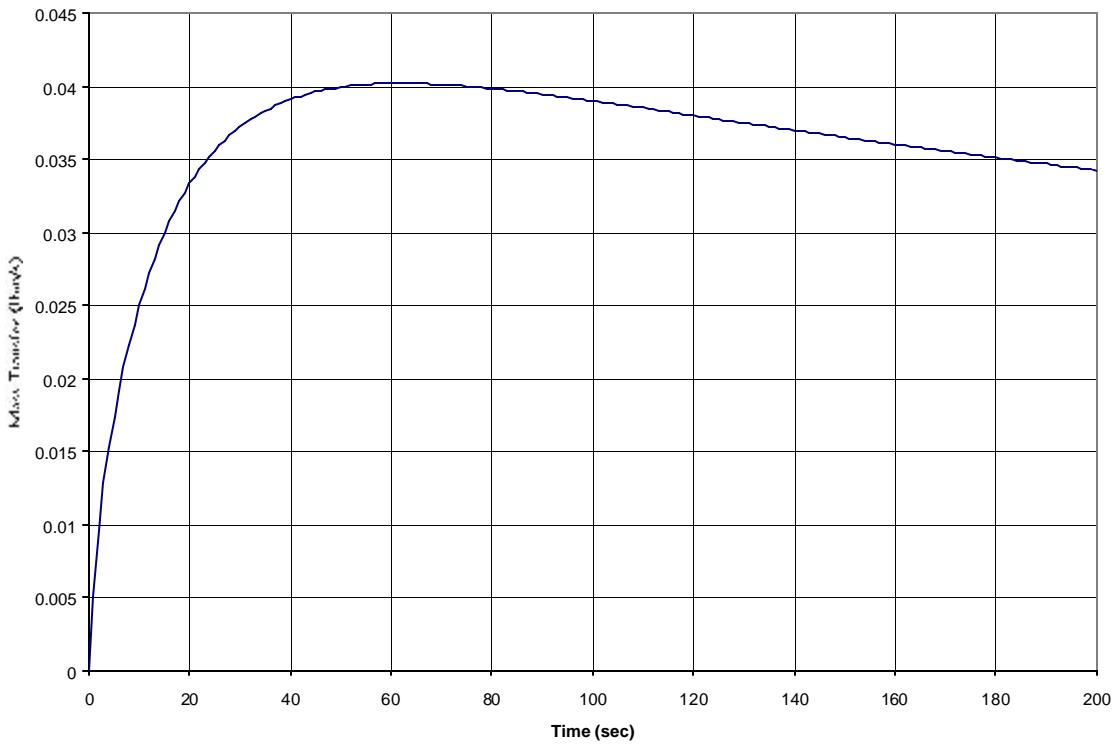


Figure 5.10.7. - GOX Mass Transfer Rate History

where

$$w_p^0 = \mathbf{r}_G^0 \Delta V \quad (5.10.6)$$

$$C = \frac{(\mathbf{r} c_p^0 \mathbf{d})_{wall}}{(\mathbf{r} c_p)_G^0 D_{eq}} \frac{T_s}{T_0} \quad (5.10.7)$$

$$S = \frac{h \mathbf{q}_T}{(\mathbf{r} c_p)_G^0 D_{eq}} \frac{T_s}{T_0} \quad (5.10.8)$$

$$Q = \frac{\dot{q} \mathbf{q}_T}{(\mathbf{r} c_p)_G^0 D_{eq} T_0} \quad (5.10.9)$$

Van Dresar [41] later modified this correlation by redefining D_{eq} as shown in equation 5.10.10.

$$D_{eq} = 4 \frac{\Delta V}{A_{sw}} \quad (5.10.10)$$

For this validation exercise, the tank is assumed to be cylindrical and therefore the tank diameter is used in place of Van Dresar's equivalent diameter definition. The tank characteristics used are those values utilized in the GFSSP test model. Also, the ideal pressurant properties of $c_{p_G}^0 = 1.24 \frac{Btu}{lbm - R}$ and $r_G^0 = 0.06087 \frac{lbm}{ft^3}$ are found using the helium inlet conditions of $P_0 = 95$ psia and $T_0 = 120$ °F. The saturation temperature of LOX (T_s) is taken to be -264 °F. The heat transfer coefficient is calculated to be $h = 1.05e-03 \frac{Btu}{ft^2 - s - R}$ by taking the average value of the heat transfer coefficients calculated by GFSSP at each time step. The change in propellant volume is the value predicted by the GFSSP test model and ambient heat flux is neglected in this model. The constants p_1 through p_8 are provided by Epstein and Anderson [40] and are shown in Table 5.10.3 below.

Table 5.10.3. - Constants for LOX Propellant

p_1	0.775
p_2	0.209
p_3	3.57
p_4	0.790
p_5	0.755
p_6	0.271
p_7	0.236
p_8	0.895

Solving equations 5.10.7 through 5.10.9 and substituting into equation 5.10.5 gives $\frac{w_p}{w_p^0} = 1.58$. Solving equation 5.10.6 gives $w_p^0 = 28.9$ lbm. The GFSSP output file predicts a required pressurant mass of approximately 41.68 lbm. Dividing this number by the ideal pressurant mass gives a GFSSP predicted collapse factor of 1.44. Therefore the predicted discrepancy of GFSSP with respect to Epstein's method is 8.86%. It is believed that this discrepancy is due mainly to the sensitivity of the pressurization process to the heat transfer coefficient, which is difficult to calculate accurately.

5.11 Example 11 - Power Balancing of a Turbopump Assembly

Problem Considered:

This example, Example 11, illustrates the modeling of the mechanical coupling between two flow components. In the turbopump assembly shown in Figure 5.11.1, a co-axial shaft mechanically connects the pump and turbine. The power required by the pump must be transmitted from the turbine in order for the system to be in balance. The purpose of this example is to demonstrate this power balancing for a turbopump when used in a Gas Turbine Cycle. The physical plausibility of the predicted results was demonstrated by performing parametric studies on shaft speed.

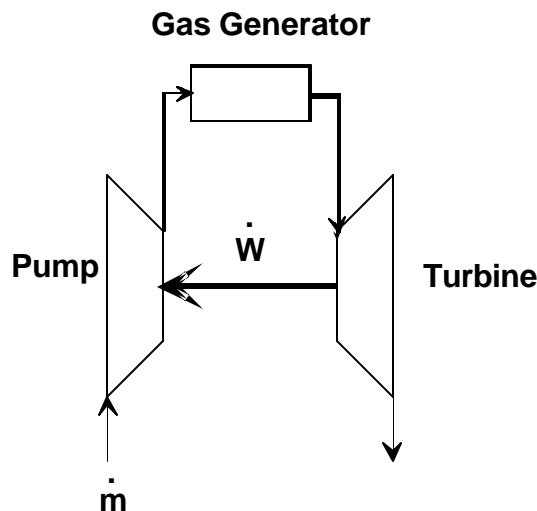


Figure 5.11.1 - Simplified Turbopump Assembly

GFSSP Model:

A model of the turbopump portion of a flow circuit is shown in Figure 5.11.2. This model consists of an inlet from a hydrogen tank, a turbopump assembly (pump, turbine and a connection between them {shaft}), two heat exchangers, a bypass dump outlet and an outlet to the power turbine. The first of the heat exchangers (denoted on Figure 5.11.2 as the Regenerator) is used to heat a small portion of the main LH₂ flow by using the “hotter” hydrogen exiting the turbine, while the remainder of the LH₂ flow bypasses this heat exchanger. The second heat exchanger is used to boil and superheat the hydrogen by means of external heat addition. The shaft speed for this model is set in the input file to 80,000 rpm.

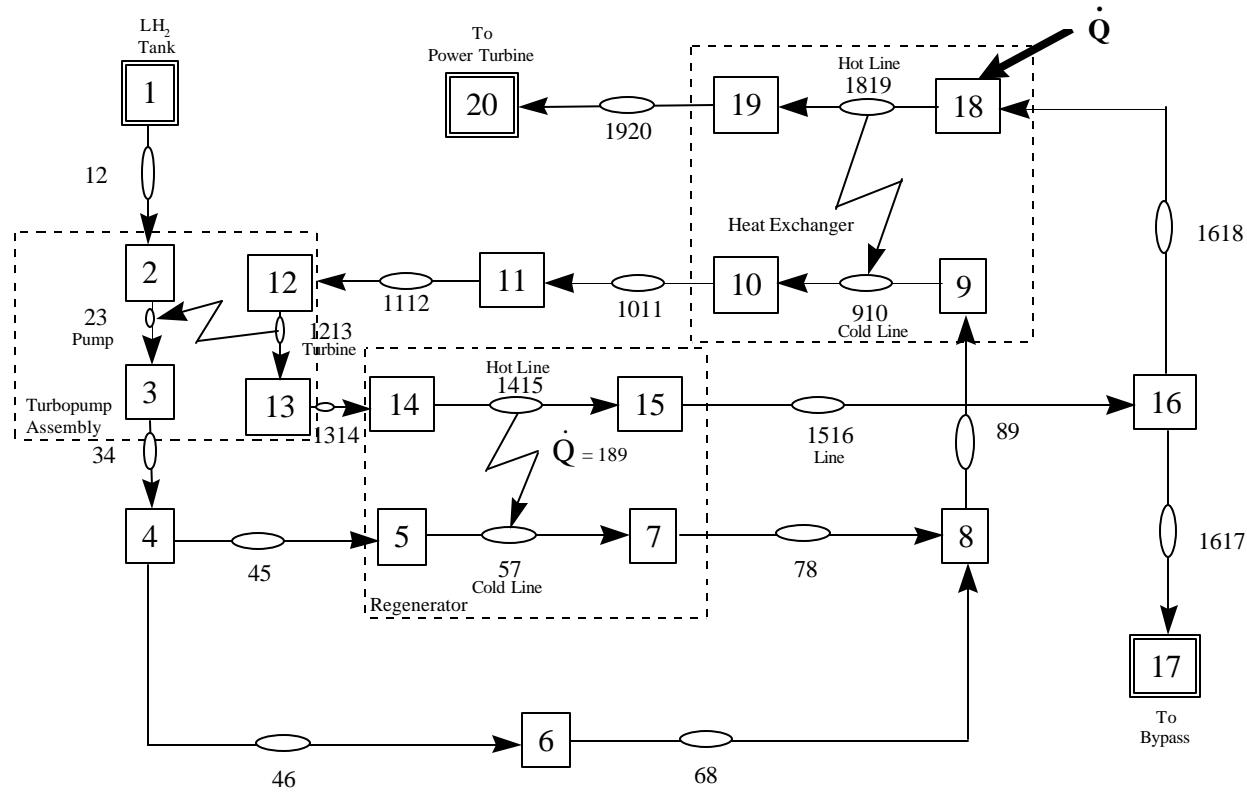


Figure 5.11.2 – A Flow Circuit Containing Turbopump Assembly

This model uses the following options:

- Branch Resistance Options:
 1. Pipe Flow (Option -01),
 2. Pump with Pump Efficiency (Option -15),
 3. Valve with a Given C_v (Option -16).
 - Special Options:
 1. Heat Exchanger (2), (Logical Variable HEX),
 2. Turbopump Assembly (1) , (Logical Variable TPA).

Results:

Appendix P contains the input, pump characteristics and output files for this example (ex11.dat, pump23.dat and ex11.out). The results of the study are illustrated in Figure 5.11.3.

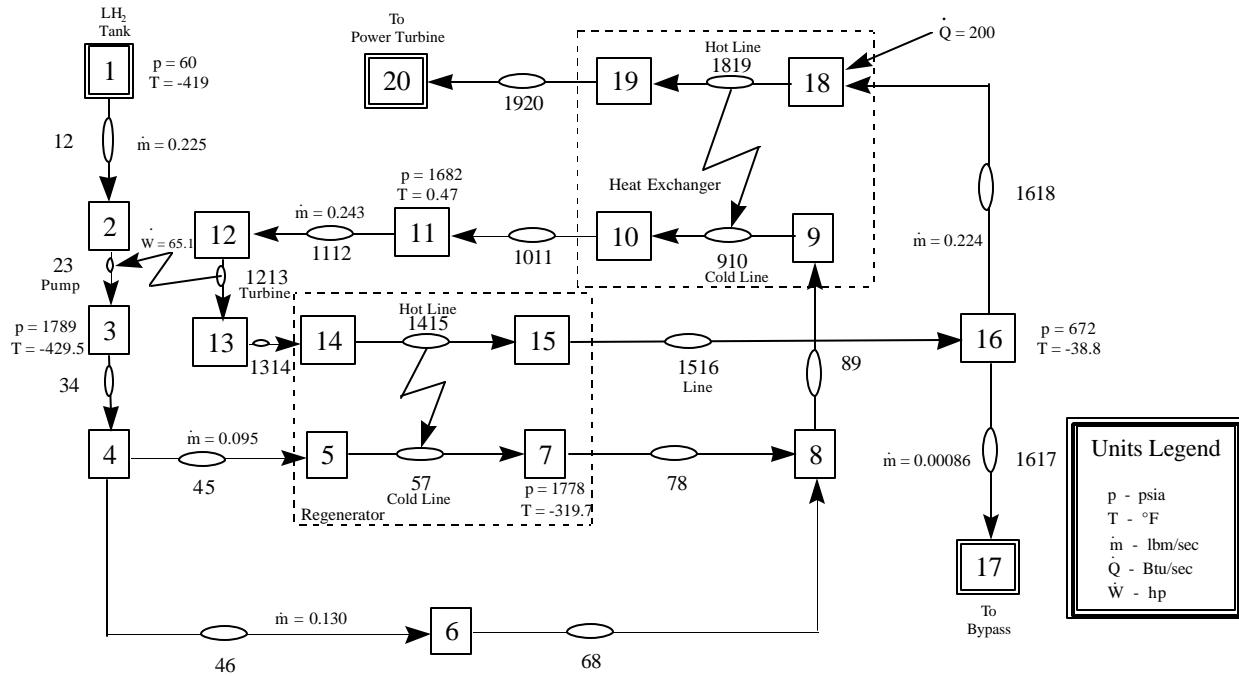


Figure 5.11.3 - GFSSP RCS Model Results

Parametric Study

In order to verify this complicated model, a parametric study on the shaft speed of the turbopump was conducted. Figures 5.11.4, 5.11.5 and 5.11.6 illustrate the results of this model. Figure 5.11.4 illustrates the pressure differential across the turbopump for both the pump and the turbine as a function of the shaft speed. Figure 5.11.5 illustrates the hydrogen mass flow rate through the turbopump as a function of the shaft speed. Figure 5.11.6 illustrates the torque and horsepower transmitted in the turbopump as a function of the shaft speed. As each of these figures illustrates, a functional relationship is identifiable for each predicted variable as a function of shaft speed.

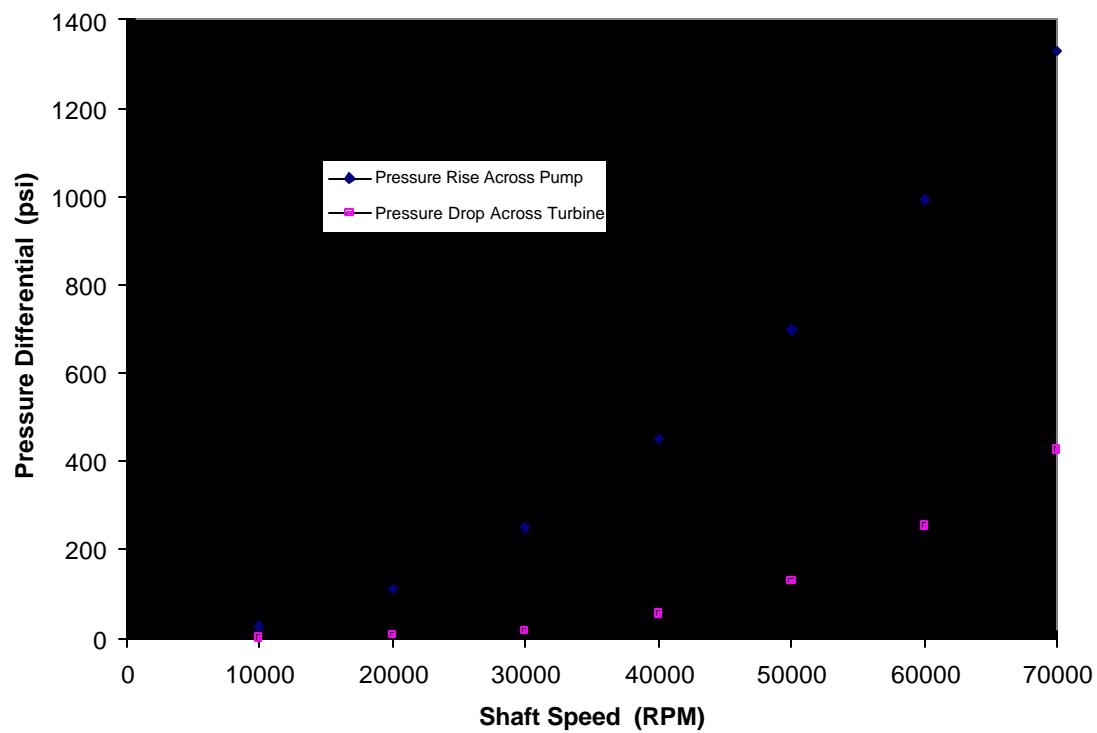


Figure 5.11.4 - Parametric Study Results: Turbopump Pressure Differential

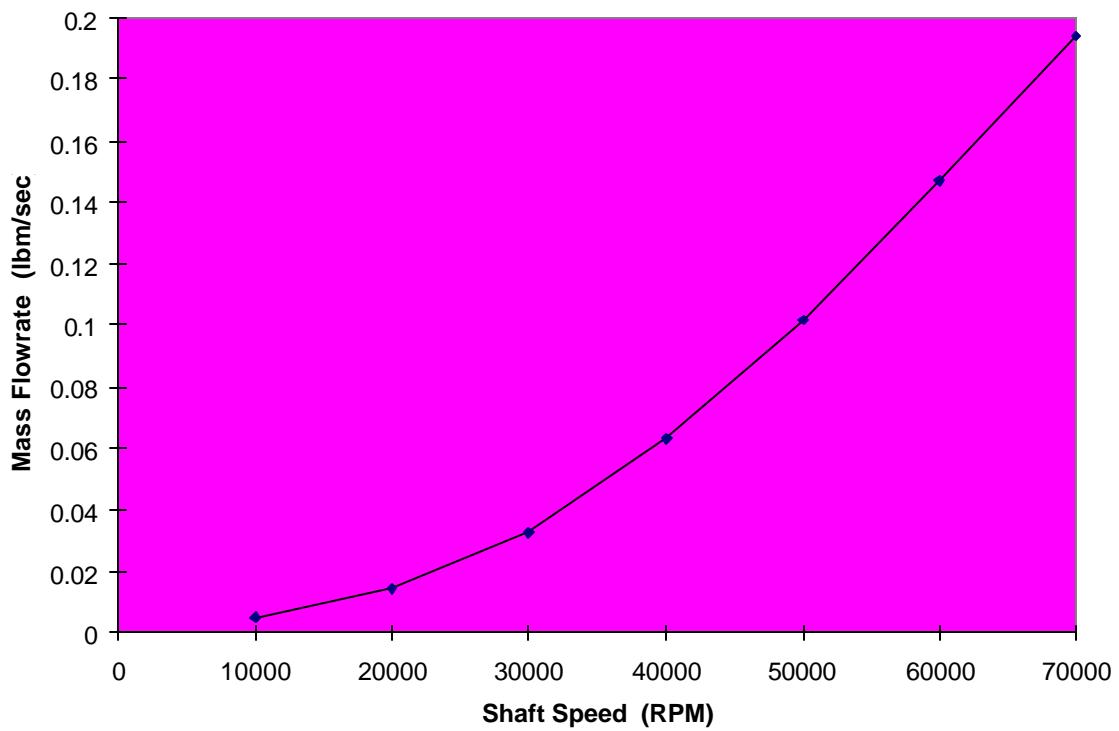


Figure 5.11.5 - Parametric Study Results: Turbopump Hydrogen Mass Flow Rate

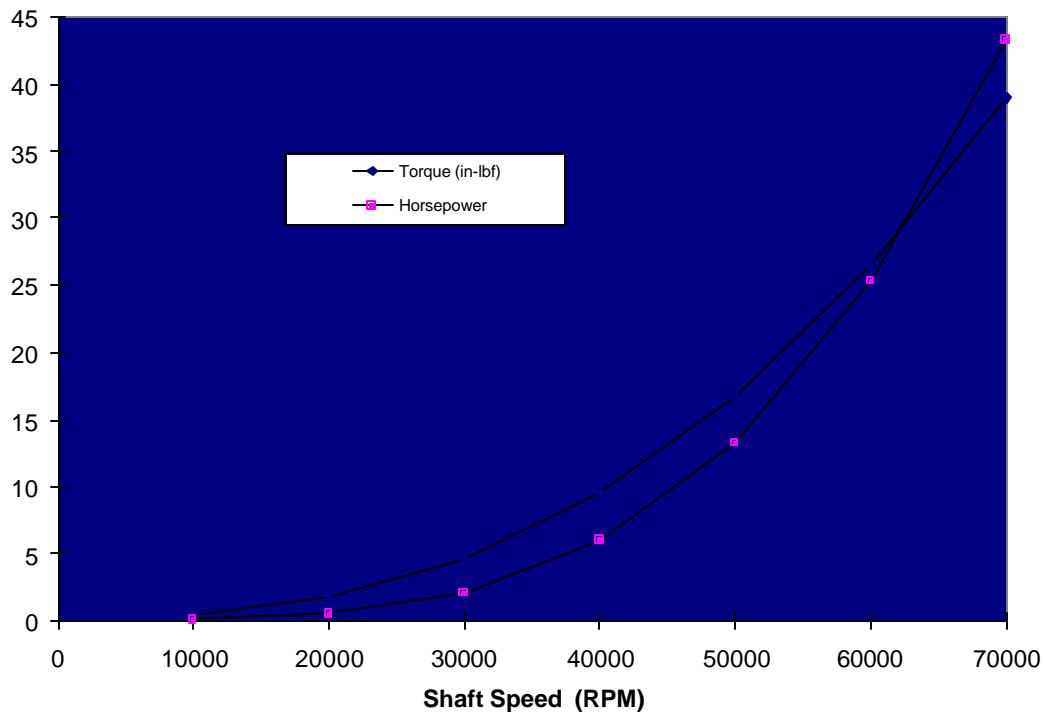


Figure 5.11.6 - Parametric Study Results: Turbopump Torque and Horsepower

5.12 Example 12 - Helium Pressurization of LOX and RP-1 Propellant Tanks

Problem Considered:

Example 10 illustrates the use of the pressurization option in modeling ullage and propellant conditions in a tank. In this example we will construct an integrated model consisting of two propellant tanks, a flow network for the ullage pressurant supply from a Facility interface and engine propellant feed lines. The pressurization system of Propulsion Test Article 1(PTA1) consists of a liquid oxygen (LOX) tank and an RP-1 tank that are both pressurized by helium. This configuration is represented in the schematic shown in Figure 5.12.1. The objective of the present example is to develop an integrated mathematical model from the helium supply line to the engine inlet to model sixty seconds of engine operations. The model has three primary functions. They are:

- To predict the flow rate and pressure distribution of the helium supply line feeding both the LOX and RP-1 tanks,
- To predict the ullage conditions considering heat transfer between the ullage, propellant and the tank wall, as well as mass transfer from propellant to ullage,
- To predict the propellant conditions leaving the tank.

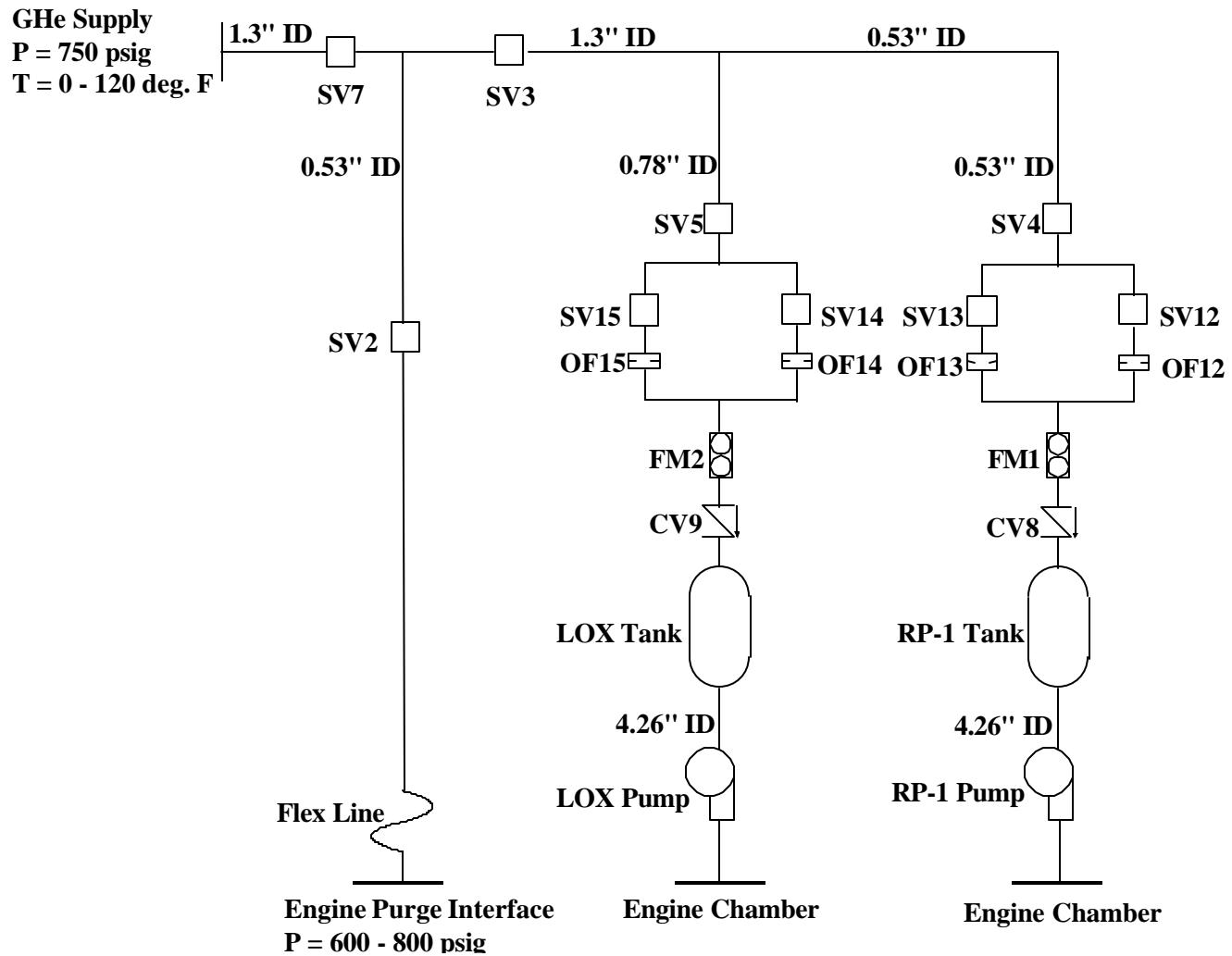


Figure 5.12.1. - Propulsion Test Article 1 Helium Pressurization System Schematic

GFSSP Model:

A GFSSP model of the Helium Pressurization System of LOX and RP-1 Tanks is shown in Figure 5.12.2. The model consists of 65 nodes and 64 branches. The model extends from facility interface to engine purge and engine chamber interfaces. It includes all piping and its fittings, orifices and valves. Both RP-1 and Liquid Oxygen (LOX) tanks and pumps are included in the model. Each propellant tank has a diffuser and control valve. Pressure and temperatures are specified at the interfaces, which are represented by six boundary nodes listed in Table 5.12.1.

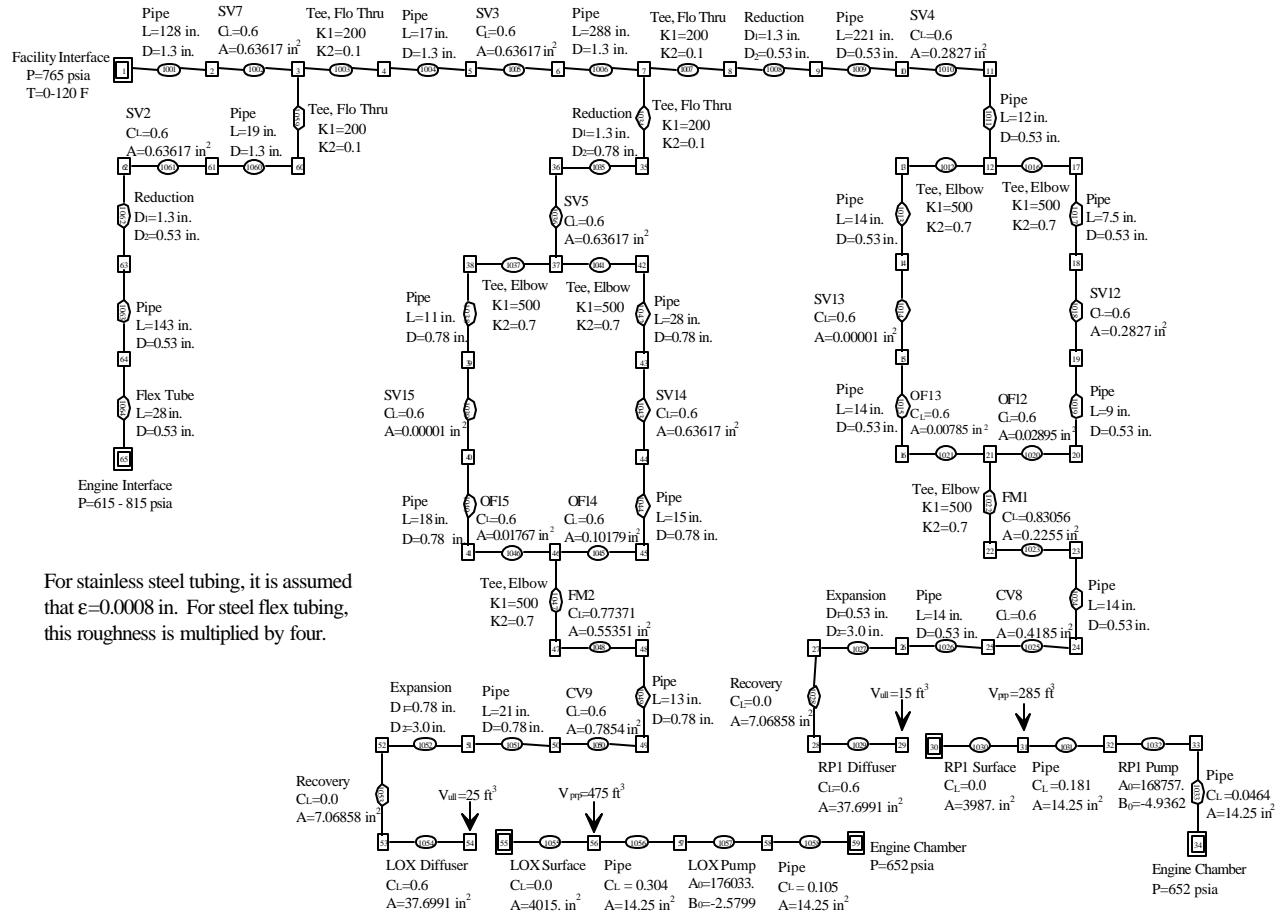


Figure 5.12.2 - GFSSP Model of the Pressurization System of Example 12

Table 5.12.1. - Boundary Nodes of Helium Pressurization Flow Circuit

Boundary Node	Interface
1	Facility Interface
65	Engine Interface (Purge)
55	Ullage-propellant interface(LOX Tank)
59	LOX Engine Chamber Interface
30	Ullage-propellant interface(RP-1 Tank)
34	RP-1 Engine Chamber Interface

It may be noted that the nodes representing ullage-propellant interface (Node 55 and 30) are pseudo boundary nodes. The code uses the calculated ullage pressure at the previous time step instead of pressures provided by the user through history files. Helium enters into the system from the facility interface where it is distributed into three parallel branches. The first branching takes place after 128 inches of pipeline and this branch supplies

helium to the engine for engine purges. The second branching takes place 305 inches downstream of the first branch and this branch supplies helium to the LOX tank. The rest of the helium goes to pressurize the RP-1 tank. The lines leading to the LOX and RP-1 tanks each have two parallel legs, one of which remains closed during operation. The left leg of the circuit is used to pressurize the tank during pre-pressurization operation while the right leg of the circuit is used to pressurize the tank during pressurization stand-by and engine operations. In the model discussed in this report, setting a high resistance in the appropriate branches eliminated the flow to the left leg.

Results:

The input and output files including history files of Example 12 have been attached in Appendix Q. The GFSSP model shown in Figure 5.12.2 was run for a 60-second engine operation period. At the beginning of the model run, the control valve nominal set points are 72 psia for the LOX tank and 55 psia for the RP-1 tank with plus or minus 3 psi tolerances. After 3 seconds they drop 5 psi to 67 psia for the LOX tank and 50 psia for the RP-1 tank with plus or minus 3 psi tolerances. The output file contains pressure, temperature and density at all nodes as well as flow rate, velocity and pressure drop at all branches for selected time steps.

Figure 5.12.3 shows the predicted pressure history of the RP-1 ullage, RP-1 tank bottom, LOX ullage and LOX tank bottom pressures. The difference in pressure between the tank bottom and ullage is the gravitational head, which slowly reduces as propellant is drained from the tank. The wavy nature of the pressure profiles is due to the control valves, which are set to close or open as the tank bottom pressures exceed prescribed tolerances. It is observed that the frequency of pressure oscillation is larger in the LOX tank than the RP-1 tank. This observation is attributable to the higher flow rates associated with the LOX tank as compared to those required for the RP-1 tank.

Figure 5.12.4 shows the predicted ullage temperature history in the RP-1 tank. Initially wall and propellant temperatures were assumed equal at 70 °F. Heat transfer between ullage gas and wall is not very significant in the RP-1 tank and as a result the tank wall temperature rises only a degree or so during the 60 second engine operation. Ullage temperature, on the other hand, increases by about 29 °F due to mixing and pressurization. Ullage temperature diminishes during the period of valve closure because of the heat transfer from ullage gas to wall.

Figure 5.12.5 shows the heat transfer history for the RP-1 tank. The ullage to propellant heat transfer rises for the first 30 seconds then levels off with a peak value of 0.186 Btu/s, mirroring the RP-1 ullage temperature behavior. The ullage to wall heat transfer, however, continues to grow throughout engine operation, achieving a maximum value of 1.1 Btu/s. This continuous rise is due to the ever-increasing tank wall area exposed to ullage gas as propellant is expelled from the tank.

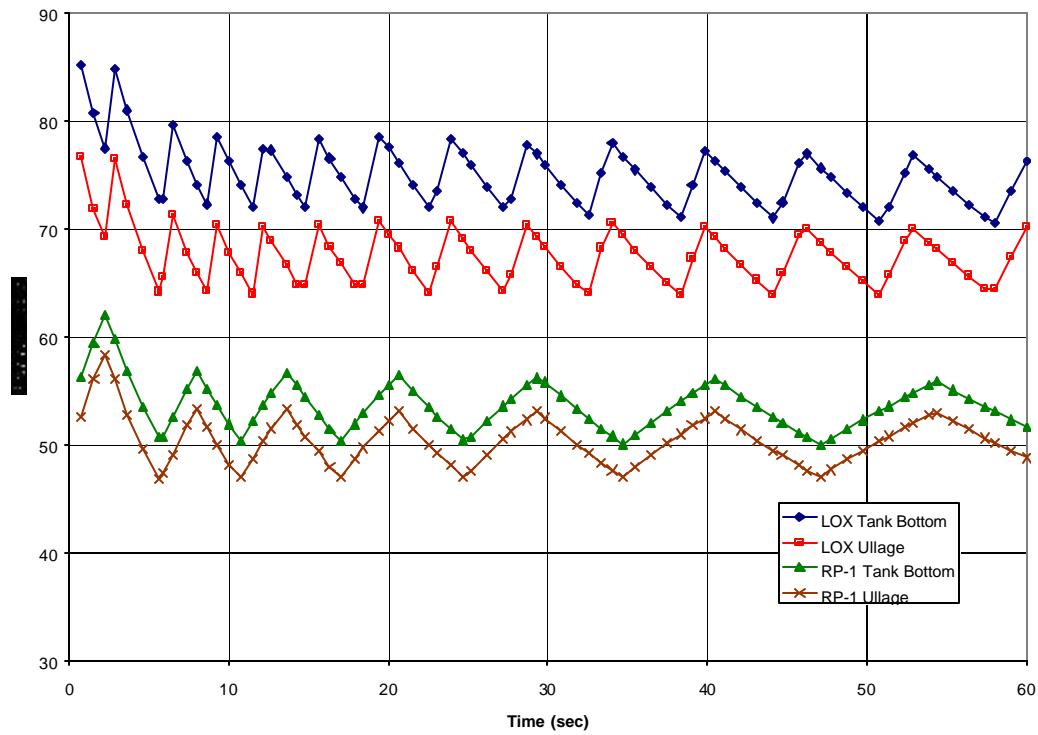


Figure 5.12.3. - Propellant Tank Pressure History

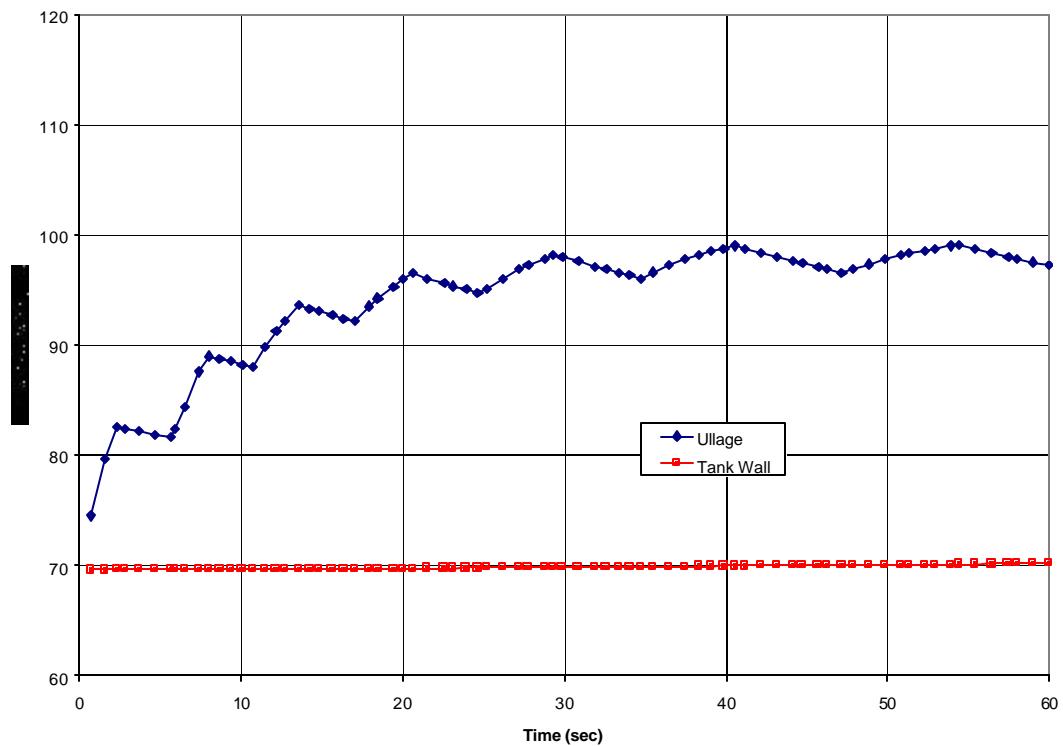


Figure 5.12.4 - RP-1 Temperature History

The predicted ullage temperature history in the LOX tank is shown in Figure 5.12.6. The LOX ullage temperature is assumed to be initially at -260 °F and the tank wall temperature is assumed to be initially at -300 °F. The tank wall temperature rise is more pronounced in the LOX tank than the RP-1 tank, rising 8°F over the course of the 60-second run. The ullage temperature, on the other hand, rises about 162 °F. The higher temperature rise in the LOX tank is primarily due to the fact that the LOX ullage is initially assumed to be at -260 °F and mixes with helium at 120 °F. On the other hand, the initial temperature difference in the RP-1 ullage is much smaller. The other contributing factor is the higher helium flow rate into the LOX tank.

Figure 5.12.7 shows the LOX tank heat transfer history. The LOX heat transfer curves follow a similar pattern to the RP-1 tank heat transfer curves, but on a much greater scale. The ullage to propellant heat transfer achieves a maximum value of 2.78 Btu/s and ullage to wall heat transfer peaks at 23.2 Btu/s.

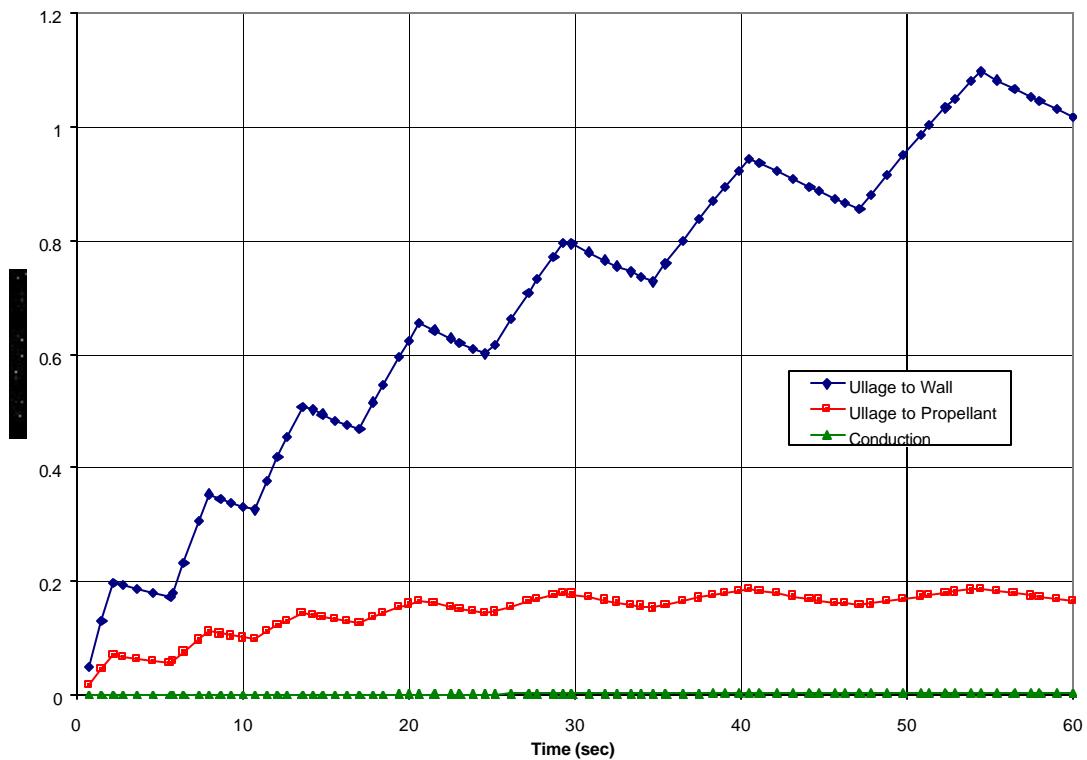


Figure 5.12.5 - RP-1 Heat Transfer History

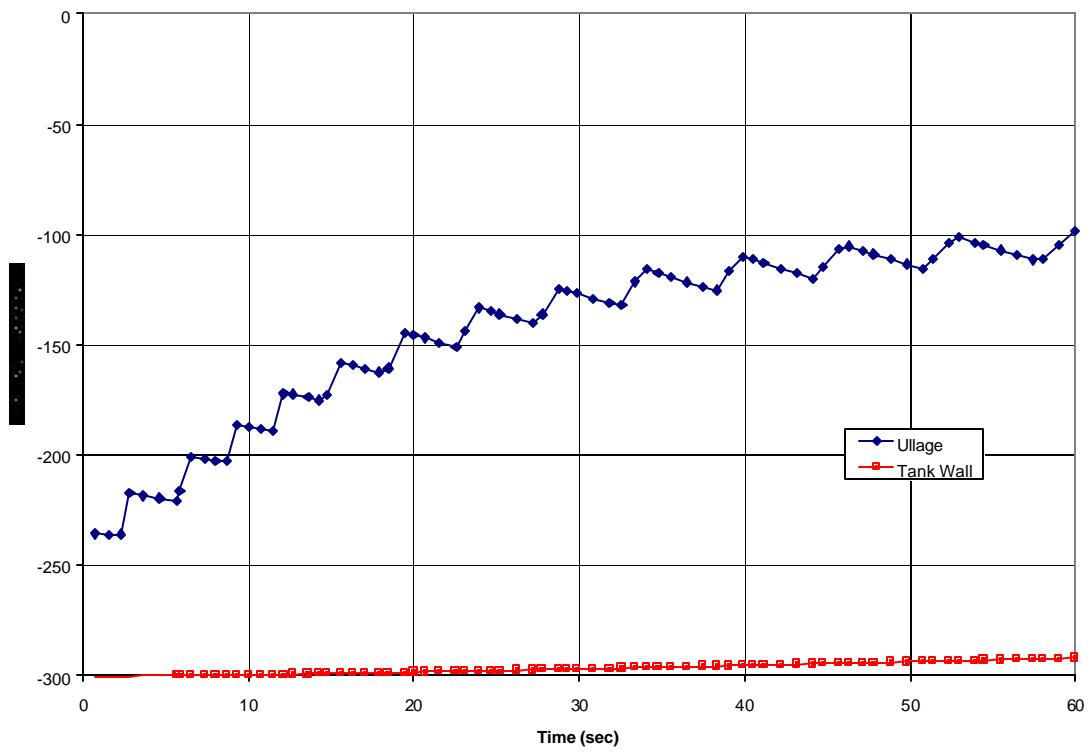


Figure 5.12.6 - LOX Temperature History

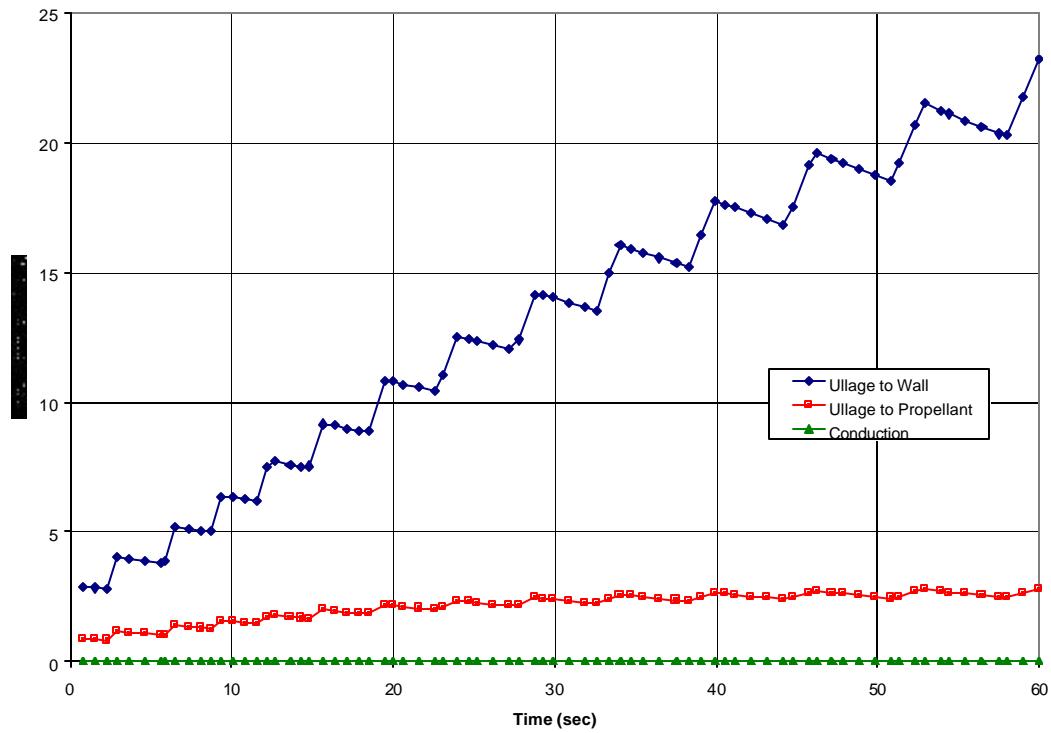


Figure 5.12.7 - LOX Tank Heat Transfer History

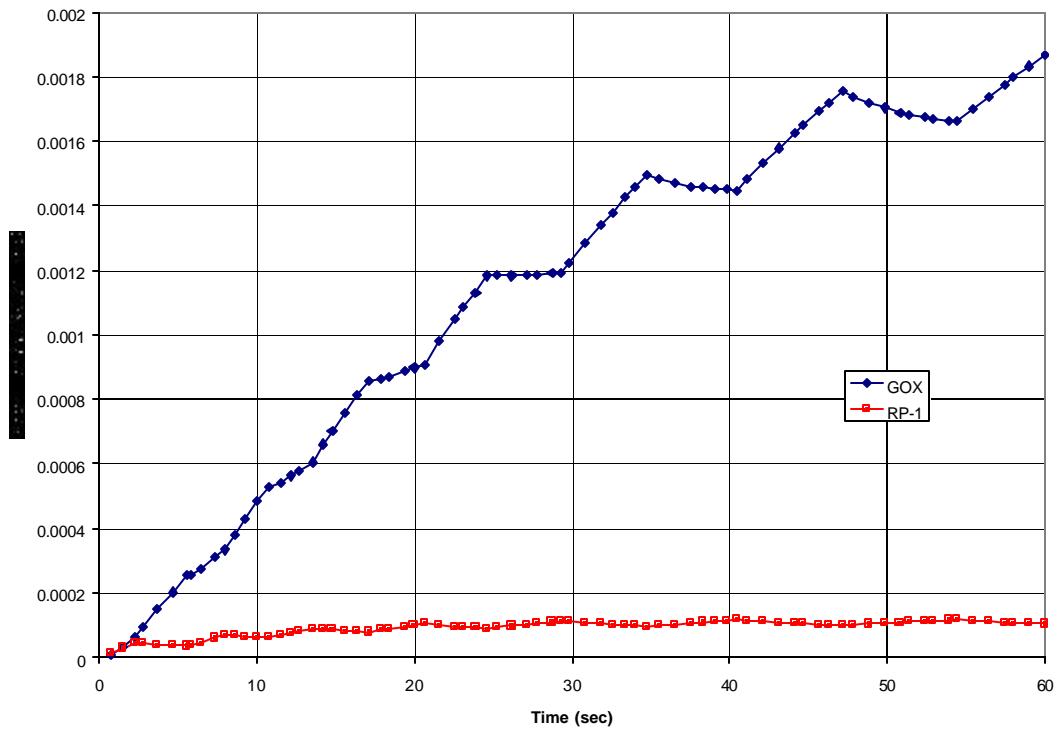


Figure 5.12.8 - Mass Transfer History of Propellant

The mass transfer history of propellant into the ullage for the LOX and RP-1 tanks is shown in Figure 5.12.8. The mass transfer of propellant to ullage was calculated using the user subroutines discussed in Section 5.10 (Example 10). The mass transfer rate of GOX into the LOX tank ullage is much larger than that of vaporized RP-1 into the RP-1 tank ullage due to the higher heat transfer rates seen in the LOX tank. At the end of the 60-second run, the mass concentration of GOX in the LOX tank ullage is 0.15 while the mass concentration of vaporized RP-1 in the RP-1 tank ullage is 0.034.

The propellant flow rates are shown in Figure 5.12.9 to be 139 lbm/s for LOX and 64 lbm/s for RP-1. The constant propellant flow rate predictions are a result of the RP-1 and LOX pumps. The branches upstream and downstream of the pumps have been adjusted to reproduce the pressure drops associated with the flow paths between the tanks and pump inlets and pump exits and engine chamber. This was done because of a lack of detailed flow path geometry downstream of the propellant tanks.

While propellant is discharged to the engine, ullage volume increases. The increase in the ullage volume in the RP-1 and LOX tanks is shown in Figure 5.12.10. The initial ullage volume of the RP-1 tank was assumed to be 15 ft³ while the LOX tank initial ullage volume was assumed to be 25 ft³. The ullage volumes increase linearly to 90 ft³ and 141 ft³ for the RP-1 and LOX tanks respectively.

Figure 5.12.11 shows the helium flow rates in the system. Helium flow rate varies over time due to the opening and closing of the control valves during this time period. The flow from the facility interface is distributed to three branches. A nearly constant flow rate (about 0.4 lbm/sec) is predicted to the engine

purge interface for engine purges. The maximum flow rates to the LOX and RP-1 tanks are about 0.34 lbm/sec and 0.085 lbm/sec respectively. Table 5.12.2 shows a comparison of GFSSP helium flow predictions with McRight's [42] pressurization analysis model.

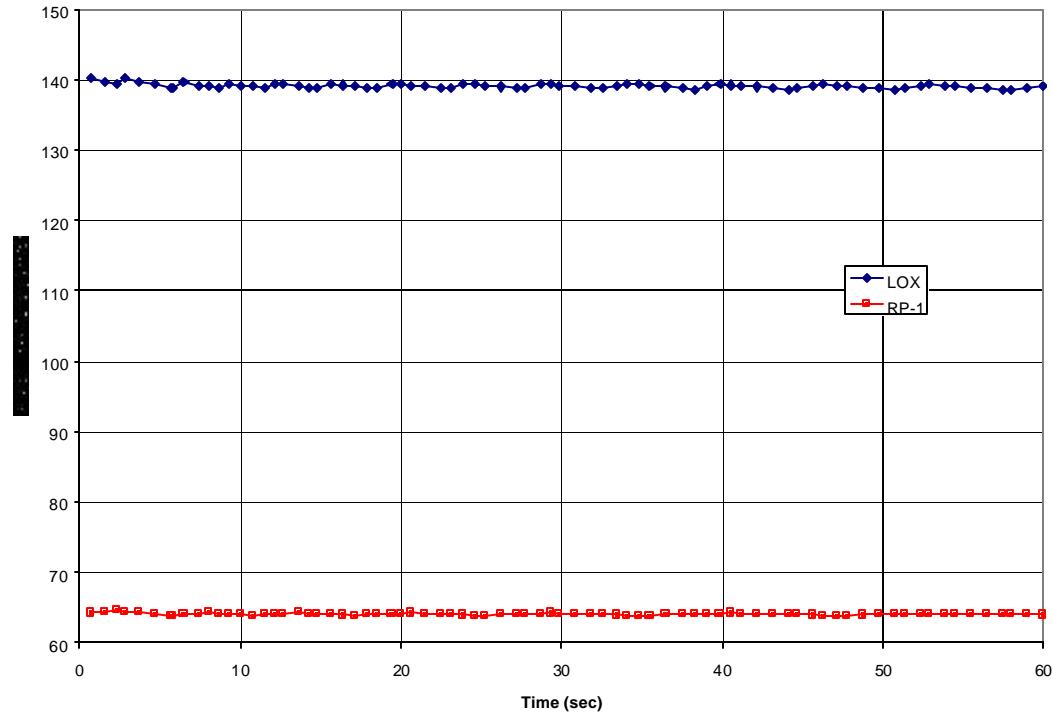


Figure 5.12.9 - Propellant Flowrate History

Table 5.12.2 Comparison between GFSSP and McRight's [42] Helium Flowrates

Facility	GFSSP (lbm/sec)			Facility	McRight (lbm/sec)		
	LOX	RP-1	Purge		LOX	RP-1	Purge
0.825	0.34	0.085	0.4	1.00	0.35	0.1	0.55

The comparison shown in Table 5.12.2 appears reasonable considering the fact that McRight's analysis did not consider pressure loss in lines and fittings and choked flow rate through the orifice was calculated based on a facility pressure of 765 psia. GFSSP calculates pressure drop through the line and therefore the choked flow rate at lower pressure is evidently less than McRight's prediction.

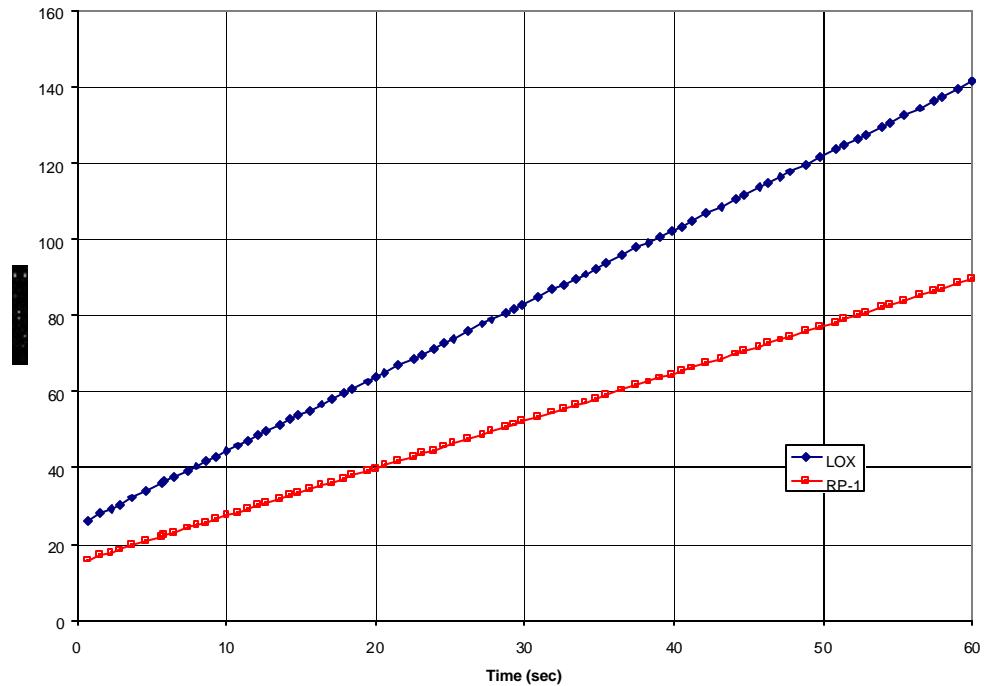


Figure 5.12.10 - Ullage Volume History in Propellant Tanks

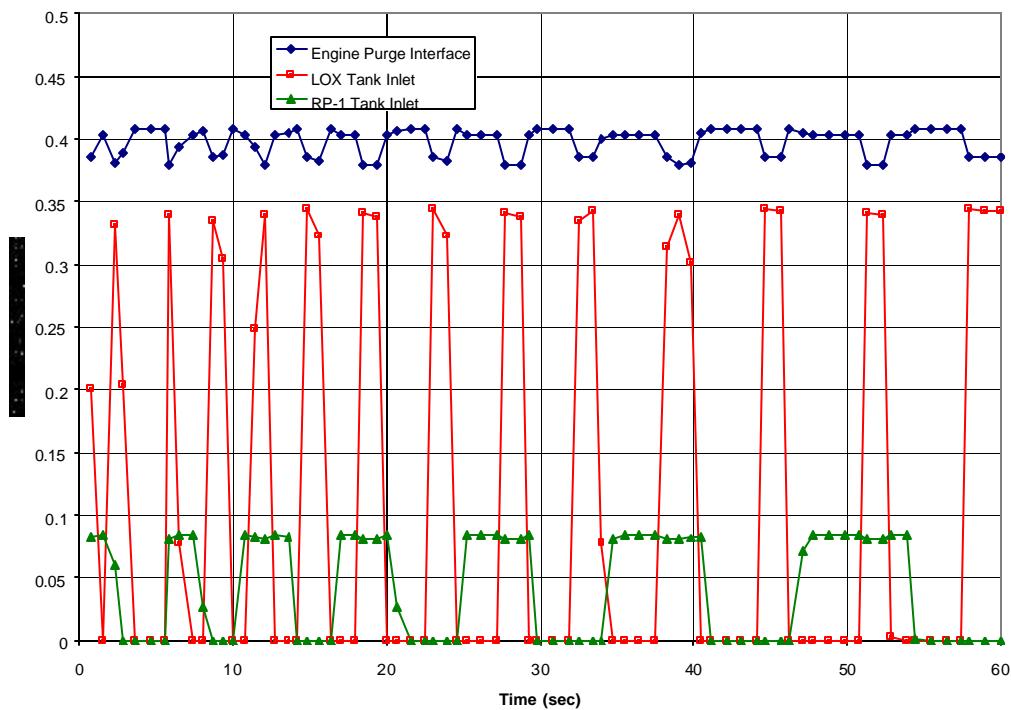


Figure 5.12.11 - Helium Flowrate History

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APPENDIX A

DERIVATION OF K_f FOR PIPE FLOW

It is assumed that there is a dynamic equilibrium that exists between the friction and the pressure forces. Therefore, the momentum conservation equation can be expressed as:

$$P_u - P_d = K_f m^2 \quad (A-1)$$

Where K_f is a function of f , L , D and ρ .

For a fully developed pipe flow, the momentum conservation equation can be written as:

$$\frac{t}{r} \frac{p}{\rho} DL = (P_u - P_d) \frac{\rho D^2}{4} \quad (A-2)$$

The Darcy friction factor, f , can be expressed as:

$$f = \frac{8 t g_c}{r u^2} \quad (A-3)$$

From the continuity equation:

$$u = \frac{4m}{r p D^2} \quad (A-4)$$

Substituting Equations A-3 and A-4 into Equation A-2:

$$P_u - P_d = \frac{8 f L m^2}{g_c r p^2 D^5} \quad (A-5)$$

Therefore,

$$K_f = \frac{8 f L}{g_c r p^2 D^5} \quad (A-6)$$

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APPENDIX B

NEWTON-RAPHSON METHOD OF SOLVING COUPLED NONLINEAR SYSTEMS OF ALGEBRAIC EQUATIONS

The application of the Newton-Raphson Method involves the following 7 steps:

1. Develop the governing equations.

The equations are expressed in the following form:

$$\begin{aligned} f_1(x_1, x_2, x_3, \dots, x_n) &= 0 \\ f_2(x_1, x_2, x_3, \dots, x_n) &= 0 \\ \dots & \\ f_n(x_1, x_2, x_3, \dots, x_n) &= 0 \end{aligned} \tag{B-1}$$

If there are n number of unknown variables, there are n number of equations.

2. Guess a solution for the equations.

Guess $x_1^*, x_2^*, x_3^*, \dots, x_n^*$ as an initial solution for the governing equations

3. Calculate the residuals of each equation.

When the guessed solutions are substituted into Equation B-1, the right hand side of the equation is not zero. The non-zero value is the residual.

$$\begin{aligned} f_1(x_1^*, x_2^*, x_3^*, \dots, x_n^*) &= R_1 \\ f_2(x_1^*, x_2^*, x_3^*, \dots, x_n^*) &= R_2 \\ \dots & \\ f_n(x_1^*, x_2^*, x_3^*, \dots, x_n^*) &= R_n \end{aligned} \tag{B-2}$$

The intent of the solution scheme is to correct $x_1^*, x_2^*, x_3^*, \dots, x_n^*$ with a set of corrections $x_1^{'}, x_2^{'}, x_3^{'}, \dots, x_n^{'}$ such that $R_1, R_2, R_3, \dots, R_n$ are zero.

4. Develop a set of correction equations for all variables.

First construct the matrix of influence coefficients:

$$\begin{matrix} \frac{\partial f_1}{\partial x_1} & \frac{\partial f_1}{\partial x_2} & \frac{\partial f_1}{\partial x_3} & \dots & \frac{\partial f_1}{\partial x_n} \\ \frac{\partial f_2}{\partial x_1} & \frac{\partial f_2}{\partial x_2} & \frac{\partial f_2}{\partial x_3} & \dots & \frac{\partial f_2}{\partial x_n} \\ \dots & \dots & \dots & \dots & \dots \\ \frac{\partial f_n}{\partial x_1} & \frac{\partial f_n}{\partial x_2} & \frac{\partial f_n}{\partial x_3} & \dots & \frac{\partial f_n}{\partial x_n} \end{matrix}$$

Then construct the set of simultaneous equations for corrections:

$$\begin{bmatrix} \frac{\partial f_1}{\partial x_1} & \frac{\partial f_1}{\partial x_2} & \frac{\partial f_1}{\partial x_3} & \dots & \frac{\partial f_1}{\partial x_n} \\ \frac{\partial f_2}{\partial x_1} & \frac{\partial f_2}{\partial x_2} & \frac{\partial f_2}{\partial x_3} & \dots & \frac{\partial f_2}{\partial x_n} \\ \dots & \dots & \dots & \dots & \dots \\ \frac{\partial f_n}{\partial x_1} & \frac{\partial f_n}{\partial x_2} & \frac{\partial f_n}{\partial x_3} & \dots & \frac{\partial f_n}{\partial x_n} \end{bmatrix} \begin{bmatrix} x'_1 \\ x'_2 \\ \vdots \\ x'_n \end{bmatrix} = \begin{bmatrix} R_1 \\ R_2 \\ \vdots \\ R_n \end{bmatrix}$$

5. Solve for $x'_1, x'_2, x'_3, \dots, x'_n$ by solving the simultaneous equations.

6. Apply correction to each variable.

7. Iterate until the corrections become very small.

APPENDIX C

SUCCESSIVE SUBSTITUTION METHOD OF SOLVING COUPLED NONLINEAR SYSTEMS OF ALGEBRAIC EQUATIONS

The application of the successive substitution method involves the following steps:

1. Develop the governing equations:

$$\begin{aligned}x_1 &= f_1(x_1, x_2, x_3, \dots, x_n) \\x_2 &= f_2(x_1, x_2, x_3, \dots, x_n) \\&\dots \\x_n &= f_n(x_1, x_2, x_3, \dots, x_n)\end{aligned}\tag{C-1}$$

If there are n number of unknown variables, there are n number of equations.

2. Guess a solution for the equations:

Guess $x_1^*, x_2^*, x_3^*, \dots, x_n^*$ as an initial solution for the governing equations.

3. Compute new values of $x_1, x_2, x_3, \dots, x_n$ by substituting $x_1^*, x_2^*, x_3^*, \dots, x_n^*$ in the right hand side of Equation C-1.
4. Under-relax the computed new value:
$$x = (1 - \alpha)x^* + \alpha x$$
where α is the under-relaxation parameter.
5. Replace $x_1^*, x_2^*, x_3^*, \dots, x_n^*$ with the computed value of $x_1, x_2, x_3, \dots, x_n$ from Step 4.
6. Repeat Steps 3 to 5 until convergence.

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APPENDIX D

GLOSSARY OF FORTRAN VARIABLES IN THE COMMON BLOCK

GFSSP contains sixteen common blocks of variables. The following is a listing of the common blocks and the variables contained within them along with a description of each including units where applicable. Note that the units of several variables described in the common block are different in the input and output files. GFSSP converts the units of the following variables prior to solving the conservation equations:

Variable	Input/Output Unit	GFSSP Unit
Length	inches	feet
Area	inches ²	feet ²
Volume	inches ³	feet ³
Angle	Degree	Radian
Pressure	lb./in ²	lb./ft ²
Temperature	°F	°R

Variable	Description
1. COMMON/CFILNUM/	Common block for file numbers.
NWRTE	File number for the command line preprocessor output file.
NPRNT	File number for the main output file.
NREAD	File number for the input deck.
NGSPK	File number for the GASPAK swap file.
NFNOD	File number for the node restart file.
NGFSOUT	File number for the GFSSP.OUT output file.
NFBR	File number for the branch restart file.
NGASP	File number for the GASP.OUT output file.
NHSTN	File number for the HISTN.XLS output file.
NHSTB	File number for the HISTBR.XLS output file.
NHSTF	File number for the input history files (except rotational and control valve history files).
NCVHST	File number for maximum and minimum pressure history of control valves.
NCVCHR1	File number for time schedule history of open valve characteristics of control valve sub-options.
NCVCHR2	File number for time schedule history of closed valve characteristics of control valve sub-options.
NHSTROT	File number for the input rotational history file.
NERROR	File number for the ERROR.XLS output file.
NRP1DAT	File number for the RP-1 property files.
NUSR1	User defined file number/integer.
NUSR2	User defined file number/integer.
NUSR3	User defined file number/integer.
NUSR4	User defined file number/integer.
NUSR5	User defined file number/integer.
NUSR6	User defined file number/integer.
NUSR7	User defined file number/integer.
NUSR8	User defined file number/integer.

NUSR9	User defined file number/integer.
NUSR10	User defined file number/integer.
2. COMMON/CNODEI/	
NNODES	Total number of nodes.
NINT	Total number of internal nodes.
NBND	Total number of boundary nodes.
NODREF	Reference node number.
NODE()	User assigned node number.
INDEX()	Index number to distinguish between internal and boundary node (1-internal node, 2-boundary node).
INODE()	Internal node number.
IBNODE()	Boundary node number.
NUMBR()	Number of branches connected to an internal node.
NAMEBR(,)	Name of branches connected to an internal node.
NMNODE	Number of nodes with moving boundary.
NRNODE	Number of nodes with reaction.
IVERS	Version number of the code.
3. COMMON/CNODEF/	
P()	Pressure (lb_f/ft^2).
PM()	Pressure (lb_f/ft^2) at previous time step.
RHO()	Density (lb_m/ft^3).
RHOM()	Density (lb_m/ft^3) at previous time step.
ZL()	Not used.
H()	Specific enthalpy (Btu/lb_m).
HM()	Specific enthalpy (Btu/lb_m) at previous time step.
TF()	Temperature ($^\circ\text{R}$).
TM()	Temperature ($^\circ\text{R}$) at previous time step.
CX(,)	Mass specie concentration.
CXM(,)	Mass specie concentration at previous time step.
COND()	Thermal conductivity ($\text{Btu}/\text{ft}\cdot\text{sec}\cdot{}^\circ\text{R}$).
EMU()	Absolute viscosity ($\text{lb}_m/\text{ft}\cdot\text{sec}$).
GAMA()	Ratio of specific heats.
CM(,)	Molar specie concentration.
RNODE()	Gas constant ($\text{lb}_f\cdot\text{ft} / \text{lb}_m\cdot{}^\circ\text{R}$).
RNODEM()	Gas constant ($\text{lb}_f\cdot\text{ft} / \text{lb}_m\cdot{}^\circ\text{R}$) at previous time step.
XV()	Mass fraction of vapor in mixture.
Z()	Compressibility factor.
ZM()	Compressibility factor at the previous time step.
AREAN()	Surface area of node (ft^2) for thrust calculation.
VOLUME()	Node volume (ft^3).
VOLUMEM()	Node volume (ft^3) at previous time step.
CVNODE()	Specific heat at constant volume ($\text{Btu}/\text{lbm}\cdot{}^\circ\text{R}$).
EM()	Mass (lb_m).
EMM()	Mass (lb_m) at previous time step.
U()	Specific internal energy ($\text{Btu}/\text{lbm}\cdot{}^\circ\text{R}$).
UM()	Specific internal energy ($\text{Btu}/\text{lbm}\cdot{}^\circ\text{R}$) at previous time step.
EMS()	Mass source (lb_m/sec) at node.
HSORCE()	Heat source (Btu/sec or Btu/lb_m) at node.
NAMEND(,)	Neighboring nodes of an internal node for conduction calculation
DISTC(,)	Distance between internal and neighboring node (ft).

AREAC(,)	Surface area of heat conduction between internal and neighboring node (ft ²).
NABOR()	Same as NUMBR(I)
VBOUND()	Velocity of moving boundary (ft/sec), for moving boundary option.
HSORCR()	Heat source (Btu/sec) due to chemical reaction.
H2()	Hydrogen concentration in the reaction product.
O2()	Oxygen concentration in the reaction product.
H2O()	Water concentration in the reaction product.
ENTROPY()	Specific entropy (Btu/lb _m -°R).
ENTRPYM()	Specific entropy (Btu/lb _m -°R) at previous time step.
CPNODE()	Specific heat at constant pressure (Btu/lb _m -°R)
GIBBS()	Not used.
EXERGY()	Not used.
PR()	Prandtl Number
SGEN()	Entropy generation rate (Btu/sec-°R).
TSOURCE()	Not used.

4. COMMON/CBRANCH/

NBR	Total number of branches in a model.
IBRANCH()	User defined branch number.
IBRUN()	Upstream node number for a given branch.
IBRDN()	Downstream node number for a given branch.
FLOWR()	Mass flow rate (lb _m /sec).
FLOWRM()	Mass flow rate (lb _m /sec) at the previous time step.
AK()	Flow resistance coefficient, K_f , (lb _f -sec ² /(ft-lb _m) ²) for the branch.
AKM()	Flow resistance coefficient, K_f , (lb _f -sec ² /(ft-lb _m) ²) for the branch at the previous time step.
AREA()	Branch cross-sectional area (ft ²).
AREAM()	Branch cross-sectional area (ft ²) at the previous time step.
CLF()	Not used.
EL()	Not used.
D()	Not used.
SR()	Not used.
IOPT()	Branch resistance option number (1-pipe flow, etc.).
DELP()	Pressure differential across the branch.
AREAUP()	Not used.
AREADN()	Not used.
ANGLE()	Angle (radians) between branch and the gravity vector. Used when gravity is activated.
NONBR()	Not used.
NOUBR()	Number of upstream branches for a given branch.
NODBR()	Number of downstream branches for a given branch.
NMUBR(,)	Name of each upstream branch for a given branch.
NMDBR(,)	Name of each downstream branch for a given branch.
ANGUBR(,)	Angle (radians) between current branch and each upstream branch. Used in the longitudinal inertia option.
ANGDBR(,)	Angle (radians) between current branch and each downstream branch. Used in the longitudinal inertia option.
VEL()	Velocity (ft/sec) of the fluid in a given branch.
VELM()	Velocity (ft/sec) of the fluid in a given branch at the previous time step.
RADU()	Upstream node radius from axis of rotation (for rotation option).
RADD()	Downstream node radius from axis of rotation (for rotation option).
RPM()	Rotational speed (in RPM) for rotation option.

AKROT()	Fluid slip factor, K_{rotation} , for rotation (ratio of fluid rotational speed to solid rotational speed).
NRBR	Number of rotating branches.
NMBR	Number of branch with momentum source.
NIBR	Number of branches with longitudinal inertia.
AREAS(,)	Not used.
DISTS(,)	Not used.
NMnbr(,)	Not used.
BRPR1()	Branch resistance input variable 1 (used in all branch resistance options).
BRPR1M()	Branch resistance input variable 1 at the previous time step.
BRPR2()	Branch resistance input variable 2.
BRPR2M()	Branch resistance input variable 2.
BRPR3()	Branch resistance input variable 3.
BRPR3M()	Branch resistance input variable 3 at the previous time step.
BRPR4()	Branch resistance input variable 4.
BRPR4M()	Branch resistance input variable 4 at the previous time step.
BRPR5()	Branch resistance input variable 5.
BRPR5M()	Branch resistance input variable 5 at the previous time step.
BRPR6()	Branch resistance input variable 6.
BRPR6M()	Branch resistance input variable 6 at the previous time step.
SORCE()	Momentum source (lb_f).
VOLBRN()	Branch volume (ft^3).
VOLBRNM()	Branch volume (ft^3) at previous time step.
PIPET()	Not used.
EMOD()	Not used.
EMACH()	Branch Mach number.
SOLID()	Not used.
AREASB()	Not used.
DISTSB()	Not used.
VELSB()	Not used.

5. COMMON/CPROP/

NF	Total number of fluids in a given model.
NF1	$\text{NF} - 1$
NFL	Number of fluids available in the library.
WM()	Molecular weights of fluids in the library.
RGAS()	Gas constants ($\text{lb}_f \cdot \text{ft} / \text{lb}_m \cdot {}^\circ\text{R}$) of fluids in the library.
DELH()	Reference enthalpy (Btu / lb_m) of fluids in the library.
DELH1()	Reference enthalpy (Btu / lb_m) of fluids with respect to 1 st reference point.
DELH2()	Reference enthalpy (Btu / lb_m) of fluids with respect to 2 nd reference point.
NAMEF()	Character identifier for fluids in the library.
NHREF	Index for specifying reference point for enthalpy calculation for mixture.
IFLUID()	Character identifier for fluid index in a model.
NFLUID()	Character identifier for fluid index in the fluid library.
NDATA()	Not used.
PREF	Reference pressure ($\text{lb}_f / \text{ft}^2$).
TREF	Reference temperature (${}^\circ\text{R}$).
RHOREF	Reference density ($\text{lb}_m / \text{ft}^3$).
EMUREF	Reference absolute viscosity ($\text{lb}_m / \text{ft} \cdot \text{sec}$).
G	Gravitational acceleration (32.174 ft/sec ²).

GC	Force conversion factor ($32.174 \text{ ft-lb}_m/\text{lb}_f\text{-sec}^2$).
PI	$\pi(3.1415926)$.
HEQ	Energy conversion factor ($778.16 \text{ ft-lb}_f/\text{Btu}$).
GAMREF	Reference ratio of specific heats.
RREF	Reference gas constant.
CPREF	Reference specific heat at constant pressure ($\text{Btu/lb}_m\text{-}^\circ\text{R}$).
AKREF	Reference conductivity ($\text{Btu/ft}\text{-sec}\text{-}^\circ\text{R}$).
DELHGP()	Reference enthalpy (Btu/lb_m) of fluids in the GASPAK library.
GSPMIN()	Minimum allowable pressure for fluids in GASP library.
GSPMAX()	Maximum allowable pressure for fluids in GASP library.
GSTMIN()	Minimum allowable temperature for fluids in GASP library.
GSTMAX()	Maximum allowable temperature for fluids in GASP library.
NCVFL()	Identifier of fluids in GASPAK library that do not have thermophysical properties.
GPPMIN()	Minimum allowable pressure for fluids in GASPAK library.
GPPMAX()	Maximum allowable pressure for fluids in GASPAK library.
GPTMIN()	Minimum allowable temperature for fluids in GASPAK library.
GPTMAX()	Maximum allowable temperature for fluids in GASPAK library.

6. COMMON/CNUM/

	Common block for control variables
NVAR	Total number of variables to be solved in a model.
TLRNCE	Convergence criteria of Newton-Raphson scheme.
ITMAX	Maximum allowable number of Newton-Raphson iterations.
ITER	Number of outer loop iterations (reset every time step).
ITERNR	Number of Newton-Raphson iterations (reset every time the Newton-Raphson loop is called).
ITERT	Total number of iterations (reset every time step).
ISTEP	Number of time steps.
DIFK	Fractional change in flow resistance coefficient between successive iterations.
TAU	Time (sec).
DTAU	Time step (sec).
TIMEF	Start time (sec).
TIMEL	End time (sec).
AFACT	Not used.
GFACT	Not used.
V()	Variable array for Newton-Raphson scheme.
NAME()	Name of variable array for Newton-Raphson scheme.
NPSTEP	Interval of printout for an unsteady calculation.
DIFD	Fractional change in density between successive iterations.
RELAXK	Under-relaxation parameter for the K-factor, K_f . NOTE: User must specify that $0 < \text{RELAXK} < 1$.
RELAXD	Under-relaxation parameter for the density. NOTE: User must specify that $0 < \text{RELAXD} < 1$.
RELAXH	Under-relaxation parameter for the enthalpy/entropy. NOTE: User must specify that $0 < \text{RELAXH} < 1$.
NITER	Maximum number of outer iterations if SIMULA is false (set in the input deck).
ITERMIN	Minimum number of iterations if SIMULA is false (currently set at 5).
CC	Convergence criteria (set in the input deck).

7. COMMON/CHEX/	Common block for Heat Exchanger related variables.
NHEX	Number of heat exchangers in a model.
NODHIN()	Upstream node of branch carrying hot fluid.
NODHEX()	Downstream node of branch carrying hot fluid.
NODCIN()	Upstream node of branch carrying cold fluid.
NODCEX()	Downstream node of branch carrying cold fluid.
IBRHOT()	Branch carrying hot fluid.
IBRCLD()	Branch carrying cold fluid.
HEXEFF()	Heat exchanger effectiveness.
ITYPHX()	Index number to describe the type of heat exchanger: 1- Counter flow, 2-Parallel flow.
ARHOT()	Heat transfer area in hot side (ft ²).
ARCOLD()	Heat transfer area in cold side (ft ²).
UA()	Product of overall heat transfer coefficient and area (Btu/sec-°R).
8. COMMON/CTPA/	Common block for Turbopump related variables.
NTPA	Number of turbopumps in a model.
IBRPMP()	Pump branch number.
IBRTRB()	Turbine branch number.
NODPMP()	Node number upstream of pump.
NODTRB()	Node number upstream of turbine.
SPEED()	Operating speed (RPM) of the turbopump.
EFFTRB()	Turbine efficiency.
TORQUE()	Calculated required torque.
HPOWER()	Horsepower of the pump.
DIATRB()	Turbine diameter (ft). Input file uses in.
PSITRD()	Flow coefficient of the turbine at the design point.
ETATRB()	Efficiency of turbine at design point.
PSITR()	Flow coefficient of the turbine at the operating point.
9. COMMON/CTVM/	Common block for Transverse Momentum variables.
NTM	Number of branches for which transverse momentum is calculated.
IBRANCHT()	Name of branch for which transverse momentum will be calculated.
NUMBERL()	Number of parallel branches used to calculate transverse momentum for a given branch.
NAMEL(,)	Name of each parallel branch for a given branch.
ANGLEL(,)	Angle (radians) between each parallel branch and the current branch. NOTE: If the branches are perfectly parallel and in opposite directions, this angle is π)
NUMBERT(,)	Number of branches connecting each parallel branch and the current branch.
NAMELT(, ,)	Name of each connecting branch, corresponding to each parallel branch for the current branch.
ANGLELT(, ,)	Angle (radians) between each connecting branch and the current branch.
10. COMMON/CSHR/	Common block for Shear variables.
NSHR	Number of branches for which shear will be calculated.
IBRNCHSH()	Name of branch for which shear will be calculated.
NUMBRSH()	Number of parallel branches, which will contribute to the shear of the current branch.
NAMESH(,)	Names of the parallel branches, which will contribute to the shear of the current branch.

ANGLESH(,)	Angle (radians) between each parallel branch and the current branch. NOTE: If the branches are perfectly parallel and in opposite directions, this angle is π
AREASH(,)	Shear area (ft^2) between each parallel branch and the current branch
DISTSH(,)	Distance (ft) between the each parallel branch and the current branch.
NSOLID()	Number of solid wall adjacent to the current branch.
VSOLID(,)	Velocity (ft/sec) of each solid corresponding to the current branch.
ANGSOLID(,)	Angle (radians) between each solid walls corresponding to the current branch.
AREASOL(,)	Shear area (ft^2) between each solid wall corresponding to the current branch.
DISTSOL(,)	Distance (ft) between each solid wall corresponding to the current branch.
ENTSHR()	Entropy generated due to shear for the current branch.

11. COMMON/CTRANS/

VOLN(,)	Node volume (in^3) - time (sec) array used in the input history file for the variable geometry option.
VOLB(,)	Branch volume (in^3) - time (sec) array used in the input history file for the variable geometry option.
AREAB(,)	Branch area (in^2) - time (sec) array used in the input history file for the variable geometry option.
HEIGHT(,)	Branch height (in) - time (sec) array used in the input history file for the variable geometry option. This array is only used for branch resistance option 3 (non-circular duct).
WIDTH(,)	Branch width (in) - time (sec) array used in the input history file for the variable geometry option. This array is only used for branch resistance option 3 (non-circular duct).
TIMEG()	Time (sec) array used in history files.
NGSTEP	Number of lines of time-data information in a history file.
ARNMB(,)	Nodal normal area (in^2) - time (sec) array used in the input history file for the variable geometry option when the moving boundary option is used.
VELMB(,)	Nodal normal velocity (ft/sec) - time (sec) array used in the input history file for the variable geometry option when the moving boundary option is used.
AREANB()	Area of the moving boundary (ft^2) of an internal node for the variable geometry option when the moving boundary option is used.
TIMER()	Time (sec) used in history file for variable rotation option.
RPMT()	Rotational speed (RPM) used in history file for variable rotation option.

12. COMMON/CPRESS/

NTANK	Number of pressurization tanks in a model.
NODUL()	Node number representing ullage in a given tank.
NODULB()	Pseudo boundary node representing the interface between ullage and propellant.
NODPRP()	Node number representing propellant tank pressure and temperature.
IBRPRP()	Branch number representing propellant flow rate.
TNKAR()	Tank surface area (ft^2) for heat transfer with ullage gas.
TNKTH()	Tank thickness (ft) for heat conduction calculation in tank wall.
TNKRHO()	Tank density (lb_m/ft^3) for heat conduction calculation in tank wall.
TNKCP()	Tank specific heat ($\text{Btu}/\text{lb}_m \cdot ^\circ\text{R}$) for heat conduction calculation in tank wall.

Common block for Transient variables.

Node volume (in^3) - time (sec) array used in the input history file for the variable geometry option.

Branch volume (in^3) - time (sec) array used in the input history file for the variable geometry option.

Branch area (in^2) - time (sec) array used in the input history file for the variable geometry option.

Branch height (in) - time (sec) array used in the input history file for the variable geometry option. This array is only used for branch resistance option 3 (non-circular duct).

Branch width (in) - time (sec) array used in the input history file for the variable geometry option. This array is only used for branch resistance option 3 (non-circular duct).

Time (sec) array used in history files.

Number of lines of time-data information in a history file.

Nodal normal area (in^2) - time (sec) array used in the input history file for the variable geometry option when the moving boundary option is used.

Nodal normal velocity (ft/sec) - time (sec) array used in the input history file for the variable geometry option when the moving boundary option is used.

Time (sec) used in history file for variable rotation option.

Rotational speed (RPM) used in history file for variable rotation option.

Common block for Pressurization variables.

Number of pressurization tanks in a model.

Node number representing ullage in a given tank.

Pseudo boundary node representing the interface between ullage and propellant.

Node number representing propellant tank pressure and temperature.

Branch number representing propellant flow rate.

Tank surface area (ft^2) for heat transfer with ullage gas.

Tank thickness (ft) for heat conduction calculation in tank wall.

Tank density (lb_m/ft^3) for heat conduction calculation in tank wall.

Tank specific heat ($\text{Btu}/\text{lb}_m \cdot ^\circ\text{R}$) for heat conduction calculation in tank wall.

ELHC()	Length scale (ft) for computing Grashoff number.
ARHC()	Surface area for heat transfer (ft^2) between ullage and propellant.
FCTHC()	Factor controlling the magnitude of heat transfer coefficient (Default value = 1)
TNKTM()	Tank temperature ($^{\circ}\text{R}$)
TNKTMM()	Tank temperature ($^{\circ}\text{R}$) at the previous time step.
QULWAL()	Heat transfer rate (Btu/sec) between ullage and wall.
QULPRP()	Heat transfer rate (Btu/sec) between ullage and propellant.
EMDPRP()	Not used.
HFG()	Not used.
TSAT()	Not used.
TNKCON()	Tank conductivity (Btu/ $\text{ft}\cdot\text{sec}\cdot^{\circ}\text{R}$)
QCOND()	Heat transfer rate (Btu/sec) between ullage exposed tank surface and propellant exposed tank surface.

13. COMMON/CVALVE/

DTAUIN	A temporary variable that stores the data file time step (sec) input by the user. Used by subroutine CTRLVLV when determining minimum time step.
NVALVE	Number of control valves in the model.
DVTAU()	User prescribed time step (sec) for each sub-option 2 or 3 control valve
IVOPT()	Sub-option of each control valve (1=instantaneous, 2=linear, 3=non-linear).
NOVDAT()	Number of open characteristics data points for suboption 2 and 3 control valves. Used for reading open characteristics data.
NCVDAT()	Number of close characteristics data points for suboption 2 and 3 control valves. Used for reading close characteristics data.
OVTIM(,)	Time schedule (sec) for open valve characteristics for suboption 2 and 3 control valves. Used in calculating transient open valve characteristics.
CVTIM(,)	Time schedule (sec) for close valve characteristics for suboption 2 and 3 control valves. Used in calculating transient close valve characteristics.
OVCL(,)	Transient opening valve flow coefficient history for suboption 2 and 3 control valves. Used in calculating transient open valve characteristics.
CVCL(,)	Transient closing valve flow coefficient history for suboption 2 and 3 control valves. Used in calculating transient close valve characteristics.
OVAR(,)	Transient opening valve flow area history (in^2) for suboption 2 and 3 control valves. Used in calculating transient open valve characteristics.
CVAR(,)	Transient closing valve flow area history (in^2) for suboption 2 and 3 control valves. Used in calculating transient close valve characteristics.
VAREA()	Flow area (ft^2) calculated in the subroutine CTRLVLV for each control valve. Used for calculating flow resistance for the control valve in subroutine KFACT18.
VCL()	Flow coefficient calculated in the subroutine CTRLVLV for each control valve. Used for calculating flow resistance for the control valve in subroutine KFACT18.
TIMEV(,)	Time schedule (sec) for the pressure tolerance files for each control

PMAXV(,)	valve. Used for determining the state for each control valve (The states are fully open, fully closed, opening, closing). Maximum pressure tolerance (psia) history for each control valve. Used for determining the state of each control valve (The states are fully open, fully closed, opening, closing).
PMINV(,)	Minimum pressure tolerance (psia) history for each control valve. Used for determining the state of each control valve (The states are fully open, fully closed, opening, closing).
NVDAT()	Number of pressure tolerance file data points for each control valve. Used in reading pressure tolerance data.

14. COMMON/CCONV/

FACTP	Common block for conversion factor variables. Conversion factor for pressure (to convert to and from psf and psi, 144.).
FACTV	Conversion factor for Volume (to convert to and from in ³ and ft ³ , 1728.).
FACTA	Conversion factor for area (to convert to and from in ² and ft ² , 144.).
FACTL	Conversion factor for length (to convert to and from in and ft, 12.).
FACTT	Conversion factor for area (to convert to and from °F and °R, 459.6).
FACTTH	Conversion factor for angle (to convert to and from degree to radian, 0.01745)
FACTVS	Not used.

15. COMMON/CLOGIC/

STEADY	Common block for logical variables. NOTE: a declaration of these variables as logical variables must follow this common block. Logical variable to indicate if the model is steady state, quasi-steady (a series of steady state runs with changing boundary conditions and/or geometry; requires TRANSV to be false), or fully unsteady (requires TRANSV to be true).
DENCON	Logical variable to indicate if the model will use a user defined constant density fluid. NOTE: this option is ONLY valid for steady state and the energy equation will NOT be solved.
GRAVITY	Logical variable to indicate if the model will account for gravity in branches where a branch length is associated.
ENERGY	Logical variable to indicate if the model will solve one of the two forms of the energy equation within the code. Required for all fluids except when DENCON is true.
MIXTURE	Logical variable to indicate if the model is using more than one fluid. NOTE: not valid if DENCON is true.
CHOKED	Logical variable to indicate if the model will calculate choked flow.
CHOK()	Logical variable to indicate if an individual branch will have choked flow calculated.
THRUST	Logical variable to indicate if the model will calculate thrust (b_f) using pressure and thrust area (current formulation neglects thrust from linear inertia).
RESTART	Not used.
TRANSV	Logical variable to indicate if the model will operate in an unsteady mode. NOTE: requires STEADY to be false.
INERTIA	Logical variable to indicate if the model will include linear inertia in the calculation of the momentum equation.
CONDX	Logical variable to indicate if the model will calculate thermal conduction between nodes.
TWOD	Not used.

PRINTI	Logical variable to indicate if the main output file will contain the initial guess at the flow field.
ROTATION	Logical variable to indicate if the model contains branches where rotation will contribute a momentum source/sink.
ROTATE()	Logical variable indicating if an individual branch will have rotation included as a momentum source/sink. NOTE: requires ROTATION to be true.
BUOYANCY	Logical variable to indicate if the model will consider buoyancy (density variation) effects in a gravity field. NOTE: requires GRAVITY to be true.
HRATE	Logical variable to indicate if heat sources are in BTU/sec (true) or BTU/lb _m (false).
INVAL	Logical variable to indicate if the model will read in previously saved data from two restart files for node and branch data.
SAVER	Logical variable to indicate if the model will write data into two restart files to be used for later restarting of the model.
HEX	Logical variable to indicate if the model includes heat exchangers.
MSOURCE	Logical variable to indicate if the model contains additional momentum sources (in addition to pumps).
MOMSOR()	Logical variable to indicate which branches have additional momentum sources. NOTE: requires MSOURCE to be true.
HCOEF	An additional option for heat exchanger calculation; if true UA is calculated, otherwise it must be specified.
MOVBND	Logical variable to indicate if the model contains nodes which have a moving boundary.
MVBND()	Logical variable to indicate which nodes contain a moving boundary. NOTE: requires MOVBND to be true.
REACTING	Option for activating chemical reaction. NOTE: equilibrium reaction of hydrogen and oxygen is only available.
REACTION()	Logical variable indicating if an individual node will have chemical reaction.
TPA	Logical variable to indicate if the model includes turbopump assemblies.
TPABR()	Logical variable indicating if an individual branch represents pump or turbine.
ELASTIC	Not used.
VARGEO	Logical variable to indicate if the model will consider variable geometries (time dependent geometries). NOTE: requires STEADY to be false.
TVM	Logical variable to indicate if the model will consider the transverse component of inertia in the momentum equation (transverse momentum).
TRNSM()	Logical variable to indicate which branches will consider transverse momentum. NOTE: requires TVM to be true.
SHEARE	Logical variable to indicate if the model will consider shear stress instead of using a friction factor on at least one branch within the model.
SHER()	Logical variable to indicate which branches will consider shear stress instead of friction. NOTE: requires SHEARE to be true.
ADDPROP	Logical variable to indicate if the model will use a fluid thermodynamic/thermophysical property package other than that which is already incorporated into the code. When ADDPROP is false, GASP and WASP are used; when GASPAK is true, the commercially available code Gaspak is required (along with a licence).

PRNTIN	Logical variable to indicate if the main output file will contain the input variables.
PRNTADD	Logical variable to indicate if the main output file will contain additional thermodynamic output data for each internal node.
PRESS	Logical variable to indicate if the model will contain pressurization of a tank. NOTE: requires STEADY to be false and TRANSV to be true.
INSUC	Logical variable to activate calculation of initial guess by using a successive substitution method.
VARROT	Logical variable to indicate if the model will have time dependent rotation. NOTE: requires ROTATION to be true, ROTATE to be true for at least one branch and STEADY to be false.
VOPEN()	Logical variable that stores the initial position of the valve (T=Open, F=Closed). Used in initializing valve settings.
VFLOW()	A logical variable that indicates whether or not there is flow through a control valve (T=CL & A >0, F=CL & A = 0). Used in flow resistance calculations by subroutine KFACT18.
INERT()	Logical variable to activate longitudinal inertia calculation in a given branch.
NORMAL	Logical variable to activate normal stress calculation in a given branch.
SIMULA	Logical variable to indicate if the user would like the model to be solved using a totally simultaneous solution scheme or a modified scheme (inner & outer loop for first five iterations of a given time step, then simultaneous).
SIMUL	Logical variable set by SIMULA at the beginning of each time step. See description of SIMULA.
SECONDL	Logical variable to indicate if the model will solve the energy equation using the first law of thermodynamics (false, uses enthalpy) or the second law of thermodynamics (true, uses entropy)
FRICTBP	Logical variable used to override SIMULA and bypass the simultaneous solution scheme.
USETUP	Logical variable to allow the user to customize the input deck. Used in association with the USRSET subroutine (user subroutine).
LAMINAR	Logical variable used in conjunction with the SHEARE logical variable. When set to false, shear stress is calculated using a modified Prandtl mixing length model for branch to branch interaction and the log-law of the wall for branch to solid interaction. When set to true, shear stress is calculated from the derivative of the velocity and the fluid viscosity.
TRANSQ	Logical variable used to identify that heat addition will vary with time using user supplied data in history file(s). Requires TRANSV to be true.
TRQ()	Logical variable used to identify which nodes will have a time variant heat added. Requires TRANSQ to be true.
DFLI	Logical variable used to identify between two formulations for longitudinal inertia (requires INERTIA to be active). If set to true in a user subroutine, the differential form of longitudinal inertia will be active, else the original formulation will be active.

16. COMMON/CUSER/

Common block for user defined variables. For use in the User Subroutines.	
SORCEMAS()	User defined mass source. Usually defined in the SORCEM user subroutine.
SORCEMOM()	User defined momentum source. Usually defined in the SORCEF user subroutine.
SOURCECON(,)	User defined specie concentration source. Usually defined in the SOURCEC user subroutine.
SORCEH()	User defined heat source. Usually defined in the SOURCEH user subroutine.
USRVAR1()	User defined one dimensional variable. Used to pass information between different user subroutines.
USRVAR2()	User defined one dimensional variable. Used to pass information between different user subroutines.
USRVAR3()	User defined one dimensional variable. Used to pass information between different user subroutines.
USRVAR4()	User defined one dimensional variable. Used to pass information between different user subroutines.
USRVAR5()	User defined one dimensional variable. Used to pass information between different user subroutines.
USRVAR6()	User defined one dimensional variable. Used to pass information between different user subroutines.
USRVAR7()	User defined one dimensional variable. Used to pass information between different user subroutines.
USRVAR8()	User defined one dimensional variable. Used to pass information between different user subroutines.
USRVAR9()	User defined one dimensional variable. Used to pass information between different user subroutines.
USRVAR10()	User defined one dimensional variable. Used to pass information between different user subroutines.
USRVAR11(,)	User defined two dimensional variable. Used to pass information between different user subroutines.
USRVAR12(,)	User defined two dimensional variable. Used to pass information between different user subroutines.
USRVAR13(,)	User defined two dimensional variable. Used to pass information between different user subroutines.
USRVAR14(,,)	User defined three dimensional variable. Used to pass information between different user subroutines.

APPENDIX E

LISTING OF BLANK USER SUBROUTINES

```

C*****
C
C      ***** GFSSP USER SUBROUTINES *****
C
C*****
C      SUBROUTINE USRINT IS CALLED FROM INIT TO SPECIFY INITIAL VALUES COMPUTED
C              BY USER SPECIFIED THERMODYNAMIC PROPERTY PACKAGE
C
C      SUBROUTINE SORCEM(IPN,TERMU) IS CALLED FROM EQNS FOR MASS SOURCES.
C              IN THIS ROUTINE THE USER DEFINES ANY ADDITIONAL MASS
C              SOURCES TO THE MODEL (MASS SOURCES ARE IN LBM/SEC).  USER
C              CAN MODIFY TRANSIENT TERM BY REDEFINING THE ARGUMENT TERMU.
C
C      SUBROUTINE SORCEF(I,TERM0,TERM1,TERM2,TERM3,TERM4,TERM5,TERM6,TERM7,
C              TERM8,TERM9,TERM10,TERM100) IS CALLED FROM EQNS FOR
C              MOMENTUM SOURCES.  USER CAN MODIFY INDIVIDUAL TERMS OR
C              DEFINE ADDITIONAL MOMENTUM SOURCES THROUGH TERM100.
C
C      SUBROUTINE SORCEQ(IPN,TERMD) IS CALLED FROM THE ENERGY ROUTINE (EITHER
C              ENTHALPY OR ENTROPY).  IN THIS ROUTINE THE USER DEFINES
C              ANY ADDITIONAL HEAT SOURCES TO THE MODEL (HEAT SOURCES
C              ARE IN BTU/SEC)
C
C      SUBROUTINE SORCEC IS CALLED FROM THE SPECIES CONCENTRATION ROUTINE
C              IN THIS ROUTINE THE USER DEFINES ANY ADDITIONAL SPECIES
C              CONCENTRATION SOURCES TO THE MODEL (CONCENTRATION SOURCES
C              ARE IN MASS FRACTIONS SUCH THAT THE SUM OF ALL OF THE
C              CONCENTRATIONS EQUALS 1.0)
C
C      SUBROUTINE KFUSER(I,RHOU,EMUU,AKNEW) IS CALLED FROM THE RESIST ROUTINE.
C              THE USER DEFINES ANY VARIATION OF THE K-FACTOR OF A BRANCH
C              SUCH THAT THE K-FACTOR IS DEFINED AS THE PRESSURE DROP
C              DIVIDED BY THE MASS FLOW RATE^2 (PRESSURE IS IN PSF, FLOW
C              RATE IS IN LBM/SEC; I.E. THE K-FACTOR IS IN PSF-SEC^2/
C              (LBM-FT)^2)
C
C      SUBROUTINE PRPUSER IS CALLED FROM THE DENSITY ROUTINE.  IN THIS
C              ROUTINE THE USER ADDS OR MODIFIES FLUID PROPERTIES (ALLOWS
C              FOR USER SPECIFIED FLUID)
C
C      SUBROUTINE TSTEP IS CALLED FROM THE MAIN ROUTINE.  IN THIS ROUTINE
C              THE USER CAN MODIFY THE Timestep, DTAU, FOR AN UNSTEADY
C              MODEL (DTAU IS IN SECONDS)
C
C      SUBROUTINE BNDUSER IS CALLED FROM THE BOUND ROUTINE.  IN THIS ROUTINE
C              THE USER CAN MODIFY BOUNDARY CONDITIONS AND GEOMETRY AT
C              EACH Timestep FOR AN UNSTEADY MODEL (PRESSURE IS IN PSF,
C              TEMPERATURE IS IN DEG. R, LENGTH {ETC.} IS IN FT, AREA IS
C              IN FT^2, VOLUME IS IN FT^3)
C
C      SUBROUTINE PRNUSER IS CALLED FROM THE PRINT ROUTINE.  IN THIS ROUTINE
C              THE USER CAN MODIFY ADD ADDITIONAL OUTPUT FILES SPECIFIC
C              TO A PARTICULAR MODEL
C
```

```

C      SUBROUTINE FILNUM IS CALLED FROM THE MAIN ROUTINE.  IN THIS ROUTINE
C          ESTABLISHES THE FILE NUMBERS THAT ARE TO BE OPENED FOR ALL
C          FILES IN GFSSP, AND INCLUDES 10 USER FILE NUMBERS FOR USE
C          IN THE PRNUSET SUBROUTINE
C
C      SUBROUTINE USRSET IS CALLED FROM THE READIN ROUTINE.  IN THIS ROUTINE
C          THE USER SETS UP THE MAJORITY OF THE MODEL; ONLY A DUMMY
C          SEGMENT OF AN INPUT FILE IS NECESSARY TO BE READ, WITH THE
C          REMAINDER OF THE MODEL SETUP IN THIS SUBROUTINE.
C
C
C*****SUBROUTINE FILENUM
C      PURPOSE: ESTABLISH THE FORTRAN FILE NUMBERS FOR READING &
C              WRITING OF INFORMATION
C*****
C      INCLUDE 'COMBLK.FOR'
C*****
C
C      FILES ALREADY WITHIN GFSSP
C
C          NWRTE = FILE # CORRESPONDING TO THE WRITEIN SUBROUTINE
C                  (WRITING INPUT DECK FROM COMMAND LINE PREPROCESSOR)
C          NPRNT = FILE # CORRESPONDING TO THE PRINT SUBROUTINE
C                  (WRITING THE MAIN OUTPUT FILE)
C          NREAD = FILE # CORRESPONDING TO THE READIN SUBROUTINE
C                  (READING IN THE INPUT DECK)
C          NGSPK = FILE # CORRESPONDING TO A NON-GASP PROPERTY PACKAGE
C          NFNOD = FILE # CORRESPONDING TO THE FNODE RESTART FILE
C          NGFSOUT = FILE # CORRESPONDING TO THE GFSSP.OUT FILE
C                  (DEBUGGING FILE)
C          NFBR = FILE # CORRESPONDING TO THE FBRANCH RESTART FILE
C          NGASP = FILE # CORRESPONDING TO THE GASP.OUT FILE
C                  (DEBUGGING FILE)
C          NHSTN = FILE # CORRESPONDING TO THE HISTN.XLS FILE
C          NHSTB = FILE # CORRESPONDING TO THE HISTBR.XLS FILE
C          NHSTF = FILE # CORRESPONDING TO B.C. & VARGEO HISTORY FILES
C          NCVHST = FILE # CORRESPONDING TO THE CONTROL VALVE HISTORY FILE
C          NCVCHR1 = FILE # CORRESPONDING TO THE FIRST OF TWO CONTROL
C                  VALVE FILES
C          NCVCHR2 = FILE # CORRESPONDING TO THE SECOND OF TWO CONTROL
C                  VALVE FILES
C          NHSTROT = FILE # CORRESPONDING TO THE VARIABLE ROTATION
C                  HISTORY FILE
C          NERROR = FILE # CORRESPONDING TO THE ERROR.XLS FILE
C          NRP1DAT = FILE # CORRESPONDING TO THE RP1 PROPERTY DATA FILES
C
C          NGSPK=1
C          NPRNT=10
C          NFNOD=11
C          NGFSOUT=12
C          NFBR=13
C          NREAD=15
C          NGASP=17

```

```

NHSTN=18
NHSTB=19
NWRTE=20
NHSTF=21
NCVHST=28
NCVCHR1=29
NCVCHR2=30
NHSTROT=35
NERROR=55
NRP1DAT=51

C
C FILE NUMBERS FOR USER DEFINED FILES (THESE FILES CAN BE USED
C IN ANY OF THE USER SUBROUTINES; HOWEVER, MOST LIKELY USE IS
C IN THE PRNUSED SUBROUTINE). COMMENT OUT FILE NUMBERS NOT IN USE.
C

C      NUSR1=
C      NUSR2=
C      NUSR3=
C      NUSR4=
C      NUSR5=
C      NUSR6=
C      NUSR7=
C      NUSR8=
C      NUSR9=
C      NUSR10=

C
      RETURN
      END
*****
      SUBROUTINE USRINT
C      PURPOSE: PROVIDE INITIAL CONDITIONS WHEN ALTERNATE THERMODYNAMIC
C                  PROPERTY PACKAGE IS USED
*****
      INCLUDE 'COMBLK.FOR'
*****
C      ADD CODE HERE
      RETURN
      END
*****
      SUBROUTINE SORCEM(IPN,TERMU)
C      PURPOSE: ADD MASS SOURCES
C      IPN - GFSSP INDEX NUMBER FOR NODE
C      TERMU - UNSTEADY TERM IN MASS CONSERVATION EQUATION
*****
      INCLUDE 'COMBLK.FOR'
*****
C      ADD CODE HERE
      RETURN
      END
*****
      SUBROUTINE SORCEF(I,TERM0,TERM1,TERM2,TERM3,TERM4,TERM5,TERM6,
&                      TERM7,TERM8,TERM9,TERM10,TERM100)
C      PURPOSE: ADD MOMENTUM SOURCES (LBF)

```

```

C      I - GFSSP INDEX NUMBER FOR BRANCH
C      TERM0 - UNSTEADY TERM IN MOMENTUM CONSERVATION EQUATION
C      TERM1 - LONGITUDINAL INERTIA
C      TERM2 - PRESSURE GRADIENT
C      TERM3 - GRAVITY FORCE
C      TERM4 - FRICTION FORCE
C      TERM5 - CENTRIFUGAL FORCE
C      TERM6 - EXTERNAL MOMENTUM SOURCE DUE TO PUMP
C      TERM7 - MOMENTUM SOURCE DUE TO TRANSVERSE FLOW(MULTI-DIMENSIONAL MODEL)
C      TERM8 - MOMENTUM SOURCE DUE TO SHEAR(MULTI-DIMENSIONAL MODEL)
C      TERM9 - VARIABLE GEOMETRY UNSTEADY TERM
C      TERM10 - NORMAL STRESS
C      TERM100 - USER SUPPLIED MOMENTUM SOURCE
C*****
C      INCLUDE 'COMBLK.FOR'
C*****
C      ADD CODE HERE
C      RETURN
C      END

C*****
SUBROUTINE SORCEQ(IPN,TERMD)
C      PURPOSE: ADD HEAT SOURCES
C      IPN - GFSSP INDEX NUMBER FOR NODE
C      TERMD - COMPONENT OF LINEARIZED SOURCE TERM APPEARING IN THE
C              DENOMINATOR OF THE ENTHALPY OR ENTROPY EQUATION
C*****
C      INCLUDE 'COMBLK.FOR'
C*****
C      ADD CODE HERE
C      RETURN
C      END

C*****
SUBROUTINE SORCEC
C      PURPOSE: ADD CONCENTRATION SOURCES
C*****
C      INCLUDE 'COMBLK.FOR'
C*****
C      ADD CODE HERE
C      RETURN
C      END

C*****
SUBROUTINE KFUSER(I,RHOU,EMUU,AKNEW)
C      PURPOSE: ADD A NEW RESISTANCE OPTION
C*****
C      INCLUDE 'COMBLK.FOR'
C*****
C      ADD CODE HERE
C      RETURN
C      END

```

```

C*****SUBROUTINE PRPUSER
C      PURPOSE: ADD NEW FLUID PROPERTY
C*****
C      INCLUDE 'COMBLK.FOR'
C*****
C      ADD CODE HERE
      RETURN
      END

C*****SUBROUTINE TSTEP
C      PURPOSE: MODIFY TIME STEP
C*****
C      INCLUDE 'COMBLK.FOR'
C*****
C      ADD CODE HERE
C      FRICTBP = .TRUE.
      DFLI = .FALSE.
      RETURN
      END

C*****SUBROUTINE BNDUSER
C      PURPOSE: MODIFY BOUNDARY CONDITIONS
C*****
C      INCLUDE 'COMBLK.FOR'
C*****
C      ADD CODE HERE
      RETURN
      END

C*****SUBROUTINE PRNUSET
C      PURPOSE: ADD NEW OUTPUT
C*****
C      INCLUDE 'COMBLK.FOR'
C*****
C      ADD CODE HERE
      RETURN
      END

C*****SUBROUTINE USRSET
C      PURPOSE: USER SETS UP THE MAJORITY OF THE MODEL
C*****
C      INCLUDE 'COMBLK.FOR'
C*****
C      ADD CODE HERE
C
C      THIS IS THE DEFAULT CODE FOR THIS BLOCK, COMMENT THIS OUT WHEN
C      CREATING A MODEL WITHIN THIS SUBROUTINE
C
      WRITE(*,*) ' '
      WRITE(*,*) ' USER ROUTINE USRSET DOES NOT HAVE A MODEL DEVELOPED'
      WRITE(*,*) ' '

```

```
      WRITE(*,*) ' OPEN THE USER SUBROUTINE FILE AND MODIFY SUBROUTINE'
      WRITE(*,*) ' USRSET TO DEVELOP MODEL OR CHANGE LOGICAL VARIABLE'
      WRITE(*,*) ' USETUP TO FALSE AND DEVELOP MODEL IN INPUT FILE'
      WRITE(*,*) ' '
C      STOP
C
C      END OF DEFAULT CODE
C
      RETURN
      END

C***** END OF USER SUBROUTINES *****
C*****
```

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APPENDIX F

INPUT AND OUTPUT DATA FILES FROM EXAMPLE 1

Simulation of a Flow System Consisting of a Pump, Valve and Pipe Line

Contents	Page
Example 1 Input File	F-2
Example 2 Output File	F-4

GFSSP VERSION
 300
 ANALYST
 ALOK MAJUMDAR
 INPUT DATA FILE NAME
 EX1.DAT
 OUTPUT FILE NAME
 EX1.OUT
 TITLE
 PUMP-SYSTEM CHARACTERISTICS
 USSETUP
 F
 DENCON GRAVITY ENERGY MIXTURE THRUST STEADY TRANSV SAVER
 F T T F F T F F
 HEX HCOEF REACTING INERTIA CONDX GASPAK PRINTI ROTATION
 F F F F F F F
 BUOYANCY HRATE INVAL MSORCE MOVBNF TPA VARGEO TVM
 F F F F F F F
 SHEAR PRNTIN PRNTADD LAMINAR TRANSQ
 F F F T F
 PRESS INSUC VARROT
 F F F
 NORMAL SIMUL SECONDL
 F T T
 NNODES NINT NBR NF
 4 2 3 1
 RELAXK RELAXD RELAXH CC NITER
 1.000 0.500 1.000 0.100E-03 500
 NFLUID(I), I= 1,NF
 11
 NODE INDEX
 1 2
 2 1
 3 1
 4 2
 NODE PRES (PSI) TEMP(DEGF) MASS SOURC HEAT SOURC THRST AREA
 1 0.1470E+02 0.6000E+02 0.0000E+00 0.0000E+00 0.0000E+00
 2 0.1000E+02 0.6000E+02 0.0000E+00 0.0000E+00 0.0000E+00
 3 0.4803E+02 0.6000E+02 0.0000E+00 0.0000E+00 0.0000E+00
 4 0.1470E+02 0.6000E+02 0.0000E+00 0.0000E+00 0.0000E+00
 INODE NUMBR BRANCH 1 BRANCH 2 BRANCH 3 BRANCH 4 BRANCH 5 BRANCH 6
 2 2 12 23
 3 2 23 34
 BRANCH UPNODE DNNOODE OPTION
 12 1 2 14
 23 2 3 13
 34 3 4 1
 BRANCH OPTION -14: PUMP CONST1, PUMP CONST2, AREA
 12 30888.00000 -0.00081 201.06177
 BRANCH OPTION -13: DIA, K1, K2, AREA

```
23      6.00000  1000.00000    0.10000  28.27431
BRANCH OPTION -1: LENGTH, DIA, EPSD, ANGLE, AREA
 34 18000.00000   6.00000    0.00500   95.74000   28.27431
BRANCH NOUBR     NMUBR
 12      0
 23      1      12
 34      1      23
BRANCH NODBR     NMDBR
 12      1      23
 23      1      34
 34      0
BRANCH
 12
UPSTRM BR.    ANGLE
DNSTRM BR.    ANGLE
 23      0.00
BRANCH
 23
UPSTRM BR.    ANGLE
 12      0.00
DNSTRM BR.    ANGLE
 34      0.00
BRANCH
 34
UPSTRM BR.    ANGLE
 23      0.00
DNSTRM BR.    ANGLE
NODE DATA FILE
FNODE.DAT
BRANCH DATA FILE
FBRANCH.DAT
```

G F S S P (Version 3.0)
Generalized Fluid System Simulation Program
September, 1999
Developed by Sverdrup Technology
Copyright (C) by Marshall Space Flight Center

A generalized computer program to calculate flow
rates, pressures, temperatures and concentrations
in a flow network.

TITLE :PUMP-SYSTEM CHARACTERISTICS

ANALYST :ALOK MAJUMDAR

FILEIN :ex1.dat

FILEOUT :EX1.OUT

LOGICAL VARIABLES

DENCON = F

GRAVITY = T

ENERGY = T

MIXTURE = F

THRUST = F

STEADY = T

TRANSV = F

SAVER = F

HEX = F

HCOEF = F

REACTING = F

INERTIA = F

CONDX = F

TWOD = F

PRINTI = F

ROTATION = F

BUOYANCY = F

HRATE = F

INVAL = F

MSOURCE = F

MOVBND = F

TPA = F

VARGEO = F

TVM = F

SHEAR = F

PRNTIN = F

PRNTADD = F

ADDPROP = F

PRESS = F

INSUC = F

VARROT = F

NORMAL = F
SECONDL = T

NNODES = 4
NINT = 2
NBR = 3
NF = 1
NVAR = 5
NHREF = 2

FLUIDS: H2O

BOUNDARY NODES

NODE	P (PSI)	T (F)	RHO (LBM/FT^3)	AREA (IN^2)
1	0.1470E+02	0.6000E+02	0.6237E+02	0.0000E+00
4	0.1470E+02	0.6000E+02	0.6237E+02	0.0000E+00

SOLUTION

INTERNAL NODES

NODE	P(PSI)	TF(F)	Z	RHO (LBM/FT^3)	EM(LBM)	QUALITY
2	0.2290E+03	0.6003E+02	0.1186E-01	0.6241E+02	0.0000E+00	0.0000E+00
3	0.2288E+03	0.6003E+02	0.1185E-01	0.6241E+02	0.0000E+00	0.0000E+00

BRANCHES

BRANCH	KFACTOR (LBF-S^2/(LBM-FT)^2)	DELP (PSI)	FLOW RATE (LBM/SEC)	VELOCITY (FT/SEC)	REYN. NO.	MACH NO.	ENTROPY GEN. BTU/(R-SEC)	LOST WORK LBF-FT/SEC
12	0.000E+00	-0.214E+03	0.191E+03	0.219E+01	0.241E+06	0.183E-02	0.000E+00	0.000E+00
23	0.764E-03	0.193E+00	0.191E+03	0.156E+02	0.644E+06	0.130E-01	0.210E-03	0.848E+02
34	0.591E+00	0.214E+03	0.191E+03	0.156E+02	0.644E+06	0.130E-01	0.162E+00	0.657E+05

***** TOTAL ENTROPY GENERATION = 0.163E+00 BTU/(R-SEC) *****

**** TOTAL WORK LOST = 0.120E+03 HP ****

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APPENDIX G

INPUT AND OUTPUT DATA FILES FROM EXAMPLE 2

Simulation of a Water Distribution Network

Contents	Page
Example 2 Input File	G-2
Example 2 Output File	G-7

GFSSP VERSION
 300
 ANALYST
 ALOK MAJUMDAR
 INPUT DATA FILE NAME
 EX2.DAT
 OUTPUT FILE NAME
 EX2.OUT
 TITLE
 SIMULATION OF A WATER DISTRIBUTION NETWORK
 USETUP
 F
 DENCON GRAVITY ENERGY MIXTURE THRUST STEADY TRANSV SAVER
 T F F F T F F
 HEX HCOEF REACTING INERTIA CONDX GASPAK PRINTI ROTATION
 F F F F F F F
 BUOYANCY HRATE INVAL MSORCE MOVBND TPA VARGEO TVM
 F T F F F F F
 SHEAR PRNTIN PRNTADD LAMINAR TRANSQ
 F F F T F
 PRESS INSUC VARROT
 F F F
 NORMAL SIMUL SECONDL
 F T T
 NNODES NINT NBR NF
 9 5 10 0
 RELAXK RELAXD RELAXH CC NITER
 1.000 0.500 1.000 0.100E-03 500
 RHOREF EMUREF
 62.4000 0.660000E-03
 NODE INDEX
 1 2
 2 1
 3 2
 4 2
 5 1
 6 1
 7 1
 8 1
 9 2
 NODE PRES (PSI) MASS SOURC HEAT SOURC THRST AREA
 1 0.5000E+02 0.0000E+00 0.0000E+00 0.0000E+00
 2 0.4960E+02 0.0000E+00 0.0000E+00 0.0000E+00
 3 0.4800E+02 0.0000E+00 0.0000E+00 0.0000E+00
 4 0.4500E+02 0.0000E+00 0.0000E+00 0.0000E+00
 5 0.4840E+02 0.0000E+00 0.0000E+00 0.0000E+00
 6 0.4740E+02 0.0000E+00 0.0000E+00 0.0000E+00

7	0.4920E+02	0.0000E+00	0.0000E+00	0.0000E+00			
8	0.4640E+02	0.0000E+00	0.0000E+00	0.0000E+00			
9	0.4600E+02	0.0000E+00	0.0000E+00	0.0000E+00			
INODE	NUMBR	BRANCH 1	BRANCH 2	BRANCH 3	BRANCH 4	BRANCH 5	BRANCH 6
2	3	12	25	27			
5	4	25	53	56	57		
6	3	56	64	68			
7	3	27	57	78			
8	3	78	68	89			
BRANCH	UPNODE	DNNODE	OPTION				
12	1	2	1				
25	2	5	1				
27	2	7	1				
53	5	3	1				
56	5	6	1				
57	5	7	1				
64	6	4	1				
68	6	8	1				
78	7	8	1				
89	8	9	1				
BRANCH	OPTION -1:	LENGTH, DIA, EPSD, ANGLE, AREA					
12	120.00000	6.00000	0.00180	0.00000	28.27431		
BRANCH	OPTION -1:	LENGTH, DIA, EPSD, ANGLE, AREA					
25	2400.00000	6.00000	0.00180	0.00000	28.27431		
BRANCH	OPTION -1:	LENGTH, DIA, EPSD, ANGLE, AREA					
27	2400.00000	5.00000	0.00180	0.00000	19.63494		
BRANCH	OPTION -1:	LENGTH, DIA, EPSD, ANGLE, AREA					
53	120.00000	5.00000	0.00180	0.00000	19.63494		
BRANCH	OPTION -1:	LENGTH, DIA, EPSD, ANGLE, AREA					
56	2400.00000	4.00000	0.00180	0.00000	12.56636		
BRANCH	OPTION -1:	LENGTH, DIA, EPSD, ANGLE, AREA					
57	1440.00000	4.00000	0.00180	0.00000	12.56636		
BRANCH	OPTION -1:	LENGTH, DIA, EPSD, ANGLE, AREA					
64	120.00000	4.00000	0.00180	0.00000	12.56636		
BRANCH	OPTION -1:	LENGTH, DIA, EPSD, ANGLE, AREA					
68	1440.00000	4.00000	0.00180	0.00000	12.56636		
BRANCH	OPTION -1:	LENGTH, DIA, EPSD, ANGLE, AREA					
78	2400.00000	4.00000	0.00180	0.00000	12.56636		
BRANCH	OPTION -1:	LENGTH, DIA, EPSD, ANGLE, AREA					
89	120.00000	5.00000	0.00180	0.00000	19.63494		
BRANCH	NOUBR	NMUBR					
12	0						
25	2	12	27				
27	2	12	25				
53	3	25	56	57			
56	3	25	53	57			
57	3	25	53	56			

64	2	56	68
68	2	56	64
78	2	27	57
89	2	78	68
BRANCH	NODBR	NMDBR	
12	2	25	27
25	3	53	56
27	2	57	78
53	0		
56	2	64	68
57	2	27	78
64	0		
68	2	78	89
78	2	68	89
89	0		
BRANCH	12		
UPSTRM BR.	ANGLE		
DNSTRM BR.	ANGLE		
25	0.00		
27	0.00		
BRANCH	25		
UPSTRM BR.	ANGLE		
12	0.00		
27	0.00		
DNSTRM BR.	ANGLE		
53	0.00		
56	0.00		
57	0.00		
BRANCH	27		
UPSTRM BR.	ANGLE		
12	0.00		
25	0.00		
DNSTRM BR.	ANGLE		
57	0.00		
78	0.00		
BRANCH	53		
UPSTRM BR.	ANGLE		
25	0.00		
56	0.00		
57	0.00		
DNSTRM BR.	ANGLE		
BRANCH	56		

UPSTRM BR. ANGLE
25 0.00
53 0.00
57 0.00
DNSTRM BR. ANGLE
64 0.00
68 0.00
BRANCH
57
UPSTRM BR. ANGLE
25 0.00
53 0.00
56 0.00
DNSTRM BR. ANGLE
27 0.00
78 0.00
BRANCH
64
UPSTRM BR. ANGLE
56 0.00
68 0.00
DNSTRM BR. ANGLE
BRANCH
68
UPSTRM BR. ANGLE
56 0.00
64 0.00
DNSTRM BR. ANGLE
78 0.00
89 0.00
BRANCH
78
UPSTRM BR. ANGLE
27 0.00
57 0.00
DNSTRM BR. ANGLE
68 0.00
89 0.00
BRANCH
89
UPSTRM BR. ANGLE
78 0.00
68 0.00
DNSTRM BR. ANGLE
NODE DATA FILE
FNODE.DAT
BRANCH DATA FILE

FBRANCH.DAT

```
*****
 G F S S P (Version 3.0)
 Generalized Fluid System Simulation Program
 September, 1999
 Developed by Sverdrup Technology
 Copyright (C) by Marshall Space Flight Center
```

A generalized computer program to calculate flow
rates, pressures, temperatures and concentrations
in a flow network.

```
*****
TITLE      :SIMULATION OF A WATER DISTRIBUTION NETWORK
ANALYST    :ALOK MAJUMDAR
FILEIN     :EX2.DAT
FILEOUT    :EX2.OUT
LOGICAL VARIABLES
DENCON     =   T
GRAVITY    =   F
ENERGY     =   F
MIXTURE    =   F
THRUST     =   F
STEADY     =   T
TRANSV     =   F
SAVER      =   F
HEX         =   F
HCOEF       =   F
REACTING    =   F
INERTIA    =   F
CONDX      =   F
TWOD        =   F
PRINTI     =   F
ROTATION    =   F
BUOYANCY   =   F
HRATE      =   T
INVAL      =   F
MSOURCE    =   F
MOVBND    =   F
TPA         =   F
VARGEO     =   F
TVM         =   F
SHEAR      =   F
PRNTIN     =   F
PRNTADD    =   F
GASPAK     =   F
```

```

PRESS      =   F
INSUC     =   F
VARROT    =   F
NORMAL    =   F
SECONDL   =   T

NNODES    =     9
NINT      =     5
NBR       =    10
NF        =     0
NVAR      =    15
NHREF     =     2

RHOREF    =    62.4000 LBM/FT**3
EMUREF    =  0.6600E-03 LBM/FT-SEC

```

BOUNDARY NODES

NODE	P (PSI)	AREA (IN^2)
1	0.5000E+02	0.0000E+00
3	0.4800E+02	0.0000E+00
4	0.4500E+02	0.0000E+00
9	0.4600E+02	0.0000E+00

SOLUTION

INTERNAL NODES

NODE	P(PSI)	EM(LBM)
2	0.4979E+02	0.0000E+00
5	0.4810E+02	0.0000E+00
6	0.4535E+02	0.0000E+00
7	0.4833E+02	0.0000E+00
8	0.4600E+02	0.0000E+00

BRANCHES

BRANCH	KFACTOR (LBF-S^2/(LBM-FT)^2)	DELP (PSI)	FLOW RATE (LBM/SEC)	VELOCITY (FT/SEC)	REYN. NO.	MACH NO.	ENTROPY GEN. BTU/(R-SEC)	LOST WORK LBF-FT/SEC
12	0.301E-02	0.210E+00	0.100E+03	0.817E+01	0.386E+06	0.000E+00	0.135E-03	0.484E+02
25	0.609E-01	0.169E+01	0.631E+02	0.515E+01	0.244E+06	0.000E+00	0.687E-03	0.246E+03
27	0.154E+00	0.146E+01	0.370E+02	0.435E+01	0.171E+06	0.000E+00	0.349E-03	0.125E+03
53	0.762E-02	0.104E+00	0.444E+02	0.522E+01	0.206E+06	0.000E+00	0.300E-04	0.107E+02
56	0.469E+00	0.275E+01	0.291E+02	0.534E+01	0.168E+06	0.000E+00	0.516E-03	0.184E+03
57	0.301E+00	-0.224E+00	-0.104E+02	-0.190E+01	0.599E+05	0.000E+00	0.150E-04	0.536E+01
64	0.230E-01	0.355E+00	0.471E+02	0.864E+01	0.272E+06	0.000E+00	0.108E-03	0.385E+02
68	0.289E+00	-0.650E+00	-0.180E+02	-0.331E+01	0.104E+06	0.000E+00	0.755E-04	0.270E+02
78	0.471E+00	0.232E+01	0.267E+02	0.490E+01	0.154E+06	0.000E+00	0.400E-03	0.143E+03

89 0.858E-02 0.447E-02 0.866E+01 0.102E+01 0.401E+05 0.000E+00 0.249E-06 0.892E-01

***** TOTAL ENTROPY GENERATION = 0.232E-02 BTU/(R-SEC) *****

**** TOTAL WORK LOST = 0.151E+01 HP ****

SOLUTION SATISFIED CONVERGENCE CRITERION OF 0.100E-03 IN 11 ITERATIONS
TAU = 0.100000E+09 ISTEP = 1

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APPENDIX H

INPUT AND OUTPUT DATA FILES FROM EXAMPLE 3

Simulation of Compressible Flow in a Converging-Diverging Nozzle

<u>Contents</u>	<u>Page</u>
Example 3 Input File	H-2
Example 3 Output File	H-8

```

GFSSP VERSION
 300
ANALYST
Alok Majumdar
INPUT DATA FILE NAME
EX3.DAT
OUTPUT FILE NAME
EX3.OUT
TITLE
Converging/Diverging Nozzle Using Steam
USETUP
  F
DENCON GRAVITY ENERGY MIXTURE THRUST STEADY TRANSV SAVER
  F   F   T   F   T   F   F
HEX HCOEF REACTING INERTIA CONDX GASPAK PRINTI ROTATION
  F   F   F   T   F   F   F
BUOYANCY HRATE INVAL MSORCE MOVBND TPA VARGEO TVM
  F   F   F   F   F   F   F
SHEAR PRNTIN PRNTADD LAMINAR TRANSQ
  F   F   F   T   F
PRESS INSUC VARROT
  F   F
NORMAL SIMUL SECONDL
  F   T   T
NNODES NINT NBR NF
  17   15   16   1
RELAXK RELAXD RELAXH CC NITER
  1.000   0.500   1.000   0.100E-03   500
NFLUID(I), I= 1,NF
  11
NODE INDEX
  1   2
  2   1
  3   1
  4   1
  5   1
  6   1
  7   1
  8   1
  9   1
 10   1
 11   1
 12   1
 13   1
 14   1
 15   1
 16   1

```

17	2						
NODE	PRES (PSI)	TEMP(DEGF)	MASS SOURC	HEAT SOURC	THRST	AREA	
1	0.1500E+03	0.1000E+04	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	
2	0.1444E+03	0.1000E+04	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	
3	0.1388E+03	0.1000E+04	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	
4	0.1331E+03	0.1000E+04	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	
5	0.1275E+03	0.1000E+04	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	
6	0.1219E+03	0.1000E+04	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	
7	0.1163E+03	0.1000E+04	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	
8	0.1106E+03	0.1000E+04	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	
9	0.1050E+03	0.1000E+04	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	
10	0.1000E+03	0.1000E+04	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	
11	0.1000E+03	0.1000E+04	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	
12	0.1000E+03	0.1000E+04	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	
13	0.1000E+03	0.1000E+04	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	
14	0.1000E+03	0.1000E+04	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	
15	0.1000E+03	0.1000E+04	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	
16	0.6563E+02	0.1000E+04	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	
17	0.6000E+02	0.1000E+04	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	
INODE	NUMBR	BRANCH 1	BRANCH 2	BRANCH 3	BRANCH 4	BRANCH 5	BRANCH 6
2	2	12	23				
3	2	23	34				
4	2	34	45				
5	2	45	56				
6	2	56	67				
7	2	67	78				
8	2	78	89				
9	2	89	910				
10	2	910	1011				
11	2	1011	1112				
12	2	1213	1112				
13	2	1213	1314				
14	2	1314	1415				
15	2	1415	1516				
16	2	1516	1617				
BRANCH	UPNODE	DNNODE	OPTION				
12	1	2	2				
23	2	3	2				
34	3	4	2				
45	4	5	2				
56	5	6	2				
67	6	7	2				
78	7	8	2				
89	8	9	2				
910	9	10	2				
1011	10	11	2				
1112	11	12	2				

1213	12	13	2
1314	13	14	2
1415	14	15	2
1516	15	16	2
1617	16	17	2
BRANCH OPTION -2: FLOW COEF, AREA			
12	0.00000	0.35870	
BRANCH OPTION -2: FLOW COEF, AREA			
23	0.00000	0.27170	
BRANCH OPTION -2: FLOW COEF, AREA			
34	0.00000	0.22430	
BRANCH OPTION -2: FLOW COEF, AREA			
45	0.00000	0.20830	
BRANCH OPTION -2: FLOW COEF, AREA			
56	0.00000	0.19010	
BRANCH OPTION -2: FLOW COEF, AREA			
67	0.00000	0.19490	
BRANCH OPTION -2: FLOW COEF, AREA			
78	0.00000	0.22550	
BRANCH OPTION -2: FLOW COEF, AREA			
89	0.00000	0.28750	
BRANCH OPTION -2: FLOW COEF, AREA			
910	0.00000	0.39480	
BRANCH OPTION -2: FLOW COEF, AREA			
1011	0.00000	0.56400	
BRANCH OPTION -2: FLOW COEF, AREA			
1112	0.00000	0.76330	
BRANCH OPTION -2: FLOW COEF, AREA			
1213	0.00000	0.99270	
BRANCH OPTION -2: FLOW COEF, AREA			
1314	0.00000	1.25200	
BRANCH OPTION -2: FLOW COEF, AREA			
1415	0.00000	1.46680	
BRANCH OPTION -2: FLOW COEF, AREA			
1516	0.00000	1.57030	
BRANCH OPTION -2: FLOW COEF, AREA			
1617	0.00000	1.62860	
BRANCH NOUBR NMUBR			
12	0		
23	1	12	
34	1	23	
45	1	34	
56	1	45	
67	1	56	
78	1	67	
89	1	78	
910	1	89	

1011	1	910
1112	1	1011
1213	1	1112
1314	1	1213
1415	1	1314
1516	1	1415
1617	1	1516

BRANCH	NODBR	NMDBR
12	1	23
23	1	34
34	1	45
45	1	56
56	1	67
67	1	78
78	1	89
89	1	910
910	1	1011
1011	1	1112
1112	1	1213
1213	1	1314
1314	1	1415
1415	1	1516
1516	1	1617
1617	0	

BRANCH	12	
UPSTRM BR.	ANGLE	
DNSTRM BR.	ANGLE	
23	0.00	

BRANCH	23	
UPSTRM BR.	ANGLE	
12	0.00	
DNSTRM BR.	ANGLE	
34	0.00	

BRANCH	34	
UPSTRM BR.	ANGLE	
23	0.00	
DNSTRM BR.	ANGLE	
45	0.00	

BRANCH	45	
UPSTRM BR.	ANGLE	
34	0.00	
DNSTRM BR.	ANGLE	
56	0.00	

BRANCH
 56
 UPSTRM BR. ANGLE
 45 0.00
 DNSTRM BR. ANGLE
 67 0.00

BRANCH
 67
 UPSTRM BR. ANGLE
 56 0.00
 DNSTRM BR. ANGLE
 78 0.00

BRANCH
 78
 UPSTRM BR. ANGLE
 67 0.00
 DNSTRM BR. ANGLE
 89 0.00

BRANCH
 89
 UPSTRM BR. ANGLE
 78 0.00
 DNSTRM BR. ANGLE
 910 0.00

BRANCH
 910
 UPSTRM BR. ANGLE
 89 0.00
 DNSTRM BR. ANGLE
 1011 0.00

BRANCH
 1011
 UPSTRM BR. ANGLE
 910 0.00
 DNSTRM BR. ANGLE
 1112 0.00

BRANCH
 1112
 UPSTRM BR. ANGLE
 1011 0.00
 DNSTRM BR. ANGLE
 1213 0.00

BRANCH
 1213
 UPSTRM BR. ANGLE
 1112 0.00
 DNSTRM BR. ANGLE

```
    1314      0.00
BRANCH
    1314
UPSTRM BR. ANGLE
    1213      0.00
DNSTRM BR. ANGLE
    1415      0.00
BRANCH
    1415
UPSTRM BR. ANGLE
    1314      0.00
DNSTRM BR. ANGLE
    1516      0.00
BRANCH
    1516
UPSTRM BR. ANGLE
    1415      0.00
DNSTRM BR. ANGLE
    1617      0.00
BRANCH
    1617
UPSTRM BR. ANGLE
    1516      0.00
DNSTRM BR. ANGLE
NUMBER OF BRANCHES WITH INERTIA
    16
    12
    23
    34
    45
    56
    67
    78
    89
    910
   1011
   1112
   1213
   1314
   1415
   1516
   1617
NODE DATA FILE
FNODE.DAT
BRANCH DATA FILE
FBRANCH.DAT
```

```
*****
 G F S S P (Version 3.0)
 Generalized Fluid System Simulation Program
 September, 1999
 Developed by Sverdrup Technology
 Copyright (C) by Marshall Space Flight Center
```

A generalized computer program to calculate flow rates, pressures, temperatures and concentrations in a flow network.

```
*****
TITLE      :Converging/Diverging Nozzle Using Steam
ANALYST    :Alok Majumdar
FILEIN     :EX3.DAT
FILEOUT    :EX3.OUT
LOGICAL VARIABLES
DENCON     =   F
GRAVITY    =   F
ENERGY     =   T
MIXTURE    =   F
THRUST     =   F
STEADY     =   T
TRANSV     =   F
SAVER      =   F
HEX         =   F
HCOEF       =   F
REACTING    =   F
INERTIA    =   T
CONDX      =   F
TWOD        =   F
PRINTI     =   F
ROTATION    =   F
BUOYANCY   =   F
HRATE       =   F
INVAL       =   F
MSOURCE    =   F
MOVBND     =   F
TPA         =   F
VARGEO     =   F
TVM         =   F
SHEAR       =   F
PRNTIN     =   F
PRNTADD    =   F
ADDPROP    =   F
```

PRESS = F
INSUC = F
VARROT = F
NORMAL = F
SECONDL = T

NNODES = 17
NINT = 15
NBR = 16
NF = 1
NVAR = 31
NHREF = 2

FLUIDS: H2O

BOUNDARY NODES

NODE	P (PSI)	T (F)	RHO (LBM/FT ³)	AREA (IN ²)
1	0.1500E+03	0.1000E+04	0.1736E+00	0.0000E+00
17	0.6000E+02	0.1000E+04	0.6919E-01	0.0000E+00

SOLUTION

INTERNAL NODES

NODE	P (PSI)	TF (F)	Z	RHO (LBM/FT ³)	EM (LBM)	QUALITY
2	0.1500E+03	0.1000E+04	0.9939E+00	0.1736E+00	0.0000E+00	0.1000E+01
3	0.1373E+03	0.9725E+03	0.9939E+00	0.1620E+00	0.0000E+00	0.1000E+01
4	0.1197E+03	0.9305E+03	0.9941E+00	0.1455E+00	0.0000E+00	0.1000E+01
5	0.1045E+03	0.8897E+03	0.9942E+00	0.1308E+00	0.0000E+00	0.1000E+01
6	0.8213E+02	0.8199E+03	0.9944E+00	0.1084E+00	0.0000E+00	0.1000E+01
7	0.5974E+02	0.7321E+03	0.9946E+00	0.8463E-01	0.0000E+00	0.1000E+01
8	0.4267E+02	0.6445E+03	0.9948E+00	0.6523E-01	0.0000E+00	0.1000E+01
9	0.3498E+02	0.5953E+03	0.9949E+00	0.5597E-01	0.0000E+00	0.1000E+01
10	0.4116E+02	0.6354E+03	0.9949E+00	0.6344E-01	0.0000E+00	0.1000E+01
11	0.5165E+02	0.6935E+03	0.9947E+00	0.7561E-01	0.0000E+00	0.1000E+01
12	0.5650E+02	0.7172E+03	0.9946E+00	0.8106E-01	0.0000E+00	0.1000E+01
13	0.5839E+02	0.7260E+03	0.9946E+00	0.8315E-01	0.0000E+00	0.1000E+01
14	0.5930E+02	0.7301E+03	0.9946E+00	0.8415E-01	0.0000E+00	0.1000E+01
15	0.5974E+02	0.7321E+03	0.9946E+00	0.8463E-01	0.0000E+00	0.1000E+01
16	0.5991E+02	0.7328E+03	0.9946E+00	0.8483E-01	0.0000E+00	0.1000E+01

BRANCHES

BRANCH	KFACTOR (LBF-S ² / (LBM-FT) ²)	DELP (PSI)	FLOW RATE (LBM/SEC)	VELOCITY (FT/SEC)	REYN. NO.	MACH NO.	ENTROPY GEN. BTU/(R-SEC)	LOST WORK LBF-FT/SEC
--------	--	---------------	------------------------	----------------------	-----------	----------	-----------------------------	-------------------------

12	0.000E+00	0.000E+00	0.336E+00	0.778E+03	0.376E+06	0.342E+00	0.000E+00	0.000E+00
23	0.000E+00	0.127E+02	0.336E+00	0.103E+04	0.432E+06	0.452E+00	0.000E+00	0.000E+00
34	0.000E+00	0.176E+02	0.336E+00	0.133E+04	0.485E+06	0.592E+00	0.000E+00	0.000E+00
45	0.000E+00	0.153E+02	0.336E+00	0.160E+04	0.520E+06	0.720E+00	0.000E+00	0.000E+00
56	0.000E+00	0.223E+02	0.336E+00	0.195E+04	0.563E+06	0.890E+00	0.000E+00	0.000E+00
67	0.000E+00	0.224E+02	0.336E+00	0.229E+04	0.591E+06	0.107E+01	0.000E+00	0.000E+00
78	0.000E+00	0.171E+02	0.336E+00	0.254E+04	0.596E+06	0.123E+01	0.000E+00	0.000E+00
89	0.000E+00	0.769E+01	0.336E+00	0.258E+04	0.576E+06	0.130E+01	0.000E+00	0.000E+00
910	0.000E+00	-0.617E+01	0.336E+00	0.219E+04	0.518E+06	0.112E+01	0.000E+00	0.000E+00
1011	0.000E+00	-0.105E+02	0.336E+00	0.135E+04	0.415E+06	0.682E+00	0.000E+00	0.000E+00
1112	0.000E+00	-0.485E+01	0.336E+00	0.840E+03	0.336E+06	0.413E+00	0.000E+00	0.000E+00
1213	0.000E+00	-0.189E+01	0.336E+00	0.602E+03	0.288E+06	0.293E+00	0.000E+00	0.000E+00
1314	0.000E+00	-0.903E+00	0.336E+00	0.465E+03	0.254E+06	0.226E+00	0.000E+00	0.000E+00
1415	0.000E+00	-0.443E+00	0.336E+00	0.393E+03	0.234E+06	0.190E+00	0.000E+00	0.000E+00
1516	0.000E+00	-0.174E+00	0.336E+00	0.365E+03	0.226E+06	0.177E+00	0.000E+00	0.000E+00
1617	0.000E+00	-0.857E-01	0.336E+00	0.351E+03	0.221E+06	0.170E+00	0.000E+00	0.000E+00

***** TOTAL ENTROPY GENERATION = 0.000E+00 BTU/(R-SEC) *****

**** TOTAL WORK LOST = 0.000E+00 HP ****

SOLUTION SATISFIED CONVERGENCE CRITERION OF 0.100E-03 IN 45 ITERATIONS
 TAU = 0.100000E+09 ISTEP = 1

APPENDIX I

INPUT AND OUTPUT DATA FILES FROM EXAMPLE 4

Simulation of the Mixing of Combustion Gases and a Cold Gas Stream

<u>Contents</u>	<u>Page</u>
Example 4 Input File	I-2
Example 4 Output File	I-4

GFSSP VERSION
 300
 ANALYST
 ALOK MAJUMDAR
 INPUT DATA FILE NAME
 EX4.DAT
 OUTPUT FILE NAME
 EX4.OUT
 TITLE
 SIMULATION OF THE MIXING OF COMBUSTION GAS AND COLD STREAM
 USETUP
 F
 DENCON GRAVITY ENERGY MIXTURE THRUST STEADY TRANSV SAVER
 F F T T F T F F
 HEX HCOEF REACTING INERTIA CONDX GSPAK PRINTI ROTATION
 F F F F F F F F
 BUOYANCY HRATE INVAL MSORCE MOVBND TPA VARGEO TVM
 F F F F F F F
 SHEAR PRNTIN PRNTADD LAMINAR TRANSQ
 F F F T F
 PRESS INSUC VARROT
 F F F
 NORMAL SIMUL SECONDL
 F F T
 NNODES NINT NBR NF
 4 1 3 2
 RELAXK RELAXD RELAXH CC NITER
 1.000 0.500 1.000 0.100E-03 500
 NFLUID(I), I= 1,NF
 11 6
 NODE INDEX
 1 2
 2 2
 3 1
 4 2
 NODE PRES (PSI) TEMP (DEGF) MASS SOURC HEAT SOURC THRST AREA CONCENTRATION
 1 0.5000E+03 0.1500E+04 0.0000E+00 0.0000E+00 0.0000E+00 0.9000E+00 0.1000
 2 0.5000E+03 0.8000E+02 0.0000E+00 0.0000E+00 0.0000E+00 0.0000E+00 1.0000
 3 0.3382E+03 0.1500E+04 0.0000E+00 0.0000E+00 0.0000E+00 0.9000E+00 0.1000
 4 0.1470E+02 0.8000E+02 0.0000E+00 0.0000E+00 0.0000E+00 0.5000E+00 0.5000
 INODE NUMBR BRANCH 1 BRANCH 2 BRANCH 3 BRANCH 4 BRANCH 5 BRANCH 6
 3 3 13 23 34
 BRANCH UPNODE DNNODE OPTION
 13 1 3 2
 23 2 3 2
 34 3 4 2

```

BRANCH OPTION -2: FLOW COEF, AREA
 13      0.60000      1.00000
BRANCH OPTION -2: FLOW COEF, AREA
 23      0.60000      1.00000
BRANCH OPTION -2: FLOW COEF, AREA
 34      0.60000      1.00000
BRANCH    NOUBR      NMUBR
 13          0
 23          0
 34          2      13      23
BRANCH    NODBR      NMDBR
 13          2      23      34
 23          2      13      34
 34          0
BRANCH
 13
UPSTRM BR.    ANGLE
DNSTRM BR.    ANGLE
 23      0.00
 34      0.00
BRANCH
 23
UPSTRM BR.    ANGLE
DNSTRM BR.    ANGLE
 13      0.00
 34      0.00
BRANCH
 34
UPSTRM BR.    ANGLE
 13      0.00
 23      0.00
DNSTRM BR.    ANGLE
NODE DATA FILE
FNODE.DAT
BRANCH DATA FILE
FBRANCH.DAT

```

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Generalized Fluid System Simulation Program
September, 1999
Developed by Sverdrup Technology
Copyright (C) by Marshall Space Flight Center

A generalized computer program to calculate flow
rates, pressures, temperatures and concentrations
in a flow network.

TITLE :SIMULATION OF THE MIXING OF COMBUSTION GAS AND COLD STREAM
ANALYST :ALOK MAJUMDAR
FILEIN :EX4.DAT
FILEOUT :EX4.OUT
LOGICAL VARIABLES
DENCON = F
GRAVITY = F
ENERGY = T
MIXTURE = T
THRUST = F
STEADY = T
TRANSV = F
SAVER = F
HEX = F
HCOEF = F
REACTING = F
INERTIA = F
CONDX = F
TWOD = F
PRINTI = F
ROTATION = F
BUOYANCY = F
HRATE = F
INVAL = F
MSOURCE = F
MOVBNDF = F
TPA = F
VARGEO = F
TVM = F
SHEAR = F
PRNTIN = F
PRNTADD = T
GASPAK = F

PRESS = F
INSUC = F
VARROT = F
NORMAL = F
SECONDL = T

NNODES = 4
NINT = 1
NBR = 3
NF = 2
NVAR = 4
NHREF = 2

FLUIDS: H2O O2

BOUNDARY NODES

NODE	P (PSI)	T (F)	RHO (LBM/FT ³)	AREA (IN ²)	CONCENTRATIONS	
					H2O	O2
1	0.5000E+03	0.1500E+04	0.3931E+00	0.0000E+00	0.9000E+00	0.1000E+00
2	0.5000E+03	0.8000E+02	0.2819E+01	0.0000E+00	0.0000E+00	0.1000E+01
4	0.1470E+02	0.8000E+02	0.4725E+02	0.0000E+00	0.5000E+00	0.5000E+00

SOLUTION

INTERNAL NODES

NODE	P(PSI)	TF(F)	Z	RHO (LBM/FT ³)	EM(LBM)	CONC	
						H2O	O2
3	0.4823E+03	0.7990E+03	0.9928E+00	0.8968E+00	0.0000E+00	0.2447E+00	0.7553

NODE	H BTU/LB	ENTROPY BTU/LB-R	EMU LBM/FT-SEC	COND BTU/FT-S-R	CP BTU/LB-R	GAMA	
						H2O	O2
3	0.7213E+03	0.1562E+01	0.2239E-04	0.8873E-05	0.4087E+00	0.1258E+01	

BRANCHES

BRANCH	KFACTOR (LBF-S ² /(LBM-FT) ²)	DELP (PSI)	FLOW RATE (LBM/SEC)	VELOCITY (FT/SEC)	REYN. NO.	MACH NO.	ENTROPY GEN. BTU/(R-SEC)	LOST WORK LBF-FT/SEC
13	0.228E+04	0.177E+02	0.106E+01	0.387E+03	0.512E+06	0.151E+00	0.450E-02	0.685E+04
23	0.317E+03	0.177E+02	0.283E+01	0.145E+03	0.268E+07	0.131E+00	0.610E-02	0.256E+04
34	0.998E+03	0.468E+03	0.389E+01	0.625E+03	0.235E+07	0.352E+00	0.669E-01	0.655E+05

***** TOTAL ENTROPY GENERATION = 0.775E-01 BTU/(R-SEC) *****

**** TOTAL WORK LOST = 0.136E+03 HP ****

WARNING! T out of fluid property range at node 1

WARNING! T out of fluid property range at node 3

SOLUTION SATISFIED CONVERGENCE CRITERION OF 0.100E-03 IN 25 ITERATIONS
TAU = 0.100000E+09ISTEP = 1

APPENDIX J

INPUT AND OUTPUT DATA FILES FROM EXAMPLE 5

Simulation of a Flow System Involving a Heat Exchanger

<u>Contents</u>	<u>Page</u>
Example 5 Input File	J-2
Example 5 Output File	J-5

GFSSP VERSION
 300
 ANALYST
 Todd Steadman
 INPUT DATA FILE NAME
 EX5.DAT
 OUTPUT FILE NAME
 EX5.OUT
 TITLE
 Simulation of a counter flow heat exchanger
 USETUP
 F
 DENCON GRAVITY ENERGY MIXTURE THRUST STEADY TRANSV SAVER
 F F T F T F F
 HEX HCOEF REACTING INERTIA CONDX GASPAK PRINTI ROTATION
 T F F F F T F
 BUOYANCY HRATE INVAL MSORCE MOVBND TPA VARGEO TVM
 F T F F F F F
 SHEAR PRNTIN PRNTADD LAMINAR TRANSQ
 F F F T F
 PRESS INSUC VARROT
 F F F
 NORMAL SIMUL SECONDL
 F T T
 NNODES NINT NBR NF
 8 4 6 1
 RELAXK RELAXD RELAXH CC NITER
 1.000 0.500 1.000 0.100E-03 500
 NFLUID(I), I= 1,NF
 11
 NODE INDEX
 1 2
 2 1
 3 1
 4 2
 5 2
 6 1
 7 1
 8 2
 NODE PRES (PSI) TEMP(DEGF) MASS SOURC HEAT SOURC THRST AREA
 1 0.5000E+02 0.1000E+03 0.0000E+00 0.0000E+00 0.0000E+00
 2 0.4583E+02 0.1000E+03 0.0000E+00 0.0000E+00 0.0000E+00
 3 0.2917E+02 0.1000E+03 0.0000E+00 0.0000E+00 0.0000E+00
 4 0.2500E+02 0.8000E+02 0.0000E+00 0.0000E+00 0.0000E+00
 5 0.5000E+02 0.6000E+02 0.0000E+00 0.0000E+00 0.0000E+00
 6 0.4583E+02 0.6000E+02 0.0000E+00 0.0000E+00 0.0000E+00
 7 0.2917E+02 0.6000E+02 0.0000E+00 0.0000E+00 0.0000E+00

8	0.2500E+02	0.7000E+02	0.0000E+00	0.0000E+00	0.0000E+00		
INODE	NUMBR	BRANCH 1	BRANCH 2	BRANCH 3	BRANCH 4	BRANCH 5	BRANCH 6
2	2	12	23				
3	2	23	34				
6	2	56	67				
7	2	67	78				
BRANCH	UPNODE	DNNODE	OPTION				
12	1	2	1				
23	2	3	1				
34	3	4	1				
56	5	6	1				
67	6	7	1				
78	7	8	1				
BRANCH	OPTION -1:	LENGTH, DIA, EPSD, ANGLE, AREA					
12	10.00000	0.25000 0.00000 0.00000	0.04909				
BRANCH	OPTION -1:	LENGTH, DIA, EPSD, ANGLE, AREA					
23	10.00000	0.25000 0.00000 0.00000	0.04909				
BRANCH	OPTION -1:	LENGTH, DIA, EPSD, ANGLE, AREA					
34	10.00000	0.25000 0.00000 0.00000	0.04909				
BRANCH	OPTION -1:	LENGTH, DIA, EPSD, ANGLE, AREA					
56	10.00000	0.50000 0.00000 0.00000	0.19635				
BRANCH	OPTION -1:	LENGTH, DIA, EPSD, ANGLE, AREA					
67	10.00000	0.50000 0.00000 0.00000	0.19635				
BRANCH	OPTION -1:	LENGTH, DIA, EPSD, ANGLE, AREA					
78	10.00000	0.50000 0.00000 0.00000	0.19635				
BRANCH	NOUBR	NMUBR					
12	0						
23	1	12					
34	1	23					
56	0						
67	1	56					
78	1	67					
BRANCH	NODBR	NMDBR					
12	1	23					
23	1	34					
34	0						
56	1	67					
67	1	78					
78	0						
BRANCH		12					
	UPSTRM BR.	ANGLE					
	DNSTRM BR.	ANGLE					
	23	0.00					
BRANCH		23					
	UPSTRM BR.	ANGLE					

```
    12      0.00
DNSTRM BR.    ANGLE
    34      0.00
BRANCH
    34
UPSTRM BR.    ANGLE
    23      0.00
DNSTRM BR.    ANGLE
BRANCH
    56
UPSTRM BR.    ANGLE
DNSTRM BR.    ANGLE
    67      0.00
BRANCH
    67
UPSTRM BR.    ANGLE
    56      0.00
DNSTRM BR.    ANGLE
    78      0.00
BRANCH
    78
UPSTRM BR.    ANGLE
    67      0.00
DNSTRM BR.    ANGLE
NUMBER OF HEAT EXCHANGERS
    1
IBRHOT IBRCLD ITYPHX ARHOT ARCOLD UA HEXEFF
 23 67 1  0.00000   0.00000   1.10375   1.50000
NODE DATA FILE
FNODE.DAT
BRANCH DATA FILE
FBRANCH.DAT
```

```
*****
 G F S S P (Version 3.0)
 Generalized Fluid System Simulation Program
 September, 1999
 Developed by Sverdrup Technology
 Copyright (C) by Marshall Space Flight Center
```

A generalized computer program to calculate flow rates, pressures, temperatures and concentrations in a flow network.

```
*****
TITLE      :Simulation of a counter flow heat exchanger
ANALYST    :Todd Steadman
FILEIN     :ex5.dat
FILEOUT    :EX5.OUT
LOGICAL VARIABLES
DENCON     =   F
GRAVITY    =   F
ENERGY     =   T
MIXTURE    =   F
THRUST     =   F
STEADY     =   T
TRANSV     =   F
SAVER      =   F
HEX         =   T
HCOEF      =   F
REACTING   =   F
INERTIA    =   F
CONDX      =   F
TWOD       =   F
PRINTI     =   T
ROTATION   =   F
BUOYANCY   =   F
HRATE      =   T
INVAL      =   F
MSOURCE   =   F
MOVBND    =   F
TPA        =   F
VARGEO     =   F
TVM        =   F
SHEAR      =   F
PRNTIN    =   F
PRNTADD   =   F
ADDPROP   =   F
```

PRESS = F
INSUC = F
VARROT = F
NORMAL = F
SECONDL = T

NNODES = 8
NINT = 4
NBR = 6
NF = 1
NVAR = 10
NHREF = 2

FLUIDS: H2O

BOUNDARY NODES

NODE	P (PSI)	T (F)	RHO (LBM/FT ³)	AREA (IN ²)
1	0.5000E+02	0.1000E+03	0.6201E+02	0.0000E+00
4	0.2500E+02	0.8000E+02	0.6222E+02	0.0000E+00
5	0.5000E+02	0.6000E+02	0.6238E+02	0.0000E+00
8	0.2500E+02	0.7000E+02	0.6231E+02	0.0000E+00

SOLUTION

INTERNAL NODES

NODE	P(PSI)	TF(F)	Z	RHO (LBM/FT ³)	EM(LBM)	QUALITY
2	0.4185E+02	0.1000E+03	0.2025E-02	0.6200E+02	0.0000E+00	0.0000E+00
3	0.3370E+02	0.7180E+02	0.1709E-02	0.6229E+02	0.0000E+00	0.0000E+00
6	0.4163E+02	0.6002E+02	0.2157E-02	0.6237E+02	0.0000E+00	0.0000E+00
7	0.3327E+02	0.6451E+02	0.1709E-02	0.6235E+02	0.0000E+00	0.0000E+00

BRANCHES

BRANCH	KFACTOR (LBF-S ² /(LBM-FT) ²)	DELP (PSI)	FLOW RATE (LBM/SEC)	VELOCITY (FT/SEC)	REYN. NO.	MACH NO.	ENTROPY GEN. BTU/(R-SEC)	LOST WORK LBF-FT/SEC
12	0.150E+04	0.815E+01	0.885E+00	0.419E+02	0.118E+06	0.333E-01	0.384E-04	0.167E+02
23	0.150E+04	0.815E+01	0.885E+00	0.419E+02	0.118E+06	0.333E-01	0.384E-04	0.167E+02
34	0.160E+04	0.870E+01	0.885E+00	0.417E+02	0.844E+05	0.343E-01	0.430E-04	0.178E+02
56	0.412E+02	0.837E+01	0.541E+01	0.636E+02	0.219E+06	0.530E-01	0.258E-03	0.104E+03
67	0.412E+02	0.837E+01	0.541E+01	0.636E+02	0.219E+06	0.530E-01	0.258E-03	0.104E+03
78	0.407E+02	0.827E+01	0.541E+01	0.637E+02	0.234E+06	0.528E-01	0.253E-03	0.103E+03

***** TOTAL ENTROPY GENERATION = 0.890E-03 BTU/(R-SEC) *****

***** TOTAL WORK LOST = 0.661E+00 HP *****

SOLUTION SATISFIED CONVERGENCE CRITERION OF 0.100E-03 IN 10 ITERATIONS
TAU = 0.10000E+09 ISTEP = 1

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APPENDIX K

INPUT AND OUTPUT DATA FILES FROM EXAMPLE 6

Radial Flow on a Rotating Disk

Contents	Page
Example 6 Input File	K-2
Example 6 Output File	K-7

```

GFSSP VERSION
 300
ANALYST
Paul Schallhorn
INPUT DATA FILE NAME
EX6.DAT
OUTPUT FILE NAME
EX6.OUT
TITLE
EXAMPLE6 - RADIAL FLOW ON A ROTATING DISK
USETUP
  F
DENCON GRAVITY ENERGY MIXTURE THRUST STEADY TRANSV SAVER
  F      F      T      F      T      F      F
HEX HCOEF REACTING INERTIA CONDX GASPAK PRINTI ROTATION
  F      F      F      T      F      F      T
BUOYANCY HRATE INVAL MSORCE MOVBND TPA VARGEO TVM
  F      F      F      F      F      F      F
SHEAR PRNTIN PRNTADD LAMINAR TRANSQ
  F      F      F      T      F
PRESS INSUC VARROT
  F      F      F
NORMAL SIMUL SECONDL
  F      T      T
NNODES NINT NBR NF
  13    11    12    1
RELAXK RELAXD RELAXH CC NITER
  1.000  0.500  1.000  0.100E-03  500
NFLUID(I), I= 1,NF
  11
NODE INDEX
  1      2
  2      1
  3      1
  4      1
  5      1
  6      1
  7      1
  8      1
  9      1
 10     1
 11     1
 12     1
 13     2
NODE PRES (PSI) TEMP(DEGF) MASS SOURC HEAT SOURC THRST AREA
  1  0.9000E+02  0.8000E+02  0.0000E+00  0.0000E+00  0.0000E+00
  2  0.8500E+02  0.8000E+02  0.0000E+00  0.0000E+00  0.0000E+00

```

3	0.1000E+03	0.8000E+02	0.0000E+00	0.0000E+00	0.0000E+00		
4	0.1000E+03	0.8000E+02	0.0000E+00	0.0000E+00	0.0000E+00		
5	0.1000E+03	0.8000E+02	0.0000E+00	0.0000E+00	0.0000E+00		
6	0.1000E+03	0.8000E+02	0.0000E+00	0.0000E+00	0.0000E+00		
7	0.1000E+03	0.8000E+02	0.0000E+00	0.0000E+00	0.0000E+00		
8	0.1000E+03	0.8000E+02	0.0000E+00	0.0000E+00	0.0000E+00		
9	0.1000E+03	0.8000E+02	0.0000E+00	0.0000E+00	0.0000E+00		
10	0.1000E+03	0.8000E+02	0.0000E+00	0.0000E+00	0.0000E+00		
11	0.1000E+03	0.8000E+02	0.0000E+00	0.0000E+00	0.0000E+00		
12	0.3500E+02	0.8000E+02	0.0000E+00	0.0000E+00	0.0000E+00		
13	0.3000E+02	0.8000E+02	0.0000E+00	0.0000E+00	0.0000E+00		
INODE	NUMBR	BRANCH 1	BRANCH 2	BRANCH 3	BRANCH 4	BRANCH 5	BRANCH 6
2	2	12	23				
3	2	23	34				
4	2	34	45				
5	2	45	56				
6	2	56	67				
7	2	67	78				
8	2	78	89				
9	2	89	910				
10	2	910	1011				
11	2	1011	1112				
12	2	1112	1213				
BRANCH	UPNODE	DNNODE	OPTION				
12	1	2	2				
23	2	3	2				
34	3	4	2				
45	4	5	2				
56	5	6	2				
67	6	7	2				
78	7	8	2				
89	8	9	2				
910	9	10	2				
1011	10	11	2				
1112	11	12	2				
1213	12	13	2				
BRANCH	OPTION -2:	FLOW COEF, AREA					
12	0.00000	3.14159					
BRANCH	OPTION -2:	FLOW COEF, AREA					
23	0.00000	1.80415					
BRANCH	OPTION -2:	FLOW COEF, AREA					
34	0.00000	3.22181					
BRANCH	OPTION -2:	FLOW COEF, AREA					
45	0.00000	4.67676					
BRANCH	OPTION -2:	FLOW COEF, AREA					
56	0.00000	5.72314					
BRANCH	OPTION -2:	FLOW COEF, AREA					

```

67      0.00000   6.20628
BRANCH OPTION -2: FLOW COEF, AREA
78      0.00000   68.32968
BRANCH OPTION -2: FLOW COEF, AREA
89      0.00000   6.20628
BRANCH OPTION -2: FLOW COEF, AREA
910     0.00000   5.72314
BRANCH OPTION -2: FLOW COEF, AREA
1011    0.00000   4.67676
BRANCH OPTION -2: FLOW COEF, AREA
1112    0.00000   3.46056
BRANCH OPTION -2: FLOW COEF, AREA
1213    0.02189   6.22999
BRANCH    NOUBR    NMUBR
  12      0
  23      1      12
  34      1      23
  45      1      34
  56      1      45
  67      1      56
  78      1      67
  89      1      78
  910     1      89
 1011    1      910
 1112    1      1011
 1213    1      1112
BRANCH    NODBR    NMDBR
  12      1      23
  23      1      34
  34      1      45
  45      1      56
  56      1      67
  67      1      78
  78      1      89
  89      1      910
  910     1      1011
 1011    1      1112
 1112    1      1213
 1213    0
BRANCH
  12
UPSTRM BR.    ANGLE
DNSTRM BR.    ANGLE
  23      90.00
BRANCH
  23
UPSTRM BR.    ANGLE

```

12	90.00
DNSTRM BR.	ANGLE
34	0.00
BRANCH	
34	
UPSTRM BR.	ANGLE
23	0.00
DNSTRM BR.	ANGLE
45	0.00
BRANCH	
45	
UPSTRM BR.	ANGLE
34	0.00
DNSTRM BR.	ANGLE
56	0.00
BRANCH	
56	
UPSTRM BR.	ANGLE
45	0.00
DNSTRM BR.	ANGLE
67	0.00
BRANCH	
67	
UPSTRM BR.	ANGLE
56	0.00
DNSTRM BR.	ANGLE
78	90.00
BRANCH	
78	
UPSTRM BR.	ANGLE
67	90.00
DNSTRM BR.	ANGLE
89	90.00
BRANCH	
89	
UPSTRM BR.	ANGLE
78	90.00
DNSTRM BR.	ANGLE
910	0.00
BRANCH	
910	
UPSTRM BR.	ANGLE
89	0.00
DNSTRM BR.	ANGLE
1011	0.00
BRANCH	
1011	

```

UPSTRM BR.    ANGLE
      910      0.00
DNSTRM BR.    ANGLE
      1112      0.00
BRANCH
      1112
UPSTRM BR.    ANGLE
      1011      0.00
DNSTRM BR.    ANGLE
      1213      90.00
BRANCH
      1213
UPSTRM BR.    ANGLE
      1112      90.00
DNSTRM BR.    ANGLE
NUMBER OF BRANCHES WITH INERTIA
      12
      12
      23
      34
      45
      56
      67
      78
      89
      910
     1011
     1112
     1213
NUMBER OF ROTATING BRANCHES
      9
BRANCH   UPST RAD    DNST RAD      RPM        K ROT
      23  0.125000E+01  0.225000E+01  0.500000E+04  0.867100E+00
      34  0.225000E+01  0.362500E+01  0.500000E+04  0.815800E+00
      45  0.362500E+01  0.468750E+01  0.500000E+04  0.763000E+00
      56  0.468750E+01  0.537500E+01  0.500000E+04  0.725200E+00
      67  0.537500E+01  0.550000E+01  0.500000E+04  0.707600E+00
      89  0.550000E+01  0.537500E+01  0.500000E+04  0.712900E+00
      910 0.537500E+01  0.468750E+01  0.500000E+04  0.734900E+00
     1011 0.468750E+01  0.362500E+01  0.500000E+04  0.782400E+00
     1112 0.362500E+01  0.265000E+01  0.500000E+04  0.837600E+00
NODE DATA FILE
FNODE.DAT
BRANCH DATA FILE
FBRANCH.DAT

```

```
*****
 G F S S P (Version 3.0)
 Generalized Fluid System Simulation Program
 September, 1999
 Developed by Sverdrup Technology
 Copyright (C) by Marshall Space Flight Center
```

A generalized computer program to calculate flow
rates, pressures, temperatures and concentrations
in a flow network.

```
*****
TITLE      :EXAMPLE6 - RADIAL FLOW ON A ROTATING DISK
ANALYST    :Paul Schallhorn
FILEIN     :EX6.DAT
FILEOUT    :EX6.OUT
LOGICAL VARIABLES
DENCON     =   F
GRAVITY    =   F
ENERGY     =   T
MIXTURE    =   F
THRUST     =   F
STEADY     =   T
TRANSV     =   F
SAVER      =   F
HEX         =   F
HCOEF       =   F
REACTING    =   F
INERTIA    =   T
CONDX      =   F
TWOD        =   F
PRINTI     =   F
ROTATION    =   T
BUOYANCY   =   F
HRATE      =   F
INVAL      =   F
MSOURCE    =   F
MOVBND    =   F
TPA         =   F
VARGEO     =   F
TVM         =   F
SHEAR      =   F
PRNTIN     =   T
PRNTADD    =   F
GASPAK     =   F
```

PRESS = F
INSUC = F
VARROT = F
NORMAL = F
SECONDL = T

NNODES = 13
NINT = 11
NBR = 12
NF = 1
NVAR = 23
NHREF = 2

FLUIDS: H2O

BOUNDARY NODES

NODE	P (PSI)	T (F)	RHO (LBM/FT^3)	AREA (IN^2)
1	0.9000E+02	0.8000E+02	0.6224E+02	0.0000E+00
13	0.3000E+02	0.8000E+02	0.6223E+02	0.0000E+00

INPUT SPECIFICATIONS FOR INTERNAL NODES

NODE	AREA (IN^2)	MASS (LBM/S)	HEAT (BTU/LBM)
2	0.0000E+00	0.0000E+00	0.0000E+00
3	0.0000E+00	0.0000E+00	0.0000E+00
4	0.0000E+00	0.0000E+00	0.0000E+00
5	0.0000E+00	0.0000E+00	0.0000E+00
6	0.0000E+00	0.0000E+00	0.0000E+00
7	0.0000E+00	0.0000E+00	0.0000E+00
8	0.0000E+00	0.0000E+00	0.0000E+00
9	0.0000E+00	0.0000E+00	0.0000E+00
10	0.0000E+00	0.0000E+00	0.0000E+00
11	0.0000E+00	0.0000E+00	0.0000E+00
12	0.0000E+00	0.0000E+00	0.0000E+00

BRANCH	UPNODE	DNNODE	OPTION
12	1	2	2
23	2	3	2
34	3	4	2
45	4	5	2
56	5	6	2
67	6	7	2
78	7	8	2
89	8	9	2
910	9	10	2

1011	10	11	2
1112	11	12	2
1213	12	13	2
BRANCH OPTION -2: FLOW COEF, AREA			
12	0.00000	3.14159	
BRANCH OPTION -2: FLOW COEF, AREA			
23	0.00000	1.80415	
BRANCH OPTION -2: FLOW COEF, AREA			
34	0.00000	3.22181	
BRANCH OPTION -2: FLOW COEF, AREA			
45	0.00000	4.67676	
BRANCH OPTION -2: FLOW COEF, AREA			
56	0.00000	5.72314	
BRANCH OPTION -2: FLOW COEF, AREA			
67	0.00000	6.20628	
BRANCH OPTION -2: FLOW COEF, AREA			
78	0.00000	68.32968	
BRANCH OPTION -2: FLOW COEF, AREA			
89	0.00000	6.20628	
BRANCH OPTION -2: FLOW COEF, AREA			
910	0.00000	5.72314	
BRANCH OPTION -2: FLOW COEF, AREA			
1011	0.00000	4.67676	
BRANCH OPTION -2: FLOW COEF, AREA			
1112	0.00000	3.46056	
BRANCH OPTION -2: FLOW COEF, AREA			
1213	0.02189	6.22999	

SOLUTION

INTERNAL NODES

NODE	P(PSI)	TF(F)	Z	RHO (LBM/FT^3)	EM(LBM)	QUALITY
2	0.9000E+02	0.8000E+02	0.4500E-02	0.6224E+02	0.0000E+00	0.0000E+00
3	0.1237E+03	0.8001E+02	0.6182E-02	0.6224E+02	0.0000E+00	0.0000E+00
4	0.1924E+03	0.8002E+02	0.9617E-02	0.6226E+02	0.0000E+00	0.0000E+00
5	0.2582E+03	0.8004E+02	0.1290E-01	0.6227E+02	0.0000E+00	0.0000E+00
6	0.3047E+03	0.8005E+02	0.1522E-01	0.6228E+02	0.0000E+00	0.0000E+00
7	0.3134E+03	0.8005E+02	0.1566E-01	0.6228E+02	0.0000E+00	0.0000E+00
8	0.3134E+03	0.8005E+02	0.1566E-01	0.6228E+02	0.0000E+00	0.0000E+00
9	0.3046E+03	0.8005E+02	0.1522E-01	0.6228E+02	0.0000E+00	0.0000E+00
10	0.2568E+03	0.8004E+02	0.1283E-01	0.6227E+02	0.0000E+00	0.0000E+00
11	0.1876E+03	0.8002E+02	0.9379E-02	0.6225E+02	0.0000E+00	0.0000E+00
12	0.1327E+03	0.8001E+02	0.6636E-02	0.6224E+02	0.0000E+00	0.0000E+00

BRANCHES

BRANCH	KFACTOR (LBF-S^2/(LBM-FT)^2)	DELP (PSI)	FLOW RATE (LBM/SEC)	VELOCITY (FT/SEC)	REYN. NO.	MACH NO.	ENTROPY GEN. BTU/(R-SEC)	LOST WORK LBF-FT/SEC
12	0.000E+00	0.000E+00	0.729E+01	0.537E+01	0.965E+05	0.437E-02	0.000E+00	0.000E+00
23	0.000E+00	-0.337E+02	0.729E+01	0.935E+01	0.127E+06	0.762E-02	0.000E+00	0.000E+00
34	0.000E+00	-0.688E+02	0.729E+01	0.524E+01	0.953E+05	0.426E-02	0.000E+00	0.000E+00
45	0.000E+00	-0.658E+02	0.729E+01	0.361E+01	0.792E+05	0.294E-02	0.000E+00	0.000E+00
56	0.000E+00	-0.465E+02	0.729E+01	0.295E+01	0.716E+05	0.240E-02	0.000E+00	0.000E+00
67	0.000E+00	-0.871E+01	0.729E+01	0.272E+01	0.687E+05	0.221E-02	0.000E+00	0.000E+00
78	0.000E+00	0.000E+00	0.729E+01	0.247E+00	0.207E+05	0.201E-03	0.000E+00	0.000E+00
89	0.000E+00	0.884E+01	0.729E+01	0.272E+01	0.687E+05	0.221E-02	0.000E+00	0.000E+00
910	0.000E+00	0.478E+02	0.729E+01	0.295E+01	0.716E+05	0.240E-02	0.000E+00	0.000E+00
1011	0.000E+00	0.692E+02	0.729E+01	0.361E+01	0.792E+05	0.294E-02	0.000E+00	0.000E+00
1112	0.000E+00	0.549E+02	0.729E+01	0.487E+01	0.920E+05	0.397E-02	0.000E+00	0.000E+00
1213	0.278E+03	0.103E+03	0.729E+01	0.271E+01	0.686E+05	0.221E-02	0.413E-02	0.173E+04

***** TOTAL ENTROPY GENERATION = 0.413E-02 BTU/(R-SEC) *****

**** TOTAL WORK LOST = 0.315E+01 HP ****

SOLUTION SATISFIED CONVERGENCE CRITERION OF 0.100E-03 IN 5 ITERATIONS
 TAU = 0.100000E+09 ISTEP = 1

APPENDIX L

INPUT AND OUTPUT DATA FILES FROM EXAMPLE 7

Flow in a Long Bearing Squeeze Film Damper

Contents	Page
Example 7 Input File	L-2
Example 7 Output File	L-9

```

GFSSP VERSION
 300
ANALYST
Paul Schallhorn
INPUT DATA FILE NAME
EX7.DAT
OUTPUT FILE NAME
EX7.OUT
TITLE
Example 7 - Long Bearing Squeeze Film Damper
USETUP
  F
DENCON GRAVITY ENERGY MIXTURE THRUST STEADY TRANSV SAVER
  T   F   F     F   F   T   F   F
HEX HCOEF REACTING INERTIA CONDX GASPAK PRINTI ROTATION
  F   F   F     F   F   T   F
BUOYANCY HRATE INVAL MSORCE MOVBND TPA VARGEO TVM
  F   F   F     F   T   F   F
SHEAR PRNTIN PRNTADD LAMINAR TRANSQ
  F   F   F     T   F
PRESS INSUC VARROT
  F   F   F
NORMAL SIMUL SECONDL
  F   T   T
NNODES NINT NBR NF
  20   18   19   0
RELAXK RELAXD RELAXH CC NITER
  1.000   0.500   1.000   0.100E-03   500
RHOREF EMUREF
  57.806   0.005932
NODE INDEX
  1   2
  2   1
  3   1
  4   1
  5   1
  6   1
  7   1
  8   1
  9   1
 10   1
 11   1
 12   1
 13   1
 14   1
 15   1
 16   1

```

```

17      1
18      1
19      1
20      2
NODE  PRES (PSI)  MASS SOURC  HEAT SOURC  THRST AREA
 1  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
 2  0.1000E+02  0.0000E+00  0.0000E+00  0.0000E+00
 3  0.1000E+03  0.0000E+00  0.0000E+00  0.0000E+00
 4  0.1000E+03  0.0000E+00  0.0000E+00  0.0000E+00
 5  0.1000E+03  0.0000E+00  0.0000E+00  0.0000E+00
 6  0.1000E+03  0.0000E+00  0.0000E+00  0.0000E+00
 7  0.1000E+03  0.0000E+00  0.0000E+00  0.0000E+00
 8  0.1000E+03  0.0000E+00  0.0000E+00  0.0000E+00
 9  0.1000E+03  0.0000E+00  0.0000E+00  0.0000E+00
10  0.1000E+03  0.0000E+00  0.0000E+00  0.0000E+00
11  0.1000E+03  0.0000E+00  0.0000E+00  0.0000E+00
12  0.1000E+03  0.0000E+00  0.0000E+00  0.0000E+00
13  0.1000E+03  0.0000E+00  0.0000E+00  0.0000E+00
14  0.1000E+03  0.0000E+00  0.0000E+00  0.0000E+00
15  0.1000E+03  0.0000E+00  0.0000E+00  0.0000E+00
16  0.1000E+03  0.0000E+00  0.0000E+00  0.0000E+00
17  0.1000E+03  0.0000E+00  0.0000E+00  0.0000E+00
18  0.1000E+03  0.0000E+00  0.0000E+00  0.0000E+00
19  0.5263E+01  0.0000E+00  0.0000E+00  0.0000E+00
20  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00
INODE  NUMBR  BRANCH 1  BRANCH 2  BRANCH 3  BRANCH 4  BRANCH 5  BRANCH 6
 2      2          12          23
 3      2          23          34
 4      2          34          45
 5      2          45          56
 6      2          56          67
 7      2          67          78
 8      2          78          89
 9      2          89          910
10     2          910         1011
11     2          1011        1112
12     2          1112        1213
13     2          1213        1314
14     2          1314        1415
15     2          1415        1516
16     2          1516        1617
17     2          1617        1718
18     2          1718        1819
19     2          1819        1920
BRANCH  UPNODE  DNNODE  OPTION
 12      1          2          3
 23      2          3          3

```

34	3	4	3		
45	4	5	3		
56	5	6	3		
67	6	7	3		
78	7	8	3		
89	8	9	3		
910	9	10	3		
1011	10	11	3		
1112	11	12	3		
1213	12	13	3		
1314	13	14	3		
1415	14	15	3		
1516	15	16	3		
1617	16	17	3		
1718	17	18	3		
1819	18	19	3		
1920	19	20	3		
BR OPT -> 3-1, LENGTH, HEIGHT, WIDTH, TYPE, AREA					
12	0.82673	0.01258	0.94000	1.00000	0.01182
BR OPT -> 3-1, LENGTH, HEIGHT, WIDTH, TYPE, AREA					
23	0.82673	0.01799	0.94000	1.00000	0.01691
BR OPT -> 3-1, LENGTH, HEIGHT, WIDTH, TYPE, AREA					
34	0.82673	0.02822	0.94000	1.00000	0.02653
BR OPT -> 3-1, LENGTH, HEIGHT, WIDTH, TYPE, AREA					
45	0.82673	0.04217	0.94000	1.00000	0.03964
BR OPT -> 3-1, LENGTH, HEIGHT, WIDTH, TYPE, AREA					
56	0.82673	0.05832	0.94000	1.00000	0.05482
BR OPT -> 3-1, LENGTH, HEIGHT, WIDTH, TYPE, AREA					
67	0.82673	0.07492	0.94000	1.00000	0.07043
BR OPT -> 3-1, LENGTH, HEIGHT, WIDTH, TYPE, AREA					
78	0.82673	0.09018	0.94000	1.00000	0.08477
BR OPT -> 3-1, LENGTH, HEIGHT, WIDTH, TYPE, AREA					
89	0.82673	0.10244	0.94000	1.00000	0.09629
BR OPT -> 3-1, LENGTH, HEIGHT, WIDTH, TYPE, AREA					
910	0.82673	0.11037	0.94000	1.00000	0.10375
BR OPT -> 3-1, LENGTH, HEIGHT, WIDTH, TYPE, AREA					
1011	0.82673	0.11311	0.94000	1.00000	0.10633
BR OPT -> 3-1, LENGTH, HEIGHT, WIDTH, TYPE, AREA					
1112	0.82673	0.11037	0.94000	1.00000	0.10375
BR OPT -> 3-1, LENGTH, HEIGHT, WIDTH, TYPE, AREA					
1213	0.82673	0.10244	0.94000	1.00000	0.09629
BR OPT -> 3-1, LENGTH, HEIGHT, WIDTH, TYPE, AREA					
1314	0.82673	0.09018	0.94000	1.00000	0.08477
BR OPT -> 3-1, LENGTH, HEIGHT, WIDTH, TYPE, AREA					
1415	0.82673	0.07492	0.94000	1.00000	0.07043
BR OPT -> 3-1, LENGTH, HEIGHT, WIDTH, TYPE, AREA					
1516	0.82673	0.05832	0.94000	1.00000	0.05482

BR OPT -> 3-1, LENGTH, HEIGHT, WIDTH, TYPE, AREA					
1617	0.82673	0.04217	0.94000	1.00000	0.03964
BR OPT -> 3-1, LENGTH, HEIGHT, WIDTH, TYPE, AREA					
1718	0.82673	0.02822	0.94000	1.00000	0.02653
BR OPT -> 3-1, LENGTH, HEIGHT, WIDTH, TYPE, AREA					
1819	0.82673	0.01799	0.94000	1.00000	0.01691
BR OPT -> 3-1, LENGTH, HEIGHT, WIDTH, TYPE, AREA					
1920	0.82673	0.01258	0.94000	1.00000	0.01182
BRANCH	NOUBR	NMUBR			
12		0			
23		1	12		
34		1	23		
45		1	34		
56		1	45		
67		1	56		
78		1	67		
89		1	78		
910		1	89		
1011		1	910		
1112		1	1011		
1213		1	1112		
1314		1	1213		
1415		1	1314		
1516		1	1415		
1617		1	1516		
1718		1	1617		
1819		1	1718		
1920		1	1819		
BRANCH	NODBR	NMDBR			
12		1	23		
23		1	34		
34		1	45		
45		1	56		
56		1	67		
67		1	78		
78		1	89		
89		1	910		
910		1	1011		
1011		1	1112		
1112		1	1213		
1213		1	1314		
1314		1	1415		
1415		1	1516		
1516		1	1617		
1617		1	1718		
1718		1	1819		
1819		1	1920		

1920	0
BRANCH	
12	
UPSTRM BR.	ANGLE
DNSTRM BR.	ANGLE
23	0.00
BRANCH	
23	
UPSTRM BR.	ANGLE
12	0.00
DNSTRM BR.	ANGLE
34	0.00
BRANCH	
34	
UPSTRM BR.	ANGLE
23	0.00
DNSTRM BR.	ANGLE
45	0.00
BRANCH	
45	
UPSTRM BR.	ANGLE
34	0.00
DNSTRM BR.	ANGLE
56	0.00
BRANCH	
56	
UPSTRM BR.	ANGLE
45	0.00
DNSTRM BR.	ANGLE
67	0.00
BRANCH	
67	
UPSTRM BR.	ANGLE
56	0.00
DNSTRM BR.	ANGLE
78	0.00
BRANCH	
78	
UPSTRM BR.	ANGLE
67	0.00
DNSTRM BR.	ANGLE
89	0.00
BRANCH	
89	
UPSTRM BR.	ANGLE
78	0.00
DNSTRM BR.	ANGLE

	910	0.00
BRANCH	910	
UPSTRM BR.	ANGLE	
89	0.00	
DNSTRM BR.	ANGLE	
1011	0.00	
BRANCH	1011	
UPSTRM BR.	ANGLE	
910	0.00	
DNSTRM BR.	ANGLE	
1112	0.00	
BRANCH	1112	
UPSTRM BR.	ANGLE	
1011	0.00	
DNSTRM BR.	ANGLE	
1213	0.00	
BRANCH	1213	
UPSTRM BR.	ANGLE	
1112	0.00	
DNSTRM BR.	ANGLE	
1314	0.00	
BRANCH	1314	
UPSTRM BR.	ANGLE	
1213	0.00	
DNSTRM BR.	ANGLE	
1415	0.00	
BRANCH	1415	
UPSTRM BR.	ANGLE	
1314	0.00	
DNSTRM BR.	ANGLE	
1516	0.00	
BRANCH	1516	
UPSTRM BR.	ANGLE	
1415	0.00	
DNSTRM BR.	ANGLE	
1617	0.00	
BRANCH	1617	
UPSTRM BR.	ANGLE	
1516	0.00	

```

DNSTRM BR.    ANGLE
  1718      0.00
BRANCH
  1718
UPSTRM BR.    ANGLE
  1617      0.00
DNSTRM BR.    ANGLE
  1819      0.00
BRANCH
  1819
UPSTRM BR.    ANGLE
  1718      0.00
DNSTRM BR.    ANGLE
  1920      0.00
BRANCH
  1920
UPSTRM BR.    ANGLE
  1819      0.00
DNSTRM BR.    ANGLE
NUMBER OF NODES WITH MOVING BOUNDARY
  18
NODE AREAN VBOUND
  2 0.777126E+00  0.256180E+00
  3 0.777126E+00  0.484598E+00
  4 0.777126E+00  0.660503E+00
  5 0.777126E+00  0.764832E+00
  6 0.777126E+00  0.786280E+00
  7 0.777126E+00  0.722522E+00
  8 0.777126E+00  0.580468E+00
  9 0.777126E+00  0.375510E+00
 10 0.777126E+00  0.129861E+00
 11 0.777126E+00 -0.129861E+00
 12 0.777126E+00 -0.375510E+00
 13 0.777126E+00 -0.580468E+00
 14 0.777126E+00 -0.722522E+00
 15 0.777126E+00 -0.786280E+00
 16 0.777126E+00 -0.764832E+00
 17 0.777126E+00 -0.660503E+00
 18 0.777126E+00 -0.484598E+00
 19 0.777126E+00 -0.256180E+00
NODE DATA FILE
FNODE.DAT
BRANCH DATA FILE
FBRANCH.DAT

```

```
*****
 G F S S P (Version 3.0)
 Generalized Fluid System Simulation Program
 September, 1999
 Developed by Sverdrup Technology
 Copyright (C) by Marshall Space Flight Center
```

A generalized computer program to calculate flow
rates, pressures, temperatures and concentrations
in a flow network.

```
*****
TITLE      :Example 7 - Long Bearing Squeeze Film Damper
ANALYST    :Paul Schallhorn
FILEIN     :EX7.DAT
FILEOUT    :EX7.OUT
LOGICAL VARIABLES
DENCON     =   T
GRAVITY    =   F
ENERGY     =   F
MIXTURE    =   F
THRUST     =   F
STEADY     =   T
TRANSV     =   F
SAVER      =   F
HEX         =   F
HCOEF       =   F
REACTING    =   F
INERTIA    =   F
CONDX      =   F
TWOD        =   F
PRINTI     =   T
ROTATION    =   F
BUOYANCY   =   F
HRATE      =   F
INVAL      =   F
MSOURCE    =   F
MOVBNDF   =   T
TPA         =   F
VARGEO     =   F
TVM         =   F
SHEAR      =   F
PRNTIN     =   F
PRNTADD    =   F
GASPAK     =   F
```

```

PRESS      =   F
INSUC     =   F
VARROT    =   F
NORMAL    =   F
SECONDL   =   T

NNODES    =    20
NINT      =    18
NBR       =    19
NF        =     0
NVAR      =    37
NHREF     =     2

RHOREF    =    57.8060 LBM/FT**3
EMUREF    =   0.5932E-02 LBM/FT-SEC

```

BOUNDARY NODES

NODE	P (PSI)	AREA (IN^2)
1	0.0000E+00	0.0000E+00
20	0.0000E+00	0.0000E+00

SOLUTION

INTERNAL NODES

NODE	P(PSI)	EM(LBM)
2	0.1365E+02	0.0000E+00
3	0.1273E+02	0.0000E+00
4	0.9717E+01	0.0000E+00
5	0.7660E+01	0.0000E+00
6	0.5812E+01	0.0000E+00
7	0.4250E+01	0.0000E+00
8	0.2901E+01	0.0000E+00
9	0.1690E+01	0.0000E+00
10	0.5550E+00	0.0000E+00
11	-0.5550E+00	0.0000E+00
12	-0.1690E+01	0.0000E+00
13	-0.2901E+01	0.0000E+00
14	-0.4250E+01	0.0000E+00
15	-0.5812E+01	0.0000E+00
16	-0.7660E+01	0.0000E+00
17	-0.9717E+01	0.0000E+00
18	-0.1273E+02	0.0000E+00
19	-0.1365E+02	0.0000E+00

BRANCHES

BRANCH	KFACTOR (LBF-S^2/(LBM-FT)^2)	DELP (PSI)	FLOW RATE (LBM/SEC)	VELOCITY (FT/SEC)	REYN. NO.	MACH NO.	ENTROPY GEN. BTU/(R-SEC)	LOST WORK LBF-FT/SEC
12	0.441E+06	-0.137E+02	-0.667E-01	-0.141E+02	0.140E+04	0.000E+00	0.635E-05	0.227E+01
23	0.767E+06	0.925E+00	0.132E-01	0.194E+01	0.231E+03	0.000E+00	0.849E-07	0.304E-01
34	0.161E+05	0.301E+01	0.164E+00	0.154E+02	0.230E+04	0.000E+00	0.345E-05	0.123E+01
45	0.216E+04	0.206E+01	0.370E+00	0.233E+02	0.425E+04	0.000E+00	0.531E-05	0.190E+01
56	0.718E+03	0.185E+01	0.609E+00	0.277E+02	0.594E+04	0.000E+00	0.784E-05	0.280E+01
67	0.308E+03	0.156E+01	0.854E+00	0.302E+02	0.735E+04	0.000E+00	0.929E-05	0.332E+01
78	0.167E+03	0.135E+01	0.108E+01	0.317E+02	0.846E+04	0.000E+00	0.101E-04	0.363E+01
89	0.110E+03	0.121E+01	0.126E+01	0.326E+02	0.927E+04	0.000E+00	0.106E-04	0.380E+01
910	0.861E+02	0.113E+01	0.138E+01	0.331E+02	0.976E+04	0.000E+00	0.109E-04	0.389E+01
1011	0.795E+02	0.111E+01	0.142E+01	0.332E+02	0.993E+04	0.000E+00	0.110E-04	0.392E+01
1112	0.861E+02	0.113E+01	0.138E+01	0.331E+02	0.976E+04	0.000E+00	0.109E-04	0.389E+01
1213	0.110E+03	0.121E+01	0.126E+01	0.326E+02	0.927E+04	0.000E+00	0.106E-04	0.380E+01
1314	0.167E+03	0.135E+01	0.108E+01	0.317E+02	0.846E+04	0.000E+00	0.101E-04	0.363E+01
1415	0.308E+03	0.156E+01	0.854E+00	0.302E+02	0.735E+04	0.000E+00	0.929E-05	0.332E+01
1516	0.718E+03	0.185E+01	0.609E+00	0.277E+02	0.594E+04	0.000E+00	0.784E-05	0.280E+01
1617	0.216E+04	0.206E+01	0.370E+00	0.233E+02	0.425E+04	0.000E+00	0.531E-05	0.190E+01
1718	0.161E+05	0.301E+01	0.164E+00	0.154E+02	0.230E+04	0.000E+00	0.345E-05	0.123E+01
1819	0.767E+06	0.925E+00	0.132E-01	0.194E+01	0.231E+03	0.000E+00	0.849E-07	0.304E-01
1920	0.441E+06	-0.137E+02	-0.667E-01	-0.141E+02	0.140E+04	0.000E+00	0.635E-05	0.227E+01

***** TOTAL ENTROPY GENERATION = 0.139E-03 BTU/(R-SEC) *****

**** TOTAL WORK LOST = 0.904E-01 HP ****

SOLUTION SATISFIED CONVERGENCE CRITERION OF 0.100E-03 IN 20 ITERATIONS
 TAU = 0.100000E+09 ISTEP = 1

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APPENDIX M

INPUT AND OUTPUT DATA FILES FROM EXAMPLE 8

Simulation of the Blow Down of a Pressurized Tank

Contents	Page
Example 8 Input File	M-2
Example 8 User Subroutine	M-4
Example 8 Output File (Partial)	M-77

```

GFSSP VERSION
300
ANALYST
Alok Majumdar
INPUT DATA FILE NAME
EX8.DAT
OUTPUT FILE NAME
EX8.OUT
TITLE
Simulation of the Blow Down of a Pressurized Tank
USETUP
F
DENCON GRAVITY ENERGY MIXTURE THRUST STEADY TRANSV SAVER
  F   F     T     F   F     T     F
HEX HCOEF REACTING INERTIA CONDX GASPAK PRINTI ROTATION
  F   F     F     F   F     T     T     F
BUOYANCY HRATE INVAL MSOURCE MOVBND TPA VARGEO TVM
  F   F     F     F   F     F     F
SHEAR PRNTIN PRNTADD LAMINAR TRANSQ
  F   F     F     T     F
PRESS INSUC VARROT
  F   F     F
NORMAL SIMUL SECONDL
  F     T     T
NNODES NINT NBR NF
  2     1     1     1
RELAXK RELAXD RELAXH CC NITER
  1.000  0.500  1.000  0.100E-03  500
DTAU TIMEF TIMEL NPSTEP
  0.1000E+01  0.0000E+00  0.2000E+03      25
NFLUID(I), I= 1,NF
  33
RREF CPREF GAMREF EMUREF AKREF
  53.33  0.24  1.4  1.26E-05  4.133E-06
NODE INDEX
  1     1
  2     2
NODE PRES (PSI) TEMP(DEGF) MASS SOURC HEAT SOURC THRST AREA
  1  0.1000E+03  0.8000E+02  0.0000E+00  0.0000E+00  0.0000E+00  0.1728E+05
  hist2.dat
INODE NUMBR BRANCH 1 BRANCH 2 BRANCH 3 BRANCH 4 BRANCH 5 BRANCH 6

```

```
      1      1      12
BRANCH    UPNODE     DNNODE     OPTION
      12      1      2      2
BRANCH OPTION -2: FLOW COEF, AREA
      12   1.00000   0.00785
INITIAL FLOWRATES IN BRANCHES FOR UNSTEADY FLOW
      12   0.01770
BRANCH    NOUBR     NMUBR
      12      0
BRANCH    NODBR     NMDBR
      12      0
BRANCH
      12
UPSTRM BR.     ANGLE
DNSTRM BR.     ANGLE
NODE DATA FILE
FNODE.DAT
BRANCH DATA FILE
FBRANCH.DAT
```

```

C*****
C
C      ***** GFSSP USER SUBROUTINES *****
C
C*****
C
C      SUBROUTINE USRINT IS CALLED FROM INIT TO SPECIFY INITIAL VALUES COMPUTED
C          BY USER SPECIFIED THERMODYNAMIC PROPERTY PACKAGE
C
C      SUBROUTINE SORCEM(IPN,TERMU) IS CALLED FROM EQNS FOR MASS SOURCES.
C          IN THIS ROUTINE THE USER DEFINES ANY ADDITIONAL MASS
C          SOURCES TO THE MODEL (MASS SOURCES ARE IN LBM/SEC).  USER
C          CAN MODIFY TRANSIENT TERM BY REDEFINING THE ARGUMENT TERMU.
C      SUBROUTINE SORCEF(I,TERM0,TERM1,TERM2,TERM3,TERM4,TERM5,TERM6,TERM7,
C          TERM8,TERM9,TERM10,TERM100) IS CALLED FROM EQNS FOR
C          MOMENTUM SOURCES.  USER CAN MODIFY INDIVIDUAL TERMS OR
C          DEFINE ADDITIONAL MOMENTUM SOURCES THROUGH TERM100.
C
C      SUBROUTINE SORCEQ IS CALLED FROM EITHER THE ENERGY ROUTINE (EITHER
C          ENTHALPY OR ENTROPY).  IN THIS ROUTINE THE USER DEFINES
C          ANY ADDITIONAL HEAT SOURCES TO THE MODEL (HEAT SOURCES
C          ARE IN BTU/SEC)
C
C      SUBROUTINE SORCEC IS CALLED FROM THE SPECIES CONCENTRATION ROUTINE
C          IN THIS ROUTINE THE USER DEFINES ANY ADDITIONAL SPECIES
C          CONCENTRATION SOURCES TO THE MODEL (CONCENTRATION SOURCES
C          ARE IN MASS FRACTIONS SUCH THAT THE SUM OF ALL OF THE
C          CONCENTRATIONS EQUALS 1.0)
C
C      SUBROUTINE KFUSER IS CALLED FROM THE RESIST ROUTINE.  IN THIS ROUTINE
C          THE USER DEFINES ANY VARIATION OF THE K-FACTOR OF A BRANCH
C          SUCH THAT THE K-FACTOR IS DEFINED AS THE PRESSURE DROP
C          DIVIDED BY THE MASS FLOW RATE^2 (PRESSURE IS IN PSF, FLOW
C          RATE IS IN LBM/SEC; I.E. THE K-FACTOR IS IN PSF-SEC^2/
C          (LBM-FT)^2)
C
C      SUBROUTINE PRPUSER IS CALLED FROM THE DENSITY ROUTINE.  IN THIS
C          ROUTINE THE USER ADDS OR MODIFIES FLUID PROPERTIES (ALLOWS
C          FOR USER SPECIFIED FLUID)
C
C      SUBROUTINE TSTEP IS CALLED FROM THE MAIN ROUTINE.  IN THIS ROUTINE

```

```

C           THE USER CAN MODIFY THE Timestep, DTAU, FOR AN UNSTEADY
C           MODEL (DTAU IS IN SECONDS)
C
C           SUBROUTINE BNDUSER IS CALLED FROM THE BOUND ROUTINE.  IN THIS ROUTINE
C           THE USER CAN MODIFY BOUNDARY CONDITIONS AND GEOMETRY AT
C           EACH Timestep FOR AN UNSTEADY MODEL (PRESSURE IS IN PSF,
C           TEMPERATURE IS IN DEG. R, LENGTH {ETC.} IS IN FT, AREA IS
C           IN FT^2, VOLUME IS IN FT^3)
C
C           SUBROUTINE PRNUSER IS CALLED FROM THE PRINT ROUTINE.  IN THIS ROUTINE
C           THE USER CAN MODIFY ADD ADDITIONAL OUTPUT FILES SPECIFIC
C           TO A PARTICULAR MODEL
C
C           SUBROUTINE FILNUM IS CALLED FROM THE MAIN ROUTINE.  IN THIS ROUTINE
C           ESTABLISHES THE FILE NUMBERS THAT ARE TO BE OPENED FOR ALL
C           FILES IN GFSSP, AND INCLUDES 10 USER FILE NUMBERS FOR USE
C           IN THE PRNUSER SUBROUTINE
C
C           SUBROUTINE USRSET IS CALLED FROM THE READIN ROUTINE.  IN THIS ROUTINE
C           THE USER SETS UP THE MAJORITY OF THE MODEL; ONLY A DUMMY
C           SEGMENT OF AN INPUT FILE IS NECESSARY TO BE READ, WITH THE
C           REMAINDER OF THE MODEL SETUP IN THIS SUBROUTINE.
C
C
C*****SUBROUTINE FILENUM
C      PURPOSE: ESTABLISH THE FORTRAN FILE NUMBERS FOR READING &
C              WRITING OF INFORMATION
C*****
C      INCLUDE 'COMBLK.FOR'
C*****
C      FILES ALREADY WITHIN GFSSP
C
C      NWRTE = FILE # CORRESPONDING TO THE WRITEIN SUBROUTINE
C              (WRITING INPUT DECK FROM COMMAND LINE PREPROCESSOR)
C      NPRNT = FILE # CORRESPONDING TO THE PRINT SUBROUTINE
C              (WRITING THE MAIN OUTPUT FILE)
C      NREAD = FILE # CORRESPONDING TO THE READIN SUBROUTINE
C              (READING IN THE INPUT DECK)
C      NGSPK = FILE # CORRESPONDING TO A NON-GASP PROPERTY PACKAGE

```

```

C      NFNOD = FILE # CORRESPONDING TO THE FNODE RESTART FILE
C      NGFSOUT = FILE # CORRESPONDING TO THE GFSSP.OUT FILE
C          (DEBUGGING FILE)
C      NFBR = FILE # CORRESPONDING TO THE FBRANCH RESTART FILE
C      NGASP = FILE # CORRESPONDING TO THE GASP.OUT FILE
C          (DEBUGGING FILE)
C      NHSTN = FILE # CORRESPONDING TO THE HISTN.XLS FILE
C      NHSTB = FILE # CORRESPONDING TO THE HISTBR.XLS FILE
C      NHSTF = FILE # CORRESPONDING TO B.C. & VARGEO HISTORY FILES
C      NCVHST = FILE # CORRESPONDING TO THE CONTROL VALVE HISTORY FILE
C      NCVCHR1 = FILE # CORRESPONDING TO THE FIRST OF TWO CONTROL
C          VALVE FILES
C      NCVCHR2 = FILE # CORRESPONDING TO THE SECOND OF TWO CONTROL
C          VALVE FILES
C      NHSTROT = FILE # CORRESPONDING TO THE VARIABLE ROTATION
C          HISTORY FILE
C      NERROR = FILE # CORRESPONDING TO THE ERROR.XLS FILE
C      NRP1DAT = FILE # CORRESPONDING TO THE RP1 PROPERTY DATA FILES
C

      NGSPK=1
      NPRNT=10
      NFNOD=11
      NGFSOUT=12
      NFBR=13
      NREAD=15
      NGASP=17
      NHSTN=18
      NHSTB=19
      NWRTE=20
      NHSTF=21
      NCVHST=28
      NCVCHR1=29
      NCVCHR2=30
      NHSTROT=35
      NERROR=55
      NRP1DAT=51

C      FILE NUMBERS FOR USER DEFINED FILES (THESE FILES CAN BE USED
C      IN ANY OF THE USER SUBROUTINES; HOWEVER, MOST LIKELY USE IS
C      IN THE PRNUSEN SUBROUTINE).  COMMENT OUT FILE NUMBERS NOT IN USE.
C

      NUSR1= 14

```

```

C      NUSR2=
C      NUSR3=
C      NUSR4=
C      NUSR5=
C      NUSR6=
C      NUSR7=
C      NUSR8=
C      NUSR9=
C      NUSR10=

      RETURN
      END
*****
      SUBROUTINE USRINT
C      PURPOSE: TO SUPPLY INITIAL AND BOUNDARY VALUES USING AN USER SPECIFIED
C              THERMODYNAMIC PROPERTY PACKAGE
*****
      INCLUDE 'COMBLK.FOR'

      ADD CODE HERE
      IF (ADDPROP) THEN
          CALL INITGP
      ENDIF
      RETURN
      END

*****
      SUBROUTINE SORCEM(IPN,TERMU)
C      PURPOSE: ADD MASS SOURCES
C      IPN - GFSSP INDEX NUMBER FOR NODE
C      TERMU - UNSTEADY TERM IN MASS CONSERVATION EQUATION
*****
      INCLUDE 'COMBLK.FOR'

      ADD CODE HERE
      RETURN
      END

*****
      SUBROUTINE SORCEF(I,TERMO,TERM1,TERM2,TERM3,TERM4,TERM5,TERM6,
&                  TERM7,TERM8,TERM9,TERM10,TERM100)
C      PURPOSE: ADD MOMENTUM SOURCES (LBF)
C      I - GFSSP INDEX NUMBER FOR BRANCH

```

```

C      TERM0 - UNSTEADY TERM IN MOMENTUM CONSERVATION EQUATION
C      TERM1 - LONGITUDINAL INERTIA
C      TERM2 - PRESSURE GRADIENT
C      TERM3 - GRAVITY FORCE
C      TERM4 - FRICTION FORCE
C      TERM5 - CENTRIFUGAL FORCE
C      TERM6 - EXTERNAL MOMETUM SOURCE DUE TO PUMP
C      TERM7 - MOMENTUM SOURCE DUE TO TRANSVERSE FLOW(MULTI-DIMENSIONAL MODEL)
C      TERM8 - MOMENTUM SOURCE DUE TO SHEAR(MULTI-DIMENSIONAL MODEL)
C      TERM9 - VARIABLE GEOMETRY UNSTEADY TERM
C      TERM10 - NORMAL STRESS
C      TERM100 - USER SUPPLIED MOMENTUM SOURCE
C*****
C      INCLUDE 'COMBLK.FOR'
C*****
C      ADD CODE HERE
C      RETURN
C      END
C*****
C      SUBROUTINE SORCEQ(IPN,TERMD)
C      PURPOSE: ADD HEAT SOURCES
C      IPN - GFSSP INDEX NUMBER FOR NODE
C      TERMD - COMPONENT OF LINEARIZED SOURCE TERM APPEARING IN THE
C              DENOMINATOR OF THE ENTHALPY OR ENTROPY EQUATION
C*****
C      INCLUDE 'COMBLK.FOR'
C*****
C      ADD CODE HERE
C      LOGICAL ISOTHRM
C      ISOTHRM = .FALSE.
C      IF (ISOTHRM) THEN
C          HC = 1.E10
C          HAREA = 1.
C          TWALL = 540.

C      SPECIFY NODE TO INCLUDE HEAT TRANSFER
C      NODE1 = 1
C      DO II = 1, NNODS
C          IF (NODE1 .EQ. NODE(II)) IP = II
C      ENDDO
C      IF (IPN .EQ. IP) THEN

```

```

        SORCEH( IP ) = HC*HAREA*TWALL
        TERMD=HC*HAREA/CPREF
    ENDIF
ENDIF ! IF (ISOTHRM) ..
RETURN
END
C*****
SUBROUTINE SORCEC
C   PURPOSE: ADD CONCENTRATION SOURCES
C*****
INCLUDE 'COMBLK.FOR'
C*****
C   ADD CODE HERE
RETURN
END
C*****
SUBROUTINE KFUSER(AKNEW)
C   PURPOSE: ADD A NEW RESISTANCE OPTION
C*****
INCLUDE 'COMBLK.FOR'
C*****
C   ADD CODE HERE
RETURN
END

C*****
SUBROUTINE PRPUSER
C   PURPOSE: ADD NEW FLUID PROPERTY
C*****
INCLUDE 'COMBLK.FOR'
C*****
C   ADD CODE HERE
CALL DENSTGP
RETURN
END

C*****
SUBROUTINE TSTEP
C   PURPOSE: MODIFY TIME STEP
C*****
INCLUDE 'COMBLK.FOR'

```

```

C*****
C      ADD CODE HERE
C      RETURN
C      END

C*****
SUBROUTINE BNDUSER
C      PURPOSE: MODIFY BOUNDARY CONDITIONS
C*****
INCLUDE 'COMBLK.FOR'
C*****
C      ADD CODE HERE
C      IF (ADDPROP) THEN

      CALL BOUNDGP

ENDIF

RETURN
END

C*****
SUBROUTINE PRNUSER
C      PURPOSE: ADD NEW OUTPUT
C*****
INCLUDE 'COMBLK.FOR'
C*****
C      ADD CODE HERE
C

C      GENERATE EXCEL FILE FOR PLOT
IF (MOD(ISTEP,NPSTEP).NE.0) RETURN
OPEN (NUSR1,FILE = 'EX82.XLS',STATUS = 'UNKNOWN')
NODE1 = 1
NODE2 = 2
BRNCH1 = 12
C      DETERMINE INDICES OF NODES & BRANCHES
DO II = 1, NNODES
  IF (NODE1 .EQ. NODE(II)) IP1 = II
  IF (NODE2 .EQ. NODE(II)) IP2 = II
ENDDO
DO II = 1, NBR

```

```

IF (BRNCH1 .EQ. IBRANCH(II)) IB1 = II
ENDDO
PRS1 = P(IP1)/144.
PRS2 = P(IP2)/144.
DELP12 = PRS1-PRS2
TEMP1 = TF(IP1)
FLW12 = FLOWR(IB1)
WRITE(NUSR1,1) TAU,PRS1,PRS2,DELP12,TEMP1,FLW12
1 FORMAT(6E15.7)
RETURN
END
C*****
SUBROUTINE USRSET
C PURPOSE: ADD MASS & MOMENTUM SOURCES
C*****
INCLUDE 'COMBLK.FOR'
C*****
C ADD CODE HERE
C
C THIS IS THE DEFAULT CODE FOR THIS BLOCK, COMMENT THIS OUT WHEN
C CREATING A MODEL WITHIN THIS SUBROUTINE
C
      WRITE(*,*) ''
      WRITE(*,*) ' USER ROUTINE USRSET DOES NOT HAVE A MODEL DEVELOPED'
      WRITE(*,*) ''
      WRITE(*,*) ' OPEN THE USER SUBROUTINE FILE AND MODIFY SUBROUTINE'
      WRITE(*,*) ' USRSET TO DEVELOP MODEL OR CHANGE LOGICAL VARIABLE'
      WRITE(*,*) ' USETUP TO FALSE AND DEVELOP MODEL IN INPUT FILE'
      WRITE(*,*) ''
C     STOP
C
C END OF DEFAULT CODE
C
      RETURN
END
C*****
SUBROUTINE DENSTGP
C PURPOSE: CALCULATE DENSITY AND OTHER PROPERTIES FROM ADDPROP
C*****
INCLUDE 'COMBLK.FOR'
C*****

```

```

CHARACTER INPAR1*1, INPAR2*1, COFILE*64, OUTPAR*2, MESSAG*72
DOUBLE PRECISION VALU1, VALU2, PROP(0:31,0:2)
INTEGER IDID, IOUNIT

C
CHARACTER*11 UCONA, UARRAY
DOUBLE PRECISION CONST
LOGICAL BYPASS
DIMENSION CONST(0:21), UCONA(0:21), UARRAY(0:31)
DIMENSION RHOF(50), EMUF(50), CONDF1(50), GAMAF(50), ZF(50)
DIMENSION XVF(50)
DATA RCONST /1545./

C
C      OPEN AN OUTPUT FILE TO WRITE MESSAGES OF GASPAK
OPEN (NGSPK, FILE = 'USER.OUT', STATUS='UNKNOWN')
C      SELECT PRECISON
CALL PRECIS(2)
C      SPECIFY THE FLUID BY NAMING ITS COEFFICIENT FILE
IF(NFLUID(1) .EQ. 12 .OR. NFLUID(1) .EQ. 33) BYPASS=.TRUE.

IF (.NOT. BYPASS) THEN

      CALL SETFLUID(COFILE,NFLUID(1),1)
      CALL READCF(COFILE, IDID)
      IF (IDID .LT. 0) THEN
          CALL GASERR(MESSAG, IDID)
          WRITE(NGSPK,86) MESSAG
          STOP 'COEFFICIENT FILE ERROR IN GASPAK'
      ENDIF
C      SELECT UNIT
      IOUNIT=4
C      SELECT PARAMETERS TO BE CALCULATED
      OUTPAR = '**'
C      FIND FIXED PARAMETERS FOR THAT FLUID
      CALL UNILIB(IOUNIT)
      CALL GASCON(CONST,UCONA)
      WRITE(NGSPK,81) COFILE
      DO J = 1,15
          WRITE(NGSPK,82) J, CONST(J), UCONA(J)
      ENDDO

```

```

ENDIF! (IF (.NOT. BYPASS) . . .)

IF (.NOT. MIXTURE .AND. ENERGY) THEN
C***  

C      FOR PURE FLUID
C***  

C      CALCULATE PROPERTIES AT THE INTERNAL NODE
DIFD=0.  

DO I = 1,NINT
    NUMBER=INODE(I)
C      FIND INDEX FOR INODE(I)
    DO II = 1, NNODES
        IF (NUMBER .EQ. NODE(II)) IP = II
    ENDDO

    IF (.NOT. BYPASS) THEN

        INPAR1 = 'P'
        IF(P(IP).GT. 0) THEN
            VALU1 = P(IP)/144.

        IF (SECONDL) THEN
            INPAR2 = 'S'
            VALU2 = ENTROPY(IP)
            CALL CALC(IDID,PROP,OUTPAR,INPAR1,VALU1,INPAR2,VALU2,
&                      COFILE,IOUNIT)
        ELSE

            INPAR2 = 'H'
            VALU2 = H(IP)
            CALL CALC(IDID,PROP,OUTPAR,INPAR1,VALU1,INPAR2,VALU2,
&                      COFILE,IOUNIT)
        ENDIF

C      WRITE AN ERROR MESSAGE IF THE CALCULATION FAILED
        IF (IDID .LT. 0) THEN
            CALL GASERR(MESSAG, IDID)
            WRITE(NGSPK,86) MESSAG
            STOP 'CALCULATION FAILURE IN GASPAK'
        ENDIF

```

```

RHOOLD=RHO(IP)
RHONEW=PROP(3,0)
DIFD=MAX(DIFD,ABS(RHONEW-RHOOLD)/RHOOLD)
RHO(IP)=(1.-RELAXD)*RHOOLD + RELAXD*RHONEW

TF(IP)=PROP(2,0)

C           XV(IP)=PROP(0,0)
COND(F(IP)=PROP(22,0)
EMUOLD=EMU(IP)
EMU(IP)=PROP(21,0)
IF(EMU(IP).EQ.0.0) EMU(IP)=EMUOLD
GAMA(IP)=PROP(11,0)
RNODE(IP)=CONST(1)*HEQ
ENTROPY(IP)=PROP(4,0)
H(IP)=PROP(5,0)
PR(IP)=PROP(24,0)
CVNODE(IP)=PROP(9,0)
CPNODE(IP)=PROP(10,0)
Z(IP)=P(IP)/(RHO(IP)*RNODE(IP)*TF(IP))
IF ((IDID.EQ.1) .OR. (IDID.EQ.2)) THEN
  IF (Z(IP) .LT. 0.9) THEN
    XV(IP)=0.0
  ELSE
    XV(IP)=1.0
  ENDIF
ENDIF
IF (IDID.EQ.3) XV(IP)=PROP(0,0)
IF (IDID.EQ.4) XV(IP)=0.0
IF (IDID.EQ.5) XV(IP)=1.0
C FOR WATER,R11,R12,R22,R32,R123,R124,R125,R134a,R152a,
C AND AMMONIA VISCOSITY & CONDUCTIVITY ARE COMPUTED FROM
C ASHRAE CORRELATIONS
DO L=1,11
  IF (NFLUID(1) .EQ. NCVFL(L)) THEN
    IF (Z(IP) .LT. 0.5) THEN
      INDX = 1
    ELSE
      INDX = 3
    ENDIF
    TEMP = TF(IP)

```

```

        QUAL=XV(IP)
        NAFL=NFLUID(1)
        CALL CONDCTV(NAFL,INDX,QUAL,TEMP,CONDCT)
        CALL VISCTY(NAFL,INDX,QUAL,TEMP,VISC)
        CONDF(IP) = CONDCT
        EMU(IP) = VISC
    ENDIF
ENDDO
ENDIF ! ( IF P(IP) .GT. 0 )
ENDIF !(IF ( .NOT. BYPASS ))

C      SUPPLY PROPERTIES OF RP1 & IDEAL GAS
C      RP-1
        IF (NFLUID(1) .EQ. 12 ) THEN
            PRS = P(IP)/144.
            TEMP = TF(IP)
C      OBTAIN TEMPERATURE & DENSITY
        CALL RP1(4,1,PRS,TEMP,HIP,RHOIP,CPC,GAMAC,EMUC,AKC,SC,KR,ITER)
        RHOOLD=RHO(IP)
        RHONEW=RHOIP
        DIFD=MAX(DIFD,ABS(RHONEW-RHOOLD)/RHOOLD)
        RHO(IP)=(1.-RELAXD)*RHOOLD + RELAXD*RHONEW
        Z(IP)=P(IP)/(RHO(IP)*RGAS(NFLUID(1))*TF(IP))
        RNODE(IP)=RGAS(NFLUID(1))
        H(IP)=HIP
C      OBTAIN VISCOSITY
        CALL RP1(4,8,PRS,TEMP,HIP,RHOIP,CPC,GAMAC,EMUC,AKC,SC,KR,ITER)
C      OBTAIN GAMA
        CALL RP1(4,4,PRS,TEMP,HIP,RHOIP,CPC,GAMAC,EMUC,AKC,SC,KR,ITER)
C      OBTAIN CONDUCTIVITY
        CALL RP1(4,16,PRS,TEMP,HIP,RHOIP,CPC,GAMAC,EMUC,AKC,SC,KR,ITER)
        EMU(IP)=EMUC
        GAMA(IP)=GAMAC
        CONDF(IP)=AKC
    ENDIF
C      IDEAL GAS
        IF (NFLUID(1) .EQ. 33) THEN
            IF (SECONDL) THEN
                FACT=(ENTROPY(IP)+RREF*LOG(P(IP)/PREF)/HEQ)/CPREF
                TF(IP)=TREF*EXP(FACT)

```

```

ELSE
  TF(IP)=H(IP)/CPREF
ENDIF

RHOOLD=RHO(IP)
RHONEW=P(IP)/(RREF*TF(IP))
DIFD=MAX(DIFD,ABS(RHONEW-RHOOLD)/RHOOLD)
RHO(IP)=(1.-RELAXD)*RHOOLD + RELAXD*RHONEW
Z(IP)=1.0
RNODE(IP)=RREF
GAMA(IP)=GAMREF
EMU(IP)=EMUREF
COND(IP)=AKREF
CPNODE(IP)=CPREF
ENDIF

ENDDO

ELSE
C*****
C      MIXTURE
C      CALCULATE MOLAR CONCENTRATION
DIFD=0.0
DO I = 1, NINT
  NUMBER = INODE(I)
  DO II = 1, NNODS
    IF (NUMBER .EQ. NODE(II)) IP = II
  ENDDO
C      OBTAIN PROPERTIES OF INDIVIDUAL SPECIES
  DO J = 1,NF
    IF (CM(IP,J) .NE. 0) THEN
      ENTHJ=H(IP)-DELHGP(NFLUID(J))
      PJ=P(IP)/144.
      IF (NFLUID(J).EQ.12.OR.NFLUID(J).EQ.33) BYPASS = .TRUE.
      IF (.NOT. BYPASS) THEN
C      SPECIFY THE FLUID BY NAMING ITS COEFFICIENT FILE
        CALL SETFLUID(COFILE,NFLUID(J),J)
        CALL READCF(COFILE, IDID)
        IF (IDID .LT. 0) THEN
          CALL GASERR(MESSAG, IDID)

```

```

        WRITE(NGSPK,86) MESSAG
        STOP 'COEFFICIENT FILE ERROR'
        ENDIF
C      SELECT UNIT
        IOUNIT = 4
C      SELECT PARAMETERS TO BE CALCULATED
        OUTPAR = '***'
C      FIND FIXED PARAMETERS FOR THAT FLUID
        CALL UNILIB(IOUNIT)
        CALL GASCON(CONST,UCONA)
        INPAR1='P'
        VALU1=PJ
        INPAR2='H'
        VALU2=H(IP)-DELHGP(NFLUID(J))
        CALL CALC(IDID,PROP,OUTPAR,INPAR1,VALU1,INPAR2,VALU2,
&          COFILE,IOUNIT)
C      WRITE AN ERROR MESSAGE IF THE CALCULATION FAILED
        IF (IDID .LT. 0) THEN
          CALL GASERR(MESSAG, IDID)
          WRITE (NGSPK,86) MESSAG
          STOP 'CALCULATION 1 FAILURE'
        ENDIF
C      XVF(J)=PROP(0,0)
        RHOF(J)=PROP(3,0)
        EMUF(J)=PROP(21,0)
        CONDF1(J)=PROP(22,0)
        GAMAF(J)=PROP(11,0)
        RGAS(NFLUID(J))=CONST(1)*HEQ
        ZF(J)=PJ*144./(RHOF(J)*RGAS(NFLUID(J))*TF(IP))
        IF ((IDID .EQ. 1) .OR. (IDID .EQ. 2)) THEN
          IF (ZF(J) .LT. 0.9) THEN
            XVF(J)=0.0
          ELSE
            XVF(J)=1.0
          ENDIF
        ENDIF
        IF (IDID .EQ. 3) XVF(J)=PROP(0,0)
        IF (IDID .EQ. 4) XVF(J)=0.0
        IF (IDID .EQ. 5) XVF(J)=1.0
C      FOR WATER,R11,R12,R22,R32,R123,R124,R125,R134a,R152a,
C      AND AMMONIA VISCOSITY & CONDUCTIVITY ARE COMPUTED FROM

```

```

C      ASHRAE CORRELATIONS
DO LL=1,11
  IF (NFLUID(J) .EQ. NCVFL(LL)) THEN
    IF (ZF(J) .LT. 0.5) THEN
      INDX = 1
    ELSE
      INDX = 3
    ENDIF
    TEMP = TF(IP)
    QUAL=XVF(J)
    NAFL=NFLUID(J)
    CALL CONDCTV(NAFL,INDX,QUAL,TEMP,CONDCT)
    CALL VISCTY(NAFL,INDX,QUAL,TEMP,VISC)
    CONDF1(J) = CONDCT
    EMUF(J) = VISC
  ENDIF
ENDDO

ENDIF ! (IF (.NOT. BYPASS..))

C OBTAIN PROPERTIES OF RP1 & IDEAL GAS, IF NECESSARY
C RP-1
  IF (NFLUID(J) .EQ. 12) THEN
C OBTAIN DENSITY
    CALL RP1(4,1,PJ,TEMPJ,ENTHJ,RHOBJ,CPC,GAMAC,EMUC,AKC,SC,KR
    & ,ITER)
    RHOBJ=RHOBJ
C OBTAIN VISCOSITY
    CALL RP1(4,8,PJ,TEMPJ,ENTHJ,RHOBJ,CPC,GAMAC,EMUC,AKC,SC,KR
    & ,ITER)
    EMUF(J)=EMUC
C OBTAIN GAMA
    CALL RP1(4,4,PJ,TEMPJ,ENTHJ,RHOBJ,CPC,GAMAC,EMUC,AKC,SC,KR
    & ,ITER)
    GAMAF(J)=GAMAC
C OBTAIN CONDUCTIVITY
    CALL RP1(4,16,PJ,TEMP,ENTHJ,RHOBJ,CPC,GAMAC,EMUC,AKC,SC,KR
    & ,ITER)
    CONDF1(J)=AKC
  ENDIF
C*****

```

```

C      IDEAL GAS
C
IF (NFLUID(J) .EQ. 33) THEN
  RHOF(J)=PJ*144./(RREF*TF(IP))
  EMUF(J)=EMUREF
  GAMAF(J)=GAMREF
  ZF(J)=1.0
ENDIF

ENDIF !(IF CM(IP,J) .NE. 0...)
ENDDO !(DO J = 1,NF..)

C      CALCULATE MIXTURE PROPERTIES

SUMG=0.0
SUMMW=0.0
SUMMR=0.0
SUMM=0.0
SUMZ=0.0
SUMCON=0.0
DO J = 1, NF
  SUMG=SUMG+GAMAF(J)*CM(IP,J)
  SUMM=SUMM+CM(IP,J)*EMUF(J)
  SUMZ=SUMZ+CM(IP,J)*ZF(J)
  SUMMW=SUMMW+CM(IP,J)*WM(NFLUID(J))
  SUMR=SUMR+CM(IP,J)*RGAS(NFLUID(J))
  SUMCON=SUMCON+CM(IP,J)*COND1(J)
ENDDO
Z(IP)=SUMZ
RHOMOL=P(IP)/(RCONST*Z(IP)*TF(IP))
RHONEW=RHOMOL*SUMMW
RHOOLD=RHO(IP)
DIFD=MAX(DIFD,ABS(RHONEW-RHOOLD)/RHOOLD)
RHO(IP)=(1.-RELAXD)*RHOOLD+RELAXD*RHONEW
EMU(IP)=SUMM
GAMA(IP)=SUMG
RNODE(IP)=SUMR
COND(IP)=SUMCON

ENDDO !(DO IP =

```

```

CALL MIXTGP

ENDIF ! ( IF (.NOT. MIXTURE...)

RETURN
81  FORMAT('FIXED PTS FROM ',A11)
82  FORMAT(I5,G16.4,A11)
86  FORMAT(1X, A72)
END
C*****
SUBROUTINE MIXTGP
C   PURPOSE: CALCULATE MIXTURE TEMPERATURE USING GASPAK
C*****
INCLUDE 'COMBLK.FOR'
C*****
DIMENSION CPF(100,10)
CHARACTER INPAR1*1, INPAR2*1, COFILE*64, OUTPAR*2, MESSAG*72
DOUBLE PRECISION VALU1, VALU2, PROP(0:31,0:2)
INTEGER IDID, IOUNIT
C
CHARACTER*11 UCONA, UARRAY
DOUBLE PRECISION CONST
LOGICAL BYPASS
DIMENSION CONST(0:21), UCONA(0:21), UARRAY(0:31)

DO I = 1,NINT
  NUMBER = INODE(I)
  DO II = 1, NNODES
    IF (NUMBER .EQ. NODE(II)) IPN=II
  ENDDO
  SUMN=0.0
  SUMD=0.0
  SUMVW=0.0
  SUMPW=0.0
  DO J = 1,NUMBR(I)
    NUMBER = NAMEBR(I,J)
    DO JJ = 1,NBR
      IF (NUMBER .EQ. IBRANCH(JJ)) IP = JJ
    ENDDO
  END
END

```

```

NUMUP=IBRUN(IP)
NUMDN=IBRDN(IP)
DO II = 1,NNODES
  IF (NUMUP .EQ. NODE(II)) IPUP = II
  IF (NUMDN .EQ. NODE(II)) IPDN = II
ENDDO

C COMPUTE VISCOUS AND PRESSURE WORK
  IF (INODE(I) .EQ. IBRDN(IP)) THEN
    SUMVW=SUMVW+AK(IP)*FLOWR(IP)**2*AREA(IP)*ABS(VEL(IP))/HEQ
    SUMPW=SUMPW+(P(IPDN)-P(IPUP))*AREA(IP)*VEL(IP)/HEQ
  ENDIF
C COMPUTE ENERGY INFLUX & OUTFLUX FROM THE CONTROL VOLUME
  IF (INODE(I) .EQ. IBRUN(IP)) THEN
    SUMNQJ=0.0
    SUMDQJ=0.0
    DO JF = 1,NF
C COMPUTE CP AT DOWNSTREAM NODE
    IF (NFLUID(JF) .EQ. 12 .OR. NFLUID(JF) .EQ. 33)
      & BYPASS = .TRUE.
    IF (.NOT. BYPASS) THEN
C SPECIFY THE FLUID BY NAMING ITS COEFFICIENT FILE
      CALL SETFLUID(COFILE,NFLUID(JF),JF)
      CALL READCF(COFILE,getID)
      IF (getID .LT. 0) THEN
        CALL GASERR(MESSAG,getID)
        WRITE (NGSPK,86) MESSAG
        STOP 'COEFFICIENT FILE ERROR'
      ENDIF
C SELECT UNIT
      IOUNIT = 4
C SELECT PARAMETERS TO BE CALCULATED
      OUTPAR = '***'
C FIND FIXED PARAMETERS FOR THAT FLUID
      CALL UNILIB(IOUNIT)
      CALL GASCON(CONST,UCONA)
C DETERMINE IF IT IS AN INTERNAL NODE
  IF (INDEX(IPDN) .EQ. 1) THEN
    PJ = P(IPDN)/144.
    ENTHJ=H(IPDN)-DELHGP(NFLUID(JF))
    INPAR1='P'

```

```

VALU1=PJ
INPAR2='H'
VALU2=ENTHJ
ELSE
PJ=P(IPDN)/144.
INPAR1='P'
VALU1=PJ
INPAR2='T'
VALU2=TF(IPDN)
ENDIF
CALL CALC(IDID,PROP,OUTPAR,INPAR1,VALU1,INPAR2,VALU2,COFILE,
&           IOUNIT)
C      WRITE AN ERROR MESSAGE IF THE CALCULATION FAILED
      IF (IDID .LT. 0) THEN
        CALL GASERR(MESSAG, IDID)
        WRITE(NGSPK,86) MESSAG
        STOP 'CALCULATION 1 FAILURE'
      ENDIF
      CPF(IPDN,JF) = PROP(10,0)

      ENDIF ! (IF (.NOT. BYPASS..))

C      SUPPLY CP OF RP1 & IDEAL GAS
C      RP1
      IF (NFLUID(JF) .EQ. 12) THEN
C      DETERMINE IF IT IS AN INTERNAL NODE
      IF (INDEX(IPDN) .EQ. 1 ) THEN
        PJ=P(IPDN)/144.
        ENTHJ = H(IPDN)-DELHGP(NFLUID(JF))
        CALL RP1(4,4,PJ,TEMPJ,ENTHJ,RHOBJ,CPC,GAMAC,EMUC,AKC,SC,KR,
&                 ITER)
      ELSE
        PJ=P(IPDN)/144.
        TEMPJ=TF(IPDN)
        CALL RP1(1,4,PJ,TEMPJ,ENTHJ,RHOBJ,CPC,GAMAC,EMUC,AKC,SC,KR,
&                 ITER)
      ENDIF
      CPF(IPDN,JF)=CPC
    ENDIF
C      IDEAL GAS
    IF (NFLUID(JF) .EQ. 33) CPF(IPDN,JF) = CPREF

```

```

SUMNQJ=SUMNQJ+CPF(IPDN,JF)*TF(IPDN)*CX(IPDN,JF)*
&           MAX(-FLOWR(IP),0.0)
SUMDQJ=SUMDQJ+CPF(IPDN,JF)*CX(IPDN,JF)*MAX(-FLOWR(IP),0.0)

ENDDO ! (DO JF=1,NF..)

SUMN=SUMN+SUMNQJ
SUMD=SUMD+SUMDQJ

ELSE ! IF (INODE(I) .EQ. IBRUN(IP)).. )

SUMNQJ=0.0
SUMDQJ=0.0
DO JF = 1,NF
C COMPUTE CP AT UPSTREAM NODE
  IF (NFLUID(JF) .EQ. 12 .OR. NFLUID(JF) .EQ. 33)
&     BYPASS = .TRUE.
    IF (.NOT. BYPASS) THEN
C   SPECIFY THE FLUID BY NAMING ITS COEFFICIENT FILE
      CALL SETFLUID(COFILE,NFLUID(JF),JF)
      CALL READCF(COFILE,getID)
      IF (getID .LT. 0) THEN
        CALL GASERR(MESSAG,getID)
        WRITE (NGSPK,86) MESSAG
        STOP 'COEFFICIENT FILE ERROR'
      ENDIF
C   SELECT UNIT
      IOUNIT = 4
C   SELECT PARAMETERS TO BE CALCULATED
      OUTPAR = '***'
C   FIND FIXED PARAMETERS FOR THAT FLUID
      CALL UNILIB(IOUNIT)
      CALL GASCON(CONST,UCONA)

C   DETERMINE IF IT IS AN INTERNAL NODE

IF (INDEX(IPUP) .EQ. 1) THEN
  PJ = P(IPUP)/144.
  ENTHJ=H(IPDN)-DELHGP(NFLUID(JF))
  INPAR1='P'

```

```

VALU1=PJ
INPAR2='H'
VALU2=ENTHJ
ELSE
PJ=P(IPUP)/144.
INPAR1='P'
VALU1=PJ
INPAR2='T'
VALU2=TF(IPUP)
ENDIF
CALL CALC(IDID,PROP,OUTPAR,INPAR1,VALU1,INPAR2,VALU2,COFILE,
&           IOUNIT)
C      WRITE AN ERROR MESSAGE IF THE CALCULATION FAILED
IF (IDID .LT. 0) THEN
  CALL GASERR(MESSAG, IDID)
  WRITE(NGSPK,86) MESSAG
  STOP 'CALCULATION 1 FAILURE'
ENDIF
CPF(IPUP,JF)=PROP(10,0)

ENDIF !(IF .NOT. BYPASS..)

C      SUPPLY CP OF RP1 & IDEAL GAS
C      RP1
IF (NFLUID(JF) .EQ. 12) THEN
C      DETERMINE IF IT IS AN INTERNAL NODE
IF (INDEX(IPUP) .EQ. 1 ) THEN
PJ=P(IPUP)/144.
ENTHJ = H(IPUP)-DELHGP(NFLUID(JF))
CALL RP1(4,4,PJ,TEMPJ,ENTHJ,RHOBJ,CPC,GAMAC,EMUC,AKC,SC,KR,
&           ITER)
ELSE
PJ=P(IPDN)/144.
TEMPJ=TF(IPUP)
CALL RP1(1,4,PJ,TEMPJ,ENTHJ,RHOBJ,CPC,GAMAC,EMUC,AKC,SC,KR,
&           ITER)
ENDIF
CPF(IPUP,JF)=CPC
ENDIF
C      IDEAL GAS
IF (NFLUID(JF) .EQ. 33) CPF(IPUP,JF) = CPREF

```

```

SUMNQJ=SUMNQJ+CPF(IPUP,JF)*TF(IPUP)*CX(IPUP,JF)*
&      MAX(FLOWR(IP),0.0)
SUMDQJ=SUMDQJ+CPF(IPUP,JF)*CX(IPUP,JF)*MAX(FLOWR(IP),0.0)

ENDDO ! DO JF = 1,NF

SUMN=SUMN+SUMNQJ
SUMD=SUMD+SUMDQJ

ENDIF ! IF (INODE..

ENDDO ! DO J = 1, NUMBR(I).. 

IF (HRATE) THEN
FACTM=1.0
ELSE
FACTM=SUMD
ENDIF

C COMPUTE NODE TEMPERATURE
TF(IPN)=(SUMN+FACTM*HSOURCE(IPN)+SUMPW+SUMVW)/SUMD
ENDDO ! (DO I = 1,NINT..)
RETURN
86 FORMAT(1X, A72)
END

C*****
SUBROUTINE CONDCTV(NF,I,X,TEMPR,TC)
C
C This subroutine calculates the thermal conductivity of water,R-11, R-12, R-22,
C and ammonia from tabulated constants and equations set forth in 'Thermophysical
C Properties of Refrigerants' for the year 1976 as published by the American Society
C of Heating, Refrigerating and Air-Conditioning Engineers, Inc. The fluid, its
C temperature and its phase are the inputs used in selecting the correct
C constants for calculation. This subroutine also provides the thermal conductivity
C of R-32, R-123, R-124, R-125, R-134a and R-152a using the liquid and vapor conductivity
C values at 14.7 psi and the appropriate saturation temperature as given by the NIST
C properties program REFPROP. This method requires the mole fraction of the fluid as
C an additional input.
C
C*****

```

```

C
C      Set temperature range values for water phases
C
C          DATA H2OL1,H2OL2,H2OL3,H2OL4/273.,400.,600.,645./
C          DATA H2OSV1,H2OSV2,H2OSV3,H2OSV4/273.,500.,600.,640./
C          DATA H2OV1,H2OV2,H2OV3,H2OV4/373.,600.,800.,1000./

C
C      Set temperature range values for refrigerant phases
C
C          DATA R11L1,R11L2,R11SV1,R11SV2,R11SV3/165.,390.,300.,425.,465./
C          DATA R11V1,R11V2,R12L1,R12L2/270.,420.,144.,344./
C          DATA R12SV1,R12SV2,R12V1,R12V2/244.,356.,244.,478./
C          DATA R22L1,R22L2,R22SV1,R22SV2/144.,340.,225.,325./
C          DATA R22V1,R22V2/233.,644./

C
C      Set temperature range values for ammonia phases
C
C          DATA AMML1,AMML2/200.,350./
C          DATA AMMSV1,AMMSV2,AMMSV3,AMMSV4/440.,580.,700.,730./
C          DATA AMMV1,AMMV2,AMMV3/240.,600.,900./

C
C      Convert temperature from Rankine to Kelvin,
C      Celsius, and Farenheit
C
C          TEMPF=TEMPL-460.
C          TEMPK=TEMPL/1.8
C          TEMP=TEMPK-273.

C
C      DETERMINE FLUID FROM VALUE OF NF
C
C          IF (NF .EQ. 11) THEN
C              GO TO 5
C          ELSE IF (NF .EQ. 22) THEN
C              GO TO 15
C          ELSE IF (NF .EQ. 23) THEN
C              GO TO 25
C          ELSE IF (NF .EQ. 24) THEN
C              GO TO 35
C          ELSE IF (NF .EQ. 25) THEN
C              GO TO 45
C          ELSE IF (NF .EQ. 26) THEN

```

```

        GO TO 55
ELSE IF (NF .EQ. 27) THEN
        GO TO 65
ELSE IF (NF .EQ. 28) THEN
        GO TO 75
ELSE IF (NF .EQ. 29) THEN
        GO TO 85
ELSE IF (NF .EQ. 30) THEN
        GO TO 95
ELSE IF (NF .EQ. 32) THEN
        GO TO 105
ELSE
C This should never happen during normal program operation
        PRINT*, 'CONDCTV DOES NOT PROVIDE CONDUCTIVITY FOR FLUID',NF
        TCSI=0.0
        GO TO 500
ENDIF
C
C Determine phase of water from value of I:
C           I=1, Liquid
C           I=2, Saturated Vapor
C           I=3, Vapor
C If index number other than above, print warning and set thermal conductivity
C to zero
C
5     IF (I .EQ. 1) THEN
        GO TO 6
ELSE IF (I .EQ. 2) THEN
        GO TO 7
ELSE IF (I .EQ. 3) THEN
        GO TO 8
ELSE
C This should never happen during normal program operation
        PRINT *, 'IMPROPER H2O PHASE INDEX NUMBER IN CONDCTV'
        TCSI=0.0
        GO TO 500
ENDIF
C
C Determine liquid phase constants from temperature and calculate thermal
C conductivity. Range: 273K - 645K. If out of range print warning and return
C an approximate thermal conductivity value using constants from closest known range.

```

```

C
6      IF (TEMPK .LT. H2OL1) THEN
C These values assumed to apply to all temperatures below 273K in order to
C avoid returning a zero thermal conductivity to GFSSP.
      A=-0.61694
      B=7.17851E-03
      C=-1.167E-05
      D=4.70358E-09
      GO TO 9
ELSE IF (TEMPK .LE. H2OL2) THEN
      A=-0.61694
      B=7.17851E-03
      C=-1.167E-05
      D=4.70358E-09
      GO TO 10
ELSE IF (TEMPK .LE. H2OL3) THEN
      A=-0.14532
      B=4.02217E-03
      C=-4.64993E-06
      D=-4.89256E-10
      GO TO 10
ELSE IF (TEMPK .LE. H2OL4) THEN
      A=190.40348
      B=-0.941305
      C=1.5584704E-03
      D=-8.6195286E-07
      GO TO 10
ELSE
C These values assumed to apply to all temperatures above 645K in order to
C avoid returning a zero thermal conductivity to GFSSP.
      A=190.40348
      B=-0.941305
      C=1.5584704E-03
      D=-8.6195286E-07
      GO TO 9
END IF
9      WRITE(NGFSOUT,*) 'T OUT OF RANGE OF H2O LIQUID PROPS IN CONDCTV'
10     TCSI=A+(B*TEMPK)+(C*(TEMPK**2))+(D*(TEMPK**3))
      GO TO 500
C
C Determine saturated vapor constants from temperature and calculate thermal

```

```

C conductivity. Range: 273K - 640K. If out of range print warning and return
C an approximate thermal conductivity value using constants from closest known range.
C
7   IF (TEMPK .LT. H2OSV1) THEN
C These values assumed to apply to all temperatures below 273K in order to
C avoid returning a zero thermal conductivity to GFSSP.
      A=-0.039991
      B=4.48666E-04
      C=-1.24255E-06
      D=1.35385E-09
      GO TO 11
ELSE IF (TEMPK .LE. H2OSV2) THEN
      A=-0.039991
      B=4.48666E-04
      C=-1.24255E-06
      D=1.35385E-09
      GO TO 12
ELSE IF (TEMPK .LE. H2OSV3) THEN
      A=-4.30376
      B=0.025038
      C=-4.85793E-05
      D=3.17793E-08
      GO TO 12
ELSE IF (TEMPK .LE. H2OSV4) THEN
      A=-148.0836
      B=0.735872
      C=-1.220443E-03
      D=6.759907E-07
      GO TO 12
ELSE
C These values assumed to apply to all temperatures above 640K in order to
C avoid returning a zero thermal conductivity to GFSSP.
      A=-148.0836
      B=0.735872
      C=-1.220443E-03
      D=6.759907E-07
      GO TO 11
END IF
11 WRITE(NGFSOUT,'(T OUT OF RANGE OF H2O SAT VAPOR PROPS IN CONDCTV'
12 TCSI=A+(B*TEMPK)+(C*(TEMPK**2))+(D*(TEMPK**3))
GO TO 500

```

```

C
C   Determine vapor constants from temperature and calculate thermal conductivity.
C   Range: 373K - 1000K. If out of range print warning and return an approximate thermal
C   conductivity value using constants from closest known range.
C
8      IF (TEMPK .LT. H2OV1) THEN
C These values assumed to apply to all temperatures below 373K in order to
C avoid returning a zero thermal conductivity to GFSSP.
      A=-138.818
      B=4.80327E+05
      C=-4.88631E+07
      GO TO 13
ELSE IF (TEMPK .LE. H2OV2) THEN
      A=-138.818
      B=4.80327E+05
      C=-4.88631E+07
      GO TO 14
ELSE IF (TEMPK .LE. H2OV3) THEN
      A=-3.40306
      B=3.30796E+05
      C=-7.28429E+06
      GO TO 14
ELSE IF (TEMPK .LE. H2OV4) THEN
      A=98.3080
      B=1.72643E+05
      C=5.43128E+07
      GO TO 14
ELSE
C These values assumed to apply to all temperatures above 1000K in order to
C avoid returning a zero thermal conductivity to GFSSP.
      A=98.3080
      B=1.72643E+05
      C=5.43128E+07
      GO TO 13
END IF
13     WRITE(NGFSOUT,*) 'T OUT OF RANGE OF H2O VAPOR PROPS IN CONDCTV'
14     TCSI=SQRT(TEMPK)/(A+(B/TEMPK)+(C/(TEMPK**2)))
      GO TO 500
C
C   Determine phase of R-11 from value of I:
C           I=1, Liquid

```

```

C           I=2, Saturated Vapor
C           I=3, Vapor
C If index number other than above, print warning and set thermal conductivity
C to zero.
C
15      IF (I .EQ. 1) THEN
          GO TO 16
    ELSE IF (I .EQ. 2) THEN
          GO TO 17
    ELSE IF (I .EQ. 3) THEN
          GO TO 18
    ELSE
C This should never happen during normal program operation.
        PRINT*, 'IMPROPER R11 PHASE INDEX NUMBER IN CONDCTV'
        TCSI=0.0
        GO TO 500
    ENDIF
C
C Determine liquid phase constants from temperature and calculate thermal
C conductivity. Range: 165K - 390K. If out of range print warning and return
C an approximate thermal conductivity value using constants from closest known range.
C
C           NOTE: Temperature range checks are in terms of K and
C           actual equations are in terms of degrees C. However,
C           units of equation remain W/m-K.
C
16      IF (TEMPK .LT. R11L1) THEN
C These values assumed to apply to all temperatures below 165K in order to
C avoid returning a zero thermal conductivity to GFSSP.
        TCSI=0.0945-(2.81E-4*TEMPC)
        GO TO 19
    ELSE IF (TEMPK .LE. R11L2) THEN
        TCSI=0.0945-(2.81E-4*TEMPC)
        GO TO 500
    ELSE
C These values assumed to apply to all temperatures above 390K in order to
C avoid returning a zero thermal conductivity to GFSSP.
        TCSI=0.0945-(2.81E-4*TEMPC)
        GO TO 19
    ENDIF
19      WRITE(NGFSOUT,*) 'T OUT OF RANGE OF R11 LIQUID PROPS IN CONDCTV'

```

```

GO TO 500
C
C Determine saturated vapor constants from temperature and calculate thermal
C conductivity. Range: 300K - 465K. If out of range print warning and return
C an approximate thermal conductivity value using constants from closest known range.
C
C           NOTE: For T > 425 K, equations are in terms of degrees F.
C           However, units of equation remain W/m-K
C
17   IF (TEMPK .LT. R11SV1) THEN
C These values assumed to apply to all temperatures below 300K in order to
C avoid returning a zero thermal conductivity to GFSSP.
    TCSI=-0.00649+(4.771E-5*TEMPK)
    GO TO 20
  ELSE IF (TEMPK .LE. R11SV2) THEN
    TCSI=-0.00649+(4.771E-5*TEMPK)
    GO TO 500
  ELSE IF (TEMPK .LE. R11SV3) THEN
    TCSI=-0.631543+(5.85935E-3*TEMPF)-(1.7771E-5*(TEMPF**2))
&      +(1.80285E-6*(TEMPF**3))
    GO TO 500
  ELSE
C These values assumed to apply to all temperatures above 465K in order to
C avoid returning a zero thermal conductivity to GFSSP.
    TCSI=-0.631543+(5.85935E-3*TEMPF)-(1.7771E-5*(TEMPF**2))
&      +(1.80285E-6*(TEMPF**3))
    GO TO 20
  ENDIF
20   WRITE(NGFSOUT,*)'T OUT OF RANGE OF R11 SAT VAPOR PROPS IN CONDCTV'
    GO TO 500
C
C Determine vapor constants from temperature and calculate thermal conductivity.
C Range: 270K - 420K. If out of range print warning and return an approximate thermal
C conductivity value using constants from closest known range.
C
C           NOTE: Temperature range checks are in terms of K and
C           actual equations are in terms of degrees F. However,
C           units of equation remain W/m-K.
C
18   IF (TEMPK .LT. R11V1) THEN
C These values assumed to apply to all temperatures below 270K in order to

```

```

C   avoid returning a zero thermal conductivity to GFSSP.
    TCSI=0.00597101+(2.28456E-5*TEMPF)
    GO TO 21
ELSE IF (TEMPK .LE. R11V2) THEN
    TCSI=0.00597101+(2.28456E-5*TEMPF)
    GO TO 500
ELSE
C These values assumed to apply to all temperatures above 420K in order to
C avoid returning a zero thermal conductivity to GFSSP.
    TCSI=0.00597101+(2.28456E-5*TEMPF)
    GO TO 21
ENDIF
21    WRITE(NGFSOUT,*)'T OUT OF RANGE OF R11 VAPOR PROPS IN CONDCTV'
    GO TO 500
C
C Determine phase of R-12 from value of I:
C           I=1, Liquid
C           I=2, Saturated Vapor
C           I=3, Vapor
C If index number other than above, print warning and set thermal conductivity
C to zero.
C
25    IF (I .EQ. 1) THEN
        GO TO 26
    ELSE IF (I .EQ. 2) THEN
        GO TO 27
    ELSE IF (I .EQ. 3) THEN
        GO TO 28
    ELSE
C This should never happen during normal program operation.
        PRINT*, 'IMPROPER R12 PHASE INDEX NUMBER IN CONDCTV'
        TCSI=0.0
        GO TO 500
    ENDIF
C
C Determine liquid phase constants from temperature and calculate thermal
C conductivity. Range: 144K - 344K. If out of range print warning and return
C an approximate thermal conductivity value using constants from closest known range.
C
C           NOTE: Temperature range checks are in terms of K and
C                   actual equations are in terms of degrees C. However,

```

```

C           units of equation remain W/m-K.

C
26      IF (TEMPK .LT. R12L1) THEN
C These values assumed to apply to all temperatures below 144K in order to
C avoid returning a zero thermal conductivity to GFSSP.
      TCSI=0.0783-(0.000366*TEMPC)
      GO TO 29
ELSE IF (TEMPK .LE. R12L2) THEN
      TCSI=0.0783-(0.000366*TEMPC)
      GO TO 500
ELSE
C These values assumed to apply to all temperatures above 344K in order to
C avoid returning a zero thermal conductivity to GFSSP.
      TCSI=0.0783-(0.000366*TEMPC)
      GO TO 29
ENDIF
29      WRITE(NGFSOUT,'(T OUT OF RANGE OF R12 LIQUID PROPS IN CONDCTV'
      GO TO 500
C
C Determine saturated vapor constants from temperature and calculate thermal
C conductivity. Range: 244K - 356K. If out of range print warning and return
C an approximate thermal conductivity value using constants from closest known range.
C
C           NOTE: Temperature range checks are in terms of K and
C           actual equations are in terms of degrees F. However,
C           units of equation remain W/m-K.
C
27      IF (TEMPK .LT. R12SV1) THEN
C These values assumed to apply to all temperatures below 244K in order to
C avoid returning a zero thermal conductivity to GFSSP.
      TCSI=7.44906E-3+(2.67941E-5*TEMPC)+(2.7736E-6*(TEMPC**2))
      GO TO 30
ELSE IF (TEMPK .LE. R12SV2) THEN
      TCSI=7.44906E-3+(2.67941E-5*TEMPC)+(2.7736E-6*(TEMPC**2))
      GO TO 500
ELSE
C These values assumed to apply to all temperatures above 356K in order to
C avoid returning a zero thermal conductivity to GFSSP.
      TCSI=7.44906E-3+(2.67941E-5*TEMPC)+(2.7736E-6*(TEMPC**2))
      GO TO 30
ENDIF

```

```

30      WRITE(NGFSOUT,*)'T OUT OF RANGE OF R12 SAT VAPOR PROPS IN CONDCTV'
         GO TO 500
C
C   Determine vapor constants from temperature and calculate thermal conductivity.
C   Range: 244K - 478K. If out of range print warning and return an approximate thermal
C   conductivity value using constants from closest known range.
C
C           NOTE: Temperature range checks are in terms of K and
C                   actual equations are in terms of R. However,
C                   units of equation remain W/m-K.
C
28      IF (TEMPK .LT. R12V1) THEN
C   These values assumed to apply to all temperatures below 244K in order to
C   avoid returning a zero thermal conductivity to GFSSP.
        TCSI=SQRT(TEMPR)/(420.391+(7.167492E+5/TEMPR) +
        & (1.886802E+8/(TEMPR**2)))
        GO TO 31
    ELSE IF (TEMPK .LE. R12V2) THEN
        TCSI=SQRT(TEMPR)/(420.391+(7.167492E+5/TEMPR) +
        & (1.886802E+8/(TEMPR**2)))
        GO TO 500
    ELSE
C   These values assumed to apply to all temperatures above 478K in order to
C   avoid returning a zero thermal conductivity to GFSSP.
        TCSI=SQRT(TEMPR)/(420.391+(7.167492E+5/TEMPR) +
        & (1.886802E+8/(TEMPR**2)))
        GO TO 31
    ENDIF
31      WRITE(NGFSOUT,*)'T OUT OF RANGE OF R12 VAPOR PROPS IN CONDCTV'
         GO TO 500
C
C   Determine phase of R-22 from value of I:
C           I=1, Liquid
C           I=2, Saturated Vapor
C           I=3, Vapor
C   If index number other than above, print warning and set thermal conductivity
C   to zero.
C
35      IF (I .EQ. 1) THEN
         GO TO 36
    ELSE IF (I .EQ. 2) THEN

```

```

        GO TO 37
    ELSE IF (I .EQ. 3) THEN
        GO TO 38
    ELSE
C     This should never happen during normal program operation.
        PRINT*, 'IMPROPER R22 PHASE INDEX NUMBER IN CONDCTV'
        TCSI=0.0
        GO TO 500
    ENDIF

C
C     Determine liquid phase constants from temperature and calculate thermal
C     conductivity. Range: 144K - 340K. If out of range print warning and return
C     an approximate thermal conductivity value using constants from closest known range.
C
C             NOTE: Temperature range checks are in terms of K and
C                     actual equations are in terms of degrees C. However,
C                     units of equation remain W/m-K.
C
36     IF (TEMPK .LT. R22L1) THEN
C     These values assumed to apply to all temperatures below 144K in order to
C     avoid returning a zero thermal conductivity to GFSSP.
        TCSI=0.1001-(0.000495*TEMPC)
        GO TO 39
    ELSE IF (TEMPK .LE. R22L2) THEN
        TCSI=0.1001-(0.000495*TEMPC)
        GO TO 500
    ELSE
C     These values assumed to apply to all temperatures above 340K in order to
C     avoid returning a zero thermal conductivity to GFSSP.
        TCSI=0.1001-(0.000495*TEMPC)
        GO TO 39
    ENDIF
39     WRITE(NGFSOUT,*) 'T OUT OF RANGE OF R22 LIQUID PROPS IN CONDCTV'
        GO TO 500

C
C     Determine saturated vapor constants from temperature and calculate thermal
C     conductivity. Range: 225K - 325K. If out of range print warning and return
C     an approximate thermal conductivity value using constants from closest known range.
C
37     IF (TEMPK .LT. R22SV1) THEN
C     These values assumed to apply to all temperatures below 225K in order to

```

```

C   avoid returning a zero thermal conductivity to GFSSP.
    TCSI=-0.007605+(6.2306E-5*TEMPK)
    GO TO 40
ELSE IF (TEMPK .LE. R22SV2) THEN
    TCSI=-0.007605+(6.2306E-5*TEMPK)
    GO TO 500
ELSE
C These values assumed to apply to all temperatures above 325K in order to
C avoid returning a zero thermal conductivity to GFSSP.
    TCSI=-0.007605+(6.2306E-5*TEMPK)
    GO TO 40
ENDIF
40    WRITE(NGFSOUT,*)'T OUT OF RANGE OF R22 SAT VAPOR PROPS IN CONDCTV'
    GO TO 500
C
C Determine vapor constants from temperature and calculate thermal conductivity.
C Range: 233K - 644K. If out of range print warning and return an approximate thermal
C conductivity value using constants from closest known range.
C
38    IF (TEMPK .LT. R22V1) THEN
C These values assumed to apply to all temperatures below 233K in order to
C avoid returning a zero thermal conductivity to GFSSP.
    TCSI=-0.007+(6.E-5*TEMPK)
    GO TO 41
ELSE IF (TEMPK .LE. R22V2) THEN
    TCSI=-0.007+(6.E-5*TEMPK)
    GO TO 500
ELSE
C These values assumed to apply to all temperatures above 644K in order to
C avoid returning a zero thermal conductivity to GFSSP.
    TCSI=-0.007+(6.E-5*TEMPK)
    GO TO 41
ENDIF
41    WRITE(NGFSOUT,*)'T OUT OF RANGE OF R22 VAPOR PROPS IN CONDCTV'
    GO TO 500
C
C R-32 thermal conductivity calculated using saturated liquid and vapor conductivity
C found using REFPROP for conditions of 14.7 psi and -61.32 deg. F.
C
45    IF (X .LE. 0.0) THEN
C Vapor

```

```

        TC=1.51E-06
    ELSE IF (X .LT. 1.0) THEN
        TC=((1-X)*3.07E-05)+(X*1.51E-06)
    ELSE
C     Liquid
        TC=3.07E-05
    ENDIF
    RETURN

C
C     R-123 thermal conductivity calculated using saturated liquid and vapor conductivity
C     found using REFPROP for conditions of 14.7 psi and 81.75 deg. F.
C

55      IF (X .LE. 0.0) THEN
C     Vapor
        TC=1.58E-06
    ELSE IF (X .LT. 1.0) THEN
        TC=((1-X)*1.27E-05)+(X*1.58E-06)
    ELSE
C     Liquid
        TC=1.27E-05
    ENDIF
    RETURN

C
C     R-124 thermal conductivity calculated using saturated liquid and vapor conductivity
C     found using REFPROP for conditions of 14.7 psi and 10.17 deg. F.
C

65      IF (X .LE. 0.0) THEN
C     Vapor
        TC=1.48E-06
    ELSE IF (X .LT. 1.0) THEN
        TC=((1-X)*1.31E-05)+(X*1.48E-06)
    ELSE
C     Liquid
        TC=1.31E-05
    ENDIF
    RETURN

C
C     R-125 thermal conductivity calculated using saturated liquid and vapor conductivity
C     found using REFPROP for conditions of 14.7 psi and -55. deg. F.
C

75      IF (X .LE. 0.0) THEN

```

```

C   Vapor
      TC=1.43E-06
      ELSE IF (X .LT. 1.0) THEN
          TC=((1-X)*1.49E-05)+(X*1.43E-06)
      ELSE
C   Liquid
      TC=1.49E-05
      ENDIF
      RETURN
C
C   R-134a thermal conductivity calculated using saturated liquid and vapor conductivity
C   found using REFPROP for conditions of 14.7 psi and -15.26 deg. F.
C
85     IF (X .LE. 0.0) THEN
C   Vapor
      TC=1.59E-06
      ELSE IF (X .LT. 1.0) THEN
          TC=((1-X)*1.72E-05)+(X*1.59E-06)
      ELSE
C   Liquid
      TC=1.72E-05
      ENDIF
      RETURN
C
C   R-152a thermal conductivity calculated using saturated liquid and vapor conductivity
C   found using REFPROP for conditions of 14.7 psi and -11.58 deg. F.
C
95     IF (X .LE. 0.0) THEN
C   Vapor
      TC=1.71E-06
      ELSE IF (X .LT. 1.0) THEN
          TC=((1-X)*2.16E-05)+(X*1.71E-06)
      ELSE
C   Liquid
      TC=2.16E-05
      ENDIF
      RETURN
C
C   Determine phase of ammonia from value of I:
C           I=1, Liquid
C           I=2, Saturated Vapor

```

```

C           I=3, Vapor
C   If index number other than above, print warning and set thermal conductivity
C   to zero
C
105      IF (I .EQ. 1) THEN
          GO TO 106
        ELSE IF (I .EQ. 2) THEN
          GO TO 107
        ELSE IF (I .EQ. 3) THEN
          GO TO 108
        ELSE
C   This should never happen during normal program operation
          PRINT *, 'IMPROPER NH3 PHASE INDEX NUMBER IN CONDCTV'
          TCSI=0.0
          GO TO 500
        ENDIF
C
C   Determine liquid phase constants from temperature and calculate thermal
C   conductivity. Range: 200K - 350K. If out of range print warning and return
C   an approximate thermal conductivity value using constants from closest known range.
C
C   NOTE: The lower limit for the ammonia liquid phase properties was not listed
C         explicitly in the ASHRAE guide. It was taken from Table 29
C         on page 150 of the ASHRAE guide to be 200K(-100 F).
C
106      IF (TEMPK .LT. AMML1) THEN
C   These values assumed to apply to all temperatures below 200K in order to
C   avoid returning a zero thermal conductivity to GFSSP.
          GO TO 109
        ELSEIF (TEMPK .LE. AMML2) THEN
          GO TO 110
        ELSE
C   These values assumed to apply to all temperatures above 350K in order to
C   avoid returning a zero thermal conductivity to GFSSP.
          GO TO 109
        ENDIF
109      WRITE(NGFSOUT,*)'T OUT OF RANGE OF NH3 LIQUID PROPS IN CONDCTV'
110      TCSI=1.17130-(0.002315*TEMPK)
          GO TO 500
C
C   Determine saturated vapor constants from temperature and calculate thermal

```

```

C conductivity. Range: 440R - 730R. If out of range print warning and return
C an approximate thermal conductivity value using constants from closest known range.
C
C NOTE: The ammonia sat vapor temperature check range is in R as opposed to K.
C In addition, the formula for ammonia sat vapor range is calculated using degrees F.
C The result of that formula is already in correct units and is returned directly
C to the main program after calculation.
C
107   IF (TEMPR .LT. AMMSV1) THEN
C These values assumed to apply to all temperatures below 440R in order to
C avoid returning a zero thermal conductivity to GFSSP.
      A=0.0115774
      B=0.0000295
      C=3.423E-07
      GO TO 111
ELSEIF (TEMPR .LE. AMMSV2) THEN
      A=0.0115774
      B=0.0000295
      C=3.423E-07
      GO TO 112
ELSEIF (TEMPR .LE. AMMSV3) THEN
      A=0.0182143
      B=-8.39E-05
      C=8.036E-07
      GO TO 112
ELSEIF (TEMPR .LE. AMMSV4) THEN
      A=2.34340
      B=-0.0192
      C=4.0E-05
      GO TO 112
ELSE
C These values assumed to apply to all temperatures below 730R in order to
C avoid returning a zero thermal conductivity to GFSSP.
      A=2.34340
      B=-0.0192
      C=4.0E-05
      GO TO 111
ENDIF
111  WRITE(NGFSOUT,'(T OUT OF RANGE OF NH3 SAT VAPOR PROPS IN CONDCTV'
112  TC=(A+(B*(TEMPR-460.))+((C*((TEMPR-460.)**2))/3600.
      RETURN

```

```

C
C   Determine vapor constants from temperature and calculate thermal conductivity.
C   Range: 240K - 900K. If out of range print warning and return an approximate thermal
C   conductivity value using constants from closest known range.
C
108     IF (TEMPK .LT. AMMV1) THEN
C   These values assumed to apply to all temperatures below 240K in order to
C   avoid returning a zero thermal conductivity to GFSSP.
        A=44.1058
        B=1.62E+05
        C=3.06E+07
        D=-5.93E+09
        GO TO 113
    ELSEIF (TEMPK .LE. AMMV2) THEN
        A=44.1058
        B=1.62E+05
        C=3.06E+07
        D=-5.93E+09
        GO TO 114
    ELSEIF (TEMPK .LE. AMMV3) THEN
        A=140.701
        B=-3.72E+04
        C=1.810E+08
        D=-4.50E+10
        GO TO 114
    ELSE
C   These values assumed to apply to all temperatures above 900K in order to
C   avoid returning a zero thermal conductivity to GFSSP.
        A=140.701
        B=-3.72E+04
        C=1.810E+08
        D=-4.50E+10
        GO TO 113
    ENDIF
113    WRITE(NGFSOUT,'(T OUT OF RANGE OF NH3 VAPOR PROPS IN CONDCTV'
114    TCSI=SQRT(TEMPK)/(A+(B/TEMPK)+(C/(TEMPK**2))+(D/(TEMPK**3)))
        GO TO 500
C
C   Convert thermal conductivity from W/m-K to Btu/s-ft-R
C
500    TC=TCSI*0.0001605

```

```

RETURN
END
C*****
SUBROUTINE VISCTY(NF,I,X,TEMPR,V)
C
C This subroutine calculates the viscosity of water, R-11, R-12, R-22, and ammonia
C from tabulated constants and equations set forth in 'Thermophysical Properties
C of Refrigerants' for the year 1976 as published by the American Society of Heating,
C Refrigerating and Air-Conditioning Engineers, Inc. The fluid, its temperature and
C its phase are the inputs used in selecting the correct constants for calculation.
C This subroutine also provides the viscosity of R-32, R-123, R-124, R-125, R-134a,
C and R-152a using the saturated liquid and vapor viscosities at 14.7 psi and the
C appropriate saturation temperature as given by the NIST properties program REFPROP.
C This method requires the mole fraction of the fluid as an additional input.
C
C*****
C Set temperature range values for water phases
C
DATA H2OL1,H2OL2,H2OL3,H2OL4,H2OL5/273.,350.,500.,620.,640./
DATA H2OSV1,H2OSV2,H2OSV3,H2OSV4/373.,500.,600.,640./
DATA H2OV1,H2OV2,H2OV3,H2OV4/280.,500.,750.,1000./

C Set temperature range values for refrigerant phases
C
DATA R11L1,R11L2,R11L3/200.,350.,380./
DATA R11SV1,R11SV2,R11V1,R11V2/290.,470.,230.,500./
DATA R12L1,R12L2,R12L3/170.,340.,380./
DATA R12SV1,R12SV2,R12V1,R12V2/240.,380.,250.,470./
DATA R22L1,R22L2,R22L3/168.,310.,360./
DATA R22SV1,R22SV2,R22V1,R22V2/230.,350.,250.,500./

C Set temperature range values for ammonia phases
C
DATA AMML1,AMML2/240.,390./
DATA AMMSV1,AMMSV2,AMMSV3/240.,350.,390./
DATA AMMV1,AMMV2,AMMV3/200.,500.,1000./

C Convert temperature from Rankine to Kelvin
C
TEMPK=TEMPR/1.8

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C
C      DETERMINE FLUID FROM VALUE OF NF
C
IF (NF .EQ. 11) THEN
    GO TO 5
ELSE IF (NF .EQ. 22) THEN
    GO TO 15
ELSE IF (NF .EQ. 23) THEN
    GO TO 25
ELSE IF (NF .EQ. 24) THEN
    GO TO 35
ELSE IF (NF .EQ. 25) THEN
    GO TO 45
ELSE IF (NF .EQ. 26) THEN
    GO TO 55
ELSE IF (NF .EQ. 27) THEN
    GO TO 65
ELSE IF (NF .EQ. 28) THEN
    GO TO 75
ELSE IF (NF .EQ. 29) THEN
    GO TO 85
ELSE IF (NF .EQ. 30) THEN
    GO TO 95
ELSE IF (NF .EQ. 32) THEN
    GO TO 105
ELSE
C This should never happen during normal program operation
    PRINT*, 'VISCTY DOES NOT PROVIDE VISCOSITY FOR FLUID',NF
    VSI=0.0
    GO TO 500
ENDIF
C
C      Determine phase of water from value of I:
C          I=1, Liquid
C          I=2, Saturated Vapor
C          I=3, Vapor
C      If index number other than above, print warning and set viscosity to zero
C
5     IF (I .EQ. 1) THEN
        GO TO 6
ELSE IF (I .EQ. 2) THEN

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        GO TO 7
ELSE IF (I .EQ. 3) THEN
    GO TO 8
ELSE
C This should never happen during normal program operation
    PRINT *, 'IMPROPER H2O PHASE INDEX NUMBER IN VISCTY'
    VSI=0.0
    GO TO 500
ENDIF
C
C Determine liquid phase constants from temperature and calculate viscosity
C Range: 273K - 640K. If out of range print warning and return an approximate
C value of viscosity using constants from closest known range.
C

6   IF (TEMPK .LT. H2OL1) THEN
C These values assumed to apply to all temperatures below 273K in order to
C avoid returning a zero viscosity to GFSSP.
    A=0.030185
    B=-2191.6
    C=6.38605E+05
    GO TO 9
ELSE IF (TEMPK .LE. H2OL2) THEN
    A=0.030185
    B=-2191.6
    C=6.38605E+05
    GO TO 10
ELSE IF (TEMPK .LE. H2OL3) THEN
    A=-3.2295
    B=13.18574
    C=2.65531E+05
    GO TO 10
ELSE IF (TEMPK .LE. H2OL4) THEN
    A=-8.77361
    B=5875.87
    C=-1.28275E+06
    GO TO 10
ELSE IF (TEMPK .LE. H2OL5) THEN
    VSI=(51.616887-(0.25235392*TEMPK)+(4.1242857E-4*(TEMPK**2))
&           -(2.25E-7*(TEMPK**3)))/1000.
    GO TO 500

```

```

      ELSE
C   These values assumed to apply to all temperatures above 640K in order to
C   avoid returning a zero viscosity to GFSSP.
      A=-8.77361
      B=5875.87
      C=-1.28275E+06
      GO TO 9
END IF
9  WRITE(NGFSOUT,*) 'T OUT OF RANGE OF H2O LIQUID PROPS IN VISCTY'
10 VSI=(EXP(A+(B/TEMPK)+(C/(TEMPK**2)))/1000.
      GO TO 500
C
C   Determine saturated vapor constants from temperature and calculate viscosity
C   Range: 373K - 640K. If out of range print warning and return an approximate
C   value of viscosity using constants from closest known range.
C
7  IF (TEMPK .LT. H2OSV1) THEN
C   These values assumed to apply to all temperatures below 373K in order to
C   avoid returning a zero viscosity to GFSSP.
      A=-27.79084
      B=0.21142
      C=-3.84498E-04
      D=2.7822E-07
      GO TO 11
ELSE IF (TEMPK .LE. H2OSV2) THEN
      A=-27.79084
      B=0.21142
      C=-3.84498E-04
      D=2.7822E-07
      GO TO 12
ELSE IF (TEMPK .LE. H2OSV3) THEN
      A=-580.0762
      B=3.35383
      C=-6.34324E-03
      D=4.04429E-06
      GO TO 12
ELSE IF (TEMPK .LE. H2OSV4) THEN
      A=-14155.30286
      B=70.53207
      C=-0.117171429
      D=6.5E-05

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```

        GO TO 12
    ELSE
C   These values assumed to apply to all temperatures above 640K in order to
C   avoid returning a zero viscosity to GFSSP.
        A=-14155.30286
        B=70.53207
        C=-0.117171429
        D=6.5E-05
        GO TO 11
    END IF
11    WRITE(NGFSOUT,*) 'T OUT OF RANGE OF H2O SAT VAPOR PROPS IN VISCTY'
12    VSI=(A+(B*TEMPK)+(C*(TEMPK**2))+(D*(TEMPK**3)))/1000000.
        GO TO 500
C
C   Determine vapor constants from temperature and calculate viscosity
C   Range: 280K - 1000K. If out of range print warning and return an approximate
C   value of viscosity using constants from closest known range.
C
8      IF (TEMPK .LT. H2OV1) THEN
C   These values assumed to apply to all temperatures below 280K in order to
C   avoid returning a zero viscosity to GFSSP.
        A=0.500699
        B=365.423
        C=16018.
        GO TO 13
    ELSE IF (TEMPK .LE. H2OV2) THEN
        A=0.500699
        B=365.423
        C=16018.
        GO TO 14
    ELSE IF (TEMPK .LE. H2OV3) THEN
        A=0.368683
        B=490.099
        C=-13608.
        GO TO 14
    ELSE IF (TEMPK .LE. H2OV4) THEN
        A=0.309818
        B=575.159
        C=-44383.
        GO TO 14
    ELSE

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C These values assumed to apply to all temperatures above 1000K in order to
C avoid returning a zero viscosity to GFSSP.
      A=0.309818
      B=575.159
      C=-44383.
      GO TO 13
END IF
13  WRITE(NGFSOUT,*) 'T OUT OF RANGE OF H2O VAPOR PROPS IN VISCTY'
14  VSI=(SQRT(TEMPK)/(A+(B/TEMPK)+(C/(TEMPK**2))))/1000000.
      GO TO 500
C
C Determine phase of R-11 from value of I:
C           I=1, Liquid
C           I=2, Saturated Vapor
C           I=3, Vapor
C If index number other than above, print warning and set viscosity to zero
C
15  IF (I .EQ. 1) THEN
      GO TO 16
ELSE IF (I .EQ. 2) THEN
      GO TO 17
ELSE IF (I .EQ. 3) THEN
      GO TO 18
ELSE
C This should never happen during normal program operation
      PRINT*, 'IMPROPER R-11 PHASE INDEX NUMBER'
      VSI=0.0
      GO TO 500
ENDIF
C
C Determine liquid phase constants from temperature and calculate viscosity
C Range: 200K - 380K. If out of range print warning and return an approximate
C value of viscosity using constants from closest known range.
C
16  IF (TEMPK .LT. R11L1) THEN
C These values assumed to apply to all temperatures below 200K in order to
C avoid returning a zero viscosity to GFSSP.
      A=-3.6859
      B=840.172
      C=0.
      GO TO 19

```

```

ELSE IF (TEMPK .LE. R11L2) THEN
  A=-3.6859
  B=840.172
  C=0.
  GO TO 20
ELSE IF (TEMPK .LE. R11L3) THEN
  A=-21.6083
  B=14409.
  C=-2.5608E+06
  GO TO 20
ELSE
C These values assumed to apply to all temperatures above 380K in order to
C avoid returning a zero viscosity to GFSSP.
  A=-21.6083
  B=14409.
  C=-2.5608E+06
  GO TO 19
ENDIF
19 WRITE(NGFSOUT,*)'T OUT OF RANGE OF R11 LIQUID PROPS IN VISCTY'
20 VSI =(EXP(A+(B/TEMPK)+(C/(TEMPK**2 ))))/1000.
  GO TO 500
C
C Determine saturated vapor constants from temperature and calculate viscosity
C Range: 290K - 470K. If out of range print warning and return an approximate
C value of viscosity using constants from closest known range.
C
17 IF (TEMPK .LT. R11SV1) THEN
C These values assumed to apply to all temperatures below 290K in order to
C avoid returning a zero viscosity to GFSSP.
  VSI=(-0.30672+(2.66248E-3*TEMPK)-(7.43805E-6*(TEMPK**2 ))
  & +(6.97587E-9*(TEMPK**3 ))/1000.
  GO TO 21
ELSE IF (TEMPK .LE. R11SV2) THEN
  VSI=(-0.30672+(2.66248E-3*TEMPK)-(7.43805E-6*(TEMPK**2 ))
  & +(6.97587E-9*(TEMPK**3 ))/1000.
  GO TO 500
ELSE
C These values assumed to apply to all temperatures above 470K in order to
C avoid returning a zero viscosity to GFSSP.
  VSI=(-0.30672+(2.66248E-3*TEMPK)-(7.43805E-6*(TEMPK**2 ))
  & +(6.97587E-9*(TEMPK**3 ))/1000.

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        GO TO 21
      ENDIF
21      WRITE(NGFSOUT,*) 'T OUT OF RANGE OF R11 SAT VAPOR PROPS IN VISCTY'
        GO TO 500
C
C   Determine vapor constants from temperature and calculate viscosity
C   Range: 230K - 500K. If out of range print warning and return an approximate
C   value of viscosity using constants from closest known range.
C
18      IF (TEMPK .LT. R11V1) THEN
C   These values assumed to apply to all temperatures below 230K in order to
C   avoid returning a zero viscosity to GFSSP.
        VSI=(SQRT(TEMPK)/(0.43547+(511.161/TEMPK)
        &           -(50128./(TEMPK**2)))/1000000.
        GO TO 22
      ELSE IF (TEMPK .LE. R11V2) THEN
        VSI=(SQRT(TEMPK)/(0.43547+(511.161/TEMPK)
        &           -(50128./(TEMPK**2)))/1000000.
        GO TO 500
      ELSE
C   These values assumed to apply to all temperatures above 500K in order to
C   avoid returning a zero viscosity to GFSSP.
        VSI=(SQRT(TEMPK)/(0.43547+(511.161/TEMPK)
        &           -(50128./(TEMPK**2)))/1000000.
        GO TO 22
      ENDIF
22      WRITE(NGFSOUT,*) 'T OUT OF RANGE OF R11 VAPOR PROPS IN VISCTY'
        GO TO 500
C
C   Determine phase of R-12 from value of I:
C       I=1, Liquid
C       I=2, Saturated Vapor
C       I=3, Vapor
C   If index number other than above, print warning and set viscosity to zero
C
25      IF (I .EQ. 1) THEN
        GO TO 26
      ELSE IF (I .EQ. 2) THEN
        GO TO 27
      ELSE IF (I .EQ. 3) THEN
        GO TO 28

```

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    ELSE
C   This should never happen during normal program operation
        PRINT*, 'IMPROPER R12 PHASE INDEX NUMBER'
        VSI=0.0
        GO TO 500
    ENDIF

C
C   Determine liquid phase constants from temperature and calculate viscosity
C   Range: 170K - 380K. If out of range print warning and return an approximate
C   value of viscosity using constants from closest known range.
C

26     IF (TEMPK .LT. R12L1) THEN
C   These values assumed to apply to all temperatures below 170K in order to
C   avoid returning a zero viscosity to GFSSP.
        VSI=(EXP(-3.81728+(681.713/TEMPK)))/1000.
        GO TO 29

        ELSE IF (TEMPK .LE. R12L2) THEN
        VSI=(EXP(-3.81728+(681.713/TEMPK)))/1000.
        GO TO 500

        ELSE IF (TEMPK .LE. R12L3) THEN
        VSI=(-2.3601+(0.01591*TEMPK)-(0.000025*(TEMPK**2)))/1000.
        GO TO 500

        ELSE
C   These values assumed to apply to all temperatures above 380K in order to
C   avoid returning a zero viscosity to GFSSP.
        VSI=(-2.3601+(0.01591*TEMPK)-(0.000025*(TEMPK**2)))/1000.
        GO TO 29
    ENDIF

29     WRITE(NGFSOUT,*) 'T OUT OF RANGE OF R12 LIQUID PROPS IN VISCTY'
        GO TO 500

C
C   Determine saturated vapor constants from temperature and calculate viscosity
C   Range: 240K - 380K. If out of range print warning and return an approximate
C   value of viscosity using constants from closest known range.
C

27     IF (TEMPK .LT. R12SV1) THEN
C   These values assumed to apply to all temperatures below 240K in order to
C   avoid returning a zero viscosity to GFSSP.
        VSI=(-0.16244+(1.7545E-3*TEMPK)-(5.99112E-6*(TEMPK**2))
&           +(6.96937E-9*(TEMPK**3)))/1000.
        GO TO 30

```

```

ELSE IF (TEMPK .LE. R12SV2) THEN
    VSI=(-0.16244+(1.7545E-3*TEMPK)-(5.99112E-6*(TEMPK**2))
&           +(6.96937E-9*(TEMPK**3)))/1000.
    GO TO 500
ELSE
C These values assumed to apply to all temperatures above 380K in order to
C avoid returning a zero viscosity to GFSSP.
    VSI=(-0.16244+(1.7545E-3*TEMPK)-(5.99112E-6*(TEMPK**2))
&           +(6.96937E-9*(TEMPK**3)))/1000.
    GO TO 30
ENDIF
30   WRITE(NGFSOUT,*) 'T OUT OF RANGE OF R12 SAT VAPOR PROPS IN VISCTY'
    GO TO 500
C
C Determine vapor constants from temperature and calculate viscosity
C Range: 250K - 470K. If out of range print warning and return an approximate
C value of viscosity using constants from closest known range.
C
28   IF (TEMPK .LT. R12V1) THEN
C These values assumed to apply to all temperatures below 250K in order to
C avoid returning a zero viscosity to GFSSP.
    VSI=(SQRT(TEMPK)/(0.75309+(188.969/TEMPK)
&           -(803.786/(TEMPK**2))))/1000000.
    GO TO 31
ELSE IF(TEMPK .LE. R12V2) THEN
    VSI=(SQRT(TEMPK)/(0.75309+(188.969/TEMPK)
&           -(803.786/(TEMPK**2))))/1000000.
    GO TO 500
ELSE
C These values assumed to apply to all temperatures above 470K in order to
C avoid returning a zero viscosity to GFSSP.
    VSI=(SQRT(TEMPK)/(0.75309+(188.969/TEMPK)
&           -(803.786/(TEMPK**2))))/1000000.
    GO TO 31
ENDIF
31   WRITE(NGFSOUT,*) 'T OUT OF RANGE OF R12 VAPOR PROPS IN VISCTY'
    GO TO 500
C
C Determine phase of R-22 from value of I:
C           I=1, Liquid
C           I=2, Saturated Vapor

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C           I=3, Vapor
C   If index number other than above, print warning and set viscosity to zero
C
35      IF (I .EQ. 1) THEN
          GO TO 36
      ELSE IF (I .EQ. 2) THEN
          GO TO 37
      ELSE IF (I .EQ. 3) THEN
          GO TO 38
      ELSE
C This should never happen during normal program operation
          PRINT*, 'IMPROPER R22 PHASE INDEX NUMBER'
          VSI=0.0
          GO TO 500
      ENDIF
C
C Determine liquid phase constants from temperature and calculate viscosity
C Range: 168K - 360K.  If out of range print warning and return an approximate
C value of viscosity using constants from closest known range.
C
36      IF (TEMPK .LT. R22L1) THEN
C These values assumed to apply to all temperatures below 168K in order to
C avoid returning a zero viscosity to GFSSP.
          VSI=(EXP(-3.39554+(532.855/TEMPK)))/1000.
          GO TO 39
      ELSE IF (TEMPK .LE. R22L2) THEN
          VSI=(EXP(-3.39554+(532.855/TEMPK)))/1000.
          GO TO 500
      ELSE IF (TEMPK .LE. R22L3) THEN
          VSI=(-1.65108+(1.24147E-2*TEMPK)-(2.09286E-5*(TEMPK**2)))
&          /1000.
          GO TO 500
      ELSE
C These values assumed to apply to all temperatures above 360K in order to
C avoid returning a zero viscosity to GFSSP.
          VSI=(-1.65108+(1.24147E-2*TEMPK)-(2.09286E-5*(TEMPK**2)))
&          /1000.
          GO TO 39
      ENDIF
39      WRITE(NGFSOUT,*) 'T OUT OF RANGE OF R22 LIQUID PROPS IN VISCTY'
          GO TO 500

```

```

C
C Determine saturated vapor constants from temperature and calculate viscosity
C Range: 230K - 350K. If out of range print warning and return an approximate
C value of viscosity using constants from closest known range.
C
37      IF (TEMPK .LT. R22SV1) THEN
C These values assumed to apply to all temperatures below 230K in order to
C avoid returning a zero viscosity to GFSSP.
      VSI=(-0.031501+(4.20115E-4*TEMPK)-(1.5084E-6*(TEMPK**2))
      & +(2.02506E-9*(TEMPK**3)))/1000.
      GO TO 40
      ELSE IF (TEMPK .LE. R22SV2) THEN
      VSI=(-0.031501+(4.20115E-4*TEMPK)-(1.5084E-6*(TEMPK**2))
      & +(2.02506E-9*(TEMPK**3)))/1000.
      GO TO 500
      ELSE
C These values assumed to apply to all temperatures above 350K in order to
C avoid returning a zero viscosity to GFSSP.
      VSI=(-0.031501+(4.20115E-4*TEMPK)-(1.5084E-6*(TEMPK**2))
      & +(2.02506E-9*(TEMPK**3)))/1000.
      GO TO 40
      ENDIF
40      WRITE(NGFSOUT,*)'T OUT OF RANGE OF R22 SAT VAPOR PROPS IN VISCTY'
      GO TO 500
C
C Determine vapor constants from temperature and calculate viscosity
C Range: 250K - 500K. If out of range print warning and return an approximate
C value of viscosity using constants from closest known range.
C
38      IF (TEMPK .LT. R22V1) THEN
C These values assumed to apply to all temperatures below 250K in order to
C avoid returning a zero viscosity to GFSSP.
      VSI=(SQRT(TEMPK)/(0.61943+(239.551/TEMPK)
      & -(7605.74/(TEMPK**2)))/1000000.
      GO TO 41
      ELSE IF (TEMPK .LE. R22V2) THEN
      VSI=(SQRT(TEMPK)/(0.61943+(239.551/TEMPK)
      & -(7605.74/(TEMPK**2)))/1000000.
      GO TO 500
      ELSE
C These values assumed to apply to all temperatures above 500K in order to

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```

C   avoid returning a zero viscosity to GFSSP.
      VSI=(SQRT(TEMPK)/(0.61943+(239.551/TEMPK)
      &           -(7605.74/(TEMPK**2)))/1000000.
      GO TO 41
      ENDIF
41      WRITE(NGFSOUT,*) 'T OUT OF RANGE OF R22 VAPOR PROPS IN VISCTY'
      GO TO 500
C
C   R-32 viscosity calculated using saturated liquid and vapor viscosity
C   found using REFPROP for conditions of 14.7 psi and -61.32 deg. F.
C
45      IF (X .LE. 0.0) THEN
C   Vapor
      V=6.19E-06
      ELSE IF (X .LT. 1.0) THEN
          V=((1-X)*1.81E-04)+(X*6.19E-06)
      ELSE
C   Liquid
      V=1.81E-04
      ENDIF
      RETURN
C
C   R-123 viscosity calculated using saturated liquid and vapor viscosity
C   found using REFPROP for conditions of 14.7 psi and 81.75 deg. F.
C
55      IF (X .LE. 0.0) THEN
C   Vapor
      V=7.14E-06
      ELSE IF (X .LT. 1.0) THEN
          V=((1-X)*2.72E-04)+(X*7.14E-06)
      ELSE
C   Liquid
      V=2.72E-04
      ENDIF
      RETURN
C
C   R-124 viscosity calculated using saturated liquid and vapor viscosity
C   found using REFPROP for conditions of 14.7 psi and 10.17 deg. F.
C
65      IF (X .LE. 0.0) THEN
C   Vapor

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      V=6.85E-06
      ELSE IF (X .LT. 1.0) THEN
        V=((1-X)*2.66E-04)+(X*6.85E-06)
      ELSE
C     Liquid
        V=2.66E-04
      ENDIF
      RETURN
C
C     R-125 viscosity calculated using saturated liquid and vapor viscosity
C     found using REFPROP for conditions of 14.7 psi and -55. deg. F.
C
75      IF (X .LE. 0.0) THEN
C     Vapor
        V=6.61E-06
        ELSE IF (X .LT. 1.0) THEN
          V=((1-X)*2.80E-04)+(X*6.61E-06)
        ELSE
C     Liquid
          V=2.80E-04
        ENDIF
        RETURN
C
C     R-134a viscosity calculated using saturated liquid and vapor viscosity
C     found using REFPROP for conditions of 14.7 psi and -15.26 deg. F.
C
85      IF (X .LE. 0.0) THEN
C     Vapor
        V=6.58E-06
        ELSE IF (X .LT. 1.0) THEN
          V=((1-X)*2.75E-04)+(X*6.58E-06)
        ELSE
C     Liquid
          V=2.75E-04
        ENDIF
        RETURN
C
C     R-152a viscosity calculated using saturated liquid and vapor viscosity
C     found using REFPROP for conditions of 14.7 psi and -11.58 deg. F.
C
95      IF (X .LE. 0.0) THEN

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C   Vapor
      V=5.72E-06
      ELSE IF (X .LT. 1.0) THEN
          V=((1-X)*1.91E-04)+(X*5.72E-06)
      ELSE
C   Liquid
      V=1.91E-04
      ENDIF
      RETURN
C
C   Determine phase of ammonia from value of I:
C       I=1, Liquid
C       I=2, Saturated Vapor
C       I=3, Vapor
C   If index number other than above, print warning and set viscosity to zero
C
105    IF (I .EQ. 1) THEN
        GO TO 106
    ELSE IF (I .EQ. 2) THEN
        GO TO 107
    ELSE IF (I .EQ. 3) THEN
        GO TO 108
    ELSE
C   This should never happen during normal program operation
        PRINT *, 'IMPROPER NH3 PHASE INDEX NUMBER IN CONDCTV'
        VSI=0.0
        GO TO 500
    ENDIF
C
C   Determine liquid phase constants from temperature and calculate viscosity
C   Range: 240K - 390K.  If out of range print warning and return an approximate
C   value of viscosity using constants from closest known range.
C
106    IF (TEMPK .LT. AMML1) THEN
C   These values assumed to apply to all temperatures below 240K in order to
C   avoid returning a zero viscosity to GFSSP.
        GO TO 109
    ELSEIF (TEMPK .LE. AMML2) THEN
        GO TO 110
    ELSE
C   These values assumed to apply to all temperatures above 390K in order to

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C   avoid returning a zero viscosity to GFSSP.
      GO TO 109
      ENDIF
109  WRITE(NGFSOUT,*) 'T OUT OF RANGE OF NH3 LIQUID PROPS IN VISCTY'
110  VSI=(EXP(-7.9732+(2614.41/TEMPK)-(243288./(TEMPK**2)))/1000.
      GO TO 500
C
C   Determine saturated vapor constants from temperature and calculate viscosity
C   Range: 240K - 390K. If out of range print warning and return an approximate
C   value of viscosity using constants from closest known range.
C
107  IF (TEMPK .LT. AMMSV1) THEN
C   These values assumed to apply to all temperatures below 240K in order to
C   avoid returning a zero viscosity to GFSSP.
      A=-5.35E-03
      B=1.142E-04
      C=-3.36E-07
      D=4.727E-10
      GO TO 111
ELSEIF (TEMPK .LE. AMMSV2) THEN
      A=-5.35E-03
      B=1.142E-04
      C=-3.36E-07
      D=4.727E-10
      GO TO 112
ELSEIF (TEMPK .LE. AMMSV3) THEN
      A=-0.8064
      B=6.873E-03
      C=-1.94E-05
      D=1.833E-08
      GO TO 112
ELSE
C   These values assumed to apply to all temperatures above 390K in order to
C   avoid returning a zero viscosity to GFSSP.
      A=-0.8064
      B=6.873E-03
      C=-1.94E-05
      D=1.833E-08
      GO TO 111
ENDIF
111  WRITE(NGFSOUT,*) 'T OUT OF RANGE OF NH3 SAT VAPOR PROPS IN VISCTY'

```

```

112      VSI=(A+(B*TEMPK)+(C*(TEMPK**2))+(D*(TEMPK**3)))/1000.
          GO TO 500
C
C   Determine vapor constants from temperature and calculate viscosity
C   Range: 200K - 1000K. If out of range print warning and return an approximate
C   value of viscosity using constants from closest known range.
C
108      IF (TEMPK .LT. AMMV1) THEN
C   These values assumed to apply to all temperatures below 200K in order to
C   avoid returning a zero viscosity to GFSSP.
          A=0.41986
          B=492.273
          C=-34532.
          D=2.74E+05
          GO TO 113
      ELSEIF (TEMPK .LE. AMMV2) THEN
          A=0.41986
          B=492.273
          C=-34532.
          D=2.74E+05
          GO TO 114
      ELSEIF (TEMPK .LE. AMMV3) THEN
          A=0.43106
          B=481.745
          C=-31700.
          D=0.0
          GO TO 114
      ELSE
C   These values assumed to apply to all temperatures above 1000K in order to
C   avoid returning a zero viscosity to GFSSP.
          A=0.43106
          B=481.745
          C=-31700.
          D=0.0
          GO TO 113
      ENDIF
113      WRITE(NGFSOUT,'(T OUT OF RANGE OF NH3 VAPOR PROPS IN VISCTY'
114      VSI=(SQRT(TEMPK)/(A+(B/TEMPK)+(C/(TEMPK**2))+
& (D/(TEMPK**3))))/1000000.
          GO TO 500
C

```

```

C   Convert viscosity from kg/m-s to lbm/ft-s
C
500      V=VSI/1.4882
          RETURN
          END
C*****
SUBROUTINE CHKGSPK
C
C   This subroutine checks the final values of pressure and temperature
C   at each node in order to determine if they are out of GASPAK's property
C   range for the fluid or fluids present at that node.  If there are any
C   nodes with pressure and/or temperature out of range a warning is
C   written to the user's output file.
C
C*****
INCLUDE 'COMBLK.FOR'
C*****
C
C   Define all routine specific variables
C
      INTEGER I, J, L, PFLAG, TFLAG
C
C   Check to see if the fluid is one of the refrigerants for
C   which the REFPROP sat. liquid and sat. vapor scheme is used.
C   If so, print a warning statement to this effect.
C
      DO L=1,NF
        DO M=5,10
          IF (NFLUID(L) .EQ. NCVFL(M)) WRITE(NPRNT,99)NAMEF(NFLUID(L))
        ENDDO
      ENDDO
C
C   Start the loop to check fluid ranges at each node.
C
      DO I=1,NNODES
        PFLAG=0
        TFLAG=0
C
C   Compare the pressures and temperatures to the ranges of each fluid
C   present in the current node and flag if they are out of range for
C   any one of the fluids present.

```

```

C
DO J=1,NF
    IF (NFLUID(J) .EQ. 33) GO TO 25
    IF (CX(I,J) .GT. 1.0E-04) THEN
        IF (P(I) .LT. GPPMIN(NFLUID(J)) .OR.
& P(I) .GT. GPPMAX(NFLUID(J))) THEN
            PFLAG=PFLAG+1
        ENDIF
        IF (TF(I) .LT. GPTMIN(NFLUID(J)) .OR.
& TF(I) .GT. GPTMAX(NFLUID(J))) THEN
            TFLAG=TFLAG+1
        ENDIF
    ENDIF
    CONTINUE
25
ENDDO
C
C If pressure and/or temperature at the current node
C was flagged write a warning to the user's output file.
C
IF ((PFLAG .GT. 0) .OR. (TFLAG .GT. 0)) THEN
    IF (.NOT. STEADY) WRITE(NPRNT,100) ISTEP
ENDIF
IF (PFLAG .GT. 0) THEN
    WRITE (NPRNT,101) NODE(I)
ENDIF
IF (TFLAG .GT. 0) THEN
    WRITE (NPRNT,102) NODE(I)
ENDIF
ENDDO
99 FORMAT(//,2X,'WARNING! Reynolds number calculated',
& ' using reference viscosity for',A5)
100 FORMAT(//,2X,'AT ISTEP=',I4)
101 FORMAT(//,2X,'WARNING! P out of fluid property range at node',I4)
102 FORMAT(//,2X,'WARNING! T out of fluid property range at node',I4)
RETURN
END
C*****
SUBROUTINE INITGP
C PURPOSE: OBTAIN PROPERTIES FROM GASPAK
C*****
INCLUDE 'COMBLK.FOR'

```

```

C*****
CHARACTER INPAR1*1, INPAR2*1, COFILE*64, OUTPAR*2, MESSAG*72
DOUBLE PRECISION VALU1, VALU2, PROP(0:31,0:2)
INTEGER IDID, IOUNIT
C
CHARACTER*11 UCONA, UARRAY
DOUBLE PRECISION CONST
LOGICAL BYPASS
DIMENSION CONST(0:21), UCONA(0:21), UARRAY(0:31)
DIMENSION RHOF(12), EMUF(12), ENTH(12), GAMAF(12), ZF(12), CONDF1(12)
DIMENSION XVF(12)
C OPEN AN OUTPUT FILE TO WRITE MESSAGES OF GSPAK
OPEN (NGSPK, FILE = 'USER.OUT', STATUS='UNKNOWN')
C SELECT PRECISON
CALL PRECIS(2)

IF(NFLUID(1) .EQ. 12 .OR. NFLUID(1) .EQ. 33) BYPASS = .TRUE.

IF( .NOT. BYPASS) THEN

C SPECIFY THE FLUID BY NAMING ITS COEFFICIENT FILE
CALL SETFLUID(COFILE,NFLUID(1),1)
CALL READCF(COFILE, IDID)
IF (IDID .LT. 0) THEN
    CALL GASERR(MESSAG, IDID)
    WRITE(NGSPK,86) MESSAG
    STOP 'COEFFICIENT FILE ERROR'
ENDIF
C SELECT UNIT
IOUNIT=4
C SELECT PARAMETERS TO BE CALCULATED
OUTPAR = '***'
C FIND FIXED PARAMETERS FOR THAT FLUID
CALL UNILIB(IOUNIT)
CALL GASCON(CONST,UCONA)
WRITE(NGSPK,81) COFILE
DO J = 1,15
    WRITE(NGSPK,82) J, CONST(J), UCONA(J)
ENDDO

ENDIF ! IF (.NOT. BYPASS)

```

```

C***  

C      FOR PURE FLUID  

C***  

IF (.NOT. MIXTURE .AND. ENERGY) THEN  

IF(NFLUID(1) .EQ. 12 .OR. NFLUID(1) .EQ. 33) BYPASS = .TRUE.  

IF( .NOT. BYPASS) THEN  

C      SPECIFY THE FLUID BY NAMING ITS COEFFICIENT FILE  

CALL SETFLUID(COFILE,NFLUID(1),1)  

CALL READCF(COFILE, IDID)  

IF (IDID .LT. 0) THEN  

    CALL GASERR(MESSAG, IDID)  

    WRITE(NGSPK,86) MESSAG  

    STOP 'COEFFICIENT FILE ERROR'  

ENDIF  

C      SELECT UNIT  

IOUNIT=4  

C      SELECT PARAMETERS TO BE CALCULATED  

OUTPAR ='***'  

C      FIND FIXED PARAMETERS FOR THAT FLUID  

CALL UNILIB(IOUNIT)  

CALL GASCON(CONST,UCONA)  

WRITE(NGSPK,81) COFILE  

DO J = 1,15  

    WRITE(NGSPK,82) J, CONST(J),UCONA(J)
ENDDO  

ENDIF ! IF ( .NOT. BYPASS)  

C      CALCULATE PROPERTIES AT THE INTERNAL NODE  

DO I = 1,NINT  

    NUMBER=INODE(I)  

C      FIND INDEX FOR INODE(I)  

    DO II = 1, NNODS  

        IF (NUMBER .EQ. NODE(II)) IP = II
    ENDDO  

IF(.NOT. BYPASS) THEN

```

```

INPAR1 = 'P'
VALU1 = P(IP)/144.
INPAR2 = 'T'
VALU2 = TF(IP)
CALL CALC(IDID,PROP,OUTPAR,INPAR1,VALU1,INPAR2,VALU2,
&           COFILE,IOUNIT)
C      WRITE AN ERROR MESSAGE IF THE CALCULATION FAILED
      IF (IDID .LT. 0) THEN
        CALL GASERR(MESSAG,IDID)
        WRITE(NGSPK,86) MESSAG
        STOP 'CALCULATION 1 FAILURE'
      ENDIF
C      XV(IP)=PROP(0,0)
      RHO(IP)=PROP(3,0)
      H(IP)=PROP(5,0)
      CONDF(IP)=PROP(22,0)
      EMU(IP)=PROP(21,0)
      GAMA(IP)=PROP(11,0)
      RNODE(IP)=CONST(1)*HEQ
      ENTROPY(IP)=PROP(4,0)
      PR(IP)=PROP(24,0)
      CVNODE(IP)=PROP(9,0)
      CPNODE(IP)=PROP(10,0)
      Z(IP)=P(IP)/(RHO(IP)*RNODE(IP)*TF(IP))
      IF ((IDID .EQ. 1) .OR. (IDID .EQ. 2)) THEN
        IF (Z(IP) .LT. 0.9) THEN
          XV(IP)=0.0
        ELSE
          XV(IP)=1.0
        ENDIF
      ENDIF
      IF (IDID .EQ. 3) XV(IP)=PROP(0,0)
      IF (IDID .EQ. 4) XV(IP)=0.0
      IF (IDID .EQ. 5) XV(IP)=1.0
C      FOR WATER,R11,R12,R22,R32,R123,R124,R125,R134a,R152a,
C      AND AMMONIA VISCOSITY & CONDUCTIVITY ARE COMPUTED FROM
C      ASHRAE CORRELATIONS
      DO L=1,11
        IF (NFLUID(1) .EQ. NCVFL(L)) THEN
          IF (Z(IP) .LT. 0.5) THEN
            INDX = 1

```

```

ELSE
    INDX = 3
ENDIF
TEMP = TF(IP)
QUAL=XV(IP)
NAFL=NFLUID(1)
CALL CONDCTV(NAFL,INDX,QUAL,TEMP,CONDCT)
CALL VISCTY(NAFL,INDX,QUAL,TEMP,VISC)
CONDF(IP) = CONDCT
EMU(IP) = VISC
ENDIF
ENDDO

ENDIF
C      SUPPLY PROPERTIES OF RP1 & IDEAL GAS
C      RP-1
IF (NFLUID(1) .EQ. 12 ) THEN
    PRS = P(IP)/144.
    TEMP = TF(IP)
C      OBTAIN ENTHALPY & DENSITY
    CALL RP1(1,1,PRS,TEMP,HIP,RHOIP,CPC,GAMAC,EMUC,AKC,SC,KR,ITER)
    RHO(IP)=RHOIP
    Z(IP)=P(IP)/(RHO(IP)*RGAS(NFLUID(1))*TF(IP))
    RNODE(IP)=RGAS(NFLUID(1))
    H(IP)=HIP
C      OBTAIN VISCOSITY
    CALL RP1(1,8,PRS,TEMP,HIP,RHOIP,CPC,GAMAC,EMUC,AKC,SC,KR,ITER)
C      OBTAIN GAMA
    CALL RP1(1,4,PRS,TEMP,HIP,RHOIP,CPC,GAMAC,EMUC,AKC,SC,KR,ITER)
C      OBTAIN CONDUCTIVITY
    CALL RP1(1,16,PRS,TEMP,HIP,RHOIP,CPC,GAMAC,EMUC,AKC,SC,KR,ITER)
    EMU(IP)=EMUC
    GAMA(IP)=GAMAC
    CONDF(IP)=AKC
    ENTROPY(IP)=SC
ENDIF
C      IDEAL GAS
IF (NFLUID(1) .EQ. 33) THEN
    RHO(IP)=P(IP)/(RREF*TF(IP))
    Z(IP)=1.0
    ENTROPY(IP)=CPREF*LOG(TF(IP)/TREF)-RREF*LOG(P(IP)/PREF)/HEQ

```

```

EMU( IP )=EMUREF
GAMA( IP )=GAMREF
COND( IP )=AKREF
RNODE( IP )=RREF
H( IP )=CPREF*TF( IP )
ENDIF

ENDDO
C      CALCULATE PROPERTIES AT THE BOUNDARY NODES
DO I = 1, NNODES

      IF ( INDEX( I ) .EQ. 2 ) THEN

          IF ( .NOT. BYPASS ) THEN

              INPAR1 = 'P'
              VALU1=P(I)/144.
              INPAR2 = 'T'
              VALU2 = TF(I)
              CALL CALC( IDID,PROP,OUTPAR,INPAR1,VALU1,INPAR2,VALU2,
&                      COFILE,IOUNIT)
C      WRITE AN ERROR MESSAGE IF THE CALCULATION FAILED
          IF ( IDID .LT. 0 ) THEN
              CALL GASERR(MESSAG, IDID)
              WRITE(NGSPK,86) MESSAG
              STOP 'CALCULATION 1 FAILURE'
          ENDIF
C      XV(I)=PROP(0,0)
          RHO( I )=PROP( 3 , 0 )
          H( I )=PROP( 5 , 0 )
          COND( I )=PROP( 22 , 0 )
          EMU( I )=PROP( 21 , 0 )
          GAMA( I )=PROP( 11 , 0 )
          RNODE( I )=CONST(1)*HEQ
          ENTROPY( I )=PROP( 4 , 0 )
          PR( I )=PROP( 24 , 0 )
          CVNODE( I )=PROP( 9 , 0 )
          CPNODE( I )=PROP( 10 , 0 )
          Z( I )=P( I )/(RHO( I )*RNODE( I )*TF( I ))
          IF (( IDID .EQ. 1 ) .OR. ( IDID .EQ. 2 )) THEN
              IF ( Z(IP) .LT. 0.9 ) THEN

```

```

        XV(IP)=0.0
    ELSE
        XV(IP)=1.0
    ENDIF
ENDIF
IF (IDID .EQ. 3) XV(IP)=PROP(0,0)
IF (IDID .EQ. 4) XV(IP)=0.0
IF (IDID .EQ. 5) XV(IP)=1.0
C     FOR WATER,R11,R12,R22,R32,R123,R124,R125,R134a,R152a,
C     AND AMMONIA VISCOSITY & CONDUCTIVITY ARE COMPUTED FROM
C     ASHRAE CORRELATIONS
DO L=1,11
    IF (NFLUID(1) .EQ. NCVFL(L)) THEN
        IF (Z(I) .LT. 0.5) THEN
            INDX = 1
        ELSE
            INDX = 3
        ENDIF
        TEMP = TF(I)
        QUAL=XV(I)
        NAFL=NFLUID(1)
        CALL CONDCTV(NAFL,INDX,QUAL,TEMP,CONDCT)
        CALL VISCTY(NAFL,INDX,QUAL,TEMP,VISC)
        CONDF(I) = CONDCT
        EMU(I) = VISC
    ENDIF
ENDDO
ENDIF !( IF .NOT. BYPASS..)

C     SUPPLY PROPERTIES OF RP1 & IDEAL GAS
C     RP-1
    IF (NFLUID(1) .EQ. 12 ) THEN
        PRS = P(I)/144.
        TEMP = TF(I)
    ENDIF
C     OBTAIN ENTHALPY & DENSITY
    CALL RP1(1,1,PRS,TEMP,HIP,RHOIP,CPC,GAMAC,EMUC,AKC,SC,KR,ITER)
    RHO(I)=RHOIP
    Z(I)=P(I)/(RHO(I)*RGAS(NFLUID(1))*TF(I))
    RNODE(I)=RGAS(NFLUID(1))
    H(I)=HIP

```

```

C      OBTAIN VISCOSITY
      CALL RP1(1,8,PRS,TEMP,HIP,RHOIP,CPC,GAMAC,EMUC,AKC,SC,KR,ITER)
C      OBTAIN GAMA
      CALL RP1(1,4,PRS,TEMP,HIP,RHOIP,CPC,GAMAC,EMUC,AKC,SC,KR,ITER)
C      OBTAIN CONDUCTIVITY
      CALL RP1(1,16,PRS,TEMP,HIP,RHOIP,CPC,GAMAC,EMUC,AKC,SC,KR,ITER)
      EMU(I)=EMUC
      GAMA(I)=GAMAC
      CONDF(I)=AKC
      ENTROPY(I)=SC
      ENDIF
C      IDEAL GAS
      IF (NFLUID(1) .EQ. 33) THEN
          RHO(I)=P(I)/(RREF*TF(I))
          Z(I)=1.0
          ENTROPY(IP)=CPREF*LOG(TF(IP)/TREF)-RREF*LOG(P(IP)/PREF)/HEQ
          EMU(I)=EMUREF
          GAMA(I)=GAMREF
          CONDF(I)=AKREF
          RNODE(I)=RREF
          ENDIF
      ENDIF
ENDDO
ELSE
C*****
C      FOR MIXTURE
C      CALCULATE MOLAR CONCENTRATION
      CALL MOLC
C      CALCULATE PROPERTIES AT INTERNAL AND BOUNDARY NODES
      DO IP = 1,NNODES
C      OBTAIN PROPERTIES OF INDIVIDUAL SPECIES
      DO J = 1, NF
          IF (CM(IP,J) .NE. 0) THEN
              PJ=CM(IP,J)*P(IP)/144.
              TEMP=TF(IP)
              IF (NFLUID(J) .EQ. 12 .OR. NFLUID(J) .EQ. 33)
&                  BYPASS = .TRUE.

```

```

        IF (.NOT. BYPASS) THEN
C      SPECIFY THE FLUID BY NAMING ITS COEFFICIENT FILE
          CALL SETFLUID(COFILE,NFLUID(J),J)
          CALL READCF(COFILE, IDID)
          IF (IDID .LT. 0) THEN
            CALL GASERR(MESSAG, IDID)
            WRITE(NGSPK,86) MESSAG
            STOP 'COEFFICIENT FILE ERROR'
          ENDIF
C      SELECT UNIT
          IOUNIT = 4
C      SELECT PARAMETERS TO BE CALCULATED
          OUTPAR = '***'
C      FIND FIXED PARAMETERS FOR THAT FLUID
          CALL UNILIB(IOUNIT)
          CALL GASCON(CONST,UCONA)
          INPAR1 = 'P'
          VALU1 = PJ
          INPAR2 = 'T'
          VALU2 = TF(IP)
          CALL CALC(IDID,PROP,OUTPAR,INPAR1,VALU1,INPAR2,VALU2,
&                      COFILE,IOUNIT)
C      WRITE AN ERROR MESSAGE IF THE CALCULATION FAILED
          IF (IDID .LT. 0) THEN
            CALL GASERR(MESSAG, IDID)
            WRITE (NGSPK,86) MESSAG
            STOP 'CALCULATION 1 FAILURE'
          ENDIF
C      XVF(J)=PROP(0,0)
          RHOF(J)=PROP(3,0)
          ENTH(J)=PROP(5,0)+DELHGP(NFLUID(J))
          EMUF(J)=PROP(21,0)
          CONDF1(J)=PROP(22,0)
          GAMAF(J)=PROP(11,0)
          RGAS(NFLUID(J))=CONST(1)*HEQ
          ZF(J)=PJ*144./(RHOF(J)*RGAS(NFLUID(J))*TF(IP))
          IF ((IDID .EQ. 1) .OR. (IDID .EQ. 2)) THEN
            IF (Z(IP) .LT. 0.9) THEN
              XVF(J)=0.0
            ELSE
              XVF(J)=1.0
            ENDIF
          ENDIF
        ENDIF
      ENDIF
    ENDIF
  ENDIF
ENDIF

```

```

        ENDIF
    ENDIF
    IF (IDID .EQ. 3) XVF(J)=PROP(0,0)
    IF (IDID .EQ. 4) XVF(J)=0.0
    IF (IDID .EQ. 5) XVF(J)=1.0
C      FOR WATER,R11,R12,R22,R32,R123,R124,R125,R134a,R152a,
C      AND AMMONIA VISCOSITY & CONDUCTIVITY ARE COMPUTED FROM
C      ASHRAE CORRELATIONS
    DO LL=1,11
        IF (NFLUID(J) .EQ. NCVFL(LL)) THEN
            IF (ZF(J) .LT. 0.5) THEN
                INDX = 1
            ELSE
                INDX = 3
            ENDIF
            TEMP = TF(IP)
            QUAL=XVF(J)
            NAFL=NFLUID(J)
            CALL CONDCTV(NAFL,INDX,QUAL,TEMP,CONDCT)
            CALL VISCTY(NAFL,INDX,QUAL,TEMP,VISC)
            CONDF1(J) = CONDCT
            EMUF(J) = VISC
        ENDIF
    ENDDO
    ENDIF ! (IF (.NOT. BYPASS..))
C OBTAIN PROPERTIES OF RP1 & IDEAL GAS, IF NECESSARY
C RP-1
    IF (NFLUID(J) .EQ. 12) THEN
C OBTAIN ENTHALPY & DENSITY
        CALL RP1(1,1,PJ,TEMP,ENTHJ,RHOBJ,CPC,GAMAC,EMUC,AKC,SC,KR
        & ,ITER)
        ENTH(J)=ENTHJ
        RHOBJ=RHOBJ
C OBTAIN VISCOSITY
        CALL RP1(1,8,PJ,TEMP,ENTHJ,RHOBJ,CPC,GAMAC,EMUC,AKC,SC,KR
        & ,ITER)
        EMUF(J)=EMUC
C OBTAIN GAMA
        CALL RP1(1,4,PJ,TEMP,ENTHJ,RHOBJ,CPC,GAMAC,EMUC,AKC,SC,KR
        & ,ITER)
        GAMAF(J)=GAMAC

```

```

C      OBTAIN CONDUCTIVITY
      CALL RP1(1,16,PJ,TEMP,ENTHJ,RHOJ,CPC,GAMAC,EMUC,AKC,SC,KR
&          ,ITER)
      CONDF1(J)=AKC
      ENDIF
C*****
C      IDEAL GAS
C
      IF (NFLUID(J) .EQ. 33) THEN
          ENTH(J)=CPREF*TEMP
          RHOJ(PJ)=PJ*144./ (RREF*TEMP)
          EMUF(J)=EMUREF
          GAMAF(J)=GAMREF
          ZF(J)=1.0
      ENDIF

      ENDIF !(IF CM(IP,J) .NE. 0...)
ENDDO ! (DO J = 1,NF..)

C      CALCULATE MIXTURE PROPERTIES

      SUMDN=0.0
      SUMDD=0.0
      SUMH=0.0
      SUMM=0.0
      SUMZ=0.0
      SUMG=0.0
      SUMCON=0.0
      DO J = 1, NF
          SUMDN=SUMDN+RHOJ(NFLUID(J))*CM(IP,J)
          SUMDD=SUMDD+CM(IP,J)*RGAS(NFLUID(J))
          SUMH=SUMH+CX(IP,J)*ENTH(J)
          SUMM=SUMM+EMUF(J)*CM(IP,J)
          SUMZ=SUMZ+CM(IP,J)*ZF(J)
          SUMG=SUMG+CM(IP,J)*GAMAF(J)
          SUMCON=SUMCON+CM(IP,J)*CONDF1(J)
      ENDDO
      RHO(IP)=SUMDN/SUMDD
      Z(IP)=SUMZ
      H(IP)=SUMH

```

```

EMU( IP )=SUMM
GAMA( IP )=SUMG
RNODE( IP )=SUMDD
CONDF( IP )=SUMCON

ENDDO !(DO IP = )

ENDIF ! ( IF (.NOT. MIXTURE...)

RETURN

81   FORMAT('FIXED PTS FROM ',A11)
82   FORMAT(I5,G16.4,A11)
86   FORMAT(1X,A72)
END
C*****
SUBROUTINE SETFLUID(COFILE,NFLUID,J)
C PURPOSE: SELECT DATA FILE
C*****
CHARACTER*64, COFILE
DIMENSION NFLUID(50)
IF (NFLUID(J) .EQ. 1) COFILE= 'HE89.GAS'
IF (NFLUID(J) .EQ. 2) COFILE= 'CH489.GAS'
IF (NFLUID(J) .EQ. 3) COFILE= 'NE91.GAS'
IF (NFLUID(J) .EQ. 4) COFILE= 'N286.GAS'
IF (NFLUID(J) .EQ. 5) COFILE= 'CO85.GAS'
IF (NFLUID(J) .EQ. 6) COFILE= 'O285.GAS'
IF (NFLUID(J) .EQ. 7) COFILE= 'ARGON83.GAS'
IF (NFLUID(J) .EQ. 8) COFILE= 'CO289.GAS'
IF (NFLUID(J) .EQ. 9) COFILE= 'PH275.GAS'
IF (NFLUID(J) .EQ. 10) COFILE= 'NH291.GAS'
IF (NFLUID(J) .EQ. 11) COFILE= 'H2089.GAS'
IF (NFLUID(J) .EQ. 12) COFILE= 'rpl.gas'
IF (NFLUID(J) .EQ. 13) COFILE= 'ISOB86.GAS'
IF (NFLUID(J) .EQ. 14) COFILE= 'NORB86.GAS'
IF (NFLUID(J) .EQ. 15) COFILE= 'D286.GAS'
IF (NFLUID(J) .EQ. 16) COFILE= 'C2H686.GAS'
IF (NFLUID(J) .EQ. 17) COFILE= 'C2H486.GAS'
IF (NFLUID(J) .EQ. 18) COFILE= 'H2S93.GAS'
IF (NFLUID(J) .EQ. 19) COFILE= 'KR90.GAS'
IF (NFLUID(J) .EQ. 20) COFILE= 'C3H886.GAS'

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IF (NFLUID(J) .EQ. 21) COFILE= 'XE90.GAS'
IF (NFLUID(J) .EQ. 22) COFILE= 'R1191.GAS'
IF (NFLUID(J) .EQ. 23) COFILE= 'R1291.GAS'
IF (NFLUID(J) .EQ. 24) COFILE= 'R2291.GAS'
IF (NFLUID(J) .EQ. 25) COFILE= 'R32N93.GAS'
IF (NFLUID(J) .EQ. 26) COFILE= 'R123N93.GAS'
IF (NFLUID(J) .EQ. 27) COFILE= 'R124N93.GAS'
IF (NFLUID(J) .EQ. 28) COFILE= 'R125N93.GAS'
IF (NFLUID(J) .EQ. 29) COFILE= 'R134AT93.GAS'
IF (NFLUID(J) .EQ. 30) COFILE= 'R152AT94.GAS'
IF (NFLUID(J) .EQ. 31) COFILE= 'NF380.GAS'
IF (NFLUID(J) .EQ. 32) COFILE= 'NH379.GAS'
RETURN
END
C*****
C          SUBROUTINE BOUNDGP
C          PURPOSE: OBTAIN PROPERTIES OF BOUNDARY NODES FROM GSPAK
C*****
C          INCLUDE 'COMBLK.FOR'
C*****
CHARACTER INPAR1*1, INPAR2*1, COFILE*64, OUTPAR*2, MESSAG*72
DOUBLE PRECISION VALU1, VALU2, PROP(0:31,0:2)
INTEGER IDID, IOUNIT
C
CHARACTER*11 UCONA, UARRAY
DOUBLE PRECISION CONST
DIMENSION CONST(0:21), UCONA(0:21), UARRAY(0:31)
C
OPEN AN OUTPUT FILE TO WRITE MESSAGES OF GSPAK
OPEN (NGSPK, FILE = 'USER.OUT', STATUS='UNKNOWN')
C
SELECT PRECISON
CALL PRECIS(2)
C
SPECIFY THE FLUID BY NAMING ITS COEFFICIENT FILE

IF(NFLUID(1).LT.33) THEN

    CALL SETFLUID(COFILE,NFLUID(1),1)
    CALL READCF(COFILE,IDID)
    IF (IDID .LT. 0) THEN
        CALL GASERR(MESSAG, IDID)
        WRITE(NGSPK,86) MESSAG
        STOP 'COEFFICIENT FILE ERROR'

```

```

ENDIF
C   SELECT UNIT
IOUNIT=4
C   SELECT PARAMETERS TO BE CALCULATED
OUTPAR = '***'
C   FIND FIXED PARAMETERS FOR THAT FLUID
CALL UNILIB(IOUNIT)
CALL GASCON(CONST,UCONA)
WRITE(NGSPK,81) COFILE
DO J = 1,15
WRITE(NGSPK,82) J, CONST(J),UCONA(J)
ENDDO
81 FORMAT('FIXED PTS FROM ',A11)
82 FORMAT(I5,G16.4,A11)
86 FORMAT(1X, A72)

ENDIF ! (IF(NFLUID(1))...)

C   CALCULATE PROPERTIES AT THE BOUNDARY NODES
DO I = 1, NNODES
  IF (INDEX(I) .EQ. 2) THEN
    IF(NFLUID(1).LT.33) THEN
      INPAR1 = 'P'
      VALU1=P(I)/144.
      INPAR2 = 'T'
      VALU2 = TF(I)
      CALL CALC(IDID,PROP,OUTPAR,INPAR1,VALU1,INPAR2,VALU2,
      &           COFILE,IOUNIT)
    C   WRITE AN ERROR MESSAGE IF THE CALCULATION FAILED
      IF (IDID .LT. 0) THEN
        CALL GASERR(MESSAG,IDID)
        WRITE(NGSPK,86) MESSAG
        STOP 'CALCULATION 1 FAILURE'
      ENDIF
    C   XV(I)=PROP(0,0)
    RHO(I)=PROP(3,0)
    H(I)=PROP(5,0)
    CONDF(I)=PROP(22,0)
    EMU(I)=PROP(21,0)
  ENDIF
END

```

```

GAMA( I )=PROP( 11 , 0 )
RNODE( I )=CONST( 1 )*HEQ
ENTROPY( I )=PROP( 4 , 0 )
PR( I )=PROP( 24 , 0 )
CVNODE( I )=PROP( 9 , 0 )
CPNODE( I )=PROP( 10 , 0 )
Z( I )=P( I )/( RHO( I )*RNODE( I )*TF( I ))
IF (( IDID .EQ. 1 ) .OR. ( IDID .EQ. 2 )) THEN
  IF ( Z( I ) .LT. 0.9 ) THEN
    XV( I )=0.0
  ELSE
    XV( I )=1.0
  ENDIF
ENDIF
IF ( IDID .EQ. 3 ) XV( I )=PROP( 0 , 0 )
IF ( IDID .EQ. 4 ) XV( I )=0.0
IF ( IDID .EQ. 5 ) XV( I )=1.0
C      FOR WATER,R11,R12,R22,R32,R123,R124,R125,R134a,R152a,
C      AND AMMONIA VISCOSITY & CONDUCTIVITY ARE COMPUTED FROM
C      ASHRAE CORRELATIONS
DO L=1,11
  IF (NFLUID(1) .EQ. NCVFL(L)) THEN
    IF (Z( I ) .LT. 0.5 ) THEN
      INDX = 1
    ELSE
      INDX = 3
    ENDIF
    TEMP = TF( I )
    QUAL=XV( I )
    NAFL=NFLUID(1)
    CALL CONDCTV(NAFL,INDX,QUAL,TEMP,CONDCT)
    CALL VISCTY(NAFL,INDX,QUAL,TEMP,VISC)
    CONDF(I) = CONDCT
    EMU(I) = VISC
  ENDIF
ENDDO
ENDIF ! ( IF (NFLUID(1)...)
C
C      IDEAL GAS

```

```

C
IF (NFLUID(1) .EQ. 33) THEN
RHO(I)=P(I)/(RREF*TF(I))
Z(I)=1.0
ENTROPY(I)=CPREF*LOG(TF(I)/TREF)-RREF*LOG(P(I)/PREF)/HEQ
EMU(I)=EMUREF
GAMA(I)=GAMREF
COND(I)=AKREF
RNODE(I)=RREF
ENDIF

ENDIF ! (IF INDEX(I)...)
C
ENDDO
RETURN
END
C*****
C*****
C          ***** END OF USER SUBROUTINES *****
C*****

```

G F S S P (Version 3.0)
Generalized Fluid System Simulation Program
September, 1999
Developed by Sverdrup Technology
Copyright (C) by Marshall Space Flight Center

A generalized computer program to calculate flow
rates, pressures, temperatures and concentrations
in a flow network.

TITLE :Simulation of the Blow Down of a Pressurized Tank
ANALYST :Alok Majumdar
FILEIN :EX8.DAT
FILEOUT :EX8.OUT
LOGICAL VARIABLES
DENCON = F
GRAVITY = F
ENERGY = T
MIXTURE = F
THRUST = F
STEADY = F
TRANSV = T
SAVER = F
HEX = F
HCOEF = F
REACTING = F
INERTIA = F
CONDX = F
TWOD = F
PRINTI = T
ROTATION = F
BUOYANCY = F

HRATE = F
INVAL = F
MSOURCE = F
MOVBND = F
TPA = F
VARGEO = F
TVM = F
SHEAR = F
PRNTIN = F
PRNTADD = F
ADDPROP = T
PRESS = F
INSUC = F
VARROT = F
NORMAL = F
SECONDL = T

NNODES = 2
NINT = 1
NBR = 1
NF = 1
NVAR = 3
NHREF = 2

FLUIDS: IDEL

BOUNDARY NODES

NODE	P (PSI)	T (F)	RHO (LB/M/FT^3)	AREA (IN^2)
2	0.1470E+02	0.8000E+02	0.7356E-01	0.0000E+00

ISTEP = 25 TAU = 0.25000E+02

BOUNDARY NODES

NODE	P(PSI)	TF(F)	Z(COMP) (LB/M/F)	R T^3)	HO	QUALITY
2	0.1470E+02	0.8000E+02	0.1000E+01	0.7356E-01	0.0000E+00	

SOLUTION

INTERNAL NODES

NODE	P(PSI)	TF(F)	Z	RHO (LBM/FT ³)	EM(LBM)	QUALITY
1	0.8831E+02	0.6118E+02	0.1000E+01	0.4579E+00	0.4579E+01	0.0000E+00

BRANCHES

BRANCH	KFACTOR (LBF-S ² /(LBM-FT) ²)	DELP (PSI)	FLOW RATE (LBM/SEC)	VELOCITY (FT/SEC)	REYN. NO.	MACH NO.	ENTROPY GEN. BTU/(R-SEC)	LOST WORK LBF-FT/SEC
12	0.114E+08	0.736E+02	0.162E-01	0.647E+03	0.196E+06	0.579E+00	0.260E-03	0.105E+03

***** TOTAL ENTROPY GENERATION = 0.260E-03 BTU/(R-SEC) *****

***** TOTAL WORK LOST = 0.191E+00 HP *****

ISTEP = 50 TAU = 0.50000E+02

BOUNDARY NODES

NODE	P(PSI)	TF(F)	Z(COMP)	R (LBM/F T ³)	HO	QUALITY
2	0.1470E+02	0.8000E+02	0.1000E+01	0.7356E-01		0.0000E+00

SOLUTION

INTERNAL NODES

NODE	P(PSI)	TF(F)	Z	RHO (LBM/FT ³)	EM(LBM)	QUALITY
1	0.7816E+02	0.4333E+02	0.1000E+01	0.4196E+00	0.4196E+01	0.0000E+00

BRANCHES

BRANCH	KFACTOR (LBF-S ² /(LBM-FT) ²)	DELP (PSI)	FLOW RATE (LBM/SEC)	VELOCITY (FT/SEC)	REYN. NO.	MACH NO.	ENTROPY GEN. BTU/(R-SEC)	LOST WORK LBF-FT/SEC
12	0.125E+08	0.635E+02	0.146E-01	0.636E+03	0.176E+06	0.579E+00	0.234E-03	0.915E+02

***** TOTAL ENTROPY GENERATION = 0.234E-03 BTU/(R-SEC) *****

***** TOTAL WORK LOST = 0.166E+00 HP *****

```

ISTEP = 200          TAU = 0.20000E+03
BOUNDARY NODES
  NODE    P(PSI)      TF(F)      Z(COMP)      R      HO      QUALITY
              (LBM/F      T^3)
  2     0.1470E+02  0.8000E+02  0.1000E+01  0.7356E-01  0.0000E+00

SOLUTION
INTERNAL NODES
  NODE    P(PSI)      TF(F)      Z          RHO          EM(LBM)      QUALITY
              (LBM/FT^3)
  1     0.3915E+02 -0.4677E+02  0.1000E+01  0.2561E+00  0.2561E+01  0.0000E+00

BRANCHES
BRANCH      KFACTOR      DELP      FLOW RATE      VELOCITY      REYN. NO.      MACH NO.      ENTROPY GEN.      LOST WORK
              (LBF-S^2/(LBM-FT)^2) (PSI)      (LBM/SEC)      (FT/SEC)      BTU/(R-SEC)      LBF-FT/SEC
  12     0.204E+08     0.244E+02     0.804E-02     0.576E+03     0.976E+05     0.579E+00     0.129E-03     0.415E+02

```

***** TOTAL ENTROPY GENERATION = 0.129E-03 BTU/(R-SEC) *****

***** TOTAL WORK LOST = 0.755E-01 HP *****

```

SOLUTION SATISFIED CONVERGENCE CRITERION OF 0.100E-03 IN 7 ITERATIONS
TAU = 200.000      ISTEP = 200

```

APPENDIX N

INPUT AND OUTPUT DATA FILES FROM EXAMPLE 9

A Reciprocating Piston-Cylinder

Contents	Page
Example 9 Input File	N-2
Example 9 History File	N-4
Example 9 Output File (Partial)	N-10

```

GFSSP VERSION
300
ANALYST
PAS
INPUT DATA FILE NAME
EX9.DAT
OUTPUT FILE NAME
EX9.OUT
TITLE
Piston-Cylinder Benchmark Problem (only internal nodes)
USETUP
    F
DENCON GRAVITY ENERGY MIXTURE THRUST STEADY TRANSV SAVER
    F      F      T      F      F      T      F
HEX HCOEF REACTING INERTIA CONDX GASPAK PRINTI ROTATION
    F      F      F      F      F      F      F
BUOYANCY HRATE INVAL MSORCE MOVBND TPA VARGEO TVM
    F      F      F      F      T      F      F
SHEAR PRNTIN PRNTADD LAMINAR TRANSQ
    F      F      F      T      F
PRESS INSUC VARROT
    F      F      F
NORMAL SIMUL SECONDL
    F      F      T
NNODES NINT NBR NF
    2      2      1      1
RELAXK RELAXD RELAXH CC NITER
    1.000  0.500  1.000  0.100E-03   500
DTAU TIMEF TIMEL NPSTEP
    0.1000E-03 0.0000E+00 0.5000E-01       1
NFLUID(I), I= 1,NF
    4
NODE INDEX
    1      1
    2      1
NODE PRES (PSI) TEMP(DEGF) MASS SOURC HEAT SOURC THRST AREA
    1 0.1470E+02 0.7500E+02 0.0000E+00 0.0000E+00 0.0000E+00 0.2474E+02
    2 0.1470E+02 0.7500E+02 0.0000E+00 0.0000E+00 0.0000E+00 0.2474E+02
E12VGHST.DAT
INODE NUMBR BRANCH 1 BRANCH 2 BRANCH 3 BRANCH 4 BRANCH 5 BRANCH 6
    1      1      12

```

```
      2      1      12
BRANCH    UPNODE     DNNODE     OPTION
      12      1      2      2
BRANCH OPTION -2: FLOW COEF, AREA
      12      0.00000    7.06858
BRANCH INITIAL FLOWRATE
      12      0
BRANCH NOUBR     NMUBR
      12      0
BRANCH NODBR     NMDBR
      12      0
BRANCH
      12
UPSTRM BR.      ANGLE
DNSTRM BR.      ANGLE
NUMBER OF NODES WITH MOVING BOUNDARY
      2
NODE
      1
      2
NODE DATA FILE
FNODE.DAT
BRANCH DATA FILE
FBRANCH.DAT
```

VARIABLE GEOMETRY HISTORY FILE

41
0.000000 0.0000 0.0000
0.001250 0.0000 0.0000
0.002500 0.0000 0.0000
0.003750 0.0000 0.0000
0.005000 0.0000 0.0000
0.006250 0.0000 0.0000
0.007500 0.0000 0.0000
0.008750 0.0000 0.0000
0.010000 0.0000 0.0000
0.011250 0.0000 0.0000
0.012500 0.0000 0.0000
0.013750 0.0000 0.0000
0.015000 0.0000 0.0000
0.016250 0.0000 0.0000
0.017500 0.0000 0.0000
0.018750 0.0000 0.0000
0.020000 0.0000 0.0000
0.021250 0.0000 0.0000
0.022500 0.0000 0.0000
0.023750 0.0000 0.0000
0.025000 0.0000 0.0000
0.026250 0.0000 0.0000
0.027500 0.0000 0.0000
0.028750 0.0000 0.0000
0.030000 0.0000 0.0000
0.031250 0.0000 0.0000
0.032500 0.0000 0.0000
0.033750 0.0000 0.0000
0.035000 0.0000 0.0000
0.036250 0.0000 0.0000
0.037500 0.0000 0.0000
0.038750 0.0000 0.0000
0.040000 0.0000 0.0000
0.041250 0.0000 0.0000
0.042500 0.0000 0.0000
0.043750 0.0000 0.0000
0.045000 0.0000 0.0000
0.046250 0.0000 0.0000

0.047500	0.0000	0.0000
0.048750	0.0000	0.0000
0.050000	0.0000	0.0000

BRANCH VOLUME

0.000000	49.48004
0.001250	49.21895
0.002500	48.44213
0.003750	47.16871
0.005000	45.43005
0.006250	43.26896
0.007500	40.73865
0.008750	37.90143
0.010000	34.82716
0.011250	31.59153
0.012500	28.27423
0.013750	24.95692
0.015000	21.72130
0.016250	18.64704
0.017500	15.80983
0.018750	13.27954
0.020000	11.11847
0.021250	9.379835
0.022500	8.106441
0.023750	7.329646
0.025000	7.068578
0.026250	7.329646
0.027500	8.106441
0.028750	9.379835
0.030000	11.11847
0.031250	13.27954
0.032500	15.80983
0.033750	18.64704
0.035000	21.72130
0.036250	24.95692
0.037500	28.27423
0.038750	31.59153
0.040000	34.82716
0.041250	37.90143
0.042500	40.73865
0.043750	43.26896
0.045000	45.43005

0.046250	47.16871
0.047500	48.44213
0.048750	49.21895
0.050000	49.48004
BRANCH AREA	
0.000000	7.06858347
0.001250	7.06858347
0.002500	7.06858347
0.003750	7.06858347
0.005000	7.06858347
0.006250	7.06858347
0.007500	7.06858347
0.008750	7.06858347
0.010000	7.06858347
0.011250	7.06858347
0.012500	7.06858347
0.013750	7.06858347
0.015000	7.06858347
0.016250	7.06858347
0.017500	7.06858347
0.018750	7.06858347
0.020000	7.06858347
0.021250	7.06858347
0.022500	7.06858347
0.023750	7.06858347
0.025000	7.06858347
0.026250	7.06858347
0.027500	7.06858347
0.028750	7.06858347
0.030000	7.06858347
0.031250	7.06858347
0.032500	7.06858347
0.033750	7.06858347
0.035000	7.06858347
0.036250	7.06858347
0.037500	7.06858347
0.038750	7.06858347
0.040000	7.06858347
0.041250	7.06858347
0.042500	7.06858347
0.043750	7.06858347

0.045000	7.06858347
0.046250	7.06858347
0.047500	7.06858347
0.048750	7.06858347
0.050000	7.06858347
1	
0.000000	7.06858347
0.001250	7.06858347
0.002500	7.06858347
0.003750	7.06858347
0.005000	7.06858347
0.006250	7.06858347
0.007500	7.06858347
0.008750	7.06858347
0.010000	7.06858347
0.011250	7.06858347
0.012500	7.06858347
0.013750	7.06858347
0.015000	7.06858347
0.016250	7.06858347
0.017500	7.06858347
0.018750	7.06858347
0.020000	7.06858347
0.021250	7.06858347
0.022500	7.06858347
0.023750	7.06858347
0.025000	7.06858347
0.026250	7.06858347
0.027500	7.06858347
0.028750	7.06858347
0.030000	7.06858347
0.031250	7.06858347
0.032500	7.06858347
0.033750	7.06858347
0.035000	7.06858347
0.036250	7.06858347
0.037500	7.06858347
0.038750	7.06858347
0.040000	7.06858347
0.041250	7.06858347
0.042500	7.06858347

0.043750	7.06858347	-11.10725
0.045000	7.06858347	-9.232962
0.046250	7.06858347	-7.131329
0.047500	7.06858347	-4.854099
0.048750	7.06858347	-2.457345
0.050000	7.06858347	0.000000
2		
0.000000	7.06858347	0.000000
0.001250	7.06858347	2.457263
0.002500	7.06858347	4.854020
0.003750	7.06858347	7.131254
0.005000	7.06858347	9.232895
0.006250	7.06858347	11.10719
0.007500	7.06858347	12.70799
0.008750	7.06858347	13.99588
0.010000	7.06858347	14.93914
0.011250	7.06858347	15.51456
0.012500	7.06858347	15.70795
0.013750	7.06858347	15.51456
0.015000	7.06858347	14.93916
0.016250	7.06858347	13.99590
0.017500	7.06858347	12.70802
0.018750	7.06858347	11.10722
0.020000	7.06858347	9.232928
0.021250	7.06858347	7.131292
0.022500	7.06858347	4.854059
0.023750	7.06858347	2.457304
0.025000	7.06858347	0.000000
0.026250	7.06858347	-2.457222
0.027500	7.06858347	-4.853980
0.028750	7.06858347	-7.131217
0.030000	7.06858347	-9.232861
0.031250	7.06858347	-11.10716
0.032500	7.06858347	-12.70797
0.033750	7.06858347	-13.99586
0.035000	7.06858347	-14.93913
0.036250	7.06858347	-15.51455
0.037500	7.06858347	-15.70795
0.038750	7.06858347	-15.51457
0.040000	7.06858347	-14.93917
0.041250	7.06858347	-13.99592

0.042500	7.06858347	-12.70804
0.043750	7.06858347	-11.10725
0.045000	7.06858347	-9.232962
0.046250	7.06858347	-7.131329
0.047500	7.06858347	-4.854099
0.048750	7.06858347	-2.457345
0.050000	7.06858347	0.000000

```
*****
      G F S S P (Version 3.0)
      Generalized Fluid System Simulation Program
      September, 1999
      Developed by Sverdrup Technology
      Copyright (C) by Marshall Space Flight Center
```

A generalized computer program to calculate flow
rates, pressures, temperatures and concentrations
in a flow network.

```
*****
TITLE      :Piston-Cylinder Benchmark Problem (only internal nodes)
ANALYST    :PAS
FILEIN     :EX9.DAT
FILEOUT    :EX9.OUT
LOGICAL VARIABLES
DENCON     =  F
GRAVITY    =  F
ENERGY     =  T
MIXTURE    =  F
THRUST     =  F
STEADY     =  F
TRANSV     =  T
SAVER      =  F
HEX         =  F
HCOEF       =  F
REACTING   =  F
INERTIA    =  F
CONDX      =  F
TWOD        =  F
PRINTI     =  F
ROTATION   =  F
BUOYANCY   =  F
HRATE      =  F
INVAL      =  F
MSOURCE   =  F
MOVBND    =  T
TPA        =  F
```

VARGEO = T
TVM = F
SHEAR = F
PRNTIN = F
PRNTADD = F
GASPAK = F
PRESS = F
INSUC = F
VARROT = F
NORMAL = F
SECONDL = T

NNODES = 4
NINT = 4
NBR = 4
NF = 1
NVAR = 12
NHREF = 2

FLUIDS: N2

BOUNDARY NODES

NODE	P (PSI)	T (F)	RHO (LBM/FT ³)	AREA (IN ²)
------	------------	----------	-------------------------------	----------------------------

ISTEP = 1 TAU = 0.10000E-03

BOUNDARY NODES

NODE	P(PSI)	TF(F)	Z(COMP) (LBM/F)	R T ³	HO	QUALITY
------	--------	-------	--------------------	---------------------	----	---------

SOLUTION

INTERNAL NODES

NODE	P(PSI)	TF(F)	Z	RHO (LBM/FT ³)	EM(LBM)	QUALITY
1	0.2172E+02	0.1381E+03	0.1000E+01	0.9484E-01	0.1358E-02	0.1000E+01
2	0.2172E+02	0.1381E+03	0.1000E+01	0.9484E-01	0.1358E-02	0.1000E+01
3	0.2172E+02	0.1381E+03	0.1000E+01	0.9484E-01	0.2745E-02	0.1000E+01

4 0.2172E+02 0.1381E+03 0.1000E+01 0.9484E-01 0.2745E-02 0.1000E+01

BRANCHES

BRANCH	KFACTOR (LBF-S^2/(LBM-FT)^2)	DELP (PSI)	FLOW RATE (LBM/SEC)	VELOCITY (FT/SEC)	REYN. NO.	MACH NO.	ENTROPY GEN. BTU/(R-SEC)	LOST WORK LBF-FT/SEC
12	0.000E+00	0.000E+00	-0.464E-10	-0.998E-08	0.182E-04	0.819E-11	0.000E+00	0.000E+00
23	0.000E+00	0.000E+00	-0.330E+01	-0.501E+04	0.343E+07	0.411E+01	0.000E+00	0.000E+00
34	0.396E+12	0.000E+00	0.483E-10	0.733E-07	0.502E-04	0.601E-10	0.101E-23	0.469E-18
41	0.000E+00	0.000E+00	0.330E+01	0.501E+04	0.343E+07	0.411E+01	0.000E+00	0.000E+00

***** TOTAL ENTROPY GENERATION = 0.101E-23 BTU/(R-SEC) *****

***** TOTAL WORK LOST = 0.853E-21 HP *****

ISTEP = 10 TAU = 0.10000E-02

BOUNDARY NODES

NODE	P(PSI)	TF(F)	Z(COMP) (LBM/F)	R	HO	QUALITY

SOLUTION

INTERNAL NODES

NODE	P(PSI)	TF(F)	Z	RHO (LBM/FT^3)	EM(LBM)	QUALITY
1	0.2176E+02	0.1384E+03	0.1000E+01	0.9498E-01	0.1354E-02	0.1000E+01
2	0.2176E+02	0.1384E+03	0.1000E+01	0.9498E-01	0.1354E-02	0.1000E+01
3	0.2176E+02	0.1384E+03	0.1000E+01	0.9498E-01	0.2748E-02	0.1000E+01
4	0.2176E+02	0.1384E+03	0.1000E+01	0.9498E-01	0.2748E-02	0.1000E+01

BRANCHES

BRANCH	KFACTOR (LBF-S^2/(LBM-FT)^2)	DELP (PSI)	FLOW RATE (LBM/SEC)	VELOCITY (FT/SEC)	REYN. NO.	MACH NO.	ENTROPY GEN. BTU/(R-SEC)	LOST WORK LBF-FT/SEC
12	0.000E+00	0.000E+00	-0.453E-10	-0.973E-08	0.177E-04	0.798E-11	0.000E+00	0.000E+00
23	0.000E+00	0.000E+00	0.385E-02	0.583E+01	0.400E+04	0.478E-02	0.000E+00	0.000E+00
34	0.395E+12	0.000E+00	0.483E-10	0.732E-07	0.502E-04	0.600E-10	0.101E-23	0.468E-18
41	0.000E+00	0.000E+00	-0.385E-02	-0.583E+01	0.400E+04	0.478E-02	0.000E+00	0.000E+00

***** TOTAL ENTROPY GENERATION = 0.101E-23 BTU/(R-SEC) *****

***** TOTAL WORK LOST = 0.851E-21 HP *****

ISTEP = 30 TAU = 0.30000E-02

BOUNDARY NODES

NODE	P(PSI)	TF(F)	Z(COMP)	R (LBM/F)	HO T^3	QUALITY
------	--------	-------	---------	--------------	-----------	---------

SOLUTION

INTERNAL NODES

NODE	P(PSI)	TF(F)	Z	RHO (LBM/FT^3)	EM(LBM)	QUALITY
1	0.2204E+02	0.1405E+03	0.1000E+01	0.9584E-01	0.1329E-02	0.1000E+01
2	0.2204E+02	0.1405E+03	0.1000E+01	0.9584E-01	0.1329E-02	0.1000E+01
3	0.2204E+02	0.1405E+03	0.1000E+01	0.9584E-01	0.2773E-02	0.1000E+01
4	0.2204E+02	0.1405E+03	0.1000E+01	0.9584E-01	0.2773E-02	0.1000E+01

BRANCHES

BRANCH	KFACTOR (LBF-S^2/(LBM-FT)^2)	DELP (PSI)	FLOW RATE (LBM/SEC)	VELOCITY (FT/SEC)	REYN. NO.	MACH NO.	ENTROPY GEN. BTU/(R-SEC)	LOST WORK LBF-FT/SEC
12	0.000E+00	0.000E+00	-0.447E-10	-0.950E-08	0.174E-04	0.778E-11	0.000E+00	0.000E+00
23	0.000E+00	0.000E+00	0.191E-01	0.287E+02	0.198E+05	0.235E-01	0.000E+00	0.000E+00
34	0.393E+12	0.000E+00	0.483E-10	0.725E-07	0.500E-04	0.594E-10	0.987E-24	0.461E-18
41	0.000E+00	0.000E+00	-0.191E-01	-0.287E+02	0.198E+05	0.235E-01	0.000E+00	0.000E+00

***** TOTAL ENTROPY GENERATION = 0.987E-24 BTU/(R-SEC) *****

***** TOTAL WORK LOST = 0.838E-21 HP *****

ISTEP = 40 TAU = 0.40000E-02

BOUNDARY NODES

NODE	P(PSI)	TF(F)	Z(COMP)	R (LBM/F)	HO T^3	QUALITY
------	--------	-------	---------	--------------	-----------	---------

SOLUTION

INTERNAL NODES

NODE	P (PSI)	TF (F)	Z	RHO (LBM/FT^3)	EM (LBM)	QUALITY
1	0.2227E+02	0.1424E+03	0.1000E+01	0.9656E-01	0.1308E-02	0.1000E+01
2	0.2227E+02	0.1424E+03	0.1000E+01	0.9656E-01	0.1308E-02	0.1000E+01
3	0.2227E+02	0.1424E+03	0.1000E+01	0.9656E-01	0.2794E-02	0.1000E+01
4	0.2227E+02	0.1424E+03	0.1000E+01	0.9656E-01	0.2794E-02	0.1000E+01

BRANCHES

BRANCH	KFACTOR (LBF-S^2/(LBM-FT)^2)	DELP (PSI)	FLOW RATE (LBM/SEC)	VELOCITY (FT/SEC)	REYN. NO.	MACH NO.	ENTROPY GEN. BTU/(R-SEC)	LOST WORK LBF-FT/SEC
12	0.000E+00	0.000E+00	-0.393E-10	-0.829E-08	0.153E-04	0.678E-11	0.000E+00	0.000E+00
23	0.000E+00	0.000E+00	0.264E-01	0.394E+02	0.273E+05	0.322E-01	0.000E+00	0.000E+00
34	0.391E+12	0.000E+00	0.483E-10	0.720E-07	0.499E-04	0.588E-10	0.971E-24	0.455E-18
41	0.000E+00	0.000E+00	-0.264E-01	-0.394E+02	0.273E+05	0.322E-01	0.000E+00	0.000E+00

***** TOTAL ENTROPY GENERATION = 0.971E-24 BTU/(R-SEC) *****

***** TOTAL WORK LOST = 0.827E-21 HP *****

APPENDIX O

INPUT AND OUTPUT DATA FILES FROM EXAMPLE 10

Pressurization of a Propellant Tank

Contents	Page
Example 10 Input File	O-2
Example 10 History Files	O-4
Example 10 User Subroutine	O-5
Example 10 Output File (Partial)	O-20

```

GFSSP VERSION
    300
ANALYST
Todd Steadman
INPUT DATA FILE NAME
ex10.dat
OUTPUT FILE NAME
ex10.out
TITLE
Pressurization Option Test Model
USETUP
    F
DENCON GRAVITY ENERGY MIXTURE THRUST STEADY TRANSV SAVER
    F      F      T      T      F      F      T      F
HEX HCOEF REACTING INERTIA CONDX GASPAK PRINTI ROTATION
    F      F      F      F      F      F      T      F
BUOYANCY HRATE INVAL MSORCE MOVBND TPA VARGEO TVM
    F      T      F      F      F      F      F      F
SHEAR PRNTIN PRNTADD LAMINAR TRANSQ
    F      F      F      T      F
PRESS INSUC VARROT
    T      F      F
NORMAL SIMUL SECONDL
    T      T      F
NNODES NINT NBR NF
    5      2      3      2
RELAXK RELAXD RELAXH CC NITER
    1.000  0.500  1.000  0.100E-02  100
DTAU TIMEF TIMEL NPSTEP
    0.10000E+00 0.0000E+00 0.2000E+03      10
NFLUID(I), I= 1,NF
    1      6
NODE INDEX
    1      2
    2      1
    3      2
    4      1
    5      2
NODE PRES (PSI) TEMP(DEGF) MASS SOURC          HEAT SOURC THRST AREA CONCENTRATION
    2  0.6700E+02 -0.2640E+03  0.0000E+00  0.0000E+00  0.0000E+00  0.4320E+05 1.0000 0.0000
    4  0.7476E+02 -0.2640E+03  0.0000E+00  0.0000E+00  0.0000E+00  0.8208E+06 0.0000 1.0000
ex10h1.dat
ex10h3.dat
ex10h5.dat
INODE NUMBR BRANCH 1 BRANCH 2 BRANCH 3 BRANCH 4 BRANCH 5 BRANCH 6
    2      1      12
    4      2      34      45

```

```

BRANCH UPNODE DNNODE OPTION
 12      1      2      2
 34      3      4      2
 45      4      5      2
BRANCH OPTION -2: FLOW COEF, AREA
 12    0.60000  0.78500
BRANCH OPTION -2: FLOW COEF, AREA
 34    0.00000  4015.00000
BRANCH OPTION -2: FLOW COEF, AREA
 45    0.30430  14.25000
INITIAL FLOWRATES IN BRANCHES FOR UNSTEADY FLOW
 12    1.00000
 34    0.01000
 45    0.01000
BRANCH NOUBR NMUBR
 12      0
 34      0
 45      1      34
BRANCH NODBR NMDBR
 12      0
 34      1      45
 45      0
BRANCH
 12
UPSTRM BR. ANGLE
DNSTRM BR. ANGLE
BRANCH
 34
UPSTRM BR. ANGLE
DNSTRM BR. ANGLE
 45    0.00
BRANCH
 45
UPSTRM BR. ANGLE
 34    0.00
DNSTRM BR. ANGLE
NUMBER OF TANKS IN THE CIRCUIT
 1
NODUL NODULB NODPRP IBRPRP TNKAR TNKTH TNKRHOTNKCP TNKCON ARHC FCTHC TNKTM
 2      3      4      34 6431.91  0.375 170.00  0.20 0.0362 4015.00  1.00 -264.00
 NODE DATA FILE
FNODE.DAT
 BRANCH DATA FILE
FBRANCH.DAT

```

EXAMPLE 10 HISTORY FILES**EX10H1.DAT**

2
0.0 95.00 120.00 1.0 0.0
1000 95.00 120.00 1.0 0.0

EX10H3.DAT

2
0.00 74.76 -264.0 0.0 1.0
1000 74.76 -264.0 0.0 1.0

EX10H5.DAT

2
0.00 50.00 -264.00 0.00 1.00
1000 50.00 -264.00 0.00 1.00

```

*****
C      **** GFSSP USER SUBROUTINES ****
C
C*****SUBROUTINE USRINT IS CALLED FROM INIT TO SPECIFY INITIAL VALUES COMPUTED
C          BY USER SPECIFIED THERMODYNAMIC PROPERTY PACKAGE
C
C          SUBROUTINE SORCEM(IPN,TERMU) IS CALLED FROM EQNS FOR MASS SOURCES.
C              IN THIS ROUTINE THE USER DEFINES ANY ADDITIONAL MASS
C              SOURCES TO THE MODEL (MASS SOURCES ARE IN LBM/SEC).  USER
C              CAN MODIFY TRANSIENT TERM BY REDEFINING THE ARGUMENT TERMU.
C
C          SUBROUTINE SORCEF(I,TERM0,TERM1,TERM2,TERM3,TERM4,TERM5,TERM6,TERM7,
C              TERM8,TERM9,TERM10,TERM100) IS CALLED FROM EQNS FOR
C              MOMENTUM SOURCES.  USER CAN MODIFY INDIVIDUAL TERMS OR
C              DEFINE ADDITIONAL MOMENTUM SOURCES THROUGH TERM100.
C
C          SUBROUTINE SOURCEQ IS CALLED FROM EITHER THE ENERGY ROUTINE (EITHER
C              ENTHALPY OR ENTROPY).  IN THIS ROUTINE THE USER DEFINES
C              ANY ADDITIONAL HEAT SOURCES TO THE MODEL (HEAT SOURCES
C              ARE IN BTU/SEC)
C
C          SUBROUTINE SORCEC IS CALLED FROM THE SPECIES CONCENTRATION ROUTINE
C              IN THIS ROUTINE THE USER DEFINES ANY ADDITIONAL SPECIES
C              CONCENTRATION SOURCES TO THE MODEL (CONCENTRATION SOURCES
C              ARE IN MASS FRACTIONS SUCH THAT THE SUM OF ALL OF THE
C              CONCENTRATIONS EQUALS 1.0)
C
C          SUBROUTINE KFUSER IS CALLED FROM THE RESIST ROUTINE.  IN THIS ROUTINE
C              THE USER DEFINES ANY VARIATION OF THE K-FACTOR OF A BRANCH
C              SUCH THAT THE K-FACTOR IS DEFINED AS THE PRESSURE DROP
C              DIVIDED BY THE MASS FLOW RATE^2 (PRESSURE IS IN PSF, FLOW
C              RATE IS IN LBM/SEC; I.E. THE K-FACTOR IS IN PSF-SEC^2/
C              (LBM-FT)^2)
C
C          SUBROUTINE PRPUSER IS CALLED FROM THE DENSITY ROUTINE.  IN THIS
C              ROUTINE THE USER ADDS OR MODIFIES FLUID PROPERTIES (ALLOWS
C              FOR USER SPECIFIED FLUID)
C
C          SUBROUTINE TSTEP IS CALLED FROM THE MAIN ROUTINE.  IN THIS ROUTINE
C              THE USER CAN MODIFY THE Timestep, DTAU, FOR AN UNSTEADY
C              MODEL (DTAU IS IN SECONDS)
C
C          SUBROUTINE BNDUSER IS CALLED FROM THE BOUND ROUTINE.  IN THIS ROUTINE
C              THE USER CAN MODIFY BOUNDARY CONDITIONS AND GEOMETRY AT
C              EACH Timestep FOR AN UNSTEADY MODEL (PRESSURE IS IN PSF,

```

```

C      TEMPERATURE IS IN DEG. R, LENGTH {ETC.} IS IN FT, AREA IS
C      IN FT^2, VOLUME IS IN FT^3)
C
C      SUBROUTINE PRNUSEN IS CALLED FROM THE PRINT ROUTINE.  IN THIS ROUTINE
C      THE USER CAN MODIFY ADD ADDITIONAL OUTPUT FILES SPECIFIC
C      TO A PARTICULAR MODEL
C
C      SUBROUTINE FILNUM IS CALLED FROM THE MAIN ROUTINE.  IN THIS ROUTINE
C      ESTABLISHES THE FILE NUMBERS THAT ARE TO BE OPENED FOR ALL
C      FILES IN GFSSP, AND INCLUDES 10 USER FILE NUMBERS FOR USE
C      IN THE PRNUSEN SUBROUTINE
C
C      SUBROUTINE USRSET IS CALLED FROM THE READIN ROUTINE.  IN THIS ROUTINE
C      THE USER SETS UP THE MAJORITY OF THE MODEL; ONLY A DUMMY
C      SEGMENT OF AN INPUT FILE IS NECESSARY TO BE READ, WITH THE
C      REMAINDER OF THE MODEL SETUP IN THIS SUBROUTINE.
C
C
C*****SUBROUTINE FILNUM
C      PURPOSE: ESTABLISH THE FORTRAN FILE NUMBERS FOR READING &
C              WRITING OF INFORMATION
C*****INCLUDE 'COMBLK.FOR'
C*****FILES ALREADY WITHIN GFSSP
C
C      NWRTE = FILE # CORRESPONDING TO THE WRITEIN SUBROUTINE
C              (WRITING INPUT DECK FROM COMMAND LINE PREPROCESSOR)
C      NPRNT = FILE # CORRESPONDING TO THE PRINT SUBROUTINE
C              (WRITING THE MAIN OUTPUT FILE)
C      NREAD = FILE # CORRESPONDING TO THE READIN SUBROUTINE
C              (READING IN THE INPUT DECK)
C      NGSPK = FILE # CORRESPONDING TO A NON-GASP PROPERTY PACKAGE
C      NFNOD = FILE # CORRESPONDING TO THE FNODE RESTART FILE
C      NGFSOUT = FILE # CORRESPONDING TO THE GFSSP.OUT FILE
C              (DEBUGGING FILE)
C      NFBR = FILE # CORRESPONDING TO THE FBRANCH RESTART FILE
C      NGASP = FILE # CORRESPONDING TO THE GASP.OUT FILE
C              (DEBUGGING FILE)
C      NHSTN = FILE # CORRESPONDING TO THE HISTN.XLS FILE
C      NHSTB = FILE # CORRESPONDING TO THE HISTBR.XLS FILE
C      NHSTF = FILE # CORRESPONDING TO B.C. & VARGEO HISTORY FILES
C      NCVHST = FILE # CORRESPONDING TO THE CONTROL VALVE HISTORY FILE
C      NCVCHR1 = FILE # CORRESPONDING TO THE FIRST OF TWO CONTROL
C              VALVE FILES

```

```

C      NCVCHR2 = FILE # CORRESPONDING TO THE SECOND OF TWO CONTROL
C          VALVE FILES
C      NHSTROT = FILE # CORRESPONDING TO THE VARIABLE ROTATION
C          HISTORY FILE
C      NERROR = FILE # CORRESPONDING TO THE ERROR.XLS FILE
C      NRP1DAT = FILE # CORRESPONDING TO THE RP1 PROPERTY DATA FILES
C
C      NGSPK=1
C      NPRNT=10
C      NFNOD=11
C      NGFSOUT=12
C      NFBR=13
C      NREAD=15
C      NGASP=17
C      NHSTN=18
C      NHSTB=19
C      NWRTE=20
C      NHSTF=21
C      NCVHST=28
C      NCVCHR1=29
C      NCVCHR2=30
C      NHSTROT=35
C      NERROR=55
C      NRP1DAT=51
C
C      FILE NUMBERS FOR USER DEFINED FILES (THESE FILES CAN BE USED
C      IN ANY OF THE USER SUBROUTINES; HOWEVER, MOST LIKELY USE IS
C      IN THE PRNUSED SUBROUTINE).  COMMENT OUT FILE NUMBERS NOT IN USE.
C
C      NUSR1=
C      NUSR2=
C      NUSR3=
C      NUSR4=
C      NUSR5=
C      NUSR6=
C      NUSR7=
C      NUSR8=
C      NUSR9=
C      NUSR10=
C
C      RETURN
C      END
C*****
C      SUBROUTINE USRINT
C      PURPOSE: PROVIDE INITIAL CONDITIONS WHEN ALTERNATE THERMODYNAMIC
C              PROPERTY PACKAGE IS USED
C*****

```

```

INCLUDE 'COMBLK.FOR'
*****
C
C      ADD CODE HERE
C      RETURN
C      END
*****
SUBROUTINE SORCEM(IPN,TERMU)
C      PURPOSE: ADD MASS SOURCES
C      IPN - GFSSP INDEX NUMBER FOR NODE
C      TERMU - UNSTEADY TERM IN MASS CONSERVATION EQUATION
*****
INCLUDE 'COMBLK.FOR'
*****
C
C      ADD CODE HERE
C      RETURN
C      END
*****
SUBROUTINE SORCEF(I,TERM0,TERM1,TERM2,TERM3,TERM4,TERM5,TERM6,
&                  TERM7,TERM8,TERM9,TERM10,TERM100)
C      PURPOSE: ADD MOMENTUM SOURCES (LBF)
C      I - GFSSP INDEX NUMBER FOR BRANCH
C      TERM0 - UNSTEADY TERM IN MOMENTUM CONSERVATION EQUATION
C      TERM1 - LONGITUDINAL INERTIA
C      TERM2 - PRESSURE GRADIENT
C      TERM3 - GRAVITY FORCE
C      TERM4 - FRICTION FORCE
C      TERM5 - CENTRIFUGAL FORCE
C      TERM6 - EXTERNAL MOMETUM SOURCE DUE TO PUMP
C      TERM7 - MOMENTUM SOURCE DUE TO TRANSVERSE FLOW(MULTI-DIMENSIONAL MODEL)
C      TERM8 - MOMENTUM SOURCE DUE TO SHEAR(MULTI-DIMENSIONAL MODEL)
C      TERM9 - VARIABLE GEOMETRY UNSTEADY TERM
C      TERM10 - NORMAL STRESS
C      TERM100 - USER SUPPLIED MOMENTUM SOURCE
*****
INCLUDE 'COMBLK.FOR'
*****
C
C      ADD CODE HERE
C      RETURN
C      END
*****
SUBROUTINE SORCEQ(IPN,TERMD)
C      PURPOSE: ADD HEAT SOURCES
C      IPN - GFSSP INDEX NUMBER FOR NODE
C      TERMD - COMPONENT OF LINEARIZED SOURCE TERM APPEARING IN THE
C              DENOMINATOR OF THE ENTHALPY OR ENTROPY EQUATION
*****

```

```

INCLUDE 'COMBLK.FOR'
C*****
C*****
C     ADD CODE HERE
RETURN
END
C*****
SUBROUTINE SORCEC
C*****
INCLUDE 'COMBLK.FOR'
C*****
C     ADD CODE HERE
C PURPOSE: COMPUTE MASS TRANSFER OF PROPELLANT INTO THE ULLAGE
C          DURING TANK PRESSURIZATION
LOGICAL NOMASS
CHARACTER*8, FLUID

IF (PRESS) THEN
    NOMASS=.FALSE.
    IF (NOMASS) THEN
        GO TO 10
    ENDIF
    DO I=1, NTANK
C FIND NODE INDICES
        DO II=1, NNODES
            NUMBER=NODE(II)
            IF (NUMBER .EQ. NODUL(I))IPUL=II
            IF (NUMBER .EQ. NODPRP(I))IPRP=II
        ENDDO
C FIND MASS TRANSFER FROM HEAT TRANSFER
        SORCEMAS(IPUL)=0.0
        DO J=1,NF
            DIFFLU=ABS(1.0-CX(IPRP,J))
            IF (DIFFLU .LE. 1.0E-04) THEN
                NFLU=NFLUID(J)
                KFLU=J
            ENDIF !(IF (DIFFLU...
        ENDDO !(DO J=1,NF...
        IF (NFLU.EQ.4)FLUID='NITROGEN'
        IF (NFLU.EQ.6)FLUID='OXYGEN'
        IF (NFLU.EQ.10)FLUID='HYDROGEN'
        IF (NFLU.EQ.12)FLUID='RPI'
        CALL SATPRP(FLUID,P(IPUL),TSAT(I),HFG(I))
        SORCECON(IPUL,KFLU)=QULPRP(I)/(HFG(I)+CPNODE(IPRP)
&           *MAX(TSAT(I)-TF(IPUL),0.0))
        SORCEMAS(IPUL)=SORCEMAS(IPUL)+SORCECON(IPUL,KFLU)
        SORCEMAS(IPRP)=-SORCEMAS(IPUL)

```

```

        ENDDO !(DO I=1,NTANK)
        ENDIF !(IF(PRESS))
10    CONTINUE
        RETURN
        END

C*****
C      SUBROUTINE KFUSER(AKNEW)
C      PURPOSE: ADD A NEW RESISTANCE OPTION
C*****
INCLUDE 'COMBLK.FOR'
C*****
C      ADD CODE HERE
        RETURN
        END

C*****
C      SUBROUTINE PRPUSER
C      PURPOSE: ADD NEW FLUID PROPERTY
C*****
INCLUDE 'COMBLK.FOR'
C*****
C      ADD CODE HERE
        RETURN
        END

C*****
C      SUBROUTINE TSTEP
C      PURPOSE: MODIFY TIME STEP
C*****
INCLUDE 'COMBLK.FOR'
C*****
C      ADD CODE HERE
C      FRICTBP = .TRUE.
C      DFLI = .FALSE.
        RETURN
        END

C*****
C      SUBROUTINE BNDUSER
C      PURPOSE: MODIFY BOUNDARY CONDITIONS
C*****
INCLUDE 'COMBLK.FOR'
C*****
C      ADD CODE HERE
        RETURN
        END

```

```

C*****
      SUBROUTINE PRNUSET
C     PURPOSE: ADD NEW OUTPUT
C*****
      INCLUDE 'COMBLK.FOR'
C*****
C     ADD CODE HERE
C     GENERATE EXCEL FILE FOR PLOT
      OPEN (NUSR1,FILE = 'EX11.XLS',STATUS = 'UNKNOWN')
      VOLULG=VOLUME(2)
      VOLPRP=VOLUME(4)
      TFTNK1=TNKTM(1)-460.
      WRITE(NUSR1,200) TAU,QULWAL(1),QULPRP(1),
      & QCOND(1),VOLULG,VOLPRP,TFTNK1,SORCECON(2,2),
      & CX(2,2)
200   FORMAT (2X,E12.6,100(2X,2E12.6))
      RETURN
      END
C*****
      SUBROUTINE USRSET
C     PURPOSE: USER SETS UP THE MAJORITY OF THE MODEL
C*****
      INCLUDE 'COMBLK.FOR'
C*****
C     ADD CODE HERE
C
C     THIS IS THE DEFAULT CODE FOR THIS BLOCK, COMMENT THIS OUT WHEN
C     CREATING A MODEL WITHIN THIS SUBROUTINE
C
      WRITE(*,*) ' '
      WRITE(*,*) ' USER ROUTINE USRSET DOES NOT HAVE A MODEL DEVELOPED'
      WRITE(*,*) ' '
      WRITE(*,*) ' OPEN THE USER SUBROUTINE FILE AND MODIFY SUBROUTINE'
      WRITE(*,*) ' USRSET TO DEVELOP MODEL OR CHANGE LOGICAL VARIABLE'
      WRITE(*,*) ' USETUP TO FALSE AND DEVELOP MODEL IN INPUT FILE'
      WRITE(*,*) ' '
      C     STOP
C
C     END OF DEFAULT CODE
C
      RETURN
      END
C*****
C          **** END OF USER SUBROUTINES ****
C          *

```

```

C *
C*****SUBROUTINE SATPRP(FLUID,PRS,STRT,HTVAP)
C
C THIS SUBROUTINE CALCULATES
C   ** SATURATION TEMPERATURE FROM VAPOR PRESSURE RELATION **
C   ** ENTHALPY OF EVAPORATION FROM CLAPEYRON EQUATION *****
C   ** SATPRP UTILIZED ENGLISH UNITS IN CALCULATIONS *****
C ****CHARACTER*8, FLUID
C **** FO(PEOS,TEOS): VAPOR PRESSURE RELATION FOR OXYGEN *****
C **** FN(PEOS,TEOS): VAPOR PRESSURE RELATION FOR NITROGEN *****
C **** FH(PEOS,TEOS): VAPOR PRESSURE RELATION FOR HYDROGEN *****
C **** FR(PEOS,TEOS): VAPOR PRESSURE RELATION FOR RP-1 *****
C **** FDASHO(TEOS): GRADIENT OF VAPOR PRESSURE CURVE FOR OXYGEN **
C **** FDASHN(TEOS): GRADIENT OF VAPOR PRESSURE CURVE FOR NITROGEN **
C **** FDASHH(TEOS): GRADIENT OF VAPOR PRESSURE CURVE FOR HYDROGEN **
C **** FDASHR(TEOS): GRADIENT OF VAPOR PRESSURE CURVE FOR RP-1 *****
C **** A,B,C & D ARE CONSTANTS OF VAPOR PRESSURE RELATION *****
C
FO(PEOS,TEOS) = ALOG(PEOS) -81.65833 + 2856.85477/TEOS +
&13.04607*ALOG(TEOS) - 0.03101*TEOS
FN(PEOS,TEOS) = ALOG(PEOS) + 76.60382 - 117.1873/TEOS - 17.40608
&*ALOG(TEOS) + 0.05372*TEOS
FH(PEOS,TEOS)=ALOG(PEOS)-11.403728+211.94778/TEOS+1.22794
&*ALOG(TEOS)-0.040478*TEOS
FR(PEOS,TEOS)=ALOG(PEOS) + 3551.8 - 888437.6/TEOS - 68.05
&*ALOG(TEOS) -2.73183*TEOS
FDASHO(TEOS) = -2856.85477/(TEOS*TEOS) + 13.04607/TEOS - 0.03101
FDASHN(TEOS) = 117.1873/(TEOS*TEOS) - 17.4068/TEOS + 0.05372
FDASHH(TEOS)=-211.94778/(TEOS*TEOS)+1.22794/TEOS-0.040478
FDASHR(TEOS)=888437.6/(TEOS*TEOS) - 68.05/TEOS - 2.73183
DATA RLX,CNRG/0.5,0.001/
PEOS=PRS/144.
ITER=0
IF (FLUID.EQ.'OXYGEN') GO TO 100
IF (FLUID.EQ.'NITROGEN') GO TO 200
IF (FLUID.EQ.'HYDROGEN') GO TO 333
IF (FLUID.EQ.'RP1') GO TO 444
C
100  CONTINUE
C DATA FOR OXYGEN IN ENGLISH UNITS
C TEOS IS IN DEG R; PEOS IS IN PSIA
A =81.65833
B = -2856.85477
C ==-13.04607
D = 0.03101

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C      NOTE: TEOS IS A GUESS TEMPERATURE
C      TEOS= 135.
C      GO TO 1000
C
200    CONTINUE
C      DATA FOR NITROGEN IN ENGLISH UNITS
C      TEOS IS DEG R; PEOS IS IN PSIA
C      A = 67.78808
C      B = -2156.13382
C      C = -10.97167
C      D = 0.0327
C      NOTE: TEOS IS A GUESS TEMPERATURE
C      TEOS = 209.2
C      GO TO 1000
C
333    CONTINUE
C      DATA FOR HYDROGEN IN ENGLISH UNITS
C      TEOS IS IN DEG R ; PEOS IS IN PSI
C      A=11.403728
C      B=-211.94778
C      C=-1.22794
C      D=0.040478
C      NOTE: TEOS IS A GUESS TEMPERATURE
C      TEOS=PEOS/2.7586
C      GO TO 1000
C
444    CONTINUE
C      DATA FOR RP-1 IN ENGLISH UNITS
C      TEOS IS IN DEG R ; PEOS IS IN PSI
C      A=-3551.8
C      B=888437.6
C      C=68.05
C      D=2.73183
C      NOTE: TEOS IS A GUESS TEMPERATURE
C      TEOS=855.
C      GO TO 1000
C      THE FOLLOWING LOOP CALCULATES STRT AND HTVAP
C
1000   CONTINUE
IF (ITER .GT. 1000) THEN
  WRITE(*,*) 'SAT TMP EQN DID NOT CONVERGE'
  GO TO 5000
ENDIF
C      CALCULATE TEOS FROM VAPOR-PRESSURE RELATION USING NEWTON-
C      RAPHSON METHOD
C
IF (FLUID.EQ.'OXYGEN') ANUM =-FO(PEOS,TEOS)

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```

IF (FLUID.EQ.'NITROGEN') ANUM =-FN(PEOS,TEOS)
IF (FLUID.EQ.'HYDROGEN') ANUM=-FH(PEOS,TEOS)
IF (FLUID.EQ.'RP1') ANUM=-FR(PEOS,TEOS)
IF (FLUID.EQ.'OXYGEN') DENOM = FDASHO(TEOS)
IF (FLUID.EQ.'NITROGEN') DENOM = FDASHN(TEOS)
IF (FLUID.EQ.'HYDROGEN') DENOM = FDASHH(TEOS)
IF (FLUID.EQ.'RP1') DENOM = FDASHR(TEOS)
TDASH = ANUM/DENOM
TEOS = TEOS + RLX*TDASH
IF (FLUID.EQ.'OXYGEN') RES = FO(PEOS,TEOS)
IF (FLUID.EQ.'NITROGEN') RES = FN(PEOS,TEOS)
IF (FLUID.EQ.'HYDROGEN') RES=FH(PEOS,TEOS)
IF (FLUID.EQ.'RP1') RES=FR(PEOS,TEOS)
ITER = ITER + 1
IF (ABS(RES).GT.CNVRG) GO TO 1000
STRT = TEOS
C VG AND VF ARE IN CUBIC FEET PER POUND-MASS
CALL BWR(FLUID,PEOS,STRT,VG,VF)
C HFG IS IN BTU PER POUND-MASS
DPDT = PEOS*(-B/(STRT**2) + C/STRT + D)
HTVAP = STRT*(VG-VF)*DPDT*(144.*0.0012849)
5000 CONTINUE
RETURN
END
C*****
C***** SUBROUTINE BWR(FLUID,PBWR,TBWR,VG,VF)
C *****
C CHARACTER*8 ,FLUID
LOGICAL SUCCES
F(PR,VR,TR,B,C,D,C4,BETA,GAMA)=(PR*VR)/TR-1.-(B/VR)-
&(C/VR**2)-(D/VR**5)-(C4/(TR**3*VR**2))*((BETA+GAMA/VR**2)*
&EXP(-GAMA/VR**2))
C *** LEE-KELSER CONSTANTS FOR SIMPLE FLUID ***
DATA B1S,B2S,B3S,B4S/0.1181193,0.265728,0.15479,0.030323/
DATA C1S,C2S,C3S,C4S/0.0236744,0.0186984,0.0,0.042724/
DATA D1S,D2S/0.155488E-04,0.623689E-04/
DATA BETAS,GAMAS/0.65392,0.060167/
C *** LEE-KELSER CONSTANTS FOR REFERENCE FLUID ***
DATA B1R,B2R,B3R,B4R/0.2026579,0.331511,0.027655,0.203488/
DATA C1R,C2R,C3R,C4R/0.0313385,0.0503618,0.016901,0.041577/
DATA D1R,D2R/0.48736E-04,0.07403361E-04/
DATA BETAR,GAMAR/1.226,0.03754/
DATA OMEGAR/0.3978/
DATA RCONST,CC/8.31434,0.001/
DATA RELAX,FACT/0.5,2./
VG=0.

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```

VF=0.

C ***** OBTAIN CRITICAL CONSTANTS *****
CALL CONST1(FLUID,PC,TC,TB,WMOL)
C *** CONVERT P FROM PSI TO PASCALS
PK=PBWR/1.45E-04
C *** CONVERT PK FROM PASCALS TO KILO-PASCALS
PK=PK/1000.
C *** CONVERT T FROM DEG R TO DEG K
TEMPF=TBWR-460.
TEMPC=(5./9.)*(TEMPF-32.)
TK=TEMPC+273.16
C *** CALCULATE VG FOR RP-1 ONLY
IF (FLUID .EQ. 'RP1') THEN
C GAS CONSTANT FOR RP1 ADJUSTED BY 1000 TO ACCOUNT FOR KPA IN IDEAL GAS EQN
RRP1=8315/(WMOL*1000)
VG=(RRP1*TK)/PK
GO TO 40
ENDIF
C *** CHECK TO SEE IF STATE POINT FALLS IN INACCURACY WINDOW FOR **
C ** HYDROGEN ONLY
PKI=PK
TKI=TK
IF(FLUID.EQ.'HYDROGEN')THEN
CALL INTERPOLE(PKI,TKI,VG)
ENDIF
IF(VG.EQ.0.)GO TO 30
IF(VG.NE.0.)GO TO 40
30 PR=PK/PC
TR=TK/TC
C *** CALCULATE IDEAL REDUCED VOLUME OF A SIMPLE FLUID ***
B=B1S-(B2S/TR)-(B3S/TR**2)-(B4S/TR**3)
C=C1S-(C2S/TR)+(C3S/TR**3)
D=D1S+(D2S/TR)
C INITIAL GUESS IS FROM IDEAL GAS LAW
VMOL=RCONST*TK/PK
VMIDEAL=VMOL
C DETERMINE THE INITIAL RANGE OF VR
VR1=(VMIDEAL*PC)/(RCONST*TC)
VR2=10.*VR1
C **** FIND THRESHOLD FROM ZBRAC ****
CALL ZBRAC(PR,VR1,VR2,TR,B,C,D,C4S,BETAS,GAMAS,SUCCES)
C **** OBTAIN SOLUTION (=VR) *****
VRS=RTBIS(PR,VR1,VR2,TR,B,C,D,C4S,BETAS,GAMAS,CC,J1)
ZS=(PR*VRS)/TR
C **** CALCULATE THE IDEAL REDUCED VOLUME OF REFERENCE FLUID ****
B=B1R-(B2R/TR)-(B3R/TR**2)-(B4R/TR**3)
C=C1R-(C2R/TR)+(C3R/TR**3)

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```

D=D1R+(D2R/TR)
C **** USE VR FROM SIMPLE FLUID AS FIRST GUESS ****
C *** OBTAIN THRESHOLD ****
VR1=VRS
VR2=2.*VRS
CALL ZBRAC(PR,VR1,VR2,TR,B,C,D,C4R,BETAR,GAMAR,SUCCES)
C **** OBTAIN A SOLUTION (=VR) ****
VRR=RTBIS(PR,VR1,VR2,TR,B,C,D,C4R,BETAR,GAMAR,CC,J2)
ITER=J1+J2
ZR=(PR*VRR)/TR
C **** CALCULATE THE ACENTRIC FACTOR; OMEGA ****
C ** FIRST CONVERT PC FROM KPA TO ATM ***
PCA=PC*(0.009867)
THETA=TB/TC
ALPHA=- ALOG(PCA)-5.97214+(6.09648/THETA)+1.28862*
&ALOG(THETA)-0.169347*(THETA**6)
BETA=15.2518-(15.6875/THETA)-13.4721*ALOG(THETA)+*
&0.43577*(THETA**6)
OMEGA=ALPHA/BETA
C *** CALCULATE COMPRESSIBILITY FACTOR FOR THE FLUID OF INTEREST ***
ZBWR=ZS+(OMEGA/OMEGAR)*(ZR-ZS)
VR=(ZBWR*TR)/PR
VMOL=(VR*RCONST*TC)/PC
VG=VMOL/WMOL
C *** CONVERT VG FROM M**3/KG TO FT**3/LBM ****
40 CONTINUE
VG=VG*16.018067
IF (FLUID.EQ.'OXYGEN')VF=-0.34614+1.1286E-02*TBWR-1.3837E-04
&*(TBWR**2)+8.2613E-07*(TBWR**3)-2.4007E-09*(TBWR**4)+*
&2.7247E-12*(TBWR**5)
IF(FLUID.EQ.'HYDROGEN')VF=-13.132+1.7962*TBWR-9.4964E-02
&*(TBWR**2)+2.464E-03*(TBWR**3)-3.1377E-05*(TBWR**4)
&+1.5712E-07*(TBWR**5)
IF (FLUID.EQ.'NITROGEN')VF=-0.01204 + 0.00061*TBWR
&-4.23216E-06*TBWR*TBWR +1.06765E-08*TBWR*TBWR*TBWR
C*** CONVERT VF FROM M**3/KG TO FT**3/LBM
C IF(FLUID.EQ.'NITROGEN') VF=VF*16.018067
IF (FLUID.EQ.'HYDROGEN' .AND. TBWR .GT. 59) VF=0.
IF (FLUID.EQ.'RP1')VF=0.01923
RETURN
END
C ****
FUNCTION RTBIS(PR,VR1,VR2,TR,B,C,D,C4,BETA,GAMA,CC,J)
C USING BISECTION, FIND THE ROOT OF A FUNCTION F KNOWN TO LIE
C BETWEEN VR1 AND VR2. THE ROOT, RETURNED AS RTBIS, WILL BE
C REFINED UNTIL ITS ACCURACY IS (+/-)CC.

```

```

C ****
C      PARAMETER ( JMAX=40 )
C      F(PR,VR,TR,B,C,D,C4,BETA,GAMA)=PR*VR/TR-1.-B/VR-C/VR**2-D/VR**5
& -C4/(TR**3*VR**2)*(BETA+GAMA/VR**2)*EXP(-GAMA/VR**2)
      FMID=F(PR,VR2,TR,B,C,D,C4,BETA,GAMA)
      F1=F(PR,VR1,TR,B,C,D,C4,BETA,GAMA)
      IF(F1*FMID.GE.0.) PRINT*, 'ROOT MUST BE BRACKETED FOR
& BISECTION.'
C ** ORIENT THE SEARCH SO THAT F1 > 0 LIES AT VR+DELVR ***
      IF(F1.LT.0.) THEN
        RTBIS=VR1
        DELVR=VR2-VR1
      ELSE
        RTBIS=VR2
        DELVR=VR1-VR2
      ENDIF
      DO 11 J= 1,JMAX
        DELVR=DELVR*0.5
        XMID=RTBIS+DELVR
        FMID=F(PR,XMID,TR,B,C,D,C4,BETA,GAMA)
        IF(FMID.LE.0.)RTBIS=XMID
        IF(ABS(DELVR/XMID).LT.CC.OR.FMID.EQ.0.)RETURN
11    CONTINUE
      PRINT*, ' TOO MANY BISECTIONS'
      END
C ****
C      SUBROUTINE CONST1(FLUID,PC,TC,TB,WMOL)
C
C ****
C      CHARACTER*8,FLUID
C      IF(FLUID.EQ.'OXYGEN')THEN
C      *** CRITICAL CONSTANTS ARE IN DEG K AND KPA RESPECTIVELY ***
C      TC=154.576
C      PC=5.0427E03
C      WMOL=31.9999
C      *** BOILING PT IS AT 1 ATM IN DEG K ***
C      TB=90.2
C      ENDIF
C      IF(FLUID.EQ.'HYDROGEN')THEN
C      *** CRITICAL CONSTANTS ARE IN DEG K AND KPA RESPECTIVELY ***
C      TC=33.19
C      PC=1315.
C      WMOL=2.106
C      *** BOILING PT IS AT 1 ATM IN DEG K ***
C      TB=20.4
C      ENDIF
C      IF(FLUID.EQ.'NITROGEN') THEN

```

```

TC=126.2
PC=3390
WMOL=28.013
TB=77.347
ENDIF
IF (FLUID.EQ.'RP1') THEN
TC=658.
PC=1820.
WMOL=170.33
TB=489.
ENDIF
RETURN
END
C ****
C SUBROUTINE ZBRAC(PR,VR1,VR2,TR,B,C,D,C4,BETA,GAMA,SUCCES)
C GIVEN A FUNCTION F AND AN INITIAL GUESSED RANGE VR1 TO VR2,
C THE ROUTINE EXPANDS THE RANGE GEOMETRICALLY UNTIL A ROOT IS
C BRACKETED BY THE RETURN VALUES VR1 AND VR2 (IN WHICH CASE
C SUCCES RETURNS AS .TRUE.) OR UNTIL THE RANGE BECOMES
C UNACCEPTABLY LARGE (IN WHICH CASE SUCCES RETURNS AS .FALSE.).
C
C ****
C PARAMETER (FACTOR=1.25,NTRY=50)
LOGICAL SUCCES
F(PR,VR,TR,B,C,D,C4,BETA,GAMA)=PR*VR/TR-1.-B/VR-C/VR**2-D/VR**5
& -C4/(TR**3*VR**2)*(BETA+GAMA/VR**2)*EXP(-GAMA/VR**2)
IF(VR1.EQ.VR2)PRINT*, 'YOU HAVE TO GUESS AN INITIAL RANGE'
F1=F(PR,VR1,TR,B,C,D,C4,BETA,GAMA)
F2=F(PR,VR2,TR,B,C,D,C4,BETA,GAMA)
SUCCES=.TRUE.
DO 11 J=1,NTRY
  IF(F1*F2.LT.0.)RETURN
  IF(ABS(F1).LT.ABS(F2))THEN
    VR1=VR1+FACTOR*(VR1-VR2)
    VR1=AMAX1(0.001,VR1)
    F1=F(PR,VR1,TR,B,C,D,C4,BETA,GAMA)
  ELSE
    VR2=VR2+FACTOR*(VR2-VR1)
    F2=F(PR,VR2,TR,B,C,D,C4,BETA,GAMA)
  ENDIF
11  CONTINUE
  SUCCES=.FALSE.
  RETURN
END
C ****
C ****
C SUBROUTINE INTERPOLE(PK,TK,VGP)

```

```

C THIS SUBROUTINE CALCULATES THE SPECIFIC VOLUME OF VAPOR OR
C SUPERHEATED VAPOR USING INTERPOLATION IN TWO-DIMENSIONS
C ****
      LOGICAL SUCCESS
      DIMENSION P(50),T(50),VG(50,50)
      OPEN(UNIT=20,FILE='HYDROGEN.IN',STATUS='OLD')
      DATA NX,NY/5,5/
      READ(20,*)(P(IX),IX=1,NX)
      DO 100 IY=1,NY
      READ(20,*)T(IY),(VG(IX,IY),IX=1,NX)
100    CONTINUE
      CLOSE (20)
C *** DETERMINE THE LOCATION OF PRESSURE AND TEMPERATURE IN THE TABLE
      SUCCESS=.FALSE.
      DO IX=1,NX
      IF(PK.GE.P(IX).AND.PK.LT.P(IX+1)) THEN
      SUCCESS=.TRUE.
      IXP=IX
      ENDIF
      ENDDO
      IF(.NOT.SUCCESS)THEN
      PRINT*, 'GIVEN PRESSURE IS NOT WITHIN THE RANGE'
      GO TO 10
      ENDIF
      SUCCESS=.FALSE.
      DO IY=1,NY
      IF(TK.GE.T(IY).AND.TK.LT.T(IY+1))THEN
      SUCCESS=.TRUE.
      IYP=IY
      ENDIF
      ENDDO
      IF(.NOT.SUCCESS)THEN
      PRINT*, 'GIVEN TEMPERATURE IS NOT WITHIN THE RANGE'
      GO TO 10
      ENDIF
C ** CALCULATE INTERPOLATING FACTOR
      FACTP=(PK-P(IXP))/(P(IXP+1)-P(IXP))
      FACTT=(TK-T(IYP))/(T(IYP+1)-T(IYP))
      VGP=(1.-FACTP)*(1.-FACTT)*VG(IXP,IYP)+FACTP*(1.-FACTT)
      &*VG(IXP+1,IYP)+FACTP*FACTT*VG(IXP+1,IYP+1)+
      &(1.-FACTP)*FACTT*VG(IXP,IYP+1)
      GO TO 30
10    VGP=0.
30    RETURN
      END
C*****

```

```
*****
 G F S S P (Version 3.0)
 Generalized Fluid System Simulation Program
 September, 1999
 Developed by Sverdrup Technology
 Copyright (C) by Marshall Space Flight Center
```

A generalized computer program to calculate flow rates, pressures, temperatures and concentrations in a flow network.

```
*****
TITLE      :Pressurization Option Test Model
ANALYST    :Todd Steadman
FILEIN     :EX10.DAT
FILEOUT    :ex10.out
LOGICAL VARIABLES
DENCON     =   F
GRAVITY    =   F
ENERGY     =   T
MIXTURE    =   T
THRUST     =   F
STEADY     =   F
TRANSV     =   T
SAVER      =   F
HEX         =   F
HCOEF      =   F
REACTING   =   F
INERTIA    =   F
CONDX      =   F
TWOD       =   F
PRINTI     =   T
ROTATION   =   F
BUOYANCY   =   F
HRATE      =   T
INVAL      =   F
MSOURCE   =   F
MOVBND    =   F
TPA        =   F
VARGEO    =   F
TVM        =   F
SHEAR      =   F
PRNTIN    =   T
PRNTADD   =   T
GASPAK    =   F
```

PRESS = T
INSUC = F
VARROT = F
NORMAL = T
SECONDL = F

NNODES = 5
NINT = 2
NBR = 3
NF = 2
NVAR = 7
NHREF = 2

FLUIDS: HE O2

BOUNDARY NODES

NODE	P (PSI)	T (F)	RHO (LBM/FT^3)	AREA (IN^2)	CONCENTRATIONS	
					HE	O2
1	0.9500E+02	0.1200E+03	0.6091E-01	0.0000E+00	0.1000E+01	0.0000E+00
3	0.7470E+02	-0.2640E+03	0.6510E+02	0.0000E+00	0.0000E+00	0.1000E+01
5	0.5000E+02	-0.2640E+03	0.8191E+00	0.0000E+00	0.0000E+00	0.1000E+01

INPUT SPECIFICATIONS FOR INTERNAL NODES

NODE	AREA (IN^2)	MASS (LBM/S)	HEAT (BTU/S)
2	0.0000E+00	0.0000E+00	0.0000E+00
4	0.0000E+00	-0.1000E-01	0.0000E+00

BRANCH	UPNODE	DNNODE	OPTION
12	1	2	2
34	3	4	2
45	4	5	2

BRANCH OPTION -2: FLOW COEF, AREA

12 0.60000 0.78500

BRANCH OPTION -2: FLOW COEF, AREA

34 0.00000 4015.00000

BRANCH OPTION -2: FLOW COEF, AREA

45 0.30430 14.25000

INITIAL GUESS FOR INTERNAL NODES

NODE	P(PSI)	TF(F)	Z(COMP)	RHO (L BM/FT^3)	CONCENTRATIONS	
2	0.6700E+02	-0.2640E+03	0.1006E+01	0.1270E+00	0.1000E+01	0.0000E+00

4 0.7476E+02 -0.2640E+03 0.1751E-01 0.6510E+02 0.0000E+00 0.1000E+01

TRIAL SOLUTION

BRANCH	DELP(PSI)	FLOWRATE(LBM/SEC)
12	0.0000	1.0000
34	0.0000	0.0100
45	0.0000	0.0100

NUMBER OF PRESSURIZATION SYSTEMS = 1

NODUL	NODPRP	QULPPR	QULWAL	QCOND	TNKTM	VOLPROP	VOLULG
2	4	0.0000	0.0000	0.0000	195.6000	475.0000	25.0000

ISTEP = 100 TAU = 0.10000E+02

BOUNDARY NODES

NODE	P(PSI)	TF(F)	Z(COMP)	RHO (LBM/F) T^3)	CONCENTRATIONS		
1	0.9500E+02	0.1200E+03	0.0000E+00	0.6091E-01	0.1000E+01	0.0000E+00	HE O2
3	0.9815E+02	-0.2640E+03	0.0000E+00	0.6510E+02	0.0000E+00	0.1000E+01	
5	0.5000E+02	-0.2640E+03	0.0000E+00	0.8191E+00	0.0000E+00	0.1000E+01	

SOLUTION

INTERNAL NODES

NODE	P(PSI)	TF(F)	Z	RHO (LBM/FT^3)	EM(LBM)	CONC	HE	O2
2	0.9083E+02	-0.1318E+03	0.1006E+01	0.1028E+00	0.5042E+01	0.1000E+01	0.0000	
4	0.9815E+02	-0.2640E+03	0.2297E-01	0.6514E+02	0.2938E+05	0.0000E+00		1.0000

NODE	H BTU/LB	ENTROPY BTU/LB-R	EMU LBM/FT-SEC	COND BTU/FT-S-R	CP BTU/LB-R	GAMA
2	0.2495E+03	0.5983E+01	0.9721E-05	0.1806E-04	0.1242E+01	0.1668E+01
4	0.7491E+02	0.7813E+00	0.8488E-04	0.1823E-04	0.4227E+00	0.2028E+01

BRANCHES

BRANCH	KFACTOR (LBF-S^2/(LBM-FT)^2)	DELP (PSI)	FLOW RATE (LBM/SEC)	VELOCITY (FT/SEC)	REYN. NO.	MACH NO.	ENTROPY GEN. BTU/(R-SEC)	LOST WORK LBF-FT/SEC
12	0.238E+05	0.417E+01	0.159E+00	0.478E+03	0.168E+06	0.138E+00	0.347E-02	0.157E+04
34	0.000E+00	0.000E+00	0.162E+03	0.894E-01	0.410E+06	0.114E-03	0.000E+00	0.000E+00
45	0.263E+00	0.481E+02	0.162E+03	0.252E+02	0.686E+07	0.321E-01	0.114E+00	0.173E+05

NUMBER OF PRESSURIZATION SYSTEMS = 1
 NODUL NODPRP QULPPR P QULWAL QCOND TNKTM VOLPROP VOLULG
 2 4 2.0196 8.7399 0.0022 196.4587 450.9388 49.0611

ISTEP = 300 TAU = 0.30000E+02

BOUNDARY NODES

NODE	P(PSI)	TF(F)	Z(COMP)	RHO (LBM/F T^3)	CONCENTRATIONS		
					HE	O2	
1	0.9500E+02	0.1200E+03	0.0000E+00	0.6091E-01	0.1000E+01	0.0000E+00	
3	0.9661E+02	-0.2640E+03	0.0000E+00	0.6510E+02	0.0000E+00	0.1000E+01	
5	0.5000E+02	-0.2640E+03	0.0000E+00	0.8191E+00	0.0000E+00	0.1000E+01	

SOLUTION

INTERNAL NODES

NODE	P(PSI)	TF(F)	Z	RHO (LBM/FT^3)	EM(LBM)	CONC	
						HE	O2
2	0.9009E+02	-0.6572E+02	0.1005E+01	0.8490E-01	0.8362E+01	0.1000E+01	0.0000
4	0.9661E+02	-0.2640E+03	0.2261E-01	0.6514E+02	0.2615E+05	0.0000E+00	1.0000
<hr/>							
NODE	H BTU/LB	ENTROPY BTU/LB-R	EMU LBM/FT-SEC	COND BTU/FT-S-R	CP BTU/LB-R	GAMA	
2	0.2495E+03	0.6215E+01	0.1100E-04	0.2041E-04	0.1242E+01	0.1668E+01	
4	0.7491E+02	0.7813E+00	0.8487E-04	0.1822E-04	0.4227E+00	0.2028E+01	

BRANCHES

BRANCH	KFACTOR (LBF-S^2/(LBM-FT)^2)	DELP (PSI)	FLOW RATE (LBM/SEC)	VELOCITY (FT/SEC)	REYN. NO.	MACH NO.	ENTROPY GEN. BTU/(R-SEC)	LOST WORK LBF-FT/SEC
12	0.238E+05	0.491E+01	0.172E+00	0.519E+03	0.182E+06	0.150E+00	0.443E-02	0.200E+04
34	0.000E+00	0.000E+00	0.160E+03	0.880E-01	0.403E+06	0.112E-03	0.000E+00	0.000E+00
45	0.263E+00	0.466E+02	0.160E+03	0.248E+02	0.675E+07	0.316E-01	0.108E+00	0.165E+05

NUMBER OF PRESSURIZATION SYSTEMS = 1
 NODUL NODPRP QULPPR P QULWAL QCOND TNKTM VOLPROP VOLULG
 2 4 3.1060 20.3639 0.0129 200.0219 401.5074 98.4923

ISTEP = 600 TAU = 0.60000E+02

BOUNDARY NODES

NODE	P(PSI)	TF(F)	Z(COMP)	RHO (LBM/F T^3)	CONCENTRATIONS		

						HE	O2
1	0.9500E+02	0.1200E+03	0.0000E+00	0.6091E-01	0.1000E+01	0.0000E+00	
3	0.9465E+02	-0.2640E+03	0.0000E+00	0.6510E+02	0.0000E+00	0.1000E+01	
5	0.5000E+02	-0.2640E+03	0.0000E+00	0.8191E+00	0.0000E+00	0.1000E+01	

SOLUTION

INTERNAL NODES

NODE	P (PSI)	TF (F)	Z	RHO (LBM/FT ³)	EM(LBM)	CONC	HE	O2
2	0.8931E+02	-0.4629E+02	0.1005E+01	0.8023E-01	0.1374E+02	0.1000E+01	0.0000	
4	0.9465E+02	-0.2640E+03	0.2216E-01	0.6514E+02	0.2141E+05	0.0000E+00	1.0000	

NODE	H BTU/LB	ENTROPY BTU/LB-R	EMU LBM/FT-SEC	COND BTU/FT-S-R	CP BTU/LB-R	GAMA
2	0.2495E+03	0.6279E+01	0.1137E-04	0.2108E-04	0.1242E+01	0.1667E+01
4	0.7491E+02	0.7813E+00	0.8485E-04	0.1822E-04	0.4228E+00	0.2029E+01

BRANCHES

BRANCH	KFACTOR (LBF-S ² /LBM-FT) ²	DELP (PSI)	FLOW RATE (LBM/SEC)	VELOCITY (FT/SEC)	REYN. NO.	MACH NO.	ENTROPY GEN. BTU/(R-SEC)	LOST WORK LBF-FT/SEC
12	0.238E+05	0.569E+01	0.185E+00	0.558E+03	0.196E+06	0.161E+00	0.552E-02	0.249E+04
34	0.000E+00	0.000E+00	0.156E+03	0.861E-01	0.395E+06	0.110E-03	0.000E+00	0.000E+00
45	0.263E+00	0.447E+02	0.156E+03	0.243E+02	0.661E+07	0.309E-01	0.101E+00	0.154E+05

NUMBER OF PRESSURIZATION SYSTEMS = 1

NODUL	NODPRP	QULPPR	QULWAL	QCOND	TNKTM	VOLPROP	VOLULG
2	4	3.4085	32.7731	0.0388	206.4272	328.7459	171.2537

SOLUTION SATISFIED CONVERGENCE CRITERION OF 0.100E-02 IN 5 ITERATIONS
 TAU = 59.9997 ISTEP = 600

SOLUTION SATISFIED CONVERGENCE CRITERION OF 0.100E-02 IN 5 ITERATIONS
 TAU = 60.0997 ISTEP = 601

SOLUTION SATISFIED CONVERGENCE CRITERION OF 0.100E-02 IN 5 ITERATIONS
 TAU = 60.1997 ISTEP = 602

SOLUTION SATISFIED CONVERGENCE CRITERION OF 0.100E-02 IN 5 ITERATIONS
 TAU = 60.2997 ISTEP = 603

SOLUTION SATISFIED CONVERGENCE CRITERION OF 0.100E-02 IN 5 ITERATIONS
TAU = 60.3997 ISTEP = 604

SOLUTION SATISFIED CONVERGENCE CRITERION OF 0.100E-02 IN 5 ITERATIONS
TAU = 60.4996 ISTEP = 605

SOLUTION SATISFIED CONVERGENCE CRITERION OF 0.100E-02 IN 5 ITERATIONS
TAU = 60.5996 ISTEP = 606

SOLUTION SATISFIED CONVERGENCE CRITERION OF 0.100E-02 IN 5 ITERATIONS
TAU = 60.6996 ISTEP = 607

SOLUTION SATISFIED CONVERGENCE CRITERION OF 0.100E-02 IN 5 ITERATIONS
TAU = 60.7996 ISTEP = 608

SOLUTION SATISFIED CONVERGENCE CRITERION OF 0.100E-02 IN 5 ITERATIONS
TAU = 60.8996 ISTEP = 609

ISTEP = 610 TAU = 0.61000E+02
BOUNDARY NODES

NODE	P(PSI)	TF(F)	Z(COMP)	RHO (LBM/F T^3)	CONCENTRATIONS		
1	0.9500E+02	0.1200E+03	0.0000E+00	0.6091E-01	0.1000E+01	0.0000E+00	HE O2
3	0.9459E+02	-0.2640E+03	0.0000E+00	0.6510E+02	0.0000E+00	0.1000E+01	
5	0.5000E+02	-0.2640E+03	0.0000E+00	0.8191E+00	0.0000E+00	0.1000E+01	

SOLUTION
INTERNAL NODES

NODE	P(PSI)	TF(F)	Z	RHO (LBM/FT^3)	EM(LBM)	CONC	HE	O2
2	0.8929E+02	-0.4618E+02	0.1005E+01	0.8019E-01	0.1393E+02	0.1000E+01	0.0000	
4	0.9459E+02	-0.2640E+03	0.2214E-01	0.6514E+02	0.2126E+05	0.0000E+00	1.0000	

NODE	H BTU/LB	ENTROPY BTU/LB-R	EMU LBM/FT-SEC	COND BTU/FT-S-R	CP BTU/LB-R	GAMA
2	0.2495E+03	0.6280E+01	0.1138E-04	0.2108E-04	0.1242E+01	0.1667E+01

4 0.7491E+02 0.7813E+00 0.8485E-04 0.1822E-04 0.4228E+00 0.2028E+01

BRANCHES

BRANCH	KFACTOR (LBF-S^2/(LBM-FT)^2)	DELP (PSI)	FLOW RATE (LBM/SEC)	VELOCITY (FT/SEC)	REYN. NO.	MACH NO.	ENTROPY GEN. BTU/(R-SEC)	LOST WORK LBF-FT/SEC
12	0.238E+05	0.571E+01	0.186E+00	0.559E+03	0.196E+06	0.161E+00	0.555E-02	0.250E+04
34	0.000E+00	0.000E+00	0.156E+03	0.860E-01	0.394E+06	0.110E-03	0.000E+00	0.000E+00
45	0.263E+00	0.446E+02	0.156E+03	0.242E+02	0.660E+07	0.309E-01	0.101E+00	0.154E+05

ISTEP =2000 TAU = 0.20000E+03

BOUNDARY NODES

NODE	P(PSI)	TF(F)	Z(COMP) (LBM/F)	RHO T^3)	CONCENTRATIONS		
					HE	O2	
1	0.9500E+02	0.1200E+03	0.0000E+00	0.6091E-01	0.1000E+01	0.0000E+00	
3	0.8795E+02	-0.2640E+03	0.0000E+00	0.6510E+02	0.0000E+00	0.1000E+01	
5	0.5000E+02	-0.2640E+03	0.0000E+00	0.8191E+00	0.0000E+00	0.1000E+01	

SOLUTION

INTERNAL NODES

NODE	P(PSI)	TF(F)	Z	RHO (LBM/FT^3)	EM(LBM)	CONC	
						HE	O2
2	0.8784E+02	-0.7391E+02	0.1005E+01	0.8454E-01	0.4171E+02	0.1000E+01	0.0000
4	0.8795E+02	-0.2640E+03	0.2059E-01	0.6513E+02	0.4284E+03	0.0000E+00	1.0000
<hr/>							
NODE	H BTU/LB	ENTROPY BTU/LB-R	EMU LBM/FT-SEC	COND BTU/FT-S-R	CP BTU/LB-R	GAMA	
2	0.2495E+03	0.6202E+01	0.1085E-04	0.2013E-04	0.1242E+01	0.1668E+01	
4	0.7491E+02	0.7814E+00	0.8478E-04	0.1822E-04	0.4229E+00	0.2029E+01	

BRANCHES

BRANCH	KFACTOR (LBF-S^2/(LBM-FT)^2)	DELP (PSI)	FLOW RATE (LBM/SEC)	VELOCITY (FT/SEC)	REYN. NO.	MACH NO.	ENTROPY GEN. BTU/(R-SEC)	LOST WORK LBF-FT/SEC
12	0.238E+05	0.716E+01	0.208E+00	0.626E+03	0.220E+06	0.181E+00	0.780E-02	0.352E+04
34	0.000E+00	0.000E+00	0.144E+03	0.794E-01	0.364E+06	0.101E-03	0.000E+00	0.000E+00
45	0.263E+00	0.379E+02	0.144E+03	0.224E+02	0.610E+07	0.285E-01	0.794E-01	0.121E+05

NUMBER OF PRESSURIZATION SYSTEMS = 1
NODUL NODPRP QULPRP QULWAL QCOND TNKTM VOLPROP VOLULG
2 4 2.9379 57.9879 6.5483 232.0949 6.5784 493.421

APPENDIX P

INPUT AND OUTPUT DATA FILES FROM EXAMPLE 11

Power Balancing of a Turbopump Assembly

Contents	Page
Example 11 Input File	P-2
Example 11 Pump Characteristic Data File	P-10
Example 11 Output File	P-11

```

GFSSP VERSION
 300
ANALYST
akm
INPUT DATA FILE NAME
ex11.dat
OUTPUT FILE NAME
ex11.out
TITLE
POWER BALANCING OF A GAS TURBINE CYCLE
USETUP
  F
DENCON GRAVITY ENERGY MIXTURE THRUST STEADY TRANSV SAVER
  F   F   T   F   T   F   F
HEX HCOEF REACTING INERTIA CONDX GASPAK PRINTI ROTATION
  T   F   F   F   F   F   F
BUOYANCY HRATE INVAL MSORCE MOVBND TPA VARGEO TVM
  F   T   F   F   T   F   F
SHEAR PRNTIN PRNTADD LAMINAR TRANSQ
  F   F   F   T   F
PRESS INSUC VARROT
  F   F   F
NORMAL SIMUL SECONDL
  F   T   F
NNODES NINT NBR NF
  20   17   20   1
RELAXK RELAXD RELAXH CC NITER
  0.500   0.500   0.500   0.100E-03   150
NFLUID(I), I= 1,NF
  10
NODE INDEX
  1   2
  2   1
  3   1
  4   1
  5   1
  6   1
  7   1
  8   1
  9   1
 10   1
 11   1
 12   1
 13   1
 14   1
 15   1
 16   1

```

17	2							
18	1							
19	1							
20	2							
NODE	PRES (PSI)	TEMP(DEGF)	MASS	SOURC	HEAT	SOURC	THRST	AREA
1	0.6000E+02	-0.4190E+03	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
2	0.2923E+02	-0.4190E+03	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
3	0.2847E+02	-0.4190E+03	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
4	0.2770E+02	-0.4190E+03	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
5	0.2694E+02	-0.4190E+03	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
6	0.2694E+02	-0.4190E+03	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
7	0.2617E+02	-0.4190E+03	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
8	0.2541E+02	-0.4190E+03	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
9	0.2464E+02	-0.4190E+03	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
10	0.2388E+02	-0.4190E+03	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
11	0.2311E+02	-0.4190E+03	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
12	0.2235E+02	-0.4190E+03	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
13	0.2158E+02	-0.4190E+03	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
14	0.2082E+02	-0.4190E+03	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
15	0.2005E+02	-0.4190E+03	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
16	0.1547E+02	-0.4190E+03	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
17	0.1470E+02	0.8000E+02	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
18	0.1470E+02	-0.4190E+03	0.0000E+00	0.2000E+03	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
19	0.1547E+02	-0.4190E+03	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
20	0.1470E+02	0.8000E+02	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
INODE	NUMBR	BRANCH 1	BRANCH 2	BRANCH 3	BRANCH 4	BRANCH 5	BRANCH 6	
2	2	12	23					
3	2	23	34					
4	3	34	46	45				
5	2	45	57					
6	2	46	68					
7	2	57	78					
8	3	78	68	89				
9	2	89	910					
10	2	910	1011					
11	2	1011	1112					
12	2	1112	1213					
13	2	1213	1314					
14	2	1314	1415					
15	2	1415	1516					
16	3	1516	1617	1618				
18	2	1618	1819					
19	2	1819	1920					
BRANCH	UPNODE	DNNODE	OPTION					
12	1	2	16					
23	2	3	15					
34	3	4	16					

46	4	6	1		
45	4	5	1		
57	5	7	1		
68	6	8	1		
78	7	8	1		
89	8	9	16		
910	9	10	1		
1011	10	11	1		
1112	11	12	16		
1213	12	13	15		
1314	13	14	1		
1415	14	15	1		
1516	15	16	1		
1617	16	17	16		
1618	16	18	16		
1819	18	19	1		
1920	19	20	1		
BRANCH OPTION -16: CV, AREA					
12	2.87700	0.19635			
BRANCH OPTION -15: HORSEPOWER, EFFICIENCY, AREA					
23	0.00000	0.80000	0.12112		
BRANCH OPTION -16: CV, AREA					
34	2.19300	0.19635			
BRANCH OPTION -1: LENGTH, DIA, EPSD, ANGLE, AREA					
46	100.00000	0.39270	0.00250	0.00000	0.12112
BRANCH OPTION -1: LENGTH, DIA, EPSD, ANGLE, AREA					
45	100.00000	0.39270	0.00250	0.00000	0.12112
BRANCH OPTION -1: LENGTH, DIA, EPSD, ANGLE, AREA					
57	100.00000	0.39270	0.00250	0.00000	0.12112
BRANCH OPTION -1: LENGTH, DIA, EPSD, ANGLE, AREA					
68	100.00000	0.39270	0.00250	0.00000	0.12112
BRANCH OPTION -1: LENGTH, DIA, EPSD, ANGLE, AREA					
78	100.00000	0.39270	0.00250	0.00000	0.12112
BRANCH OPTION -16: CV, AREA					
89	3.55400	0.19635			
BRANCH OPTION -1: LENGTH, DIA, EPSD, ANGLE, AREA					
910	100.00000	0.39270	0.00250	0.00000	0.12112
BRANCH OPTION -1: LENGTH, DIA, EPSD, ANGLE, AREA					
1011	100.00000	0.39270	0.00250	0.00000	0.12112
BRANCH OPTION -16: CV, AREA					
1112	3.55400	0.19635			
BRANCH OPTION -15: HORSEPOWER, EFFICIENCY, AREA					
1213	0.00000	1.00000	0.019635		
BRANCH OPTION -1: LENGTH, DIA, EPSD, ANGLE, AREA					
1314	100.00000	0.39270	0.00250	0.00000	0.12112
BRANCH OPTION -1: LENGTH, DIA, EPSD, ANGLE, AREA					
1415	100.00000	0.39270	0.00250	0.00000	0.12112

```

BRANCH OPTION -1: LENGTH, DIA, EPSD, ANGLE, AREA
  1516 100.00000      0.39270      0.00250      0.00000      0.12112
BRANCH OPTION -16: CV, AREA
  1617 0.00354      0.01000
BRANCH OPTION -16: CV, AREA
  1618 3.55400      0.19635
BRANCH OPTION -1: LENGTH, DIA, EPSD, ANGLE, AREA
  1819 100.00000      0.39270      0.00250      0.00000      0.12112
BRANCH OPTION -1: LENGTH, DIA, EPSD, ANGLE, AREA
  1920 100.00000      0.39270      0.00250      0.00000      0.12112
BRANCH NOUBR NMUBR
  12      0
  23      1      12
  34      1      23
  46      1      34
  45      1      34
  57      1      45
  68      1      46
  78      1      57
  89      2      78      68
  910     1      89
  1011    1      910
  1112    1      1011
  1213    1      1112
  1314    1      1213
  1415    1      1314
  1516    1      1415
  1617    2      1516      1618
  1618    2      1516      1617
  1819    1      1618
  1920    1      1819
BRANCH NODBR NMDBR
  12      1      23
  23      1      34
  34      1      46
  46      1      68
  45      1      57
  57      1      78
  68      2      78      89
  78      2      68      89
  89      1      910
  910     1      1011
  1011    1      1112
  1112    1      1213
  1213    1      1314
  1314    1      1415
  1415    1      1516

```

1516 2 1617 1618

1617 0

1618 1 1819

1819 1 1920

1920 0

BRANCH

12

UPSTRM BR. ANGLE

DNSTRM BR. ANGLE

23 0.00

BRANCH

23

UPSTRM BR. ANGLE

12 0.00

DNSTRM BR. ANGLE

34 0.00

BRANCH

34

UPSTRM BR. ANGLE

23 0.00

DNSTRM BR. ANGLE

46 0.00

BRANCH

46

UPSTRM BR. ANGLE

34 0.00

DNSTRM BR. ANGLE

68 0.00

BRANCH

45

UPSTRM BR. ANGLE

34 0.00

DNSTRM BR. ANGLE

57 0.00

BRANCH

57

UPSTRM BR. ANGLE

45 0.00

DNSTRM BR. ANGLE

78 0.00

BRANCH

68

UPSTRM BR. ANGLE

46 0.00

DNSTRM BR. ANGLE

78 0.00

89 0.00

BRANCH
 78
 UPSTRM BR. ANGLE
 57 0.00
 DNSTRM BR. ANGLE
 68 0.00
 89 0.00

BRANCH
 89
 UPSTRM BR. ANGLE
 78 0.00
 68 0.00
 DNSTRM BR. ANGLE
 910 0.00

BRANCH
 910
 UPSTRM BR. ANGLE
 89 0.00
 DNSTRM BR. ANGLE
 1011 0.00

BRANCH
 1011
 UPSTRM BR. ANGLE
 910 0.00
 DNSTRM BR. ANGLE
 1112 0.00

BRANCH
 1112
 UPSTRM BR. ANGLE
 1011 0.00
 DNSTRM BR. ANGLE
 1213 0.00

BRANCH
 1213
 UPSTRM BR. ANGLE
 1112 0.00
 DNSTRM BR. ANGLE
 1314 0.00

BRANCH
 1314
 UPSTRM BR. ANGLE
 1213 0.00
 DNSTRM BR. ANGLE
 1415 0.00

BRANCH
 1415
 UPSTRM BR. ANGLE

```

      1314    0.00
DNSTRM BR. ANGLE
      1516    0.00
BRANCH
      1516
      UPSTRM BR. ANGLE
      1415    0.00
DNSTRM BR. ANGLE
      1617    0.00
      1618    0.00
BRANCH
      1617
      UPSTRM BR. ANGLE
      1516    0.00
      1618    0.00
DNSTRM BR. ANGLE
      1618
BRANCH
      1618
      UPSTRM BR. ANGLE
      1516    0.00
      1617    0.00
DNSTRM BR. ANGLE
      1819    0.00
BRANCH
      1819
      UPSTRM BR. ANGLE
      1618    0.00
DNSTRM BR. ANGLE
      1920    0.00
BRANCH
      1920
      UPSTRM BR. ANGLE
      1819    0.00
DNSTRM BR. ANGLE
NUMBER OF HEAT EXCHANGERS
      2
IBRHOT IBRCLD ITYPHX ARHOT ARCOLD UA HEXEFF
1415  57  0  0.00000  0.00000  0.00000  0.80000
1819  910 0  0.00000  0.00000  0.00000  0.90000
NUMBER OF TURBOPUMP ASSEMBLY IN THE CIRCUIT
      1
IBRPMP IBRTRB SPEED(RPM)  EFFTURB  DIATRB PSITRD
      23  1213  0.800E+05  0.500E+00  3.435  0.4
PUMP CHARACTERISTICS CURVE DATA FILE
PUMP23.DAT
NODE DATA FILE
FNODE.DAT

```

BRANCH DATA FILE
FBRANCH.DAT

Example 11 Pump Characteristic Data File

PUMP23.DAT

```
18
0.000      8.680E-06  0.000
3.035E-05   8.971E-06  8.8724E-10
6.071E-05   9.190E-06  9.7065E-10
9.106E-05   9.341E-06  1.0804E-09
1.214E-04   9.436E-06  1.2166E-09
1.518E-04   9.486E-06  1.3393E-09
1.821E-04   9.486E-06  1.4570E-09
2.125E-04   9.445E-06  1.5644E-09
2.428E-04   9.372E-06  1.6733E-09
2.732E-04   9.263E-06  1.7872E-09
3.035E-04   9.117E-06  1.9105E-09
3.339E-04   8.935E-06  2.0558E-09
3.643E-04   8.753E-06  2.2161E-09
3.718E-04   8.689E-06  2.2698E-09
3.749E-04   8.625E-06  2.2869E-09
3.794E-04   8.479E-06  2.3215E-09
3.807E-04   8.388E-06  2.3281E-09
3.810E-04   0.000E+00  0.000
```

```
*****
 G F S S P (Version 3.0)
 Generalized Fluid System Simulation Program
 September, 1999
 Developed by Sverdrup Technology
 Copyright (C) by Marshall Space Flight Center
```

A generalized computer program to calculate flow rates, pressures, temperatures and concentrations in a flow network.

```
*****
TITLE      :POWER BALANCING OF A GAS TURBINE CYCLE
ANALYST    :akm
FILEIN     :EX11.DAT
FILEOUT    :ex11.out
LOGICAL VARIABLES
DENCON     =   F
GRAVITY    =   F
ENERGY     =   T
MIXTURE    =   F
THRUST     =   F
STEADY     =   T
TRANSV     =   F
SAVER      =   F
HEX         =   T
HCOEF       =   F
REACTING    =   F
INERTIA    =   F
CONDX      =   F
TWOD        =   F
PRINTI     =   F
ROTATION    =   F
BUOYANCY   =   F
HRATE      =   T
INVAL      =   F
MSOURCE    =   F
MOVBND     =   F
TPA         =   T
VARGEO     =   F
TVM         =   F
SHEAR      =   F
PRNTIN     =   F
PRNTADD    =   F
ADDPROP    =   F
```

PRESS = F
INSUC = F
VARROT = F
NORMAL = F
SECONDL = F

NNODES = 20
NINT = 17
NBR = 20
NF = 1
NVAR = 37
NHREF = 2

FLUIDS: H2

BOUNDARY NODES

NODE	P (PSI)	T (F)	RHO (LBM/FT ³)	AREA (IN ²)
1	0.6000E+02	-0.4190E+03	0.4267E+01	0.0000E+00
17	0.1470E+02	0.8000E+02	0.5112E-02	0.0000E+00
20	0.1470E+02	0.8000E+02	0.5112E-02	0.0000E+00

IBRPMP	IBRTRB	SPEED(RPM)	ETATRB	PSITR	TORQUE(LB-IN)	HPOWER
23	1213	0.800E+05	0.000E+00	0.000E+00	0.000E+00	0.000E+00

SOLUTION

INTERNAL NODES

NODE	P(PSI)	TF(F)	Z	RHO (LBM/FT ³)	EM(LBM)	QUALITY
2	0.5539E+02	-0.4190E+03	0.6009E-01	0.4262E+01	0.0000E+00	0.0000E+00
3	0.1789E+04	-0.4074E+03	0.1370E+01	0.4700E+01	0.0000E+00	0.0000E+00
4	0.1782E+04	-0.4073E+03	0.1363E+01	0.4695E+01	0.0000E+00	0.0000E+00
5	0.1781E+04	-0.4073E+03	0.1362E+01	0.4694E+01	0.0000E+00	0.0000E+00
6	0.1778E+04	-0.4072E+03	0.1359E+01	0.4692E+01	0.0000E+00	0.0000E+00
7	0.1780E+04	-0.1474E+03	0.1091E+01	0.9815E+00	0.0000E+00	0.1000E+01
8	0.1773E+04	-0.3070E+03	0.1063E+01	0.2054E+01	0.0000E+00	0.1000E+01
9	0.1767E+04	-0.3070E+03	0.1062E+01	0.2048E+01	0.0000E+00	0.1000E+01
10	0.1743E+04	0.1450E+03	0.1065E+01	0.5086E+00	0.0000E+00	0.1000E+01
11	0.1647E+04	0.1454E+03	0.1061E+01	0.4819E+00	0.0000E+00	0.1000E+01
12	0.1620E+04	0.1455E+03	0.1060E+01	0.4744E+00	0.0000E+00	0.1000E+01
13	0.1079E+04	0.8809E+02	0.1043E+01	0.3548E+00	0.0000E+00	0.1000E+01
14	0.9411E+03	0.8855E+02	0.1038E+01	0.3108E+00	0.0000E+00	0.1000E+01
15	0.7837E+03	-0.5602E+01	0.1035E+01	0.3135E+00	0.0000E+00	0.1000E+01
16	0.6278E+03	-0.5286E+01	0.1028E+01	0.2526E+00	0.0000E+00	0.1000E+01

18	0.5772E+03	0.2464E+03	0.1020E+01	0.1505E+00	0.0000E+00	0.1000E+01
19	0.2543E+03	-0.2255E+03	0.1008E+01	0.2023E+00	0.0000E+00	0.1000E+01

BRANCHES

BRANCH	KFACTOR (LBF-S^2/(LBM-FT)^2)	DELP (PSI)	FLOW RATE (LBM/SEC)	VELOCITY (FT/SEC)	REYN. NO.	MACH NO.	ENTROPY GEN. BTU/(R-SEC)	LOST WORK LBF-FT/SEC
12	0.132E+05	0.460E+01	0.224E+00	0.386E+02	0.894E+06	0.278E-01	0.110E-02	0.349E+02
23	0.000E+00	-0.173E+04	0.224E+00	0.626E+02	0.114E+07	0.450E-01	0.000E+00	0.000E+00
34	0.206E+05	0.720E+01	0.224E+00	0.350E+02	0.687E+06	0.249E-01	0.122E-02	0.495E+02
46	0.300E+05	0.441E+01	0.145E+00	0.368E+02	0.569E+06	0.262E-01	0.483E-03	0.197E+02
45	0.302E+05	0.131E+01	0.790E-01	0.200E+02	0.309E+06	0.142E-01	0.779E-04	0.317E+01
57	0.302E+05	0.131E+01	0.790E-01	0.200E+02	0.309E+06	0.142E-01	0.779E-04	0.317E+01
68	0.300E+05	0.441E+01	0.145E+00	0.369E+02	0.571E+06	0.261E-01	0.483E-03	0.197E+02
78	0.143E+06	0.620E+01	0.790E-01	0.956E+02	0.692E+06	0.292E-01	0.295E-03	0.717E+02
89	0.179E+05	0.627E+01	0.224E+00	0.802E+02	0.188E+07	0.307E-01	0.831E-03	0.987E+02
910	0.681E+05	0.238E+02	0.224E+00	0.130E+03	0.239E+07	0.498E-01	0.317E-02	0.376E+03
1011	0.275E+06	0.962E+02	0.224E+00	0.525E+03	0.133E+07	0.114E+00	0.130E-01	0.611E+04
1112	0.764E+05	0.267E+02	0.224E+00	0.342E+03	0.105E+07	0.745E-01	0.381E-02	0.179E+04
1213	0.000E+00	0.541E+03	0.224E+00	0.347E+04	0.332E+07	0.757E+00	0.000E+00	0.000E+00
1314	0.394E+06	0.138E+03	0.224E+00	0.752E+03	0.144E+07	0.173E+00	0.295E-01	0.126E+05
1415	0.450E+06	0.157E+03	0.224E+00	0.859E+03	0.144E+07	0.197E+00	0.384E-01	0.164E+05
1516	0.446E+06	0.156E+03	0.224E+00	0.851E+03	0.163E+07	0.216E+00	0.455E-01	0.161E+05
1617	0.147E+12	0.613E+03	0.775E-03	0.442E+02	0.197E+05	0.112E-01	0.766E-03	0.271E+03
1618	0.146E+06	0.506E+02	0.224E+00	0.649E+03	0.128E+07	0.165E+00	0.183E-01	0.646E+04
1819	0.929E+06	0.323E+03	0.224E+00	0.177E+04	0.122E+07	0.358E+00	0.126E+00	0.691E+05
1920	0.689E+06	0.240E+03	0.224E+00	0.132E+04	0.256E+07	0.466E+00	0.209E+00	0.381E+05
1								
IBRPMP	IBRTTRB	SPEED(RPM)	ETATRB	PSITR	TORQUE(LB-IN)	HPOWER		
23	1213	0.800E+05	0.578E+00	0.269E+00	0.512E+02	0.650E+02		

SOLUTION SATISFIED CONVERGENCE CRITERION OF 0.100E-03 IN 114 ITERATIONS
TAU = 0.100000E+09 ISTEP = 1

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APPENDIX-Q
INPUT AND OUTPUT DATA FILES FROM EXAMPLE 12

Helium Pressurization of LOX and RP-1 Propellant Tank

<u>Contents</u>	<u>Page</u>
Example 12 Input File	Q-2
Example 12 History Files	Q-28
Example 12 Output File (Partial)	Q-31

```

GFSSP VERSION
 300
ANALYST
Todd Steadman
INPUT DATA FILE NAME
ex12.dat
OUTPUT FILE NAME
ex12.out
TITLE
PTA1 Final Pressurization Model w/Pumps & Mass Transfer(eng op: 0 to 60)
USETUP
  F
DENCON GRAVITY ENERGY MIXTURE THRUST STEADY TRANSV SAVER
  F      F      T      T      F      F      T      F
HEX HCOEF REACTING INERTIA CONDX GASPAK PRINTI ROTATION
  F      F      F      T      F      F      F      F
BUOYANCY HRATE INVAL MSORCE MOVBND TPA VARGEO TVM
  F      T      F      F      F      F      F      F
SHEAR PRNTIN PRNTADD LAMINAR TRANSQ
  F      F      F      T      F
PRESS INSUC VARROT
  T      F      F
NORMAL SIMUL SECONDL
  F      T      F
NNODES NINT NBR NF
  65    59    64    3
RELAXK RELAXD RELAXH CC NITER
  1.000  0.500  1.000  0.100E-02   50
DTAU TIMEF TIMEL NPSTEP
  0.1000E+00  0.0000E+00  0.6000E+02   10
NFLUID(I), I= 1,NF
  1      6     12
NODE INDEX
  1      2
  2      1
  3      1
  4      1
  5      1
  6      1
  7      1
  8      1

```

9	1
10	1
11	1
12	1
13	1
14	1
15	1
16	1
17	1
18	1
19	1
20	1
21	1
22	1
23	1
24	1
25	1
26	1
27	1
28	1
29	1
30	2
31	1
32	1
33	1
34	2
35	1
36	1
37	1
38	1
39	1
40	1
41	1
42	1
43	1
44	1
45	1
46	1
47	1
48	1
49	1

```

50   1
51   1
52   1
53   1
54   1
55   2
56   1
57   1
58   1
59   2
60   1
61   1
62   1
63   1
64   1
65   2

NODE PRES (PSI) TEMP(DEGF) MASS SOURC          HEAT SOURC THRST AREA CONCENTRATION
 2  0.7620E+03  0.1200E+03  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  1.0000  0.0000  0.0000
 3  0.7413E+03  0.1201E+03  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  1.0000  0.0000  0.0000
 4  0.7412E+03  0.1201E+03  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  1.0000  0.0000  0.0000
 5  0.7411E+03  0.1201E+03  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  1.0000  0.0000  0.0000
 6  0.7352E+03  0.1203E+03  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  1.0000  0.0000  0.0000
 7  0.7332E+03  0.1203E+03  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  1.0000  0.0000  0.0000
 8  0.7332E+03  0.1203E+03  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  1.0000  0.0000  0.0000
 9  0.7328E+03  0.1203E+03  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  1.0000  0.0000  0.0000
10  0.7264E+03  0.1203E+03  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  1.0000  0.0000  0.0000
11  0.7253E+03  0.1203E+03  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  1.0000  0.0000  0.0000
12  0.7249E+03  0.1203E+03  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  1.0000  0.0000  0.0000
13  0.7249E+03  0.1203E+03  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  1.0000  0.0000  0.0000
14  0.7249E+03  0.1203E+03  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  1.0000  0.0000  0.0000
15  0.9137E+02  0.1254E+03  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  1.0000  0.0000  0.0000
16  0.9137E+02  0.1254E+03  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  1.0000  0.0000  0.0000
17  0.7235E+03  0.1203E+03  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  1.0000  0.0000  0.0000
18  0.7233E+03  0.1203E+03  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  1.0000  0.0000  0.0000
19  0.7222E+03  0.1203E+03  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  1.0000  0.0000  0.0000
20  0.7219E+03  0.1203E+03  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  1.0000  0.0000  0.0000
21  0.9136E+02  0.1254E+03  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  1.0000  0.0000  0.0000
22  0.8061E+02  0.1255E+03  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  1.0000  0.0000  0.0000
23  0.7225E+02  0.1256E+03  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  1.0000  0.0000  0.0000
24  0.6817E+02  0.1257E+03  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  1.0000  0.0000  0.0000
25  0.6267E+02  0.1256E+03  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00  1.0000  0.0000  0.0000

```

26	0.5796E+02	0.1257E+03	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	1.0000	0.0000	0.0000
27	0.4999E+02	0.1258E+03	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	1.0000	0.0000	0.0000
28	0.5000E+02	0.1258E+03	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	1.0000	0.0000	0.0000
29	0.5000E+02	0.7000E+02	0.0000E+00	0.0000E+00	0.0000E+00	0.2592E+05	1.0000	0.0000	0.0000
31	0.5357E+02	0.7000E+02	0.0000E+00	0.0000E+00	0.0000E+00	0.4925E+06	0.0000	0.0000	1.0000
32	0.2713E+02	0.7000E+02	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000	0.0000	0.0000
33	0.9590E+03	0.7000E+02	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000	0.0000	1.0000
35	0.7331E+03	0.1203E+03	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	1.0000	0.0000
36	0.7322E+03	0.1203E+03	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	1.0000	0.0000
37	0.7283E+03	0.1203E+03	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	1.0000	0.0000
38	0.7283E+03	0.1203E+03	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	1.0000	0.0000
39	0.7283E+03	0.1203E+03	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	1.0000	0.0000
40	0.1528E+03	0.1249E+03	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	1.0000	0.0000
41	0.1528E+03	0.1249E+03	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	1.0000	0.0000
42	0.7243E+03	0.1204E+03	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	1.0000	0.0000
43	0.7225E+03	0.1204E+03	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	1.0000	0.0000
44	0.7186E+03	0.1203E+03	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	1.0000	0.0000
45	0.7176E+03	0.1203E+03	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	1.0000	0.0000
46	0.1528E+03	0.1249E+03	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	1.0000	0.0000
47	0.1340E+03	0.1250E+03	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	1.0000	0.0000
48	0.1174E+03	0.1252E+03	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	1.0000	0.0000
49	0.1122E+03	0.1252E+03	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	1.0000	0.0000
50	0.9573E+02	0.1254E+03	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	1.0000	0.0000
51	0.8544E+02	0.1255E+03	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	1.0000	0.0000
52	0.6701E+02	0.1256E+03	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	1.0000	0.0000
53	0.6701E+02	0.1256E+03	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	1.0000	0.0000
54	0.6700E+02	-.2600E+03	0.0000E+00	0.0000E+00	0.0000E+00	0.4320E+05	1.0000	0.0000	0.0000
56	0.7552E+02	-.3000E+03	0.0000E+00	0.0000E+00	0.0000E+00	0.8208E+06	0.0000	1.0000	0.0000
57	0.4300E+02	-.3000E+03	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000	1.0000	0.0000
58	0.9190E+03	-.3000E+03	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000	1.0000	0.0000
60	0.7412E+03	0.1201E+03	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	1.0000	0.0000
61	0.7411E+03	0.1201E+03	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	1.0000	0.0000
62	0.7364E+03	0.1203E+03	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	1.0000	0.0000
63	0.7291E+03	0.1203E+03	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	1.0000	0.0000
64	0.6430E+03	0.1210E+03	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	1.0000	0.0000

ex12hs1.dat
 ex12hs2.dat
 ex12hs3.dat
 ex12hs4.dat
 ex12hs5.dat
 ex12hs6.dat

INODE	NUMBR	BRANCH 1	BRANCH 2	BRANCH 3	BRANCH 4	BRANCH 5	BRANCH 6
2	2	1001	1002				
3	3	1002	1003	1059			
4	2	1003	1004				
5	2	1004	1005				
6	2	1005	1006				
7	3	1006	1007	1034			
8	2	1007	1008				
9	2	1008	1009				
10	2	1009	1010				
11	2	1010	1011				
12	3	1011	1012	1016			
13	2	1012	1013				
14	2	1013	1014				
15	2	1014	1015				
16	2	1015	1021				
17	2	1016	1017				
18	2	1017	1018				
19	2	1018	1019				
20	2	1019	1020				
21	3	1020	1021	1022			
22	2	1022	1023				
23	2	1023	1024				
24	2	1024	1025				
25	2	1025	1026				
26	2	1026	1027				
27	2	1027	1028				
28	2	1028	1029				
29	1	1029					
31	2	1030	1031				
32	2	1031	1032				
33	2	1032	1033				
35	2	1034	1035				
36	2	1035	1036				
37	3	1036	1037	1041			
38	2	1037	1038				
39	2	1038	1039				
40	2	1039	1040				
41	2	1040	1046				
42	2	1041	1042				
43	2	1042	1043				

44	2	1043	1044
45	2	1044	1045
46	3	1045	1046
47	2	1047	1048
48	2	1048	1049
49	2	1049	1050
50	2	1050	1051
51	2	1051	1052
52	2	1052	1053
53	2	1053	1054
54	1	1054	
56	2	1055	1056
57	2	1056	1057
58	2	1057	1058
60	2	1059	1060
61	2	1060	1061
62	2	1061	1062
63	2	1062	1063
64	2	1063	1064
BRANCH	UPNODE	DNNODE	OPTION
1001	1	2	1
1002	2	3	2
1003	3	4	13
1059	3	60	13
1004	4	5	1
1005	5	6	2
1006	6	7	1
1007	7	8	13
1034	7	35	13
1008	8	9	7
1009	9	10	1
1010	10	11	2
1011	11	12	1
1012	12	13	13
1016	12	17	13
1013	13	14	1
1014	14	15	2
1015	15	16	1
1021	16	21	2
1017	17	18	1
1018	18	19	18

1019	19	20	1
1020	20	21	2
1022	21	22	13
1023	22	23	2
1024	23	24	1
1025	24	25	2
1026	25	26	1
1027	26	27	8
1028	27	28	2
1029	28	29	2
1030	30	31	2
1031	31	32	2
1032	32	33	14
1033	33	34	2
1035	35	36	7
1036	36	37	2
1037	37	38	13
1041	37	42	13
1038	38	39	1
1039	39	40	2
1040	40	41	1
1046	41	46	2
1042	42	43	1
1043	43	44	18
1044	44	45	1
1045	45	46	2
1047	46	47	13
1048	47	48	2
1049	48	49	1
1050	49	50	2
1051	50	51	1
1052	51	52	8
1053	52	53	2
1054	53	54	2
1055	55	56	2
1056	56	57	2
1057	57	58	14
1058	58	59	2
1060	60	61	1
1061	61	62	2
1062	62	63	7

1063	63	64	1	
1064	64	65	1	
BRANCH OPTION -1: LENGTH, DIA, EPSD, ANGLE, AREA				
1001	128.00000	1.30000	0.00062	0.00000
				1.32732
BRANCH OPTION -2: FLOW COEF, AREA				
1002	0.60000	0.63617		
BRANCH OPTION -13: DIA, K1, K2, AREA				
1003	1.30000	200.00000	0.10000	1.32732
BRANCH OPTION -13: DIA, K1, K2, AREA				
1059	1.30000	200.00000	0.10000	1.32732
BRANCH OPTION -1: LENGTH, DIA, EPSD, ANGLE, AREA				
1004	17.00000	1.30000	0.00062	0.00000
				1.32732
BRANCH OPTION -2: FLOW COEF, AREA				
1005	0.60000	0.63617		
BRANCH OPTION -1: LENGTH, DIA, EPSD, ANGLE, AREA				
1006	288.00000	1.30000	0.00062	0.00000
				1.32732
BRANCH OPTION -13: DIA, K1, K2, AREA				
1007	1.30000	200.00000	0.10000	1.32732
BRANCH OPTION -13: DIA, K1, K2, AREA				
1034	1.30000	200.00000	0.10000	1.32732
BRANCH OPTION -7: PIPE DIA, REDUCED DIA, AREA				
1008	1.30000	0.53000	1.32732	
BRANCH OPTION -1: LENGTH, DIA, EPSD, ANGLE, AREA				
1009	221.00000	0.53000	0.00151	0.00000
				0.22062
BRANCH OPTION -2: FLOW COEF, AREA				
1010	0.60000	0.28270		
BRANCH OPTION -1: LENGTH, DIA, EPSD, ANGLE, AREA				
1011	12.00000	0.53000	0.00151	0.00000
				0.22062
BRANCH OPTION -13: DIA, K1, K2, AREA				
1012	0.53000	500.00000	0.70000	0.22062
BRANCH OPTION -13: DIA, K1, K2, AREA				
1016	0.53000	500.00000	0.70000	0.22062
BRANCH OPTION -1: LENGTH, DIA, EPSD, ANGLE, AREA				
1013	14.00000	0.53000	0.00151	0.00000
				0.22062
BRANCH OPTION -2: FLOW COEF, AREA				
1014	0.60000	0.00001		
BRANCH OPTION -1: LENGTH, DIA, EPSD, ANGLE, AREA				
1015	14.00000	0.53000	0.00151	0.00000
				0.22062
BRANCH OPTION -2: FLOW COEF, AREA				
1021	0.60000	0.00785		
BRANCH OPTION -1: LENGTH, DIA, EPSD, ANGLE, AREA				

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1017      7.50000    0.53000    0.00151    0.00000    0.22062
BR OPT-> 18-2, SUBOPT, FLOW COEF, AREA, CTRL NODE, INIT POS
1018      2    0.60000    0.28270    29.0000    T
BR OPT-> 18-2(continued), CYCLE TIME, CYCLE STEPS, PR TOL FILE
          0.05000    5.00000
ex14rp1.dat
BRANCH OPTION -1: LENGTH, DIA, EPSD, ANGLE, AREA
1019      9.00000    0.53000    0.00151    0.00000    0.22062
BRANCH OPTION -2: FLOW COEF, AREA
1020      0.60000    0.02895
BRANCH OPTION -13: DIA, K1, K2, AREA
1022      0.53000    500.00000    0.70000    0.22062
BRANCH OPTION -2: FLOW COEF, AREA
1023      0.83056    0.22550
BRANCH OPTION -1: LENGTH, DIA, EPSD, ANGLE, AREA
1024     14.00000    0.53000    0.00151    0.00000    0.22062
BRANCH OPTION -2: FLOW COEF, AREA
1025      0.60000    0.41850
BRANCH OPTION -1: LENGTH, DIA, EPSD, ANGLE, AREA
1026     14.00000    0.53000    0.00151    0.00000    0.22062
BRANCH OPTION -8: PIPE DIA, EXP DIA, AREA
1027      0.53000    3.00000    0.22062
BRANCH OPTION -2: FLOW COEF, AREA
1028      0.00000    7.06858
BRANCH OPTION -2: FLOW COEF, AREA
1029      0.60000    37.69910
BRANCH OPTION -2: FLOW COEF, AREA
1030      0.00000    3987.00000
BRANCH OPTION -2: FLOW COEF, AREA
1031      0.18100    14.25000
BRANCH OPTION -14: PUMP CONST1, PUMP CONST2, AREA
1032    168757.    -4.9362    14.2500
BRANCH OPTION -2: FLOW COEF, AREA
1033      0.04640    14.25000
BRANCH OPTION -7: PIPE DIA, REDUCED DIA, AREA
1035      1.30000    0.78000    1.32732
BRANCH OPTION -2: FLOW COEF, AREA
1036      0.60000    0.63617
BRANCH OPTION -13: DIA, K1, K2, AREA
1037      0.78000    500.00000    0.70000    0.47784
BRANCH OPTION -13: DIA, K1, K2, AREA

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1041      0.78000   500.00000    0.70000    0.47784
BRANCH OPTION -1: LENGTH, DIA, EPSD, ANGLE, AREA
1038     11.00000     0.78000     0.00103     0.00000     0.47784
BRANCH OPTION -2: FLOW COEF, AREA
1039     0.60000     0.00001
BRANCH OPTION -1: LENGTH, DIA, EPSD, ANGLE, AREA
1040     18.00000     0.78000     0.00103     0.00000     0.47784
BRANCH OPTION -2: FLOW COEF, AREA
1046     0.60000     0.01767
BRANCH OPTION -1: LENGTH, DIA, EPSD, ANGLE, AREA
1042     28.00000     0.78000     0.00103     0.00000     0.47784
BR OPT-> 18-2, SUBOPT, FLOW COEF, AREA, CTRL NODE, INIT POS
1043      2     0.60000     0.63617     54.0000     T
BR OPT-> 18-2(continued), CYCLE TIME, CYCLE STEPS, PR TOL FILE
          0.05000     5.00000
ex14lox.dat
BRANCH OPTION -1: LENGTH, DIA, EPSD, ANGLE, AREA
1044     15.00000     0.78000     0.00103     0.00000     0.47784
BRANCH OPTION -2: FLOW COEF, AREA
1045     0.60000     0.10179
BRANCH OPTION -13: DIA, K1, K2, AREA
1047     0.78000   500.00000    0.70000    0.47784
BRANCH OPTION -2: FLOW COEF, AREA
1048     0.77371     0.55351
BRANCH OPTION -1: LENGTH, DIA, EPSD, ANGLE, AREA
1049     13.00000     0.78000     0.00103     0.00000     0.47784
BRANCH OPTION -2: FLOW COEF, AREA
1050     0.60000     0.78540
BRANCH OPTION -1: LENGTH, DIA, EPSD, ANGLE, AREA
1051     21.00000     0.78000     0.00103     0.00000     0.47784
BRANCH OPTION -8: PIPE DIA, EXP DIA, AREA
1052     0.78000     3.00000     0.47784
BRANCH OPTION -2: FLOW COEF, AREA
1053     0.00000     7.06858
BRANCH OPTION -2: FLOW COEF, AREA
1054     0.60000     37.69910
BRANCH OPTION -2: FLOW COEF, AREA
1055     0.00000   4015.00000
BRANCH OPTION -2: FLOW COEF, AREA
1056     0.30400     14.25000
BRANCH OPTION -14: PUMP CONST1, PUMP CONST2, AREA

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1057    176033.    -2.5799    14.2500
BRANCH OPTION -2: FLOW COEF, AREA
1058    0.10500    14.25000
BRANCH OPTION -1: LENGTH, DIA, EPSD, ANGLE, AREA
1060    19.00000    1.30000    0.00062    0.00000    1.32732
BRANCH OPTION -2: FLOW COEF, AREA
1061    0.60000    0.63617
BRANCH OPTION -7: PIPE DIA, REDUCED DIA, AREA
1062    1.30000    0.53000    1.32732
BRANCH OPTION -1: LENGTH, DIA, EPSD, ANGLE, AREA
1063    143.00000    0.53000    0.00151    0.00000    0.22062
BRANCH OPTION -1: LENGTH, DIA, EPSD, ANGLE, AREA
1064    28.00000    0.53000    0.00604    0.00000    0.22062
INITIAL FLOWRATES IN BRANCHES FOR UNSTEADY FLOW
1001    0.80300
1002    0.80300
1003    0.42300
1059    0.38000
1004    0.42300
1005    0.42300
1006    0.42300
1007    0.08200
1034    0.34100
1008    0.08200
1009    0.08200
1010    0.08200
1011    0.08200
1012    0.00010
1016    0.08190
1013    0.00010
1014    0.00010
1015    0.00010
1021    0.00010
1017    0.08190
1018    0.08190
1019    0.08190
1020    0.08190
1022    0.08190
1023    0.08190
1024    0.08190
1025    0.08190

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1026		0.08190
1027		0.08190
1028		0.08190
1029		0.08190
1030		64.0000
1031		64.0000
1032		64.0000
1033		64.0000
1035		0.34100
1036		0.34100
1037		0.00010
1041		0.34090
1038		0.00010
1039		0.00010
1040		0.00010
1046		0.00010
1042		0.34090
1043		0.34090
1044		0.34090
1045		0.34090
1047		0.34090
1048		0.34090
1049		0.34090
1050		0.34090
1051		0.34090
1052		0.34090
1053		0.34090
1054		0.34090
1055		140.000
1056		140.000
1057		140.000
1058		140.000
1060		0.38000
1061		0.38000
1062		0.38000
1063		0.38000
1064		0.38000
BRANCH	NOUBR	NMUBR
1001		0
1002		1 1001
1003		2 1002 1059

1059	2	1002	1003
1004	1	1003	
1005	1	1004	
1006	1	1005	
1007	2	1006	1034
1034	2	1006	1007
1008	1	1007	
1009	1	1008	
1010	1	1009	
1011	1	1010	
1012	2	1011	1016
1016	2	1011	1012
1013	1	1012	
1014	1	1013	
1015	1	1014	
1021	1	1015	
1017	1	1016	
1018	1	1017	
1019	1	1018	
1020	1	1019	
1022	2	1021	1020
1023	1	1022	
1024	1	1023	
1025	1	1024	
1026	1	1025	
1027	1	1026	
1028	1	1027	
1029	1	1028	
1030	0		
1031	1	1030	
1032	1	1031	
1033	1	1032	
1035	1	1034	
1036	1	1035	
1037	2	1036	1041
1041	2	1036	1037
1038	1	1037	
1039	1	1038	
1040	1	1039	
1046	1	1040	
1042	1	1041	

1043	1	1042
1044	1	1043
1045	1	1044
1047	2	1046 1045
1048	1	1047
1049	1	1048
1050	1	1049
1051	1	1050
1052	1	1051
1053	1	1052
1054	1	1053
1055	0	
1056	1	1055
1057	1	1056
1058	1	1057
1060	1	1059
1061	1	1060
1062	1	1061
1063	1	1062
1064	1	1063
BRANCH	NODBR	NMDBR
1001	1	1002
1002	2	1003 1059
1003	1	1004
1059	1	1060
1004	1	1005
1005	1	1006
1006	2	1007 1034
1007	1	1008
1034	1	1035
1008	1	1009
1009	1	1010
1010	1	1011
1011	2	1012 1016
1012	1	1013
1016	1	1017
1013	1	1014
1014	1	1015
1015	1	1021
1021	2	1020 1022
1017	1	1018

1018	1	1019
1019	1	1020
1020	2	1021
		1022
1022	1	1023
1023	1	1024
1024	1	1025
1025	1	1026
1026	1	1027
1027	1	1028
1028	1	1029
1029	0	
1030	1	1031
1031	1	1032
1032	1	1033
1033	0	
1035	1	1036
1036	2	1037
		1041
1037	1	1038
1041	1	1042
1038	1	1039
1039	1	1040
1040	1	1046
1046	2	1045
		1047
1042	1	1043
1043	1	1044
1044	1	1045
1045	2	1046
		1047
1047	1	1048
1048	1	1049
1049	1	1050
1050	1	1051
1051	1	1052
1052	1	1053
1053	1	1054
1054	0	
1055	1	1056
1056	1	1057
1057	1	1058
1058	0	
1060	1	1061
1061	1	1062

1062	1	1063
1063	1	1064
1064	0	
BRANCH		
1001		
UPSTRM	BR.	ANGLE
DNSTRM	BR.	ANGLE
1002		0.00
BRANCH		
1002		
UPSTRM	BR.	ANGLE
1001		0.00
DNSTRM	BR.	ANGLE
1003		0.00
1059		0.00
BRANCH		
1003		
UPSTRM	BR.	ANGLE
1002		0.00
1059		0.00
DNSTRM	BR.	ANGLE
1004		0.00
BRANCH		
1059		
UPSTRM	BR.	ANGLE
1002		0.00
1003		0.00
DNSTRM	BR.	ANGLE
1060		0.00
BRANCH		
1004		
UPSTRM	BR.	ANGLE
1003		0.00
DNSTRM	BR.	ANGLE
1005		0.00
BRANCH		
1005		
UPSTRM	BR.	ANGLE
1004		0.00
DNSTRM	BR.	ANGLE
1006		0.00

BRANCH
1006
UPSTRM BR. ANGLE
1005 0.00
DNSTRM BR. ANGLE
1007 0.00
1034 0.00
BRANCH
1007
UPSTRM BR. ANGLE
1006 0.00
1034 0.00
DNSTRM BR. ANGLE
1008 0.00
BRANCH
1034
UPSTRM BR. ANGLE
1006 0.00
1007 0.00
DNSTRM BR. ANGLE
1035 0.00
BRANCH
1008
UPSTRM BR. ANGLE
1007 0.00
DNSTRM BR. ANGLE
1009 0.00
BRANCH
1009
UPSTRM BR. ANGLE
1008 0.00
DNSTRM BR. ANGLE
1010 0.00
BRANCH
1010
UPSTRM BR. ANGLE
1009 0.00
DNSTRM BR. ANGLE
1011 0.00
BRANCH
1011

```
UPSTRM BR. ANGLE
 1010  0.00
DNSTRM BR. ANGLE
 1012  0.00
 1016  0.00
BRANCH
 1012
UPSTRM BR. ANGLE
 1011  0.00
 1016  0.00
DNSTRM BR. ANGLE
 1013  0.00
BRANCH
 1016
UPSTRM BR. ANGLE
 1011  0.00
 1012  0.00
DNSTRM BR. ANGLE
 1017  0.00
BRANCH
 1013
UPSTRM BR. ANGLE
 1012  0.00
DNSTRM BR. ANGLE
 1014  0.00
BRANCH
 1014
UPSTRM BR. ANGLE
 1013  0.00
DNSTRM BR. ANGLE
 1015  0.00
BRANCH
 1015
UPSTRM BR. ANGLE
 1014  0.00
DNSTRM BR. ANGLE
 1021  0.00
BRANCH
 1021
UPSTRM BR. ANGLE
 1015  0.00
```

DNSTRM	BR.	ANGLE
1020		0.00
1022		0.00
BRANCH		
	1017	
UPSTRM	BR.	ANGLE
	1016	0.00
DNSTRM	BR.	ANGLE
	1018	0.00
BRANCH		
	1018	
UPSTRM	BR.	ANGLE
	1017	0.00
DNSTRM	BR.	ANGLE
	1019	0.00
BRANCH		
	1019	
UPSTRM	BR.	ANGLE
	1018	0.00
DNSTRM	BR.	ANGLE
	1020	0.00
BRANCH		
	1020	
UPSTRM	BR.	ANGLE
	1019	0.00
DNSTRM	BR.	ANGLE
	1021	0.00
	1022	0.00
BRANCH		
	1022	
UPSTRM	BR.	ANGLE
	1021	0.00
	1020	0.00
DNSTRM	BR.	ANGLE
	1023	0.00
BRANCH		
	1023	
UPSTRM	BR.	ANGLE
	1022	0.00
DNSTRM	BR.	ANGLE
	1024	0.00

BRANCH
1024
UPSTRM BR. ANGLE
1023 0.00
DNSTRM BR. ANGLE
1025 0.00
BRANCH
1025
UPSTRM BR. ANGLE
1024 0.00
DNSTRM BR. ANGLE
1026 0.00
BRANCH
1026
UPSTRM BR. ANGLE
1025 0.00
DNSTRM BR. ANGLE
1027 0.00
BRANCH
1027
UPSTRM BR. ANGLE
1026 0.00
DNSTRM BR. ANGLE
1028 0.00
BRANCH
1028
UPSTRM BR. ANGLE
1027 0.00
DNSTRM BR. ANGLE
1029 0.00
BRANCH
1029
UPSTRM BR. ANGLE
1028 0.00
DNSTRM BR. ANGLE
BRANCH
1030
UPSTRM BR. ANGLE
DNSTRM BR. ANGLE
1031 0.00
BRANCH

1031		
UPSTRM BR.	ANGLE	
1030	0.00	
DNSTRM BR.	ANGLE	
1032	0.00	
BRANCH		
1032		
UPSTRM BR.	ANGLE	
1031	0.00	
DNSTRM BR.	ANGLE	
1033	0.00	
BRANCH		
1033		
UPSTRM BR.	ANGLE	
1032	0.00	
DNSTRM BR.	ANGLE	
BRANCH		
1035		
UPSTRM BR.	ANGLE	
1034	0.00	
DNSTRM BR.	ANGLE	
1036	0.00	
BRANCH		
1036		
UPSTRM BR.	ANGLE	
1035	0.00	
DNSTRM BR.	ANGLE	
1037	0.00	
1041	0.00	
BRANCH		
1037		
UPSTRM BR.	ANGLE	
1036	0.00	
1041	0.00	
DNSTRM BR.	ANGLE	
1038	0.00	
BRANCH		
1041		
UPSTRM BR.	ANGLE	
1036	0.00	
1037	0.00	

```
DNSTRM BR. ANGLE
 1042   0.00
BRANCH
 1038
UPSTRM BR. ANGLE
 1037   0.00
DNSTRM BR. ANGLE
 1039   0.00
BRANCH
 1039
UPSTRM BR. ANGLE
 1038   0.00
DNSTRM BR. ANGLE
 1040   0.00
BRANCH
 1040
UPSTRM BR. ANGLE
 1039   0.00
DNSTRM BR. ANGLE
 1046   0.00
BRANCH
 1046
UPSTRM BR. ANGLE
 1040   0.00
DNSTRM BR. ANGLE
 1045   0.00
 1047   0.00
BRANCH
 1042
UPSTRM BR. ANGLE
 1041   0.00
DNSTRM BR. ANGLE
 1043   0.00
BRANCH
 1043
UPSTRM BR. ANGLE
 1042   0.00
DNSTRM BR. ANGLE
 1044   0.00
BRANCH
 1044
```

UPSTRM BR. ANGLE
1043 0.00
DNSTRM BR. ANGLE
1045 0.00
BRANCH
1045
UPSTRM BR. ANGLE
1044 0.00
DNSTRM BR. ANGLE
1046 0.00
1047 0.00
BRANCH
1047
UPSTRM BR. ANGLE
1046 0.00
1045 0.00
DNSTRM BR. ANGLE
1048 0.00
BRANCH
1048
UPSTRM BR. ANGLE
1047 0.00
DNSTRM BR. ANGLE
1049 0.00
BRANCH
1049
UPSTRM BR. ANGLE
1048 0.00
DNSTRM BR. ANGLE
1050 0.00
BRANCH
1050
UPSTRM BR. ANGLE
1049 0.00
DNSTRM BR. ANGLE
1051 0.00
BRANCH
1051
UPSTRM BR. ANGLE
1050 0.00
DNSTRM BR. ANGLE

	1052	0.00
BRANCH		
	1052	
UPSTRM BR.	ANGLE	
	1051	0.00
DNSTRM BR.	ANGLE	
	1053	0.00
BRANCH		
	1053	
UPSTRM BR.	ANGLE	
	1052	0.00
DNSTRM BR.	ANGLE	
	1054	0.00
BRANCH		
	1054	
UPSTRM BR.	ANGLE	
	1053	0.00
DNSTRM BR.	ANGLE	
BRANCH		
	1055	
UPSTRM BR.	ANGLE	
DNSTRM BR.	ANGLE	
	1056	0.00
BRANCH		
	1056	
UPSTRM BR.	ANGLE	
	1055	0.00
DNSTRM BR.	ANGLE	
	1057	0.00
BRANCH		
	1057	
UPSTRM BR.	ANGLE	
	1056	0.00
DNSTRM BR.	ANGLE	
	1058	0.00
BRANCH		
	1058	
UPSTRM BR.	ANGLE	
	1057	0.00
DNSTRM BR.	ANGLE	
BRANCH		

```

1060
UPSTRM BR. ANGLE
1059 0.00
DNSTRM BR. ANGLE
1061 0.00
BRANCH
1061
UPSTRM BR. ANGLE
1060 0.00
DNSTRM BR. ANGLE
1062 0.00
BRANCH
1062
UPSTRM BR. ANGLE
1061 0.00
DNSTRM BR. ANGLE
1063 0.00
BRANCH
1063
UPSTRM BR. ANGLE
1062 0.00
DNSTRM BR. ANGLE
1064 0.00
BRANCH
1064
UPSTRM BR. ANGLE
1063 0.00
DNSTRM BR. ANGLE
NUMBER OF BRANCHES WITH INERTIA
7
1008
1020
1027
1035
1045
1052
1062
NUMBER OF TANKS IN THE CIRCUIT
2
NODUL NODULB NODPRP IBRPRP TNKAR TNKTH TNKRHOTNKCP ELHC ARHC FCTHC TNKTM
29 30 31 1030 5441.96 0.38 170.00 0.2000 0.03622 3987. 1.00 70.00

```

54 55 56 1055 6431.91 0.375 170.00 0.2000 0.03622 4015. 1.00 -300.00
NODE DATA FILE
FNDPUMP.DAT
BRANCH DATA FILE
FBRPUMP.DAT

EXAMPLE 12 HISTORY FILES**EX12HS1.DAT**

```
3
-500  765.00  120.0  1.00  0.00  0.00
0     765.00  120.0  1.00  0.00  0.00
300   765.00  120.0  1.00  0.00  0.00
```

EX12HS2.DAT

```
6
-500. 14.700  70.00  0.00  0.00  1.00
-499. 20.000  70.00  0.00  0.00  1.00
-420. 20.000  70.00  0.00  0.00  1.00
-419. 50.000  70.00  0.00  0.00  1.00
0     50.000  70.00  0.00  0.00  1.00
300   50.000  70.00  0.00  0.00  1.00
```

EX12HS3.DAT

```
5
-500    14.700  70.00  0.00  0.00  1.00
-420    14.700  70.00  0.00  0.00  1.00
-418    652.00  70.00  0.00  0.00  1.00
0      652.00  70.00  0.00  0.00  1.00
300    652.00  70.00  0.00  0.00  1.00
```

EX12HS4.DAT

```
6
-500. 14.700  -300.  0.00  1.00  0.00
-499. 20.000  -300.  0.00  1.00  0.00
-420. 20.000  -300.  0.00  1.00  0.00
-419. 67.000  -300.  0.00  1.00  0.00
0     67.000  -300.  0.00  1.00  0.00
300   67.000  -300.  0.00  1.00  0.00
```

EX12HS5.DAT

```
5
-500    14.700   -300.   0.00   1.00   0.00
-420    14.700   -300.   0.00   1.00   0.00
-419    652.00   -300.   0.00   1.00   0.00
0       652.00   -300.   0.00   1.00   0.00
300    652.00   -300.   0.00   1.00   0.00
```

EX12HS6.DAT

```
3
-500.  615.00   120.0   1.00   0.00   0.00
0      615.00   120.0   1.00   0.00   0.00
300   615.00   120.0   1.00   0.00   0.00
```

```

C*****
C      **** GFSSP USER SUBROUTINES ****
C
C*****
C***** SUBROUTINE PRNUSER
C PURPOSE: ADD NEW OUTPUT
C*****
C***** INCLUDE 'COMBLK.FOR'
C*****
C ADD CODE HERE
C GENERATE EXCEL FILE FOR PLOT
OPEN (NUSR1,FILE = 'EX12.XLS',STATUS = 'UNKNOWN')
VOLUL1=VOLUME(29)
VOLUL2=VOLUME(54)
TFTNK1=TNKTM(1)-460.
TFTNK2=TNKTM(2)-460.
WRITE(NUSR1,200) TAU,QULWAL(1),QULWAL(2),QULPRP(1),QULPRP(2),
& QCOND(1),QCOND(2),VOLUL1,VOLUL2,TFTNK1,TFTNK2,
& SORCECON(29,3),SORCECON(54,2),CX(29,3),CX(54,2)
200 FORMAT (2X,E12.6,100(2X,2E12.6))
RETURN
END

```

NOTE: All other user subroutines are identical with Example 10 (Appendix O)

```
*****
 G F S S P (Version 3.0)
 Generalized Fluid System Simulation Program
 September, 1999
 Developed by Sverdrup Technology
 Copyright (C) by Marshall Space Flight Center
```

A generalized computer program to calculate flow rates, pressures, temperatures and concentrations in a flow network.

```
*****
TITLE      :PTA1 Final Pressurization Model w/Pumps & Mass Transfer(eng op: 0 to 60)
ANALYST    :Todd Steadman
FILEIN     :ex14.dat
FILEOUT    :ex14.out
LOGICAL VARIABLES
DENCON     =  F
GRAVITY    =  F
ENERGY     =  T
MIXTURE    =  T
THRUST     =  F
STEADY     =  F
TRANSV     =  T
SAVER      =  F
HEX         =  F
HCOEF       =  F
REACTING   =  F
INERTIA    =  T
CONDX      =  F
TWOD        =  F
PRINTI     =  F
ROTATION   =  F
BUOYANCY   =  F
HRATE      =  T
INVAL      =  F
MSOURCE    =  F
MOVBND    =  F
TPA         =  F
```

VARGEO = F
 TVM = F
 SHEAR = F
 PRNTIN = T
 PRNTADD = T
 GASPAK = F
 PRESS = T
 INSUC = F
 VARROT = F
 NORMAL = F
 SECONDL = F

NNODES = 65
 NINT = 59
 NBR = 64
 NF = 3
 NVAR = 182
 NHREF = 2

FLUIDS: HE O2 RP1

BOUNDARY NODES

NODE	P (PSI)	T (F)	RHO (LBM/FT^3)	AREA (IN^2)	CONCENTRATIONS		
					HE	O2	RP1
1	0.7650E+03	0.1200E+03	0.4783E+00	0.0000E+00	0.1000E+01	0.0000E+00	0.0000
30	0.5355E+02	0.7000E+02	0.4962E+02	0.0000E+00	0.0000E+00	0.0000E+00	1.0000
34	0.6520E+03	0.7000E+02	0.5006E+02	0.0000E+00	0.0000E+00	0.0000E+00	1.0000
55	0.7548E+02	-0.3000E+03	0.7173E+02	0.0000E+00	0.0000E+00	0.1000E+01	0.0000
59	0.6520E+03	-0.3000E+03	0.7227E+02	0.0000E+00	0.0000E+00	0.1000E+01	0.0000
65	0.6150E+03	0.1200E+03	0.3867E+00	0.0000E+00	0.1000E+01	0.0000E+00	0.0000

INPUT SPECIFICATIONS FOR INTERNAL NODES

NODE	AREA (IN^2)	MASS (LBM/S)	HEAT (BTU/S)
2	0.0000E+00	0.0000E+00	0.0000E+00
3	0.0000E+00	0.0000E+00	0.0000E+00
4	0.0000E+00	0.0000E+00	0.0000E+00
5	0.0000E+00	0.0000E+00	0.0000E+00
6	0.0000E+00	0.0000E+00	0.0000E+00

7	0.0000E+00	0.0000E+00	0.0000E+00
8	0.0000E+00	0.0000E+00	0.0000E+00
9	0.0000E+00	0.0000E+00	0.0000E+00
10	0.0000E+00	0.0000E+00	0.0000E+00
11	0.0000E+00	0.0000E+00	0.0000E+00
12	0.0000E+00	0.0000E+00	0.0000E+00
13	0.0000E+00	0.0000E+00	0.0000E+00
14	0.0000E+00	0.0000E+00	0.0000E+00
15	0.0000E+00	0.0000E+00	0.0000E+00
16	0.0000E+00	0.0000E+00	0.0000E+00
17	0.0000E+00	0.0000E+00	0.0000E+00
18	0.0000E+00	0.0000E+00	0.0000E+00
19	0.0000E+00	0.0000E+00	0.0000E+00
20	0.0000E+00	0.0000E+00	0.0000E+00
21	0.0000E+00	0.0000E+00	0.0000E+00
22	0.0000E+00	0.0000E+00	0.0000E+00
23	0.0000E+00	0.0000E+00	0.0000E+00
24	0.0000E+00	0.0000E+00	0.0000E+00
25	0.0000E+00	0.0000E+00	0.0000E+00
26	0.0000E+00	0.0000E+00	0.0000E+00
27	0.0000E+00	0.0000E+00	0.0000E+00
28	0.0000E+00	0.0000E+00	0.0000E+00
29	0.0000E+00	0.0000E+00	0.0000E+00
31	0.0000E+00	-0.6400E+02	0.0000E+00
32	0.0000E+00	0.0000E+00	0.0000E+00
33	0.0000E+00	0.0000E+00	0.0000E+00
35	0.0000E+00	0.0000E+00	0.0000E+00
36	0.0000E+00	0.0000E+00	0.0000E+00
37	0.0000E+00	0.0000E+00	0.0000E+00
38	0.0000E+00	0.0000E+00	0.0000E+00
39	0.0000E+00	0.0000E+00	0.0000E+00
40	0.0000E+00	0.0000E+00	0.0000E+00
41	0.0000E+00	0.0000E+00	0.0000E+00
42	0.0000E+00	0.0000E+00	0.0000E+00
43	0.0000E+00	0.0000E+00	0.0000E+00
44	0.0000E+00	0.0000E+00	0.0000E+00
45	0.0000E+00	0.0000E+00	0.0000E+00
46	0.0000E+00	0.0000E+00	0.0000E+00
47	0.0000E+00	0.0000E+00	0.0000E+00
48	0.0000E+00	0.0000E+00	0.0000E+00
49	0.0000E+00	0.0000E+00	0.0000E+00

50	0.0000E+00	0.0000E+00	0.0000E+00
51	0.0000E+00	0.0000E+00	0.0000E+00
52	0.0000E+00	0.0000E+00	0.0000E+00
53	0.0000E+00	0.0000E+00	0.0000E+00
54	0.0000E+00	0.0000E+00	0.0000E+00
56	0.0000E+00	-0.1400E+03	0.0000E+00
57	0.0000E+00	0.0000E+00	0.0000E+00
58	0.0000E+00	0.0000E+00	0.0000E+00
60	0.0000E+00	0.0000E+00	0.0000E+00
61	0.0000E+00	0.0000E+00	0.0000E+00
62	0.0000E+00	0.0000E+00	0.0000E+00
63	0.0000E+00	0.0000E+00	0.0000E+00
64	0.0000E+00	0.0000E+00	0.0000E+00

BRANCH	UPNODE	DNNODE	OPTION
1001	1	2	1
1002	2	3	2
1003	3	4	13
1059	3	60	13
1004	4	5	1
1005	5	6	2
1006	6	7	1
1007	7	8	13
1034	7	35	13
1008	8	9	7
1009	9	10	1
1010	10	11	2
1011	11	12	1
1012	12	13	13
1016	12	17	13
1013	13	14	1
1014	14	15	2
1015	15	16	1
1021	16	21	2
1017	17	18	1
1018	18	19	18
1019	19	20	1
1020	20	21	2
1022	21	22	13
1023	22	23	2
1024	23	24	1

1025	24	25	2
1026	25	26	1
1027	26	27	8
1028	27	28	2
1029	28	29	2
1030	30	31	2
1031	31	32	2
1032	32	33	14
1033	33	34	2
1035	35	36	7
1036	36	37	2
1037	37	38	13
1041	37	42	13
1038	38	39	1
1039	39	40	2
1040	40	41	1
1046	41	46	2
1042	42	43	1
1043	43	44	18
1044	44	45	1
1045	45	46	2
1047	46	47	13
1048	47	48	2
1049	48	49	1
1050	49	50	2
1051	50	51	1
1052	51	52	8
1053	52	53	2
1054	53	54	2
1055	55	56	2
1056	56	57	2
1057	57	58	14
1058	58	59	2
1060	60	61	1
1061	61	62	2
1062	62	63	7
1063	63	64	1
1064	64	65	1

BRANCH OPTION -1: LENGTH, DIA, EPSD, ANGLE, AREA
1001 128.00000 1.30000 0.00062 0.00000 1.32732
BRANCH OPTION -2: FLOW COEF, AREA

```

1002      0.60000    0.63617
BRANCH OPTION -13: DIA, K1, K2, AREA
1003      1.30000    200.00000    0.10000    1.32732
BRANCH OPTION -13: DIA, K1, K2, AREA
1059      1.30000    200.00000    0.10000    1.32732
BRANCH OPTION -1: LENGTH, DIA, EPSD, ANGLE, AREA
1004      17.00000    1.30000    0.00062    0.00000    1.32732
BRANCH OPTION -2: FLOW COEF, AREA
1005      0.60000    0.63617
BRANCH OPTION -1: LENGTH, DIA, EPSD, ANGLE, AREA
1006      288.00000    1.30000    0.00062    0.00000    1.32732
BRANCH OPTION -13: DIA, K1, K2, AREA
1007      1.30000    200.00000    0.10000    1.32732
BRANCH OPTION -13: DIA, K1, K2, AREA
1034      1.30000    200.00000    0.10000    1.32732
BRANCH OPTION -7: PIPE DIA, REDUCED DIA, AREA
1008      1.30000    0.53000    1.32732
BRANCH OPTION -1: LENGTH, DIA, EPSD, ANGLE, AREA
1009      221.00000    0.53000    0.00151    0.00000    0.22062
BRANCH OPTION -2: FLOW COEF, AREA
1010      0.60000    0.28270
BRANCH OPTION -1: LENGTH, DIA, EPSD, ANGLE, AREA
1011      12.00000    0.53000    0.00151    0.00000    0.22062
BRANCH OPTION -13: DIA, K1, K2, AREA
1012      0.53000    500.00000    0.70000    0.22062
BRANCH OPTION -13: DIA, K1, K2, AREA
1016      0.53000    500.00000    0.70000    0.22062
BRANCH OPTION -1: LENGTH, DIA, EPSD, ANGLE, AREA
1013      14.00000    0.53000    0.00151    0.00000    0.22062
BRANCH OPTION -2: FLOW COEF, AREA
1014      0.60000    0.00001
BRANCH OPTION -1: LENGTH, DIA, EPSD, ANGLE, AREA
1015      14.00000    0.53000    0.00151    0.00000    0.22062
BRANCH OPTION -2: FLOW COEF, AREA
1021      0.60000    0.00785
BRANCH OPTION -1: LENGTH, DIA, EPSD, ANGLE, AREA
1017      7.50000    0.53000    0.00151    0.00000    0.22062
BR OPT-> 18-2, SUBOPT, FLOW COEF, AREA, CTRL NODE, INIT POS
1018      2      0.60000    0.28270    29.00000    T
BR OPT-> 18-2(continued), CYCLE TIME, CYCLE STEPS, PR TOL FILE
0.05000    5.00000    ex14rp1.dat

```

```

BRANCH OPTION -1: LENGTH, DIA, EPSD, ANGLE, AREA
 1019    9.00000    0.53000    0.00151    0.00000      0.22062
BRANCH OPTION -2: FLOW COEF, AREA
 1020    0.60000    0.02895
BRANCH OPTION -13: DIA, K1, K2, AREA
 1022    0.53000    500.00000    0.70000      0.22062
BRANCH OPTION -2: FLOW COEF, AREA
 1023    0.83056    0.22550
BRANCH OPTION -1: LENGTH, DIA, EPSD, ANGLE, AREA
 1024   14.00000    0.53000    0.00151    0.00000      0.22062
BRANCH OPTION -2: FLOW COEF, AREA
 1025    0.60000    0.41850
BRANCH OPTION -1: LENGTH, DIA, EPSD, ANGLE, AREA
 1026   14.00000    0.53000    0.00151    0.00000      0.22062
BRANCH OPTION -8: PIPE DIA, EXP DIA, AREA
 1027    0.53000    3.00000    0.22062
BRANCH OPTION -2: FLOW COEF, AREA
 1028    0.00000    7.06858
BRANCH OPTION -2: FLOW COEF, AREA
 1029    0.60000    37.69910
BRANCH OPTION -2: FLOW COEF, AREA
 1030    0.00000    3987.00000
BRANCH OPTION -2: FLOW COEF, AREA
 1031   0.18100    14.25000
BRANCH OPTION -14: PUMP CONST1, PUMP CONST2 AREA
 1032168757.00000   -4.93620    14.25000
BRANCH OPTION -2: FLOW COEF, AREA
 1033    0.04640    14.25000
BRANCH OPTION -7: PIPE DIA, REDUCED DIA, AREA
 1035    1.30000    0.78000    1.32732
BRANCH OPTION -2: FLOW COEF, AREA
 1036    0.60000    0.63617
BRANCH OPTION -13: DIA, K1, K2, AREA
 1037    0.78000    500.00000    0.70000      0.47784
BRANCH OPTION -13: DIA, K1, K2, AREA
 1041    0.78000    500.00000    0.70000      0.47784
BRANCH OPTION -1: LENGTH, DIA, EPSD, ANGLE, AREA
 1038   11.00000    0.78000    0.00103    0.00000      0.47784
BRANCH OPTION -2: FLOW COEF, AREA
 1039    0.60000    0.00001
BRANCH OPTION -1: LENGTH, DIA, EPSD, ANGLE, AREA

```

```

1040    18.00000    0.78000    0.00103    0.00000    0.47784
BRANCH OPTION -2: FLOW COEF, AREA
1046    0.60000    0.01767
BRANCH OPTION -1: LENGTH, DIA, EPSD, ANGLE, AREA
1042    28.00000    0.78000    0.00103    0.00000    0.47784
BR OPT-> 18-2, SUBOPT, FLOW COEF, AREA, CTRL NODE, INIT POS
1043    2    0.60000    0.63617    54.00000    T
BR OPT-> 18-2(continued), CYCLE TIME, CYCLE STEPS, PR TOL FILE
          0.05000    5.00000  ex14lox.dat
BRANCH OPTION -1: LENGTH, DIA, EPSD, ANGLE, AREA
1044    15.00000    0.78000    0.00103    0.00000    0.47784
BRANCH OPTION -2: FLOW COEF, AREA
1045    0.60000    0.10179
BRANCH OPTION -13: DIA, K1, K2, AREA
1047    0.78000    500.00000    0.70000    0.47784
BRANCH OPTION -2: FLOW COEF, AREA
1048    0.77371    0.55351
BRANCH OPTION -1: LENGTH, DIA, EPSD, ANGLE, AREA
1049    13.00000    0.78000    0.00103    0.00000    0.47784
BRANCH OPTION -2: FLOW COEF, AREA
1050    0.60000    0.78540
BRANCH OPTION -1: LENGTH, DIA, EPSD, ANGLE, AREA
1051    21.00000    0.78000    0.00103    0.00000    0.47784
BRANCH OPTION -8: PIPE DIA, EXP DIA, AREA
1052    0.78000    3.00000    0.47784
BRANCH OPTION -2: FLOW COEF, AREA
1053    0.00000    7.06858
BRANCH OPTION -2: FLOW COEF, AREA
1054    0.60000    37.69910
BRANCH OPTION -2: FLOW COEF, AREA
1055    0.00000    4015.00000
BRANCH OPTION -2: FLOW COEF, AREA
1056    0.30400    14.25000
BRANCH OPTION -14: PUMP CONST1, PUMP CONST2 AREA
1057176033.00000    -2.57990    14.25000
BRANCH OPTION -2: FLOW COEF, AREA
1058    0.10500    14.25000
BRANCH OPTION -1: LENGTH, DIA, EPSD, ANGLE, AREA
1060    19.00000    1.30000    0.00062    0.00000    1.32732
BRANCH OPTION -2: FLOW COEF, AREA
1061    0.60000    0.63617

```

BRANCH OPTION -7: PIPE DIA, REDUCED DIA, AREA
 1062 1.30000 0.53000 1.32732
 BRANCH OPTION -1: LENGTH, DIA, EPSD, ANGLE, AREA
 1063 143.00000 0.53000 0.00151 0.00000 0.22062
 BRANCH OPTION -1: LENGTH, DIA, EPSD, ANGLE, AREA
 1064 28.00000 0.53000 0.00604 0.00000 0.22062

NUMBER OF PRESSURIZATION SYSTEMS = 2
 NODUL NODPRP QULPRP QULWAL QCOND TNKTM VOLPROP VOLULG
 29 31 0.0000 0.0000 0.0000 529.6000 284.8826 15.1290
 54 56 0.0000 0.0000 0.0000 159.6000 474.8048 25.1951

ISTEP = 160 TAU = 0.10240E+02
 BOUNDARY NODES
 NODE P(PSI) TF(F) Z(COMP) RHO CONCENTRATIONS
 (LBM/F T^3)
 HE O2 RP1
 1 0.7650E+03 0.1200E+03 0.0000E+00 0.4783E+00 0.1000E+01 0.0000E+00 0.0000
 30 0.5048E+02 0.7000E+02 0.0000E+00 0.4962E+02 0.0000E+00 0.0000E+00 1.0000
 34 0.6520E+03 0.7000E+02 0.0000E+00 0.5006E+02 0.0000E+00 0.0000E+00 1.0000
 55 0.7235E+02 -0.3000E+03 0.0000E+00 0.7173E+02 0.0000E+00 0.1000E+01 0.0000
 59 0.6520E+03 -0.3000E+03 0.0000E+00 0.7227E+02 0.0000E+00 0.1000E+01 0.0000
 65 0.6150E+03 0.1200E+03 0.0000E+00 0.3867E+00 0.1000E+01 0.0000E+00 0.0000

SOLUTION
 INTERNAL NODES
 NODE P(PSI) TF(F) Z RHO EM(LBM) CONC
 (LBM/FT^3)
 HE O2 RP1
 2 0.7579E+03 0.1200E+03 0.1029E+01 0.4740E+00 0.2330E-01 0.1000E+01 0.0000 0.0000
 3 0.7311E+03 0.1200E+03 0.1028E+01 0.4577E+00 0.2005E-10 0.1000E+01 0.0000 0.0000
 4 0.7309E+03 0.1200E+03 0.1028E+01 0.4576E+00 0.2988E-02 0.1000E+01 0.0000 0.0000
 5 0.7303E+03 0.1200E+03 0.1028E+01 0.4572E+00 0.2985E-02 0.1000E+01 0.0000 0.0000
 6 0.7198E+03 0.1200E+03 0.1028E+01 0.4508E+00 0.4987E-01 0.1000E+01 0.0000 0.0000
 7 0.7104E+03 0.1200E+03 0.1027E+01 0.4451E+00 0.4923E-01 0.1000E+01 0.0000 0.0000
 8 0.7104E+03 0.1200E+03 0.1027E+01 0.4451E+00 -0.1206E-10 0.1000E+01 0.0000 0.0000
 9 0.7096E+03 0.1200E+03 0.1027E+01 0.4446E+00 0.6272E-02 0.1000E+01 0.0000 0.0000

10	0.6919E+03	0.1200E+03	0.1027E+01	0.4337E+00	0.6120E-02	0.1000E+01	0.0000	0.0000
11	0.6886E+03	0.1200E+03	0.1026E+01	0.4316E+00	0.3307E-03	0.1000E+01	0.0000	0.0000
12	0.6875E+03	0.1200E+03	0.1026E+01	0.4310E+00	0.3303E-03	0.1000E+01	0.0000	0.0000
13	0.6875E+03	0.1200E+03	0.1026E+01	0.4310E+00	0.3853E-03	0.1000E+01	0.0000	0.0000
14	0.6875E+03	0.1201E+03	0.1026E+01	0.4309E+00	0.3852E-03	0.1000E+01	0.0000	0.0000
15	0.1348E+03	0.1201E+03	0.1005E+01	0.8625E-01	0.7710E-04	0.1000E+01	0.0000	0.0000
16	0.1348E+03	0.1200E+03	0.1005E+01	0.8626E-01	0.7711E-04	0.1000E+01	0.0000	0.0000
17	0.6834E+03	0.1200E+03	0.1026E+01	0.4285E+00	0.2052E-03	0.1000E+01	0.0000	0.0000
18	0.6828E+03	0.1200E+03	0.1026E+01	0.4281E+00	0.2050E-03	0.1000E+01	0.0000	0.0000
19	0.6793E+03	0.1200E+03	0.1026E+01	0.4259E+00	0.2448E-03	0.1000E+01	0.0000	0.0000
20	0.6785E+03	0.1200E+03	0.1026E+01	0.4255E+00	0.2445E-03	0.1000E+01	0.0000	0.0000
21	0.1348E+03	0.1200E+03	0.1005E+01	0.8627E-01	-0.7064E-12	0.1000E+01	0.0000	0.0000
22	0.1142E+03	0.1200E+03	0.1005E+01	0.7314E-01	-0.1350E-11	0.1000E+01	0.0000	0.0000
23	0.9749E+02	0.1200E+03	0.1004E+01	0.6250E-01	0.5586E-04	0.1000E+01	0.0000	0.0000
24	0.8910E+02	0.1200E+03	0.1004E+01	0.5715E-01	0.5107E-04	0.1000E+01	0.0000	0.0000
25	0.7722E+02	0.1200E+03	0.1003E+01	0.4956E-01	0.4428E-04	0.1000E+01	0.0000	0.0000
26	0.6665E+02	0.1200E+03	0.1003E+01	0.4279E-01	0.3823E-04	0.1000E+01	0.0000	0.0000
27	0.4715E+02	0.1200E+03	0.1002E+01	0.3029E-01	-0.2563E-11	0.1000E+01	0.0000	0.0000
28	0.4715E+02	0.1200E+03	0.1002E+01	0.3029E-01	0.5930E-13	0.1000E+01	0.0000	0.0000
29	0.4715E+02	0.8793E+02	0.1002E+01	0.3206E-01	0.8973E+00	0.1000E+01	0.0000	0.0000
31	0.5048E+02	0.7000E+02	0.3079E-01	0.4962E+02	0.1350E+05	0.0000E+00	0.0000	1.0000
32	0.2339E+02	0.7000E+02	0.1427E-01	0.4960E+02	0.0000E+00	0.0000E+00	0.0000	1.0000
33	0.1058E+04	0.7000E+02	0.6363E+00	0.5034E+02	0.0000E+00	0.0000E+00	0.0000	1.0000
35	0.7103E+03	0.1200E+03	0.1027E+01	0.4450E+00	0.5463E-12	0.1000E+01	0.0000	0.0000
36	0.7080E+03	0.1200E+03	0.1027E+01	0.4436E+00	-0.7598E-11	0.1000E+01	0.0000	0.0000
37	0.6986E+03	0.1200E+03	0.1027E+01	0.4379E+00	-0.1457E-10	0.1000E+01	0.0000	0.0000
38	0.6986E+03	0.1201E+03	0.1027E+01	0.4378E+00	0.6659E-03	0.1000E+01	0.0000	0.0000
39	0.6986E+03	0.1202E+03	0.1027E+01	0.4377E+00	0.6658E-03	0.1000E+01	0.0000	0.0000
40	0.1595E+03	0.1201E+03	0.1006E+01	0.1020E+00	0.2539E-03	0.9993E+00	0.0000	0.0007
41	0.1596E+03	0.1200E+03	0.1006E+01	0.1021E+00	0.2541E-03	0.9993E+00	0.0000	0.0007
42	0.6889E+03	0.1200E+03	0.1026E+01	0.4319E+00	0.1672E-02	0.1000E+01	0.0000	0.0000
43	0.6850E+03	0.1200E+03	0.1026E+01	0.4296E+00	0.1663E-02	0.1000E+01	0.0000	0.0000
44	0.6104E+03	0.1200E+03	0.1024E+01	0.3836E+00	0.7961E-03	0.1000E+01	0.0000	0.0000
45	0.6073E+03	0.1200E+03	0.1023E+01	0.3817E+00	0.7922E-03	0.1000E+01	0.0000	0.0000
46	0.1759E+03	0.1200E+03	0.1007E+01	0.1124E+00	-0.4457E-11	0.1000E+01	0.0000	0.0000
47	0.1524E+03	0.1200E+03	0.1006E+01	0.9743E-01	-0.3438E-11	0.1000E+01	0.0000	0.0000
48	0.1312E+03	0.1200E+03	0.1005E+01	0.8396E-01	0.1510E-03	0.1000E+01	0.0000	0.0000
49	0.1231E+03	0.1200E+03	0.1005E+01	0.7882E-01	0.1417E-03	0.1000E+01	0.0000	0.0000
50	0.1026E+03	0.1200E+03	0.1004E+01	0.6578E-01	0.1910E-03	0.1000E+01	0.0000	0.0000
51	0.8777E+02	0.1200E+03	0.1004E+01	0.5628E-01	0.1634E-03	0.1000E+01	0.0000	0.0000
52	0.6434E+02	0.1200E+03	0.1003E+01	0.4130E-01	-0.9976E-11	0.1000E+01	0.0000	0.0000

53	0.6434E+02	0.1200E+03	0.1003E+01	0.4130E-01	0.2511E-14	0.1000E+01	0.0000	0.0000
54	0.6432E+02	-0.1899E+03	0.1005E+01	0.8854E-01	0.3959E+01	0.1000E+01	0.0000	0.0000
56	0.7235E+02	-0.3000E+03	0.1885E-01	0.7174E+02	0.3266E+05	0.0000E+00	1.0000	0.0000
57	0.4033E+02	-0.3000E+03	0.1051E-01	0.7171E+02	0.0000E+00	0.0000E+00	1.0000	0.0000
58	0.9176E+03	-0.3000E+03	0.2365E+00	0.7250E+02	0.0000E+00	0.0000E+00	1.0000	0.0000
60	0.7310E+03	0.1200E+03	0.1028E+01	0.4576E+00	0.3340E-02	0.1000E+01	0.0000	0.0000
61	0.7309E+03	0.1200E+03	0.1028E+01	0.4576E+00	0.3339E-02	0.1000E+01	0.0000	0.0000
62	0.7265E+03	0.1200E+03	0.1028E+01	0.4549E+00	0.0000E+00	0.1000E+01	0.0000	0.0000
63	0.7198E+03	0.1200E+03	0.1028E+01	0.4508E+00	0.4115E-02	0.1000E+01	0.0000	0.0000
64	0.6408E+03	0.1200E+03	0.1025E+01	0.4025E+00	0.4394E-02	0.1000E+01	0.0000	0.0000

NODE	H	ENTROPY	EMU	COND	CP	GAMA
	BTU/LB	BTU/LB-R	LBM/FT-SEC	BTU/FT-S-R	BTU/LB-R	
2	0.7333E+03	0.5636E+01	0.1454E-04	0.2671E-04	0.1244E+01	0.1670E+01
3	0.7332E+03	0.5654E+01	0.1454E-04	0.2670E-04	0.1244E+01	0.1670E+01
4	0.7332E+03	0.5654E+01	0.1454E-04	0.2670E-04	0.1244E+01	0.1670E+01
5	0.7332E+03	0.5655E+01	0.1454E-04	0.2670E-04	0.1244E+01	0.1670E+01
6	0.7334E+03	0.5662E+01	0.1454E-04	0.2670E-04	0.1244E+01	0.1670E+01
7	0.7334E+03	0.5668E+01	0.1454E-04	0.2670E-04	0.1244E+01	0.1670E+01
8	0.7334E+03	0.5669E+01	0.1454E-04	0.2670E-04	0.1244E+01	0.1670E+01
9	0.7334E+03	0.5669E+01	0.1454E-04	0.2670E-04	0.1244E+01	0.1670E+01
10	0.7333E+03	0.5682E+01	0.1454E-04	0.2669E-04	0.1243E+01	0.1670E+01
11	0.7333E+03	0.5684E+01	0.1454E-04	0.2669E-04	0.1243E+01	0.1670E+01
12	0.7333E+03	0.5685E+01	0.1454E-04	0.2669E-04	0.1243E+01	0.1670E+01
13	0.7333E+03	0.5685E+01	0.1454E-04	0.2669E-04	0.1243E+01	0.1670E+01
14	0.7333E+03	0.5685E+01	0.1454E-04	0.2669E-04	0.1243E+01	0.1670E+01
15	0.7333E+03	0.6495E+01	0.1447E-04	0.2654E-04	0.1242E+01	0.1667E+01
16	0.7333E+03	0.6495E+01	0.1447E-04	0.2654E-04	0.1242E+01	0.1667E+01
17	0.7333E+03	0.5688E+01	0.1453E-04	0.2669E-04	0.1243E+01	0.1670E+01
18	0.7333E+03	0.5688E+01	0.1453E-04	0.2669E-04	0.1243E+01	0.1670E+01
19	0.7333E+03	0.5691E+01	0.1453E-04	0.2669E-04	0.1243E+01	0.1670E+01
20	0.7333E+03	0.5691E+01	0.1453E-04	0.2669E-04	0.1243E+01	0.1670E+01
21	0.7333E+03	0.6495E+01	0.1447E-04	0.2654E-04	0.1242E+01	0.1667E+01
22	0.7333E+03	0.6577E+01	0.1447E-04	0.2654E-04	0.1242E+01	0.1667E+01
23	0.7334E+03	0.6656E+01	0.1446E-04	0.2653E-04	0.1242E+01	0.1667E+01
24	0.7335E+03	0.6700E+01	0.1446E-04	0.2653E-04	0.1241E+01	0.1667E+01
25	0.7333E+03	0.6771E+01	0.1446E-04	0.2653E-04	0.1241E+01	0.1667E+01
26	0.7334E+03	0.6844E+01	0.1446E-04	0.2652E-04	0.1241E+01	0.1667E+01
27	0.7334E+03	0.7016E+01	0.1446E-04	0.2652E-04	0.1241E+01	0.1667E+01
28	0.7334E+03	0.7016E+01	0.1446E-04	0.2652E-04	0.1241E+01	0.1667E+01

29	0.6641E+03	0.6946E+01	0.1387E-04	0.2548E-04	0.1241E+01	0.1667E+01
31	0.2640E+02	0.0000E+00	0.1067E-02	0.2178E-04	0.3408E+00	0.1400E+01
32	0.2595E+02	0.0000E+00	0.1057E-02	0.2176E-04	0.3408E+00	0.1400E+01
33	0.4170E+02	0.0000E+00	0.1474E-02	0.2218E-04	0.3408E+00	0.1400E+01
35	0.7334E+03	0.5669E+01	0.1454E-04	0.2670E-04	0.1244E+01	0.1670E+01
36	0.7334E+03	0.5670E+01	0.1454E-04	0.2670E-04	0.1244E+01	0.1670E+01
37	0.7333E+03	0.5677E+01	0.1454E-04	0.2669E-04	0.1244E+01	0.1670E+01
38	0.7333E+03	0.5677E+01	0.1454E-04	0.2670E-04	0.1244E+01	0.1670E+01
39	0.7333E+03	0.5677E+01	0.1454E-04	0.2670E-04	0.1244E+01	0.1670E+01
40	0.7333E+03	0.6407E+01	0.1448E-04	0.2655E-04	0.1241E+01	0.1667E+01
41	0.7333E+03	0.6407E+01	0.1448E-04	0.2655E-04	0.1241E+01	0.1667E+01
42	0.7334E+03	0.5684E+01	0.1454E-04	0.2669E-04	0.1243E+01	0.1670E+01
43	0.7334E+03	0.5687E+01	0.1453E-04	0.2669E-04	0.1243E+01	0.1670E+01
44	0.7332E+03	0.5744E+01	0.1453E-04	0.2667E-04	0.1243E+01	0.1669E+01
45	0.7332E+03	0.5747E+01	0.1453E-04	0.2667E-04	0.1243E+01	0.1669E+01
46	0.7333E+03	0.6362E+01	0.1447E-04	0.2655E-04	0.1242E+01	0.1667E+01
47	0.7332E+03	0.6434E+01	0.1447E-04	0.2655E-04	0.1242E+01	0.1667E+01
48	0.7333E+03	0.6508E+01	0.1447E-04	0.2654E-04	0.1242E+01	0.1667E+01
49	0.7333E+03	0.6540E+01	0.1447E-04	0.2654E-04	0.1242E+01	0.1667E+01
50	0.7334E+03	0.6630E+01	0.1446E-04	0.2653E-04	0.1242E+01	0.1667E+01
51	0.7334E+03	0.6708E+01	0.1446E-04	0.2653E-04	0.1241E+01	0.1667E+01
52	0.7333E+03	0.6862E+01	0.1446E-04	0.2652E-04	0.1241E+01	0.1667E+01
53	0.7333E+03	0.6862E+01	0.1446E-04	0.2652E-04	0.1241E+01	0.1667E+01
54	0.2545E+03	0.5912E+01	0.8539E-05	0.1584E-04	0.1242E+01	0.1668E+01
56	0.5979E+02	0.6961E+00	0.1417E-03	0.2073E-04	0.4202E+00	0.1730E+01
57	0.5974E+02	0.6963E+00	0.1413E-03	0.2072E-04	0.4204E+00	0.1732E+01
58	0.6116E+02	0.6911E+00	0.1519E-03	0.2107E-04	0.4144E+00	0.1695E+01
60	0.7332E+03	0.5654E+01	0.1454E-04	0.2670E-04	0.1244E+01	0.1670E+01
61	0.7332E+03	0.5654E+01	0.1454E-04	0.2670E-04	0.1244E+01	0.1670E+01
62	0.7334E+03	0.5657E+01	0.1454E-04	0.2670E-04	0.1244E+01	0.1670E+01
63	0.7334E+03	0.5662E+01	0.1454E-04	0.2670E-04	0.1244E+01	0.1670E+01
64	0.7334E+03	0.5720E+01	0.1453E-04	0.2668E-04	0.1243E+01	0.1670E+01

BRANCHES

BRANCH	KFACTOR (LBF-S^2/(LBM-FT)^2)	DELP (PSI)	FLOW RATE (LBM/SEC)	VELOCITY (FT/SEC)	REYN. NO.	MACH NO.	ENTROPY GEN. BTU/(R-SEC)	LOST WORK LBF-FT/SEC
1001	0.682E+03	0.708E+01	0.912E+00	0.207E+03	0.737E+06	0.596E-01	0.240E-02	0.108E+04
1002	0.467E+04	0.269E+02	0.911E+00	0.435E+03	0.106E+07	0.125E+00	0.165E-01	0.743E+04
1003	0.709E+02	0.151E+00	0.554E+00	0.131E+03	0.448E+06	0.379E-01	0.584E-04	0.263E+02
1059	0.710E+02	0.627E-01	0.357E+00	0.846E+02	0.288E+06	0.244E-01	0.156E-04	0.704E+01
1004	0.965E+02	0.614E+00	0.556E+00	0.132E+03	0.450E+06	0.380E-01	0.805E-04	0.363E+02

1005	0.484E+04	0.105E+02	0.559E+00	0.277E+03	0.652E+06	0.798E-01	0.409E-02	0.185E+04
1006	0.165E+04	0.936E+01	0.627E+00	0.151E+03	0.507E+06	0.435E-01	0.200E-02	0.902E+03
1007	0.735E+02	0.836E-02	0.128E+00	0.312E+02	0.103E+06	0.899E-02	0.765E-06	0.345E+00
1034	0.729E+02	0.137E+00	0.520E+00	0.127E+03	0.421E+06	0.366E-01	0.512E-04	0.231E+02
1008	0.755E+04	0.857E+00	0.128E+00	0.312E+02	0.103E+06	0.899E-02	0.786E-04	0.354E+02
1009	0.140E+06	0.177E+02	0.131E+00	0.192E+03	0.259E+06	0.554E-01	0.156E-02	0.706E+03
1010	0.258E+05	0.335E+01	0.137E+00	0.160E+03	0.239E+06	0.463E-01	0.337E-03	0.152E+03
1011	0.784E+04	0.101E+01	0.137E+00	0.207E+03	0.272E+06	0.597E-01	0.103E-03	0.466E+02
1012	0.366E+05	-0.109E-03	-0.693E-03	-0.105E+01	0.137E+04	0.302E-03	0.627E-10	0.283E-04
1016	0.311E+05	0.411E+01	0.138E+00	0.209E+03	0.274E+06	0.603E-01	0.420E-03	0.189E+03
1013	0.415E+05	0.374E-02	-0.316E-03	-0.477E+00	0.626E+03	0.137E-03	0.671E-11	0.303E-05
1014	0.208E+14	0.553E+03	0.619E-04	0.207E+04	0.182E+05	0.597E+00	0.253E-04	0.114E+02
1015	0.111E+07	0.849E-02	-0.588E-04	-0.411E+00	0.117E+03	0.119E-03	0.578E-11	0.261E-05
1021	0.168E+09	-0.329E-01	-0.180E-03	-0.363E+02	0.190E+04	0.105E-01	0.251E-07	0.113E-01
1017	0.493E+04	0.643E+00	0.138E+00	0.210E+03	0.274E+06	0.607E-01	0.673E-04	0.304E+02
1018	0.262E+05	0.348E+01	0.138E+00	0.165E+03	0.242E+06	0.475E-01	0.359E-03	0.162E+03
1019	0.595E+04	0.783E+00	0.138E+00	0.212E+03	0.275E+06	0.612E-01	0.822E-04	0.371E+02
1020	0.251E+07	0.544E+03	0.138E+00	0.162E+04	0.758E+06	0.467E+00	0.347E-01	0.157E+05
1022	0.155E+06	0.206E+02	0.138E+00	0.105E+04	0.276E+06	0.302E+00	0.106E-01	0.476E+04
1023	0.126E+06	0.167E+02	0.138E+00	0.121E+04	0.273E+06	0.349E+00	0.101E-01	0.454E+04
1024	0.631E+05	0.838E+01	0.138E+00	0.144E+04	0.276E+06	0.417E+00	0.592E-02	0.267E+04
1025	0.894E+05	0.119E+02	0.138E+00	0.832E+03	0.200E+06	0.240E+00	0.917E-02	0.414E+04
1026	0.796E+05	0.106E+02	0.138E+00	0.182E+04	0.276E+06	0.525E+00	0.941E-02	0.425E+04
1027	0.147E+06	0.195E+02	0.138E+00	0.211E+04	0.276E+06	0.608E+00	0.201E-01	0.907E+04
1028	0.000E+00	0.000E+00	0.138E+00	0.930E+02	0.487E+05	0.268E-01	0.000E+00	0.000E+00
1029	0.208E+02	0.276E-02	0.138E+00	0.174E+02	0.211E+05	0.503E-02	0.402E-05	0.181E+01
1030	0.000E+00	0.000E+00	0.643E+02	0.468E-01	0.129E+05	0.101E-03	0.000E+00	0.000E+00
1031	0.976E+00	0.271E+02	0.632E+02	0.129E+02	0.213E+06	0.278E-01	0.121E-01	0.497E+04
1032	0.000E+00	-0.103E+04	0.632E+02	0.129E+02	0.214E+06	0.278E-01	0.000E+00	0.000E+00
1033	0.146E+02	0.406E+03	0.632E+02	0.127E+02	0.154E+06	0.274E-01	0.178E+00	0.735E+05
1035	0.123E+04	0.231E+01	0.520E+00	0.127E+03	0.421E+06	0.366E-01	0.865E-03	0.390E+03
1036	0.499E+04	0.937E+01	0.520E+00	0.265E+03	0.608E+06	0.766E-01	0.351E-02	0.158E+04
1037	0.912E+04	0.000E+00	-0.302E-03	-0.205E+00	0.406E+03	0.591E-04	0.127E-11	0.571E-06
1041	0.515E+04	0.970E+01	0.521E+00	0.358E+03	0.702E+06	0.103E+00	0.368E-02	0.166E+04
1038	0.179E+05	0.138E-01	-0.121E-03	-0.818E-01	0.163E+03	0.236E-04	0.159E-12	0.718E-07
1039	0.205E+14	0.539E+03	0.616E-04	0.203E+04	0.181E+05	0.585E+00	0.242E-04	0.109E+02
1040	0.115E+05	-0.109E+00	-0.474E-02	-0.140E+02	0.641E+04	0.403E-02	0.266E-07	0.120E-01
1046	0.255E+08	-0.163E+02	-0.959E-02	-0.695E+03	0.675E+05	0.201E+00	0.444E-03	0.200E+03
1042	0.237E+04	0.385E+01	0.521E+00	0.363E+03	0.702E+06	0.105E+00	0.172E-02	0.776E+03
1043	0.397E+05	0.746E+02	0.520E+00	0.274E+03	0.607E+06	0.790E-01	0.288E-01	0.130E+05
1044	0.143E+04	0.309E+01	0.470E+00	0.370E+03	0.634E+06	0.107E+00	0.861E-03	0.388E+03

1045	0.226E+06	0.432E+03	0.421E+00	0.156E+04	0.123E+07	0.450E+00	0.979E-01	0.442E+05
1047	0.201E+05	0.236E+02	0.411E+00	0.110E+04	0.556E+06	0.318E+00	0.275E-01	0.124E+05
1048	0.180E+05	0.212E+02	0.411E+00	0.110E+04	0.517E+06	0.317E+00	0.285E-01	0.129E+05
1049	0.569E+04	0.808E+01	0.405E+00	0.145E+04	0.548E+06	0.420E+00	0.999E-02	0.450E+04
1050	0.184E+05	0.204E+02	0.400E+00	0.930E+03	0.422E+06	0.269E+00	0.331E-01	0.149E+05
1051	0.117E+05	0.149E+02	0.394E+00	0.181E+04	0.534E+06	0.521E+00	0.243E-01	0.109E+05
1052	0.220E+05	0.234E+02	0.391E+00	0.209E+04	0.530E+06	0.605E+00	0.520E-01	0.235E+05
1053	0.000E+00	0.000E+00	0.391E+00	0.193E+03	0.138E+06	0.557E-01	0.000E+00	0.000E+00
1054	0.153E+02	0.162E-01	0.391E+00	0.362E+02	0.597E+05	0.104E-01	0.491E-04	0.221E+02
1055	0.000E+00	0.000E+00	0.145E+03	0.723E-01	0.218E+06	0.110E-03	0.000E+00	0.000E+00
1056	0.239E+00	0.320E+02	0.139E+03	0.196E+02	0.351E+07	0.299E-01	0.718E-01	0.892E+04
1057	0.000E+00	-0.877E+03	0.139E+03	0.196E+02	0.352E+07	0.299E-01	0.000E+00	0.000E+00
1058	0.199E+01	0.266E+03	0.139E+03	0.193E+02	0.328E+07	0.298E-01	0.590E+00	0.732E+05
1060	0.110E+03	0.692E-01	0.359E+00	0.852E+02	0.291E+06	0.246E-01	0.248E-04	0.112E+02
1061	0.483E+04	0.440E+01	0.362E+00	0.179E+03	0.423E+06	0.517E-01	0.111E-02	0.502E+03
1062	0.737E+04	0.671E+01	0.362E+00	0.864E+02	0.293E+06	0.249E-01	0.171E-02	0.769E+03
1063	0.875E+05	0.791E+02	0.365E+00	0.529E+03	0.724E+06	0.153E+00	0.210E-01	0.946E+04
1064	0.281E+05	0.258E+02	0.366E+00	0.594E+03	0.727E+06	0.171E+00	0.761E-02	0.343E+04

NUMBER OF PRESSURIZATION SYSTEMS = 2

NODUL	NODPRP	QULPRP	QULWAL	QCOND	TNKTM	VOLPROP	VOLULG
29	31	0.0963	0.3220	0.0002	529.6501	272.0208	27.9909
54	56	1.4683	6.0304	0.0020	160.3903	455.2793	44.7207

ISTEP = 440 TAU = 0.30320E+02

BOUNDARY NODES

NODE	P(PSI)	TF(F)	Z(COMP)	RHO (LBM/F T^3)	CONCENTRATIONS		
					HE	O2	RPL
1	0.7650E+03	0.1200E+03	0.0000E+00	0.4783E+00	0.1000E+01	0.0000E+00	0.0000
30	0.5160E+02	0.7000E+02	0.0000E+00	0.4962E+02	0.0000E+00	0.0000E+00	1.0000
34	0.6520E+03	0.7000E+02	0.0000E+00	0.5006E+02	0.0000E+00	0.0000E+00	1.0000
55	0.7333E+02	-0.3000E+03	0.0000E+00	0.7173E+02	0.0000E+00	0.1000E+01	0.0000
59	0.6520E+03	-0.3000E+03	0.0000E+00	0.7227E+02	0.0000E+00	0.1000E+01	0.0000
65	0.6150E+03	0.1200E+03	0.0000E+00	0.3867E+00	0.1000E+01	0.0000E+00	0.0000

SOLUTION

INTERNAL NODES

NODE	P (PSI)	TF (F)	Z	RHO	EM (LBM)	CONC	HE	O2	RP1
				(LBM/FT^3)					
2	0.7642E+03	0.1200E+03	0.1029E+01	0.4778E+00	0.2349E-01	0.1000E+01	0.0000	0.0000	
3	0.7588E+03	0.1200E+03	0.1029E+01	0.4746E+00	-0.4011E-10	0.1000E+01	0.0000	0.0000	
4	0.7588E+03	0.1200E+03	0.1029E+01	0.4746E+00	0.3099E-02	0.1000E+01	0.0000	0.0000	
5	0.7588E+03	0.1200E+03	0.1029E+01	0.4746E+00	0.3099E-02	0.1000E+01	0.0000	0.0000	
6	0.7588E+03	0.1200E+03	0.1029E+01	0.4746E+00	0.5249E-01	0.1000E+01	0.0000	0.0000	
7	0.7588E+03	0.1200E+03	0.1029E+01	0.4746E+00	0.5249E-01	0.1000E+01	0.0000	0.0000	
8	0.7588E+03	0.1200E+03	0.1029E+01	0.4746E+00	-0.4689E-10	0.1000E+01	0.0000	0.0000	
9	0.7588E+03	0.1200E+03	0.1029E+01	0.4746E+00	0.6695E-02	0.1000E+01	0.0000	0.0000	
10	0.7588E+03	0.1200E+03	0.1029E+01	0.4746E+00	0.6695E-02	0.1000E+01	0.0000	0.0000	
11	0.7588E+03	0.1200E+03	0.1029E+01	0.4746E+00	0.3635E-03	0.1000E+01	0.0000	0.0000	
12	0.7588E+03	0.1200E+03	0.1029E+01	0.4746E+00	0.3635E-03	0.1000E+01	0.0000	0.0000	
13	0.7588E+03	0.1200E+03	0.1029E+01	0.4746E+00	0.4241E-03	0.1000E+01	0.0000	0.0000	
14	0.7588E+03	0.1200E+03	0.1029E+01	0.4746E+00	0.4241E-03	0.1000E+01	0.0000	0.0000	
15	0.4843E+02	0.1200E+03	0.1002E+01	0.3111E-01	0.2780E-04	0.1000E+01	0.0000	0.0000	
16	0.4843E+02	0.1200E+03	0.1002E+01	0.3111E-01	0.2780E-04	0.1000E+01	0.0000	0.0000	
17	0.7588E+03	0.1200E+03	0.1029E+01	0.4746E+00	0.2272E-03	0.1000E+01	0.0000	0.0000	
18	0.7588E+03	0.1200E+03	0.1029E+01	0.4746E+00	0.2272E-03	0.1000E+01	0.0000	0.0000	
19	0.4841E+02	0.1200E+03	0.1002E+01	0.3110E-01	0.1787E-04	0.1000E+01	0.0000	0.0000	
20	0.4841E+02	0.1200E+03	0.1002E+01	0.3110E-01	0.1787E-04	0.1000E+01	0.0000	0.0000	
21	0.4841E+02	0.1200E+03	0.1002E+01	0.3110E-01	0.2699E-12	0.1000E+01	0.0000	0.0000	
22	0.4841E+02	0.1200E+03	0.1002E+01	0.3110E-01	-0.1121E-11	0.1000E+01	0.0000	0.0000	
23	0.4841E+02	0.1200E+03	0.1002E+01	0.3110E-01	0.2779E-04	0.1000E+01	0.0000	0.0000	
24	0.4841E+02	0.1200E+03	0.1002E+01	0.3110E-01	0.2779E-04	0.1000E+01	0.0000	0.0000	
25	0.4841E+02	0.1200E+03	0.1002E+01	0.3110E-01	0.2779E-04	0.1000E+01	0.0000	0.0000	
26	0.4841E+02	0.1200E+03	0.1002E+01	0.3110E-01	0.2779E-04	0.1000E+01	0.0000	0.0000	
27	0.4841E+02	0.1200E+03	0.1002E+01	0.3110E-01	-0.2299E-11	0.1000E+01	0.0000	0.0000	
28	0.4841E+02	0.1200E+03	0.1002E+01	0.3110E-01	-0.1936E-14	0.1000E+01	0.0000	0.0000	
29	0.4841E+02	0.9657E+02	0.1002E+01	0.3241E-01	0.1742E+01	0.1000E+01	0.0000	0.0000	
31	0.5160E+02	0.7000E+02	0.3147E-01	0.4962E+02	0.1222E+05	0.0000E+00	0.0000	1.0000	
32	0.2445E+02	0.7000E+02	0.1492E-01	0.4960E+02	0.0000E+00	0.0000E+00	0.0000	1.0000	
33	0.1059E+04	0.7000E+02	0.6368E+00	0.5035E+02	0.0000E+00	0.0000E+00	0.0000	1.0000	
35	0.7588E+03	0.1200E+03	0.1029E+01	0.4746E+00	0.4101E-10	0.1000E+01	0.0000	0.0000	
36	0.7588E+03	0.1200E+03	0.1029E+01	0.4746E+00	0.4035E-10	0.1000E+01	0.0000	0.0000	
37	0.7588E+03	0.1200E+03	0.1029E+01	0.4746E+00	-0.5775E-10	0.1000E+01	0.0000	0.0000	
38	0.7588E+03	0.1200E+03	0.1029E+01	0.4746E+00	0.7218E-03	0.1000E+01	0.0000	0.0000	
39	0.7588E+03	0.1200E+03	0.1029E+01	0.4745E+00	0.7217E-03	0.1000E+01	0.0000	0.0000	
40	0.6570E+02	0.1200E+03	0.1003E+01	0.4218E-01	0.1049E-03	0.1000E+01	0.0000	0.0000	
41	0.6570E+02	0.1200E+03	0.1003E+01	0.4218E-01	0.1049E-03	0.1000E+01	0.0000	0.0000	

42	0.7588E+03	0.1200E+03	0.1029E+01	0.4746E+00	0.1837E-02	0.1000E+01	0.0000	0.0000
43	0.7588E+03	0.1200E+03	0.1029E+01	0.4746E+00	0.1837E-02	0.1000E+01	0.0000	0.0000
44	0.6570E+02	0.1200E+03	0.1003E+01	0.4218E-01	0.8746E-04	0.1000E+01	0.0000	0.0000
45	0.6570E+02	0.1200E+03	0.1003E+01	0.4218E-01	0.8746E-04	0.1000E+01	0.0000	0.0000
46	0.6570E+02	0.1200E+03	0.1003E+01	0.4218E-01	-0.3615E-11	0.1000E+01	0.0000	0.0000
47	0.6570E+02	0.1200E+03	0.1003E+01	0.4218E-01	0.1094E-10	0.1000E+01	0.0000	0.0000
48	0.6570E+02	0.1200E+03	0.1003E+01	0.4218E-01	0.7579E-04	0.1000E+01	0.0000	0.0000
49	0.6570E+02	0.1200E+03	0.1003E+01	0.4218E-01	0.7579E-04	0.1000E+01	0.0000	0.0000
50	0.6570E+02	0.1200E+03	0.1003E+01	0.4218E-01	0.1224E-03	0.1000E+01	0.0000	0.0000
51	0.6570E+02	0.1200E+03	0.1003E+01	0.4218E-01	0.1224E-03	0.1000E+01	0.0000	0.0000
52	0.6570E+02	0.1200E+03	0.1003E+01	0.4218E-01	-0.1364E-10	0.1000E+01	0.0000	0.0000
53	0.6570E+02	0.1200E+03	0.1003E+01	0.4218E-01	-0.8193E-15	0.1000E+01	0.0000	0.0000
54	0.6570E+02	-0.1197E+03	0.1004E+01	0.7181E-01	0.6019E+01	0.1000E+01	0.0000	0.0000
56	0.7333E+02	-0.3000E+03	0.1910E-01	0.7174E+02	0.2986E+05	0.0000E+00	1.0000	0.0000
57	0.4126E+02	-0.3000E+03	0.1075E-01	0.7171E+02	0.0000E+00	0.0000E+00	1.0000	0.0000
58	0.9180E+03	-0.3000E+03	0.2366E+00	0.7250E+02	0.0000E+00	0.0000E+00	1.0000	0.0000
60	0.7587E+03	0.1200E+03	0.1029E+01	0.4745E+00	0.3463E-02	0.1000E+01	0.0000	0.0000
61	0.7586E+03	0.1200E+03	0.1029E+01	0.4745E+00	0.3462E-02	0.1000E+01	0.0000	0.0000
62	0.7532E+03	0.1200E+03	0.1029E+01	0.4712E+00	0.0000E+00	0.1000E+01	0.0000	0.0000
63	0.7450E+03	0.1200E+03	0.1029E+01	0.4662E+00	0.4255E-02	0.1000E+01	0.0000	0.0000
64	0.6472E+03	0.1200E+03	0.1025E+01	0.4064E+00	0.4437E-02	0.1000E+01	0.0000	0.0000

NODE	H	ENTROPY	EMU	COND	CP	GAMA
	BTU/LB	BTU/LB-R	LBM/FT-SEC	BTU/FT-S-R	BTU/LB-R	
2	0.7333E+03	0.5632E+01	0.1454E-04	0.2671E-04	0.1244E+01	0.1670E+01
3	0.7332E+03	0.5636E+01	0.1454E-04	0.2671E-04	0.1244E+01	0.1670E+01
4	0.7332E+03	0.5636E+01	0.1454E-04	0.2671E-04	0.1244E+01	0.1670E+01
5	0.7332E+03	0.5636E+01	0.1454E-04	0.2671E-04	0.1244E+01	0.1670E+01
6	0.7334E+03	0.5636E+01	0.1454E-04	0.2671E-04	0.1244E+01	0.1670E+01
7	0.7334E+03	0.5636E+01	0.1454E-04	0.2671E-04	0.1244E+01	0.1670E+01
8	0.7334E+03	0.5636E+01	0.1454E-04	0.2671E-04	0.1244E+01	0.1670E+01
9	0.7334E+03	0.5636E+01	0.1454E-04	0.2671E-04	0.1244E+01	0.1670E+01
10	0.7333E+03	0.5636E+01	0.1454E-04	0.2671E-04	0.1244E+01	0.1670E+01
11	0.7333E+03	0.5636E+01	0.1454E-04	0.2671E-04	0.1244E+01	0.1670E+01
12	0.7333E+03	0.5636E+01	0.1454E-04	0.2671E-04	0.1244E+01	0.1670E+01
13	0.7333E+03	0.5636E+01	0.1454E-04	0.2671E-04	0.1244E+01	0.1670E+01
14	0.7333E+03	0.5636E+01	0.1454E-04	0.2671E-04	0.1244E+01	0.1670E+01
15	0.7333E+03	0.7003E+01	0.1446E-04	0.2652E-04	0.1241E+01	0.1667E+01
16	0.7333E+03	0.7003E+01	0.1446E-04	0.2652E-04	0.1241E+01	0.1667E+01
17	0.7333E+03	0.5636E+01	0.1454E-04	0.2671E-04	0.1244E+01	0.1670E+01

18	0.7333E+03	0.5636E+01	0.1454E-04	0.2671E-04	0.1244E+01	0.1670E+01
19	0.7333E+03	0.7003E+01	0.1446E-04	0.2652E-04	0.1241E+01	0.1667E+01
20	0.7333E+03	0.7003E+01	0.1446E-04	0.2652E-04	0.1241E+01	0.1667E+01
21	0.7333E+03	0.7003E+01	0.1446E-04	0.2652E-04	0.1241E+01	0.1667E+01
22	0.7333E+03	0.7003E+01	0.1446E-04	0.2652E-04	0.1241E+01	0.1667E+01
23	0.7334E+03	0.7003E+01	0.1446E-04	0.2652E-04	0.1241E+01	0.1667E+01
24	0.7335E+03	0.7003E+01	0.1446E-04	0.2652E-04	0.1241E+01	0.1667E+01
25	0.7333E+03	0.7003E+01	0.1446E-04	0.2652E-04	0.1241E+01	0.1667E+01
26	0.7334E+03	0.7003E+01	0.1446E-04	0.2652E-04	0.1241E+01	0.1667E+01
27	0.7334E+03	0.7003E+01	0.1446E-04	0.2652E-04	0.1241E+01	0.1667E+01
28	0.7334E+03	0.7003E+01	0.1446E-04	0.2652E-04	0.1241E+01	0.1667E+01
29	0.6641E+03	0.6952E+01	0.1403E-04	0.2576E-04	0.1241E+01	0.1667E+01
31	0.2640E+02	0.0000E+00	0.1067E-02	0.2178E-04	0.3408E+00	0.1400E+01
32	0.2595E+02	0.0000E+00	0.1058E-02	0.2177E-04	0.3408E+00	0.1400E+01
33	0.4170E+02	0.0000E+00	0.1474E-02	0.2218E-04	0.3408E+00	0.1400E+01
35	0.7334E+03	0.5636E+01	0.1454E-04	0.2671E-04	0.1244E+01	0.1670E+01
36	0.7334E+03	0.5636E+01	0.1454E-04	0.2671E-04	0.1244E+01	0.1670E+01
37	0.7333E+03	0.5636E+01	0.1454E-04	0.2671E-04	0.1244E+01	0.1670E+01
38	0.7333E+03	0.5636E+01	0.1454E-04	0.2671E-04	0.1244E+01	0.1670E+01
39	0.7333E+03	0.5636E+01	0.1454E-04	0.2671E-04	0.1244E+01	0.1670E+01
40	0.7333E+03	0.6852E+01	0.1446E-04	0.2653E-04	0.1241E+01	0.1667E+01
41	0.7333E+03	0.6852E+01	0.1446E-04	0.2653E-04	0.1241E+01	0.1667E+01
42	0.7334E+03	0.5636E+01	0.1454E-04	0.2671E-04	0.1244E+01	0.1670E+01
43	0.7334E+03	0.5636E+01	0.1454E-04	0.2671E-04	0.1244E+01	0.1670E+01
44	0.7332E+03	0.6852E+01	0.1446E-04	0.2652E-04	0.1241E+01	0.1667E+01
45	0.7332E+03	0.6852E+01	0.1446E-04	0.2652E-04	0.1241E+01	0.1667E+01
46	0.7333E+03	0.6852E+01	0.1446E-04	0.2653E-04	0.1241E+01	0.1667E+01
47	0.7332E+03	0.6852E+01	0.1446E-04	0.2653E-04	0.1241E+01	0.1667E+01
48	0.7333E+03	0.6852E+01	0.1446E-04	0.2653E-04	0.1241E+01	0.1667E+01
49	0.7333E+03	0.6852E+01	0.1446E-04	0.2653E-04	0.1241E+01	0.1667E+01
50	0.7334E+03	0.6852E+01	0.1446E-04	0.2653E-04	0.1241E+01	0.1667E+01
51	0.7334E+03	0.6852E+01	0.1446E-04	0.2652E-04	0.1241E+01	0.1667E+01
52	0.7333E+03	0.6852E+01	0.1446E-04	0.2652E-04	0.1241E+01	0.1667E+01
53	0.7333E+03	0.6852E+01	0.1446E-04	0.2652E-04	0.1241E+01	0.1667E+01
54	0.2545E+03	0.6189E+01	0.9951E-05	0.1849E-04	0.1242E+01	0.1668E+01
56	0.5979E+02	0.6961E+00	0.1417E-03	0.2073E-04	0.4202E+00	0.1730E+01
57	0.5974E+02	0.6963E+00	0.1413E-03	0.2072E-04	0.4204E+00	0.1732E+01
58	0.6116E+02	0.6911E+00	0.1519E-03	0.2107E-04	0.4144E+00	0.1695E+01
60	0.7332E+03	0.5636E+01	0.1454E-04	0.2671E-04	0.1244E+01	0.1670E+01
61	0.7332E+03	0.5636E+01	0.1454E-04	0.2671E-04	0.1244E+01	0.1670E+01
62	0.7334E+03	0.5639E+01	0.1454E-04	0.2671E-04	0.1244E+01	0.1670E+01

63	0.7334E+03	0.5645E+01	0.1454E-04	0.2671E-04	0.1244E+01	0.1670E+01
64	0.7334E+03	0.5715E+01	0.1453E-04	0.2668E-04	0.1243E+01	0.1670E+01

BRANCHES

BRANCH	KFACTOR (LBF-S^2/(LBM-FT)^2)	DELP (PSI)	FLOW RATE (LBM/SEC)	VELOCITY (FT/SEC)	REYN. NO.	MACH NO.	ENTROPY GEN. BTU/(R-SEC)	LOST WORK LBF-FT/SEC
1001	0.706E+03	0.818E+00	0.408E+00	0.926E+02	0.330E+06	0.267E-01	0.223E-03	0.101E+03
1002	0.463E+04	0.536E+01	0.408E+00	0.194E+03	0.477E+06	0.558E-01	0.146E-02	0.660E+03
1003	0.693E+03	0.000E+00	0.153E-03	0.349E-01	0.123E+03	0.101E-04	0.115E-13	0.520E-08
1059	0.684E+02	0.792E-01	0.408E+00	0.933E+02	0.330E+06	0.269E-01	0.218E-04	0.982E+01
1004	0.261E+04	0.000E+00	0.153E-03	0.349E-01	0.123E+03	0.101E-04	0.435E-13	0.196E-07
1005	0.466E+04	0.000E+00	0.153E-03	0.729E-01	0.178E+03	0.210E-04	0.777E-13	0.350E-07
1006	0.443E+05	0.000E+00	0.153E-03	0.349E-01	0.123E+03	0.101E-04	0.737E-12	0.333E-06
1007	0.131E+04	0.000E+00	0.768E-04	0.176E-01	0.621E+02	0.507E-05	0.278E-14	0.125E-08
1034	0.132E+04	0.000E+00	0.759E-04	0.174E-01	0.613E+02	0.500E-05	0.271E-14	0.122E-08
1008	0.512E+05	0.000E+00	0.768E-04	0.176E-01	0.621E+02	0.507E-05	0.109E-12	0.490E-07
1009	0.244E+07	0.109E-03	0.768E-04	0.106E+00	0.152E+03	0.305E-04	0.518E-11	0.234E-05
1010	0.236E+05	0.000E+00	0.768E-04	0.825E-01	0.135E+03	0.238E-04	0.500E-13	0.226E-07
1011	0.133E+06	0.000E+00	0.768E-04	0.106E+00	0.152E+03	0.305E-04	0.281E-12	0.127E-06
1012	0.760E+05	0.000E+00	0.736E-04	0.101E+00	0.146E+03	0.292E-04	0.142E-12	0.639E-07
1016	0.113E+07	0.000E+00	0.320E-05	0.440E-02	0.634E+01	0.127E-05	0.173E-15	0.778E-10
1013	0.162E+06	0.000E+00	0.736E-04	0.101E+00	0.146E+03	0.292E-04	0.301E-12	0.136E-06
1014	0.189E+14	0.710E+03	0.736E-04	0.223E+04	0.217E+05	0.644E+00	0.352E-04	0.159E+02
1015	0.243E+07	0.949E-04	0.743E-04	0.156E+01	0.148E+03	0.450E-03	0.710E-10	0.320E-04
1021	0.467E+09	0.182E-01	0.750E-04	0.442E+02	0.793E+03	0.128E-01	0.140E-07	0.633E-02
1017	0.199E+07	0.000E+00	0.320E-05	0.440E-02	0.634E+01	0.127E-05	0.305E-15	0.137E-09
1018	0.100E+17	0.710E+03	0.320E-05	0.343E-02	0.560E+01	0.990E-06	0.153E-05	0.689E+00
1019	0.319E+08	0.339E-05	0.364E-05	0.763E-01	0.725E+01	0.220E-04	0.109E-12	0.493E-07
1020	0.343E+08	0.339E-05	0.407E-05	0.651E+00	0.224E+02	0.188E-03	0.165E-12	0.746E-07
1022	0.111E+07	0.475E-04	0.791E-04	0.166E+01	0.158E+03	0.479E-03	0.390E-10	0.176E-04
1023	0.295E+06	0.136E-04	0.791E-04	0.162E+01	0.156E+03	0.469E-03	0.104E-10	0.470E-05
1024	0.226E+07	0.983E-04	0.798E-04	0.167E+01	0.159E+03	0.483E-03	0.818E-10	0.369E-04
1025	0.164E+06	0.678E-05	0.804E-04	0.890E+00	0.116E+03	0.257E-03	0.610E-11	0.275E-05
1026	0.223E+07	0.102E-03	0.811E-04	0.170E+01	0.162E+03	0.491E-03	0.847E-10	0.382E-04
1027	0.425E+06	0.203E-04	0.818E-04	0.172E+01	0.163E+03	0.495E-03	0.166E-10	0.748E-05
1028	0.000E+00	0.000E+00	0.818E-04	0.536E-01	0.288E+02	0.155E-04	0.000E+00	0.000E+00
1029	0.203E+02	0.000E+00	0.818E-04	0.100E-01	0.125E+02	0.290E-05	0.790E-15	0.356E-09
1030	0.000E+00	0.000E+00	0.631E+02	0.459E-01	0.127E+05	0.992E-04	0.000E+00	0.000E+00
1031	0.976E+00	0.271E+02	0.633E+02	0.129E+02	0.213E+06	0.278E-01	0.121E-01	0.498E+04
1032	0.000E+00	-0.103E+04	0.633E+02	0.129E+02	0.215E+06	0.278E-01	0.000E+00	0.000E+00
1033	0.146E+02	0.407E+03	0.633E+02	0.127E+02	0.154E+06	0.274E-01	0.179E+00	0.737E+05

1035	0.986E+04	0.000E+00	0.759E-04	0.174E-01	0.613E+02	0.500E-05	0.201E-13	0.908E-08
1036	0.466E+04	0.000E+00	0.759E-04	0.362E-01	0.886E+02	0.104E-04	0.952E-14	0.430E-08
1037	0.199E+05	0.000E+00	0.727E-04	0.462E-01	0.980E+02	0.133E-04	0.358E-13	0.162E-07
1041	0.354E+06	0.000E+00	0.316E-05	0.201E-02	0.425E+01	0.579E-06	0.522E-16	0.235E-10
1038	0.274E+05	0.000E+00	0.727E-04	0.462E-01	0.980E+02	0.133E-04	0.493E-13	0.222E-07
1039	0.189E+14	0.693E+03	0.727E-04	0.221E+04	0.214E+05	0.637E+00	0.339E-04	0.153E+02
1040	0.481E+06	0.203E-04	0.759E-04	0.542E+00	0.103E+03	0.156E-03	0.110E-10	0.498E-05
1046	0.680E+08	0.294E-02	0.790E-04	0.153E+02	0.557E+03	0.441E-02	0.176E-08	0.795E-03
1042	0.161E+07	0.000E+00	0.316E-05	0.201E-02	0.425E+01	0.579E-06	0.236E-15	0.107E-09
1043	0.100E+17	0.693E+03	0.316E-05	0.151E-02	0.369E+01	0.435E-06	0.147E-05	0.664E+00
1044	0.526E+07	0.000E+00	0.578E-05	0.413E-01	0.783E+01	0.119E-04	0.534E-13	0.241E-07
1045	0.205E+07	0.000E+00	0.840E-05	0.282E+00	0.247E+02	0.813E-04	0.638E-13	0.288E-07
1047	0.195E+06	0.136E-04	0.874E-04	0.625E+00	0.118E+03	0.180E-03	0.684E-11	0.309E-05
1048	0.417E+05	0.000E+00	0.874E-04	0.539E+00	0.110E+03	0.156E-03	0.146E-11	0.660E-06
1049	0.294E+06	0.203E-04	0.897E-04	0.641E+00	0.122E+03	0.185E-03	0.111E-10	0.503E-05
1050	0.344E+05	0.000E+00	0.920E-04	0.400E+00	0.972E+02	0.115E-03	0.141E-11	0.635E-06
1051	0.445E+06	0.271E-04	0.956E-04	0.683E+00	0.130E+03	0.197E-03	0.205E-10	0.923E-05
1052	0.666E+05	0.678E-05	0.993E-04	0.709E+00	0.135E+03	0.205E-03	0.343E-11	0.155E-05
1053	0.000E+00	0.000E+00	0.993E-04	0.480E-01	0.350E+02	0.138E-04	0.000E+00	0.000E+00
1054	0.149E+02	0.000E+00	0.993E-04	0.899E-02	0.151E+02	0.260E-05	0.769E-15	0.347E-09
1055	0.000E+00	0.000E+00	0.138E+03	0.690E-01	0.208E+06	0.105E-03	0.000E+00	0.000E+00
1056	0.239E+00	0.321E+02	0.139E+03	0.196E+02	0.352E+07	0.299E-01	0.720E-01	0.894E+04
1057	0.000E+00	-0.877E+03	0.139E+03	0.196E+02	0.353E+07	0.299E-01	0.000E+00	0.000E+00
1058	0.199E+01	0.266E+03	0.139E+03	0.194E+02	0.328E+07	0.299E-01	0.591E+00	0.734E+05
1060	0.106E+03	0.122E+00	0.408E+00	0.934E+02	0.330E+06	0.269E-01	0.336E-04	0.152E+02
1061	0.466E+04	0.540E+01	0.408E+00	0.195E+03	0.477E+06	0.562E-01	0.148E-02	0.669E+03
1062	0.711E+04	0.823E+01	0.408E+00	0.940E+02	0.330E+06	0.271E-01	0.228E-02	0.103E+04
1063	0.845E+05	0.978E+02	0.408E+00	0.572E+03	0.809E+06	0.165E+00	0.274E-01	0.123E+05
1064	0.278E+05	0.322E+02	0.408E+00	0.656E+03	0.810E+06	0.189E+00	0.103E-01	0.465E+04

NUMBER OF PRESSURIZATION SYSTEMS = 2

NODUL	NODPRP	QULPRP	QULWAL	QCOND	TNKTM	VOLPROP	VOLULG
29	31	0.1595	0.7269	0.0012	529.8492	246.2590	53.7529
54	56	2.5148	14.7714	0.0105	163.3136	416.1695	83.8305

ISTEP = 820 TAU = 0.59770E+02

BOUNDARY NODES

NODE	P(PSI)	TF(F)	Z(COMP) (LBM/F)	RHO T^3	CONCENTRATIONS		
					HE	O2	RP1
1	0.7650E+03	0.1200E+03	0.0000E+00	0.4783E+00	0.1000E+01	0.0000E+00	0.0000
30	0.5152E+02	0.7000E+02	0.0000E+00	0.4962E+02	0.0000E+00	0.0000E+00	1.0000
34	0.6520E+03	0.7000E+02	0.0000E+00	0.5006E+02	0.0000E+00	0.0000E+00	1.0000
55	0.7641E+02	-0.3000E+03	0.0000E+00	0.7173E+02	0.0000E+00	0.1000E+01	0.0000
59	0.6520E+03	-0.3000E+03	0.0000E+00	0.7227E+02	0.0000E+00	0.1000E+01	0.0000
65	0.6150E+03	0.1200E+03	0.0000E+00	0.3867E+00	0.1000E+01	0.0000E+00	0.0000

SOLUTION

INTERNAL NODES

NODE	P(PSI)	TF(F)	Z	RHO (LBM/FT^3)	EM(LBM)	CONC			
							HE	O2	RP1
2	0.7634E+03	0.1200E+03	0.1029E+01	0.4773E+00	0.2347E-01	0.1000E+01	0.0000	0.0000	0.0000
3	0.7528E+03	0.1200E+03	0.1029E+01	0.4710E+00	0.2774E-10	0.1000E+01	0.0000	0.0000	0.0000
4	0.7528E+03	0.1200E+03	0.1029E+01	0.4709E+00	0.3075E-02	0.1000E+01	0.0000	0.0000	0.0000
5	0.7528E+03	0.1200E+03	0.1029E+01	0.4709E+00	0.3075E-02	0.1000E+01	0.0000	0.0000	0.0000
6	0.7518E+03	0.1200E+03	0.1029E+01	0.4703E+00	0.5202E-01	0.1000E+01	0.0000	0.0000	0.0000
7	0.7513E+03	0.1200E+03	0.1029E+01	0.4700E+00	0.5199E-01	0.1000E+01	0.0000	0.0000	0.0000
8	0.7513E+03	0.1200E+03	0.1029E+01	0.4700E+00	-0.2978E-10	0.1000E+01	0.0000	0.0000	0.0000
9	0.7498E+03	0.1200E+03	0.1029E+01	0.4691E+00	0.6617E-02	0.1000E+01	0.0000	0.0000	0.0000
10	0.7207E+03	0.1200E+03	0.1028E+01	0.4516E+00	0.6368E-02	0.1000E+01	0.0000	0.0000	0.0000
11	0.7153E+03	0.1200E+03	0.1027E+01	0.4483E+00	0.3432E-03	0.1000E+01	0.0000	0.0000	0.0000
12	0.7136E+03	0.1200E+03	0.1027E+01	0.4473E+00	0.3425E-03	0.1000E+01	0.0000	0.0000	0.0000
13	0.7136E+03	0.1200E+03	0.1027E+01	0.4473E+00	0.3995E-03	0.1000E+01	0.0000	0.0000	0.0000
14	0.7136E+03	0.1200E+03	0.1027E+01	0.4473E+00	0.3995E-03	0.1000E+01	0.0000	0.0000	0.0000
15	0.1681E+03	0.1200E+03	0.1007E+01	0.1076E+00	0.9608E-04	0.1000E+01	0.0000	0.0000	0.0000
16	0.1681E+03	0.1200E+03	0.1007E+01	0.1076E+00	0.9608E-04	0.1000E+01	0.0000	0.0000	0.0000
17	0.7071E+03	0.1200E+03	0.1027E+01	0.4434E+00	0.2121E-03	0.1000E+01	0.0000	0.0000	0.0000
18	0.7060E+03	0.1200E+03	0.1027E+01	0.4428E+00	0.2118E-03	0.1000E+01	0.0000	0.0000	0.0000
19	0.7005E+03	0.1200E+03	0.1027E+01	0.4394E+00	0.2522E-03	0.1000E+01	0.0000	0.0000	0.0000
20	0.6992E+03	0.1200E+03	0.1027E+01	0.4387E+00	0.2518E-03	0.1000E+01	0.0000	0.0000	0.0000
21	0.1682E+03	0.1200E+03	0.1007E+01	0.1076E+00	0.1151E-11	0.1000E+01	0.0000	0.0000	0.0000
22	0.1411E+03	0.1200E+03	0.1006E+01	0.9030E-01	0.8249E-11	0.1000E+01	0.0000	0.0000	0.0000
23	0.1189E+03	0.1200E+03	0.1005E+01	0.7614E-01	0.6805E-04	0.1000E+01	0.0000	0.0000	0.0000
24	0.1076E+03	0.1200E+03	0.1004E+01	0.6895E-01	0.6164E-04	0.1000E+01	0.0000	0.0000	0.0000
25	0.9147E+02	0.1200E+03	0.1004E+01	0.5863E-01	0.5242E-04	0.1000E+01	0.0000	0.0000	0.0000
26	0.7689E+02	0.1200E+03	0.1003E+01	0.4930E-01	0.4409E-04	0.1000E+01	0.0000	0.0000	0.0000

27	0.4916E+02	0.1200E+03	0.1002E+01	0.3157E-01	0.1816E-11	0.1000E+01	0.0000	0.0000
28	0.4916E+02	0.1200E+03	0.1002E+01	0.3157E-01	0.2442E-15	0.1000E+01	0.0000	0.0000
29	0.4915E+02	0.9769E+02	0.1002E+01	0.3283E-01	0.2999E+01	0.1000E+01	0.0000	0.0000
31	0.5152E+02	0.7000E+02	0.3143E-01	0.4962E+02	0.1035E+05	0.0000E+00	0.0000	1.0000
32	0.2438E+02	0.7000E+02	0.1488E-01	0.4960E+02	0.0000E+00	0.0000E+00	0.0000	1.0000
33	0.1059E+04	0.7000E+02	0.6367E+00	0.5034E+02	0.0000E+00	0.0000E+00	0.0000	1.0000
35	0.7513E+03	0.1200E+03	0.1029E+01	0.4700E+00	0.7233E-11	0.1000E+01	0.0000	0.0000
36	0.7513E+03	0.1200E+03	0.1029E+01	0.4700E+00	-0.2973E-10	0.1000E+01	0.0000	0.0000
37	0.7513E+03	0.1200E+03	0.1029E+01	0.4700E+00	0.2064E-10	0.1000E+01	0.0000	0.0000
38	0.7513E+03	0.1200E+03	0.1029E+01	0.4700E+00	0.7148E-03	0.1000E+01	0.0000	0.0000
39	0.7513E+03	0.1200E+03	0.1029E+01	0.4700E+00	0.7148E-03	0.1000E+01	0.0000	0.0000
40	0.6985E+02	0.1200E+03	0.1003E+01	0.4484E-01	0.1116E-03	0.1000E+01	0.0000	0.0000
41	0.6985E+02	0.1200E+03	0.1003E+01	0.4484E-01	0.1116E-03	0.1000E+01	0.0000	0.0000
42	0.7513E+03	0.1200E+03	0.1029E+01	0.4700E+00	0.1820E-02	0.1000E+01	0.0000	0.0000
43	0.7513E+03	0.1200E+03	0.1029E+01	0.4700E+00	0.1820E-02	0.1000E+01	0.0000	0.0000
44	0.6985E+02	0.1200E+03	0.1003E+01	0.4483E-01	0.9298E-04	0.1000E+01	0.0000	0.0000
45	0.6985E+02	0.1200E+03	0.1003E+01	0.4483E-01	0.9298E-04	0.1000E+01	0.0000	0.0000
46	0.6985E+02	0.1200E+03	0.1003E+01	0.4483E-01	-0.5010E-11	0.1000E+01	0.0000	0.0000
47	0.6985E+02	0.1200E+03	0.1003E+01	0.4483E-01	0.6648E-11	0.1000E+01	0.0000	0.0000
48	0.6985E+02	0.1200E+03	0.1003E+01	0.4483E-01	0.8058E-04	0.1000E+01	0.0000	0.0000
49	0.6985E+02	0.1200E+03	0.1003E+01	0.4483E-01	0.8058E-04	0.1000E+01	0.0000	0.0000
50	0.6985E+02	0.1200E+03	0.1003E+01	0.4483E-01	0.1302E-03	0.1000E+01	0.0000	0.0000
51	0.6985E+02	0.1200E+03	0.1003E+01	0.4483E-01	0.1302E-03	0.1000E+01	0.0000	0.0000
52	0.6985E+02	0.1200E+03	0.1003E+01	0.4483E-01	-0.1995E-11	0.1000E+01	0.0000	0.0000
53	0.6985E+02	0.1200E+03	0.1003E+01	0.4483E-01	-0.7269E-14	0.1000E+01	0.0000	0.0000
54	0.6985E+02	-0.8413E+02	0.1004E+01	0.6912E-01	0.9737E+01	0.1000E+01	0.0000	0.0000
56	0.7641E+02	-0.3000E+03	0.1990E-01	0.7174E+02	0.2576E+05	0.0000E+00	1.0000	0.0000
57	0.4418E+02	-0.3000E+03	0.1151E-01	0.7171E+02	0.0000E+00	0.0000E+00	1.0000	0.0000
58	0.9193E+03	-0.3000E+03	0.2369E+00	0.7250E+02	0.0000E+00	0.0000E+00	1.0000	0.0000
60	0.7528E+03	0.1200E+03	0.1029E+01	0.4709E+00	0.3436E-02	0.1000E+01	0.0000	0.0000
61	0.7526E+03	0.1200E+03	0.1029E+01	0.4708E+00	0.3436E-02	0.1000E+01	0.0000	0.0000
62	0.7475E+03	0.1200E+03	0.1029E+01	0.4677E+00	0.0000E+00	0.1000E+01	0.0000	0.0000
63	0.7396E+03	0.1200E+03	0.1028E+01	0.4629E+00	0.4225E-02	0.1000E+01	0.0000	0.0000
64	0.6457E+03	0.1200E+03	0.1025E+01	0.4055E+00	0.4427E-02	0.1000E+01	0.0000	0.0000

NODE	H BTU/LB	ENTROPY BTU/LB-R	EMU LBM/FT-SEC	COND BTU/FT-S-R	CP BTU/LB-R	GAMA
2	0.7333E+03	0.5633E+01	0.1454E-04	0.2671E-04	0.1244E+01	0.1670E+01
3	0.7332E+03	0.5640E+01	0.1454E-04	0.2671E-04	0.1244E+01	0.1670E+01
4	0.7332E+03	0.5640E+01	0.1454E-04	0.2671E-04	0.1244E+01	0.1670E+01

5	0.7332E+03	0.5640E+01	0.1454E-04	0.2671E-04	0.1244E+01	0.1670E+01
6	0.7334E+03	0.5640E+01	0.1454E-04	0.2671E-04	0.1244E+01	0.1670E+01
7	0.7334E+03	0.5641E+01	0.1454E-04	0.2671E-04	0.1244E+01	0.1670E+01
8	0.7334E+03	0.5641E+01	0.1454E-04	0.2671E-04	0.1244E+01	0.1670E+01
9	0.7334E+03	0.5642E+01	0.1454E-04	0.2671E-04	0.1244E+01	0.1670E+01
10	0.7333E+03	0.5661E+01	0.1454E-04	0.2670E-04	0.1244E+01	0.1670E+01
11	0.7333E+03	0.5665E+01	0.1454E-04	0.2670E-04	0.1244E+01	0.1670E+01
12	0.7333E+03	0.5666E+01	0.1454E-04	0.2670E-04	0.1244E+01	0.1670E+01
13	0.7333E+03	0.5666E+01	0.1454E-04	0.2670E-04	0.1244E+01	0.1670E+01
14	0.7333E+03	0.5666E+01	0.1454E-04	0.2670E-04	0.1244E+01	0.1670E+01
15	0.7333E+03	0.6385E+01	0.1447E-04	0.2655E-04	0.1242E+01	0.1667E+01
16	0.7333E+03	0.6385E+01	0.1447E-04	0.2655E-04	0.1242E+01	0.1667E+01
17	0.7333E+03	0.5671E+01	0.1454E-04	0.2670E-04	0.1244E+01	0.1670E+01
18	0.7333E+03	0.5672E+01	0.1454E-04	0.2670E-04	0.1244E+01	0.1670E+01
19	0.7333E+03	0.5675E+01	0.1454E-04	0.2670E-04	0.1244E+01	0.1670E+01
20	0.7333E+03	0.5676E+01	0.1454E-04	0.2669E-04	0.1244E+01	0.1670E+01
21	0.7333E+03	0.6385E+01	0.1447E-04	0.2655E-04	0.1242E+01	0.1667E+01
22	0.7333E+03	0.6472E+01	0.1447E-04	0.2654E-04	0.1242E+01	0.1667E+01
23	0.7334E+03	0.6557E+01	0.1447E-04	0.2654E-04	0.1242E+01	0.1667E+01
24	0.7335E+03	0.6607E+01	0.1447E-04	0.2653E-04	0.1242E+01	0.1667E+01
25	0.7333E+03	0.6687E+01	0.1446E-04	0.2653E-04	0.1241E+01	0.1667E+01
26	0.7334E+03	0.6774E+01	0.1446E-04	0.2653E-04	0.1241E+01	0.1667E+01
27	0.7334E+03	0.6996E+01	0.1446E-04	0.2652E-04	0.1241E+01	0.1667E+01
28	0.7334E+03	0.6996E+01	0.1446E-04	0.2652E-04	0.1241E+01	0.1667E+01
29	0.6641E+03	0.6947E+01	0.1405E-04	0.2580E-04	0.1241E+01	0.1667E+01
31	0.2640E+02	0.0000E+00	0.1067E-02	0.2178E-04	0.3408E+00	0.1400E+01
32	0.2595E+02	0.0000E+00	0.1058E-02	0.2177E-04	0.3408E+00	0.1400E+01
33	0.4170E+02	0.0000E+00	0.1474E-02	0.2218E-04	0.3408E+00	0.1400E+01
35	0.7334E+03	0.5641E+01	0.1454E-04	0.2671E-04	0.1244E+01	0.1670E+01
36	0.7334E+03	0.5641E+01	0.1454E-04	0.2671E-04	0.1244E+01	0.1670E+01
37	0.7333E+03	0.5641E+01	0.1454E-04	0.2671E-04	0.1244E+01	0.1670E+01
38	0.7333E+03	0.5641E+01	0.1454E-04	0.2671E-04	0.1244E+01	0.1670E+01
39	0.7333E+03	0.5641E+01	0.1454E-04	0.2671E-04	0.1244E+01	0.1670E+01
40	0.7333E+03	0.6821E+01	0.1446E-04	0.2653E-04	0.1241E+01	0.1667E+01
41	0.7333E+03	0.6821E+01	0.1446E-04	0.2653E-04	0.1241E+01	0.1667E+01
42	0.7334E+03	0.5641E+01	0.1454E-04	0.2671E-04	0.1244E+01	0.1670E+01
43	0.7334E+03	0.5641E+01	0.1454E-04	0.2671E-04	0.1244E+01	0.1670E+01
44	0.7332E+03	0.6821E+01	0.1446E-04	0.2653E-04	0.1241E+01	0.1667E+01
45	0.7332E+03	0.6821E+01	0.1446E-04	0.2653E-04	0.1241E+01	0.1667E+01
46	0.7333E+03	0.6821E+01	0.1446E-04	0.2653E-04	0.1241E+01	0.1667E+01
47	0.7332E+03	0.6821E+01	0.1446E-04	0.2653E-04	0.1241E+01	0.1667E+01

48	0.7333E+03	0.6821E+01	0.1446E-04	0.2653E-04	0.1241E+01	0.1667E+01
49	0.7333E+03	0.6821E+01	0.1446E-04	0.2653E-04	0.1241E+01	0.1667E+01
50	0.7334E+03	0.6821E+01	0.1446E-04	0.2653E-04	0.1241E+01	0.1667E+01
51	0.7334E+03	0.6821E+01	0.1446E-04	0.2653E-04	0.1241E+01	0.1667E+01
52	0.7333E+03	0.6821E+01	0.1446E-04	0.2653E-04	0.1241E+01	0.1667E+01
53	0.7333E+03	0.6821E+01	0.1446E-04	0.2653E-04	0.1241E+01	0.1667E+01
54	0.2545E+03	0.6282E+01	0.1064E-04	0.1976E-04	0.1242E+01	0.1667E+01
56	0.5979E+02	0.6961E+00	0.1417E-03	0.2074E-04	0.4202E+00	0.1730E+01
57	0.5974E+02	0.6963E+00	0.1413E-03	0.2072E-04	0.4204E+00	0.1731E+01
58	0.6116E+02	0.6911E+00	0.1519E-03	0.2107E-04	0.4144E+00	0.1695E+01
60	0.7332E+03	0.5640E+01	0.1454E-04	0.2671E-04	0.1244E+01	0.1670E+01
61	0.7332E+03	0.5640E+01	0.1454E-04	0.2671E-04	0.1244E+01	0.1670E+01
62	0.7334E+03	0.5643E+01	0.1454E-04	0.2671E-04	0.1244E+01	0.1670E+01
63	0.7334E+03	0.5648E+01	0.1454E-04	0.2671E-04	0.1244E+01	0.1670E+01
64	0.7334E+03	0.5716E+01	0.1453E-04	0.2668E-04	0.1243E+01	0.1670E+01

BRANCHES

BRANCH	KFACTOR (LBF-S^2/(LBM-FT)^2)	DELP (PSI)	FLOW RATE (LBM/SEC)	VELOCITY (FT/SEC)	REYN. NO.	MACH NO.	ENTROPY GEN. BTU/(R-SEC)	LOST WORK LBF-FT/SEC
1001	0.694E+03	0.163E+01	0.572E+00	0.130E+03	0.462E+06	0.374E-01	0.602E-03	0.272E+03
1002	0.463E+04	0.105E+02	0.572E+00	0.271E+03	0.668E+06	0.783E-01	0.403E-02	0.182E+04
1003	0.693E+02	0.145E-01	0.174E+00	0.400E+02	0.140E+06	0.115E-01	0.171E-05	0.771E+00
1059	0.690E+02	0.760E-01	0.398E+00	0.918E+02	0.322E+06	0.265E-01	0.205E-04	0.926E+01
1004	0.102E+03	0.291E-01	0.174E+00	0.400E+02	0.140E+06	0.115E-01	0.251E-05	0.113E+01
1005	0.470E+04	0.985E+00	0.174E+00	0.835E+02	0.203E+06	0.241E-01	0.116E-03	0.524E+02
1006	0.173E+04	0.507E+00	0.175E+00	0.403E+02	0.141E+06	0.116E-01	0.434E-04	0.196E+02
1007	0.694E+02	0.149E-01	0.176E+00	0.406E+02	0.142E+06	0.117E-01	0.178E-05	0.802E+00
1034	0.298E+04	0.000E+00	-0.331E-04	-0.763E-02	0.268E+02	0.220E-05	0.510E-15	0.230E-09
1008	0.714E+04	0.153E+01	0.176E+00	0.406E+02	0.142E+06	0.117E-01	0.183E-03	0.826E+02
1009	0.132E+06	0.291E+02	0.176E+00	0.245E+03	0.349E+06	0.706E-01	0.340E-02	0.153E+04
1010	0.248E+05	0.539E+01	0.177E+00	0.200E+03	0.310E+06	0.576E-01	0.675E-03	0.305E+03
1011	0.749E+04	0.167E+01	0.177E+00	0.258E+03	0.351E+06	0.743E-01	0.206E-03	0.927E+02
1012	0.709E+05	0.000E+00	-0.910E-04	-0.132E+00	0.180E+03	0.382E-04	0.265E-12	0.119E-06
1016	0.299E+05	0.652E+01	0.177E+00	0.258E+03	0.351E+06	0.745E-01	0.826E-03	0.372E+03
1013	0.891E+06	-0.271E-03	-0.142E-04	-0.204E-01	0.281E+02	0.590E-05	0.125E-13	0.565E-08
1014	0.200E+14	0.545E+03	0.627E-04	0.202E+04	0.185E+05	0.582E+00	0.244E-04	0.110E+02
1015	0.643E+06	-0.502E-03	-0.812E-04	-0.495E+00	0.162E+03	0.143E-03	0.711E-11	0.321E-05
1021	0.135E+09	-0.477E-01	-0.225E-03	-0.385E+02	0.238E+04	0.111E-01	0.318E-07	0.143E-01
1017	0.473E+04	0.106E+01	0.177E+00	0.261E+03	0.352E+06	0.752E-01	0.132E-03	0.595E+02
1018	0.253E+05	0.551E+01	0.177E+00	0.204E+03	0.311E+06	0.588E-01	0.706E-03	0.319E+03
1019	0.573E+04	0.128E+01	0.177E+00	0.263E+03	0.352E+06	0.759E-01	0.161E-03	0.728E+02

1020	0.243E+07	0.531E+03	0.177E+00	0.201E+04	0.971E+06	0.580E+00	0.688E-01	0.310E+05
1022	0.124E+06	0.271E+02	0.177E+00	0.107E+04	0.353E+06	0.310E+00	0.143E-01	0.644E+04
1023	0.102E+06	0.222E+02	0.177E+00	0.125E+04	0.349E+06	0.362E+00	0.139E-01	0.627E+04
1024	0.514E+05	0.113E+02	0.177E+00	0.152E+04	0.353E+06	0.438E+00	0.832E-02	0.375E+04
1025	0.741E+05	0.162E+02	0.177E+00	0.884E+03	0.256E+06	0.255E+00	0.132E-01	0.597E+04
1026	0.668E+05	0.146E+02	0.177E+00	0.197E+04	0.353E+06	0.569E+00	0.140E-01	0.632E+04
1027	0.127E+06	0.278E+02	0.177E+00	0.234E+04	0.353E+06	0.677E+00	0.318E-01	0.143E+05
1028	0.000E+00	0.000E+00	0.177E+00	0.114E+03	0.623E+05	0.330E-01	0.000E+00	0.000E+00
1029	0.200E+02	0.434E-02	0.177E+00	0.214E+02	0.270E+05	0.618E-02	0.777E-05	0.350E+01
1030	0.000E+00	0.000E+00	0.636E+02	0.463E-01	0.128E+05	0.999E-04	0.000E+00	0.000E+00
1031	0.976E+00	0.271E+02	0.633E+02	0.129E+02	0.213E+06	0.278E-01	0.121E-01	0.498E+04
1032	0.000E+00	-0.103E+04	0.633E+02	0.129E+02	0.215E+06	0.278E-01	0.000E+00	0.000E+00
1033	0.146E+02	0.407E+03	0.633E+02	0.127E+02	0.154E+06	0.274E-01	0.179E+00	0.737E+05
1035	0.188E+05	0.000E+00	-0.331E-04	-0.763E-02	0.268E+02	0.220E-05	0.321E-14	0.145E-08
1036	0.471E+04	0.000E+00	-0.331E-04	-0.159E-01	0.386E+02	0.459E-05	0.806E-15	0.363E-09
1037	0.318E+05	0.000E+00	0.413E-04	0.265E-01	0.556E+02	0.764E-05	0.106E-13	0.477E-08
1041	0.198E+05	0.000E+00	-0.744E-04	-0.477E-01	0.100E+03	0.138E-04	0.384E-13	0.173E-07
1038	0.356E+05	0.000E+00	0.566E-04	0.363E-01	0.762E+02	0.105E-04	0.304E-13	0.137E-07
1039	0.190E+14	0.681E+03	0.718E-04	0.220E+04	0.211E+05	0.634E+00	0.332E-04	0.150E+02
1040	0.464E+06	0.203E-04	0.740E-04	0.498E+00	0.100E+03	0.144E-03	0.930E-11	0.420E-05
1046	0.639E+08	0.258E-02	0.763E-04	0.139E+02	0.537E+03	0.400E-02	0.140E-08	0.633E-03
1042	0.144E+06	-0.109E-03	-0.356E-04	-0.228E-01	0.480E+02	0.659E-05	0.307E-13	0.138E-07
1043	0.100E+17	0.681E+03	0.313E-05	0.151E-02	0.366E+01	0.435E-06	0.145E-05	0.654E+00
1044	0.571E+07	0.000E+00	0.501E-05	0.337E-01	0.679E+01	0.972E-05	0.355E-13	0.160E-07
1045	0.193E+07	0.678E-05	0.689E-05	0.217E+00	0.202E+02	0.627E-04	0.311E-13	0.140E-07
1047	0.190E+06	0.678E-05	0.832E-04	0.559E+00	0.113E+03	0.161E-03	0.541E-11	0.244E-05
1048	0.392E+05	0.000E+00	0.832E-04	0.483E+00	0.105E+03	0.139E-03	0.112E-11	0.503E-06
1049	0.292E+06	0.136E-04	0.848E-04	0.570E+00	0.115E+03	0.165E-03	0.881E-11	0.398E-05
1050	0.324E+05	0.678E-05	0.864E-04	0.353E+00	0.913E+02	0.102E-03	0.103E-11	0.466E-06
1051	0.450E+06	0.203E-04	0.891E-04	0.599E+00	0.121E+03	0.173E-03	0.157E-10	0.708E-05
1052	0.627E+05	0.678E-05	0.917E-04	0.616E+00	0.124E+03	0.178E-03	0.239E-11	0.108E-05
1053	0.000E+00	0.000E+00	0.917E-04	0.417E-01	0.323E+02	0.120E-04	0.000E+00	0.000E+00
1054	0.140E+02	0.000E+00	0.917E-04	0.781E-02	0.140E+02	0.225E-05	0.535E-15	0.241E-09
1055	0.000E+00	0.000E+00	0.139E+03	0.694E-01	0.209E+06	0.106E-03	0.000E+00	0.000E+00
1056	0.239E+00	0.322E+02	0.139E+03	0.196E+02	0.352E+07	0.299E-01	0.725E-01	0.901E+04
1057	0.000E+00	-0.875E+03	0.139E+03	0.196E+02	0.353E+07	0.299E-01	0.000E+00	0.000E+00
1058	0.199E+01	0.267E+03	0.139E+03	0.194E+02	0.329E+07	0.299E-01	0.595E+00	0.739E+05
1060	0.107E+03	0.117E+00	0.398E+00	0.918E+02	0.322E+06	0.265E-01	0.317E-04	0.143E+02
1061	0.470E+04	0.518E+01	0.399E+00	0.192E+03	0.465E+06	0.553E-01	0.140E-02	0.631E+03
1062	0.716E+04	0.790E+01	0.399E+00	0.924E+02	0.322E+06	0.267E-01	0.215E-02	0.969E+03
1063	0.851E+05	0.938E+02	0.399E+00	0.562E+03	0.790E+06	0.162E+00	0.258E-01	0.116E+05

1064 0.279E+05 0.307E+02 0.399E+00 0.642E+03 0.791E+06 0.185E+00 0.964E-02 0.435E+04

NUMBER OF PRESSURIZATION SYSTEMS = 2
NODUL NODPRP QULPRP QULWAL QCOND TNKTM VOLPROP VOLULG
29 31 0.1675 1.0503 0.0033 530.1813 208.6691 91.3427
54 56 3.1132 25.8916 0.0299 168.6995 359.1160 140.8844

SOLUTION SATISFIED CONVERGENCE CRITERION OF 0.100E-02 IN 6 ITERATIONS
TAU = 59.7696 ISTEP = 820

SOLUTION SATISFIED CONVERGENCE CRITERION OF 0.100E-02 IN 13 ITERATIONS
TAU = 59.8696 ISTEP = 821

SOLUTION SATISFIED CONVERGENCE CRITERION OF 0.100E-02 IN 6 ITERATIONS
TAU = 59.9696 ISTEP = 822

SOLUTION SATISFIED CONVERGENCE CRITERION OF 0.100E-02 IN 6 ITERATIONS
TAU = 60.0696 ISTEP = 823

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APPENDIX – R

INTERACTIVE SESSION WITH GFSSP PREPROCESSOR

```
> cd d:\alok\gfssp\vers3.0  
> prep3
```

d:\alok\gfssp\vers3.0>prep3

Interactive Preprocessor for
G F S S P (Version 3.0)
Generalized Fluid System Simulation Program
November, 1999
Developed by Sverdrup Technology
Copyright (C) by Marshall Space Flight Center

A generalized computer program to calculate flow rates, pressures, temperatures and concentrations in a flow network.

ENTER PROBLEM TITLE (80 CHARACTERS)

PUMP-SYSTEM CHARACTERISTICS

INPUT LOGICAL OPTIONS, PLEASE ANSWER YES(Y) OR NO(N)

DO YOU WISH TO SETUP YOUR MODEL IN THE USER SUBROUTINE USRSET? NO

IS DENSITY CONSTANT IN THE CIRCUIT? n

IS FLOW TRANSIENT? **NO**

DO YOU WANT TO ACTIVATE GRAVITY? N

DO YOU WANT TO ACTIVATE BUOYANCY? n

DO YOU WANT TO ACTIVATE INERTIA? n

DO YOU WANT TO ACTIVATE ROTATION? :

IS THERE ANY MOMENTUM SOURCE? N

IS AXIAL THRUST CALCULATION REQUIRED IN THE CIRCUIT? n

IS THERE ANY MOVING BOUNDARY? N

DO YOU WANT SECOND LAW FORMULATION? **y**es

ARE THERE ANY HEAT SOURCES? **n**

DO YOU WANT TO ACTIVATE HEAT CONDUCTION? **N**

IS THERE ANY HEAT EXCHANGER IN THE CIRCUIT? **N**

IS THERE ANY TURBO-PUMP ASSEMBLY IN THE CIRCUIT? **n**

IS THE FLUID A MIXTURE? **n**

WHICH THERMODYNAMIC PACKAGE TO BE USED ?

1- GASP ; 2- ADDPROP

SELECT YOUR OPTION

1

GFSSP HAS A LIBRARY OF THE FOLLOWING FLUIDS:

1	-	HELIUM
2	-	METHANE
3	-	NEON
4	-	NITROGEN
5	-	CARBON-MONOXIDE
6	-	OXYGEN
7	-	ARGON
8	-	CARBON-DIOXIDE
9	-	FLUORINE
10	-	HYDROGEN
11	-	WATER
12	-	RP1

NOTE: RP1 PROPERTY RANGE HAS LIMITED VALIDITY;
PRESSURE RANGE: .01 TO 1400 PSI
TEMPERATURE RANGE: 400 TO 800 R

ENTER INDEX NUMBER OF FLUID **1**

11

DO YOU WANT TO ACTIVATE TRANSVERSE MOMENTUM? **n**

DO YOU WANT TO ACTIVATE SHEAR? **n**

DO YOU WANT TO USE SUCCESSIVE SUBSTITUTION METHOD FOR INITIAL GUESS? **n**

DO YOU WANT PRINT OUT OF INITIAL FIELD VALUES? **n**

DO YOU WANT TO SUPRESS PRINT OUT OF INPUT DATA? **y**

DO YOU WANT EXTENDED PRINT OUT? **n**

** PROVIDE NODE INFORMATION **

ENTER TOTAL NUMBER OF NODES

4

ENTER NUMBER ASSIGNED TO NODE **1**

1
IS IT AN INTERNAL NODE?
n

ENTER NUMBER ASSIGNED TO NODE 2
2

IS IT AN INTERNAL NODE?
y

ENTER NUMBER ASSIGNED TO NODE 3
3

IS IT AN INTERNAL NODE?
y

ENTER NUMBER ASSIGNED TO NODE 4
4

IS IT AN INTERNAL NODE?
n

** PROVIDE BRANCH INFORMATION **

HOW MANY BRANCHES ARE CONNECTED WITH NODE 2?
2

ENTER BRANCH NUMBER(J = 1 OF 2) OF NODE 2
12

ENTER UPSTREAM NODE OF BRANCH NO. 12
1
ENTER DOWNSTREAM NODE OF BRANCH NO. 12
2

SELECT RESISTANCE OPTION FOR BRANCHES:

OPTION - 1: PIPE FLOW
OPTION - 2: FLOW THROUGH RESTRICTION
OPTION - 3: NON-CIRCULAR DUCT
OPTION - 4: PIPE FLOW WITH ENTRANCE & EXIT LOSS
OPTION - 5: THIN SHARP ORIFICE
OPTION - 6: THICK ORIFICE
OPTION - 7: SQUARE REDUCTION
OPTION - 8: SQUARE EXPANSION
OPTION - 9: ROTATING ANNULAR DUCT
OPTION - 10: ROTATING RADIAL DUCT
OPTION - 11: LABY SEAL
OPTION - 12: FACE SEAL
OPTION - 13: COMMON FITTINGS & VALVES
OPTION - 14: PUMP CHARACTERISTICS
OPTION - 15: PUMP POWER PRESCRIPTION
OPTION - 16: VALVE WITH GIVEN CV
OPTION - 17: VISCOJET RESTRICTION
OPTION - 19: USER SPECIFIED

14

ENTER A, B, AND AREA (IN**2) OF BRANCH 12
30888.00,-0.0081,201.06177

ENTER BRANCH NUMBER(J = 2 OF 2) OF NODE 2
23

ENTER UPSTREAM NODE OF BRANCH NO. 23
2

ENTER DOWNSTREAM NODE OF BRANCH NO. 23
3

SELECT RESISTANCE OPTION FOR BRANCHES:

OPTION - 1: PIPE FLOW
OPTION - 2: FLOW THROUGH RESTRICTION
OPTION - 3: NON-CIRCULAR DUCT
OPTION - 4: PIPE FLOW WITH ENTRANCE & EXIT LOSS
OPTION - 5: THIN SHARP ORIFICE
OPTION - 6: THICK ORIFICE
OPTION - 7: SQUARE REDUCTION
OPTION - 8: SQUARE EXPANSION
OPTION - 9: ROTATING ANNULAR DUCT
OPTION - 10: ROTATING RADIAL DUCT
OPTION - 11: LABY SEAL
OPTION - 12: FACE SEAL
OPTION - 13: COMMON FITTINGS & VALVES
OPTION - 14: PUMP CHARACTERISTICS
OPTION - 15: PUMP POWER PRESCRIPTION
OPTION - 16: VALVE WITH GIVEN CV
OPTION - 17: VISCOJET RESTRICTION
OPTION - 19: USER SPECIFIED

13

ENTER DIA (IN), K1, & K2 OF BRANCH 23
6.00,1000.00,0.100

HOW MANY BRANCHES ARE CONNECTED WITH NODE 3?
2

ENTER BRANCH NUMBER(J = 1 OF 2) OF NODE 3
23

THE INFORMATION ABOUT THIS BRANCH IS AVAILABLE
ENTER BRANCH NUMBER(J = 2 OF 2) OF NODE 3
34

ENTER UPSTREAM NODE OF BRANCH NO. 34
3

ENTER DOWNSTREAM NODE OF BRANCH NO. 34
4

SELECT RESISTANCE OPTION FOR BRANCHES:

OPTION - 1: PIPE FLOW
OPTION - 2: FLOW THROUGH RESTRICTION
OPTION - 3: NON-CIRCULAR DUCT
OPTION - 4: PIPE FLOW WITH ENTRANCE & EXIT LOSS
OPTION - 5: THIN SHARP ORIFICE
OPTION - 6: THICK ORIFICE
OPTION - 7: SQUARE REDUCTION
OPTION - 8: SQUARE EXPANSION

OPTION - 9: ROTATING ANNULAR DUCT
OPTION - 10: ROTATING RADIAL DUCT
OPTION - 11: LABY SEAL
OPTION - 12: FACE SEAL
OPTION - 13: COMMON FITTINGS & VALVES
OPTION - 14: PUMP CHARACTERISTICS
OPTION - 15: PUMP POWER PRESCRIPTION
OPTION - 16: VALVE WITH GIVEN CV
OPTION - 17: VISCOJET RESTRICTION
OPTION - 19: USER SPECIFIED

1
ENTER LENGTH (IN), DIAMETER (IN), & ROUGHNESS FACTOR(E/D) OF BRANCH 34
18000.00,6.00,0.005
ENTER ANGLE WITH GRAVITY VECTOR (90 DEG FOR HORIZONTAL AXIS) FOR BRANCH NO.
34
95.74
** PROVIDE VALUES IN THE BOUNDARY NODES **
ENTER PRESSURE (PSIA) & TEMPERATURE (DEG F) FOR NODE 1
14.70,60
ENTER PRESSURE (PSIA) & TEMPERATURE (DEG F) FOR NODE 4
14.70,60
HOW MANY INTERNAL NODES HAVE SPECIFIED FLOWRATES? **0**
HOW MANY INTERNAL NODES HAVE SPECIFIED HEAT SOURCES? **0**
ENTER FILENAME FOR WRITING THE INPUT DATA **EX1.DAT**
ENTER FILENAME FOR WRITING THE OUTPUT DATA **EX1.OUT**
ENTER ANALYST NAME **ALOK MAJUMDAR**