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A GENERALIZED FLUID SYSTEM SIMULATION PROGRAM TO MODEL FLOW DISTRIBUTION IN FLUID NETWORKS

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FOREWARD

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 impeller shaft 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 Marshall Space Flight Center (MSFC) as 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 an "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.

This document details the GFSSP 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 are described in this chapter. The solution procedure implemented in GFSSP is also 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 is 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).

ACKNOWLEDGMENTS

The author would like to acknowledge several individuals for their contributions to this effort. The author would like to acknowledge Mr. Tom Beasley of Sverdrup Technology for his continuous encouragement and support throughout the period of code development. Mr. Beasley has provided a great deal of useful information on flow resistance that has been incorporated into the code. Ms. Katherine Van Hooser of MSFC has been contributory in testing many versions of the code and has made numerous useful suggestions to make it more user friendly. The author would also like to acknowledge Mr. Bruce Tiller of MSFC for testing early versions of the code and for providing benchmark data for the verification of the code. Mr. John Bailey of Sverdrup Technology has conducted a very systematic investigation to check the accuracy of various resistance options by comparing the code's predictions with existing commercial codes. Mr. Bailey's models have been included in this report as an example. Mr. Bailey also has made a significant contribution in the preparation of this document. Mr. Paul Schallhorn of Sverdrup Technology contributed in the area of code verification. He developed a rotating disk model which has also been included as an example for demonstration purposes. Dr. Bob Hendricks and Ms. Angela Haferd of Lewis Research Center provided all the help necessary to integrate the thermodynamic property programs in the code. The author would also like to acknowledge Mr. Doug Richards of McDonnell Douglas Aerospace for many useful discussions and constructive suggestions. The author would also like to acknowledge the workshop attendees for their participation and many useful suggestions on code development and documentation.

ABSTRACT

This report describes a general purpose computer program for analyzing flow and pressure distribution in a complex network. The program is capable of modeling phase changes, compressibility, mixture thermodynamics and external body forces such as gravity and centrifugal. The program's preprocessor allows the user to interactively develop a fluid network simulation consisting of nodes and branches. Mass, energy and specie conservation equations are solved at the nodes; the momentum conservation equations are solved in the branches.

The program contains subroutines for computing "real fluid" thermodynamic and thermophysical properties for 11 fluids. The fluids are: helium, methane, neon, nitrogen, carbon monoxide, oxygen, argon, carbon dioxide, fluorine, hydrogen, water and kerosine (RP-1). The program also has the option of using any incompressible fluid with constant density and viscosity.

Fifteen different resistance/source options are provided for modeling momentum sources or sinks in the branches. The options are: 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, face seal, common fittings and valves, pump characteristics, pump power and valve with a given loss coefficient.

The system of equations describing the fluid network are solved by a hybrid numerical method that is a combination of the Newton-Raphson and successive substitution methods. This report also illustrates the application of the code through seven demonstrated example problems. The examples are: 1) Series flow circuit with common pipe fittings and a valve, 2) Series flow circuit with common pipe fittings, a valve and a pump, 3) Flow distribution in a parallel flow manifold, 4) Flow distribution in a parallel flow manifold with heat sources and phase changes, 5) Mixing of cryogenic fluids in an inter-propellant seal flow circuit of a turbopump, 6) Quasi-steady calculation of Example 5, and 7) Flow in a rotating disk cavity.

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

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NOMENCLATURE

Symbol	Description
A	Area (in^2)
A_0	Pump Characteristic Curve Coefficient
B_0	Pump Characteristic Curve Coefficient
C_L	Flow Coefficient
c	Clearance (in)
$c_{i,k}$	Mass concentration of k^{th} specie at i^{th} node
c_p	Specific heat (Btu/lb ^{o} 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 lb-ft/lb_f-sec^2)
h	Enthalpy (Btu/lb)
K_f	Flow Resistance Coefficient (/lb_f-sec^2/$(lb\text{-}ft)^2$)
K_{rot}	Non-dimensional Rotating Flow Resistance Coefficient
K_1	Non-Dimensional Head Loss Factor
K_i	Inlet Loss Coefficient
K_e	Exit Loss Coefficient
L	Length (in)
M	Molecular weight
m	pitch (in)
$\dot{m}$	Mass Flow Rate (lb/sec)
N	Revolutions Per Minute (rpm)
n	Number of Teeth
p	Pressure (lb_f/ in^2)
P	Pump Power (hp)
Q	Heat source (Btu/sec)
Re	Reynolds Number ($Re = \rho uD/\mu$)
R	Gas constant (lb_f-ft/lb-R)
r	Radius (in)
S	Momentum Source (lb_f)
T	Temperature (^{o} F)
u	Velocity (ft/sec)
V	Volume (in^3)
x_k	Mole fraction of k^{th} specie
z	Compressibility factor

Symbol	Description

Greek

ρ	Density (lb/ft^3)
θ	Angle Between Branch Flow Velocity Vector And Gravity Vector (deg)
ω	Angular Velocity (rad/sec)
ε	Absolute Roughness (in)
ε/D	Relative Roughness
α	Multiplier for Labyrinth Seal Resistance
η	Efficiency
Δh	Head Loss (ft)
μ	Viscosity (lb/ft-sec)
ν	Kinematic viscosity (ft^2/sec)
$\bar{\rho}$	Molar density ($lb\text{-}mol/ft^3$)
γ	Specific heat ratio

1 INTRODUCTION

1.1 BACKGROUND

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 flow branches with 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. A Generalized Fluid System Simulation Program (GFSSP) has been developed to accurately predict the axial thrust from the predicted pressure distributions in a turbopump assembly. The flow network was resolved into nodes and branches. In each branch the momentum equation was solved and in each node the conservation of mass, energy and species were solved. The solution of these equations provide the pressures at the nodes and flow rates in the branches.

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, GFSSP was developed as a general fluid flow system solver capable of handling phase change, compressibility and mixture thermodynamics and it included the capability to model external body forces such as gravity and centrifugal effects. The program's preprocessor allows the user to interactively develop a fluid network simulation consisting of nodes and branches.

Since GFSSP's initial release in August, 1994, and subsequent releases in December, 1994, February, 1995, and October, 1995, GFSSP has been utilized to model a variety of fluid flow problems. This report documents 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. These examples include: 1) Series flow circuit with common pipe fittings and a valve, 2) Series flow circuit with common pipe fittings, a valve and a pump, 3) Flow distribution in a parallel flow manifold, 4) Flow distribution in a parallel flow manifold with heat sources and phase changes, 5) Mixing of cryogenic fluids in an inter-propellant seal flow circuit of a turbopump, 6) Quasi-steady calculation of Example 5, and 7) Flow in a rotating disk cavity.

1.2 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 solutions generated by hand, but it has also been widely employed for use in computer generated solutions. But as computers allowed much larger networks to be analyzed, it become 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 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 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 aerospace industries 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.

1.3 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 on SSME turbopump used a very simplified form of momentum equation. The momentum equations used in Reference 5 and Reference 6 only considered pressure and friction forces. A more generalized form of momentum equation is necessary to account for rotational effects. The momentum equation used in the current program includes inertia, pressure, friction, gravity, centrifugal and any external momentum sources. The frictional effects 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 two thermodynamic property programs, GASP and WASP [13,14]. 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, water. 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 has an option of modeling any incompressible fluid of constant density and viscosity.

The task of the computational model is to obtain a simultaneous solution of the governing equations. This system of equations is solved by a novel numerical procedure which is a combination of Newton-Raphson and successive substitution methods. This algorithm has been incorporated into GFSSP. GFSSP also includes a preprocessor. With the help of the 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 code development was carried out in several stages. At the end of each stage, a workshop was held where the latest version of the code was released 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 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 new generation 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. A good agreement was obtained [17] between test data and GFSSP predictions.

The capability to include external body forces, such as a pump, as a momentum source was added into the current version of GFSSP (Version 1.4) of the program. This version also provides the user with the capability to model rotational flow in turbo-machine. Another major feature of GFSSP Version 1.4 is its enhanced capability to model different types of resistance in a flow network. Fifteen different resistance/source options are 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, face seal, common fittings and valves, pump characteristics, pump power and valve with a given loss coefficient. The additional features of the code was verified by comparing GFSSP predictions with two other commercial codes[3,4]. The GFSSP predictions compared [18] favorably with the other two codes. This report documents Version 1.4 of the code.

2.0 MATHEMATICAL FORMULATION

2.1 PROBLEM DEFINITION

GFSSP assumes a newtonian, steady, non-reacting and one dimensional flow in the flow circuit. The flow could 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. At each node, scalar properties such as pressures, temperatures, enthalpies, and mixture concentrations are computed. The flow rates (vector properties) are computed at the branches. Nodes are either boundary nodes or internal nodes. Pressures, temperatures, and concentrations of fluid species are specified at the boundary nodes. 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 is a portion of the propellant flow circuit, where a helium buffer is used to prevent the mixing of hydrogen and oxygen leakage flow, in Pratt & Whitney's High Pressure Oxygen Turbopump Secondary Flow Circuit.

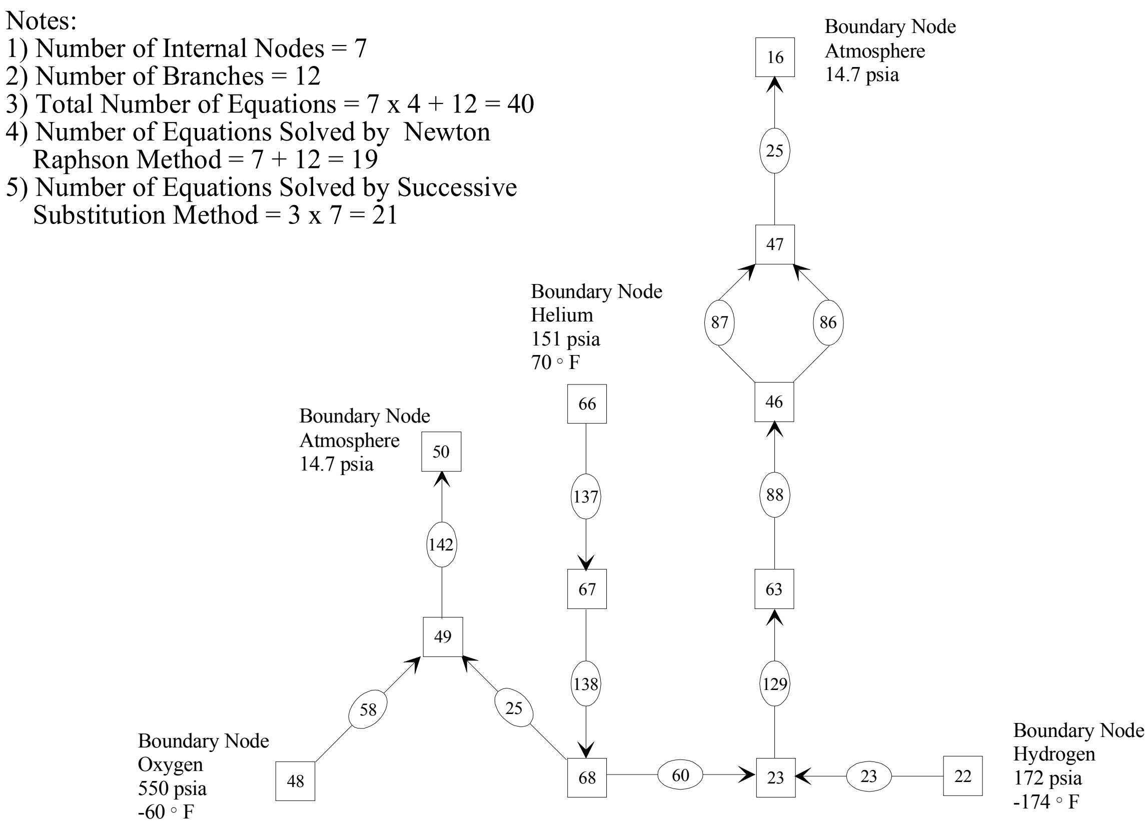


Figure 2.1 - onter-propellant Ssal Ffow cCicuit in a tTubopump.

In Figure 2.1 the nodes are represented by square boxes and branches are represented by elliptical boxes. The nodes and branches 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, 66, and 22 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 internal nodes and flow rates in all branches.

2.2 GOVERNING EQUATIONS

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. The schematic of the nodes and branches and the indexing system used by GFSSP is shown in Figure 2.2.

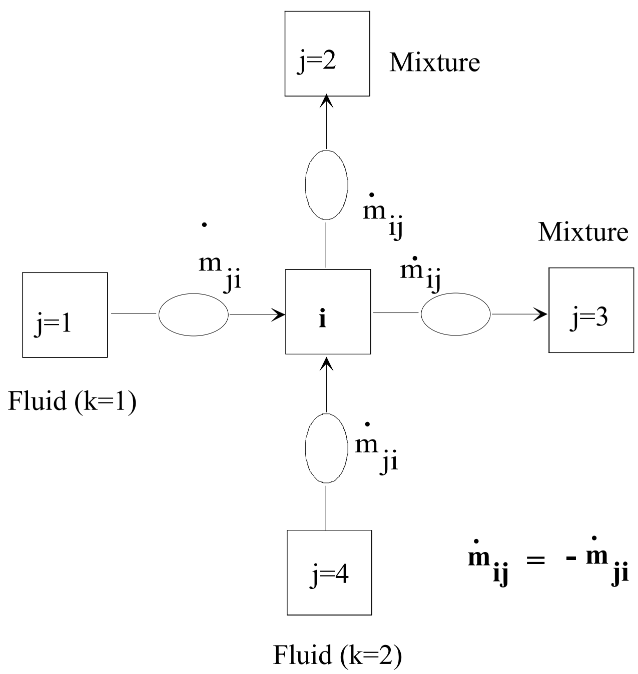


Figure 2.2 - Schematic of GFSSP Nodes and Branches and Indexing Practice

2.2.1 Mass Conservation Equation

$$\sum_{j=1}^{j=n} \dot{m}_{ij} = 0 \qquad \text{(Equation 2.1)}$$

Equation 2.1 requires that the net mass flow from a given node must equate to zero. In other words, the total mass flow rate into a node is equal to the total mass flow rate out of the node.

2.2.2 Momentum Conservation Equation

The flow rate in a branch is calculated from the momentum conservation equation (Equation 2.2) which represents the balance of fluid forces acting on a given branch. 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.

$$\frac{\dot{m}_{ij}}{g_c}\left(u_i - u_u\right) = \left(p_i - p_j\right)A + \frac{\rho g V \cos\theta}{g_c} - K_f \dot{m}_{ij}\left|\dot{m}_{ij}\right| A + \frac{\rho\, K_{\mathrm{rot}}^2 \omega^2 A}{2\, g_c}\left(r_j^2 - r_i^2\right) + S \qquad \text{(Eq.2.2)}$$

Inertia Pressure Gravity Friction Centrifugal Source

The term in the left hand side of the momentum equation represents the inertia of the fluid. This term is significant when there is a large change in area or density from branch to branch. The first term in the right hand side of the momentum equation represents the pressure gradient in the branch. The pressures are located at the upstream and downstream face of a branch. The second term represents the effect of gravity. The gravity vector makes an angle (θ) with the flow direction vector. The third 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 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. The fourth 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 2.3. K_{rot} is the factor representing the fluid rotation. K_{rot} is unity when the fluid and the surrounding solid surface rotates with the same speed. This term also requires a knowledge of the distances between the upstream and downstream faces of the branch from the axis of rotation. A detailed description of source term, S, appears in Sections 2.2.7.14 and 2.2.7.15 of this report.

2.2.3 Energy Conservation Equation

$$\sum_{j=1}^{j=n} \left\{ MAX\left[-\dot{m}_{ij},0\right]h_j - MAX\left[\dot{m}_{ij},0\right]h_i \right\} + Q_i = 0 \qquad \text{(Equation 2.3)}$$

The energy conservation equation, Equation 2.3, 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. The MAX operator used in Equation 2.3 is known as an upwind differencing scheme which has been extensively employed in the numerical solution of Navier-Stokes equations in convective heat transfer and fluid flow [19] applications. 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.

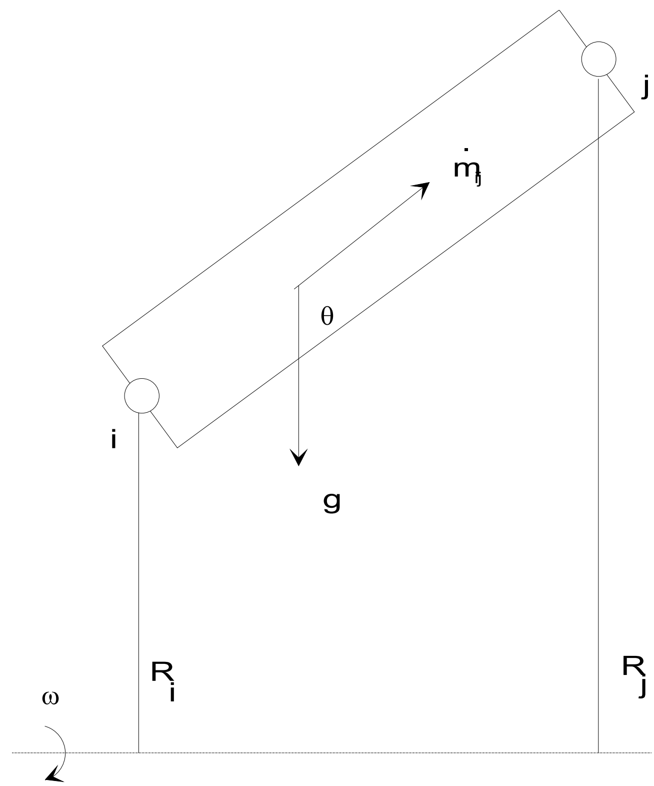


Figure 2.3 - Schematic of a Branch Showing the Gravity and Rotation

2.2.4 Fluid

Specie Conservation Equation

The flow network shown in Figure 2.1 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. Suppose there are n number of fluids in the mixture. The concentration for the k^{th} specie can be written as

$$\sum_{j=1}^{j=n} \left\{ MAX\left[-\dot{m}_{ij},0\right] c_{j,k} - MAX\left[\dot{m}_{ij},0\right] c_{i,k} \right\} = 0 \qquad \text{(Equation 2.4)}$$

Equation 2.4 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.

2.2.5 Thermodynamic and Thermophysical Properties

The momentum conservation equation, Equation 2.2, requires the knowledge of the density and viscosity of the fluid within the branch. These properties are functions of the temperatures, pressures and concentrations of fluid species for a mixture. Two thermodynamic property routines have been integrated with the program to provide the required property data. GASP [6] provides the thermodynamic and transport properties for ten fluids. These fluids are Hydrogen, Oxygen, Helium, Nitrogen, Methane, Carbon Dioxide, Carbon Monoxide, Argon, Neon and Fluorine. WASP [7] provides the thermodynamic and transport properties for water and steam. 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 determine the required properties from the table.

2.2.6 Mixture Property Calculations

In this section, the procedure of estimating the density and temperature of mixtures of real fluids is described. The density of individual components of the mixture is calculated from GASP, WASP or the RP-1 property table using the pressures and the enthalpies of the fluid. Let us assume that n number of fluids are mixing in the i^{th} node. At node i, pressure, p_i, and enthalpy, h_i, 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.

GFSSP calculates the mixture property using the following steps:

1. Calculate T_k and ρ_k from p_i and h_i using the thermodynamic property routines of the program.

2. Calculate the compressibility of each component of the mixture, z_j, from the equation of state for a real gas.

$$z_k = \frac{p_i}{\rho_k R_k T_k} \qquad \text{(Equation 2.5)}$$

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

3. Calculate T_i by taking a molar average of component temperatures, T_j, obtained in Step 1.

$$T_i = \sum_{k=1}^{k=n} c_{p,k} x_k T_k \Big/ \sum_{k=1}^{k=n} c_{p,k} x_k \qquad \text{(Equation 2.6)}$$

Where c_{pj} is the molar specific heat and x_j is the mole-fraction of j^{th} specie.

4. Calculate compressibility of mixture, Z_i by taking molar average of component compressibility obtained in Step 2.

$$z_i = \sum_{k=1}^{k=n} x_k z_k \qquad \text{(Equation 2.7)}$$

Equation 2.7 is derived from Amagat's law of partial volume [10].

5. Calculate the molar density of the mixture, $\overline{\rho}_i$, from the equation of state.

$$\overline{\rho}_i = \frac{p_i}{z_i \overline{\overline{R}}\ T} \qquad \text{(Equation 2.8)}$$

Where $\overline{\overline{R}}$ is the Universal Gas Constant.

6. Calculate the mixture molecular weight, M_i, by taking the molar average of the component molecular weights, M_k

.

$$M_i = \sum_{k=1}^{k=n} x_k M_k \qquad \text{(Equation 2.9)}$$

7. Calculate the mass density, ρ_i, from the the molar density and the molecular weight that was obtained from Step 5 and Step 6 respectively.

$$\rho_i = \overline{\rho}_i M_i \qquad \text{(Equation 2.10)}$$

8. Calculate the viscosity and the specific heat ratio of the mixture by taking the molar average of the component properties, μ_k and γ_k.

$$\mu_i = \sum_{k=1}^{k=n} x_k \mu_k \qquad \text{(Equation 2.11)}$$

$$\gamma_i = \sum_{k=1}^{k=n} x_k \gamma_k \qquad \text{(Equation 2.12)}$$

2.2.7 Friction Calculation

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 1.

Option	Type of Resistance	Input Parameters	Option	Type of Resistance	Input Parameters
1	Pipe flow	L (in), D (in), ε/D	9	Rotating annular duct	L (in), r_o (in), r_i (in), N (rpm)
2	Fflow though restriction	C_L, A (in^2)	10	Rotating radial duct	L (in), D (in), N (rpm)
3	Non-circular duct	INACTIVE	11	Labyrinth seal	r_i (in), c (in), m (in), n, α
4	Pipe with entrance and exit loss	L (in), D (in), ε/D, K_i, K_e	12	Face seal	r_i (in), c (in), L (in)
5	Thin, sharp orifice	D_1 (in), D_2 (in)	13	Common fittings and valves (two K method)	D (in), K_1, K_2
6	Thick orifice	L (in), D_1 (in), D_2 (in)	14	Pump characteristics[1]	A_0, B_0, A (in^2)
7	Square Reduction	D_1 (in), D_2 (in)	15	Pump power	P (hp), η, A (in^2)
8	Square Expansion	D_1 (in), D_2 (in)	16	Valve with given C_v	C_v , A

Table 2.1 - Resistance Options in GFSSP

[1] Pump characteristics are expressed as $\Delta p = A_0 + B_0 \dot{m}^2$

Δp - Pressure rise, lbf/ft^2

$\dot{m}$ - Flow rate, lbm/sec

2.2.7.1 Branch

Option 1 (Pipe Flow)

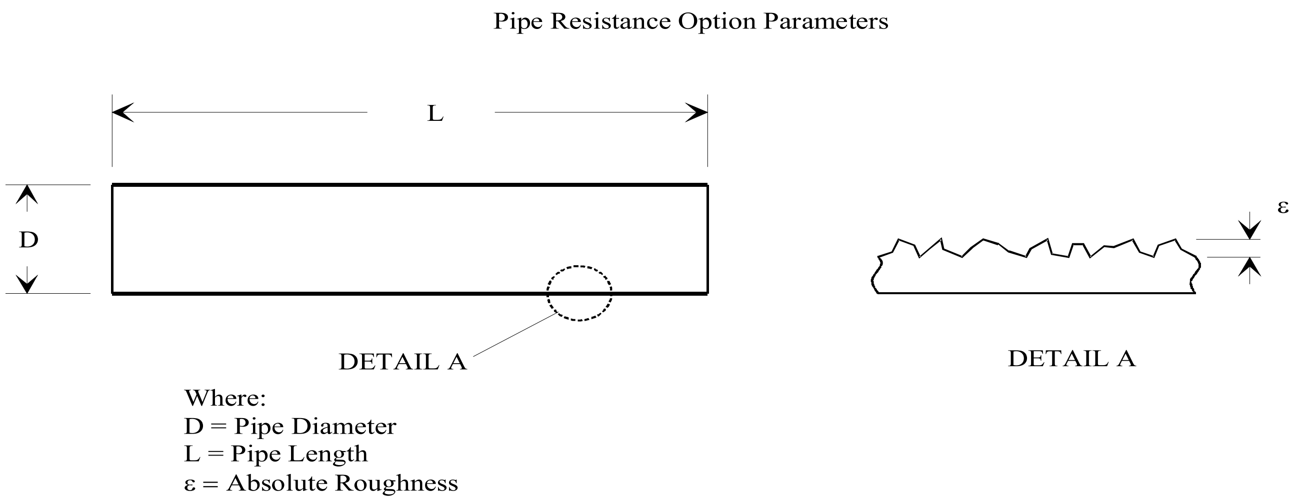


Figure 2.4 - Pipe Resistance Option Parameters

Figure 2.4 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 (Appendix - A) as:

$$K_f = \frac{8fL}{\rho_u \pi^2 D^5 g_c} \qquad \text{(Equation 2.13)}$$

Where ρ_u is the density of the fluid at the upstream node of a given branch.

The Darcy friction factor f is determined from Colebrook Equation [10] which is expressed as:

$$\frac{1}{\sqrt{f}} = -2\log\left[\frac{\varepsilon}{3.7D} + \frac{2.51}{\mathrm{Re}\sqrt{f}}\right] \qquad \text{(Equation 2.14)}$$

Where ε/D and Re are the surface roughness factor and Reynolds number respectively. It should be noted that

2.2.7.2 Branch

Option 2 (Flow Through 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:

$$K_f = \frac{1}{2 g_c \rho_u C_L^2 A^2} \qquad \text{(Equation 2.15)}$$

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

$$\Delta h = K \frac{u^2}{2g} \qquad \text{(Equation 2.16)}$$

K and C_L are related as:

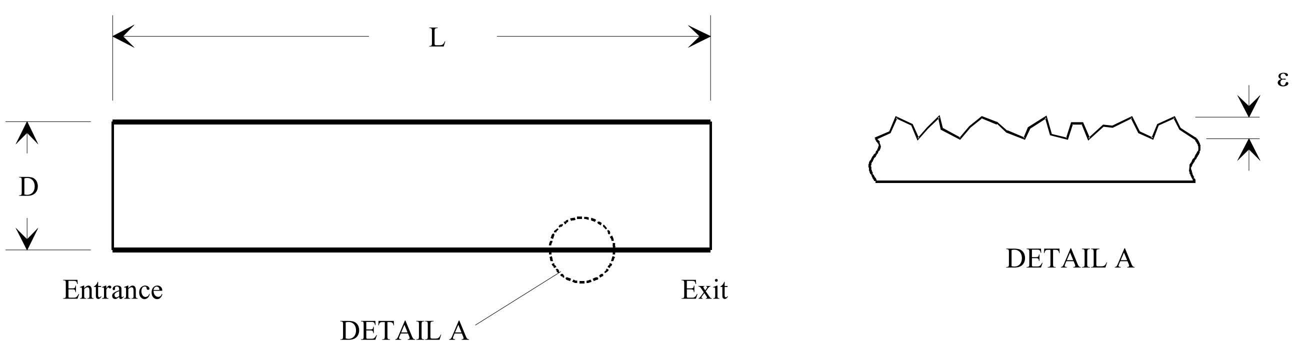
$$C_L = \frac{1}{\sqrt{K}} \qquad \text{(Equation 2.17)}$$

2.2.7.3 Branch
Option 3 (Non-circular Duct)

This option is currently inactive. Under this option frictional effects in non-circular ducts will be modeled.

2.2.7.4 Branch Option 4 (Pipe with Entrance and Exit Lloss)

Pipe With Entrance and/or Exit Loss



Where:
D = Pipe Diameter
L = Pipe Length
ε = Absolute Roughness
K_i = Entrance Loss Coefficient
K_e = Exit Loss Coefficient

Figure 2.5 - Pipe With Entrance and/or Exit Loss Resistance Option Parameters

Figure 2.5 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 friction loss in a pipe, entrance and exit losses are also calculated. For this option, K_f can be expressed as:

$$K_f = \frac{8 K_i}{\rho_u \pi^2 D^4 g_c} + \frac{8 fL}{\rho_u \pi^2 D^5 g_c} + \frac{8 K_e}{\rho_u \pi^2 D^4 g_c} \qquad \text{(Equation 2.18)}$$

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

2.2.7.5 Branch Option 5 (Thin Sharp Orifice)

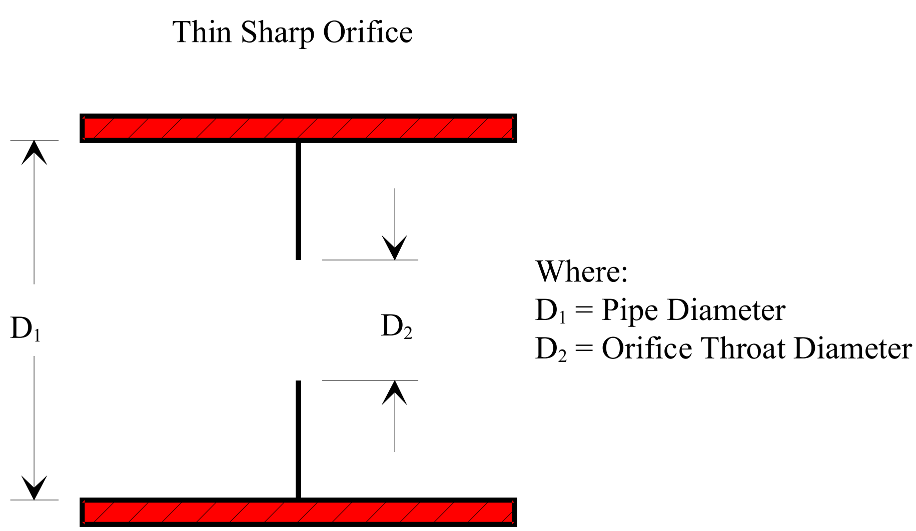


Figure 2.6 - Thin Sharp Orifice Resistance Option Parameters

Figure 2.6 shows the thin sharp orifice resistance option parameters that are required by GFSSP. This option considers the branch as a thin sharp orifice with pipe diameter as D_1 and orifice diameter as D_2. For this option, K_f can be expressed [11] as:

$$K_f = \frac{K_1}{2 g_c \rho_u A^2} \qquad \text{(Equation 2.19)}$$

Where, for upstream Re ≤ 2500:

$$K_1 = \left[2.72 + \left(\frac{D_2}{D_1}\right)^2 \left(\frac{120}{\text{Re}} - 1\right)\right]\left[1 - \left(\frac{D_2}{D_1}\right)^2\right]\left[\left(\frac{D_1}{D_2}\right)^4 - 1\right] \qquad \text{(Equation 2.20)}$$

For upstream Re > 2500:

$$K_1 = \left[2.72 - \left(\frac{D_2}{D_1}\right)^2 \left(\frac{4000}{\text{Re}}\right)\right]\left[1 - \left(\frac{D_2}{D_1}\right)^2\right]\left[\left(\frac{D_1}{D_2}\right)^4 - 1\right] \qquad \text{(Equation 2.21)}$$

2.2.7.6 <u>Branch Option 6 (Thick Oorifice)</u>

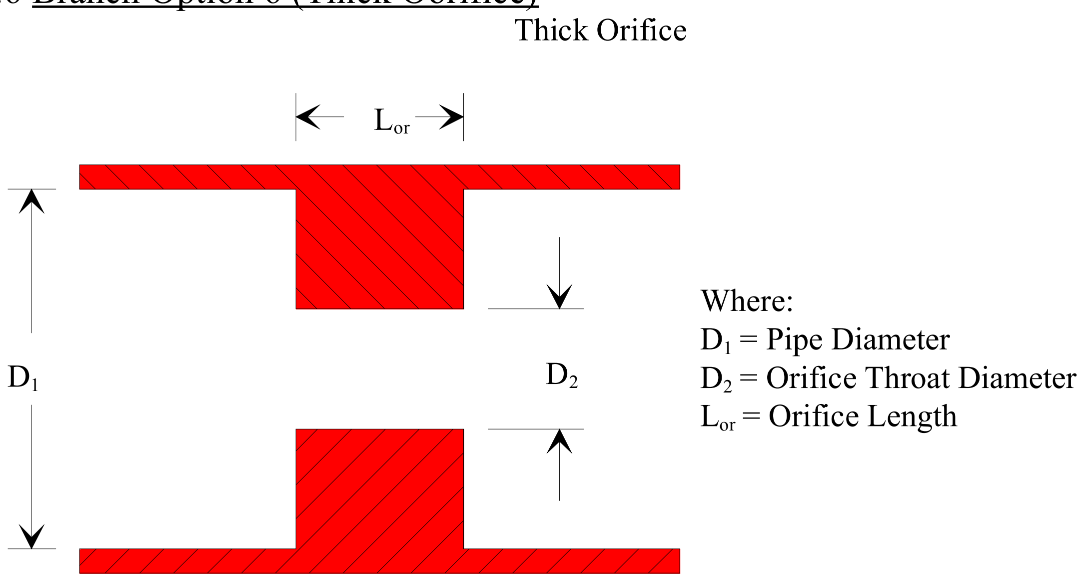


Figure 2.7 - Thick Orifice Resistance Option Parameters

Figure 2.7 shows the thick orifice resistance option parameters that are required by GFSSP. This option models the branch as a thick orifice with the pipe diameter as D_1 orifice diameter as D_2 and length of the orifice as L_{or}. For this option, K_f can be expressed as in Equation 2.19. However, the K_1 in Equation 2.19 is calculated [11] from the following expressions.

For upstream Re $\leq$ 2500:

$$K_1 = \left[2.72 + \left(\frac{D_2}{D_1}\right)^2 \left(\frac{120}{\text{Re}} - 1\right)\right]\left[1 - \left(\frac{D_2}{D_1}\right)^2\right]\left[\left(\frac{D_1}{D_2}\right)^4 - 1\right]\left[0.584 + \frac{0.0936}{\left(L_{or}/D_2\right)^{1.5} + 0.225}\right] \qquad \text{(Eq. 2.22)}$$

For upstream Re > 2500:

$$K_1 = \left[2.72 - \left(\frac{D_2}{D_1}\right)^2 \left(\frac{4000}{\text{Re}}\right)\right]\left[1 - \left(\frac{D_2}{D_1}\right)^2\right]\left[\left(\frac{D_1}{D_2}\right)^4 - 1\right]\left[0.584 + \frac{0.0936}{\left(L_{or}/D_2\right)^{1.5} + 0.225}\right] \quad \text{(Eq. 2.23)}$$

2.2.7.7 Branch

Option 7 (Square Reduction)

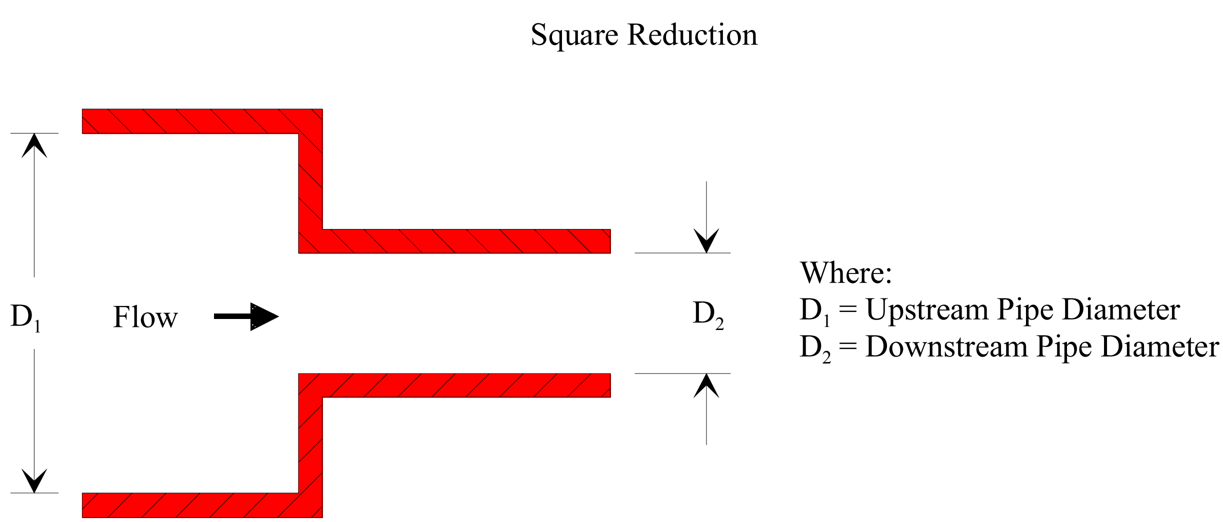


Figure 2.8 - GFSSP Square Reduction Resistance Option Parameters

Figure 2.8 shows the square reduction resistance option parameters that are required by GFSSP. This option considers the branch as a square reduction. The diameters of upstream and downstream pipes are D_1 and D_2 respectively. For this option, K_f can be expressed as in Equation 2.19. However, the K_1 in Equation 2.19 is calculated from the following expressions [11]. 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 ≤ 2500:

$$K_1 = \left[1.2 + \frac{160}{\text{Re}}\right]\left[\left(\frac{D_1}{D_2}\right)^4 - 1\right] \quad \text{(Equation 2.24)}$$

For upstream Re > 2500:

$$K_1 = \left[0.6 + 0.48 f\right]\left(\frac{D_1}{D_2}\right)^2 \left[\left(\frac{D_1}{D_2}\right)^2 - 1\right]^2 \qquad \text{(Equation 2.25)}$$

2.2.7.8 Branch

Option 8 (Square Expansion)

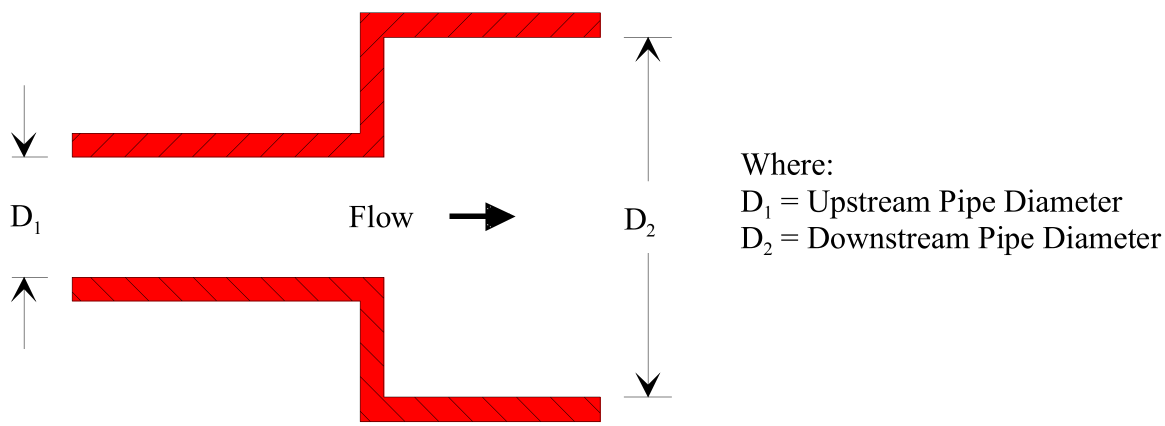


Figure 2.9 - Square Expansion Resistance Option Parameters

Figure 2.9 shows the square expansion resistance option parameters that are required by GFSSP. This option considers the branch as a square expansion. The diameters of upstream and downstream pipes are D_1 and D_2 respectively. For this option, K_f can be expressed as in Equation 2.19. However, the K_1 in Equation 2.19 is calculated from the following expressions [11]. 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.*

For upstream Re $\leq$ 4000:

$$K_1 = 2\left[1 - \left(\frac{D_1}{D_2}\right)^4\right] \qquad \text{(Equation 2.26)}$$

For upstream Re > 4000:

$$K_1 = \left[1 + 0.8f\right]\left[1 - \left(\frac{D_1}{D_2}\right)^2\right]^2 \qquad \text{(Equation 2.27)}$$

2.2.7.9 Branch

Option 9 (Rotating Annular Duct)

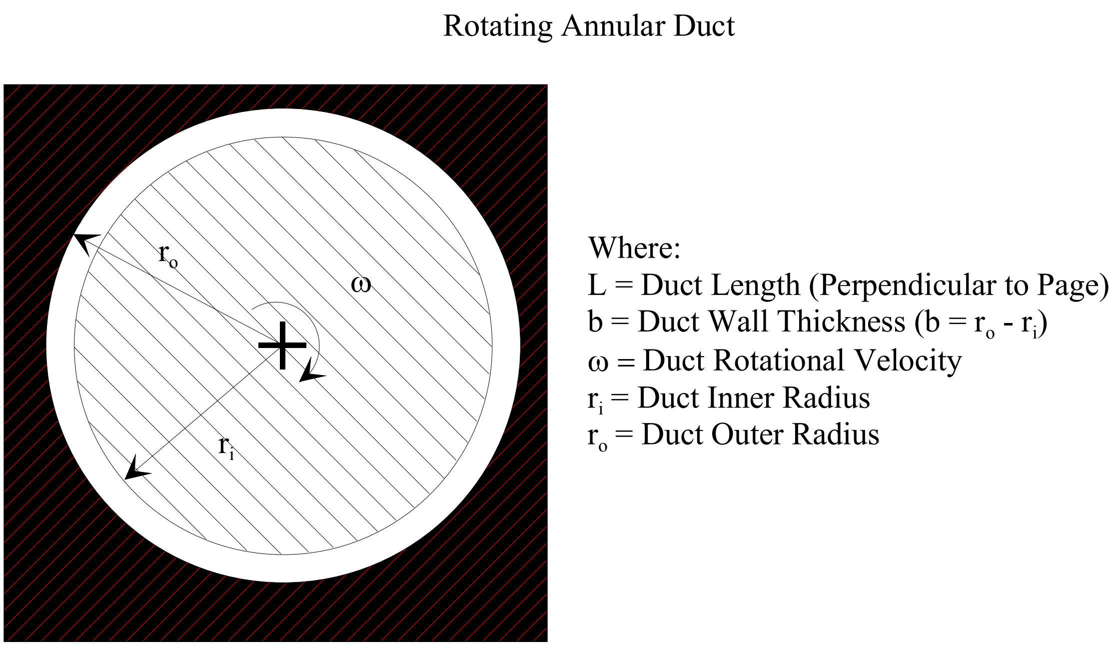


Figure 2.10 - Rotating Annular Duct Resistance Option Parameters

Figure 2.10 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_0, and r_i respectively. The inner surface is rotating at N rpm (N=30ω/π). For this option, K_f can be expressed as:

$$K_f = \frac{fL}{\rho_u \pi^2 A^2 g_c \left(r_0 - r_i\right)} \qquad \text{(Equation 2.28)}$$

The friction factor, f, in equation 2.28 was calculated from the following expressions [12]:

$$f_{0T} = 0.077\left(Ru\right)^{-0.24} \qquad \text{(Equation 2.29)}$$

Where:

$$Ru = \frac{\rho_u u\, 2\left(r_0 - r_i\right)}{\mu} \qquad \text{(Equation 2.30)}$$

And u is the tean axial velocity, therefore:

$$\frac{f}{f_{0T}} = \left[1 + 0.7656\left(\frac{\omega r_i}{2u}\right)^2\right]^{0.38} \qquad \text{(Equation 2.31)}$$

2.2.7.10 Branch

Option 10 (Rotating Radial Duct)

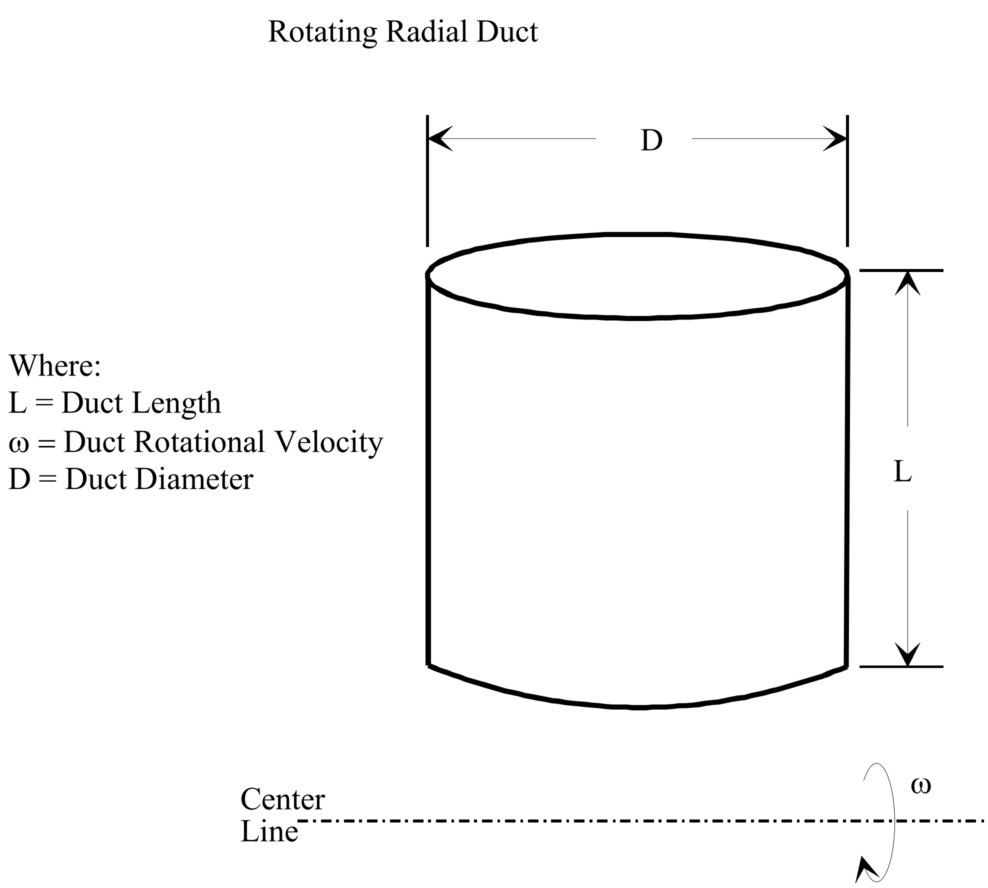


Figure 2.11 - Rotating Radial Duct Resistance Option Parameters

Figure 2.11 shows the rotating radial duct resistance option parameters that are required by GFSSP. This option considers the branch as a rotating radial duct. 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:

$$K_f = \frac{8fL}{\rho_u \pi^2 D^5 g_c} \qquad \text{(Equation 2.32)}$$

The friction factor, *f*, in equation 2.28 was calculated from the following expressions [13]:

$$f_{0T} = 0.0791(Ru)^{-0.25} \qquad \text{(Equation 2.33)}$$

$$\frac{f}{f_{0T}} = 0.942 + 0.058\left[\left(\frac{\omega D}{u}\right)\left(\frac{\omega D^2}{\nu}\right)\right]^{0.282} \qquad \text{(Equation 2.34)}$$

2.2.7.11 Branch Option 11 (Labyrinth Sseal)

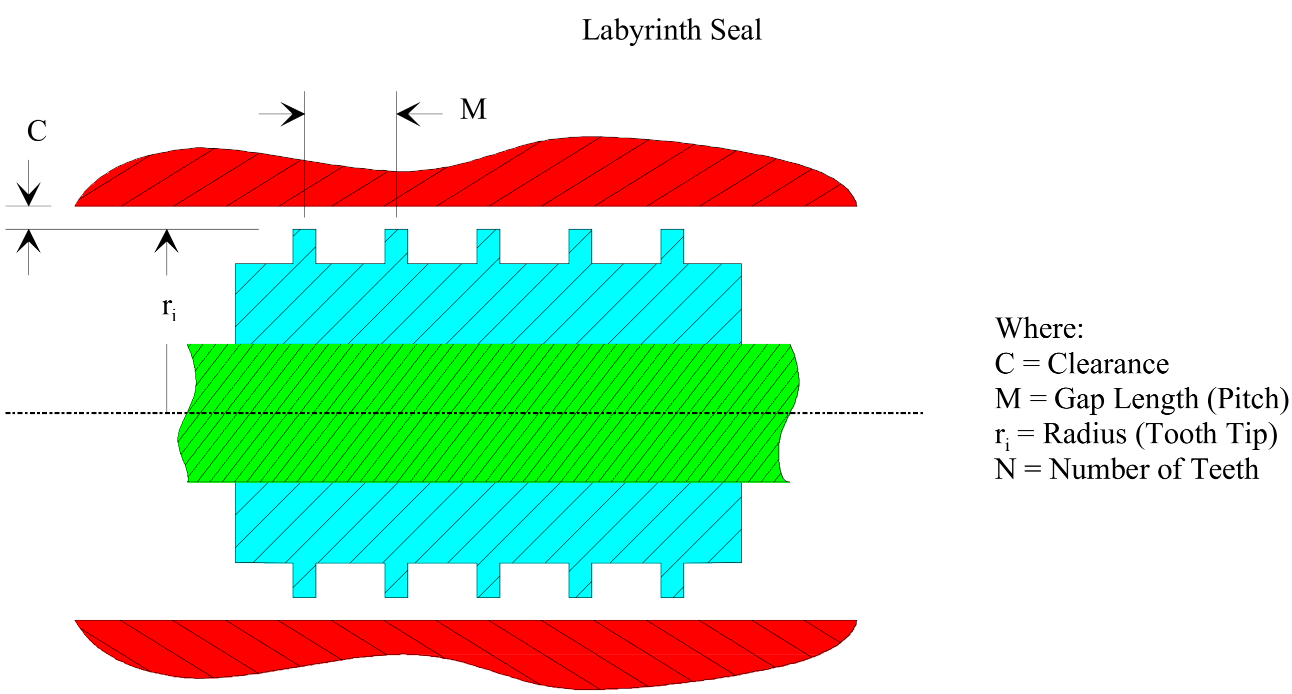


Figure 2.12 - Labyrinth Seal Resistance Option Parameters

Figure 2.13 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, pitch are n, c and m respectively. For this option, K_f can be expressed [14] as:

$$K_f = \frac{\left(1/\varepsilon^2 + 0.5\right) n + 1.5}{2 g_c \rho_u \alpha^2 A^2} \qquad \text{(Equation 2.35)}$$

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

$$\varepsilon = \sqrt{\frac{1}{1 - \frac{(n-1)\, c/m}{n(c/m + 0.02)}}} \qquad \text{(Equation 2.36)}$$

For a straight labyrinth seal A should be set to unity. For a stepped labyrinth seal A should be less than unity.

2.2.7.12 Branch Option 12 (Face Sseal)

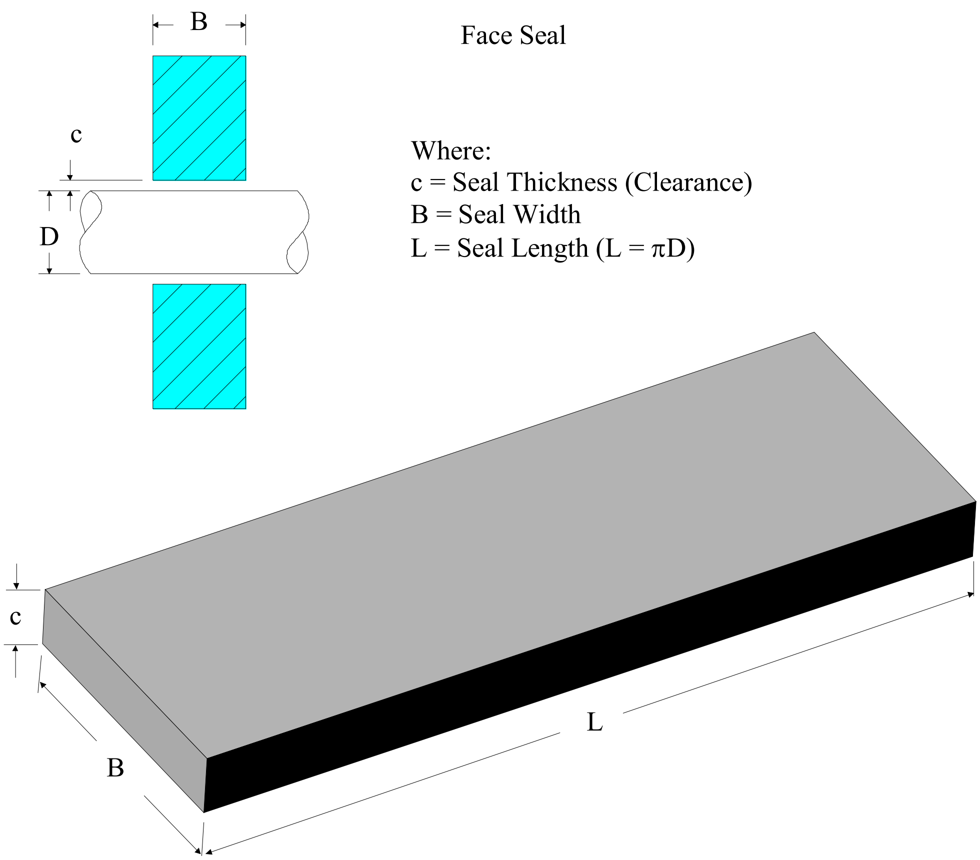


Figure 2.13 - Face Seal Resistance Option Parameters

Figure 2.13 shows the face seal resistance option parameters that are required by GFSSP. This option considers the branch as a face seal. The length, inner diameter and clearance of the seal are *L*, *D* and *c* respectively. For this option, K_f can be expressed [15] as:

$$K_f = \frac{12 \mu L \rho}{\pi g_c D c^3 \left| \dot{m} \right|} \qquad \text{(Equation 2.37)}$$

2.2.7.13 Branch

Option 13 (Common Fittings & Valves)

This option considers the branch as a common fittings or valves. The resistance in common fittings and valves can be computed by two-K method [16]. For this option, K_f can be expressed as:

$$K_f = \frac{K_1 / \mathrm{Re} + K_\infty (1 + 1/D)}{2 g_c \rho_u A^2} \qquad \text{(Equation 2.38)}$$

Where:

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

The constants K_1 and K_∞ for common fittings and valves are listed in Table 2.

$_f$ can be expressed as: qua)
Where:
K
D = Internal diameter of attachfor comm

2.2.7.14 Branch Option 14 (Pump Ccharacterisics)

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

$$\Delta p = A_0 + B_0 \dot{m}^2 \qquad \text{(Equation 2.39)}$$

Where:

Δp - Pressure rise, lbf/ft^2
$\dot{m}$ - Flow rate, lbm/sec

The momentum source, S in Equation 2.2 is then expressed as:

$$S = \Delta p \, A \qquad \text{(Equation 2.40)}$$

Fitting Type			K_1	K_∞
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, Flow Through Branch	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 ($\beta = d_{orifice}/d_{pipe}$)	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

Table 2.2 - Constants for Two K Method of Hooper (Reference 3) for Fittings/Valves (GFSSP Resistance Option 13)

2.2.7.15 Branch Option 15 (Pump Hhorsepower)

This option considers the branch as a pump with a given horsepower, P, and efficiency, η. The momentum source, S, in Equation 2.2 is then expressed as:

$$S = \frac{550\,\rho_u P \eta A}{\dot{m}} \qquad \text{(Equation 2.41)}$$

2.2.7.16 Branch Resistance Option 16 (Valve with a Given Loss Coefficient)

This option considers the branch as a valve with a given C_v. For this option, K_f, can be expressed as:

$$K_f = \frac{4.68 \times 10^5}{\rho_u C_v^2} \qquad \text{(Equation 2.42)}$$

2.3 SOLUTION PROCEDURE

In the sample circuit shown in Figure 2.1, pressures, temperatures, and concentrations of hydrogen and oxygen are to be calculated for the 7 internal nodes; flow rates are to be calculated in the 12 branches. Therefore, the total number of equations to be solved is 40 (= 7 X 4 +12). There is no explicit equation for pressure. The pressures are implicitly computed from the mass conservation equation (Equation 2.1). The flow rates are calculated from Equation 2.2. The inertia and friction terms are nonlinear in Equation 2.2. The pressures and mass flow rates appear in the flow rate equations. The enthalpy and concentrations are solved using Equations 2.3 and 2.4 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 [20] 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 values of the variables in successive iterations becomes negligible. The advantages of a 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.

In the Newton-Raphson method, 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 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 iterative. 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 of a large amount of computer memory. Details of the Newton-Raphson method appear in Appendix A.

In GFSSP, a combination of the successive substitution method and the Newton-Raphson method is used to solve the set of equations. 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 which are more strongly coupled are solved by Newton-Raphson method. The equations which 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.

It may be further mentioned that the solution of compressible flow problems requires two iterative cycles. In compressible flows, the density is a function of pressure and temperature and the resistance coefficient (K_f) in Equation 2.1 is a function of density. Therefore, the flow resistance parameters are recalculated after attaining a converged solution for the problem with the initial flow resistance parameters. The iterative cycle for the flow resistance calculations is continued until the differences in flow resistance, densities and enthalpies in successive iteration cycles are less than the specified convergence criterion for the problem.

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 Macintosh and Silicon Graphics. The code was developed with a modular structure to facilitate adding new capabilities in the future. The flow chart of the program is shown in Figure 3.1. The main routine controls all program operations and makes the decisions whether to continue or stop the current iterative cycle of 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 and WASP, that provide the necessary thermodynamic and thermophysical property data required to solve the resulting system of equations.

3.1 PREPROCESSOR

The preprocessor consists of three subroutines. PREPROP is an interactive routine that allows the user to select necessary options for flow model. The options include compressibility, mixture thermodynamics and axial thrust calculations. All network information including numbering and classification of nodes, the connecting branches, information to calculate branch resistance, the initial and boundary conditions are provided through interactive dialogue with the user. At the end of the interactive session, the input data are written (WRITEIN) in a text file. The code reads the data file through subroutine READIN.

3.2 SOLVER

The main and the set of subroutines under this group perform five major functions. 1) Generation of trial solution based on initial guess 2) Newton-Raphson solution of conservation equations. 3) Successive substitution method of solving concentration equation. 4) Calculation of resistance in branches. 5) Prints input/output variables of the problem. INIT generates trial solution by interacting with thermodynamic property code GASP and WASP. Subroutine NEWTON conducts the Newton-Raphson solution of mass conservation, flow rates and energy conservation equations with the help of EQNS, COEF, SOLVE and UPDATE. The subroutine EQNS generate 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 for the corrections the variables are updated in subroutine UPDATE. The resistancesfor each branch are calculated in RESIST after calculating densities at each node in the subroutine DENSITY.

3.3 THERMODYNAMIC PROPERTY PACKAGE

The thermodynamic property package consists of two separate programs GASP and WASP programs and RP-1 tables. GASP and WASP programs consist of a number of subroutines. GASP provides thermodynamic properties of ten fluids: helium, methane, neon, nitrogen, carbon monoxide, oxygen, argon, carbon dioxide, fluorine and hydrogen. WASP provides thermodynamic properties of water. RP-1 properties are provided in the form of tables. Subroutine RP1 searches the required property values from these tables. These property subroutines are called from two subroutines, INIT and DENSITY. In subroutine INIT, enthalpies and densities are computed from given pressures and temperatures at 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.

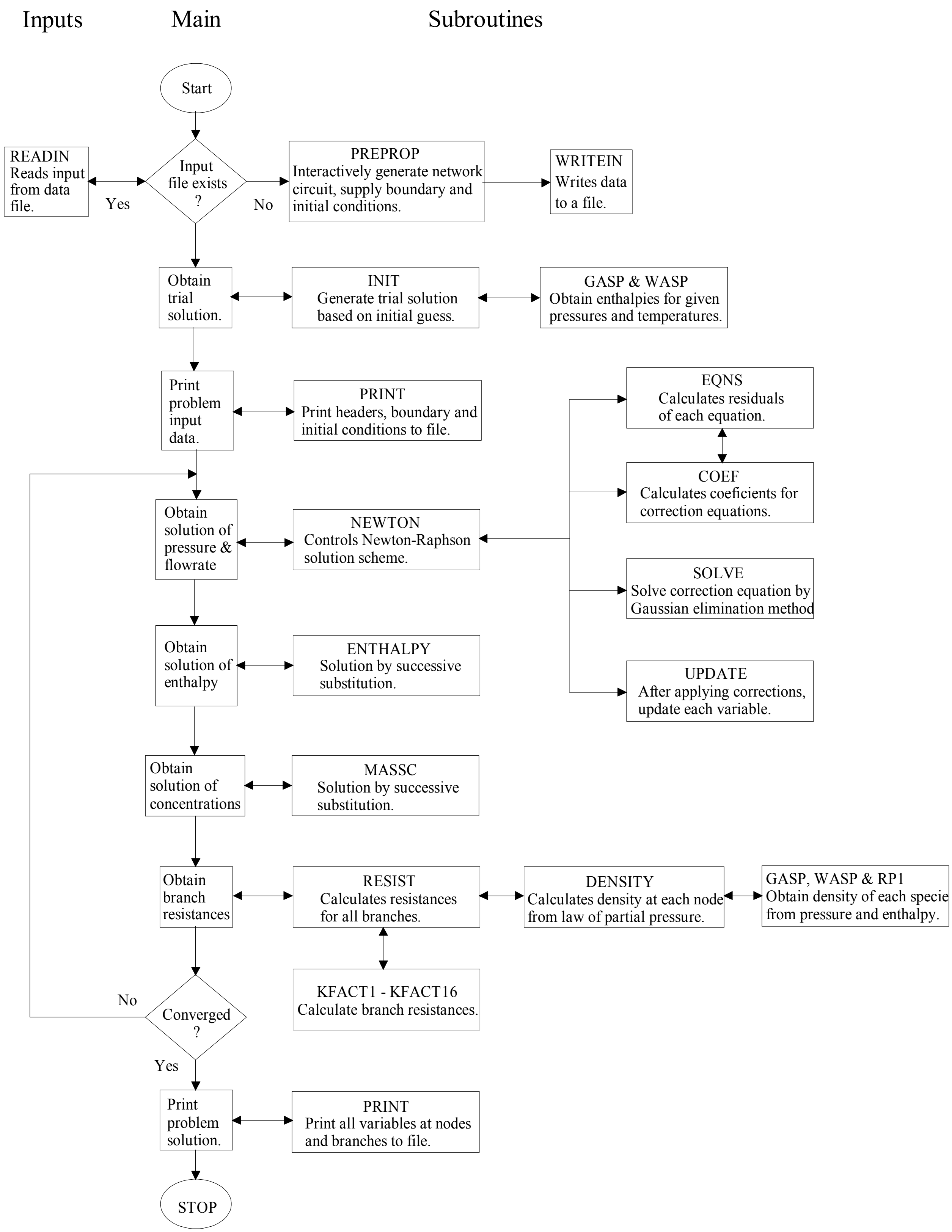


Figure 3.1 The GFSSP Flowchart

4.0 USER'S GUIDE

The purpose of this chapter is to explain how to create a data file, for any given flow circuit, with the help of the GFSSP interactive preprocessor. In order to run the code on a PC, the user must type at the DOS prompt:

C:\ GFSSP1P4

The first question the code will ask:

" DO YOU WANT TO READ A DATA FILE? "

If the user answers 'yes' to this question, the code will prompt the user to supply the existing input data file. After a successful reading of the input data file, the code will ask the user to supply the name of the solution output file that the code will create and GFSSP will proceed to calculate a solution to the specified data file. If the user answers 'no' to the first question, a call to preprocessor subroutine will be invoked and the interactive session will begin.

The preprocessor prompts the user for all of the necessary information to create the input data file. At the end of the interactive session, the code writes this input data into a file who's name was specified by the user at the end of the interactive session. Before building the desired model, the preprocessor will prompt the user to input a problem title of less than or equal to 80 characters. After this information has been input the preprocessor will proceed to construct the model.

The sequence of inputs to the preprocessor are as follows:

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

4.1 SELECTION OF MODEL OPTIONS

During this 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 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. The logical variables and their meaning appear in Table 4.1. 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 questions will be asked in sequence:

"IS FLOW TRANSIENT?"

GFSSP has the capability of modeling quasi-steady state flow circuit. In quasi-steady state mode, the boundary conditions are allowed to be a function of time.

If the user answers 'no' to this question, a steady state flow will be assumed. If the answer was 'yes', the code will ask the user to supply the time step, the start time and the stop 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 the data requested by the preprocessor, the program will not proceed until it receives the correct number of values.

The next preprocessor question is:

"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 must 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 the user must select the fluid from the GFSSP library of fluids. In the case of a mixture, the user will be required to select from a list of fluids. These related questions will be asked at the end of the "model options" session.

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. The user will be asked to supply the orientation of the branches with respect to the gravitational force vector during the 'branch information' 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 were natural convection occurs, the fluid experiences a buoyancy force because of density differences in the presence of 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 'miscellaneous information' session.

The next question the preprocessor will ask is:

"DO YOU WANT TO ACTIVATE INERTIA?"

If the inertia force of the fluid is important to consider in the flow circuit to be analyzed, user must activate this option by responding with a 'y' to the prompt. Also, if there is a significant change in the density and the area in a flow passage within the model, the inertia option should be activated. If this option is selected the user will also be required later in this session to provide the angle between the upstream and downstream branches.

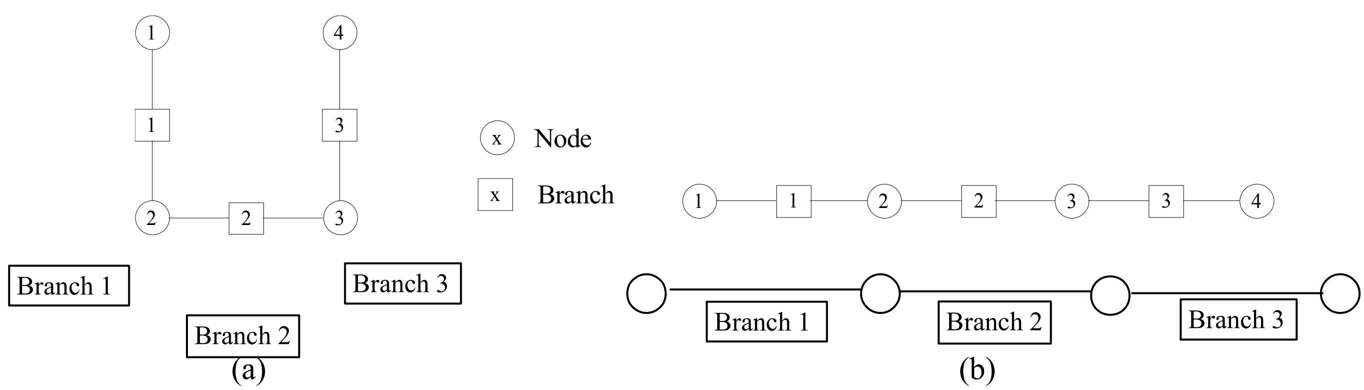


Figure 4.1 - Examples of Flow Circuit Arrangement to Demonstrate the Effect of Fluid Inertia.

In Figure 4.1(a), the fluid flowing in Branch 2 experiences no inertial effects from the fluid flowing in Branch 1, assuming 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(b), the fluid flowing in Branch 2 experiences the total effect of the inertial force from Branch 1, assuming the flow is from Branch 1 to Branch 2 and the angle between these branches is zero. In the data file, the angles between 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.

The next preprocessor question is:

"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. 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 'miscellaneous information' session.

The next preprocessor question is:

"IS AXIAL THRUST CALCULATION REQUIRED IN THE CIRCUIT?"

GFSSP provides an option to calculate the axial thrust created in a flow circuit. This axial thrust is created when there exists a pressure differential between opposing faces of a mechanism that is being modeled, such as a turbine disk. If this 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 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 chose 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.

The next preprocessor question is:

"ARE THERE ANY HEAT SOURCES?"

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'. During the 'miscellaneous information' session, the user will be required to identify the nodes where heat loads are applied and the magnitude of heat loads in each of the identified nodes.

The next preprocessor question is:

"DO YOU WANT TO ACTVATE HEAT CONDUCTION?"

The user can activate the heat conduction option between nodes by answering 'y' to this question. 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 session.

The next preprocessor question is:

"IS THE FLUID A MIXTURE?"

Once the user answers this question, either ‘y’ or ‘n’, the code will print a list of fluids. GFSSP can calculate the properties of the listed fluids. If the mixture option is not chosen, the user needs to identify only one fluid from the list. If the user answers ‘y’ to the previousdingstion, 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 from the given list. GFSSP requires a reference point for enthalpies for mixture calculation. It is recommended that the triple point of water should be used for reference point. NHREF must be kept at its default value of 2 to maintain the recommended reference point.

4.2

4.2 NODE INFORMATION

In this session, the user will first be required to supply the total number of nodes. The code will then ask 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. The user is then required to identify 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, user must supply those values because GFSSP does not distinguish between inflow and outflow boundary during problem setup. A boundary node can have either an inflow or outflow depending upon the specified boundary condition.

4.3

4.3 BRANCH INFORMATION

In this section, the user is required to provide all of the necessary information concerning each of the branches. 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 user to supply the number of branches connected with each internal node.

For each branch, the user must supply:

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

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.

4.4 BOUNDARY CONDITIONS

4.4

In this session, the user is required to supply pressures, temperatures and concentrations at all of the boundary nodes. For transient calculations, user is required to supply the filename containing the history data.

4.5 MISCELLANEOUS INFORMATION

4.5

The user will be prompted to supply any additional information necessary for the model closure starting with:

"HOW MANY INTERNAL NODES HAVE SPECIFIED FLOWRATES?"

GFSSP requires the specification of pressure at all of the boundary nodes. The code calculates 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 sources 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.

he next question the preprocessor will ask is:If ththe user will be prompted with the question:

"HOW MANY INTERNAL NODES HAVE SPECIFIED HEAT SOURCES?"

The user is prompted to supply the number of internal nodes with specified heat sources if there are any heat sources or sinks in any of the internal nodes 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. 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.

If buoyancy is activated, the code will ask the user to supply the reference node to use for determining the density. The buoyancy force will be calculated with respect to the density of the reference point.

If the rotational option is activated in the code, 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 supplied number of branches:

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

Finally the user will be asked to provide a filename for the data file to be created. An example of the complete interactive session of creating a data file is provided in Appendix B.

4.6 DESCRIPTION OF INPUT DATA FILE

The previous sections describe how to create a GFSSP model of a fluid flow network using the GFSSP preprocessor. This section describes the structure of the GFSSP input data file that is created by the preprocessor. Example input data files can be found in Appendix C.
The data in the GFSSP input data file can be classified into the following 11 sections:

1. <u>Title</u>:

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

2. Logical Variables:

Table 3 contains a listing of the GFSSP logical variables and their options.

3. Node, Branch and Fluid Information:

NNODES	- Number of nodes.
NINT	- Number of internal nodes.
NBR	- Number of branches.
NF	- Number of fluids.
NHREF	- Reference index for fluid (this must be 2).

4. 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).

5. Index Number for Fluids:

NFLUID(I), I = 1, NF : Index number for each fluid is printed in this line. Table 4.2 shows the fluids that are available in GFSSP.

Variable	Meaning
DENCON	= T; Uses constant density and viscosity supplied by the user.
	= F; All thermodynamic and thermophysical properties are computed.
GRAVITY	= T; Gravitational force will be calculated for branches utilizing Resistance Option 1 or 4.
	= F; Gravitational force is not calculated.
ENERGY	= T; Energy equation is solved (for DENCON = F and/or with heat sources).
	= F; Energy equation is not solved.
MIXTURE	= T; For more than one fluid in the circuit.
	= F; For a single fluid in the circuit.
THRUST	= T; Thrust is calculated from node pressures and areas.
	= F; Thrust is not calculated.
STEADY	= T; Performs one steady state calculation.
	= F; Performs quasi-steady calculation with given time history of boundary conditions.
TRANSV	= F; This must always be set to FALSE.
INERTIA	= T; Inertial effect of fluid is considered.
	= F; Inertial effect is neglected.
CONDX	= F; This option must be set to FALSE.
TWOD	= F; This must be set to FALSE.
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; Rotation is not activated.
BUOYANCY	= T; This option activates buoyancy when GRAVITY = .TRUE.
HRATE	= T; Heat source is in Btu/sec
	= F; Heat source is in Btu/lbm

Table 4.1 - GFSSP Logical Variables

3.
4.
5.

6. Nodes and Indices:

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

7. Node Information:

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

Index	Fluid
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	RP-1

Table 4.2 - Fluids Available in GFSSP

8. <u>Branch Connection</u>:

The number of branches for every internal node is defined. Every branch connected with the internal node is also defined.

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.

6.
7.
8.

9. <u>Branch Information</u>:

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.

10. <u>Inertia Information</u>:

In order to account for 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 every 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.

11. Rotation Information:

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

5.0 EXAMPLES

The purpose of this chapter is to demonstrate the major features of the code through seven example problems. These demonstration problems are:

1. Series flow circuit with common pipe fittings and a valve.
2. Series flow circuit with common pipe fittings, a valve and a pump.
3. Flow distribution in a parallel flow manifold
4. Flow distribution in a parallel flow manifold with heat sources and phase changes.
5. Mixing of cryogenic fluids in an inter-propellant seal flow circuit of a turbopump.
6. Quasi-steady calculation of Example 5.
7. Flow in a rotating disk.

5.1 EXAMPLE 1 - SERIES FLOW CIRCUIT WITH COMMON PIPE FITTINGS AND A VALVE

This example illustrates a model of a flow circuit where several pipes are joined in series with the help of common pipe fittings such as a gate valve, reducer, expander and elbow. Two orifices are also placed in the line. The purpose of this example is to demonstrate the use of various resistance options in the code. Figure 5.1 shows the flow circuit consisting of 16 nodes and 15 branches. Node 1 and Node 16 are boundary nodes where pressures and temperatures are specified. Nodes 2 through Node 15 are internal nodes where pressures and temperatures are calculated by the code. The code also calculates the flow rates in each branch. The resistance option and geometrical parameters of every branch are shown in the figure. Branch 45 is a dummy branch with no resistance. In the following example, this branch will be used to locate a pump. The input and output data files from Example 1 are provided in Appendix D.

Several runs were made with this model to generate a system characteristics curve. The system characteristics can be described by plotting the system inlet to outlet pressure differential with the corresponding flow rate. The model was run with 6 different inlet pressures (50, 100, 150, 250, 300 and 350 psia) at Node 1. The pressure at the outlet (Node 16) was kept at 14.7 psia. The assigned pressure differentials and calculated flow rates are shown in Table 5.1. The predicted system characteristics are shown graphically in Figure 5.2.

Pressure differential (psi)	Flow rate (lbm/sec)
35.3	798
85.3	1350
135.3	1750
235.3	2340
285.3	2590
335.3	2820

Table 5.1 - System Characteristic Data of Example 1

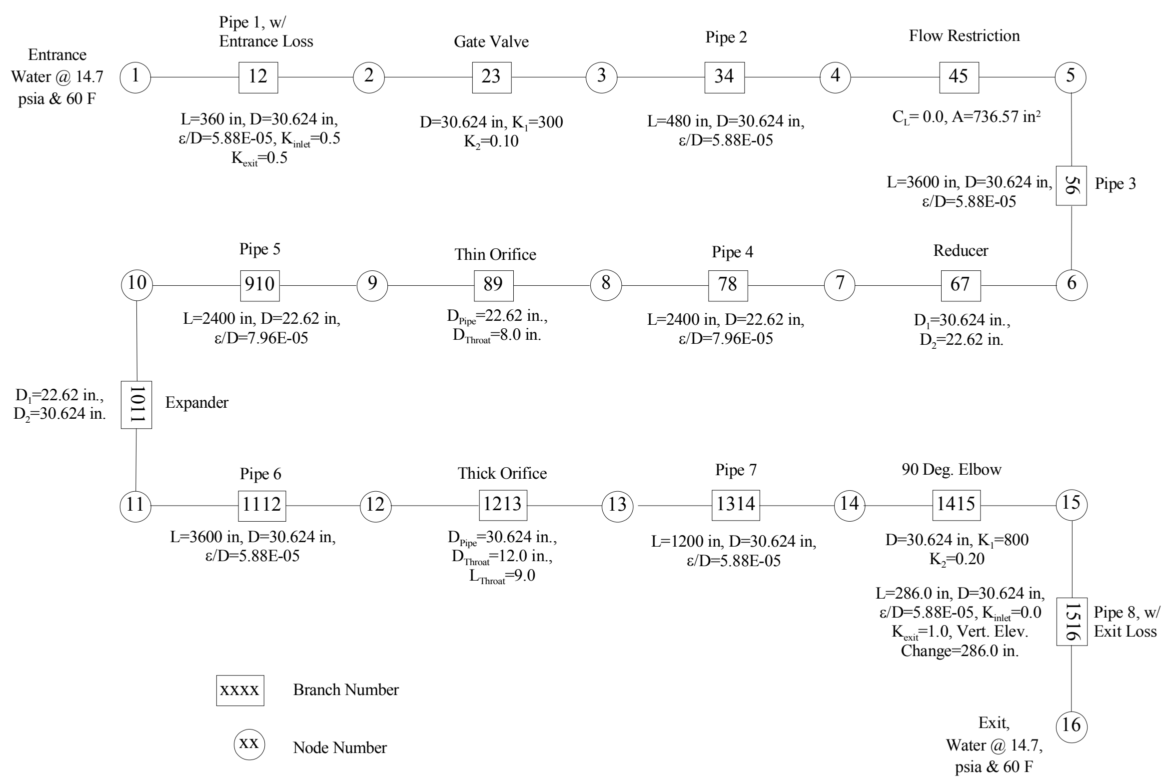


Figure 5.1 - Example 1 Flow Circuit

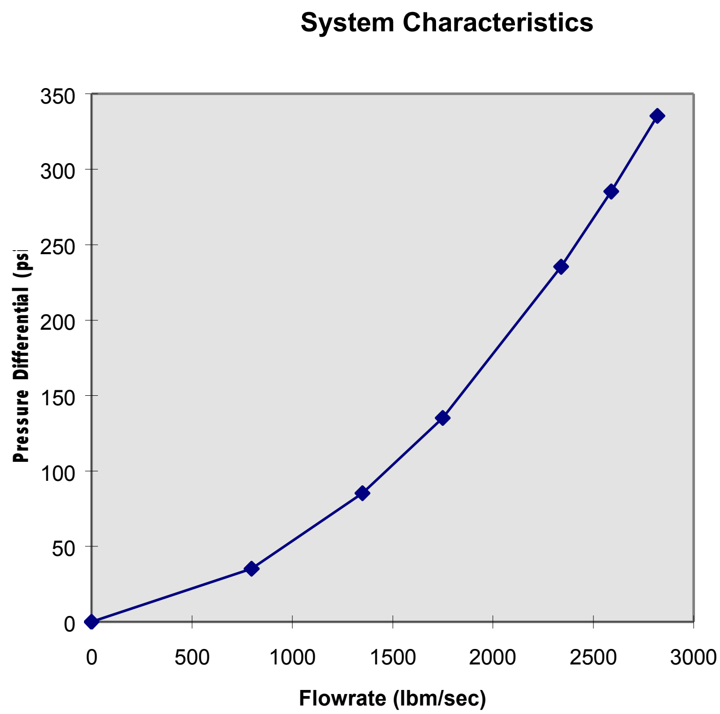


Figure 5.2 - Example 1 Predicted System Characteristics

5.2 EXAMPLE 2 - SERIES FLOW CIRCUIT WITH COMMON PIPE FITTINGS, A VALVE AND A PUMP

This example is an extension of Example 1. The purpose of this example problem is to demonstrate how to incorporate a pump into a flow circuit. The dummy branch in Example 1, branch 45, was used to locate the pump. The flow circuit is shown in Figure 5.3 and the pump characteristics curve is shown in Figure 5.4. The combined pump and system characteristics is shown in Figure 5.5. The input and output data files from Example 2 are provided in Appendix E.

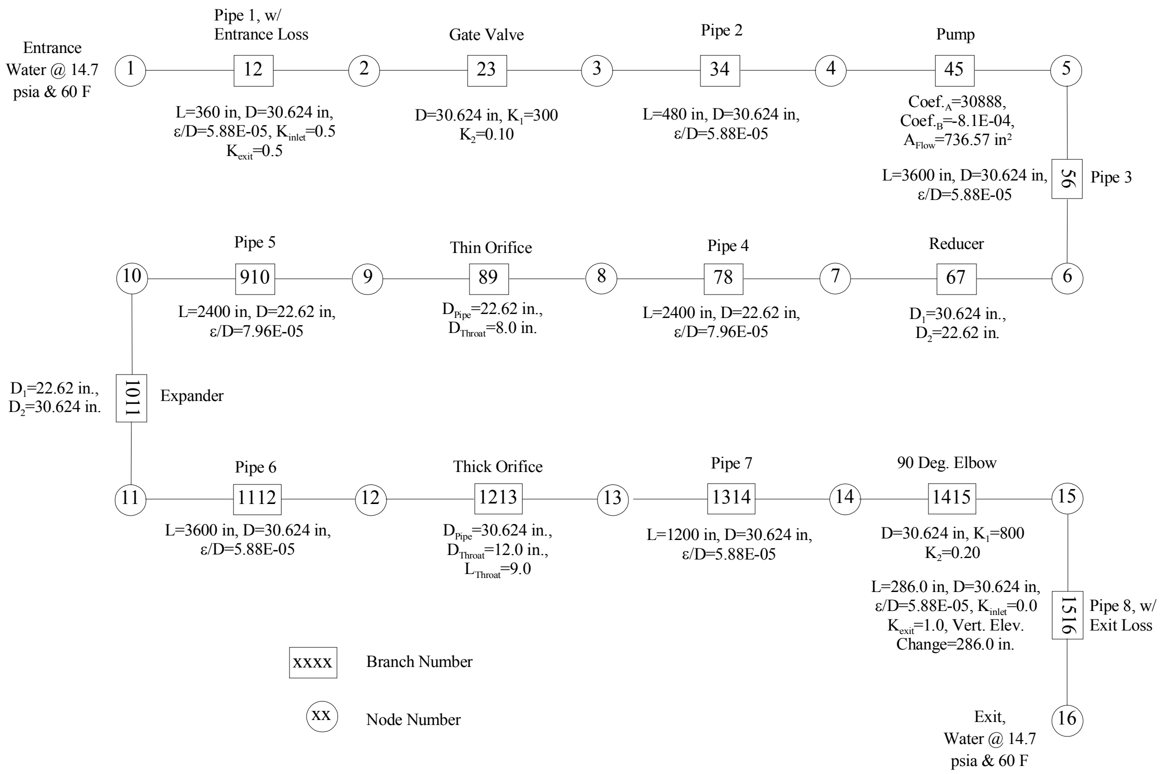


Figure 5.3 - Example 2 Flow Circuit

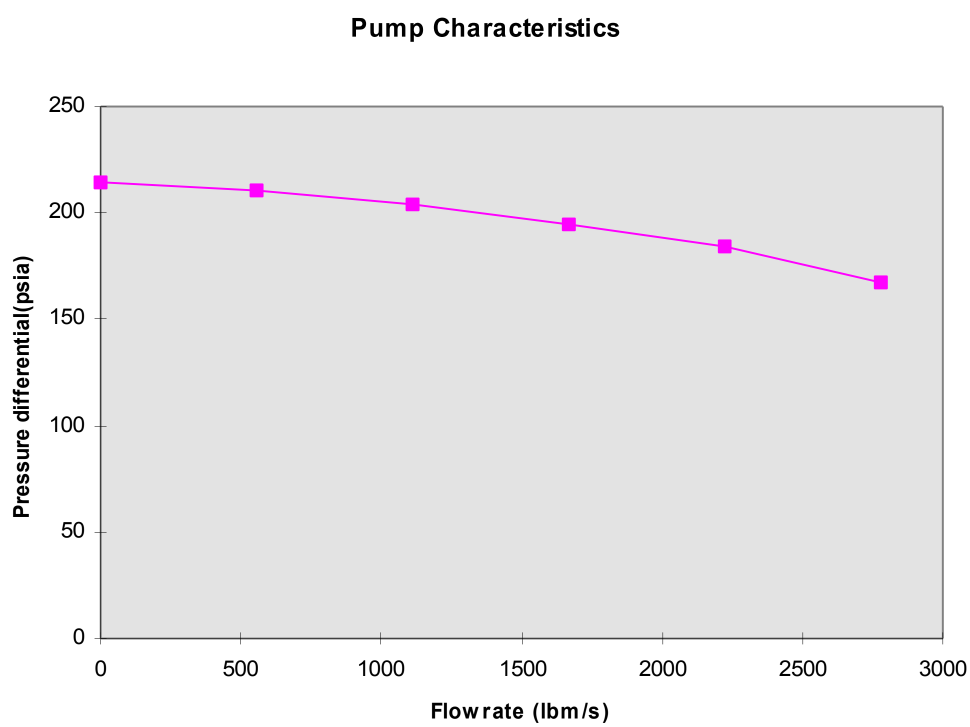


Figure 5.4 - Pump Characteristics Curve for Example 2

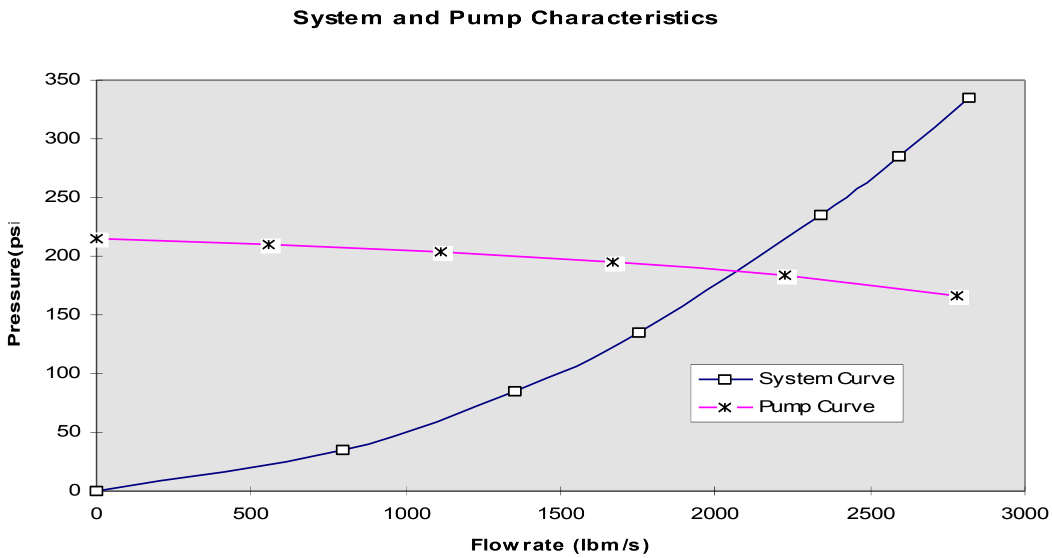


Figure 5.5 - Combined Pump And System Characteristics

5.3 EXAMPLE 3 - FLOW DISTRIBUTION IN A PARALLEL FLOW MANIFOLD

This example illustrates the use of the code for analyzing a parallel flow circuit. A parallel flow manifold is shown in Figure 5.6. The flow enters the dividing header at the bottom-left corner of the flow circuit shown in the figure. The flow is divided into six lateral branches and enters into a combining header. Finally, the flow leaves the combining header. The flow has to overcome the frictional losses in the pipe and the gravitational head. Figure 5.7 shows the GFSSP model of the parallel flow manifold. The working fluid is water. Node 1 and Node 20 are boundary nodes where the pressures and temperatures are specified. The dividing and combining headers are made of 1 inch inner diameter pipe. The lateral pipes are made of 0.4 inch inner diameter pipe. The height of the lateral pipes is 12 feet. The purpose of the GFSSP model is to predict the flow rate in the system and flow distribution in the lateral branches.

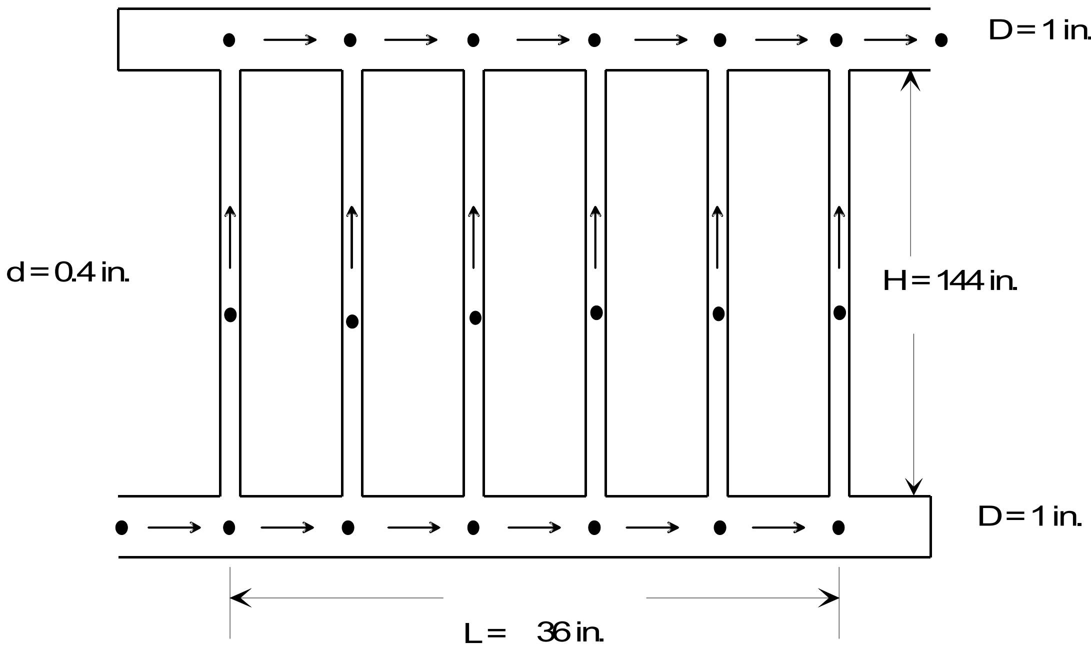


Figure 5.6 Example 3 Parallel Flow Manifold

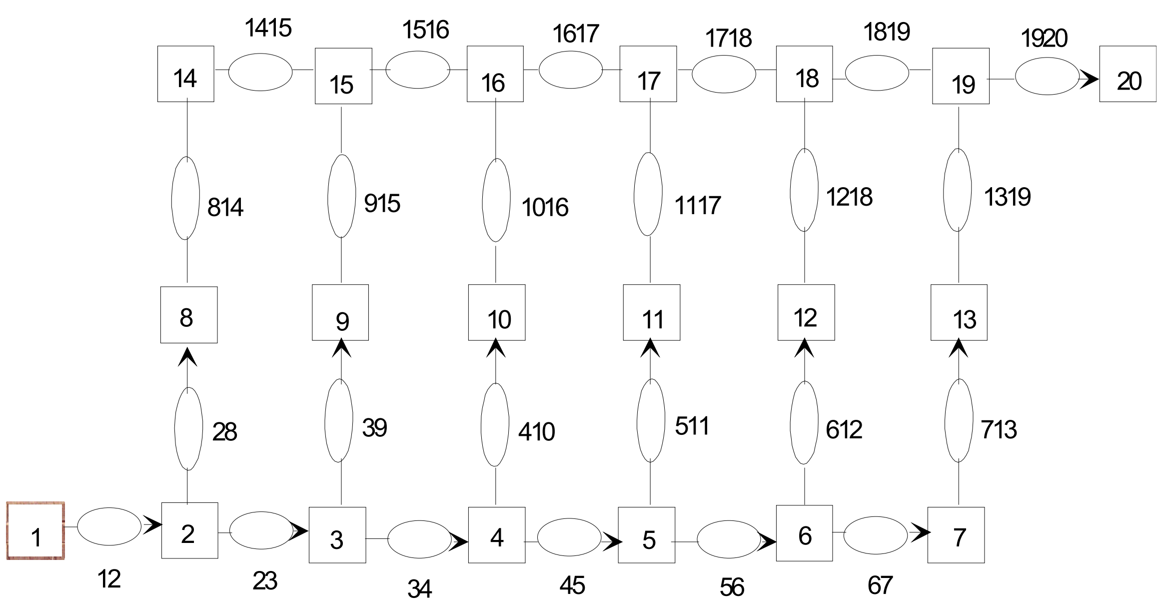


Figure 5.7 GFSSP Model for Example 3

The input and output data files for Example 3 are provided in Appendix F. For a pressure differential of 8 psi, the calculated flow rate in the manifold is 1.44 lb/sec. The extent of the non-uniformity in the lateral branches ($(\dot{m}_{713} - \dot{m}_{28})/\dot{m}_{28}$) is about 16 percent.

5.4 EXAMPLE 4 - FLOW DISTRIBUTION IN A PARALLEL FLOW MANIFOLD WITH HEAT SOURCES AND PHASE CHANGES

The purpose of this example is to demonstrate the use of heat sources and phase changes related to the supplied heat. The physical system from Example 3 was modified for this example. Heat was added at the midpoint of the lateral branches which were represented by Node 8 through Node 13. It can be observed in the output file that a liquid and vapor mixture exists in Node 8 through Node 19. The pressure differential is maintained at the same value as in Example 3 (8 psi). The total heat load of the system was 207.4 Btu/sec. It may be noted that in this example the "Btu/lb" heat rate option was used. The above mentioned number was determined from the calculated flow rate. The predicted flow rate was 0.319 lb/sec. The calculated flow non-uniformity was only 2.1 percent. The input and output data files from Example 4 are provided in Appendix G.

5.5 EXAMPLE 5 - MIXING OF CRYOGENIC FLUIDS IN AN INTER-PROPELLANT SEAL FLOW CIRCUIT OF A TURBO-PUMP

The purpose of this example is to demonstrate an example of fluid mixing in a circuit. A sample flow circuit, consisting of 12 nodes and 12 branches, is shown in Figure 5.8. Figure 5.8 represents a portion of an inter propellant flow circuit where a helium buffer is used to prevent the mixing of hydrogen and oxygen leakage flow in a typical turbopump flow circuit.

In Figure 5.8 the nodes are represented by the square boxes and the branches are represented by the elliptical boxes. The nodes and branches 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, 66, and 22. The pressures and temperatures that are specified at these nodes are shown in the figure. Nodes 50 and 16 are outflow boundaries where pressures are specified. The mixtures of helium-oxygen and helium-hydrogen exit through these nodes. The GFSSP model calculates pressures, temperatures, and concentrations at all internal nodes and flow rates in all branches. The input and output files of this example are provided in Appendix H.

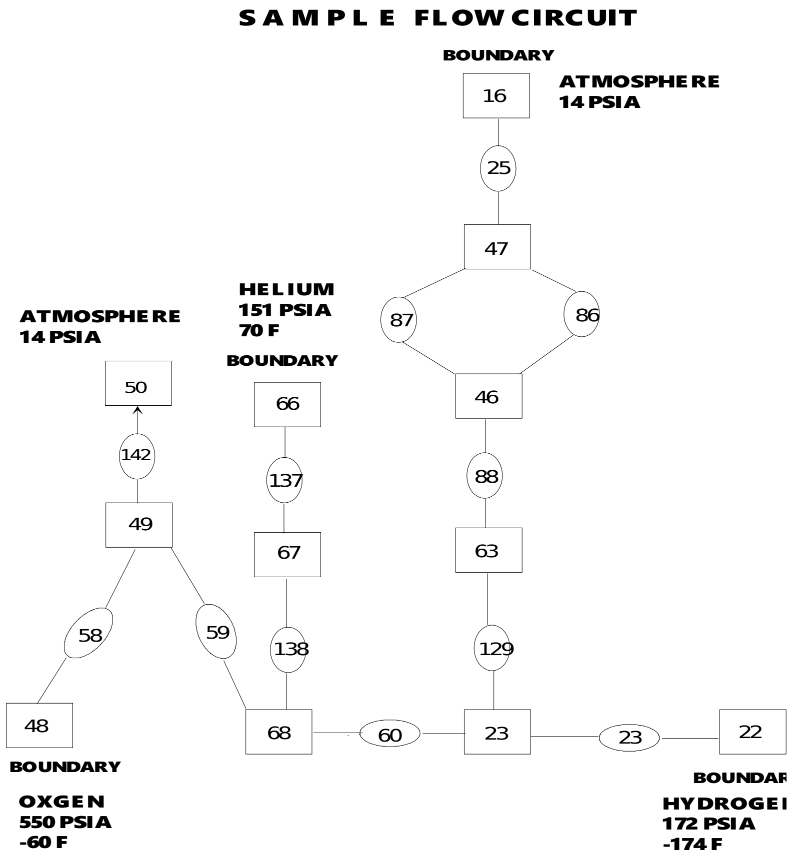


Figure 5.8 - Inter Propellant Flow Circuit of Example 5

are provided in Appendix H.

5.6 EXAMPLE 6 - QUASI-STEADY CALCULATION OF EXAMPLE 5

This example is an extension of Example 5. A quasi-steady model of the inter-propellant seal flow circuit has been developed. In a quasi-steady mode (STEADY = FALSE), all values at the boundary nodes must be specified in data files. The name of these data files must appear in GFSSP input file. In this example, the pressures, temperatures and concentrations history were provided in boundary nodes through HIST48.DAT, HIST50.DAT, HIST66.DAT, HIST16.DAT and HIST22.DAT. The calculations were performed for 15 seconds at an interval of 1 second. The input and output files of this example are provided in Appendix I.

5.7 EXAMPLE 7 - FLOW IN A ROTATING DISC CAVITY

This example illustrates the rotational effect (centrifugal force contribution) of GFSSP by a model of water flowing through a closed impeller [21]. The impeller is schematically shown in figure 5.9a, and the GFSSP model circuit is shown in Figure 5.9b below. 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 are calculated as the average cross sectional area for each branch $\left(A_{\text{branch ab}} = \frac{1}{r_b - r_a} \int_{r_a}^{r_b} 2\pi r dr \right)$. 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 higher pressure rise for radially outward flow.) For this example the effects of friction have been neglected for the rotating branches. The input and output files of this example are provided in Appendix J.

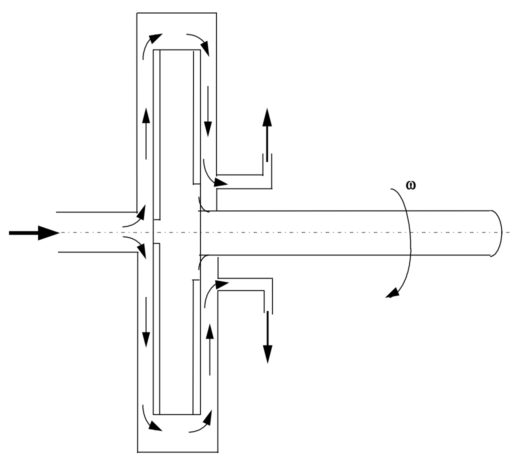


Figure 5.9a Physical Situation for Example 7

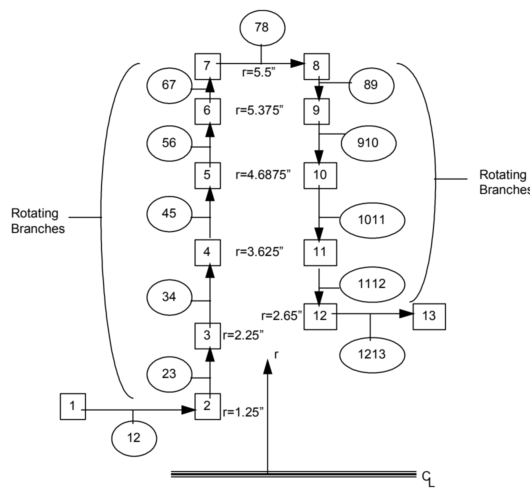


Figure 5.9b GFSSP Model for Example 7

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APPENDIX A

DERIVATION OF K_F FOR PIPE FLOW

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:

$$P_u - P_d = K_f \dot{m}^2 \qquad \text{(A-1)}$$

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:

$$\tau \ \pi \ DL = \left(P_u - P_d\right)\frac{\pi D^2}{4} \qquad \text{(A-2)}$$

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

$$f = \frac{8 \ \tau \ g_c}{\rho u^2} \qquad \text{(A-3)}$$

From the continuity equation:

$$u = \frac{4\dot{m}}{\rho \ \pi \ D^2} \qquad \text{(A-4)}$$

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

$$P_u - P_d = \frac{8fL}{g_c \rho \ \pi^2 D^5} \qquad \text{(A-6)}$$

Therefore,

$$K_f = \frac{8fL}{g_c \rho \ \pi^2 D^5} \qquad \text{(A-7)}$$

APPENDIX B

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

Newton-Raphson Method of Solving Coupled Nonlinear System 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:

$$f_1(x_1, x_2, x_3, ...x_n) = 0$$
$$f_2(x_1, x_2, x_3, ...x_n) = 0 \quad \text{(B-1)}$$
$$.......................................$$
$$f_n(x_1, x_2, x_3, ...x_n) = 0$$

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

2. Guess a solution for the equations.

Guess $x_1^*, x_2^*, x_3^*, ...x_n^*$ 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.

$$f_1(x_1^*, x_2^*, x_3^*, ...x_n^*) = R_1$$
$$f_2(x_1^*, x_2^*, x_3^*, ...x_n^*) = R_2 \quad \text{(B-2)}$$
$$.......................................$$
$$f_n(x_1^*, x_2^*, x_3^*, ...x_n^*) = R_n$$

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

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

First construct the matrix of influence coefficients:

$$\frac{\partial f_1}{\partial x_1} \; \frac{\partial f_1}{\partial x_2} \; \frac{\partial f_1}{\partial x_3} \cdots\cdots \frac{\partial f_1}{\partial x_n}$$

$$\frac{\partial f_2}{\partial x_1} \; \frac{\partial f_2}{\partial x_2} \; \frac{\partial f_2}{\partial x_3} \cdots\cdots \frac{\partial f_2}{\partial x_n}$$

$$\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots$$

$$\frac{\partial f_n}{\partial x_1} \; \frac{\partial f_n}{\partial x_2} \; \frac{\partial f_n}{\partial x_3} \cdots\cdots \frac{\partial f_n}{\partial x_n}$$

Then construct the set of simultaneous equations for corrections:

$$\begin{bmatrix} \frac{\partial f_1}{\partial x_1} & \frac{\partial f_1}{\partial x_2} & \frac{\partial f_1}{\partial x_3} \cdots\cdots & \frac{\partial f_1}{\partial x_n} \\ \frac{\partial f_2}{\partial x_1} & \frac{\partial f_2}{\partial x_2} & \frac{\partial f_2}{\partial x_3} \cdots\cdots & \frac{\partial f_2}{\partial x_n} \\ \cdots\cdots & \cdots\cdots & \cdots\cdots & \cdots\cdots \\ \frac{\partial f_n}{\partial x_1} & \frac{\partial f_n}{\partial x_2} & \frac{\partial f_n}{\partial x_3} \cdots\cdots & \frac{\partial f_n}{\partial x_n} \end{bmatrix} \begin{bmatrix} x_1' \\ x_2' \\ \\ x_n' \end{bmatrix} = \begin{bmatrix} R_1 \\ R_2 \\ \\ R_n \end{bmatrix}$$

5. Solve for $x_1', x_2', x_3', \ldots\ldots x_n'$ 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

Successive Substitution Method of Solving Coupled Nonlinear System of Algebraic Equations

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

1. Develop the governing equations:

$$x_1 = f_1(x_1, x_2, x_3, ...x_n)$$
$$x_2 = f_2(x_1, x_2, x_3, ...x_n) \qquad \text{C-1}$$
$$.......................................$$
$$x_n = f_n(x_1, x_2, x_3, ...x_n)$$

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

2. Guess a solution for the equations:

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

3. Compute new values of $x_1, x_2, x_3, ...x_n$ by substituting $x_1^*, x_2^*, x_3^*, ...x_n^*$ 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 $x_1^*, x_2^*, x_3^*, ...x_n^*$ with the computed value of $x_1, x_2, x_3, ...x_n$ from Step 4.
6. Repeat Steps 3 to 5 until convergence.

APPENDIX D

INPUT AND OUTPUT DATA FILES FROM EXAMPLE 1

Contents **Page**

```
TITLE
FLOW COEFICIENTS
   DENCON  GRAVITY  ENERGY  MIXTURE THRUST STEADY      TRANSV
       F       T       T       F       F       T       F
     INERTIA  CONDX    TWOD   PRINTI ROTATION   BUOYANCY HRATE
       T       F       F       T       F       F       F
NNODES NINT NBR  NF NHREF
    16    14    15     1     2
RELAXK  RELAXD  RELAXH
    1.000000    0.500000    1.000000
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     2
PRESSURE TEMPERATURE
     1  0.5000E+02  0.6000E+02  0.0000E+00  0.0000E+00  0.0000E+00
     2  0.1469E+02  0.6000E+02  0.0000E+00  0.0000E+00  0.0000E+00
     3  0.1468E+02  0.6000E+02  0.0000E+00  0.0000E+00  0.0000E+00
     4  0.1467E+02  0.6000E+02  0.0000E+00  0.0000E+00  0.0000E+00
     5  0.1466E+02  0.6000E+02  0.0000E+00  0.0000E+00  0.0000E+00
     6  0.1465E+02  0.6000E+02  0.0000E+00  0.0000E+00  0.0000E+00
     7  0.1464E+02  0.6000E+02  0.0000E+00  0.0000E+00  0.0000E+00
     8  0.1463E+02  0.6000E+02  0.0000E+00  0.0000E+00  0.0000E+00
     9  0.1462E+02  0.6000E+02  0.0000E+00  0.0000E+00  0.0000E+00
    10  0.1461E+02  0.6000E+02  0.0000E+00  0.0000E+00  0.0000E+00
    11  0.1460E+02  0.6000E+02  0.0000E+00  0.0000E+00  0.0000E+00
    12  0.1459E+02  0.6000E+02  0.0000E+00  0.0000E+00  0.0000E+00
    13  0.1458E+02  0.6000E+02  0.0000E+00  0.0000E+00  0.0000E+00
    14  0.1457E+02  0.6000E+02  0.0000E+00  0.0000E+00  0.0000E+00
```

```
    15  0.1456E+02  0.6000E+02  0.0000E+00  0.0000E+00  0.0000E+00
    16  0.1470E+02  0.6000E+02  0.0000E+00  0.0000E+00  0.0000E+00
INODE   NUMBR          NAMEBR
     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
BRANCH   UPNODE  DNNODE  OPTION
    12     1     2     4
    23     2     3    13
    34     3     4     1
    45     4     5     2
    56     5     6     1
    67     6     7     7
    78     7     8     1
    89     8     9     5
   910     9    10     1
  1011    10    11     8
  1112    11    12     1
  1213    12    13     6
  1314    13    14     1
  1415    14    15    13
  1516    15    16     4
BRANCH  OPTION -4  LENGTH  DIA EPSD ANGLE AREA
    12   360.00000    30.62400     0.00006     0.50000     0.00000    90.00000   736.56891
BRANCH OPTION -13 DIA K1  K2  AREA
    23    30.62400   300.00000     0.10000   736.56891
BRANCH  OPTION -1  LENGTH  DIA EPSD ANGLE AREA
    34   480.00000    30.62400     0.00006    90.00000   736.56891
BRANCH OPTION -2 FLOW COEF     AREA
    45     0.00      736.57001
BRANCH  OPTION -1  LENGTH  DIA EPSD ANGLE AREA
    56  3600.00000    30.62400     0.00006    90.00000   736.56891
BRANCH OPTION -7  PIPE DIA RED. DIA AREA
```

```
    67    30.62400    22.62000   401.85999
BRANCH  OPTION -1  LENGTH  DIA EPSD ANGLE AREA
    78  2400.00000    22.62000     0.00008    90.00000   401.85999
BRANCH OPTION - 5 PIPE DIA ORIFICE DIA AREA
    89    22.62000    8.00000   401.85999
BRANCH  OPTION -1  LENGTH  DIA EPSD ANGLE AREA
   910  2400.00000    22.62000     0.00008    90.00000   401.85999
BRANCH OPTION -8 PIPE DIA EXP DIA AREA
  1011    22.62000    30.62400   736.56891
BRANCH  OPTION -1  LENGTH  DIA EPSD ANGLE AREA
  1112  3600.00000    30.62400     0.00006    90.00000   736.56891
BRANCH OPTION -6 LENGTH PIPE DIA ORIFICE DIA AR   EA
  1213     9.00000    30.62400    12.00000   736.56891
BRANCH  OPTION -1  LENGTH  DIA EPSD ANGLE AREA
  1314  1200.00000    30.62400     0.00006    90.00000   736.56891
BRANCH OPTION -13 DIA K1  K2  AREA
  1415    30.62400   800.00000     0.20000   736.56891
BRANCH  OPTION -4  LENGTH  DIA EPSD ANGLE AREA
  1516   286.00000    30.62400     0.00006     0.00000     1.00000   180.00000   736.56891
 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
 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      0
BRANCH
          12
UPSTREAM  ANGLE
DOWNSTREAM  ANGLE
    23    0.0000
BRANCH
          23
UPSTREAM  ANGLE
    12    0.0000
DOWNSTREAM  ANGLE
    34    0.0000
BRANCH
          34
UPSTREAM  ANGLE
    23    0.0000
DOWNSTREAM  ANGLE
    45    0.0000
BRANCH
          45
UPSTREAM  ANGLE
    34    0.0000
DOWNSTREAM  ANGLE
    56    0.0000
BRANCH
          56
UPSTREAM  ANGLE
    45    0.0000
DOWNSTREAM  ANGLE
    67    0.0000
BRANCH
          67
UPSTREAM  ANGLE
    56    0.0000
DOWNSTREAM  ANGLE
    78    0.0000
BRANCH
          78
```

```
UPSTREAM  ANGLE
    67    0.0000
DOWNSTREAM  ANGLE
    89    0.0000
BRANCH
          89
UPSTREAM  ANGLE
    78    0.0000
DOWNSTREAM  ANGLE
   910    0.0000
BRANCH
         910
UPSTREAM  ANGLE
    89    0.0000
DOWNSTREAM  ANGLE
  1011    0.0000
BRANCH
        1011
UPSTREAM  ANGLE
   910    0.0000
DOWNSTREAM  ANGLE
  1112    0.0000
BRANCH
        1112
UPSTREAM  ANGLE
  1011    0.0000
DOWNSTREAM  ANGLE
  1213    0.0000
BRANCH
        1213
UPSTREAM  ANGLE
  1112    0.0000
DOWNSTREAM  ANGLE
  1314    0.0000
BRANCH
        1314
UPSTREAM  ANGLE
  1213    0.0000
DOWNSTREAM  ANGLE
  1415    0.0000
BRANCH
        1415
UPSTREAM  ANGLE
  1314    0.0000
```

```
DOWNSTREAM  ANGLE
  1516   90.0000
BRANCH
        1516
UPSTREAM  ANGLE
  1415   90.0000
DOWNSTREAM  ANGLE
```

```
**** GENERAL FLUID SYSTEM SIMULATION PROGRAM ****
 ****************** VERSION 1.4.1 ****************

  TITLE      :FLOW COEFICIENTS
  DATE       :9/11/97
  ANALYST    :jwb
  FILEIN     :example1.dat
  FILEOUT    :example1.out
   LOGICAL VARIABLES
  DENCON   =  F
  GRAVITY  =  T
  ENERGY   =  T
  MIXTURE  =  F
  THRUST   =  F
  STEADY   =  T
  TRANSV   =  F
  INERTIA  =  T
  CONDX    =  F
  TWOD     =  F
  PRINTI   =  T
  ROTATION =  F
  BUOYANCY =  F
  HRATE    =  F


  NNODES   =   16
  NINT     =   14
  NBR      =   15
  NF       =    1
  NVAR     =   29
  NHREF    =    2


  FLUIDS:  H2O

BOUNDARY NODES
 NODE       P          T        RHO         AREA
          (PSI)       (F)   (LBM/FT^3)   (IN^2)
     1     50.0000   60.0000   62.3766    0.0000
    16     14.7000   60.0000   62.3694    0.0000

 INPUT SPECIFICATIONS FOR INTERNAL NODES
NODE        AREA       MASS      HEAT
NODE       (IN^2)    (LBM/S)  (BTU/LBM)
```

```
     2      0.0000    0.0000    0.0000
     3      0.0000    0.0000    0.0000
     4      0.0000    0.0000    0.0000
     5      0.0000    0.0000    0.0000
     6      0.0000    0.0000    0.0000
     7      0.0000    0.0000    0.0000
     8      0.0000    0.0000    0.0000
     9      0.0000    0.0000    0.0000
    10      0.0000    0.0000    0.0000
    11      0.0000    0.0000    0.0000
    12      0.0000    0.0000    0.0000
    13      0.0000    0.0000    0.0000
    14      0.0000    0.0000    0.0000
    15      0.0000    0.0000    0.0000

BRANCH   UPNODE    DNNODE    OPTION
    12         1         2         4
    23         2         3        13
    34         3         4         1
    45         4         5         2
    56         5         6         1
    67         6         7         7
    78         7         8         1
    89         8         9         5
   910         9        10         1
  1011        10        11         8
  1112        11        12         1
  1213        12        13         6
  1314        13        14         1
  1415        14        15        13
  1516        15        16         4
BRANCH  OPTION -4:  LENGTH, DIA, EPSD, ANGLE, AREA
    12   360.00000    30.62400     0.00006     0.50000     0.00000    90.00000   736.56891
BRANCH OPTION -13:  DIA, K1,  K2, AREA
    23    30.62400   300.00000     0.10000   736.56891
BRANCH  OPTION -1:   LENGTH, DIA, EPSD, ANGLE, AREA
    34   480.00000    30.62400     0.00006    90.00000   736.56891
BRANCH OPTION -2:  FLOW COEF, AREA
    45     0.00000   736.57001
BRANCH  OPTION -1:   LENGTH, DIA, EPSD, ANGLE, AREA
    56  3600.00000    30.62400     0.00006    90.00000   736.56891
BRANCH OPTION -7:   PIPE DIA, REDUCED DIA, AREA
    67    30.62400    22.62000   401.85999
BRANCH  OPTION -1:   LENGTH, DIA, EPSD, ANGLE, AREA
```

```
    78  2400.00000    22.62000     0.00008    90.00000   401.85999
BRANCH OPTION - 5:  PIPE DIA, ORIFICE DIA, AREA
    89    22.62000     8.00000   401.85999
BRANCH  OPTION -1:   LENGTH, DIA, EPSD, ANGLE, AREA
   910  2400.00000    22.62000     0.00008    90.00000   401.85999
BRANCH OPTION -8:  PIPE DIA, EXP DIA, AREA
  1011    22.62000    30.62400   736.56891
BRANCH  OPTION -1:   LENGTH, DIA, EPSD, ANGLE, AREA
  1112  3600.00000    30.62400     0.00006    90.00000   736.56891
BRANCH OPTION -6:  LENGTH, PIPE DIA, ORIFICE DIA, AREA
  1213     9.00000    30.62400    12.00000   736.56891
BRANCH  OPTION -1:   LENGTH, DIA, EPSD, ANGLE, AREA
  1314  1200.00000    30.62400     0.00006    90.00000   736.56891
BRANCH OPTION -13:  DIA, K1,  K2, AREA
  1415    30.62400   800.00000     0.20000   736.56891
BRANCH  OPTION -4:  LENGTH, DIA, EPSD, ANGLE, AREA
  1516   286.00000    30.62400     0.00006     0.00000     1.00000   180.00000   736.56891

INITIAL GUESS FOR INTERNAL NODES

   NODE    P(PSI)   T(F)      Z(COMP)    RHO         QUALITY
                                      (LBM/FT^3)
     2     14.6900   60.0000    0.0008   62.3694    0.0000
     3     14.6800   60.0000    0.0008   62.3694    0.0000
     4     14.6700   60.0000    0.0008   62.3694    0.0000
     5     14.6600   60.0000    0.0008   62.3694    0.0000
     6     14.6500   60.0000    0.0008   62.3694    0.0000
     7     14.6400   60.0000    0.0008   62.3694    0.0000
     8     14.6300   60.0000    0.0008   62.3694    0.0000
     9     14.6200   60.0000    0.0008   62.3694    0.0000
    10     14.6100   60.0000    0.0008   62.3693    0.0000
    11     14.6000   60.0000    0.0008   62.3694    0.0000
    12     14.5900   60.0000    0.0008   62.3694    0.0000
    13     14.5800   60.0000    0.0008   62.3694    0.0000
    14     14.5700   60.0000    0.0008   62.3694    0.0000
    15     14.5600   60.0000    0.0008   62.3694    0.0000

 TRIAL SOLUTION
  BRANCH    DELP(PSI)   FLOWRATE(LBM/SEC)
    12        35.3100     0.0100
    23         0.0100     0.0100
    34         0.0100     0.0100
    45         0.0100     0.0100
    56         0.0100     0.0100
```

67	0.0100	0.0100
78	0.0100	0.0100
89	0.0100	0.0100
910	0.0100	0.0100
1011	0.0100	0.0100
1112	0.0100	0.0100
1213	0.0100	0.0100
1314	0.0100	0.0100
1415	0.0100	0.0100
1516	-0.1400	0.0100

SOLUTION

INTERNAL NODES

NODE	P(PSI)	T(F)	Z	RHO	QUALITY (LBM/FT^3)
2	49.9759	59.9997	0.0026	62.3748	0.0000
3	49.9715	60.0005	0.0026	62.3748	0.0000
4	49.9652	59.9997	0.0026	62.3748	0.0000
5	49.9652	59.9997	0.0026	62.3748	0.0000
6	49.9177	59.9997	0.0026	62.3747	0.0000
7	49.6428	60.0008	0.0026	62.3747	0.0000
8	49.4195	60.0006	0.0026	62.3747	0.0000
9	28.2181	60.0620	0.0015	62.3712	0.0000
10	27.9949	60.0621	0.0015	62.3712	0.0000
11	28.0037	60.0611	0.0015	62.3712	0.0000
12	27.9562	60.0616	0.0014	62.3712	0.0000
13	25.1793	60.0705	0.0013	62.3707	0.0000
14	25.1635	60.0699	0.0013	62.3707	0.0000
15	25.1547	60.0699	0.0013	62.3707	0.0000

BRANCHES

BRANCH	KFACTOR (LBF-S^2/(LBM-FT)^2)	DELP (PSI)	FLOW RATE (LBM/SEC)	VELOCITY (FT/SEC)	REYN. NO.	MACH NO.
12	0.631E-05	0.241E-01	0.798E+03	0.250E+01	0.528E+06	0.209E-02
23	0.989E-06	0.438E-02	0.798E+03	0.250E+01	0.528E+06	0.209E-02
34	0.259E-05	0.633E-02	0.798E+03	0.250E+01	0.528E+06	0.209E-02
45	0.000E+00	0.000E+00	0.798E+03	0.250E+01	0.528E+06	0.209E-02
56	0.194E-04	0.475E-01	0.798E+03	0.250E+01	0.528E+06	0.209E-02
67	0.881E-05	0.275E+00	0.798E+03	0.459E+01	0.714E+06	0.382E-02
78	0.563E-04	0.223E+00	0.798E+03	0.459E+01	0.714E+06	0.382E-02
89	0.479E-02	0.212E+02	0.798E+03	0.459E+01	0.714E+06	0.382E-02
910	0.563E-04	0.223E+00	0.798E+03	0.459E+01	0.715E+06	0.382E-02

1011	0.667E-05	-0.878E-02	0.798E+03	0.250E+01	0.528E+06	0.209E-02
1112	0.194E-04	0.475E-01	0.798E+03	0.250E+01	0.528E+06	0.209E-02
1213	0.627E-03	0.278E+01	0.798E+03	0.250E+01	0.528E+06	0.209E-02
1314	0.648E-05	0.158E-01	0.798E+03	0.250E+01	0.528E+06	0.209E-02
1415	0.198E-05	0.877E-02	0.798E+03	0.250E+01	0.528E+06	0.209E-02
1516	0.108E-04	0.105E+02	0.798E+03	0.251E+01	0.528E+06	0.209E-02

SOLUTION SATISFIED CONVERGENCE CRITERION OF 0.00100 IN 14 ITERATIONS

APPENDIX E

INPUT AND OUTPUT DATA FILES FROM EXAMPLE 2

Contents **Page**

```
TITLE
FLOW COEFICIENTS
   DENCON  GRAVITY  ENERGY  MIXTURE THRUST STEADY      TRANSV
       F       T       T       F       F       T       F
     INERTIA  CONDX    TWOD   PRINTI ROTATION   BUOYANCY HRATE
       T       F       F       T       F       F       F
NNODES NINT NBR  NF NHREF
    16    14    15     1     2
RELAXK  RELAXD  RELAXH
    1.000000    0.500000    1.000000
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     2
PRESSURE TEMPERATURE
     1  0.1470E+02  0.6000E+02  0.0000E+00  0.0000E+00  0.0000E+00
     2  0.1469E+02  0.6000E+02  0.0000E+00  0.0000E+00  0.0000E+00
     3  0.1468E+02  0.6000E+02  0.0000E+00  0.0000E+00  0.0000E+00
     4  0.1467E+02  0.6000E+02  0.0000E+00  0.0000E+00  0.0000E+00
     5  0.1466E+02  0.6000E+02  0.0000E+00  0.0000E+00  0.0000E+00
     6  0.1465E+02  0.6000E+02  0.0000E+00  0.0000E+00  0.0000E+00
     7  0.1464E+02  0.6000E+02  0.0000E+00  0.0000E+00  0.0000E+00
     8  0.1463E+02  0.6000E+02  0.0000E+00  0.0000E+00  0.0000E+00
     9  0.1462E+02  0.6000E+02  0.0000E+00  0.0000E+00  0.0000E+00
    10  0.1461E+02  0.6000E+02  0.0000E+00  0.0000E+00  0.0000E+00
```

```
    11  0.1460E+02  0.6000E+02  0.0000E+00  0.0000E+00  0.0000E+00
    12  0.1459E+02  0.6000E+02  0.0000E+00  0.0000E+00  0.0000E+00
    13  0.1458E+02  0.6000E+02  0.0000E+00  0.0000E+00  0.0000E+00
    14  0.1457E+02  0.6000E+02  0.0000E+00  0.0000E+00  0.0000E+00
    15  0.1456E+02  0.6000E+02  0.0000E+00  0.0000E+00  0.0000E+00
    16  0.1470E+02  0.6000E+02  0.0000E+00  0.0000E+00  0.0000E+00
INODE   NUMBR         NAMEBR
     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
BRANCH   UPNODE  DNNODE  OPTION
    12     1     2     4
    23     2     3    13
    34     3     4     1
    45     4     5    14
    56     5     6     1
    67     6     7     7
    78     7     8     1
    89     8     9     5
   910     9    10     1
  1011    10    11     8
  1112    11    12     1
  1213    12    13     6
  1314    13    14     1
  1415    14    15    13
  1516    15    16     4
BRANCH  OPTION -4  LENGTH  DIA EPSD ANGLE AREA
    12   360.00000    30.62400     0.00006     0.50000     0.00000    90.00000   736.56891
BRANCH OPTION -13 DIA K1  K2  AREA
```

```
    23    30.62400   300.00000     0.10000   736.56891
BRANCH  OPTION -1  LENGTH  DIA EPSD ANGLE AREA
    34   480.00000    30.62400     0.00006    90.00000   736.56891
BRANCH OPTION -14 PUMP CONST1  PUMP CONST2         AREA
    45 30888.00000    -0.00081   736.57001
BRANCH  OPTION -1  LENGTH  DIA EPSD ANGLE AREA
    56  3600.00000    30.62400     0.00006    90.00000   736.56891
BRANCH OPTION -7  PIPE DIA RED. DIA AREA
    67    30.62400    22.62000   401.85999
BRANCH  OPTION -1  LENGTH  DIA EPSD ANGLE AREA
    78  2400.00000    22.62000     0.00008    90.00000   401.85999
BRANCH OPTION - 5 PIPE DIA ORIFICE DIA AREA
    89    22.62000    8.00000   401.85999
BRANCH  OPTION -1  LENGTH  DIA EPSD ANGLE AREA
   910  2400.00000    22.62000     0.00008    90.00000   401.85999
BRANCH OPTION -8 PIPE DIA EXP DIA AREA
  1011    22.62000    30.62400   736.56891
BRANCH  OPTION -1  LENGTH  DIA EPSD ANGLE AREA
  1112  3600.00000    30.62400     0.00006    90.00000   736.56891
BRANCH OPTION -6 LENGTH PIPE DIA ORIFICE DIA AR   EA
  1213     9.00000    30.62400    12.00000   736.56891
BRANCH  OPTION -1  LENGTH  DIA EPSD ANGLE AREA
  1314  1200.00000    30.62400     0.00006    90.00000   736.56891
BRANCH OPTION -13 DIA K1  K2  AREA
  1415    30.62400   800.00000     0.20000   736.56891
BRANCH  OPTION -4  LENGTH  DIA EPSD ANGLE AREA
  1516   286.00000    30.62400     0.00006     0.00000     1.00000   180.00000   736.56891
 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
 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     0
BRANCH
          12
UPSTREAM  ANGLE
DOWNSTREAM  ANGLE
    23    0.0000
BRANCH
          23
UPSTREAM  ANGLE
    12    0.0000
DOWNSTREAM  ANGLE
    34    0.0000
BRANCH
          34
UPSTREAM  ANGLE
    23    0.0000
DOWNSTREAM  ANGLE
    45    0.0000
BRANCH
          45
UPSTREAM  ANGLE
    34    0.0000
```

```
DOWNSTREAM  ANGLE
    56    0.0000
BRANCH
          56
UPSTREAM  ANGLE
    45    0.0000
DOWNSTREAM  ANGLE
    67    0.0000
BRANCH
          67
UPSTREAM  ANGLE
    56    0.0000
DOWNSTREAM  ANGLE
    78    0.0000
BRANCH
          78
UPSTREAM  ANGLE
    67    0.0000
DOWNSTREAM  ANGLE
    89    0.0000
BRANCH
          89
UPSTREAM  ANGLE
    78    0.0000
DOWNSTREAM  ANGLE
   910    0.0000
BRANCH
         910
UPSTREAM  ANGLE
    89    0.0000
DOWNSTREAM  ANGLE
  1011    0.0000
BRANCH
        1011
UPSTREAM  ANGLE
   910    0.0000
DOWNSTREAM  ANGLE
  1112    0.0000
BRANCH
        1112
```

```
UPSTREAM  ANGLE
  1011    0.0000
DOWNSTREAM  ANGLE
  1213    0.0000
BRANCH
        1213
UPSTREAM  ANGLE
  1112    0.0000
DOWNSTREAM  ANGLE
  1314    0.0000
BRANCH
        1314
UPSTREAM  ANGLE
  1213    0.0000
DOWNSTREAM  ANGLE
  1415    0.0000
BRANCH
        1415
UPSTREAM  ANGLE
  1314    0.0000
DOWNSTREAM  ANGLE
  1516   90.0000
BRANCH
        1516
UPSTREAM  ANGLE
  1415   90.0000
DOWNSTREAM  ANGLE
```

```
 **** GENERAL FLUID SYSTEM SIMULATION PROGRAM ****
 ***************** VERSION 1.4.1 ****************

  TITLE     :FLOW COEFICIENTS
  DATE      :9/11/97
  ANALYST   :jwb
  FILEIN    :example2.dat
  FILEOUT   :example2.out
   LOGICAL VARIABLES
  DENCON   =  F
  GRAVITY  =  T
  ENERGY   =  T
  MIXTURE  =  F
  THRUST   =  F
  STEADY   =  T
  TRANSV   =  F
  INERTIA  =  T
  CONDX    =  F
  TWOD     =  F
  PRINTI   =  T
  ROTATION =  F
  BUOYANCY =  F
  HRATE    =  F


  NNODES   =   16
  NINT     =   14
  NBR      =   15
  NF       =    1
  NVAR     =   29
  NHREF    =    2


  FLUIDS:  H2O

BOUNDARY NODES
 NODE       P         T       RHO        AREA
         (PSI)      (F)   (LBM/FT^3)   (IN^2)
    1     14.7000   60.0000   62.3694    0.0000
   16     14.7000   60.0000   62.3694    0.0000
```

INPUT SPECIFICATIONS FOR INTERNAL NODES

NODE NODE	AREA (IN^2)	MASS (LBM/S)	HEAT (BTU/LBM)
2	0.0000	0.0000	0.0000
3	0.0000	0.0000	0.0000
4	0.0000	0.0000	0.0000
5	0.0000	0.0000	0.0000
6	0.0000	0.0000	0.0000
7	0.0000	0.0000	0.0000
8	0.0000	0.0000	0.0000
9	0.0000	0.0000	0.0000
10	0.0000	0.0000	0.0000
11	0.0000	0.0000	0.0000
12	0.0000	0.0000	0.0000
13	0.0000	0.0000	0.0000
14	0.0000	0.0000	0.0000
15	0.0000	0.0000	0.0000

BRANCH	UPNODE	DNNODE	OPTION
12	1	2	4
23	2	3	13
34	3	4	1
45	4	5	14
56	5	6	1
67	6	7	7
78	7	8	1
89	8	9	5
910	9	10	1
1011	10	11	8
1112	11	12	1
1213	12	13	6
1314	13	14	1
1415	14	15	13
1516	15	16	4

BRANCH OPTION -4: LENGTH, DIA, EPSD, ANGLE, AREA

12	360.00000	30.62400	0.00006	0.50000	0.00000	90.00000	736.56891

BRANCH OPTION -13: DIA, K1, K2, AREA

23	30.62400	300.00000	0.10000	736.56891

BRANCH OPTION -1: LENGTH, DIA, EPSD, ANGLE, AREA

```
    34   480.00000    30.62400     0.00006    90.00000   736.56891
BRANCH OPTION -14:  PUMP CONST1, PUMP CONST2, AREA
    45 30888.00000    -0.00081   736.57001
BRANCH  OPTION -1:   LENGTH, DIA, EPSD, ANGLE, AREA
    56  3600.00000    30.62400     0.00006    90.00000   736.56891
BRANCH OPTION -7:   PIPE DIA, REDUCED DIA, AREA
    67    30.62400    22.62000   401.85999
BRANCH  OPTION -1:   LENGTH, DIA, EPSD, ANGLE, AREA
    78  2400.00000    22.62000     0.00008    90.00000   401.85999
BRANCH OPTION - 5:  PIPE DIA, ORIFICE DIA, AREA
    89    22.62000     8.00000   401.85999
BRANCH  OPTION -1:   LENGTH, DIA, EPSD, ANGLE, AREA
   910  2400.00000    22.62000     0.00008    90.00000   401.85999
BRANCH OPTION -8:  PIPE DIA, EXP DIA, AREA
  1011    22.62000    30.62400   736.56891
BRANCH  OPTION -1:   LENGTH, DIA, EPSD, ANGLE, AREA
  1112  3600.00000    30.62400     0.00006    90.00000   736.56891
BRANCH OPTION -6:  LENGTH, PIPE DIA, ORIFICE DIA, AREA
  1213     9.00000    30.62400    12.00000   736.56891
BRANCH  OPTION -1:   LENGTH, DIA, EPSD, ANGLE, AREA
  1314  1200.00000    30.62400     0.00006    90.00000   736.56891
BRANCH OPTION -13:  DIA, K1,  K2, AREA
  1415    30.62400   800.00000     0.20000   736.56891
BRANCH  OPTION -4:  LENGTH, DIA, EPSD, ANGLE, AREA
  1516   286.00000    30.62400     0.00006     0.00000     1.00000   180.00000   736.56891

INITIAL GUESS FOR INTERNAL NODES

   NODE    P(PSI)   T(F)      Z(COMP)    RHO         QUALITY
                                      (LBM/FT^3)
     2     14.6900   60.0000    0.0008   62.3694    0.0000
     3     14.6800   60.0000    0.0008   62.3694    0.0000
     4     14.6700   60.0000    0.0008   62.3694    0.0000
     5     14.6600   60.0000    0.0008   62.3694    0.0000
     6     14.6500   60.0000    0.0008   62.3694    0.0000
     7     14.6400   60.0000    0.0008   62.3694    0.0000
     8     14.6300   60.0000    0.0008   62.3694    0.0000
     9     14.6200   60.0000    0.0008   62.3694    0.0000
    10     14.6100   60.0000    0.0008   62.3693    0.0000
    11     14.6000   60.0000    0.0008   62.3694    0.0000
```

12	14.5900	60.0000	0.0008	62.3694	0.0000
13	14.5800	60.0000	0.0008	62.3694	0.0000
14	14.5700	60.0000	0.0008	62.3694	0.0000
15	14.5600	60.0000	0.0008	62.3694	0.0000

TRIAL SOLUTION

BRANCH	DELP(PSI)	FLOWRATE(LBM/SEC)
12	0.0100	0.0100
23	0.0100	0.0100
34	0.0100	0.0100
45	0.0100	0.0100
56	0.0100	0.0100
67	0.0100	0.0100
78	0.0100	0.0100
89	0.0100	0.0100
910	0.0100	0.0100
1011	0.0100	0.0100
1112	0.0100	0.0100
1213	0.0100	0.0100
1314	0.0100	0.0100
1415	0.0100	0.0100
1516	-0.1400	0.0100

SOLUTION

INTERNAL NODES

NODE	P(PSI)	T(F)	Z	RHO	QUALITY (LBM/FT^3)
2	14.5094	59.9999	0.0008	62.3693	0.0000
3	14.4783	60.0006	0.0008	62.3694	0.0000
4	14.4141	60.0005	0.0007	62.3693	0.0000
5	203.3027	59.4653	0.0105	62.4001	0.0000
6	202.8212	59.4660	0.0105	62.4000	0.0000
7	200.8584	59.4737	0.0104	62.3997	0.0000
8	199.3500	59.4758	0.0103	62.3995	0.0000
9	47.9473	59.9057	0.0025	62.3748	0.0000
10	46.4391	59.9099	0.0024	62.3745	0.0000
11	46.5021	59.9098	0.0024	62.3746	0.0000
12	46.0207	59.9112	0.0024	62.3745	0.0000

13	26.1837	59.9678	0.0014	62.3713	0.0000
14	26.0232	59.9685	0.0013	62.3712	0.0000
15	25.9608	59.9688	0.0013	62.3712	0.0000

BRANCHES

BRANCH	KFACTOR (LBF-S^2/(LBM-FT)^2)	DELP (PSI)	FLOW RATE (LBM/SEC)	VELOCITY (FT/SEC)	REYN. NO.	MACH NO.
12	0.615E-05	0.191E+00	0.213E+04	0.669E+01	0.141E+07	0.558E-02
23	0.985E-06	0.312E-01	0.213E+04	0.669E+01	0.141E+07	0.558E-02
34	0.219E-05	0.642E-01	0.213E+04	0.669E+01	0.141E+07	0.558E-02
45	0.000E+00	-0.189E+03	0.213E+04	0.669E+01	0.141E+07	0.558E-02
56	0.165E-04	0.482E+00	0.213E+04	0.669E+01	0.140E+07	0.558E-02
67	0.880E-05	0.196E+01	0.213E+04	0.123E+02	0.190E+07	0.102E-01
78	0.485E-04	0.151E+01	0.213E+04	0.123E+02	0.190E+07	0.102E-01
89	0.479E-02	0.151E+03	0.213E+04	0.123E+02	0.190E+07	0.102E-01
910	0.485E-04	0.151E+01	0.213E+04	0.123E+02	0.191E+07	0.102E-01
1011	0.666E-05	-0.630E-01	0.213E+04	0.669E+01	0.141E+07	0.558E-02
1112	0.164E-04	0.482E+00	0.213E+04	0.669E+01	0.141E+07	0.558E-02
1213	0.627E-03	0.198E+02	0.213E+04	0.669E+01	0.141E+07	0.558E-02
1314	0.548E-05	0.161E+00	0.213E+04	0.669E+01	0.141E+07	0.558E-02
1415	0.197E-05	0.624E-01	0.213E+04	0.669E+01	0.141E+07	0.558E-02
1516	0.106E-04	0.113E+02	0.213E+04	0.670E+01	0.141E+07	0.558E-02

SOLUTION SATISFIED CONVERGENCE CRITERION OF 0.00100 IN 15 ITERATIONS

APPENDIX F

INPUT AND OUTPUT DATA FILES FROM EXAMPLE 3

<u>Contents</u> <u>Page</u>

```
TITLE
Parallel Flow Manifold with heat transfer and phase change
   DENCON  GRAVITY  ENERGY  MIXTURE THRUST STEADY      TRANSV
       F       T       T       F       F       T       F
     INERTIA  CONDX    TWOD   PRINTI ROTATION         BUOYANCY HRATE
       f       F       F       F       F       F       F
NNODES NINT NBR  NF NHREF
    20    18    24     1     2
RELAXK  RELAXD  RELAXH
    1.000000    0.500000    1.000000
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     1
    18     1
    19     1
    20     2
PRESSURE TEMPERATURE
     1  0.1020E+04  0.4000E+03  0.0000E+00  0.0000E+00  0.0000E+00
     2  0.1020E+04  0.4000E+03  0.0000E+00  0.0000E+00  0.0000E+00
     3  0.1019E+04  0.4000E+03  0.0000E+00  0.0000E+00  0.0000E+00
     4  0.1019E+04  0.4000E+03  0.0000E+00  0.0000E+00  0.0000E+00
     5  0.1019E+04  0.4000E+03  0.0000E+00  0.0000E+00  0.0000E+00
     6  0.1018E+04  0.4000E+03  0.0000E+00  0.0000E+00  0.0000E+00
     7  0.1018E+04  0.4000E+03  0.0000E+00  0.0000E+00  0.0000E+00
     8  0.1019E+04  0.4000E+03  0.0000E+00  0.0000E+00  0.0000E+00
     9  0.1019E+04  0.4000E+03  0.0000E+00  0.0000E+00  0.0000E+00
    10  0.1019E+04  0.4000E+03  0.0000E+00  0.0000E+00  0.0000E+00
```

11	0.1018E+04	0.4000E+03	0.0000E+00	0.0000E+00	0.0000E+00
12	0.1018E+04	0.4000E+03	0.0000E+00	0.0000E+00	0.0000E+00
13	0.1018E+04	0.4000E+03	0.0000E+00	0.0000E+00	0.0000E+00
14	0.1019E+04	0.4000E+03	0.0000E+00	0.0000E+00	0.0000E+00
15	0.1019E+04	0.4000E+03	0.0000E+00	0.0000E+00	0.0000E+00
16	0.1018E+04	0.4000E+03	0.0000E+00	0.0000E+00	0.0000E+00
17	0.1018E+04	0.4000E+03	0.0000E+00	0.0000E+00	0.0000E+00
18	0.1018E+04	0.4000E+03	0.0000E+00	0.0000E+00	0.0000E+00
19	0.1012E+04	0.4000E+03	0.0000E+00	0.0000E+00	0.0000E+00
20	0.1012E+04	0.4000E+03	0.0000E+00	0.0000E+00	0.0000E+00

INODE	NUMBR		NAMEBR	
2	3	12	28	23
3	3	23	39	34
4	3	34	410	45
5	3	45	511	56
6	3	56	612	67
7	2	67	713	
8	2	28	814	
9	2	39	915	
10	2	410	1016	
11	2	511	1117	
12	2	612	1218	
13	2	713	1319	
14	2	814	1415	
15	3	1415	915	1516
16	3	1516	1016	1617
17	3	1617	1117	1718
18	3	1718	1218	1819
19	3	1819	1319	1920

BRANCH	UPNODE	DNNODE	OPTION
12	1	2	1
28	2	8	5
23	2	3	1
39	3	9	5
34	3	4	1
410	4	10	5
45	4	5	1
511	5	11	5
56	5	6	1
612	6	12	5
67	6	7	1
713	7	13	5
814	8	14	1
915	9	15	1

```
  1016    10    16     1
  1117    11    17     1
  1218    12    18     1
  1319    13    19     1
  1415    14    15     1
  1516    15    16     1
  1617    16    17     1
  1718    17    18     1
  1819    18    19     1
  1920    19    20     1
BRANCH  OPTION -1  LENGTH  DIA EPSD ANGLE AREA
    12     6.00000     1.00000     0.00000    90.00000     0.78540
BRANCH  OPTION -5 pipe dia orifice dia area
    28     1.00000     0.40000     0.12566
BRANCH  OPTION -1  LENGTH  DIA EPSD ANGLE AREA
    23     6.00000     1.00000     0.00000    90.00000     0.78540
BRANCH OPTION - 5 PIPE DIA ORIFICE DIA AREA
    39     1.00000     0.40000     0.12566
BRANCH  OPTION -1  LENGTH  DIA EPSD ANGLE AREA
    34     6.00000     1.00000     0.00000    90.00000     0.78540
BRANCH OPTION - 5 PIPE DIA ORIFICE DIA AREA
   410     1.00000     0.40000     0.12566
BRANCH  OPTION -1  LENGTH  DIA EPSD ANGLE AREA
    45     6.00000     1.00000     0.00000    90.00000     0.78540
BRANCH OPTION - 5 PIPE DIA ORIFICE DIA AREA
   511     1.00000     0.40000     0.12566
BRANCH  OPTION -1  LENGTH  DIA EPSD ANGLE AREA
    56     6.00000     1.00000     0.00000    90.00000     0.78540
BRANCH OPTION - 5 PIPE DIA ORIFICE DIA AREA
   612     1.00000     0.40000     0.12566
BRANCH  OPTION -1  LENGTH  DIA EPSD ANGLE AREA
    67     6.00000     1.00000     0.00000    90.00000     0.78540
BRANCH OPTION - 5 PIPE DIA ORIFICE DIA AREA
   713     1.00000     0.40000     0.12566
BRANCH  OPTION -1  LENGTH  DIA EPSD ANGLE AREA
   814   144.00000     0.40000     0.00000   180.00000     0.12566
BRANCH  OPTION -1  LENGTH  DIA EPSD ANGLE AREA
   915   144.00000     0.40000     0.00000   180.00000     0.12566
BRANCH  OPTION -1  LENGTH  DIA EPSD ANGLE AREA
  1016   144.00000     0.40000     0.00000   180.00000     0.12566
BRANCH  OPTION -1  LENGTH  DIA EPSD ANGLE AREA
  1117   144.00000     0.40000     0.00000   180.00000     0.12566
BRANCH  OPTION -1  LENGTH  DIA EPSD ANGLE AREA
  1218   144.00000     0.40000     0.00000   180.00000     0.12566
```

```
BRANCH  OPTION -1  LENGTH  DIA EPSD ANGLE AREA
  1319   144.00000     0.40000     0.00000   180.00000     0.12566
BRANCH  OPTION -1  LENGTH  DIA EPSD ANGLE AREA
  1415     6.00000     1.00000     0.00000    90.00000     0.78540
BRANCH  OPTION -1  LENGTH  DIA EPSD ANGLE AREA
  1516     6.00000     1.00000     0.00000    90.00000     0.78540
BRANCH  OPTION -1  LENGTH  DIA EPSD ANGLE AREA
  1617     6.00000     1.00000     0.00000    90.00000     0.78540
BRANCH  OPTION -1  LENGTH  DIA EPSD ANGLE AREA
  1718     6.00000     1.00000     0.00000    90.00000     0.78540
BRANCH  OPTION -1  LENGTH  DIA EPSD ANGLE AREA
  1819     6.00000     1.00000     0.00000    90.00000     0.78540
BRANCH  OPTION -1  LENGTH  DIA EPSD ANGLE AREA
  1920     6.00000     1.00000     0.00000    90.00000     0.78540
 BRANCH  NOUBR  NMUBR
    12     0
    28     2    12    23
    23     2    12    28
    39     2    23    34
    34     2    23    39
   410     2    34    45
    45     2    34   410
   511     2    45    56
    56     2    45   511
   612     2    56    67
    67     2    56   612
   713     1    67
   814     1    28
   915     1    39
  1016     1   410
  1117     1   511
  1218     1   612
  1319     1   713
  1415     1   814
  1516     2  1415   915
  1617     2  1516  1016
  1718     2  1617  1117
  1819     2  1718  1218
  1920     2  1819  1319
 BRANCH  NODBR  NMDBR
    12     2    28    23
    28     1   814
    23     2    39    34
    39     1   915
```

```
    34      2   410    45
   410      1  1016
    45      2   511    56
   511      1  1117
    56      2   612    67
   612      1  1218
    67      1   713
   713      1  1319
   814      1  1415
   915      2  1415  1516
  1016      2  1516  1617
  1117      2  1617  1718
  1218      2  1718  1819
  1319      2  1819  1920
  1415      2   915  1516
  1516      2  1016  1617
  1617      2  1117  1718
  1718      2  1218  1819
  1819      2  1319  1920
  1920      0
BRANCH
          12
UPSTREAM  ANGLE
DOWNSTREAM  ANGLE
    28   90.0000
    23    0.0000
BRANCH
          28
UPSTREAM  ANGLE
    12   90.0000
    23   90.0000
DOWNSTREAM  ANGLE
   814    0.0000
BRANCH
          23
UPSTREAM  ANGLE
    12    0.0000
    28   90.0000
DOWNSTREAM  ANGLE
    39   90.0000
    34    0.0000
BRANCH
          39
UPSTREAM  ANGLE
```

```
    23   90.0000
    34   90.0000
DOWNSTREAM  ANGLE
   915    0.0000
BRANCH
          34
UPSTREAM  ANGLE
    23    0.0000
    39   90.0000
DOWNSTREAM  ANGLE
   410   90.0000
    45    0.0000
BRANCH
         410
UPSTREAM  ANGLE
    34   90.0000
    45   90.0000
DOWNSTREAM  ANGLE
  1016    0.0000
BRANCH
          45
UPSTREAM  ANGLE
    34    0.0000
   410   90.0000
DOWNSTREAM  ANGLE
   511   90.0000
    56    0.0000
BRANCH
         511
UPSTREAM  ANGLE
    45   90.0000
    56   90.0000
DOWNSTREAM  ANGLE
  1117    0.0000
BRANCH
          56
UPSTREAM  ANGLE
    45    0.0000
   511   90.0000
DOWNSTREAM  ANGLE
   612   90.0000
    67    0.0000
BRANCH
         612
```

```
UPSTREAM  ANGLE
    56   90.0000
    67   90.0000
DOWNSTREAM  ANGLE
  1218    0.0000
BRANCH
          67
UPSTREAM  ANGLE
    56    0.0000
   612   90.0000
DOWNSTREAM  ANGLE
   713   90.0000
BRANCH
         713
UPSTREAM  ANGLE
    67   90.0000
DOWNSTREAM  ANGLE
  1319    0.0000
BRANCH
         814
UPSTREAM  ANGLE
    28    0.0000
DOWNSTREAM  ANGLE
  1415   90.0000
BRANCH
         915
UPSTREAM  ANGLE
    39    0.0000
DOWNSTREAM  ANGLE
  1415   90.0000
  1516   90.0000
BRANCH
        1016
UPSTREAM  ANGLE
   410    0.0000
DOWNSTREAM  ANGLE
  1516   90.0000
  1617   90.0000
BRANCH
        1117
UPSTREAM  ANGLE
   511    0.0000
DOWNSTREAM  ANGLE
  1617   90.0000
```

```
  1718   90.0000
BRANCH
        1218
UPSTREAM  ANGLE
   612    0.0000
DOWNSTREAM  ANGLE
  1718   90.0000
  1819   90.0000
BRANCH
        1319
UPSTREAM  ANGLE
   713    0.0000
DOWNSTREAM  ANGLE
  1819   90.0000
  1920   90.0000
BRANCH
        1415
UPSTREAM  ANGLE
   814   90.0000
DOWNSTREAM  ANGLE
   915   90.0000
  1516    0.0000
BRANCH
        1516
UPSTREAM  ANGLE
  1415    0.0000
   915   90.0000
DOWNSTREAM  ANGLE
  1016   90.0000
  1617    0.0000
BRANCH
        1617
UPSTREAM  ANGLE
  1516    0.0000
  1016   90.0000
DOWNSTREAM  ANGLE
  1117   90.0000
  1718    0.0000
BRANCH
        1718
UPSTREAM  ANGLE
  1617    0.0000
  1117   90.0000
DOWNSTREAM  ANGLE
```

```
  1218   90.0000
  1819    0.0000
BRANCH
        1819
UPSTREAM  ANGLE
  1718    0.0000
  1218   90.0000
DOWNSTREAM  ANGLE
  1319   90.0000
  1920    0.0000
BRANCH
        1920
UPSTREAM  ANGLE
  1819    0.0000
  1319   90.0000
DOWNSTREAM  ANGLE
```

```
**** GENERAL FLUID SYSTEM SIMULATION PROGRAM ****
 ***************** VERSION 1.4.1 ****************

  TITLE     :Parallel Flow Manifold with heat transfer and phase change
  DATE      :9/11/97
  ANALYST   :jwb
  FILEIN    :example3.dat
  FILEOUT   :example3.out
   LOGICAL VARIABLES
  DENCON   =  F
  GRAVITY  =  T
  ENERGY   =  T
  MIXTURE  =  F
  THRUST   =  F
  STEADY   =  T
  TRANSV   =  F
  INERTIA  =  F
  CONDX    =  F
  TWOD     =  F
  PRINTI   =  F
  ROTATION =  F
  BUOYANCY =  F
  HRATE    =  F


  NNODES   =   20
  NINT     =   18
  NBR      =   24
  NF       =    1
  NVAR     =   42
  NHREF    =    2


  FLUIDS:  H2O

BOUNDARY NODES
 NODE       P          T       RHO        AREA
          (PSI)       (F)   (LBM/FT^3)   (IN^2)
     1   1020.0000  400.0000   53.9197    0.0000
    20   1012.0000  400.0000   53.9170    0.0000

 INPUT SPECIFICATIONS FOR INTERNAL NODES
NODE       AREA      MASS      HEAT
NODE      (IN^2)    (LBM/S)  (BTU/LBM)
```

2	0.0000	0.0000	0.0000
3	0.0000	0.0000	0.0000
4	0.0000	0.0000	0.0000
5	0.0000	0.0000	0.0000
6	0.0000	0.0000	0.0000
7	0.0000	0.0000	0.0000
8	0.0000	0.0000	0.0000
9	0.0000	0.0000	0.0000
10	0.0000	0.0000	0.0000
11	0.0000	0.0000	0.0000
12	0.0000	0.0000	0.0000
13	0.0000	0.0000	0.0000
14	0.0000	0.0000	0.0000
15	0.0000	0.0000	0.0000
16	0.0000	0.0000	0.0000
17	0.0000	0.0000	0.0000
18	0.0000	0.0000	0.0000
19	0.0000	0.0000	0.0000

BRANCH	UPNODE	DNNODE	OPTION
12	1	2	1
28	2	8	5
23	2	3	1
39	3	9	5
34	3	4	1
410	4	10	5
45	4	5	1
511	5	11	5
56	5	6	1
612	6	12	5
67	6	7	1
713	7	13	5
814	8	14	1
915	9	15	1
1016	10	16	1
1117	11	17	1
1218	12	18	1
1319	13	19	1
1415	14	15	1
1516	15	16	1
1617	16	17	1
1718	17	18	1
1819	18	19	1
1920	19	20	1

```
BRANCH  OPTION -1:   LENGTH, DIA, EPSD, ANGLE, AREA
    12     6.00000     1.00000     0.00000    90.00000     0.78540
BRANCH OPTION - 5:  PIPE DIA, ORIFICE DIA, AREA
    28     1.00000     0.40000     0.12566
BRANCH  OPTION -1:   LENGTH, DIA, EPSD, ANGLE, AREA
    23     6.00000     1.00000     0.00000    90.00000     0.78540
BRANCH OPTION - 5:  PIPE DIA, ORIFICE DIA, AREA
    39     1.00000     0.40000     0.12566
BRANCH  OPTION -1:   LENGTH, DIA, EPSD, ANGLE, AREA
    34     6.00000     1.00000     0.00000    90.00000     0.78540
BRANCH OPTION - 5:  PIPE DIA, ORIFICE DIA, AREA
   410     1.00000     0.40000     0.12566
BRANCH  OPTION -1:   LENGTH, DIA, EPSD, ANGLE, AREA
    45     6.00000     1.00000     0.00000    90.00000     0.78540
BRANCH OPTION - 5:  PIPE DIA, ORIFICE DIA, AREA
   511     1.00000     0.40000     0.12566
BRANCH  OPTION -1:   LENGTH, DIA, EPSD, ANGLE, AREA
    56     6.00000     1.00000     0.00000    90.00000     0.78540
BRANCH OPTION - 5:  PIPE DIA, ORIFICE DIA, AREA
   612     1.00000     0.40000     0.12566
BRANCH  OPTION -1:   LENGTH, DIA, EPSD, ANGLE, AREA
    67     6.00000     1.00000     0.00000    90.00000     0.78540
BRANCH OPTION - 5:  PIPE DIA, ORIFICE DIA, AREA
   713     1.00000     0.40000     0.12566
BRANCH  OPTION -1:   LENGTH, DIA, EPSD, ANGLE, AREA
   814   144.00000     0.40000     0.00000   180.00000     0.12566
BRANCH  OPTION -1:   LENGTH, DIA, EPSD, ANGLE, AREA
   915   144.00000     0.40000     0.00000   180.00000     0.12566
BRANCH  OPTION -1:   LENGTH, DIA, EPSD, ANGLE, AREA
  1016   144.00000     0.40000     0.00000   180.00000     0.12566
BRANCH  OPTION -1:   LENGTH, DIA, EPSD, ANGLE, AREA
  1117   144.00000     0.40000     0.00000   180.00000     0.12566
BRANCH  OPTION -1:   LENGTH, DIA, EPSD, ANGLE, AREA
  1218   144.00000     0.40000     0.00000   180.00000     0.12566
BRANCH  OPTION -1:   LENGTH, DIA, EPSD, ANGLE, AREA
  1319   144.00000     0.40000     0.00000   180.00000     0.12566
BRANCH  OPTION -1:   LENGTH, DIA, EPSD, ANGLE, AREA
  1415     6.00000     1.00000     0.00000    90.00000     0.78540
BRANCH  OPTION -1:   LENGTH, DIA, EPSD, ANGLE, AREA
  1516     6.00000     1.00000     0.00000    90.00000     0.78540
BRANCH  OPTION -1:   LENGTH, DIA, EPSD, ANGLE, AREA
  1617     6.00000     1.00000     0.00000    90.00000     0.78540
BRANCH  OPTION -1:   LENGTH, DIA, EPSD, ANGLE, AREA
  1718     6.00000     1.00000     0.00000    90.00000     0.78540
```

BRANCH OPTION -1: LENGTH, DIA, EPSD, ANGLE, AREA

1819	6.00000	1.00000	0.00000	90.00000	0.78540

BRANCH OPTION -1: LENGTH, DIA, EPSD, ANGLE, AREA

1920	6.00000	1.00000	0.00000	90.00000	0.78540

SOLUTION

INTERNAL NODES

NODE	P(PSI)	T(F)	Z	RHO	QUALITY
					(LBM/FT^3)
2	1019.9667	399.9988	0.0370	53.9198	0.0000
3	1019.9426	399.9980	0.0369	53.9198	0.0000
4	1019.9265	399.9985	0.0369	53.9197	0.0000
5	1019.9169	399.9990	0.0369	53.9197	0.0000
6	1019.9122	399.9985	0.0369	53.9197	0.0000
7	1019.9108	399.9979	0.0369	53.9197	0.0000
8	1019.2312	399.9991	0.0369	53.9195	0.0000
9	1019.2126	399.9993	0.0369	53.9195	0.0000
10	1019.1995	399.9990	0.0369	53.9195	0.0000
11	1019.1899	399.9991	0.0369	53.9195	0.0000
12	1019.1822	399.9993	0.0369	53.9194	0.0000
13	1019.1754	399.9992	0.0369	53.9194	0.0000
14	1012.0892	400.0070	0.0367	53.9170	0.0000
15	1012.0878	400.0072	0.0367	53.9170	0.0000
16	1012.0831	400.0069	0.0367	53.9169	0.0000
17	1012.0735	400.0068	0.0367	53.9169	0.0000
18	1012.0574	400.0072	0.0367	53.9169	0.0000
19	1012.0333	400.0068	0.0367	53.9168	0.0000

BRANCHES

BRANCH	KFACTOR	DELP	FLOW RATE	VELOCITY	REYN. NO.	MACH NO.
	(LBF-S^2/(LBM-FT)^2)	(PSI)	(LBM/SEC)	(FT/SEC)		
12	0.107E+01	0.333E-01	0.212E+01	0.722E+01	0.366E+06	0.404E-02
28	0.839E+03	0.735E+00	0.355E+00	0.755E+01	0.153E+06	0.422E-02
23	0.111E+01	0.241E-01	0.177E+01	0.602E+01	0.305E+06	0.336E-02
39	0.839E+03	0.730E+00	0.354E+00	0.752E+01	0.152E+06	0.420E-02
34	0.116E+01	0.161E-01	0.142E+01	0.481E+01	0.244E+06	0.269E-02
410	0.839E+03	0.727E+00	0.353E+00	0.751E+01	0.152E+06	0.419E-02
45	0.124E+01	0.966E-02	0.106E+01	0.361E+01	0.183E+06	0.202E-02
511	0.839E+03	0.727E+00	0.353E+00	0.751E+01	0.152E+06	0.419E-02
56	0.136E+01	0.467E-02	0.709E+00	0.241E+01	0.122E+06	0.135E-02
612	0.839E+03	0.730E+00	0.354E+00	0.752E+01	0.152E+06	0.420E-02
67	0.161E+01	0.141E-02	0.355E+00	0.121E+01	0.612E+05	0.675E-03

713	0.839E+03	0.735E+00	0.355E+00	0.755E+01	0.153E+06	0.422E-02
814	0.302E+04	0.714E+01	0.355E+00	0.755E+01	0.153E+06	0.422E-02
915	0.303E+04	0.712E+01	0.354E+00	0.752E+01	0.152E+06	0.420E-02
1016	0.303E+04	0.712E+01	0.353E+00	0.751E+01	0.152E+06	0.419E-02
1117	0.303E+04	0.712E+01	0.353E+00	0.751E+01	0.152E+06	0.419E-02
1218	0.303E+04	0.712E+01	0.354E+00	0.752E+01	0.152E+06	0.420E-02
1319	0.302E+04	0.714E+01	0.355E+00	0.755E+01	0.153E+06	0.422E-02
1415	0.161E+01	0.141E-02	0.355E+00	0.121E+01	0.612E+05	0.675E-03
1516	0.136E+01	0.467E-02	0.709E+00	0.241E+01	0.122E+06	0.135E-02
1617	0.124E+01	0.966E-02	0.106E+01	0.361E+01	0.183E+06	0.202E-02
1718	0.116E+01	0.161E-01	0.142E+01	0.481E+01	0.244E+06	0.269E-02
1819	0.111E+01	0.241E-01	0.177E+01	0.602E+01	0.305E+06	0.336E-02
1920	0.107E+01	0.333E-01	0.212E+01	0.723E+01	0.366E+06	0.404E-02

SOLUTION SATISFIED CONVERGENCE CRITERION OF 0.00100 IN 32 ITERATIONS

APPENDIX G

INPUT AND OUTPUT DATA FILES FROM EXAMPLE 4

Contents **Page**

```
TITLE
Parallel Flow Manifold with heat transfer and phase change
   DENCON  GRAVITY  ENERGY  MIXTURE THRUST STEADY      TRANSV
       F       T       T       F       F       T       F
     INERTIA  CONDX    TWOD   PRINTI ROTATION         BUOYANCY HRATE
       F       F       F       F       F       F       f
NNODES NINT NBR  NF NHREF
    20    18    24     1     2
RELAXK  RELAXD  RELAXH
    1.000000    0.500000    1.000000
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     1
    18     1
    19     1
    20     2
PRESSURE TEMPERATURE
     1  0.1020E+04  0.4000E+03  0.0000E+00  0.0000E+00  0.0000E+00
     2  0.1020E+04  0.4000E+03  0.0000E+00  0.0000E+00  0.0000E+00
     3  0.1019E+04  0.4000E+03  0.0000E+00  0.0000E+00  0.0000E+00
     4  0.1019E+04  0.4000E+03  0.0000E+00  0.0000E+00  0.0000E+00
     5  0.1019E+04  0.4000E+03  0.0000E+00  0.0000E+00  0.0000E+00
     6  0.1018E+04  0.4000E+03  0.0000E+00  0.0000E+00  0.0000E+00
```

7	0.1018E+04	0.4000E+03	0.0000E+00	0.0000E+00	0.0000E+00
8	0.1019E+04	0.4000E+03	0.0000E+00	6.5000E+02	0.0000E+00
9	0.1019E+04	0.4000E+03	0.0000E+00	6.5000E+02	0.0000E+00
10	0.1019E+04	0.4000E+03	0.0000E+00	6.5000E+02	0.0000E+00
11	0.1018E+04	0.4000E+03	0.0000E+00	6.5000E+02	0.0000E+00
12	0.1018E+04	0.4000E+03	0.0000E+00	6.5000E+02	0.0000E+00
13	0.1018E+04	0.4000E+03	0.0000E+00	6.5000E+02	0.0000E+00
14	0.1019E+04	0.4000E+03	0.0000E+00	0.0000E+00	0.0000E+00
15	0.1019E+04	0.4000E+03	0.0000E+00	0.0000E+00	0.0000E+00
16	0.1018E+04	0.4000E+03	0.0000E+00	0.0000E+00	0.0000E+00
17	0.1018E+04	0.4000E+03	0.0000E+00	0.0000E+00	0.0000E+00
18	0.1018E+04	0.4000E+03	0.0000E+00	0.0000E+00	0.0000E+00
19	0.1012E+04	0.4000E+03	0.0000E+00	0.0000E+00	0.0000E+00
20	0.1012E+04	0.4000E+03	0.0000E+00	0.0000E+00	0.0000E+00

INODE	NUMBR	NAMEBR		
2	3	12	28	23
3	3	23	39	34
4	3	34	410	45
5	3	45	511	56
6	3	56	612	67
7	2	67	713	
8	2	28	814	
9	2	39	915	
10	2	410	1016	
11	2	511	1117	
12	2	612	1218	
13	2	713	1319	
14	2	814	1415	
15	3	1415	915	1516
16	3	1516	1016	1617
17	3	1617	1117	1718
18	3	1718	1218	1819
19	3	1819	1319	1920

BRANCH	UPNODE	DNNODE	OPTION
12	1	2	1
28	2	8	5
23	2	3	1
39	3	9	5
34	3	4	1
410	4	10	5

```
    45     4     5     1
   511     5    11     5
    56     5     6     1
   612     6    12     5
    67     6     7     1
   713     7    13     5
   814     8    14     1
   915     9    15     1
  1016    10    16     1
  1117    11    17     1
  1218    12    18     1
  1319    13    19     1
  1415    14    15     1
  1516    15    16     1
  1617    16    17     1
  1718    17    18     1
  1819    18    19     1
  1920    19    20     1
BRANCH  OPTION -1  LENGTH  DIA EPSD ANGLE AREA
    12     6.00000     1.00000     0.00000    90.00000     0.78540
BRANCH  OPTION -5 pipe dia orifice dia area
    28     1.00000     0.40000     0.12566
BRANCH  OPTION -1  LENGTH  DIA EPSD ANGLE AREA
    23     6.00000     1.00000     0.00000    90.00000     0.78540
BRANCH OPTION - 5 PIPE DIA ORIFICE DIA AREA
    39     1.00000     0.40000     0.12566
BRANCH  OPTION -1  LENGTH  DIA EPSD ANGLE AREA
    34     6.00000     1.00000     0.00000    90.00000     0.78540
BRANCH OPTION - 5 PIPE DIA ORIFICE DIA AREA
   410     1.00000     0.40000     0.12566
BRANCH  OPTION -1  LENGTH  DIA EPSD ANGLE AREA
    45     6.00000     1.00000     0.00000    90.00000     0.78540
BRANCH OPTION - 5 PIPE DIA ORIFICE DIA AREA
   511     1.00000     0.40000     0.12566
BRANCH  OPTION -1  LENGTH  DIA EPSD ANGLE AREA
    56     6.00000     1.00000     0.00000    90.00000     0.78540
BRANCH OPTION - 5 PIPE DIA ORIFICE DIA AREA
   612     1.00000     0.40000     0.12566
BRANCH  OPTION -1  LENGTH  DIA EPSD ANGLE AREA
    67     6.00000     1.00000     0.00000    90.00000     0.78540
```

```
BRANCH OPTION - 5 PIPE DIA ORIFICE DIA AREA
   713     1.00000     0.40000     0.12566
BRANCH  OPTION -1  LENGTH  DIA EPSD ANGLE AREA
   814   144.00000     0.40000     0.00000   180.00000     0.12566
BRANCH  OPTION -1  LENGTH  DIA EPSD ANGLE AREA
   915   144.00000     0.40000     0.00000   180.00000     0.12566
BRANCH  OPTION -1  LENGTH  DIA EPSD ANGLE AREA
  1016   144.00000     0.40000     0.00000   180.00000     0.12566
BRANCH  OPTION -1  LENGTH  DIA EPSD ANGLE AREA
  1117   144.00000     0.40000     0.00000   180.00000     0.12566
BRANCH  OPTION -1  LENGTH  DIA EPSD ANGLE AREA
  1218   144.00000     0.40000     0.00000   180.00000     0.12566
BRANCH  OPTION -1  LENGTH  DIA EPSD ANGLE AREA
  1319   144.00000     0.40000     0.00000   180.00000     0.12566
BRANCH  OPTION -1  LENGTH  DIA EPSD ANGLE AREA
  1415     6.00000     1.00000     0.00000    90.00000     0.78540
BRANCH  OPTION -1  LENGTH  DIA EPSD ANGLE AREA
  1516     6.00000     1.00000     0.00000    90.00000     0.78540
BRANCH  OPTION -1  LENGTH  DIA EPSD ANGLE AREA
  1617     6.00000     1.00000     0.00000    90.00000     0.78540
BRANCH  OPTION -1  LENGTH  DIA EPSD ANGLE AREA
  1718     6.00000     1.00000     0.00000    90.00000     0.78540
BRANCH  OPTION -1  LENGTH  DIA EPSD ANGLE AREA
  1819     6.00000     1.00000     0.00000    90.00000     0.78540
BRANCH  OPTION -1  LENGTH  DIA EPSD ANGLE AREA
  1920     6.00000     1.00000     0.00000    90.00000     0.78540
 BRANCH  NOUBR  NMUBR
    12     0
    28     2    12    23
    23     2    12    28
    39     2    23    34
    34     2    23    39
   410     2    34    45
    45     2    34   410
   511     2    45    56
    56     2    45   511
   612     2    56    67
    67     2    56   612
   713     1    67
   814     1    28
```

```
   915     1    39
  1016     1   410
  1117     1   511
  1218     1   612
  1319     1   713
  1415     1   814
  1516     2  1415   915
  1617     2  1516  1016
  1718     2  1617  1117
  1819     2  1718  1218
  1920     2  1819  1319
 BRANCH  NODBR  NMDBR
    12     2    28    23
    28     1   814
    23     2    39    34
    39     1   915
    34     2   410    45
   410     1  1016
    45     2   511    56
   511     1  1117
    56     2   612    67
   612     1  1218
    67     1   713
   713     1  1319
   814     1  1415
   915     2  1415  1516
  1016     2  1516  1617
  1117     2  1617  1718
  1218     2  1718  1819
  1319     2  1819  1920
  1415     2   915  1516
  1516     2  1016  1617
  1617     2  1117  1718
  1718     2  1218  1819
  1819     2  1319  1920
  1920     0
BRANCH
          12
UPSTREAM  ANGLE
DOWNSTREAM  ANGLE
```

```
    28   90.0000
    23    0.0000
BRANCH
          28
UPSTREAM  ANGLE
    12   90.0000
    23   90.0000
DOWNSTREAM  ANGLE
   814    0.0000
BRANCH
          23
UPSTREAM  ANGLE
    12    0.0000
    28   90.0000
DOWNSTREAM  ANGLE
    39   90.0000
    34    0.0000
BRANCH
          39
UPSTREAM  ANGLE
    23   90.0000
    34   90.0000
DOWNSTREAM  ANGLE
   915    0.0000
BRANCH
          34
UPSTREAM  ANGLE
    23    0.0000
    39   90.0000
DOWNSTREAM  ANGLE
   410   90.0000
    45    0.0000
BRANCH
         410
UPSTREAM  ANGLE
    34   90.0000
    45   90.0000
DOWNSTREAM  ANGLE
  1016    0.0000
BRANCH
```

```
          45
UPSTREAM  ANGLE
    34    0.0000
   410   90.0000
DOWNSTREAM  ANGLE
   511   90.0000
    56    0.0000
BRANCH
         511
UPSTREAM  ANGLE
    45   90.0000
    56   90.0000
DOWNSTREAM  ANGLE
  1117    0.0000
BRANCH
          56
UPSTREAM  ANGLE
    45    0.0000
   511   90.0000
DOWNSTREAM  ANGLE
   612   90.0000
    67    0.0000
BRANCH
         612
UPSTREAM  ANGLE
    56   90.0000
    67   90.0000
DOWNSTREAM  ANGLE
  1218    0.0000
BRANCH
          67
UPSTREAM  ANGLE
    56    0.0000
   612   90.0000
DOWNSTREAM  ANGLE
   713   90.0000
BRANCH
         713
UPSTREAM  ANGLE
    67   90.0000
```

```
DOWNSTREAM  ANGLE
  1319    0.0000
BRANCH
         814
UPSTREAM  ANGLE
    28    0.0000
DOWNSTREAM  ANGLE
  1415   90.0000
BRANCH
         915
UPSTREAM  ANGLE
    39    0.0000
DOWNSTREAM  ANGLE
  1415   90.0000
  1516   90.0000
BRANCH
        1016
UPSTREAM  ANGLE
   410    0.0000
DOWNSTREAM  ANGLE
  1516   90.0000
  1617   90.0000
BRANCH
        1117
UPSTREAM  ANGLE
   511    0.0000
DOWNSTREAM  ANGLE
  1617   90.0000
  1718   90.0000
BRANCH
        1218
UPSTREAM  ANGLE
   612    0.0000
DOWNSTREAM  ANGLE
  1718   90.0000
  1819   90.0000
BRANCH
        1319
UPSTREAM  ANGLE
   713    0.0000
```

```
DOWNSTREAM  ANGLE
  1819   90.0000
  1920   90.0000
BRANCH
        1415
UPSTREAM  ANGLE
   814   90.0000
DOWNSTREAM  ANGLE
   915   90.0000
  1516    0.0000
BRANCH
        1516
UPSTREAM  ANGLE
  1415    0.0000
   915   90.0000
DOWNSTREAM  ANGLE
  1016   90.0000
  1617    0.0000
BRANCH
        1617
UPSTREAM  ANGLE
  1516    0.0000
  1016   90.0000
DOWNSTREAM  ANGLE
  1117   90.0000
  1718    0.0000
BRANCH
        1718
UPSTREAM  ANGLE
  1617    0.0000
  1117   90.0000
DOWNSTREAM  ANGLE
  1218   90.0000
  1819    0.0000
BRANCH
        1819
UPSTREAM  ANGLE
  1718    0.0000
  1218   90.0000
DOWNSTREAM  ANGLE
```

```
  1319   90.0000
  1920    0.0000
BRANCH
        1920
UPSTREAM  ANGLE
  1819    0.0000
  1319   90.0000
DOWNSTREAM  ANGLE
```

```
**** GENERAL FLUID SYSTEM SIMULATION PROGRAM ****
 ***************** VERSION 1.4.1 ****************

  TITLE     :Parallel Flow Manifold with heat transfer and phase change
  DATE      :9/11/97
  ANALYST   :jwb
  FILEIN    :example4.dat
  FILEOUT   :example4.out
   LOGICAL VARIABLES
  DENCON   =  F
  GRAVITY  =  T
  ENERGY   =  T
  MIXTURE  =  F
  THRUST   =  F
  STEADY   =  T
  TRANSV   =  F
  INERTIA  =  F
  CONDX    =  F
  TWOD     =  F
  PRINTI   =  F
  ROTATION =  F
  BUOYANCY =  F
  HRATE    =  F


  NNODES   =   20
  NINT     =   18
  NBR      =   24
  NF       =    1
  NVAR     =   42
  NHREF    =    2


  FLUIDS:  H2O

BOUNDARY NODES
 NODE        P          T        RHO         AREA
           (PSI)       (F)   (LBM/FT^3)   (IN^2)
     1   1020.0000  400.0000   53.9197     0.0000
    20   1012.0000  400.0000   53.9170     0.0000
```

INPUT SPECIFICATIONS FOR INTERNAL NODES

NODE NODE	AREA (IN^2)	MASS (LBM/S)	HEAT (BTU/LBM)
2	0.0000	0.0000	0.0000
3	0.0000	0.0000	0.0000
4	0.0000	0.0000	0.0000
5	0.0000	0.0000	0.0000
6	0.0000	0.0000	0.0000
7	0.0000	0.0000	0.0000
8	0.0000	0.0000	650.0000
9	0.0000	0.0000	650.0000
10	0.0000	0.0000	650.0000
11	0.0000	0.0000	650.0000
12	0.0000	0.0000	650.0000
13	0.0000	0.0000	650.0000
14	0.0000	0.0000	0.0000
15	0.0000	0.0000	0.0000
16	0.0000	0.0000	0.0000
17	0.0000	0.0000	0.0000
18	0.0000	0.0000	0.0000
19	0.0000	0.0000	0.0000

BRANCH	UPNODE	DNNODE	OPTION
12	1	2	1
28	2	8	5
23	2	3	1
39	3	9	5
34	3	4	1
410	4	10	5
45	4	5	1
511	5	11	5
56	5	6	1
612	6	12	5
67	6	7	1
713	7	13	5
814	8	14	1
915	9	15	1
1016	10	16	1
1117	11	17	1

```
  1218        12        18         1
  1319        13        19         1
  1415        14        15         1
  1516        15        16         1
  1617        16        17         1
  1718        17        18         1
  1819        18        19         1
  1920        19        20         1
BRANCH  OPTION -1:   LENGTH, DIA, EPSD, ANGLE, AREA
    12     6.00000     1.00000     0.00000    90.00000     0.78540
BRANCH OPTION - 5:  PIPE DIA, ORIFICE DIA, AREA
    28     1.00000     0.40000     0.12566
BRANCH  OPTION -1:   LENGTH, DIA, EPSD, ANGLE, AREA
    23     6.00000     1.00000     0.00000    90.00000     0.78540
BRANCH OPTION - 5:  PIPE DIA, ORIFICE DIA, AREA
    39     1.00000     0.40000     0.12566
BRANCH  OPTION -1:   LENGTH, DIA, EPSD, ANGLE, AREA
    34     6.00000     1.00000     0.00000    90.00000     0.78540
BRANCH OPTION - 5:  PIPE DIA, ORIFICE DIA, AREA
   410     1.00000     0.40000     0.12566
BRANCH  OPTION -1:   LENGTH, DIA, EPSD, ANGLE, AREA
    45     6.00000     1.00000     0.00000    90.00000     0.78540
BRANCH OPTION - 5:  PIPE DIA, ORIFICE DIA, AREA
   511     1.00000     0.40000     0.12566
BRANCH  OPTION -1:   LENGTH, DIA, EPSD, ANGLE, AREA
    56     6.00000     1.00000     0.00000    90.00000     0.78540
BRANCH OPTION - 5:  PIPE DIA, ORIFICE DIA, AREA
   612     1.00000     0.40000     0.12566
BRANCH  OPTION -1:   LENGTH, DIA, EPSD, ANGLE, AREA
    67     6.00000     1.00000     0.00000    90.00000     0.78540
BRANCH OPTION - 5:  PIPE DIA, ORIFICE DIA, AREA
   713     1.00000     0.40000     0.12566
BRANCH  OPTION -1:   LENGTH, DIA, EPSD, ANGLE, AREA
   814   144.00000     0.40000     0.00000   180.00000     0.12566
BRANCH  OPTION -1:   LENGTH, DIA, EPSD, ANGLE, AREA
   915   144.00000     0.40000     0.00000   180.00000     0.12566
BRANCH  OPTION -1:   LENGTH, DIA, EPSD, ANGLE, AREA
  1016   144.00000     0.40000     0.00000   180.00000     0.12566
BRANCH  OPTION -1:   LENGTH, DIA, EPSD, ANGLE, AREA
  1117   144.00000     0.40000     0.00000   180.00000     0.12566
```

BRANCH OPTION -1: LENGTH, DIA, EPSD, ANGLE, AREA

BRANCH	LENGTH	DIA	EPSD	ANGLE	AREA
1218	144.00000	0.40000	0.00000	180.00000	0.12566

BRANCH OPTION -1: LENGTH, DIA, EPSD, ANGLE, AREA

BRANCH	LENGTH	DIA	EPSD	ANGLE	AREA
1319	144.00000	0.40000	0.00000	180.00000	0.12566

BRANCH OPTION -1: LENGTH, DIA, EPSD, ANGLE, AREA

BRANCH	LENGTH	DIA	EPSD	ANGLE	AREA
1415	6.00000	1.00000	0.00000	90.00000	0.78540

BRANCH OPTION -1: LENGTH, DIA, EPSD, ANGLE, AREA

BRANCH	LENGTH	DIA	EPSD	ANGLE	AREA
1516	6.00000	1.00000	0.00000	90.00000	0.78540

BRANCH OPTION -1: LENGTH, DIA, EPSD, ANGLE, AREA

BRANCH	LENGTH	DIA	EPSD	ANGLE	AREA
1617	6.00000	1.00000	0.00000	90.00000	0.78540

BRANCH OPTION -1: LENGTH, DIA, EPSD, ANGLE, AREA

BRANCH	LENGTH	DIA	EPSD	ANGLE	AREA
1718	6.00000	1.00000	0.00000	90.00000	0.78540

BRANCH OPTION -1: LENGTH, DIA, EPSD, ANGLE, AREA

BRANCH	LENGTH	DIA	EPSD	ANGLE	AREA
1819	6.00000	1.00000	0.00000	90.00000	0.78540

BRANCH OPTION -1: LENGTH, DIA, EPSD, ANGLE, AREA

BRANCH	LENGTH	DIA	EPSD	ANGLE	AREA
1920	6.00000	1.00000	0.00000	90.00000	0.78540

SOLUTION

INTERNAL NODES

NODE	P(PSI)	T(F)	Z	RHO (LBM/FT^3)	QUALITY
2	1019.9930	399.9988	0.0370	53.9198	0.0000
3	1019.9880	399.9974	0.0370	53.9198	0.0000
4	1019.9847	399.9990	0.0370	53.9198	0.0000
5	1019.9827	399.9982	0.0370	53.9198	0.0000
6	1019.9818	399.9983	0.0370	53.9198	0.0000
7	1019.9814	399.9983	0.0370	53.9198	0.0000
8	1019.8688	547.2317	0.5612	3.0317	0.7440
9	1019.8638	547.2311	0.5612	3.0317	0.7440
10	1019.8602	547.2307	0.5612	3.0317	0.7440
11	1019.8577	547.2303	0.5612	3.0317	0.7440
12	1019.8560	547.2302	0.5612	3.0316	0.7440
13	1019.8545	547.2300	0.5612	3.0316	0.7440
14	1012.2543	546.3177	0.5622	3.0064	0.7441
15	1012.2504	546.3173	0.5622	3.0064	0.7441
16	1012.2371	546.3158	0.5622	3.0064	0.7441
17	1012.2097	546.3124	0.5622	3.0063	0.7441
18	1012.1638	546.3069	0.5622	3.0061	0.7441

19	1012.0953	546.2987	0.5622	3.0059	0.7441

BRANCHES

BRANCH	KFACTOR (LBF-S^2/(LBM-FT)^2)	DELP (PSI)	FLOW RATE (LBM/SEC)	VELOCITY (FT/SEC)	REYN. NO.	MACH NO.
12	0.129E+01	0.694E-02	0.881E+00	0.300E+01	0.152E+06	0.167E-02
28	0.835E+03	0.124E+00	0.146E+00	0.311E+01	0.631E+05	0.174E-02
23	0.135E+01	0.499E-02	0.735E+00	0.250E+01	0.127E+06	0.140E-02
39	0.835E+03	0.124E+00	0.146E+00	0.311E+01	0.631E+05	0.174E-02
34	0.142E+01	0.336E-02	0.589E+00	0.200E+01	0.101E+06	0.112E-02
410	0.835E+03	0.124E+00	0.147E+00	0.311E+01	0.631E+05	0.174E-02
45	0.152E+01	0.195E-02	0.442E+00	0.150E+01	0.762E+05	0.840E-03
511	0.835E+03	0.125E+00	0.147E+00	0.312E+01	0.632E+05	0.174E-02
56	0.169E+01	0.977E-03	0.295E+00	0.100E+01	0.509E+05	0.561E-03
612	0.835E+03	0.126E+00	0.147E+00	0.313E+01	0.635E+05	0.175E-02
67	0.203E+01	0.326E-03	0.148E+00	0.503E+00	0.255E+05	0.281E-03
713	0.835E+03	0.127E+00	0.148E+00	0.315E+01	0.638E+05	0.176E-02
814	0.495E+05	0.761E+01	0.146E+00	0.553E+02	0.222E+06	0.243E-01
915	0.495E+05	0.761E+01	0.146E+00	0.553E+02	0.222E+06	0.243E-01
1016	0.495E+05	0.762E+01	0.147E+00	0.554E+02	0.222E+06	0.243E-01
1117	0.494E+05	0.765E+01	0.147E+00	0.555E+02	0.222E+06	0.243E-01
1218	0.494E+05	0.769E+01	0.147E+00	0.557E+02	0.223E+06	0.244E-01
1319	0.494E+05	0.776E+01	0.148E+00	0.559E+02	0.224E+06	0.245E-01
1415	0.263E+02	0.391E-02	0.146E+00	0.893E+01	0.887E+05	0.392E-02
1516	0.224E+02	0.133E-01	0.293E+00	0.179E+02	0.177E+06	0.784E-02
1617	0.205E+02	0.273E-01	0.439E+00	0.268E+02	0.266E+06	0.118E-01
1718	0.192E+02	0.459E-01	0.586E+00	0.357E+02	0.355E+06	0.157E-01
1819	0.184E+02	0.686E-01	0.733E+00	0.447E+02	0.444E+06	0.196E-01
1920	0.177E+02	0.953E-01	0.881E+00	0.538E+02	0.534E+06	0.236E-01

SOLUTION SATISFIED CONVERGENCE CRITERION OF 0.00100 IN 69 ITERATIONS

APPENDIX H

INPUT AND OUTPUT DATA FILES FROM EXAMPLE 5

Contents **Page**

```
TITLE
Sample Flow Circuit of a turbopump
   DENCON  GRAVITY  ENERGY  MIXTURE THRUST STEADY      TRANSV
       F       F       T       T       F       T       F
     INERTIA  CONDX    TWOD   PRINTI ROTATION         BUOYANCY HRATE
       T       F       F       F       F       F       F
NNODES NINT NBR  NF NHREF
    12     7    12     3     2
RELAXK  RELAXD  RELAXH
    1.000000    0.500000    1.000000
NFLUID(I), I= 1,NF
     6    10     1
NODE INDEX
    48     2
    49     1
    50     2
    68     1
    67     1
    66     2
    23     1
    63     1
    46     1
    47     1
    16     2
    22     2
NODE PRESSURE TEMPERATURE MASS SOURCE HEAT         SOURCE NODE AREA CONCENTRATIONS
    48  0.5500E+03 -0.6000E+02  0.0000E+00  0.0000E+00  0.0000E+00 1.0000 0.0000 0.0000
    49  0.5054E+03 -0.6000E+02  0.0000E+00  0.0000E+00  0.0000E+00 1.0000 0.0000 0.0000
    50  0.1470E+02  0.8000E+02  0.0000E+00  0.0000E+00  0.0000E+00 0.5000 0.0000 0.5000
    68  0.5500E+03  0.7000E+02  0.0000E+00  0.0000E+00  0.0000E+00 0.0000 0.0000 1.0000
    67  0.1064E+03  0.7000E+02  0.0000E+00  0.0000E+00  0.0000E+00 0.0000 0.0000 1.0000
    66  0.1510E+03  0.7000E+02  0.0000E+00  0.0000E+00  0.0000E+00 0.0000 0.0000 1.0000
    23  0.1274E+03 -0.1740E+03  0.0000E+00  0.0000E+00  0.0000E+00 0.0000 0.0000 1.0000
    63  0.8278E+02 -0.1740E+03  0.0000E+00  0.0000E+00  0.0000E+00 0.0000 0.0000 1.0000
    46  0.3817E+02 -0.1740E+03  0.0000E+00  0.0000E+00  0.0000E+00 0.0000 0.0000 1.0000
    47  0.5931E+02 -0.1740E+03  0.0000E+00  0.0000E+00  0.0000E+00 0.0000 0.0000 1.0000
    16  0.1470E+02  0.8000E+02  0.0000E+00  0.0000E+00  0.0000E+00 0.0000 0.5000 0.5000
    22  0.1720E+03 -0.1740E+03  0.0000E+00  0.0000E+00  0.0000E+00 0.0000 1.0000 0.0000
INODE   NUMBR         NAMEBR
    49     3    58   142    59
    68     3    59   138    60
    67     2   138   137
    23     3    60   129    23
    63     2   129    88
```

```
    46     3    88    87    86
    47     3    87    86    25
BRANCH   UPNODE  DNNODE  OPTION
    58    48    49     2
   142    49    50     2
    59    68    49     2
   138    67    68     2
    60    68    23     2
   137    66    67     2
   129    23    63     2
    23    22    23     2
    88    63    46     2
    87    46    47     2
    86    46    47     2
    25    47    16     2
BRANCH OPTION -2 FLOW COEF AREA
    58     0.22000     0.04000
BRANCH OPTION -2 FLOW COEF AREA
   142     0.74000     0.78500
BRANCH OPTION -2 FLOW COEF AREA
    59     0.34000     0.03000
BRANCH OPTION -2 FLOW COEF AREA
   138     0.66000     0.09000
BRANCH OPTION -2 FLOW COEF AREA
    60     0.35440     0.03000
BRANCH OPTION -2 FLOW COEF AREA
   137     0.88000     0.09000
BRANCH OPTION -2 FLOW COEF AREA
   129     0.79000     0.78540
BRANCH OPTION -2 FLOW COEF AREA
    23     0.24000     0.04000
BRANCH OPTION -2 FLOW COEF AREA
    88     0.71000     0.79000
BRANCH OPTION -2 FLOW COEF AREA
    87     0.79000     0.37000
BRANCH OPTION -2 FLOW COEF AREA
    86     0.37000     0.46000
BRANCH OPTION -2 FLOW COEF AREA
    25     0.51000     1.09000
 BRANCH  NOUBR  NMUBR
    58     0
   142     2    58    59
    59     2   138    60
   138     1   137
```

```
    60      2    59   138
   137      0
   129      2    60    23
    23      0
    88      1   129
    87      2    88    86
    86      2    88    87
    25      2    87    86
  BRANCH  NODBR  NMDBR
    58      2   142    59
   142      0
    59      2    58   142
   138      2    59    60
    60      2   129    23
   137      1   138
   129      1    88
    23      2    60   129
    88      2    87    86
    87      2    86    25
    86      2    87    25
    25      0
BRANCH
          58
UPSTREAM  ANGLE
DOWNSTREAM  ANGLE
   142    0.0000
    59    0.0000
BRANCH
         142
UPSTREAM  ANGLE
    58    0.0000
    59    0.0000
DOWNSTREAM  ANGLE
BRANCH
          59
UPSTREAM  ANGLE
   138    0.0000
    60    0.0000
DOWNSTREAM  ANGLE
    58    0.0000
   142    0.0000
BRANCH
         138
UPSTREAM  ANGLE
```

```
   137    0.0000
DOWNSTREAM  ANGLE
    59    0.0000
    60    0.0000
BRANCH
          60
UPSTREAM  ANGLE
    59    0.0000
   138    0.0000
DOWNSTREAM  ANGLE
   129    0.0000
    23    0.0000
BRANCH
         137
UPSTREAM  ANGLE
DOWNSTREAM  ANGLE
   138    0.0000
BRANCH
         129
UPSTREAM  ANGLE
    60    0.0000
    23    0.0000
DOWNSTREAM  ANGLE
    88    0.0000
BRANCH
          23
UPSTREAM  ANGLE
DOWNSTREAM  ANGLE
    60    0.0000
   129    0.0000
BRANCH
          88
UPSTREAM  ANGLE
   129    0.0000
DOWNSTREAM  ANGLE
    87    0.0000
    86    0.0000
BRANCH
          87
UPSTREAM  ANGLE
    88    0.0000
    86    0.0000
DOWNSTREAM  ANGLE
    86    0.0000
```

```
    25    0.0000
BRANCH
          86
UPSTREAM  ANGLE
    88    0.0000
    87    0.0000
DOWNSTREAM  ANGLE
    87    0.0000
    25    0.0000
BRANCH
          25
UPSTREAM  ANGLE
    87    0.0000
    86    0.0000
DOWNSTREAM  ANGLE
```

```
**** GENERAL FLUID SYSTEM SIMULATION PROGRAM ****
 ***************** VERSION 1.4.1 ****************

  TITLE     :Sample Flow Circuit of a turbopump
  DATE      :9/11/97
  ANALYST   :jwb
  FILEIN    :example5.dat
  FILEOUT   :example5.out
   LOGICAL VARIABLES
  DENCON   =  F
  GRAVITY  =  F
  ENERGY   =  T
  MIXTURE  =  T
  THRUST   =  F
  STEADY   =  T
  TRANSV   =  F
  INERTIA  =  T
  CONDX    =  F
  TWOD     =  F
  PRINTI   =  F
  ROTATION =  F
  BUOYANCY =  F
  HRATE    =  F


  NNODES   =   12
  NINT     =    7
  NBR      =   12
  NF       =    3
  NVAR     =   19
  NHREF    =    2


  FLUIDS:  O2   H2   HE

BOUNDARY NODES
 NODE       P          T        RHO         AREA      CONCENTRATIONS
          (PSI)       (F)   (LBM/FT^3)   (IN^2)
                                                          O2         H2         HE
    48    550.0000  -60.0000    4.4582    0.0000    1.0000    0.0000    0.0000
    50     14.7000   80.0000    0.0090    0.0000    0.5000    0.0000    0.5000
    66    151.0000   70.0000    0.1057    0.0000    0.0000    0.0000    1.0000
    16     14.7000   80.0000    0.0034    0.0000    0.0000    0.5000    0.5000
    22    172.0000 -174.0000    0.1123    0.0000    0.0000    1.0000    0.0000
```

INPUT SPECIFICATIONS FOR INTERNAL NODES

NODE NODE	AREA (IN^2)	MASS (LBM/S)	HEAT (BTU/LBM)
49	0.0000	0.0000	0.0000
68	0.0000	0.0000	0.0000
67	0.0000	0.0000	0.0000
23	0.0000	0.0000	0.0000
63	0.0000	0.0000	0.0000
46	0.0000	0.0000	0.0000
47	0.0000	0.0000	0.0000

BRANCH	UPNODE	DNNODE	OPTION
58	48	49	2
142	49	50	2
59	68	49	2
138	67	68	2
60	68	23	2
137	66	67	2
129	23	63	2
23	22	23	2
88	63	46	2
87	46	47	2
86	46	47	2
25	47	16	2

```
BRANCH OPTION -2:  FLOW COEF, AREA
    58     0.22000     0.04000
BRANCH OPTION -2:  FLOW COEF, AREA
   142     0.74000     0.78500
BRANCH OPTION -2:  FLOW COEF, AREA
    59     0.34000     0.03000
BRANCH OPTION -2:  FLOW COEF, AREA
   138     0.66000     0.09000
BRANCH OPTION -2:  FLOW COEF, AREA
    60     0.35440     0.03000
BRANCH OPTION -2:  FLOW COEF, AREA
   137     0.88000     0.09000
BRANCH OPTION -2:  FLOW COEF, AREA
   129     0.79000     0.78540
BRANCH OPTION -2:  FLOW COEF, AREA
    23     0.24000     0.04000
BRANCH OPTION -2:  FLOW COEF, AREA
    88     0.71000     0.79000
BRANCH OPTION -2:  FLOW COEF, AREA
```

```
    87     0.79000     0.37000
BRANCH OPTION -2:  FLOW COEF, AREA
    86     0.37000     0.46000
BRANCH OPTION -2:  FLOW COEF, AREA
    25     0.51000     1.09000
```

SOLUTION

INTERNAL NODES

NODE	P(PSI)	T(F)	Z	RHO	CONCENTRATIONS (LBM/FT^3)	O2	H2	HE
49	51.7079	-49.2406	1.0171	0.2594	0.9393	0.0000	0.0607	
68	136.7143	70.1127	1.0059	0.0957	0.0000	0.0000	1.0000	
67	146.0602	70.0390	1.0063	0.1022	0.0000	0.0000	1.0000	
23	23.5624	-118.6942	0.9293	0.0178	0.0000	0.5630	0.4370	
63	19.3548	-118.6914	0.9291	0.0147	0.0000	0.5630	0.4370	
46	18.0815	-118.6906	0.9290	0.0137	0.0000	0.5630	0.4370	
47	15.9282	-118.6892	0.9289	0.0121	0.0000	0.5630	0.4370	

BRANCHES

BRANCH	KFACTOR (LBF-S^2/(LBM-FT)^2)	DELP (PSI)	FLOW RATE (LBM/SEC)	VELOCITY (FT/SEC)	REYN. NO.	MACH NO.
58	0.933E+06	0.498E+03	0.277E+00	0.224E+03	0.161E+07	0.227E+00
142	0.368E+04	0.370E+02	0.295E+00	0.209E+03	0.393E+06	0.116E+00
59	0.324E+08	0.850E+02	0.179E-01	0.898E+03	0.103E+06	0.271E+00
138	0.893E+06	0.935E+01	0.383E-01	0.599E+03	0.127E+06	0.181E+00
60	0.298E+08	0.113E+03	0.203E-01	0.102E+04	0.117E+06	0.308E+00
137	0.486E+06	0.494E+01	0.383E-01	0.579E+03	0.127E+06	0.175E+00
129	0.469E+05	0.421E+01	0.465E-01	0.478E+03	0.142E+06	0.148E+00
23	0.311E+08	0.148E+03	0.262E-01	0.840E+03	0.460E+06	0.272E+00
88	0.698E+05	0.127E+01	0.465E-01	0.578E+03	0.141E+06	0.179E+00
87	0.275E+06	0.215E+01	0.248E-01	0.704E+03	0.110E+06	0.218E+00
86	0.812E+06	0.215E+01	0.218E-01	0.497E+03	0.866E+05	0.154E+00
25	0.864E+05	0.123E+01	0.465E-01	0.510E+03	0.120E+06	0.158E+00

SOLUTION SATISFIED CONVERGENCE CRITERION OF 0.00100 IN   45 ITERATIONS

APPENDIX I

INPUT AND OUTPUT DATA FILES FROM EXAMPLE 6

Contents **Page**

```
TITLE
SAMPLE FLOW CIRCUIT FOR QUASI-STEADY FLOW
DENCON  GRAVITY ENERGY MIXTURE THRUST   STEADY  TRANSV
    F       F       T       T       F       F       F
INERTIA  CONDX   TWOD  PRINTI ROTATION BUOYANCY HRATE
    F       F       F       F       F       F       F
NNODES   NINT  NBR    NF  NHREF
    12     7    12     3     2
RELAXK  RELAXD  RELAXH
  1.000   0.500   1.000
DTAU TIMEF TIMEL
  1.000   0.000  15.000
NFLUID(I), I= 1,NF
     6    10     1
  NODE INDEX
    48     2
    49     1
    50     2
    68     1
    67     1
    66     2
    23     1
    63     1
    46     1
    47     1
    16     2
    22     2
 NODE  PRES (PSI)  TEMP(DEGF)  MASS SOURC           HEAT SOURC  THRST AREA CONCENTRATION
    49  0.1000E+02  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00 0.0000 0.0000 1.0000
    68  0.1833E+02  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00 0.0000 0.0000 1.0000
    67  0.1000E+02  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00 0.0000 0.0000 1.0000
    23  0.1000E+02  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00 0.0000 0.0000 1.0000
    63  0.1000E+03  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00 0.0000 0.0000 1.0000
    46  0.1000E+03  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00 0.0000 0.0000 1.0000
    47  0.8333E+01  0.0000E+00  0.0000E+00  0.0000E+00  0.0000E+00 0.0000 0.0000 1.0000
     1    HIST48.DAT
     2    HIST50.DAT
     3    HIST66.DAT
     4    HIST16.DAT
     5    HIST22.DAT
 INODE   NUMBR     BRANCH 1   BRANCH 2   BRANCH 3   BRANCH 4   BRANCH 5   BRANCH 6
    49       3          58        142         59
    68       3          59        138         60
    67       2         138        137
```

```
    23       3          60       129        23
    63       2         129        88
    46       3          88        87        86
    47       3          87        86        25
BRANCH   UPNODE    DNNODE    OPTION
    58         48        49        2
   142         49        50        2
    59         68        49        2
   138         67        68        2
    60         68        23        2
   137         66        67        2
   129         23        63        2
    23         22        23        2
    88         63        46        2
    87         46        47        2
    86         46        47        2
    25         47        16        2
BRANCH OPTION -2:  FLOW COEF, AREA
    58     0.21760     0.04290
BRANCH OPTION -2:  FLOW COEF, AREA
   142     0.74000     0.78500
BRANCH OPTION -2:  FLOW COEF, AREA
    59     0.34390     0.03250
BRANCH OPTION -2:  FLOW COEF, AREA
   138     0.65780     0.09420
BRANCH OPTION -2:  FLOW COEF, AREA
    60     0.35440     0.03250
BRANCH OPTION -2:  FLOW COEF, AREA
   137     0.88800     0.09420
BRANCH OPTION -2:  FLOW COEF, AREA
   129     0.79300     0.78540
BRANCH OPTION -2:  FLOW COEF, AREA
    23     0.23630     0.04220
BRANCH OPTION -2:  FLOW COEF, AREA
    88     0.70900     0.78540
BRANCH OPTION -2:  FLOW COEF, AREA
    87     0.78800     0.37120
BRANCH OPTION -2:  FLOW COEF, AREA
    86     0.46300     0.37120
BRANCH OPTION -2:  FLOW COEF, AREA
    25     0.51200     1.09360
BRANCH   NOUBR    NMUBR
    58        0
   142        2       58       59
```

```
    59        2      138       60
   138        1      137
    60        2       59      138
   137        0
   129        2       60       23
    23        0
    88        1      129
    87        2       88       86
    86        2       88       87
    25        2       87       86
BRANCH   NODBR    NMDBR
    58        2      142       59
   142        0
    59        2       58      142
   138        2       59       60
    60        2      129       23
   137        1      138
   129        1       88
    23        2       60      129
    88        2       87       86
    87        2       86       25
    86        2       87       25
    25        0
BRANCH
          58
  UPSTRM BR.    ANGLE
  DNSTRM BR.    ANGLE
          142     0.00
           59     0.00
BRANCH
         142
  UPSTRM BR.    ANGLE
           58     0.00
           59     0.00
  DNSTRM BR.    ANGLE
BRANCH
          59
  UPSTRM BR.    ANGLE
          138     0.00
           60     0.00
  DNSTRM BR.    ANGLE
           58     0.00
          142     0.00
BRANCH
```

```
          138
   UPSTRM BR.    ANGLE
           137     0.00
   DNSTRM BR.    ANGLE
            59     0.00
            60     0.00
BRANCH
           60
   UPSTRM BR.    ANGLE
            59     0.00
           138     0.00
   DNSTRM BR.    ANGLE
           129     0.00
            23     0.00
BRANCH
          137
   UPSTRM BR.    ANGLE
   DNSTRM BR.    ANGLE
           138     0.00
BRANCH
          129
   UPSTRM BR.    ANGLE
            60     0.00
            23     0.00
   DNSTRM BR.    ANGLE
            88     0.00
BRANCH
           23
   UPSTRM BR.    ANGLE
   DNSTRM BR.    ANGLE
            60     0.00
           129     0.00
BRANCH
           88
   UPSTRM BR.    ANGLE
           129     0.00
   DNSTRM BR.    ANGLE
            87     0.00
            86     0.00
BRANCH
           87
   UPSTRM BR.    ANGLE
            88     0.00
            86     0.00
```

```
  DNSTRM BR.    ANGLE
           86     0.00
           25     0.00
BRANCH
          86
  UPSTRM BR.    ANGLE
           88     0.00
           87     0.00
  DNSTRM BR.    ANGLE
           87     0.00
           25     0.00
BRANCH
          25
  UPSTRM BR.    ANGLE
           87     0.00
           86     0.00
  DNSTRM BR.    ANGLE
```

```
**** GENERAL FLUID SYSTEM SIMULATION PROGRAM ****
 ***************** VERSION 1.4.1 ****************

  TITLE     :SAMPLE FLOW CIRCUIT FOR QUASI-STEADY FLOW
  DATE      :9/11/97
  ANALYST   :jwb
  FILEIN    :example6.dat
  FILEOUT   :example6.out
   LOGICAL VARIABLES
  DENCON   =  F
  GRAVITY  =  F
  ENERGY   =  T
  MIXTURE  =  T
  THRUST   =  F
  STEADY   =  F
  TRANSV   =  F
  INERTIA  =  F
  CONDX    =  F
  TWOD     =  F
  PRINTI   =  F
  ROTATION =  F
  BUOYANCY =  F
  HRATE    =  F


  NNODES   =   12
  NINT     =    7
  NBR      =   12
  NF       =    3
  NVAR     =   19
  NHREF    =    2


  FLUIDS:  O2   H2   HE

BOUNDARY NODES
 NODE       P         T       RHO        AREA      CONCENTRATIONS
          (PSI)      (F)   (LBM/FT^3)   (IN^2)
                                                        O2        H2        HE
    48    550.0000  -60.0000    4.4582    0.0000    1.0000    0.0000    0.0000
    50     14.7000   70.0000    0.0092    0.0000    0.5000    0.0000    0.5000
    66    151.0000   70.0000    0.1057    0.0000    0.0000    0.0000    1.0000
    16     14.7000   70.0000    0.0035    0.0000    0.0000    0.5000    0.5000
    22    172.0000 -174.0000    0.1123    0.0000    0.0000    1.0000    0.0000
```

```
 INPUT SPECIFICATIONS FOR INTERNAL NODES
NODE        AREA      MASS      HEAT
NODE       (IN^2)    (LBM/S)  (BTU/LBM)
    49      0.0000    0.0000    0.0000
    68      0.0000    0.0000    0.0000
    67      0.0000    0.0000    0.0000
    23      0.0000    0.0000    0.0000
    63      0.0000    0.0000    0.0000
    46      0.0000    0.0000    0.0000
    47      0.0000    0.0000    0.0000

BRANCH   UPNODE    DNNODE    OPTION
    58         48        49         2
   142         49        50         2
    59         68        49         2
   138         67        68         2
    60         68        23         2
   137         66        67         2
   129         23        63         2
    23         22        23         2
    88         63        46         2
    87         46        47         2
    86         46        47         2
    25         47        16         2
BRANCH OPTION -2:  FLOW COEF, AREA
    58     0.21760     0.04290
BRANCH OPTION -2:  FLOW COEF, AREA
   142     0.74000     0.78500
BRANCH OPTION -2:  FLOW COEF, AREA
    59     0.34390     0.03250
BRANCH OPTION -2:  FLOW COEF, AREA
   138     0.65780     0.09420
BRANCH OPTION -2:  FLOW COEF, AREA
    60     0.35440     0.03250
BRANCH OPTION -2:  FLOW COEF, AREA
   137     0.88800     0.09420
BRANCH OPTION -2:  FLOW COEF, AREA
   129     0.79300     0.78540
BRANCH OPTION -2:  FLOW COEF, AREA
    23     0.23630     0.04220
BRANCH OPTION -2:  FLOW COEF, AREA
    88     0.70900     0.78540
BRANCH OPTION -2:  FLOW COEF, AREA
```

87	0.78800	0.37120

BRANCH OPTION -2: FLOW COEF, AREA

86	0.46300	0.37120

BRANCH OPTION -2: FLOW COEF, AREA

25	0.51200	1.09360

ISTEP = 1 TAU = 0.10000E+01

BOUNDARY NODES

NODE	P(PSI)	T(F)	Z(COMP)	RHO (LBM/FT^3)	CONCENTRATIONS O2	H2	HE
48	550.0000	-60.0000	0.0000	4.4582	1.0000	0.0000	0.0000
50	14.7000	70.0000	0.0000	0.0092	0.5000	0.0000	0.5000
66	151.0000	70.0000	0.0000	0.1057	0.0000	0.0000	1.0000
16	14.7000	70.0000	0.0000	0.0035	0.0000	0.5000	0.5000
22	172.0000	-174.0000	0.0000	0.1123	0.0000	1.0000	0.0000

SOLUTION

INTERNAL NODES

NODE	P(PSI)	T(F)	Z	RHO (LBM/FT^3)	CONCENTRATIONS O2	H2	HE
49	21.6744	-44.4310	1.0207	0.1013	0.9277	0.0000	0.0723
68	130.6775	70.1604	1.0056	0.0915	0.0000	0.0000	1.0000
67	144.0175	70.0551	1.0062	0.1008	0.0000	0.0000	1.0000
23	20.5725	-113.1038	0.9306	0.0156	0.0000	0.5293	0.4707
63	19.5772	-113.1028	0.9305	0.0149	0.0000	0.5293	0.4707
46	18.2701	-113.1015	0.9305	0.0139	0.0000	0.5293	0.4707
47	16.2569	-113.0994	0.9304	0.0124	0.0000	0.5293	0.4707

BRANCHES

BRANCH	KFACTOR (LBF-S^2/(LBM-FT)^2)	DELP (PSI)	FLOW RATE (LBM/SEC)	VELOCITY (FT/SEC)	REYN. NO.	MACH NO.
58	0.829E+06	0.528E+03	0.303E+00	0.228E+03	0.170E+07	0.231E+00
142	0.942E+04	0.697E+01	0.326E+00	0.591E+03	0.432E+06	0.312E+00
59	0.282E+08	0.109E+03	0.236E-01	0.114E+04	0.131E+06	0.345E+00
138	0.832E+06	0.133E+02	0.480E-01	0.728E+03	0.156E+06	0.220E+00
60	0.265E+08	0.110E+03	0.244E-01	0.118E+04	0.135E+06	0.357E+00
137	0.436E+06	0.698E+01	0.480E-01	0.695E+03	0.156E+06	0.210E+00
129	0.531E+05	0.995E+00	0.519E-01	0.609E+03	0.151E+06	0.188E+00
23	0.289E+08	0.151E+03	0.275E-01	0.835E+03	0.470E+06	0.271E+00

88	0.698E+05	0.131E+01	0.519E-01	0.640E+03	0.151E+06	0.197E+00
87	0.271E+06	0.201E+01	0.327E-01	0.913E+03	0.138E+06	0.282E+00
86	0.785E+06	0.201E+01	0.192E-01	0.536E+03	0.812E+05	0.166E+00
25	0.831E+05	0.156E+01	0.519E-01	0.554E+03	0.128E+06	0.171E+00

ISTEP = 2 TAU = 0.20000E+01

BOUNDARY NODES

NODE	P(PSI)	T(F)	Z(COMP)	RHO (LBM/FT^3)	CONCENTRATIONS			
						O2	H2	HE
48	550.0000	-60.0000	0.0000	4.4582	1.0000	0.0000	0.0000	
50	14.7000	70.0000	0.0000	0.0092	0.5000	0.0000	0.5000	
66	96.4800	70.0000	0.0000	0.0677	0.0000	0.0000	1.0000	
16	14.7000	70.0000	0.0000	0.0035	0.0000	0.5000	0.5000	
22	172.0000	-174.0000	0.0000	0.1123	0.0000	1.0000	0.0000	

SOLUTION

INTERNAL NODES

NODE	P(PSI)	T(F)	Z	RHO	CONCENTRATIONS (LBM/FT^3)			
						O2	H2	HE
49	20.5724	-59.2076	1.0183	0.1140	0.9543	0.0000	0.0457	
68	84.3891	70.0955	1.0037	0.0592	0.0000	0.0000	1.0000	
67	92.3146	70.0329	1.0040	0.0648	0.0000	0.0000	1.0000	
23	18.9882	-131.4034	0.9295	0.0142	0.0000	0.6457	0.3543	
63	18.2443	-131.4036	0.9294	0.0136	0.0000	0.6457	0.3543	
46	17.2759	-131.4039	0.9294	0.0129	0.0000	0.6457	0.3543	
47	15.8054	-131.4044	0.9293	0.0118	0.0000	0.6457	0.3543	

BRANCHES

BRANCH	KFACTOR (LBF-S^2/(LBM-FT)^2)	DELP (PSI)	FLOW RATE (LBM/SEC)	VELOCITY (FT/SEC)	REYN. NO.	MACH NO.
58	0.829E+06	0.529E+03	0.303E+00	0.228E+03	0.170E+07	0.231E+00
142	0.838E+04	0.587E+01	0.318E+00	0.511E+03	0.432E+06	0.311E+00
59	0.435E+08	0.638E+02	0.145E-01	0.109E+04	0.806E+05	0.328E+00
138	0.130E+07	0.793E+01	0.297E-01	0.700E+03	0.967E+05	0.211E+00
60	0.410E+08	0.654E+02	0.152E-01	0.113E+04	0.840E+05	0.342E+00
137	0.680E+06	0.417E+01	0.297E-01	0.671E+03	0.967E+05	0.203E+00
129	0.585E+05	0.744E+00	0.428E-01	0.552E+03	0.145E+06	0.173E+00
23	0.289E+08	0.153E+03	0.276E-01	0.840E+03	0.473E+06	0.272E+00
88	0.762E+05	0.968E+00	0.428E-01	0.575E+03	0.145E+06	0.180E+00
87	0.292E+06	0.147E+01	0.270E-01	0.809E+03	0.133E+06	0.253E+00

86	0.845E+06	0.147E+01	0.158E-01	0.475E+03	0.782E+05	0.149E+00
25	0.870E+05	0.111E+01	0.428E-01	0.477E+03	0.123E+06	0.149E+00

ISTEP = 3 TAU = 0.30000E+01

BOUNDARY NODES

NODE	P(PSI)	T(F)	Z(COMP)	RHO (LBM/FT^3)	CONCENTRATIONS			
						O2	H2	HE
48	550.0000	-60.0000	0.0000	4.4582	1.0000	0.0000	0.0000	
50	14.7000	70.0000	0.0000	0.0092	0.5000	0.0000	0.5000	
66	123.7400	70.0000	0.0000	0.0867	0.0000	0.0000	1.0000	
16	14.7000	70.0000	0.0000	0.0035	0.0000	0.5000	0.5000	
22	172.0000	-174.0000	0.0000	0.1123	0.0000	1.0000	0.0000	

SOLUTION

INTERNAL NODES

NODE	P(PSI)	T(F)	Z	RHO	CONCENTRATIONS (LBM/FT^3)			
						O2	H2	HE
49	21.1259	-51.4221	1.0201	0.1070	0.9408	0.0000	0.0592	
68	107.5339	70.1279	1.0047	0.0754	0.0000	0.0000	1.0000	
67	118.1691	70.0439	1.0051	0.0828	0.0000	0.0000	1.0000	
23	19.7593	-121.7611	0.9287	0.0149	0.0000	0.5819	0.4181	
63	18.8923	-121.7607	0.9287	0.0143	0.0000	0.5819	0.4181	
46	17.7579	-121.7602	0.9286	0.0134	0.0000	0.5819	0.4181	
47	16.0227	-121.7594	0.9285	0.0121	0.0000	0.5819	0.4181	

BRANCHES

BRANCH	KFACTOR (LBF-S^2/(LBM-FT)^2)	DELP (PSI)	FLOW RATE (LBM/SEC)	VELOCITY (FT/SEC)	REYN. NO.	MACH NO.
58	0.829E+06	0.529E+03	0.303E+00	0.228E+03	0.170E+07	0.231E+00
142	0.892E+04	0.643E+01	0.322E+00	0.552E+03	0.431E+06	0.310E+00
59	0.342E+08	0.864E+02	0.191E-01	0.112E+04	0.106E+06	0.339E+00
138	0.101E+07	0.106E+02	0.389E-01	0.718E+03	0.127E+06	0.217E+00
60	0.322E+08	0.878E+02	0.198E-01	0.116E+04	0.110E+06	0.352E+00
137	0.531E+06	0.557E+01	0.389E-01	0.685E+03	0.127E+06	0.207E+00
129	0.556E+05	0.867E+00	0.474E-01	0.582E+03	0.148E+06	0.181E+00
23	0.289E+08	0.152E+03	0.276E-01	0.838E+03	0.472E+06	0.272E+00
88	0.728E+05	0.113E+01	0.474E-01	0.608E+03	0.148E+06	0.189E+00
87	0.281E+06	0.174E+01	0.298E-01	0.863E+03	0.136E+06	0.268E+00
86	0.813E+06	0.174E+01	0.175E-01	0.507E+03	0.797E+05	0.157E+00
25	0.849E+05	0.132E+01	0.474E-01	0.516E+03	0.126E+06	0.160E+00

ISTEP = 4 TAU = 0.40000E+01

BOUNDARY NODES

NODE	P(PSI)	T(F)	Z(COMP)	RHO (LBM/FT^3)	CONCENTRATIONS	O2	H2	HE
48	550.0000	-60.0000	0.0000	4.4582	1.0000	0.0000	0.0000	
50	14.7000	70.0000	0.0000	0.0092	0.5000	0.0000	0.5000	
66	151.0000	70.0000	0.0000	0.1057	0.0000	0.0000	1.0000	
16	14.7000	70.0000	0.0000	0.0035	0.0000	0.5000	0.5000	
22	172.0000	-174.0000	0.0000	0.1123	0.0000	1.0000	0.0000	

SOLUTION

INTERNAL NODES

NODE	P(PSI)	T(F)	Z	RHO	CONCENTRATIONS (LBM/FT^3)	O2	H2	HE
49	21.6734	-44.4365	1.0208	0.1013	0.9277	0.0000	0.0723	
68	130.6795	70.1604	1.0056	0.0915	0.0000	0.0000	1.0000	
67	144.0198	70.0551	1.0062	0.1008	0.0000	0.0000	1.0000	
23	20.5735	-113.1108	0.9306	0.0156	0.0000	0.5294	0.4706	
63	19.5789	-113.1099	0.9306	0.0149	0.0000	0.5294	0.4706	
46	18.2715	-113.1085	0.9305	0.0139	0.0000	0.5294	0.4706	
47	16.2571	-113.1065	0.9304	0.0124	0.0000	0.5294	0.4706	

BRANCHES

BRANCH	KFACTOR (LBF-S^2/(LBM-FT)^2)	DELP (PSI)	FLOW RATE (LBM/SEC)	VELOCITY (FT/SEC)	REYN. NO.	MACH NO.
58	0.829E+06	0.528E+03	0.303E+00	0.228E+03	0.170E+07	0.231E+00
142	0.942E+04	0.697E+01	0.326E+00	0.591E+03	0.432E+06	0.312E+00
59	0.282E+08	0.109E+03	0.236E-01	0.114E+04	0.131E+06	0.345E+00
138	0.833E+06	0.133E+02	0.480E-01	0.729E+03	0.156E+06	0.220E+00
60	0.265E+08	0.110E+03	0.244E-01	0.118E+04	0.135E+06	0.357E+00
137	0.436E+06	0.698E+01	0.480E-01	0.695E+03	0.156E+06	0.210E+00
129	0.531E+05	0.995E+00	0.519E-01	0.609E+03	0.151E+06	0.188E+00
23	0.289E+08	0.151E+03	0.275E-01	0.835E+03	0.470E+06	0.271E+00
88	0.698E+05	0.131E+01	0.519E-01	0.640E+03	0.151E+06	0.198E+00
87	0.271E+06	0.201E+01	0.327E-01	0.914E+03	0.138E+06	0.282E+00
86	0.785E+06	0.201E+01	0.192E-01	0.537E+03	0.812E+05	0.166E+00
25	0.832E+05	0.156E+01	0.519E-01	0.554E+03	0.128E+06	0.171E+00

ISTEP = 5 TAU = 0.50000E+01

BOUNDARY NODES

NODE	P(PSI)	T(F)	Z(COMP)	RHO (LBM/FT^3)	CONCENTRATIONS			
						O2	H2	HE
48	550.0000	-60.0000	0.0000	4.4582	1.0000	0.0000	0.0000	
50	14.7000	70.0000	0.0000	0.0092	0.5000	0.0000	0.5000	
66	14.7000	70.0000	0.0000	0.0103	0.0000	0.0000	1.0000	
16	14.7000	70.0000	0.0000	0.0035	0.0000	0.5000	0.5000	
22	172.0000	-174.0000	0.0000	0.1123	0.0000	1.0000	0.0000	

SOLUTION

INTERNAL NODES

NODE	P(PSI)	T(F)	Z	RHO	CONCENTRATIONS (LBM/FT^3)			
						O2	H2	HE
49	18.6091	-91.5336	0.9968	0.1513	1.0000	0.0000	0.0000	
68	15.5103	-97.7043	0.9553	0.0410	0.8479	0.1521	0.0000	
67	14.9934	-97.9212	0.9560	0.0397	0.8479	0.1521	0.0000	
23	16.7947	-174.4283	1.0014	0.0111	0.0000	1.0000	0.0000	
63	16.4167	-174.4295	1.0014	0.0108	0.0000	1.0000	0.0000	
46	15.9329	-174.4309	1.0014	0.0105	0.0000	1.0000	0.0000	
47	15.2162	-174.4330	1.0014	0.0100	0.0000	1.0000	0.0000	

BRANCHES

BRANCH	KFACTOR (LBF-S^2/(LBM-FT)^2)	DELP (PSI)	FLOW RATE (LBM/SEC)	VELOCITY (FT/SEC)	REYN. NO.	MACH NO.
58	0.829E+06	0.531E+03	0.304E+00	0.229E+03	0.170E+07	0.232E+00
142	0.631E+04	0.391E+01	0.299E+00	0.362E+03	0.439E+06	0.404E+00
59	0.171E+08	-0.310E+01	-0.512E-02	-0.150E+03	0.369E+05	0.167E+00
138	0.205E+07	-0.517E+00	-0.603E-02	-0.225E+03	0.876E+04	0.719E-01
60	0.220E+09	-0.128E+01	-0.917E-03	-0.368E+03	0.181E+05	0.120E+00
137	0.116E+07	-0.293E+00	-0.603E-02	-0.232E+03	0.871E+04	0.744E-01
129	0.752E+05	0.378E+00	0.269E-01	0.446E+03	0.108E+06	0.145E+00
23	0.289E+08	0.155E+03	0.278E-01	0.846E+03	0.476E+06	0.274E+00
88	0.962E+05	0.484E+00	0.269E-01	0.457E+03	0.108E+06	0.149E+00
87	0.359E+06	0.717E+00	0.170E-01	0.627E+03	0.987E+05	0.204E+00
86	0.104E+07	0.717E+00	0.996E-02	0.368E+03	0.580E+05	0.120E+00
25	0.103E+06	0.516E+00	0.269E-01	0.354E+03	0.913E+05	0.115E+00

ISTEP = 6 TAU = 0.60000E+01

BOUNDARY NODES

NODE	P(PSI)	T(F)	Z(COMP)	RHO (LBM/FT^3)	CONCENTRATIONS	O2	H2	HE
48	550.0000	-60.0000	0.0000	4.4582	1.0000	0.0000	0.0000	
50	14.7000	70.0000	0.0000	0.0092	0.5000	0.0000	0.5000	
66	14.7000	70.0000	0.0000	0.0103	0.0000	0.0000	1.0000	
16	14.7000	70.0000	0.0000	0.0035	0.0000	0.5000	0.5000	
22	172.0000	-174.0000	0.0000	0.1123	0.0000	1.0000	0.0000	

SOLUTION

INTERNAL NODES

NODE	P(PSI)	T(F)	Z	RHO	CONCENTRATIONS (LBM/FT^3)	O2	H2	HE
49	18.6091	-91.5336	0.9968	0.1513	1.0000	0.0000	0.0000	
68	15.5104	-97.7010	0.9553	0.0410	0.8479	0.1521	0.0000	
67	14.9934	-97.9123	0.9560	0.0397	0.8479	0.1521	0.0000	
23	16.7949	-174.4283	1.0014	0.0111	0.0000	1.0000	0.0000	
63	16.4168	-174.4295	1.0014	0.0108	0.0000	1.0000	0.0000	
46	15.9330	-174.4309	1.0014	0.0105	0.0000	1.0000	0.0000	
47	15.2162	-174.4330	1.0014	0.0100	0.0000	1.0000	0.0000	

BRANCHES

BRANCH	KFACTOR (LBF-S^2/(LBM-FT)^2)	DELP (PSI)	FLOW RATE (LBM/SEC)	VELOCITY (FT/SEC)	REYN. NO.	MACH NO.
58	0.829E+06	0.531E+03	0.304E+00	0.229E+03	0.170E+07	0.232E+00
142	0.631E+04	0.391E+01	0.299E+00	0.362E+03	0.439E+06	0.404E+00
59	0.171E+08	-0.310E+01	-0.512E-02	-0.150E+03	0.369E+05	0.167E+00
138	0.205E+07	-0.517E+00	-0.603E-02	-0.225E+03	0.876E+04	0.719E-01
60	0.220E+09	-0.128E+01	-0.917E-03	-0.368E+03	0.181E+05	0.120E+00
137	0.116E+07	-0.293E+00	-0.603E-02	-0.233E+03	0.871E+04	0.744E-01
129	0.752E+05	0.378E+00	0.269E-01	0.446E+03	0.108E+06	0.145E+00
23	0.289E+08	0.155E+03	0.278E-01	0.846E+03	0.476E+06	0.274E+00
88	0.962E+05	0.484E+00	0.269E-01	0.457E+03	0.108E+06	0.149E+00
87	0.359E+06	0.717E+00	0.170E-01	0.627E+03	0.987E+05	0.204E+00
86	0.104E+07	0.717E+00	0.996E-02	0.369E+03	0.580E+05	0.120E+00
25	0.103E+06	0.516E+00	0.269E-01	0.354E+03	0.913E+05	0.115E+00

ISTEP = 7 TAU = 0.70000E+01

BOUNDARY NODES

NODE	P(PSI)	T(F)	Z(COMP)	RHO	CONCENTRATIONS

NODE	P(PSI)	T(F)	Z(COMP)	RHO (LBM/FT^3)	O2	H2	HE
48	550.0000	-60.0000	0.0000	4.4582	1.0000	0.0000	0.0000
50	14.7000	70.0000	0.0000	0.0092	0.5000	0.0000	0.5000
66	14.7000	70.0000	0.0000	0.0103	0.0000	0.0000	1.0000
16	14.7000	70.0000	0.0000	0.0035	0.0000	0.5000	0.5000
22	172.0000	-174.0000	0.0000	0.1123	0.0000	1.0000	0.0000

SOLUTION

INTERNAL NODES

NODE	P(PSI)	T(F)	Z	RHO (LBM/FT^3)	CONCENTRATIONS O2	H2	HE
49	18.6091	-91.5337	0.9968	0.1513	1.0000	0.0000	0.0000
68	15.5105	-97.6996	0.9553	0.0410	0.8479	0.1521	0.0000
67	14.9935	-97.9159	0.9560	0.0397	0.8479	0.1521	0.0000
23	16.7949	-174.4283	1.0014	0.0111	0.0000	1.0000	0.0000
63	16.4169	-174.4295	1.0014	0.0108	0.0000	1.0000	0.0000
46	15.9330	-174.4309	1.0014	0.0105	0.0000	1.0000	0.0000
47	15.2162	-174.4330	1.0014	0.0100	0.0000	1.0000	0.0000

BRANCHES

BRANCH	KFACTOR (LBF-S^2/(LBM-FT)^2)	DELP (PSI)	FLOW RATE (LBM/SEC)	VELOCITY (FT/SEC)	REYN. NO.	MACH NO.
58	0.829E+06	0.531E+03	0.304E+00	0.229E+03	0.170E+07	0.232E+00
142	0.631E+04	0.391E+01	0.299E+00	0.362E+03	0.439E+06	0.404E+00
59	0.171E+08	-0.310E+01	-0.512E-02	-0.150E+03	0.369E+05	0.167E+00
138	0.205E+07	-0.517E+00	-0.603E-02	-0.225E+03	0.876E+04	0.719E-01
60	0.220E+09	-0.128E+01	-0.917E-03	-0.368E+03	0.181E+05	0.120E+00
137	0.116E+07	-0.293E+00	-0.603E-02	-0.233E+03	0.871E+04	0.744E-01
129	0.752E+05	0.378E+00	0.269E-01	0.446E+03	0.108E+06	0.145E+00
23	0.289E+08	0.155E+03	0.278E-01	0.846E+03	0.476E+06	0.274E+00
88	0.962E+05	0.484E+00	0.269E-01	0.457E+03	0.108E+06	0.149E+00
87	0.359E+06	0.717E+00	0.170E-01	0.627E+03	0.987E+05	0.204E+00
86	0.104E+07	0.717E+00	0.996E-02	0.369E+03	0.580E+05	0.120E+00
25	0.103E+06	0.516E+00	0.269E-01	0.354E+03	0.913E+05	0.115E+00

ISTEP = 8 TAU = 0.80000E+01

BOUNDARY NODES

NODE	P(PSI)	T(F)	Z(COMP)	RHO (LBM/FT^3)	CONCENTRATIONS O2	H2	HE

48	550.0000	-60.0000	0.0000	4.4582	1.0000	0.0000	0.0000
50	14.7000	70.0000	0.0000	0.0092	0.5000	0.0000	0.5000
66	14.7000	70.0000	0.0000	0.0103	0.0000	0.0000	1.0000
16	14.7000	70.0000	0.0000	0.0035	0.0000	0.5000	0.5000
22	172.0000	-174.0000	0.0000	0.1123	0.0000	1.0000	0.0000

SOLUTION
INTERNAL NODES

NODE	P(PSI)	T(F)	Z	RHO (LBM/FT^3)	CONCENTRATIONS O2	H2	HE
49	18.6091	-91.5337	0.9968	0.1513	1.0000	0.0000	0.0000
68	15.5105	-97.6992	0.9553	0.0410	0.8479	0.1521	0.0000
67	14.9935	-97.9134	0.9560	0.0397	0.8479	0.1521	0.0000
23	16.7949	-174.4283	1.0014	0.0111	0.0000	1.0000	0.0000
63	16.4169	-174.4295	1.0014	0.0108	0.0000	1.0000	0.0000
46	15.9331	-174.4309	1.0014	0.0105	0.0000	1.0000	0.0000
47	15.2162	-174.4330	1.0014	0.0100	0.0000	1.0000	0.0000

BRANCHES

BRANCH	KFACTOR (LBF-S^2/(LBM-FT)^2)	DELP (PSI)	FLOW RATE (LBM/SEC)	VELOCITY (FT/SEC)	REYN. NO.	MACH NO.
58	0.829E+06	0.531E+03	0.304E+00	0.229E+03	0.170E+07	0.232E+00
142	0.631E+04	0.391E+01	0.299E+00	0.362E+03	0.439E+06	0.404E+00
59	0.171E+08	-0.310E+01	-0.512E-02	-0.150E+03	0.369E+05	0.167E+00
138	0.205E+07	-0.517E+00	-0.603E-02	-0.225E+03	0.876E+04	0.719E-01
60	0.220E+09	-0.128E+01	-0.917E-03	-0.368E+03	0.181E+05	0.120E+00
137	0.116E+07	-0.293E+00	-0.603E-02	-0.233E+03	0.871E+04	0.744E-01
129	0.752E+05	0.378E+00	0.269E-01	0.446E+03	0.108E+06	0.145E+00
23	0.289E+08	0.155E+03	0.278E-01	0.846E+03	0.476E+06	0.274E+00
88	0.962E+05	0.484E+00	0.269E-01	0.457E+03	0.108E+06	0.149E+00
87	0.359E+06	0.717E+00	0.170E-01	0.627E+03	0.987E+05	0.204E+00
86	0.104E+07	0.717E+00	0.996E-02	0.369E+03	0.580E+05	0.120E+00
25	0.103E+06	0.516E+00	0.269E-01	0.354E+03	0.913E+05	0.115E+00

ISTEP = 9 TAU = 0.90000E+01

BOUNDARY NODES

NODE	P(PSI)	T(F)	Z(COMP)	RHO (LBM/FT^3)	CONCENTRATIONS O2	H2	HE
48	550.0000	-60.0000	0.0000	4.4582	1.0000	0.0000	0.0000
50	14.7000	70.0000	0.0000	0.0092	0.5000	0.0000	0.5000

66	14.7000	70.0000	0.0000	0.0103	0.0000	0.0000	1.0000
16	14.7000	70.0000	0.0000	0.0035	0.0000	0.5000	0.5000
22	172.0000	-174.0000	0.0000	0.1123	0.0000	1.0000	0.0000

SOLUTION
INTERNAL NODES

NODE	P(PSI)	T(F)	Z	RHO (LBM/FT^3)	CONCENTRATIONS O2	H2	HE
49	18.6091	-91.5337	0.9968	0.1513	1.0000	0.0000	0.0000
68	15.5105	-97.7001	0.9553	0.0410	0.8479	0.1521	0.0000
67	14.9935	-97.9134	0.9560	0.0397	0.8479	0.1521	0.0000
23	16.7950	-174.4283	1.0014	0.0111	0.0000	1.0000	0.0000
63	16.4169	-174.4295	1.0014	0.0108	0.0000	1.0000	0.0000
46	15.9331	-174.4309	1.0014	0.0105	0.0000	1.0000	0.0000
47	15.2163	-174.4330	1.0014	0.0100	0.0000	1.0000	0.0000

BRANCHES

BRANCH	KFACTOR (LBF-S^2/(LBM-FT)^2)	DELP (PSI)	FLOW RATE (LBM/SEC)	VELOCITY (FT/SEC)	REYN. NO.	MACH NO.
58	0.829E+06	0.531E+03	0.304E+00	0.229E+03	0.170E+07	0.232E+00
142	0.631E+04	0.391E+01	0.299E+00	0.362E+03	0.439E+06	0.404E+00
59	0.171E+08	-0.310E+01	-0.512E-02	-0.150E+03	0.369E+05	0.167E+00
138	0.205E+07	-0.517E+00	-0.603E-02	-0.225E+03	0.876E+04	0.719E-01
60	0.220E+09	-0.128E+01	-0.917E-03	-0.368E+03	0.181E+05	0.120E+00
137	0.116E+07	-0.294E+00	-0.603E-02	-0.233E+03	0.871E+04	0.744E-01
129	0.752E+05	0.378E+00	0.269E-01	0.446E+03	0.108E+06	0.145E+00
23	0.289E+08	0.155E+03	0.278E-01	0.846E+03	0.476E+06	0.274E+00
88	0.962E+05	0.484E+00	0.269E-01	0.457E+03	0.108E+06	0.149E+00
87	0.359E+06	0.717E+00	0.170E-01	0.627E+03	0.987E+05	0.204E+00
86	0.104E+07	0.717E+00	0.996E-02	0.369E+03	0.580E+05	0.120E+00
25	0.103E+06	0.516E+00	0.269E-01	0.354E+03	0.913E+05	0.115E+00

ISTEP = 10 TAU = 0.10000E+02
BOUNDARY NODES

NODE	P(PSI)	T(F)	Z(COMP)	RHO (LBM/FT^3)	CONCENTRATIONS	O2	H2	HE
48	550.0000	-60.0000	0.0000	4.4582	1.0000	0.0000	0.0000	
50	14.7000	70.0000	0.0000	0.0092	0.5000	0.0000	0.5000	
66	14.7000	70.0000	0.0000	0.0103	0.0000	0.0000	1.0000	
16	14.7000	70.0000	0.0000	0.0035	0.0000	0.5000	0.5000	

22	172.0000	-174.0000	0.0000	0.1123	0.0000	1.0000	0.0000

SOLUTION
INTERNAL NODES

NODE	P(PSI)	T(F)	Z	RHO (LBM/FT^3)	CONCENTRATIONS O2	H2	HE
49	18.6091	-91.5337	0.9968	0.1513	1.0000	0.0000	0.0000
68	15.5105	-97.6949	0.9553	0.0410	0.8479	0.1521	0.0000
67	14.9935	-97.9134	0.9560	0.0397	0.8479	0.1521	0.0000
23	16.7950	-174.4283	1.0014	0.0111	0.0000	1.0000	0.0000
63	16.4169	-174.4295	1.0014	0.0108	0.0000	1.0000	0.0000
46	15.9331	-174.4309	1.0014	0.0105	0.0000	1.0000	0.0000
47	15.2163	-174.4330	1.0014	0.0100	0.0000	1.0000	0.0000

BRANCHES

BRANCH	KFACTOR (LBF-S^2/(LBM-FT)^2)	DELP (PSI)	FLOW RATE (LBM/SEC)	VELOCITY (FT/SEC)	REYN. NO.	MACH NO.
58	0.829E+06	0.531E+03	0.304E+00	0.229E+03	0.170E+07	0.232E+00
142	0.631E+04	0.391E+01	0.299E+00	0.362E+03	0.439E+06	0.404E+00
59	0.171E+08	-0.310E+01	-0.512E-02	-0.150E+03	0.369E+05	0.167E+00
138	0.205E+07	-0.517E+00	-0.603E-02	-0.225E+03	0.876E+04	0.719E-01
60	0.220E+09	-0.128E+01	-0.917E-03	-0.368E+03	0.181E+05	0.120E+00
137	0.116E+07	-0.294E+00	-0.603E-02	-0.233E+03	0.871E+04	0.744E-01
129	0.752E+05	0.378E+00	0.269E-01	0.446E+03	0.108E+06	0.145E+00
23	0.289E+08	0.155E+03	0.278E-01	0.846E+03	0.476E+06	0.274E+00
88	0.962E+05	0.484E+00	0.269E-01	0.457E+03	0.108E+06	0.149E+00
87	0.359E+06	0.717E+00	0.170E-01	0.627E+03	0.987E+05	0.204E+00
86	0.104E+07	0.717E+00	0.996E-02	0.369E+03	0.580E+05	0.120E+00
25	0.103E+06	0.516E+00	0.269E-01	0.354E+03	0.913E+05	0.115E+00

ISTEP = 11   TAU = 0.11000E+02

BOUNDARY NODES

NODE	P(PSI)	T(F)	Z(COMP)	RHO (LBM/FT^3)	CONCENTRATIONS O2	H2	HE
48	550.0000	-60.0000	0.0000	4.4582	1.0000	0.0000	0.0000
50	14.7000	70.0000	0.0000	0.0092	0.5000	0.0000	0.5000
66	41.9600	70.0000	0.0000	0.0295	0.0000	0.0000	1.0000
16	14.7000	70.0000	0.0000	0.0035	0.0000	0.5000	0.5000
22	172.0000	-174.0000	0.0000	0.1123	0.0000	1.0000	0.0000

SOLUTION

INTERNAL NODES

NODE	P(PSI)	T(F)	Z	RHO (LBM/FT^3)	CONCENTRATIONS	O2	H2	HE
49	19.4096	-78.1734	1.0090	0.1343	0.9828	0.0000	0.0172	
68	38.1674	70.0300	1.0018	0.0268	0.0000	0.0000	1.0000	
67	40.6435	70.0103	1.0019	0.0286	0.0000	0.0000	1.0000	
23	17.6347	-149.5577	0.9414	0.0124	0.0000	0.8292	0.1708	
63	17.1136	-149.5651	0.9414	0.0120	0.0000	0.8292	0.1708	
46	16.4420	-149.5749	0.9414	0.0116	0.0000	0.8292	0.1708	
47	15.4366	-149.5898	0.9414	0.0109	0.0000	0.8292	0.1708	

BRANCHES

BRANCH	KFACTOR (LBF-S^2/(LBM-FT)^2)	DELP (PSI)	FLOW RATE (LBM/SEC)	VELOCITY (FT/SEC)	REYN. NO.	MACH NO.
58	0.829E+06	0.531E+03	0.304E+00	0.229E+03	0.170E+07	0.231E+00
142	0.711E+04	0.471E+01	0.309E+00	0.422E+03	0.438E+06	0.335E+00
59	0.961E+08	0.188E+02	0.530E-02	0.875E+03	0.294E+05	0.264E+00
138	0.294E+07	0.248E+01	0.110E-01	0.589E+03	0.359E+05	0.178E+00
60	0.905E+08	0.205E+02	0.572E-02	0.943E+03	0.317E+05	0.285E+00
137	0.156E+07	0.132E+01	0.110E-01	0.571E+03	0.359E+05	0.172E+00
129	0.670E+05	0.521E+00	0.335E-01	0.495E+03	0.128E+06	0.159E+00
23	0.289E+08	0.154E+03	0.278E-01	0.843E+03	0.475E+06	0.274E+00
88	0.863E+05	0.672E+00	0.335E-01	0.510E+03	0.128E+06	0.164E+00
87	0.326E+06	0.101E+01	0.211E-01	0.707E+03	0.117E+06	0.227E+00
86	0.943E+06	0.101E+01	0.124E-01	0.416E+03	0.689E+05	0.133E+00
25	0.947E+05	0.737E+00	0.335E-01	0.406E+03	0.108E+06	0.130E+00

ISTEP = 12 TAU = 0.12000E+02

BOUNDARY NODES

NODE	P(PSI)	T(F)	Z(COMP)	RHO (LBM/FT^3)	CONCENTRATIONS	O2	H2	HE
48	550.0000	-60.0000	0.0000	4.4582	1.0000	0.0000	0.0000	
50	14.7000	70.0000	0.0000	0.0092	0.5000	0.0000	0.5000	
66	69.2200	70.0000	0.0000	0.0486	0.0000	0.0000	1.0000	
16	14.7000	70.0000	0.0000	0.0035	0.0000	0.5000	0.5000	
22	172.0000	-174.0000	0.0000	0.1123	0.0000	1.0000	0.0000	

SOLUTION

INTERNAL NODES

NODE	P(PSI)	T(F)	Z	RHO	CONCENTRATIONS (LBM/FT^3)			
						O2	H2	HE
49	19.9997	-68.0274	1.0150	0.1228	0.9682	0.0000	0.0318	
68	61.2655	70.0628	1.0027	0.0430	0.0000	0.0000	1.0000	
67	66.4756	70.0217	1.0030	0.0467	0.0000	0.0000	1.0000	
23	18.2750	-142.4209	0.9357	0.0134	0.0000	0.7257	0.2743	
63	17.6474	-142.4220	0.9356	0.0129	0.0000	0.7257	0.2743	
46	16.8345	-142.4235	0.9356	0.0123	0.0000	0.7257	0.2743	
47	15.6090	-142.4258	0.9356	0.0114	0.0000	0.7257	0.2743	

BRANCHES

BRANCH	KFACTOR (LBF-S^2/(LBM-FT)^2)	DELP (PSI)	FLOW RATE (LBM/SEC)	VELOCITY (FT/SEC)	REYN. NO.	MACH NO.
58	0.829E+06	0.530E+03	0.303E+00	0.228E+03	0.170E+07	0.231E+00
142	0.778E+04	0.530E+01	0.313E+00	0.468E+03	0.434E+06	0.317E+00
59	0.600E+08	0.413E+02	0.995E-02	0.103E+04	0.552E+05	0.310E+00
138	0.180E+07	0.521E+01	0.204E-01	0.669E+03	0.665E+05	0.202E+00
60	0.565E+08	0.430E+02	0.105E-01	0.108E+04	0.581E+05	0.326E+00
137	0.947E+06	0.274E+01	0.204E-01	0.642E+03	0.665E+05	0.194E+00
129	0.620E+05	0.628E+00	0.382E-01	0.523E+03	0.142E+06	0.165E+00
23	0.289E+08	0.154E+03	0.277E-01	0.842E+03	0.474E+06	0.273E+00
88	0.804E+05	0.813E+00	0.382E-01	0.541E+03	0.142E+06	0.171E+00
87	0.305E+06	0.123E+01	0.240E-01	0.756E+03	0.130E+06	0.238E+00
86	0.884E+06	0.123E+01	0.141E-01	0.444E+03	0.766E+05	0.140E+00
25	0.899E+05	0.909E+00	0.382E-01	0.440E+03	0.121E+06	0.139E+00

ISTEP = 13 TAU = 0.13000E+02

BOUNDARY NODES

NODE	P(PSI)	T(F)	Z(COMP)	RHO (LBM/FT^3)	CONCENTRATIONS			
						O2	H2	HE
48	550.0000	-60.0000	0.0000	4.4582	1.0000	0.0000	0.0000	
50	14.7000	70.0000	0.0000	0.0092	0.5000	0.0000	0.5000	
66	96.4800	70.0000	0.0000	0.0677	0.0000	0.0000	1.0000	
16	14.7000	70.0000	0.0000	0.0035	0.0000	0.5000	0.5000	
22	172.0000	-174.0000	0.0000	0.1123	0.0000	1.0000	0.0000	

SOLUTION

INTERNAL NODES

NODE	P(PSI)	T(F)	Z	RHO	CONCENTRATIONS (LBM/FT^3)

						O2	H2	HE
49	20.5685	-59.2268	1.0183	0.1140	0.9543	0.0000	0.0457	
68	84.3946	70.0955	1.0037	0.0592	0.0000	0.0000	1.0000	
67	92.3208	70.0329	1.0040	0.0647	0.0000	0.0000	1.0000	
23	18.9912	-131.4286	0.9296	0.0142	0.0000	0.6459	0.3541	
63	18.2469	-131.4288	0.9295	0.0136	0.0000	0.6459	0.3541	
46	17.2779	-131.4292	0.9295	0.0129	0.0000	0.6459	0.3541	
47	15.8063	-131.4297	0.9294	0.0118	0.0000	0.6459	0.3541	

BRANCHES

BRANCH	KFACTOR (LBF-S^2/(LBM-FT)^2)	DELP (PSI)	FLOW RATE (LBM/SEC)	VELOCITY (FT/SEC)	REYN. NO.	MACH NO.
58	0.829E+06	0.529E+03	0.303E+00	0.228E+03	0.170E+07	0.231E+00
142	0.837E+04	0.587E+01	0.318E+00	0.511E+03	0.432E+06	0.311E+00
59	0.436E+08	0.638E+02	0.145E-01	0.109E+04	0.805E+05	0.328E+00
138	0.130E+07	0.793E+01	0.297E-01	0.701E+03	0.966E+05	0.212E+00
60	0.410E+08	0.654E+02	0.151E-01	0.113E+04	0.840E+05	0.342E+00
137	0.680E+06	0.416E+01	0.297E-01	0.670E+03	0.966E+05	0.202E+00
129	0.586E+05	0.744E+00	0.428E-01	0.553E+03	0.145E+06	0.173E+00
23	0.289E+08	0.153E+03	0.276E-01	0.840E+03	0.473E+06	0.272E+00
88	0.762E+05	0.969E+00	0.428E-01	0.576E+03	0.145E+06	0.180E+00
87	0.292E+06	0.147E+01	0.269E-01	0.810E+03	0.133E+06	0.253E+00
86	0.845E+06	0.147E+01	0.158E-01	0.476E+03	0.782E+05	0.149E+00
25	0.870E+05	0.111E+01	0.428E-01	0.478E+03	0.123E+06	0.149E+00

ISTEP = 14 TAU = 0.14000E+02

BOUNDARY NODES

NODE	P(PSI)	T(F)	Z(COMP)	RHO (LBM/FT^3)	CONCENTRATIONS			
						O2	H2	HE
48	550.0000	-60.0000	0.0000	4.4582	1.0000	0.0000	0.0000	
50	14.7000	70.0000	0.0000	0.0092	0.5000	0.0000	0.5000	
66	123.7400	70.0000	0.0000	0.0867	0.0000	0.0000	1.0000	
16	14.7000	70.0000	0.0000	0.0035	0.0000	0.5000	0.5000	
22	172.0000	-174.0000	0.0000	0.1123	0.0000	1.0000	0.0000	

SOLUTION

INTERNAL NODES

NODE	P(PSI)	T(F)	Z	RHO	CONCENTRATIONS (LBM/FT^3)			
						O2	H2	HE
49	21.1259	-51.4222	1.0201	0.1070	0.9408	0.0000	0.0592	

68	107.5339	70.1279	1.0047	0.0754	0.0000	0.0000	1.0000
67	118.1691	70.0439	1.0051	0.0828	0.0000	0.0000	1.0000
23	19.7593	-121.7611	0.9287	0.0149	0.0000	0.5819	0.4181
63	18.8923	-121.7607	0.9287	0.0143	0.0000	0.5819	0.4181
46	17.7579	-121.7602	0.9286	0.0134	0.0000	0.5819	0.4181
47	16.0227	-121.7595	0.9285	0.0121	0.0000	0.5819	0.4181

BRANCHES

BRANCH	KFACTOR (LBF-S^2/(LBM-FT)^2)	DELP (PSI)	FLOW RATE (LBM/SEC)	VELOCITY (FT/SEC)	REYN. NO.	MACH NO.
58	0.829E+06	0.529E+03	0.303E+00	0.228E+03	0.170E+07	0.231E+00
142	0.892E+04	0.643E+01	0.322E+00	0.552E+03	0.431E+06	0.310E+00
59	0.342E+08	0.864E+02	0.191E-01	0.112E+04	0.106E+06	0.339E+00
138	0.101E+07	0.106E+02	0.389E-01	0.718E+03	0.127E+06	0.217E+00
60	0.322E+08	0.878E+02	0.198E-01	0.116E+04	0.110E+06	0.352E+00
137	0.531E+06	0.557E+01	0.389E-01	0.685E+03	0.127E+06	0.207E+00
129	0.556E+05	0.867E+00	0.474E-01	0.582E+03	0.148E+06	0.181E+00
23	0.289E+08	0.152E+03	0.276E-01	0.838E+03	0.472E+06	0.272E+00
88	0.728E+05	0.113E+01	0.474E-01	0.608E+03	0.148E+06	0.189E+00
87	0.281E+06	0.174E+01	0.298E-01	0.863E+03	0.136E+06	0.268E+00
86	0.813E+06	0.174E+01	0.175E-01	0.507E+03	0.797E+05	0.157E+00
25	0.849E+05	0.132E+01	0.474E-01	0.516E+03	0.126E+06	0.160E+00

ISTEP = 15 TAU = 0.15000E+02

BOUNDARY NODES

NODE	P(PSI)	T(F)	Z(COMP)	RHO (LBM/FT^3)	CONCENTRATIONS		
					O2	H2	HE
48	550.0000	-60.0000	0.0000	4.4582	1.0000	0.0000	0.0000
50	14.7000	70.0000	0.0000	0.0092	0.5000	0.0000	0.5000
66	151.0000	70.0000	0.0000	0.1057	0.0000	0.0000	1.0000
16	14.7000	70.0000	0.0000	0.0035	0.0000	0.5000	0.5000
22	172.0000	-174.0000	0.0000	0.1123	0.0000	1.0000	0.0000

SOLUTION

INTERNAL NODES

NODE	P(PSI)	T(F)	Z	RHO (LBM/FT^3)	CONCENTRATIONS		
					O2	H2	HE
49	21.6734	-44.4365	1.0208	0.1013	0.9277	0.0000	0.0723
68	130.6795	70.1604	1.0056	0.0915	0.0000	0.0000	1.0000
67	144.0198	70.0551	1.0062	0.1008	0.0000	0.0000	1.0000

23	20.5735	-113.1108	0.9306	0.0156	0.0000	0.5294	0.4706
63	19.5789	-113.1099	0.9306	0.0149	0.0000	0.5294	0.4706
46	18.2715	-113.1085	0.9305	0.0139	0.0000	0.5294	0.4706
47	16.2571	-113.1065	0.9304	0.0124	0.0000	0.5294	0.4706

BRANCHES

BRANCH	KFACTOR (LBF-S^2/(LBM-FT)^2)	DELP (PSI)	FLOW RATE (LBM/SEC)	VELOCITY (FT/SEC)	REYN. NO.	MACH NO.
58	0.829E+06	0.528E+03	0.303E+00	0.228E+03	0.170E+07	0.231E+00
142	0.942E+04	0.697E+01	0.326E+00	0.591E+03	0.432E+06	0.312E+00
59	0.282E+08	0.109E+03	0.236E-01	0.114E+04	0.131E+06	0.345E+00
138	0.833E+06	0.133E+02	0.480E-01	0.729E+03	0.156E+06	0.220E+00
60	0.265E+08	0.110E+03	0.244E-01	0.118E+04	0.135E+06	0.357E+00
137	0.436E+06	0.698E+01	0.480E-01	0.695E+03	0.156E+06	0.210E+00
129	0.531E+05	0.995E+00	0.519E-01	0.609E+03	0.151E+06	0.188E+00
23	0.289E+08	0.151E+03	0.275E-01	0.835E+03	0.470E+06	0.271E+00
88	0.698E+05	0.131E+01	0.519E-01	0.640E+03	0.151E+06	0.198E+00
87	0.271E+06	0.201E+01	0.327E-01	0.914E+03	0.138E+06	0.282E+00
86	0.785E+06	0.201E+01	0.192E-01	0.537E+03	0.812E+05	0.166E+00
25	0.832E+05	0.156E+01	0.519E-01	0.554E+03	0.128E+06	0.171E+00

SOLUTION SATISFIED CONVERGENCE CRITERION OF 0.00100 IN 24 ITERATIONS

APPENDIX J

INPUT AND OUTPUT DATA FILES FROM EXAMPLE 7

<u>**Contents**</u> <u>**Page**</u>

```
TITLE
Rotating Flow Example - Water Flow in Impeller w/o Friction
   DENCON  GRAVITY  ENERGY  MIXTURE THRUST STEADY      TRANSV
       F       F       T       F       F       T       F
     INERTIA  CONDX    TWOD   PRINTI ROTATION         BUOYANCY HRATE
       T       F       F       F       T       F       F
NNODES NINT NBR  NF NHREF
    13    11    12     1     2
RELAXK  RELAXD  RELAXH
    1.000000    0.500000    1.000000
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
PRESSURE TEMPERATURE
     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  0.8000E+02  0.8000E+02  0.0000E+00  0.0000E+00  0.0000E+00
     4  0.7500E+02  0.8000E+02  0.0000E+00  0.0000E+00  0.0000E+00
     5  0.7000E+02  0.8000E+02  0.0000E+00  0.0000E+00  0.0000E+00
     6  0.6500E+02  0.8000E+02  0.0000E+00  0.0000E+00  0.0000E+00
     7  0.6000E+02  0.8000E+02  0.0000E+00  0.0000E+00  0.0000E+00
     8  0.5500E+02  0.8000E+02  0.0000E+00  0.0000E+00  0.0000E+00
     9  0.5000E+02  0.8000E+02  0.0000E+00  0.0000E+00  0.0000E+00
    10  0.4500E+02  0.8000E+02  0.0000E+00  0.0000E+00  0.0000E+00
    11  0.4000E+02  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         NAMEBR
     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     5.72134
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     5.72134
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     0.00000     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
UPSTREAM  ANGLE
DOWNSTREAM  ANGLE
    23   90.0000
BRANCH
          23
UPSTREAM  ANGLE
    12   90.0000
DOWNSTREAM  ANGLE
    34    0.0000
BRANCH
          34
UPSTREAM  ANGLE
    23    0.0000
DOWNSTREAM  ANGLE
    45    0.0000
```

```
BRANCH
          45
UPSTREAM  ANGLE
    34    0.0000
DOWNSTREAM  ANGLE
    56    0.0000
BRANCH
          56
UPSTREAM  ANGLE
    45    0.0000
DOWNSTREAM  ANGLE
    67    0.0000
BRANCH
          67
UPSTREAM  ANGLE
    56    0.0000
DOWNSTREAM  ANGLE
    78   90.0000
BRANCH
          78
UPSTREAM  ANGLE
    67   90.0000
DOWNSTREAM  ANGLE
    89   90.0000
BRANCH
          89
UPSTREAM  ANGLE
    78   90.0000
DOWNSTREAM  ANGLE
   910    0.0000
BRANCH
         910
UPSTREAM  ANGLE
    89    0.0000
DOWNSTREAM  ANGLE
  1011    0.0000
BRANCH
        1011
UPSTREAM  ANGLE
   910    0.0000
DOWNSTREAM  ANGLE
  1112    0.0000
BRANCH
        1112
```

```
UPSTREAM  ANGLE
  1011    0.0000
DOWNSTREAM  ANGLE
  1213   90.0000
BRANCH
        1213
UPSTREAM  ANGLE
  1112   90.0000
DOWNSTREAM  ANGLE
NUMBER OF ROTATING BRANCH
     9
BRANCH   RADU  RADD  RPM  AKROT
    23  0.1250E+01  0.2250E+01  0.5000E+04  0.8671E+00
    34  0.2250E+01  0.3625E+01  0.5000E+04  0.8158E+00
    45  0.3625E+01  0.4688E+01  0.5000E+04  0.7630E+00
    56  0.4688E+01  0.5375E+01  0.5000E+04  0.7252E+00
    67  0.5375E+01  0.5500E+01  0.5000E+04  0.7076E+00
    89  0.5500E+01  0.5375E+01  0.5000E+04  0.7129E+00
   910  0.5375E+01  0.4688E+01  0.5000E+04  0.7349E+00
  1011  0.4688E+01  0.3625E+01  0.5000E+04  0.7824E+00
  1112  0.3625E+01  0.2650E+01  0.5000E+04  0.8376E+00
```

```
**** GENERAL FLUID SYSTEM SIMULATION PROGRAM ****
 ****************** VERSION 1.4.1 ****************

  TITLE     :Rotating Flow Example - Water Flow in Impeller w/o Friction
  DATE      :9/11/97
  ANALYST   :jwb
  FILEIN    :example7.dat
  FILEOUT   :example7.out
   LOGICAL VARIABLES
  DENCON   =  F
  GRAVITY  =  F
  ENERGY   =  T
  MIXTURE  =  F
  THRUST   =  F
  STEADY   =  T
  TRANSV   =  F
  INERTIA  =  T
  CONDX    =  F
  TWOD     =  F
  PRINTI   =  F
  ROTATION =  T
  BUOYANCY =  F
  HRATE    =  F


  NNODES   =   13
  NINT     =   11
  NBR      =   12
  NF       =    1
  NVAR     =   23
  NHREF    =    2


  FLUIDS:  H2O

BOUNDARY NODES
 NODE       P          T       RHO        AREA
          (PSI)       (F)   (LBM/FT^3)   (IN^2)
     1     90.0000   80.0000   62.2367    0.0000
    13     30.0000   80.0000   62.2250    0.0000

 INPUT SPECIFICATIONS FOR INTERNAL NODES
NODE       AREA      MASS      HEAT
NODE      (IN^2)    (LBM/S)  (BTU/LBM)
```

```
     2      0.0000    0.0000    0.0000
     3      0.0000    0.0000    0.0000
     4      0.0000    0.0000    0.0000
     5      0.0000    0.0000    0.0000
     6      0.0000    0.0000    0.0000
     7      0.0000    0.0000    0.0000
     8      0.0000    0.0000    0.0000
     9      0.0000    0.0000    0.0000
    10      0.0000    0.0000    0.0000
    11      0.0000    0.0000    0.0000
    12      0.0000    0.0000    0.0000

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     5.72134
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     5.72134
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	0.00000	6.22999

SOLUTION

INTERNAL NODES

NODE	P(PSI)	T(F)	Z	RHO (LBM/FT^3)	QUALITY
2	90.0000	79.9996	0.0045	62.2362	0.0000
3	-1.2197	80.0000	0.0040	62.2347	0.0000
4	90.0128	79.9999	0.0045	62.2352	0.0000
5	159.1147	79.8114	0.0080	62.2424	0.0000
6	206.9063	79.6793	0.0103	62.2471	0.0000
7	216.0827	79.6542	0.0108	62.2477	0.0000
8	216.0782	79.6551	0.0108	62.2472	0.0000
9	207.2266	79.6794	0.0104	62.2457	0.0000
10	166.6182	79.7904	0.0083	62.2407	0.0000
11	95.0713	79.9857	0.0048	62.2324	0.0000
12	33.3399	80.1548	0.0017	62.2251	0.0000

BRANCHES

BRANCH	KFACTOR (LBF-S^2/(LBM-FT)^2)	DELP (PSI)	FLOW RATE (LBM/SEC)	VELOCITY (FT/SEC)	REYN. NO.	MACH NO.
12	0.000E+00	0.000E+00	0.570E+02	0.420E+02	0.754E+06	0.342E-01
23	0.000E+00	0.912E+02	0.570E+02	0.731E+02	0.996E+06	0.595E-01
34	0.000E+00	-0.912E+02	0.570E+02	0.409E+02	0.745E+06	0.333E-01
45	0.000E+00	-0.691E+02	0.570E+02	0.282E+02	0.618E+06	0.230E-01
56	0.000E+00	-0.478E+02	0.570E+02	0.230E+02	0.558E+06	0.188E-01
67	0.000E+00	-0.918E+01	0.570E+02	0.212E+02	0.535E+06	0.173E-01
78	0.000E+00	0.453E-02	0.570E+02	0.193E+01	0.161E+06	0.157E-02
89	0.000E+00	0.885E+01	0.570E+02	0.212E+02	0.535E+06	0.173E-01
910	0.000E+00	0.406E+02	0.570E+02	0.230E+02	0.557E+06	0.188E-01
1011	0.000E+00	0.715E+02	0.570E+02	0.282E+02	0.617E+06	0.230E-01
1112	0.000E+00	0.617E+02	0.570E+02	0.381E+02	0.719E+06	0.310E-01
1213	0.000E+00	0.334E+01	0.570E+02	0.212E+02	0.537E+06	0.173E-01

SOLUTION SATISFIED CONVERGENCE CRITERION OF 0.00100 IN 8 ITERATIONS

APPENDIX K

INTERACTIVE SESSION WITH GFSSP PREPROCESSOR

epsgi1{vnhooser}1: **gfssp1p4**

```
 ***********************************************
          G F S S P (Version 1.4 t8)
     General Fluid System Simulation Program
              JANUARY, 1996

  An interactive computer program to calculate flow
  rates, pressures, temperatures and concentrations
  in a flow network.
 ***********************************************
```

DO YOU WANT TO READ AN INPUT DATA FILE?

no
ENTER PROBLEM TITLE(80 CHARACTERS)

FLOW COEFFICIENTS
INPUT LOGICAL OPTIONS, PLEASE ANSWER YES(Y) OR NO(N)
IS FLOW TRANSIENT?
NO
IS DENSITY CONSTANT IN THE CIRCUIT?
n
DO YOU WANT TO ACTIVATE GRAVITY?
Y
DO YOU WANT TO ACTIVATE BUOYANCY?
N
DO YOU WANT TO ACTIVATE INERTIA?
y
DO YOU WANT TO ACTIVATE ROTATION?
n
IS AXIAL THRUST CALCULATION REQUIRED IN THE CIRCUIT?
No
ARE THERE ANY HEAT SOURCES?
n
DO YOU WANT TO ACTIVATE HEAT CONDUCTION?
n
IS THE FLUID A MIXTURE?
no
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

ENTER INDEX NUMBER OF FLUID 1

22
INVALID ANSWER: CHOOSE A NUMBER BETWEEN 1 AND 12

ENTER INDEX NUMBER OF FLUID 1

11
** PROVIDE NODE INFORMATION **
ENTER TOTAL NUMBER OF NODES

2
INVALID ANSWER: YOU MUST HAVE AT LEAST 1 INTERNAL & 2 BOUNDARY NODES.
ENTER TOTAL NUMBER OF NODES
16
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?
Yes
ENTER NUMBER ASSIGNED TO NODE 5

5
IS IT AN INTERNAL NODE?
YES
ENTER NUMBER ASSIGNED TO NODE 6

6
IS IT AN INTERNAL NODE?
yes
ENTER NUMBER ASSIGNED TO NODE 7

7
IS IT AN INTERNAL NODE?
yep
ENTER NUMBER ASSIGNED TO NODE 8

8
IS IT AN INTERNAL NODE?
y
ENTER NUMBER ASSIGNED TO NODE 9

9
IS IT AN INTERNAL NODE?
y
ENTER NUMBER ASSIGNED TO NODE 10

10
IS IT AN INTERNAL NODE?
y
ENTER NUMBER ASSIGNED TO NODE 11

11
IS IT AN INTERNAL NODE?
y
ENTER NUMBER ASSIGNED TO NODE 12

12
IS IT AN INTERNAL NODE?
y
ENTER NUMBER ASSIGNED TO NODE 13

13
IS IT AN INTERNAL NODE?
y
ENTER NUMBER ASSIGNED TO NODE 14

14
IS IT AN INTERNAL NODE?
y
ENTER NUMBER ASSIGNED TO NODE 15

15
IS IT AN INTERNAL NODE?
y
ENTER NUMBER ASSIGNED TO NODE 16

16
IS IT AN INTERNAL NODE?
n
** PROVIDE BRANCH INFORMATION **
HOW MANY BRANCHES ARE CONNECTED WITH NODE 2?

1
INVALID ANSWER: EACH NODE MUST HAVE AT LEAST TWO BRANCHES.
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: VISCOUS RESISTANCE (WALL FUNCTION) - INACTIVE
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

19
INVALID OPTION: PLEASE TRY AGAIN
4
ENTER LENGTH (IN), DIAMETER (IN), & ROUGHNESS OF BRANCH 12

360
30.624
0.00006
ENTER ENTRANCE & EXIT LOSS COEFFICIENTS OF BRANCH 12

0.5
0
ENTER ANGLE WITH GRAVITY VECTOR (90 DEG FOR HORIZONTAL AXIS) FOR BRANCH NO. 12

90
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: VISCOUS RESISTANCE (WALL FUNCTION) - INACTIVE
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

13
ENTER DIA (IN), K1, & K2 OF BRANCH 23

30.624, 300, 0.1
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

88
INVALID NODE NUMBER, TRY AGAIN
ENTER DOWNSTREAM NODE OF BRANCH NO. 34

4
SELECT RESISTANCE OPTION FOR BRANCHES:
OPTION - 1: PIPE FLOW
OPTION - 2: FLOW THROUGH RESTRICTION
OPTION - 3: VISCOUS RESISTANCE (WALL FUNCTION) - INACTIVE
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

1

ENTER LENGTH (IN), DIAMETER (IN), & ROUGHNESS OF BRANCH 34

480, 30.624
0.00006
ENTER ANGLE WITH GRAVITY VECTOR (90 DEG FOR HORIZONTAL AXIS) FOR BRANCH NO. 34

90
HOW MANY BRANCHES ARE CONNECTED WITH NODE 4?

2
ENTER BRANCH NUMBER(J = 1 OF 2) OF NODE 4

34
THE INFORMATION ABOUT THIS BRANCH IS AVAILABLE
ENTER BRANCH NUMBER(J = 2 OF 2) OF NODE 4

45
ENTER UPSTREAM NODE OF BRANCH NO. 45

4
ENTER DOWNSTREAM NODE OF BRANCH NO. 45

5
SELECT RESISTANCE OPTION FOR BRANCHES:
OPTION - 1: PIPE FLOW
OPTION - 2: FLOW THROUGH RESTRICTION
OPTION - 3: VISCOUS RESISTANCE (WALL FUNCTION) - INACTIVE
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

14
ENTER A, B, AND AREA (IN**2) OF BRANCH 45

30888 -.0081 736.57001
HOW MANY BRANCHES ARE CONNECTED WITH NODE 5?

2
ENTER BRANCH NUMBER(J = 1 OF 2) OF NODE 5

45
THE INFORMATION ABOUT THIS BRANCH IS AVAILABLE
ENTER BRANCH NUMBER(J = 2 OF 2) OF NODE 5

56
ENTER UPSTREAM NODE OF BRANCH NO. 56

5
ENTER DOWNSTREAM NODE OF BRANCH NO. 56

6
SELECT RESISTANCE OPTION FOR BRANCHES:
OPTION - 1: PIPE FLOW
OPTION - 2: FLOW THROUGH RESTRICTION
OPTION - 3: VISCOUS RESISTANCE (WALL FUNCTION) - INACTIVE
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

1
ENTER LENGTH (IN), DIAMETER (IN), & ROUGHNESS OF BRANCH 56

3600 30.624 0.00006
ENTER ANGLE WITH GRAVITY VECTOR (90 DEG FOR HORIZONTAL AXIS) FOR BRANCH NO. 56

90
HOW MANY BRANCHES ARE CONNECTED WITH NODE 6?

2
ENTER BRANCH NUMBER(J = 1 OF 2) OF NODE 6

56
THE INFORMATION ABOUT THIS BRANCH IS AVAILABLE
ENTER BRANCH NUMBER(J = 2 OF 2) OF NODE 6

67
ENTER UPSTREAM NODE OF BRANCH NO. 67

6
ENTER DOWNSTREAM NODE OF BRANCH NO. 67

7
SELECT RESISTANCE OPTION FOR BRANCHES:
OPTION - 1: PIPE FLOW
OPTION - 2: FLOW THROUGH RESTRICTION
OPTION - 3: VISCOUS RESISTANCE (WALL FUNCTION) - INACTIVE
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

7
ENTER UPSTREAM PIPE DIA (IN) & REDUCED DIA (IN) OF BRANCH   67

30.624   22.62
HOW MANY BRANCHES ARE CONNECTED WITH NODE   7?

2
ENTER BRANCH NUMBER(J = 1 OF 2) OF NODE   7

67
THE INFORMATION ABOUT THIS BRANCH IS AVAILABLE
ENTER BRANCH NUMBER(J = 2 OF 2) OF NODE   7

78
ENTER UPSTREAM NODE OF BRANCH NO.   78

7
ENTER DOWNSTREAM NODE OF BRANCH NO.   78

8
SELECT RESISTANCE OPTION FOR BRANCHES:
OPTION - 1: PIPE FLOW
OPTION - 2: FLOW THROUGH RESTRICTION
OPTION - 3: VISCOUS RESISTANCE (WALL FUNCTION) - INACTIVE
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

1
ENTER LENGTH (IN), DIAMETER (IN), & ROUGHNESS OF BRANCH   78

2400   22.62   0.00008

ENTER ANGLE WITH GRAVITY VECTOR (90 DEG FOR HORIZONTAL AXIS) FOR BRANCH NO. 78

90
HOW MANY BRANCHES ARE CONNECTED WITH NODE 8?

2
ENTER BRANCH NUMBER(J = 1 OF 2) OF NODE 8

78
THE INFORMATION ABOUT THIS BRANCH IS AVAILABLE
ENTER BRANCH NUMBER(J = 2 OF 2) OF NODE 8

89
ENTER UPSTREAM NODE OF BRANCH NO. 89

8
ENTER DOWNSTREAM NODE OF BRANCH NO. 89

9
SELECT RESISTANCE OPTION FOR BRANCHES:
OPTION - 1: PIPE FLOW
OPTION - 2: FLOW THROUGH RESTRICTION
OPTION - 3: VISCOUS RESISTANCE (WALL FUNCTION) - INACTIVE
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

5
ENTER PIPE AND ORIFICE DIAMETERS (IN) OF BRANCH 89

22.62 8
HOW MANY BRANCHES ARE CONNECTED WITH NODE 9?

2
ENTER BRANCH NUMBER(J = 1 OF 2) OF NODE 9

89
THE INFORMATION ABOUT THIS BRANCH IS AVAILABLE
ENTER BRANCH NUMBER(J = 2 OF 2) OF NODE 9

910
ENTER UPSTREAM NODE OF BRANCH NO. 910

9

ENTER DOWNSTREAM NODE OF BRANCH NO.   910

10
SELECT RESISTANCE OPTION FOR BRANCHES:
OPTION - 1: PIPE FLOW
OPTION - 2: FLOW THROUGH RESTRICTION
OPTION - 3: VISCOUS RESISTANCE (WALL FUNCTION) - INACTIVE
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

1
ENTER LENGTH (IN), DIAMETER (IN), & ROUGHNESS OF BRANCH   910

2400   22.62   0.00008
ENTER ANGLE WITH GRAVITY VECTOR (90 DEG FOR HORIZONTAL AXIS) FOR BRANCH NO.   910

90
HOW MANY BRANCHES ARE CONNECTED WITH NODE   10?

2
ENTER BRANCH NUMBER(J = 1 OF 2) OF NODE   10

910
THE INFORMATION ABOUT THIS BRANCH IS AVAILABLE
ENTER BRANCH NUMBER(J = 2 OF 2) OF NODE   10

1011
ENTER UPSTREAM NODE OF BRANCH NO.   1011

10
ENTER DOWNSTREAM NODE OF BRANCH NO.   1011

11
SELECT RESISTANCE OPTION FOR BRANCHES:
OPTION - 1: PIPE FLOW
OPTION - 2: FLOW THROUGH RESTRICTION
OPTION - 3: VISCOUS RESISTANCE (WALL FUNCTION) - INACTIVE
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

8
ENTER UPSTREAM PIPE DIA (IN) & EXPANDED DIA (IN) OF BRANCH 1011

22.62
30.624
HOW MANY BRANCHES ARE CONNECTED WITH NODE 11?

2
ENTER BRANCH NUMBER(J = 1 OF 2) OF NODE 11

1011
THE INFORMATION ABOUT THIS BRANCH IS AVAILABLE
ENTER BRANCH NUMBER(J = 2 OF 2) OF NODE 11

1112
ENTER UPSTREAM NODE OF BRANCH NO. 1112

11
ENTER DOWNSTREAM NODE OF BRANCH NO. 1112

12
SELECT RESISTANCE OPTION FOR BRANCHES:
OPTION - 1: PIPE FLOW
OPTION - 2: FLOW THROUGH RESTRICTION
OPTION - 3: VISCOUS RESISTANCE (WALL FUNCTION) - INACTIVE
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

1
ENTER LENGTH (IN), DIAMETER (IN), & ROUGHNESS OF BRANCH 1112

3600 30.624 0.00006
ENTER ANGLE WITH GRAVITY VECTOR (90 DEG FOR HORIZONTAL AXIS) FOR BRANCH NO. 1112

90

HOW MANY BRANCHES ARE CONNECTED WITH NODE 12?

2
ENTER BRANCH NUMBER(J = 1 OF 2) OF NODE 12

1112
THE INFORMATION ABOUT THIS BRANCH IS AVAILABLE
ENTER BRANCH NUMBER(J = 2 OF 2) OF NODE 12

1213
ENTER UPSTREAM NODE OF BRANCH NO. 1213

12
ENTER DOWNSTREAM NODE OF BRANCH NO. 1213

13
SELECT RESISTANCE OPTION FOR BRANCHES:
OPTION - 1: PIPE FLOW
OPTION - 2: FLOW THROUGH RESTRICTION
OPTION - 3: VISCOUS RESISTANCE (WALL FUNCTION) - INACTIVE
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

6
ENTER LENGTH,PIPE DIA (IN), & ORIFICE DIA(IN) OF BRANCH 1213

9 30.624 12
HOW MANY BRANCHES ARE CONNECTED WITH NODE 13?

2
ENTER BRANCH NUMBER(J = 1 OF 2) OF NODE 13

1213
THE INFORMATION ABOUT THIS BRANCH IS AVAILABLE
ENTER BRANCH NUMBER(J = 2 OF 2) OF NODE 13

1314
ENTER UPSTREAM NODE OF BRANCH NO. 1314

13
ENTER DOWNSTREAM NODE OF BRANCH NO. 1314

14
SELECT RESISTANCE OPTION FOR BRANCHES:

OPTION - 1: PIPE FLOW
OPTION - 2: FLOW THROUGH RESTRICTION
OPTION - 3: VISCOUS RESISTANCE (WALL FUNCTION) - INACTIVE
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

1
ENTER LENGTH (IN), DIAMETER (IN), & ROUGHNESS OF BRANCH 1314

1200 30.624 0.00006
ENTER ANGLE WITH GRAVITY VECTOR (90 DEG FOR HORIZONTAL AXIS) FOR BRANCH NO. 1314

90
HOW MANY BRANCHES ARE CONNECTED WITH NODE 14?

2
ENTER BRANCH NUMBER(J = 1 OF 2) OF NODE 14

1314
THE INFORMATION ABOUT THIS BRANCH IS AVAILABLE
ENTER BRANCH NUMBER(J = 2 OF 2) OF NODE 14

1415
ENTER UPSTREAM NODE OF BRANCH NO. 1415

14
ENTER DOWNSTREAM NODE OF BRANCH NO. 1415

15
SELECT RESISTANCE OPTION FOR BRANCHES:
OPTION - 1: PIPE FLOW
OPTION - 2: FLOW THROUGH RESTRICTION
OPTION - 3: VISCOUS RESISTANCE (WALL FUNCTION) - INACTIVE
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

13
ENTER DIA (IN), K1, & K2 OF BRANCH 1415

30.624 800 .2
HOW MANY BRANCHES ARE CONNECTED WITH NODE 15?

2
ENTER BRANCH NUMBER(J = 1 OF 2) OF NODE 15

1415
THE INFORMATION ABOUT THIS BRANCH IS AVAILABLE
ENTER BRANCH NUMBER(J = 2 OF 2) OF NODE 15

1516
ENTER UPSTREAM NODE OF BRANCH NO. 1516

15
ENTER DOWNSTREAM NODE OF BRANCH NO. 1516

16
SELECT RESISTANCE OPTION FOR BRANCHES:
OPTION - 1: PIPE FLOW
OPTION - 2: FLOW THROUGH RESTRICTION
OPTION - 3: VISCOUS RESISTANCE (WALL FUNCTION) - INACTIVE
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

4
ENTER LENGTH (IN), DIAMETER (IN), & ROUGHNESS OF BRANCH 1516

286
30.624 0.00006
ENTER ENTRANCE & EXIT LOSS COEFFICIENTS OF BRANCH 1516

0
1
ENTER ANGLE WITH GRAVITY VECTOR (90 DEG FOR HORIZONTAL AXIS) FOR BRANCH NO. 1516

180

```
 ** PROVIDE VALUES IN THE BOUNDARY NODES **
  ENTER PRESSURE (PSIA) & TEMPERATURE (DEG F) FOR NODE      1

14.7
60
  ENTER PRESSURE (PSIA) & TEMPERATURE (DEG F) FOR NODE     16

14.7 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
EXAMPLE2.DAT

epsgi1{vnhooser}2: gfssp1p4
  ************************************************
            G F S S P (Version 1.4 t8)
      General Fluid System Simulation Program
                  JANUARY, 1996

   An interactive computer program to calculate flow
   rates, pressures, temperatures and concentrations
   in a flow network.
  ************************************************


  DO YOU WANT TO READ AN INPUT DATA FILE?

y
  ENTER INPUT DATA FILENAME

EXAMPLE2.DAT
  ENTER OUTPUT FILENAME

EXAMPLE2.OUT
  ENTER DATE( WITHIN 15 CHARACTERS)

9/19/96
  ENTER ANALYST NAME(WITHIN 30 CHARACTERS)

K. Van Hooser
 ITER(RESISTANCE)=           1ITER(NEWTON-RAPHSON)=           3
 DIFK =    1.000000    DIFD =   0.0000000E+00DIFH =   0.0000000E+00
 ITER(RESISTANCE)=           2ITER(NEWTON-RAPHSON)=          11
 DIFK =   0.5327495    DIFD =   4.5107395E-04DIFH =   0.0000000E+00
 ITER(RESISTANCE)=           3ITER(NEWTON-RAPHSON)=           2
 DIFK =   1.7930759E-04DIFD =   2.2637263E-04DIFH =   0.0000000E+00
epsgi1{vnhooser}3:
```