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Generalized Fluid System Simulation Program, Version 6.0

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March 2016

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PREFACE

The motivation to develop a general purpose computer program to compute pressure and flow distribution in a complex fluid network came from the need to calculate the axial load on the bearings in a turbopump. During the early years of space shuttle main engine development, several specific purpose codes were developed to model the 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, development of the Generalized Fluid System Simulation Program (GFSSP) was started at Marshall Space Flight Center (MSFC) in March 1994. The objective was to develop a general fluid flow system solver capable of handling phase change, compressibility, and mixture thermodynamics. Emphasis was given to construct a user-friendly program using a modular structured code. The intent of this effort was that an engineer with an undergraduate background in fluid mechanics and thermodynamics should be able to rapidly develop a reliable model. The interest in modular code development was intended to facilitate future modifications to the program.

The code development was carried out in several phases. At the end of each phase a workshop was held where the latest version of the code was released to MSFC engineers for testing, verification, and feedback. The steady state version of GFSSP (version 1.4) was first released in October 1996. This version is also commercially available through the Open Channel Foundation. The unsteady version was released in October 1997 (version 2.0). A graphical user interface (GUI) for GFSSP was developed and was part of version 3.0 which was released in November 1999. GFSSP (version 3.0) won the NASA Software of the Year award in 2001. Fluid transient (water hammer) capability was added in version 4.0 that was released in March 2003. Conjugate heat transfer capability was added in version 5.0 which was released in February 2007. The main highlights of the present version (version 6.0) are: (1) extension of mixture option to handle phase change, (2) multiple pressure and flow regulators in a flow circuit, (3) fixed flow rate and the International System of Units option, (4) two-dimensional flow modeling within a flow network system, and (5) extension of user-specified fluid property table to handle phase change.

This Technical Publication provides a detailed discussion of the data structure, mathematical formulation, computer program, GUI, and includes a number of example problems. Section 1 provides an introduction and overview of the code. Data structure of the code is described in section 2. The mathematical formulation that includes the description of governing equations and the solution procedure for solving the equations is described in section 3. The program structure is discussed in section 4. Section 5 describes GFSSP's GUI, which is called visual thermofluid dynamic analyzer for systems and components (VTASC). Several example problems are described in section 6. The new user may skip sections 2 through 4 initially, but will benefit from these sections after gaining some experience with the code.

EXECUTIVE SUMMARY

The Generalized Fluid System Simulation Program (GFSSP) is a general purpose computer program for analyzing steady state and time-dependent flow rates, pressures, temperatures, and concentrations in a complex flow network. The program is capable of modeling real fluids with phase changes, compressibility, mixture thermodynamics, conjugate heat transfer between solid and fluid, fluid transients, pumps, compressors, and external body forces such as gravity and centrifugal. The thermofluid system to be analyzed is discretized into nodes, branches, and conductors. The scalar properties such as pressure, temperature, and concentrations are calculated at nodes. Mass flow rates and heat transfer rates are computed in branches and conductors. The graphical user interface allows users to build their models using the 'point, drag, and click' method; the users can also run their models and post-process the results in the same environment.

Two thermodynamic property programs (GASP/WASP and GASPAK) provide required thermodynamic and thermophysical properties for 36 fluids: helium, methane, neon, nitrogen, carbon monoxide, oxygen, argon, carbon dioxide, fluorine, hydrogen, parahydrogen, water, kerosene (RP-1), isobutene, butane, deuterium, ethane, ethylene, hydrogen sulfide, krypton, propane, xenon, R-11, R-12, R-22, R-32, R-123, R-124, R-125, R-134A, R-152A, nitrogen trifluoride, ammonia, hydrogen peroxide, and air. The program also provides the options of using any incompressible fluid with constant density and viscosity or ideal gas. The users can also supply property tables for fluids that are not in the library.

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

GFSSP employs a finite volume formulation of mass, momentum, and energy conservation equations in conjunction with the thermodynamic equations of state for real fluids as well as energy conservation equations for the solid. The system of equations describing the fluid network is solved by a hybrid numerical method that is a combination of the Newton-Raphson and successive substitution methods. The application and verification of the code has been demonstrated through 30 example problems.

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LIST OF ACRONYMS, SYMBOLS, AND ABBREVIATIONS

CFD	computational fluid dynamics
FVM	finite volume method
GFSSP	Generalized Fluid System Simulation Program
GN_2	gaseous nitrogen
GOX	gaseous oxygen
GUI	graphical user interface
He	helium
LH_2	liquid hydrogen
LOX	liquid oxygen
MHTB	multipurpose hydrogen testbed
MLI	multilayer insulation
MOC	method of characteristics
MSFC	Marshall Space Flight Center (NASA)
NBS	National Bureau of Standards
RP-1	rocket propellent-1
SASS	simultaneous adjustment with successive substitution
SI	International System of Units
SIMPLE	semi-implicit pressure-linked equation
SP	solver and property
TP	Technical Publication
TPA	turbopump assembly
TVS	thermodynamic vent system
US	User Subroutine
VTASC	Visual Thermofluid dynamic Analyzer for Systems and Components

NOMENCLATURE

A	area (in^2)
A_0	pump characteristic curve coefficient
a	length (in)
a_{fluid}	speed of sound for LOX (ft/s)
B	passage width ($B = \pi D$)
B_0	pump characteristic curve coefficient
b	length (in); duct wall thickness ($b = r_o - r_i$)
C	heat capacity (Btu/s-°R)
C_0	pump characteristic curve coefficient
C_c	convergence criterion
C_L	flow coefficient
C_p	specific heat (Btu/lb °F)
C_v	flow coefficient for a valve
c	concentration; clearance (in)
$c_{i,k}$	mass concentration of kth specie at ith node
D,d	diameter (in)
D_f	degradation factor
f	Darcy friction factor
G	bound mass (lb/ft^2-s)
g	gravitational acceleration (ft/s^2); specific heat ratio
g_c	conversion constant (= 32.174 $lb\text{-}ft/lb_f\text{-}s^2$)
H	enthalpy (Btu/lb)
h	enthalpy (Btu/lb); heat transfer coefficient (Btu/ft^2-s-°R)
h_{fg}	enthalpy of evaporation

NOMENCLATURE (Continued)

i	index of a neighboring node of the jth node
J	mechanical equivalent of heat (778 ft-lb_f/Btu)
j	index of a neighboring node of the ith node
K, K_1	nondimensional head loss factor
K_e	exit loss coefficient
K_f	flow resistance coefficient (lb_f-s^2/$(lb\text{-}ft)^2$)
$K_{rotation}$	nondimensional rotating flow resistance coefficient
K_i	inlet loss coefficient
k	thermal conductivity (Btu/ft-s-°R)
k_v	empirical factor
L	length (in)
$L*$	critical length of the pipe
L_Ω	resistance of the Joule-Thompson device
M	molecular weight
m	resident mass (lb); gap length (pitch)
$\dot{m}$	mass flow rate (lb/s)
m_p	pitch (in)
N	revolutions per minute (rpm); number of iterations; number of data
N_B	number of branches
N_E	number of equations
N_N	number of nodes
Nu	Nusselt number
n	number of teeth
P	pump power (hp); interstitial gas pressure (torr)
Po	Poiseuille number
P_R	reservoir pressure
Pr	Prandtl number
p	pressure (lb_f /in^2)
$Q, \dot{q}$	heat source (Btu/s); volumetric flow rate of water at 60 °F (gal/min)

NOMENCLATURE (Continued)

R	gas constant (lb_f-ft/lb-°R)
Re	Reynolds number (Re = $\rho uD/m$)
R_o	outer radius (in)
r	radius (in)
S	momentum source (lb_f); entropy (Btu/lb-R)
$\dot{S}$	entropy generation (Btu/s-°R)
s	entropy (Btu/lb-°R)
T	fluid temperature (°F)
T_s	solid temperature (°F); saturation temperature (°F)
u	velocity (ft/s)
$\dot{V}$	volumetic flow rate (ft^3/s)
V	volume (in^3)
V_f	viscosity correction factor
v	specific volume (ft^3/lb)
v_f	specific volume of a liquid (ft^3/lb)
v_g	specific volume of a gas (ft^3/lb)
w	Joule-Thomson device flow rate (lbm/hr); width
wt	dimensionless time
x	quality and mass fraction
x_k	molar concentrations
Y	two-phase factor in Miropolskii's equation
z	compressibility factor

Greek

α	multiplier for Labyrinth seal resistance; under-relaxation parameter
β	ratio of orifice diameter to inside pipe diameter
γ	specific heat
Δh	head loss (ft)
$\Delta\tau$	time step (s)
δ	distances between velocity locations (ft)

NOMENCLATURE (Continued)

δ_{ij}	distance between two solid nodes (ft)
ε	absolute roughness (in), heat exchanger effectiveness, Labyrinth seal carryover factor; radius of orbit to the clearance
ε/D	relative roughness
ε_{ij}	emissivity
θ	angle between branch flow velocity vector and gravity vector (deg); angle between neighboring branches for computing shear (deg)
θ_r	time required to drain pressurized propellant tank (s)
η	efficiency
μ	viscosity (lb/ft-s)
ν	kinematic viscosity (ft^2/s)
ρ	density (lb/ft^3)
$\bar{\rho}$	molar density (lb-mol/ft^3)
σ	Stefan-Boltzman constant ($= 4.7611 \times 10^{-13}$ Btu/ft^2-R^4-s)
τ	time (s)
ω	angular velocity (rad/s); running speed (rpm)

Subscript

0	time equals zero
a	relating to inlet radius
amb	ambient
B	back
b	relating to outlet radius
c	cold
cr	critical
d	downstream
Dis	discharge
eff	effective
F	front
f	liquid
g	vapor

NOMENCLATURE (Continued)

gen	generation
h	hot
Im	impeller
i	node; inner
ij	branch
k	index of the fluid component in a fluid mixture
l	liquid
norm	normal
o	outer
or	orifice
p	parallel branch
prop	propellant
S	solid
s	entropy
trans	transverse
Turb	turbine
u	upstream branch
v	vapor

TECHNICAL PUBLICATION

GENERALIZED FLUID SYSTEM SIMULATION PROGRAM, VERSION 6.0

1. INTRODUCTION

The need for a generalized computer program for thermofluid analysis in a flow network has been felt for a long time in aerospace industries. Designers of thermofluid systems often need to know pressures, temperatures, flow rates, concentrations, and heat transfer rates at different parts of a flow circuit for steady state or transient conditions. Such applications occur in propulsion systems for tank pressurization, internal flow analysis of rocket engine turbopumps, chilldown of cryogenic tanks and transfer lines, and many other applications of gas-liquid systems involving fluid transients and conjugate heat and mass transfer. Computer resource requirements to perform time-dependent, three-dimensional Navier-Stokes computational fluid dynamics (CFD) analysis of such systems are prohibitive and therefore are not practical. A possible recourse is to construct a fluid network consisting of a group of flow branches such as pipes and ducts that are joined together at a number of nodes. They can range from simple systems consisting of a few nodes and branches to very complex networks containing many flow branches simulating valves, orifices, bends, pumps, and turbines. In the analysis of existing or proposed networks, node pressures, temperatures, and concentrations at the system boundaries are usually known. The problem is to determine all internal nodal pressures, temperatures, concentrations, and branch flow rates. Such schemes are known as network flow analysis methods and they use largely empirical information to model fluid friction and heat transfer. For example, an accurate prediction of axial thrust in a liquid rocket engine turbopump requires the modeling of fluid flow in a very complex network. Such a network involves the flow of cryogenic fluid through extremely narrow passages, flow between rotating and stationary surfaces, phase changes, mixing of fluids, and heat transfer. Propellant feed system designers are often required to analyze pressurization or blowdown processes in flow circuits consisting of many series and parallel flow branches containing various pipe fittings and valves using cryogenic fluids. The designers of a fluid system are also required to know the maximum pressure in the pipe line after a sudden valve closure or opening.

Available commercial codes are generally suitable for steady state, single-phase incompressible flow. Because of the proprietary nature of such codes, it is not possible to extend their capability to satisfy the above-mentioned needs. In the past, specific purpose codes were developed to model the space shuttle main engine 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, the Generalized Fluid System Simulation Program (GFSSP)[1] has been developed at NASA Marshall Space Flight Center (MSFC) as a general fluid flow system solver capable of handling phase changes, compressibility, mixture thermodynamics, and transient operations. It also includes the capability to model external body forces such as gravity and centrifugal effects in a complex flow network. The objective of the present effort is to (a) develop 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.

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

This Technical Publication (TP) documents the data structure, mathematical formulation, computer program, and graphical user interface (GUI). Use of the code is illustrated by 30 example problems. It also documents the verification and validation effort conducted by code developers and users. This section also presents an overview of the subsequent sections to provide users with a global perspective of the code.

1.1 Network Flow Analysis Methods

The oldest method for systematically solving a problem consisting of steady flow in a pipe network is the Hardy Cross method.[2] Not only is this method suited for hand calculations, but it has also been widely employed for use in computer-generated solutions. But as computers allowed much larger networks to be analyzed, it became apparent that the convergence of the Hardy Cross method might be very slow or even fail to provide a solution in some cases. The main reason for this numerical difficulty is that the Hardy Cross method does not solve the system of equations simultaneously. It considers a portion of the flow network to determine the continuity and momentum errors. The head loss and the flow rates are corrected and then it proceeds to an adjacent portion of the circuit. This process is continued until the whole circuit is completed. This sequence of operations is repeated until the continuity and momentum errors are minimized. It is evident that the Hardy Cross method belongs in the category of successive substitution methods and it is likely that it may encounter convergence difficulties for large circuits. In later years, the Newton-Raphson method has been utilized[3] to solve large networks. The Newton-Raphson method solves all the governing equations simultaneously and is numerically more stable and reliable than successive substitution methods.

The network analysis method[4] has been widely used in thermal analysis codes (SINDA/G[5] and SINDA/FLUINT[6]) using an electric analog. The partial differential equation of heat conduction is discretized into finite difference form expressing temperature of a node in terms of temperatures of neighboring nodes and ambient nodes. The set of finite difference equations is solved to calculate temperature of the solid nodes and heat fluxes between the nodes. There have been some limited applications of thermal network analysis methods to model fluid flows. Such attempts did not go far because of the inability of heat conduction equations to handle the nonlinear fluid inertia term. There has been limited success in modeling compressible and two-phase flows by such methods.

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At MSFC, another system analysis code, ROCETS[7] is routinely used for simulating flow in rocket engines. ROCETS has a very flexible architecture where users develop the system model by integrating component modules such as pumps, turbines, and valves. The user can also build any model of specific components to integrate into the system model. ROCETS solves the system of equations by a modified Newton-Raphson method.[8]

The finite volume method (FVM) has been widely used in solving Navier-Stokes equations in CFD.[9] The FVM divides the flow domain into a discrete number of control volumes and determines the conservation equations for mass, momentum, energy, and species for each control volume. Simultaneous solutions of these conservation equations provide the pressure, velocity components, temperature, and concentrations representative of the discrete control volumes. The numerical method is called 'pressure based' if the pressures are calculated from the mass conservation equation and density from the equation of state. On the other hand, a 'density based' numerical method uses the mass conservation equation to calculate density of the fluid and pressure from the equation of state. GFSSP uses a pressure-based FVM as the foundation of its numerical scheme.

1.1.1 Network Definitions

GFSSP constructs a fluid network using fluid and solid nodes. The fluid circuit is constructed with boundary nodes, internal nodes, and branches (fig. 1) while the solid circuit is constructed with solid nodes, ambient nodes, and conductors. The solid and fluid nodes are connected with solid-fluid conductors. Users must specify conditions such as pressure, temperature, and concentration of species at the boundary nodes. These variables are calculated at the internal nodes by solving conservation equations of mass, energy, and species in conjunction with the thermodynamic equation of state. Each internal node is a control volume where there is inflow and outflow of mass, energy, and species at the boundaries of the control volume. The internal node also has resident mass, energy, and concentration. The momentum conservation equation is expressed in flow rates and is solved in branches. At the solid node, the energy conservation equation for solid is solved to compute temperature of the solid node. Figure 1 shows a schematic and GFSSP flow circuit of a counter flow heat exchanger. Hot nitrogen gas is flowing through a pipe, colder nitrogen is flowing counter to the hot stream in the annulus pipe, and heat transfer occurs through metal tubes. The problem considered is to calculate flow rates and temperature distributions in both streams.

1.2 Units and Sign Conventions

GFSSP uses British gravitational units (commonly known as engineering units). Table 1 describes the units of variables used in the code. The units in the second column are the units that appear in the input and output data files. Users must specify the values in these units in their model. The units that are listed in the third column are internal to the code and used during the solution of the equations. These units must be used in user-provided subroutines. The user has the option of entering the International System of Units (SI) into the preprocessor; these will be converted to engineering units when written to the input file (see sec. 5.1.3). GFSSP uses standard sign conventions for mass and heat transfer. Mass and heat input to a node is considered positive. Similarly mass and heat output from a node is considered negative.

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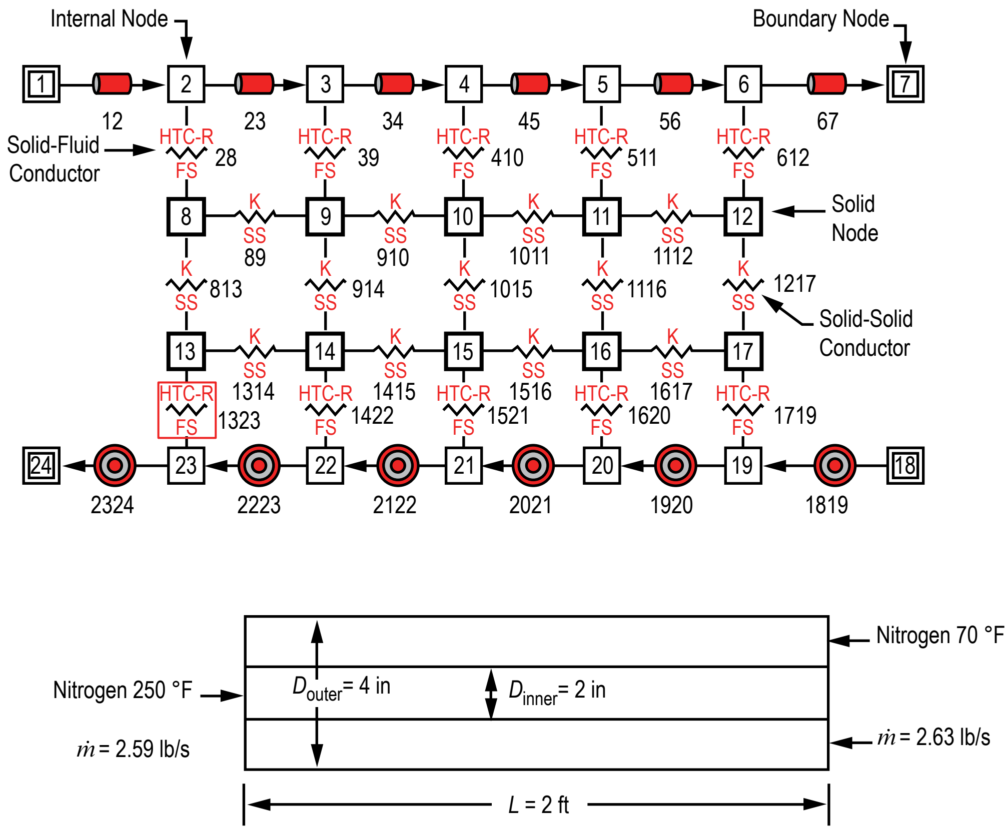

Figure 1. A typical flow network consists of fluid node, solid node, flow branches, and conductors.

Table 1. Units of variables in input/output and solver module.

Variables	Input/Output	Solver Module
Length	inches	feet
Area	inches^2	feet^2
Pressure	psia	psf
Temperature	°F	°R
Mass injection	lbm/s	lbm/s
Heat source	Btu/s or Btu/lbm	Btu/s or Btu/lbm

1.3 Data Structure

GFSSP has a unique data structure (fig. 2) that allows constructing all possible arrangements of a flow network with no limit on the number of elements. The elements of a flow network are boundary nodes, internal nodes, and branches. For conjugate heat transfer problems, there are three additional elements: solid node, ambient node, and conductor. The relationship between a fluid node and a branch as well as a solid node and conductor is defined by a set of relational geometric properties. For example, the relational geometric properties of a node are number and name of branches connected to it. With the help of these properties, it is possible to define any structure of the network as it progresses through every junction of the network. The positive or negative flow direction is also defined locally. Unlike a structured coordinate system, there is no global definition of flow direction and origin. The development of a flow network can start from any point and can proceed in any direction.

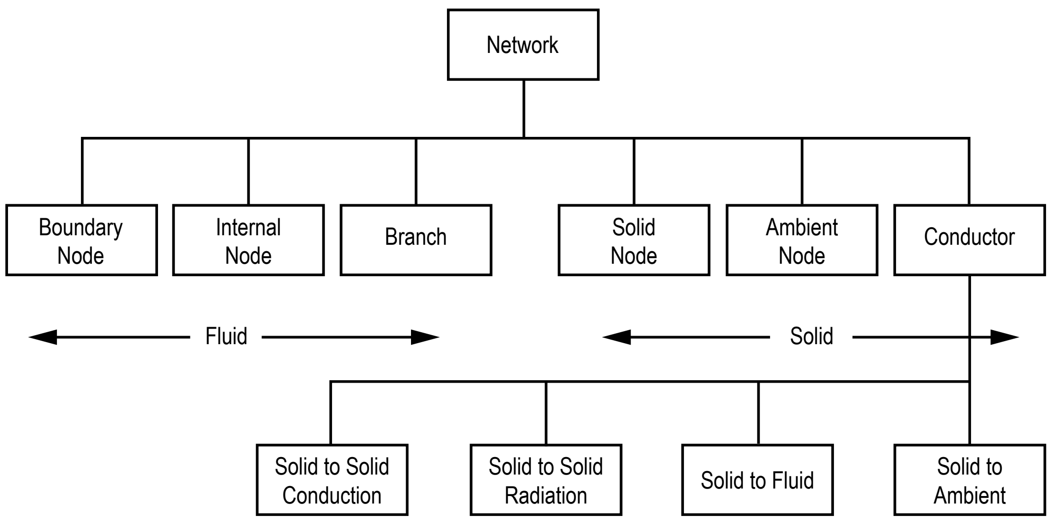

Figure 2. Data structure of the fluid-solid network has six major elements.

All elements of a network have properties. The properties can be classified into two categories: geometric and thermofluid. Geometric properties are again classified into two subcategories: relational and quantitative. Relational properties define the relationship of the element with the neighboring elements. Quantitative properties include geometric parameters such as area, length, and volume. GFSSP's data structure is discussed in detail in section 2.

1.4 Mathematical Formulation

GFSSP solves the conservation equations of mass and momentum in internal nodes and branches to calculate fluid properties. It also solves for energy conservation equations to calculate temperatures of solid nodes. Table 2 shows the mathematical closure that describes the unknown variables and the available equations to solve the variables. Pressure, temperature, species concentration, and resident mass in a control volume are calculated at the internal nodes, whereas the flow

Table 2. Mathematical closure.

Unknown Variables	Available Equations to Solve
Pressure	Mass conservation equation
Flow rate	Momentum conservation equation
Fluid temperature	Energy conservation equation of fluid
Solid temperature	Energy conservation equation of solid
Species concentrations	Conservation equations for species
Fluid mass (unsteady flow)	Thermodynamic equation of state

rate is calculated at the branch. The equations are coupled and nonlinear; therefore, they are solved by an iterative numerical scheme. GFSSP employs a unique numerical scheme known as simultaneous adjustment with successive substitution (SASS), which is a combination of Newton-Raphson and successive substitution methods. The coupling of equations is shown in figure 3. The mass and momentum conservation equations and the equation of state are solved by the Newton-Raphson method while the conservation of energy and species are solved by the successive substitution method.

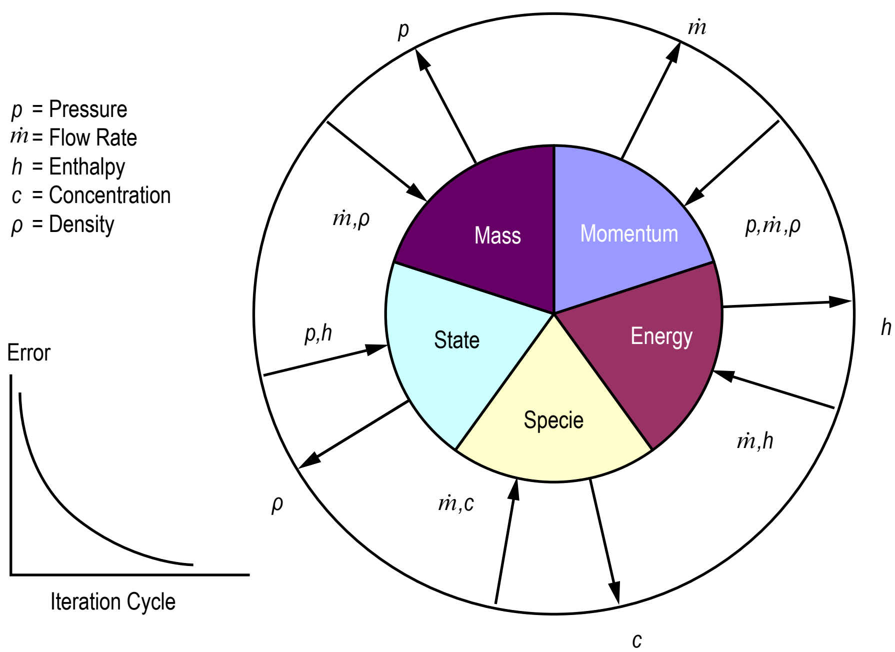

Figure 3. Schematic of mathematical closure of GFSSP—coupling of thermodynamics and fluid dynamics.

The total number of equations to be solved is determined from the number of internal nodes and branches. Figure 4 shows a typical interpropellant flow circuit in a rocket engine turbopump. In this circuit there are five boundary nodes and seven internal nodes. These nodes are connected by 12 branches. There are three inlet boundary nodes (48, 66, and 22) where oxygen, helium, and hydrogen enter into the fluid circuit. Mixtures of helium-hydrogen and helium-oxygen exit the circuit-through boundary nodes numbered 50 and 16, respectively. At each internal node, four equations

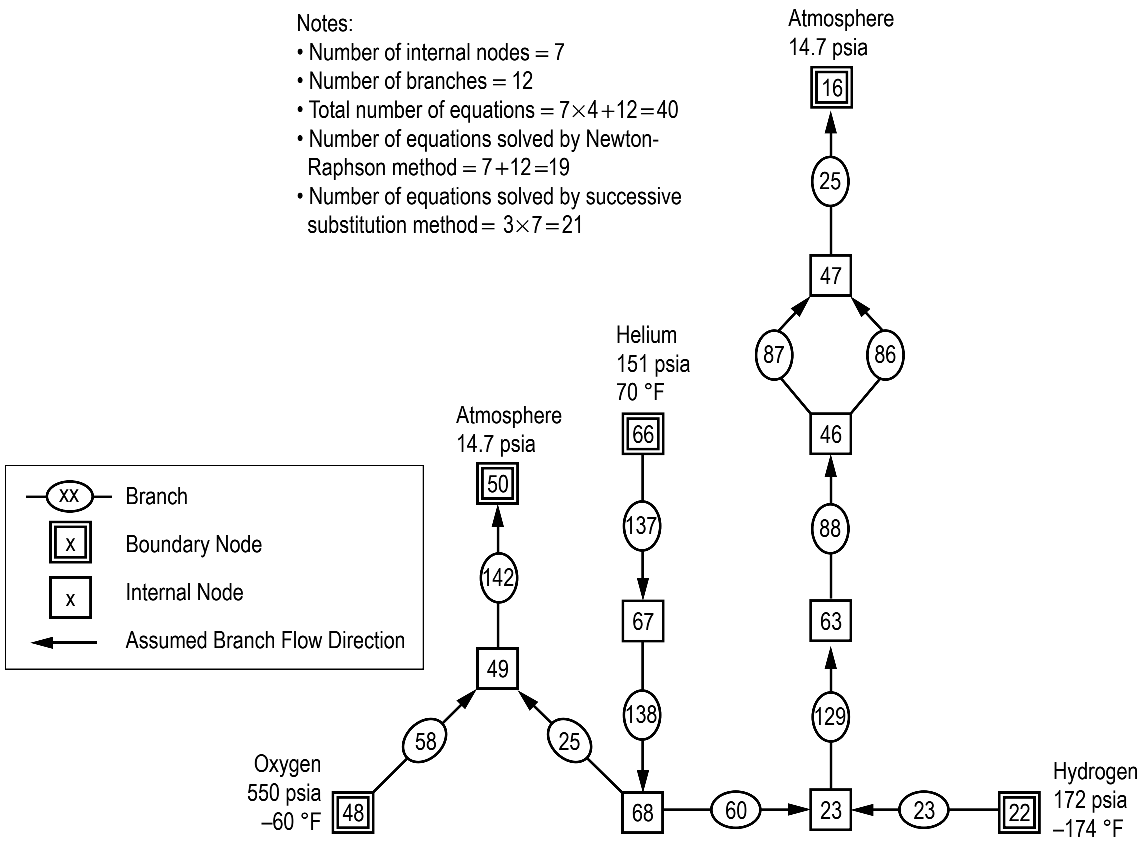

Figure 4. Interpropellant seal flow circuit in a rocket engine turbopump.

are solved to calculate pressure, temperature, and two concentrations. It should be noted that in a mixture of three components, concentrations of two components are solved. The concentration of the third component is determined from the fact that the sum of all concentrations must be unity. Flow rates are calculated in 12 branches. Therefore, GFSSP solves for 40 $(=7\times4+12)$ equations to calculate all required variables in the circuit. Since the example problem is at steady state, resident mass in the control volume was not calculated. The transient model of the same fluid circuit would require the solution of 47 $(=7\times5+12)$ equations at each time step of the simulation. The mathematical formulation has been described in detail in section 3.

1.5 Fluid Properties

GFSSP is linked with two thermodynamic property programs, GASP[10] and WASP[11] and GASPAK,[12] that provide thermodynamic and thermophysical properties of selected fluids. Both programs cover a range of pressure and temperature that allows fluid properties to be evaluated for liquid, liquid-vapor (saturation), and vapor region. GASP and WASP provide properties of 12 fluids (table 3). GASPAK includes a library of 35 fluids (table 4).

Table 3. Fluids available in GASP and WASP.

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. Fluids available in GASPAK.

Index	Fluid	Index	Fluid
1	Helium	19	Krypton
2	Methane	20	Propane
3	Neon	21	Xenon
4	Nitrogen	22	R-11
5	Carbon monoxide	23	R-12
6	Oxygen	24	R-22
7	Argon	25	R-32
8	Carbon dioxide	26	R-123
9	Parahydrogen	27	R-124
10	Hydrogen	28	R-125
11	Water	29	R-134A
12	RP-1	30	R-152A
13	Isobutane	31	Nitrogen trifloride
14	Butane	32	Ammonia
15	Deuterium	33	Ideal gas
16	Ethane	34	Hydrogen peroxide
17	Ethylene	35	Air
18	Hydrogen sulfide		

1.6 Flow Resistances

In network flow analysis code, flow resistances are modeled by empirical laws. These empirical laws have been incorporated to model flow resistances for pipe flow, orifices, valves, and various pipe fittings. GFSSP models these flow resistances in the momentum conservation equation as a friction term. There are 24 different resistance options available to users to choose from. There is also a provision for introducing a new resistance option through User Subroutines. The available resistance options are shown in table 5.

Table 5. Resistance options in GFSSP.

Option	Type of Resistance	Input Parameters	Option	Type of Resistance	Input Parameters
1	Pipe flow	L (in), D (in), ε/D	13	Common fittings and valves (two K method)	D (in), K_1, K_2
2	Flow-through restriction	C_L, A (in^2)	14	Pump characteristics*	A_0, B_0, C_0, A (in^2)
3	Noncircular duct	a (in), b (in)	15	Pump power	P (hp), η, A (in^2)
4	Pipe with entrance and exit loss	L (in), D (in), ε/D, K_i, K_e	16	Valve with given C_v	C_v, A
5	Thin, sharp orifice	D_1 (in), D_2 (in)	17	Joule-Thompson device	L_Ω, V_f, k_v, A
6	Thick orifice	L (in), D_1 (in), D_2 (in)	18	Control valve	See example 12 data file
7	Square reduction	D_1 (in), D_2 (in)	19	User defined	A (in^2)
8	Square expansion	D_1 (in), D_2 (in)	20	Heat exchanger core	A_f (in^2), A_s (in^2), A_c (in^2), L (in), K_c, K_e
9	Rotating annular duct	L (in), r_o (in), r_i (in), N (rpm)	21	Parallel tube	L (in), D (in), ε/D, n
10	Rotating radial duct	L (in), D (in), N (rpm)	22	Compressible orifice	C_L, A (in^2)
11	Labyrinth seal	r_i (in), c (in), m (in), n, α	23	Labyrinth seal, Egli correlation	r_i (in), c (in), m (in), n, α
12	Flow between parallel plates	r_i (in), c (in), L (in)	24	Fixed flow	Flow (lb$_m$/s), A (in^2)

*Pump characteristics are expressed as $\Delta p = A_0 + B_0\dot{m} + C_0\dot{m}^2$, Δp – Pressure rise, lbf/ft^2, $\dot{m}$ – Flow rate, lbm/s.

1.7 Program Structure

GFSSP has three major parts (fig. 5). The first part is the GUI, visual thermofluid analyzer of systems and components (VTASC). VTASC allows users to create a flow circuit by a 'point and click' paradigm. It creates the GFSSP input file after the completion of the model building process.

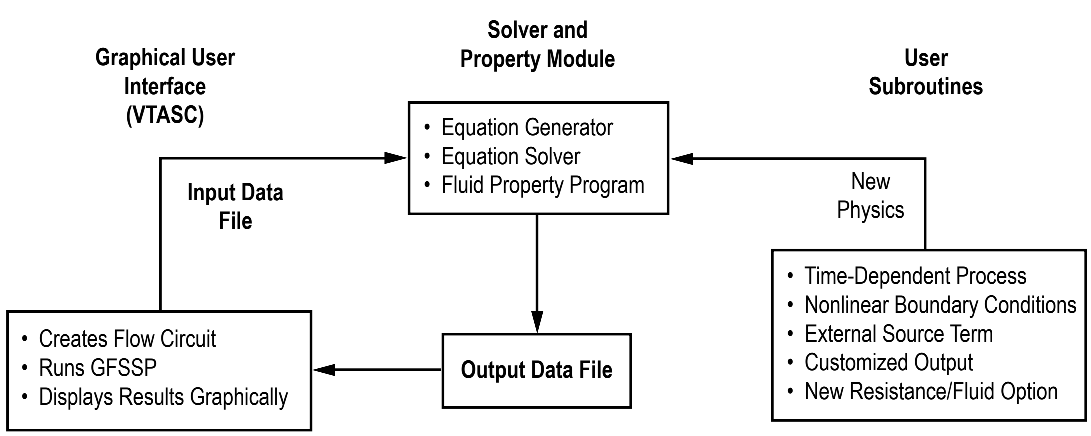

Figure 5. GFSSP's program structure showing the interaction of three major modules.

It can also create a customized GFSSP executable by compiling and linking User Subroutines with the solver module of the code. Users can run GFSSP from VTASC and post-process the results in the same environment. The second major part of the program is the solver and property module. This is the heart of the program that reads the input data file, and generates the required conservation

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equations for all internal nodes and branches with the help of thermodynamic property data. It also interfaces with User Subroutines to receive any specific inputs from users. Finally, output files are created for VTASC to read and display results. The User Subroutine is the third major part of the program. This consists of several blank subroutines that are called by the Solver Module. These subroutines allow the users to incorporate any new physical model, resistance option, fluid, etc. in the model. The computer program is discussed in detail in section 4.

1.8 Graphical User Interface

GFSSP's GUI (fig. 6) provides the users a platform to build and run their models. It also allows post-processing of results. The network flow circuit is first built using three basic elements: boundary node, internal node, and branch. Then the properties of the individual elements are assigned. Users are also required to define global options of the model that includes input/output files, fluid specification, and any special options such as rotation, heat exchanger, etc. During execution of the program, a run manager window opens up and users can monitor the progress of the numerical solution. On the completion of the run, it allows users to visualize the results in tabular form for steady state solutions and in graphical form for unsteady solutions. It also provides an interface to activate and import data to the plotting program, Winplot,[13] for post-processing. The GUI is discussed in detail in section 5.

Figure 6. GFSSP's graphical user interface, VTASC, allows creating, running, and viewing results in one environment.

1.9 Example Problems

Several example problems have been included to aid users to become familiar with different options of the code. The example problems also provide the verification and validation of the code by comparing the code's predictions with analytical solution and experimental data. These examples include the following:

(1) Simulation of a flow system containing a pump, valve, and pipe line
(2) Flow network for a water distribution system
(3) Compressible flow in a converging-diverging nozzle
(4) Mixing of combustion gases and a cold gas stream
(5) Flow in a counter flow heat exchange
(6) Radial flow in a rotating radial disk
(7) Flow in a squeeze film damper
(8) Blowdown of a pressurized tank
(9) A reciprocating piston-cylinder
(10) Pressurization of a propellant tank
(11) Power balancing of a turbopump assembly
(12) Helium pressurization of liquid oxygen (LOX) and rocket propllent-1 (RP-1) propellent tanks
(13) Steady state conduction through a circular rod
(14) Chilldown of cryogenic transfer line
(15) Fluid transient (waterhammer) due to sudden valve closure
(16) Simulation of pressure regulator downstream of a pressurized tank
(17) Simulation of flow regulator downstream of a pressurized tank
(18) Subsonic Fanno flow
(19) Subsonic Rayleigh flow
(20) Modeling of closed-cycle liquid metal (lithium) loop with heat exchanger to heat helium gas
(21) Internal flow in a turbopump
(22) Simulation of a fluid network with fixed flow rate option
(23) Helium-assisted, buoyancy-driven flow in a vertical pipe carrying LOX with ambient heat leak
(24) Simulation of relief valve in a pressurized tank
(25) Two-dimensional recirculating flow in a driven cavity
(26) Fluid transients in pipes due to sudden opening of valve
(27) Boiling water reactor
(28) No-vent tank chill and fill model
(29) Self-pressurization of a cryogenic propellant tank due to boil-off
(30) Modeling solid propellant ballistic with GFSSP.

These example problems are discussed in detail in section 6.

2. DATA STRUCTURE

Conventional CFD codes generally use a structured coordinate system to express conservation equations for mass, momentum, and energy. The examples of structured coordinate systems are rectangular cartesian, cylindrical polar, and spherical polar. In these coordinate systems, each control volume has a fixed number of neighboring control volumes with which it exchanges mass, momentum, and energy. In one dimension, each control volume has two neighbors; in two and three dimensions, it has four and six neighbors, respectively. However, in network flow analysis, a control volume can have an arbitrary number of neighbors as shown in figure 7. Therefore, the network analysis code requires a unique data structure that allows each control volume to know its neighbors. This is achieved by introducing relational properties for each control volume.

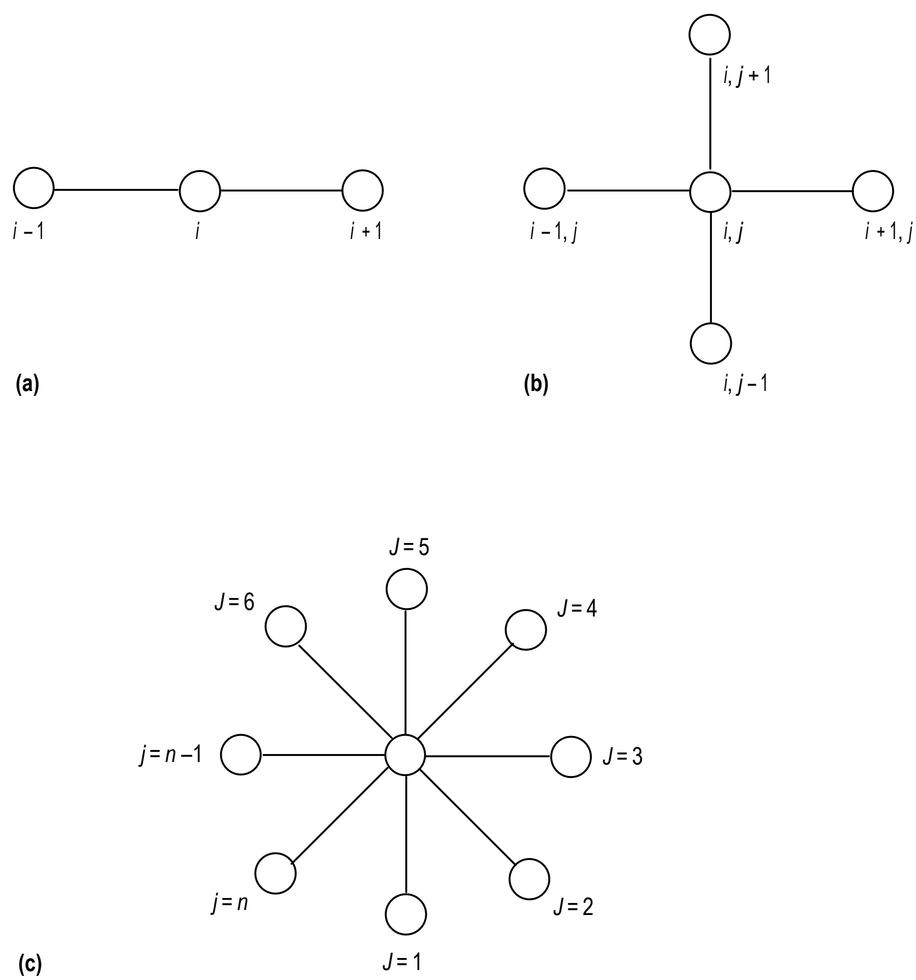

Figure 7. Examples of structured and unstructured coordinate systems: (a) One-dimensional structured coordinate, (b) two-dimensional structured coordinate, and (c) unstructured coordinate to represent flow network.

GFSSP has a unique data structure that allows constructing all possible arrangements of a flow network with no limit of number of elements. The elements of a flow network are fluid nodes and branches, solid nodes, and conductors. The relationship between a fluid node and a branch is defined by a set of relational geometric properties. Similarly, the relationship between a solid node and conductors is defined by a set of relational geometric properties. The connection between solid and fluid nodes for analyzing conjugate heat transfer is also defined by a set of relational properties. With the help of these properties, it is possible to define any structure of the network as it progresses through every junction of the network. The positive or negative flow direction is also defined locally. Unlike a structured coordinate system, there is no global definition of flow direction and origin. The development of a flow network can start from any point and can proceed in any direction. This section describes the data structure used to develop the governing equations to be described in section 3.

2.1 Network Elements and Properties

GFSSP constructs a flow network with three basic elements: (1) Boundary node, (2) internal node, and (3) branch. Thermodynamic states such as pressure, temperature, and species concentrations are assigned in boundary nodes. At internal nodes, GFSSP calculates all thermofluid dynamic variables such as pressure, temperature, enthalpy, entropy, species concentration, and thermophysical properties such as viscosity and conductivity. Flow rate and velocity are calculated in branches. A typical flow network consisting of a boundary node, internal node, and branch are shown in figure 1.

All nodes and branches are numbered arbitrarily by the user. GFSSP, however, assigns an index number to each node and branch as the user creates a new node or branch to construct a flow circuit. For example, NODE(I) represents the node number where I is the pointer of the NODE array. As nodes are created, additional pointers are added to the array. Similarly, IBRANCH(I) represents the branch number where I is the pointer of the IBRANCH array. INDEX(I) defines the type of node. For an internal node, INDEX(I) = 1, whereas for a boundary node, INDEX(I) = 2. The internal node numbers are also designated as INODE(I), where index I ranges from 1 to the total number of internal nodes.

Conjugate heat transfer modeling requires extension of the fluid network to include a network of solid nodes with interfaces between solid and fluid nodes. With this interface, convective and radiation heat transfer between solid and fluid nodes is modeled. Three additional elements—solid nodes, ambient nodes, and conductors—become part of the integrated network.

All elements have properties. The properties can be classified into two categories: geometric and thermofluid (fig. 2). Geometric properties are again classified into two subcategories: relational and quantitative. Relational properties define the relationship of the element with the neighboring elements. Quantitative properties include geometric parameters such as area, length, and volume.

2.2 Internal and Boundary Node Thermofluid Properties

The thermofluid properties (fig. 8) of internal and boundary nodes are:

• Pressure
• Temperature
• Density
• Species concentration
• Enthalpy
• Entropy
• Gas constant
• Viscosity
• Conductivity
• Specific heat ratio.

For unsteady flow, each internal node also includes thermofluid properties at the previous time step.

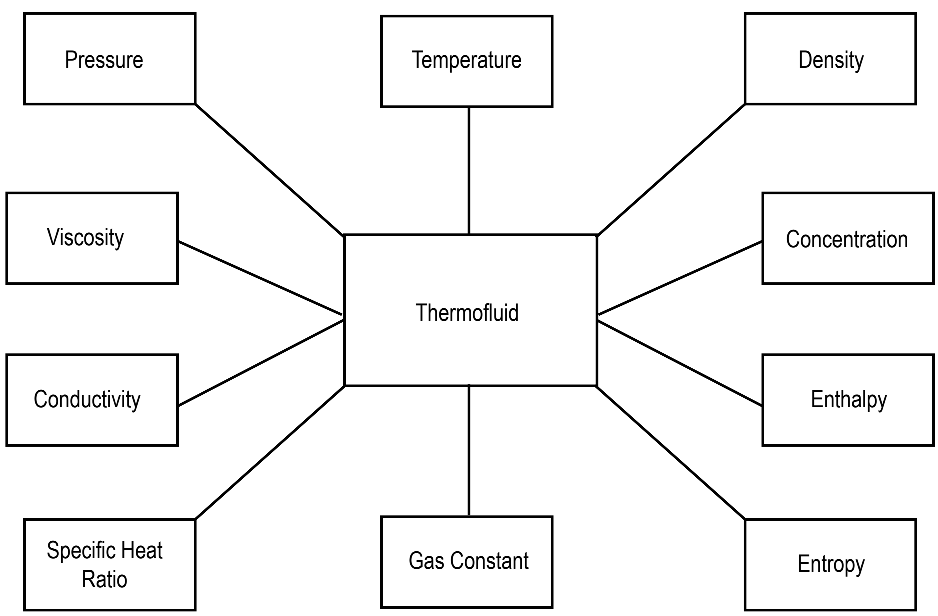

Figure 8. Thermofluid properties of internal and boundary nodes.

2.3 Internal Node Geometric Properties

The internal node has geometric properties of two kinds: relational and quantitative. The relational geometric properties of an internal node are:

- NUMBR(I), which defines the number of branches connected to the node of index I.
- NAMEBR(I,J), which defines the name of branch connected to node with index I; the index J extends from 1 to the number of branches connected to the node I, stored in NUMBR(I).

The quantitative geometric property of an internal node is node volume, which is necessary to calculate resident mass for unsteady calculation. The resident mass that determines the capacitance of the node is not required for steady state calculations. The data structure of geometric properties of an internal node is shown in figure 9. Figure 10 shows an example of relational geometric property of a node. Following are the relational geometric properties of node 1:

Number of branches connected to node I, NUMBR(I) = 4
Name of the branches connected to node I,
NAMEBR(I, 1) = 31
NAMEBR(I, 2) = 41
NAMEBR(I, 3) = 51
NAMEBR(I, 4) = 12.

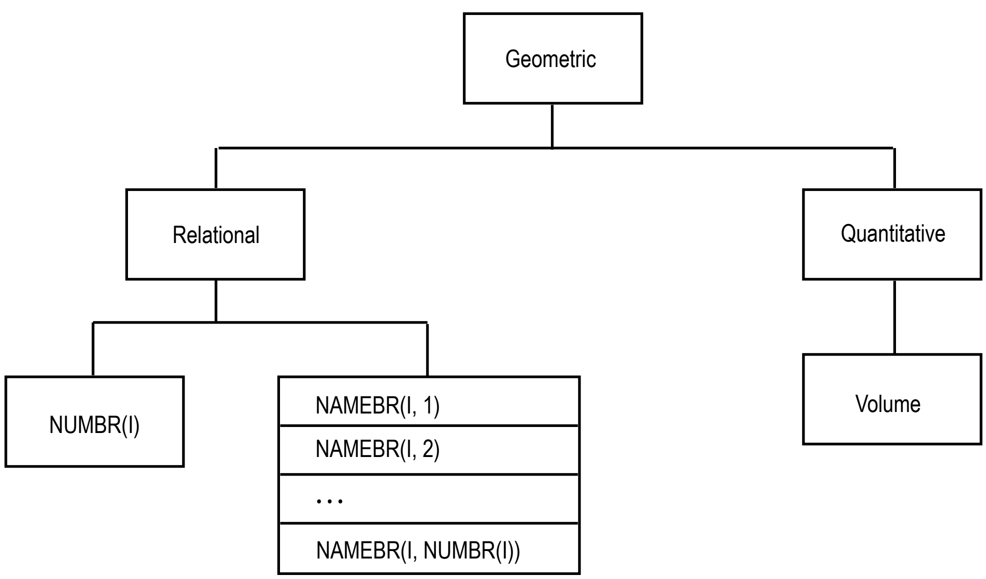

Figure 9. Data structure of geometric property of an internal node.

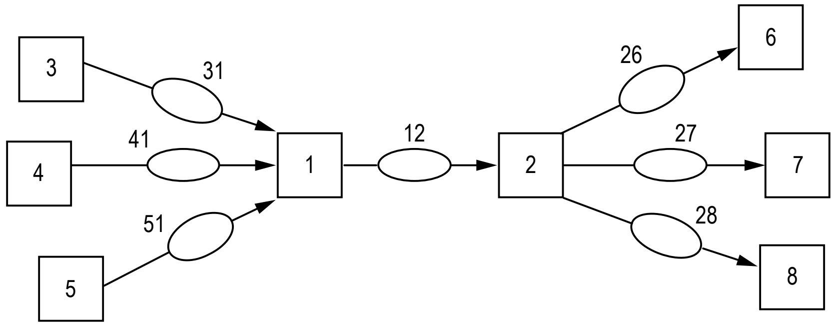

Figure 10. Example of node and branch relational properties.

2.4 Branch Properties

The branch has geometric properties of both kinds: relational and quantitative. The relational geometric properties of a branch are as follows:

- Name of upstream node
- Name of downstream node
- Number of upstream branches
- Name of upstream branches
- Number of downstream branches
- Name of downstream branches
- Index number of resistance option.

Figure 11 shows the geometric relational property of a branch. An example of those properties in a typical flow network is shown in figure 10. Each relational property of branch number 12 (IBRANCH(I) = 12) in figure 10 is now defined:

Name of upstream node, IBRUN(I) = 1
Number of upstream branches, NOUBR(I) = 3
Name of upstream branches,
NMUBR(I, 1) = 31
NMUBR(I, 2) = 41
NMUBR(I, 3) = 51

Name of downstream node, IBRDN(I) = 2
Number of downstream branches, NODBR(I) = 3
Name of downstream branches,
NMDBR(I, 1) = 26
NMDBR(I, 2) = 27
NMDBR(I, 3) = 28.

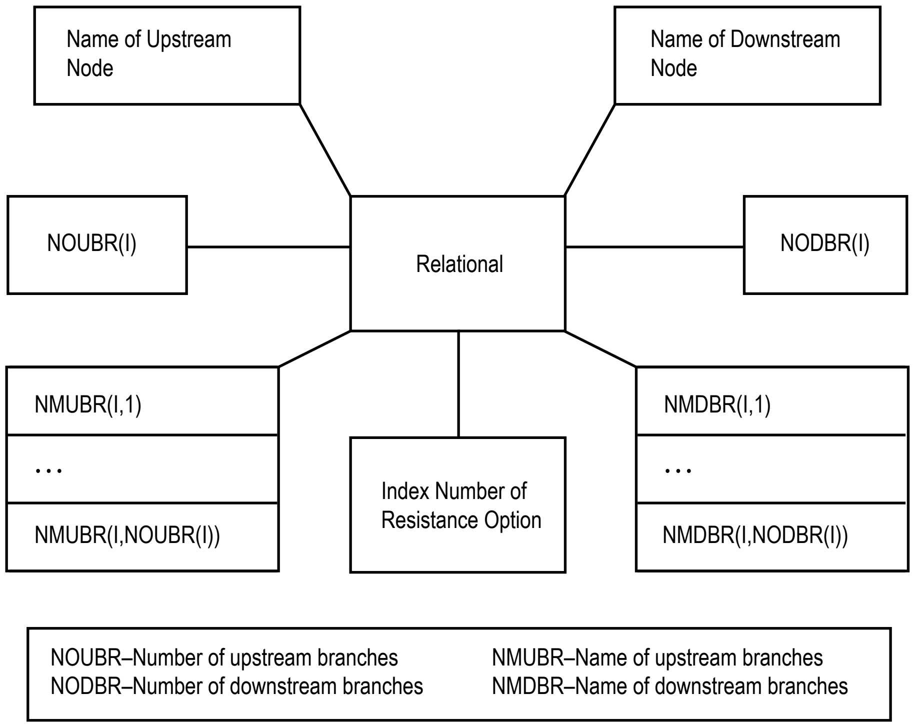

Figure 11. Relational geometric properties of a branch.

The quantitative geometric properties of a branch are:

• Area
• Volume
• Radial distance of upstream node from the axis of rotation
• Radial distance of downstream node from the axis of rotation
• Rotational speed of the branch
• Six additional generic geometric parameters to characterize a given resistance option.

The thermofluid properties of a branch (fig. 12) are:

• Flow rate
• Velocity
• Resistance coefficient.

For unsteady flow, each branch also includes the quantitative geometric and thermofluid dynamic properties at the previous time step.

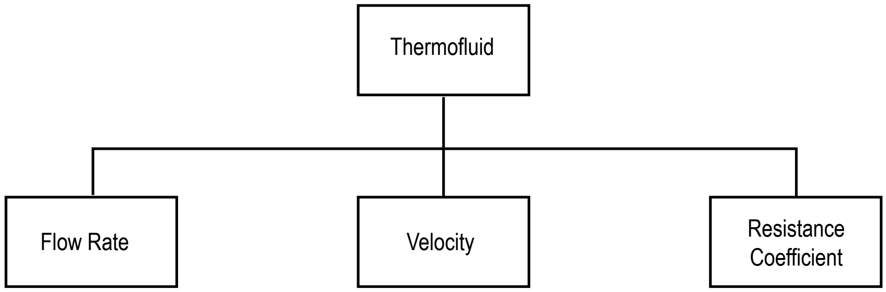

Figure 12. Thermofluid properties of a branch.

2.5 Fluid-Solid Network for Conjugate Heat Transfer

In fluid-solid network for conjugate heat transfer, solid nodes, ambient nodes, and conductors for heat transfer become part of the GFSSP network. Network elements for conjugate heat transfer are shown in figure 13. There are four types of conductors: solid to solid conduction, solid to solid radiation, solid to fluid, and solid to ambient. A typical GFSSP network for conjugate heat transfer is shown in figure 14. A solid node can be connected to a fluid node and ambient node. To determine solid temperature, conduction, convection, and radiation heat transfer between solid-solid, solid-fluid, and solid-ambient are computed.

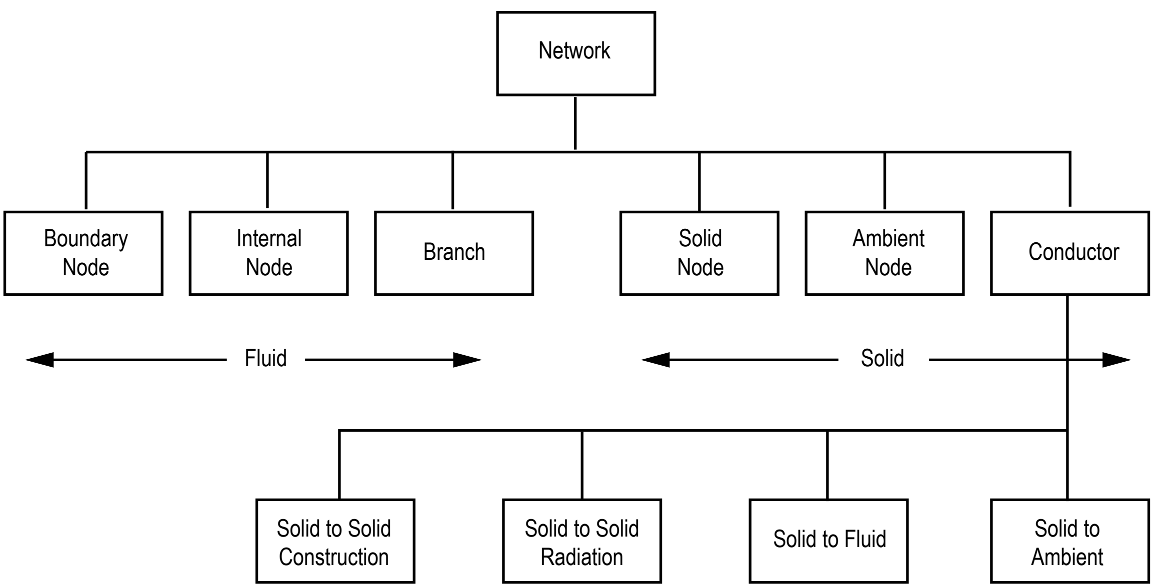

Figure 13. Network elements for conjugate heat transfer.

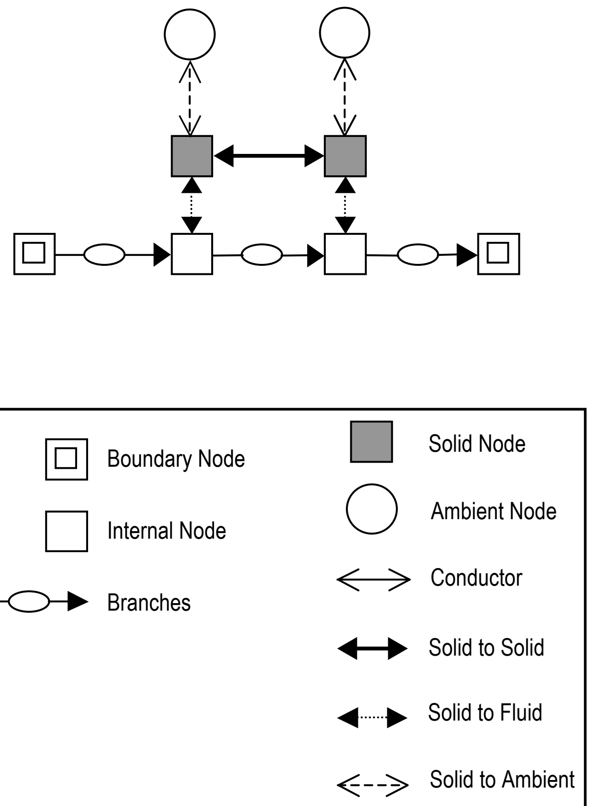

Figure 14. GFSSP network for conjugate heat transfer.

2.6 Solid Node Properties

The properties of a solid node are shown in figure 15. In addition to name, material, mass, and specific heat, there are six more relational properties that identify the number and names of solid to solid, solid to fluid, and solid to ambient conductors.

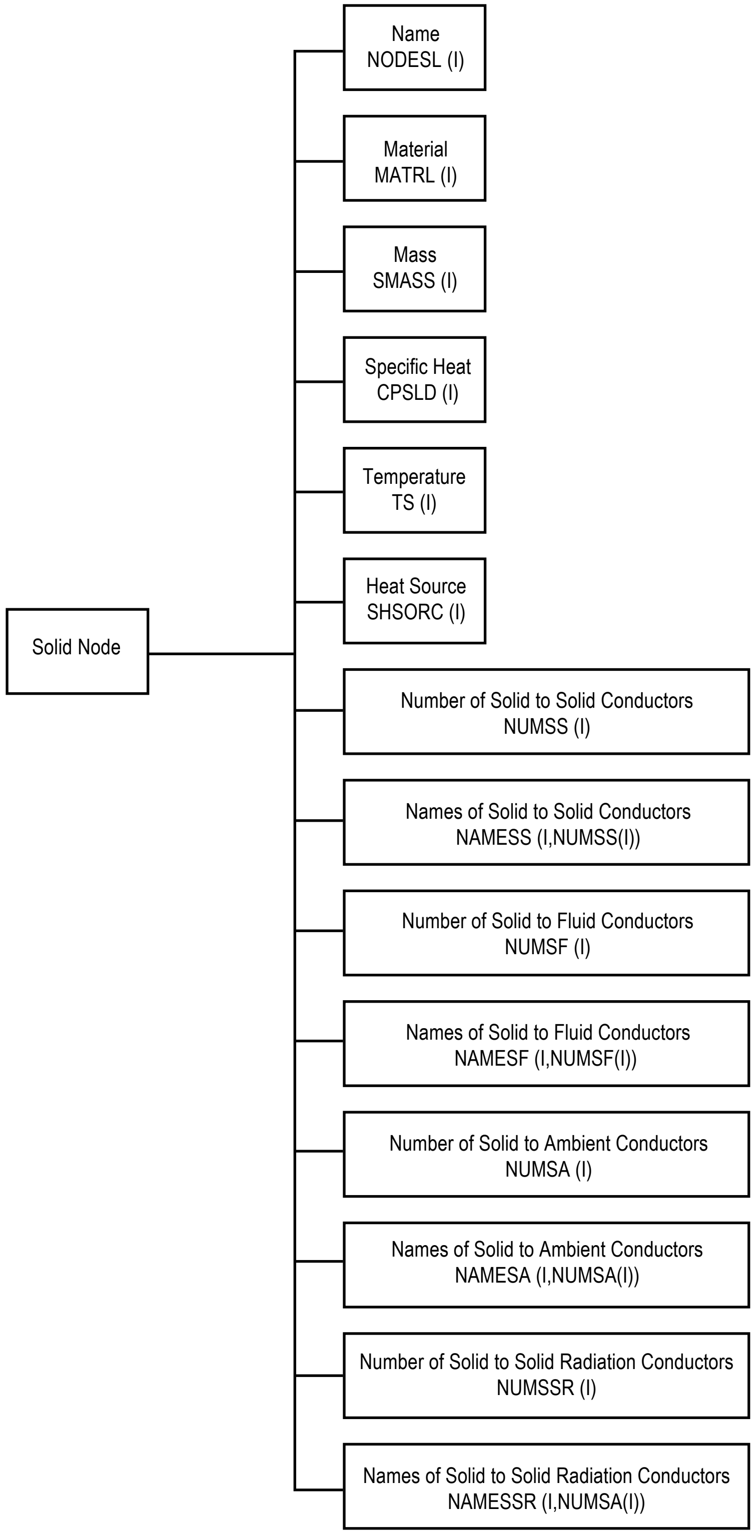

Figure 15. Properties of solid node.

2.7 Solid to Solid Conductor

The properties of a solid to solid conductor are shown in figure 16. The relational properties are names of connecting solid and fluid nodes. The geometric properties are area and distance between adjacent solid nodes. The thermophysical property includes conductivity and effective conductance.

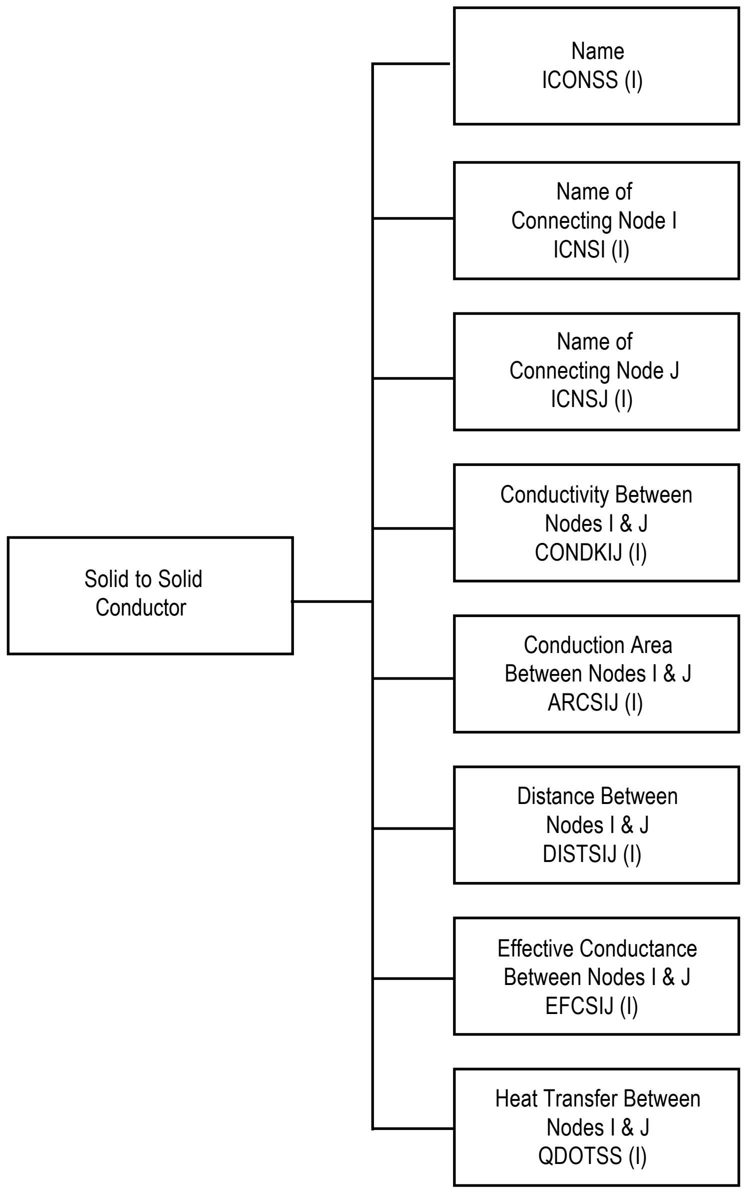

Figure 16. Properties of solid to solid conductor.

2.8 Solid to Fluid Conductor

The properties of solid to fluid conductors are shown in figure 17. The relational properties are names of connecting solid and fluid nodes. The geometric and thermofluid properties are heat transfer area, heat transfer coefficient, effective conductance, and emissivity of solid and fluid nodes.

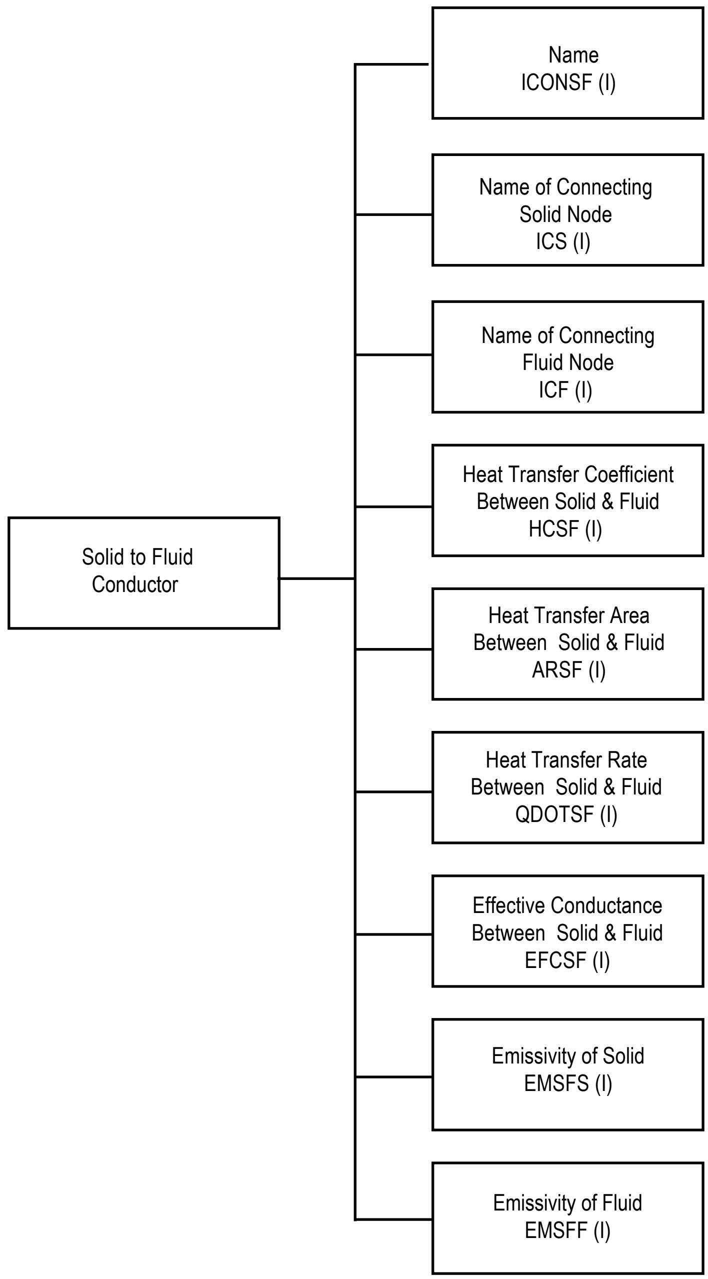

Figure 17. Properties of solid to fluid conductor.

2.9 Ambient Node Properties

Ambient node has only two properties: name and temperature (fig. 18).

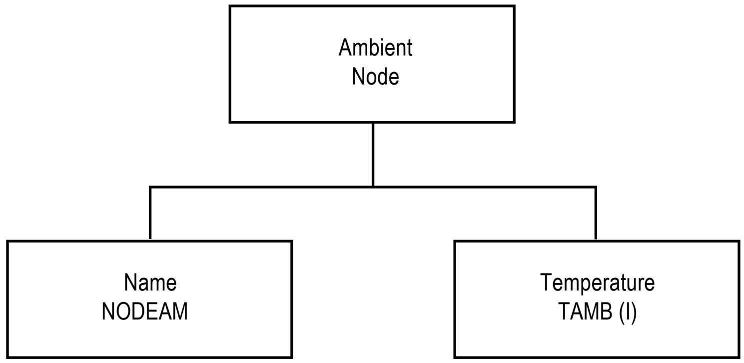

Figure 18. Properties of ambient node.

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2.10 Solid to Ambient Conductor

The properties of a solid to ambient conductor are shown in figure 19. The relational properties of a solid to ambient conductor are names of connecting solid and ambient nodes. The geometric and thermofluid properties include heat transfer area, heat transfer coefficient, effective conductance, and emissivity of solid and ambient.

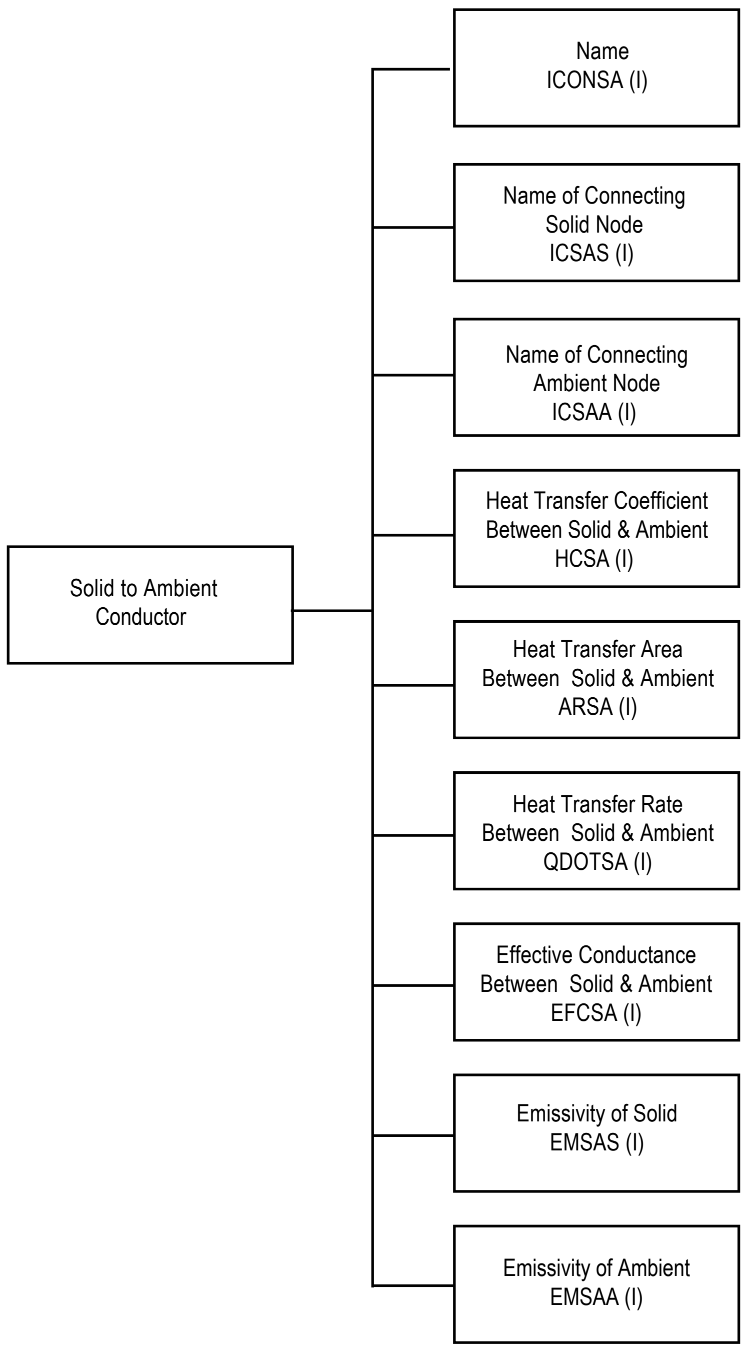

Figure 19. Properties of solid to ambient conductor.

3. MATHEMATICAL FORMULATION

GFSSP assumes a Newtonian, nonreacting and one-dimensional flow in the flow circuit. The flow can be steady or unsteady, laminar or turbulent, incompressible or compressible, with or without heat transfer, phase change, mixing, and rotation. The analysis of thermofluid dynamics in a complex network requires resolution of the system into fluid nodes and branches, and solid nodes and conductors. GFSSP calculates scalar properties such as pressure, temperature, and density at the nodes, and vector properties such as flow rates, heat fluxes at fluid branches, and conductors, respectively. Fluid nodes can be either internal nodes where properties are calculated or boundary nodes where properties are specified. Temperatures are calculated at the solid nodes and specified at the ambient nodes. This section describes all governing equations and solution procedure.

3.1 Governing Equations

Figure 20 displays a schematic showing adjacent nodes, their connecting branches, and the indexing system. In order to solve for the unknown variables, mass, energy, and fluid species, conservation equations are written for each internal node and flow rate equations are written for each branch.

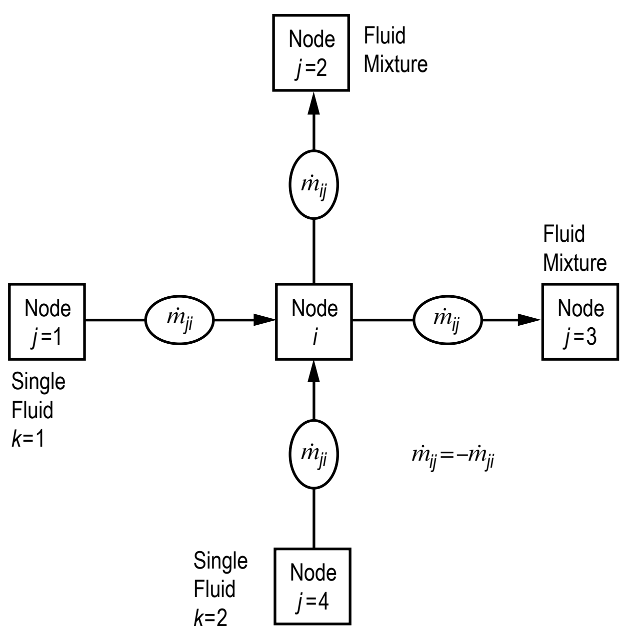

Figure 20. Schematic of GFSSP nodes, branches, and indexing practice.

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3.1.1 Mass Conservation Equation

Following is the mass conservation equation:

$$\frac{m_{\tau+\Delta\tau} - m_{\tau}}{\Delta\tau} = -\sum_{j=1}^{j=n} \dot{m}_{ij} \quad . \tag{1}$$

Equation (1) requires that for the unsteady formulation, the net mass flow from a given node must equate to the rate of change of mass in the control volume. In the steady state formulation, the left side of the equation is zero. This implies that the total mass flow rate into a node is equal to the total mass flow rate out of the node. Each term in equation (1) has the unit of lb/s.

3.1.2 Momentum Conservation Equation

The flow rate in a branch is calculated from the momentum conservation equation (eq. (2)), which represents the balance of fluid forces acting on a given branch. A typical branch configuration is shown in figure 21. 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 or other external momentum source:

$$\frac{(mu)_{\tau+\Delta\tau} - (mu)_{\tau}}{g_c \Delta\tau} + \mathrm{MAX}\left|\dot{m}_{ij}, 0\right|\left(u_{ij} - u_u\right) - \mathrm{MAX}\left|-\dot{m}_{ij}, 0\right|\left(u_{ij} - u_u\right)$$

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

$$+\mathrm{MAX}\left|\dot{m}_{\mathrm{trans}}, 0\right| \left(u_{ij} - u_p\right) - \mathrm{MAX}\left|-\dot{m}_{\mathrm{trans}}, 0\right| \left(u_{ij} - u_p\right)$$

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

$$= \left(p_i - p_j\right) A_{ij} + \frac{\rho g V \cos\theta}{g_c} - K_f\, \dot{m}_{ij} \left|\dot{m}_{ij}\right| A_{ij} + \frac{\rho K_{\mathrm{rot}}^2 \omega^2 A}{g_c} + \mu \frac{u_p - u_{ij}}{g_c \delta_{ij,p}} A_s$$

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

$$-\rho A_{\mathrm{norm}} u_{\mathrm{norm}} u_{ij} / g_c + \left(\mu_d \frac{u_d - u_{ij}}{\delta_{ij,d}} - \mu_u \frac{u_{ij} - u_u}{\delta_{ij,u}} \right) \frac{A_{ij}}{g_c} + S \quad .$$

-Moving Boundary- ----------Normal Stress--------- -Source- (2)

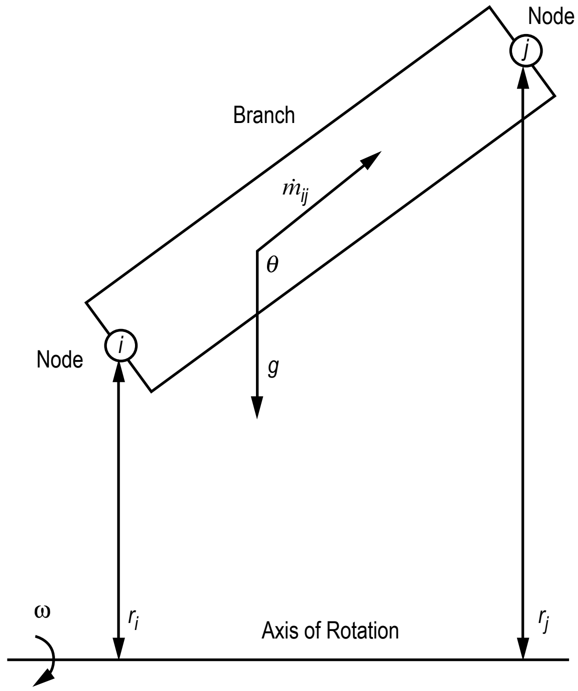

Figure 21. Schematic of a branch showing gravity and rotation.

The momentum equation consists of 11 terms. There will be no occasion when all 11 terms will be present in a control volume. Users have the ability to include or exclude all terms except the pressure term. For example, the friction and shear term will never be active at the same branch. The shear term will be activated for multidimensional flow modeling when the friction term must be set to zero. The pressure term will be active under all circumstances. The left-hand side of the momentum equation represents the inertia of the fluid. The surface and body forces applied in the control volume are assembled in the right-hand side of the equation. Each term of equation (2) has the unit of lb_f. Following are descriptions of the 11 terms:

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

(2) Longitudinal inertia—This term is important when there is a significant change in velocity in the longitudinal direction due to change in area and density. An upwind differencing scheme is used to compute the velocity differential. Flow in a converging-diverging nozzle is an example where this term must be active.

(3) Transverse inertia—This term is important for multidimensional flow. It accounts for any longitudinal momentum being transported by a transverse velocity component. Once again, an upwind differencing scheme is used to compute the velocity differential.

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

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

(6) Friction—This term represents the frictional effect. Friction was modeled as a product of K_f and the square of the flow rate and area. K_f is a function of the fluid density in the branch and the nature of the flow passage being modeled by the branch. The calculation of K_f for different types of flow passages is described in section 3.1.7.

(7) Centrifugal—This term in the momentum equation represents the effect of the centrifugal force. This term will be present only when the branch is rotating as shown in figure 21. K_{rotation} is the factor representing the fluid rotation. K_{rotation} is unity when the fluid and the surrounding solid surface rotate with the same speed. This term also requires knowledge of the distances from the axis of rotation between the upstream and downstream faces of the branch.

(8) Shear—This term represents shear force exerted on the control volume by a neighboring branch. This term is active only for multidimensional flow. The friction term is deactivated when this term is present. This term requires knowledge of distances between branches to compute the shear stress.

(9) Moving boundary—This term represents force exerted on the control volume by a moving boundary. This term is not active for multidimensional calculations.

(10) Normal stress—This term represents normal viscous force. This term is important for highly viscous flows.

(11) Source—This term represents a generic source term. Any additional force acting on the control volume can be modeled through the source term. In a system level model, a pump can be modeled by this term. A detailed description of modeling a pump by this source term (S) appears in sections 3.1.7.14 and 3.1.7.15.

A simplified form of the momentum equation has also been provided to compute flow rate for compressible flow in an orifice. For the ratio of downstream to upstream pressure,

$$\frac{p_j}{p_i} < p_{cr} \ , \tag{3a}$$

where

$$p_{cr} = \left(\frac{2}{\gamma + 1} \right)^{\frac{\gamma}{\gamma - 1}} \ . \tag{3b}$$

The flow rate in a branch is calculated from

$$\dot{m}_{ij} = C_{L_{ij}} A \sqrt{p_i \rho_i g_c \frac{2\gamma}{\gamma - 1} \left(p_{cr} \right)^{2/\gamma} \left[1 - \left(p_{cr} \right)^{(\gamma - 1)/\gamma} \right]} \ . \tag{3c}$$

If $\frac{p_j}{p_i} > p_{cr}$, the flow rate in a branch is calculated from:

$$\dot{m}_{ij} = C_{Lij} A \sqrt{p_i \rho_i g_c \frac{2\gamma}{\gamma - 1} \left(\frac{p_j}{p_i} \right)^{2/\gamma} \left[1 - \left(\frac{p_j}{p_i} \right)^{(\gamma-1)/\gamma} \right]} \; . \tag{3d}$$

It may be noted that this is a special form of the momentum equation and no other terms of the momentum equation can be activated when the compressible orifice equation (eqs. (3c) or (3d)) is in use.

3.1.3 Energy Conservation Equations

GFSSP solves for the energy conservation equations for both fluid and solid at internal fluid nodes and solid nodes. The energy conservation equation for fluid is solved for all real fluids with or without heat transfer. For conjugate heat transfer, the energy conservation equation for solid nodes is solved in conjunction with the energy equation of fluid nodes. The heat transfer between solid and fluid nodes is calculated at the interface and used in both equations as source and sink terms.

3.1.3.1 Energy Conservation Equation of Single Fluid. The energy conservation equation for node i, shown in figure 20, can be expressed following the first or second law of thermodynamics. The first law formulation uses enthalpy as the dependent variable, while the second law formulation uses entropy. The energy conservation equation based on enthalpy is shown in equation (4a):

$$\frac{m\left(h - \frac{p}{\rho J}\right)_{\tau+\Delta\tau} - m\left(h - \frac{p}{\rho J}\right)_{\tau}}{\Delta\tau} = \sum_{j=1}^{j=n} \left\{ \text{MAX}\left[-\dot{m}_{ij}, 0\right] h_j - \text{MAX}\left[\dot{m}_{ij}, 0\right] h_i \right\}$$

$$+ \frac{\text{MAX}\left[-\dot{m}_{ij}, 0\right]}{\left|\dot{m}_{ij}\right|} \left[\left(p_i - p_j\right) + K_{ij} \dot{m}_{ij}^2 \right] \left(\dot{v}_{ij} A\right) + Q_i \; . \tag{4a}$$

Equation (4a) shows that for transient flow, the rate of increase of internal energy in the control volume is equal to the rate of energy transport into the control volume minus the rate of energy transport from the control volume plus the rate of work done on the fluid by the pressure force plus the rate of work done on the fluid by the viscous force plus the rate of heat transfer into the control volume. The term $(p_i - p_j) v_{ij} A_{ij}$ represents work input to the fluid due to rotation or having a pump in the upstream branch of node i. The term $K_{ij} \dot{m}_{ij}^2 v_{ij} A_{ij}$ represents viscous work in the upstream branch of the node i where v_{ij} and A_{ij} are velocity and area of the upstream branch.

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For a steady state situation, the energy conservation equation, equation (4a), states that the net energy flow from a given node must equate to zero. In other words, the total energy leaving a node is equal to the total energy coming into the node from neighboring nodes and from any external heat sources (Q_i) coming into the node and work done on the fluid by pressure and viscous forces. The MAX operator used in equation (4a) is known as an upwind differencing scheme and has been extensively employed in the numerical solution of Navier-Stokes equations in convective heat transfer and fluid flow applications.[9] When the flow direction is not known beforehand, this operator allows the transport of energy only from its upstream neighbor. In other words, the upstream neighbor influences its downstream neighbor but not vice versa. The second term on the right-hand side represents the work done on the fluid by the pressure and viscous force. The difference between the steady and unsteady formulation lies in the left side of the equation. For a steady state situation, the left side of equation (4a) is zero, whereas in unsteady cases, the left-hand side of the equation must be evaluated.

The energy conservation equation based on entropy is shown in equation (4b):

$$\frac{(ms)_{\tau+\Delta\tau}-(ms)_{\tau}}{\Delta\tau}=\sum_{j=1}^{j=n}\left\{\mathrm{MAX}\left[-\dot{m}_{ij},0\right]s_j-\mathrm{MAX}\left[\dot{m}_{ij},0\right]s_i\right\}$$

$$+\sum_{j=1}^{j=n}\left\{\frac{\mathrm{MAX}\left[-\dot{m}_{ij},0\right]}{\left|\dot{m}_{ij}\right|}\right\}\dot{S}_{ij,gen}+\frac{Q_i}{T_i}\ . \tag{4b}$$

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

$$\dot{S}_{ij,\mathrm{gen}}=\frac{\dot{m}_{ij}\Delta p_{ij,\mathrm{viscous}}}{\rho_u T_u J}=\frac{K_f\left(\left|\dot{m}_{ij}\right|\right)^3}{\rho_u T_u J}\ . \tag{4c}$$

Equation (4b) shows that for unsteady flow, the rate of increase of entropy in the control volume is equal to the rate of entropy transport into the control volume plus the rate of entropy generation in all upstream branches due to fluid friction plus the rate of entropy added to the control volume due to heat transfer. The first term on the right-hand side of the equation represents the convective transport of entropy from neighboring nodes. The second term represents the rate of entropy generation in branches connected to the *i*th node. The third term represents entropy change due to heat transfer. Each term in equation (4b) has the unit of Btu/R-s.

3.1.3.2 Energy Conservation Equation of Fluid Species. Energy conservation equations of fluid species are necessary for modeling fluid mixtures. GFSSP asumes a fluid mixture to be homogeneous, and therefore the mass and momentum equations are identical to those of a single fluid. GFSSP has three options to model a mixture to calculate the temperature and thermophysical properties of the mixture. The first two options can be used for a mixture of gas and/or liquid as long as there is no change of phase in any mixture component. The third option handles a mixture of liquid and gas where the liquid or gas may go through a phase change. In all three options the conservation equations of fluid species are solved as described in section 3.1.4. However, the three options differ in the way energy equations are handled. In the first option (referred to as the temperature option), the energy equation is solved in terms of temperature as described in section 3.1.6. In the second option (referred to as the enthalpy-1 option), a mixture enthalpy was calculated for the energy conservation equation from enthalpies of fluid species, and temperature was calculated by an iterative method from a mixture enthalpy equation. In the third option (referred to as the enthalpy-2 option), separate energy equations for each species are solved and the temperature of the mixture is calculated by averaging the thermal mass (product of mass and specific heat) of all components. In this section, the energy conservation equations for both enthalpy options are described:

(1) Enthalpy-1 option—The enthalpy at node i in figure 20 is calculated from the following equation which is derived from the energy conservation equation expressed in terms of individual species concentration and enthalpy:

$$h_{i,\tau+\Delta\tau} = \frac{\sum_{j=1}^{j=n}\sum_{k=1}^{k=n_f} x_{j,k} h_{j,k} \mathrm{MAX}\left[-\dot{m}_{ij},0\right] + \frac{\left(mh_i\right)_\tau}{\Delta\tau} + \dot{Q}_i}{\sum_{j=1}^{j=n}\sum_{k=1}^{k=n_f} x_{j,k} \mathrm{MAX}\left[\dot{m}_{ij},0\right] + \frac{m_{\tau+\Delta\tau}}{\Delta\tau}} \quad . \tag{5}$$

The method of calculating temperature in the enthalpy-1 option is described in section 3.1.6.

(2) Enthalpy-2 option—In this option, a separate energy equation for individual species is solved. The energy equation for individual species (k) can be expressed as:

$$\frac{\left(m_i h_{ik} - \dfrac{p}{\rho_k J}\right)_{\tau+\Delta\tau} - \left(m_i h_{ik} - \dfrac{p}{\rho_k J}\right)_\tau}{\Delta\tau}$$

Transient term

$$= \sum_{j=1}^{j=n}\left\{\mathrm{MAX}\left[-\dot{m}_{ij},0\right]h_{ji} - \mathrm{MAX}\left[\dot{m}_{ij},0\right]h_{ik}\right\} + \dot{Q}_{ik} \quad .$$

Advection term Source term (6)

The external heat source is expressed as:

$$\dot{Q}_{ik} = \bar{c}_{ik}\dot{Q}_i \ ,$$

where

$\dot{Q}_i$ = external heat source, i.e., heat from solid node, etc.
$\bar{c}_{ik}$ = molar concentration of kth species in the ith node.

It may be noted that work input and viscous work were neglected in the species energy equation. The method of calculating temperature and mixture properties is also described in section 3.1.6.

3.1.3.3 Energy Conservation Equation of Solid. Typically, a solid node can be connected with other solid nodes, fluid nodes, and ambient nodes. Figure 22 shows a typical arrangement where a solid node is connected with other solid nodes, fluid nodes, and ambient nodes. The energy conservation equation for solid node i can be expressed as:

$$\frac{\partial}{\partial \tau}\left(mC_p T_s^i\right) = \sum_{j_s=1}^{n_{ss}} \dot{q}_{ss} + \sum_{j_f=1}^{n_{sf}} \dot{q}_{sf} + \sum_{j_a=1}^{n_{sa}} \dot{q}_{sa} + \dot{S}_i \ . \tag{7}$$

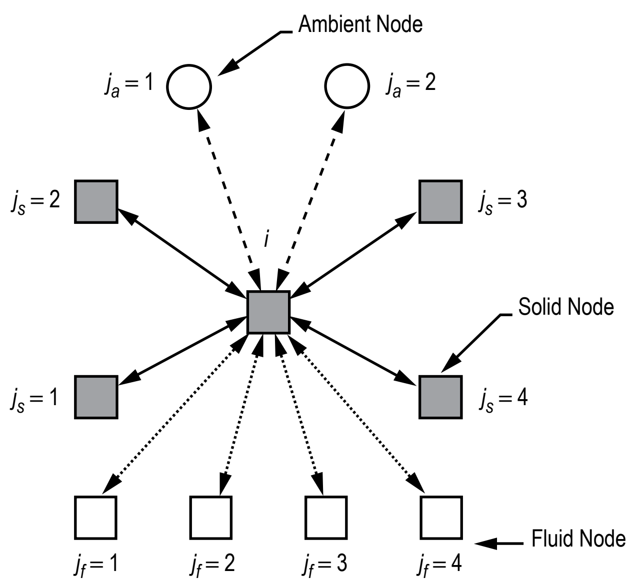

Figure 22. Schematic showing the connection of a solid node with neighboring solid, fluid, and ambient nodes.

The left-hand side of the equation represents rate of change of temperature of the solid node, i. The right-hand side of the equation represents the heat transfer from the neighboring node and heat source or sink. The heat transfer from neighboring solid, fluid, and ambient nodes, respectively, can be expressed as

$$\dot{q}_{ss} = k_{ij_s} A_{ij_s} / \delta_{ij_s} \left(T_s^{j_s} - T_s^i\right) \ , \tag{7a}$$

$$\dot{q}_{sf} = h_{ij_f} A_{ij_f} \left(T_f^{j_f} - T_s^i \right) ,\tag{7b}$$

and

$$\dot{q}_{sa} = h_{ij_a} A_{ij_a} \left(T_a^{j_a} - T_s^i \right) .\tag{7c}$$

The heat transfer rate can be expressed as a product of conductance and temperature differential. The conductance for equations (7a)–(7c) are as follows:

$$C_{ij_s} = \frac{k_{ij_s} A_{ij_s}}{\delta_{ij_s}}, \quad C_{ij_f} = h_{ij_f} A_{ij_f}, \text{ and } C_{ij_f} = h_{ij_a} A_{ij_a} ,\tag{7d}$$

respectively, where effective heat transfer coefficients for solid to fluid and solid to ambient nodes are expressed as the sum of the convection and radiation:

$$h_{ij_f} = h_{c,ij_f} + h_{r,ij_f}$$

$$h_{ij_a} = h_{c,ij_a} + h_{r,ij_a}\tag{7e}$$

and

$$h_{r,ij_f} = \frac{\sigma \left[\left(T_f^{j_f} \right)^2 + \left(T_s^i \right)^2 \right] \left[T_f^{j_f} + T_s^i \right]}{1 / \varepsilon_{ij,f} + 1 / \varepsilon_{ij,s} - 1}$$

$$h_{r,ij_a} = \frac{\sigma \left[\left(T_a^{j_a} \right)^2 + \left(T_s^i \right)^2 \right] \left[T_a^{j_a} + T_s^i \right]}{1 / \varepsilon_{ij,a} + 1 / \varepsilon_{ij,s} - 1} .\tag{7f}$$

GFSSP provides users with four different options for specifying heat transfer coefficient:

(1) User can provide a constant heat transfer coefficient.

(2) User can specify the Dittus-Boelter equation[14] for single-phase flow where the Nusselt number is expressed as:

$$\frac{h_c D}{k_f} = 0.023(\text{Re})^{0.8} (\text{Pr})^{0.33} ,\tag{7g}$$

where $\text{Re} = \rho u D / \mu_f$ and $\text{Pr} = C_p \, \mu_f / k_f$.

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(3) User can specify modified Miropolskii's correlation[15] for two-phase flow:

$$\mathrm{Nu} = 0.023\left(\mathrm{Re}_{\mathrm{mix}}\right)^{0.8}\left(\mathrm{Pr}_v\right)^{0.4}\left(Y\right)$$

$$\mathrm{Re}_{\mathrm{mix}} = \left(\frac{\rho u D}{\mu_v}\right)\left[x + \left(\frac{\rho_v}{\rho_l}\right)(1-x)\right]$$

$$\mathrm{Pr}_v = \left(\frac{C_p \mu_v}{k_v}\right)$$

$$Y = 1 - 0.1\left(\frac{\rho_l}{\rho_v} - 1\right)^{0.4}(1-x)^{0.4} \quad . \tag{7h}$$

(4) User can provide a new correlation in the User Subroutine to be described in section 4. Equation (7) can be rearranged to determine T_s^i:

$$T_s^i = \frac{\sum\limits_{j_s=1}^{n_{ss}} C_{ij_s} T_s^{j_s} + \sum\limits_{j_f=1}^{n_{sf}} C_{ij_f} T_f^{j_f} + \sum\limits_{j_a=1}^{n_{sa}} C_{ij_a} T_a^{j_a} + \dfrac{\left(mC_p\right)_m}{\Delta\tau} T_{s,m}^i + \dot{S}}{\dfrac{mC_p}{\Delta\tau} + \sum\limits_{j_s=1}^{n_{ss}} C_{ij_s} + \sum\limits_{j_f=1}^{n_{sf}} C_{ij_f} + \sum\limits_{j_a=1}^{n_{sa}} C_{ij_a}} \quad . \tag{8}$$

3.1.4 Fluid Species Conservation Equation

For a fluid mixture, density is a function of mass fraction of fluid species. In order to calculate the density of the mixture, the concentration of the individual fluid species within the branch must be determined. The concentration for the kth species can be written as

$$\frac{\left(m_i c_{i,k}\right)_{\tau+\Delta\tau} - \left(m_i c_{i,k}\right)_{\tau}}{\Delta\tau} = \sum_{j=1}^{j=n}\left\{\mathrm{MAX}\left[-\dot{m}_{ij},0\right]c_{j,k} - \mathrm{MAX}\left[\dot{m}_{ij},0\right]c_{i,k}\right\} + \dot{S}_{i,k} \quad . \tag{9}$$

For a transient flow, equation (7) states that the rate of increase of the concentration of the kth species in the control volume equals the rate of transport of the kth species into the control volume minus the rate of transport of the kth species out of the control volume plus the generation rate of the kth species in the control volume.

Like equation (4), for steady state conditions, equation (7) requires that the net mass flow of the *k*th species from a given node must equate to zero. In other words, the total mass flow rate of the given species into a node is equal to the total mass flow rate of the same species out of that node. For steady state, the left side of equation (7) is zero. For the unsteady formulation, the resident mass in the control volume is changing and therefore the left side must be computed. Each term in equation (5) has the unit of lb/s.

3.1.5 Thermodynamic and Thermophysical Properties

The momentum conservation equation, equation (2), requires knowledge of the density and the viscosity of the fluid within the branch. These properties are functions of the temperatures, pressures, and concentrations of fluid species for a mixture. Three thermodynamic property routines have been integrated into the program to provide the required fluid property data. GASP[10] provides the thermodynamic and transport properties for 10 fluids. These fluids include hydrogen, oxygen, helium, nitrogen, methane, carbon dioxide, carbon monoxide, argon, neon, and fluorine. WASP[11] provides the thermodynamic and transport properties for water and steam. For RP-1 fuel, a lookup table of properties has been generated by a modified version of GASP. An interpolation routine has been developed to extract the required properties from the tabulated data. GASPAK[12] provides thermodynamic properties for helium, methane, neon, nitrogen, carbon monoxide, oxygen, argon, carbon dioxide, hydrogen, parahydrogen, water, RP-1, isobutane, butane, deuterium, ethane, ethylene, hydrogen sulfide, krypton, propane, xenon, R-11, R-12, R-22, R-32, R-123, R-124, R-125, R-134A, R-152A, nitrogen trifluoride, ammonia, hydrogen peroxide, and air.

3.1.5.1 Equation of State for a Real Fluid. Transient flow calculations require the knowledge of resident mass in a control volume. The resident mass is calculated from the equation of state for real fluid that can be expressed as

$$m = \frac{pV}{zRT} \quad . \tag{10}$$

It may be noted that equation (10) is valid for liquid, gas, and gas-liquid mixture. For an ideal gas compressibility factor, z is unity. The compressibility factor for real gas is computed from the equation of state of real fluids using the above-mentioned thermodynamic property programs. For a two-phase mixture, z is computed from the following relation:

$$z = \frac{p}{\rho_{\text{mix}} RT} \quad , \tag{10a}$$

where

$$\rho_{\text{mix}} = \frac{\rho_l \rho_g}{x\rho_l - (1-x)\rho_g} \tag{10b}$$

and

$$x = \frac{s - s_l}{s_g - s_l} \quad . \tag{10c}$$

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3.1.6 Mixture Property Calculations

This section describes the procedures developed for GFSSP to estimate the density and temperature of mixtures of real fluids for all three mixture options. We assume that n fluids are mixing in the ith node. At node i, pressure (p) and molar concentrations (x_k) are known. The problem is to calculate the density (ρ), temperature (T), specific heat (C_p), specific heat ratio (γ), and viscosity (μ) of the mixture at the ith node.

Density by Amagat's Model. GFSSP's default mixture model uses Amagat's Law of Partial Volumes. It is suitable for liquids and ideal gas mixtures. The density of the mixture in the node (ρ_{mix}) is a function of the densities of the individual components evaluated at the temperature and total pressure of the node:

$$\frac{1}{\rho_{\text{mix}}} = \sum_{k=1}^{k=n} \frac{x_k}{\rho_k} \ . \tag{11}$$

Density by Dalton's Model. GFSSP offers the option of evaluating mixture densities using Dalton's Law of Partial Pressures for gas mixtures. This option would be used when at least one species of the gas mixture is at or below its saturation temperature and would be a liquid at the full pressure of the node, but a gas at the partial pressure of the species. The density of the mixture in the node is a function of the densities of the individual components evaluated at the temperature of the node and the partial pressure of the species:

$$\rho_{\text{mix}} = \sum_{k=1}^{k=n} \rho_k \ . \tag{12}$$

Other Properties. The compressibility factor of the mixture (Z_{mix}) is calculated from the equation of state:

$$Z_{\text{mix}} = \frac{P}{\rho_{\text{mix}} R_{\text{mix}} T} \ . \tag{13}$$

The gas constant of the mixture (R_{mix}) is the universal gas constant divided by the molecular weight of the mixture:

$$R_{\text{mix}} = \frac{R_{\text{univ}}}{\sum_{k=1}^{k=n} \bar{x}_k M_k} \ . \tag{14}$$

The viscosity, specific heat, and specific heat ratio of the mixture are calculated as the molar averages of the component properties as shown in equations (15)–(17).

$$\mu_{\text{mix}} = \sum_{k=1}^{k=m} \bar{x}_k \mu_k \ , \tag{15}$$

$$C_{p,\mathrm{mix}} = \frac{\sum_{k=1}^{k=n} C_{p,k}\,\bar{x}_k\,M_k}{\sum_{k=1}^{k=n} \bar{x}_k\,M_k}\ , \tag{16}$$

and

$$\gamma_{\mathrm{mix}} = \sum_{k=1}^{k=n} \bar{x}_k \gamma_k\ . \tag{17}$$

3.1.6.1 Mixture Temperature Option. The default method for calculating the temperature of a mixture is the Temperature option. The unsteady formulation of the energy equation (eq. (4)) is rewritten, where the enthalpy is replaced by the product of the specific heat and temperature:

$$\left(T_i\right)_{\tau+\Delta\tau} = \frac{\sum_{j=1}^{j=n} \sum_{k=1}^{k=n_f} C_{p,k,j}\, x_{k,j} T_j \mathrm{MAX}\left[-\dot{m}_{ij},0\right] + \left(C_{V,i}\ m_i T_i\right)_\tau / \Delta\tau + Q_i}{\sum_{j=1}^{j=n} \sum_{k=1}^{k=n_f} C_{p,k,j}\, x_{k,j} \mathrm{MAX}\left[\dot{m}_{ij},0\right] + \left(C_{V,i}\ m\right)_{\tau+\Delta\tau} / \Delta\tau}\ , \tag{18}$$

where $C_{p,k}$ is the molar specific heat and x_k is the mole-fraction of the kth species. It is stressed that this formulation does not handle phase-change and assumes that the specific heat is approximately constant over the temperature range of interest. It may also be noted that the work input and viscous work were neglected in this formulation of the energy equations.

3.1.6.2 Enthalpy-1 Option. The temperature is calculated by an iterative method where temperature is calculated from the following equation:

$$\sum_{k=1}^{k=n_f} x_{i,k} h_{i,k}\left(p_i, T_i\right) - h_i = 0\ . \tag{19}$$

It may be noted that equation (19) assumes Amagat's model. For Dalton's model equation (19) can be rewritten as:

$$\sum_{k=1}^{k=n_f} x_{i,k} h_{i,k}\left(p_{i,k}, T_i\right) - h_i = 0\ . \tag{19a}$$

Note that partial pressure has been used in equation (19a).

Once the temperature is calculated, the properties of individual species will be calculated from pressure and enthalpy of the individual species. For a gaseous mixture, the mixture properties will then be calculated by taking molar average of species properties as shown in equations (15)–(17).

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3.1.6.3 Enthalpy-2 Option. Temperature and other properties of individual species are calculated from node pressure and the enthalpy of the species:

$$
\begin{aligned}
T_{ik} &= f\left(p_i, h_{ik}\right) \\
\rho_{ik} &= f\left(p_i, h_{ik}\right) \\
\mu_{ik} &= f\left(p_i, h_{ik}\right) \\
K_{ik} &= f\left(p_i, h_{ik}\right) \\
C_{p_{ik}} &= f\left(p_i, h_{ik}\right) .
\end{aligned}
\tag{20}
$$

The nodal properties are calculated by averaging the properties of species as shown in equations (15)–(17).

The temperature of the node is calculated from the following relation:

$$
T_i = \frac{\sum_{k=1}^{n_f} \bar{c}_{ik} C_{p_{ik}} T_{ik}}{C_{p_i}} .
\tag{21}
$$

3.1.7 Friction Calculations

It was mentioned earlier in this TP 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 5. In this subsection, the expression of K_f for all resistance options is described.

3.1.7.1 Pipe Flow (Branch Option 1). Figure 23 shows the pipe resistance option parameters that are required by GFSSP. This option considers that the branch is a pipe with length (L), diameter (D), and surface roughness (ε). For this option, K_f can be expressed as:

$$
K_f = \frac{8 fL}{\rho_u \pi^2 D^5 g_c} ,
\tag{22}
$$

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

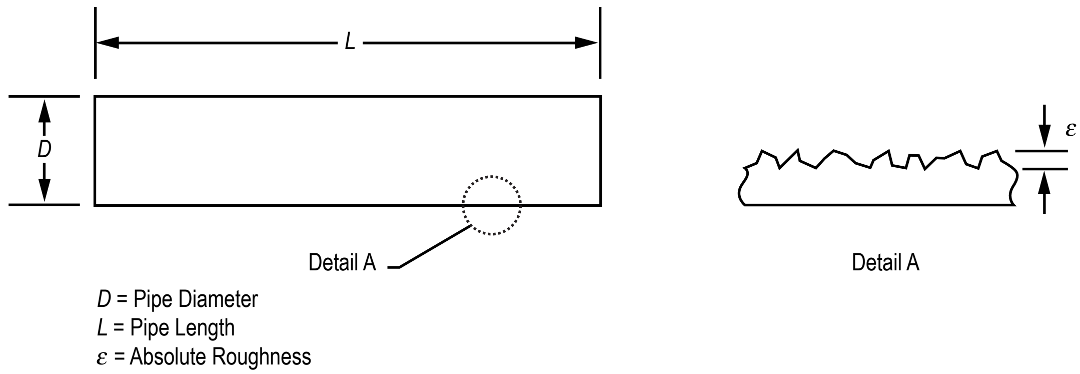

Figure 23. Pipe resistance option parameters.

The Darcy friction factor (f) is determined from the Colebrook equation,[16] which is expressed as:

$$\frac{1}{\sqrt{f}} = -2\log\left[\frac{\varepsilon}{3.7D} + \frac{2.51}{\mathrm{Re}\sqrt{f}}\right] , \tag{23}$$

where ε/D and Re are the surface roughness factor and Reynolds number, respectively. It may be mentioned that all pipe flow options assume fully developed flow.

3.1.7.2 Flow Through a Restriction (Branch Option 2). 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:

$$K_f = \frac{1}{2g_c \rho_u C_L^2 A^2} . \tag{24}$$

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

$$\Delta h = K\frac{u^2}{2g} . \tag{25}$$

K and C_L are related as:

$$C_L = \frac{1}{\sqrt{K}} . \tag{26}$$

3.1.7.3 Noncircular Duct (Branch Option 3). This option considers a duct with a noncircular cross section. Four different types of cross sections can be modeled as shown in figure 24.

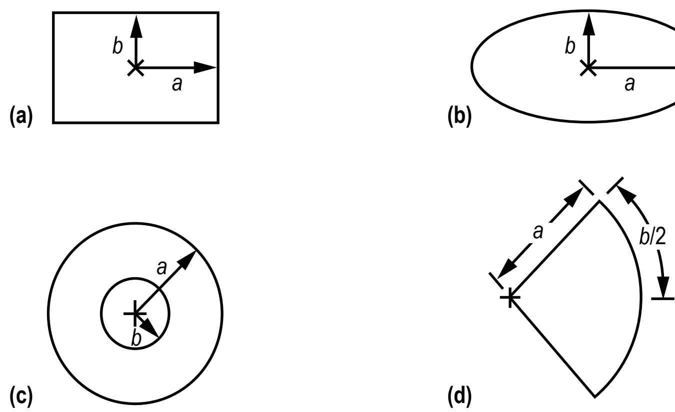

Figure 24. Noncircular duct cross section: (a) Rectangle, (b) ellipse, (c) concentrate annulus, and (d) circular sector.

White describes a procedure to estimate the friction factor in a noncircular duct.[17] This procedure consists of the following steps:

(1) Estimate the hydraulic diameter of the cross section: $D_h = (4)(\text{area})/\text{perimeter}$.

(2) Estimate the Poiseuille number (Po) for a particular cross section. The Poiseuille number can be expressed as a polynomial function of aspect ratio as shown in equation (27). Table 6 provides the coefficients for different geometries.

$$\text{Po} = A_0 + A_1\left(\frac{b}{a}\right) + A_2\left(\frac{b}{a}\right)^2 + A_3\left(\frac{b}{a}\right)^3 + A_4\left(\frac{b}{a}\right)^4 \quad . \tag{27}$$

Table 6. Poiseuille number coefficients for noncircular duct cross sections.

Coefficients	Rectangle	Ellipse	Concentric* Cylinder	Circular Section
A_0	23.9201	19.7669	22.0513	11.9852
A_1	–29.436	–4.53458	6.44473	3.01553
A_2	30.3872	–11.5239	–7.35451	–1.09712
A_3	–10.7128	22.3709	2.78999	–
A_4	–	–10.0874	–	–

*For $b/a < 0.2508$ $P_0 = A_0\left(\frac{b}{a}\right)^{A_1}$, where, $A_0 = 24.8272$, $A_1 = 0.0479888$.

(3) Calculate the friction factor for a noncircular pipe:

• Laminar flow (Re < 2,300)

$$f = \frac{4\,\text{Po}}{\text{Re}} \quad . \tag{28}$$

• Turbulent flow

– Compute the effective diameter:

$$D_{\text{eff}} = \frac{16D_h}{\text{Po}} \ . \tag{29}$$

– Compute the effective Reynolds number:

$$\text{Re}_{\text{eff}} = \frac{\dot{m}}{\mu}\frac{D_{\text{eff}}}{A} \ . \tag{30}$$

– Compute the friction factor using the Colebrook equation (eq. (23)).

(4) Compute K_f from the following expression:

$$K_f = \frac{8\,fL}{\rho_u \pi^2 D_h^5 g_c} \ . \tag{31}$$

3.1.7.4 Pipe With Entrance and Exit Loss (Branch Option 4). Figure 25 shows the pipe with entrance and/or exit loss resistance option parameters that are required by GFSSP. This option is an extension of option 1. In addition to the frictional loss in the pipe, entrance and exit losses are also calculated. For this option, K_f can be expressed as:

$$K_f = \frac{8K_i}{\rho_u \pi^2 D^4 g_c} + \frac{8\,fL}{\rho_u \pi^2 D^5 g_c} + \frac{8K_e}{\rho_u \pi^2 D^4 g_c} \ , \tag{32}$$

where K_i and K_e are the entrance and exit loss coefficients, respectively.

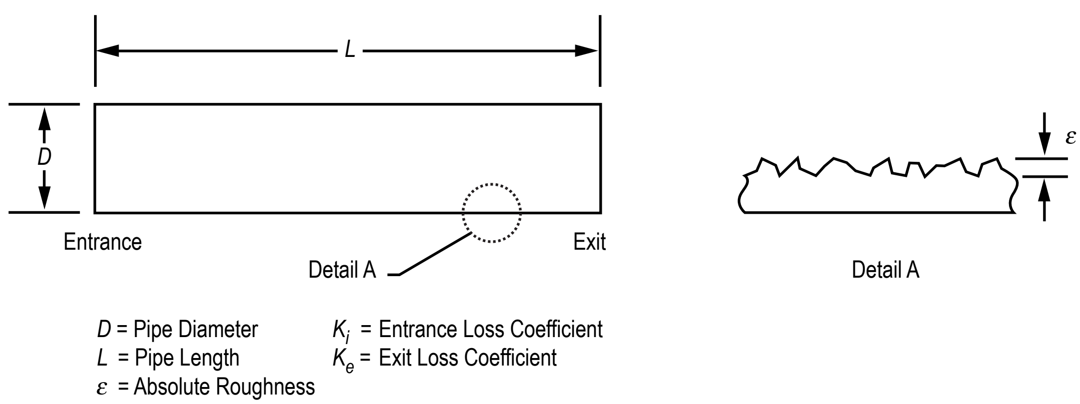

Figure 25. Pipe with entrance and/or exit loss resistance option parameters.

3.1.7.5 Thin, Sharp Orifice (Branch Option 5). Figure 26 shows the thin, sharp orifice resistance option parameters that are required by GFSSP. This option considers the branch as a thin, sharp orifice with a pipe diameter of D_1 and an orifice diameter of D_2. For this option, K_f can be expressed as:[18]

$$K_f = \frac{K_1}{2g_c \rho_u A^2} \quad , \tag{33}$$

where $A = \dfrac{\pi D_1^2}{4}$.

For upstream Re ≤ 2,500,

$$K_1 = \left[2.72 + \left(\frac{D_2}{D_1}\right)^2 \left(\frac{120}{\text{Re}} - 1\right)\right]\left[1 - \left(\frac{D_2}{D_1}\right)^2\right]\left[\left(\frac{D_1}{D_2}\right)^4 - 1\right] . \tag{34}$$

For upstream Re > 2,500,

$$K_1 = \left[2.72 - \left(\frac{D_2}{D_1}\right)^2 \left(\frac{4{,}000}{\text{Re}}\right)\right]\left[1 - \left(\frac{D_2}{D_1}\right)^2\right]\left[\left(\frac{D_1}{D_2}\right)^4 - 1\right] . \tag{35}$$

This option is recommended for subsonic and incompressible flow.

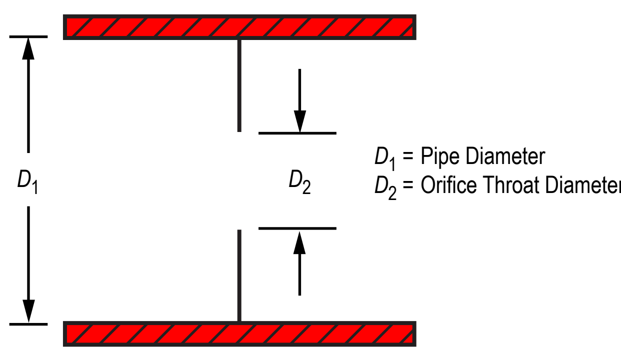

Figure 26. Thin, sharp orifice resistance option parameters.

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3.1.7.6 Thick Orifice (Branch Option 6). Figure 27 shows the thick orifice resistance option parameters that are required by GFSSP. This option models the branch as a thick orifice with a pipe diameter of D_1, an orifice diameter of D_2, and orifice length of L_{or}. This option should be used if $L_{or}/D_2 \leq 5$. If $L_{or}/D_2 > 5$, the user should use a square expansion, option 8, or a square reduction, option 7. For option 6, K_f can be expressed as in equation (33). However, the K_1 in equation (33) is calculated[18] from the following expressions:

For upstream Re ≤ 2,500,

$$K_1 = \left[2.72 + \left(\frac{D_2}{D_1}\right)^2 \left(\frac{120}{\text{Re}} - 1\right)\right]\left[1 - \left(\frac{D_2}{D_1}\right)^2\right]\left[\left(\frac{D_1}{D_2}\right)^4 - 1\right]\left[0.584 + \frac{0.0936}{\left(L_{or}/D_2\right)^{1.5} + 0.225}\right] . \quad (36)$$

For upstream Re > 2,500:

$$K_1 = \left[2.72 + \left(\frac{D_2}{D_1}\right)^2 \left(\frac{4{,}000}{\text{Re}}\right)\right]\left[1 - \left(\frac{D_2}{D_1}\right)^2\right]\left[\left(\frac{D_1}{D_2}\right)^4 - 1\right]\left[0.584 + \frac{0.0936}{\left(L_{or}/D_2\right)^{1.5} + 0.225}\right] . \quad (37)$$

This option is recommended for subsonic and incompressible flow.

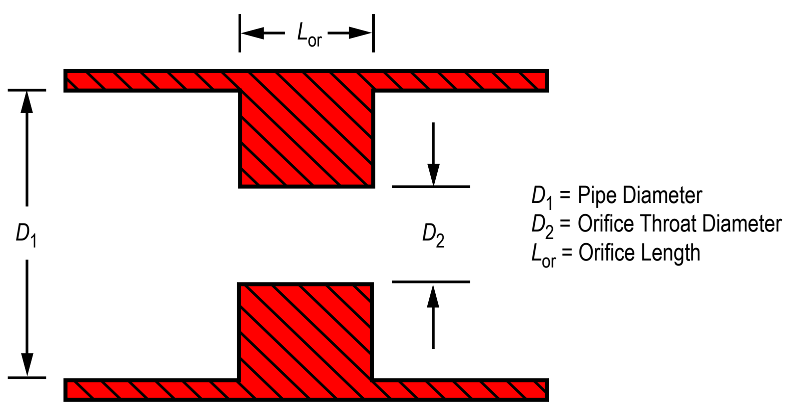

Figure 27. Thick orifice resistance option parameters.

3.1.7.7 Square Reduction (Branch Option 7). Figure 28 shows the square reduction resistance option parameters that are required by GFSSP. This option considers the branch as a square reduction. The diameters of the upstream and downstream pipes are D_1 and D_2, respectively. For this option, K_f can be expressed as in equation (33). However, the K_1 in equation (33) is calculated from the following expressions:[18]

For upstream Re ≤ 2,500,

$$K_1 = \left[1.2 + \frac{160}{\mathrm{Re}}\right]\left[\left(\frac{D_1}{D_2}\right)^4 - 1\right] . \tag{38}$$

For upstream Re > 2,500,

$$K_1 = [0.6 + 0.48f]\left(\frac{D_1}{D_2}\right)^2\left[\left(\frac{D_1}{D_2}\right)^2 - 1\right]^2 . \tag{39}$$

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.

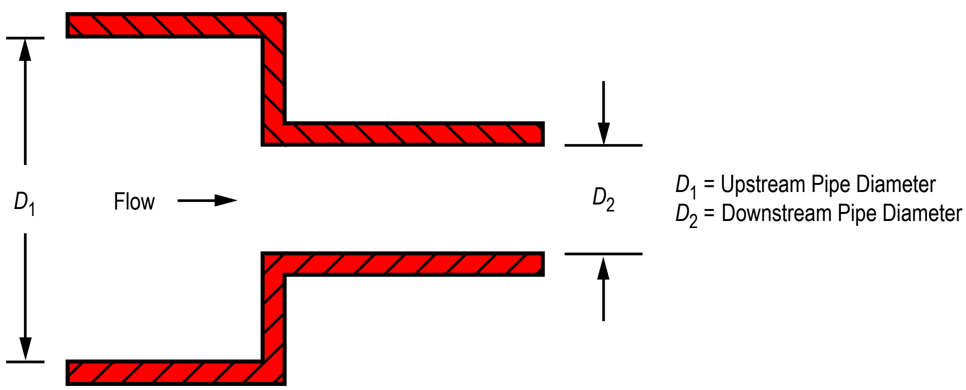

Figure 28. Square reduction resistance option parameters.

3.1.7.8 Square Expansion (Branch Option 8). Figure 29 shows the square expansion resistance option parameters that are required by GFSSP. This option considers the branch as a square expansion. The diameters of the upstream and downstream pipes are D_1 and D_2, respectively. For this option, K_f can be expressed as in equation (33). However, the K_1 in equation (33) is calculated from expressions (40) and (41).[18] The Reynolds number and friction factor that are utilized within these expressions are based on the upstream conditions. If the flow direction is opposite to what is specificed in the model input (i.e., the flow rate becomes negative), this option will automatically switch to branch option 8, the Square Expansion (sec. 3.1.7.8).

For upstream Re ≤ 4,000,

$$K_1 = 2\left[1 - \left(\frac{D_1}{D_2}\right)^4\right] . \tag{40}$$

For upstream Re > 4,000,

$$K_1 = \left[1 + 0.8f\right]\left[1 - \left(\frac{D_1}{D_2}\right)^2\right]^2 . \tag{41}$$

This option is recommended for subsonic and incompressible flow.

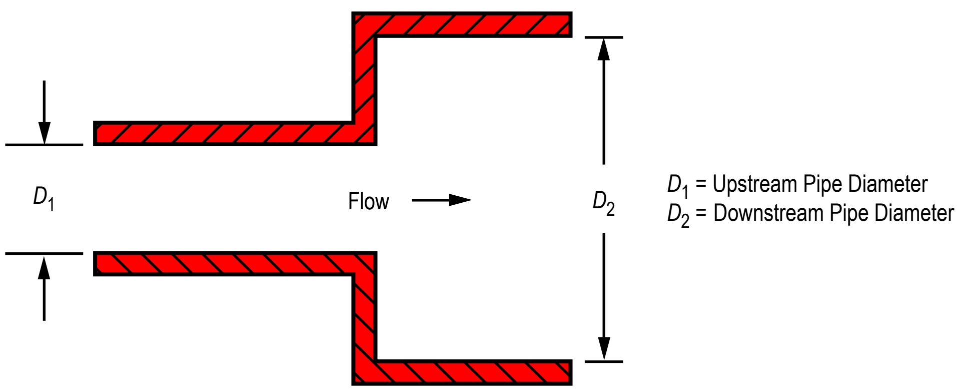

Figure 29. Square expansion resistance option parameters.

3.1.7.9 Rotating Annular Duct (Branch Option 9). Figure 30 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 radius, and inner radius of the annular passage are L, r_o, and r_i, respectively. The inner surface is rotating at N rpm ($N = 30\ \omega/\rho$). For this option, K_f can be expressed as:

$$K_f = \frac{fL}{\rho_u \pi^2 A^2 g_c \left(r_o - r_i\right)} \quad . \tag{42}$$

The friction factor (f) in equation (42) was calculated from the following expressions:[19]

$$f_{0T} = 0.077 (Ru)^{-0.24} \quad , \tag{43}$$

where

$$Ru = \frac{\rho_u u\ 2\left(r_0 - r_i\right)}{\mu} \tag{44}$$

and u is the mean axial velocity, therefore:

$$\frac{f}{f_{0T}} = \left[1 + 0.7656 \left(\frac{\omega r_i}{2u}\right)^2\right]^{0.38} \quad . \tag{45}$$

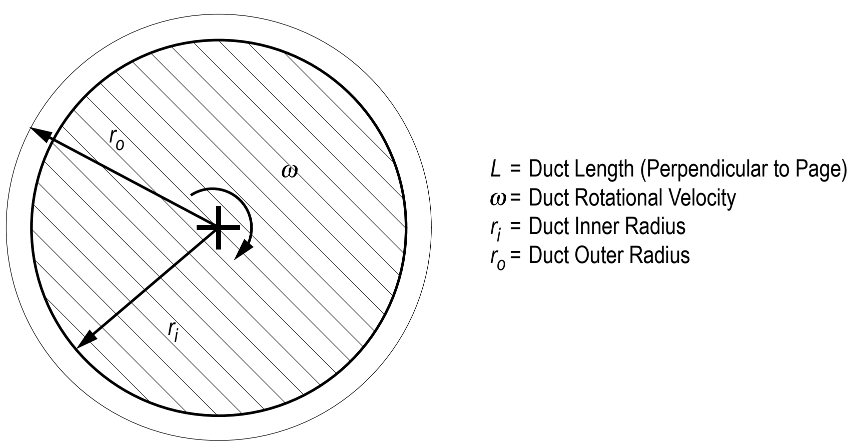

Figure 30. Rotating annular duct resistance option parameters.

3.1.7.10 Rotating Radial Duct (Branch Option 10). Figure 31 shows the rotating radial duct resistance option parameters that are required by GFSSP. This option considers the branch as a rotating radial duct. This option accounts only for the frictional losses encountered with this type of flow. Since centrifugal effects are also important in a rotating radial duct, the user must select this option and activate the rotational term in the momentum conservation equation (eq. (2)). The activation of the rotational term is explained in section 5.3.2 (fig. 68).

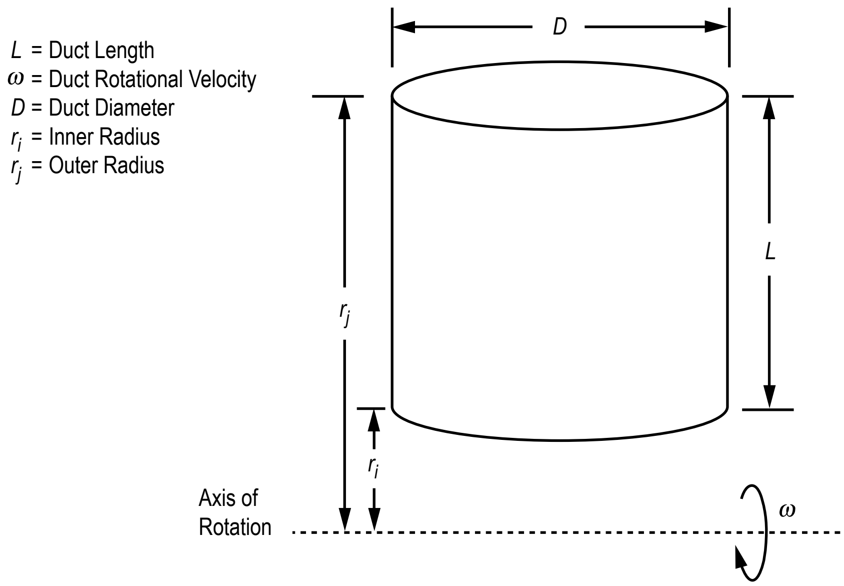

Figure 31. Rotating radial duct resistance option parameters.

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

$$K_f = \frac{8fL}{\rho_u \pi^2 D^5 g_c} \ . \tag{46}$$

The friction factor (f) in equation (46) was calculated from the following equations:[20]

$$f_{0T} = 0.0791(\mathrm{Re})^{-0.25} \tag{47}$$

and

$$\frac{f}{f_{0T}} = 0.942 + 0.058\left[\left(\frac{\omega D}{u}\right)\left(\frac{\omega D^2}{\nu}\right)\right]^{0.282} \ . \tag{48}$$

3.1.7.11 Labyrinth Seal (Branch Option 11). Figure 32 shows the labyrinth seal resistance option parameters that are required by GFSSP. This option considers the branch as a labyrinth seal. The number of teeth, clearance, and pitch are n, c, and m, respectively. For this option, K_f can be expressed as:

$$K_f = \frac{\left(1/\varepsilon^2 + 0.5\right) n + 1.5}{2 g_c \rho_u \alpha^2 A^2} \ , \tag{49}$$

where the carryover factor (ε) is expressed as:

$$\varepsilon = \sqrt{\frac{1}{1 - \frac{(n-1)\ c/m_p}{n(c/m + 0.02)}}} \ . \tag{50}$$

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

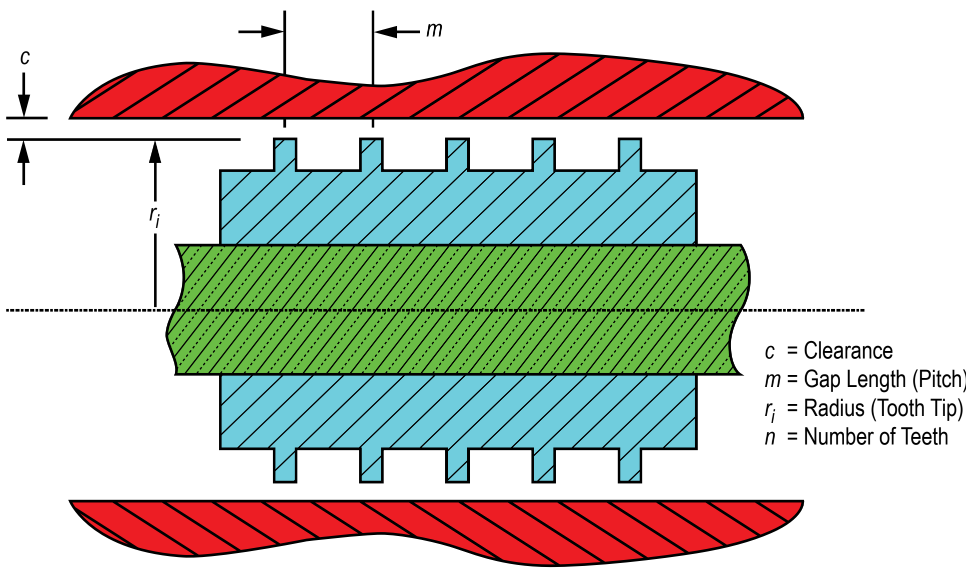

Figure 32. Labyrinth seal resistance option parameters.

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3.1.7.12 Flow Between Parallel Plates (Branch Option 12). Figure 33 shows the parallel flat plate resistance option parameters that are required by GFSSP. This option considers the branch as having laminar flow between parallel flat plates. A face seal can be modeled using this option. The flow is assumed to occur between two parallel plates separated by a distance equal to the clearance between the shaft and the housing. The effect of curvature is neglected. The length, inner diameter, and clearance of the seal are *L*, *D*, and *c*, respectively. For this option, K_f can be expressed as:[21]

$$K_f = \frac{12\mu \, L\rho}{\pi g_c D_c^3 |\dot{m}|} \quad . \tag{51}$$

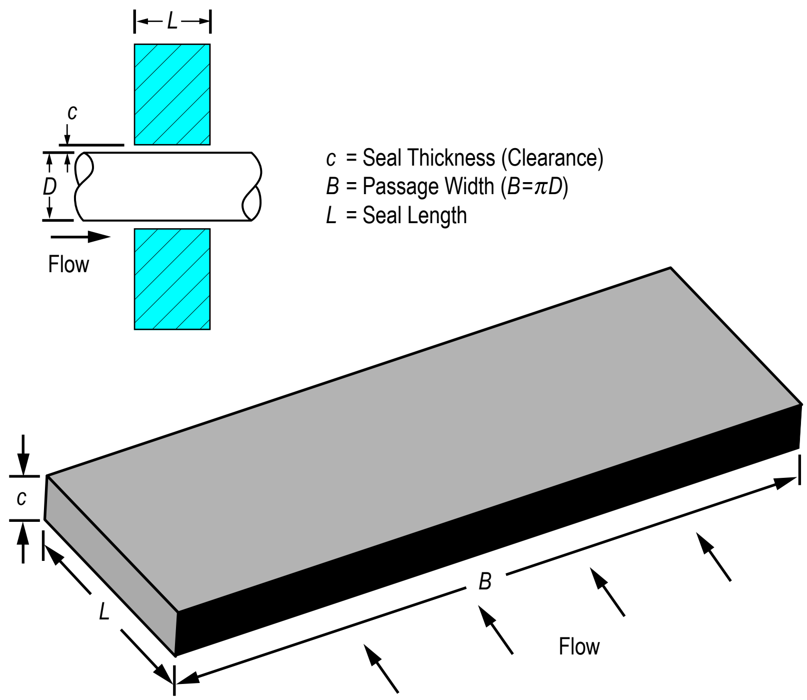

Figure 33. Parallel flat plate resistance option parameters.

3.1.7.13 Common Fittings and Valves (Branch Option 13). This option considers the branch as common fittings or valves. The resistance in common fittings and valves can be computed by the two-*K* method.[22] For this option, K_f can be expressed as:

$$K_f = \frac{K_1 / \text{Re} + K_\infty (1 + 1/D)}{2 g_c \rho_u A^2} \quad , \tag{52}$$

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 7.

Table 7. Constants for two-*K* method of hooper for fittings/valves[22] (GFSSP resistance option 13).

Fitting Type			K_1	K_∞
90° elbows	Standard (R/D = 1), screwed		800	0.4
	Standard (R/D = 1), flanged or welded		800	0.25
	Long radius (R/D = 1.5), all types		800	0.2
	Mitered (R/D = 1.5)	1 weld (90° angle)	1,000	1.15
		2 welds (45° angle)	800	0.35
		3 welds (30° angle)	800	0.3
		4 welds (22.5° angle)	800	0.27
		5 welds (18° angle)	800	0.25
45° elbows	Standard (R/D = 1), all types		500	0.2
	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		1,000	0.6
	Standard (R/D = 1), flanged or welded		1,000	0.35
	Long radius (R/D = 1.5), all types		1,000	0.3
Tee, used as elbow	Standard, screwed		500	0.7
	Long radius, screwed		800	0.4
	Standard, flanged or welded		800	0.8
	Stub-in-type branch		1,000	1
Tee, flow through	Screwed		200	0.1
	Flanged or welded		150	0.5
	Stub-in-type branch		100	–
Valves	Gate, ball, plug ($\beta = d_{orifice}/d_{pipe}$)	Full line size, β = 1	300	0.1
		Reduced trim, β = 0.9	500	0.15
		Reduced trim, β = 0.8	1,000	0.25
	Globe, standard		1,500	4
	Globe, angle or Y-type		1,000	2
	Diaphragm, dam type		1,000	2
	Butterfly		800	0.25
	Check	Lift	2,000	10
		Swing	1,500	1.5
		Tilting disk	1,000	0.5

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3.1.7.14 Pump Characteristics (Branch Option 14). This option considers the branch as a pump with given characteristics. The pump characteristics must be expressed as a curve fit of pressure rise versus flow rate:

$$\Delta p = A_0 + B_0 \dot{m} + C_0 \dot{m}^2 \ , \tag{53}$$

where

Δp = pressure rise (lbf/ft^2).
$\dot{m}$ = flow rate (lbm/s).

The user must input the intercept A_0, and the first and second order terms, B_0 and C_0, of the curve fit. The momentum source (S) in equation (2) is then expressed as:

$$S = \Delta p \ A \ . \tag{54}$$

3.1.7.15 Pump Horsepower (Branch Option 15). This option considers the branch as a pump with a given horsepower (P) and efficiency (η). The momentum source (S) in equation (2) is then expressed as:

$$S = \frac{550 \rho_u P \eta \ A}{\dot{m}} \ . \tag{55}$$

3.1.7.16 Valve With a Given Loss Coefficient (Branch Option 16). This option considers the branch as a valve with a given flow coefficient (C_v). The flow coefficient is the volume (in gallons) of water at 60 °F that will flow per minute through a valve with a pressure drop of 1 psi across the valve. The recommended formula for C_v determination with water is:

$$C_v = Q\sqrt{\frac{1}{\Delta p}} \ , \tag{56}$$

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

$$K_f = \frac{4.68 \times 10^5}{\rho_u C_v^2} \ . \tag{57}$$

3.1.7.17 Joule-Thompson Device (Branch Option 17). This option considers the branch as a Viscojet,[23] which is a specific type of flow resistance with relatively large flow passages with very high pressure drops. The flow rate through the Viscojet is given by:

$$w = 10{,}000 \ k_v \frac{V_f}{L_\Omega} \sqrt{\Delta p \ S} \ (1 - x) \ , \tag{58}$$

where w is the flow rate in lbm/hr, L_Ω is the resistance of the fluid device, k_v is an empirical factor, and V_f is the viscosity correction factor.

For this option, K_f can be expressed as:

$$K_f = \frac{18.6624}{S}\left(\frac{L_\Omega}{V_f k_v (1-x)}\right)^2 . \tag{59}$$

3.1.7.18 Control Valve (Branch Option 18). This is an exclusively transient option that considers the branch as a control valve that monitors the pressure at some arbitrary point downstream of the valve and opens and closes to maintain that pressure within a prescribed tolerance. This option was originally developed for use with the pressurization option to model on/off, or 'bang-bang,' pressurization systems as shown in figure 34. The valve is regarded as a flow restriction with a given flow coefficient (C_L) and area (A), and uses equation (24) to calculate K_f for the valve.

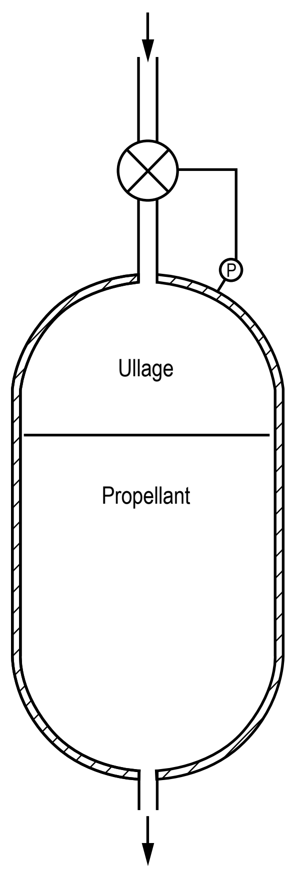

Figure 34. Control valve in a pressurization system.

The remaining inputs for the control valve option define its open/close characteristics. The suboption determines the type of open/close response of the valve (instantaneous, linear, or nonlinear) and the valve initial position describes whether the valve is initially open or closed. The control node defines the location in the model where the control valve option is to monitor and maintain the pressure while the pressure tolerance file name provides the code with the name of the file containing the pressure tolerance data for the control valve.

For a linear open/close response, the time to open/close and the number of time steps needed to complete that response are provided as additional inputs. If the length of the valve open/close time steps does not match the global time step, the program will temporarily change the global time step until the valve has fully opened/closed. The area of the valve will be linearly interpolated at each time step.

Finally, for a nonlinear open/close response, the file names for the open and close characteristics of the valve are required as additional inputs. The files detail the valve C_L and area as functions of time from the start of valve opening/closing.

3.1.7.19 User-Defined Resistance (Branch Option 19). This option allows users to create a new resistance option that is not available in the GFSSP library. Once this option is chosen, the user is required to supply the coding for calculating K_f for this option in the User Subroutine to be described in the following section. In the preprocessor, the user is required to supply the cross-sectional area of the branch.

3.1.7.20 Heat Exchanger Core (Branch Option 20). This option considers the branch as a heat exchanger core. In a typical heat exchanger core (fig. 35), the fluid goes past a tube bank to allow heat transfer between fluids in the main duct and fluids within the tubes. The free flow area is reduced and there is a larger surface area of contact between the fluid and solid walls. Sections 1 and 2 in figure 35 represent inlet and outlet of the heat exchanger core, respectively. The pressure drop through the heat exchanger core can be expressed as:[24]

$$\Delta p = \frac{G^2}{2g_c} v_1 \left[\left(K_c + 1 - \sigma^2 \right) + 2\left(\frac{v_2}{v_1} - 1 \right) + f \frac{A_s}{A_c} \frac{v_m}{v_1} - \left(1 - \sigma^2 - K_e \right) \frac{v_2}{v_1} \right] , \qquad (60)$$

where $G \left(= \frac{\dot{m}}{A} \right)$ is the mass flux.

Figure 35. Heat exchanger core.

Equation (60) can be rewritten as:

$$\Delta p = \frac{1}{2\rho_1 g_c A_c^2}\left[\left(K_c + 1 - \sigma^2\right) + 2\left(\frac{\rho_1}{\rho_2} - 1\right) + f\frac{A_s}{A_c}\frac{\rho_1}{\rho_{\text{avg}}} - \left(1 - \sigma^2 - K_e\right)\frac{\rho_1}{\rho_2}\right]\dot{m}^2 \; . \tag{61}$$

Therefore, K_f can be expressed as:

$$K_f = \frac{\left(K_c + 1 - \sigma^2\right) + 2\left(\frac{\rho_1}{\rho_2} - 1\right) + f\frac{A_s}{A_c}\frac{\rho_1}{\rho_{\text{avg}}} - \left(1 - \sigma^2 - K_e\right)\frac{\rho_1}{\rho_2}}{2\rho_1 g_c A_c^2} \; . \tag{62}$$

3.1.7.21 Parallel Tube (Branch Option 21). This option considers the branch as a parallel tube where fluid flows through n number of tubes (fig. 36). The flow is assumed to be distributed uniformly in all tubes. This resistance option calculates the pressure drop in the parallel tube. For this option, K_f can be expressed as:

$$K_f = \frac{8fL}{\rho_u \pi^2 D^5 g_c n^2} \; . \tag{63}$$

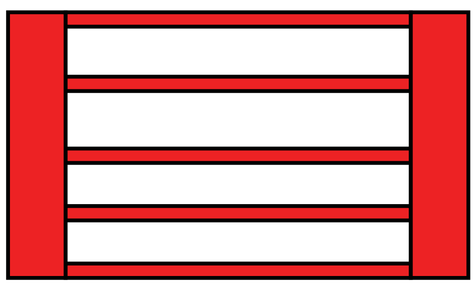

Figure 36. Parallel tube.

3.1.7.22 Compressible Orifice (Branch Option 22). This option considers the branch as an orifice for compressible flow. In this option, unlike other options, flow rate is calculated from a simplified momentum equation (eq. (3c)). There is no need to calculate K_f for this option. The input to this option is identical to option 2 (flow-through restriction).

3.1.7.23 Labyrinth Seal/Egli Correlation (Branch Option 23). This option provides an alternative formulation of flow resistances through the labyrinth seal (branch option 11). Egli developed a formulation of flow-through labyrinth seal based on the actual flow characteristics typical for a sharp-edged orifice.[25] Based on the general relations between leakage and number of throttling passages, flow resistance was calculated. The formulation also considered the effect of kinetic energy being carried from one throttling into the next. The input parameters (fig. 32) for this option are inner radius, clearance, pitch, number of teeth, and tooth tip width.

3.1.7.24 Fixed Flow (Branch Option 24). This option fixes flow rate in a given branch. The fixed flow branch can only be located adjacent to a boundary node. With this new option, the user can prescribe either pressure or flow rate as a boundary condition.

The fixed flow rate option has been implemented by introducing pump characteristics (fig. 37) of a positive displacement pump.

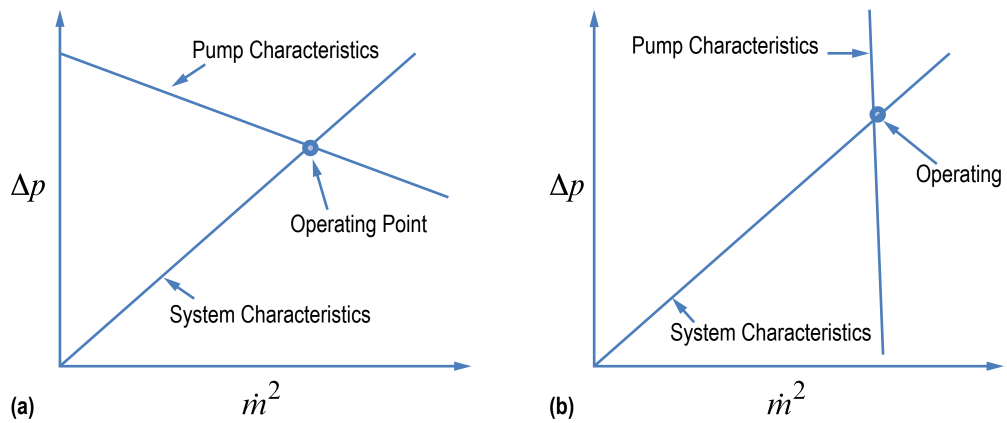

Figure 37. Implementation of fixed flow rate in a branch using pump characteristics: (a) Centrifugal pump and (b) positive displacement pump.

The pump characteristics of a positive displacement pump are expressed as: $\Delta p = A + C\dot{m}|\dot{m}|$, where $A = \alpha\, \dot{m}|\dot{m}|$; $C = -\alpha$, where $\alpha = 1 \times 10^{25}$. Substituting A and C, one gets $\dot{m} = \dot{m}|\dot{m}| \,/\, \dot{m}$.

There is a word of caution about the use of this option. The calculated pressure field may not be realistic as flow rate is calculated independent of pressure differential.

3.2 Solution Procedure

GFSSP numerically solves the governing equations described in the previous section to compute pressure, temperature, flow rate, and other fluid properties in a given flow circuit. The mathematical closure is described in table 8 where each variable and the designated governing equation to solve that variable are listed. It may be noted that the pressure is calculated from the mass conservation equation although pressure does not explicitly appear in equation (1). This is, however, possible in the iterative scheme where pressures are corrected to reduce the residual error in mass conservation equation. This practice was first implemented in a semi-implicit pressure linked equation (SIMPLE) algorithm proposed by Patankar and Spalding[26] and commonly referred to as 'pressure based' algorithm in computational fluid dynamics literature. The momentum conservation equation (eq. (2)) which contains both pressure and flow rate is solved to calculate the flow rate. The strong coupling of pressure and flow rate requires that mass and momentum conservation equations are solved simultaneously.

Table 8. Mathematical closure.

Variable Number	Variable Name	Designated Equation to Solve the Variable
1	Pressure	Mass conservation
2	Flow rate	Momentum conservation
3	Fluid enthalpy or entropy	Energy conservation of fluid
4	Solid temperature	Energy conservation of solid
5	Species concentration	Species conservation
6	Fluid mass	Thermodynamic state

The energy conservation equation can either be expressed in terms of enthalpy or entropy. The temperature, density, and other thermophysical properties, such as viscosity, conductivity, and specific heats are computed from pressure and enthalpy or entropy using thermodynamic property programs, GASP[10]/WASP[11] or GASPAK.[12] In flow circuits where solid to fluid heat transfer is present, the energy conservation equation for solids is solved to calculate the solid temperature. The rate of heat transfer between solid to fluid appears as a source or sink term in the energy conservation equations of fluid and solid.

For a mixture, the conservation equations of species are solved to compute the mass fraction of species. There are three options for solving the energy equation for a mixture as discussed in section 3.1.3.2. The method of calculating thermodynamic and thermophysical peoperties of all three options has been described in section 3.1.6.

For a transient problem, fluid mass is required in mass and momentum conservation equations (eqs. (1) and (2)). GFSSP uses the thermodynamic equation of state (eq. (10)) to calculate resident mass in an internal node where density, compressibility factor, and temperature are computed.

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

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

In GFSSP, a combination of the successive substitution method and the Newton-Raphson method is used to solve the set of equations. This method is called SASS (simultaneous adjustment with successive substitution) (fig. 38). In this scheme, the mass and momentum conservation equations are solved by the Newton-Raphson method. The energy and specie conservation equations are solved by the successive substitution method. The underlying principle for making such a division was that the equations that are more strongly coupled are solved by the Newton-Raphson method. The equations that are not strongly coupled with the other set of equations are solved by the successive substitution method. Thus, the computer memory requirement can be significantly reduced while maintaining superior numerical convergence characteristics.

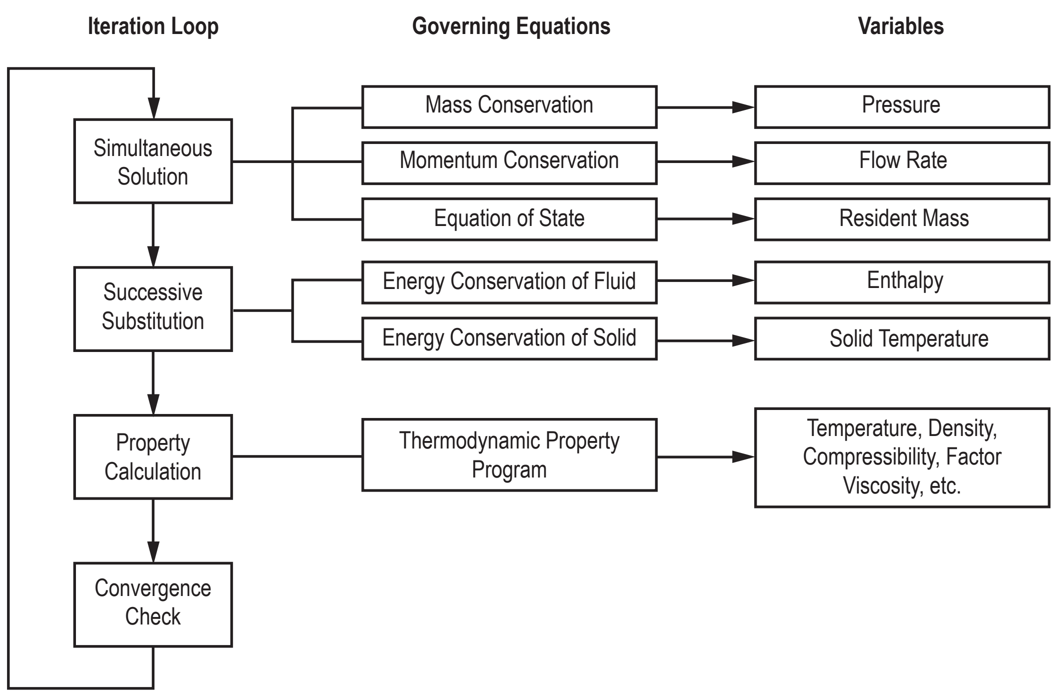

Figure 38. SASS scheme for solving governing equations.

SASS has two options available. In one option, there are two iterative loops—inner and outer. In the inner iterative loop, mass and momentum conservation equations are solved by the Newton-Raphson scheme. For unsteady formulation, the equation of state is also solved by the Newton-Raphson scheme in addition to mass and momentum conservation equations. In the outer loop, the energy and specie conservation equations are solved by the successive substitution method. The outer loop also calculates the density and other thermodynamic and thermophysical properties and the flow resistance coefficient (K_f) which is a function of density. This option is called the nonsimultaneous option. The total number of iterations in this option can be expressed as:

$$N_{\text{total}} = \sum_{i=1}^{n_o} n_i \ , \tag{64}$$

where n_o is the number of outer iterations and n_i is the number of inner iterations. The inner iterative cycle is terminated when the normalized maximum correction ($\Delta_{\max}$) is less than the convergence criterion (C_c). $\Delta_{\max}$ is determined from

$$\Delta_{\max} = \text{MAX}\left|\sum_{i=1}^{N_E} \frac{\Phi_i'}{\Phi_i}\right| \ , \tag{65}$$

where

N_E = the total number of equations solved by the Newton-Raphson scheme (N_E = number of nodes + number of branches (steady flow)

N_N = number of nodes × 2 + number of branches (unsteady flow).

The outer iteration is terminated when $\Delta_{\max}^o$ is less than the convergence criterion (C_c). $\Delta_{\max}^o$ is determined from

$$\Delta_{\max}^o = \text{MAX}\left|\Delta K_f \, , \Delta_\rho \, , \Delta_h, \text{ or } \Delta_s\right| \ , \tag{66}$$

where

$$\Delta K_f = \text{MAX}\left|\sum_{i=1}^{N_B} \frac{K_f'}{K_f}\right|$$

$$\Delta_\rho = \text{MAX}\left|\sum_{i=1}^{N_N} \frac{\rho'}{\rho}\right|$$

$$\Delta_s = \text{MAX}\left|\sum_{i=1}^{N_N} \frac{s'}{s}\right|$$

and

$$\Delta_s = \text{MAX}\left|\sum_{i=1}^{N_N} \frac{s'}{s}\right| \quad . \tag{67}$$

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

In the second option, there is only one iterative loop. During the iterative cycle mass, momentum and the equation of state are first solved by the Newton-Raphson scheme. Then the energy and specie conservation equations are solved by the successive substitution method. The iterative cycle is terminated when the normalized maximum correction ($\Delta_{\max}$) is less than the convergence criterion (C_c).

This option is called the simultaneous option and is more efficient than the nonsimultaneous option. The nonsimultaneous option, however, is more numerically stable. With the help of a logical variable, SIMUL, the user can switch between the first and second options. More detailed discussion of both options appears in section 4.

4. COMPUTER PROGRAM

The purpose of this section is to describe the structure and major functions of the program. The main objective of the computer program is to implement the numerical algorithm described in section 3 in a way which is easy to follow, modular to allow for future extension, robust, and free of errors. There are seven major functions of the computer program:

(1) Development of a flow circuit with fluid and solid nodes with branches and conductors.
(2) Development of an indexing system or data structure to define a network of fluid and solid nodes with branches and conductors.
(3) Generation of conservation equations of fluid mass, momentum, energy, species, and solid temperatures in respective nodes and branches.
(4) Calculation of thermodynamic and thermophysical properties of the fluid and solid in nodes.
(5) Numerical solution of conservation equations.
(6) Input/output.
(7) User-defined modules.

GFSSP consists of three major modules: Graphical User Interface (GUI module), Solver and Property (SP) module, and User Subroutine (US) module (fig. 39). Functions (1) and (6) are done in the GUI module, functions (2) through (6) are done in the SP module, and function (7) is done in the US module. A distinct boundary is maintained among the GUI, SP, and US modules. The GUI and US modules supply the information to the SP module through an input data file and User Subroutines. The SP module returns an output data file and plot files for graphical and text display of results. The maintenance of a strict boundary among the three modules is a key feature of GFSSP that makes the code easy to use, maintain, and upgrade. Users are not required to know the details of the computational method to become a proficient user of the code. The modularity also helps the developer to add new capabilities with minimum impact to the existing code. This section describes the SP and US modules. The GUI module is described in section 5.

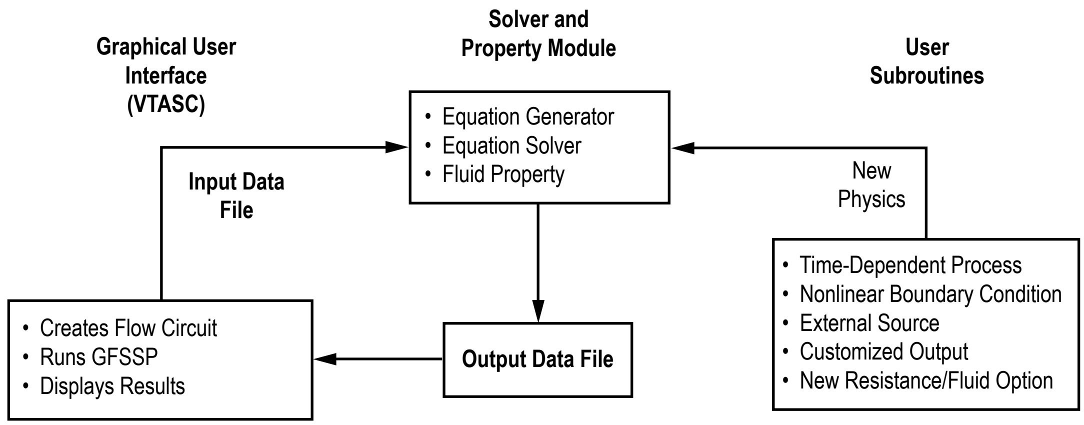

Figure 39. GFSSP process flow diagram showing interaction among three modules.

4.1 Process Flow Diagram

Figure 39 shows GFSSP's process flow diagram to describe the interaction among GUI, SP, and US modules. Users create a flow circuit in the GUI, visual thermofluid analyzer for system and components (VTASC) by a 'point, drag, and click' method. VTASC creates an input data file that is read by the SP module. The user runs the SP module from VTASC, which also reads the output data file generated by the SP module to display the results in the GUI. The VTASC also allows users to plot time-dependent results in Winplot.[13] Specialized input to the model can be supplied through User Subroutines that also interact with the SP module. Such specialized input includes time-dependent processes, nonlinear boundary conditions, and external mass, momentum, and energy sources, customized output, and new resistance and fluid options.

4.2 Solver and Property Module

The main routine and the associated set of subroutines perform seven major functions that include:

(1) Reading of the input data file generated by VTASC, GFSSP's graphical user interface.
(2) Generation of the trial solution based on the initial guess.
(3) Supply time-dependent boundary conditions for unsteady flow.
(4) Numerical solution of conservation equations by the SASS scheme.
(5) Interaction with thermodynamic property programs to calculate properties at nodes.
(6) Calculation of flow resistances in the branches.
(7) Create text output and plot files.

The flow charts of the SP module for nonsimultaneous and simultaneous schemes are shown in figures 40 and 41, respectively.

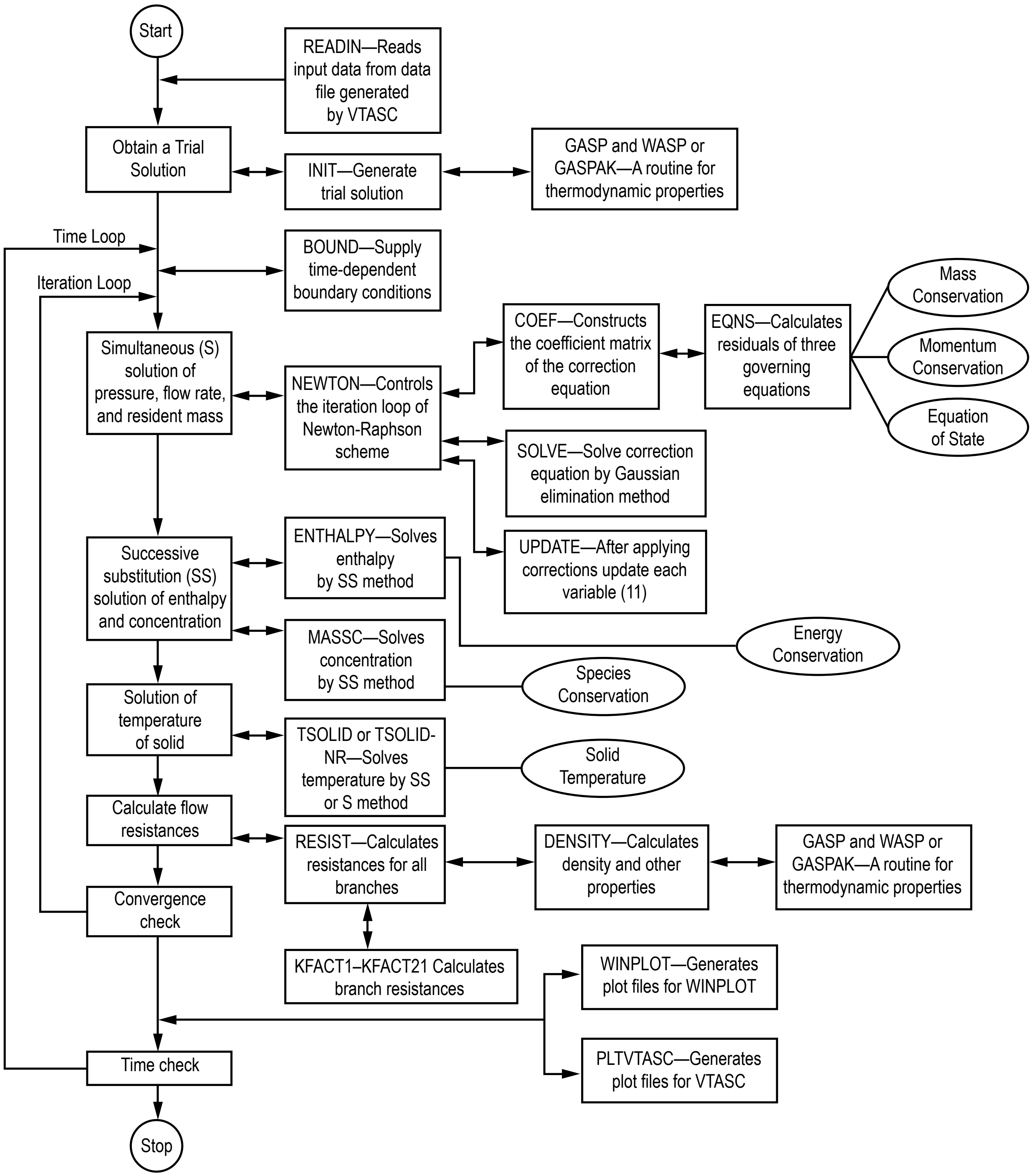

Figure 40. Flowchart of nonsimultaneous solution algorithm in SP module.

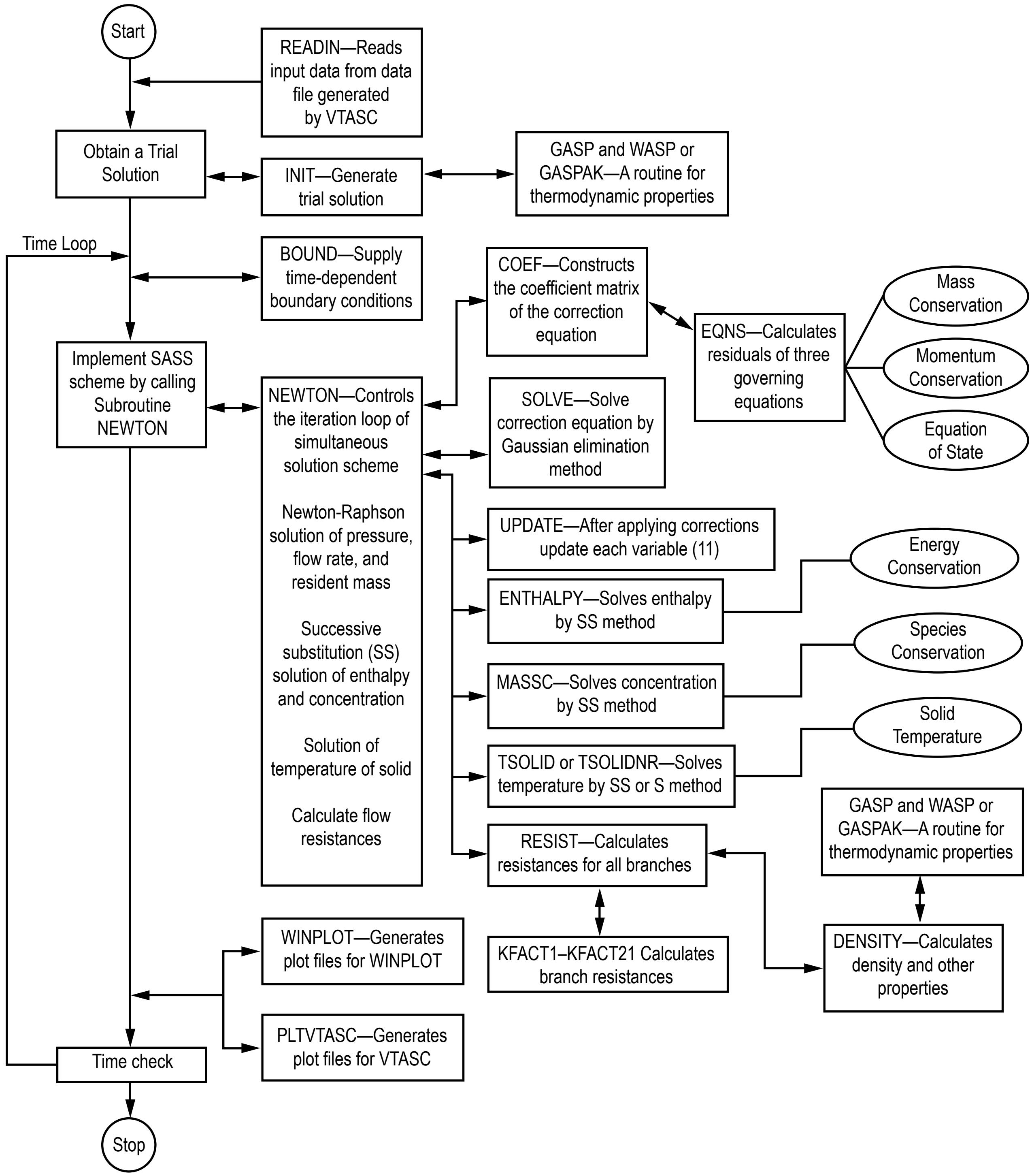

Figure 41. Flowchart of simultaneous solution algorithm in SP module.

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4.2.1 Nonsimultaneous Solution Scheme

The flow chart of nonsimultaneous solution algorithm is shown in figure 40. In this scheme, there are two iteration cycles—inner and outer. In the inner iteration cycle, the mass and momentum conservation equation and resident equation of state are solved by the Newton-Raphson scheme until convergence. During this iteration cycle, property and resistance coefficients are not updated. In the outer iteration cycle, the energy and concentration equations are solved and density and resistance coefficients are updated and a new set of Newton-Raphson iteration is started. The outer iteration loop is repeated until the fractional change in density, resistance coefficient, and enthalpy is negligible.

The subroutine READIN reads the input data file. The subroutine INIT generates a trial solution by interacting with the thermodynamic property codes GASP, WASP, and GASPAK, or the property tables. Subroutine BOUND reads any applicable time-dependent boundary conditions from the model history files. Subroutine NEWTON conducts the Newton-Raphson solution of the mass conservation, flow rate, and energy conservation equations with the help of the subroutines EQNS, COEF, SOLVE, and UPDATE. The subroutine EQNS generates the equations. The coefficients of the correction equations are calculated in COEF. The correction equations are solved by the Gaussian Elimination method in SOLVE. After applying the corrections, the variables are updated in subroutine UPDATE. This cycle of calculations is repeated until the corrections are negligible. The energy conservation equation is then solved in subroutine ENTHALPY or ENTROPY by the successive substitution scheme. For problems involving fluid mixture subroutine, MASSC is called to solve species conservation equations. For conjugate heat transfer problems, the energy conservation equations for solid nodes are solved in subroutine TSOLID or TSOLIDNR. The resistance for each branch is calculated in RESIST following the calculation of fluid densities at each node in the subroutine DENSITY. The flow resistance coefficients (K_f) for each branch are computed in subroutines KFACT1 through KFACT24 depending upon the resistance option selected for a particular branch. The convergence of the numerical scheme is checked to determine if the cycle of calculation needs to be repeated. The solver module also calls 25 User Subroutines from various subroutines as described in section 4.3.

4.2.2 Simultaneous Solution Scheme

The flowchart of the simultaneous solution algorithm is shown in figure 41. The functionality of subroutine READIN, INIT, and BOUND is identical to the nonsimultaneous scheme. In this scheme, there is only one iteration loop. The enthalpy (or entropy), concentrations, density, and resistance coefficient are updated in each Newton-Raphson iteration. Therefore, in each Newton-Raphson iteration, subroutine ENTHALPY or ENTROPY, MASSC, TSOLID or TSOLIDNR, RESIST, and DENSITY are called to compute and update all variables. The iteration loop is controlled in subroutine NEWTON. The interaction of the SP and US modules is identical to the nonsimultaneous scheme.

4.2.3 Conjugate Heat Transfer

GFSSP can model solid to fluid heat transfer which is commonly known as conjugate heat transfer. There are two solution options for solving the conservation equation for solid nodes: successive substitution and Newton-Raphson. The successive substitution scheme is implemented in subroutine TSOLID and the flowchart of the subroutine is shown in figure 42. Subroutine TSOLID calls STCOND, CONVHC, RADHCF, RADHCSA, RADHCSSR, and SLDCP to estimate different terms of the conservation equation. STCOND determines the thermal conductivity from the property table. CONVHC determines the heat transfer coefficient from GFSSP's built-in correlation. CONVHC also calls subroutine USRHCF to allow the user to provide a problem-specific heat transfer coefficient. RADHCF, RADHCSA, and RADHCSSR are three subroutines called from TSOLID to compute radiation heat transfer from solid to fluid, solid to ambient, and solid to solid, respectively. SLDCP determines the specific heat from the property table for computing the transient term. Subroutine QDOTSSCR calculates solid to solid conduction and radiation heat transfer.

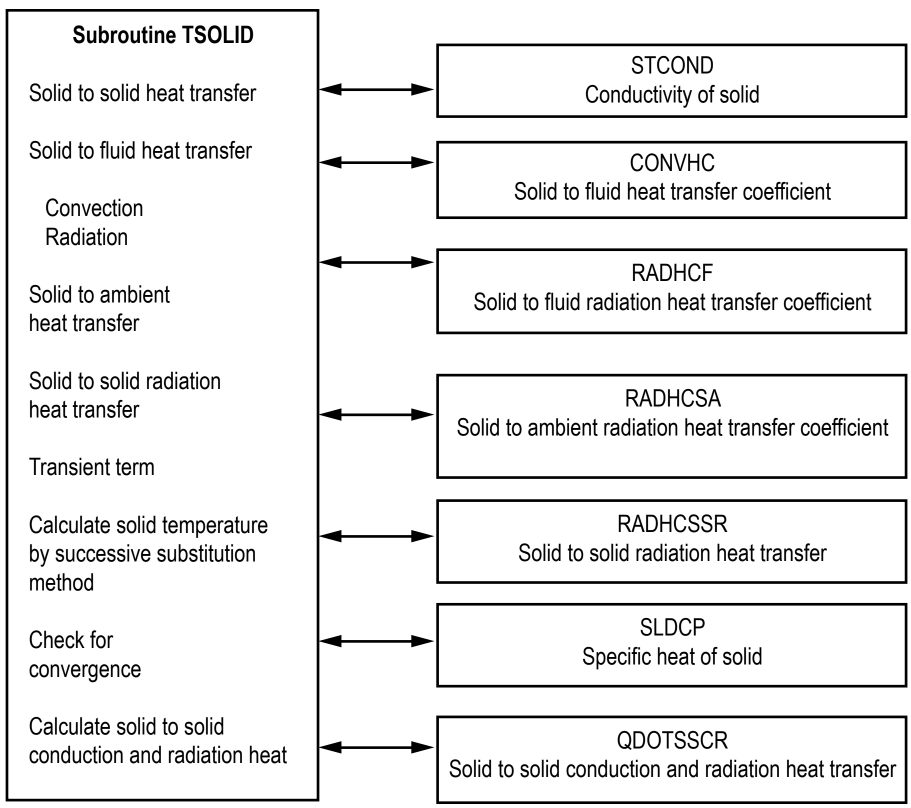

Figure 42. Solid temperature calculation by successive substitution method.

The Newton-Raphson scheme is implemented in subroutine TSOLIDNR. The flowchart of this subroutine is shown in figure 43. TSEQNS, TSCOEF, and GAUSSY are three subroutines that perform the major functions of the Newton-Raphson scheme. The residuals are calculated in TSEQNS. The flowchart of subroutine TSEQNS is shown in figure 44. TSCOEF calculates the coefficient matrix. The correction equations are solved in GAUSSY. After convergence of the numerical scheme, subroutine QDOTSSCR calculates solid to solid conduction and radiation heat transfer.

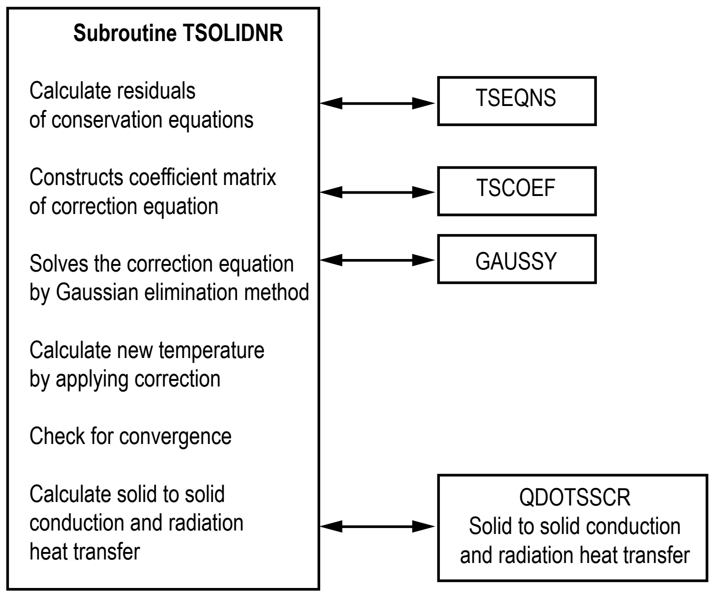

Figure 43. Solid temperature calculation by Newton-Raphson method.

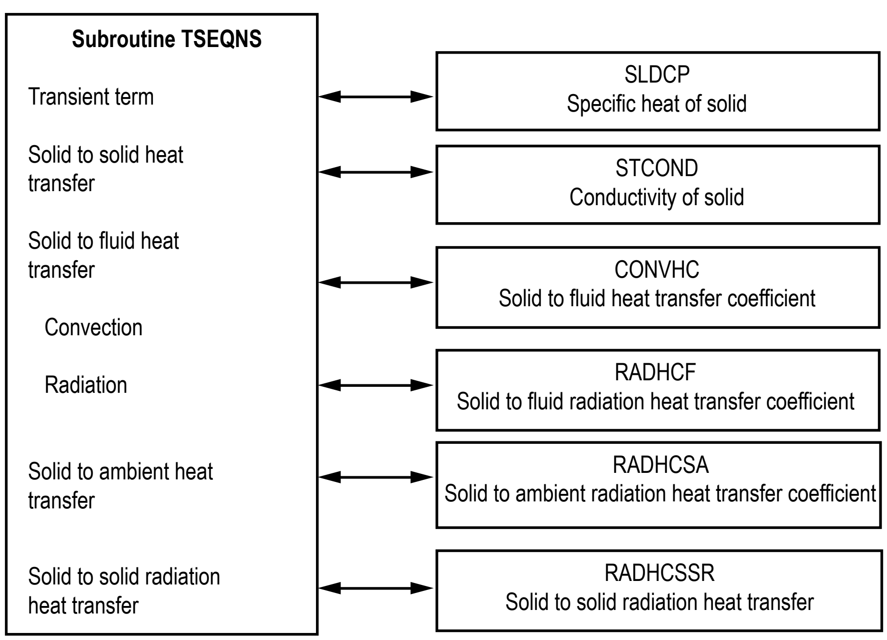

Figure 44. Calculation of residuals of energy conservation equation for Newton-Raphson method.

4.2.4 Thermodynamic Property Package

The thermodynamic property packages included in GFSSP consist of three separate programs: GASP,[10] WASP,[11] and GASPAK[12]; it also includes tabulated data for RP-1. The GASP and WASP programs consist of a number of subroutines. GASP provides the thermodynamic properties for 10 fluids: helium, methane, neon, nitrogen, carbon monoxide, oxygen, argon, carbon dioxide, fluorine, and hydrogen. WASP provides the thermodynamic properties of water. RP-1 properties are provided in the form of tables. Subroutine RP1 searches for the required property values from these tables. GASPAK provides thermodynamic properties for helium, methane, neon, nitrogen, carbon monoxide, oxygen, argon, carbon dioxide, hydrogen, parahydrogen, water, isobutane, butane, deuterium, ethane, ethylene, hydrogen sulfide, krypton, propane, xenon, R-11, R-12, R-22, R-32, R-123, R-124, R-125, R-134A, R-152A, nitrogen trifluoride, and ammonia.

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

4.3 User Subroutines

Experienced users have the ability to introduce additional capability into the code through User Subroutines. Twenty-three User Subroutines are called from various locations of the solver module. The caller and called subroutines are shown in figure 45. All necessary GFSSP variables are available through COMMON BLOCK and subroutine arguments. Users can develop many additional capabilities by developing their own code in User Subroutines. These may include the following:

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

Appropriate use of User Subroutines requires some familiarity with GFSSP variables and indexing practice. Common block variables are explained in appendix D. GFSSP indexing practice and User Subroutines are explained in the following sections. The use of User Subroutines has also been demonstrated in example 10.

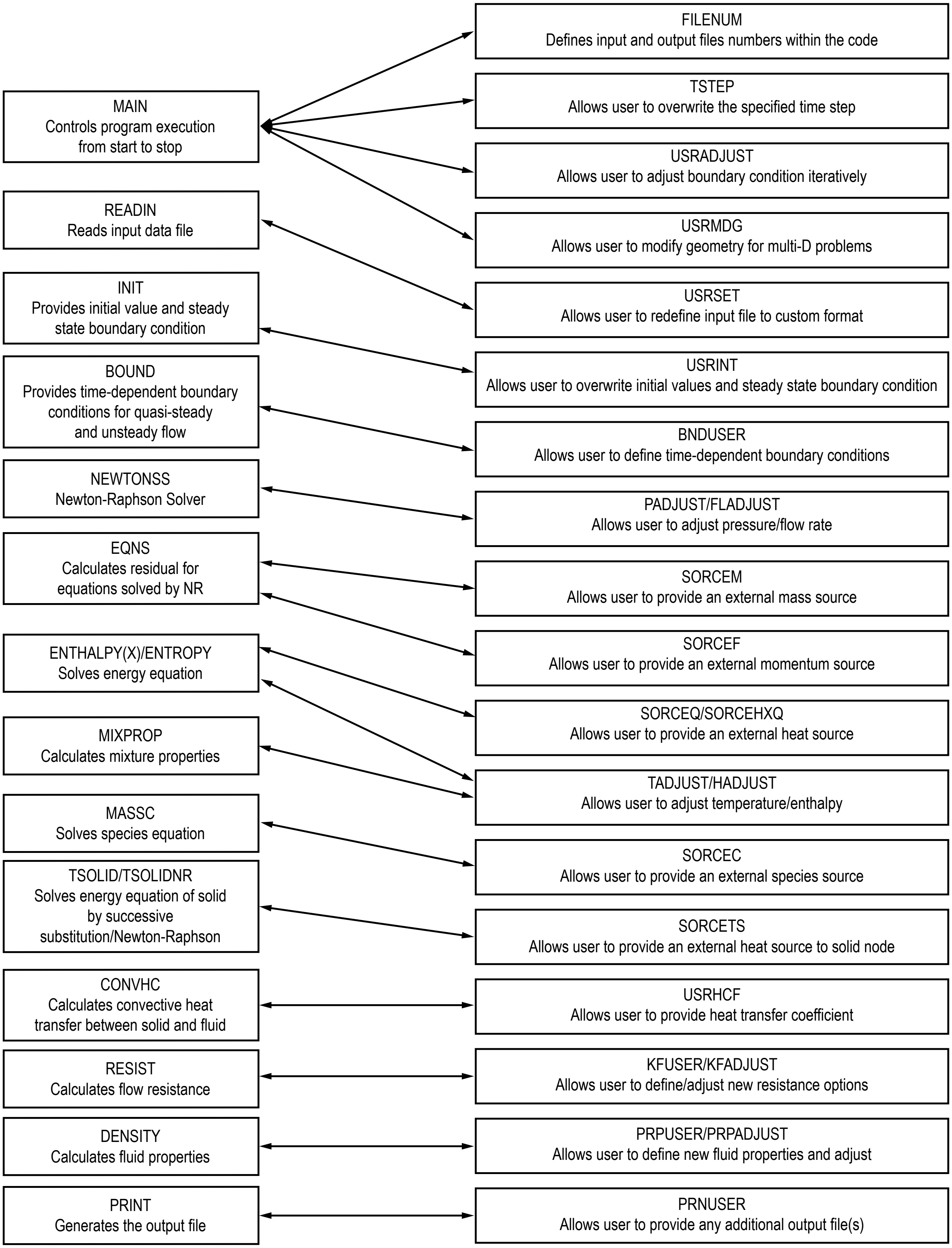

Figure 45. Interaction of User Subroutine with solver module.

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4.3.1 Indexing Practice

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

4.3.1.1 Fluid Node. User-defined fluid node names are stored in NODE-array. NODE-array includes both internal and boundary nodes. The total number of elements in NODE-array is NNODES, which represents the total number of nodes in a given model. Subroutine INDEXI finds the address location for a given node.

SUBROUTINE INDEXI (NUMBER, NODE, NNODES, IPN)

Input variables:

NUMBER: *Node* Number
NODE: Array for storing *Node*
NNODES: Number of *Nodes*

Output variable:

IPN: Location of *Node* in Array (Pointer)

4.3.1.2 Branch. User-defined branch numbers are stored in IBRANCH-array. The total number of elements in the IBRANCH-array is NBR, which represents the total number of branches in a given model. Subroutine INDEXI is also used to find the address location for a given branch.

SUBROUTINE INDEXI (NUMBER, IBRANCH, NBR, IB)

Input variables:

NUMBER: *Branch* Number
IBRANCH: Array for storing *Branch* Number
NBR: Number of *Branches*

Output variable:

IB: Location of *Branch* in Array (Pointer)

4.3.1.3 Solid Node. User-defined solid node numbers are stored in NODESL-array. The total number of elements in the NODESL-array is NSOLIDX, which represents the total number of solid nodes in a given model. Subroutine INDEXS finds the address location for a given solid node.

SUBROUTINE INDEXS (NUMBER, NODESL, NSOLIDX, IPSN)

Input variables:
NUMBER: Solid Node Number
NODESL: Array for storing Solid Node Number
NSOLIDX: Number of Solid Nodes

Output variable:
IPSN: Location of Solid Node in Array (Pointer)

4.3.1.4 Ambient Node. User-defined ambient node numbers are stored in NODEAM-array. The total number of elements in the NODEAM-array is NAMB, which represents the total number of ambient nodes in a given model. Subroutine INDEXA finds the address location for a given ambient node.

SUBROUTINE INDEXA (NUMBER, NODEAM, NAMB, IPAN)

Input variables:
NUMBER: Ambient Node Number
NODEAM: Array for storing Ambient Node Number
NAMB: Number of Ambient Nodes

Output variable:
IPAN: Location of Ambient Node in Array (Pointer)

4.3.1.5 Solid to Solid Conductor. User-defined solid to solid conductor numbers are stored in an ICONSS-array. The total number of elements in the ICONSS-array is NSSC, which represents the total number of solid to solid conductors in a given model. Subroutine INDEXSSC finds the address location for a given solid to solid conductor.

SUBROUTINE INDEXSSC (NUMBER, ICONSS, NSSC, ICSS)

Input variables:
NUMBER: Solid to Solid Conductor Number
ICONSS: Array for storing Solid to Solid Conductor Number
NSSC: Number of Solid to Solid Conductors

Output variable:
ICSS: Location of Solid to Solid Conductor in Array (Pointer)

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4.3.1.6 Solid to Fluid Conductor. User-defined solid to fluid conductor numbers are stored in ICONSF-array. The total number of elements in the ICONSF-array is NSFC, which represents the total number of solid to fluid conductors in a given model. Subroutine INDEXSFC finds the address location for a given solid to fluid conductor.

SUBROUTINE INDEXSFC (NUMBER, ICONSF, NSFC, ICSF)

Input variables:

NUMBER: Solid to Fluid Conductor Number
ICONSF: Array for storing Solid to Fluid Conductor Number
NSFC: Number of Solid to Fluid Conductors

Output variable:

ICSF: Location of Solid to Fluid Conductor in Array (Pointer)

4.3.1.7 Solid to Ambient Conductor. User-defined solid to ambient conductor numbers are stored in an ICONSA-array. The total number of elements in the ICONSA-array is NSAC, which represents the total number of solid to ambient conductors in a given model. Subroutine INDEXSAC finds the address location for a given solid to ambient conductor.

SUBROUTINE INDEXSAC (NUMBER, ICONSA, NSAC, ICSA)

Input variables:

NUMBER: Solid to Ambient Conductor Number
ICONSA: Array for storing Solid to Ambient Conductor Number
NSAC: Number of Solid to Ambient Conductors

Output variable:

ICSA: Location of Solid to Ambient Conductor in Array (Pointer)

4.3.1.8 Solid to Ambient Conductor. User-defined solid to solid radiation conductor numbers are stored in the ICONSSR-array. The total number of elements in the ICONSSR-array is NSSR, which represents the total number of solid to solid conductors in a given model. Subroutine INDEX-SAC finds the address location for a given solid to ambient conductor.

SUBROUTINE INDEXSSRC (NUMBER, ICONSSR, NSSR, ICSSR)

Input variables:

NUMBER: Solid to Solid Radiation Conductor Number
ICONSSR: Array for storing Solid to Solid Radiation Conductor Number
NSSR: Number of Solid to Solid Radiation Conductors

Output Variable:

ICSSR: Location of Solid to Solid Radiation Conductor in Array (Pointer)

4.3.2 Description of User Subroutines

Additional capabilities can be added to the code by the utilization of User Subroutines. Twenty-three blank subroutines are provided with a common block of variables. These subroutines are called from various locations in the SP module as shown in figure 45. A few subroutines also pass pertinent local variables through arguments. Users can develop their code to add new capabilities through use of these variables. A short description of each subroutine is now provided. A descrip-tion of all common block variables appears in appendix D and listing of blank User Subroutines are provided in appendix E.

4.3.2.1 Subroutine FILNUM. This subroutine is called from the main program at the beginning of computation to assign file numbers to integer names. All file numbers are assigned integer variable names in the MAIN routine of GFSSP. All file numbers are listed in this subroutine for users to make them aware what file numbers are already in use. It also includes 10 additional file numbers for possible use in User Subroutines. Users need to make sure they do not use the existing file numbers.

4.3.2.2 Subroutine USRINT. This subroutine is called from subroutine INIT. This allows the user to assign different initial values and steady state boundary conditions and overwrite the values assigned in subroutine INIT.

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

IPN – Address location of node
TERMU – Transient term of mass conservation equation.

In this subroutine, users can define any additional mass sources, EMS (IPN), at any internal node. An alternative form of the transient term in the mass conservation equation (eq. (1)) can be used by overwriting the existing TERMU.

4.3.2.4 Subroutine SORCEF. This subroutine is called from subroutine EQNS. This subroutine allows users the ability to redefine each term in the momentum equation and provides an opportunity to add external momentum sources to any branch. It has 13 arguments:

I – Address location of branch
TERM0 – Unsteady term in momentum conservation equation
TERM1 – Longitudinal inertia
TERM2 – Pressure gradient
TERM3 – Gravity force
TERM4 – Friction force
TERM5 – Centrifugal force
TERM6 – External momentum source due to pump
TERM7 – Momentum source due to transverse flow (multidimensional model)
TERM8 – Momentum source due to shear (multidimensional model)
TERM9 – Variable geometry unsteady term
TERM10 – Normal stress
TERM100 – User-supplied momentum source

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The first argument is the address location of the branch. The other 12 arguments represent the various terms of the momentum equation. The algebraic form of each term is described in equation (2). However, GFSSP's Newton-Raphson scheme solves the equation in the following form:

$$F\left(x_1, x_2, x_3, \ldots x_{nl}\right) = 0 . \tag{68}$$

The momentum equation in subroutine EQNS, therefore, appears as:

TERM0 + TERM1 – TERM2 – TERM3 + TERM4 – TERM5 – TERM6
+ TERM7 – TERM8 + TERM9 – TERM10 – TERM100 = 0. (69)

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

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

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

$$\dot{Q}_{\text{wall}} = hA\left(T_{\text{wall}} - T_F\right) . \tag{70}$$

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

$$h_i = \frac{\sum_{j=1}^{j=n} a_j h_j + h_c A T_{\text{wall}}}{\sum_{j=1}^{j=n} a_j + h_c A / C_p} . \tag{71}$$

Example of coding:

```
SORCEH(IPN) = HC*HAREA*TWALL
TERMD = HC*HAREA/CPNODE(IPN)
```

where

HC = heat transfer coefficient (Btu/ft^2-s-R)
HAREA = heat transfer area (ft^2)
TWALL = wall temperature (°R)
CPNODE(IPN) = specific heat of fluid at IPN (Btu/lb$_\text{m}$–R).

An example of adding a heat source is shown in example 8 in section 6.

4.3.2.6 Subroutine SORCEC. This subroutine is called from subroutine MASSC. This subroutine allows users to introduce a source or sink of species at any internal node. An example of uses of this subroutine appears in example 10 of section 5.

4.3.2.7 Subroutine SORCETS. This subroutine is called from subroutine TSOLID or TSOLIDNR depending upon whether the energy conservation equation for solid is solved by successive substitution or the Newton-Raphson method. This subroutine allows users to introduce heat source or sink at any solid node.

4.3.2.8. Subroutine KFUSER. This subroutine is called from subroutine RESIST. In this subroutine, users can introduce a new resistance option in any branch. It has nine arguments:

I – Address location of branch
RHOU – Upstream node density
EMUU – Upstream node viscosity
RHOUL – Upstream node liquid density
EMUL – Upstream node liquid viscosity
RHOUV – Upstream node vapor density
EMUUV – Upstream node vapor viscosity
ISATU – Flag set to 1 if node is saturated with liquid/vapor mixture
AKNEW – K_f for the branch in consideration.

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

4.3.2.9 Subroutine PRPUSER. This subroutine will be used when users want to integrate a separate thermodynamic property package instead of built-in thermodynamic property packages, GASP, WASP, and GASPAK.

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

4.3.2.11 Subroutine BNDUSER. This subroutine is called from subroutine BOUND. In this subroutine users can modify boundary conditions and geometry at each time step for an unsteady model. This subroutine must be used when users want to integrate a separate thermodynamic property package instead of the built-in thermodynamic property packages, GASP and WASP. In an unsteady model, boundary conditions are specified at each time step. The thermodynamic properties at the boundary node must be calculated at the start of a new time step. Example 8 in section 6 demonstrates the use of this subroutine.

In order to modify the geometry, users can make use of six allocated arrays (BRPR1 through BRPR6) that store the branch parameters for all resistance options. Table 9 describes the allocation of branch parameters of all resistance options to these six arrays.

Table 9. Description of branch parameters for all resistance options.

Branch Option	BRPR1	BRPR2	BRPR3	BRPR4	BRPR5	BRPR6
Pipe	Length	Diameter	ε/D			
Restriction	C_L					
Noncircular duct	Length	Height	Width	Type (1–4)		
Pipe with entrance and exit losses	Length	Diameter	ε/D	K_i	K_e	
Thin, sharp orifice	D_1	D_2				
Thick orifice	Length	D_1	D_2			
Square reduction	D_1	D_2				
Square expansion	D_1	D_2				
Rotating annular duct	Length	r_o	r_i	rpm		
Rotating radial duct	Length	Diameter	rpm			
Laby seal	Radius	Clearance, c	Pitch, m	Number of teeth, n	Multiplier, α	
Parallel plates (face seal)	Radius	Clearance, c	Length			
Fittings and valves	Diameter	K_1	K_∞			
Pump characteristics	A_0	B_0	C_0			
Pump Hp	Power, P	Efficiency, η				
Valve with C_v	C_v					
Viscojet	L_Ω	V_f	k_v			
Control valve	C_L	Control node				
User-defined	User-defined	User-defined	User-defined	User-defined	User-defined	User-defined
Heat exchanger core	Frontal area	Free-flow area	Heat transfer area	Coefficient of control	Coefficient of Exp.	Length
Parallel tubes	Length	Diameter	ε/D	Number of tubes, n		
Compressible orifice	C_L					
Laby seal, Egli correlation	Radius	No. of teeth	Tooth width	Pitch	Clearance	
Fixed flow	Flow rate					

4.3.2.12 Subroutine PRNUSER. This subroutine is called from subroutine PRINT. In this subroutine users can add additional information in GFSSP output files or can create new output files.

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

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4.3.2.14 Subroutine USRHCF. This subroutine is called from subroutine CONVHC. It has two arguments:

NUMBER – Address location of solid to fluid conductor
HCF – Heat transfer coefficient in Btu/s-ft^2-°R.

This subroutine allows users to calculate heat transfer coefficient by a correlation provided by the user to overwrite the heat transfer coefficient calculated by GFSSP's solver module.

4.3.2.15 Subroutine USRADJUST. This subroutine is called from MAIN. Users can adjust the boundary condition and introduce additional iterative cycle to achieve any desired design goal.

4.3.2.16 Subroutine SORCEHXQ. This subroutine is called from subroutine ENTHALPYX, which solves the energy equation for individual species (enthalpy-2 option for mixture, sec. 3.1.3.2). It has three arguments:

IPN – Address location of node
TERMD – Component of linearized source term appearing in the denominator of the species enthalpy equation
K – Index of the fluid species in the mixture.

This subroutine allows the user to introduce a heat source or sink at any internal node for a given species. The use of TERMD has been explained in the context of subroutine SORCEQ.

4.3.2.17 Subroutine KFADJUST. This subroutine is called from subroutine RESIST to allow users to modify the K_f value of a particular branch. It has nine arguments:

I – Address location of branch
RHOU – Upstream node density
EMUU – Upstream node viscosity
RHOUL – Upstream node liquid density
EMUL – Upstream node liquid viscosity
RHOUV – Upstream node vapor density
EMUV – Upstream node vapor viscosity
ISATU – Index to designate saturation condition (ISATU = 1) of upstream node
AKNEW – K_f for the branch in consideration.

4.3.2.18 Subroutine PRPADJUST. This subroutine is called from subroutine DENSITY and allows users to adjust any thermodynamic or thermophysical properties, if necessary.

4.3.2.19 Subroutine TADJUST. This subroutine is called from subroutine MIXPROP which calculates mixture properties and temperature for the enthalpy-2 option of modeling fluid mixture. This subroutine allows users to adjust node temperature, if necessary.

4.3.2.20 Subroutine PADJUST. This subroutine is called from subroutine NEWTONSS which controls the Newton-Raphson scheme. This subroutine allows users to adjust node pressure, if necessary.

4.3.2.21 Subroutine FLADJUST. This subroutine is called from subroutine NEWTONSS which controls the Newton-Raphson scheme. This subroutine allows users to adjust mass flow rate in the branch, if necessary.

4.3.2.22 Subroutine HADJUST. This subroutine is called from subroutine ENTHALPY, which solves for enthalpy of single fluid, and subroutine ENTHALPYX, which solves for enthalpies of all species in the mixture (enthalpy-2 option). This subroutine allows users to adjust enthalpies, if necessary.

4.3.2.23 Subroutine USRMDG. This subroutine is called from MAIN. This subroutine allows users to modify geometrical parameters for a multidimensional grid.

4.3.2.24 Utility Subroutines and Functions. User Subroutine code will sometimes use linear interpolation, for example, when calculating boundary conditions as a function of time. The user may choose to use GFSSP's built-in subroutine INTERPOL:

```
CALL INTERPOL(XVALUE, N, XARRAY, YARRAY, YVALUE)
```

Input:

XVALUE – x value at which y will be interpolated
N – size of arrays XARRAY and YARRAY
XARRAY(N) – array of increasing x values
YARRAY(N) – array of y values corresponding to XARRAY

Output:

YVALUE – y value interpolated at XVALUE

Subroutine INTERPOL is for linear interpolation only. It does not extrapolate. Out-of-range values will be set equal to the first or last value in YARRAY, as appropriate.

User Subroutines may also make use of various unit conversion functions to convert between SI and English units. For example:

REAL FUNCTION KW_BTUS(VALUE)

will convert the power in kW stored in variable VALUE to BTU/s. These conversion functions are described in the User Subroutine write-up of appendix E.

4.3.2.25 Provision of Fluid Property Call From User Subroutine. GFSSP calculates fluid properties in every node as functions of (1) pressure and temperature, (2) pressure and enthalpy, or (3) pressure and entropy. Most of the property package calls were standardized by placing them in one of three universal property call subroutines: PROPS_PT, PROPS_PH, and PROPS_PS. An additional subroutine called PROPS_PSATX is available to users who desire saturation properties at a given pressure. These subroutines call the GASP/WASP programs, RP-1 interpolation tables, and User Fluid interpolation tables. They do not call the GASPAK property program.

An advantage of the universal property call subroutines is that it provides a utility for writing User Subroutines. For example, when calculating a convection coefficient using a film temperature (mean of the fluid and solid node temperatures), the user will want properties at a different temperature than the current node temperature. These can be provided with a call to PROPS_PT. Two-phase convection coefficient correlations may require properties of the saturated liquid and vapor phases, which can be provided with calls to PROPS_PH, PROPS_PS, or PROPS_PSATX.

Subroutine PROPS_PT returns single-phase fluid properties as a function of Pressure and Temperature. It does not return saturation properties. The calling statement for PROPS_PT is:

```
CALL PROPS_PT(I_NFLUID, Z_P, Z_T, Z_RHO, Z_H, Z_CP, Z_CV,
   + Z_S, Z_GAMMA, Z_MU, Z_K, I_KR, Z_XV)
```

Input:

I_NFLUID – Integer ID Number of the Fluid
Z_P – Pressure
Z_T – Temperature

Output:

Z_RHO – Density
Z_H – Enthalpy
Z_CP – Specific heat at constant pressure
Z_CV – Specific heat at constant volume
Z_S – Entropy
Z_GAMMA – Ratio of specific heats
Z_MU – Viscosity
Z_K – Thermal conductivity
I_KR – Integer code for the fluid phase (0, unknown; 1, saturated; 2, liquid; 3, gas)
Z_XV – Quality (vapor mass fraction)

The units of the input and output properties are the same as GFSSP's internal units, and are shown in table 10. Table 11 gives the fluid ID numbers that are recognized by the PROPS subroutines. An incorrect ID number will generate an error message and stop the run.

Table 10. Fluid properties and units.

Property	English Units
Pressure (P)	psf
Temperature (T)	°R
Conductivity (k)	Btu/ft-s-R
Density (ρ)	lb/ft^3
Viscosity (μ)	lb/ft-s
Specific heat ratio (γ)	Dimensionless
Enthalpy (H)	Btu/lb
Entropy (S)	Btu/lb-R
Specific heat (C_p)	Btu/lb-R
Specific heat (C_v)	Btu/lb-R

Table 11. Fluid ID numbers and critical pressures.

ID No.	Fluid	P_{crit} (psia)	ID No.	Fluid	P_{crit} (psia)
1	GASP He	33.0	9	GASP F_2	756.4
2	GASP CH_4	671.1	10	GASP H_2	187.5
3	GASP Ne	384.9	11	WASP H_2O	3,204.0
4	GASP N_2	495.6	12	RP-1 tables	
5	GASP CO	507.4	37	User fluid 1 tables	
6	GASP O_2	737.2	38	User fluid 2 tables	
7	GASP Ar	705.6	39	User fluid 3 tables	
8	GASP CO_2	1,070.9			

Subroutine PROPS_PH returns fluid properties as a function of pressure and enthalpy. The calling statement for PROPS_PH is:

```
CALL PROPS_PH(I_NFLUID, Z_P, Z_T, Z_RHO, Z_H, Z_CP, Z_CV,
   + Z_S, Z_GAMMA, Z_MU, Z_K, I_KR, Z_XV,
   + Z_RHOL, Z_HL, Z_CPL, Z_CVL, Z_SL, Z_GAMMAL, Z_MUL, Z_KL,
   + Z_RHOV, Z_HV, Z_CPV, Z_CVV, Z_SV, Z_GAMMAV, Z_MUV, Z_KV)
```

Input:

I_NFLUID – Integer ID number of the fluid
Z_P – Pressure
Z_H – Enthalpy

Output:

The output is similar to the output of PROPS_PT, except that there are additional liquid (suffix L) and vapor (suffix V) property values returned when the fluid is saturated. If the input enthalpy falls under the saturation dome at the given pressure, variable I_KR will be returned as 1 (saturated), and the properties will be those of a homogeneous two-phase mixture with a quality of Z_XV. If the fluid is single phase at the given pressure and enthalpy, variable I_KR will be returned as 2 (liquid) or 3 (gas), and the saturated liquid and vapor property values will be zero.

Subroutine PROPS_PS returns fluid properties as a function of pressure and entropy. The calling statement for PROPS_PS is:

```
CALL PROPS_PS(I_NFLUID, Z_P, Z_T, Z_RHO, Z_H, Z_CP, Z_CV,
   + Z_S, Z_GAMMA, Z_MU, Z_K, I_KR, Z_XV,
   + Z_RHOL, Z_HL, Z_CPL, Z_CVL, Z_SL, Z_GAMMAL, Z_MUL, Z_KL,
   + Z_RHOV, Z_HV, Z_CPV, Z_CVV, Z_SV, Z_GAMMAV, Z_MUV, Z_KV)
```

Input:

I_NFLUID – Integer ID Number of the Fluid
Z_P – Pressure
Z_S – Entropy

Output:

The output and saturation functionality is similar to that of PROPS_PH. The RP-1 and user fluid interpolation table subroutines do not work as functions of entropy, so calls to PROPS_PS for these fluids will generate an error message and stop the run.

Subroutine PROPS_PSATX returns fluid properties at a given saturation pressure and quality (vapor mass fraction). The calling statement for PROPS_PSATX is:

```
CALL PROPS_PSATX(I_NFLUID, Z_P, Z_T, Z_RHO, Z_H, Z_CP, Z_CV,
   + Z_S, Z_GAMMA, Z_MU, Z_K, I_KR, Z_XV,
   + Z_RHOL, Z_HL, Z_CPL, Z_CVL, Z_SL, Z_GAMMAL, Z_MUL, Z_KL,
   + Z_RHOV, Z_HV, Z_CPV, Z_CVV, Z_SV, Z_GAMMAV, Z_MUV, Z_KV)
```

Input:

I_NFLUID – Integer ID Number of the Fluid
Z_P – Saturation Pressure
Z_XV – Quality (vapor mass fraction)

Output:

The output is similar to the saturated output from PROPS_PH and PROPS_PS. If the user only desires the liquid (suffix L) and vapor (suffix V) properties, an input Quality of zero may be used, and the quality-weighted properties ignored. At this time, this subroutine only works for GASP/WASP fluids; calls with RP-1 or user fluids will generate an error message and stop the run. Providing a saturation pressure greater than the critical pressure will also generate an error message and stop the run. Critical pressures for the GASP/WASP fluids are listed in table 11.

5. GRAPHICAL USER INTERFACE

This section introduces the visual thermofluid dynamics analyzer for systems and components (VTASC), a unique GUI designed to simplify the model building process for GFSSP. VTASC allows the user to design GFSSP models using an interactive 'point and click' paradigm. The program seeks to eliminate some of the more tedious, error prone, and time-consuming operations associated with the model building process such as the selection of unique numbers for nodes and branches, and the explicit specification of the upstream and downstream nodes for every branch. The models may be easily modified both in terms of additional nodes and branches and the model-specific data. Figure 46 shows the main VTASC window that consists of menu and toolbar options and a blank canvas.

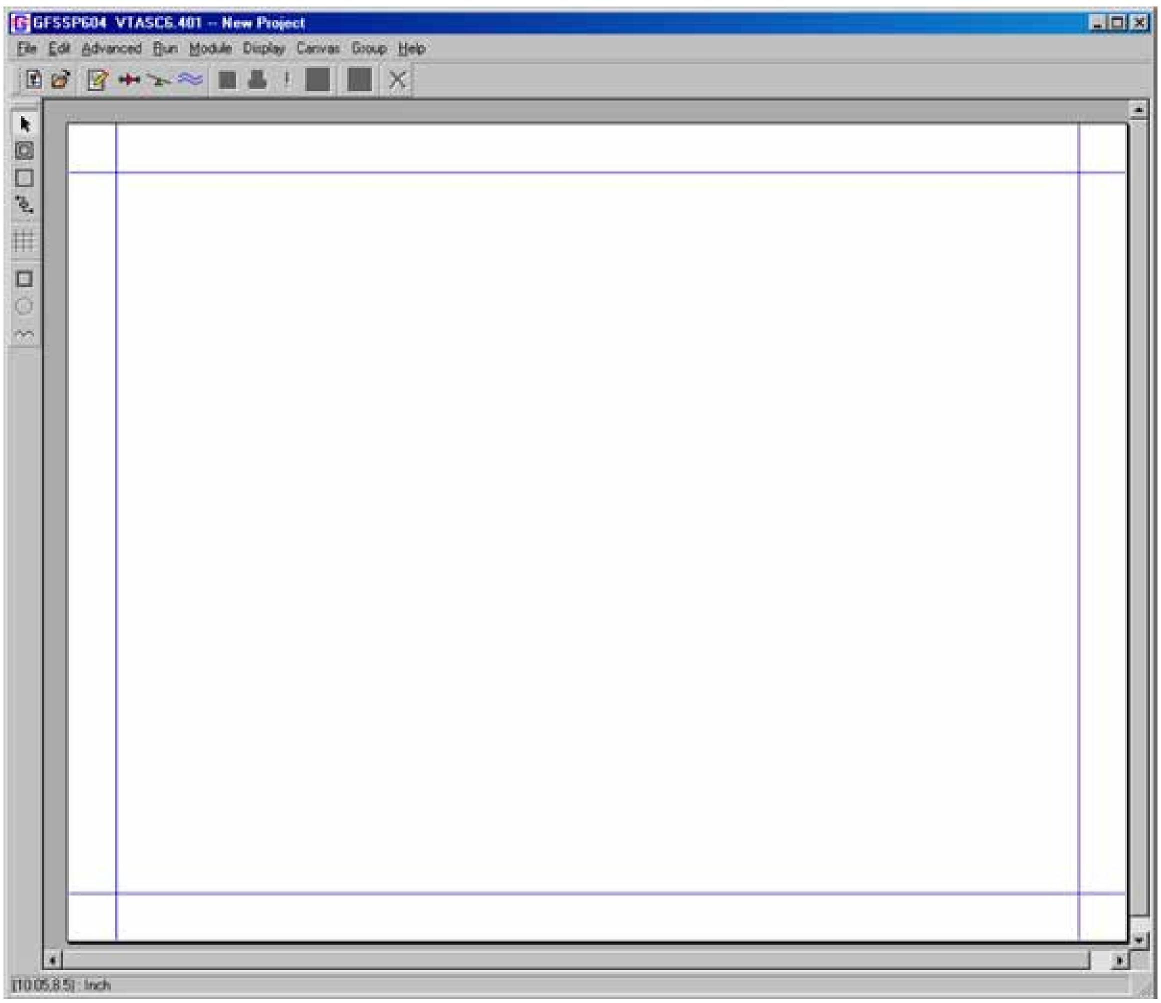


Figure 46. Main VTASC window.

Return to Menu
List of Figures

5.1 Menus

5.1.1 File Menu

The File pulldown menu, shown in figure 47, contains the functions to begin a new model, open an existing model, save the model, save the model with an alternate location and name, print the model to a printer, print an image of the model to a bitmap (.bmp extension) file, write an input file for GFSSP based on the current model, import a second model into an existing model, and exit the application. The most commonly used of these functions are available, as shortcuts, from the file input/output toolbar. In addition, the File menu contains a listing of the nine most recently saved models.

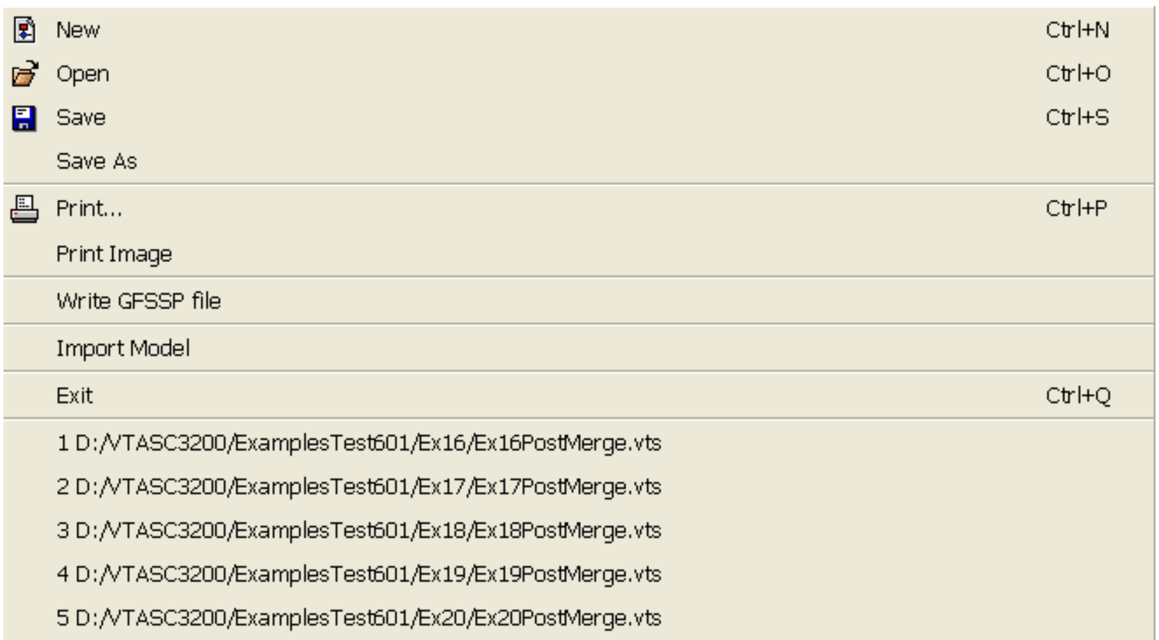


Figure 47. VTASC File menu.

The new model function will reinitialize the application to a clean state without having to exit and then restart the application; if model data are present, then the user will be prompted to continue the operation. The open model function will present a file dialog to allow the user to select a previous model; note that all model files have a '.vts' extension. The VTASC model files are not synonymous with the GFSSP input files; GFSSP compatible input files may be generated, based on the current model, as described below. The Save function allows the user to save the current model to a desired location. In the case where the model has not been previously read or saved, a file dialog will appear and allow the user to save the current model to a given location. The Save As function works identically except that a file dialog will appear in all instances. The Print function produces a Postscript file, which allows the user to print the current circuit to a printer or to a file. The Print Image function will save an image of the circuit in a bitmap file. The Write GFSSP file function will become active once the user has input the required data; this is covered in the following section. The Import Model function allows the user to insert additional models to an existing model. This function will become active once the user has created a branch. The Save and Print functions are not available until at least one node is present.

5.1.2 Edit Menu

The Edit pulldown menu, shown in figure 48, contains the functions to delete a selected item(s), activate the Global Options dialog, open an existing GFSSP output or input file using the desired editor (see Global Options User Information tab, fig. 51c), and to select all elements on the canvas. The Delete function, which is not available until at least one node is present, also appears as a shortcut from the file input/output toolbar. The Global Options dialog is discussed in detail in section 5.2.

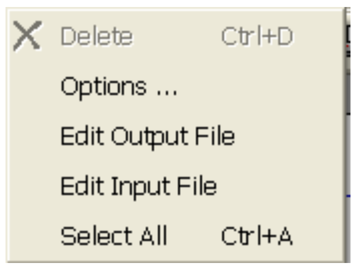


Figure 48. VTASC Edit menu.

5.1.3 Advanced Menu

The Advanced pulldown menu, shown in figure 49, contains the functions to activate dialogs for GFSSP's Advanced options such as Transient Heat, Heat Exchanger, Tank Pressurization, Turbopump, Valve Open/Close, Fluid Conduction (not active), Pressure Regulator, Flow Regulator, Pressure Relief Valve, Enable/Disable Grid Generation, Enable/Disable Conjugate Heat Transfer, and Select/Deselect SI Units. With the exception of Enable/Disable Grid Generation, Enable/Disable Conjugate Heat Transfer, and Select/Deselect SI Units, these functions are not available unless the Advanced option has been activated through the Global Options dialog. The Advanced option dialogs are discussed in detail in section 5.4. Selecting Enable Grid Generation enables the grid node on the left side of the main window. Selecting Enable Conjugate Heat Transfer will enable the three Conjugate Heat Transfer related icons on the left side of the main window. Selecting Enable SI Units will change all of the VTASC data input field labels to SI units.

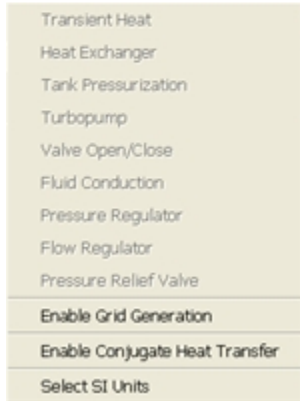


Figure 49. VTASC Advanced menu.

5.1.4 Run and Module Menus

The Run pulldown menu contains the functions to call and run GFSSP, Winplot, and GFSSP and Winplot together. These functions also appear as shortcuts from the file input/output toolbar. The third function will call Winplot and then start GFSSP. Note that Winplot is not part of the GFSSP installation package and must be obtained separately. Also note that Winplot is not made available by VTASC unless a model is defined as an unsteady model. The Module menu contains the function to activate the User Executable Build dialog. The User Executable Build dialog is discussed in detail in section 5.6.

5.1.5 Display, Canvas, Group, and Help Menus

The Display pulldown menu contains the functions to activate the Display Results/Properties dialog, clear any results/properties displayed on the canvas, and enable Quicklook. The Display Results/Properties dialog is discussed in detail in section 5.9.3. The Canvas pulldown menu contains the functions to toggle between a 1-, 2-, or 4-page canvas. The double page canvas configuration is useful for larger models that will not easily fit on a single page canvas. Note that in multiple page configurations, the user should allow for margins for printing. The Group pulldown menu provides the ability to perform move/align operations on a group of network objects that have been selected. The Help pulldown menu contains the function to activate a popup window with additional information about that particular version of VTASC, open the GFSSP User Manual, and disable/enable tooltips.

5.2 Global Options

From the Edit menu, select the menu option labeled Options… to display the Global Options dialog shown in figure 50. A left mouse click on items listed to the extreme left allows access to the desired information within the right pane. As shown, selecting the 'Instructions' option gives general instructions on the use of this dialog.

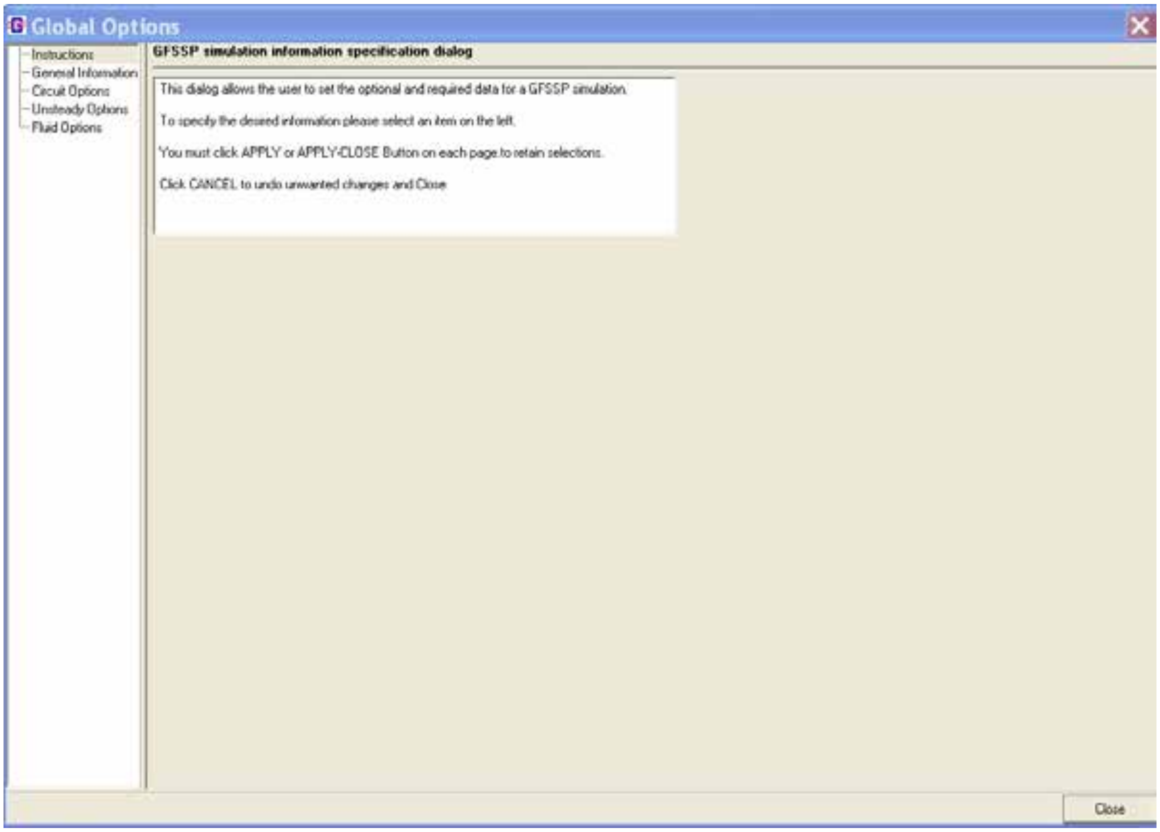
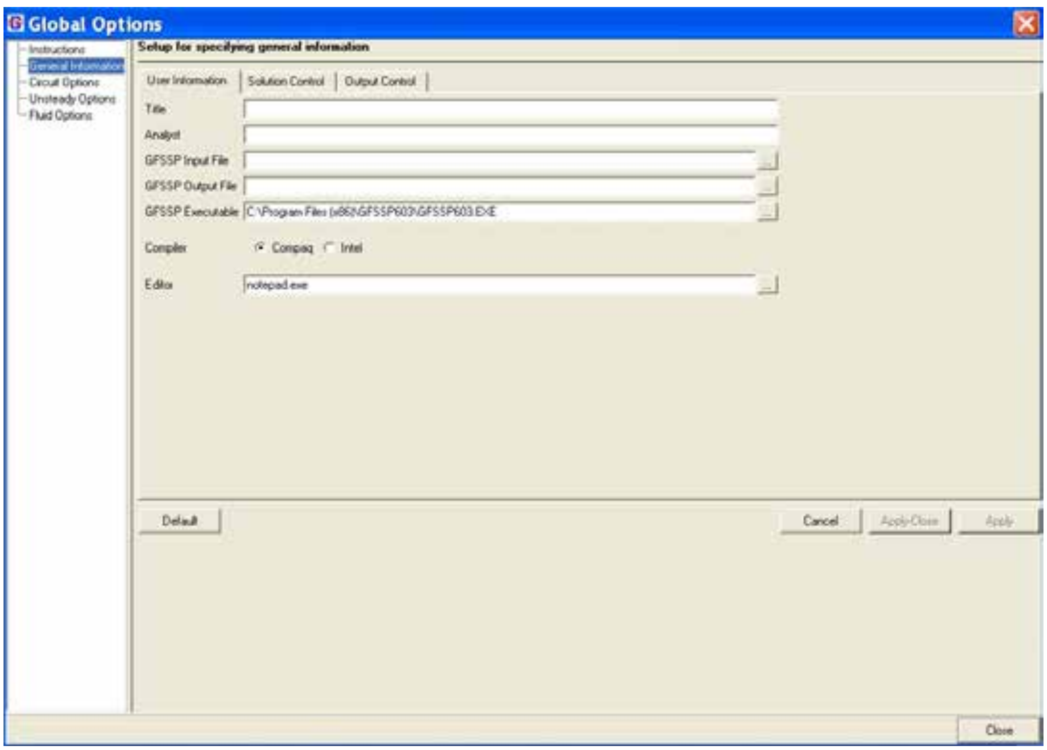


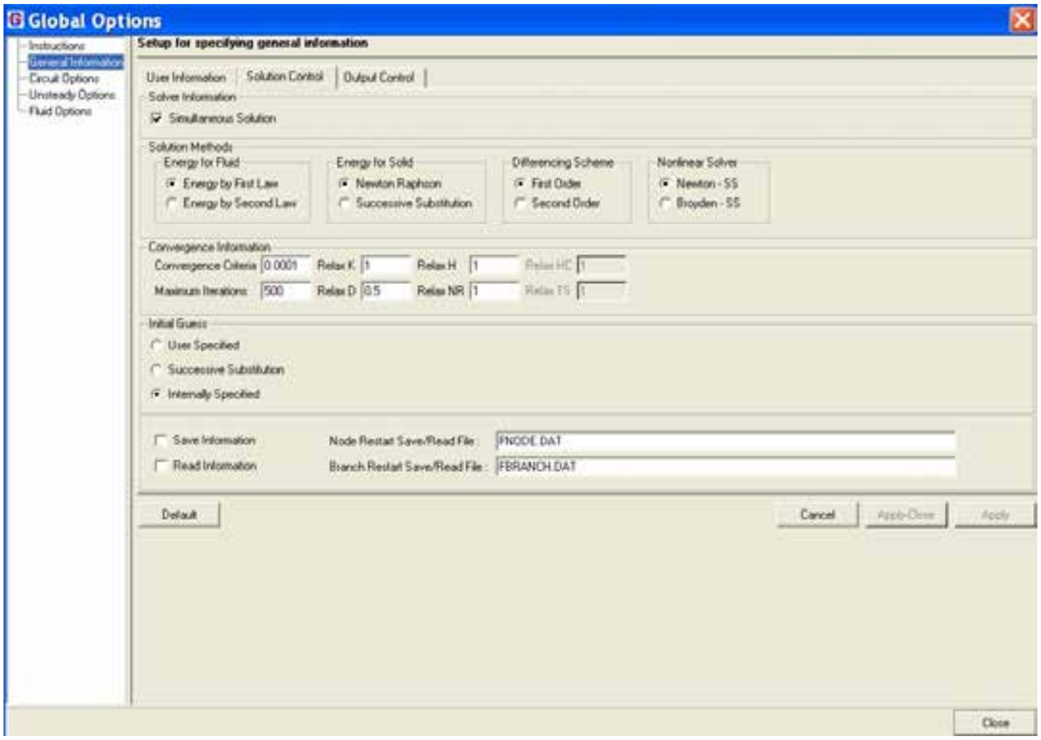
Figure 50. Global Options dialog.

5.2.1 General Information

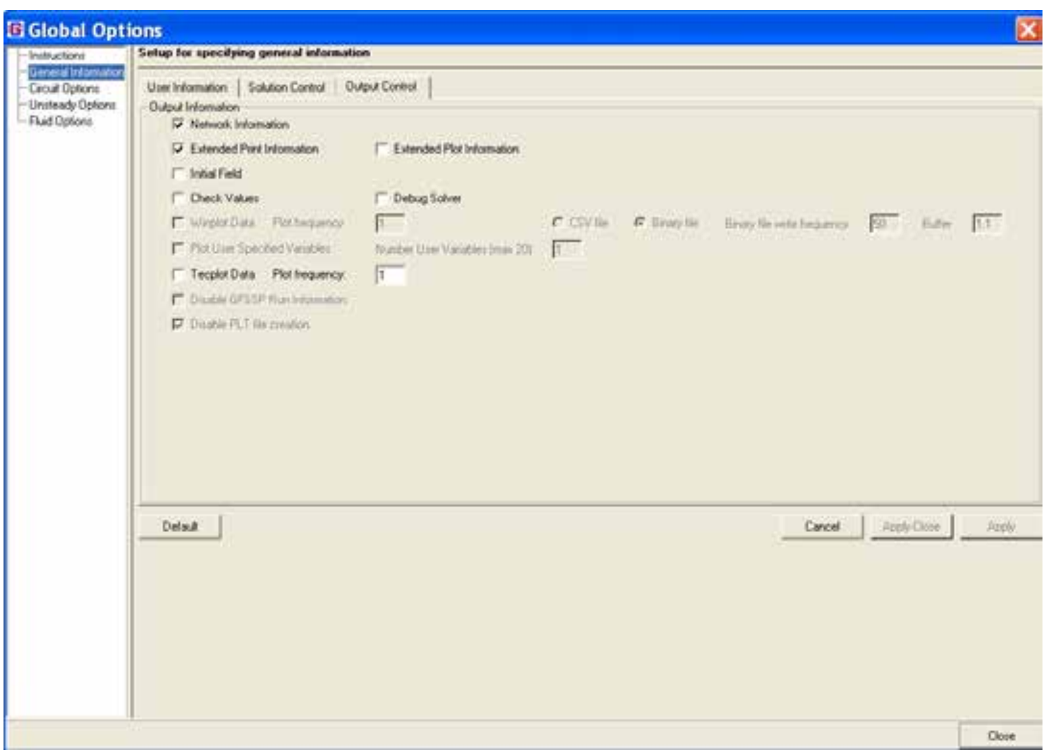
Selecting the General Information item, or toolbar alternative , displays the following dialog (fig. 51) to access User Information, Solution Control, and Output Control. The User Information tab shown in figure 51(a) allows specification of the title, name of the analyst, working directory, GFSSP compatible input file, the output file to be generated by GFSSP, and the name and location of the GFSSP executable that will be used to run the model. The working directory, which is the directory where VTASC will write the GFSSP input and output files associated with the model, is assigned by specifying a file path for the GFSSP input file. The installation version of GFSSP is the default executable defined for any new model. Note that the file menu option Write GFSSP file will become active only when the input and output GFSSP files have been specified. The Compiler radio button allows the user to select either Compaq or Intel Fortran to compile user subroutines. The default text editor for input, output, and history files is Notepad. The user may switch to another editor (e.g., Textpad) by browsing to the executable in the Editor box.



(a)



(b)



(c)

Figure 51. General information dialogs: (a) User Information tab, (b) Solution Control tab, and (c) Output Control tab.

The Solution Control tab shown in figure 51(b) allows specification of certain characteristics of the solution procedure of a particular model. The user can choose either a Simultaneous Solution procedure or the original Hybrid Solution scheme. The user can also choose between the First Law and Second Law of thermodynamics based solution procedures for the energy equation. For the solid energy equation, the user can select either a Newton Raphson or Successive Substitution solution scheme. For the differencing scheme, the user may select either the First Order or Second Order. For the Nonlinear Solver, the user may select either the Newton-Successive Substitution or Broyden-Successive Substitution method. In addition, the user can specify the Convergence Criteria, Maximum Iterations, Relaxation parameters, and choose the method by which the initial guess is made. The user can also specify if they wish to use restart files by checking the appropriate box. Checking the Save Information box indicates the user wishes to save the final solution to use as an initial guess in another model. Checking the Read Information box indicates the user wishes to read in a previously saved solution as an initial guess. Note that if both boxes are checked, GFSSP will overwrite the initial restart files during the simulation. Two restart files are used by GFSSP for both saving and reading information. One file is used for node information and one for branch information. The user may name the restart files using the designated text boxes.

The Output Control tab shown in figure 51(c) allows specification of the type of data to output during the GFSSP simulation as well as requesting certain values to be checked for reasonableness, and requesting various messages for model debugging purposes. The solution check can be activated by choosing Check Values. The output options consist of inclusion (default) or suppression of: (1) Network Information (print), (2) Extended Thermodynamic and Thermophysical Information at the nodes (print/plot), (3) Initial Flow Field (print), and (4) Winplot data (plot). For Winplot data, the user can define whether and how often GFSSP writes output to the Winplot data files (the default is 1, which writes output at every time step) as well as the type of file that is generated (comma separated value files or a binary file formatted for the Winplot plot program). If Binary file is selected, the user may select the number of plot records to buffer for each write to the binary file. The Buffer entry (default 1.1) is a way to give allowance for possible increase in the data (decrease in time step) to be written. Checking CSV will cause GFSSP to write a comma-separated variables file, which can be processed by Excel.

GFSSP provides a way for a user to define variables to be plotted. User-defined variables are defined in one of the subroutines in the User Subroutine file, found in the installation folder. Checking Tecplot Data will cause GFSSP to write data to a file that is suitable for input into the Tecplot program.

Checking Disable GFSSP Run Information will stop GFSSP from writing back to VTASC in the GFSSP Run Dialog. This has been found to be helpful for long-running models. GFSSP will create <modelname>.PLT files, which provide output data that can be used to present results within VTASC. Disabling (default) will prevent these files from being created.

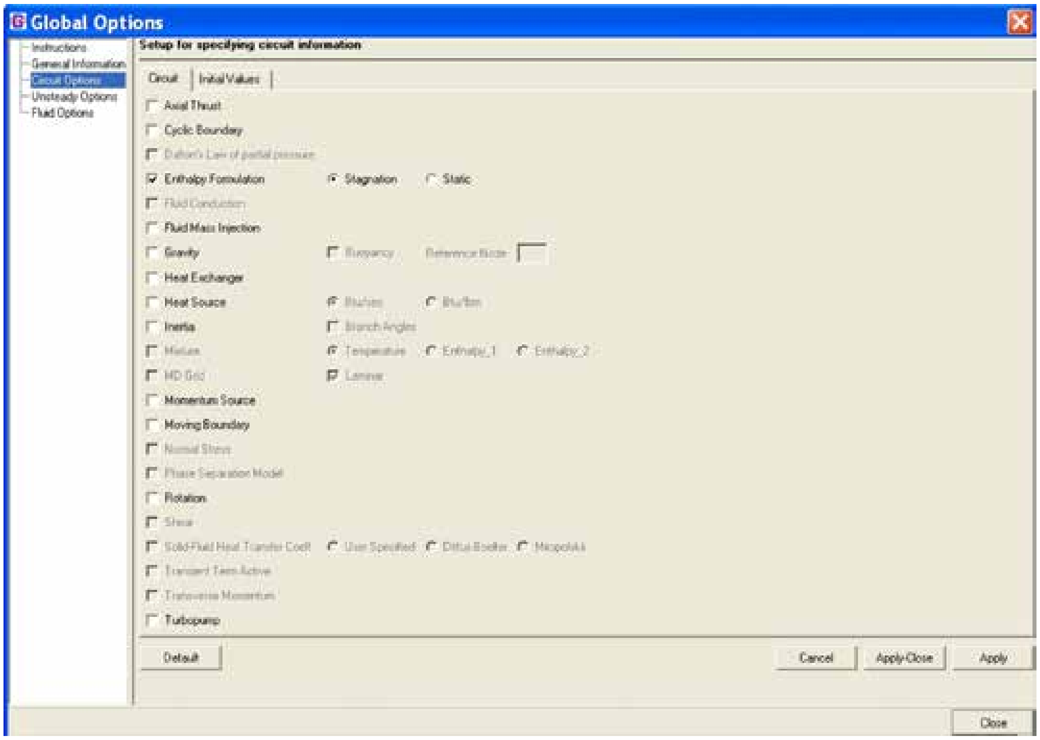
Note that the Apply or Apply-Close button must be pressed to accept modifications to the data in any of the tabs. To reset the data to default on all three tabs press Default and then the Accept buttons. The Cancel button closes the General Information item without accepting any changes.

5.2.2 Circuit Options

Selecting the Circuit Options item, or toolbar alternative , displays the pane in figure 52, allowing access to Circuit Options and Initial Values. The Circuit tab shown in figure 52(a) allows specification of the options that will be activated for this circuit. These options include: Axial Thrust; Cyclic Boundary; Dalton's Law (only active for multiple fluid models); Enthalpy Formulation (Stagnation or Static); Fluid Conduction (activates Fluid Conduction on Advanced Menu, but is not active); Fluid Mass Injection; Gravity (enables Buoyancy and Reference Node); Heat Exchanger (activates Heat Exchanger Advanced Menu); Heat Source (with optional units); Inertia (Note that while this option allows you to choose to supply relative angles between adjacent branches, no mechanism currently exists to define those angles using VTASC. The user must manually edit the GFSSP input file to supply those angles (also discussed in sec. 5.5.13)); Mixture (with option to select method of calculations); MD-Grid; Momentum Source; Moving Boundary; Normal Stress; Phase Separation Model; Rotation; Shear; Solid-Fluid Heat Transfer Coefficient with the ability to choose method of calculation (only active for models using conjugate heat transfer); Transient Term Active; Transverse Momentum; and Turbopump (activates Turbopump Advanced Menu). Note that activating these options may require additional inputs in other areas of VTASC.

The Initial Values tab shown in figure 52(b) allows the user to set initial values of Pressure, Temperature, etc., for both boundary and interior nodes as well as solid nodes. The initial value for nodes may be changed, after the model has been built, by modifying the desired data and pressing the Apply to All button or the Apply to Selected button. For multiple fluids, the option to set default concentrations will become visible. Node ID Sequence Start gives the user the ability to specify the starting Node ID. This may be changed at any time during model creation.

(a)



(b)

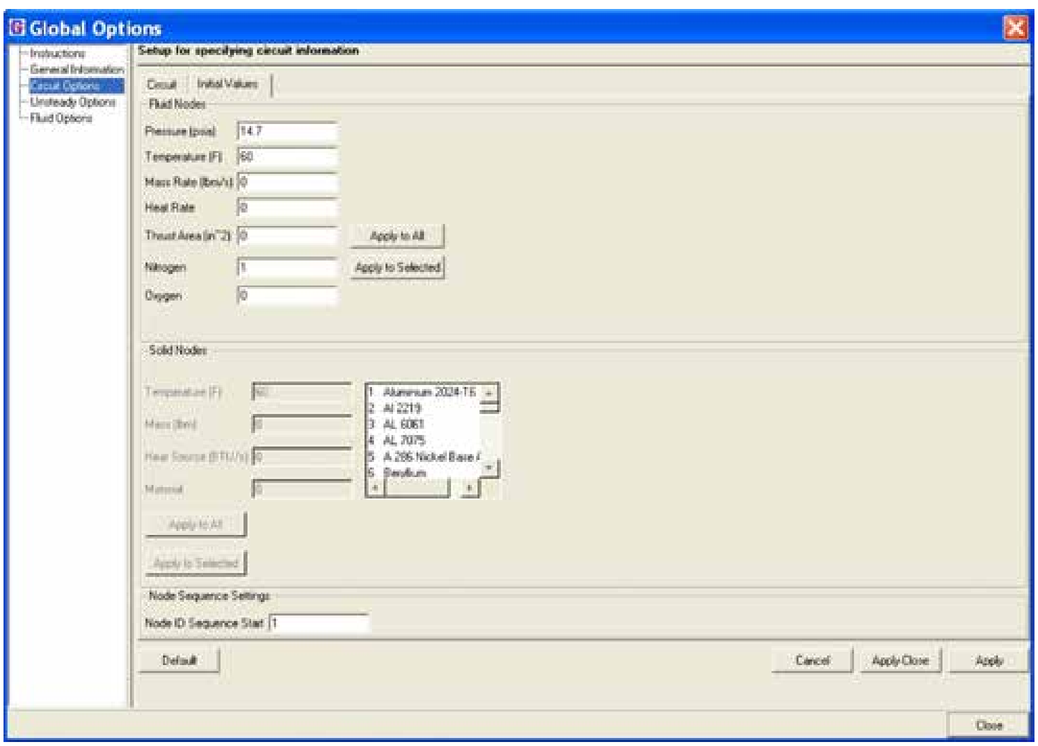


Figure 52. Circuit Options dialogs: (a) Circuit tab and (b) Initial Values tab.

5.2.3 Unsteady Options

Selecting the Unsteady Options item, or toolbar alternative , displays the dialog shown in figure 53. The Unsteady Options dialog allows users to choose from various levels of unsteady modeling. The options in this window include: Steady (default); Quasi-Steady; Time Step; Start Time (a relative time—does not have to be zero); Final Time; Print Frequency (controls print interval to all output files except Winplot files); Unsteady; Variable Rotation (user specifies variable rotation file name); Variable Geometry (user specifies the variable geometry file name); Variable Heat Load (activates Transient Heat Advanced Menu); Tank Pressurization (activates Tank Pressurization Advanced Menu); Valve Open/Close (activates Valve Open/Close Advanced Menu); Pressure Regulator (activates Pressure Regulator on Advanced Menu); Flow Regulator (activates Flow Regulator on Advanced Menu); and Pressure Relief Valve (activates Pressure Relief Valve on Advanced Menu). Note that Pressure Regulator Option 1 and Flow Regulator Option 1 are mutually exclusive in a circuit. Note that activating the unsteady options may require additional inputs in other areas of VTASC.

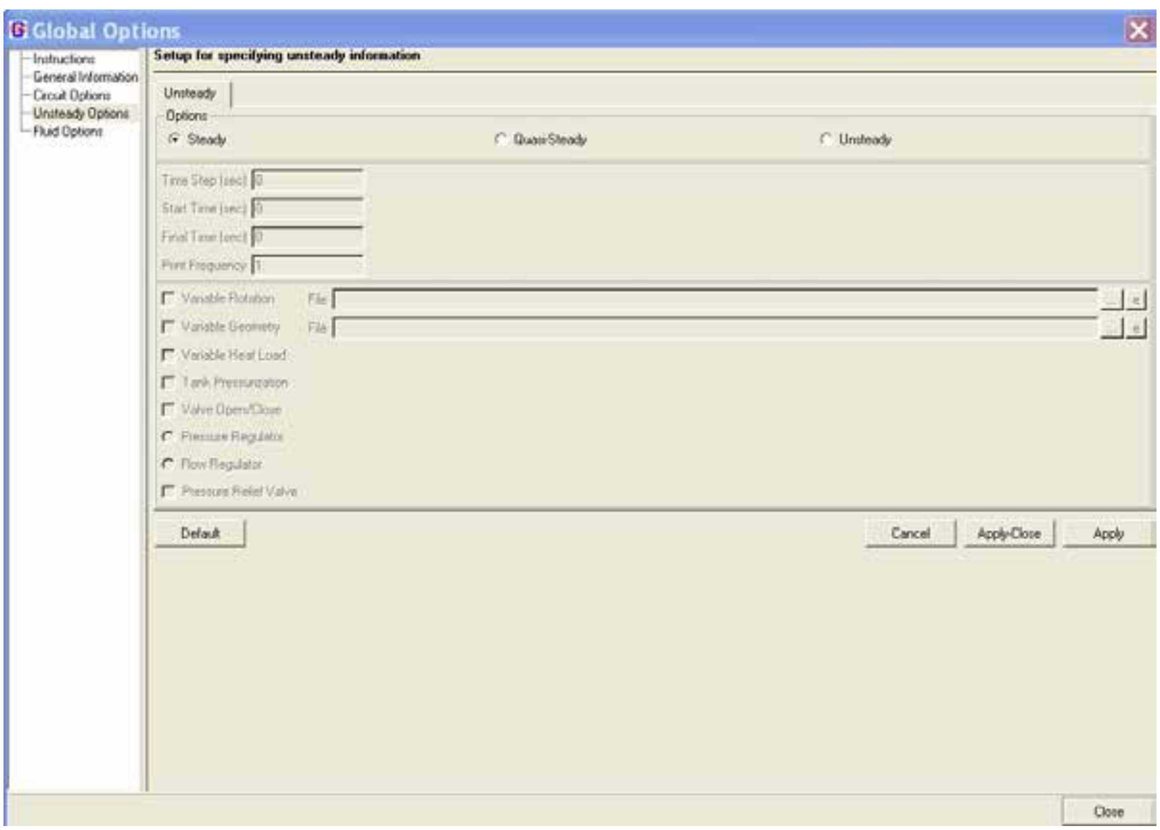


Figure 53. Unsteady Options dialog.

5.2.4 Fluid Options

Finally, selecting the Fluid Options item, or toolbar alternative , displays the dialog shown in figure 54. The Fluid Options dialog allows users to choose the thermodynamic property approach used in the model. The user can choose from the embedded thermodynamic property packages (1) GASP and WASP or (2) GASPAK. Additionally, the user can choose a constant density fluid (the energy equation is not calculated with this option and this option cannot be used with fully unsteady modeling); an ideal gas by specifying the fluid gas constant, specific heat, viscosity, thermal conductivity, reference pressure, reference temperature, reference enthalpy, and reference entropy; hydrogen peroxide, with the capability to define the mole fraction of water present in the fluid; and user-defined fluids through user-defined property files. Note that choosing the constant density fluid option causes the program to set the flow to steady and all unsteady options to be turned off.

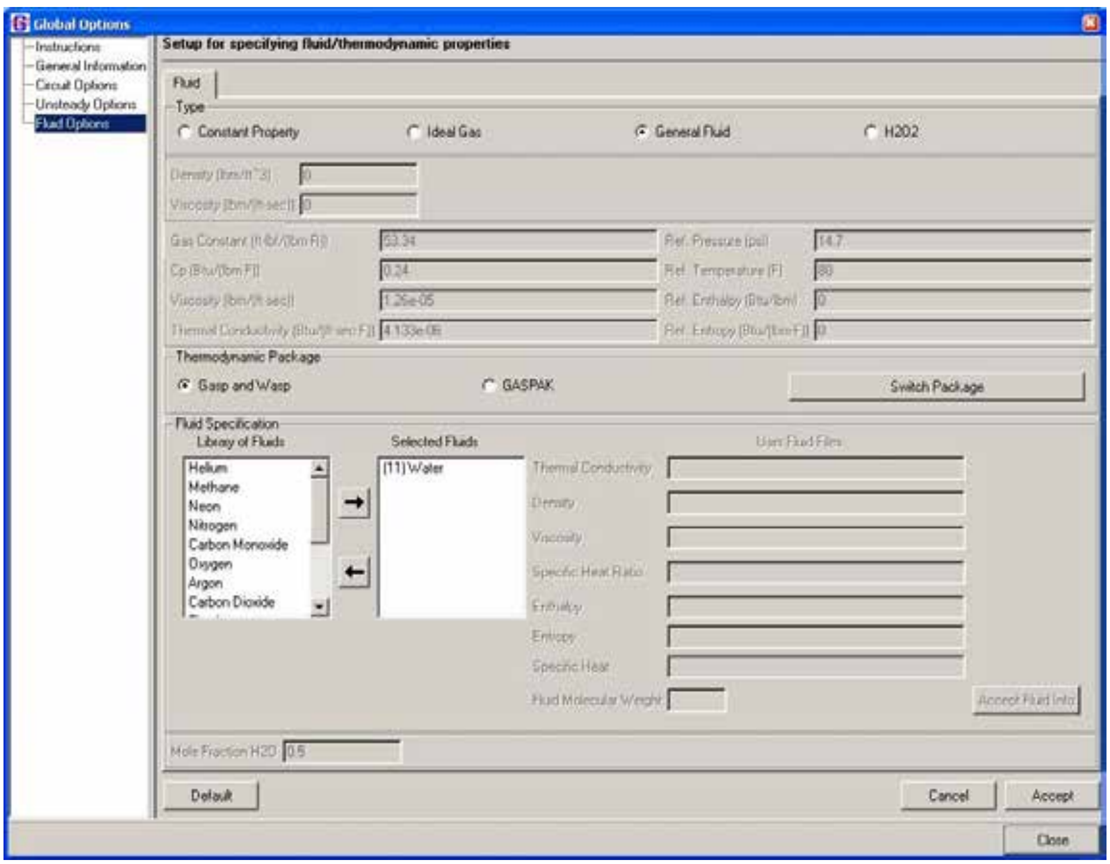


Figure 54. Fluid Options dialog.

Desired fluids from the Library of Fluids may be selected and added to the Selected Fluids list by pressing the button. Fluids may be deleted from the Selected Fluids list by selecting the unwanted fluids and pressing the button. Note that a number enclosed in parentheses appears by each selected fluid. This is the GFSSP index number for that fluid. If a user fluid is selected, VTASC will prompt the user to double-click the fluid name to supply the fluid property file names and fluid molecular weight. Note that all user-defined property files must reside in the model's working directory. The Switch Package button allows the user to switch between the two available thermodynamic property packages. The Switch Package button will only work when all selected fluids are common to both fluid libraries. Note that manually switching between the two thermodynamic property packages will delete all fluids from the selected fluids list and node properties.

5.2.4.1 Saturation Property Calculation for User-Specified Fluid. GFSSP has the capability to define a User Fluid with property interpolation tables. These tables provide seven fluid properties as functions of pressure and temperature. Beginning with v605, saturated fluid properties and phase change may be modeled with a User Fluid, provided that an eighth table of saturation properties is also supplied. A maximum of three User Fluids is permitted in a model.

Figure 55 shows the VTASC fluid options dialog as set up to define water as a User Fluid. The seven property filenames and fluid molecular weight must be provided. The eighth file providing saturation properties is optional and can be added by checking the Phase Change box.

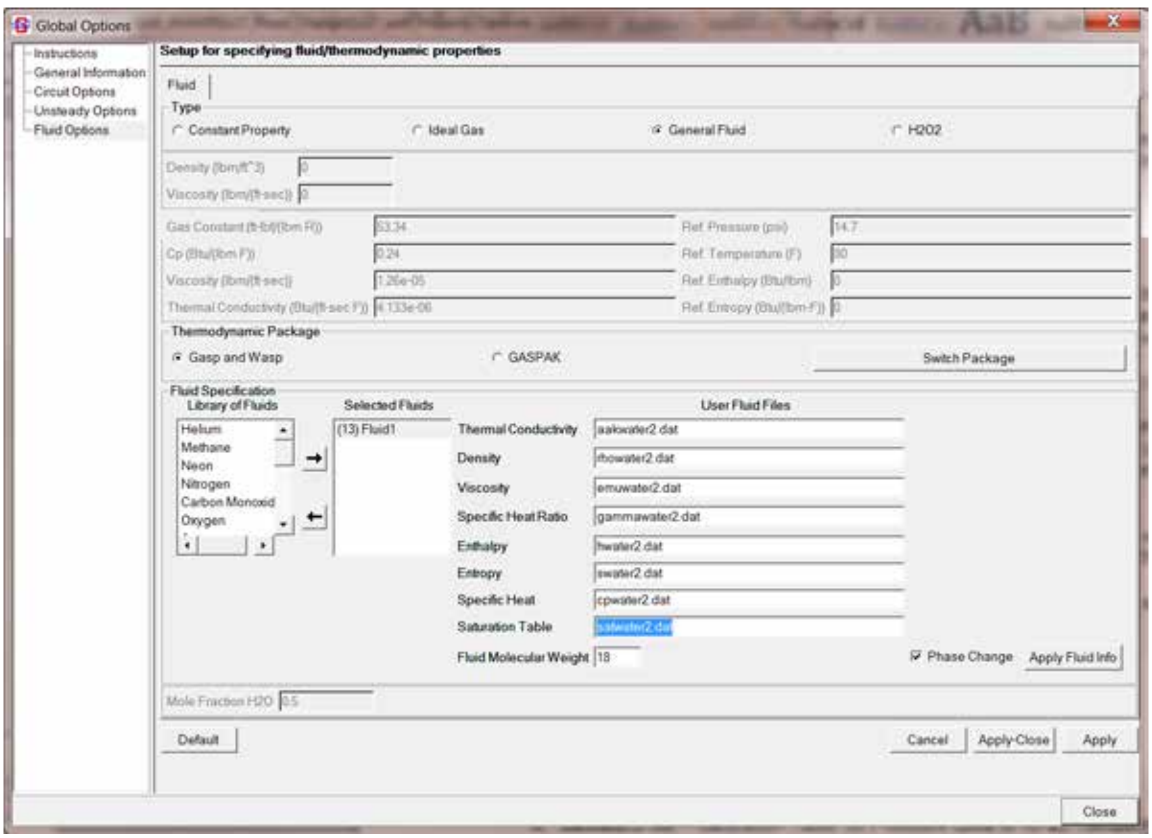


Figure 55. Defining a user fluid in the VTASC Fluid Options dialog.

The seven properties that must be provided are Thermal Conductivity, Density, Absolute Viscosity, Specific Heat Ratio, Enthalpy, Entropy, and Specific Heat. The required units depend on whether the user has developed a model in English or SI units and are shown in table 12.

Table 12. User fluid properties and units.

Property	Units	
	English	SI
Pressure (*P*)	psia	kPa
Temperature (*T*)	°R	K
Conductivity (*k*)	Btu/ft-s-R	W/m-K
Density (*ρ*)	lb/ft^3	kg/^{3}
Viscosity (*μ*)	lb/ft-s	N-s/m^2
Specific heat ratio (*γ*)	Dimensionless	Dimensionless
Enthalpy (*H*)	Btu/lb	kJ/kg
Entropy (*S*)	Btu/lb-R	kJ/kg-K
Specific heat (C_p)	Btu/lb-R	kJ/kg-K

The format of the seven property tables is:

```
NP, NT
T(1), T(2), T(3),…, T(NT)
P(1), PROP(1,1), PROP(1,2), PROP(1,3),…, PROP(1,NT)
P(2), PROP(2,1), PROP(2,2), PROP(2,3),…, PROP(2,NT)
…
P(NP), PROP(NP,1), PROP(NP,2), PROP(NP,3),…, PROP(NP,NT)
```

NP is the number of pressures and NT is the number of temperatures. There can be a maximum of 301 pressures and 301 temperatures in the property file. The pressures and temperatures must be the same in all seven files. Figure 56 shows a portion of the density file for water.

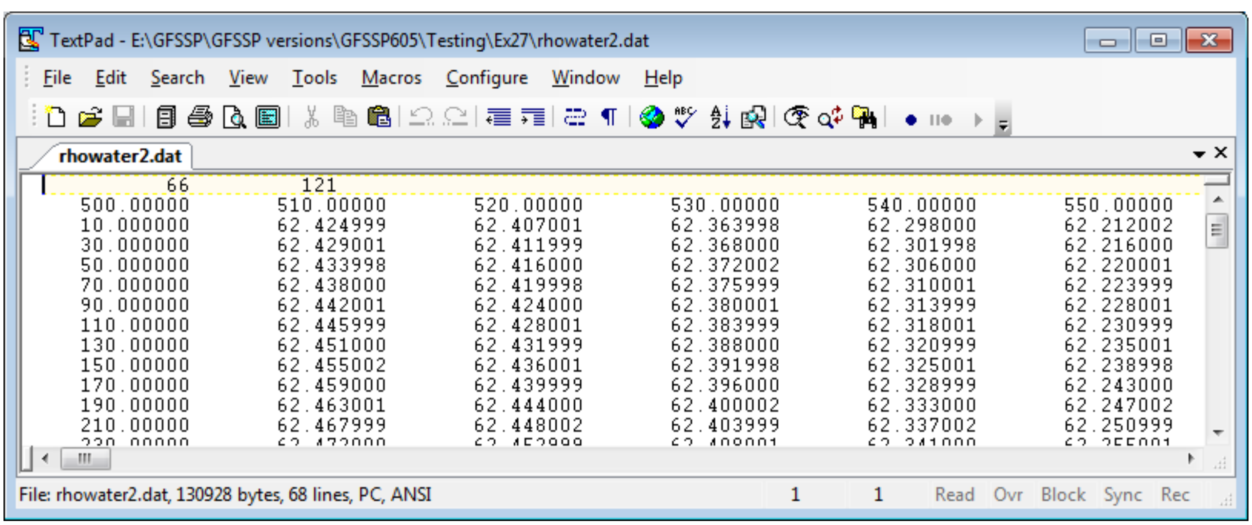
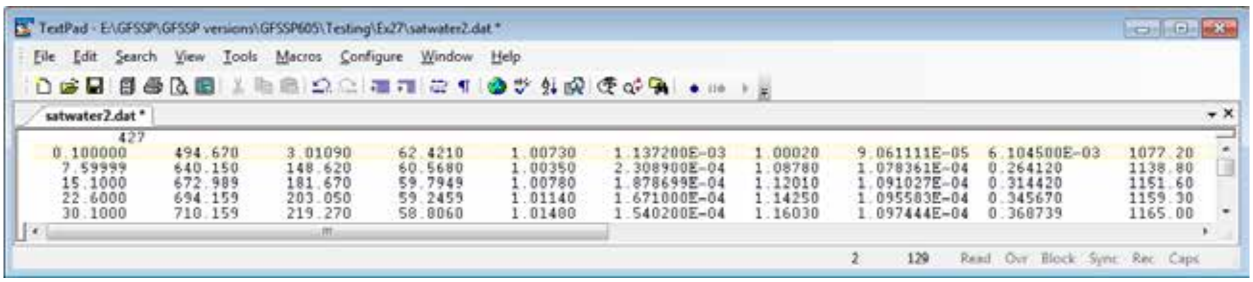


Figure 56. User fluid property file for water density.

The format of the optional eighth property file for saturation properties is:

```
NPSAT
PSAT(1), TSAT, (H, ρ, Cp, μ, γ, k, S)LIQ, (H, ρ, Cp, μ, γ, K, S)VAP
PSAT(2), TSAT, (H, ρ, Cp, μ, γ, k, S)LIQ, (H, ρ, Cp, μ, γ, K, S)VAP
…
PSAT(NPSAT), TSAT, (H, ρ, Cp, μ, γ, k, S)LIQ, (H, ρ, Cp, μ, γ, K, S)VAP
```

NPSAT is the number of saturation pressures; the maximum is 500. The saturation pressures do not need to be the same as the pressures in the seven property tables. Each line gives a saturation pressure, the corresponding saturation temperature, and the seven properties of the saturated liquid and saturated vapor. Figure 57 shows a portion of the saturated property file for water.




```
     427
 0.100000    494.670    3.01090    62.4210    1.00730    1.137200E-03    1.00020    9.061111E-05  6.104500E-03   1077.20
 7.59999     640.150    148.620    60.5680    1.00350    2.308900E-04    1.08780    1.078361E-04  0.264120       1138.80
 15.1000     672.989    181.670    59.7949    1.00780    1.878699E-04    1.12010    1.091027E-04  0.314420       1151.60
 22.6000     694.159    203.050    59.2459    1.01140    1.671000E-04    1.14250    1.095583E-04  0.345670       1159.30
 30.1000     710.159    219.270    58.8060    1.01480    1.540200E-04    1.16030    1.097444E-04  0.360739       1165.00
```

Figure 57. User fluid saturated property file.

A common source of fluid properties is the REFPROP program. Utility programs with instructions (app. F) for converting output from REFPROP into GFSSP's User Fluid format are provided in the User Fluid Utilities subfolder of the GFSSP installation folder.

General guidelines for developing user fluid tables:

- Interpolation is linear with respect to pressure and temperature. Many pressure points are recommended for compressible fluids to ensure accuracy of density interpolation.

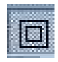
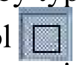
- User fluids cannot be used with the Second Law energy equation, so entropy is a printout variable only. If entropy is unknown, the user may place dummy values in the table.

- If viscosity, specific heat, and thermal conductivity are not known as functions of pressure and/or temperature, the user may use the same constant value at all pressure and/or temperature points in the table.

- If enthalpy is not known, the user may construct enthalpy tables by integrating the specific heat over temperature.

5.3 Fluid Circuit Design

5.3.1 Boundary and Internal Node Properties

The boundary node addition tool  located on the left border of VTASC is used to place boundary nodes on the drawing area, henceforth called the canvas. Upon selection of this tool the user may add boundary nodes by moving the mouse to the canvas and pressing the left mouse button. Placing a node will activate the delete function in the toolbar, edit menu, or by typing CTRL+D. Similarly, interior nodes may be added by selecting the interior node addition tool  . Note that the nodes are automatically given unique numeric identifiers. Figure 58 shows a canvas with a number of boundary and interior nodes.

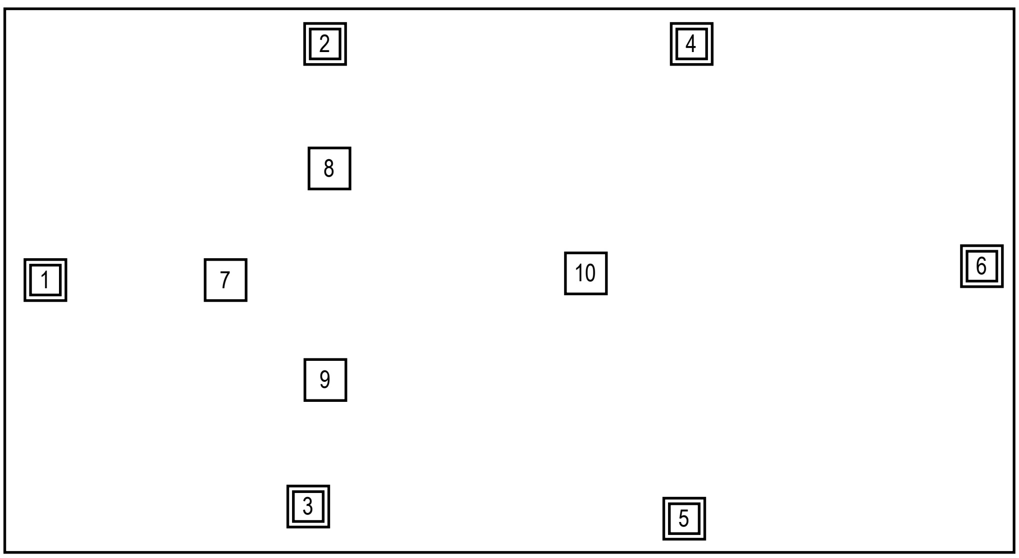


Figure 58. Boundary and interior nodes on canvas.

The selection tool  is used to select the desired node and either modify its location or enable its deletion. Positioning the mouse and pressing the left button performs the selection; upon selection, the selected node will be shown with a red border. Repositioning a node is simply performed by pressing and holding the left mouse button over a node, moving the mouse to the desired location, and releasing the left mouse button. Multiple nodes may be selected for deletion by using the Ctrl keyboard button in conjunction with the mouse. The nodes may then be deleted using the Delete toolbar button as long as they are not attached to any branches. A left mouse click within the canvas, away from any nodes, will deselect any previously selected nodes.

A right mouse click upon a node will select the node and present a popup menu (fig. 59) allowing the user to delete the node (will not work on multiple node selections and is not available if the node is connected to any branch), set the properties for the indicated node, save the node properties to a node property buffer, get the properties from the node property, or align the node either horizontally or vertically with its neighboring elements. (Horizontal alignment aligns all elements to the right of the selected node, while vertical alignment aligns all elements below the selected node.) Once a model has been run, the internal node popup menu also allows the user to activate the results dialogs, which will be discussed in section 5.8.

Figure 59. Node popup menus: (a) Boundary node and (b) internal node.

Choosing the Properties … option will present the dialog shown in figure 60. The appropriate inputs will be activated dependent upon the choices present within the Global Options dialog and the type of the selected node, whether boundary or interior. The user may modify the desired data within this dialog. To modify the concentration of a given fluid, select the desired fluid and type in the desired concentration. Note that directly upon selecting a fluid, the user may type without having to reposition the mouse. If the user wants to change the numeric identifier for a node, simply type in the desired numeric identifier (maximum of five numbers). The user may enter any desired descriptive text into the Node Description input box. Pressing the OK button will accept and adjust the revised data and the Cancel button will reject the revised data. Also, in the case of an unsteady flow, each boundary node will be automatically assigned a unique Node History File name that is subject to user modification. Checkboxes allow for selection of the node as Moving Boundary, Phase Separation Model, or Cyclic Boundary. These are enabled on Circuit Options.

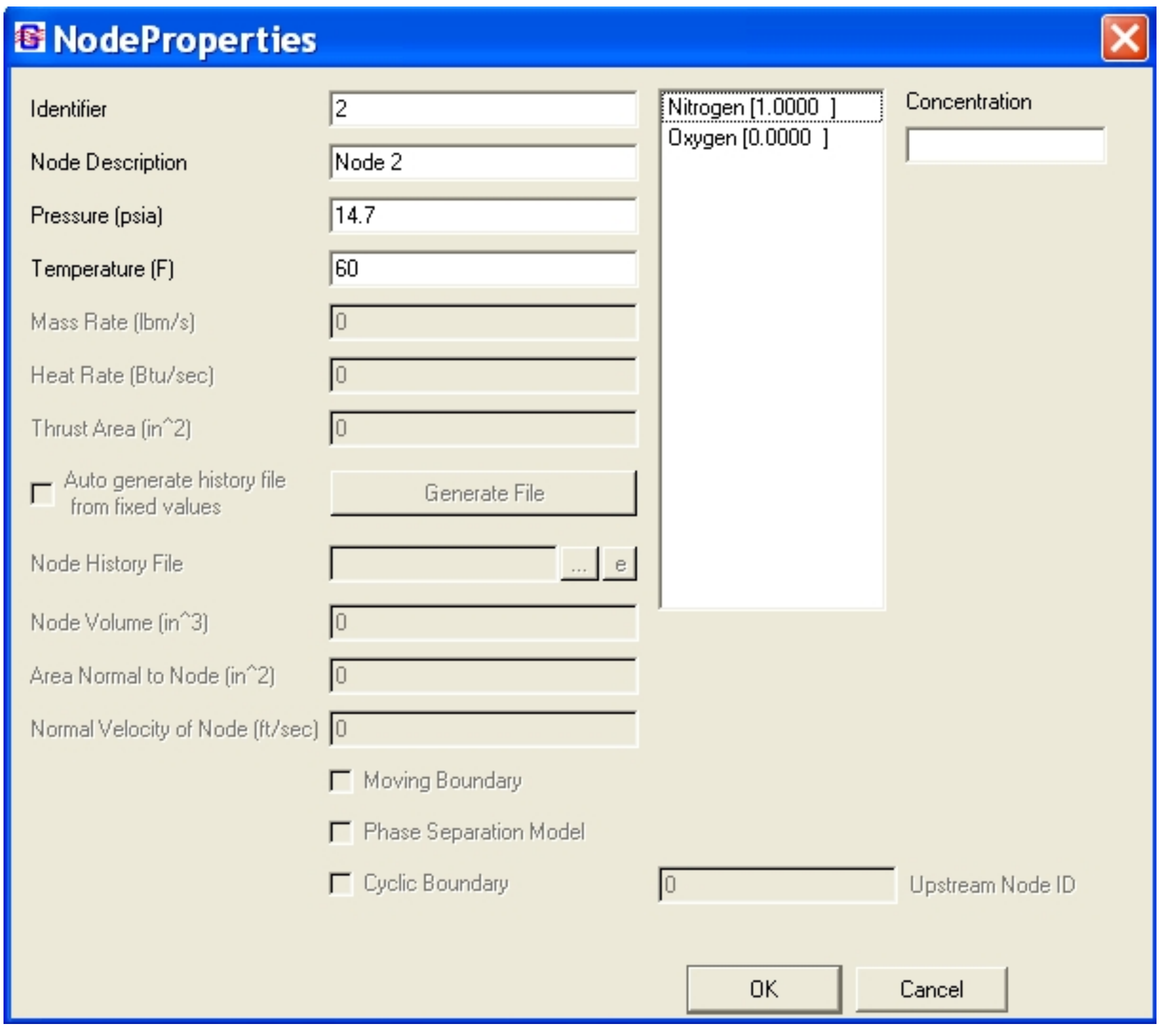


Figure 60. Node properties dialog.

5.3.2 Branch Properties

The branch addition tool  is used to specify the branches between the nodes. Selection of this tool immediately causes each interior and boundary node to be drawn with a series of ‘handles’ as denoted by the green squares in figure 61.

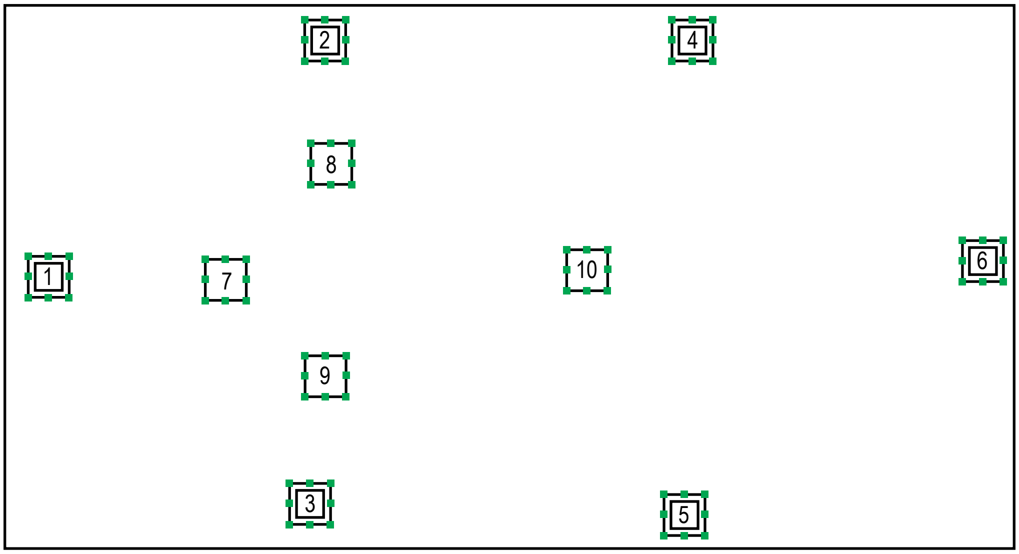


Figure 61. Nodes with branch ‘handles.’

The handles serve to clearly identify eight possible locations on a node where the initial (upstream) or terminal (downstream) points of a branch may be located. Note that an unlimited number of branches may initiate or terminate at each handle. There are two different types of branches that may be created—a directed line segment between any two nodes and two possibly discontinuous line segments. In either case, a left mouse button click on a handle will initiate a branch. Once an initial handle (specifies the upstream node) has been selected, further movement of the mouse will draw a directed line segment from that handle to the current location of the mouse, as shown in figure 62(a). For the first type of branch, selecting another handle completes the branch, as this second handle effectively specifies the downstream node (fig. 62(b)).

Figure 62. Direct line segment branch: (a) Upstream node and (b) downstream node.

The second type of branch is initiated identically; however, after selecting an initial handle, an additional anchor point may be set at any location on the canvas by a left mouse click at the desired location. The branch is then completed, as usual, by selecting another handle. This series of steps is shown in figures 63(a) and (b).

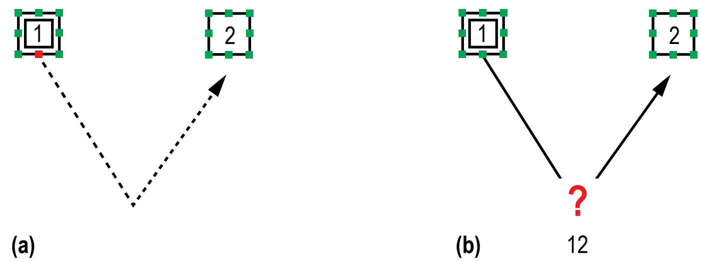


Figure 63. Two-line segment branch: (a) Upstream node and (b) downstream node.

Completing a branch will activate the delete function in the toolbar, edit menu, or by typing Ctrl+D. As shown in figures 62(b) and 63(b), a unique numeric branch identifier formed by concatenating adjacent node numbers is automatically generated and the directed arrowhead visually defines the branch upstream and downstream node relationship. A click on the branch addition tool  may be used to clear a branch currently under design and reinitialize the process. The selection tool  may be used to select the desired branch and either modify its location or enable its deletion. The Ctrl button may be used in conjunction with the mouse to select multiple branches and nodes for deletion using the Delete toolbar button. Note that a node can only be deleted using this method if all branches attached to it are deleted as well. Figure 64 shows an example fluid circuit complete with nodes and branches.

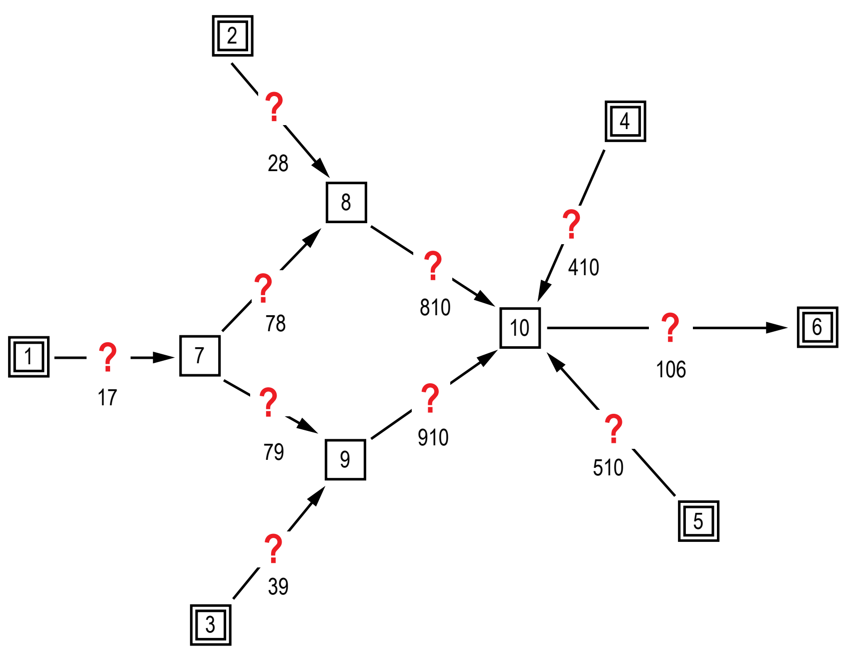


Figure 64. Example fluid circuit with complete branch connections.

Specification of a new branch shows an  image, which visually indicates that the resistance for this branch has not been specified. A right mouse click upon the image will present the popup menu shown in figure 65, which allows the user to specify the Components, i.e., the resistance for the branch; Align the branch either horizontally or vertically with its neighboring elements (horizontal alignment aligns all elements to the right of the selected branch, while Vertical Alignment aligns all elements below the selected branch); activate the Relocate ID dialog; activate the Change Branch connection dialog; or Delete the branch. The Properties option will be activated once a resistance has been selected for the branch and the Rotation/Momentum Data option will be activated in the case where either Rotation or Momentum is selected in the Global Options and for the specific branch under consideration. Once a model has been run, the Branch popup menu also allows the user to activate the results dialogs, which will be discussed in section 5.8.

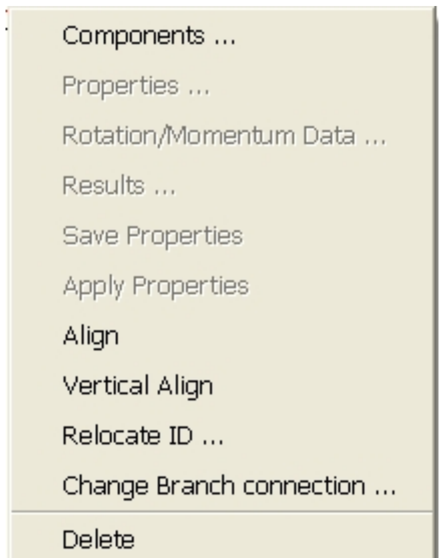


Figure 65. Branch popup menu.

Figure 66 shows the Relocate Branch ID dialog. This dialog gives the user a choice of eight locations where the branch identifier can be placed in relation to the branch element on the canvas. Figure 67 shows the Branch Connections dialog. This dialog allows the user to change the nodes that the branch connects and/or the handles where the branch attaches to each node. Note that changing the nodes connected to a branch does not automatically change the branch identifier.

Figure 66. Relocate Branch ID dialog.

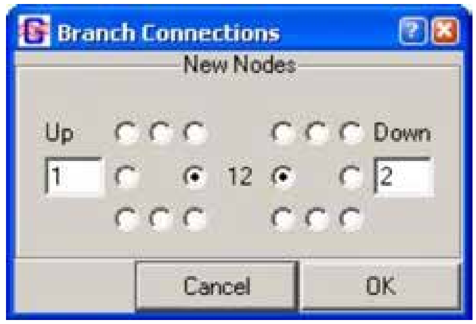


Figure 67. Change Branch Connections dialog.

Choosing the Components… option will present the Resistance Options dialog shown in figure 68. This dialog shows pictorial representations for each of the 27 (unsteady) branch resistance options currently allowed in GFSSP. Note that the Control Valve option will not be available for steady flows. The available resistance options are discussed in section 3.1.7. To assign a resistance option, left click on the desired component and click the Accept button. Figure 69 shows an example where each of the branches has been assigned a resistance option. The user may change the resistance option for a branch at any time without deleting the branch.

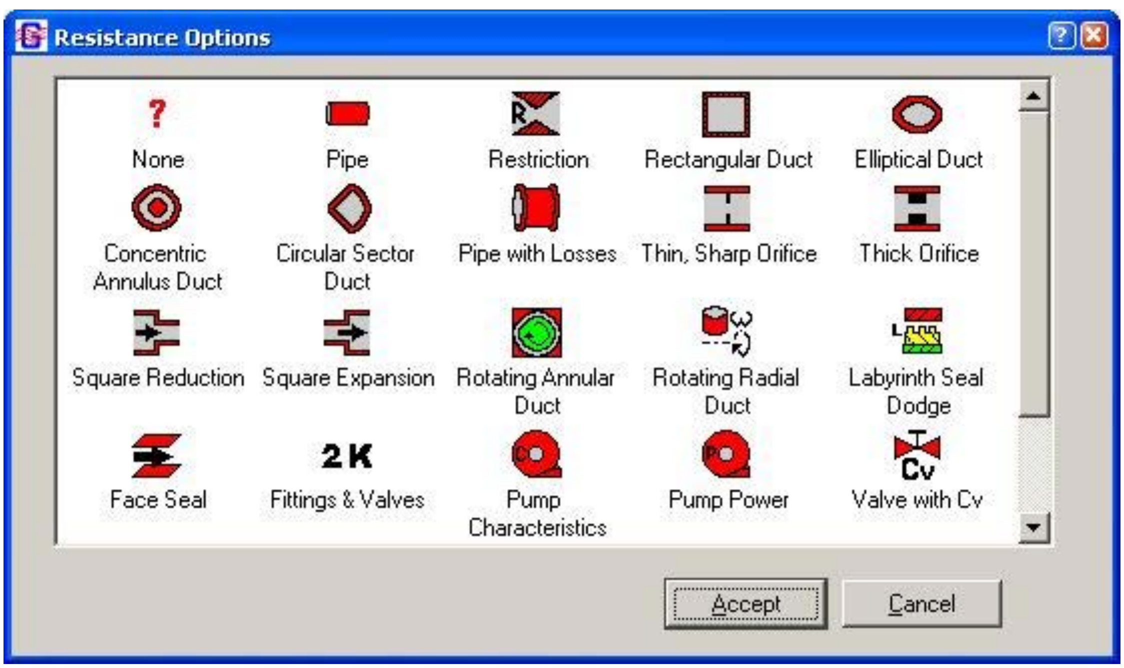


Figure 68. Branch Resistance Options dialog.

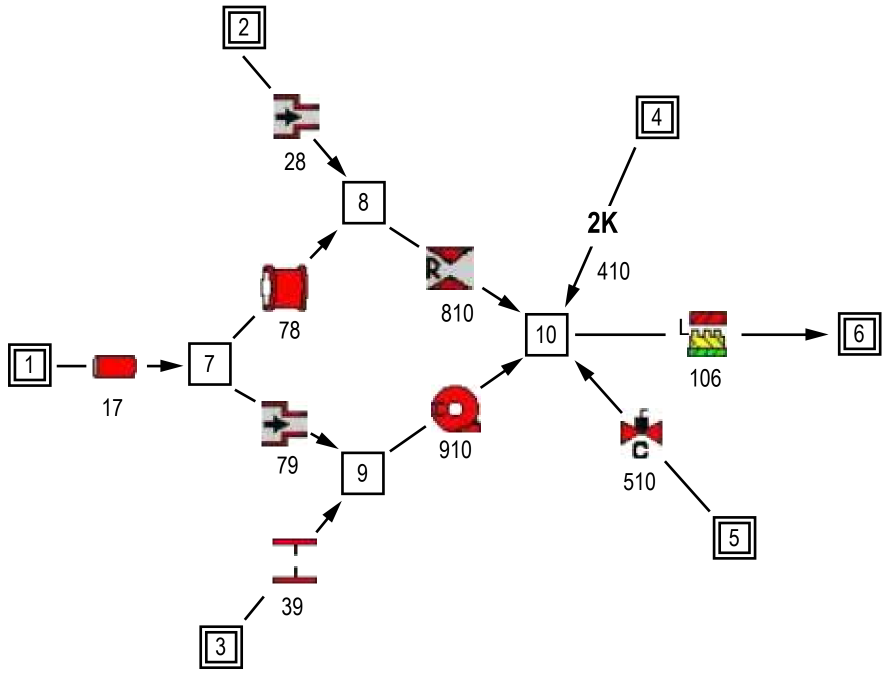


Figure 69. Example fluid circuit with Resistance options.

A right mouse click on a branch where the resistance has been specified will present the popup menu (fig. 65) with the Properties … option activated. Choosing the Properties … option will present a dialog that is specifically tailored to receive input for that Resistance option. In all instances, the properties specification dialogs behave in an identical fashion; however, the Fittings and Valves - **2K** dialog is somewhat different and will be shown as an example. Choosing the Properties option for a fitting and valve will present the dialog shown in figure 70. The user can input the desired data or use the tree structure to the right to select a desired fitting or valve. Selection of a fitting or valve from the tree will load its specific data into the fields to the left; these data may then be edited as desired. The Accept button must be pressed to apply the data.

List of Figures

Return to Menu

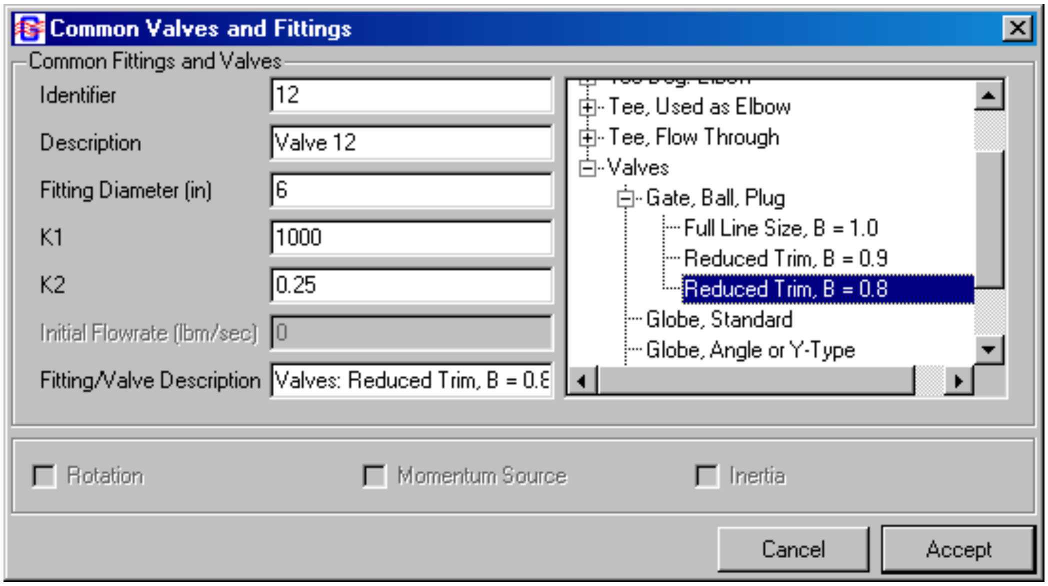


Figure 70. Fittings and valve resistance option properties dialog.

In general, the following applies to *every* resistance option. If the user wants to change the numeric identifier for a branch, simply type in the desired numeric identifier (maximum of five digits). For the unsteady case, the initial flow rate may be specified, and depending upon the selected global options, the Rotation, Momentum Source, and Inertia checkboxes may be active. Notice, in this case, that the Rotation checkbox is active and has been selected. If Rotation has been checked and Accepted, a right mouse click on the branch will present the popup menu with the Rotation/Momentum Source option active, and selecting this option will present the following dialog (fig. 71) to allow input of the relevant information.

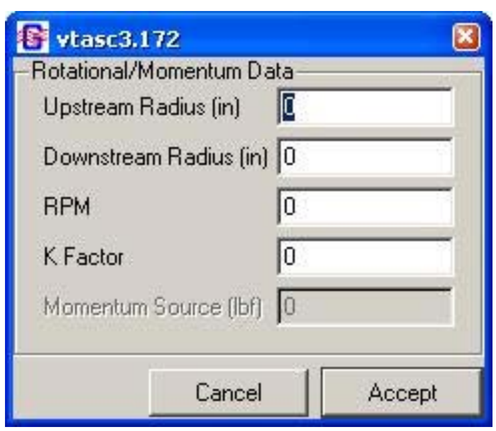


Figure 71. Rotation/Momentum dialog.

5.3.3 Conjugate Heat Transfer

The solid node , ambient node , and conductor addition tools are used to specify the conjugate heat transfer portion of a GFSSP model. These tools are inactive until the user activates Conjugate Heat Transfer by selecting it from the Advanced menu. In practice, adding solid and ambient nodes to the VTASC canvas is analogous to adding internal and boundary fluid nodes, while adding conductors is an identical process to adding fluid resistance branches.

A right mouse click on an ambient node reveals a popup menu identical to the fluid boundary node popup menu shown in figure 59(a), while the Solid Node popup menu is similar to the Fluid Internal Node popup menu shown in figure 59(b). The Properties dialog for a solid node is shown in figure 72. For a solid node, all inputs are required at each node. A list of available materials is shown at the right of the dialog. When the user left mouse clicks the desired material from the list, the GFSSP index number for that material is automatically written to the Material input box. The Ambient Node Properties dialog shown in figure 73 requires a temperature and, optionally, a history file (unsteady) as a modeling input.

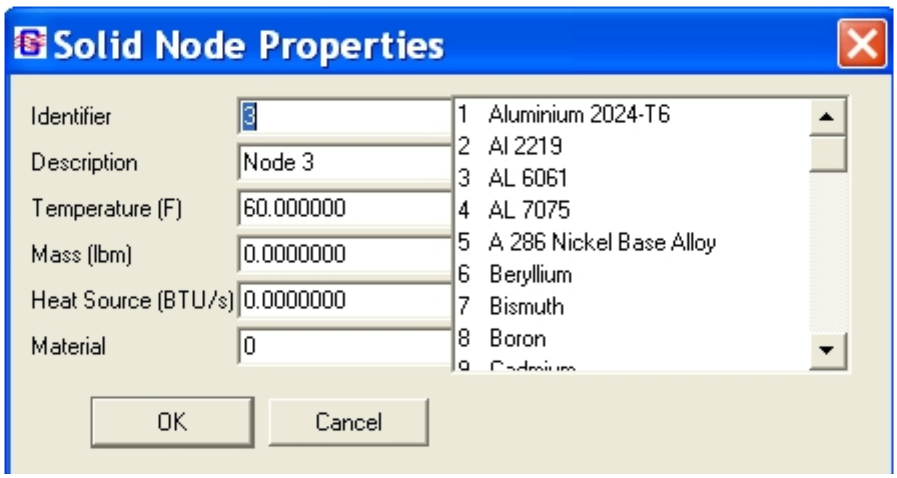


Figure 72. Solid Node Properties dialog.

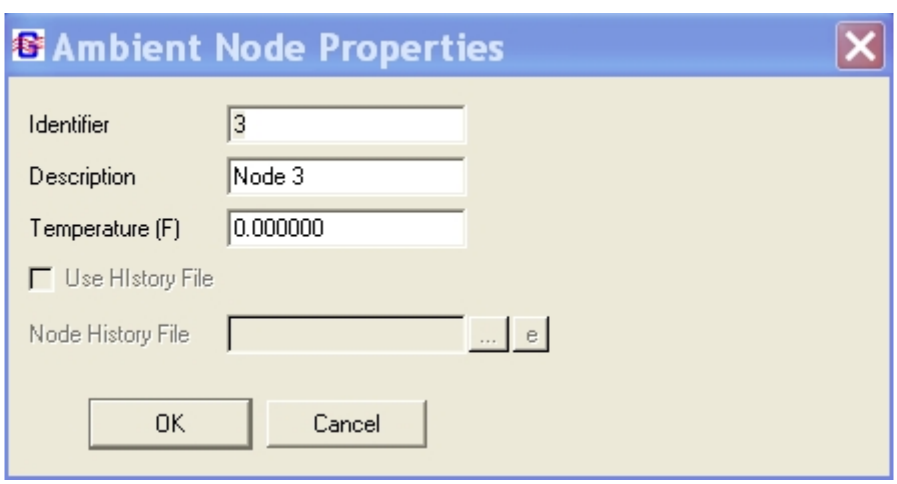


Figure 73. Ambient Node Properties dialog.

The Conductors popup menu (fig. 74) is very similar to the Fluid Branch popup menu (fig. 65). The only differences are that a Conductors option replaces the Components option; there is no need for a Rotation/Momentum option, and the Change Branch Connection option is here named the Change Conductor connection option. (The functionality is identical to the Change Branch Connection option).

Figure 74. Conductors popup menu.

When the user first adds a conductor to the canvas, VTASC indicates that the conductor type is undefined using this symbol . The user defines the type of conductor by selecting the Conductors option from the conductor popup menu. This opens the Conductors dialog shown in figure 75. The user must select the appropriate type of conductor and click the Accept button. Note that VTASC will not allow the user to select a conductor type that is inconsistent with the types of nodes attached to that particular conductor (e.g., a solid-ambient convection conductor type cannot be applied to a conductor connecting two solid nodes). As with fluid resistance branches, once the conductor type has been defined, the Properties option becomes active in the conductor popup menu. Selecting the Properties option activates a Properties dialog where the user supplies characteristics that are specific to that conductor type.

5.3.4 Import Model

VTASC provides the ability to easily combine two or more models using the Import Model function on the File menu (see fig. 47). Any two models (vts) can be combined in either order, with few exceptions/limitations. The imported model node and branch locations will be maintained. User information, solution control, and output control information will not be imported; only models with General Fluid specified will be imported; fluid conduction (inactive), fluid mass injection, momentum source, and normal stress will not be imported. Component ID conflicts will trigger a dialog giving the user an opportunity to resolve the conflict. Any inconsistencies will generate informational messages. Example 23 utilizes the file import feature.

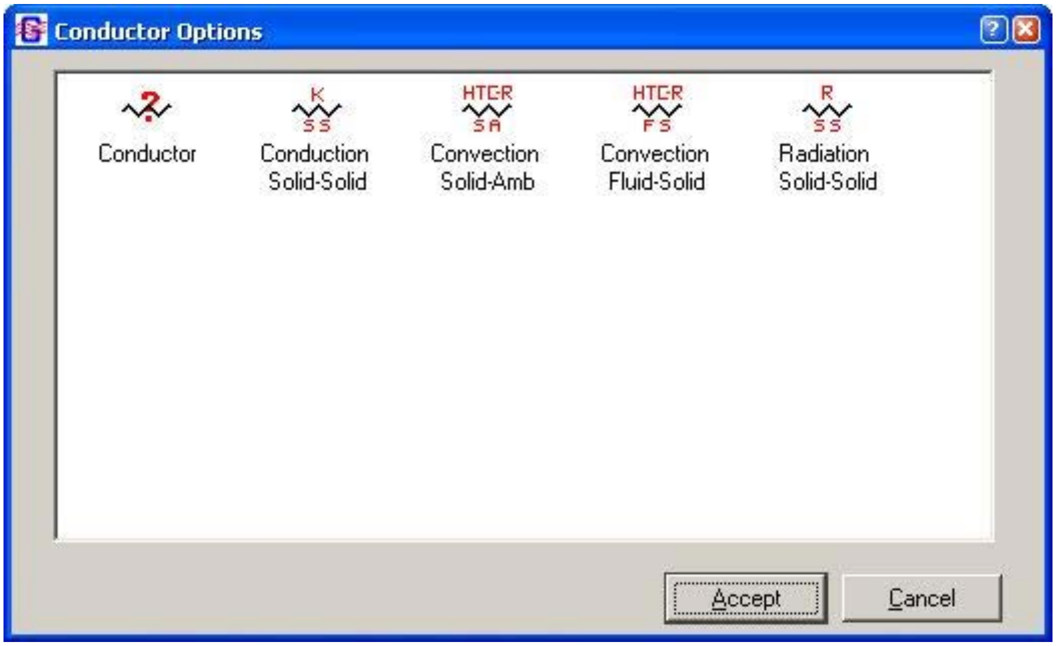


Figure 75. Conductors dialog.

5.4 Advanced Options

GFSSP contains many advanced features: Transient Heat Load, Heat Exchanger, Tank Pressurization, Turbopump, Valve Open/Close, Fluid Conduction (not active), Pressure Regulator, Flow Regulator, and Pressure Relief Valve. If any or all of the advanced features are selected (via Circuit Options or Unsteady Options), the user can input the appropriate information by selecting the option corresponding to the feature from the Advanced menu (see fig. 49).

The dialogs for each of the advanced options operate in an identical fashion. The user may add any number of components to that option by pressing the Add button. To modify the data for a particular component, the user must select the component of interest, modify the data, and press the Accept button. To delete a component, press the Delete button after a component has been selected.

5.4.1 Transient Heat

The Transient Heat Load option dialog is shown in figure 76. This option is activated from the Circuit Options pane on the Global Options menu (see sec. 5.2.3). The user provides the fluid node where the heat load is applied and the name and location of a history file containing the heat load as a function of time.

Figure 76. Transient Heat Load option dialog.

5.4.2 Heat Exchanger

The Heat Exchanger option dialog is shown in figure 77. This option is activated from the Circuit Options pane on the Global Options menu (see sec. 5.2.2). The user has the option of modeling a Counter Flow or Parallel Flow heat exchanger. The user supplies the branch numbers that will be identified as the Hot and Cold Branches as well as a value for Heat Exchanger Effectiveness. If the user enters a Heat Exchanger Effectiveness value between 0 and 1, GFSSP will perform calculations based on that effectiveness. If the user enters a value >1, this prompts GFSSP to internally calculate the effectiveness. In the latter case, the user must also supply a value of UA (the product of the overall conductance for heat transfer and the surface area on which that conductance is based).

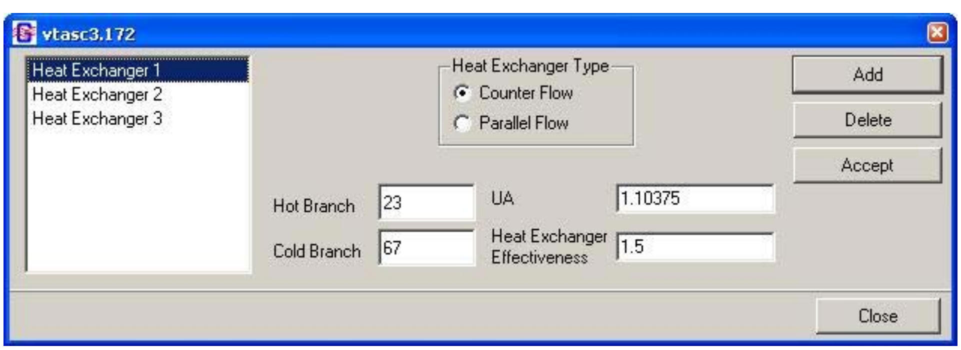


Figure 77. Heat Exchanger option dialog.

5.4.3 Tank Pressurization

The Tank Pressurization option dialog is shown in figure 78. This option is activated from the Unsteady Options pane on the Global Options menu (see sec. 5.2.4). The user has the option of modeling a vertically oriented cylindrical tank or a spherical tank. The user identifies the fluid nodes and fluid resistance branches in the model that represent the tank's ullage and propellant. The user is also asked to provide the initial surface areas where the ullage is interacting with (1) the propellant and (2) the tank wall. The user must also supply relevant tank characteristics (density, specific heat, and thermal conductivity of the tank wall material; tank wall thickness; and initial tank wall temperature). Finally, VTASC provides default values for the constants used in GFSSP's tank pressurization heat transfer calculations, but the user may modify these constants through this dialog if desired.

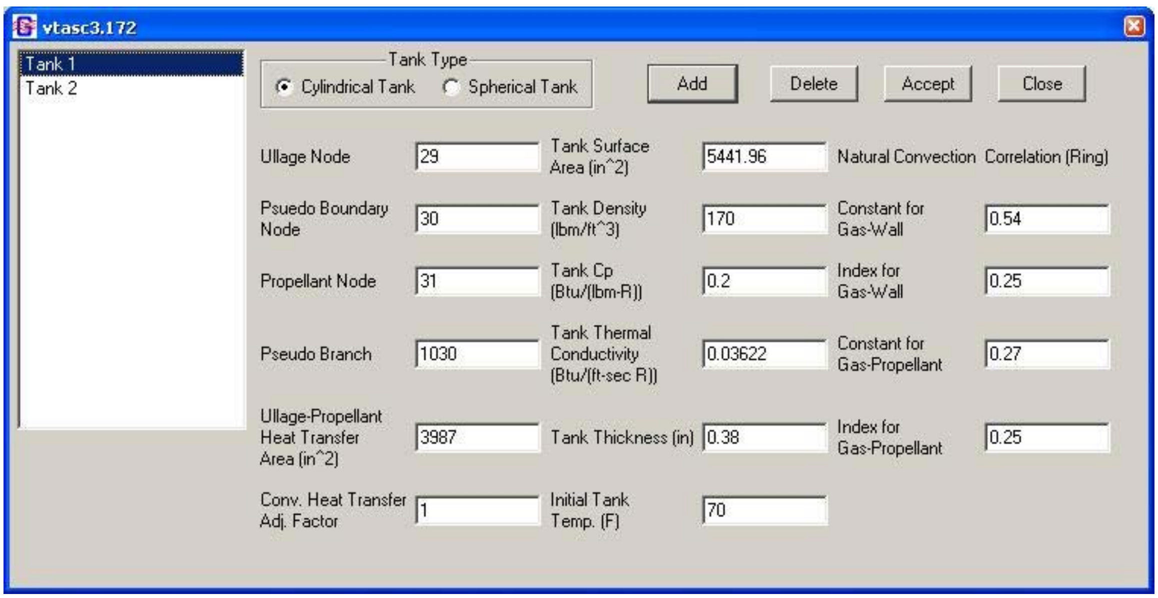


Figure 78. Tank Pressurization option dialog.

5.4.4 Turbopump

The Turbopump option dialog is shown in figure 79. This option is activated from the Circuit Options pane on the Global Options menu (see fig. 52(a)). The user supplies the fluid resistance branches that will represent the pump and the turbine. The user also supplies some characteristics of the turbine (speed, efficiency, diameter, and design point velocity ratio) as well as the name and location of a history file containing the pump characteristics (the quantities (Head/Speed^2) and (Torque/(Density*Speed^2)) as a function of (flow rate/speed).

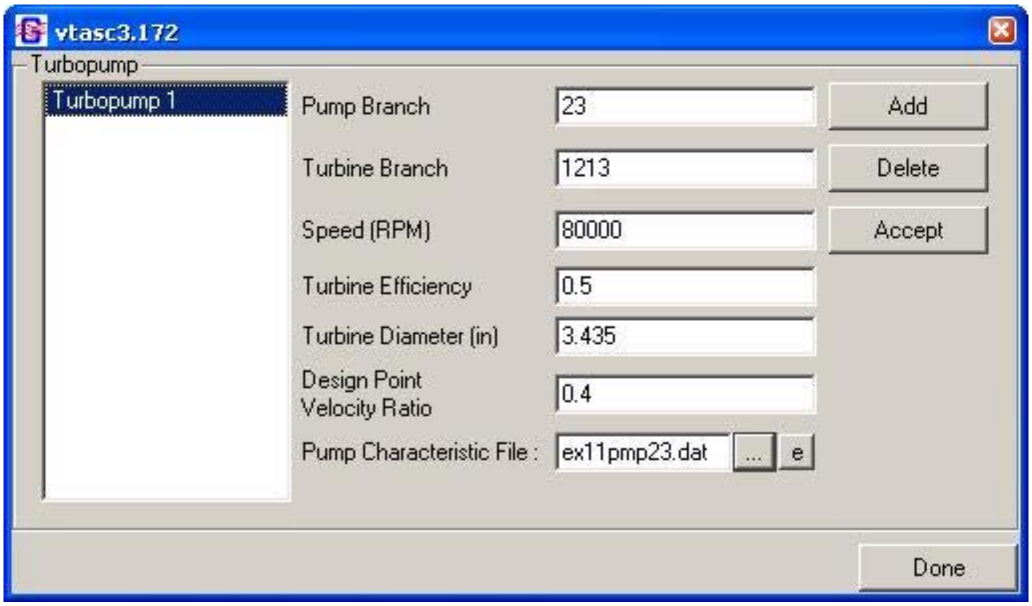


Figure 79. Turbopump option dialog.

5.4.5 Valve Open/Close

The Valve Open/Close option dialog is shown in figure 80. This option is activated from the Unsteady Options pane on the Global Options menu (see sec. 5.2.4). The user provides the fluid resistance branch that represents the valve and the name and location of a history file containing the cross-sectional flow area of the valve as a function of time.

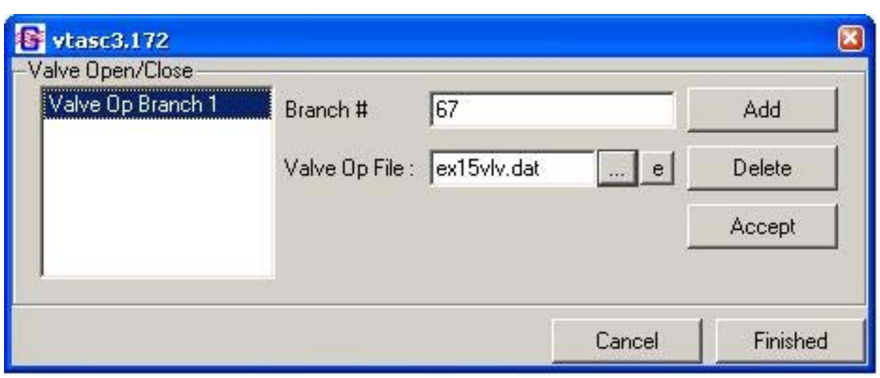


Figure 80. Valve Open/Close option dialog.

5.4.6 Fluid Conduction (Not Active)

The Fluid Conduction option dialog is shown in figure 81. This option is activated from the Circuit Options pane on the Global Options menu (see sec. 5.2.2). The user may populate the list of internal nodes in two ways. First, left mouse clicking the Load Nodes button will automatically populate the list with each internal node. Second, an individual internal node may be added to the list by typing the node identifier into the New Node input box and left mouse clicking the Add button. If the user wants to remove an internal node from the list, select that node from the list and left mouse click the Delete button. Selecting an internal node from the list reveals the list of upstream and downstream neighbors for that node. The user supplies the Area and Distance for each neighbor node by selecting that node from the Neighbor Nodes list.

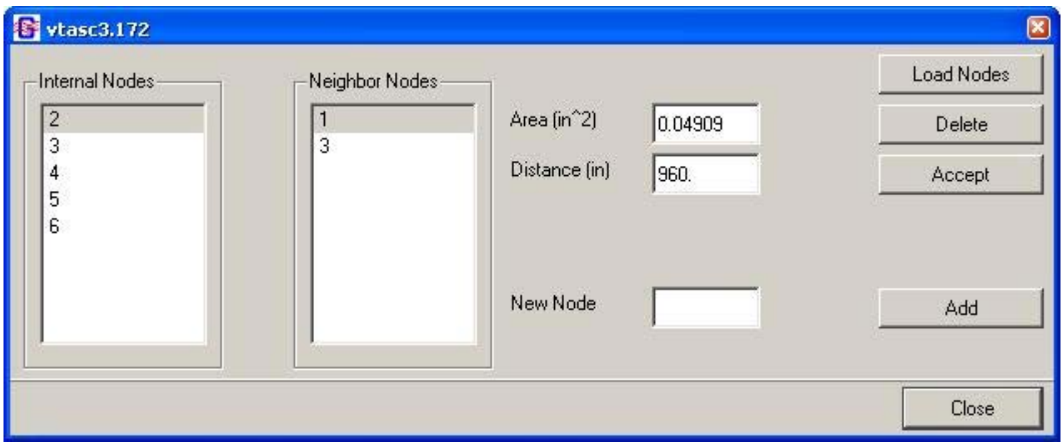


Figure 81. Fluid Conduction dialog.

5.4.7 Pressure Regulator

GFSSP offers a Pressure Regulator option to control the pressure downstream of a Restriction or Compressible Orifice branch. The Pressure Regulator option dialog is shown in figure 82. This option is activated from the Unsteady Options pane on the Global Options menu (see sec. 5.2.4). The user is given two options: Iterative algorithm (Option 1) or Forward-looking algorithm (Option 2). With the Iterative algorithm, at each time step, the regulator area is adjusted until the desired pressure is achieved, or the maximum number of iterations is reached. This option behaves like an instantly responding regulator. Note that the many iterations per time step may slow running of the model and that only one Option 1 regulator is allowed per model. With the Forward-looking algorithm, the regulator area is adjusted just once per time step, based on an empirical relation developed by reference 27. This option may run faster, but the pressure may oscillate about the setpoint for several time steps until convergence is reached. Multiple Option 2 regulators are allowed.

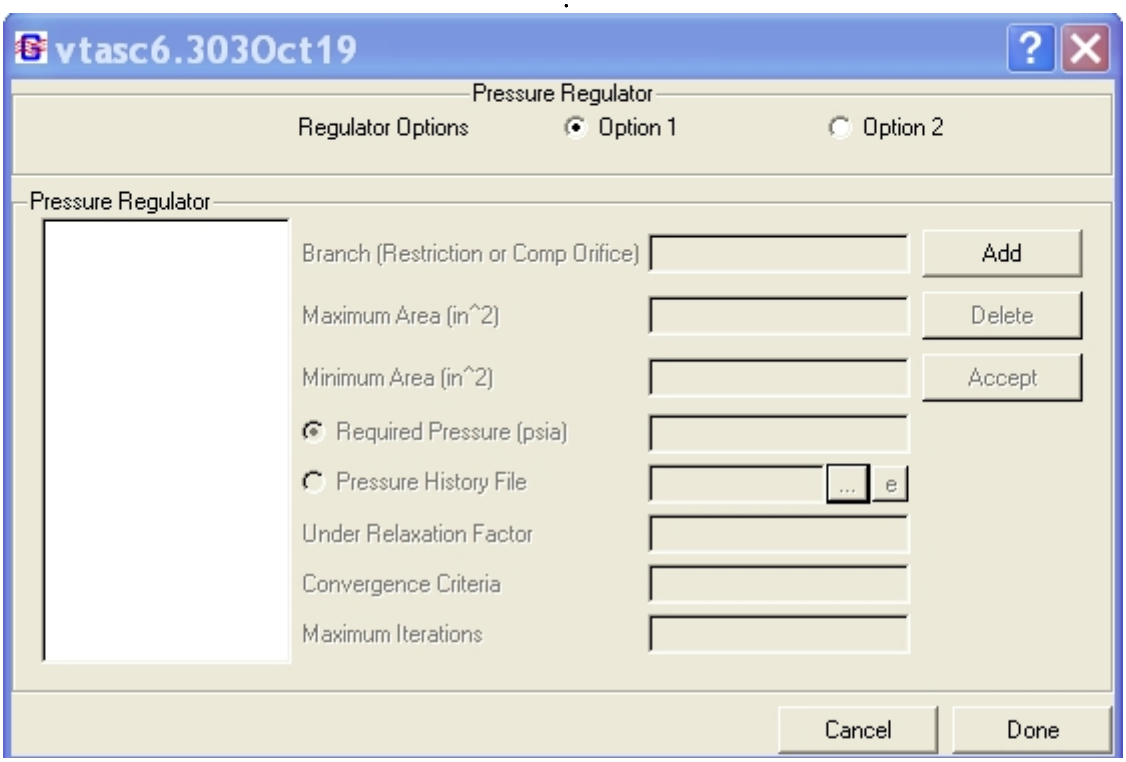


Figure 82. Pressure Regulator dialog.

The user may choose a constant required pressure, or define a pressure versus time profile in a history file. The format of the history file is:

```
NLINES
TIME1 P1
TIME2 P2
Etc….
```

NLINES is the number of TIME and P pairs in the file. TIME is given in seconds. Pressure is given in psia or kPa. The required pressure is then interpolated at each time step.

5.4.8 Flow Regulator

GFSSP offers a Flow Regulator option (fig. 83) to control the flow rate through a designated Restriction or Compressible Orifice branch. This option is activated from the Unsteady Options pane on the Global Options menu (see sec. 5.2.4).

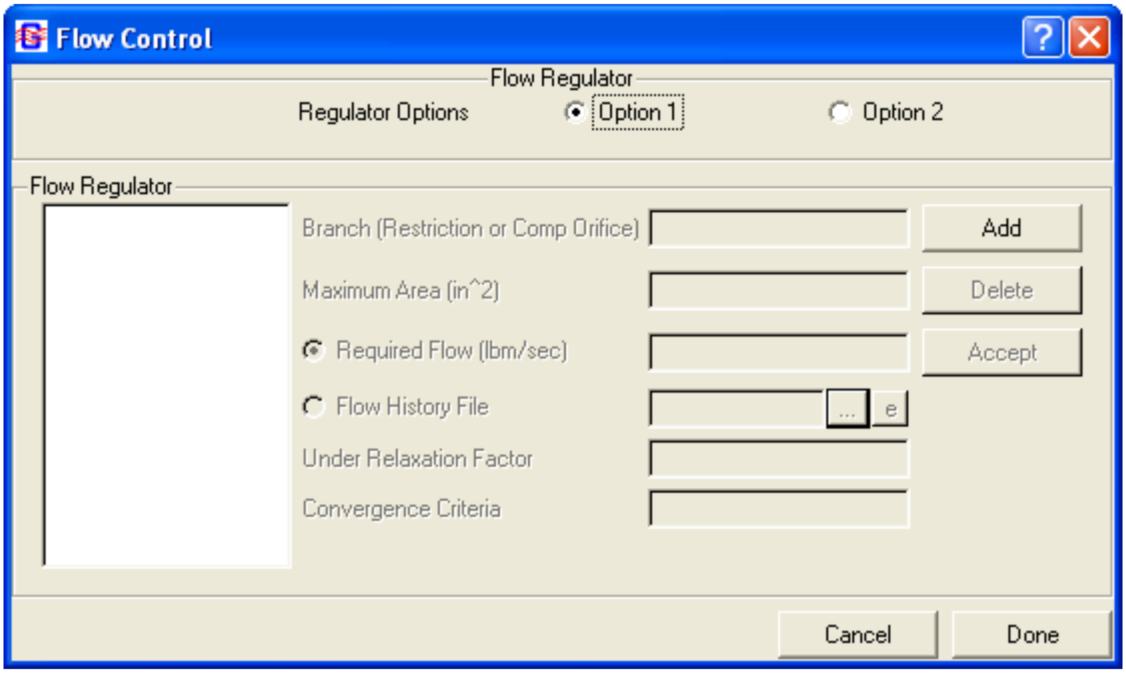


Figure 83. Flow Regulator dialog.

- Option 1—Iterative algorithm: In each time step, the regulator area is adjusted until the desired flow rate is achieved. This option acts like an instantly responding regulator. Note that the many iterations per time step may slow the model, and that only one regulator per model is allowed.

- Option 2—Marching algorithm: The regulator area is adjusted just once per time step. The area correction is based on the numerical derivative of flow rate versus area from the previous time steps. The flow rate may oscillate around the setpoint for several time steps until convergence is reached. Multiple regulators are allowed. Because other elements of the model may also affect the flow rate in the branch, the numerical derivative calculation is not exact, which may lead to improper area adjustment and an unstable model. Under-relaxation may improve the solution.

The user may choose a constant required flow rate, or one that varies with time based on a history file. The format of the history file is:

```
NLINES
TIME1 F1
TIME2 F2,
…
```

where NLINES is the number of history points, TIME is the time in seconds, and F is the desired flow rate in lb/s or kg/s.

5.4.9 Pressure Relief Valve

GFSSP allows the user to select a Restriction, Compressible Orifice, or Valve with Cv branch as a pressure relief valve. This normally closed branch will monitor the pressure differential between the upstream and downstream nodes, opening when the pressure differential exceeds a user-defined cracking pressure. The Pressure Relief Valve option dialog is shown in figure 84. This option is activated from the Unsteady Options pane on the Global Options menu (see sec. 5.2.4).

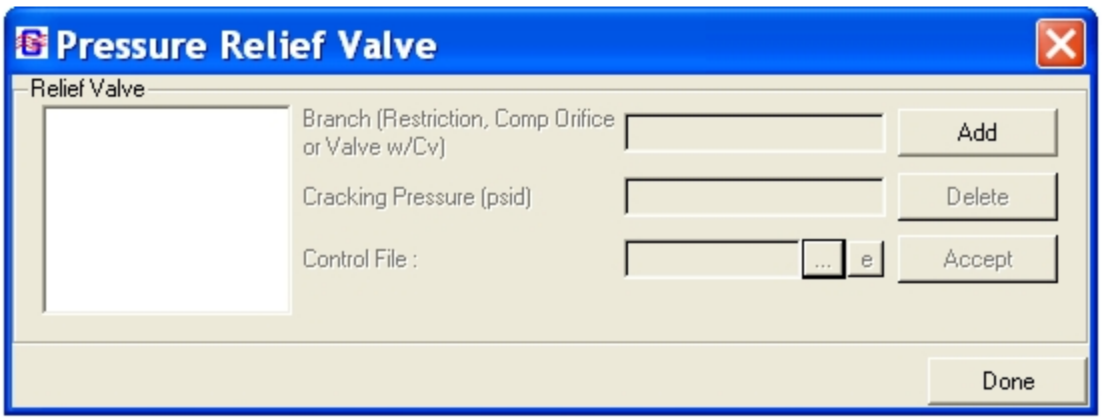


Figure 84. Pressure Relief Valve dialog.

Besides the cracking pressure (in psid or kPad), the user must supply a control file to describe the relief valve's operation. The format of the control file is:

```
NLINES
dP1 A or Cv1
dP2 A or Cv2
…
dPN A or CvN.
```

NLINES is the number of dP points in the file, and dP is the differential pressure across the valve, in psid or kPad. If using a Restriction or Compressible Orifice, A should be the area in in^2 or m^2. If using a Valve with Cv, Cv should be the value of Cv. The first pressure (dP1) is the reseating pressure, and is associated with a very small area (e.g., 1.0E-16 in^2) or small Cv (e.g. 1.0E-5).The first pressure should be less than or equal to the cracking pressure. The last point (dPN) is the pressure at which the relief valve is fully open, and is associated with the fully open area/Cv. At pressures between the reseating pressure and the fully open pressure, the area or Cv of the valve will be interpolated. At pressures greater than the last point (dPN), the fully open area/Cv value is used.

5.4.10 Grid Generation

GFSSP provides the capability to generate a two-dimensional grid using Cartesian (X,Y) or Polar (R,Z) coordinates. After this feature is enabled on the Advanced Menu, the user selects the Grid Node on the left side of the main window (fig. 46). Left-clicking on the canvas will place a Grid Node on the canvas. This node is a placeholder substituting for the actual grid to be generated. Its properties will be the parameters of the generated grid. The grid is generated by right clicking on the Grid Node and selecting Generate Grid from the menu. This will produce the Grid Property dialog (see fig. 85), which is used to generate a grid, review the grid properties, and regenerate a grid with new parameters.

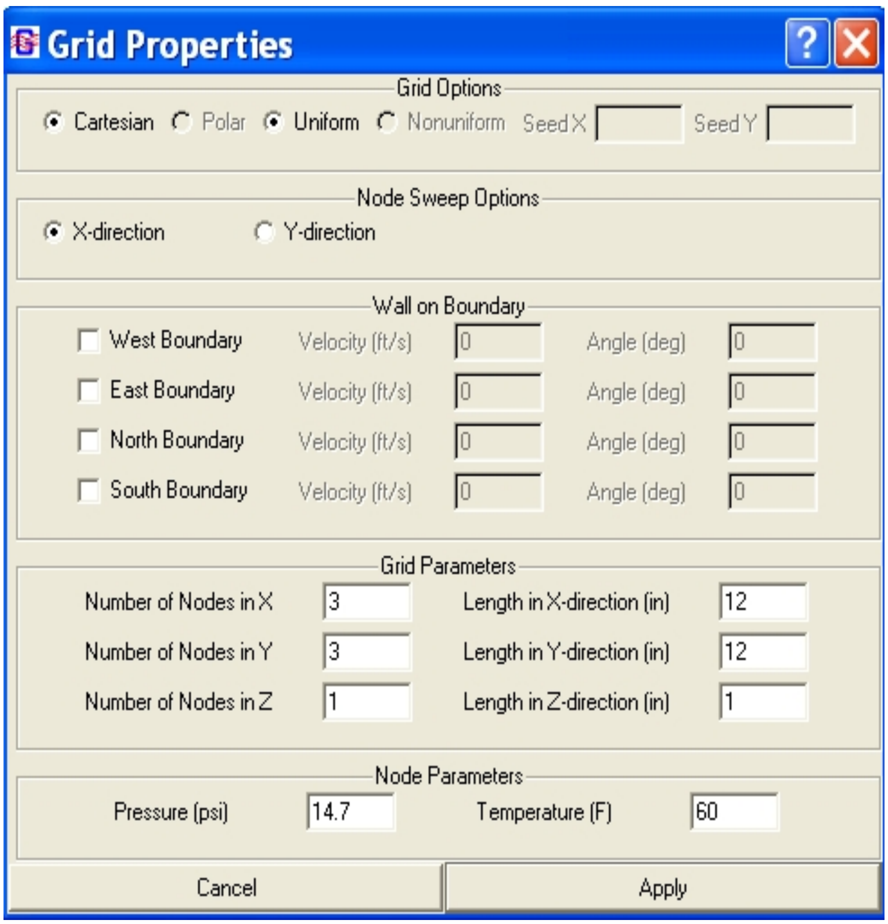


Figure 85. Grid Properties dialog.

This dialog is used to specify the parameters of the two-dimensional grid: Cartesian or Polar, Uniform or Nonuniform (requires seeds for X and Y distribution of nodes); direction of node sweep (increasing first in the X-direction or increasing first in the Y-direction); whether boundary is a wall; velocity at the boundary; angle of the wall with the coordinate direction at boundary, overall length of the cavity, and number of nodes to distribute over that length; and default Pressure and Temperature for nodes.

When the grid generation is completed a message is displayed reminding that connectivity must be established between the grid and system components. The grid is not initially displayed on the canvas. It can be shown by right-clicking on the Grid Node and selecting Select Grid (fig. 86). Node and branch properties can be reviewed, but not modified. Right-click on the canvas to hide the grid. To establish connectivity between the generated grid and the system components, connect the Grid Node with desired branch option (fig. 87). Right-click on that branch and select Resolve Grid Node Connection. This will produce the dialog shown in figure 88. Click on the desired generated node number, which will insert it into Connecting Node edit box, and click OK. The grid connecting node will have a green border when the generated grid is displayed.

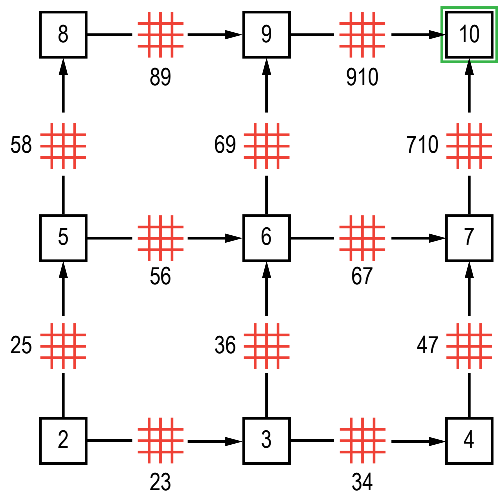


Figure 86. Generated grid (showing connecting node).

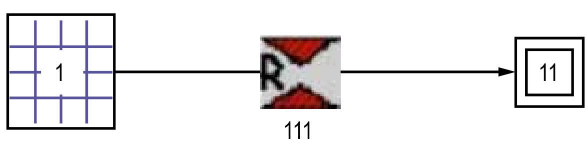


Figure 87. Circuit with grid node.

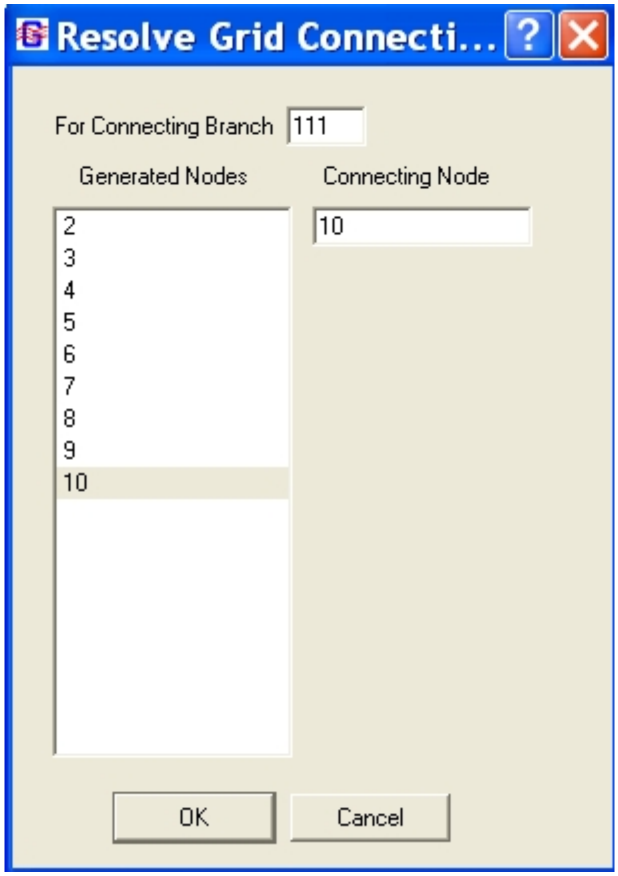


Figure 88. Resolve Grid Connectivity dialog.

To review the generated grid parameters, right click on the Grid Node and select Properties, which will display the Grid Properties dialog. The grid can then be regenerated with new parameters by entering new parameters and clicking on Regenerate Grid. This will delete the existing grid and system connectivity, and create a new grid, which will need to be reconnected to the system components.

5.4.11 International Standard Units

VTASC provides the user the option to use SI units to specify values for properties being modeled. The SI values entered are converted to English units and written to the data file to be read by GFSSP. GFSSP output will be converted into SI units for reports and plotting. For users who use the User Subroutines, conversion (SI-English) functions are available to perform the unit conver-sions. A listing of the functions is found in userrtn604.for in appendix E.

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5.5 GFSSP Input File

The primary interface between VTASC and GFSSP is the GFSSP input data file generated by VTASC. While it should not be necessary for the user to directly access the GFSSP input file for most modeling activities, knowledge of the content and format of the GFSSP input data file may be helpful in some circumstances. This section is intended to provide the user with a helpful reference for better understanding the GFSSP input data file.

5.5.1 Title Information

The GFSSP input data file always begins with the title and documentary information for the model, which are shown below. The first two entries are internally defined by VTASC. The first, the GFSSP Version, tells GFSSP what features and formatting to expect while reading the input data file. The second entry defines where the user has installed GFSSP. The user defines the remaining four entries in VTASC. They include the analyst's name, the working directory path and input data file name, output data file name, and a descriptive title for the model.

```
GFSSP VERSION
604
GFSSP INSTALLATION PATH
C:\Program Files (x86)\GFSSP604\
ANALYST
ALOK MAJUMDAR
INPUT DATA FILE NAME
D:\GFSSP604Intel\ExamplesTest\Ex1\Ex1.dat
OUTPUT FILE NAME
Ex1.out
TITLE
Simulation of a Flow System Consisting of a Pump, Valve and Pipe Line
```

5.5.2 Option Variables

The GFSSP input data file includes all of the option variable values based on the user's choices in VTASC. The user is referred to appendix D for a specific definition of each logical variable.

```
USETUP
F
DENCON         GRAVITY  ENERGY   MIXTURE  THRUST   STEADY   TRANSV   SAVER
F              T        T        F        F        T        F        F
HEX            HCOEF    REACTING INERTIA  CONDX    ADDPROP  PRINTI   ROTATION
F              F        F        F        F        F        T        F
BUOYANCY       HRATE    INVAL    MSORCE   MOVBND   TPA      VARGEO   TVM
F              T        F        F        F        F        F        F
SHEAR          PRNTIN   PRNTADD  OPVALVE  TRANSQ   CONJUG   RADIAT   Winplot
F              T        T        F        F        F        F        T
PRESS          INSUC    VARROT   CYCLIC   CHKVALS  WINFILE  DALTON   NOSTATS
F              F        F        F        F        T        F        F
NORMAL         SIMUL    SECONDL  NRSOLVT  IBDF     NOPLT    PRESREG  FLOWREG
F              T        T        F        1        T        0        0
TRANS_MOM      USERVARS PSMG     ISOLVE   PLOTADD  SIUNITS  TECPLOT  MDGEN
F              F        F        1        F        F        F        F
NUM_USER_VARS  IFR_MIX  PRINTD   SATTABL  MSORIN   PRELVLV  LAMINAR  HSTAG
1              1        F        F        F        F        T        T
```

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5.5.3 Node, Branch, and Fluid Information

This section of the GFSSP input data file defines the basic scope of the model, including: (1) the total number of nodes, (2) the number of internal nodes, (3) the number of branches, and (4) the number of fluids.

```
NNODES   NINT   NBR   NF
 4       2      3     1
```

5.5.4 Solution Control Variables

The next section of the GFSSP input data file defines the numerical parameters chosen by the user, including the three under-relaxation parameters, the convergence criteria, and the maximum number of iterations.

```
RELAXK   RELAXD   RELAXH   CC       NITER   RELAXNR   RELAXHC   RELAXTS
 1       0.5      1        0.0001   500     1         1         1
```

5.5.5 Time Control Variables

This section of the GFSSP input data file is applicable only for unsteady models. It defines the time step, initial time, final time, output file print step, and the Winplot file print step.

```
DTAU   TIMEF   TIMEL   NPSTEP   NPWSTEP   WPLSTEP   WPLBUFF
 1     0       200     25       1         50        1.1
```

5.5.6 Fluid Designation

This section of the GFSSP input data file lists the appropriate fluid definition information based on the user's selections in VTASC.

For a general fluid (GASP/WASP or GASPAK), the fluid designation lists the GFSSP index number for each selected fluid.

```
NFLUID(I),I =1,NF
 1  6  12
```

For a constant property fluid, the fluid designation lists the reference density and viscosity.

```
RHOREF   EMUREF
 62.4    0.00066
```

For an ideal gas fluid, the fluid designation lists the index number for an ideal gas and the reference properties associated with the ideal gas fluid.

```
NFLUID(I), I = 1, NF
 33
RREF     CPREF   GAMREF   EMUREF     AKREF       PREF    TREF     HREF   SREF
 53.34   0.24    1.3999   1.26e-05   4.133e-06   14.7    -459     0      0
```

For hydrogen peroxide, the fluid designation lists the index number and the mole fraction of water for the fluid.

```
NFLUID(I), I = 1, NF
34
MFRAC
0.5
```

Finally, for a user-defined fluid, the fluid designation lists the molecular weight of the fluid and the property table file names supplied by the user.

```
FLUID 1 PROPERTY FILES
28.0
AKFL1.DAT
RHOFL1.DAT
EMUFL1.DAT
GAMFL1.DAT
HFL1.DAT
SFL1.DAT
CPFL1.DAT
```

5.5.7 Node Numbering and Designation

The next section of the GFSSP input data file lists each node, designates whether that node is a boundary node (INDEX=2) or an internal node (INDEX=1), and includes a user-supplied text description of the node. Nodes are listed in the order that they are created in VTASC, which may not be in numerical order.

```
NODE    INDEX    DESCRIPTION
 1      2        «Node 1»
 2      1        «Node 2»
 3      1        "Node 3"
 4      2        "Node 4"
```

If the user has chosen to activate buoyancy, the reference node will be defined in this section right below the node listing.

```
REFERENCE NODE FOR DENSITY
 2
```

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5.5.8 Node Variables

The next section of the GFSSP input data file lists the initial properties at each node based on the user's selections in VTASC.

For a steady state model, the model boundary conditions are listed along with the internal node initial guesses. Concentrations are listed at each node in the same order the fluids are listed (see sec. 5.5.6). If the user has chosen the Constant Property Fluid option, the temperature will not appear in this listing.

```
NODE   PRES(PSI)   TEMP(DEGF)   MASS SOURC   HEAT SOURC   THRST AREA   CONCENTRATION
1      500         1500         0            0            0            0.1  0.9
2      500         80           0            0            0            1    0
3      338.2       1500         0            0            0            0.1  0.9
4      14.7        80           0            0            0            0.5  0.5
```

For an unsteady model, the internal node initial solution values are listed first in the same order they were created. These properties include the node volume property, which does not appear in a steady state model. After all of the internal nodes have been listed, each boundary node history file is listed (again, in the order they were created). Each boundary node requires a separate history file.

```
NODE  PRES(PSI)  TEMP(DEGF)  MASS SOURC  HEAT SOURC  THRST AREA  NODE-VOLUME  CONCENTRATION
1     100        80          0           0           0           17280
ex8hs2.dat
```

5.5.9 Transient Heat/Variable Geometry Information

This section of the GFSSP input data file is applicable only for unsteady models where the user has activated either the Transient Heat or Variable Geometry options.

If the user has elected to use the Variable Geometry option, the variable geometry file name will appear right below the last boundary node history file name. There is no description line associated with the variable geometry listing in the input data file.

The transient heat section of the GFSSP input data file first lists the number of nodes identified by the user as having a transient heat load. Each identified node is then listed along with the corresponding heat load file name in the order the user added their information in the Transient Heat dialog (see sec. 5.4.1).

```
Transient Heat Load Information
Number of Nodes with Transient Heat Loads
1
Transient Heat Node Number
2
Corresponding Heat Load History File Name
qdot.dat
```

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5.5.10 Node-Branch Connections

The next section of the GFSSP input data file identifies which branches are attached to each internal node. Each internal node (variable INODE) is listed in the same order they were created. The variable NUMBR defines how many branches are attached to that node. The array NAMEBR identifies which branches are attached to that node in the order they were created.

```
INODE    NUMBR    NAMEBR
2        2        12   23
3        2        23   34
```

5.5.11 Branch Flow Designation and Resistance Options

The next section of the GFSSP input data file describes the characteristics of each fluid branch. This section consists of two subsections. The first subsection identifies the upstream node, downstream node, and branch resistance option chosen by the user. This subsection also includes any text description of that branch supplied by the user.

```
BRANCH   UPNODE   DNNODE   OPTION   DESCRIPTION
12       1        2        14       "Pump 12"
23       2        3        13       "Valve 23"
34       3        4        1        "Pipe 34"
```

The second subsection lists the properties of each fluid branch as defined by the user. The branch properties are specific to each branch resistance option. They are discussed in detail in section 3.1.7.

```
BRANCH   OPTION-14   PUMP CONST1   PUMP CONST2   PUMP CONST3    AREA
12                   30888         0             -0.0008067     201.06
BRANCH   OPTION-13   DIA           K1            K2             AREA
23                   6             1000          0.1            28.274
BRANCH   OPTION -1   LENGTH        DIA           EPSD           ANGLE     AREA
34                   18000         6             0.005          95.74     28.274
```

5.5.12 Unsteady Information

The 12th section of the GFSSP input data file is applicable only for unsteady models. This section defines the initial mass flow rates in each fluid branch in the order the branches were created.

```
INITIAL FLOW RATES IN BRANCHES FOR UNSTEADY FLOW
1001    0.803
1002    0.803
1003    0.423
1004    0.423
```

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5.5.13 Inertia Information

This section of the GFSSP input data file is applicable only for models where the user has activated the Inertia option. This section is divided into four subsections. The first subsection defines a fluid branch's relationship with any upstream branches. Branches are listed in the order they were created. The variable NOUBR defines the number of upstream branches connected to a particular branch. The array NMUBR identifies which branches are attached upstream of that branch in the order they were created. The second subsection defines a fluid branch's relationship with any downstream branches. Each branch is listed in the order they were created. The variable NODBR defines the number of downstream branches connected to a particular branch. The array NMDBR identifies which branches are attached downstream of that branch in the order they were created.

```
BRANCH    NOUBR    NMUBR
12        0
23        1        12
34        1        23
BRANCH    NODBR    NMDBR
12        1        23
23        1        34
```

The third subsection allows the user to define relative angles between branches if desired. As discussed in section 5.2.2, the user must edit this section of the input data file manually. VTASC supplies a template for each branch in the order they were created. The template lists each upstream branch and corresponding angle first, then each downstream branch and corresponding angle. VTASC defines each angle as a placeholder value of zero degrees, which the user must replace with the appropriate angles.

```
BRANCH
12
 UPSTRM BR.     ANGLE
 DNSTRM BR.     ANGLE
 23             0.00000
BRANCH
23
 UPSTRM BR.     ANGLE
 12             0.00000
 DNSTRM BR.     ANGLE
 34             0.00000
```

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The fourth subsection identifies the fluid branches where the user has activated Inertia. The first number (16 in the example below) defines the number of branches where the user has activated Inertia. The subsequent lines list each branch where the user has activated Inertia in the order they were created.

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

5.5.14 Fluid Conduction Information (Not Active)

This section of the GFSSP input data file is applicable only for models where the user has activated the Fluid Conduction option. This section is divided into two subsections. The first subsection identifies how many fluid conduction nodes the user has selected. For each of these fluid nodes, the number of upstream and downstream nodes connected to that node (identified here as neighbors) is defined and each neighbor node is listed.

```
NUMBER OF FLUID CONDUCTION NODES
2
NODE   NO. OF NEIGHBORS   NEIGHBOR NODES
2      2                  1  3
3      2                  2  4
```

The second subsection defines the fluid conduction properties (area and internode distance) for the interaction between a particular node and each of its neighbors. For each node, the property of interest between that node and each neighbor is listed in the order the neighbor nodes are listed in the first subsection.

```
NODE    CONDUCTION AREAS
 2      0.04909  0.04909
 3      0.04909  0.04909
NODE    INTERNODE DISTANCES
 2      960  960
 3      960  960
```

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5.5.15 Rotation Information

This section of the GFSSP input data file is applicable only for models where the user has activated the Rotation option. This section first defines the number of branches where the user has activated Rotation. Then, each branch is identified along with the rotational information for that branch (upstream and downstream node radii from center of rotation, rotational speed, and the rotational 'slip' factor).

```
NUMBER OF ROTATING BRANCHES
9
BRANCH   UPST RAD    DNST RAD    RPM    K ROT
23       1.25        2.25        5000   0.8671
34       2.25        3.625       5000   0.8158
45       3.625       4.6875      5000   0.763
56       4.6875      5.375       5000   0.7252
67       5.375       5.5         5000   0.7076
89       5.5         5.375       5000   0.7129
910      5.375       4.6875      5000   0.7349
1011     4.6875      3.625       5000   0.7824
1112     3.625       2.65        5000   0.8376
```

5.5.16 Valve Open/Close Information

This section of the GFSSP input data file is applicable only for models where the user has activated the Valve Open/Close option. This section first defines the number of fluid branches where the user will be modeling a valve transient. Next, for each valve, the branch that will represent the valve and the valve history file name are listed.

```
NUMBER OF CLOSING/OPENING VALVES IN THE CIRCUIT
1
BRANCH
67
FILE NAME
ex15vlv.dat
```

5.5.17 Momentum Source Information

This section of the GFSSP input data file is applicable only for models where the user has activated the Momentum Source option. This section first defines the number of fluid branches where the user wishes to add a momentum source. Next, each branch where the user has defined a momentum source is listed along with the momentum source.

```
NUMBER OF BRANCHES WITH MOMENTUM SOURCE
1
BRANCH   MOMENTUM SOURCE
12       100
```

5.5.18 Heat Exchanger Information

This section of the GFSSP input data file is applicable only for models where the user has activated the Heat Exchanger option. First, the number of heat exchangers identified by the user is defined. Then, the characteristics of each heat exchanger are listed as defined by the user, including the 'hot' and 'cold' branches, the type of heat exchanger (Counter Flow=1, Parallel Flow=2), the hot and cold surface areas, UA, and the heat exchanger effectiveness. Note that the hot and cold surface areas are not currently recommended for use in GFSSP and cannot be modified using VTASC.

```
NUMBER OF HEAT EXCHANGERS
1
IBRHOT   IBRCLD   ITYPHX   ARHOT   ARCOLD   UA       HEXEFF
23       67       1        0       0        1.1038   1.5
```

5.5.19 Moving Boundary Information

This section of the GFSSP input data file is applicable only for models where the user has activated the Moving Boundary option. This section defines the number of nodes identified as having moving boundary, and lists each identified node.

```
NUMBER OF NODES WITH MOVING BOUNDARY
2
NODE
1
2
```

5.5.20 Turbopump Information

This section of the GFSSP input data file is applicable only for models where the user has activated the Turbopump option. First, the number of turbopumps in the model is listed. Then, the characteristics for each turbopump (fluid branch representing the pump, fluid branch representing the turbine, speed, turbine efficiency, turbine diameter, design point velocity ratio, and the pump characteristics curve file name) are listed.

```
NUMBER OF TURBOPUMP ASSEMBLY IN THE CIRCUIT
1
IBRPMP   IBRTRB   SPEED(RPM)   EFFTURB   DIATRB   PSITRD
23       1213     80000        0.5       3.435    0.4
PUMP CHARACTERISTICS CURVE DATA FILE
ex11pmp23.dat
```

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5.5.21 Tank Pressurization Information

This section of the GFSSP input file is applicable only for models where the user has activated the Tank Pressurization option. First, the number of pressurized propellant tanks in the model is defined. Next, the characteristics of each tank are listed including: the tank type (spherical=0, cylindrical=1); fluid node representing the ullage; ullage-propellant interface pseudo boundary node; fluid node representing the propellant; fluid branch representing the propellant surface; the initial tank wall surface area exposed to the ullage; the tank wall thickness; the tank wall material density, specific heat, and thermal conductivity; the ullage-propellant interface surface area; the heat transfer coefficient adjustment factor; the initial tank wall temperature; the heat transfer correlation ullage-propellant constants; and the heat transfer correlation ullage-tank wall constants.

```
NUMBER OF PRESSURIZATION PROPELLANT TANKS IN CIRCUIT
1
TNKTYPE   NODUL    NODULB    NODPRP    IBRPRP   TNKAR     TNKTH    TNKRHO    TNKCP
1         2        3         4         34       6431.9    0.375    170       0.2
TNKCON    ARHC     FCTHC     TNKTM     CIP      FNIP      CIW      FNIW
0.0362    4015     1         -264      0.27     0.25      0.54     0.25
```

5.5.22 Variable Rotation Information

This section of the GFSSP input file is applicable only for models where the user has activated the Variable Rotation option. The variable rotation history file name is listed in this section.

```
ROTATION DATA FILE
varrot.dat
```

5.5.23 Pressure Regulator Information

This section of the GFSSP input file is applicable only for models where the user has activated the Pressure Regulator option and specified regulator branches.

```
NUMBER OF PRESSURE REGULATOR ASSEMBLY IN THE CIRCUIT
1
PRESS REG BR   HIST FILE  MAX_AREA   PRESSURE  RELAXATION   CONVERGENCE  MAX_ITERATIONS  MIN_AREA
12             1          1.44       40        0.3          0.0001       50              1e-16
PRESSURE REGULATOR HISTORY FILE
preg_hist.dat
```

5.5.24 Flow Regulator Information

This section of the GFSSP input file is applicable only for models where the user has activated the Flow Regulator option and specified regulator branches.

```
NUMBER OF FLOW REGULATOR ASSEMBLY IN THE CIRCUIT
1
FLOW REG BR    HIST FILE    AREA    REGULATOR FLOW    RELAXATION    CONVERGENCE
12             1            0.3     0.012             1             0.001
FLOW REGULATOR HISTORY FILE
freg_hist.dat
```

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5.5.25 Phase Separation Model Information

This section of the GFSSP input file is applicable only for models where the user has activated the Phase Separation Model option and applicable nodes PSM checked.

```
NUMBER OF PHASE SEPARATION MODEL NODES
1
PHASE SEPARATION MODEL NODE LIST
4
```

5.5.26 Pressure Relief Valve Information

This section of the GFSSP input file is applicable only for models where the user has activated the Pressure Relief valve option and specified valve branches.

```
NUMBER OF PRESSURE RELIEF ASSEMBLIES IN THE CIRCUIT
 1
RELIEF VALVE BR   CRACKING PRESSURE (psid)
12                12
CORRESPONDING CONTROL FILE
ControlFile.dat
```

5.5.27 Conjugate Heat Transfer Information

This section of the GFSSP input file is applicable only for models where the user has activated Conjugate Heat Transfer. The section is divided into seven subsections.

The first subsection identifies how many solid and ambient nodes are present in the model as well as how many conductors of each type (solid-solid conduction, solid-fluid, solid-ambient, and solid-solid radiation) are present in the model.

```
NSOLID   NAMB   NSSC   NSFC   NSAC   NSSR
8        2      7      8      2      1
```

The second subsection defines the characteristics of each solid node in the order they were created. The properties of each solid node (material, mass, and initial temperature) are listed first. Then, the number of conductors of each type attached to the solid node is listed along with a text description of the solid node provided by the user. Finally, for each type of conductor, every conductor attached to that solid node is listed.

```
NODESL   MATRL   SMASS     TS         NUMSS    NUMSF    NUMSA    NUMSSR    DESCRIPTION
2        41      1.00000   70.00000   1        1        1        1         "S Node 2"
NAMESS
23
NAMESF
122
NAMESA
12
NAMESSR
24
```

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The third subsection lists each ambient node in the order they were created and lists the temperature at that node along with a text description of the ambient node provided by the user.

```
NODEAM    TAMB        DESCRIPTION
1         32.00000    "A Node 1"
```

The fourth subsection lists each solid-solid conduction conductor along with its characteristics ('upstream' solid node, 'downstream' solid node, surface area, distance and a user-supplied text description) in the order they were created.

```
ICONSS    ICNSI    ICNSJ    RCSIJ     DISTSIJ    DESCRIPTION
23        2        3        3.1415    3.00000    "Conductor 23"
```

The fifth subsection lists each solid-fluid conductor along with its characteristics including solid node; fluid node; heat transfer coefficient model (User Supplied=0, Dittus-Boelter=1, and Miropolskii=2); surface area, user-supplied heat transfer coefficient (if Model=0); emissivity of the solid; emissivity of the fluid; and user-supplied text description.

```
ICONSF  ICS  ICF  MODEL  ARSF         HCSF         EMSFS        EMSFF        DESCRIPTION
122     2    12   0      1.88500e+01  3.17000e-04  0.00000e+00  0.00000e+00  «Convection 122»
```

The sixth subsection lists each solid-ambient conductor along with it characteristics (solid node, ambient node, surface area, heat transfer coefficient, emissivity of the solid, emissivity of the ambient, and a user-supplied text description).

```
ICONSA   ICSAS   ICSAA   ARSA          HCSA          EMSAS         EMSAA         DESCRIPTION
12       2       1       3.14159e+00   2.00000e-02   0.00000e+00   0.00000e+00   «Convection 12»
```

The seventh subsection lists each solid-solid radiation conductor along with its characteristics ('upstream' solid node, 'downstream' solid node, 'upstream' surface area, 'downstream' surface area, view factor, 'upstream' emissivity, 'downstream' emissivity, and a user-supplied text description).

```
ICONSSR  ICNSRI  ICNSRJ  ARRSI    ARRSJ    VFSIJ    EMSSI    EMSSJ    DESCRIPTION
24       2       3       3.14159  3.14159  1.00000  0.70000  0.70000  «Conductor 24»
```

5.5.28 Restart Information

This section of the GFSSP input file is applicable only for models where the user has elected to Read From and/or Write to Restart Files. The section lists the node and branch restart file names.

```
RESTART NODE INFORMATION FILE
FNDEX15.DAT
RESTART BRANCH INFORMATION FILE
FBREX15.DAT
```

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5.5.29 Cyclic Boundary Information

This section of the GFSSP input file is applicable only for models where the user has activated the Cyclic Boundary option. The section lists the boundary node where the Cyclic Boundary option has been activated and the node that is upstream of the cyclic boundary node.

```
CYCLIC    BNDARY NODE    UPSTREAM NODE
1         22
```

5.6 User Executable

Advanced users may wish to take advantage of the User Subroutines to model physics not directly available in VTASC. In order to do this, the user will need access to a FORTRAN compiler so that a specialized GFSSP executable may be created. If the user has the Compaq Visual FORTRAN compiler or Intel FORTRAN compiler installed on their computer, they can create a user executable through the Build dialog (activated from the Module menu).

Figure 89 shows the Build dialog. The user supplies the User Subroutine file name and location (if other than the model's working directory). The user may browse to find the appropriate User Subroutine file and can edit the file using the buttons at the right of the User Module File text box. VTASC will automatically identify the default GFSSP, GASPAK, and GASP Object File names and locations based on the user's GFSSP installation directory. If for some reason, the user wishes to use some other object file versions, they may browse to the desired object file locations using the buttons at the right of each text box. When the user clicks the Build button, VTASC uses the Compaq Visual FORTRAN or Intel compiler to create a specialized user executable. The interaction between VTASC and the compiler is shown to the user with the display pane on the Build dialog. Any compilation errors or warnings will appear on the display pane. If the user wishes to stop the build process for any reason, clicking the Stop button will cancel the build session. If the build is successful, a specialized GFSSP executable named after the User Subroutine is created and saved to the model's working directory. Also, the user executable filename is automatically saved as the GFSSP executable filename on the User Information tab of the General Information item of the Options menu (see sec. 5.2.1). The Close button will exit the Build dialog and return the user to the VTASC window.

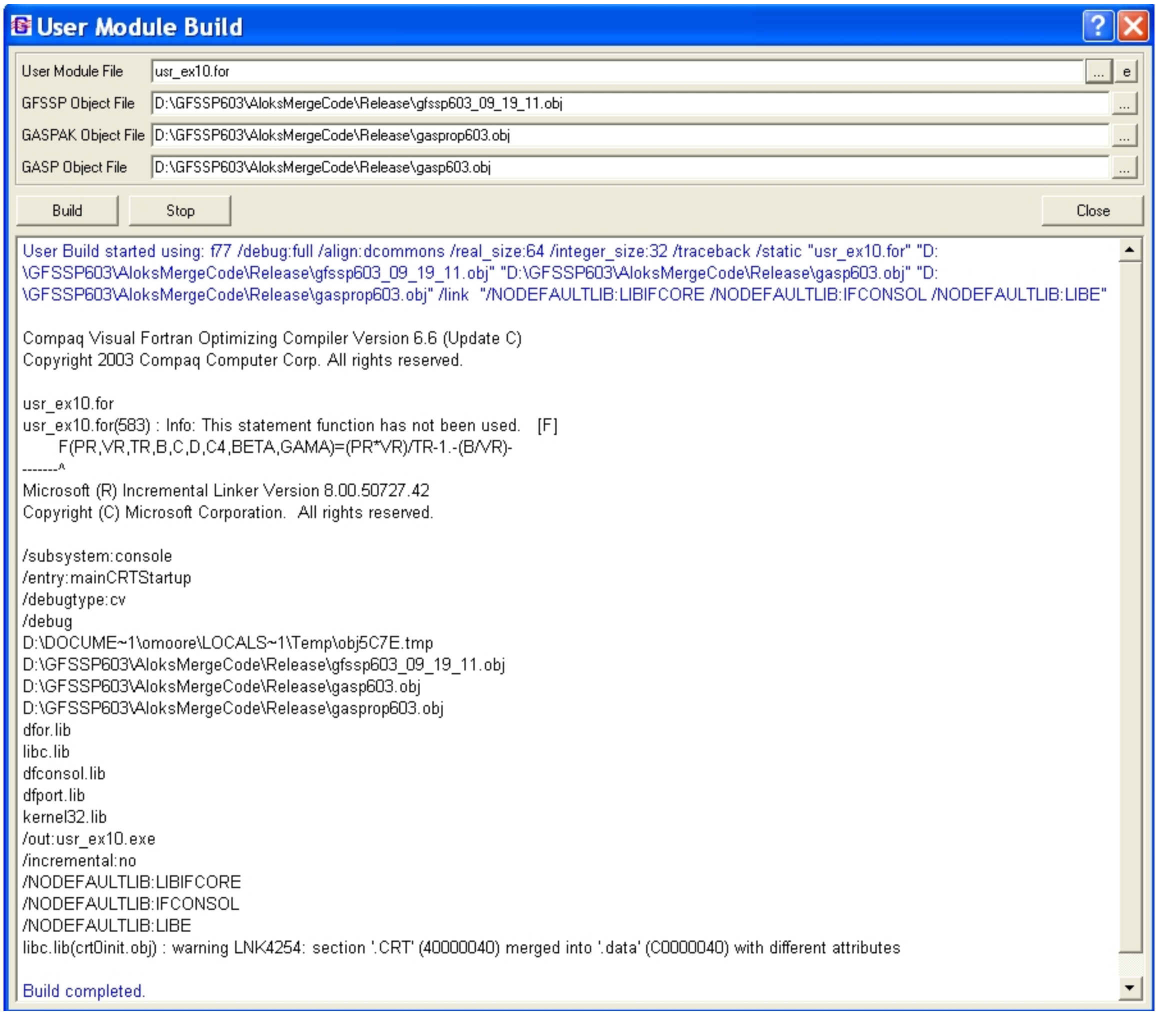

Figure 89. User Executable Build dialog.

5.7 GFSSP Execution

As noted in section 5.1.4, GFSSP can be executed directly from the VTASC environment using either the Run menu or the shortcut on the file Input/Output toolbar. When the user activates the Run GFSSP command, VTASC automatically writes the GFSSP text input file before executing GFSSP. If the text file already exists, VTASC will ask if the user wishes to overwrite the file. VTASC then executes GFSSP and opens the GFSSP Run Manager window. The appearance and function of the Run Manager depends on whether the model is a steady state or transient model.

5.7.1 Steady State Run Manager

Figure 90 shows the GFSSP Run Manager appearance for a steady state simulation. If the user wishes to stop the GFSSP simulation for any reason, the button in the upper left corner of the Run Manager will stop GFSSP execution. During execution, the Run Manager will display GFSSP-generated messages in the GFSSP display pane. After execution is complete, the GFSSP messages may be printed by clicking the Print button in the lower right corner of the Run Manager. The GFSSP-generated text output file may also be viewed after execution is complete by clicking the Edit Output button in the lower left corner of the Run Manager. Clicking the Close button will exit the Run Manager and return the user to the VTASC window.

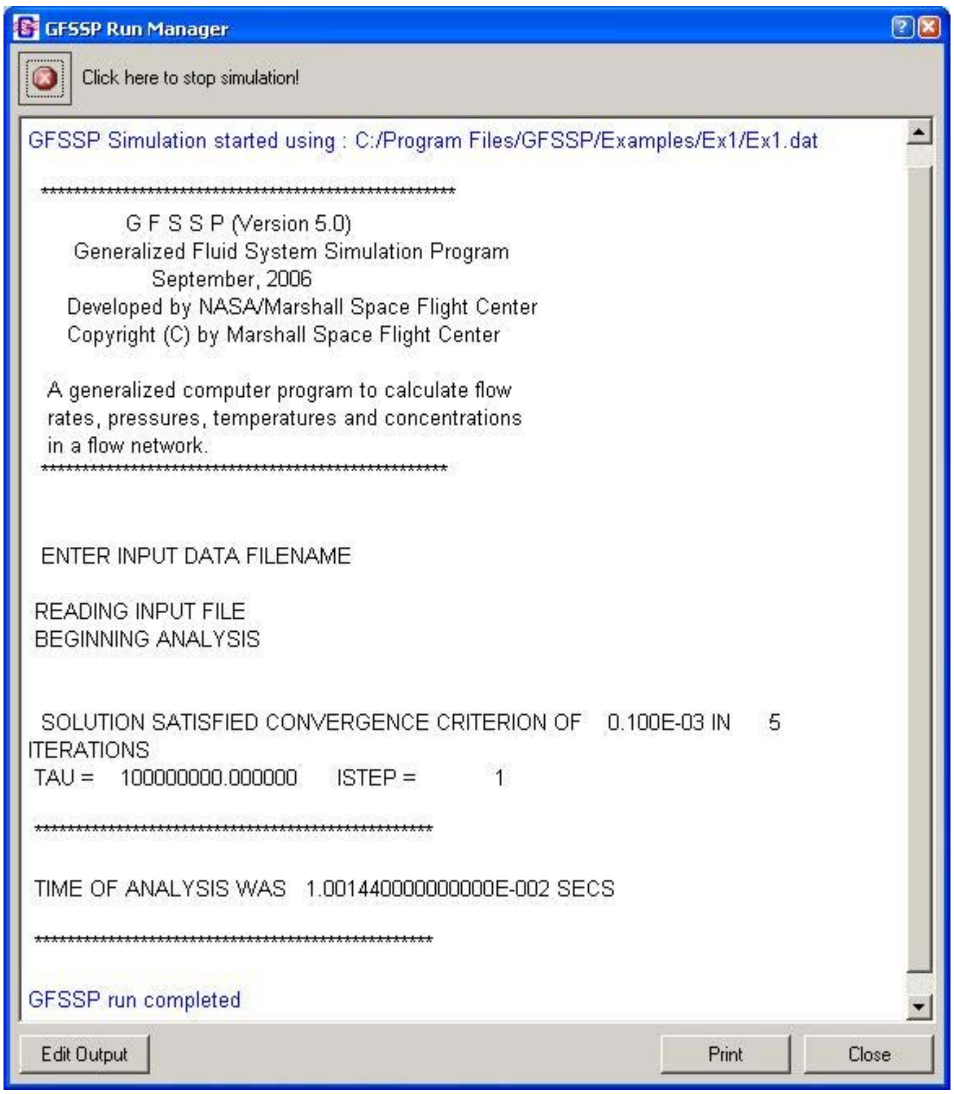

Figure 90. GFSSP Run Manager—steady state simulation.

5.7.2 Unsteady Run Manager

Figure 91 shows the GFSSP Run Manager appearance for an unsteady simulation. The only difference between the unsteady and steady Run Managers is that the GFSSP display pane appears in the top half of the Run Manager and a real-time updated plot of GFSSP's convergence behavior as a function of time appears in the bottom half of the Run Manager. See General Information, Output Control tab to stop receiving this convergence data.

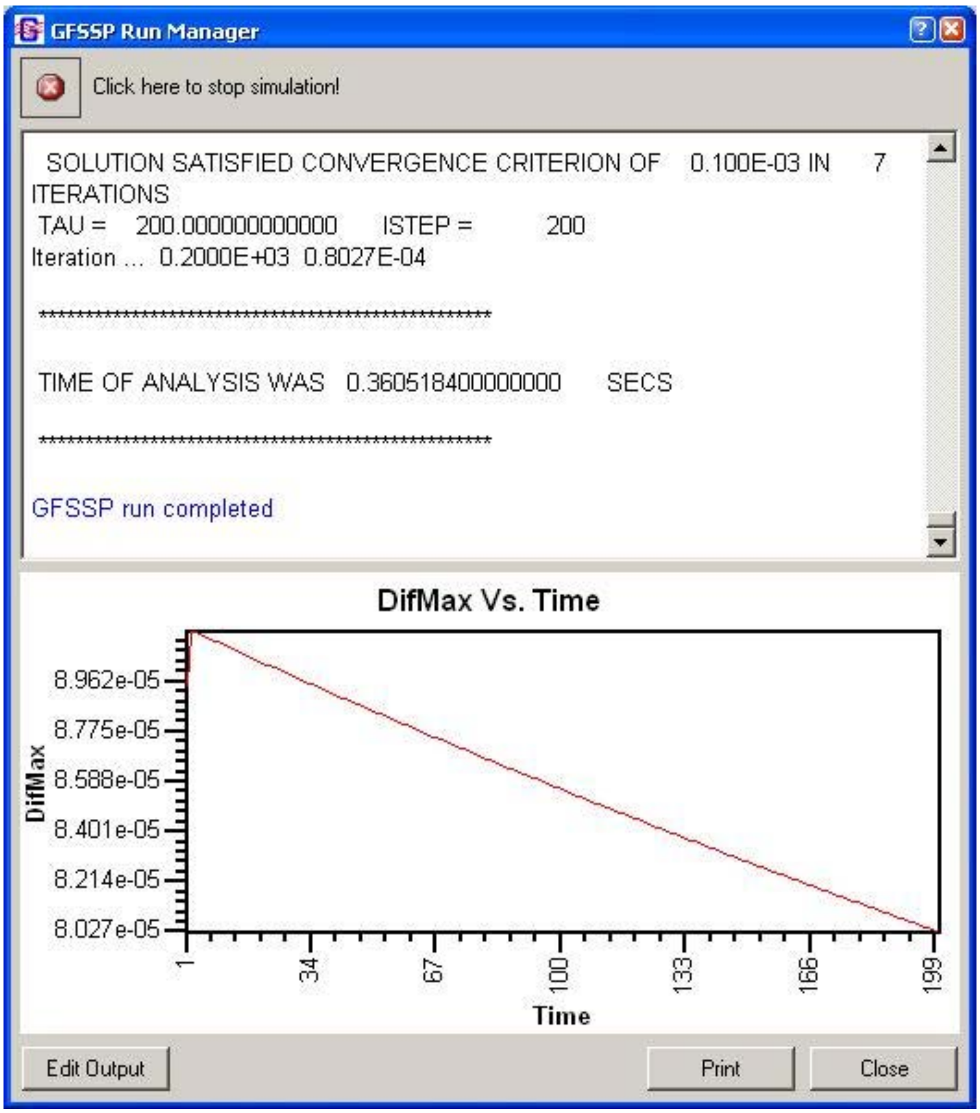

Figure 91. GFSSP Run Manager—unsteady simulation.

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5.8 GFSSP Output File

The basic GFSSP output for any simulation is the text output file. As mentioned in the previous section, once a simulation is complete the Run Manager gives the user the option of viewing the output file in a text editor. The content of the output file is dependent on the options selected by the user during VTASC model development. This section is intended to give the user an understanding of the format and general layout of the text output file.

5.8.1 Title and Data Files

Each GFSSP output file begins with the header shown below, which identifies the version of GFSSP that was used for the model simulation.

```
***************************************************
              G F S S P (Version 603)
    Generalized Fluid System Simulation Program
                   October 2011
             Built with Compaq Compiler
      To be used with VTASC 6.3, Build 603.201

   Developed by NASA/Marshall Space Flight Center
    Copyright (C) by Marshall Space Flight Center

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

Directly below the GFSSP header, the run date, the model title, analyst name, model working directory and text input file name, and text output file name as defined by the user are supplied.

```
                              RUN DATE:10/11/2011 16:22

TITLE   :Simulation of a Flow System Consisting of a Pump, Valve and Pipe Line
ANALYST:ALOK MAJUMDAR
FILEIN  :C:\Program Files\GFSSP603\Examples\Ex1\Ex1.dat
FILEOUT:Ex1.out
```

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5.8.2 Logical Variables

This section of the GFSSP output file lists the logical variable definitions as used in the simulation.

```
                                  OPTION VARIABLES

ADDPROP    BUOYANCY  CONDX    CONJUG    CYCLIC    DALTON     DENCON     ENERGY
F          F         F        F         F         F          F          T
FLOWREG    GRAVITY   HCOEF    HEX       HRATE     IFRMIX     INERTIA    INSUC
F          F         F        F         T         1          F          F
INVAL      MIXTURE   MOVBND   MSORCE    NORMAL    NRSOLVT    OPVALVE    PLOTADD
F          F         T        F         F         F          F          F
PRESREG    PRESS     PRINTI   PRNTADD   PRNTIN    RADIATION  REACTING   ROTATION
0          F         F        T         F         F          F          F
SAVER      SECONDL   SHEAR    SIMULA    SIUNITS   STEADY     THRUST     TPA
F          T         F        T         F         F          F          F
TRANS_MOM  TRANSQ    TRANSV   TVM       TWOD      USRVAR     VARGEO     VARROT
F          F         T        F         F         F          T          F
```

5.8.3 Node and Branch Information

This section of the output file documents the size and scope of the model. It lists the total number of nodes as well as the number of internal nodes, the number of branches, the number of fluids, the number of variables (or equations) in the model (this is the sum of NBR and NINT), and finally the enthalpy reference node, which is hard-coded in GFSSP as the second node.

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

5.8.4 Fluid Information

This section of the output file documents the fluids that were used in the simulation.

For a constant property fluid, the fluid information lists the reference density and viscosity.

```
RHOREF = 62.4000 LBM/FT**3
EMUREF = 0.6600E-03 LBM/FT-SEC
```

For all other fluid options, the fluid information lists each fluid in the order they were entered by the user as shown below.

```
FLUIDS: O2  H2O
```

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5.8.5 Boundary Conditions

This section of the output file documents the boundary conditions of the model, which were supplied at each boundary node by the user. For a model with multiple fluids, the pressure, temperature, density, thrust surface area of the node, and concentration of each fluid at that node are listed. A single fluid model provides the same listing with the exception of the fluid concentrations. A constant property fluid model lists only the pressure and surface area.

```
BOUNDARY NODES
NODE     P            T            RHO          AREA         CONCENTRATIONS
         (PSI)        (F)          (LBM/FT^3)   (IN^2)       O2           H2O
1        0.5000E+03   0.1500E+04   0.3931E+00   0.0000E+00   0.1000E+00   0.9000E+00
2        0.5000E+03   0.8000E+02   0.2819E+01   0.0000E+00   0.1000E+01   0.0000E+00
4        0.1470E+02   0.8000E+02   0.4725E+02   0.0000E+00   0.5000E+00   0.5000E+00
```

5.8.6 Fluid Network Information

This section of the output file is only active if the user has selected to print network information from the Global Options dialog (see sec. 5.2.1). For each internal node, the thrust surface area, mass source, and heat source designated by the user are listed. For each branch, the branch flow designation and resistance option information from the input text file (see sec. 5.5.11) are reprinted.

```
INPUT SPECIFICATIONS FOR INTERNAL NODES
NODE     AREA         MASS         HEAT
         (IN^2)       (LBM/S)      (BTU/S)
2        0.0000E+00   0.0000E+00   0.0000E+00
3        0.0000E+00   0.0000E+00   0.0000E+00
BRANCH    UPNODE   DNNODE   OPTION
12         1        2        14
23         2        3        13
34         3        4        1
BRANCH OPTION -14   PUMP CONST1   PUMP CONST2   PUMP CONST3   AREA
12                  0.309E+05     0.000E+00     -0.807E-03    0.201E+03
BRANCH OPTION -13   DI            K1            K2            AREA
23                  0.600E+01     0.100E+04     0.100E+00     0.283E+02
BRANCH OPTION -1    LENGTH        DIA           EPSD          ANGLE        AREA
34                  0.180E+05     0.600E+01     0.500E-02     0.957E+02    0.283E+02
```

5.8.7 Initial Field Information

This section of the output file is only active if the user has selected to Print the Initial Field from the Global Options dialog (see sec. 5.2.1).

For each internal node of a single fluid model, the initial guesses for pressure and temperature as well as the resulting compressibility, density, and quality from the thermodynamic property calculations are listed. For a multiple fluid model, the list is the same except that the quality is replaced with the initial guesses for the mass concentration of each fluid. For a constant property fluid model, only the initial guess for pressure is listed.

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```
INITIALGUESS FOR INTERNAL NODES
NODE     P(PSI)       TF(F)        Z(COMP)      RHO          QUALITY
                                                (LBM/FT^3)
2        0.1470E+02   0.6000E+02   0.7616E-03   0.6237E+02   0.0000E+00
3        0.1470E+02   0.6000E+02   0.7616E-03   0.6237E+02   0.0000E+00
```

For each branch, the trial solution for the pressure drop across the branch and the mass flow rate in the branch is listed.

```
TRIAL SOLUTION
BRANCH   DELP(PSI)   FLOWRATE(LBM/SEC)
12       0.0000      0.0100
23       0.0000      0.0100
34       0.0000      0.0100
```

5.8.8 Conjugate Heat Transfer Network Information

This section of the output file is only active for models where the user has activated Conjugate Heat Transfer and selected to print network information from the Global Options dialog (see sec. 5.2.1). For each solid node and conductor, the conjugate heat transfer information from the input text file (see sec. 5.5.25) is reprinted.

```
CONJUGATE HEAT TRANSFER
NSOLIDX = 8
NAMB    = 2
NSSC    = 7
NSFC    = 8
NSAC    = 2
NSSR    = 0
NODESL   MATRL   SMASS    TS        NUMSS   NUMSF   NUMSA
2        41      1.0000   70.0000   1       1       1
NAMESS
23
NAMESF
122
NAMESA
12
NODEAM   TAMB
1        32.0000
10       212.0000
ICONSS   ICNSI  ICNSJ  ARCSIJ    DISTSIJ
23       2      3      3.1416    3.0000
34       3      4      3.1416    3.0000
ICONSF   ICS    ICF    ARSF      EMSFS     EMSFF
122      2      12     18.8500   0.0000    0.0000
123      3      12     18.8500   0.0000    0.0000
ICONSA   ICSAS  ICSAA  ARSA        HCSA        EMSAS       EMSAA
12       2      1      0.3142E+01  0.2000E-01  0.0000E+00  0.0000E+00
910      9      10     0.3142E+01  0.2000E-01  0.0000E+00  0.0000E+00
```

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5.8.9 Solution Results

This section of the output file documents the solution results of the GFSSP model. If the model is unsteady, a solution will be output at each time step the user has chosen to print (defined by the Print Frequency as discussed in sec. 5.2.3). The first line in the solution will list the current time step and the time at this step.

```
 ISTEP = 25      TAU = 0.25000E+02
```

Next, the unsteady model will print out the boundary conditions at each boundary node for that time step. The format is identical to that discussed in section 5.8.5.

```
BOUNDARY NODES
NODE     P(PSI)        TF(F)         Z(COMP)       RHO           QUALITY
                                                   (LBM/FT^3)
2        0.1470E+02    0.8000E+02    0.1000E+01    0.7355E-01    0.0000E+00
```

After this line, the solution will be output in the same format for a steady model or the time step of interest in an unsteady model. For each internal node in a single fluid model, the calculated pressure, temperature, compressibility, density, resident mass, and fluid quality are listed. The listing is identical for a multiple fluid model except that the quality is replaced with the calculated mass concentration of each fluid at that node. For a constant property fluid model, only the calculated pressure and resident mass are listed. Note that for a steady model, the resident mass will always be zero.

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

If the user elects to print extended information in the Global Options dialog (see sec. 5.2.1), the output file will next list the calculated enthalpy, entropy, viscosity, thermal conductivity, specific heat, and specific heat ratio for each internal node. Note that this information will not be printed for constant property fluid models.

```
NODE    H             ENTROPY       EMU           COND          CP            GAMA
        BTU/LB        BTU/LB-R      LBM/FT-SEC    BTU/FT-S-R    BTU/LB-R
2       0.2869E+02    0.5542E-01    0.7542E-03    0.9523E-04    0.1000E+01    0.1003E+01
3       0.2869E+02    0.5542E-01    0.7542E-03    0.9523E-04    0.1000E+01    0.1003E+01
```

For each branch, the calculated resistance factor, pressure drop, mass flow rate, velocity, Reynolds number, Mach number, entropy generation, and lost work are listed.

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

If the second law is used to solve the energy equation, the total entropy generation and work lost will be listed directly below the branch solution information.

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

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

If the user has activated conjugate heat transfer for a model, the conjugate heat transfer results will be listed next in the output file.

For each solid node, the specific heat that was used is listed along with the calculated solid temperature. Note that the specific heat will be zero for steady models.

```
SOLID NODES
NODESL   CPSLD        TS
         BTU/LB F     F
2        0.000E+00    0.423E+02
3        0.000E+00    0.569E+02
```

For each solid to solid conductor, the thermal conductivity that was used is listed along with the calculated heat transfer rate.

```
SOLID TO SOLID CONDUCTOR
ICONSS    CONDKIJ       QDOTSS
          BTU/S FT F    BTU/S
23        0.261E-02     -0.333E-02
34        0.261E-02     -0.279E-02
```

For each solid to fluid conductor, the calculated heat transfer rate is listed along with the convection and radiation heat transfer coefficients that were used.

```
SOLID TO FLUID CONDUCTOR
ICONSF    QDOTSF       HCSF        HCSFR
          BTU/S        BTU/S       FT**2 F
122       -0.115E-02   0.317E-03   0.000E+00
123       -0.544E-03   0.317E-03   0.000E+00
```

For each solid to ambient conductor, the calculated heat transfer rate is listed along with the convection and radiation heat transfer coefficients that were used.

```
SOLID TO AMBIENT CONDUCTOR
ICONSA     QDOTSA        HCSA            HCSAR
           BTU/S         BTU/S FT**2     F BTU/SFT**2 F
12         0.448E-02     0.200E-01       0.000E+00
910        -0.136E-01    0.200E-01       0.000E+00
```

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For each solid to solid radiation conductor, the calculated heat transfer rate is listed along with the effective conductivity that was used.

```
SOLID TO SOLID RADIATION CONDUCTOR
ICONSSR     QDOTSSR        EFCSSR
            BTU/S          BTU/S F
79          -0.113E-06     0.421E-08
```

If the user has requested that axial thrust be calculated in the Global Options dialog (see sec. 5.2.2), the calculated axial thrust will be listed next in the output file.

```
AXIAL THRUST = -527.30169 LBF
```

If the user has activated the Turbopump advanced option (see sec. 5.4.4), the turbopump output will be listed next in the output file. First, the number of turbopumps in the model is listed (note that this value is not labeled in the output file). Then, the pump branch, turbine branch, speed, the turbine efficiency at the design point, the turbine velocity ratio at the design point, the required torque, and the horsepower are listed for each turbopump in the model.

```
  1
 IBRPMP    IBRTRB    SPEED(RPM)    ETATRB       PSITR        TORQUE(LB-IN)    HPOWER
 23        1213      0.800E+05     0.578E+00    0.269E+00    0.511E+02        0.649E+02
```

If the user has activated the Pressurization advanced option (see sec. 5.4.3), the pressurization output will be listed next in the output file. First, the number of pressurization tanks in the model is listed. Then, the ullage node, propellant node, ullage to propellant heat transfer rate, ullage to tank wall heat transfer rate, tank wall conduction heat transfer rate, tank wall temperature, propellant volume, and ullage volume are listed for each pressurization tank. Note that the labels for this output do not include the units. The units are Btu/s for the heat transfer rates, degrees Rankine for the tank wall temperature, and cubic feet for the volumes.

```
NUMBER OF PRESSURIZATION SYSTEMS = 1
NODUL    NODPRP   QULPRP   QULWAL   QCOND    TNKTM     VOLPROP    VOLULG
2        4        0.6644   2.1888   0.0000   195.6238  473.0886   26.9114
```

5.8.10 Convergence Information

The final section of the output file contains information on the convergence of the solution. It is important to remember that GASP/WASP allows extrapolation outside the stated limits of its fluid property relationships. While this allows for flexibility during the iterative process, it can occasionally lead to a final solution based on extrapolated properties. For models where the user has selected GASP/WASP, GFSSP checks the pressure and temperature at each node and prints a warning in the output file if they are outside of GASP/WASP's stated limits so that the user can verify that the results are reasonable.

```
WARNING! CHKGASP: T out of fluid property range at node  1
WARNING! CHKGASP: T out of fluid property range at node  3
```

GFSSP also prints a statement indicating whether or not the solution converged. For an unsteady model, this statement is printed at each time step. If the solution converges, the statement lists the convergence criteria and the number of iterations needed to reach convergence.

```
SOLUTION SATISFIED CONVERGENCE CRITERION 0.100E-03 IN 5 ITERATIONS
```

If the solution does not converge, the statement lists the convergence criteria, the number of iterations that were performed, and the maximum difference after the last iteration.

```
SOLUTION DID NOT SATISFY CONVERGENCE CRITERION 0.100E-02 IN 541 ITERATIONS
DIFMAX IN SUCCESSIVE ITERATION = 0.175E-02
```

If the model includes the cyclic boundary option (see sec. 5.2.2), the number of adjustment iterations and the final temperature difference are listed next in the output file.

```
 ITERADJC = 3 DIFTEM = 1.634E-16
```

This section of the output file is only active if the user has selected to print the initial field from the Global Options dialog (see sec. 5.2.1). The time and time step will be listed after the convergence information. For a steady model, the time will read 100,000,000 s and the time step will be 1.

```
 TAU = 100000000.000000   ISTEP = 1
```

The final section of the output file lists the CPU time to complete the model simulation.

```
**************************************************

 TIME OF ANALYSIS WAS 1.001440000000000E-002 SECS

**************************************************
```

5.9 Post-Processing Simulation Data

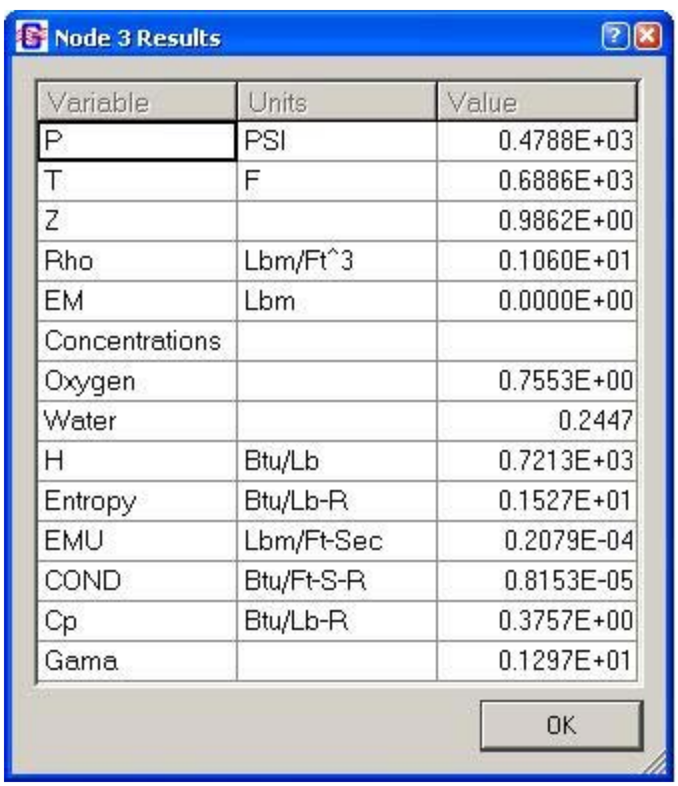
While the GFSSP output file provides a comprehensive summary of model simulation results, it is not always a practical source of information to meet the user's needs. Therefore, VTASC provides alternative methods of viewing GFSSP output for both steady and unsteady simulations.

5.9.1 Steady State Simulation Results

As mentioned in section 5.3, each GFSSP solution model element (fluid internal nodes and branches, conjugate heat transfer solid nodes and conductors) has a Results… dialog option located on their respective popup menus. After running a steady state simulation, if the user selects the Results option for a particular element, a table of results at that location will be displayed.

Figure 92 shows the internal fluid node results table for a steady state simulation with multiple fluids. For this case, the table includes the calculated pressure, temperature, compressibility, density, resident mass, and the mass concentration of each fluid at that node. The internal fluid node table contents will vary just like the fluid node solution results discussed in section 5.8.9 based on the user's selections (multiple fluid, single fluid, constant property fluid, and print extended information). Clicking the OK button will close the Results option and return the user to VTASC.

The results tables for the fluid branches, solid nodes, and conductors are the same in appearance and function as the internal fluid node table discussed above. The parameters that are listed in each table are the same parameters discussed in section 5.8.9 for each respective element.


Node 3 Results

Variable	Units	Value
P	PSI	0.4788E+03
T	F	0.6886E+03
Z		0.9862E+00
Rho	Lbm/Ft^3	0.1060E+01
EM	Lbm	0.0000E+00
Concentrations		
Oxygen		0.7553E+00
Water		0.2447
H	Btu/Lb	0.7213E+03
Entropy	Btu/Lb-R	0.1527E+01
EMU	Lbm/Ft-Sec	0.2079E-04
COND	Btu/Ft-S-R	0.8153E-05
Cp	Btu/Lb-R	0.3757E+00
Gama		0.1297E+01

OK

Figure 92. GFSSP steady state simulation results internal fluid node table.

5.9.2 Unsteady Simulation Results

There are two options available in VTASC for generating plots of unsteady simulations, depending on the user's needs: VTASC Plot and Winplot. There is also a provision of using Tecplot for plotting two-dimensional flow field.

5.9.2.1 VTASC Plot. The VTASC Plot is a built-in plotting capability within VTASC. As with the steady state results tables, it is accessed by selecting the Results… dialog from the desired model element's popup menu. The appearance and function of VTASC Plot is the same for each model element. The only difference will be the parameters available to plot, which are the same parameters discussed for each element in section 5.8.9.

Figure 93 shows the Results dialog for an unsteady simulation. Initially, the plot canvas space will be blank. The user can generate a hard copy or a bitmap of the desired plot by clicking the Print or Print to Bitmap button, respectively. The user creates the desired plot using the Properties dialog, which is activated by clicking the Properties… button. Once the user has finished, clicking the Close button will end the Results dialog and return the user to VTASC.

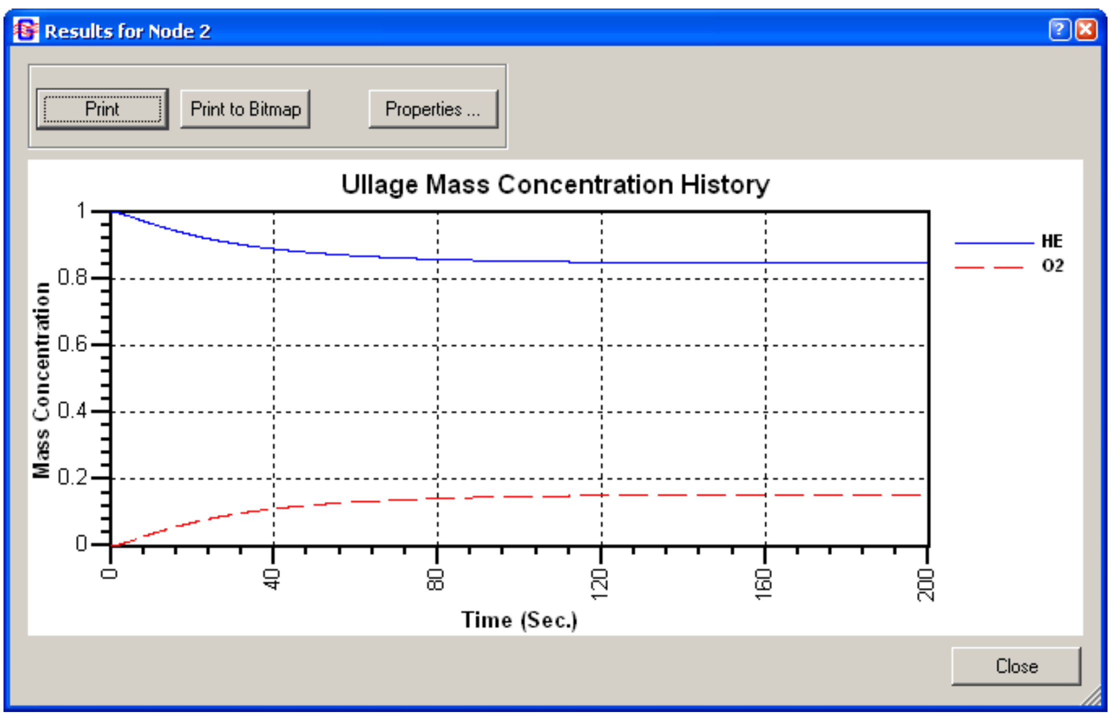
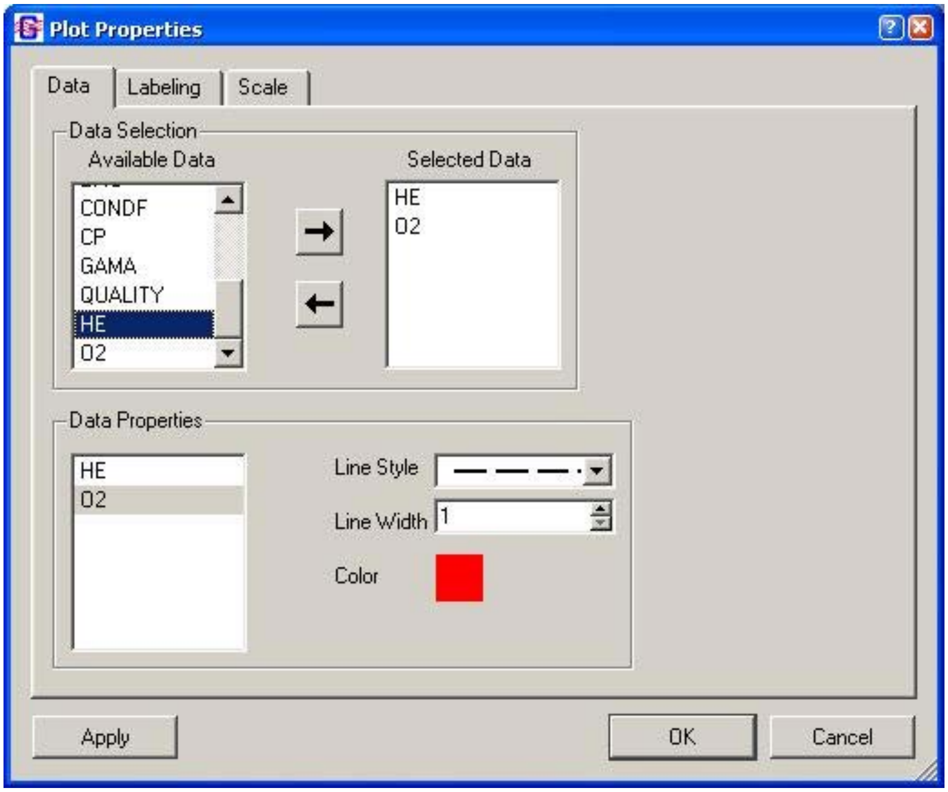


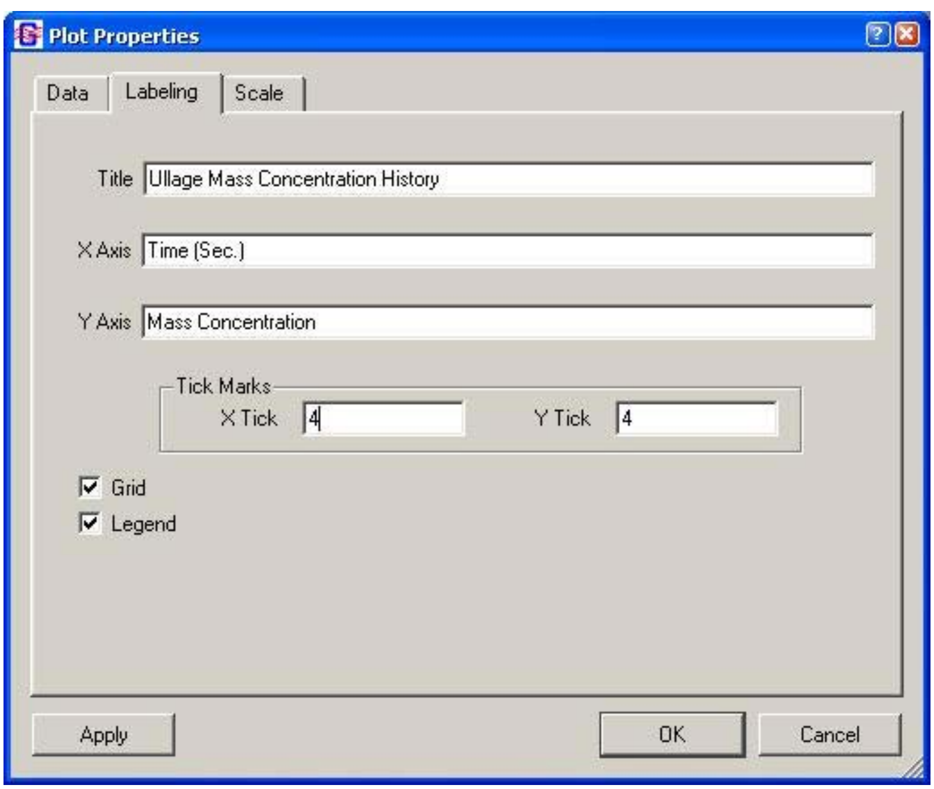
Figure 93. GFSSP Results dialog for unsteady simulation.

Figure 94 shows the Properties dialog used to create a plot of unsteady results. The dialog consists of three tabs, as well as Apply, OK, and Cancel buttons. Clicking the Apply button accepts any changes that have been made. The OK button closes the Properties dialog and returns to the Results dialog. The Cancel button fulfills the same function as the OK button.



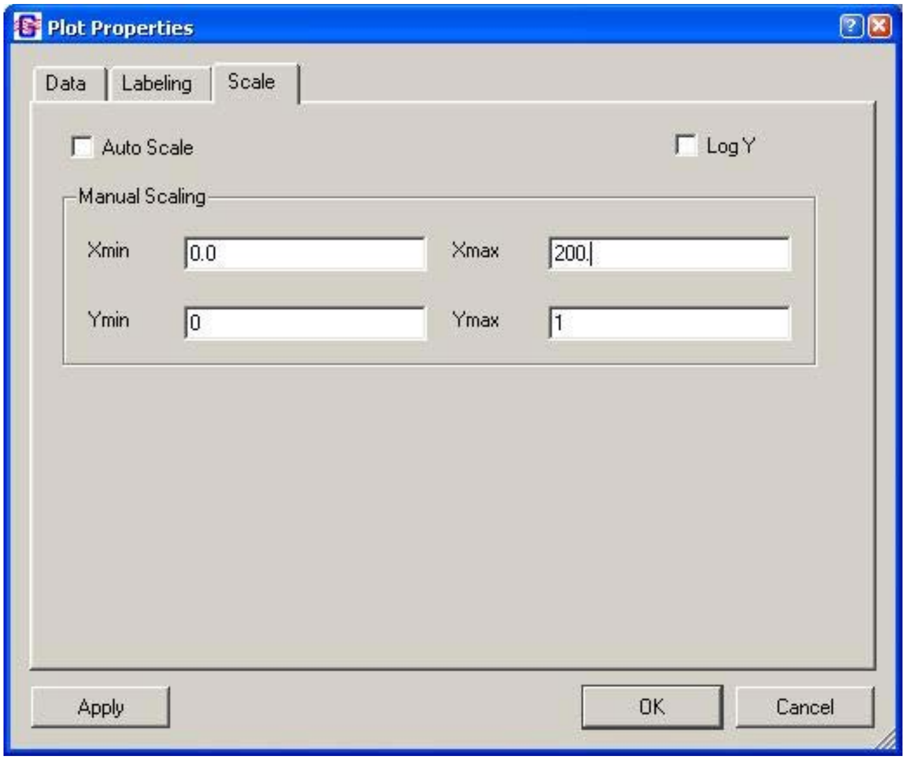
Plot Properties
Data
Labeling
Scale
Data Selection
Available Data
Selected Data
CONDF
CP
GAMA
QUALITY
HE
O2
HE
O2
Data Properties
HE
O2
Line Style
Line Width
1
Color
Apply
OK
Cancel

(a)



Plot Properties
Data
Labeling
Scale
Title
Ullage Mass Concentration History
X Axis
Time (Sec.)
Y Axis
Mass Concentration
Tick Marks
X Tick
4
Y Tick
4
Grid
Legend
Apply
OK
Cancel

(b)



(c)

Figure 94. GFSSP VTASC plot Properties dialog: (a) Data tab, (b) Labeling tab, and (c) Scale tab.

Data, the first tab (fig. 94(a)), allows the user to define the data they wish to plot. The user may select parameters for plotting using the Data Selection list at the top of the tab. The user selects plot parameters by highlighting the desired parameters in the Available Data list and clicking the button. These parameters will then be added to the Selected Data list. If the user wishes to remove parameters from the Selected Data list, highlight those parameters and click the button. Note that VTASC Plot does not have Multi-Y axis plotting capability so scale should be considered when plotting multiple parameters on a single plot. The Data Properties list at the bottom of the tab can be used to design the line style of each plot parameter. The user highlights the parameter whose line style they wish to design and then selects the line type, width, and color from the available selections on the right. Once all changes have been made to a particular parameter, click the Apply button to accept the changes.

Labeling, the second tab (fig. 94(b)), allows the user to define the Labeling parameters. Titles may be written or modified for the X and Y axes as well as the overall plot. The user may select whether or not they wish to include a grid or a legend on the plot by clicking the appropriate check-box. The user may also define the number of minor tick marks they wish to see for each axis. Once all changes have been made, click the Apply button to accept the changes.

Scale, the third tab (fig. 94(c)), allows the user to modify the scale of each axis. By default, VTASC will auto scale a plot for the user. Deselecting the Auto Scale checkbox allows the user to define the minimum and maximum values for each axis. The user also has the option of converting the Y axis to a log scale. Once all changes have been made, click the Apply button to accept the changes.

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5.9.2.2 Winplot. If the user selects the Winplot plotting option from the Global Options dialog (see sec. 5.2.1), unsteady plot files will be generated in either comma delimited or binary formats. If the user selects the comma delimited option, several files are generated. The naming convention, description, and available parameters for each file are listed in table 13. Note that the conjugate heat transfer related output files are only written if a node or conductor of that type is present in the model. If the user selects the binary format, a single file with the name convention 'filename.WPL' will be generated. This file will contain all of the available parameters for each model element as discussed in section 5.8.9 as well as DIFMAX, RSDMAX, and ITER.

Table 13. Winplot comma delimited unsteady output files.

Naming Convention	Description	Parameters
*filename*FN.CSV	Fluid node results	P (psia), T (°F), Z, ρ (lbm/ft^3), x of fluid or c of each fluid, μ (lbm/ft-s), k (Btu/ft-s-R), V (ft^3), DIFMAX, RSDMAX, ITER
*filename*B.CSV	Fluid branch results	v (ft/s), DP (psid), $\dot{m}$ (lbm/s), $\dot{S}_{gen}$ (Btu/R-s)
*filename*SN.CSV	Solid node results	$C_{p,s}$ (Btu/lbm-°F), T_s (°F)
*filename*SF.CSV	Solid-fluid conductor results	h_{csf} (Btu/s-ft^2-°F), $h_{csf,rad}$ (Btu/s-ft^2-°F) if needed, $\dot{Q}_{sf}$ (Btu/s)
*filename*SS.CSV	Solid-solid conductor results	k_{ss} (Btu/ft-s-R), $\dot{Q}_{ss}$ (Btu/s)
*filename*SA.CSV	Solid-ambient conductor results	h_{csa} (Btu/s-ft^2-°F), $h_{csa,rad}$ (Btu/s-ft^2-°F) if needed, $\dot{Q}_{sa}$ (Btu/s)
*filename*SSR.CSV	Solid-solid radiation results	$k_{eff,ssr}$ (Btu/ft-s-R), $\dot{Q}_{ssr}$ (Btu/s)

As mentioned in section 5.1.4, Winplot must be obtained separately by the user. If Winplot is installed on the user's computer, the user may open Winplot using the Run Menu's Winplot selection or the Run Winplot button on the VTASC toolbar. If the unsteady plot files already exist, they will automatically be loaded into Winplot. Otherwise, the user must reselect the Run Menu Winplot selection or toolbar Winplot button to load the plot files into Winplot. For plotting and manipulating data in Winplot, the user is referred to the Winplot user's manual.[13]

5.9.2.3 Tecplot. There is a provision of representing two-dimensional flow field using Tecplot—a commercial flow visualization software. For two-dimensional calculation, the user can activate Tecplot Data in the Output Control window under General Information. This activation allows GFSSP to create a Tecplot data file. After the completion of the run, the user can activate Tecplot in the main window by left clicking the Run Tecplot button in the top line of the canvas.

5.9.3 Display in Flow Circuit

An option exists within VTASC to display results for a particular model element on the VTASC canvas itself. The user can then observe how certain solution parameters change as adjustments are made to the model. This also allows the user to print the model with the results of interest as a hard copy or bitmap for reports or presentations. The user activates this option by first selecting the model element(s) using the selection tool. Then, as discussed in section 5.1.5, the user activates the Display Results/Properties dialog from the Display menu. Figure 95 shows an example of displaying the results on the VTASC canvas.

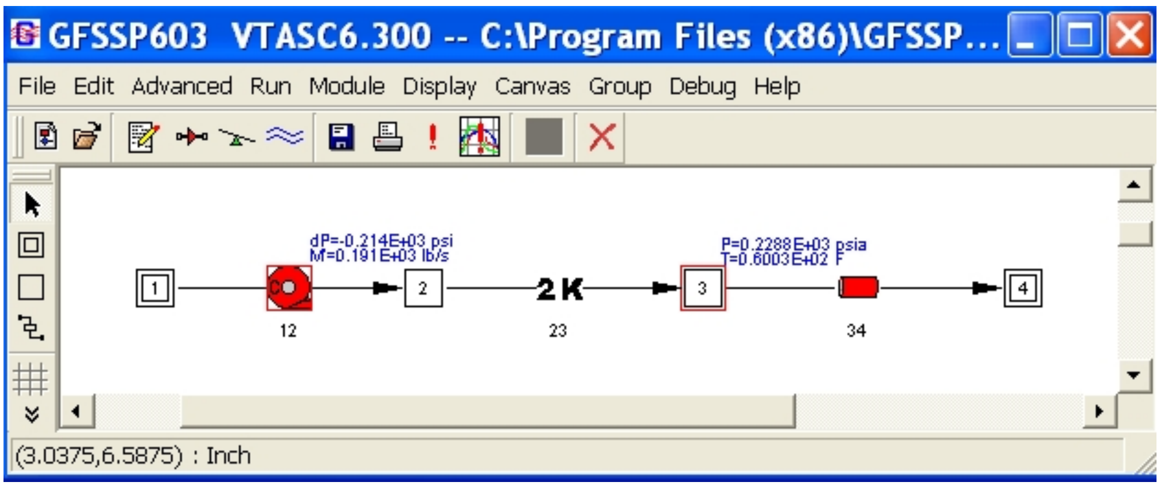

Figure 95. Display results in flow circuit example.

Figure 96 shows the Display Results/Properties dialog. The user can select a maximum of three different parameters to display for each model element. Note that display parameters cannot be varied between like model elements (i.e., the user cannot display the pressure at one fluid node and the temperature at another fluid node). The selected parameters are displayed at all selected elements of that type. Also note that the conjugate heat transfer parameter selections are not active unless the user has activated Conjugate Heat Transfer. Once the user has selected all desired display parameters, the Apply button is used to accept the changes. The OK button closes the Display Results/Properties dialog and returns the user to VTASC. The Cancel button fulfills the same function as the OK button.

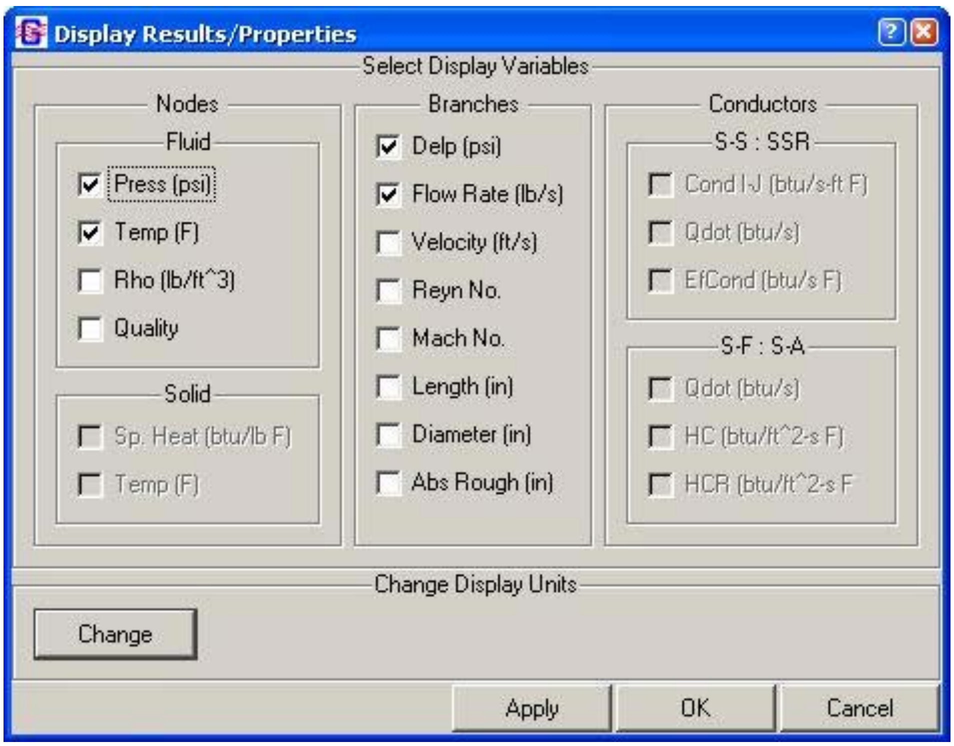

Figure 96. Display Results/Properties dialog.

The display units may be changed through the Display Property Units dialog (fig. 97) that is activated by clicking the Change button. Alternative display units are available here for certain display parameters. The user toggles between the available units choices for each parameter. The OK button closes the Display Property Units dialog and returns the user to the Display Results/Properties dialog. The Cancel button fulfills the same function as the OK button.

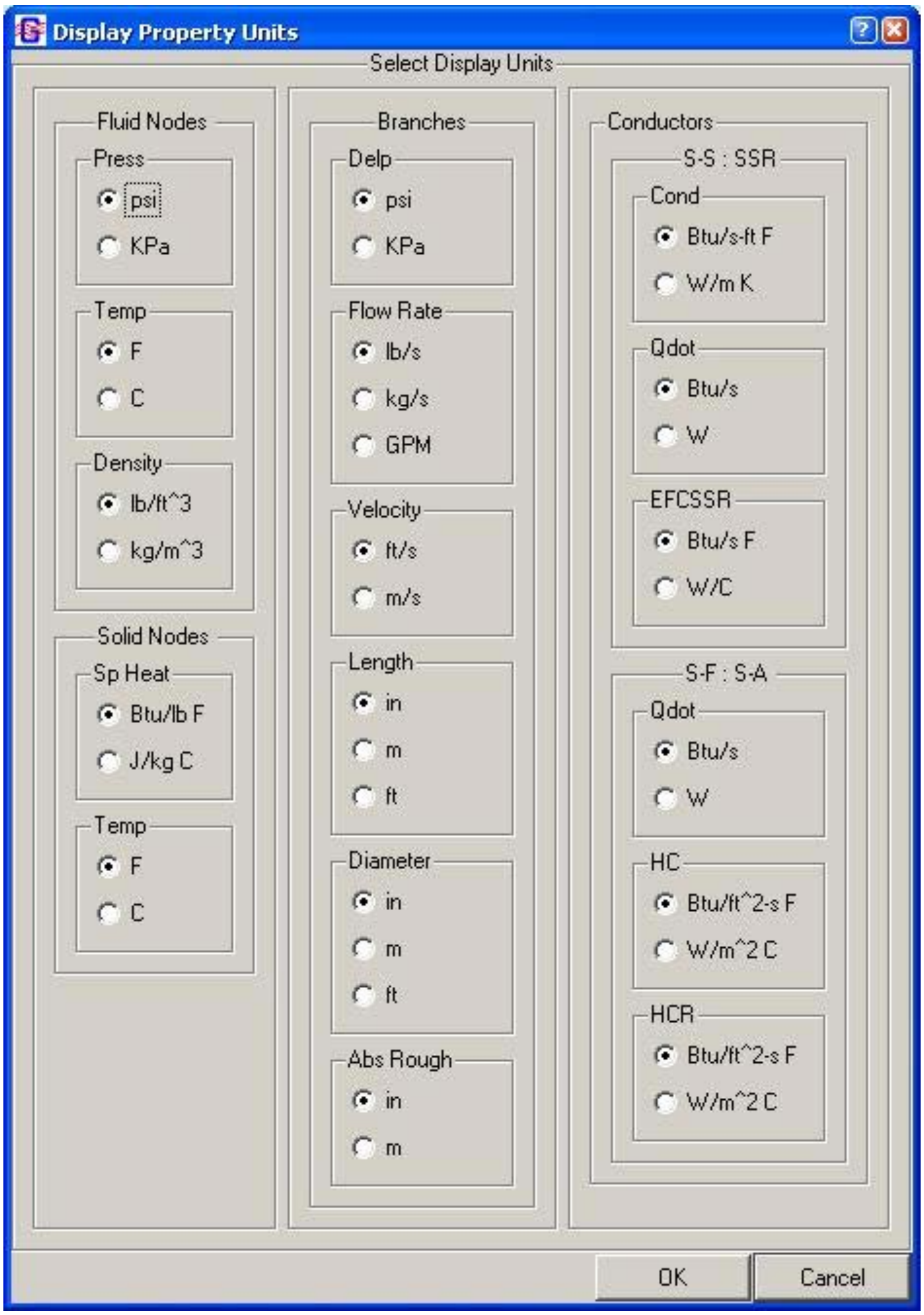

Figure 97. Display Property Units dialog.

6. EXAMPLES

This section demonstrates the major features of the code through 30 example problems, selected to serve two purposes. First, these problems will instruct the user on how to use the various options available in the code to analyze different fluid engineering problems. The other purpose of the examples contained within this section is to verify the code's predictions. This verification was accomplished by comparing the GFSSP solutions with analytical solutions, other numerical solutions, or with test data. The included demonstration problems are as follows:

(1) Simulation of a flow system consisting of a pump, valve, and pipe line.
(2) Simulation of a water distribution network.
(3) Simulation of compressible flow in a converging-diverging nozzle.
(4) Simulation of the mixing of combustion gases and a cold gas stream.
(5) Simulation of a flow system involving a heat exchanger.
(6) Radial flow on a rotating radial disk.
(7) Flow in a long-bearing squeeze film damper.
(8) Simulation of the blowdown of a pressurized tank.
(9) A reciprocating piston-cylinder.
(10) Pressurization of a propellant tank.
(11) Power balancing of a turbopump assembly.
(12) Helium pressurization of LOX and RP-1 propellant tanks.
(13) Steady state and transient conduction through a circular rod, with convection.
(14) Chilldown of a short cryogenic pipe line.
(15) Simulation of fluid transient following sudden valve closure.
(16) Simulation of pressure regulator downstream of a pressurized tank.
(17) Simulation of flow regulator downstream of a pressurized tank.
(18) Subsonic Fanno flow.
(19) Subsonic Rayleigh flow.
(20) Modeling of closed cycle liquid metal (lithium) loop with heat exchanger to heat helium gas.
(21) Internal flow in a turbopump.
(22) Simulation of a fluid network with fixed flow rate option.
(23) Helium-assisted, buoyancy-driven flow in a vertical pipe carrying LOX with ambient heat leak.
(24) Simulation of relief valve in a pressurized tank.
(25) Two-dimensional recirculating flow in a driven cavity.
(26) Fluid transients in pipes due to sudden opening of valve.
(27) Boiling water reactor.
(28) No-vent tank chill and fill model.
(29) Self-pressurization of a cryogenic propellant tank due to boil-off.
(30) Modeling solid propellant ballistic with GFSSP.

The selection of the order for these problems is partly determined by their complexities and partly due to the historical developments of new options and capabilities of the code. The first seven problems consider steady state flows and use relatively simple flow networks. Each example demonstrates use of a special option. Example 8 is a two-node model to demonstrate the use of the unsteady option. More complex unsteady flow examples are illustrated in examples 9, 10, and 12.

Options for time-dependent geometry and moving boundary are shown in example 9. Pressurization of a cryogenic propellant tank is described in example 10. This example also illustrates the use of User Subroutines to calculate evaporation and mass transfer. The application of the Turbopump and Heat Exchanger options in a typical gas turbine system is illustrated in example 11. The use of a control valve in a pressurization system consisting of both fuel and oxidant tanks is the highlight of example 12. Example 12 is the most complex example, using many options such as mixture and inertia in unsteady flow. Examples 13 and 14 introduce GFSSP's conjugate heat transfer capability. Example 13 is an adaptation of a classical heat transfer problem into GFSSP, while example 14 simulates a common conjugate heat transfer engineering application in cryogenic systems. Example 15 emphasizes GFSSP's ability to predict fluid transient phenomena. Examples 16 and 17 illustrate the use of pressure and flow regulator options which were included in version 6. Two classical problems on compressible flows (Fanno and Rayleigh flows) are described in examples 18 and 19. GFSSP solutions were compared with analytical solutions for both problems. Example 20 illustrates the modeling of a closed loop and the use of a property look-up table. The modeling of internal flow in a turbopump with interpropellant seal for axial thrust calculation is illustrated in example 21. The use of the fixed flow rate option is illustrated in example 22. The use of a new mixture option that allows phase change is demonstrated in example 23. Example 24 demonstrates the use of a pressure relief valve to allow flow out of a pressurized tank that has exceeded a defined pressure. Use of the multidimensional option is demonstrated in example 25 by modeling recirculating flow in a driven cavity. Table 14a (examples 1–15) and table 14b (examples 16–30) describe a matrix of the example problems and their use of various options to model the necessary physical processes. Several technical papers illustrate the application of GFSSP in modeling internal flow in rocket engine turbopump,[28–30] propellant tank pressurization,[31,32] chilldown of cryogenic transfer line,[33,34] propellant tank loading,[35] propellant tank boil-off,[36] fluid transient,[27,37] pressure regulator,[38] and microfluidics application.[39]

Table 14a. Use of various options in example problems—examples 1–15.

Feature	Example														
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
Conjugate heat transfer													13	14	
Constant property		2					7								
Cyclic boundary															
Fixed mass flow															
Flow regulator															
Gravity	1														
Heat exchanger					5						11				
Ideal gas								8							
Long inertia			3			6						12			
Fluid mixture				4						10		12			
Model import															
Moving boundary							7		9						
Multilayer insulation															
Multidimensional flow															
Noncircular duct							7								
Phase change														14	
Pressurization (tank)										10		12			
Pressure regulator															
Pressure relief valve															
Pump	1											12			
Solid rocket motor															
Turbopump											11				
Turbopump—internal flow															
Unsteady								8	9	10		12		14	15
User fluid															
User subroutine										10		12			
Valve O/C															15
Variable geometry									9						
Fluid transient (water hammer)															15

Table 14b. Use of various options in example problems—examples 16–30.

	Example														
Feature	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**
Conjugate heat transfer								23					28	29	
Constant property										25					
Cyclic boundary					20										
Fixed mass flow							22						28		
Flow regulator		17													
Gravity								23				27	28	29	
Heat exchanger					20										
Ideal gas	16	17													30
Long inertia			18	19								27			30
Fluid mixture								23							
Model import								23							
Moving boundary											26*				
Multilayer insulation														29	
Multidimensional flow										25					
Noncircular duct															
Phase change												27	28	29	
Pressurization (tank)														29	
Pressure regulator	16														
Pressure relief valve									24						
Pump															
Solid rocket motor															30
Turbopump															
Turbopump—internal flow						21									
Unsteady	16	17					22	23	24		26		28	29	30
User fluid					20							27			
User subroutine			18	19	20						26		28	29	30
Valve O/C											26				
Variable geometry											26*				
Fluid transient (water hammer)											26				

*Variable geometry and moving boundary handled by User Subroutine.

6.1 Example 1—Simulation of a Flow System Consisting of a Pump, Valve, and Pipe Line

6.1.1 Problem Considered

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

The system considered for this example is shown in figure 98. It consists of two reservoirs connected by 1,500 ft of 6-in-diameter pipe with a roughness factor (ε/D) of 0.005. The receiving reservoir is located at an elevation that is 150 ft higher than the supply reservoir. The head-flow characteristics of the pump considered in this problem are shown in figure 99. This pump should be used to transport water, at 60 °F, from the supply reservoir to the receiving reservoir. GFSSP will be used to determine the system flow rate and required pump horsepower.

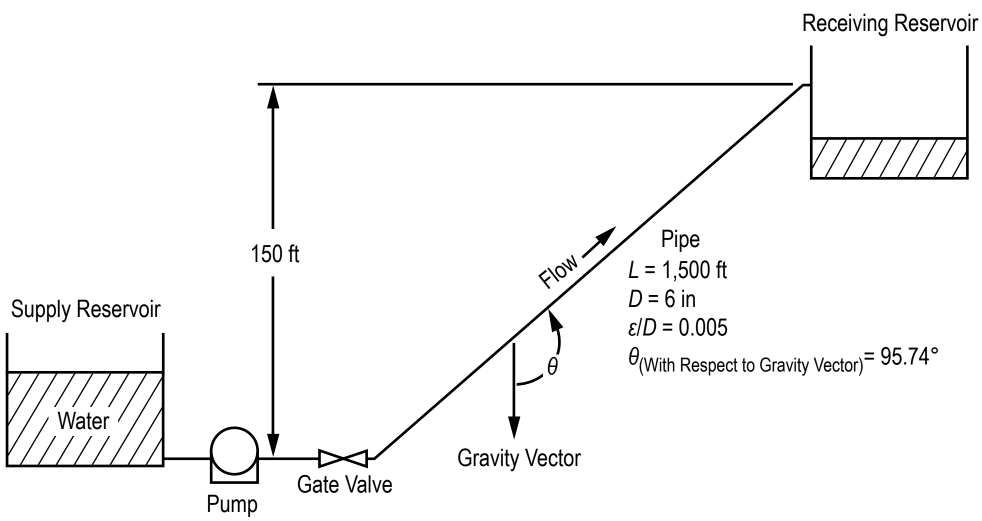

Figure 98. Schematic of pumping system and reservoirs (example 1).

6.1.2 GFSSP Model

The fluid system shown in figure 98 can be simulated with a GFSSP model consisting of four nodes and three branches as shown in figure 100(a). Nodes 1 and 4 are the boundary nodes representing the supply and receiving reservoirs that are both at 14.7 psia and 60 °F. Node 2 is an internal node representing the pump exit and the inlet to the gate valve. Node 3 is an internal node representing the exit from the gate valve and the inlet to the pipe line that connects the valve to the receiving reservoir. Branches 12, 23, and 34 represent the pump, gate valve, and pipe line, respectively. Figure 100(b) shows how this model appears in VTASC.

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

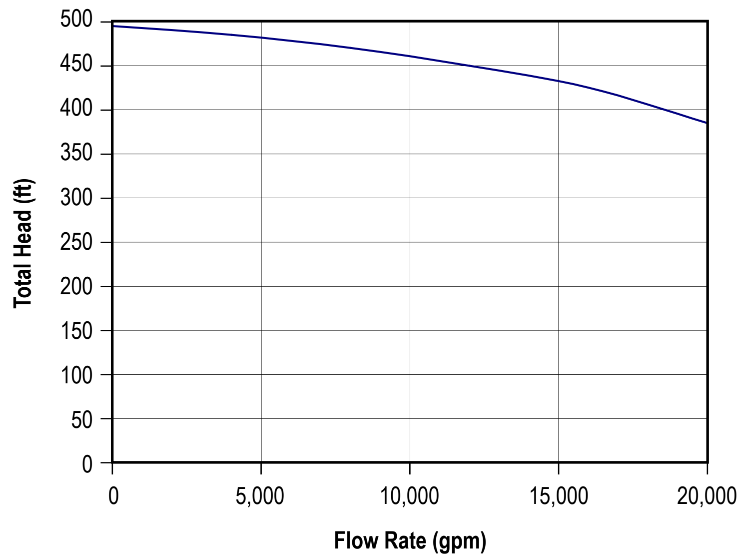

Figure 99. Manufacturer-supplied pump head-flow characteristics.

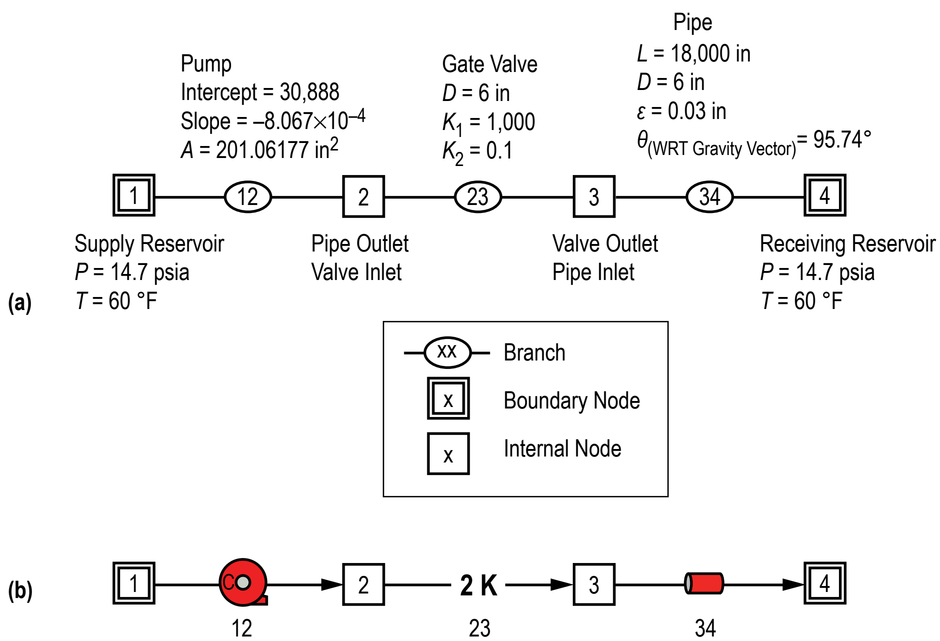

Figure 100. GFSSP model of pumping system and reservoirs: (a) Detailed schematic and (b) VTASC model.

6.1.2.1 Branch 12 (Pump). Option 14 was selected to represent the pump because this option allows the user to model a pump with a given characteristics curve using either two or three constants. For this problem, two constants, A_0 and B_0, were input as well as the pump area (area is only required for the velocity calculation). These constants represent the slope and the intercept of the $\dot{m}^2$ versus Δp curve. The following procedure is used to obtain these constants:

(1) Construct a table, based on user-selected points, from the pump characteristics curve shown in figure 99 to develop a relationship between $\dot{m}^2$ and Δp. These data are shown in table 15, where $\dot{m} = \rho Q$ and $\Delta p = \rho g/g_c\, H$.

(2) Plot the Δp and $\dot{m}^2$ data from table 15 as shown in figure 101. Note that the relationship is linear (i.e., $\Delta p = A_0 + B_0\, \dot{m}^2$). Therefore, the pump characteristic curve can be prescribed with two constants, A_0 and B_0, and the optional third constant is not necessary.

Table 15. Tabulated pump characteristics data.

Q (gpm)	$\dot{m}$ (lb/s)	Head (ft)	Δp (psf)	$\dot{m}^2$ (lb/s)^2
–	–	495	30,888	–
4,000	556.13	485	30,264	3.093×10^5
8,000	1,112.3	470	29,328	1.2372×10^6
12,000	1,668.4	450	28,080	2.784×10^6
16,000	2,224.5	425	26,520	4.9484×10^6
20,000	2,781	385	24,024	7.734×10^6

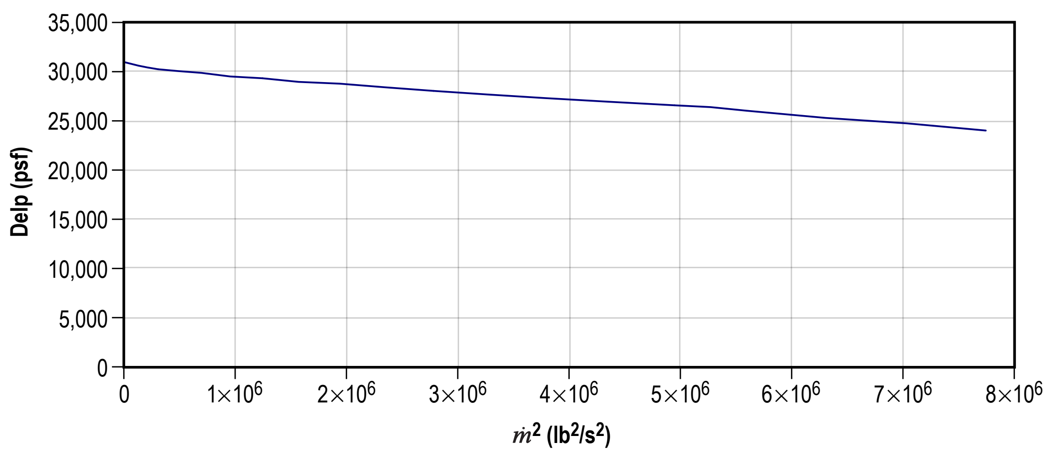

Figure 101. Pump characteristics curve in GFSSP format.

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(3) Determine the constants A_0 and B_0 from figure 101:

The intercept (Δp at $\dot{m}^2 = 0$) is A_0 = 30,888.

The slope (taken about Q = 10,000 gpm) is $B_0 = \dfrac{28{,}080 - 29{,}328}{\left(2.784\times10^6\right)-\left(1.2372\times10^6\right)} = -\left(8.067\times10^{-4}\right)$.

Since the curve is linear, the slope can be determined at any point without sacrificing accuracy. In VTASC, A_0 is entered in the intercept input box and B_0 is entered in the second order input box.

6.1.2.2 Branch 23 (Gate Valve). Option 13 was used to represent the gate valve. Option 13 requires two constants, K_1 and K_∞ (two-K method), and the internal diameter to model various pipe fittings. The two required constants were obtained from table 7 (see sec. 3) assuming a reduced trim (β = 0.8) gate valve.

6.1.2.3 Branch 34 (Pipe Line). Option 1 was used to represent the pipe line. This branch resistance option requires the user to supply the length, diameter, roughness factor (ε/D), and the angle between the gravity vector and the pipe line.

6.1.3 Results

The example 1 GFSSP input and output data files (ex1.dat and ex1.out) are included in appendix H.

The example 1 GFSSP model predicts a flow rate of 191 lb/s and the pressure rise across the pump is 214 psi. Interpolation in the table 15 data shows that the pump pressure rise for the GFSSP predicted flow rate is 213 psi, which indicates that the model is working as expected. This example demonstrates that GFSSP can accurately predict the operating point of a fluid system consisting of a pump and a pipe line with a valve.

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

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

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Table 16 shows typical system characteristics generated by performing the parametric study described above. The inlet pressures were arbitrarily selected to cover the expected operating range. The GFSSP predicted mass flow rates are shown in the third column. The flow resistance coefficients for the valve and the pipe are shown in the next two columns. The method of calculating these values is discussed in section 2. The next three columns of table 16 show hand-calculated pressure drops over the gate valve and the pipe and the pressure difference that is associated with the elevation change that exists in the example 1 model. The sum of these three losses is tabulated in the next column. The last column shows the overall pressure drop for the system for the given mass flow rate. A comparison of the values contained in the last two columns shows good agreement.

Table 16. Predicted system characteristics.

P_1 (psia)	P_4 (psia)	$\dot{m}$ (lbm/s)	$K_{f,\ gate}$ $\frac{\text{lbf-s}^2}{(\text{lb-ft})^2}$	$K_{f,\ pipe}$ $\frac{\text{lbf-s}^2}{(\text{lb-ft})^2}$	$\Delta_{p,\ gate}$ (psia)	$\Delta_{p,\ pipe}$ (psia)	$\Delta_{p,\ gravity}$ (psia)	$\Delta_{p,\ cal}$ (psia)	$\Delta_{p,\ pres}$ (psia)
150	14.7	131	0.0019	0.593	0.225	70.67	65	135.89	135.3
200	14.7	171	0.0019	0.592	0.385	120.21	65	185.59	185.3
250	14.7	203	0.0019	0.591	0.544	169.13	65	234.67	235.3
300	14.7	231	0.0019	0.591	0.704	219	65	284.71	285.3

To determine the operating point of the system with a given pump, the system characteristics can be plotted together with the pump characteristics. The system operating point will be determined by the intersection of these two curves. Figure 102 shows the example 1 fluid system characteristics, generated previously, plotted along with the pump characteristics data that are shown in table 15. As seen from this figure, the operating point predicted by this method occurs at a pressure drop of approximately 214 psid and a mass flow rate of 190 lbm/s which compares well with the predicted results from the GFSSP model containing the pump.

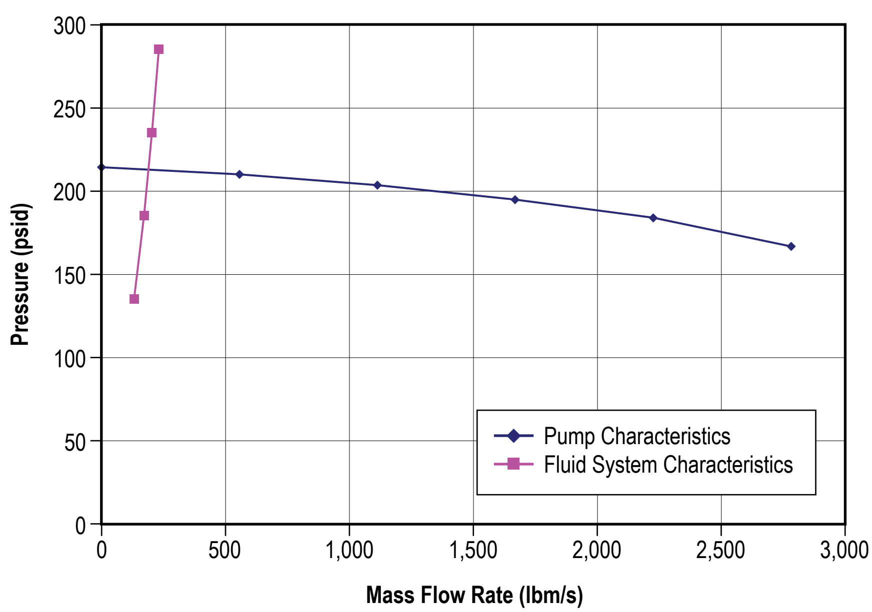

Figure 102. Fluid system operating point.

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

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

6.2 Example 2—Simulation of a Water Distribution Network

6.2.1 Problem Considered

In example 1, a single line pipe flow problem commonly encountered by pipe line designers is analyzed. In this example, an example associated with multipath systems, commonly known as flow networks, is considered. In general, water supply systems are considered as flow networks, since nearly all such systems consist of many interconnecting pipes. A 10-pipe (commercial steel) distribution system is shown in figure 103. Water at 50 psia enters the circuit at boundary node 1. Water is removed from the circuit at boundary nodes 3, 4, and 9 where pressures are also known. Use GFSSP to determine pressures at all of the remaining nodes and the flow rates in all of the pipes. The length, diameter, and roughness factors for each pipe are given in table 17. Note that pipes are designated as branches in the subsequent discussions.

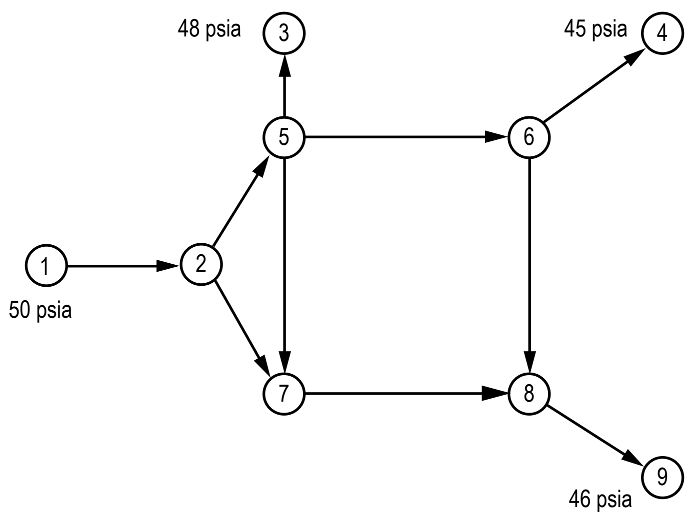

Figure 103. Water distribution network schematic (example 2).

Table 17. Water distribution network branch data.

Branch	Length (in)	Diameter (in)	Roughness Factor
12	120	6	0.0018
25	2,400	6	0.0018
27	2,400	5	0.0018
57	1,440	4	0.0018
53	120	5	0.0018
56	2,400	4	0.0018
64	120	4	0.0018
68	1,440	4	0.0018
78	2,400	4	0.0018
89	120	5	0.0018

6.2.2 GFSSP Model

The system shown in figure 103 is modeled by GFSSP in VTASC using 9 nodes and 10 branches as shown in figure 104. The fluid was assumed incompressible and therefore a constant density (DENCON = .TRUE.) option was used. Nodes 1, 3, 4, and 9 are boundary nodes where the pressures are prescribed. Node 1 represents the inlet boundary node. Nodes 3, 4, and 9 are outlet boundary nodes. All of the remaining nodes (2, 5, 6, 8, and 7) are internal nodes where the pressures are calculated. All of the branches in this circuit simulate pipes. Therefore, each branch uses branch resistance option 1. The length, diameter, and roughness factors of all branches are given in table 17.

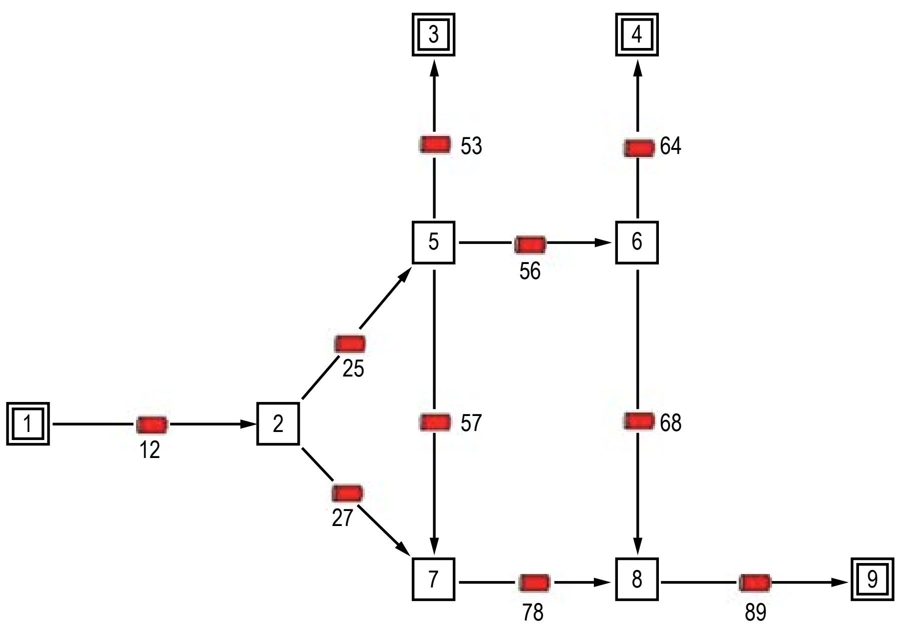

Figure 104. GFSSP model of the water distribution network.

6.2.3 Results

The input and output data files (ex2.dat and ex2.out) are shown in appendix I. The GFSSP predicted results are shown in tables 18 and 19. Table 18 lists the predicted pressures at the internal nodes in psia and feet of water. Table 19 lists the predicted flow rates in lbm/s and ft^3/s. Table 19 also provides a comparison between the GFSSP predicted results and values predicted by the Hardy Cross[2,40] method.

Table 18. GFSSP predicted pressure distribution at the internal nodes.

P_2		P_5		P_6		P_7		P_8	
psia	ft	psia	ft	psia	ft	psia	ft	psia	ft
49.8	114.92	48.11	111.02	45.34	104.63	48.35	111.58	46.01	106.18

Table 19. GFSSP and Hardy Cross method predicted branch flow rates.

	GFSSP		Hardy Cross	
Flow Rate	lb/s	ft^3/s	lb/s	ft^3/s
$\dot{m}_{12}$	100.16	1.605	100.16*	1.605*
$\dot{m}_{25}$	63.1	1.011	63.59	1.019
$\dot{m}_{27}$	37	0.593	36.58	0.5862
$\dot{m}_{53}$	44.43	0.7115	44.43*	0.7115*
$\dot{m}_{56}$	29.1	0.466	29.11	0.4665
$\dot{m}_{57}$	–10.4	–0.167	–9.93	–0.1592
$\dot{m}_{64}$	47.07	0.7548	47.07*	0.7548*
$\dot{m}_{68}$	–18	–0.288	–17.99	–0.2883
$\dot{m}_{78}$	26.7	0.428	26.64	0.427
$\dot{m}_{89}$	8.66	0.1387	8.66*	0.1387*

*Boundary flow rates are prescribed from GFSSP predictions.

Figure 105 shows a comparison between GFSSP and Hardy Cross predicted flow rates. The comparison appears reasonable considering the fact that the Hardy Cross method assumes a constant friction factor in the branch while the GFSSP computes the friction factor for all branches. Therefore, as the flow rates change, the friction factor also changes.

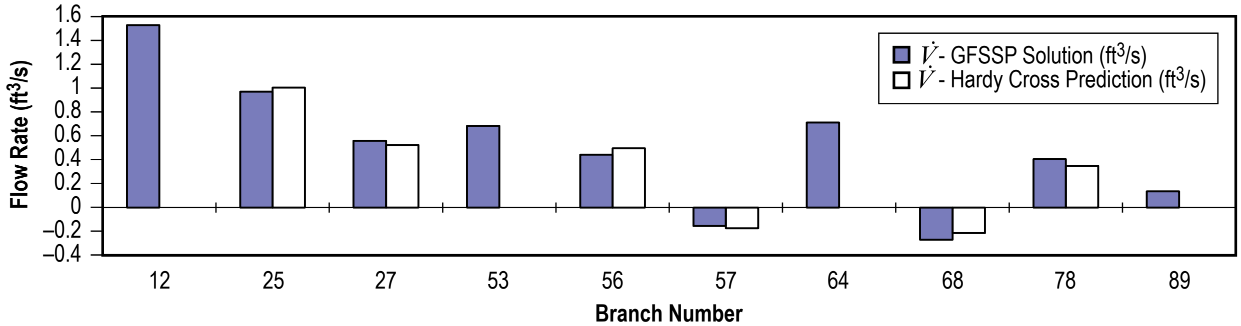

Figure 105. Flow rate comparison between GFSSP and Hardy Cross method predictions.

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

6.3.1 Problem Considered

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

The converging-diverging nozzle considered for this example is shown in figure 106. The nozzle is 6.3 in long with a 0.492-in-diameter throat. The inlet diameter of the nozzle is 0.6758 in and throat of the nozzle is located 0.158 in downstream of the inlet. The fluid considered was steam at 150 psia and 1,000 °F. The nozzle backpressure was varied from 134 to 45 psia. GFSSP is desired to predict the flow rate and the pressure distribution for different exit pressures. The predicted flow rate will also be compared with the isentropic solution.

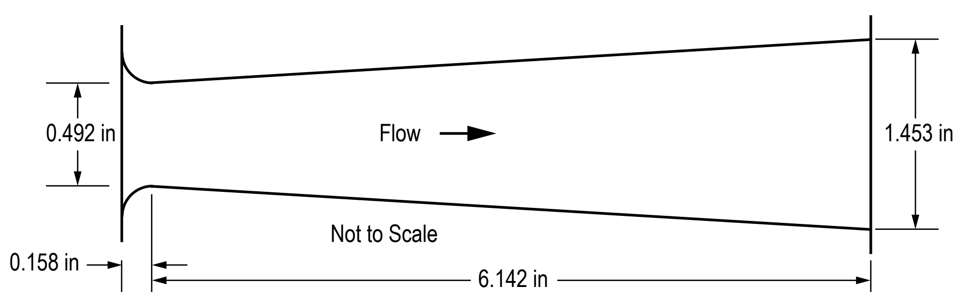

Figure 106. Converging-diverging steam nozzle schematic.

6.3.2 GFSSP Model

The fluid system shown in figure 106 can be simulated with a GFSSP model consisting of 17 nodes and 16 branches as shown in figure 107(a). Nodes 1 and 17 are the boundary nodes representing the inlet and outlet of the nozzle. All of the remaining nodes are internal nodes connected in series. GFSSP can be used to construct an isentropic model by selecting branch resistance option 2 (flow through a restriction), using a flow coefficient, C_L, set equal to zero and by setting the logical flag INERTIA = .TRUE. This option eliminates friction from the momentum equation, which represents a balance between the inertia and pressure force with the inclusion of the inertia term. Each branch assumes a constant flow area that was determined from the nozzle geometry at the mid point of the branch location. The branch information is listed in table 20. Figure 107(b) shows how this model appears in VTASC.

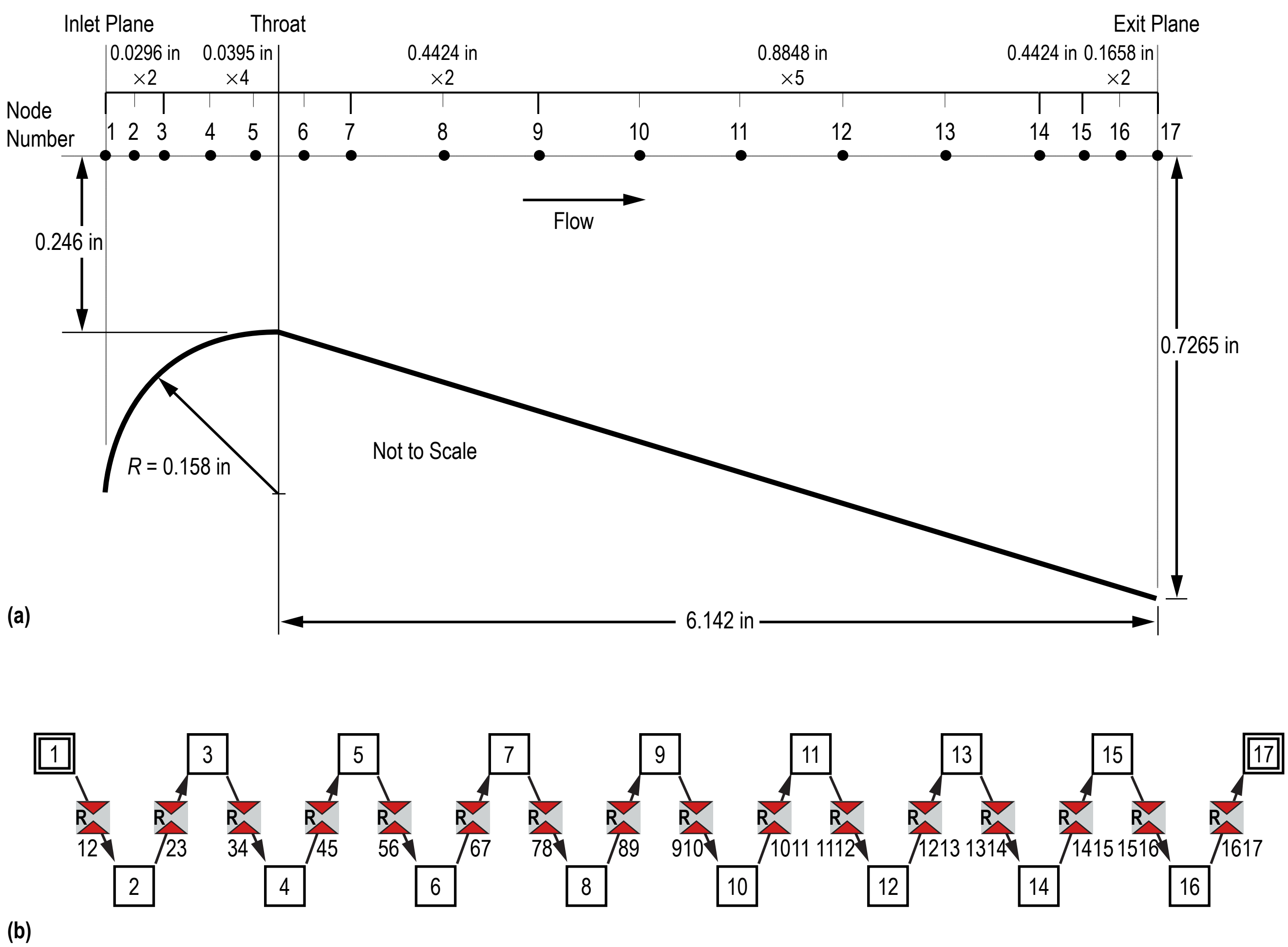

Figure 107. Converging-diverging steam nozzle model: (a) Detailed schematic and (b) VTASC model.

Table 20. Converging-diverging nozzle branch information.

Branches	Option	Area (in^2)
12	2	0.3587
23	2	0.2717
34	2	0.2243
45	2	0.2083
56	2	0.1901
67	2	0.1949
78	2	0.2255
89	2	0.2875
910	2	0.3948
1011	2	0.564
1112	2	0.7633
1213	2	0.9927
1314	2	1.252
1415	2	1.4668
1516	2	1.5703
1617	2	1.6286

It may be mentioned here that the temperature at the outlet boundary node has no influence on the solution. However, the code must be supplied with a value to satisfy the input requirements for a boundary node. In this example the temperature was specified arbitrarily to 1,000 °F at node 17. The boundary conditions are specified in table 21.

Table 21. Converging-diverging nozzle boundary conditions.

P_1 (psia)	T_1 (°F)	P_{17} (psia)	T_{17} (°F)
150	1,000	130	1,000
150	1,000	100	1,000
150	1,000	60	1,000
150	1,000	50	1,000
150	1,000	45	1,000

6.3.3 Results

The outlet boundary node pressures were varied to include 130, 100, 60, 50, and 45 psia. The input and output files (ex3.dat and ex3.out) from the example case using an exit pressure of 60 psia are included in appendix J. The predicted pressure distribu-tions for five test cases are shown in figure 108. Figure 109 shows the predicted temperature distributions for the same cases.

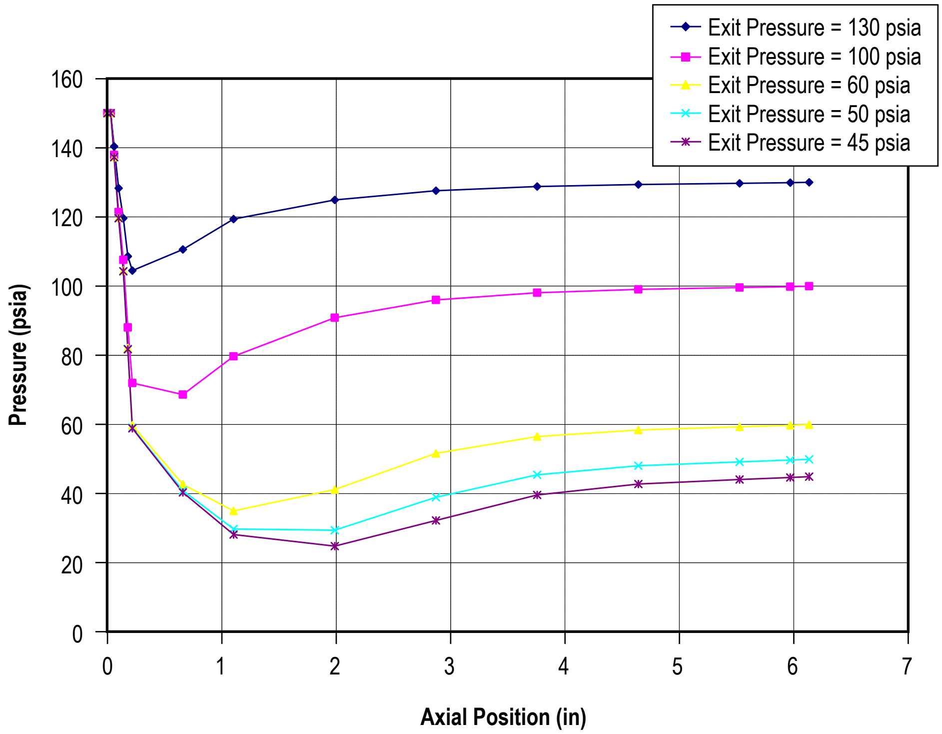

Figure 108. Predicted pressures for the isentropic steam nozzle.

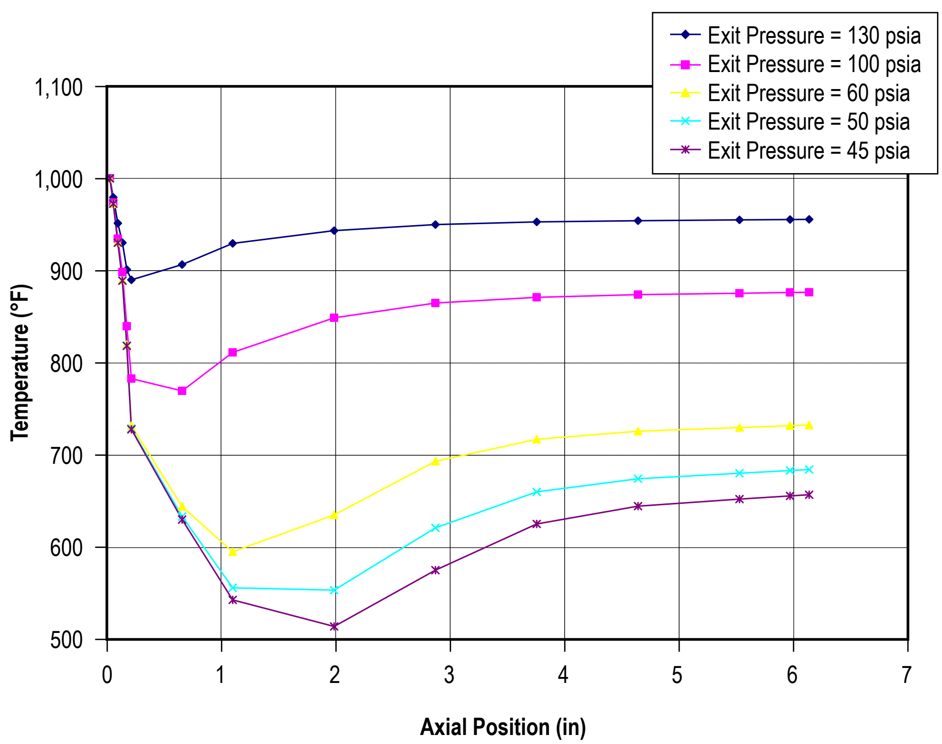

Figure 109. Predicted temperatures for the isentropic steam nozzle.

Table 22 lists the model predicted mass flow rates with varying exit pressures. As expected, the mass flow rate increased as the exit pressure was decreased until the pressure ratio decreased below the critical pressure ratio. At this point and below, the mass flow rate remained constant due to choking of the flow at the nozzle throat.

Table 22. Predicted mass flow rate with varying exit pressure.

P_{exit} (psia)	$\dot{m}$ (lbm/s)
130	0.292
100	0.329
60	0.336
50	0.337
45	0.337

The isentropic flow rate was calculated from equation (72). This equation assumes that the inlet pressure is a stagnation pressure. GFSSP's formulation assumes that the prescribed boundary conditions are taken at a static condition. The nozzle inlet velocity head component must be added to the GFSSP static inlet boundary pressure to obtain the correct nozzle inlet stagnation pressure to use in equation (72) as shown in equation (73):

$$\dot{m} = A_{\text{throat}} P_{\text{inlet}} \sqrt{\frac{g_c \, \gamma}{R \, T_{\text{inlet}}} \left(\frac{2}{\gamma + 1} \right)^{\left(\frac{\gamma+1}{\gamma-1} \right)}} \tag{72}$$

and

$$P_{\text{inlet}} = P_{\text{static}} \left(1 + \left(\frac{\gamma - 1}{2} \right) M^2 \right)^{\frac{\gamma}{\gamma-1}} \; . \tag{73}$$

A value of the specific heat ratio at the nozzle inlet boundary node was obtained from GASP, and the inlet Mach Number from the first branch connected to the inlet node in the model output data file contained in appendix J. Substituting these values into equation (73), gives the following total pressure at the nozzle inlet:

$$P_{\text{inlet}} = (150 \text{ psia}) \left(1 + \left(\frac{1.2809 - 1}{2} \right) (0.342)^2 \right)^{\frac{1.2809}{1.2809-1}} = 161.6 \text{ psia} \; . \tag{74}$$

Substituting the calculated total inlet pressure from equation (74) into equation (72) and solving for the choked mass flow rate gives a calculated isentropic choked mass flow rate of 0.327 lbm/s as shown:

$$\dot{m} = \left(0.19012\ \text{in}^2\right)\left(161.6\ \frac{\text{lbf}}{\text{in}^2}\right)\sqrt{\frac{32.174\dfrac{\text{lbm-ft}}{\text{lbf-s}^2}\ (1.281)}{85.83\dfrac{\text{lbf-ft}}{\text{lbm-°R}}1{,}460\ \text{°R}}\left(\frac{2}{1.281+1}\right)^{\frac{2.281}{0.281}}} = 0.327\ \frac{\text{lbm}}{\text{s}}\ . \quad (75)$$

As the reader can see by comparing the results shown in table 22 and equation (75), there is good agreement (approximately a 3% difference) between the GFSSP predicted choked flow rate and the calculated isentropic choked flow rate. The prediction from first law based formulation has also been compared with the second law formulation. In the first law formulation, enthalpy was used as the dependent variable and equation (3a) was used instead of equation (3b). Unlike the second law formulation where density is computed from pressure and entropy, the first law formulation calculates density from pressure and enthalpy. The comparison of choked mass flow rate for both formulations with the isentropic solution is shown in table 23. It may be noted that the entropy based formulation more accurately predicts the mass flow rate than the enthalpy based formulation.

Table 23. Comparison of choked mass flow rates.

Parameter	Second Law Formation	First Law Formation
GFSSP predicted isentropic mass flow rate	0.337 lbm/s	0.308 lbm/s
Calculated stagnation inlet pressure	161.6 psia	159.71 psia
Calculated isentropic mass flow rate	0.337 lbm/s	0.323 lbm/s
Percent difference between GFSSP predicted and calculated isentropic mass flow rates	3.06%	–4.64%

To validate GFSSP's ability to predict temperatures, the GFSSP predicted temperature at the nozzle throat was also compared with a hand-calculated temperature using equation (76). This equation assumes an isentropic process. In equation (76), the pressure P_1 was assumed to be the total pressure at the nozzle inlet that was calculated from equation (74) and the throat pressure was taken from the GFSSP output:

$$T_2 = T_1\left(\frac{P_2}{P_1}\right)^{\frac{\gamma-1}{\gamma}} = (1{,}460\ \text{°R})\left(\frac{82.13\ \text{psia}}{161.6\ \text{psia}}\right)^{\frac{1.2809-1}{1.2809}} = 1{,}258.6\ \text{°R} = 798.6\ \text{°F}\ . \quad (76)$$

The GFSSP predicted nozzle throat temperature is 819.9 °F. This temperature compares well, within 3%, with the value calculated from equation (76).

The isentropic steam nozzle model represents a reversible process in which no entropy is generated. In an actual steam nozzle there will be frictional losses that result in an increase in entropy. To demonstrate GFSSP's ability to predict the irreversibility (entropy generation) of a process, the isentropic steam nozzle model was modified to allow for frictional losses. The branch resistance option for each model branch was changed from option 2 with a $C_L = 0$, to option 1 using the branch lengths and diameters shown in figure 107 and assuming an absolute roughness of 0.01 in.

Figure 110 shows a temperature/entropy comparison between the GFSSP isentropic steam nozzle model and the GFSSP steam nozzle model with frictional losses. As one can see in the referenced figure, the isentropic model predicts no change in entropy through the nozzle while the irreversible process predicts an increase in entropy of 0.019 Btu/(lbm °R).

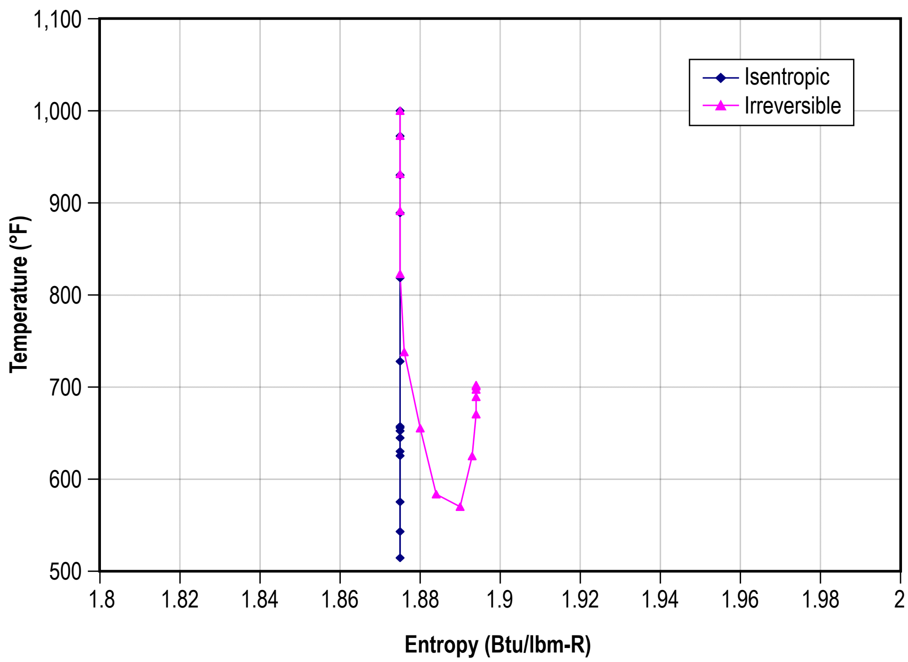

Figure 110. Temperature/entropy plot comparing the isentropic steam nozzle with an irreversible process.

6.4 Example 4—Simulation of the Mixing of Combustion Gases and a Cold Gas Stream

6.4.1 Problem Considered

In the previous examples, the fluid systems that were considered employed a single fluid. In this example, simulation of multiple fluids in a mixing process are considered. The MIXTURE logical option in the code to simulate the mixing of combustion gases and a cold gas stream by utilizing the flow system shown is demonstrated in figure 111. A mixture of hot combustion products, consisting of water vapor and oxygen, is mixed with cooler oxygen gas. The mixture temperature and composition are required to be calculated.

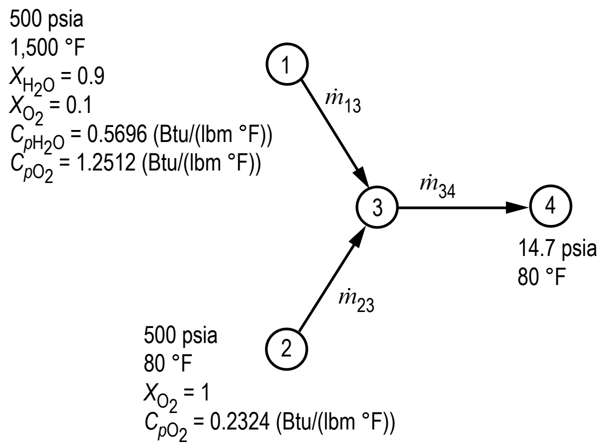

Figure 111. Mixing problem schematic (example 4).

A mixture consisting of 90% water vapor and 10% oxygen (by mass) at 500 psia and 1,500 °F mixes with pure oxygen at 500 psia and 80 °F. GFSSP is desired to predict the flow rate, mixture temperature, and composition of the mixture. A hand calculation of the mixture temperature and the composition of the mixture will also be performed to verify GFSSP's predictions.

6.4.2 GFSSP Model

The mixing chamber shown in figure 111 can be simulated with a GFSSP model consisting of four nodes and three branches as shown in figure 112. Nodes 1, 2, and 4 are the boundary nodes representing the inlet and outlet of the mixing chamber and node 3 is the internal node representing the mixing chamber. Branches 13 and 23 are represented by option 2 using a flow coefficient of 0.6 and area of 1 in^2. Branch 34 also uses a flow coefficient of 0.6 and area of 1 in^2, but it is modeled using option 22. The reason option 22 is used for branch 34 is to account for the possibility of choked flow in the branch.

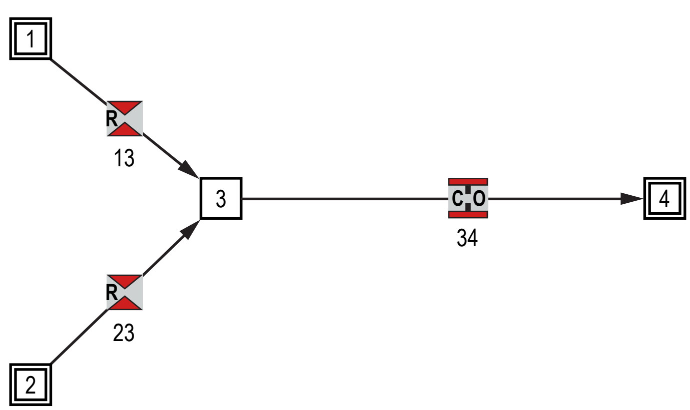

Figure 112. GFSSP model of mixing problem.

The input and output files of this example are included in appendix K as ex4.dat and ex4.out. The predicted flow rates in branches 13, 23, and 34 are 1.16, 3.10, and 4.26 lbm/s, respectively. The predicted temperature at the outlet of the mixing chamber, node 3, is 689 ºF and the composition is 24.47% water vapor and 75.53% oxygen. The mixture will not vary between nodes 3 and 4.

Now, verification of the predicted results will be done by performing hand calculations of the mixing process. The temperature of the mixture can be calculated from the energy conservation equation written for the mixing chamber. The energy conservation equation for node 3 can be written as:

$$x_{H_2O}\,\dot{m}_{13}\,C_{p,H_2O}\,T_1 + x_{O_2}\,\dot{m}_{13}\,C_{p,O_2}T_1 + \dot{m}_{23}\;C_{p,O_2}\,T_2 = \dot{m}_{34}C_{p,\text{mix}}T_3 \;. \tag{77}$$

The above equation can be rearranged to find T_3:

$$T_3 = \frac{x_{H_2O}\dot{m}_{13}C_{p,H_2O}T_1 + x_{O_2}\dot{m}_{13}C_{p,O_2}T_1 + \dot{m}_{23}\,C_{p,O_2}T_2}{\dot{m}_{34}C_{p,\text{mix}}}$$

$$= \frac{(0.9)(1.16\text{ lb/s})(0.5696\text{ Btu/lb-ºR})(1{,}960\text{ ºR}) + (0.1)(1.16\text{ lb/s})(1.2512\text{ Btu/lb-ºR})(1{,}960\text{ ºR})}{(4.26\text{ lb/s})(0.3757\text{ Btu/lb-ºR})}$$

$$+\frac{(3.1\text{ lb/s})(0.2324\text{ Btu/lb-ºR})(540\text{ ºR})}{(4.26\text{ lb/s})(0.3757\text{ Btu/lb-ºR})} = 1{,}149.1\text{ ºR or }689.5\text{ ºF}. \tag{78}$$

Equation (78) calculates the temperature to be 689.5 ºF, which compares well with the GFSSP prediction of 688.6 ºF.

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

$$X_{3,H_2O} = \frac{X_{1,H_2O}\;\dot{m}_{13}}{\dot{m}_{34}} = \frac{(0.9)(1.16\text{ lb/s})}{4.26\text{ lb/s}} = 0.2451 \tag{79}$$

and

$$X_{3,O_2} = \frac{X_{1,O_2}\;\dot{m}_{13} + \dot{m}_{23}}{\dot{m}_{34}} = \frac{(0.1)\left(1.16\text{ lb/s}\right) + 3.1\text{ lb/s}}{4.26\text{ lb/s}} = 0.7549\;. \tag{80}$$

The concentration of water vapor and oxygen from the above equations are 0.2451 and 0.7549, respectively, which also compares well with the GFSSP predictions.

6.5 Example 5—Simulation of a Flow System Involving a Heat Exchanger

6.5.1 Problem Considered

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

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

A simple counter flow heat exchanger system configuration, as shown in figure 113, was chosen for this example. As shown in figure 113, counter flow occurs when the hot branch of the heat exchanger has flow that is propagating in a direction opposite of the cold branch. This counter flow heat exchanger configuration consists of hot water, at 50 psi and 100 °F, flowing through 10 in of 0.25-in inner diameter pipe, through a 10-in-long heat exchanger and out through another 10-in-long section of 0.25-in inner diameter pipe at 25 psi. Also, cold water, at 50 psi and 60 °F flows through a 10-in section of 0.5-in inner diameter pipe, through the heat exchanger, and out through another 10-in section of 0.5-in inner diameter pipe at 25 psi. All of the pipes are assumed to have an absolute roughness of zero. At the conditions described above, $C_p = 0.9978$ Btu/lbm-°R is calculated for the hot water and $C_p = 1.0014$ Btu/lbm-°R is calculated for the cold water.

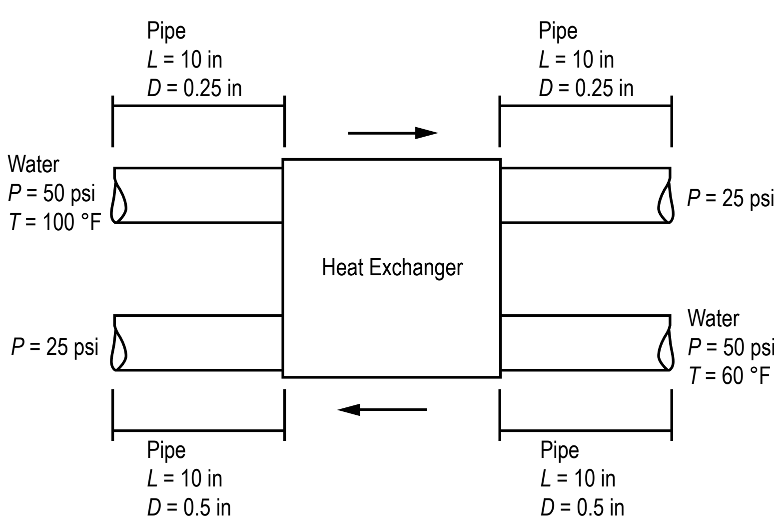

Figure 113. Flow system schematic of a heat exchanger (example 5).

6.5.2 GFSSP Model

A GFSSP model consisting of eight nodes and six branches can represent the counter flow heat exchanger system shown in figure 113. This model is shown in figure 114(a). Nodes 1, 4, 5, and 8 are boundary nodes. Nodes 1 and 5, the inlet boundary nodes for the hot and cold flow, respectively, both have a pressure of 50 psi. In addition, the boundary temperature at node 1 is 100 ºF while the boundary temperature at node 5 is 60 ºF. Nodes 4 and 8, which are the downstream boundary nodes for the hot and cold flow, both have a boundary pressure of 25 psi. Downstream boundary temperatures are not used in GFSSP calculations so 'dummy' temperature values of 80 and 70 ºF are used for the hot and cold flow downstream boundary nodes. Nodes 2 and 6 are internal nodes that represent the entrances to the heat exchanger for the hot and cold flow, respectively. In the same manner, nodes 3 and 7 are internal nodes that represent the hot and cold flow heat exchanger exits. Branches 12, 34, 56, and 78 represent the pipes leading into and out of the heat exchanger for both the hot and cold flows. Finally, branches 23 and 67 represent the hot and cold sides of the heat exchanger. Figure 114(b) shows how this model appears in VTASC.

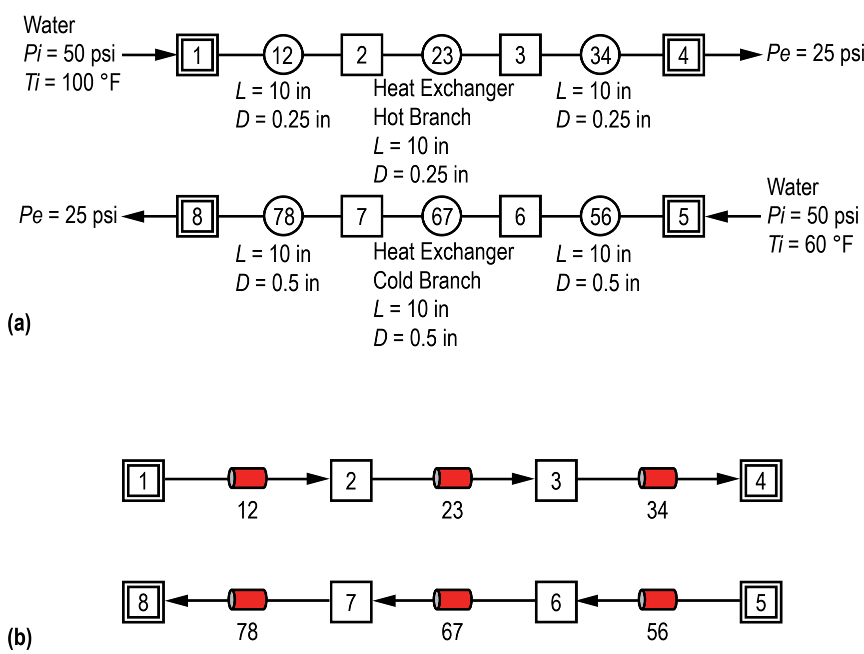

Figure 114. GFSSP model of the heat exchanger: (a) Detailed schematic and (b) VTASC model.

6.5.2.1 Branches 12, 34, 56, and 78 (Pipe Lines). Option 1 was used to represent each of the pipe sections in the heat exchanger model. The user is required to provide the length, inner diameter, and relative roughness factor (ε/D) for this branch resistance option.

6.5.2.2 Branches 23 and 67 (Heat Exchanger). Option 1 was also used to simulate the two heat exchanger branches. In addition to providing the length, inner diameter, and ε/D for the two branches, the user must designate additional information in the Heat Exchanger dialog window shown in figure 115. First, the user must add a heat exchanger using the Add button. Next, the user must input which branch represents the hot flow side of the exchanger and which branch represents the cold flow side of the exchanger. Also, the user may either designate an effectiveness between zero and 1 or enter an effectiveness >1 and designate the type of heat exchanger in the system and a value for UA. UA is the product of the overall conductance for heat transfer and the surface area on which that conductance is based.

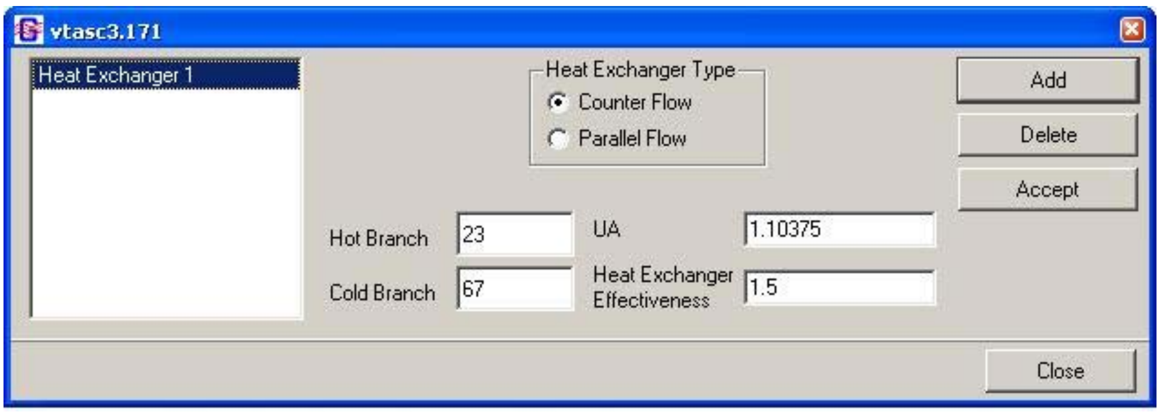

Figure 115. VTASC Heat Exchanger dialog.

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

The first area of interest is the counter flow heat exchanger effectiveness calculations. During the GFSSP preprocessor input, a value for UA and an effectiveness are input to define the heat exchanger's characteristics. For these verifications, a value for UA was assumed with the following process. It was assumed that the heat exchanger had an effectiveness of $\varepsilon = 0.7$. A GFSSP model was run with that effectiveness to obtain the mass flow rates. The mass flow rate for the cold branch was calculated to be 5.41 lbm/s and the flow rate for the hot branch was calculated to be 0.885 lbm/s. Then, equations (81) and (82) were used to calculate the hot and cold fluid capacity rates:[24]

$$C_h = \left(\dot{m}\, C_p\right)_{\text{hot branch}} = (0.885\ \text{lbm/s})(0.9978\ \text{Btu/lbm}-{}^{\circ}\text{R}) = 0.883\ \text{Btu/s-}{}^{\circ}\text{R} \tag{81}$$

and

$$C_c = \left(\dot{m}\, C_p\right)_{\text{cold branch}} = (5.41\ \text{lbm/s})(1.0014\ \text{Btu/lbm}-{}^{\circ}\text{R}) = 5.418\ \text{Btu/s-}{}^{\circ}\text{R}\ . \tag{82}$$

Based on the previously calculated values, $C_{max} = C_c$ and $C_{min} = C_h$. For the counter flow heat exchanger case, it was assumed that C_{max}, C_{min}, and ε would remain the same as the values above. Next, a counter flow exchanger performance table was used, along with the previously calculated values, to estimate the number of heat transfer units, $N_{tu} = 1.25$, for the counter flow exchanger.[24] Then equation (83) was used to calculate UA in equation (84):[24]

$$N_{tu} = \frac{\text{UA}}{C_{\min}} \tag{83}$$

and

$$\text{UA} = N_{tu}C_{\min} = (1.25)(0.883\ \text{Btu/s-°R}) = 1.10375\ \text{Btu/s-°R}\ . \tag{84}$$

A value >1 was used for the effectiveness, which instructed GFSSP to calculate the effectiveness instead of employing a user input value. For this case, the counter flow heat exchanger option was chosen. Figure 116 shows the predicted temperatures and mass flow rates from this model.

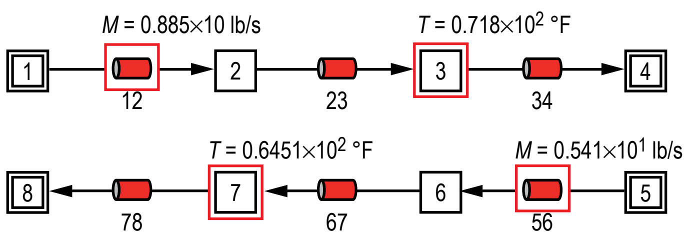

Figure 116. Temperature and flow rate predictions in heat exchanger.

The mass flow rates predicted by this model (0.885 lbm/s at branch 12 and 5.41 lbm/s at branch 56) were the same as predicted for the counter flow exchanger that was used for the assumed case. Therefore, C_c and C_h remained the same. The heat exchanger effectiveness is not included in the data written to the GFSSP output file so it was necessary to calculate the effectiveness that GFSSP used. GFSSP's effectiveness was calculated using equation (85):[24]

$$\varepsilon = \frac{C_h\left(T_{h,\text{in}} - T_{h,\text{out}}\right)}{C_{\min}\left(T_{h,\text{in}} - T_{c,\text{in}}\right)} = \frac{C_c\left(T_{c,\text{out}} - T_{c,\text{in}}\right)}{C_{\min}\left(T_{h,\text{in}} - T_{c,\text{in}}\right)}$$

$$\varepsilon = \frac{(0.883\ \text{Btu/s-°R})(560\ \text{°R} - 531.8\ \text{°R})}{(0.883\ \text{Btu/s-°R})(560\ \text{°R} - 520\ \text{°R})} = 0.705\,. \tag{85}$$

For comparison, a hand-calculated counter flow effectiveness was determined using equation (86):[24]

$$\varepsilon = \frac{1-e^{-N_{tu}\left(1-C_{\min}/C_{\max}\right)}}{1-\left(C_{\min}/C_{\max}\right)e^{-N_{tu}\left(1-C_{\min}/C_{\max}\right)}}$$

$$\varepsilon = \frac{1-e^{-1.25\left(1-\left(\frac{0.883\ \text{Btu/s-°R}}{5.418\ \text{Btu/s-°R}}\right)\right)}}{1-\left(\frac{0.883\ \text{Btu/s-°R}}{5.418\ \text{Btu/s-°R}}\right)e^{-1.25\left(1-\frac{0.883\ \text{Btu/s-°R}}{5.418\ \text{Btu/s-°R}}\right)}} = 0.688\,. \tag{86}$$

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

The second area of interest is the accuracy of GFSSP's temperature predictions at the nodes downstream of the hot and cold heat exchanger branches. Equation (85) was manipulated to come up with equations (87) and (88) which were used to hand-calculate $T_{h,\text{out}}$ and $T_{c,\text{out}}$:[24]

$$T_{h,\text{out}} = T_{h,\text{in}} - \frac{C_{\min}\left(T_{h,\text{in}} - T_{c,\text{in}}\right)\varepsilon}{C_h}$$

$$T_{h,\text{out}} = 560\ \text{°R} - \frac{(0.883\ \text{Btu/s-°R})(560\ \text{°R} - 520\ \text{°R})\,(0.688)}{(0.883\ \text{Btu/s-°R})} = 532.48\ \text{°R} = 72.48\ \text{°F} \tag{87}$$

and

$$T_{c,\text{out}} = T_{c,\text{in}} + \frac{C_{\min}\left(T_{h,\text{in}} - T_{c,\text{in}}\right)\varepsilon}{C_c}$$

$$T_{c,\text{out}} = 520\ \text{°R} - \frac{(0.883\ \text{Btu/s-°R})(560\ \text{°R}-520\ \text{°R})\,(0.688)}{(5.418\ \text{Btu/s-°R})} = 524.49\ \text{°R} = 64.49\ \text{°F}\ . \tag{88}$$

Comparing the hand-calculated values with GFSSP's temperature results of 71.8 °F at node 3 and 64.51 °F at node 7 in figure 116 shows very good agreement, verifying the heat exchanger temperature calculation process used by the GFSSP code.

6.6 Example 6—Radial Flow on a Rotating Radial Disk

6.6.1 Problem Considered

This example illustrates the rotational effect (centrifugal force contribution) capability of GFSSP by modeling the flow of water through a closed impeller.[41] The impeller has an 11-in diameter, uses water as the operating fluid, and is running at 5,000 rpm. The 'slip' of the fluid is described by the rotational K-factor (K_{rotation}). K_{rotation} is defined as the ratio of the mean circumferential fluid speed divided by the impeller speed: ($K_{\text{rotation}} = u_\theta\ / r\omega$). (Higher K_{rotation} factors translate to a higher pressure rise for radially outward flow.) A K_{rotation} for each side of the impeller has been proposed and it is the purpose of this example to validate these K_{rotation} correlations. The proposed correlations are ($K_{\text{front face}} = 0.8455 - 0.1403(r - r_i / r_o - r_i)$ for the front face; ($K_{\text{back face}} = 0.8857 - 0.1762(r - r_i / r_o - r_i)$ for the back face. It is desired to compare the results with experimental data. The impeller is schematically shown in figure 117. For this example, the effects of friction will be neglected for the rotating branches.

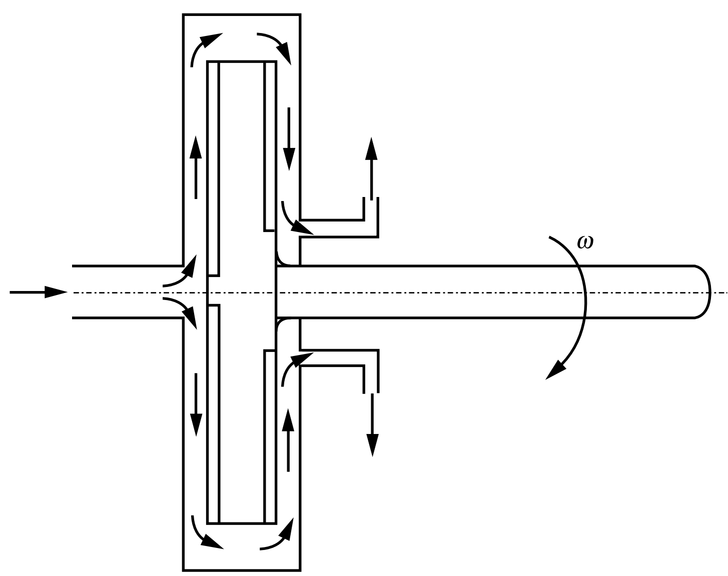

Figure 117. Flow schematic of a rotating radial disk (example 6).

6.6.2 GFSSP Model

The GFSSP model circuit is shown in figure 118. All branches are modeled using option 2. In the model, branches 23, 34, 45, 56, 67, 89, 910, 1011, and 1112 are rotating at 5,000 rpm. The inlet and outlet radii are defined in the preprocessor for each of the rotating branches. The area of each of the radial branches is calculated as the average cross-sectional area for each branch, $\left(A_{\text{branch }ab} = 1/r_b - r_a \int_a^b 2\pi r dr\right)$. Figure 118(b) shows how this model appears in VTASC.

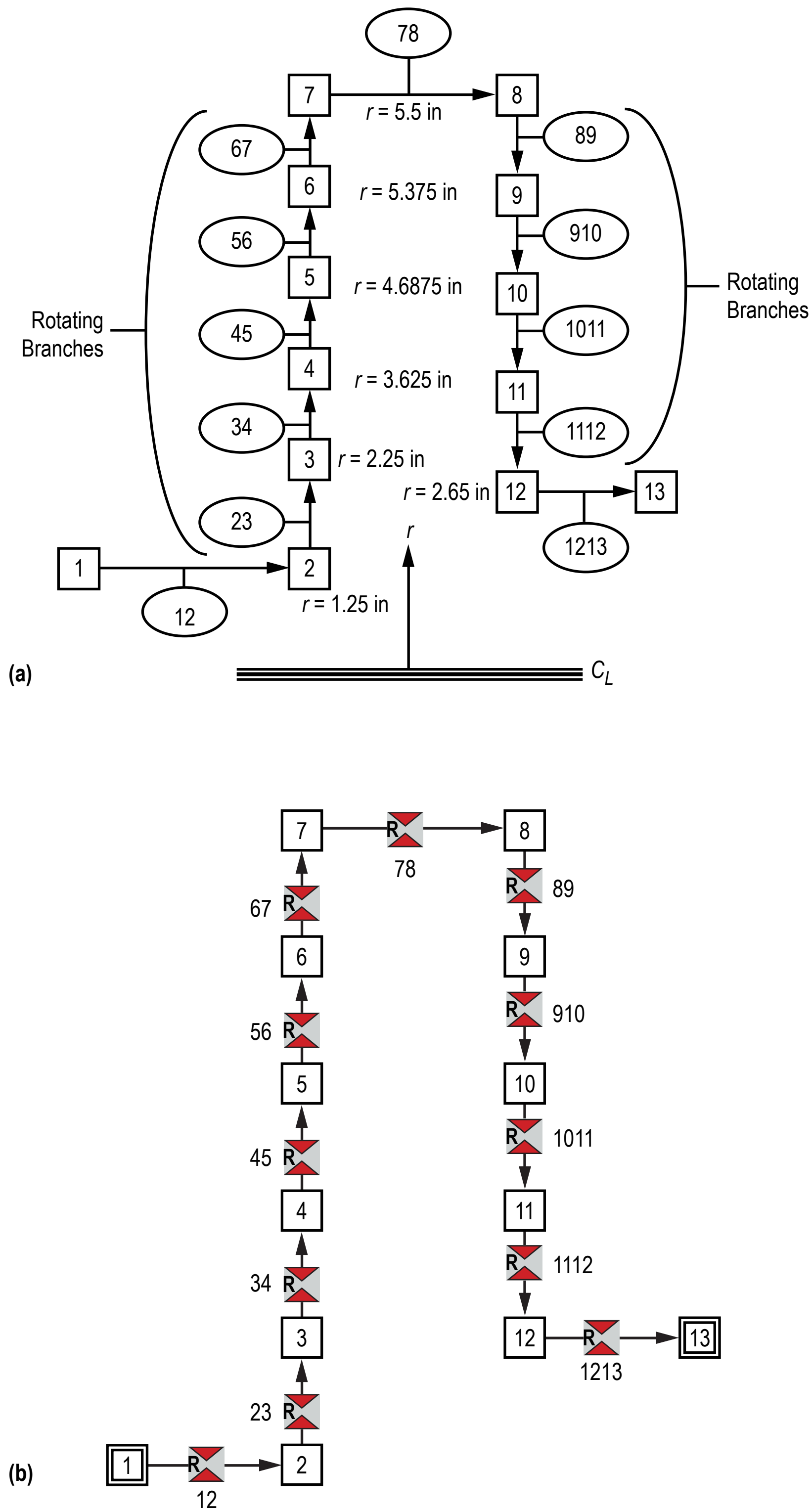

Figure 118. GFSSP model of the rotating radial disk: (a) Detailed schematic and (b) VTASC model.

6.6.3 Results

The example 6 GFSSP input and output data files (ex6.dat and ex6.out) are included in appendix M.

The pressure distribution predicted by GFSSP for the front and back faces of the impeller is shown in figure 119. As is seen in figure 119, the model results show excellent agreement with the experimental data.

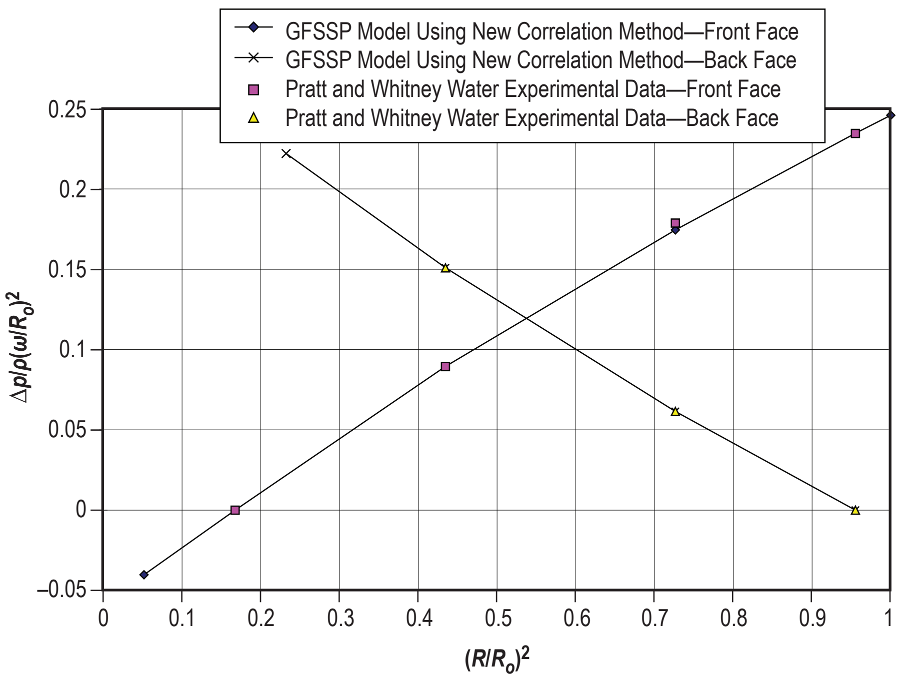

Figure 119. Comparison of GFSSP model results with experimental data.

6.7 Example 7—Flow in a Long-Bearing Squeeze Film Damper

6.7.1 Problem Considered

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

The squeeze film damper considered for this example is shown schematically in figures 120 and 121. Since the damper has sealed ends, the axial flow is neglected. The diameter (d) of the bearing is 5 in, the width (w) of the bearing is 0.94 in, the clearance (c) is 0.0625 in, and the ratio of the dynamic eccentricity (ε, radius of orbit to the clearance) is 0.82. The fluid density (ρ) is 57.806 lbm/ft^3. The fluid viscosity (μ) is 5.932×10^{-3} lbm/(ft•s). The running speed (ω) is set at 1,770 rpm (ω= 185.354 radians/s). GFSSP will be used to determine the pressure distribution around the damper and the results will be compared with experimental data.[42]

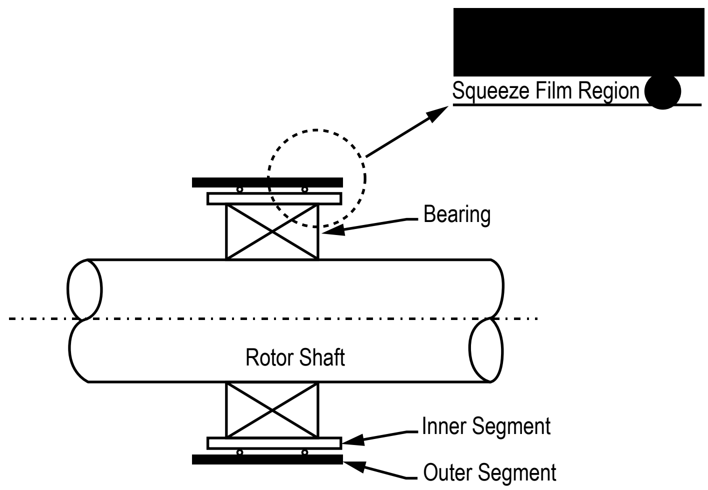

Figure 120. Squeeze film damper schematic (example 7, view 1).

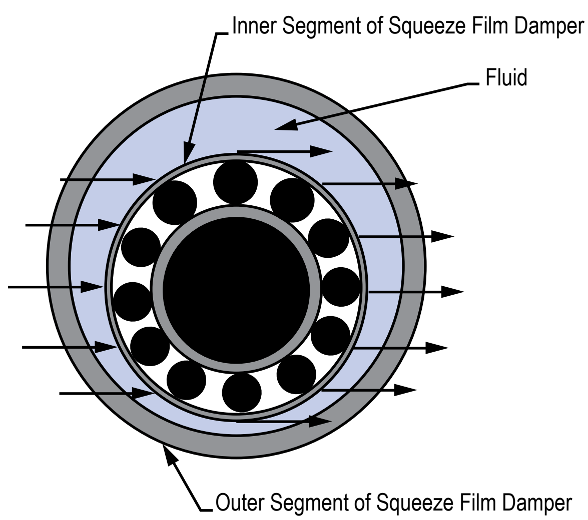

Figure 121. Squeeze film damper schematic (example 7, view 2).

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6.7.2 GFSSP Model

A GFSSP model consisting of 20 nodes and 19 branches can approximate the fluid contained within the squeeze film damper system shown in figures 120 and 121. The fluid to be used is not contained in the standard library of fluids and is assumed to be incompressible; therefore, the constant density feature of GFSSP must be used. In order to model the squeeze film damper, the damper will be 'unwrapped.' Figure 122 shows the unwrapping of the damper and the discretization of the flow region. The GFSSP model is shown in figure 123. As is shown in figure 123, nodes 1 and 20 are the boundary nodes. The branches will use branch resistance option 3—Non Circular Duct, Sub-option 1 - Rectangular Duct. The heights of the branches are given in table 24. The motion of the inner element will be simulated using the moving boundary option in GFSSP. (Only the motion of the damper normal to the inner element is modeled in this technique.) The velocity of the moving boundary is given in table 25. Setting the boundary nodes at the same pressure will simulate the periodic behavior of the damper. The boundary pressure is set at 0.0 psi.

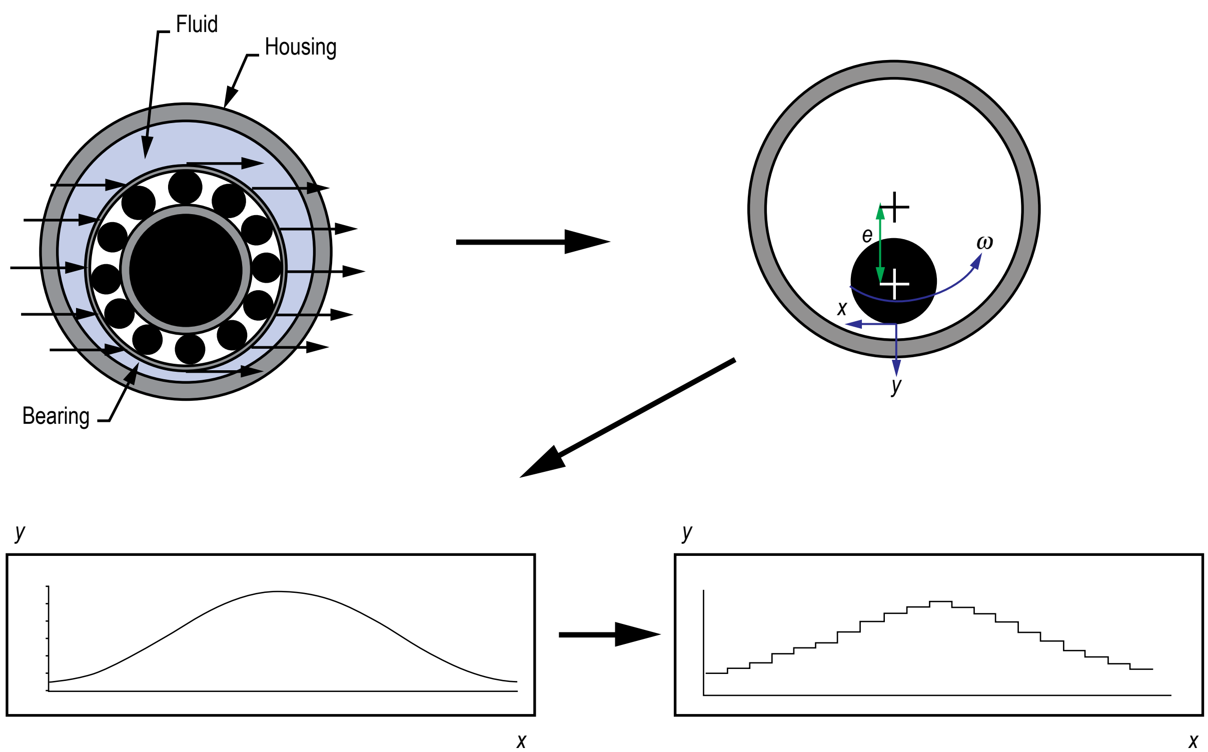

Figure 122. Unwrapping and discretization of squeeze film damper.

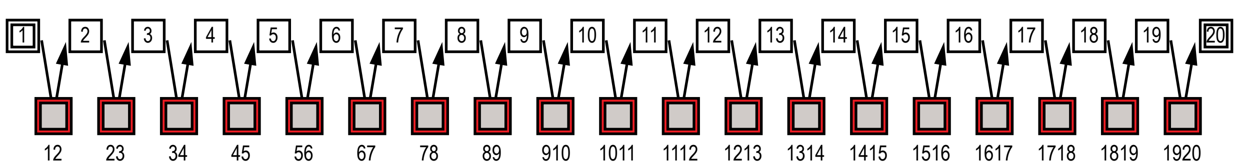

Figure 123. GFSSP model of squeeze film damper.

Table 24. Branch dimensions of squeeze film damper.

Branch Number	Width (in)	Length (in)	Height (in)
12	0.94	0.82673	0.012578
23	0.94	0.82673	0.017987
34	0.94	0.82673	0.028221
45	0.94	0.82673	0.042169
56	0.94	0.82673	0.05832
67	0.94	0.82673	0.074925
78	0.94	0.82673	0.090183
89	0.94	0.82673	0.102441
910	0.94	0.82673	0.11037
1011	0.94	0.82673	0.113113
1112	0.94	0.82673	0.11037
1213	0.94	0.82673	0.102441
1314	0.94	0.82673	0.090183
1415	0.94	0.82673	0.074925
1516	0.94	0.82673	0.05832
1617	0.94	0.82673	0.042169
1718	0.94	0.82673	0.028221
1819	0.94	0.82673	0.017987
1920	0.94	0.82673	0.012578

Table 25. Moving boundary information of squeeze film damper.

Node	Normal Area (in^2)	Velocity (ft/s)
2	0.777126	0.25618
3	0.777126	0.484598
4	0.777126	0.660503
5	0.777126	0.764832
6	0.777126	0.78628
7	0.777126	0.722522
8	0.777126	0.580468
9	0.777126	0.37551
10	0.777126	0.129861
11	0.777126	–0.129861
12	0.777126	–0.37551
13	0.777126	–0.580468
14	0.777126	–0.722522
15	0.777126	–0.78628
16	0.777126	–0.764832
17	0.777126	–0.660503
18	0.777126	–0.484598
19	0.777126	–0.25618

6.7.3 Results

The example 7 GFSSP input and output data files (ex7.dat and ex7.out) are included in appendix N.

The pressure distribution predicted by GFSSP is shown in figure 124. The plot of pressure versus angle (i.e., node position) in figure 124 shows that the pressure is symmetric about the boundary pressure of zero psi. The model results are compared to experimental results in figure 125. In figure 125, the pressure is normalized with a characteristic pressure (CpRe) and the angle has been converted to compare to a dimensionless time (*wt*) for comparison with the experimental data. As seen in figure 125, the pressure profile of the GFSSP model compares favorably with the experimental results in shape and magnitude; the only major difference between the two results is a phase shift.

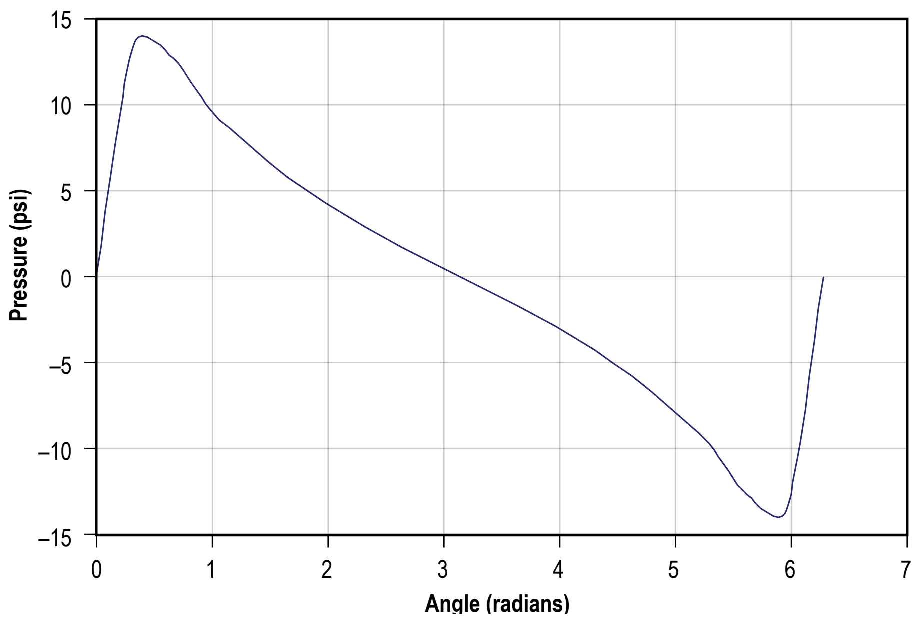

Figure 124. Predicted circumferential pressure distributions in the squeeze film damper.

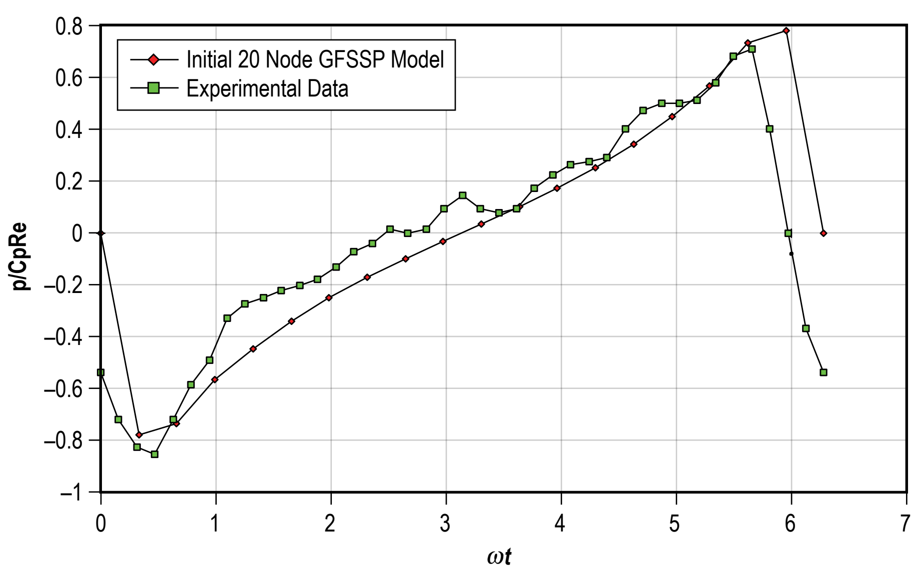

Figure 125. Comparison of GFSSP model results with experimental data or squeeze film damper.

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6.8 Example 8 —Simulation of the Blowdown of a Pressurized Tank

6.8.1 Problem Considered

In the previous examples, the simulation of steady state flow in a given flow circuit was considered. In this example, the capabilities of the unsteady flow formulation of GFSSP to simulate the process of blowing down a pressurized tank will be deployed.

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

6.8.2 GFSSP Model

The physical schematic for example 8 is shown in figure 126(a) and a schematic of the corresponding GFSSP model is shown in figure 126(b). Figure 126(c) shows how the model looks in VTASC. The venting process can be modeled with two nodes and one branch. Node 1 is an internal node that represents the tank. For the unsteady formulation, the node volume and the initial conditions must be supplied for each internal node and a history file must be supplied for each boundary node. The history file contains the pressures, temperatures, and concentrations at discrete times. At a minimum, this file should include values at the process start time and at some time corresponding to the expected process stop time. Additional times can be included to account for nonlinear variation in the values if required. The code interpolates in the history file data to determine the values for a particular instant. Shown below is a listing of EX8HS2.DAT, which is the history file of example 8, used to provide the boundary conditions for node 2. The file listing has been annotated to explain the meaning of the entries.

```
EX8HS2.DAT

      2 - Number of data points
      tau(sec)     p(psia)     T (°F)     Concentration
      0            14.700      80.00      1.00
      1000         14.700      80.00      1.00
```

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

The initial pressure within the tank (node 1) was 100 psia. Resistance option 22 was used for branch 12 with a flow coefficient of 1. Air is modeled using the ideal gas option that is available in VTASC.

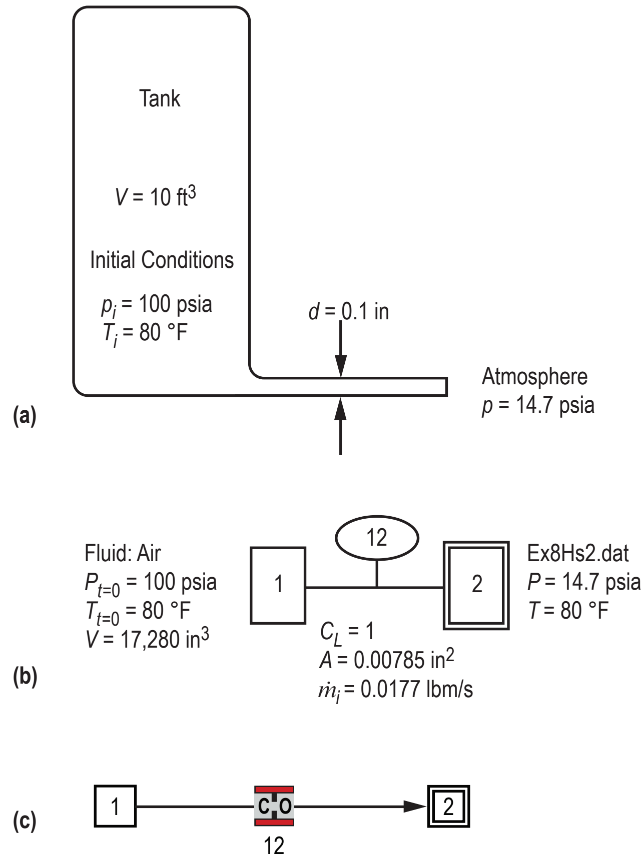


Figure 126. Venting air tank schematics: (a) Physical schematic, (b) detailed model schematic, and (c) VTASC model.

As an interesting note, this example could be used to model an isothermal process by using the SORCEQ User Subroutine. The temperature of the fluid remains constant in an isothermal process. In this example it is presumed that initially the air and tank wall are at the same temperature. During blowdown, the air temperature tends to drop. With heat transfer from the wall, temperature drop would be less compared to an isentropic process. For an isothermal process, there will be no change in temperature. This particular situation (isothermal) can be modeled by setting an infinite heat transfer coefficient between the wall and fluid in SORCEQ.

6.8.3 Results

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

6.8.3.1 Analytical Solution. The differential equation governing an isentropic blowdown process can be written as:

$$\left(\frac{p}{p_i}\right)^{(1-3\gamma)/2\gamma} \frac{d\left(p\,/\,p_i\right)}{d\tau} = \frac{\gamma A}{\rho_i V}\sqrt{\gamma g_c p_i \rho_i}\left(\frac{2}{\gamma+1}\right)^{(\gamma+1)/2(\gamma-1)} . \tag{89}$$

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

$$\tau = 0,\ \frac{p}{p_i} = 1 . \tag{90}$$

The analytical solution for p/p_i is given by Moody[43] as:

$$\frac{p}{p_i} = \left[1+\left(\frac{\gamma-1}{2}\right)\left(\frac{2}{\gamma+1}\right)^{(\gamma+1)/2(\gamma-1)}\sqrt{\frac{\gamma g_c p_i}{\rho_i}}\,\frac{A\tau}{V}\right]^{-2\gamma/(\gamma-1)} . \tag{91}$$

The analytical and GFSSP solutions are compared in figure 127. The figure shows a comparison between the GFSSP solution and the analytical solution of pressures. The difference in pressures is also shown plotted for three different time steps (1, 0.1, and 0.01 s). The discrepancies between analytical and numerical solutions are found to diminish with reduction in time step. This observation is in conformity with expectations.

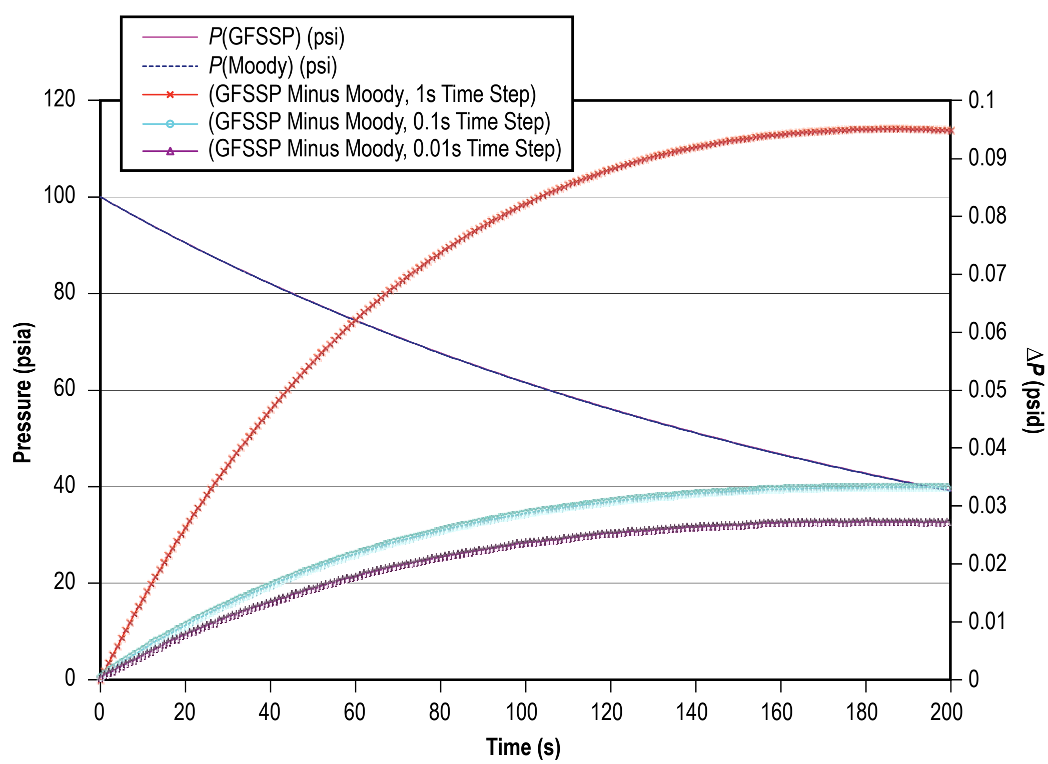


Figure 127. Comparison of the predicted pressure history by GFSSP and the analytical solution.

6.9 Example 9—A Reciprocating Piston-Cylinder

6.9.1 Problem Considered

This example further illustrates GFSSP's capability to model complex unsteady flow. Figure 128 shows the piston-cylinder configuration considered by this example problem. The cylinder has a diameter of 3 in. Within the cylinder is nitrogen gas, sealed in by a piston moving at a rotational speed of 1,200 rpm and a stroke of 3 in. GFSSP will be used to predict the pressure and temperature within the system and the results will be compared with the isentropic solution.

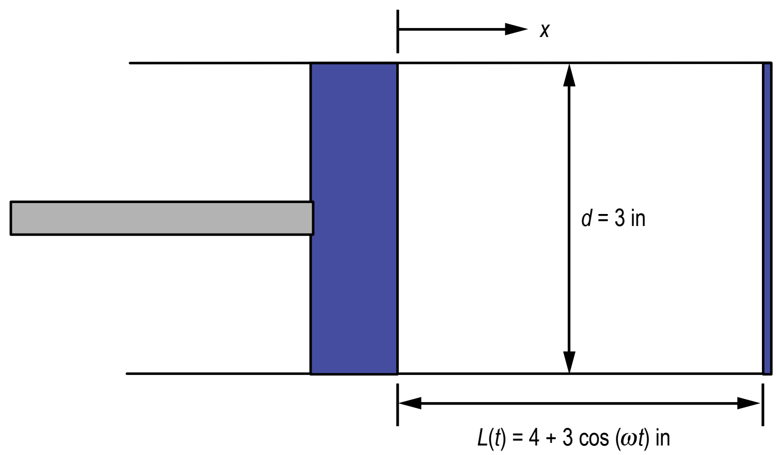


Figure 128. Piston-cylinder configuration.

6.9.2 GFSSP Model

In order to model this configuration, a coordinate transformation is utilized. In this new coordinate system, the endplate of the cylinder is modeled as another piston and the origin of the coordinate system is at the mid point between the two 'pistons.' Figure 129 demonstrates the modified piston-cylinder arrangement.

The GFSSP model of the piston-cylinder arrangement consists of two internal nodes and one branch (note: the model does not have any boundary nodes). Figure 130(a) shows the GFSSP piston-cylinder model. In order to model the motion of the piston, two special options are utilized: the moving boundary option and the variable geometry option. The moving boundary option is required to adequately model the work input by the motion of the pistons. The variable geometry option is required to model the variation of the geometry of branch 12. The initial condition of the nitrogen in the cylinder is 14.7 psia and 75 °F. Figure 130(b) shows how the model looks in VTASC.

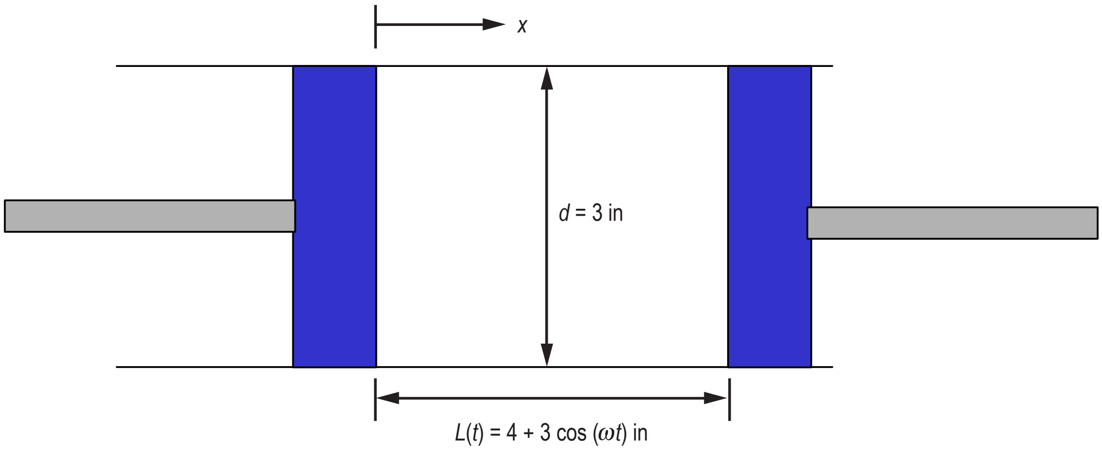


Figure 129. Coordinate transformed piston-cylinder configuration.

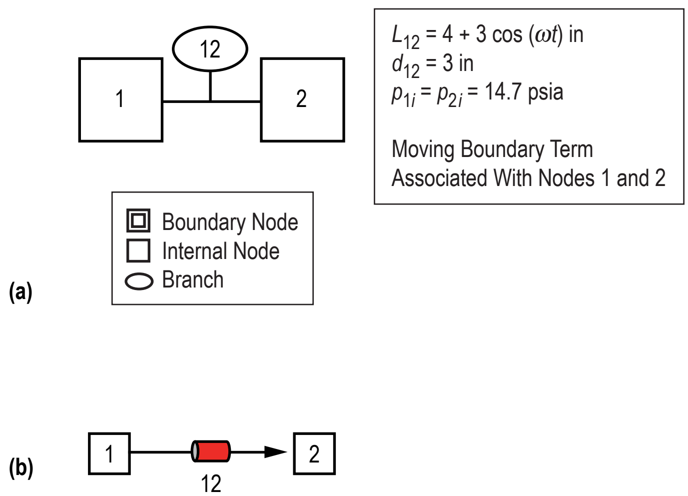


Figure 130. GFSSP model of the piston-cylinder: (a) Detailed model schematic and (b) VTASC model.

6.9.3 Results

Appendix P contains the input, variable geometry history, and output files for this example. The results of the study are compared to an analytical solution (for constant ratio of specific heat, γ). Equations (92) and (93) are used to obtain the analytical solution assuming an isentropic process:

$$T(t) = \left\{ \left(T_0 + 459.6\right) \left[\frac{\rho(t)}{\rho_0} \right]^{\gamma - 1} \right\} - 459.6 \tag{92}$$

and

$$p(t) = p_0 \left[\frac{\rho(t)}{\rho_0} \right]^{\gamma} , \tag{93}$$

where T_0, p_0, and ρ_0 are temperature, pressure, and density, respectively, at time equals zero.

Figures 131 and 132 compare the results of the GFSSP piston-cylinder model with the analytical solution from equations (92) and (93). As these figures illustrate, the GFSSP model compares favorably to the analytical solution. It should be noted that the isentropic solution uses a constant ratio of specific heats (γ), whereas GFSSP accounts for the variation of specific heat ratios with changes in temperature and pressure.

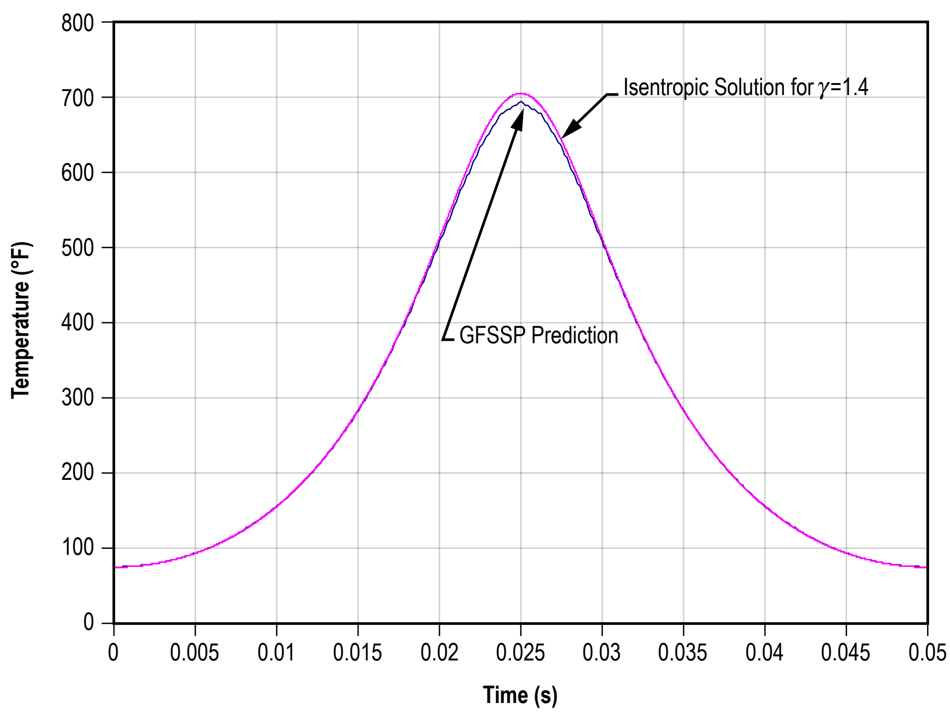


Figure 131. Predicted temperature history of piston-cylinder mode model.

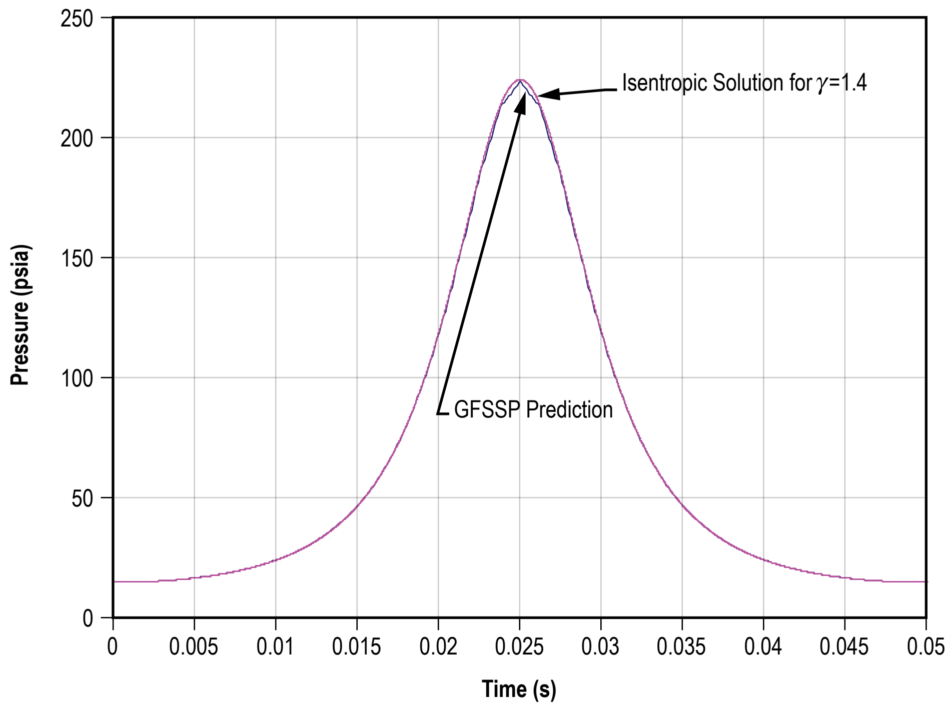


Figure 132. Predicted pressure history of piston-cylinder model.

6.10 Example 10—Pressurization of a Propellant Tank

6.10.1 Problem Considered

Example 8 demonstrates the use of GFSSP's unsteady formulation by predicting the pressure and temperature history during the blowdown of a pressurized tank. A more complex unsteady process will be considered in this example, the pressurization of a propellant tank.[32] This example will also illustrate the use of User Subroutines to construct a model of mass transfer due to evaporation of propellant to the ullage space.

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

(1) Change in ullage and propellant volume.
(2) Change in gravitational head in the tank.
(3) Heat transfer from pressurant to propellant.
(4) Heat transfer from pressurant to the tank wall.
(5) Heat conduction between the pressurant exposed tank surface and the propellant exposed tank surface.
(6) Mass transfer from propellant to ullage.

A schematic of a propellant pressurization system is shown in figure 133. It is assumed that initially the ullage space is filled with pressurant at propellant temperature. As the warm pressurant enters the ullage space, it mixes with the cold ullage gas and the temperature of the ullage gas starts to increase due to mixing and compression. Initially, the walls of the tank are also at propellant temperature. Heat transfer from the ullage gas to the propellant and the tank wall and mass transfer from the propellant to the ullage start immediately after the pressurant begins flowing into the tank. Propellant flows from the tank to the engine under the influence of ullage pressure and gravitational head in the tank. In the current model, condensation of propellant vapor has been neglected.

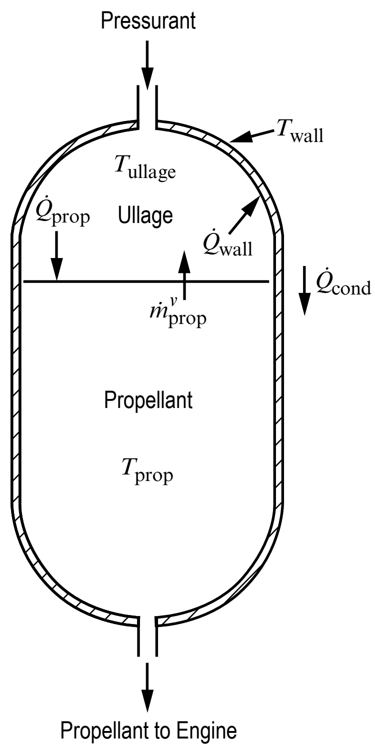


Figure 133. Schematic of propellant tank pressurization system.

6.10.2 GFSSP Model

A five-node pressurization system GFSSP test model, as shown in figure 134(a), was developed to test the implementation of the pressurization option. Helium at 95 psia and 120 °F enters the ullage space, which is initially filled with helium at 67 psia and –264 °F. Node 2 represents the ullage space, which has an initial volume of 25 ft^3. A pseudo boundary node (node 3) has been introduced to exert ullage pressure on the initial propellant volume of 475 ft^3, which is represented by node 4. The pressure at the pseudo boundary node is calculated from the ullage pressure and gravitational head and is the driving force to supply the propellant to the engine. This pressure is calculated at the beginning of each time step. Branch 12 models the tank inlet, branch 34 represents the propellant surface, and branch 45 represents the line to the engine. All three branches were modeled using a Flow Through a Restriction (option 2). The flow coefficient of branch 45 is adjusted to restrict the propellant flow such that all propellant is expelled from the tank over the course of the run. In this test model, the engine inlet pressure was set at 50 psia. Figure 134(b) shows how the model looks in VTASC. Figure 135 shows the VTASC tank pressurization dialog and inputs for example 10.

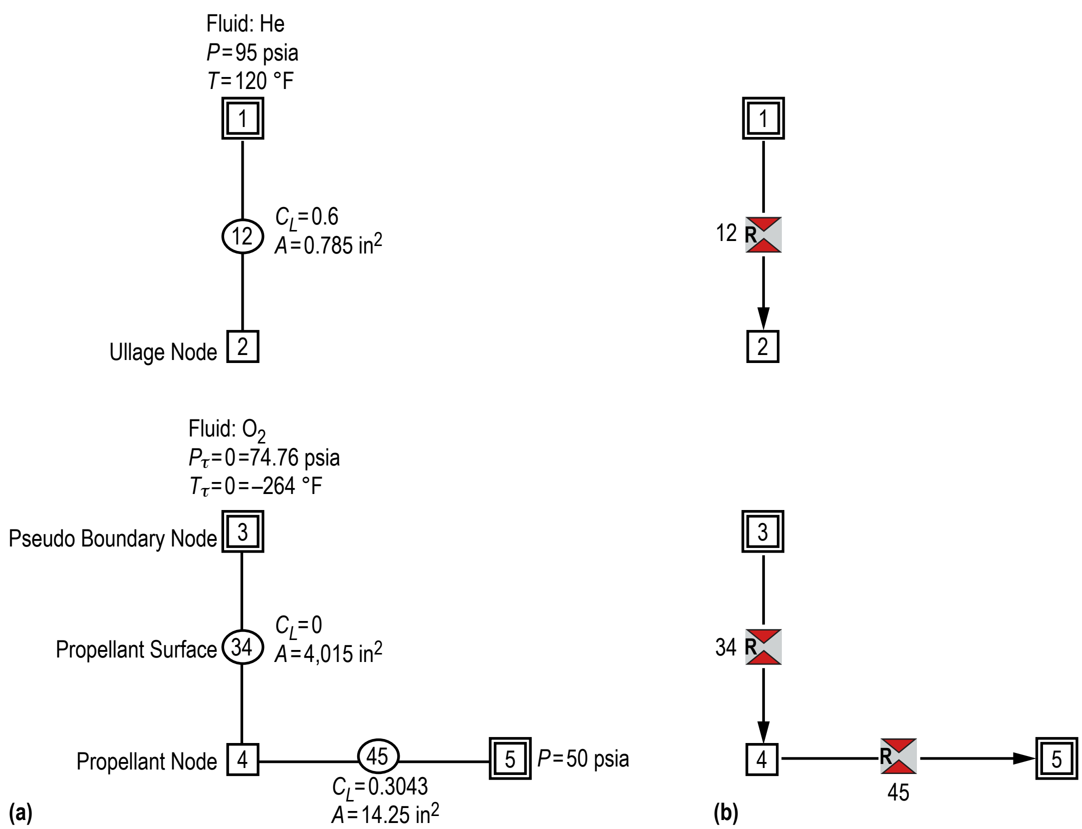


Figure 134. Simple pressurization system test model: (a) Detailed model schematic and (b) VTASC model.

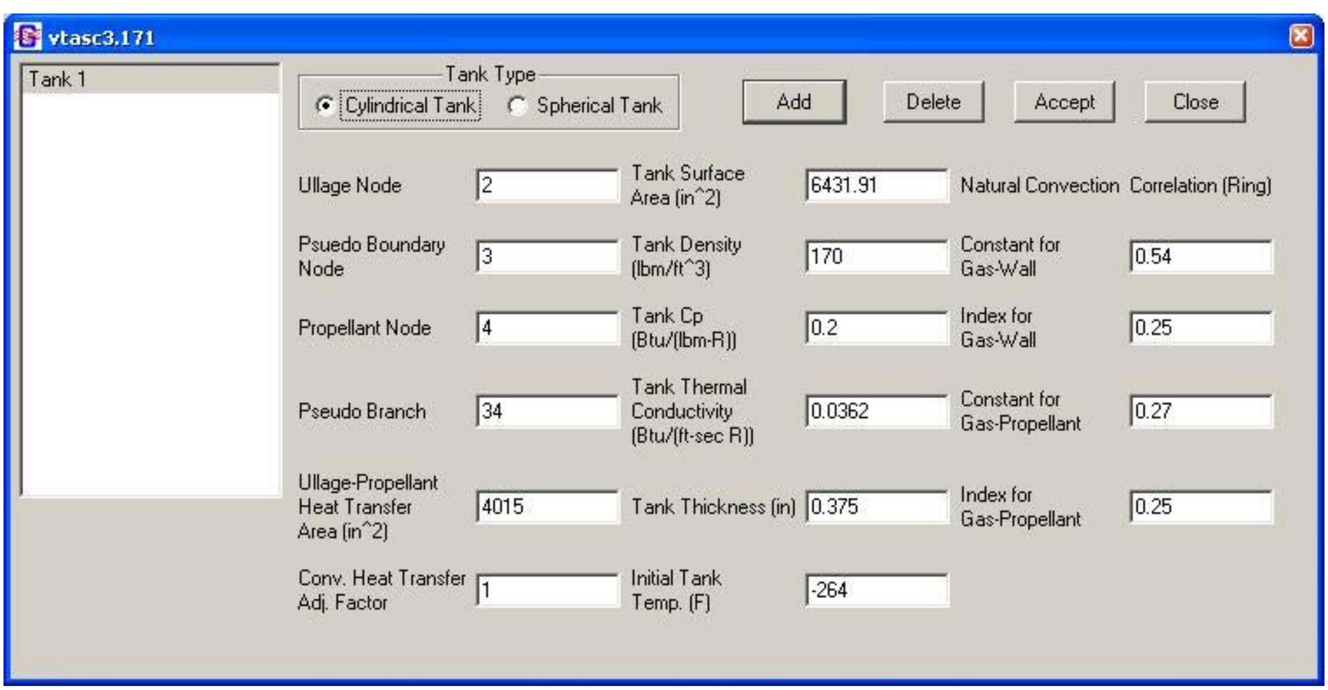


Figure 135. Example 10 tank pressurization dialog.

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

$$\dot{m}^{v}_{prop} = \frac{\dot{Q}_{prop}}{h_{fg} + c_{pf}\left(T_{sat} - T_{prop}\right)} \ . \tag{94}$$

The saturation temperature in equation (94) is calculated using the vapor pressure relation:

$$\ln p_{sat} = A + \frac{B}{T_{sat}} + C \ln T_{sat} + D T_{sat} \ , \tag{95}$$

where A, B, C, and D are fluid specific vapor pressure relation constants. Table 26 lists the values of the vapor pressure relation constants for the propellants considered in these routines.

Table 26. Vapor pressure relation constants.

Fluid	A	B	C	D
Oxygen	81.66	–2,857	–13.05	0.031
Nitrogen	67.79	–2,156	–10.97	0.0327
Hydrogen	11.4	–211.9	–1.228	0.0405
RP-1	–3,552	888,438	68.05	2.732

The enthalpy of vaporization in equation (94) is calculated using the Clapeyron equation:

$$h_{fg} = T_{sat}\left(v_g - v_f\right) \left.\frac{dP}{dT}\right|_{sat} \ , \tag{96}$$

where v_g is found using the Lee and Kesler modified BWR equation as described by Reid et al.[44] with the exception of RP-1, where v_g is calculated using the ideal gas equation. v_f is determined from the following correlation:

$$v_f = C_0 + C_1 T + C_2 T^2 + C_3 T^3 + \ldots \ , \tag{97}$$

where C_0, C_1, C_2, etc. are curve fit constants. It should be noted that in the case of RP-1, v_f is assumed to be constant at a value of 0.01923 ft^3/lbm. Table 27 lists the values of the correlation constants for the other propellants considered in these routines.

Table 27. Liquid specific volume correlation constants.

	Oxygen	Nitrogen	Hydrogen
C_0	–0.34614	–0.01204	–13.132
C_1	0.011286	0.00061	1.7962
C_2	–0.00013837	-4.23216×10^{-6}	–0.094964
C_3	8.2613×10^{-7}	1.06765×10^{-8}	0.002464
C_4	-2.4007×10^{-9}	–	-3.1377×10^{-5}
C_5	2.7247×10^{-12}	–	1.5712×10^{-7}

6.10.2.2 Subroutine SORCEC. This subroutine is called from subroutine MASSC. The purpose of this subroutine is to calculate the rate of mass transfer of propellant, $\dot{m}^{v}_{prop}$, in the ullage space due to evaporation. This subroutine can handle four liquid propellants, namely nitrogen, oxygen, hydrogen, and RP-1. For each fluid, the saturation temperature and enthalpy of evaporation were computed in subroutine SATPRP. SORCECON(IPUL,KFLU) is the source term of propellant specie in the ullage node and SORCEMAS is the mass source in the ullage node. The subroutine SATPRP calculates saturation temperature of the propellant at the prevailing ullage pressure. It employs a Newton-Raphson method to compute temperature from the vapor pressure relation shown in equation (95) It also calls subroutine BWR to calculate specific volumes of liquid and vapor at a given pressure and temperature. Finally, it calculates enthalpy of evaporation as given in equation (96).

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

6.10.3 Results

The User Subroutine input and output files including history files of example 10 have been attached in appendix Q. The pressurization system transient test model was run for 200 s with a 0.1-s time step.

Figure 136 shows both the ullage pressure and tank bottom pressure histories for the test model. After an initial pressure rise due to a 'ramping up' transient effect, both pressures begin a slow but steady decline for the remainder of the run. It should be noted that tank bottom pressure was calculated by adding ullage pressure with pressure due to the gravitational head. Figure 136 shows that as the gravitational head decreases, the ullage and tank bottom pressures slowly converge until all propellant is drained from the tank. The slow decline in ullage pressure is mainly due to the expanding ullage volume.

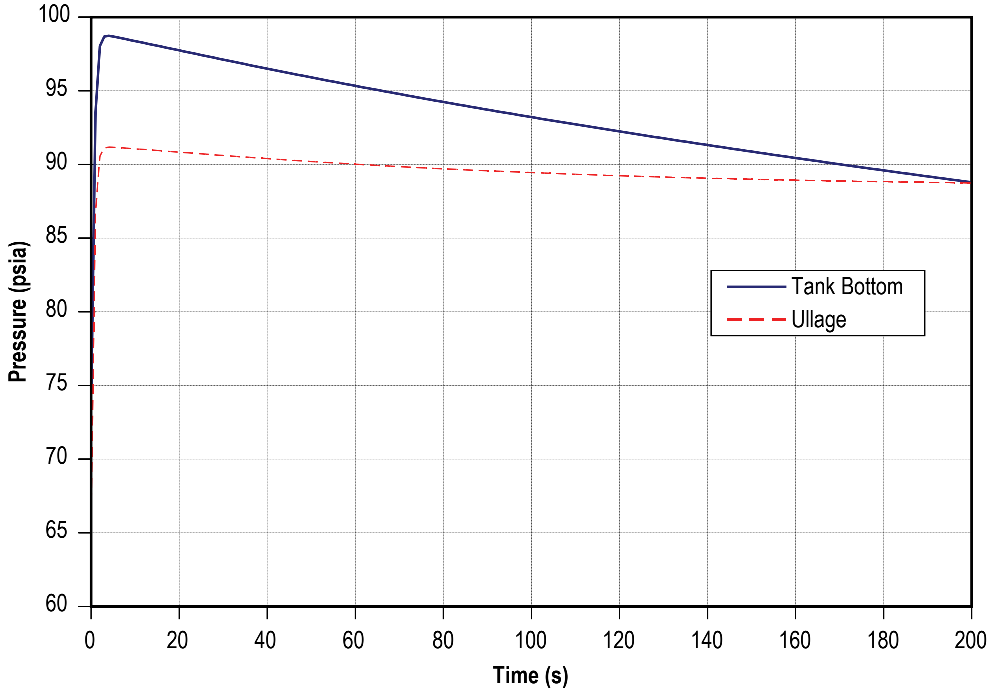


Figure 136. Ullage and tank bottom pressure history.

Figure 137 shows the histories for the ullage temperature and the tank wall temperature. This figure shows that the tank wall temperature rises 32° over the course of the model run. It reveals that the 120 °F helium gas entering the tank has an increasing effect on the tank wall as propellant is drained from the tank and the wall surface area exposed to the warmer ullage gas grows. This effect is somewhat dampened, however, because the heat gained by the wall is conducted to the portion of the tank that is submerged in LOX, which acts as a heat sink. The ullage temperature rises 192° during the first 60 s of tank pressurization before beginning a slow decline for the remainder of the simulation. This large initial temperature rise is primarily due to the mixing of hot helium gas with the relatively cold gas present in the ullage. The decline in temperature is a result of expansion due to a continuous increase of the ullage volume.

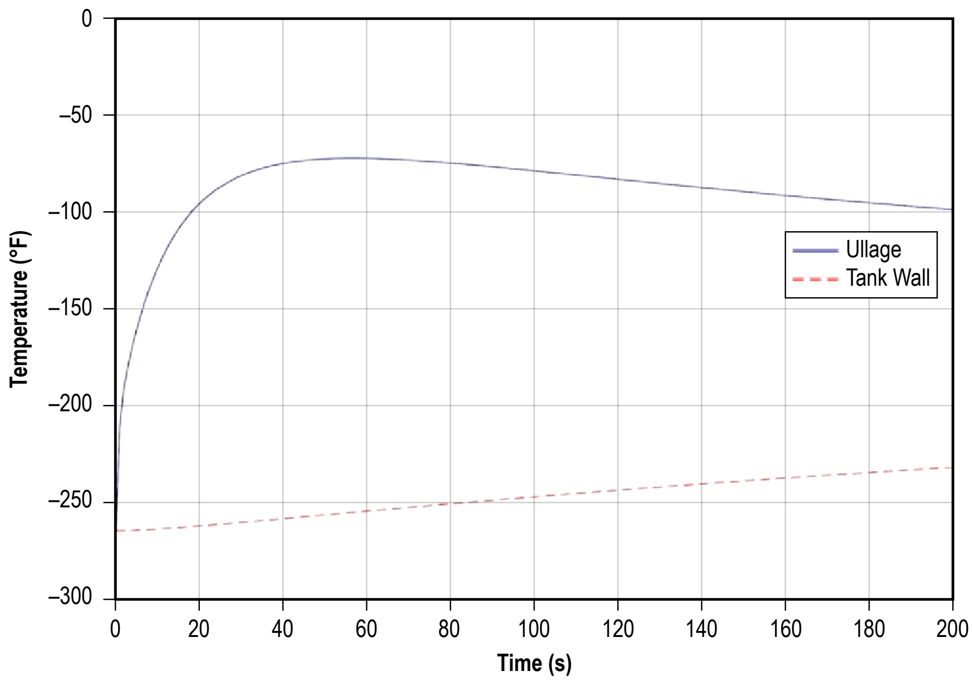


Figure 137. Ullage and tank wall temperature history.

Helium flow rate into the tank is shown in figure 138. The helium flow rate was found to drop initially as the start transient takes place, which is consistent with the 'ramp up' effect noted in figure 136. Then the flow rate begins to gradually increase as ullage pressure drops due to the expanding ullage volume. LOX flow rate into the engine is shown in figure 139. The LOX flow rate curve mirrors the ullage and tank bottom pressure curves, rising through an initial start transient to a peak value and then declining for the remainder of the run as tank pressure drops.

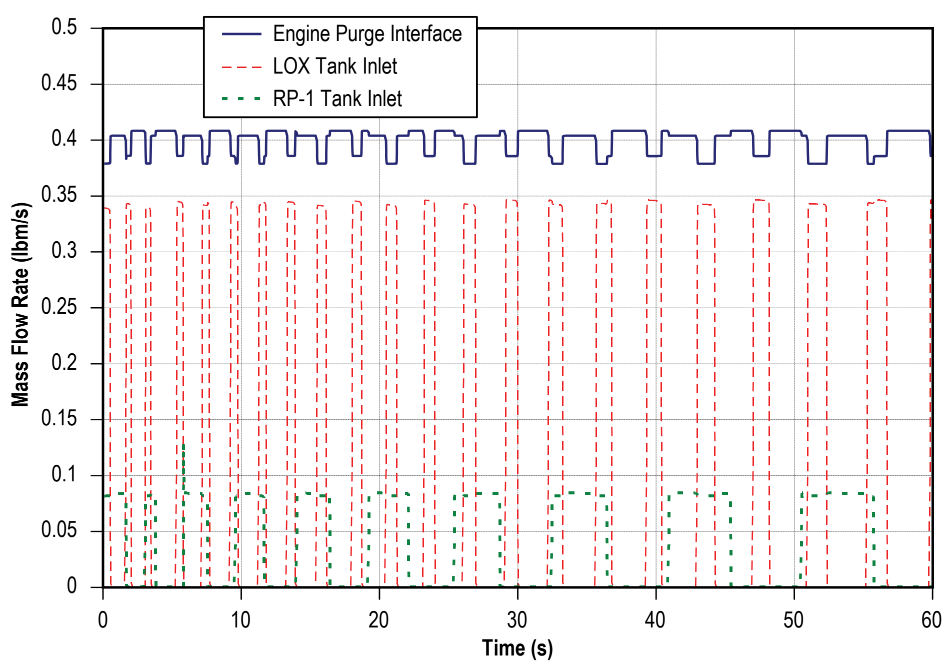


Figure 138. Helium mass flow rate history.

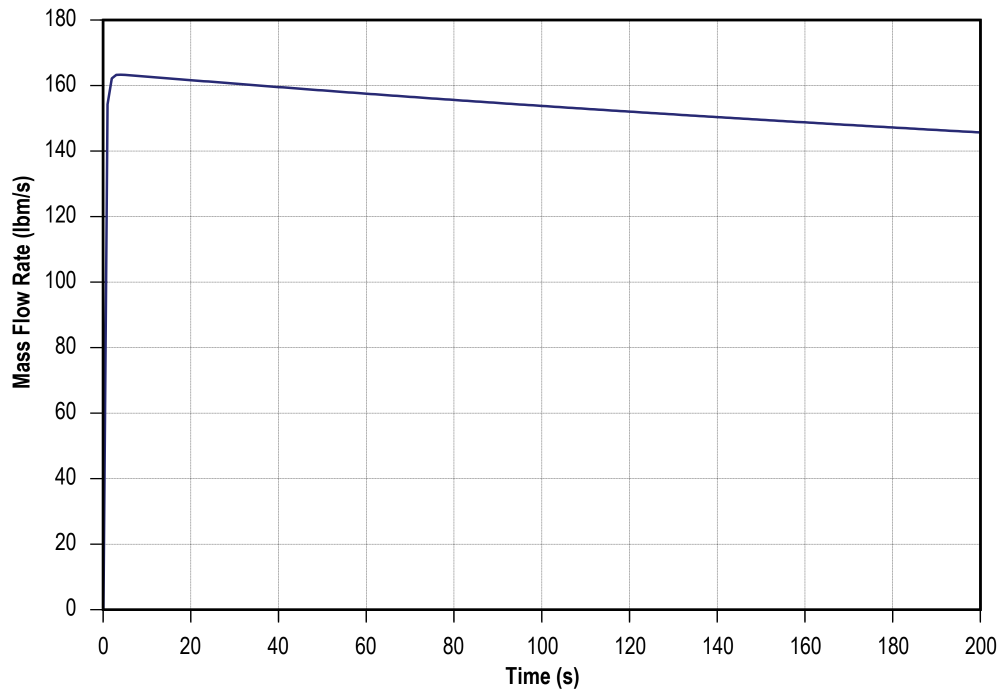


Figure 139. LOX mass flow rate history.

Figure 140 shows the mass transfer rate of gaseous oxygen (GOX) into the ullage space over the duration of the run. The mass transfer rate curve mirrors the ullage temperature curve, which is what one expects since the mass transfer is based on the ullage to propellant heat transfer, which is based on ullage temperature. GFSSP predicts a final GOX mass concentration of 0.15 in the ullage.

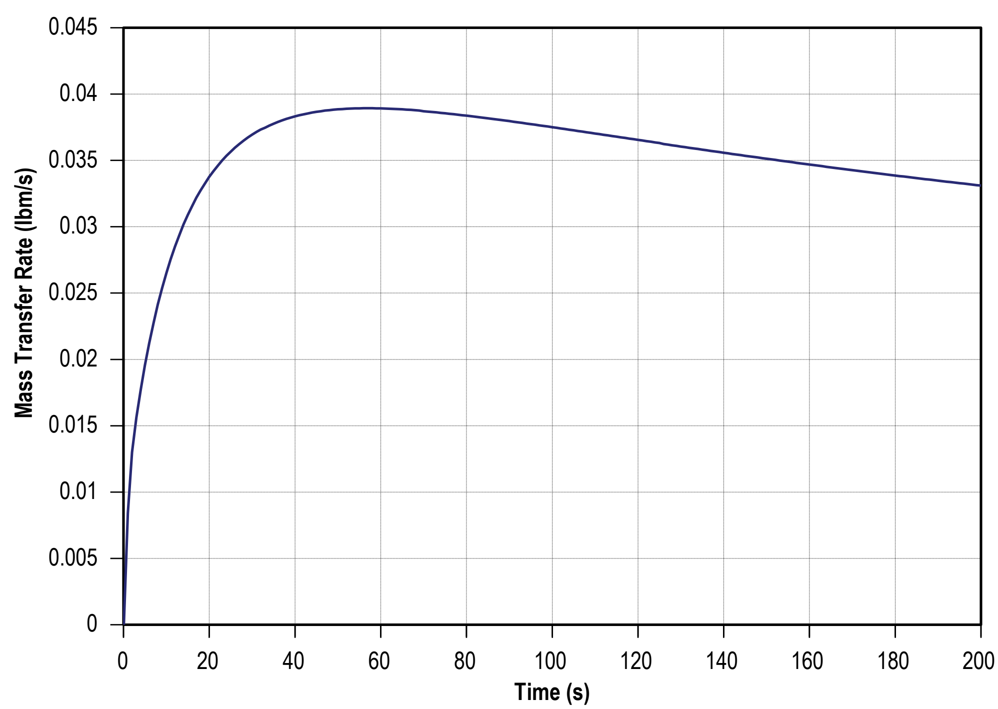


Figure 140. GOX mass transfer rate history.

As a validation, the model results were compared with a published correlation of pressurant requirements for a given displacement of propellant as published by Epstein and Anderson.[45] The correlation calculates the collapse factor, which is defined by Van Dresar[46] as a ratio of the actual pressurant consumption to an ideal pressurant consumption where no heat or mass transfer from the pressurant occurs. This correlation takes the form shown in equations (98) through (102):

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

$$\times \exp\left[-p_5 \left(\frac{1}{1+C} \right)^{p_6} \left(\frac{S}{1+S} \right)^{p_7} Q^{p_8} \right] , \tag{98}$$

where

$$w_p^0 = \rho_G^0 \Delta V \ , \tag{99}$$

$$C = \frac{\left(\rho c_p^0 \delta \right)_{\mathrm{wall}}}{\left(\rho c_p \right)_G^0 D_{eq}} \frac{T_s}{T_0} \ , \tag{100}$$

$$S = \frac{h \theta_T}{\left(\rho c_p \right)_G^0 D_{eq}} \frac{T_s}{T_0} \ , \tag{101}$$

and

$$Q = \frac{\dot{q} \theta_T}{\left(\rho c_p \right)_G^0 D_{eq} T_0} \ . \tag{102}$$

Van Dresar[46] later modified this correlation by redefining D_{eq} as shown in equation (103):

$$D_{eq} = 4 \frac{\Delta V}{A_{sw}} \ . \tag{103}$$

For this validation exercise, the tank is assumed to be cylindrical and therefore the tank diameter is used in place of Van Dresar's equivalent diameter definition. The tank characteristics used are those values utilized in the GFSSP test model. Also, the ideal pressurant properties of $c^0_{p_G} = 1.24$ Btu/lbm-R and $\rho^0_G = 0.06087$ lbm/ft^3 are found using the helium inlet conditions of $P_0 = 95$ psia and $T_0 = 120$ °F. The saturation temperature (T_s) of LOX is taken to be –264 °F. The heat transfer coefficient is calculated to be $h = 8.36 \times 10^{-4}$ Btu/ft^2-s-°R by taking the average value of the heat transfer coefficients calculated by GFSSP at each time step. The change in propellant volume is the value predicted by the GFSSP test model, and the ambient heat flux is neglected in this model. The constants p_1 through p_8 are provided by Epstein and Anderson[45] and are shown in table 28.

Table 28. Constants for LOX propellant.

p_1	0.775
p_2	0.209
p_3	3.57
p_4	0.79
p_5	0.755
p_6	0.271
p_7	0.236
p_8	0.895

Solving equations (100) through (102) and substituting into equation (98) gives $w_p / w^0_p = 1.51$. Solving equation (99) gives $w^0_p = 28.9$ lbm. The GFSSP output file predicts a required pressurant mass of approximately 46.29 lbm. Dividing this number by the ideal pressurant mass gives a GFSSP predicted collapse factor of 1.6. Therefore, the predicted discrepancy of GFSSP with respect to Epstein's method is 5.96%. It is believed that this discrepancy is due mainly to the sensitivity of the pressurization process to the heat transfer coefficient, which is difficult to calculate accurately.

6.11 Example 11—Power Balancing of a Turbopump Assembly

6.11.1 Problem Considered

Example 11 illustrates the modeling of the mechanical coupling between two flow components. In the turbopump assembly shown in figure 141, a co-axial shaft mechanically connects the pump and turbine. The power required by the pump must be transmitted from the turbine in order for the system to be in balance. The purpose of this example is to demonstrate this power balancing for a turbopump when used in a gas turbine cycle. The physical plausibility of the predicted results was demonstrated by performing parametric studies on shaft speed.

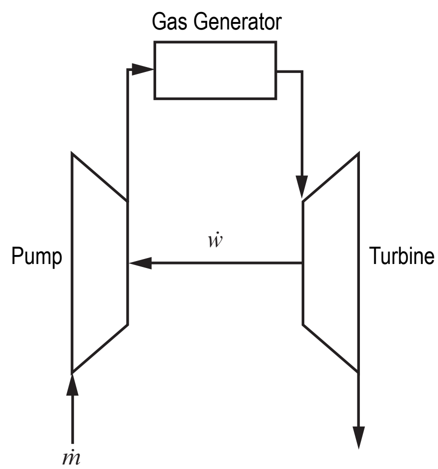


Figure 141. Simplified turbopump assembly.

6.11.2 GFSSP Model

A model of the turbopump portion of a flow circuit is shown in figure 142(a). This model consists of an inlet from a hydrogen tank, a turbopump assembly (pump, turbine, and a connection between them (shaft)), two heat exchangers, a bypass dump outlet, and an outlet to the power turbine. The first of the heat exchangers (denoted in fig. 142(a) as the Regenerator) is used to heat a small portion of the main LH_2 flow by using the 'hotter' hydrogen exiting the turbine, while the remainder of the LH_2 flow bypasses this heat exchanger. The second heat exchanger is used to boil and superheat the hydrogen by means of external heat addition. The shaft speed for this model is set in the input file to 80,000 rpm. Figure 142(b) shows how this model looks in VTASC.

This model uses the following options:

- Branch Resistance Options:
  (1) Pipe Flow (option 1).
  (2) Pump with Pump Efficiency (option 15).
  (3) Valve with a Given C_v (option 16).

- Special Options:
  (1) Heat Exchanger (2), (Logical Variable HEX).
  (2) Turbopump Assembly (1) , (Logical Variable TPA).

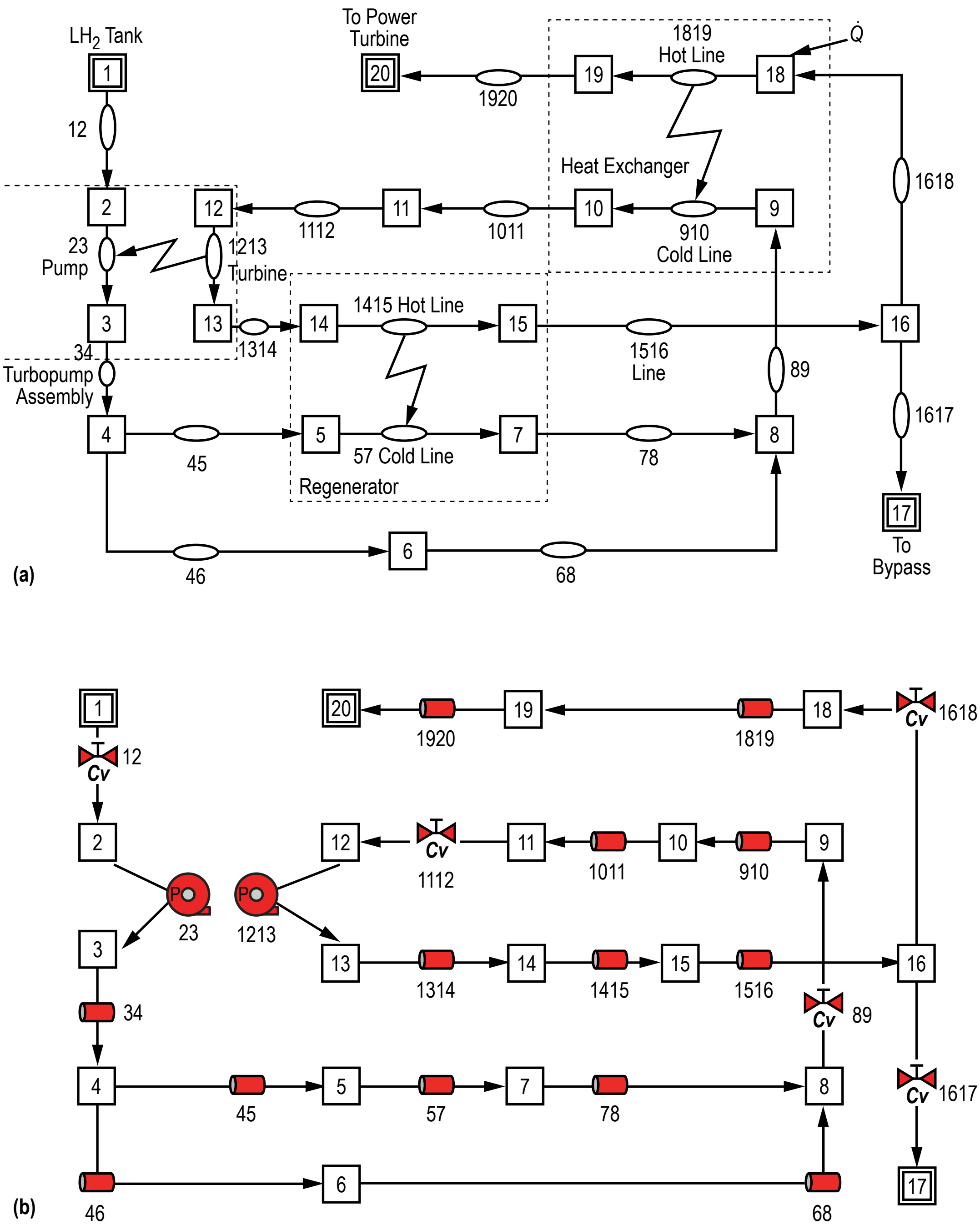


Figure 142. A flow circuit containing turbopump assembly: (a) Detailed model schematic and (b) VTASC model.

Each pipe flow branch has a length of 100 in, an inside diameter of 0.3927 in, and an absolute roughness of 0.00098175 in. Branches 89, 1112, and 1618 each have $C_v = 3.554$ and $A = 0.19635$ in^2. Branch 12 has $C_v = 2.877$ with $A = 0.19635$ in^2 while branch 1617 has $C_v = 0.00354$ with $A = 0.01$ in^2. The branch options chosen to represent the turbine (branch 1213) and the pump (branch 23) have no bearing on the model calculations except for the flow areas that are provided. For this case, option 15 was used for both branches with arbitrary inputs for pump horsepower and efficiency. The flow areas are 0.12112 in^2 for branch 23 and 0.019635 in^2 for branch 1213. The turbopump characteristics are defined in the Turbopump dialog shown in figure 143. The pump characteristic file is also shown below with annotations to explain the meanings of each value. The two Heat Exchanger dialogs are shown in figure 144(a) and (b).

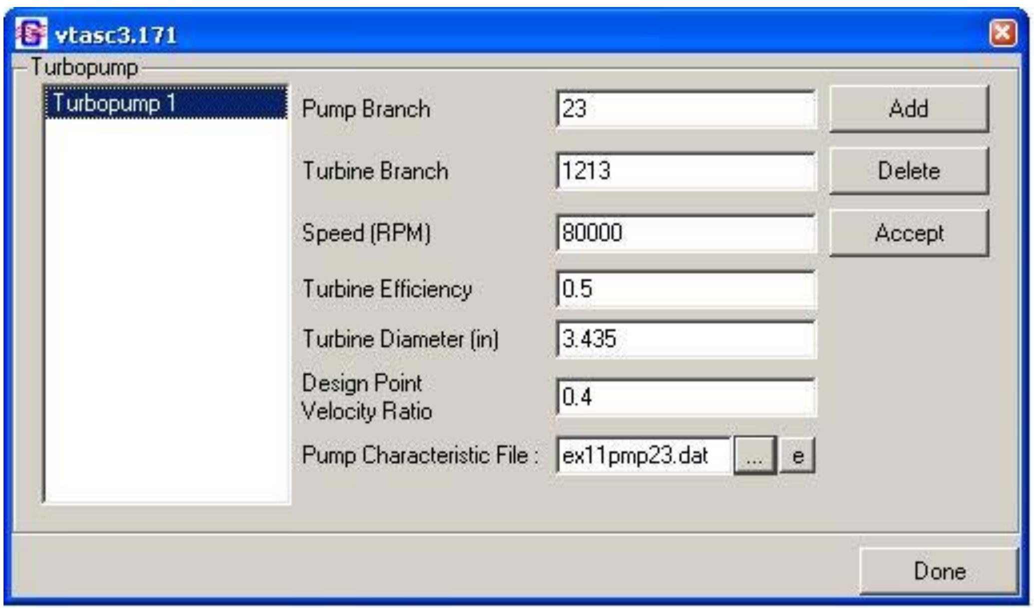
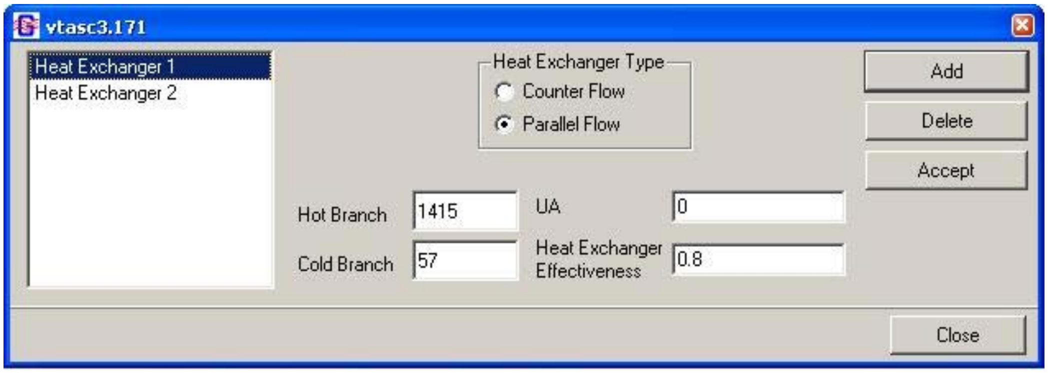
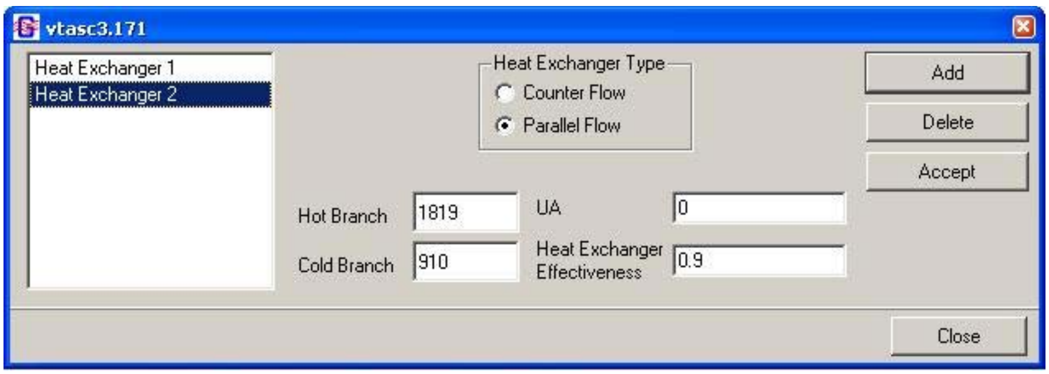


Figure 143. Example 11 Turbopump dialog.



(a)



(b)

Figure 144. Example 11 Heat Exchanger dialogs: (a) Heat Exchanger 1 and (b) Heat Exchanger 2.

EX11PMP23.DAT

18 - Number of lines of data

Flow rate/Speed	Head/Speed^2	Torque/(Density*Speed^2)
0.000 8.680E-06	0.000	
3.035E-05	8.971E-06	8.8724E-10
6.071E-05	9.190E-06	9.7065E-10
9.106E-05	9.341E-06	1.0804E-09
1.214E-04	9.436E-06	1.2166E-09
1.518E-04	9.486E-06	1.3393E-09
1.821E-04	9.486E-06	1.4570E-09
2.125E-04	9.445E-06	1.5644E-09
2.428E-04	9.372E-06	1.6733E-09
2.732E-04	9.263E-06	1.7872E-09
3.035E-04	9.117E-06	1.9105E-09
3.339E-04	8.935E-06	2.0558E-09
3.643E-04	8.753E-06	2.2161E-09
3.718E-04	8.689E-06	2.2698E-09
3.749E-04	8.625E-06	2.2869E-09
3.794E-04	8.479E-06	2.3215E-09
3.807E-04	8.388E-06	2.3281E-09
3.810E-04	0.000E+00	0.000

6.11.3 Results

Appendix R contains the input, pump characteristics, and output files for example 11 (ex11.dat, ex11pmp23.dat and ex11.out). The results of the study are illustrated in figure 145.

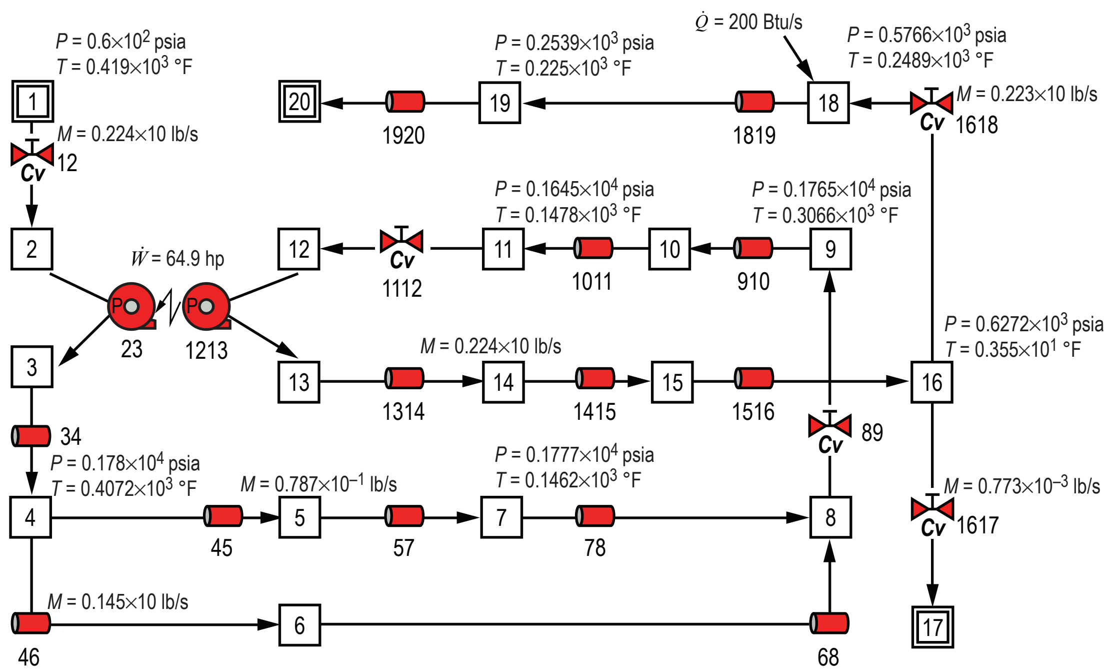


Figure 145. GFSSP RCS model results.

6.11.4 Parametric Study

In order to verify this complicated model, a parametric study on the shaft speed of the turbopump was conducted. Figures 146–148 illustrate the results of this model. Figure 146 illustrates the pressure differential across the turbopump for both the pump and the turbine as a function of the shaft speed. Figure 147 illustrates the hydrogen mass flow rate through the turbopump as a function of the shaft speed. Figure 148 illustrates the torque and horsepower transmitted in the turbopump as a function of the shaft speed. As each of these figures illustrates, a functional relationship is identifiable for each predicted variable as a function of shaft speed.

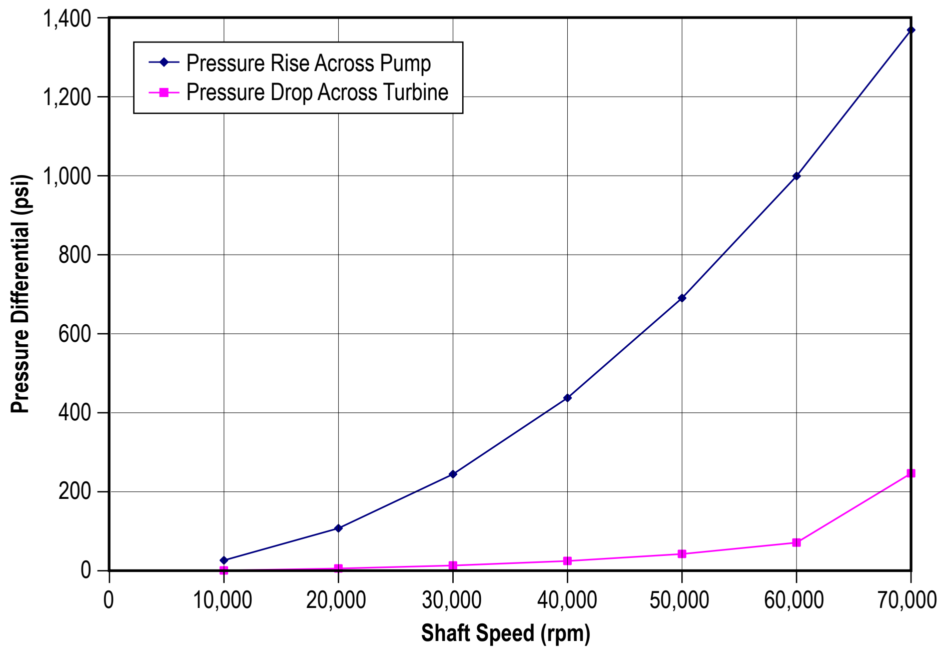


Figure 146. Parametric study results: turbopump pressure differential.

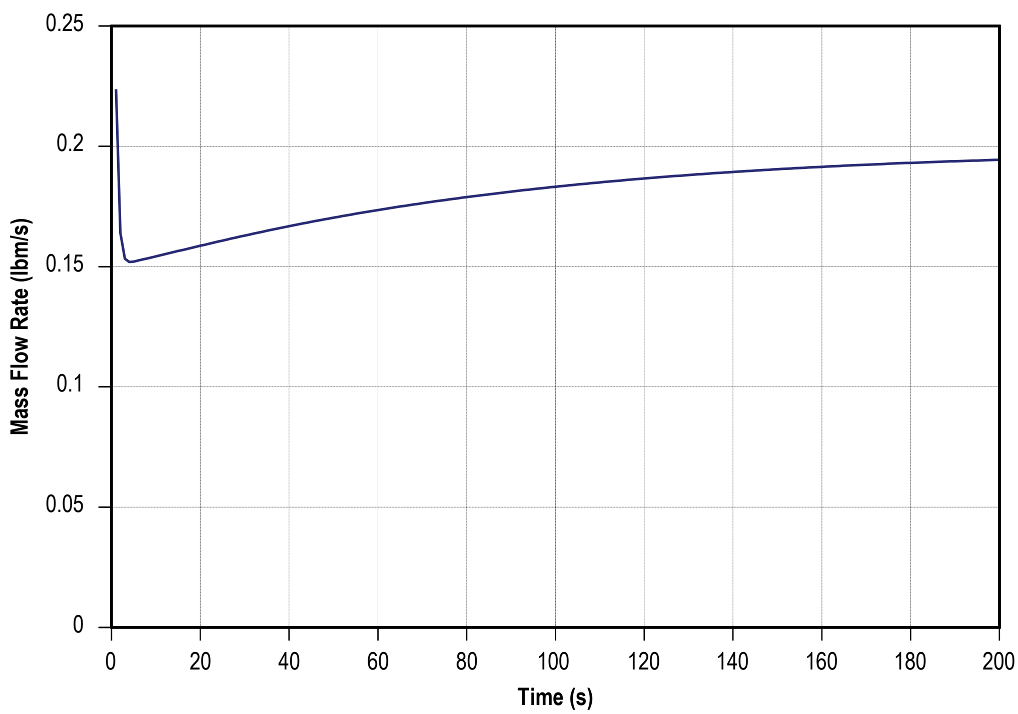


Figure 147. Parametric study results: turbopump hydrogen mass flow rate.

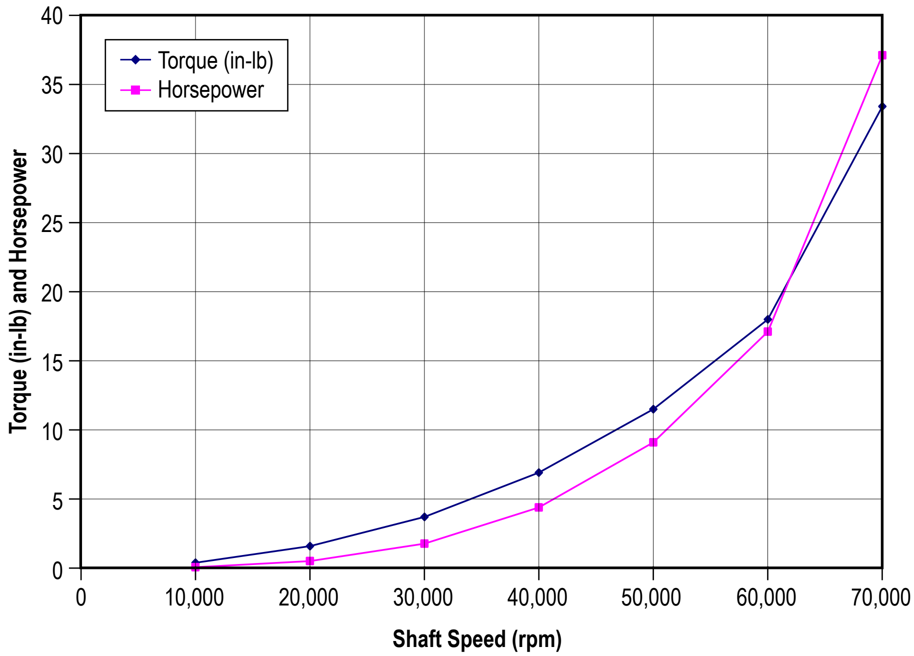


Figure 148. Parametric study results: turbopump torque and horsepower.

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

6.12.1 Problem Considered

Example 10 illustrates the use of the pressurization option in modeling ullage and propellant conditions in a tank. In this example, an integrated model consisting of two propellant tanks, a flow network for the ullage pressurant supply from a Facility interface, and engine propellant feed lines will be constructed. The pressurization system of Propulsion Test Article 1 (PTA1) consists of a LOX tank and an RP-1 tank that are both pressurized by helium. This configuration is represented in the schematic shown in figure 149. The objective of the present example is to develop an integrated mathematical model from the helium supply line to the engine inlet to model 60 s of engine operations. The model has three primary functions:

(1) To predict the flow rate and pressure distribution of the helium supply line feeding both the LOX and RP-1 tanks.

(2) To predict the ullage conditions considering heat transfer between the ullage, propellant, and the tank wall, as well as mass transfer from propellant to ullage.

(3) To predict the propellant conditions leaving the tank.

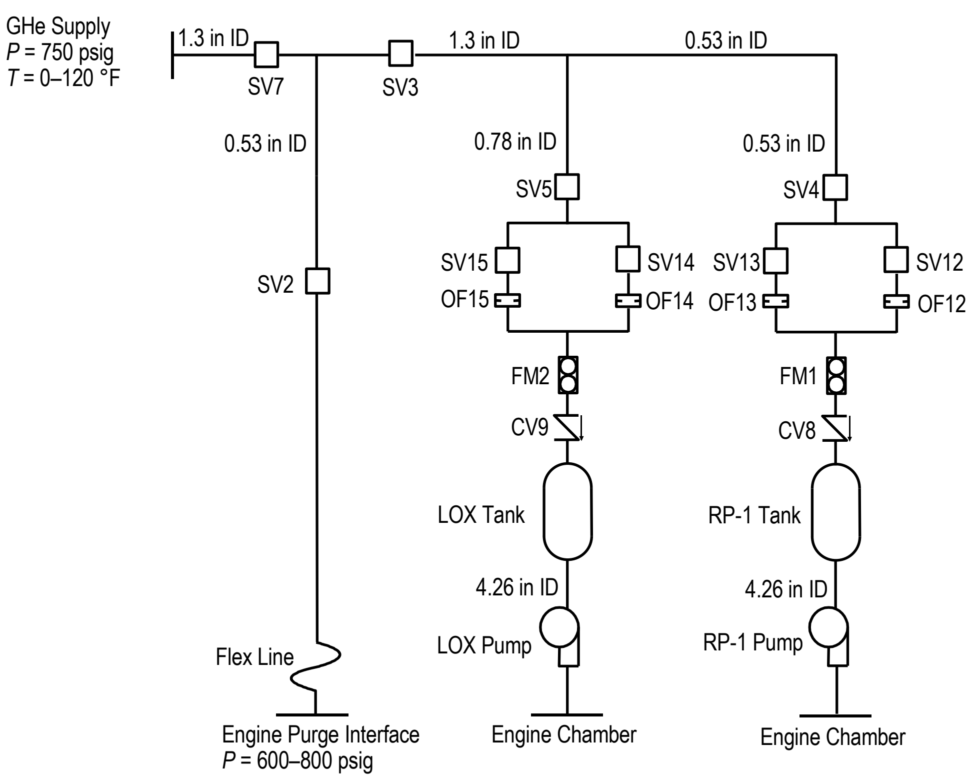

Figure 149. PTA1 helium pressurization system schematic.

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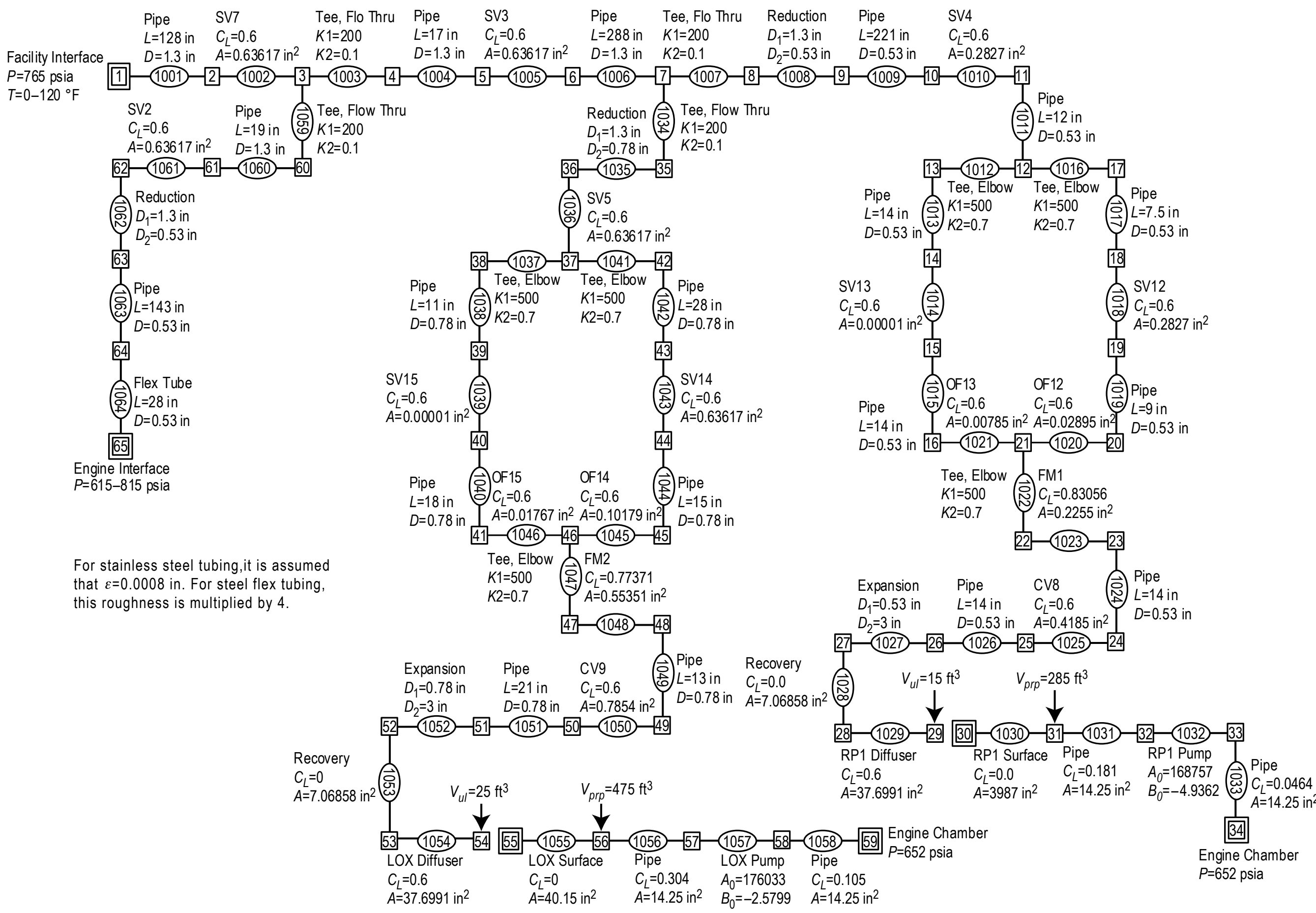
6.12.2 GFSSP Model

A GFSSP model of the helium pressurization system of LOX and RP-1 tanks is shown in figure 150(a). The model consists of 65 nodes and 64 branches. The model extends from facility interface to engine purge and engine chamber interfaces. It includes all piping and its fittings, orifices, and valves. Both RP-1 and LOX tanks and pumps are included in the model. Each propellant tank has a diffuser and control valve. Pressure and temperatures are specified at the interfaces, which are represented by six boundary nodes listed in table 29.



(a)

F150b >>

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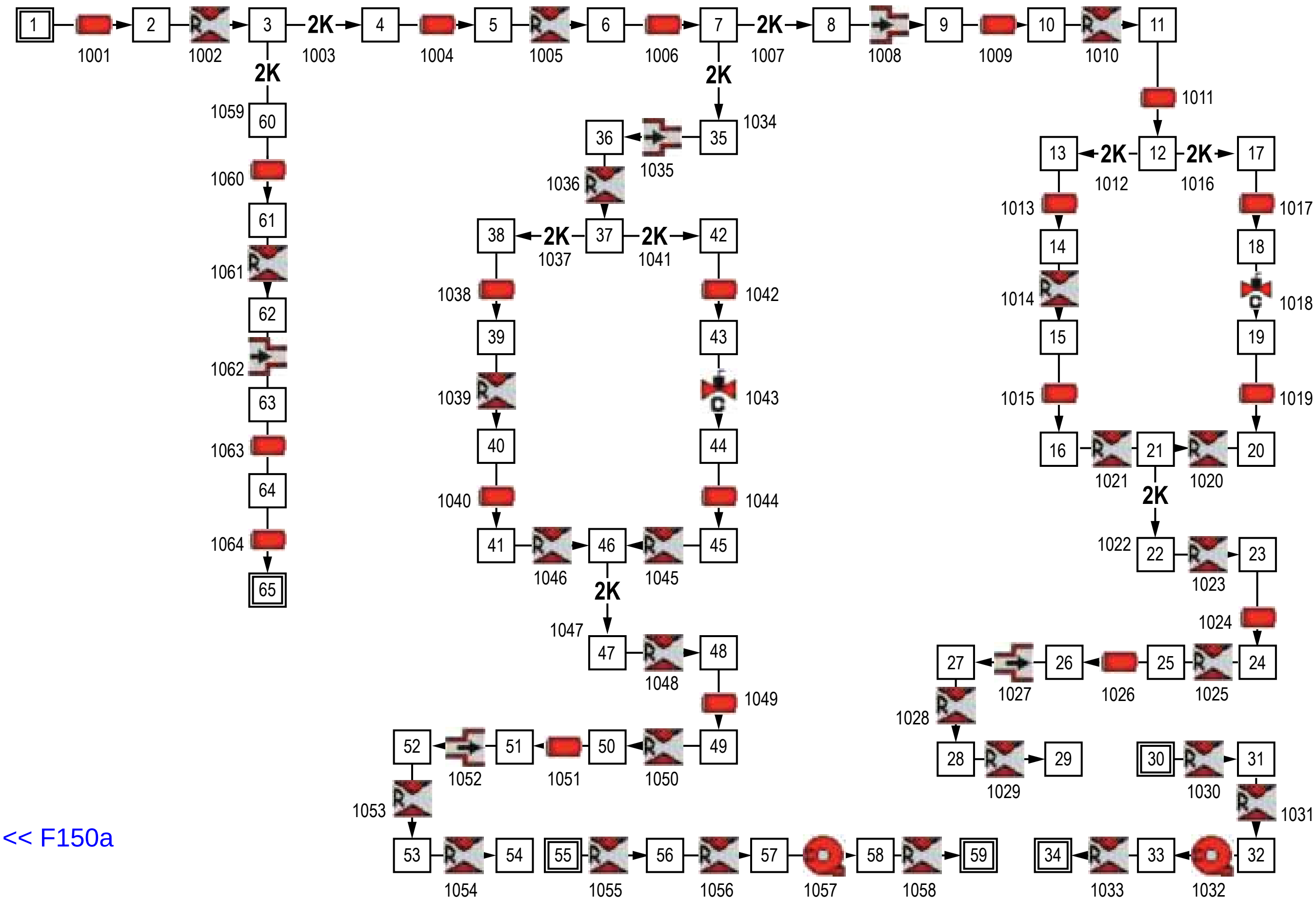

<< F150a

(b)

Figure 150. GFSSP model of the pressurization system of example 12: (a) Detailed model schematic and (b) VTASC model.

Table 29. Boundary nodes of He pressurization flow circuit.

Boundary Node	Interface
1	Facility interface
65	Engine interface (purge)
55	Ullage-propellant interface (LOX tank)
59	LOX engine chamber interface
30	Ullage-propellant interface (RP-1 tank)
34	RP-1 engine chamber interface

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

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second branching takes place 305 in downstream of the first branch and this branch supplies helium to the LOX tank. The rest of the helium goes to pressurize the RP-1 tank. The lines leading to the LOX and RP-1 tanks each have two parallel legs, one of which remains closed during operation. The left leg of the circuit is used to pressurize the tank during prepressurization operation while the right leg of the circuit is used to pressurize the tank during pressurization standby and engine operations. In the model discussed in this TP, setting a high resistance in the appropriate branches eliminated the flow to the left leg. Figure 150(b) shows how this model looks in VTASC.

6.12.3 Results

The input and output files including history files of example 12 have been attached in appendix S. The GFSSP model shown in figure 147 was run for a 60-s engine operation period. At the beginning of the model run, the control valve nominal set points are 72 psia for the LOX tank and 55 psia for the RP-1 tank with ±3 psi tolerances. After 3 s they drop 5 psi to 67 psia for the LOX tank and 50 psia for the RP-1 tank with ±3 psi tolerances. The output file contains pressure, tem-perature, and density at all nodes as well as flow rate, velocity, and pressure drop at all branches for selected time steps.

Figure 151 shows the predicted pressure history of the RP-1 ullage, RP-1 tank bottom, LOX ullage, and LOX tank bottom pressures. The difference in pressure between the tank bottom and ullage is the gravitational head, which slowly reduces as propellant is drained from the tank. The cyclic nature of the pressure profiles is due to the control valves, which are set to close or open as the tank bottom pressures exceed prescribed tolerances. It is observed that the frequency of pressure oscillation is larger in the LOX tank than the RP-1 tank. This observation is attributable to the higher flow rates associated with the LOX tank as compared to those required for the RP-1 tank.

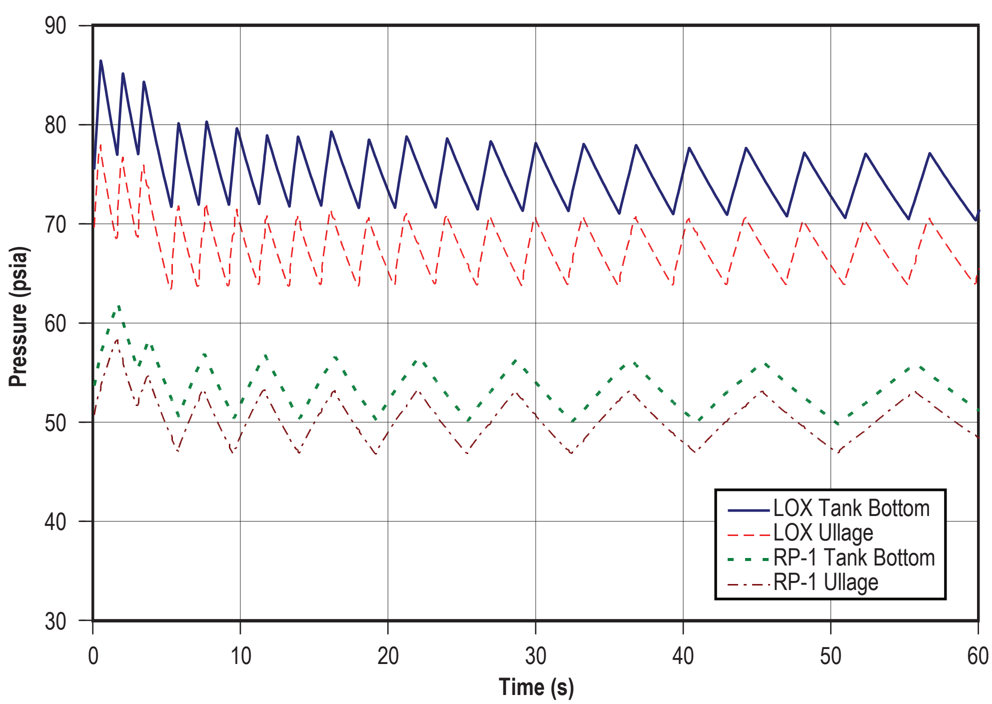

Figure 151. Propellant tank pressure history.

Figure 152 shows the predicted ullage temperature history in the RP-1 tank. Initially, wall and propellant temperatures were assumed equal at 70 °F. Heat transfer between ullage gas and the wall is not very significant in the RP-1 tank and, as a result, the tank wall temperature rises less than a degree during the 60-s engine operation. Ullage temperature, on the other hand, increases by about 42 °F due to mixing and pressurization. Ullage temperature diminishes during the period of valve closure because of the heat transfer from ullage gas to the wall.

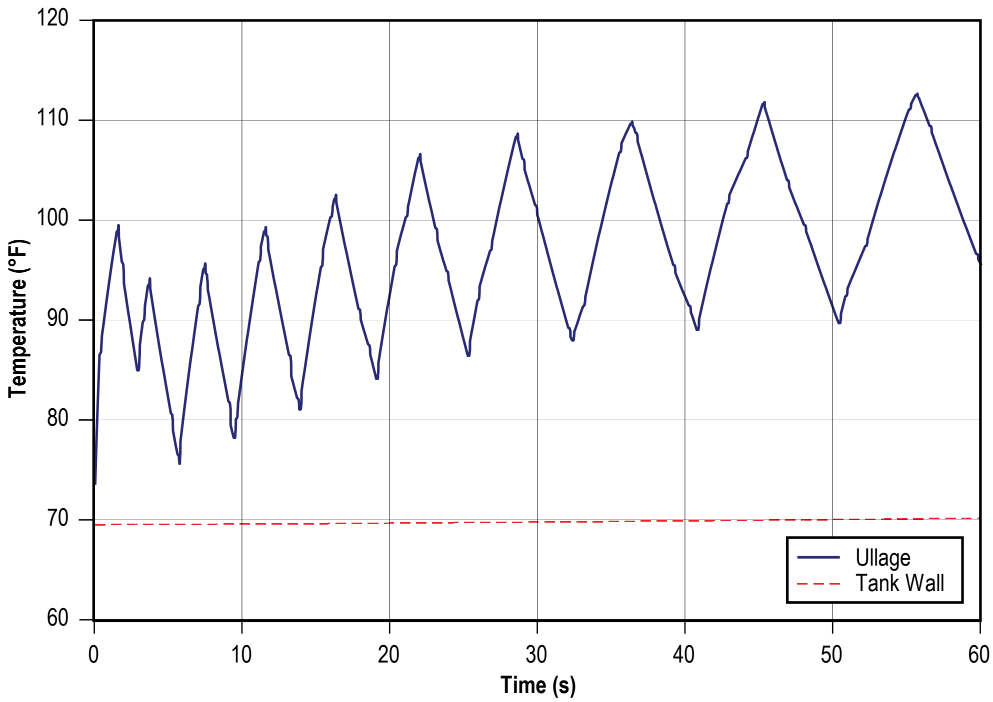

Figure 152. RP-1 temperature history.

Figure 153 shows the heat transfer history for the RP-1 tank. The ullage to propellant heat transfer rises mirrors the RP-1 ullage temperature behavior, reaching a peak value of 0.297 Btu/s. The ullage to wall heat transfer grows continuously throughout engine operation, achieving a maximum value of 1.78 Btu/s. This continuous rise is due to the ever-increasing tank wall area exposed to ullage gas as propellant is expelled from the tank. Conduction from the ullage exposed tank wall to the wetted wall is negligible compared to the heat transfer between the ullage and the wall.

The predicted ullage temperature history in the LOX tank is shown in figure 154. The LOX ullage temperature is assumed to be initially at –260 °F and the tank wall temperature is assumed to be initially at –300 °F. The tank wall temperature rise is more pronounced in the LOX tank than the RP-1 tank, rising 8 °F over the course of the 60-s run. The ullage temperature, on the other hand, rises about 147 °F. The higher temperature rise in the LOX tank is primarily due to the fact that the LOX ullage is initially assumed to be at –260 °F and mixes with helium at 120 °F. On the other hand, the initial temperature difference in the RP-1 ullage is much smaller. The other contributing factor is the higher helium flow rate into the LOX tank.

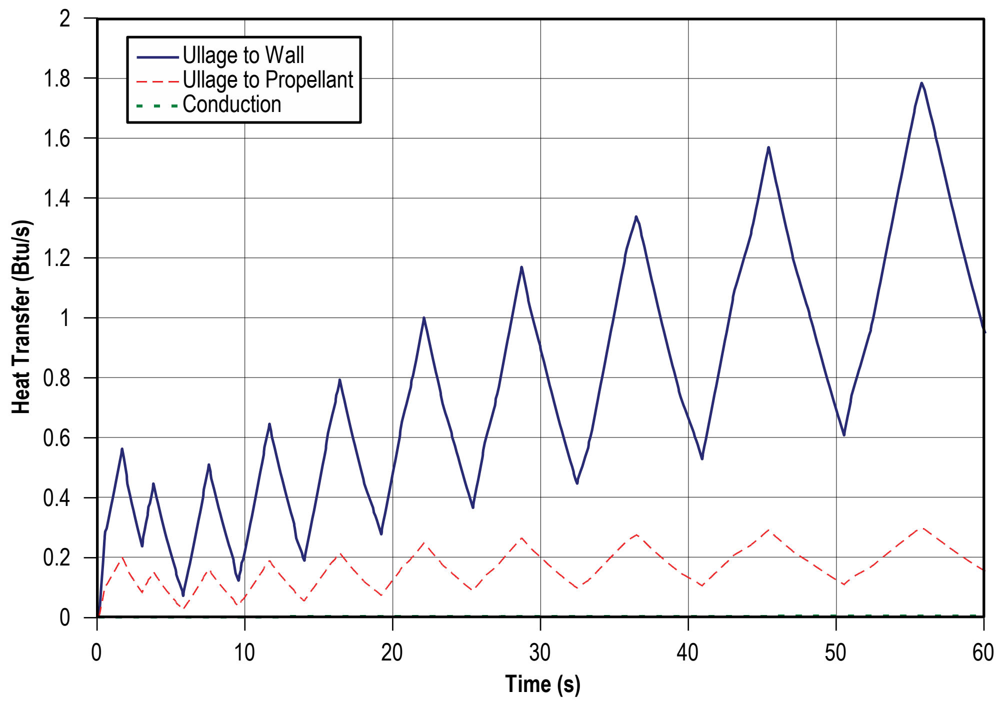

Figure 153. RP-1 heat transfer history.

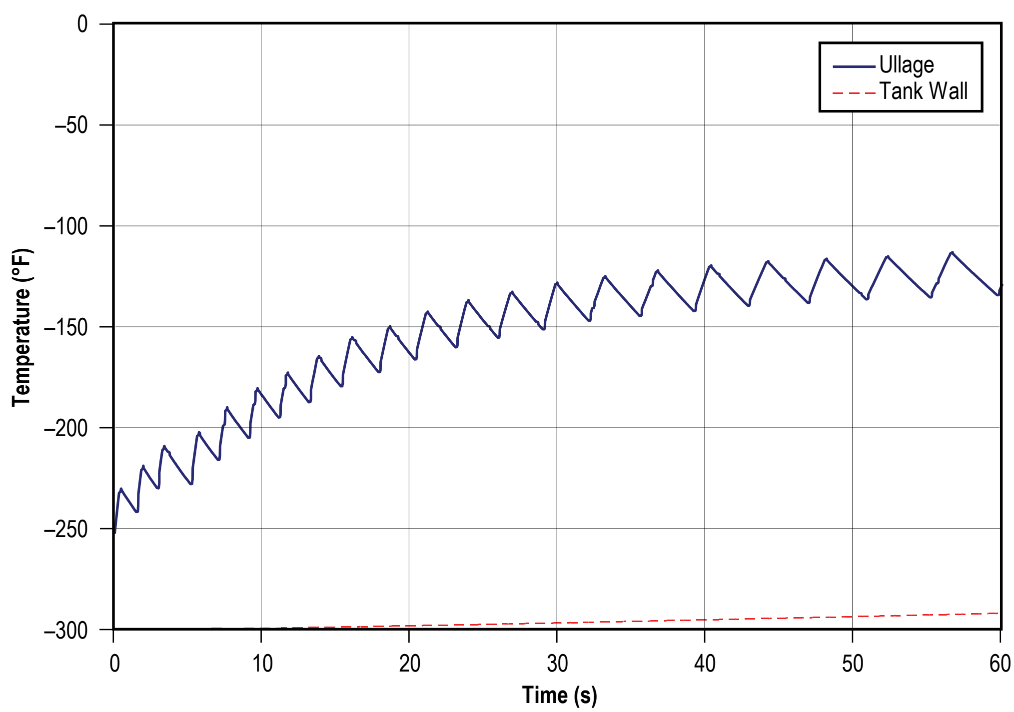

Figure 154. LOX temperature history.

Figure 155 shows the LOX tank heat transfer history. The LOX heat transfer curves follow a similar pattern to the RP-1 tank heat transfer curves, but on a much greater scale. The ullage to propellant heat transfer achieves a maximum value of 2.72 Btu/s and ullage to wall heat transfer peaks at 22.2 Btu/s.

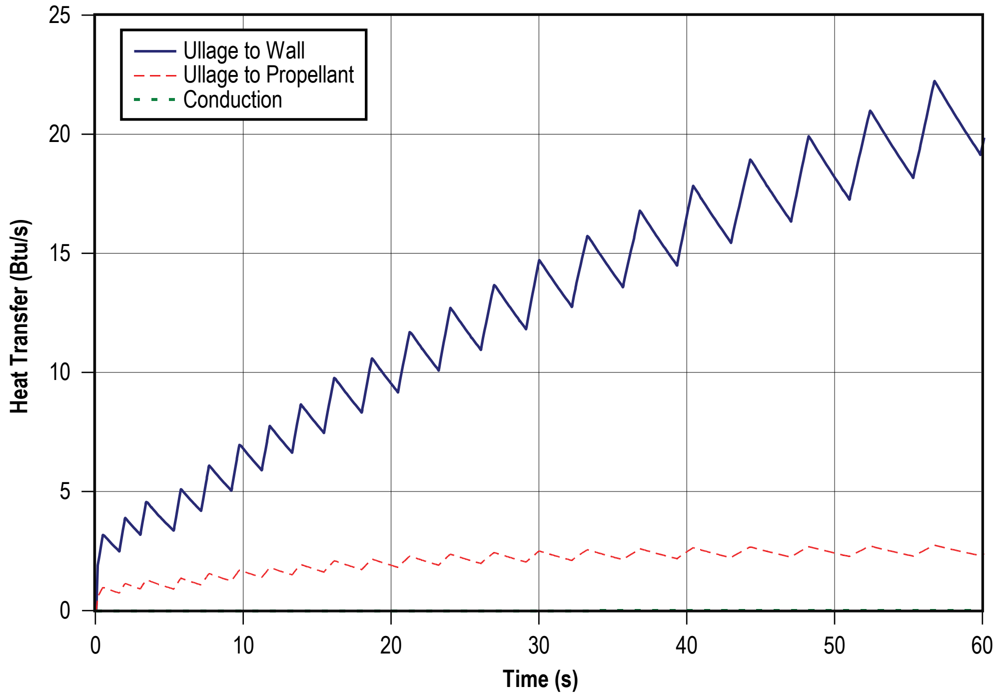

Figure 155. LOX tank heat transfer history.

The mass transfer history of propellant into the ullage for the LOX and RP-1 tanks is shown in figure 156. The mass transfer of propellant to ullage was calculated using the User Subroutines discussed in section 6.10 (example 10). The mass transfer rate of GOX into the LOX tank ullage is much larger than that of vaporized RP-1 into the RP-1 tank ullage due to the higher heat transfer rates seen in the LOX tank. At the end of the 60-s run, the mass concentration of GOX in the LOX tank ullage is 0.14, while the mass concentration of vaporized RP-1 in the RP-1 tank ullage is 0.002.

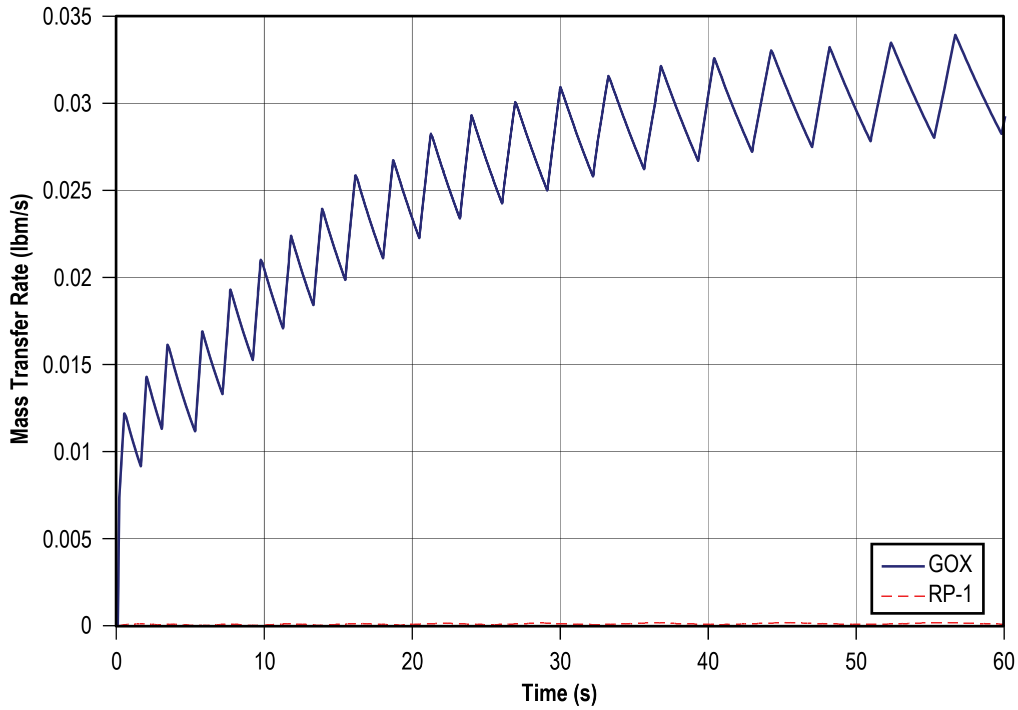

Figure 156. Mass transfer history of propellant.

The propellant flow rates shown in figure 157 are to be 139 lbm/s for LOX and 64 lbm/s for RP-1. The constant propellant flow rate predictions are a result of the RP-1 and LOX pumps. The branches upstream and downstream of the pumps have been adjusted to reproduce the pressure drops associated with the flow paths between the tanks and pump inlets and pump exits and engine chamber. This was done because of a lack of detailed flow path geometry downstream of the propellant tanks.

While propellant is discharged to the engine, ullage volume increases. The increase in the ullage volume in the RP-1 and LOX tanks is shown in figure 158. The initial ullage volume of the RP-1 tank was assumed to be 15 ft^3 while the LOX tank initial ullage volume was assumed to be 25 ft^3. The ullage volumes increase linearly to 90 ft^3 and 141 ft^3 for the RP-1 and LOX tanks, respectively.

Figure 159 shows the helium flow rates in the system. Helium flow rate varies over time due to the opening and closing of the control valves during this time period. The flow from the facility interface is distributed to three branches. A nearly constant flow rate (about 0.4 lbm/s) is predicted to the engine purge interface for engine purges. The maximum flow rates to the LOX and RP-1 tanks are about 0.34 lbm/s and 0.085 lbm/s, respectively. Table 30 shows a comparison of GFSSP helium flow predictions with McRight's[47] pressurization analysis model.

The comparison shown in table 30 appears reasonable considering the fact that McRight's analysis did not consider pressure loss in lines and fittings and choked flow rate through the orifice was calculated based on a facility pressure of 765 psia. GFSSP calculates pressure drop through the line; therefore, the choked flow rate at lower pressure is evidently less than McRight's prediction.

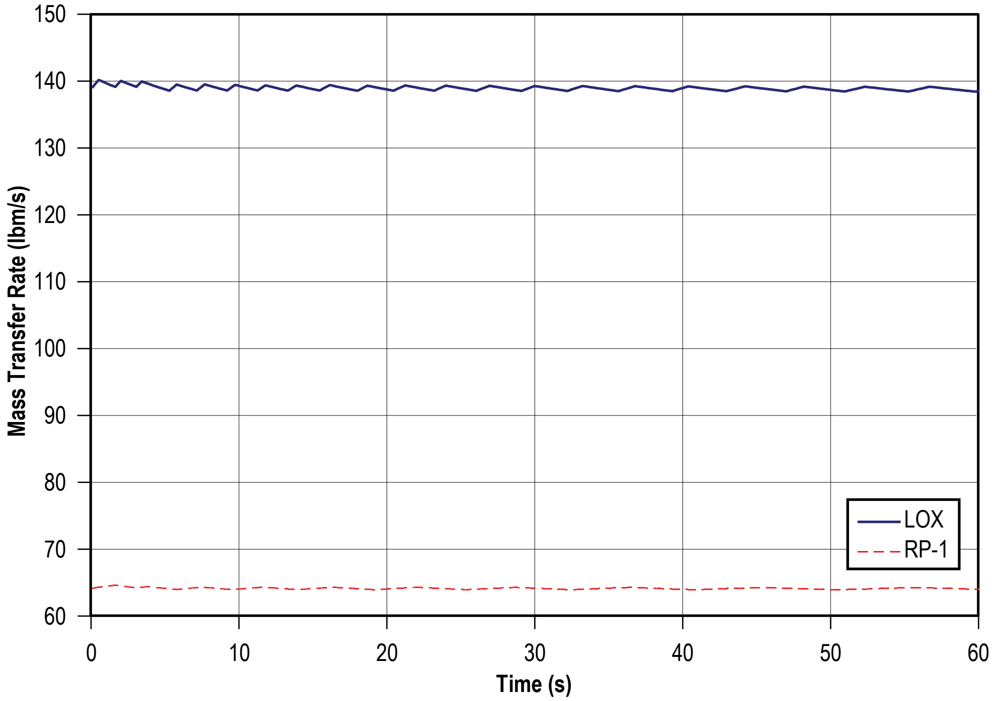

Figure 157. Propellant flow rate history.

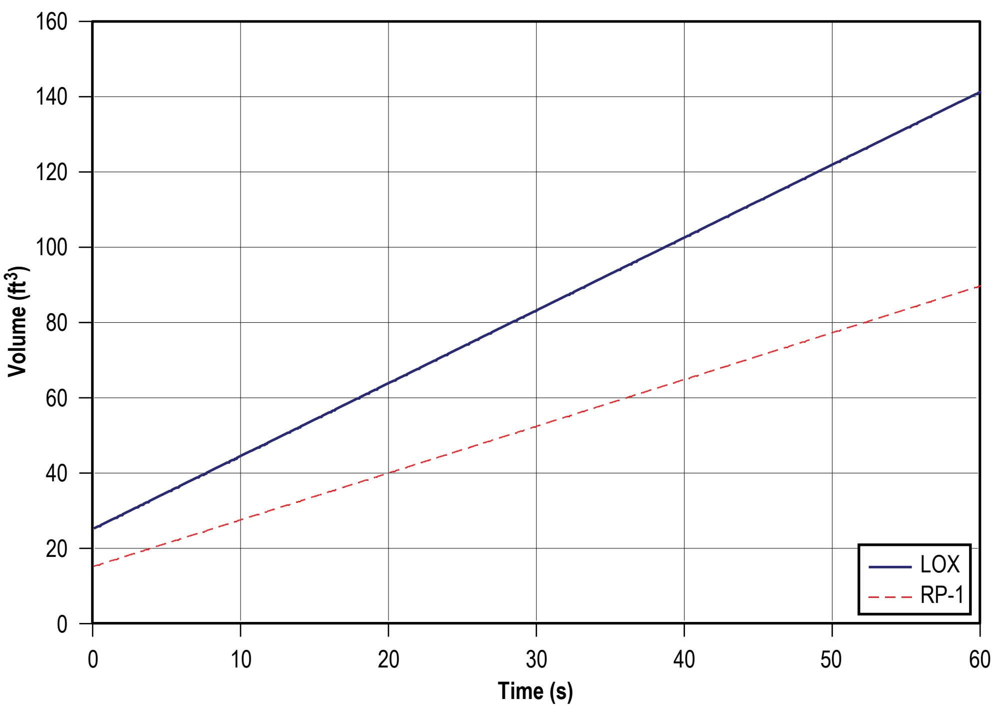

Figure 158. Ullage volume history in propellant tanks.

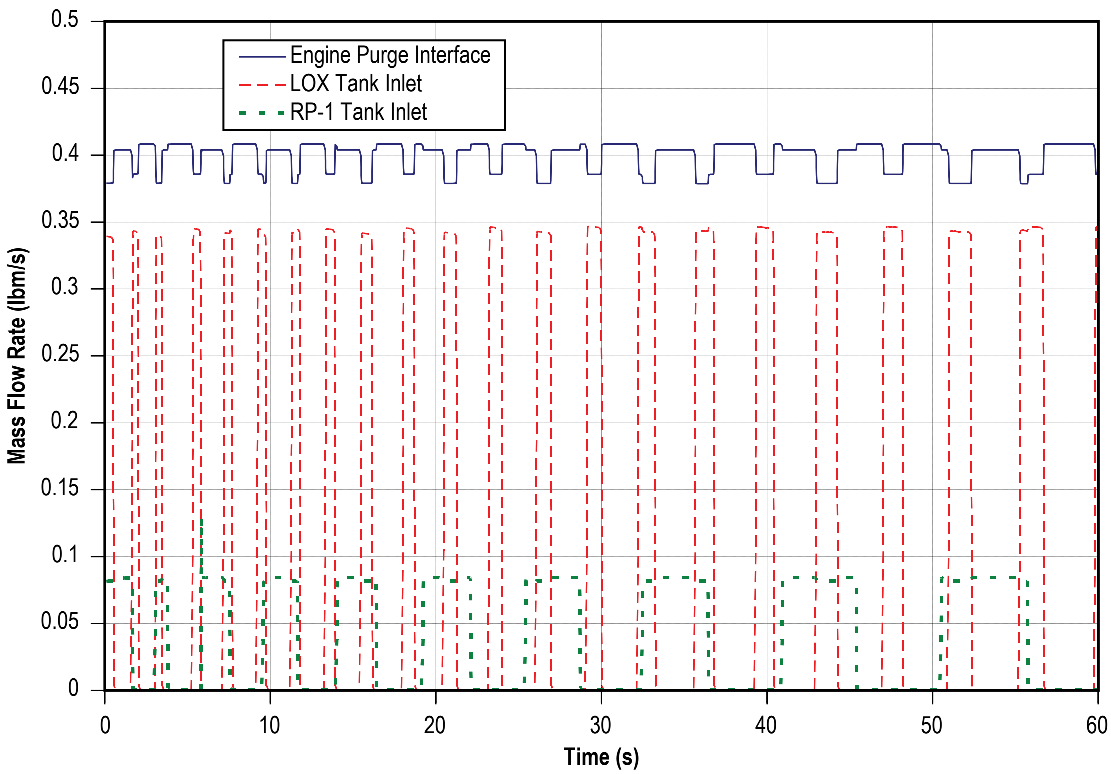

Figure 159 Helium flow rate history.

Table 30. Comparison between GFSSP and McRight's He flow rates.[47]

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

6.13 Example 13—Steady State Conduction Through a Circular Rod, With Convection

6.13.1 Problem Considered

In the previous examples, the focus has been on GFSSP's fluid modeling capabilities. In this example, GFSSP's ability to model applications with conjugate heat transfer is introduced. The verification and validation of GFSSP's conjugate heat transfer capability was performed by comparing with the known solution of a simple conduction-convection problem.[48] The heat transfer in a homogenous circular rod between two walls was considered (fig. 160). The two walls are held at temperatures of 32 and 212 °F,, respectively. The 0.167-ft-diameter rod is 2 ft in length and is initially at a temperature of 70 °F. The heat transfer coefficient between the rod and the ambient air is 1.14 Btu/ft^2-hr-R and the thermal conductivity of the rod is 9.4 Btu/ft-hr-R.

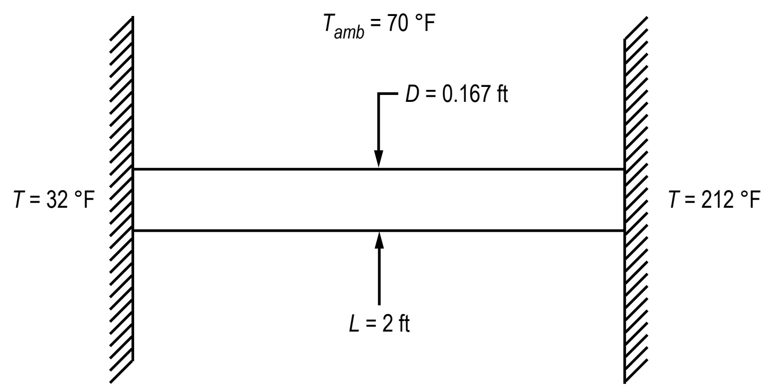

Figure 160. Schematic of circular rod connected to walls at different temperatures.

6.13.2 GFSSP Model

Figure 161(a) shows a GFSSP schematic of the system described by figure 160. The circular rod is represented by eight solid nodes and seven solid-solid conductors. Even though all of the material properties are not used for a steady state model, GFSSP still requires that placeholder values be input at each solid node. The thermal conductivity and specific heat temperature history files, which are shown below in an annotated form, are based on a user-defined material.

```
USER1K.PRP

2 - Number of lines of data
Temperature (R)   Thermal Conductivity (Btu/ft-sec-R)
0                 0.002611
1000              0.002611

USER1CP.PRP

2 - Number of lines of data
Temperature (R)   Specific Heat (Btu/lbm-R)
0                 0.1981
1000              0.1981
```

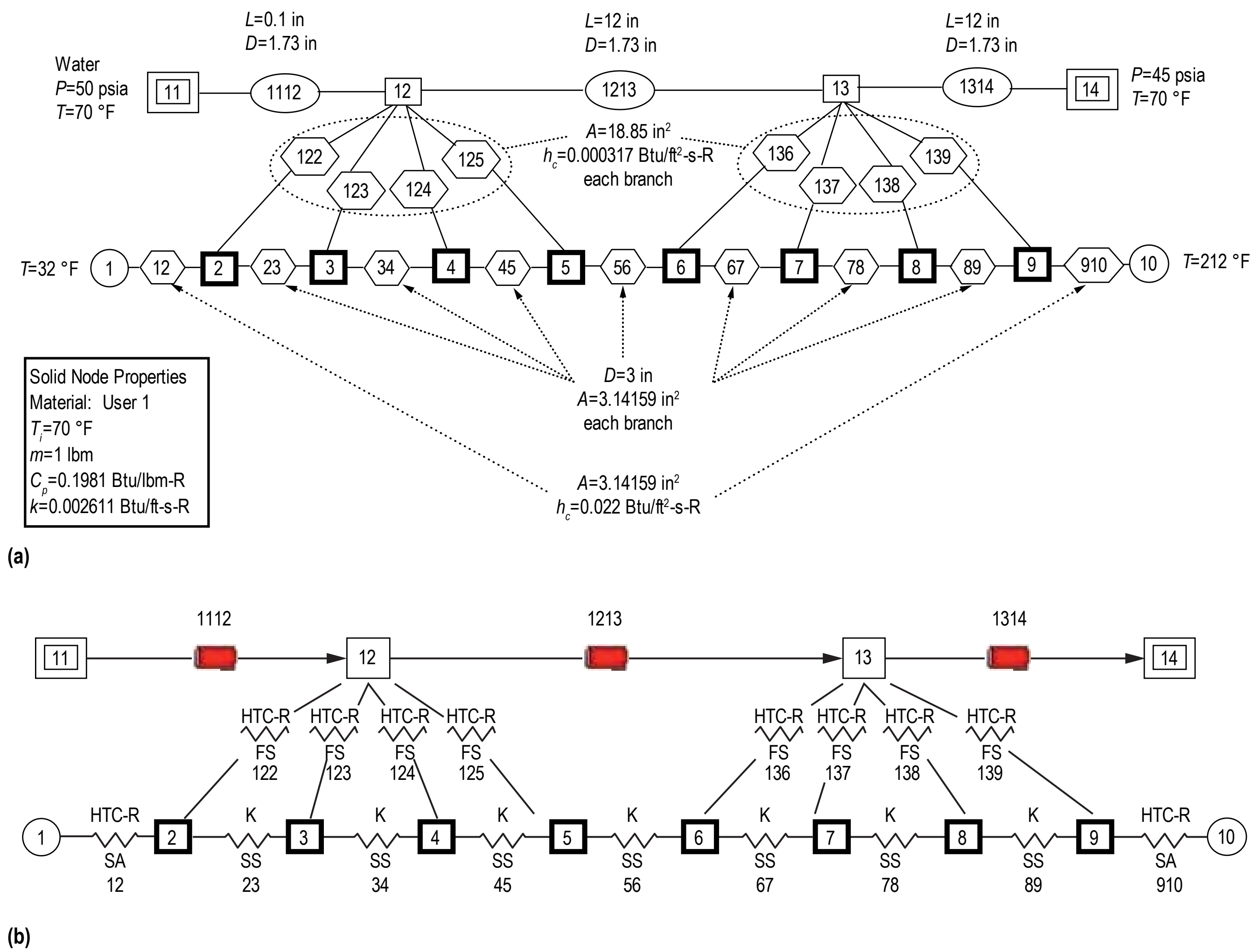

Figure 161. GFSSP model of circular rod for example 13: (a) Detailed model schematic and (b) VTASC model.

Two ambient nodes are used to model the hot and cold walls, and their interaction with the rod is modeled using two solid-ambient conductors. Because GFSSP is first and foremost a fluid analysis code, it is necessary to include a fluid flow path in any GFSSP model that is being developed. Therefore, a dummy flow circuit consisting of two boundary nodes, two internal nodes, and three pipe flow branches was used to represent the ambient environment of figure 160. The details of the flow path were arbitrarily chosen with the sole intent of maintaining a constant temperature of 70 °F at all points in the flow path to correctly simulate the ambient environment. The two internal flow nodes are connected to the solid rod by eight solid-fluid conductors that represent the heat transfer between the ambient and the rod in figure 160. Figure 161(b) shows how this model looks in VTASC.

6.13.3 Results

The input and output files including history and property files of example 13 have been attached in appendix T.

6.13.3.1 Analytical Solution. From the Thermal Analysis Workbook,[4] the differential equation of energy transport is given by:

$$\frac{d^2T}{dx^2} - \frac{4h}{Dk}\left(T - T_\infty\right) = 0 \tag{104a}$$

with boundary conditions of $T(0)$=32 °F and $T(L)$=212 °F. The closed form of the solution is given by

$$T(x) = T_{\text{amb}} + 4.653e^{\sqrt{\frac{4h}{Dk}}x} - 42.65e^{-\sqrt{\frac{4h}{Dk}}x} \; . \tag{104b}$$

Figure 162 compares GFSSP's predicted temperature distribution along the rod with the closed form solution. The comparison shows very close agreement between GFSSP and the closed form solution.

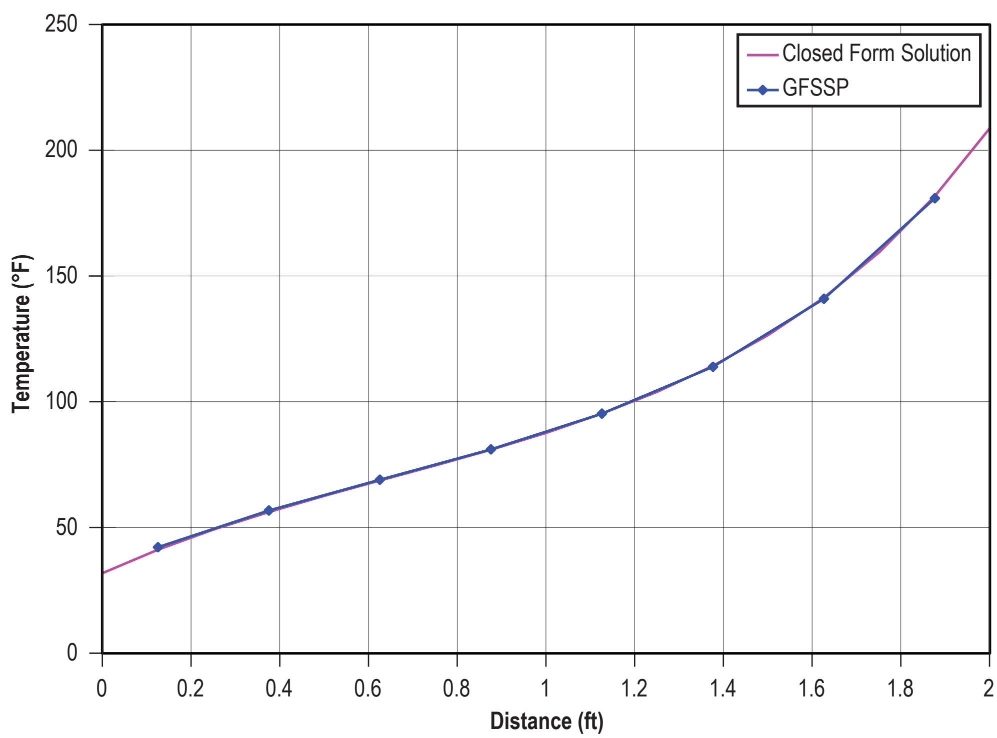

Figure 162. Comparison of GFSSP temperature prediction and closed form solution.

6.14 Example 14—Chilldown of a Cryogenic Pipe Line

6.14.1 Problem Considered

For this example, the chilldown of a cryogenic pipe line to validate GFSSP's transient conjugate heat transfer capability has been selected. In the 1960s, the National Bureau of Standards (NBS) conducted a series of chilldown experiments on a cryogenic transfer line.[49] The test set-up (fig. 163) is a vacuum-jacketed, 200-ft-long copper pipe of 5/8-in inner diameter. A pressurized 80-gal dewar feeds liquid hydrogen into the pipe that is initially at ambient temperature. The wall temperature is measured at four thermocouple stations at distances of 20, 80, 141, and 198 feet from the inlet. When the fluid touches the relatively warm pipe walls, heat transfer causes the liquid cryogen to boil and the pipe wall temperature to decrease. Eventually the pipe chills down to the liquid temperature, and the liquid front gradually travels further down the pipe line. At the outlet of the pipe line, vapor exits to the atmosphere.

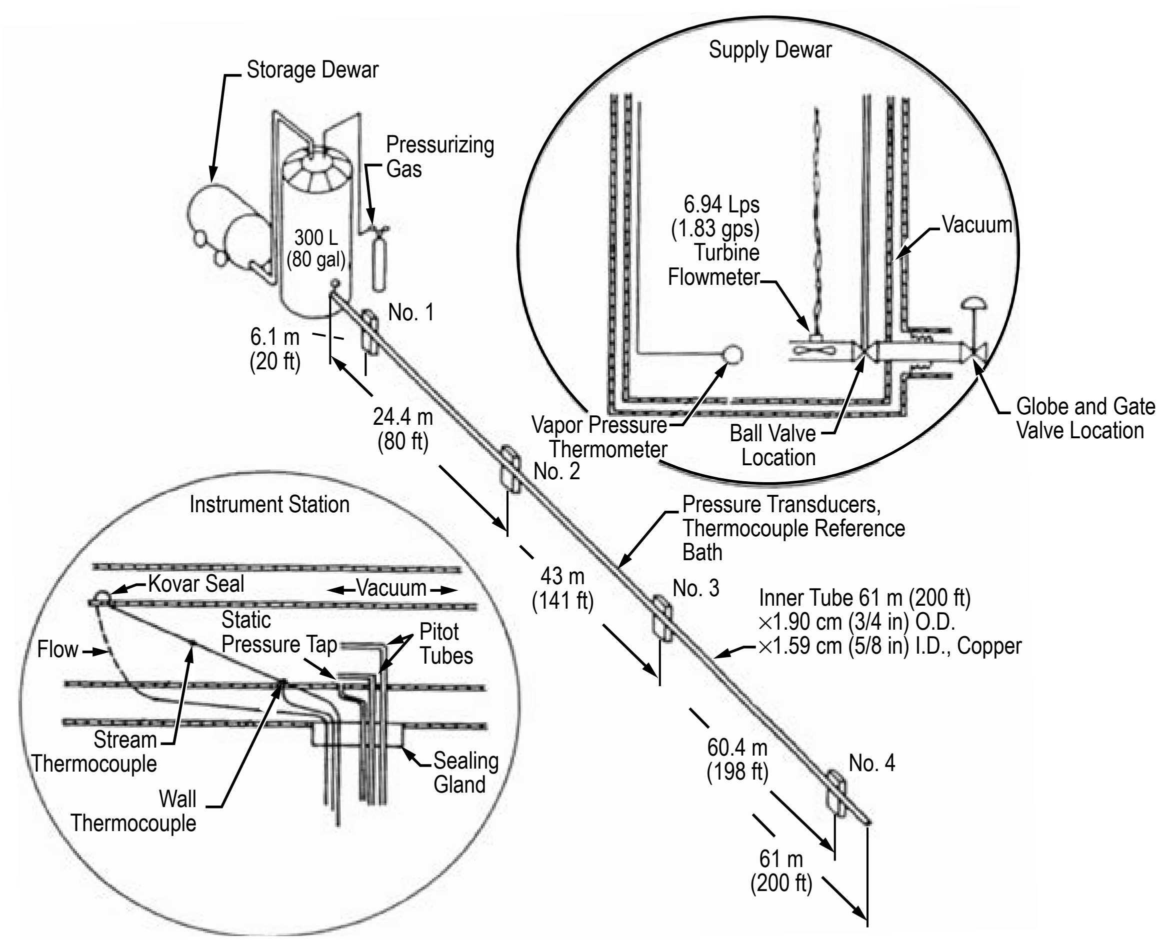

Figure 163. NBS test set-up of cryogenic transfer line.

The NBS experiments were conducted with liquid hydrogen and liquid nitrogen at various driving pressures with saturated and subcooled fluid. This example problem models one of the tests with an inlet boundary of saturated LH_2 at 74.97 psia and –411 °F.

6.14.2 GFSSP Model

Figure 164 shows the GFSSP model of the chilldown experiment. The pipe line has been discretized into 30 pipe branches, each 80 in long. The fluid nodes are connected to 31 solid nodes representing the mass of the copper pipe. The fluid and solid nodes are initially at the ambient temperature of 44 °F. Boundary node 1 represents the storage dewar at 74.97 psia and –411 °F. Boundary node 33 is the ambient atmosphere in Boulder, Colorado, at 12.05 psia. Restriction 12 represents the inlet valve, which opens during the first 0.05 s of the simulation. Restriction 3233 represents the minor loss of the pipe line exit, with a *K* factor of 1.

The solid nodes are connected to the fluid nodes by fluid to solid conductors, which model convection from the fluid to the pipe wall. The built-in Miropolskii correlation is used to calculate the convection coefficient for the two-phase flow. Because the pipe is vacuum-jacketed, heat transfer between the pipe walls and the ambient is assumed negligible.

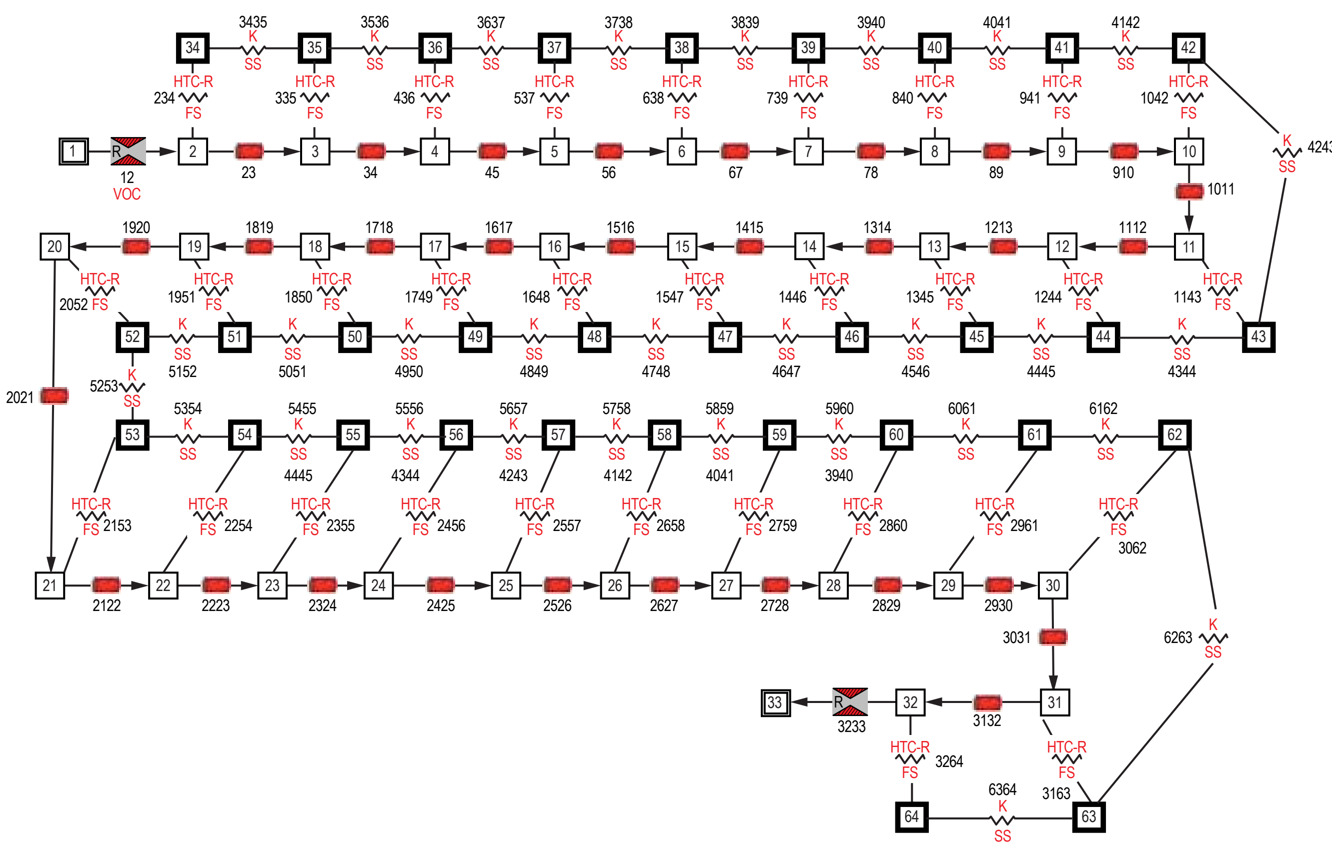

Figure 164. GFSSP model of the cryogenic pipe line.

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6.14.3 Results

Figure 165 shows GFSSP's predicted solid temperatures at each of the four stations as functions of time. These compare well to the measured temperatures. At this driving pressure, the pipe line chills down in about 70 s.

Figure 166 shows GFSSP's predicted flow rate at the entrance and mid section of the pipe line. It is noted that the flow rate at the entrance is initially very unstable. This is caused by rapid boil-off of the cryogen, leading to pressure spikes that temporarily reverse the flow rate. Such behavior was also observed during the NBS experiments. The pressure spikes during startup are seen in figure 167, plotting the pressure near the entrance and mid section of the pipe.

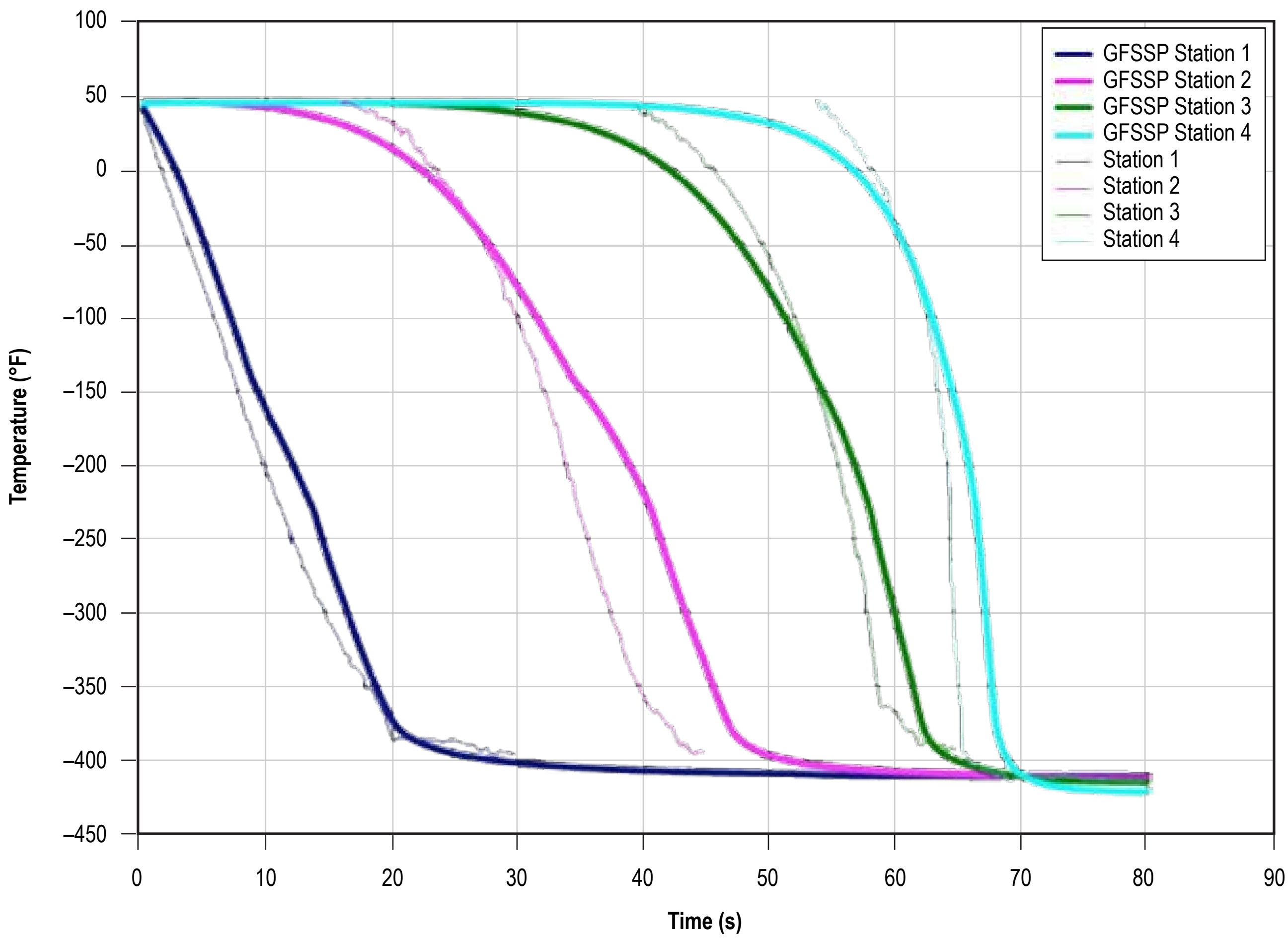

Figure 165. NBS chilldown comparison—GFSSP's predicted solid temperatures (°F) compared to measurements.

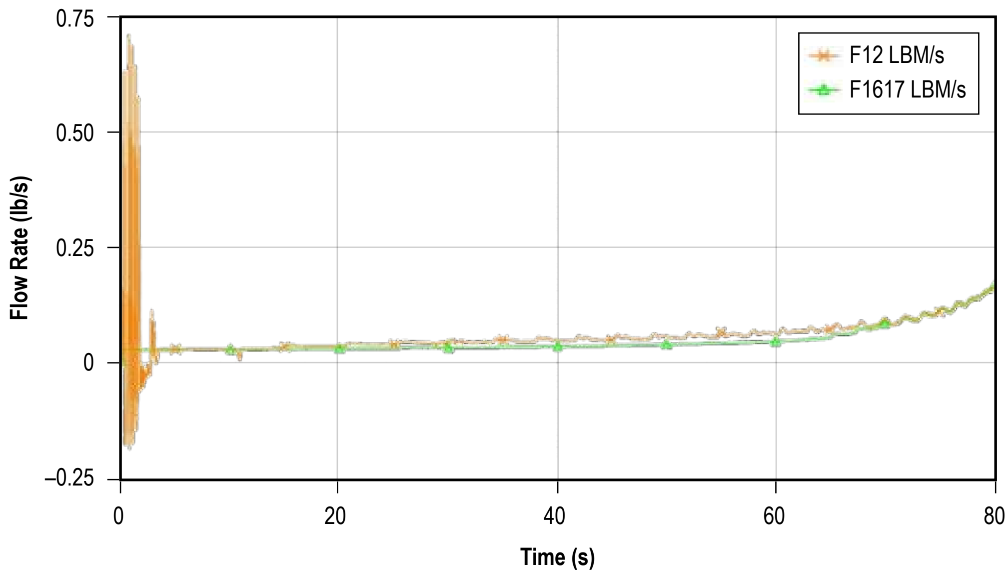

Figure 166. Predicted flow rate (lb/s) at the pipe entrance and middle.

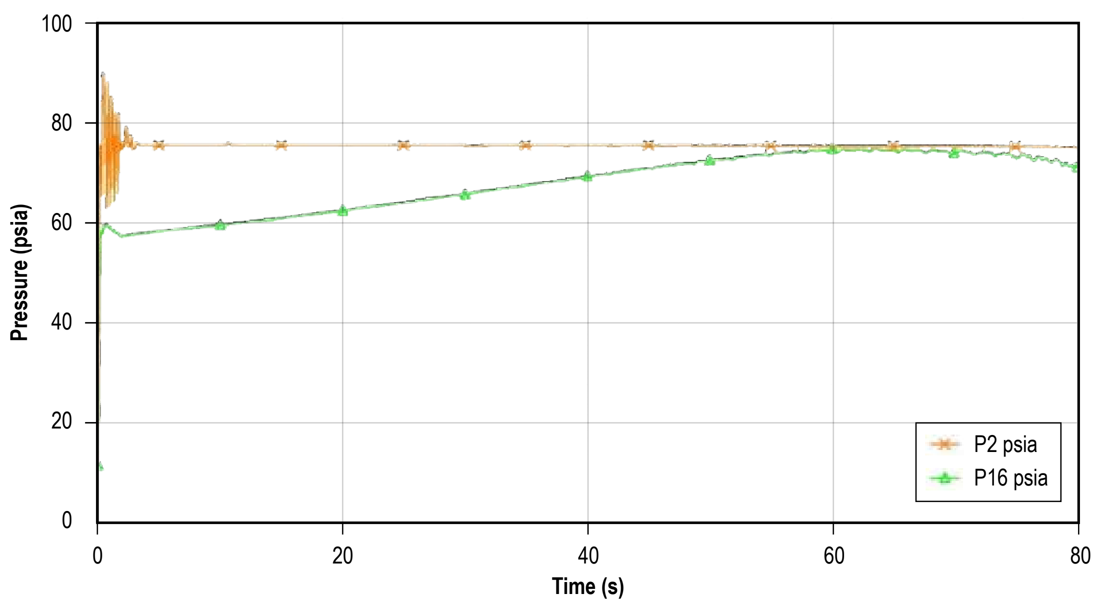

Figure 167. Predicted pressure (psia) near the pipe entrance and middle.

Figure 168 shows the predicted quality (vapor mass fraction) at the nodes corresponding to the four experimental measurement stations. The flow is initially all vapor, but then transitions to a saturated liquid-vapor mixture, and eventually becomes pure liquid flow at the upstream stations shortly after their pipe section has completely chilled down. Cross et al.[33] have generated an analytical solution to the chilldown problem by assuming constant properties and a constant convection coefficient. Figure 169 shows how a modified version of GFSSP's example 14 compares to the analytical solution.

Example 14 input and output files including history and property files are in appendix U.

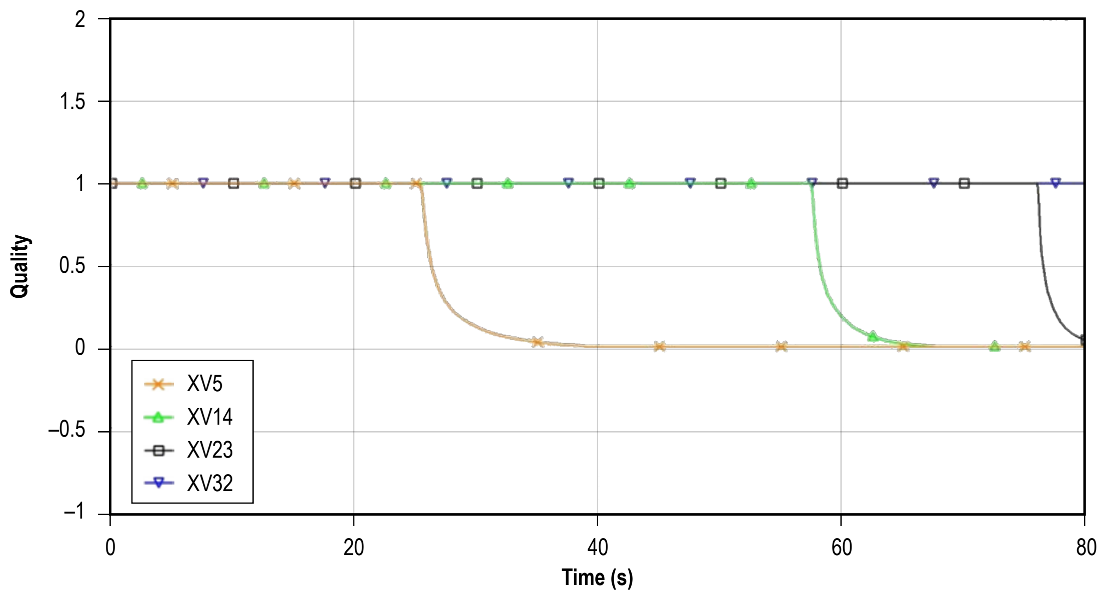

Figure 168. Predicted quality (vapor mass fraction) at the four measurement stations.

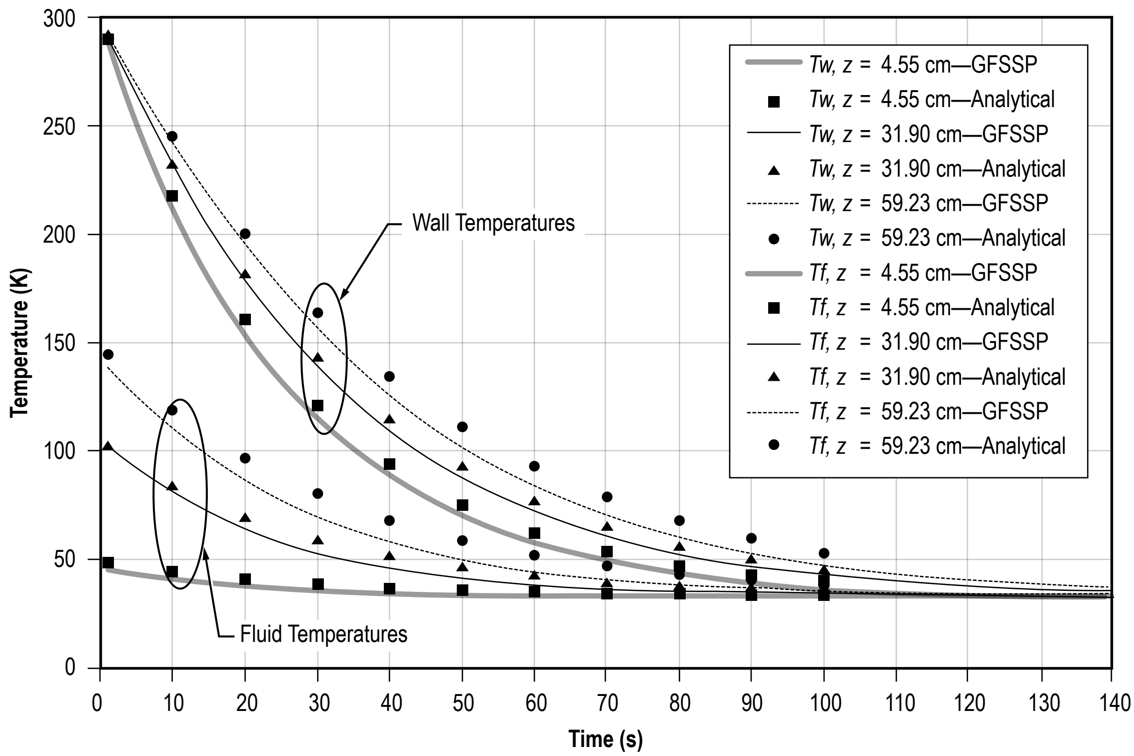

Figure 169. GFSSP's predicted wall and fluid temperatures compared to analytical solution by Cross et al.[33]

6.15 Example 15—Simulation of Fluid Transient Following Sudden Valve Closure

6.15.1 Problem Considered

This example takes advantage of GFSSP's capability to model fluid transients. Fluid transients, also known as water hammer, can have a significant impact on the design and operation of both spacecraft and launch vehicle propulsion systems. These transients often occur at system activation and shutdown, and they must be predicted accurately to ensure the structural integrity of the propulsion system fluid network.

Consider the system shown in figure 170. LOX at 500 psia and 200 °R flows through a 400-ft-long, 0.25-in inside diameter pipe line at a mass flow rate of 0.1 lbm/s. The corresponding downstream pressure is 450 psia. At time zero, a valve at the end of the pipe begins a 100-ms rapid closure. This example discusses how to predict the liquid's response to the sudden valve closure, including the maximum expected surge pressure in the line.

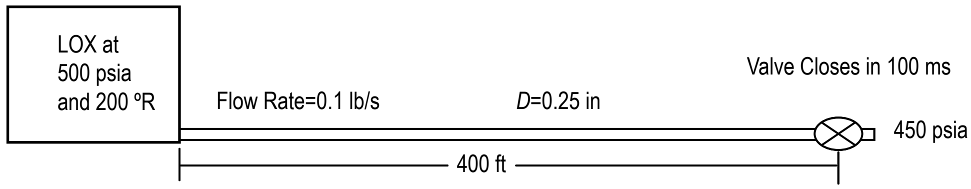

Figure 170. Schematic of a propellant tank, pipe line, and valve.

6.15.2 GFSSP Model

The GFSSP model of the propellant tank and pipe line schematic of figure 170 is shown in figure 171. The system is represented by seven nodes and six branches. Node 1 represents the propellant tank as a boundary node. Node 7 represents the downstream pressure as a boundary node. Nodes 2 to 6 are internal nodes where pressure, temperature, and density are calculated. Branches 12 to 56 represent pipe segments with an 80-ft length and 0.25-in diameter. Branch 67 represents the valve as a flow through a restriction with a flow area of 0.0491 in^2 and a flow coefficient of 0.6. In addition, GFSSP's unsteady valve open/close option is used to model the rapid valve closure in branch 67. The Valve Open/Close characteristics are defined in the Valve Open/Close dialog shown in figure 172. The Valve Open/Close characteristic file is also shown below with annotations to explain the meanings of each value. GFSSP's restart option is used to set the initial conditions of the model. The model is run as a steady state model, and the solution is saved in files FNDEX15.DAT and FBREX15.DAT. This solution is then read in as the initial solution for the transient model run.

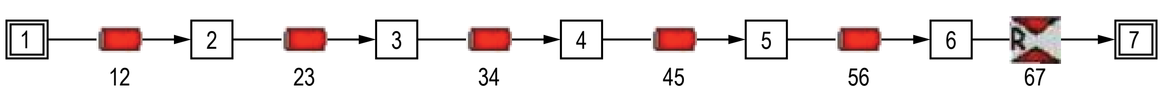

Figure 171. GFSSP model of a propellant tank, pipe line, and valve.

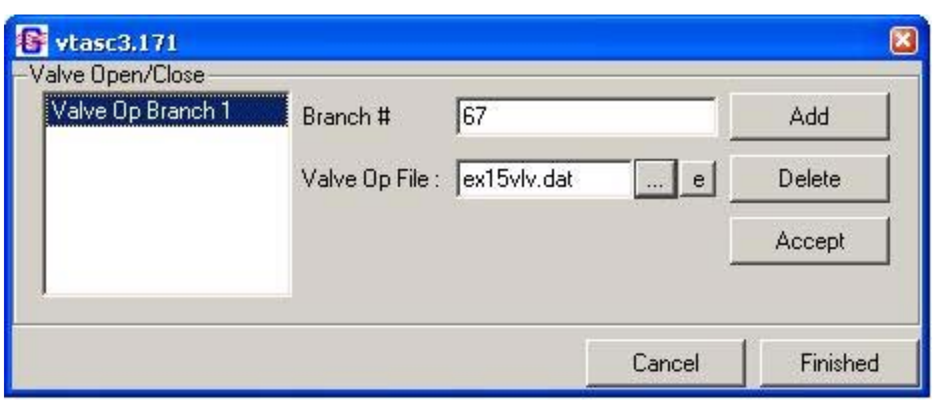

Figure 172. Example 15 Valve Open/Close dialog.

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```
EX15VLV.DAT

7 - Number of lines of data
Time (s)     Flow Area (in2)
0.00         0.0491
0.02         0.0164
0.04         0.00545
0.06         0.00182
0.08         0.00061
0.1          1.E-16
100          1.E-16
```

Some consideration should be given to the time step for this model. In order to properly model the fluid transient, a time step must be chosen that is small enough to accommodate the model discretization. This is done by calculating the Courant number, which is the period of oscillation of one branch divided by the time step (eq. (105)). For the model to properly capture the fluid transient phenomena, the Courant number should be greater than unity:

$$\text{Courant Number} = \frac{4L_{\text{branch}}}{a_{\text{fluid}}\Delta\tau} \geq 1\ . \tag{105}$$

The speed of sound (a_{fluid}) for LOX is 2,462 ft/s. Choosing a time step of 0.02 s gives a Courant number of 6.5, which satisfies the criteria for this model.

6.15.3 Results

The input and output files including history and restart files of example 15 have been attached in appendix V. Figure 173 compares GFSSP's predicted pressure at node 6 with a method of charac-teristics (MOC) solution. Both solutions compare very well in the timing and character of the pre-dicted pressure oscillations. The maximum surge pressure predicted by GFSSP is 624 psia compared to a MOC prediction of 636 psia. Additional studies have been performed using varying levels of discretization, different fluids, and even liquid-gas mixtures.[37] A sudden valve opening situation has been modeled and compared with test data.[53]

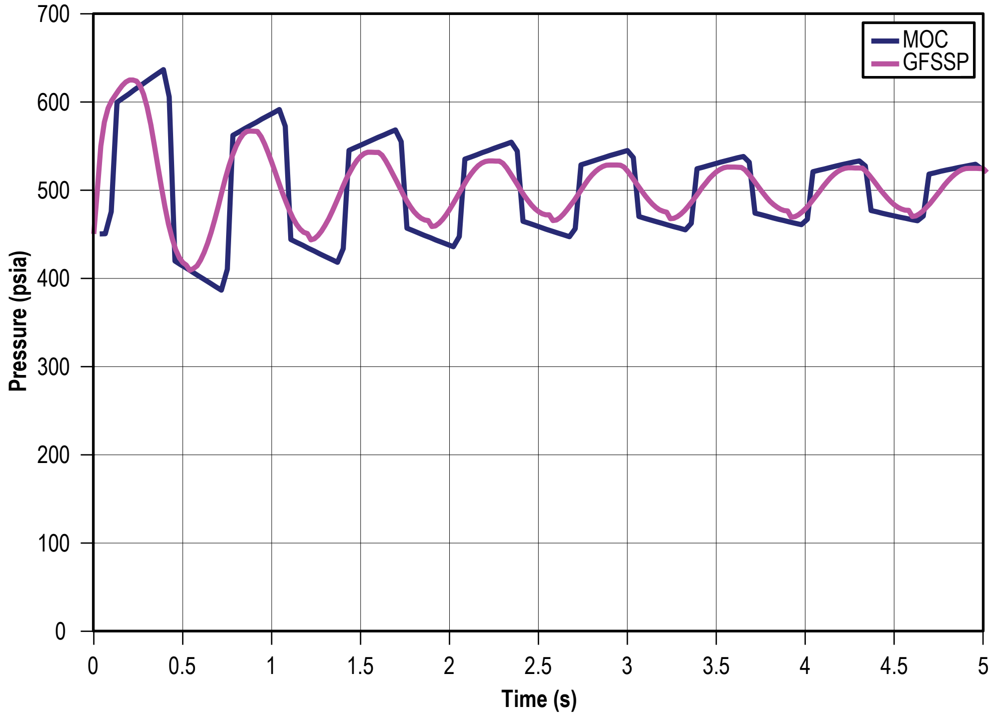

Figure 173. Comparison of GFSSP and MOC predicted pressure oscillations.

6.16 Example 16—Simulation of a Pressure Regulator Downstream of a Pressurized Tank

6.16.1 Problem Considered

This example repeats the blowdown problem of example 8, but simulates the operation of a pressure regulator downstream of the pressurized tank. Consider a tank (fig. 174) with an internal volume of 10 ft^3, containing air initially at a pressure and temperature of 100 psia and 80 °F, respectively. Air passes through a pressure regulator and is then discharged into the atmosphere through an orifice of 0.1-in diameter for a period of 150 s. GFSSP is used to determine the mass flow rate and pressure/temperature history of the tank contents during blowdown. The detailed GFSSP model schematic is shown in figure 175 while the VTASC model is shown in figure 176.

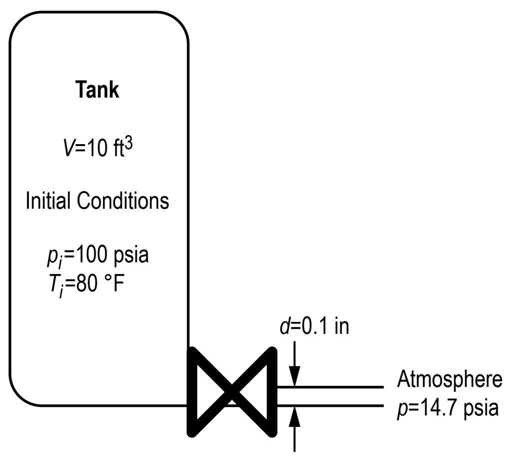

Figure 174. Tank blowdown with pressure regulator VTASC model (example 16).

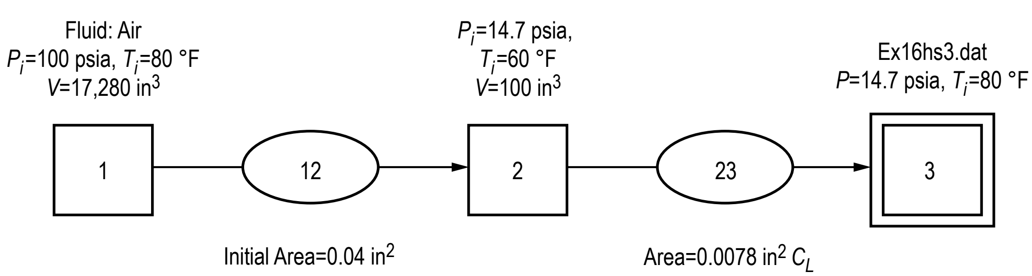

Figure 175. Tank blowdown with pressure regulator detailed model (example 16).

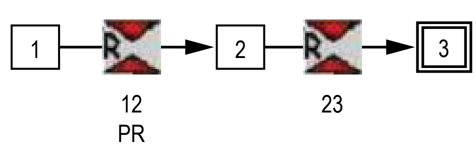

Figure 176. Tank blowdown with pressure regulator VTASC model (example 16).

6.16.2 GFSSP Model

The process is modeled with three nodes and two branches. Node 1 is an internal node that represents the tank volume, with initial pressure of 100 psia and initial temperature of 80 °F. Node 2 represents the small volume between the regulator and the outlet orifice. Node 3 represents the ambient boundary with constant pressure of 14.7 psia. The history file, ex16hs3.dat, is the same as the history file used for example 8. Resistance option 2 (Restriction) was used for branches 12 and 23. Branch 12 represents the pressure regulator with an initial flow area of 0.04 in^2. Branch 23 is the outlet orifice with a flow area of 0.00785 in^2.

The pressure regulator option is activated on the Unsteady Options page, and the dialog box is found on the Advanced menu. The option should be applied to Restriction or Compressible Orifice branches. There are two options for modeling a pressure regulator:

- Option 1 is an iterative algorithm that continuously adjusts the flow area of the branch in each time step, not leaving the time step until the desired downstream pressure is achieved (within the user-specified tolerance level), or until the maximum number of iterations is reached. Only one regulator per model is allowed. This option acts like a regulator that reacts instantly to changes in the flow network. Because it can take many iterations to find the proper area to achieve the desired pressure in each time step, this option may run slowly.

- Option 2 is a time-marching algorithm in which the regulator area is adjusted just once at the beginning of each time step, based on an empirical correlation that compares the downstream pressure from the previous time step to the desired pressure.[38] The pressure may oscillate about the setpoint for several time steps until convergence is reached. Multiple regulators are allowed with this option. As it takes a finite amount of time to reach the desired pressure, this option can more realistically model the behavior of a real pressure regulator. The time to achieve convergence can be adjusted by modifying the initial regulator area and the relaxation parameter. Because the flow area is corrected just once per time step, this option will generally run more quickly than option 1.

The pressure regulator history file for branch 12 is shown in table 31. It calls for a downstream pressure of 35 psia for the first 10 s, followed by 40 psia thereafter. The user can also set a constant pressure in the dialog box. Air is modeled using the ideal gas option.

Table 31. Pressure regulator history file for branch 12 (example 16).

4		Number of data points	
0	35	τ (s)	p (psia)
10	35		
10.01	40		
1,000	40		

6.16.3 Results

The input and output files of this example are included in appendix W as ex16.dat and ex16.out. The transient test model was run for 150 s with 0.1-s time step, using both pressure regulator options. Calculated tank and downstream pressure, tank temperature, pressure regulator flow area, and flow rate are shown in figures 177 –181. Note the gradually shrinking oscillations about the desired pressure when option 2 is used, and how option 1 reacts instantly to the change in set pressure at 10 s.

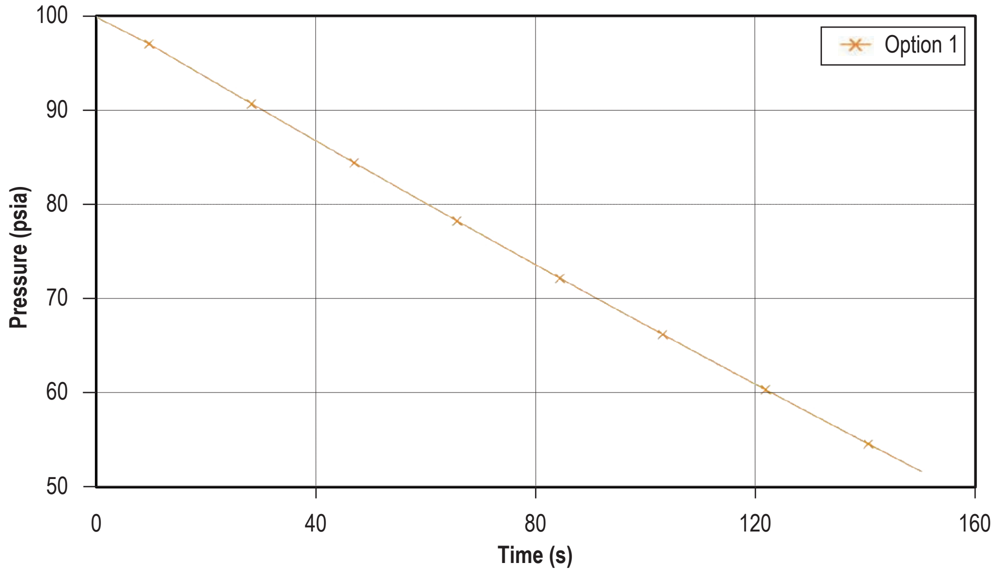

Figure 177. Tank pressure history (example 16).

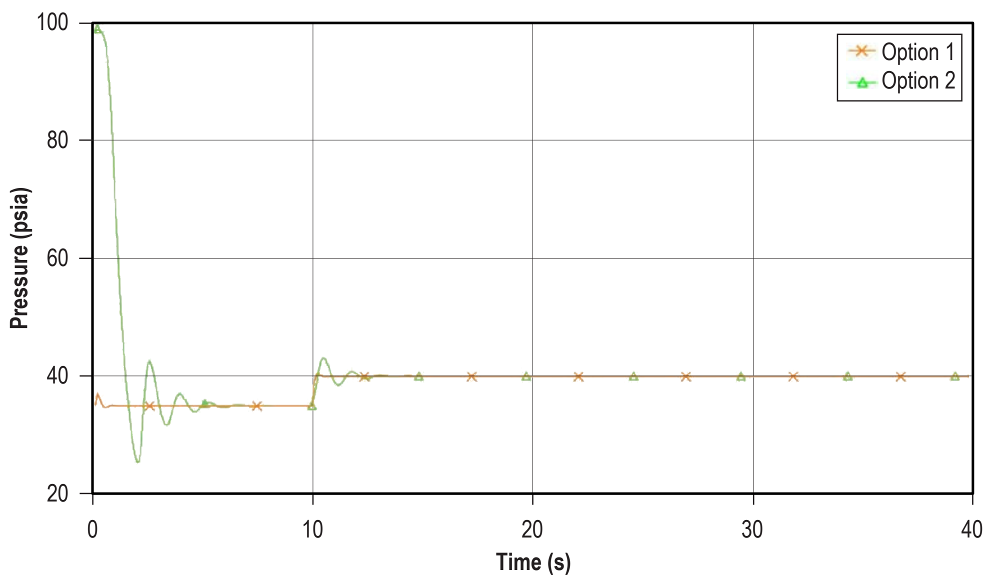

Figure 178. Pressure history downstream of pressure regulator (example 16).

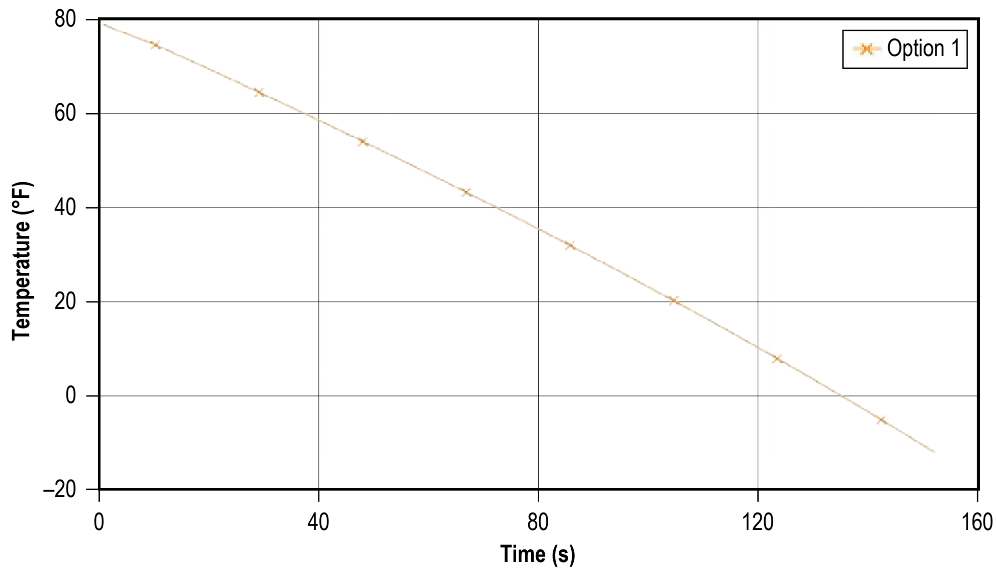

Figure 179. Tank temperature history (example 16).

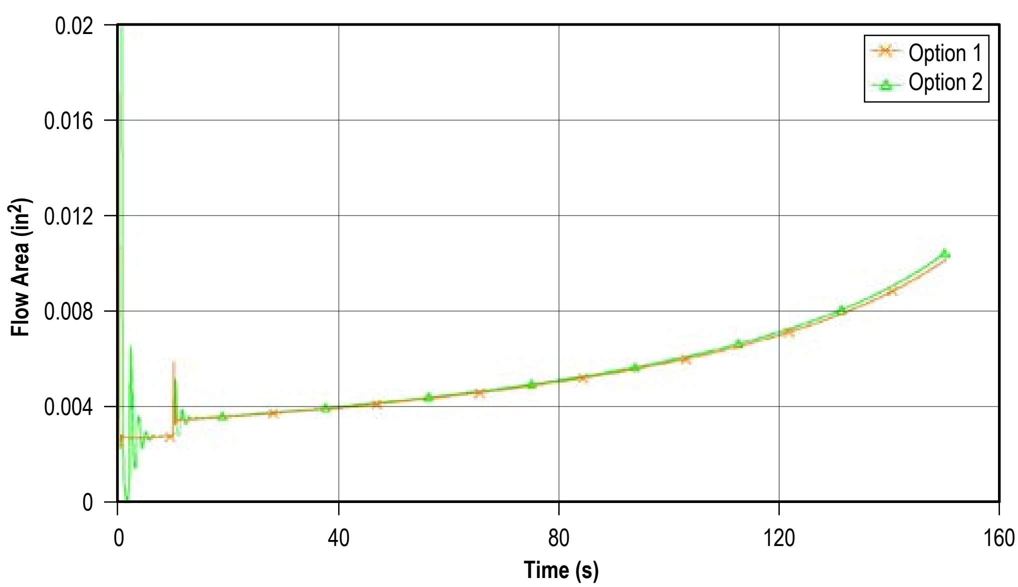

Figure 180. Pressure regulator flow area history (example 16, restrict 12).

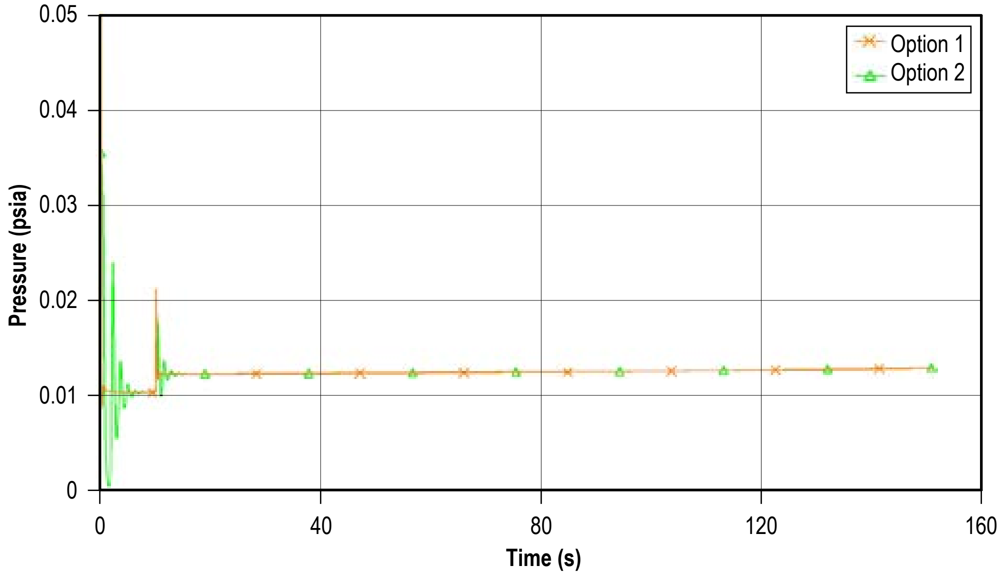

Figure 181. Pressure regulator flow rate history (example 16, restrict 12).

6.17 Example 17—Simulation of a Flow Regulator Downstream of a Pressurized Tank

6.17.1 Problem Considered

This example repeats the blowdown problem of example 8, but simulates the operation of a flow regulator downstream of the pressurized tank. Consider a tank (fig. 182) with an internal volume of 10 ft^3, containing air initially at a pressure and temperature of 100 psia and 80 °F, respectively. Air passes through a flow regulator and is then discharged into the atmosphere for a period of 20 s. GFSSP is used to determine the pressure/temperature history of the tank contents during blowdown. The detailed GFSSP model schematic is shown in figure 183 while the VTASC model is shown in figure 184.

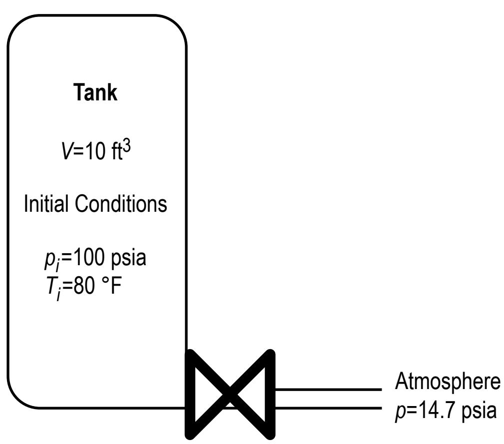

Figure 182. Tank blowdown with flow regulator schematic (example 17).

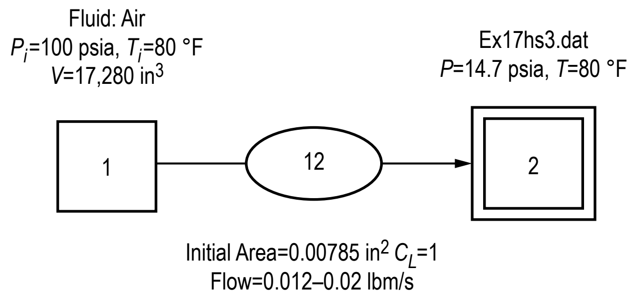

Figure 183. Tank blowdown with flow regulator detailed model (example 17).

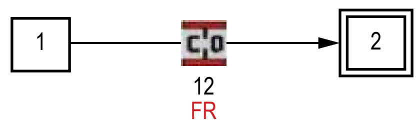

Figure 184. Tank blowdown with flow regulator VTASC model (example 17).

6.17.2 GFSSP Model

The process is modeled with two nodes and one branch. Node 1 is an internal node that represents the tank volume, with initial pressure of 100 psia and initial temperature of 80 °F. Node 2 represents the ambient boundary with a constant pressure of 14.7 psia. The history file, ex17hs3.dat, is the same as the history file used for example 8. Branch 12 represents the flow regulator, modeled with resistance option 22 (Compressible Orifice).

The flow regulator option is activated on the Unsteady Options page, and the dialog box is found on the Advanced menu. The option should be applied to Restriction or Compressible Orifice branches. There are two options for modeling a flow regulator:

- Option 1 is an iterative algorithm that continuously adjusts the flow area of the branch in each time step, not leaving the time step until the desired flow rate is achieved (within the user-specified tolerance level), or until the maximum number of iterations (currently hard-coded to 50) is reached. Only one regulator per model is allowed. This option acts like a regulator that reacts instantly to changes in the flow network. Because it can take many iterations to find the proper area to achieve the desired flow rate in each time step, this option may run slowly.

- Option 2 is a time-marching algorithm in which the regulator area is adjusted just once at the beginning of each time step, based on the numerical derivative of the change in flow rate with respect to the change in flow area, calculated from the results of the previous time steps. The flow rate may oscillate about the setpoint for several time steps until convergence is reached. Because other elements of the model may also affect the flow rate derivative, this option can be numerically unstable; under-relaxation may be required. Multiple regulators are allowed with this option. As it takes a finite amount of time to reach the desired flow rate, this option can more realistically model the behavior of a real flow regulator. The time to achieve convergence can be adjusted by modifying the initial regulator area and the relaxation parameter. Because the flow area is corrected just once per time step, this option will generally run more quickly than option 1.

The flow regulator history file is shown in table 32. It calls for a flow rate 0.012 lb/s for the first 10 s, followed by 0.020 lb/s thereafter. The user can also set a constant flow rate in the dialog box. Air is modeled using the ideal gas option.

Table 32. Flow regulator history file for branch 12 (example 17).

4	Number of Data Points
1	0.012
10	0.012
10.01	0.02
1,000	0.02

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6.17.3 Results

The input and output files of this example are included in appendix X as ex17.dat and ex17.out. The transient test model was run for 20 s with 0.5-s time step, using both flow regulator options. Calculated tank pressure and temperature, flow regulator area, and flow rate are shown in figures 185–188. Note that option 2 takes several time steps to reach the target flow rate, while option 1 reacts instantly to the change in required flow rate at 10 s.

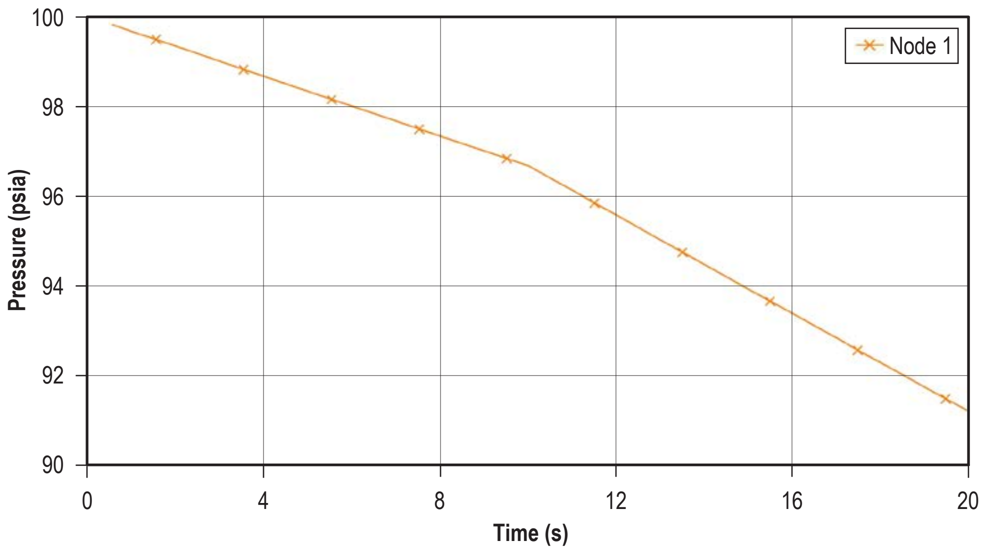

Figure 185. Tank pressure history (example 17).

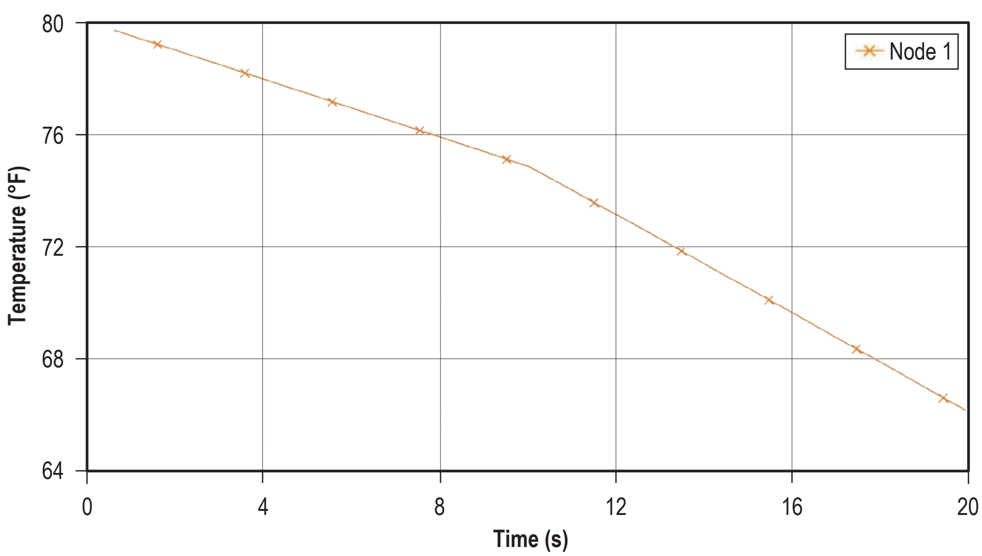

Figure 186. Tank temperature history (example 17).

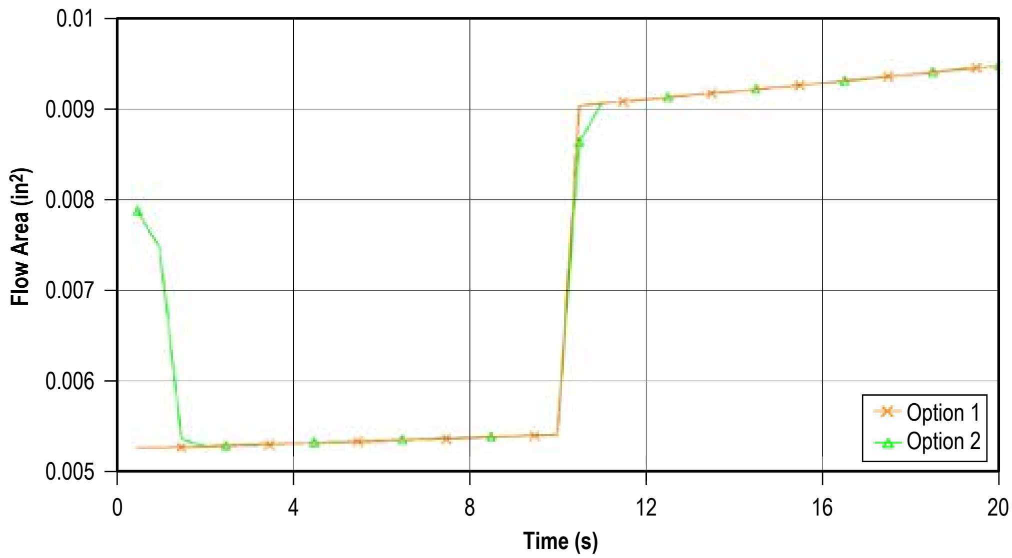

Figure 187. Flow regulator area history (example 17).

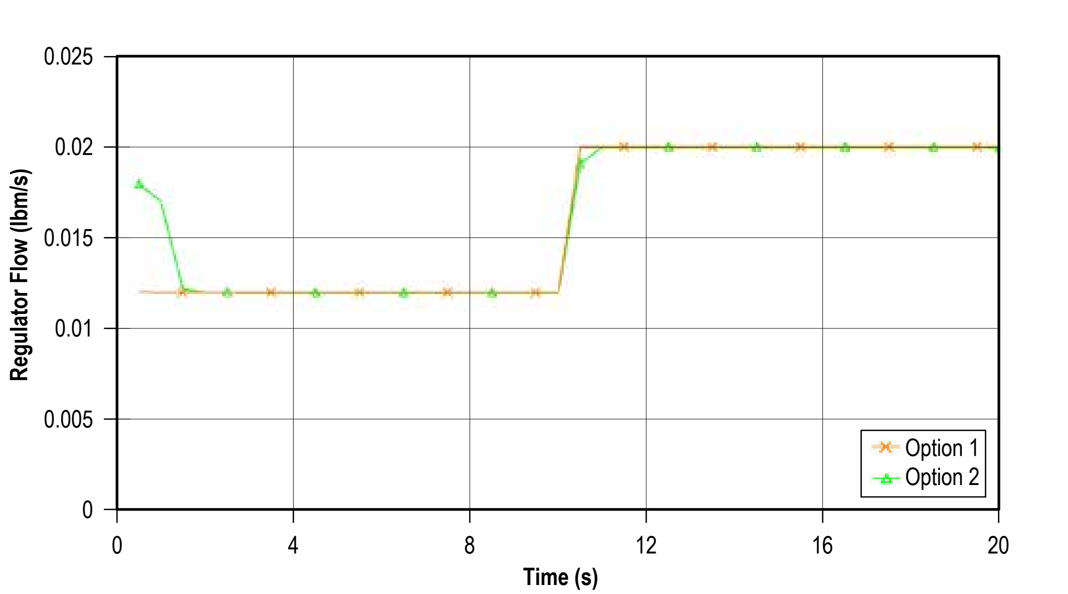

Figure 188. Flow regulator flow rate history (example 17).

6.18 Example 18—Simulation of a Subsonic Fanno Flow

6.18.1 Problem Considered

This example illustrates the capabilities of the steady state flow formulation of GFSSP to simulate subsonic Fanno flow. Fanno flow is the flow with friction in an adiabatic constant-area pipe. Consider a supply line (fig. 189) containing nitrogen gas at a pressure and temperature of 50 psia and 80 °F, respectively. Nitrogen gas is discharged into a pipe of 3,207 in length and 6 in diameter. GFSSP will be used to determine the pressure, mass flow rate, and temperature history through pipes using the Fanno flow process. These predicted values are then compared with the analytical solution.

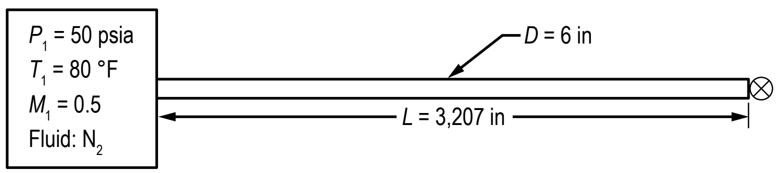

Figure 189. Fanno flow schematic (example 18).

6.18.2 GFSSP Model

GFSSP model schematic is shown in figure 190 and the VTASC model is shown in figure 191.

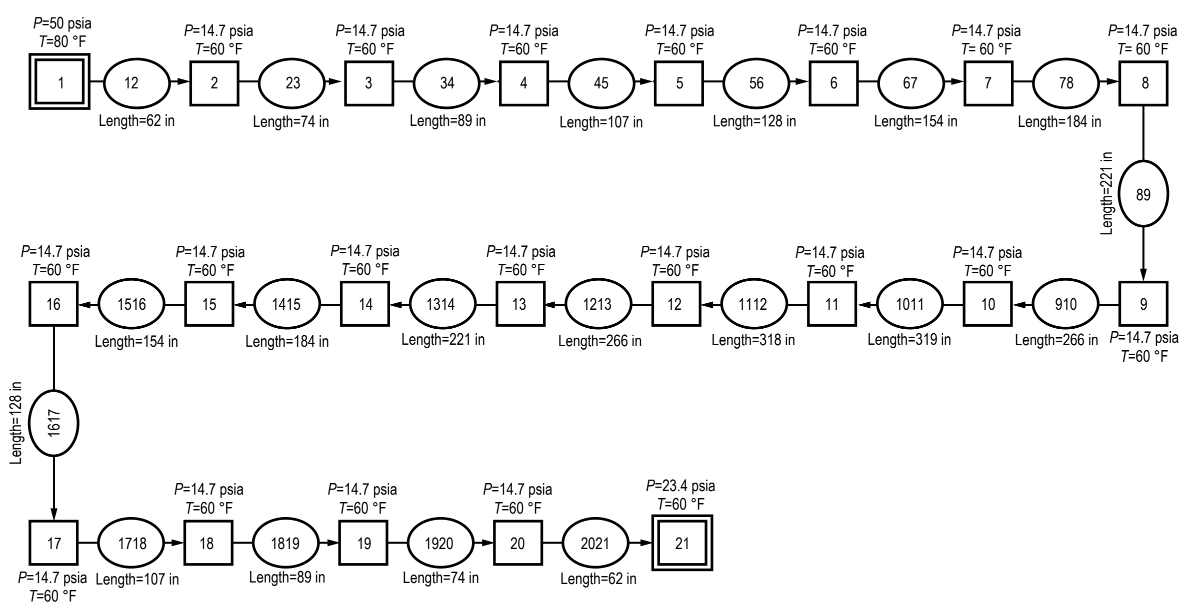

Figure 190. Fanno flow model schematic—fluid: nitrogen.

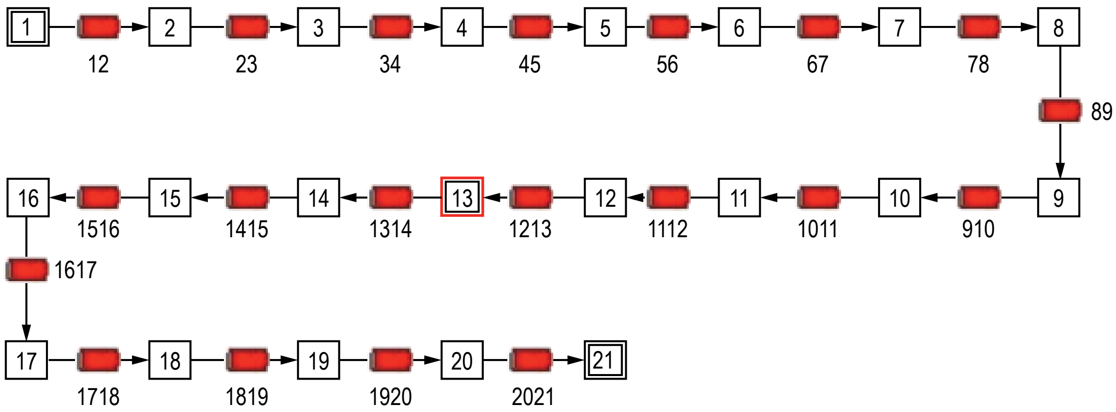

Figure 191. Fanno flow VTASC model.

The process has been modeled with 21 nodes and 20 branches. Node 1 is a boundary node that represents the supply line. For the steady state Fanno flow formulation, the node initial guess must be supplied for each internal node and conditions must be supplied for each boundary node. The initial pressure and temperature for boundary nodes 1 and 21 are shown in table 33. Resistance option 1 (pipe) was used for all branches with different lengths, as shown in table 34. For all pipes, the diameter is 6 in, and the absolute roughness is set to zero in VTASC. Inertia was activated in all branches to account for fluid acceleration caused by density change. Nitrogen gas is modeled using the general fluid option that is available in VTASC. Table 35 shows the steady state results of pressure, temperature, and density in internal nodes.

Table 33. Example 18 boundary conditions.

Boundary Node No.	Pressure (psia)	Temperature (°F)
1	50	80
21	23.4	60

Table 34. Branch properties of Fanno flow (example 18).

Branch No.	Length (in)
12	62
23	74
34	89
45	107
56	128
67	154
78	184
89	221
910	266
1011	319
1112	318
1213	266
1314	221
1415	184
1516	154
1617	128
1718	107
1819	89
1920	74
2021	62

Table 35. Example 18 internal node results.

Internal Node No.	Pressure (psi)	Temperature (°F)	Density (lbm/ft^3)
2	49.81	79.98	0.241
3	49.5	79.74	0.2396
4	49.11	79.39	0.2379
5	48.63	78.94	0.2358
6	48.05	78.37	0.2332
7	47.34	77.65	0.2301
8	46.46	76.73	0.2262
9	45.38	75.54	0.2214
10	44.04	73.97	0.2155
11	42.34	71.82	0.208
12	40.41	68.83	0.1997
13	38.45	65.07	0.1913
14	36.55	60.86	0.1834
15	34.72	56.29	0.1757
16	32.94	51.34	0.1684
17	31.19	45.9	0.1611
18	29.42	39.83	0.1539
19	27.6	32.85	0.1464
20	25.64	24.47	0.1384

This example validates GFSSP's prediction with the analytical solution. The analytical solution, discussed below, is valid for flows with heat transfer and friction. However, the friction factor must be constant throughout the length of the pipe. On the other hand, GFSSP calculates the friction factor with local properties such as density, viscosity, and velocity, and friction factor varies from branch to branch. Therefore, in order to obtain a GFSSP solution with constant friction factor, this model makes use of User Subroutine to set a constant friction factor in all branches. Subroutine KFADJUST was used to adjust K_f for a given friction factor. The analytical solution assumes a friction factor of 0.002. The listing of Subroutine KFADJUST in appendix Y shows how to implement the constant friction factor in GFSSP.

6.18.2.1 Analytical Solution of Fanno Flow. The analytical solution of compressible flow with friction requires simultaneous solution of the following mass and momentum conservation equations:

Mass Conservation:

$$\frac{d\rho}{\rho}+\frac{dA}{A}+\frac{dV}{V}=0\,. \tag{106}$$

Momentum Conservation:

$$\frac{dp}{p}+\frac{\gamma M^2}{2}+\frac{fdx}{D}+\gamma M^2\frac{dV}{V}=0\,, \tag{107}$$

where M = Mach No. = $\dfrac{V}{C}=\dfrac{V}{\sqrt{\gamma\dfrac{p}{\rho}}}$.

Using the definition of Mach number, stagnation temperature, equations (106) and (107) can be expressed as an ordinary differential equation of first order:

$$\frac{dM}{dx}=\frac{M\left(1+\dfrac{\gamma-1}{2}M^2\right)}{\left(1-M^2\right)}\left[\gamma M^2\frac{f}{D}+\frac{\left(1+\gamma M^2\right)}{2T_0}\frac{dT_0}{dx}-\gamma M^2\frac{1}{A}\frac{dA}{dx}\right], \tag{108}$$

with boundary value,

$$M(x=0)=M_1\,. \tag{108a}$$

dT_0/dx in equation (108) can be determined from the energy equation which can be expressed as:

$$q(\pi D)dx=\dot{m}C_p dT_0\,. \tag{109}$$

Given the inlet conditions (eq. (108)), the first order differential equation (eq. (108)) in M is solved to find the Mach number at any x location. As this equation is a nonlinear equation in M, this equation is solved by using the fourth order Runge-Kutta method.[27]

From Mach number, the static temperature and pressure can be determined from the following equations:

$$\frac{T(x)}{T(0)}=\frac{T_0(x)}{T_0(0)}\frac{1+\dfrac{\gamma-1}{2}(M(0))^2}{1+\dfrac{\gamma-1}{2}(M(x))^2} \tag{110}$$

and

$$\frac{p(x)}{p(0)}=\frac{A(0)}{A(x)}\frac{M(0)}{M(x)}\sqrt{\frac{T(x)}{T(0)}}\,. \tag{111}$$

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No heat transfer implies the stagnation temperature is constant and $dT_0/dx = 0$. Before presenting the results for Fanno flow, choice of pipe length as 3,207 in is explained below. From the analytical solution for Fanno flow, the critical length of the pipe (L^*) is determined from the following equation:

$$\frac{fL^*}{D} = \frac{1-M^2}{\gamma M^2} + \frac{1+\gamma}{2y} \ln\left(\frac{(1+\gamma)M^2}{2+(\gamma-1)M^2}\right). \tag{112}$$

M is the inlet Mach number. The critical length of the pipe is the length required for the flow to choke at the exit (i.e., $M = 1$ at exit). With an inlet Mach number of 0.5 and a friction factor of 0.002, and pipe diameter of 6 in, the critical length is calculated to be 3,207 in. This length is kept fixed for the cases of constant area pipes.

6.18.3 Results

Figure 192 shows a plot of the p/p^* ratio with different types of node distribution for the numerical solution compared with the analytical solution. A nonuniform node distribution with a total of 21 nodes (20 control volumes) is sufficient to get a grid-independent solution. The corresponding temperature distribution is shown in figure 193. The plots also show that the numerical solution using GFSSP agrees very well with that of the analytical solution.

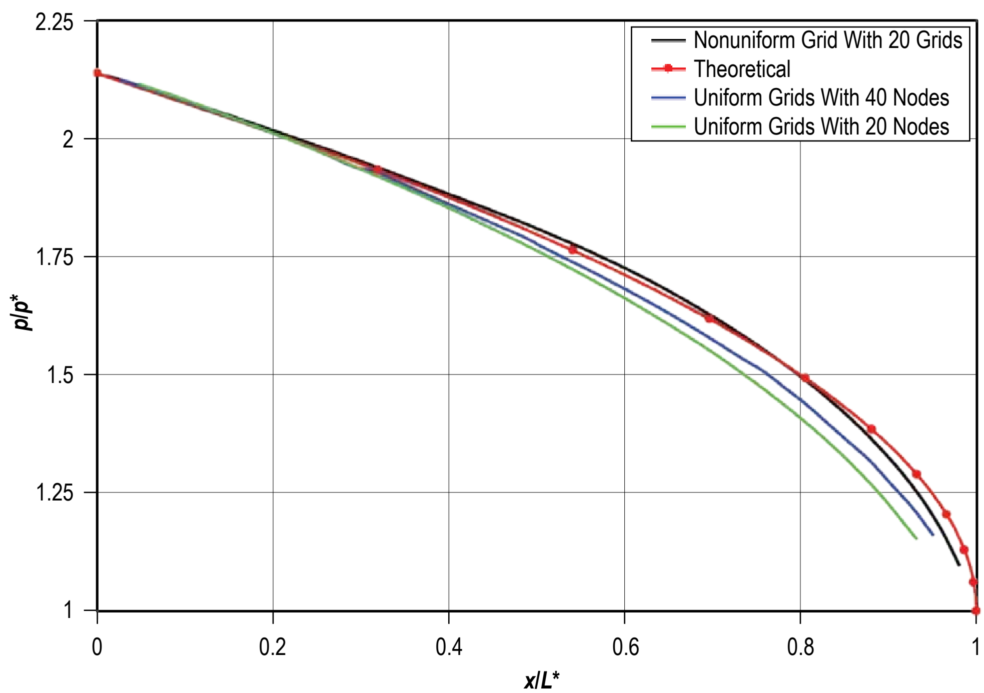

Figure 192. Pressure distribution for Fanno flow with various grid distributions.

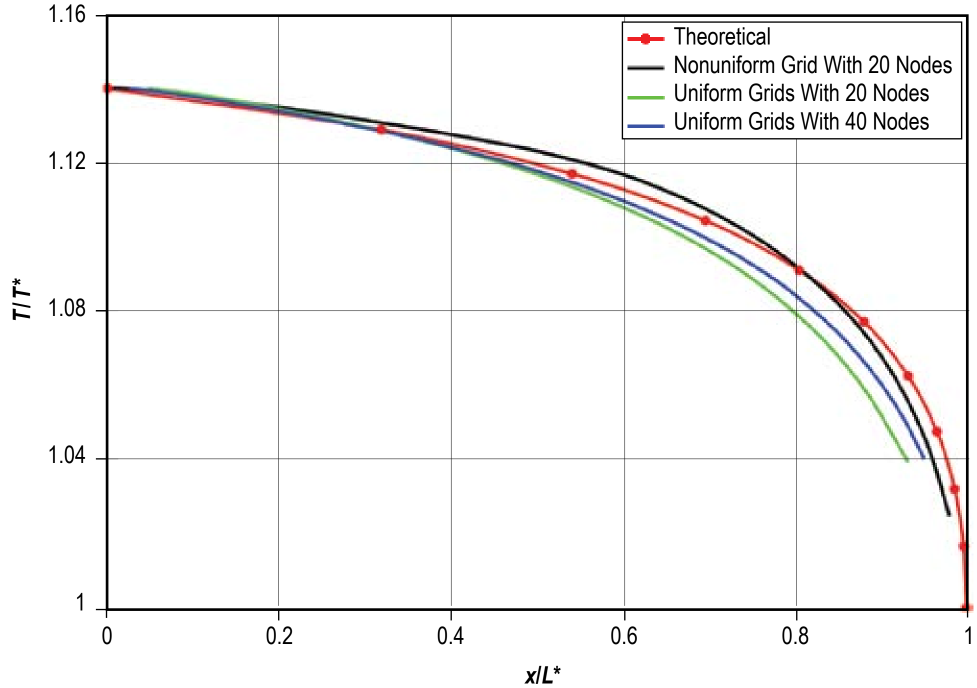

Figure 193. Temperature distribution for Fanno flow with various grid distributions.

Figure 194 shows a plot of the Mach number along the axial direction, and again the agreement with the analytical solution is quite good. The slight difference even at the inlet is because, in GFSSP, the mass flow rate is not prescribed, rather the pressure boundary condition is specified, and the flow rate is computed.

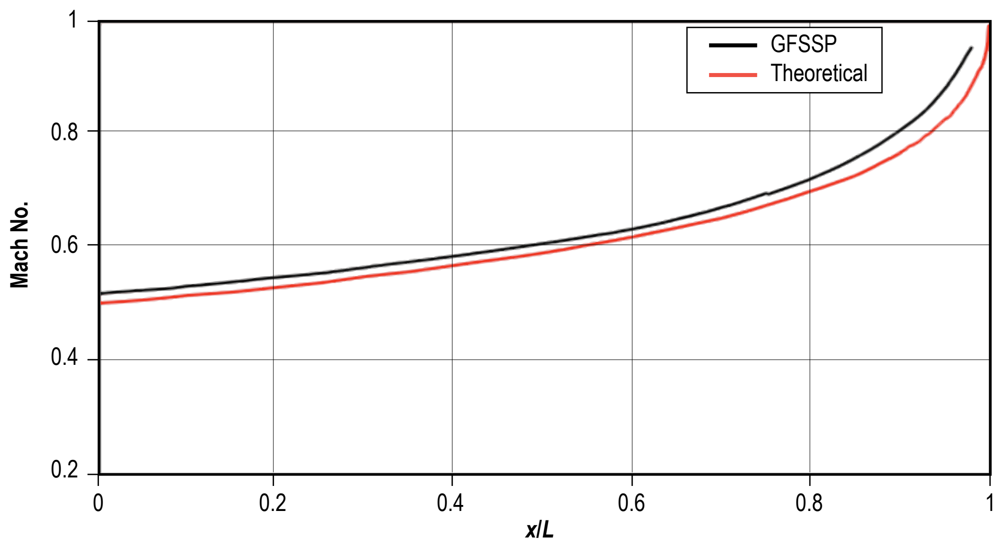

Figure 194. Fanno flow plot of Mach number along the pipe length.

6.19 Example 19—Simulation of a Subsonic Rayleigh Flow

6.19.1 Problem Considered

This example illustrates the capabilities of the steady state flow formulation of GFSSP to simulate subsonic Rayleigh flow. Rayleigh flow is the frictionless flow in a constant area pipe with heat transfer. Consider a supply line (fig. 195) containing nitrogen gas at a pressure and temperature of 50 psia and 80 °F, respectively. Nitrogen gas is flowing with an inlet Mach number of 0.5 through a pipe that is 3,207 in long and has a 6 in diameter. A heat input rate of 1,800 Btu/s has been applied along the length of the discharge pipe. GFSSP will be used to determine the pressure, mass flow rate, and temperature history through pipes using the Rayleigh flow process. These predicted values are then compared with the analytical solution. The detailed model schematic is shown in figure 196 while the VTASC model is shown in figure 197.

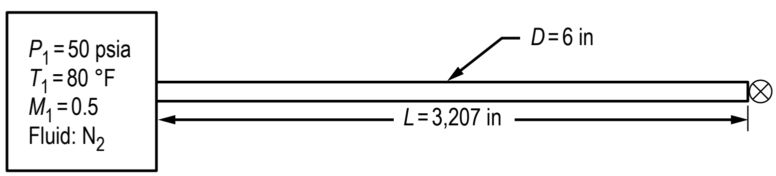

Figure 195. Tank blowdown schematic (example 19).

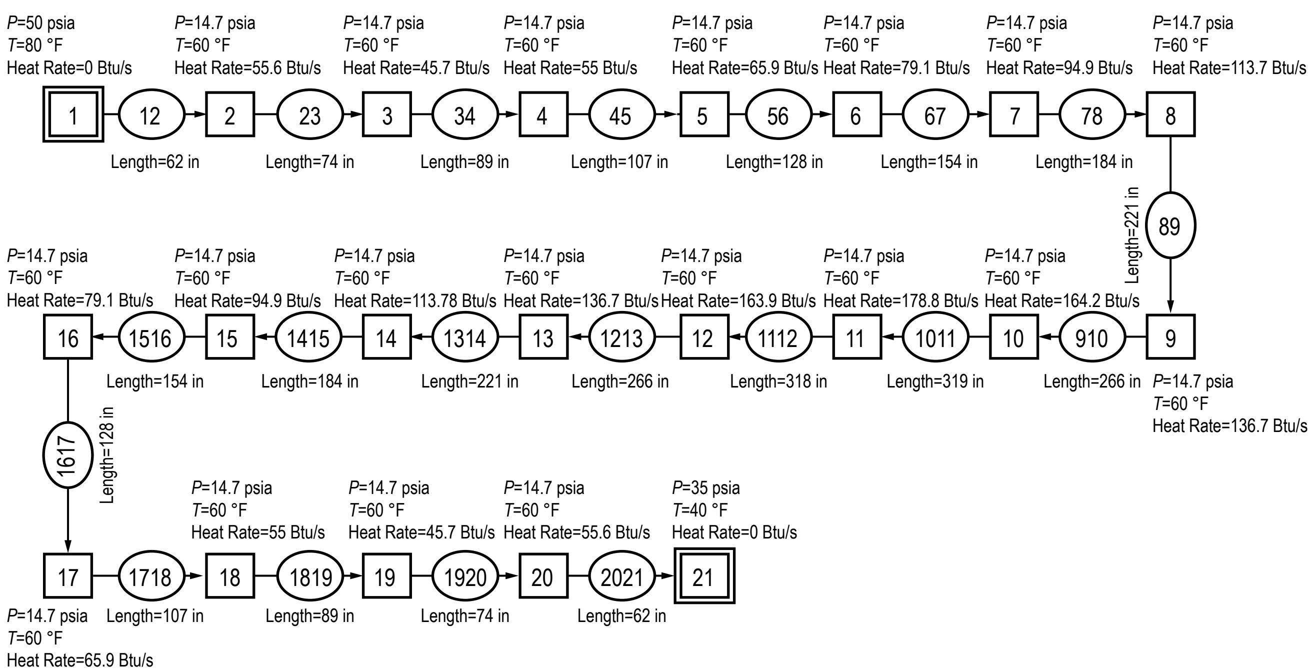

Figure 196. Pressurized tank detailed model schematic (example 19)—fluid: nitrogen.

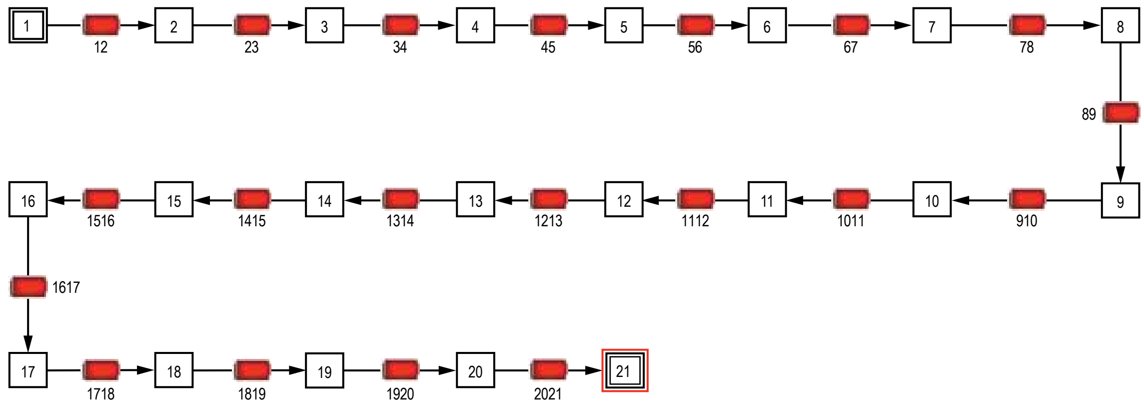

Figure 197. Rayleigh flow VTASC model (example 19).

6.19.2 GFSSP Model

The GFSSP model schematic is shown in figure 196 and the VTASC model is shown in figure 197. The process has been modeled with 21 nodes and 20 branches. Node 1 is a boundary node that represents the supply line. For the steady state Rayleigh flow formulation, the node heat rate and the initial guess must be supplied for each internal node and conditions must be supplied for each boundary node. The initial pressure and temperature for boundary nodes 1 and 21 are shown in table 36. The initial guess pressure, temperature, and heat rate for internal nodes 2 through 20 are shown in table 37. Resistance option 1 was used for all branches with different lengths, as shown in table 38. However, to simulate frictionless flow the friction factor is set to zero in the User Subroutine. Inertia was activated in all branches to account for fluid acceleration caused due to density change. Nitrogen gas is modeled using the general fluid option that is available in VTASC. Table 39 shows the steady state results of the internal node. For all pipes, the diameter is 6 in, and the absolute roughness is set to zero.

Table 36. Boundary conditions (example 19).

Boundary Node No.	Pressure (psia)	Temperature (°F)
1	50	80
21	35	40

Table 37. Internal node initial conditions (example 19).

Internal Node No.	Pressure (psia)	Temperature (°F)	Heat Rate (Btu/s)
2	14.7	60	55.6
3	14.7	60	45.7
4	14.7	60	55
5	14.7	60	65.9
6	14.7	60	79.1
7	14.7	60	94.9
8	14.7	60	113.7
9	14.7	60	136.7
10	14.7	60	164.2
11	14.7	60	178.8
12	14.7	60	163.9
13	14.7	60	136.7
14	14.7	60	113.7
15	14.7	60	94.9
16	14.7	60	79.1
17	14.7	60	65.9
18	14.7	60	55
19	14.7	60	45.7
20	14.7	60	55.6

Table 38. Branch initial conditions (example 19).

Branch No.	Length (in)
12	62
23	74
34	89
45	107
56	128
67	154
78	184
89	221
910	266
1011	319
1112	318
1213	266
1314	221
1415	184
1516	154
1617	128
1718	107
1819	89
1920	74
2021	62

Table 39. Internal node results (example 19).

Internal Node No.	Pressure (psi)	Temperature (°F)	Density (lbm/ft^3)
2	50	88.62	0.2381
3	49.75	94.94	0.2342
4	49.49	102.7	0.2297
5	49.18	111.9	0.2246
6	48.81	122.9	0.2187
7	48.35	136	0.2118
8	47.79	151.6	0.204
9	47.1	171.1	0.1951
10	46.25	192	0.1851
11	45.18	215	0.1746
12	43.92	234.8	0.1649
13	42.61	249.8	0.1566
14	41.36	261.4	0.1496
15	40.21	270.3	0.1437
16	39.16	277.1	0.1386
17	38.2	282.1	0.1343
18	37.32	285.7	0.1306
19	36.51	288.2	0.1273
20	35.78	292.6	0.124

6.19.3 Results

The main objective of this example is to validate GFSSP's prediction with the analytical solution described in section 6.18 in the context of Fanno flow. Equation (108) is valid for both heat transfer and friction. In order to obtain the solution for Rayleigh flow, friction factor in equation (108) is set to zero. Subroutine KFADJUST was used to set the zero friction factor (app. Z).

Figures 198 and 199 show the distribution of temperature and Mach number for a heat input rate of 1,800 Btu/s on the same pipe geometry that has been used for Fanno flow (example 18). The inlet Mach number is chosen as 0.5 and it has been analytically calculated that with this inlet Mach number, a heat input of 1,800 Btu/s makes the flow choked at the exit (i.e., Mach number = 1). Further increase in the heat rate will make the flow supersonic and in the present work, only subsonic flow is being considered.[27] Again, the numerical results show quite good agreement (within 5%) with the analytical solution.

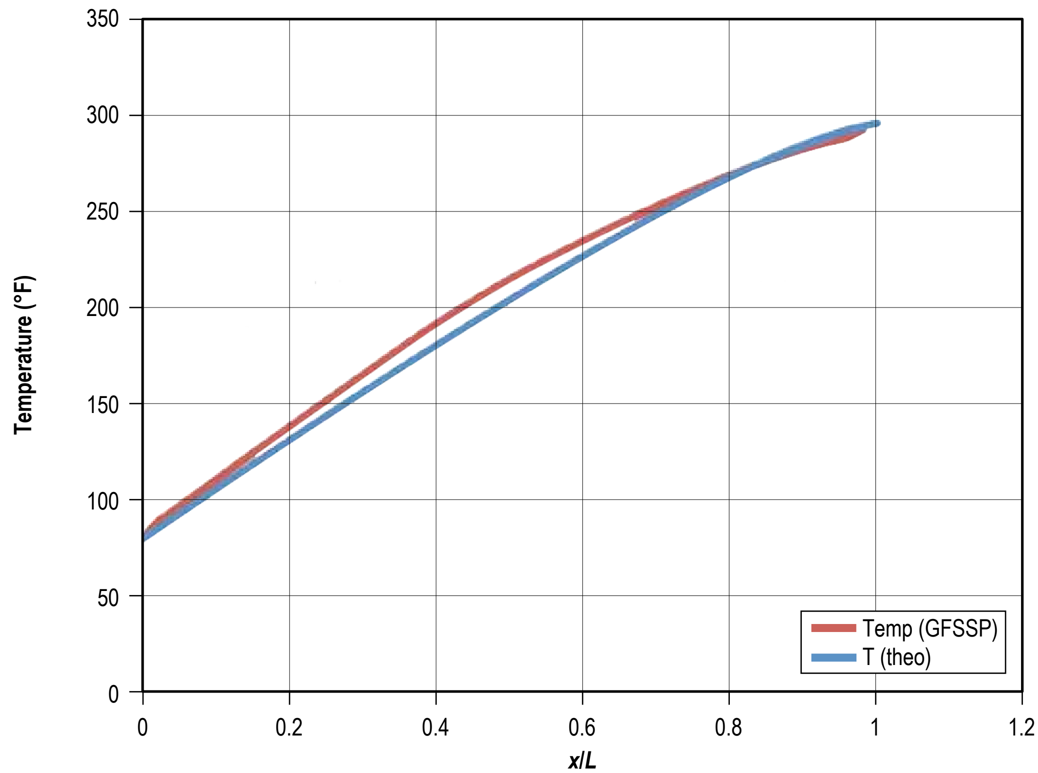

Figure 198. Temperature distribution for Rayleigh flow ($Q = 1{,}800$ Btu/s).

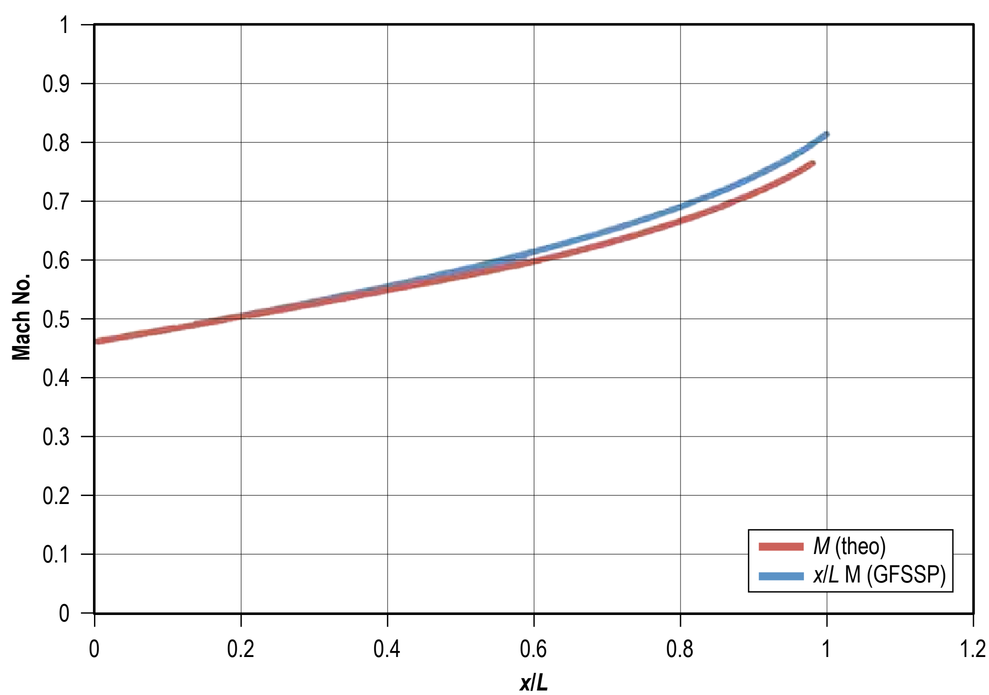

Figure 199. Mach No. distribution for Rayleigh flow ($Q = 1{,}800$ Btu/s).

6.20 Example 20—Modeling of Closed Cycle Liquid Metal (Lithium) Loop With Heat Exchanger to Heat Helium Gas

6.20.1 Problem Considered

A lithium loop with a counter flow heat exchanger system configuration, as shown in figure 200, was chosen for this example. The specific objective of the lithium circuit analysis using GFSSP was to model a closed loop with heat addition and rejection typical for a thermodynamic cycle. The model includes the pump, reactor core, heat exchanger with liquid lithium and nitrogen gas. This example also employs cyclic boundary to model a closed cycle, and illustrates the use of user-defined fluid by providing property tables because lithium properties are not available in GFSSP's thermodynamic property package. The model calculates the pressure and temperature of the fluid in each component during steady state operation.

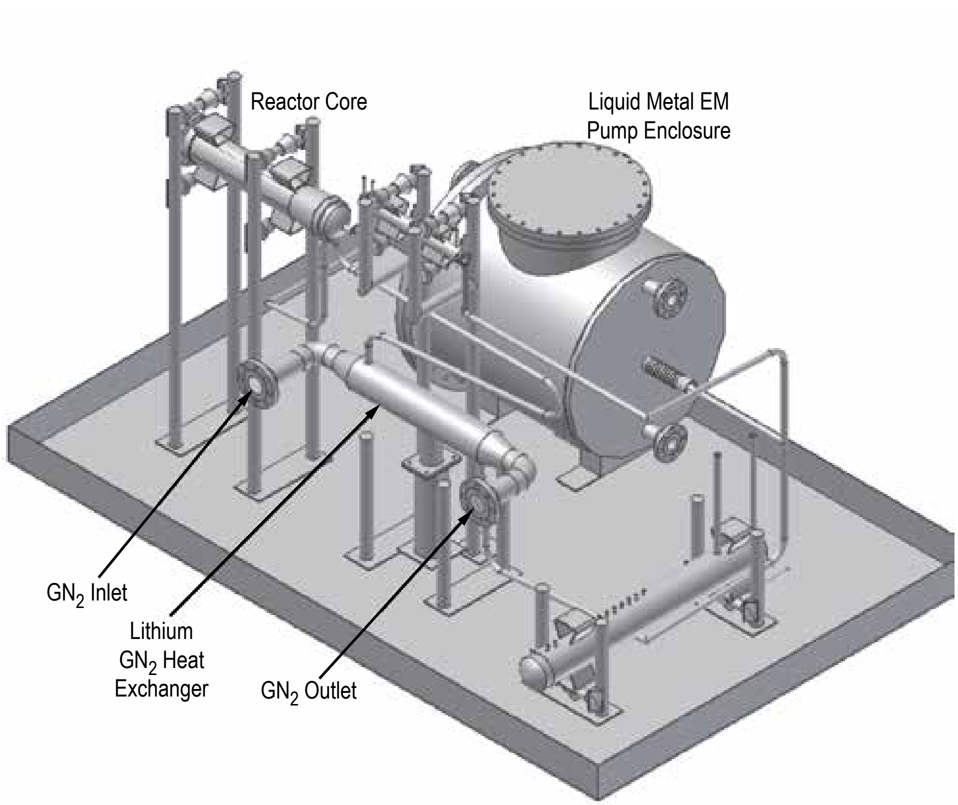

Figure 200. Lithium loop model schematic (example 20).

As shown in figure 201, counter flow heat exchange occurs when the hot branch of the heat exchanger has a flow that is propagating in a direction opposite of the cold branch. This counter flow heat exchanger configuration consists of liquid lithium, at 7 psi and 932 °F, flowing through a 46.56-in concentric annulus duct of 2.8-in inner radius and 5-in outer radius pipe. Also, from the cold side of the heat exchanger, nitrogen is flowing at 200 psi and 477 °F through a 13-in section of 3.26-in inner diameter pipe, through the heat exchanger, and out through compressible orifice of area of 0.13 in^2 and flow coefficient of 1 at 14.7 psi and 60 °F. All of the initial guess values for this problem are shown in figure 201. The style-IV pump performance is shown in figure 202, which was modeled in a User Subroutine. The lithium properties were introduced through look-up property tables.

The GFSSP analysis provides numerical predictions of pressure and temperature at various locations in the flow circuit.

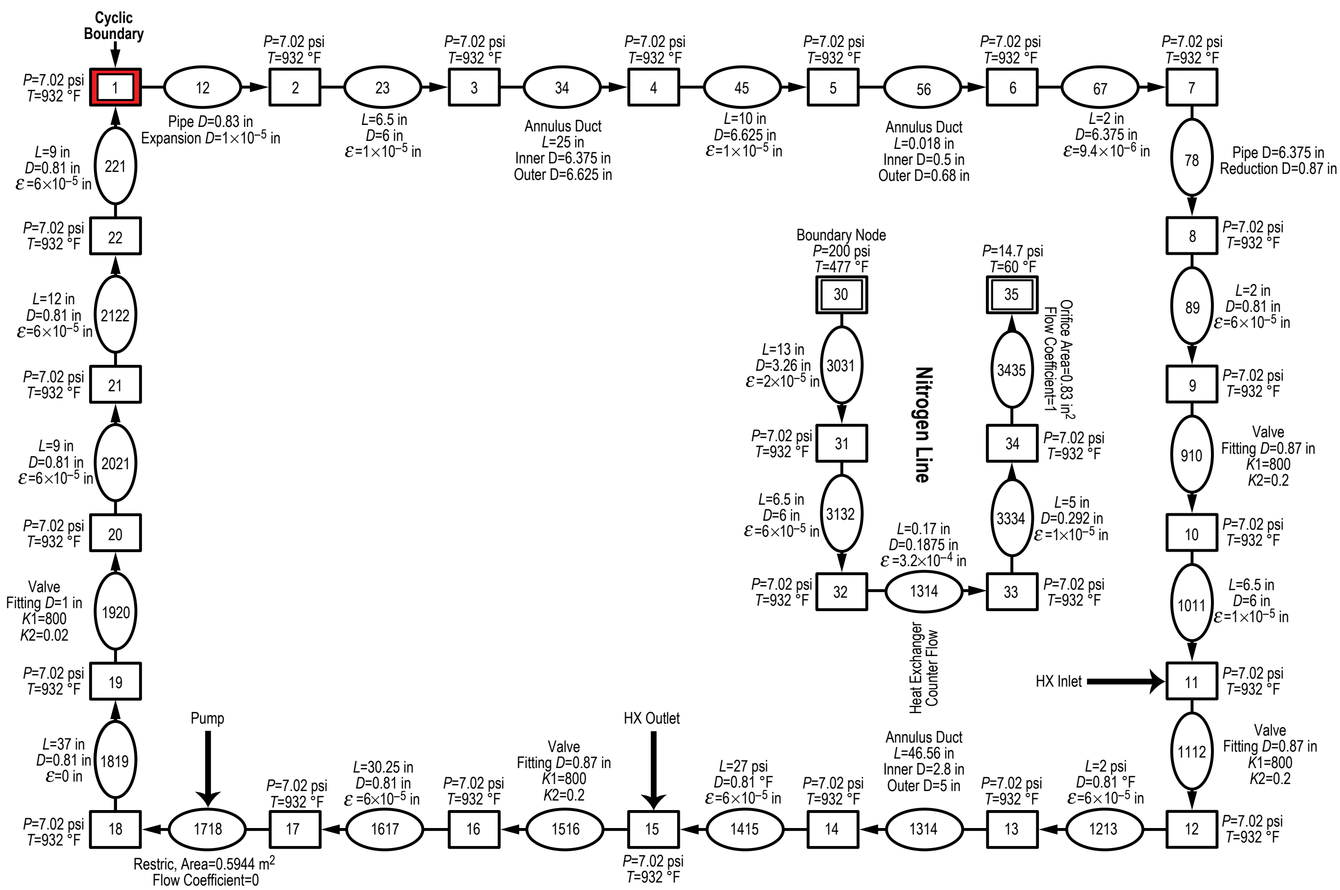

Figure 201. GFSSP model information of example 20.

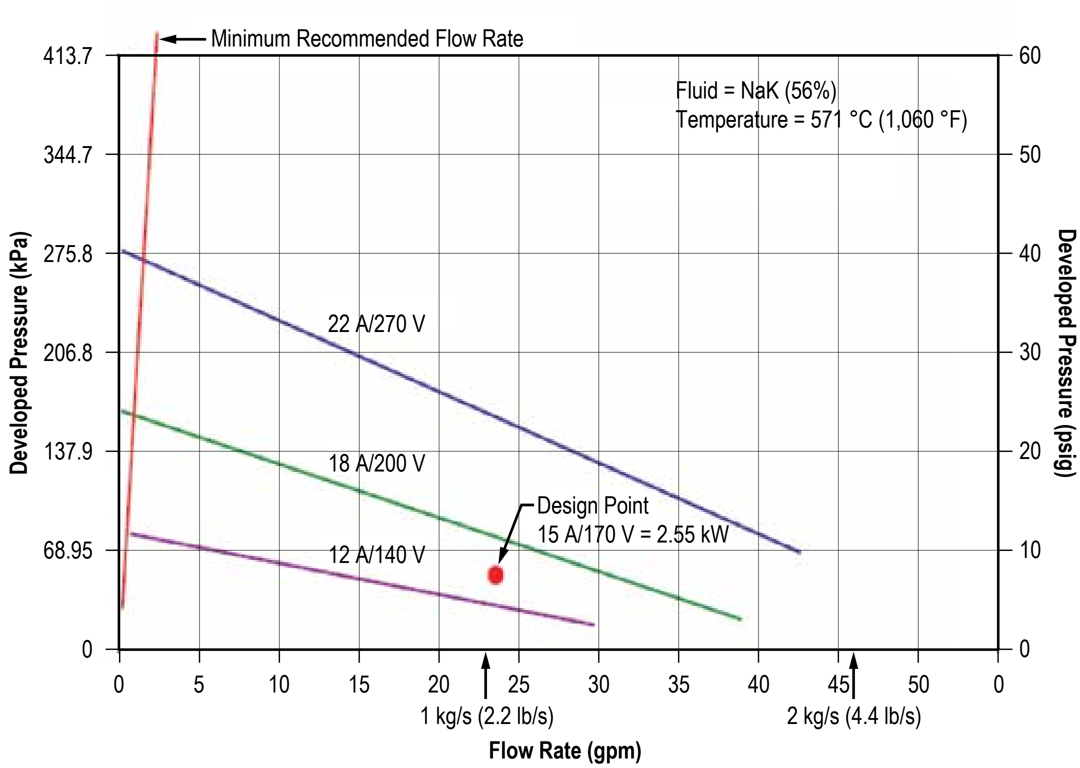

Figure 202. Style-IV ac conduction pump performance curve (reproduced from MSA Research Corp. dwg. No. C-510356).

6.20.2 GFSSP Model

A GFSSP model consisting of 28 nodes and 27 branches is used to represent the NaK test loop and counter flow heat exchanger system shown in figure 201. Nodes 1, 30, and 35 are boundary nodes. Node 1 is a cyclic boundary node at 7.02 psi and 932 °F. This implies that the temperature at node 22 must be equal to the temperature at node 1 and this must be achieved by iteration. Node 30 represents the inlet boundary node at 200 psi and 477 °F for the nitrogen cold flow of Heat Exchanger. Option 2 (Flow Through Restriction) was used for branch 1718 in place of the pump because the flow rate versus developed pressure curve has multiple curves depending on voltage, and therefore must be modeled as a momentum source in a User Subroutine. Branches 1314 and 3233 represent the hot and cold sides, respectively, of the heat exchanger. Figure 203 shows how this model appears in VTASC. GFSSP output results are shown in figure 204.

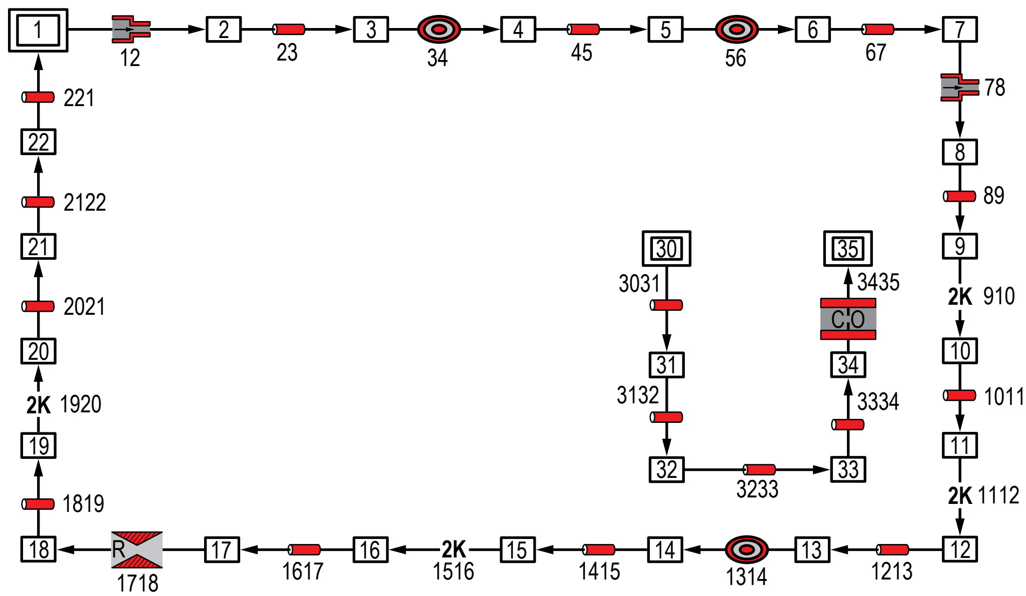

Figure 203. VTASC model of lithium loop with Heat Exchanger (example 20).

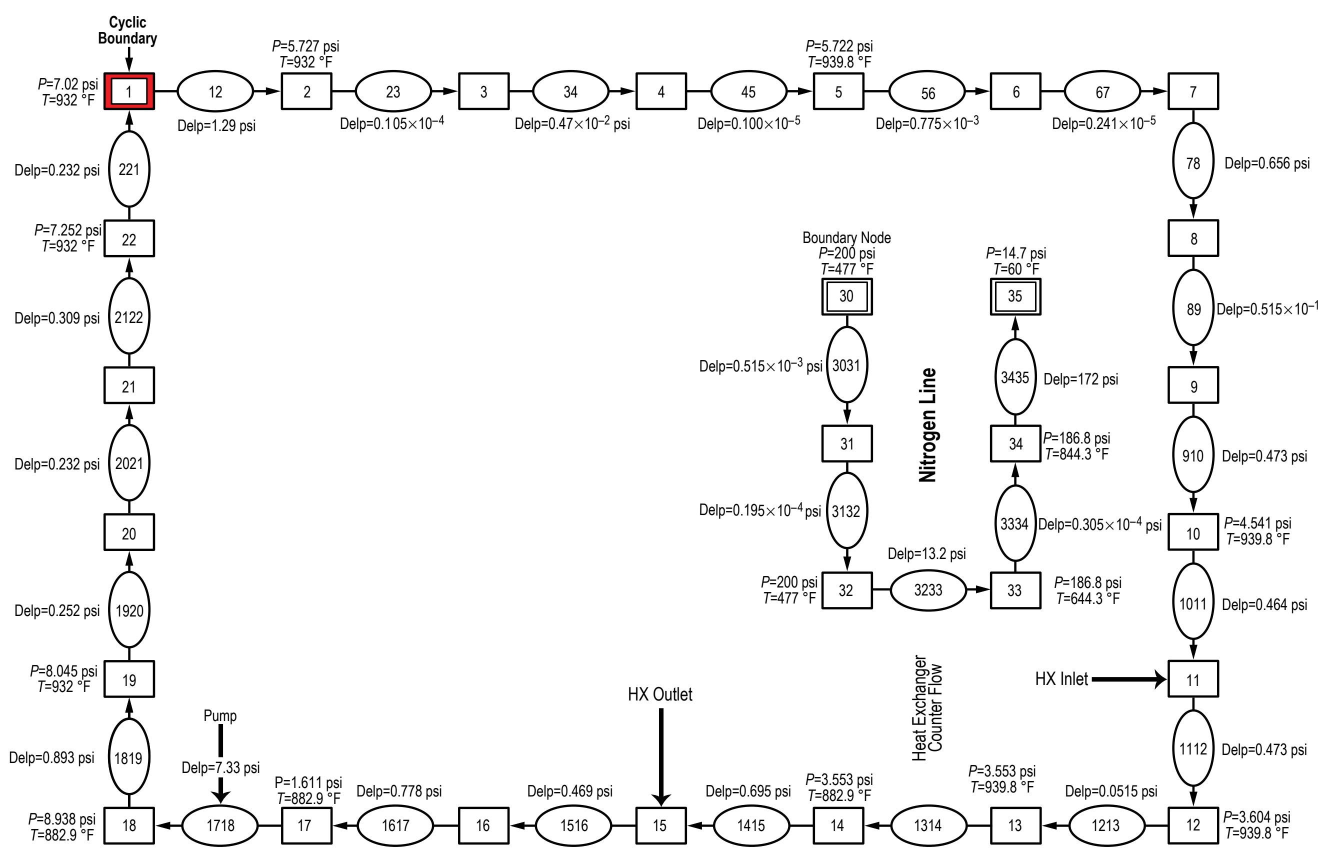

Figure 204. Model results of example 20.

6.20.3 Results

The User Subroutine input and output files of example 20 have been given in appendix AA. The model results are also shown in figures 204 and 205.

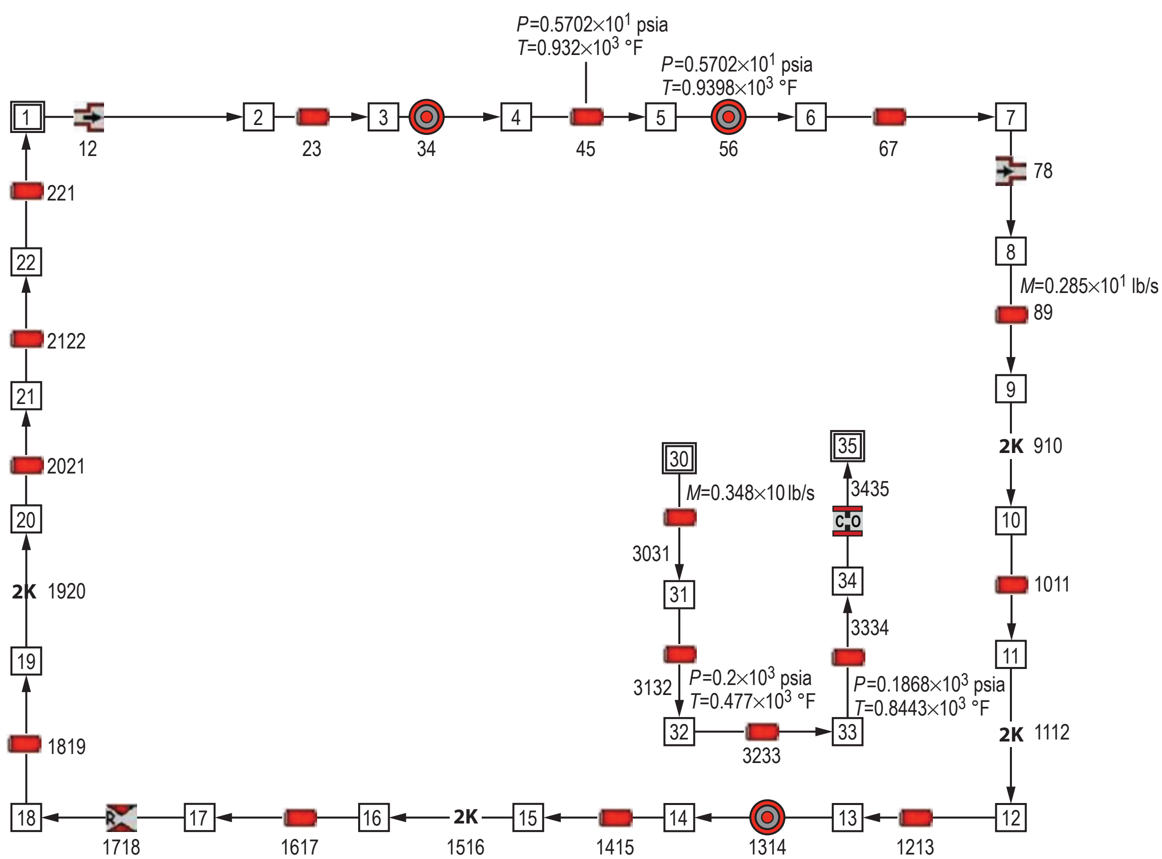

Figure 205. Sample results of example 20 is displayed in the flow circuit.

6.21 Example 21—Internal Flow in a Turbopump

6.21.1 Problem Considered

It is desired to calculate the axial thrust of the SIMPLEX turbopump operating at 25,000 rpm with LOX as the operating fluid.[29] In order to calculate axial thrust, the pressure distribution throughout the secondary flow system of the turbopump must be obtained. Figure 206 shows a schematic of the turbopump. The pressure is known at the inducer inlet, the inducer discharge, on the back face of the impeller (upstream of the Labyrinth seal), on the front face of the impeller shroud (upstream of the Labyrinth seal), at the end of the atmospheric dump lines (two dump lines), and on the front and back face of the turbine. The pressure at the exit of the impeller is not known, due to flow conditions at the pressure tap corresponding to the impeller discharge. (The value of the pressure at the impeller discharge must be estimated.) The values of pressure and temperature at these positions are listed in table 40, and are boundary conditions for the GFSSP model. Axial thrust and pressures throughout the internal flow circuit are to be calculated using GFSSP.

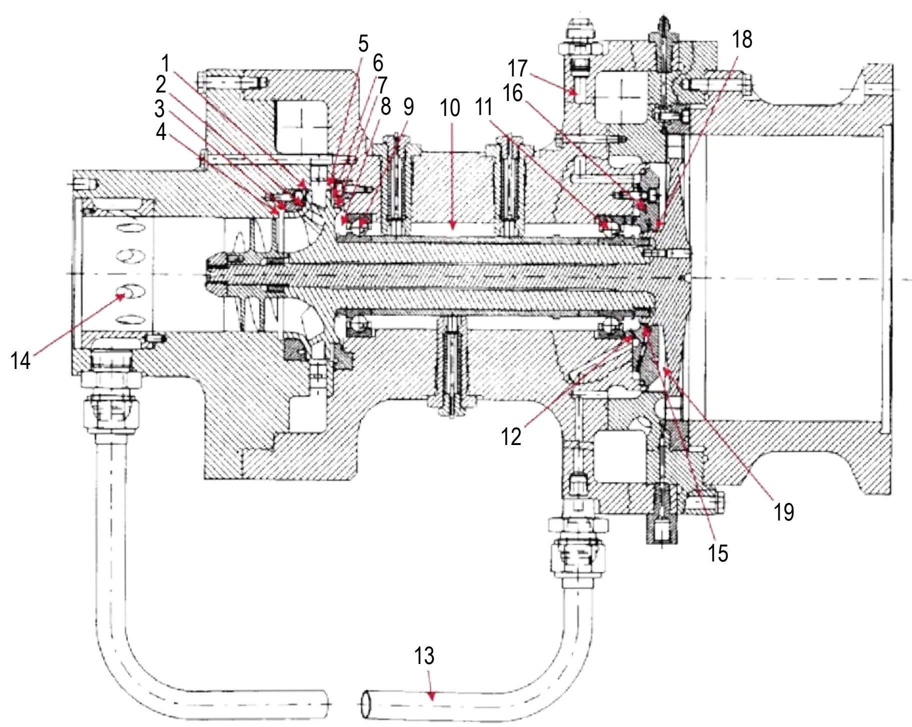

Figure 206. Schematic of the simplex turbopump with secondary flow passages indicated.

Table 40. Boundary conditions.

Location	Node No.	Pressure (psia)	Temperature (°F)
Impeller discharge	100	1,100	–286.6 (assumed)
Impeller shroud	107	1,078	–286.6 (assumed)
Impeller inlet	105	346.2	–286.6
Impeller back face	102	1,025	–286.6
Turbine front face	116	62.6	–265.6
Dump	130	14.7 (assumed)	–286.6 (assumed)
Inducer inlet	140	93.7	–286.6
Turbine back face	180	14.7 (assumed)	–286.6 (assumed)

6.21.2 GFSSP Model

Figure 206 indicates the flow passages that will be modeled using GFSSP. The modeled passages are numbered, with each number corresponding to the passage as follows:

(1) Axial flow between the impeller shroud and the housing flowing from the impeller discharge.
(2) Radially inward flow between the impeller shroud and the housing.
(3) Flow through the labyrinth seal at the end of the impeller shroud.
(4) Radially inward flow between the end of the impeller shroud and the housing flowing into the impeller inlet.
(5) Axial flow between the impeller and the housing flowing from the impeller discharge.
(6) Radially inward flow between the impeller back face and the housing.
(7) Flow through the labyrinth seal at the lip on the back face of the impeller.
(8) Radially inward flow between the impeller back face and the housing flowing into the first bearing.
(9) Flow through the first rolling element bearing.
(10) Axial flow along the impeller shaft between the bearings.
(11) Flow through the second rolling element bearing.
(12) Flow through eight radially outward holes (for return lines).
(13) Flow through two external return lines.
(14) Flow through eight radially inward holes flowing into inducer inlet.
(15) Flow through the first turbine-end labyrinth seal.
(16) Flow through 22 radially outward holes (for dump lines).
(17) Flow through two external dump lines.
(18) Flow through the second turbine-end labyrinth seal,
(19) Radially outward flow between the front face of the turbine and the housing.

Additionally, a dummy branch connects the front face and the back face of the turbine for the calculation of axial thrust.

The detailed model of the secondary flow passages for this turbopump is shown schematically in figure 207, and the VTASC model is shown in figure 208. Heat is added to nodes 110 and 112 to account for the heat transferred from the bearings. Heat is also added to node 109 to match the temperature at that node with the experimental data. As seen in figure 207, branches 2401 through 2408 and 2131 through 2138 were originally modeled as eight separate but identical pipe branches; branches 2801 through 2822 were originally 22 separate branches. In the current VTASC model seen in figure 208, these are now modeled using the Parallel Tube branch option (option 21). Because the Parallel Tube option does not include entrance and exit loss K-factors, branches 2132 and 2802 were added with equivalent lengths to produce an identical K_f.

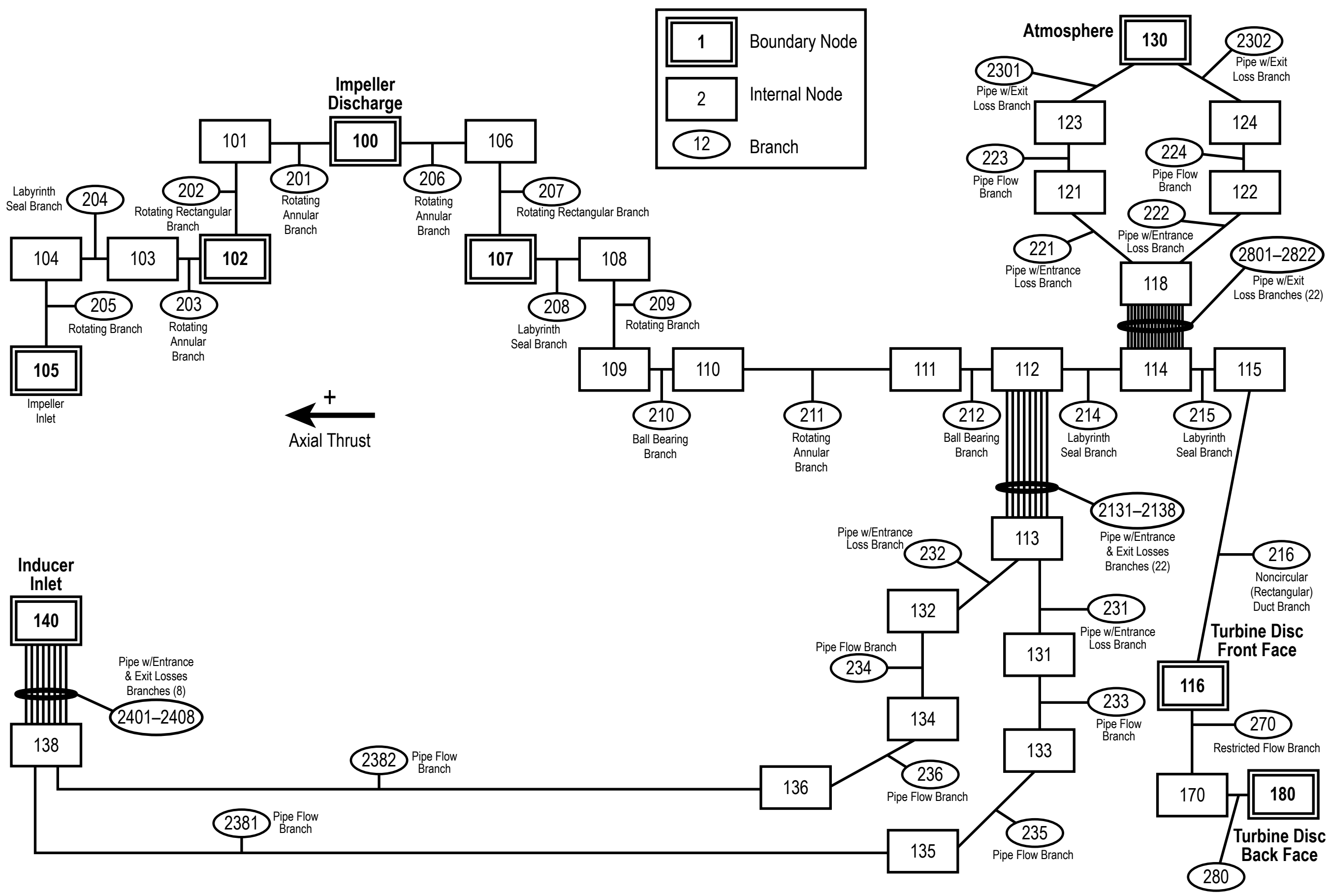

Figure 207. Simplex turbopump detailed model.

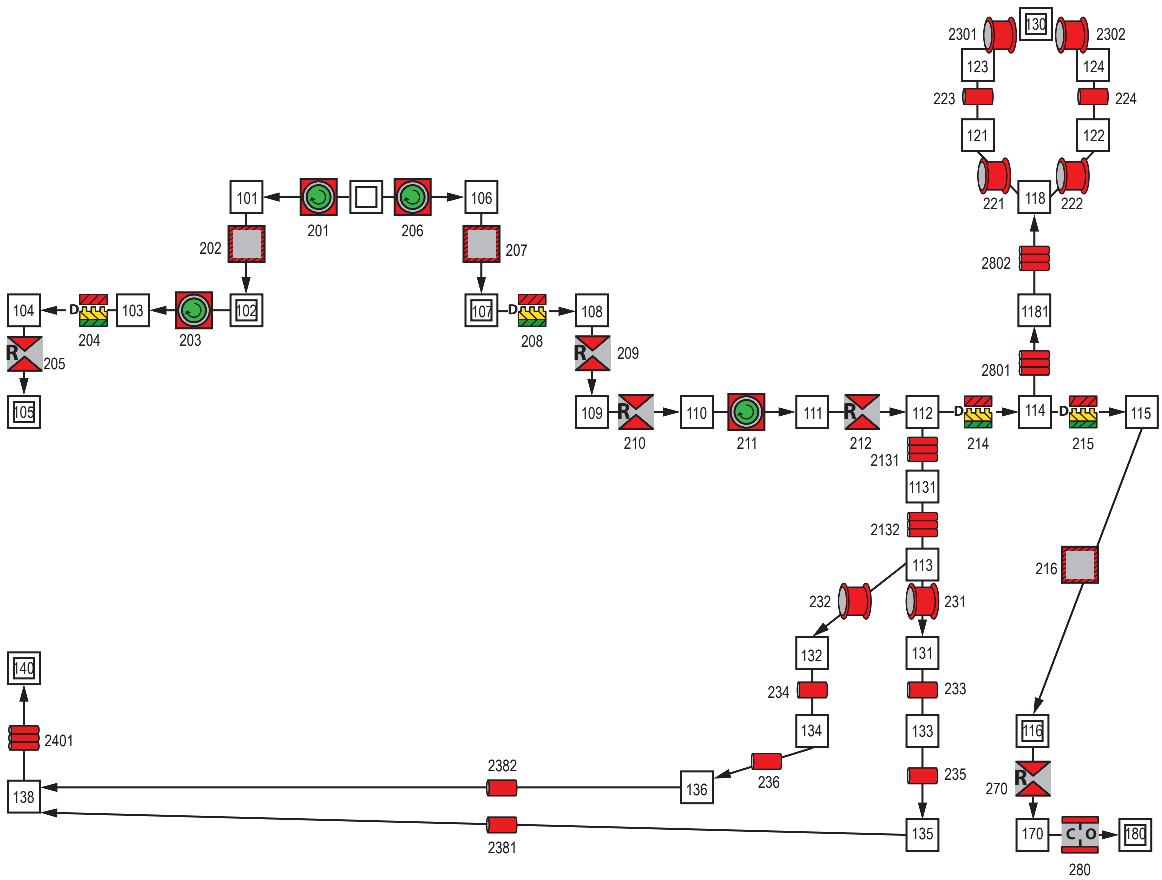

Figure 208. Simplex turbopump VTASC model.

6.21.3 Results

The input and output files of this example are included in appendix BB as ex21.dat and ex21.out. The model predicts that the axial thrust will be 567 lb_f. Figure 209 shows the calculated pressures at nodes 108 through 112, 114, and 115 comparing them to the available experimental data at nodes 109 and 112. Figure 210 shows the calculated and experimental temperatures.

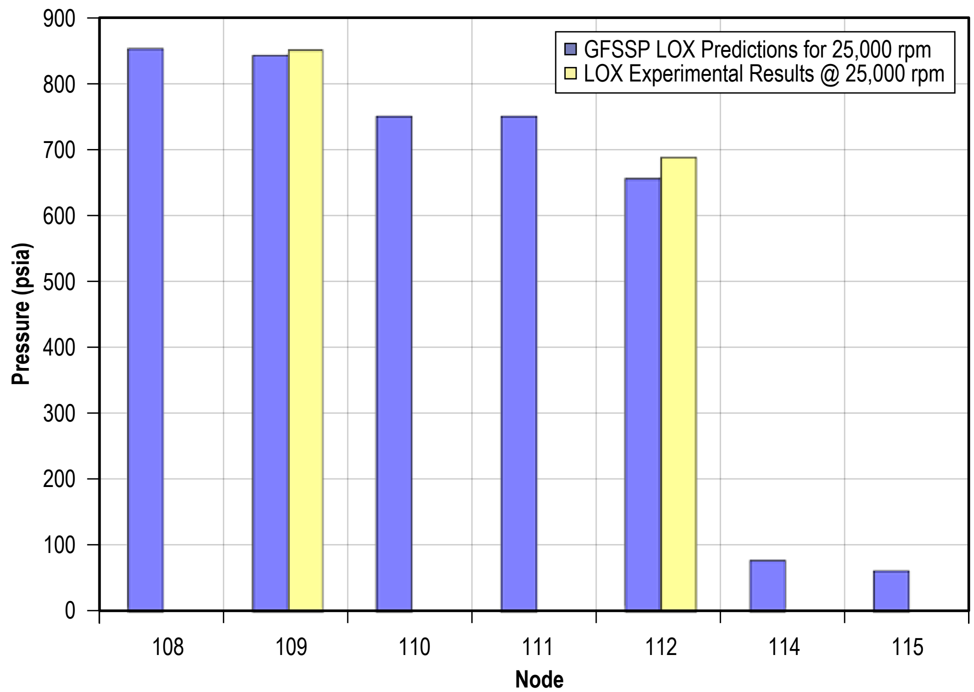

Figure 209. Simplex pressure predictions compared to experimental data.

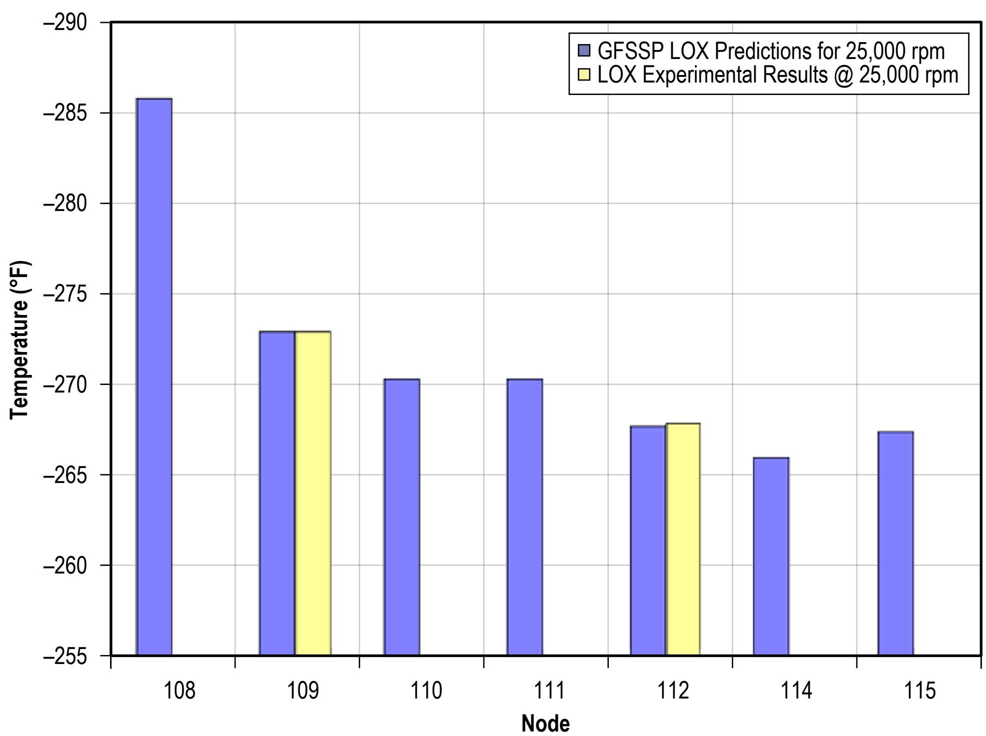

Figure 210. Simplex temperature predictions compared to experimental data.

6.22 Example 22—Simulation of a Fluid Network With Fixed Flow Rate Option

6.22.1 Problem Considered

Sometimes the boundary condition of a fluid network is given as a flow rate instead of a boundary pressure. Besides using an estimated boundary pressure and a flow regulator branch, the user could also attach a Fixed Flow branch (option 24) to a boundary node. GFSSP is always solving the conservation equations for flow rate, so the Fixed Flow branch does not set the desired flow rate, per se. Instead, it uses a nearly vertical pump curve to trick the code into solving for the branch pressure rise necessary to achieve the required flow rate (see sec. 3.1.7.24).

6.22.2 GFSSP Model

Figure 211 shows the VTASC canvas of a model with two Fixed Flow branches. Note that Fixed Flow branches must be attached to a boundary node. Water passes from node 2 through a gate valve and a 1,500-ft-long pipe to the exit boundary (node 4) at 14.7 psia. Pressures in boundary nodes 1 and 5 are arbitrarily set to 14.7 psia, and the boundary temperature is 60 °F.

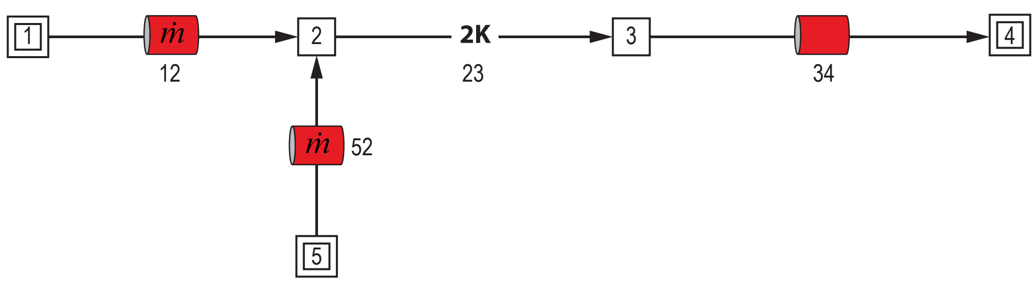

Figure 211. VTASC model of a fluid network with fixed flow rate option.

Both steady state and transient cases are modeled. In the steady state case, the required flow rates in branches 12 and 52 are 100 and –10 lb/s, respectively. Note that a negative flow rate can be handled to use a Fixed Flow branch as an exit branch.

In the transient case, history files are used to set the required flow rates. Table 41 is the history file for branch 12. In the first 10 s, the required flow decreases from 100 to 50 lb/s, after which the flow rate remains constant.

Table 41. Example 22 history file for fixed flow branch 12.

3	Number of Data Points	
2	100	200
10	50	200
20	50	200

Table 42 is the history file for branch 52. For the first 10 s, flow must exit (negative flow rate) at 10 lb/s, after which flow enters the network at 10 lb/s.

Table 42. Example 22 history file for fixed flow branch 52.

4	Number of Data Points	
0	–10	200
10	–10	200
10.1	10	200
20	10	200

6.22.3 Results

The steady state input and output files of this example are included in appendix CC as ex22ss.dat and ex22ss.out. In the steady state case, the required 100 lb/s flows into the network via branch 12, while 10 lb/s flows out branch 52. The remaining 90 lb/s exits at branch 34, satisfying conservation of mass. It is recommended that the user always verify that the program has converged on the required flow rates; if it does not succeed, rerunning with a tighter convergence criteria will usually solve the problem.

The transient input and output files of this example are included in appendix DD as ex22tr.dat and ex22tr.out. Note that although the program ran with the default convergence criteria of 1×10^{-4}, a plot of the sum of the inlet and outlet flow rates showed that conservation of mass was not achieved in every time step. This was remedied by tightening the convergence criteria to 1×10^{-5} and increasing the maximum number of iterations to 2,000.

Figure 212 is a plot of the flow rates in Fixed Flow branches 12 and 52, showing that they meet their target flow rates set by the history files. Figure 213 compares the sum of the flow rates in branches 12 and 52 with the flow rate in branch 34 to demonstrate that mass is being conserved in the system.

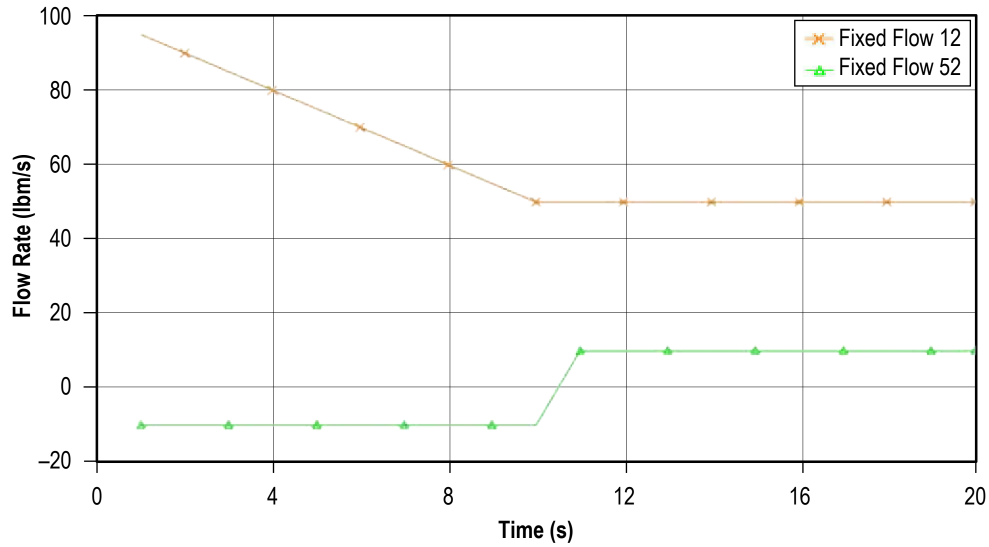

Figure 212. Flow rates in fixed flow branches.

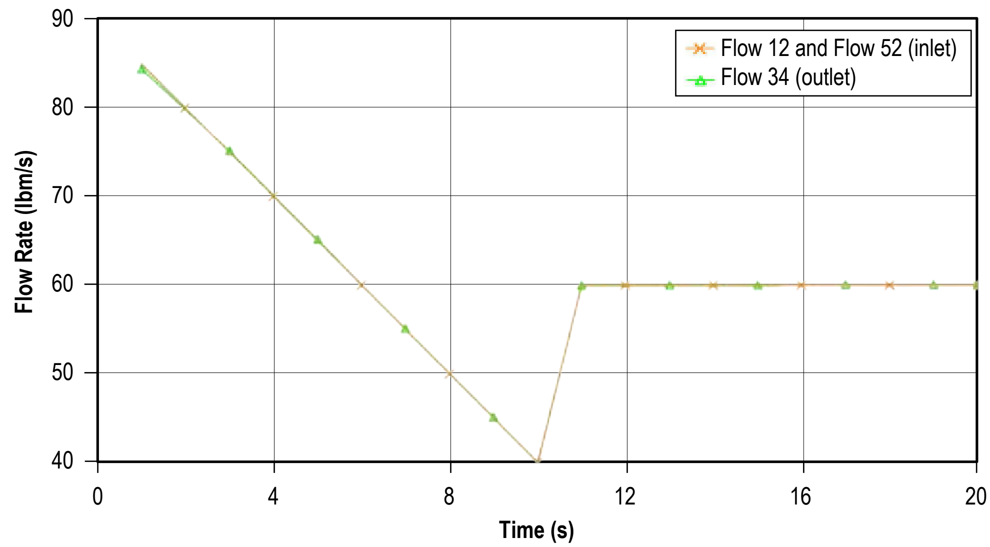

Figure 213. Comparison of inlet and outlet flow rates.

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6.23 Example 23—Helium-Assisted, Buoyancy-Driven Flow in a Vertical Pipe Carrying Liquid Oxygen With Ambient Heat Leak

6.23.1 Problem Considered

This example models a vertical pipe carrying LOX, as might be the case with a propellant recirculation line. To drive the flow without the aid of a pump, one can use buoyancy effects from heat transfer and/or helium injection. This example includes three GFSSP models in three VTASC files: a steady state model of a recirculation line, a steady state model of a helium injector, and a transient model of a recirculation line with helium injection. The third model demonstrates the use of the VTASC's file import feature to combine the first two models. It is also an example of one of GFSSP's mixture options: separate energy conservation equations for separate species.

6.23.2 GFSSP Model

Figure 214 shows the VTASC canvas of the Recirculation Line model. LOX at 55.78 psia and –272.5 °F flows from boundary node 1 up to boundary node 8 at 53 psia. The pressure differential of 2.78 psid represents the gravitational head of 6 ft of LOX, so that in the absence of heat transfer, the fluid will remain stagnant. This can be confirmed by running the model with Conjugate Heat Transfer deactivated; GFSSP will predict a flow rate near zero. The recirculation line is 6 ft long with a diameter of 1.87 in. It is discretized into six pipe branches. Five of the 6 ft are assumed to be well insulated, but 1 ft is left uninsulated, to allow heat transfer from the ambient. Solid nodes 9 and 10 represent the mass of the Inconel 718 pipe, separated by a conductor of 0.225-in thickness. There is convection from the outside wall of the pipe to a 70 °F ambient temperature with an assumed convection coefficient of 2 Btu/hr-ft^2-°F. There is also convection between the inside wall and the LOX, with the convection coefficient calculated by GFSSP using the Dittus-Boelter correlation.

Figure 215 shows the VTASC canvas of the Helium Injector model. Helium at 425 psia and 100 °F flows from boundary node 1 to boundary node 4 at 14.7 psia. The injector line is broken into two pipes of 0.152 in diameter. The pipes are connected by a small orifice with an area of 0.0012566 in^2, corresponding to a diameter of 0.04 in.

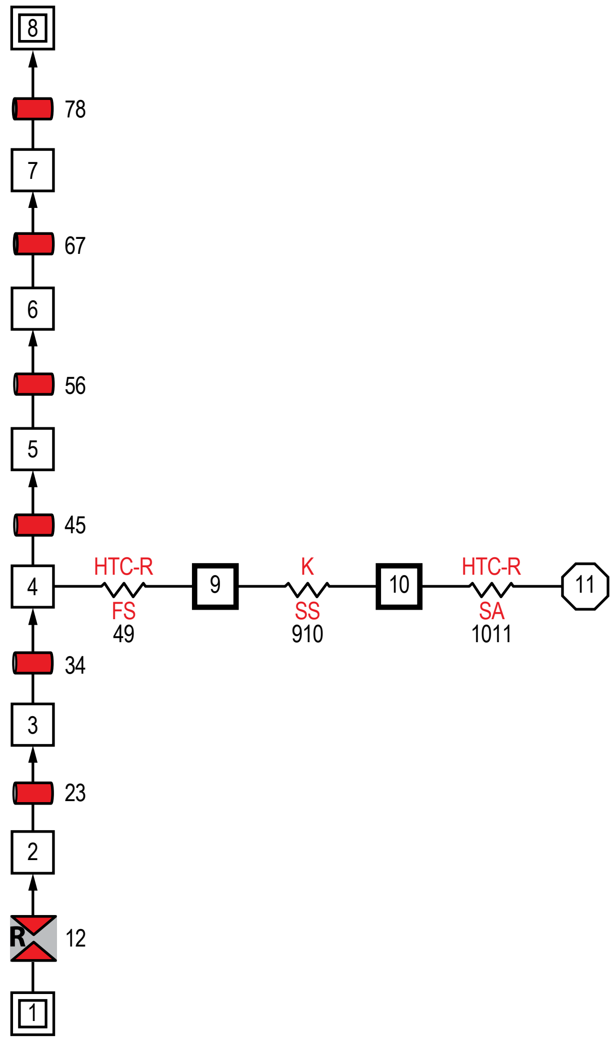

Figure 214. VTASC model of LOX recirculation line with heat transfer.

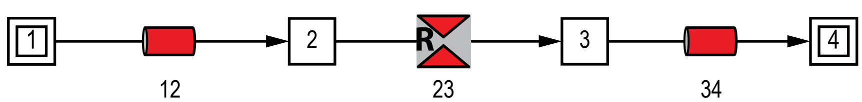

Figure 215. VTASC model of a helium injector.

Figure 216 shows the VTASC canvas of the combined models. The Recirculation Line model was imported into the Helium Injector model using the File Import feature on the VTASC's File menu. An offset of 100 was used to renumber the nodes and branches in the Recirculation Line that conflicted with node numbers in the Helium Injector.

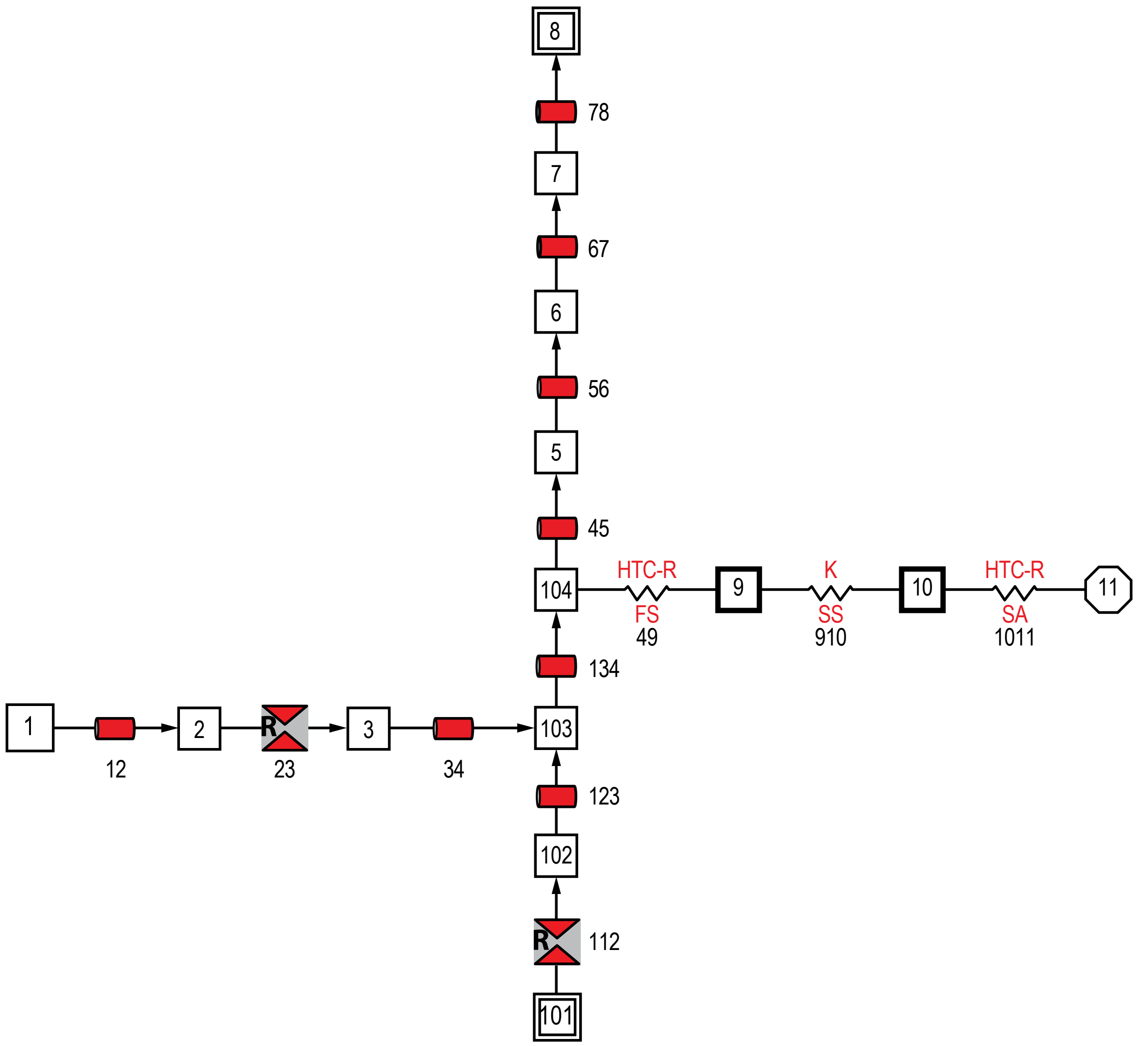

Figure 216. Combined VTASC model of LOX Recirculation Line model imported into Helium Injector model.

Helium Injector branch 34 has been connected to LOX Recirculation Line node 103, and boundary node 4 has been deleted. This allows the helium to bubble into the LOX line just below node 104, where heat transfers into the fluid. The problem is changed from steady to unsteady, with a run of 100 s at 0.1 s intervals.

Because there are two fluids, oxygen and helium, the Mixture option is enabled on the Circuit Options page. The Mixture option is changed from the default temperature solution of the energy equation (see eq. (16)) to option Enthalpy 2: Separate Energy Equations for Separate Species (see sec. 3.1.3.2). This is the only mixture option capable of handling phase change and is required to model the oxygen vapor that forms in the flow.

6.23.3 Results

The LOX recirculation line steady state model files are included in appendix EE as ex23A.dat and ex23A.out. GFSSP predicts that the heat transfer drives a flow of 0.172 lb/s in the vertical pipe. The temperature of the fluid rises from –272.5 to –271.3 °F, while its density decreases from 66.7 to 63.3 lb/ft^3. Part of the density decrease is caused by formation of oxygen vapor, indicated by the exiting fluid having a quality of 0.0014. The conjugate heat transfer calculations indicate a heat rate into the fluid of 0.106 Btu/s. The Dittus-Boelter correlation predicts the internal convection coefficient to be 33.3 Btu/hr-ft^2-°F. The solution of the Solid Energy Conservation equation gives an inner wall temperature of –248 °F.

An interesting exercise is to evaluate how efficient the heat transfer is at driving the fluid flow. The work required to achieve the predicted flow rate is:

$$\dot{W} = \frac{\dot{m}\Delta P}{\rho} = \frac{\left(0.172\ \dfrac{\text{lb}}{\text{s}}\right)\left(2.78\ \dfrac{\text{lb}_\text{f}}{\text{in}^2}\right)\left(144\ \dfrac{\text{in}^2}{\text{ft}^2}\right)}{\left(66.4\ \dfrac{\text{lb}}{\text{ft}^3}\right)\left(778\ \dfrac{\text{lb}_\text{f}-\text{ft}}{\text{Btu}}\right)} = 0.001333\ \frac{\text{Btu}}{\text{s}}\ . \tag{113}$$

Since 0.106 Btu/s of heat leak are driving this flow, the efficiency of the process is just 1.26%.

The helium injector steady state model files are included as ex23B.dat and ex23B.out in appendix FF. The predicted flow rate is 0.00163 lb/s.

The files for the unsteady model that combine the recirculation line with the helium injector are included as ex23C.dat and ex23C.out in appendix GG. Figure 217 is a plot of the flow rate of helium in the injector (F12) and of the LOX-helium mixture in the recirculation line (F56). It is seen that a small flow rate of 0.005 lb/s of helium, combined with the heat transfer into the uninsulated portion of the line, increases the flow rate to a steady value of 1.80 lb/s. Initially the flow rate is even larger because the pipe is chilling down from 70 °F, and heat transfer is greater.

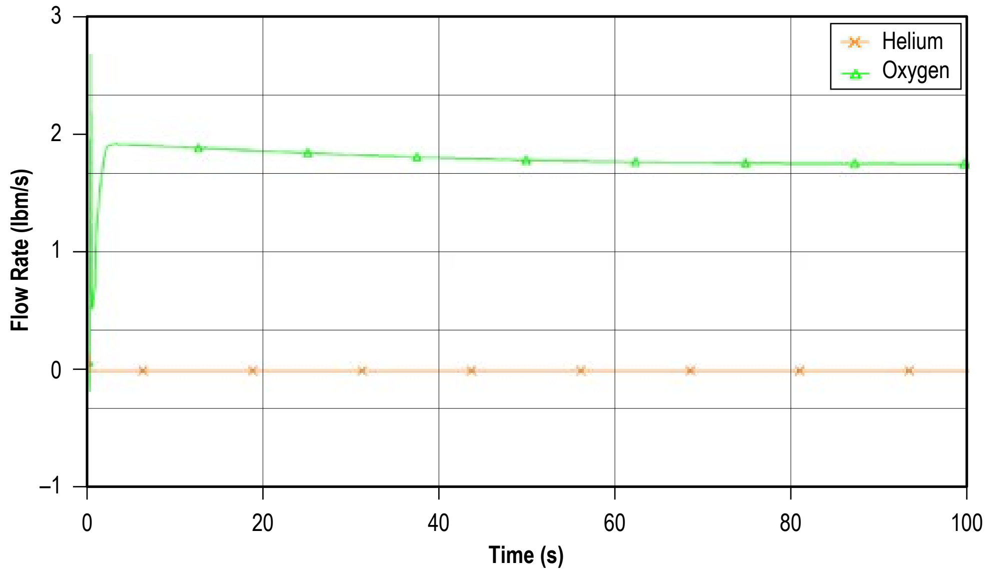

Figure 217. Helium and mixture flow rates.

Figure 218 plots the mass fractions of the two species in node 7. The exiting fluid is predicted to be 99.7% oxygen and 0.3% helium by mass.

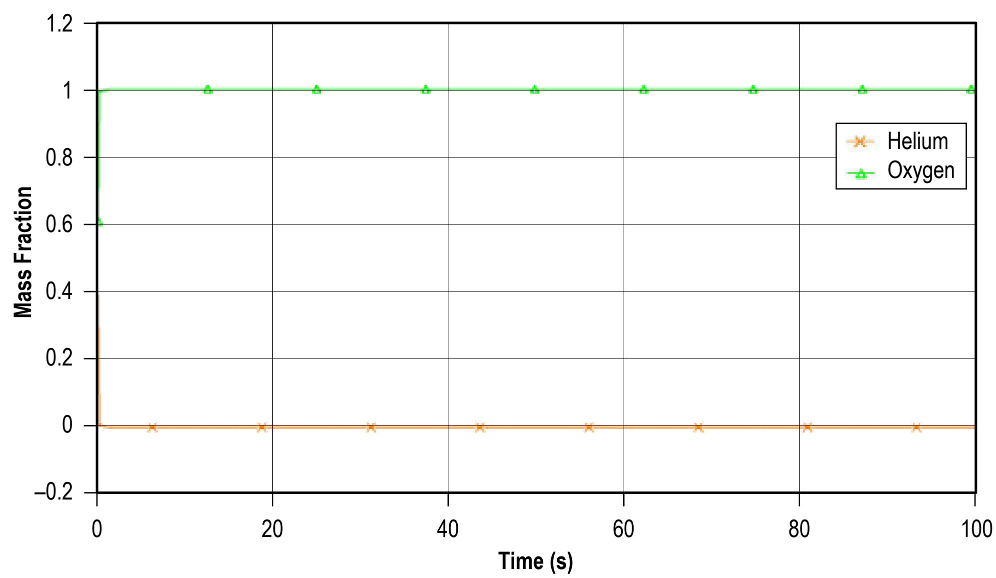

Figure 218. Mass fractions of He and O_2 at node 7.

Figure 219 plots the temperatures of solid nodes 9 and 10, representing the inner and outer uninsulated pipe walls. The temperatures fall to their steady state values in about 80 s. These steady state temperatures are slightly colder than those predicted by the recirculation model without helium injection, because the higher flow rate with helium injection increases the convection coefficient.

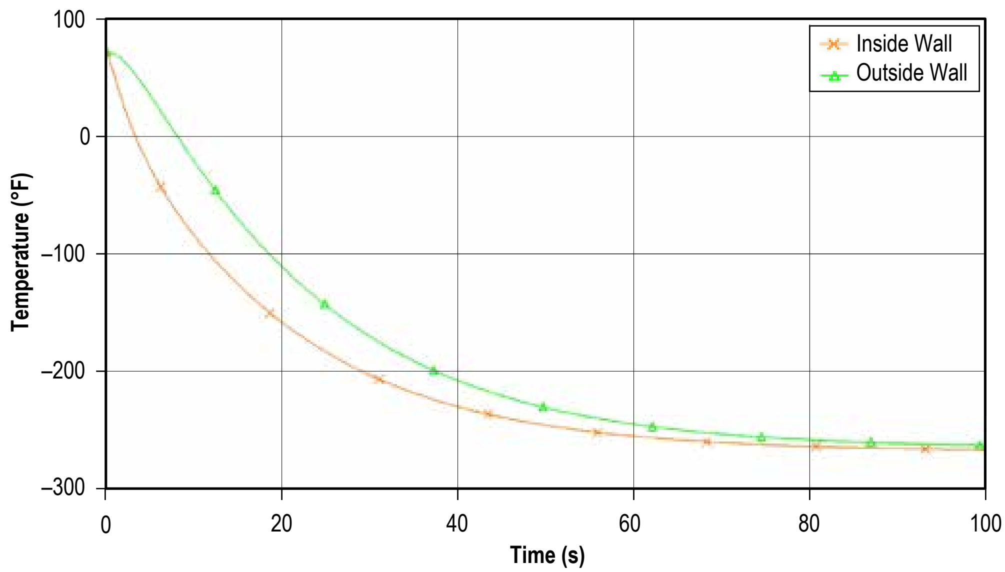

Figure 219. Inside and outside temperature of pipe wall.

6.24 Example 24—Simulation of Relief Valve in a Pressurized Tank

6.24.1 Problem Considered

This example demonstrates the use of a pressure relief valve to allow flow out of a node that has exceeded a defined pressure. This Advanced option is different from the Control Valve branch option (option 18). The control valve monitors pressure in a node and opens to allow fluid to enter the node when pressure gets too low. In contrast, the relief valve monitors pressure in a node and opens to allow fluid to exit the node when pressure gets too high.

Figure 220 shows a schematic of the system being modeled. Air at 35 psia and 70 °F flows through a 0.316-in-diameter orifice and into a 10 ft^3 tank, initially at 14.7 psia. A relief valve on top of the tank has a cracking pressure of 9.5 psid above the ambient pressure of 14.7 psia. As the tank fills with air, the relief valve will open whenever the tank pressure exceeds 24.2 psia.

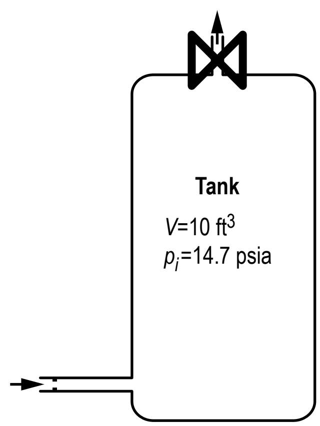

Figure 220. Example 24 relief valve schematic.

6.24.2 GFSSP Model

Figure 221 shows the VTASC canvas of the model. Boundary node 1 represents the source of high pressure air. Interior node 2 represents the 10 ft^3 tank. Boundary node 3 is the ambient environment. Compressible orifice 23 represents the pressure relief valve.

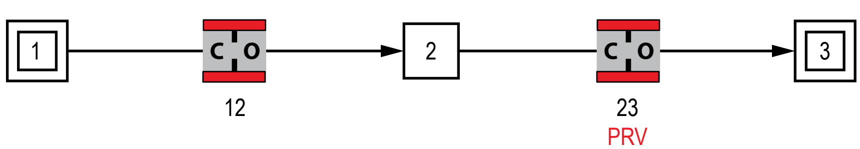

Figure 221. Example 24 relief valve VTASC model.

Table 43 shows the file that controls how far the relief valve opens as a function of the pressure differential across the valve. If a Restriction or Compressible Orifice option is used as the relief valve, then area in square inches is given as a function of pressure in psid. If a Valve with Cv Branch option is used, then area is replaced with Cv values. The first point should be the reseating pressure, which uses a very small area or Cv to represent a closed valve. The last point should be the pressure at which the valve is opened to the maximum area.

Table 43. Example 24 pressure relief valve control file.

4		Number of ΔP versus area points in interpolation table (max=20)
7	$1\text{x}10^{-16}$	ΔP (psi), A (in^2) (reseat pressure with small area)
8	0.24	
9	0.48	
10	0.72	(Max possible area for fully open valve)

6.24.3 Results

The pressure relief valve model files are included in appendix HH as ex24.dat and ex24.out. Figure 222 is a plot of the pressure in the tank over time. Whenever the pressure exceeds the cracking pressure of 9.5 psid (24.2 psia), the relief valve opens, allowing air to escape. When the pressure falls below the reseat pressure of 7 psid (21.7 psia), the relief valve closes and the tank begins to pressur-ize again.

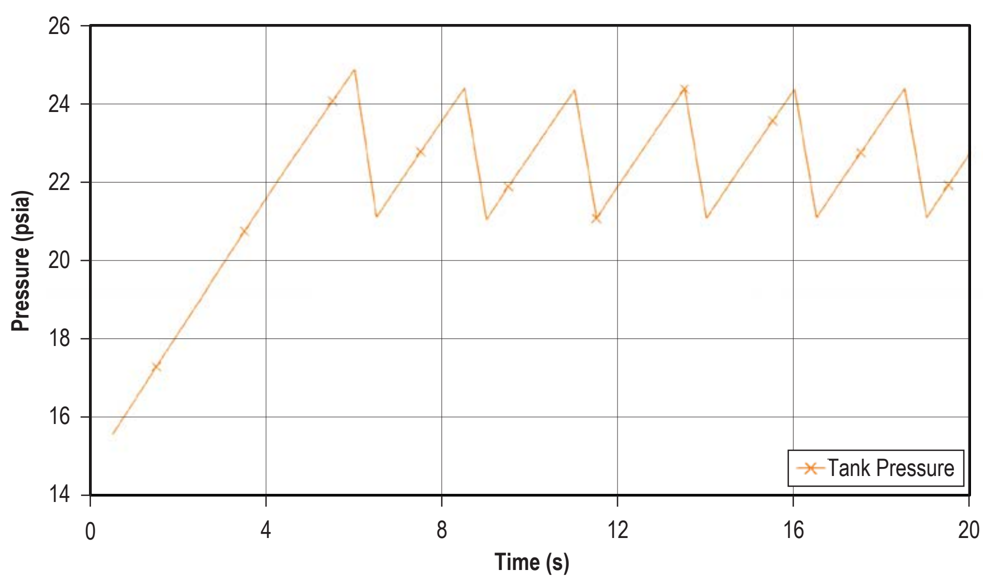

Figure 222. Pressure inside tank.

Figure 223 plots the flow rate into and out of the tank. The orange line shows that the flow into the tank is relatively steady around 0.06 lb/s. The green line plots flow out of the tank. This is normally zero, but jumps to approximately 0.3 lb/s whenever the relief valve opens.

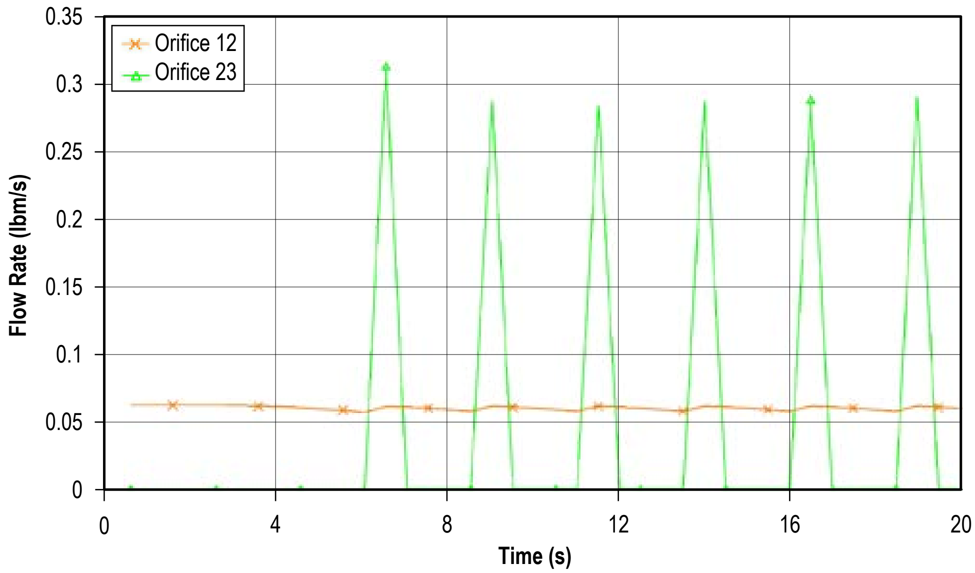

Figure 223. Flow in and out of tank.

6.25 Example 25—Two-Dimensional Recirculating Flow in a Driven Cavity

6.25.1 Problem Considered

In this example, two-dimensional recirculating flow in a square cavity[60] has been modeled using GFSSP's multidimensional flow calculation capability. In a square cavity, the flow is induced by shear interaction at the top wall as shown in figure 224. The length of each wall is 12 in. The density of the fluid is assumed constant at 1 lb_m/ft^3, and the viscosity of the fluid is assumed to be 1 $lb_m/(ft{\cdot}s)$. The bottom and side walls are fixed. The top wall is moving to the right at a constant speed of 100 ft/s. The corresponding Reynolds number for this situation is Re = 100.

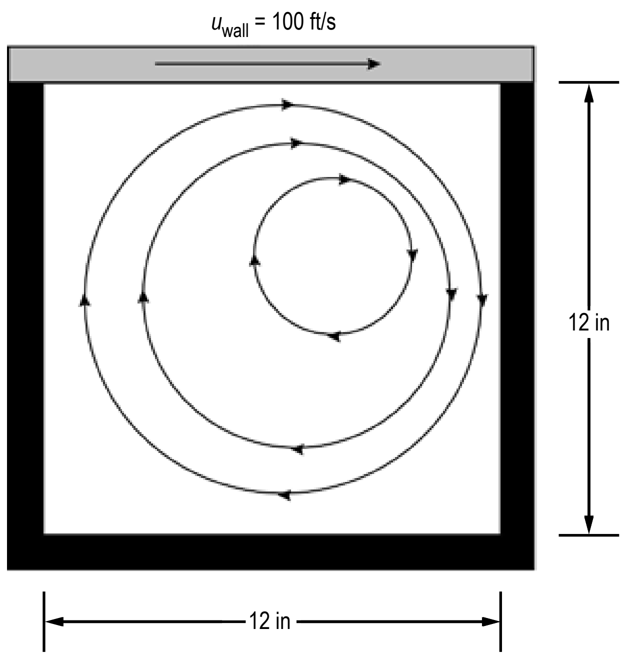

Figure 224. Flow in a shear driven square cavity.

6.25.2 GFSSP Model

The GFSSP model of the driven cavity consists of 50 nodes (49 of which are internal) and 84 branches. For numerical stability, one boundary node with an arbitrary pressure of 14.7 psi was introduced. A unit depth (1 in) was assumed for the required areas. It is assumed that the shear area for each branch is 2 in^2. The shear distance between adjacent branches is 1.71429 in and the shear distance between walls and their adjacent branches is 0.85714 in. For transverse momentum, only adjacent parallel branches were considered, and only connecting branches not associated with the boundary node were used. The constant density option was used for the fluid, and the corresponding density and viscosity used were 1 lb_m/ft^3 and 1 $lb_m/(ft{\cdot}s)$, respectively. The bottom and side walls are fixed. The top wall moves to the right at 100 ft/s. All parallel angles are 0°, and all transverse angles are 90°.

The grid generation is performed in two steps: (1) Grid Generation is activated through Advanced options and the system network is built with multidimensional elements as shown in figure 225 (a) and (b), and (2) the grid is then generated (fig. 225(b)) through a dialog box (sec. 5.4.10).

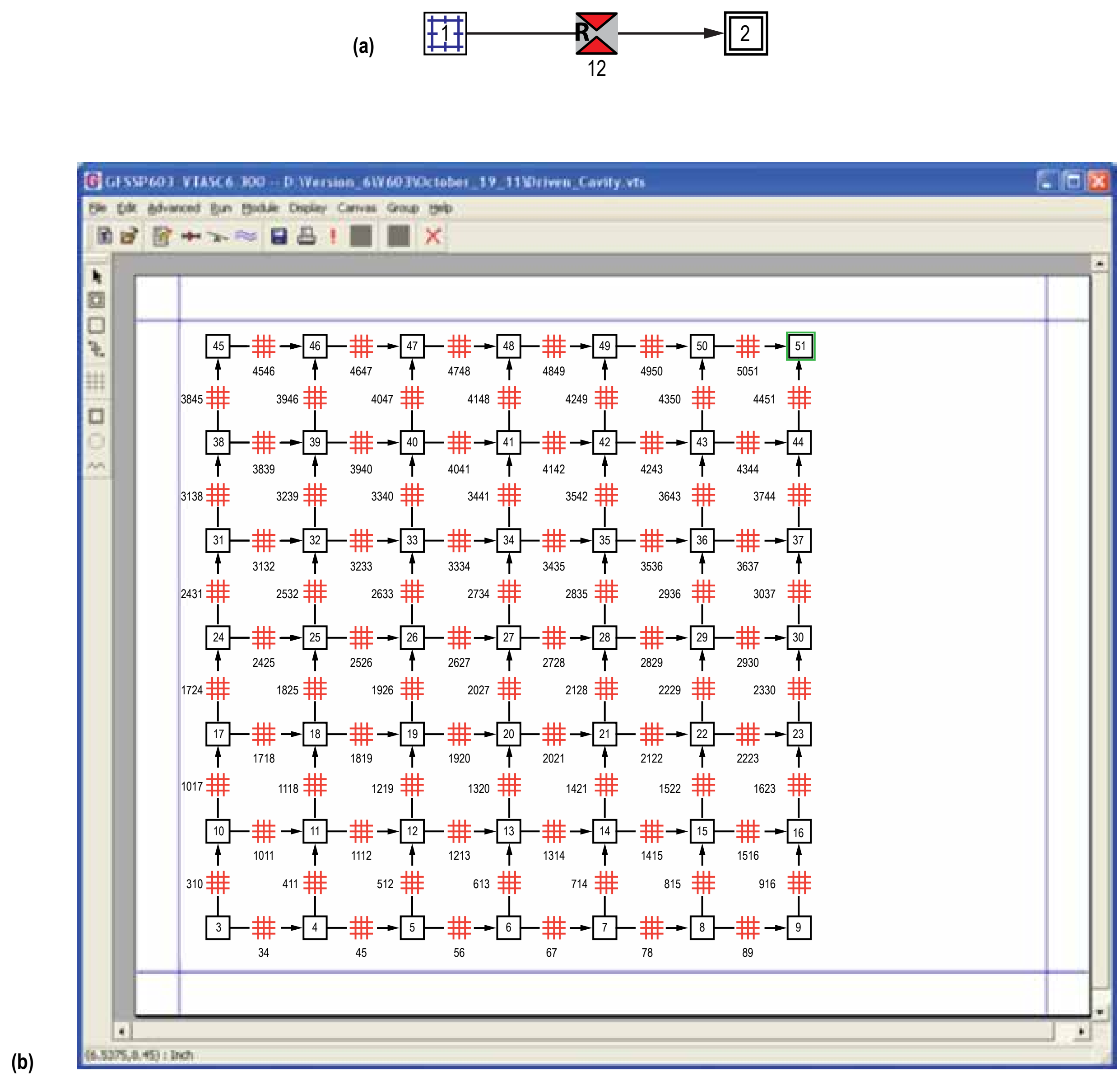

Figure 225. Two-dimensional cartesian grid generation in VTASC—element 1: (a) System network with expandable grid and (b) expandable two-dimensional cartesian grid.

6.25.3 Results

Figure 226 shows a comparison between the benchmark numerical solution and the GFSSP 7×7 node model velocity profiles along a vertical plane at the horizontal midpoint. As can be seen in figure 226, the results of this crude GFSSP model compare very favorably with the benchmark numerical solution of Burggraf.[51]

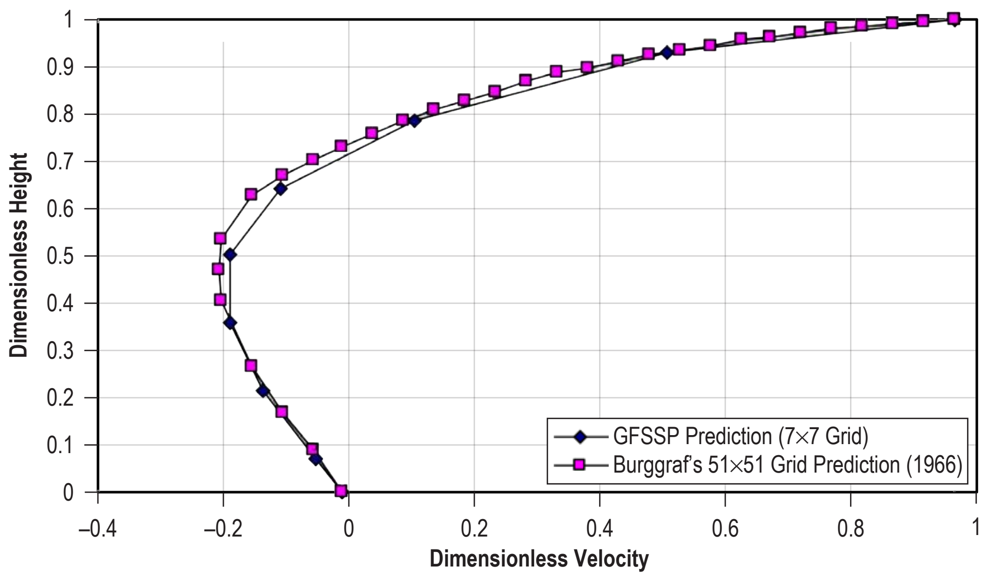

Figure 226. Shear driven square cavity centerline velocity distribution.

The predicted velocity field and pressure contours are shown in figure 227. The recirculating flow pattern and stagnation of flow near the top right corner are clearly shown in the figure. The predicted stream traces from the calculated velocity field are shown in figure 228.

Appendix II has the example 25 data as ex25.dat and ex25.out.

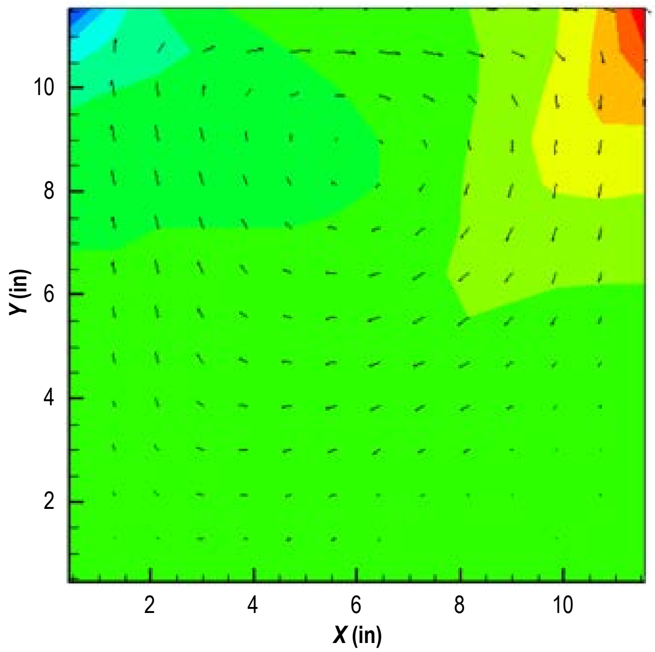

Figure 227. Predicted velocity field and pressure contours.

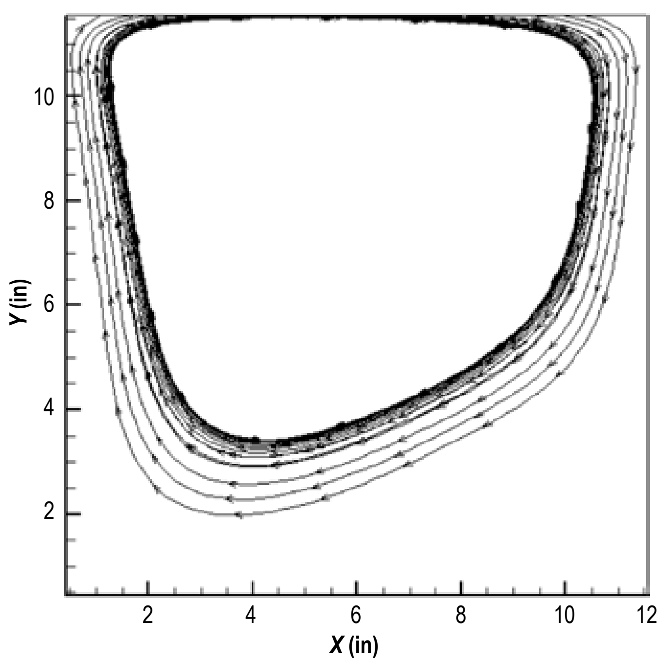

Figure 228. Predicted stream traces in the driven cavity.

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6.26 Example 26—Fluid Transients in Pipes Due to Sudden Opening of Valve

6.26.1 Problem Description

This example deals with water hammer in a pipe with entrapped air. This problem is different from example 15 as the flow regulating valve is suddenly opened as compared to suddenly closing in the case of example 15, and the results are validated against experimental data available in the literature.[52] A 1.025-in-diameter long pipe is attached to a reservoir of water at one end and closed at the other end with some entrapped air in the other end. A ball valve separates the water from the air as shown in figure 229. The ball valve is closed until about 0.15 s, and then gradually opens to 100% at about 0.4 s. This example has been set up according to the experimental study done by Lee et al.[52] The two most important controlling parameters for this problem are the reservoir pressure (p_R) and the fractional air length present in the pipe as compared to the total pipe length ($\alpha_g = L_g / L_T$). The initial length for the water volume in the pipe (L_l) is fixed to 20 ft, and initial length of air column in the pipe (L_g) varies from a low of 1.23 ft to 16.23 ft, the value of α ranging from 0.0579 to 0.448, respectively. The ratio of reservoir pressure to the initial pressure of the entrapped air ($P_R = p_R / p_{atm}$) varies from 2 to 7, i.e., the reservoir pressure (p_R) range being 29.4 to 102.9 psi. The objective of this study is to predict the transient pressure at different points along the length of the pipe.

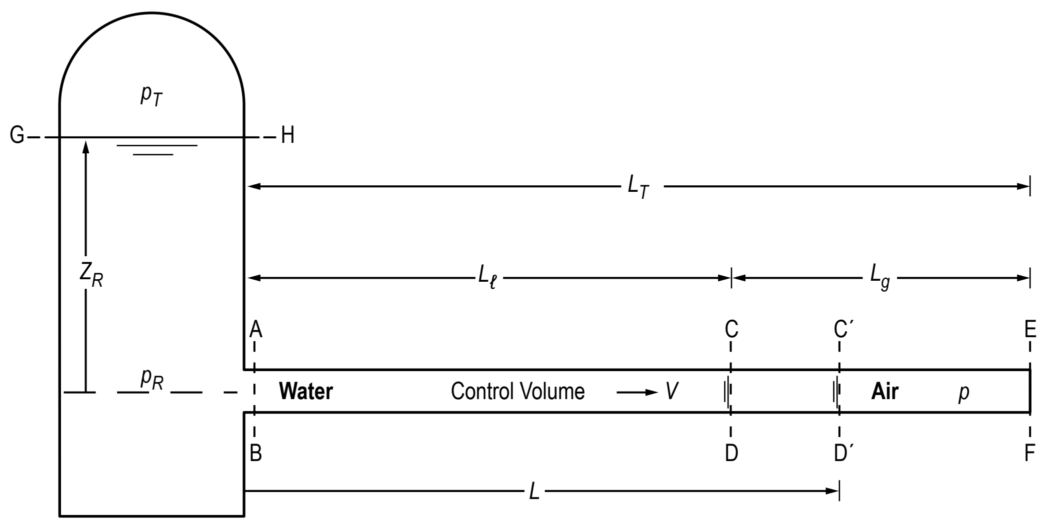

Figure 229. Schematic of the water pipe with entrapped air.

6.26.2 GFSSP Model

The GFSSP model to represent the flow of water in the pipe is shown in figure 230. The 20-ft-long pipe sector (only the water column) is divided into 10 uniform pipe segments and one restriction separating 12 nodes. Boundary node 1 represents the tank (reservoir). A User Subroutine interfaces node 12 to an unseen pseudo control volume containing air only. The pseudo control volume has a fixed mass of air, but the volume changes as it is pressurized, owing to the fluctuation of pressure at node 12. Thereby, the volume of node 12 changes as the volume of the imaginary control volume changes. The volume change in node 12 is computed by a volume balance between the volume of water and the volume of the entrapped air. The total volume ($V_{tot} = V_{air} + V_{12}$) remains constant, and must be equal to the initial total volume (since the pipe is closed at the other end). The equation of state for water (for node 12) and entrapped air as given as follows:

For water:

$$p_{12}V_{12} = Z_{12}\left(m_{12}R_{12}T_{12}\right) . \tag{114}$$

For air:

$$p_{air}V_{air} = m_{air}R_{air}T_{air} \tag{115}$$

Volume balance:

$$\left(V_{tot}\right)^0 = V_{air} + V_{12} . \tag{116}$$

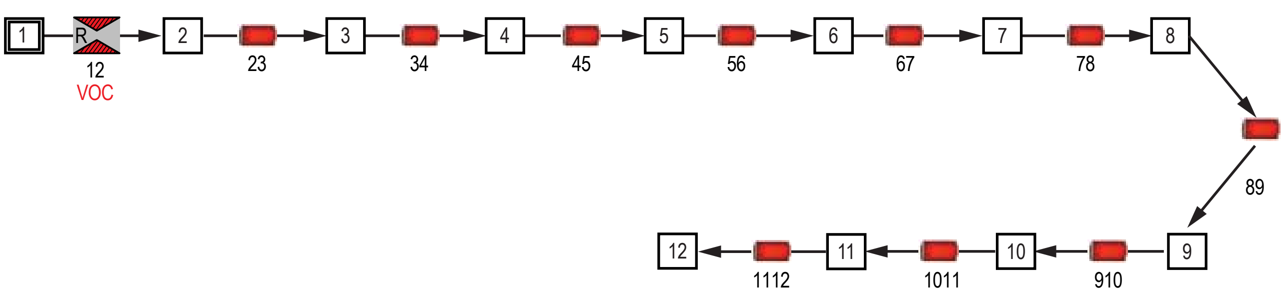

Figure 230. GFSSP model of sudden valve opening experiment of Lee and Martin.[52]

Also, across the water-air interface, due to mechanical and thermal equilibrium,

$$p_{\text{air}} = p_{12} \text{ and } T_{\text{air}} = T_{12} \,. \tag{117}$$

The volume of node 12 at any instant can be obtained by combining equations (114)–(117):

$$V_{12} = \left(V_{\text{tot}}\right)^0 / (1+\beta), \text{ where } \beta = \frac{m_{\text{air}} R_{\text{air}}}{m_{12} R_{12} Z_{12}}, \tag{118}$$

where V_{air} and V_{12} are the volume of entrapped air and volume of water in node 12.

Along with the volume adjustment for node 12, there would be a momentum source added to this node subject to air pressure from the entrapped air, and this is done through equation (119):

$$\text{Momentum Source} = -\frac{1}{g_c}\rho_{12}\frac{\left(V_{12} - V_{12}^*\right)}{\Delta\tau}u_{12} \;, \tag{119}$$

where u_{12} is the velocity at the last node, and V_{12} and V_{12}* are the volume of the 12th node at the current and previous time steps, respectively.

The volume source for node 12 is implemented in the subroutine SORCEM in the User Subroutine through the variable VOLUME(IPN). The momentum source term given in equation (119) is prescribed in subroutine SORCEF through the variable TERM100 for the last branch (branch 1112). The User Subroutine for example 26 is in appendix JJ (ex26.for dat).

The boundary condition at node 1 is provided through the history file ex26hs1.dat. The ball valve opening control is provided through the area change of the control valve over time through the data file, ex26vlv.txt.

6.26.3 Results

For the numerical solution, a time step of 0.01 s has been used. The operating conditions are: P_R = 7 and α_g = 0.45). The GFSSP input file (ex26.dat) and output file (ex26.out) are in appendix JJ. Figure 231 compares GFSSP's predicted pressure at node 12 with that of the experimental data points of Lee and Martin. The predicted results compared very well, and even though the peak pressure amplitude differs by about 7%, the frequencies of pressure oscillations matched very well.

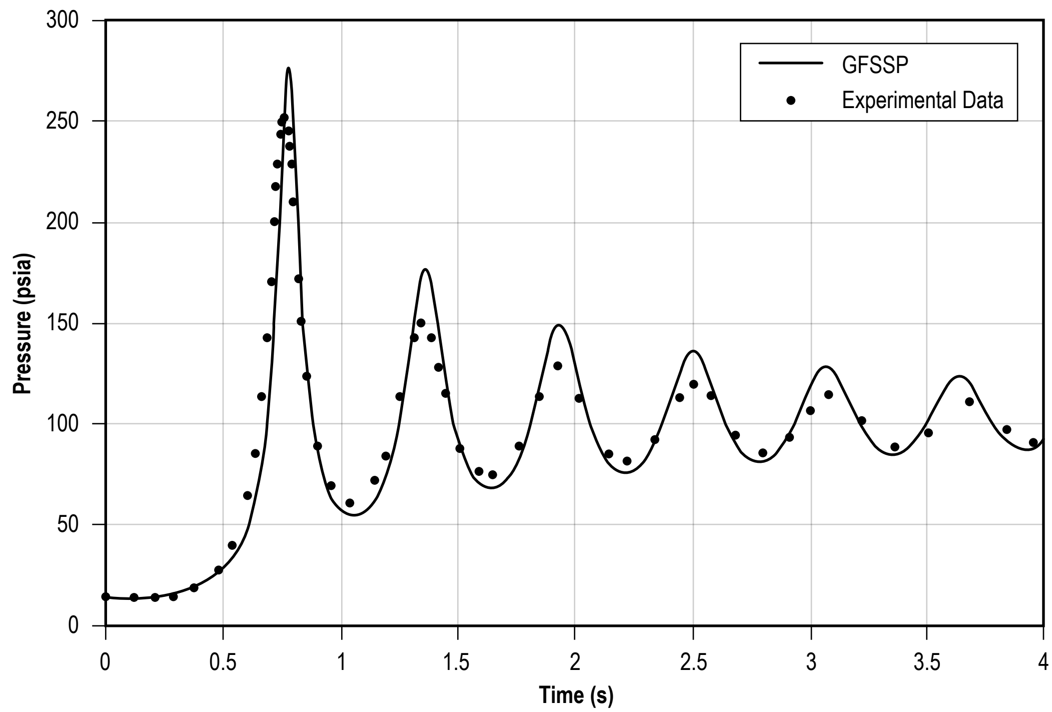

Figure 231. Comparison of GFSSP and experimental data.

A Fast Fourier Transform (fig. 232) has been conducted in the numerical model to predict the different modal frequencies of the pressure transient and has also been compared with the experimental data. More details of this example problem is available in reference 53.

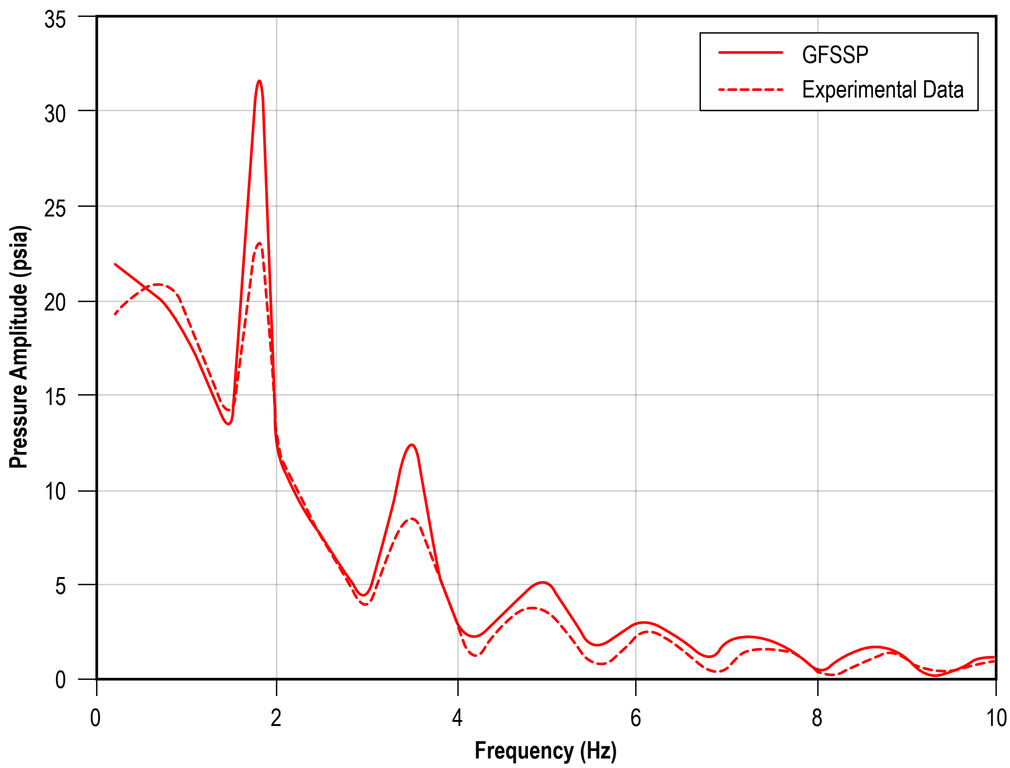

Figure 232. Fast Fourier transform for modal frequencies.

Fast Fourier Transform—A fast Fourier transform algorithm based on Danielson and Lanczos[54] has been used to transform the time domain pressure oscillations into the frequency domain. The computer program FFT_Multiple.for has been generated based on this algorithm. The time domain data are saved in a column format with time as independent variables in the first column and multiple pressures (or some other variables in time domain) in successive columns; this file is called p_t.txt, and the results are saved in a file called p_f.xls. For better accuracy, it is expected that one uses N (number of data) as a power in 2, i.e. $N = 2m$, for any integer m. However, the present code is capable of taking any number of input data, and computing the number of data to be used from here, which is a power of 2.

6.27 Example 27—Boiling Water Reactor

6.27.1 Problem Considered

The purpose of this example is to demonstrate the phase change of water in a vertical tube being heated from outside. This example also demonstrates the use of the Saturated Fluid Property Table for modeling phase change. The results of the Fluid Property Table have been verified by comparing them with the results obtained with WASP, GFSSP's built-in thermodynamic property program for water.

Figure 233(a) shows the schematic of the problem considered. A 6-ft-long, 1-in-diameter vertical water tube is being heated uniformly along the tube. The water enters the tube in a subcooled state and exits as superheated vapor. The pressures at the inlet and outlet have been prescribed. The model calculates flow rate through the tube, as well as the distribution of pressure, temperature, quality, and other thermophysical properties of water in the tube.

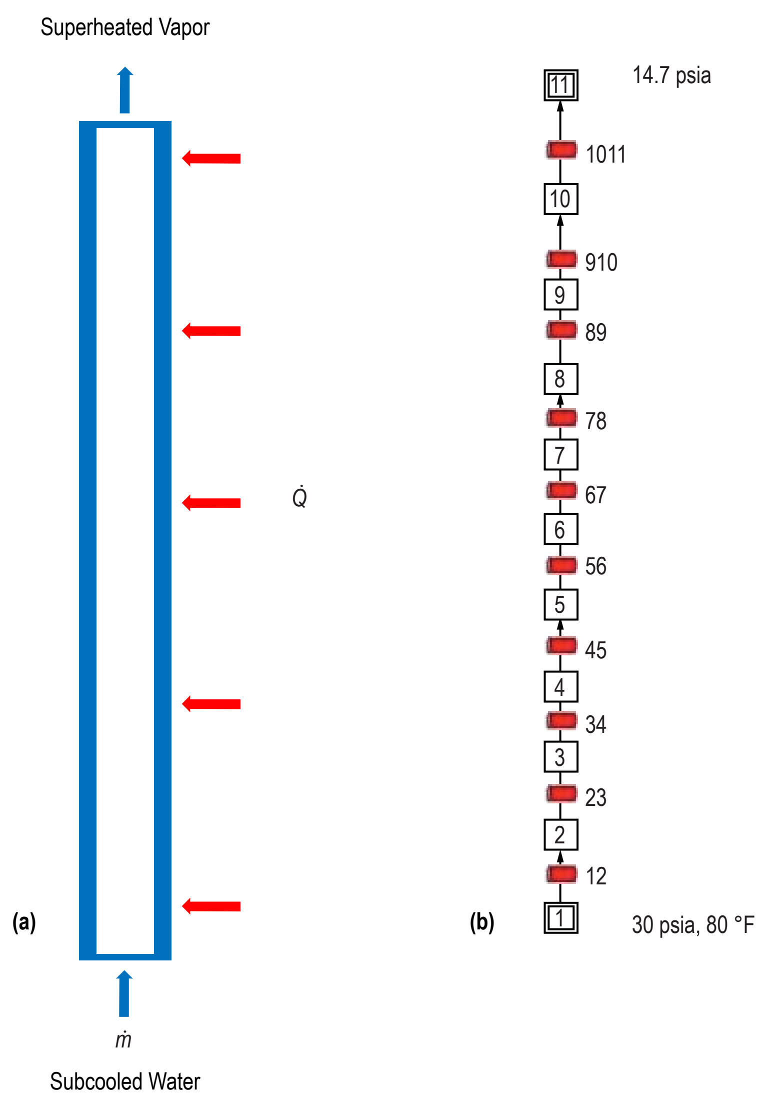

Figure 233. Boiling water reactor: (a) Problem schematic and (b) GFSSP model.

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6.27.2 GFSSP Model

The water tube has been discretized into ten equal segments resulting in ten branches, nine internal nodes, and two boundary nodes where pressures were prescribed (fig. 233(b)). Steady-state flow is assumed, and the flow rate is calculated by solving the momentum conservation equation that accounts for the pressure difference between inlet and outlet boundaries, frictional resistance, fluid inertia, and gravity. The external heat load was specified as 130 Btu/lbm in each of the nine internal nodes. The calculated flow rate was 0.113 lbm/s. Therefore, the total applied heat load was 132.21 Btu/s or 140 kW. The water enters the reactor at a highly subcooled state (80 °F; saturation temperature at 30 psia is 250.3 °F). The water leaves as superheated vapor at 354.4 °F (saturation temperature in node 10 at 15.94 psia is 216.1 °F). In the GFSSP model, gravity and inertia were activated in all fluid branches. Inertia was activated due to the large change in velocity along the pipe.

The GFSSP model was run with two different fluid options. First, the model was run with the built-in GASP/WASP property package using water (ex27_with_WASP.vts). The same model was then run with the User Fluid Property Table option (ex27_with_Property_Table.vts). In order to run with the Property Table option, eight property tables are necessary. They are:

(1) aakwater2.dat—Conductivity in Btu/s-ft-R
(2) rhowater2.dat—Density in lbm/ft^3
(3) emuwater2.dat—Absolute viscosity in lbm/ft-s
(4) gammawater2.dat—Specific heat ratio
(5) hwater2.dat—Enthalpy in Btu/lbm
(6) swater2.dat—Entropy in Btu/lbm-R
(7) cpwater2.dat—Specific heat in Btu/lbm-R
(8) satwater2.dat—Saturation table for pressure (psia), temperature (R), and enthalpy, density, specific heat, absolute viscosity, specific heat ratio, conductivity and entropy of liquid and vapor.

Figure 234 shows the Fluid Option window with eight property tables listed. It may be noted that the saturation table is required when the Phase Change box is checked.

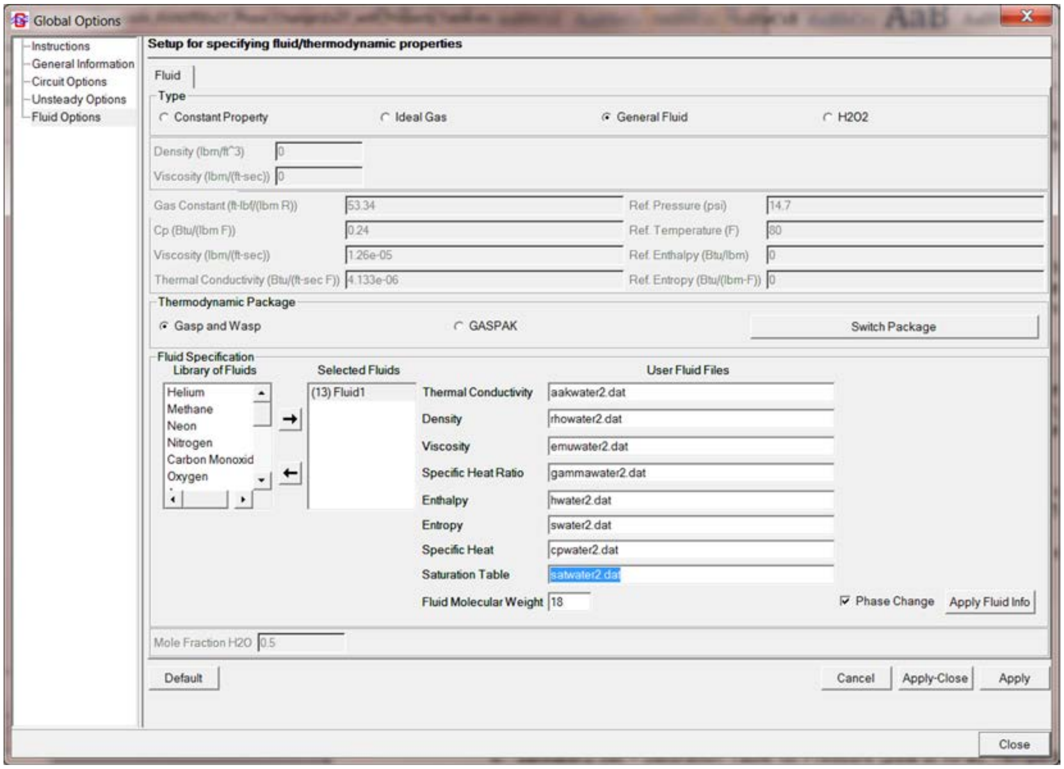

Figure 234. Fluid option in VTASC for user-specified fluid.

The method of generating property tables using the NIST-developed property program REFPROP[55] is described in appendix F.

6.27.3 Results

The input and output files for the boiling water reactor model run with the water property tables are included in appendix KK as Ex27.Table.dat and Ex27.Table.out. The files for the same model run with the WASP property package are included in appendix LL as Ex27.WASP.dat and Ex27.WASP.out.

Figure 235 shows the distribution of pressure and temperature along the length of the pipe. The distribution of quality and density is shown in Figure 236. The distribution of velocity is shown in figure 237. The pressure drops continuously from inlet to outlet due to frictional and gravitational effects. The temperature, however, first rises steadily until it reaches the saturation temperature. After reaching the boiling temperature, the temperature slightly drops due to the drop in saturation temperature at lower pressure. Once the water completely transforms to steam, temperature increases monotonically. The quality increases continuously in the tube. The quality increases monotonically from zero to 1 (fig. 236); the variation of density is very significant due to phase change and is plotted in logarithmic scale. The increase of velocity in figure 237 is another evidence of phase change as the mass flow rate is the same at all sections of the tube, but the density decreases as water turns into vapor.

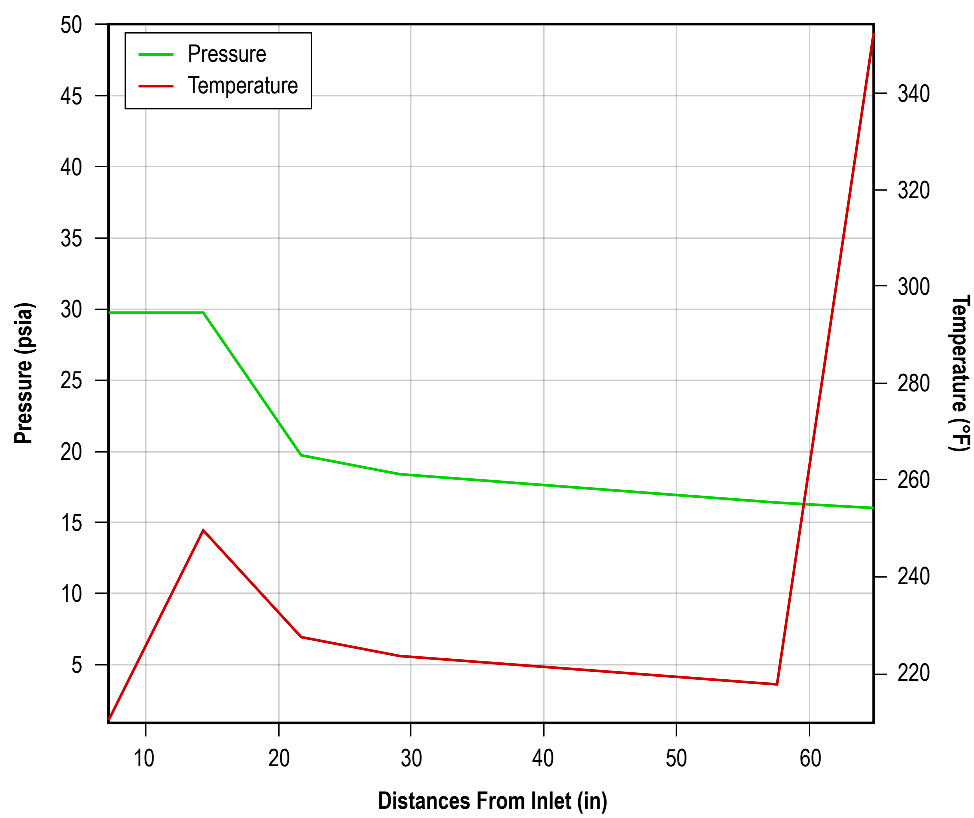

Figure 235. Pressure and temperature distribution in the vertical tube.

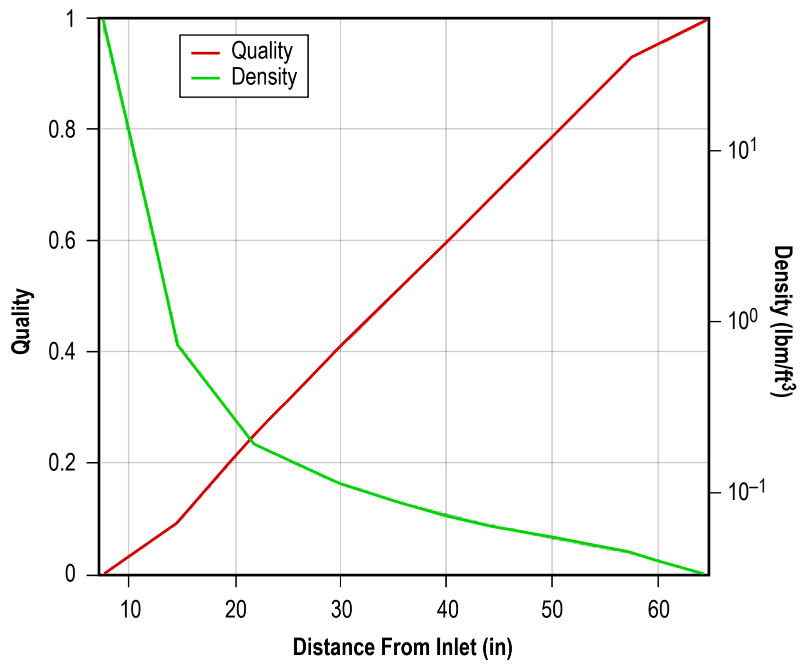

Figure 236. Distribution of quality and density in the vertical tube.

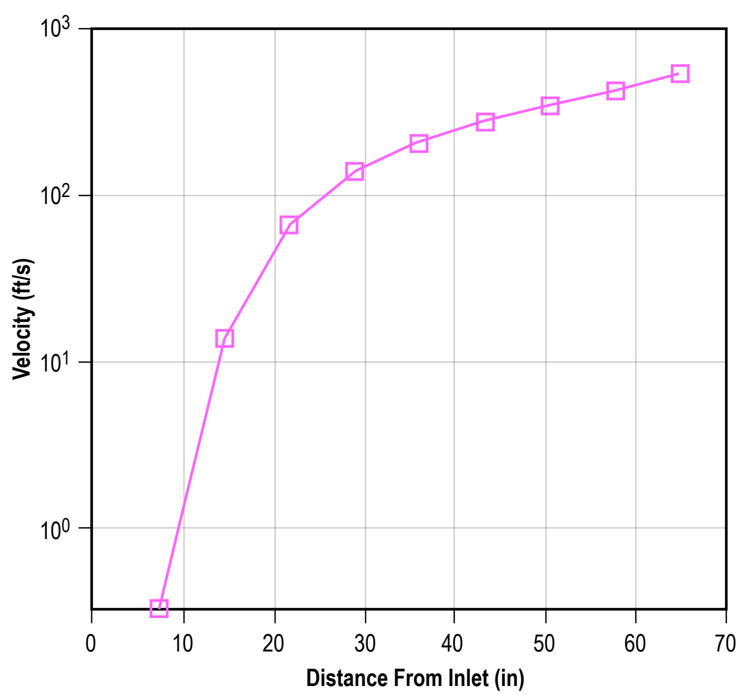

Figure 237. Distribution of velocity in the vertical tube.

The comparison between the two models is shown in table 44.

Table 44. Comparison between solutions with WASP and Property Table generated by REFPROP.

Variables	WASP	Property Table	Percent Difference
Flow rate (lbm/s)	0.1125	0.1131	0.5333
P_2 (psia)	29.745	29.747	0.00672
P_5 (psia)	18.517	18.536	0.103
P_{10} (psia)	15.946	15.935	0.069
T_2 (°F)	209.99	209.59	0.191
T_5 (°F)	223.88	223.02	0.384
T_{10} (°F)	354.39	352.55	0.519
X_2*	–	–	–
X_5	0.3906	0.3909	0.077
X_{10}	1.00	1.0	–

*X is the vapor mass fraction or quality.

6.27.3.1 Comparison of GFSSP Results With Hand Calculation. The outlet temperature can be calculated by a simple energy balance for a control volume for a given mass flow rate. The energy balance equation can be written as:

$$\dot{m}\left[C_{p,\mathrm{liq}}\left(T_{\mathrm{sat}}-T_{\mathrm{in}}\right)+h_{fg}+C_{p,\mathrm{vap}}\left(T_{\mathrm{out}}-T_{\mathrm{sat}}\right)\right]=\dot{Q}\ . \tag{120}$$

From equation (120), T_{out} can be expressed as:

$$T_{\mathrm{out}}=T_{\mathrm{sat}}+\frac{1}{C_{p,\mathrm{vap}}}\left[\frac{\dot{Q}}{\dot{m}}-C_{p,\mathrm{liq}}\left(T_{\mathrm{sat}}-T_{\mathrm{in}}\right)-h_{fg}\right]. \tag{121}$$

From REFPROP, the saturation properties at an average pressure of 22.35 psia were evaluated:

$$T_{\mathrm{sat}}=233.89\ \mathrm{^oF};\ h_{fg}=956.69\frac{\mathrm{Btu}}{\mathrm{lb_m}};\ C_{p,\mathrm{liq}}=1.0113\frac{\mathrm{Btu}}{\mathrm{lb_m\ ^oF}};\ C_{p,\mathrm{vap}}=0.5103\frac{\mathrm{Btu}}{\mathrm{lb_m\ ^oF}}\ . \tag{122}$$

From equation (121), $T_{\mathrm{out}}=346.92$ °F and GFSSP calculates $T_{10}=354.39$ °F.

The 7.47° difference between hand calculation and GFSSP calculation can be attributed to the use of average pressure and the assumption of constant specific heat in the hand calculation.

6.28 Example 28—No-Vent Tank Chill and Fill Model

6.28.1 Problem Considered

The purpose of this example is to demonstrate the simulation of the no-vent chill and fill method of chilling and filling a cryogenic tank. The practice of tank chilldown in microgravity environment is quite different than tank chilldown on the ground. On the ground, under normal gravity, a vent valve on top of the tank can be kept open to vent the vapor generated during the chilling process. The tank pressure can be kept close to atmospheric pressure while the tank is chilling down. In a microgravity environment, due to the absence of stratification, such practice may result in dumping a large amount of precious propellant overboard. The intent of the no-vent chill and fill method is to minimize the loss of propellant during chilldown of a propellant tank in a microgravity environment. The no-vent chill and fill method consists of a repeated cyclic process of charge, hold, and vent.

During the charge cycle, a small quantity of liquid cryogen is injected into the evacuated tank. Some type of spray nozzle is usually used to break the incoming liquid into droplets. Initially, the liquid flashes due to the low tank pressure, and then the remaining liquid droplets evaporate as they contact warm hydrogen vapor or the tank wall. During the hold period, the circulating flow pattern induced from the spray nozzles provides convective heat transfer from cold vapor to the tank wall. The primary mode of heat transfer during the hold is convection. At the completion of the hold period, the pressure has risen considerably and the tank is ready to be vented. Since venting occurs as an isentropic blowdown, some additional cooling may be recovered by stage-wise venting. The key parameters of this method are (1) charge magnitude, (2) spray system selection, (3) mass flow rate, (4) hold duration, (5) acceleration environment, (6) desired tank wall temperature, and (7) maximum operating pressure. A reliable and inexpensive mathematical model will help designers to perform a large amount of calculations to optimize the key parameters. A GFSSP model was developed to simulate chilldown of the LH_2 tank at the K-site Test Facility[56] and numerical predictions were compared with test data.

The test set-up at the K-site Test Facility, shown in figure 238, consists of a test tank, spray system, test tank valves, instrumentation, and the vacuum chamber.

The test tank selected was ellipsoidal with an 87-in major diameter and a 1.2 to 1 major to minor axis ratio. The two ends are joined by a short 1.5-in cylindrical section. The tank is made of 2219 aluminum chemically milled to a nominal thickness of 0.087 in. Thicker sections exist where they were required for manufacturing (mainly weld lands). The tank has a 28.35-in access flange on the top. The tank weighs 329.25 lb, and the tank's volume is 175 ft^3. The tank was originally designed for a maximum operating pressure of 80 psia. Prior to the start of testing the tank was requalified by pneumatic test for a maximum operating pressure of 50 psia. The tank is covered with a blanket of 34 layers of multilayer insulation (MLI) made with double aluminized Mylar and silk net spacers, and is supported by 12 fiberglass epoxy struts. The test environment ambient temperature was uniform and maintained at 530R $\pm$ 1R by an electrically heated shroud located outside the tank and inside the vacuum chamber.

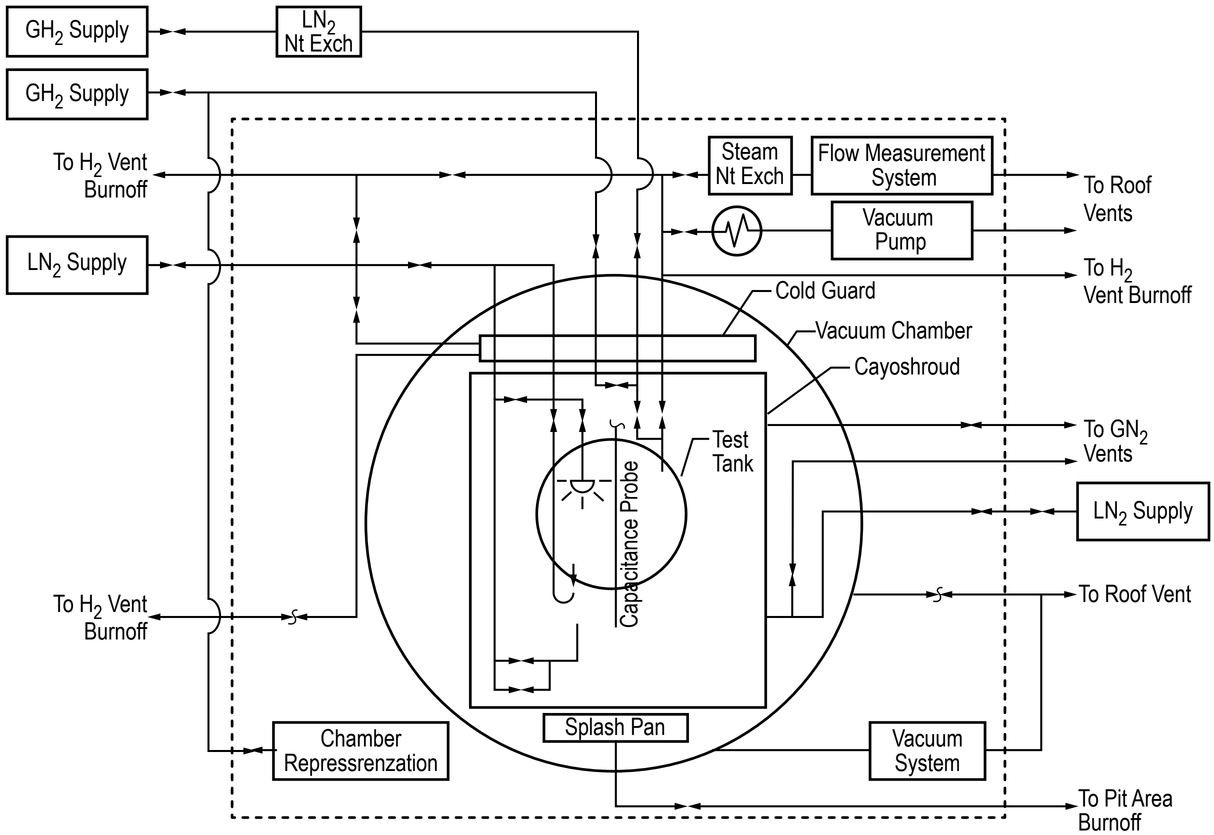

Figure 238. *K*-site test set-up for no-vent fill experiment.

6.28.2 GFSSP Model

A nine node tank (fig. 239) was built to simulate the test as described above. Boundary node 13 represents the supply tank which is supplying hydrogen at –420 °F. The total flow rate was evenly distributed through branches 131 through 139. Figure 240 shows the transformation of the actual tank configuration to the model configuration, where the tank geometry was assumed to consist of nine volumes or 'tank slices.' The total volume and surface area of heat transfer between solid and fluid are identical between the actual and model configurations. Nodes 1 through 9 represent the inside tank volume where propellants reside, transfer from one control volume to another, exchange heat with neighboring solid nodes, and change phases from liquid to vapor and vice versa. The mass and energy conservation equations are solved in the nodes, connected by branches in which the momentum equation is solved. Node 12 is another boundary node that represents the tank outlet. Nodes 10 and 11, branches 910, 1011, and 1112 represent the vent line. Nodes 1 through 9 are connected to metal solid nodes 14 through 22 through fluid to solid conductors that allow convective heat transfer between solid and fluid nodes. The model neglects axial conduction of heat.

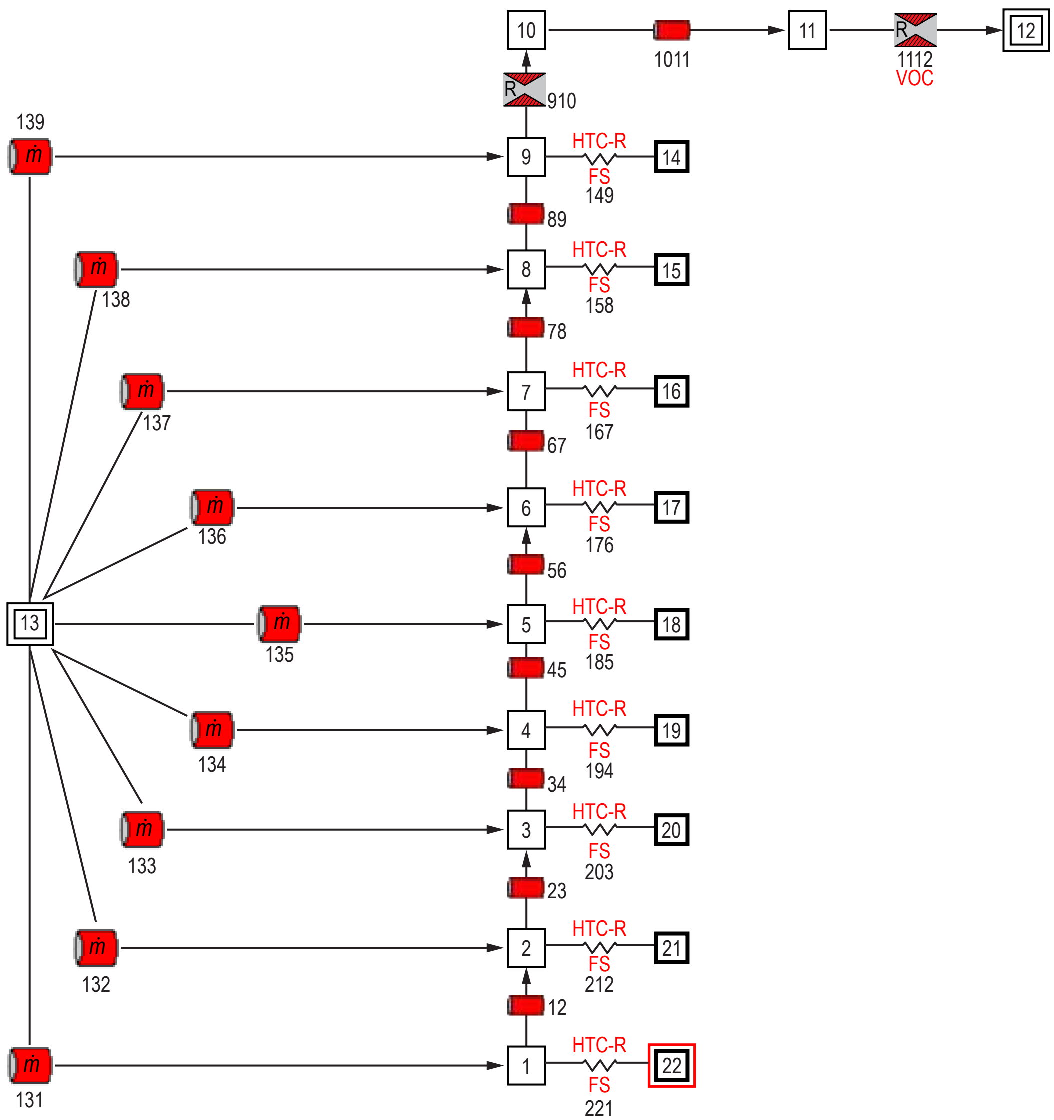

Figure 239. GFSSP nine node tank model.

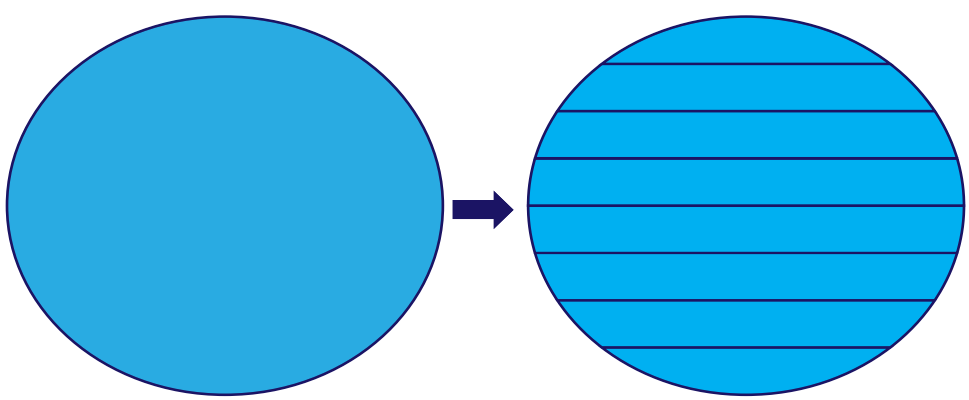

Figure 240. Conversion of LH_2 tank geometry.

Nodes 1 through 9 represent the volume of the test tank with initial pressure set to 1.97 psia and initial temperature set to –19.57 °F. The lengths and diameters of each branch that represent the tank are given in table 45. Summing the individual tank slice volumes yields a total tank volume of 301,836.93 in^3. Branch 1112, modeled as a restriction, simulates the vent valve open and close. Node 12 is a boundary node which represents the vent to ambient at pressure equal to 14.7 psia and temperature equal to 60 °F. Conductors 149, 158, 167, 176, 185, 194, 203, 212, and 221 represent the heat transfer from the hydrogen fluid to the aluminum 2219 tank wall. The heat transfer area is the surface area of each tank slice as given in table 46. Summing the individual heat transfer areas yields a total model tank heat transfer area of 21,599.43 in^2. The heat transfer coefficients were calculated from a free convection correlation.[57] Nodes 14 through 22 represent the tank material and mass which are aluminum 2219 and the masses given in table 47. Summing the individual tank slice masses yields a total model tank mass of 329.247 lb. The initial solid wall temperature was set to –19.57 °F.

Table 45. Internal model tank parameters.

Branch No.	Branch Length (in)	Branch Diameter (in)	Branch Volume (in^3)
12	11.063	38.59	4,118.72π
23	11.063	62.71	10,876.43π
34	11.063	74.61	15,395.96π
45	11.063	79.88	17,647.73π
56	11.063	79.88	17,647.73 π
67	11.063	74.61	15,395.96π
78	11.063	62.71	10,876.43π
89	11.063	38.59	4,118.72π

Table 46. Tank slice heat transfer area.

Branch	Area (in^2)	Branch	Area (in^2)
221	462.27	176	3,715.48
212	1,684.92	167	2,952.94
203	2,952.94	158	1,684.92
194	3,715.48	149	462.27
185	3,968.21		

Table 47. Tank slice mass distribution.

Node	Mass (lb)	Node	Mass (lb)
14	7.046	19	56.636
15	25.683	20	45.013
16	45.013	21	25.683
17	56.636	22	7.046
18	60.491		

6.28.3 Results

The input and output files for the no-vent chill and fill model are included in appendix MM as Ex28.dat and Ex28.out. The user subroutine code is also included.

Figure 241 shows the specified inlet flow rate and predicted pressure history. During the charging period, the pressure increases rapidly due to evaporation. During the hold period, pressure remains constant. During venting, pressure in the tank reduces rapidly. During the charging period, the flow rate was assumed constant and was obtained from the reported test data. Figure 242 shows the predicted mass history of hydrogen during the operation. There is very little hydrogen during the chilling process because of venting.

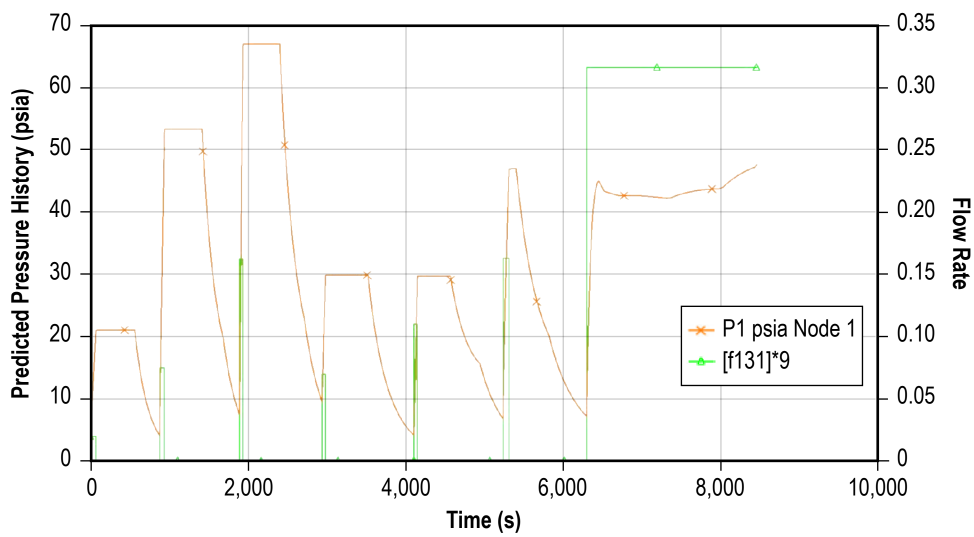

Figure 241. Specified inlet flow rate and predicted pressure history.

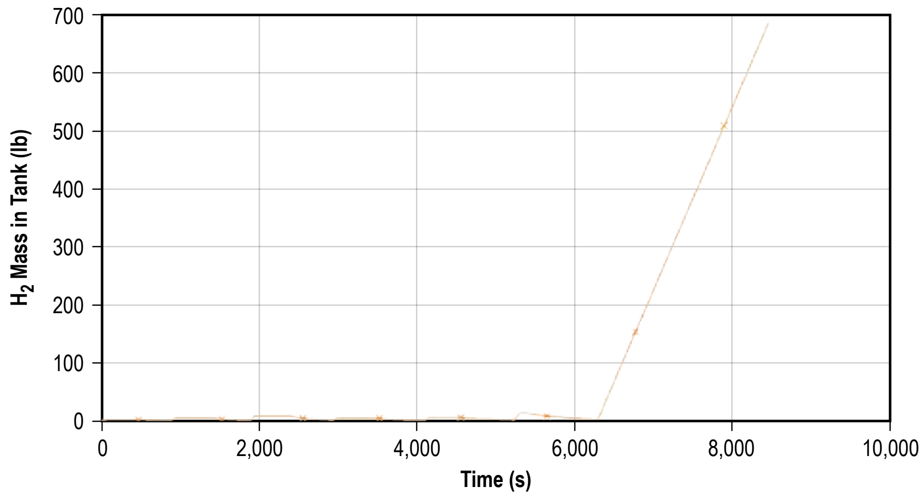

Figure 242. Predicted hydrogen mass history in the tank.

Figure 243 shows the predicted vent flow rate history during tank chilldown. Vent flow rate reaches a peak value at the opening of the vent valve and diminishes as tank pressure reduces. Figure 244 shows vapor quality at all nine nodes during the process. As expected, liquid first forms at the bottom node while the remaining nodes remain superheated. The sudden drop in the quality in the bottom node is due to the blowdown effect. Predicted propellant loss agrees quite well with estimated propellant loss during the test:

- Predicted—32.5 lb (nine node model) and 33.5 lb (one node model).
- Test—32 lb.

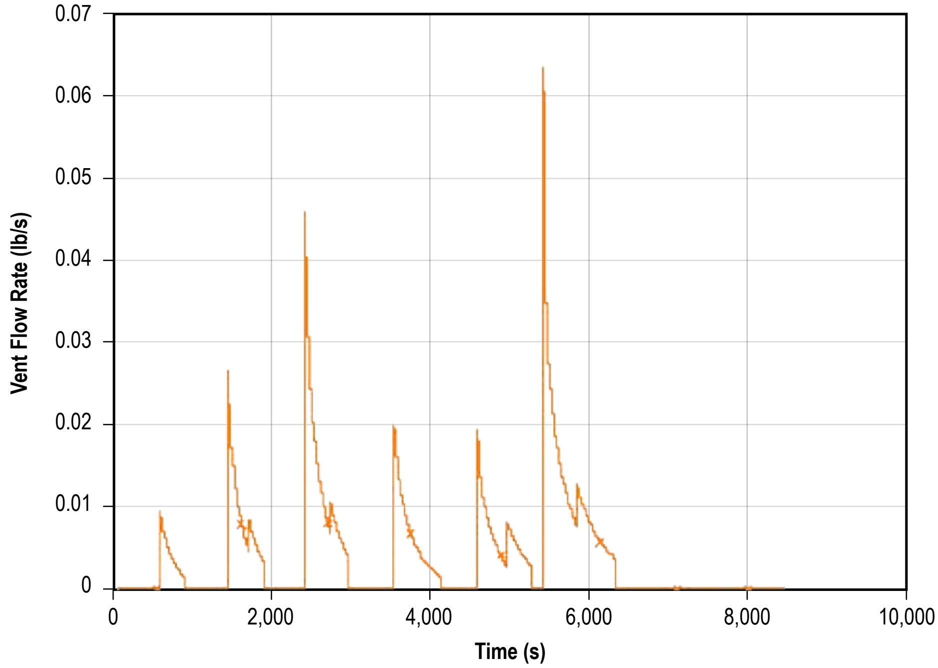

Figure 243. Predicted vent flow rate history during tank chilldown.

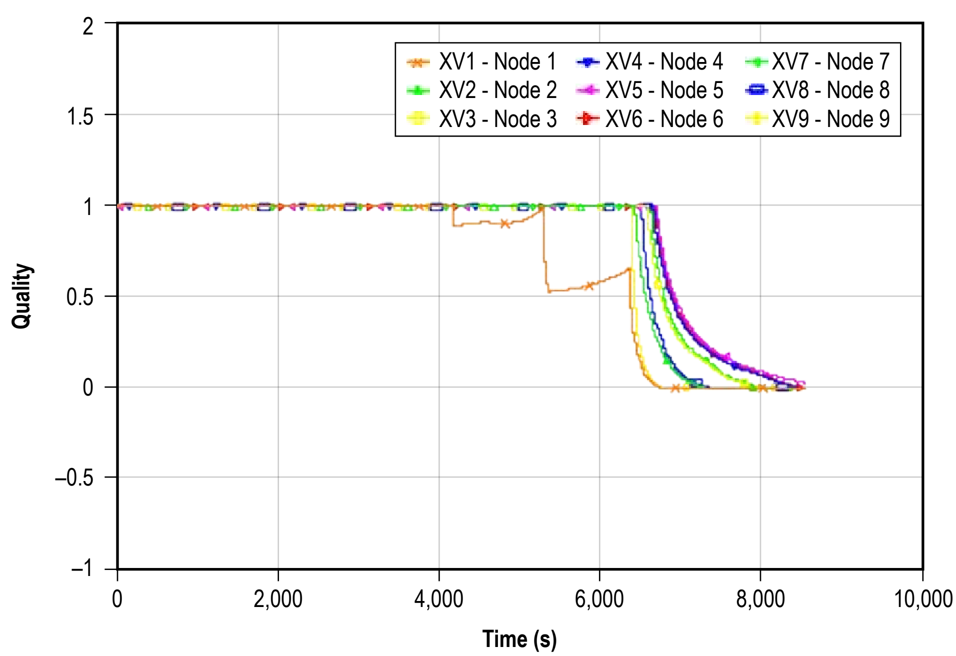

Figure 244. Predicted vapor quality during tank chilldown.

6.29 Example 29—Self-Pressurization of a Cryogenic Propellant Tank Due to Boil-Off

6.29.1 Problem Considered

The purpose of this example is to demonstrate the simulation of self-pressurization of an LH_2 tank performed under the Multipurpose Hydrogen Test Bed (MHTB) program.[58] The purpose of the MHTB program is to test a thermodynamic vent system (TVS) to reduce boil-off in a cryogenic propellant tank for long-term storage of propellant in space as shown in figure 245.

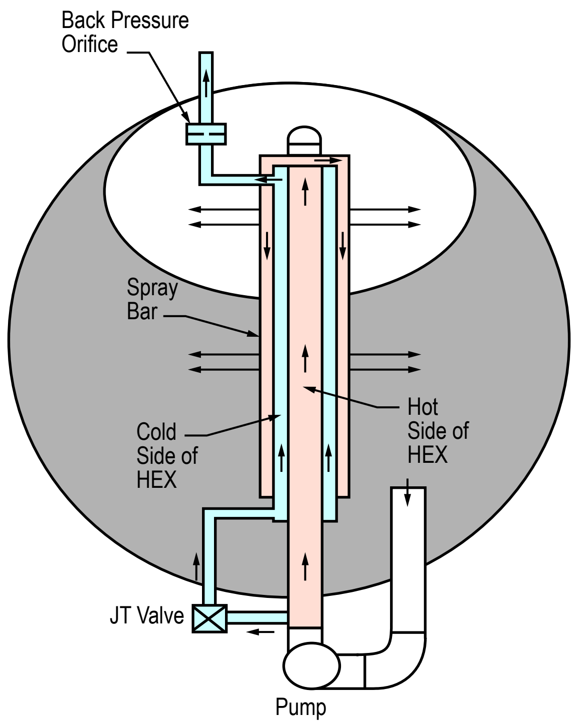

Figure 245. TVS in MHTB tank.

The MHTB 5083 aluminum tank is cylindrical in shape with a height and diameter of 10 ft and elliptic domes in both ends as shown in figure 246. It has an internal volume of 639 ft^3 and surface area of 379 ft^2. Initially, the tank is allowed to self-pressurize due to boil-off and by not allowing the vapor to vent. Once the pressure reaches the maximum allowable pressure, LH_2 is introduced into the tank through the spray bar. The pressure starts falling due to heat transfer, and when the pressure reaches the minimum allowable pressure, the spray is stopped and the tank is allowed to self-pressurize; thus, the TVS cycle continues. The purpose of the GFSSP model is to simulate the initial self-pressurization when ullage pressure rises from the initial tank pressure to the upper bound pressure when the spray starts. The GFSSP model results were then compared with the test data. A 50% fill level case was modeled to simulate the self-pressurization test.

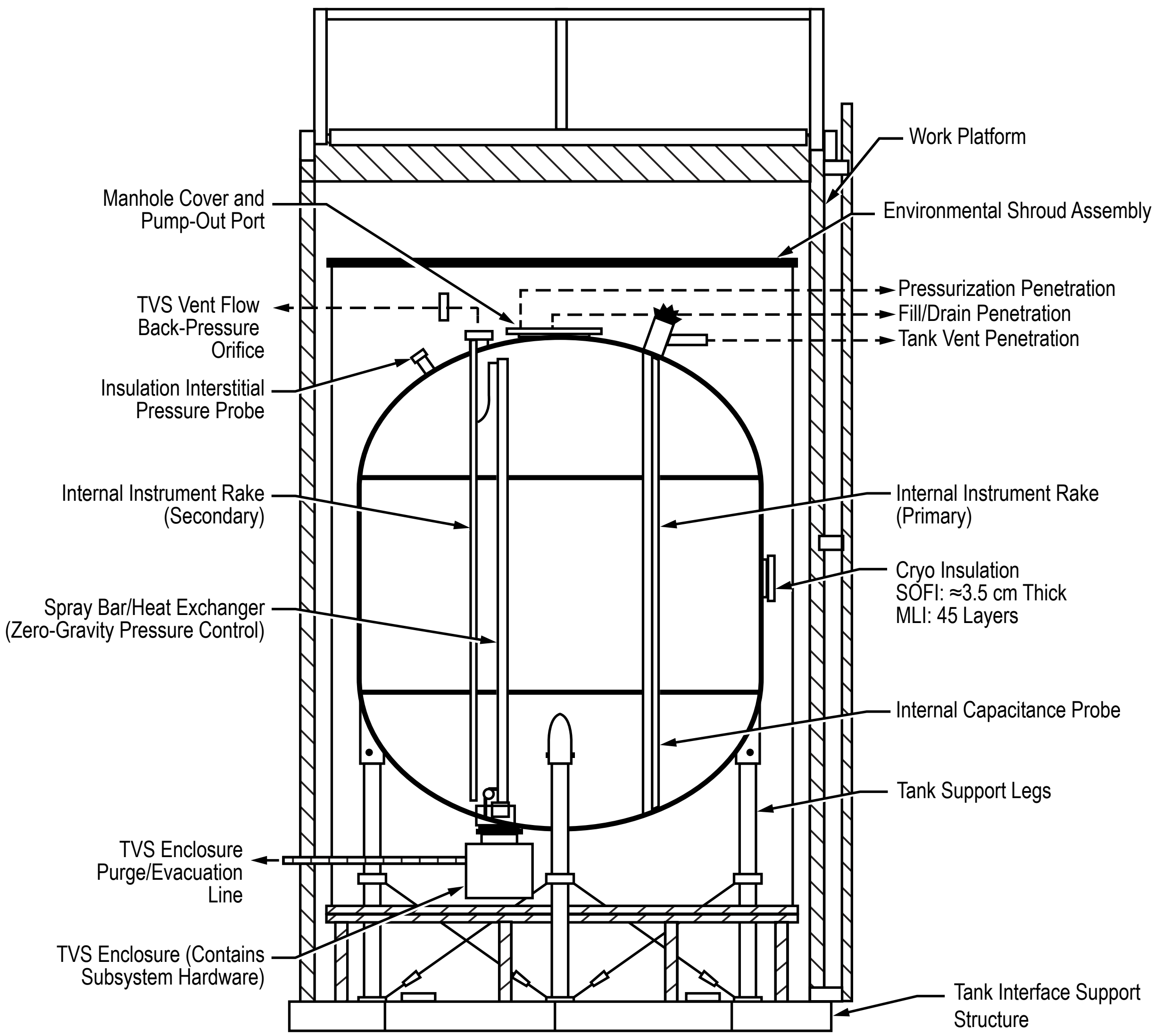

Figure 246. MHTB test tank and supporting hardware schematic.

6.29.2 GFSSP Model

Figure 247 shows the GFSSP model of self-pressurization in the MHTB tank at the 50% fill level. Node 4 represents LH_2; nodes 2, 8, 9, 10, and 11 represent the ullage at different fill levels. Node 3 is a pseudo boundary node separating LH_2 from vapor hydrogen in the ullage space. Branches 45, 164, 162, 168, 169, 1610, and 1611 are for introducing LH_2 into the tank through the TVS spray bar. These branches are currently inactive during self-pressurization of the tank. Nodes 7, 6, 12, 13, 14, and 15 are solid nodes representing the aluminum tank wall. Solid node 7 is connected with LH_2 stored in fluid node 4. In this model, heat leak through insulation is calculated in the User Subroutine and applied in the solid nodes as a source term.

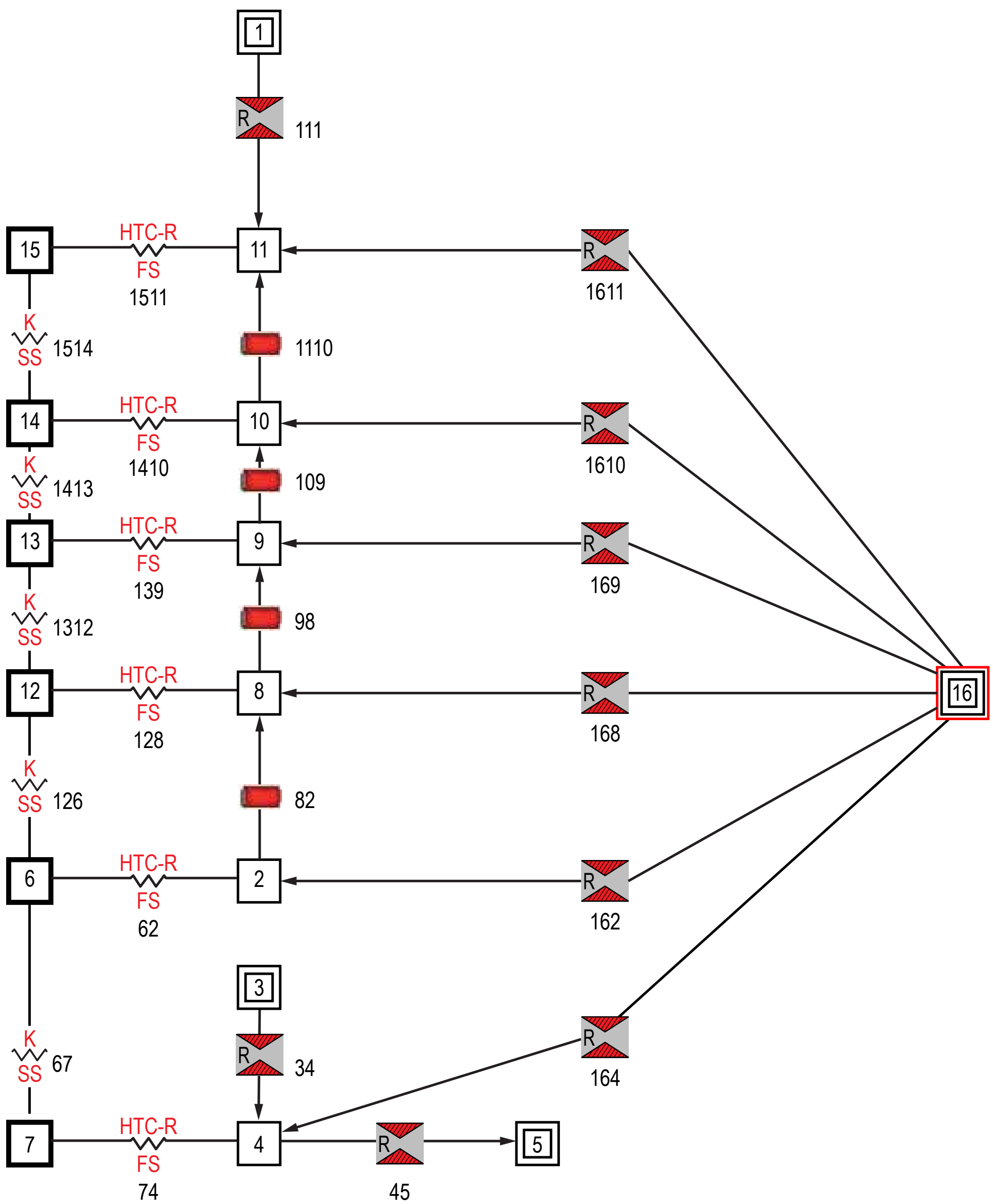

Figure 247. GFSSP model of MHTB test tank.

6.29.2.1 User Subroutine. In this model, a User Subroutine was used (1) to model evaporative mass transfer at the liquid-vapor interface, (2) to calculate the heat transfer coefficient between the wall and the fluid nodes, and (3) to calculate heat transfer through the MLI blankets.

6.29.2.1.1 Evaporative Mass Transfer at Liquid-Vapor Interface. Figure 248 shows the evaporative mass transfer process at the liquid-vapor interface. It is assumed that evaporation takes place at the interface in a thin film which contains saturated vapor at ullage pressure.

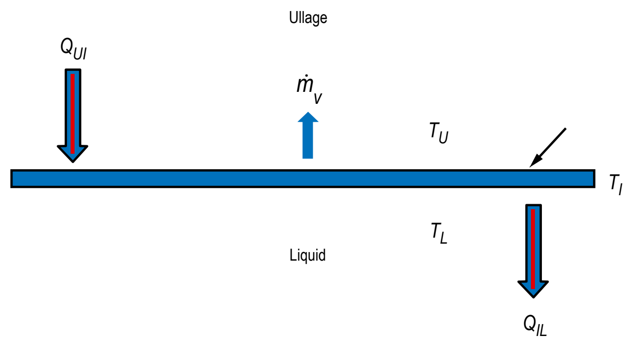

Figure 248. Schematic of evaporative mass transfer process at liquid-vapor interface.

The ullage contains superheated vapor at temperature, T_U. The interface temperature T_I is the saturation temperature at ullage pressure. The ullage to interface heat transfer, Q_{UI}, can be expressed as:

$$Q_{UI} = h_{UI} A\left(T_U - T_I\right) \tag{123}$$

where

$$h_{UI} = \frac{k_U}{h_L} , \tag{124}$$

k_U is the conductivity of vapor in the ullage and h_L is the length scale.

The interface to liquid heat transfer, Q_{IL}, can be expressed as:

$$Q_{IL} = h_{IL} A\left(T_I - T_L\right) \tag{125}$$

where

$$h_{IL} = \frac{k_L}{h_L} , \tag{126}$$

k_L is the conductivity of vapor in the ullage and h_L is the length scale.

The evaporative mass transfer is given by:

$$\dot{m} = \frac{Q_{UI} - Q_{IL}}{h_{fg}} \ , \tag{127}$$

where h_{fg} is the enthalpy of evaporation.

$\dot{m}$ was computed in Subroutine SORCEM. The variation of h_{fg} and T_I due to pressure change was neglected in this model.

6.29.2.1.2 Heat Transfer Through Multilayer Insulation Blankets. Heat transfer through MLI can be expressed by the modified Lockheed equation:[59]

$$q = \left[\frac{C_s \left(0.017 + 7.0E - 6 * \left(800.0 - T_{\text{avg}}\right) + 2.28E - 2 * \ln\left(T_{\text{avg}}\right)\right)\left(N^*\right)^{2.63}\left(T_h - T_c\right)}{N_s} \right.$$

$$\left. + \frac{C_r \varepsilon \left(T_h^{4.67} - T_c^{4.67}\right)}{N_s} + \frac{C_g P \left(T_h^{0.52} - T_c^{0.52}\right)}{N_s} \right] . \tag{128}$$

The actual heat transfer, however, was calculated by introducing a degradation factor, D_f, which is typically in the order of 3 to 5 for an LH_2 tank. The heat transfer rate through MLI was expressed as:

$$q_{\text{MLI}} = D_f q \ , \tag{129}$$

where

Constants:
- C_s = 2.4E-4
- C_r = 4.944E-10
- C_g = 14,600

Variables and units:
- q = heat flux through MLI (W/m^2)
- T_h = hot boundary temperature (K)
- T_c = cold boundary temperature (K)
- T_{avg} = average of hot and cold boundary temperature (K)

- N^* = MLI layer density (layers/cm)
- N_s = number of MLI layers
- ε = MLI layer emissivity (ε = 0.031)
- P = interstitial gas pressure (torr).

Typically, several MLI blankets constitute MLI insulation. The mathematical modeling methodology is shown in figure 249. According to the law of energy conservation,

$$Q_{\text{rad}} = Q_1 = Q_2 = Q_3 \ , \tag{130}$$

where radiative heat transfer is given as:

$$q = \frac{\sigma\left(T_{\text{amb}}^4 - T_{\text{outer}}^4\right)}{\frac{1}{\varepsilon_{\text{MLI}}} + \frac{1}{\varepsilon_{\text{shrd}}} - 1} \ . \tag{131}$$

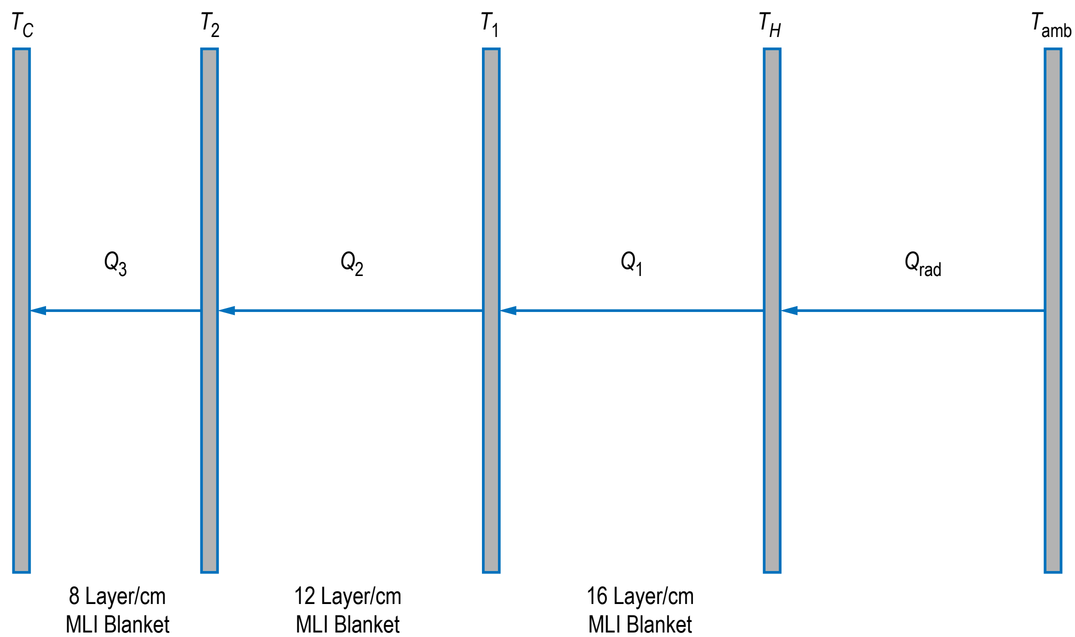

Figure 249. MLI modeling methodology.

The law of energy conservation can also be expressed as:

$$Q_2\left(T_1, T_2\right) - Q_3\left(T_2, T_c\right) = 0 \ , \tag{132}$$

$$Q_1\left(T_h, T_1\right) - Q_2\left(T_1, T_2\right) = 0 \ , \tag{133}$$

and

$$Q_{\text{rad}}\left(T_{\text{amb}}, T_H\right) - Q_1\left(T_H, T_1\right) \ . \tag{134}$$

Equations (132)–(134) are the governing equations to calculate temperature at the outer boundary and two intermediate temperatures by the Newton-Raphson method. A subroutine MLI_HEAT_RATE was developed to solve these equations. Figure 250 shows the flowchart of the subroutine which was called from Subroutine SORCETS.

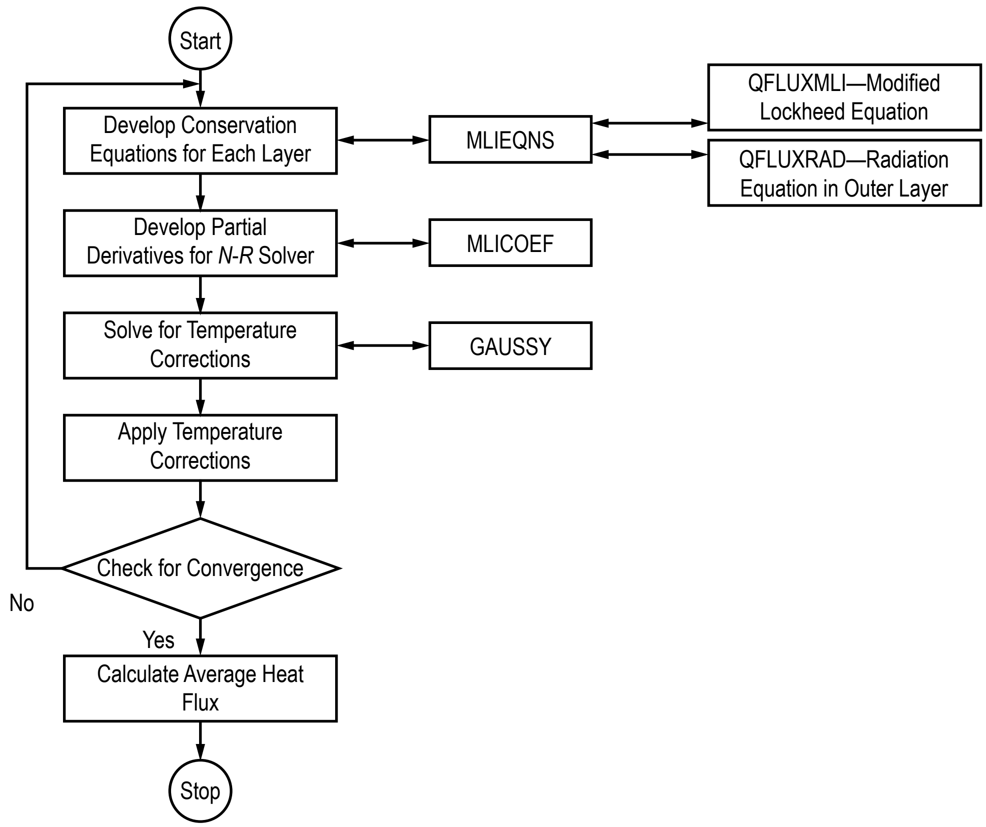

Figure 250. Flowchart of MLI_HEAT_RATE Subroutine.

6.29.2.1.3 Heat Transfer Coefficient Correlation. The heat transfer coefficient between wall and ullage was computed from a natural convection correlation for a vertical plate.[57] The set of equations used for this correlation follows:

$$\mathrm{Nu} = \left[\left(\mathrm{Nu}_l\right)^m + \left(\mathrm{Nu}_t\right)^m \right]^{1/m} \quad m = 6 \,, \tag{135}$$

$$\mathrm{Nu}_t = C_t^V \mathrm{Ra}^{1/3} / \left(1 + 1.4 \times 10^9 \, \mathrm{Pr} / \, \mathrm{Ra}\right) , \tag{136}$$

$$\mathrm{Nu}_t = \frac{2}{\ln\left(1 + 2 / \mathrm{Nu}^T\right)} \,, \tag{137}$$

$$\mathrm{Nu}^T = \bar{C}_l \mathrm{Ra}^{1/4} \,, \tag{138}$$

$$C_t^V = \frac{0.13 \mathrm{Pr}^{0.22}}{\left(1 + 0.61 \mathrm{Pr}^{0.81}\right)^{0.42}} \tag{139}$$

where

$$Gr = \frac{L^3 \rho^2 g \beta \Delta T}{\mu^2} ; \; \mathrm{Pr} = \frac{C_p \mu}{k} ; \; \mathrm{Ra} = Gr \, \mathrm{Pr} \tag{140}$$

$$\mathrm{Nu} = \frac{hL}{k} \,. \tag{141}$$

6.29.3 Results

The input and output files for the MHTB self-pressurization model are included in appendix NN as Ex29.dat and ex29.out. The user subroutine code is also included.

Figure 251 shows the comparison between GFSSP predictions (in green and blue) and the MHTB test data (in orange). GFSSP predictions of pressure are shown for a degradation factor of 1 and 2.8. The degradation factor is used to multiply equation (128) to represent the degradation of performance of the MLI. It is observed that a degradation factor of 2.8 matches the test data well.

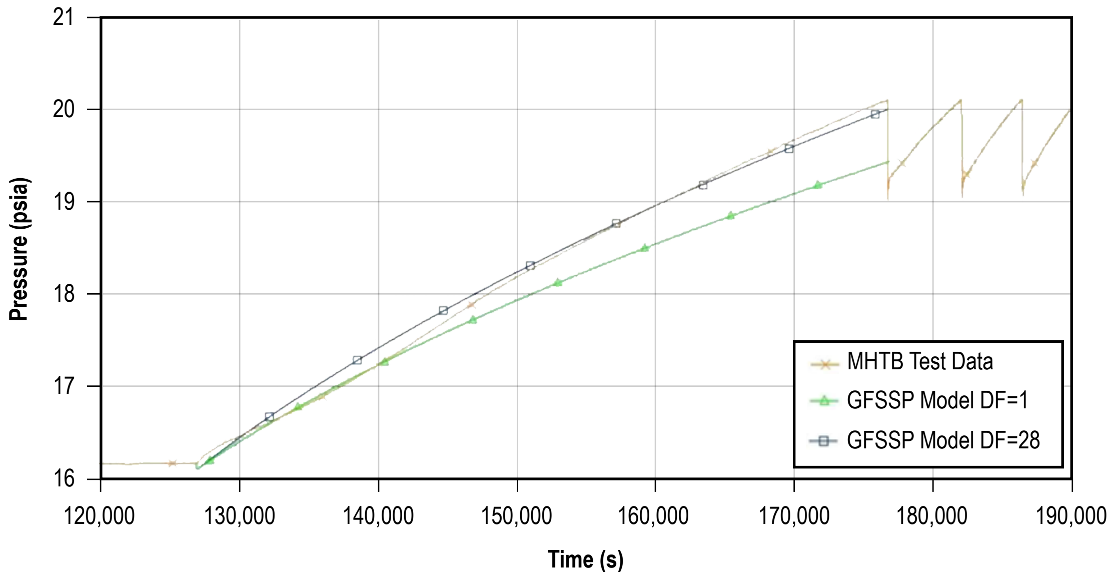

Figure 251. Application results for MHTB self-pressurization model.

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6.30 Example 30 —Modeling Solid Propellant Rocket Motor Ballistic

6.30.1 Problem Considered

This example demonstrates the use of GFSSP to model Solid Propellant Ballistic, which includes burning of solid propellant and expansion of the gas through a converging-diverging nozzle. Figure 252 shows the schematic of the chamber, orifice, and nozzle. The GFSSP model of the schematic is shown in figure 253.

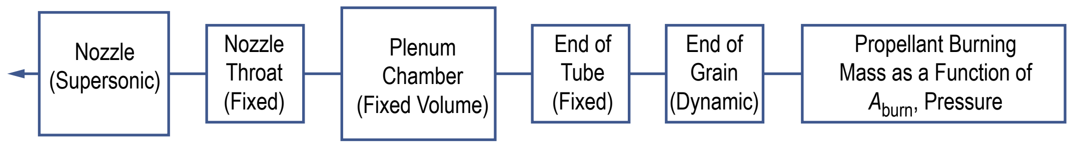

Figure 252. Schematic of a typical solid propellant rocket motor.

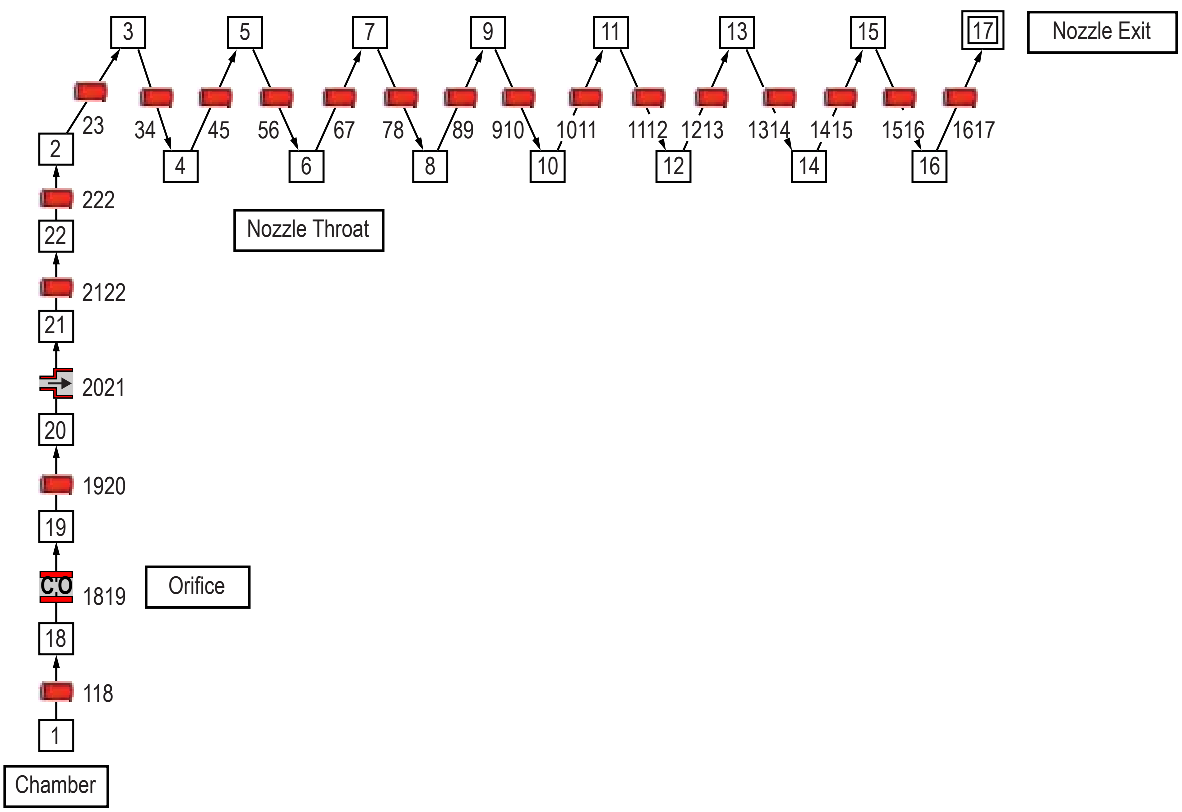

Figure 253. GFSSP model of solid propellant rocket motor.

6.30.2 GFSSP Model

The model consists of a propellant grain, orifice, and transition chamber followed by a converging-diverging nozzle. The model requires development of a User Subroutine that calculates the burn rate as a function of chamber pressure and estimates the change in the area as propellant burns.

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The purpose of the model is to calculate the pressure distribution, thrust, and area change during the burning of solid propellant.

The propellant burning rate (in/s) was expressed as follows:

$$\dot{r} = a_{BR} P_C^{n_{BR}} \quad , \tag{142}$$

where

$a_{BR} = 0.0687$
$n_{BR} = 0.3$
Propellant density, $\rho_{prop} = 0.06$ lbm/in^3.

The mass source in the chamber node (node 1) was calculated from the propellant burning rate and propellant density in User Subroutine BNDUSER.

6.30.3 Results

The input and output files for the solid propellant thruster model are included in appendix OO as Ex30.dat and Ex30.out. The user subroutine code is also included.

Figure 254 shows the pressure history in the chamber as well as at sections downstream of the chamber. The rapid pressure rise during the start and tail-off after the completion of the burn is predicted. Figure 255 shows the history of the burning rate (expressed as a mass source in lb/s) and the flow rate at the nozzle exit. The cause of the pressure rise can be explained from this figure as the mass source exceeds the flow through nozzle exit at the start. Figure 256 shows the history of area change during propellant burn. Once the propellant grain radius reaches its maximum, there is no further burning and area remains constant during the tail-off. Figure 257 shows the history of thrust during propellant burn and tail-off.

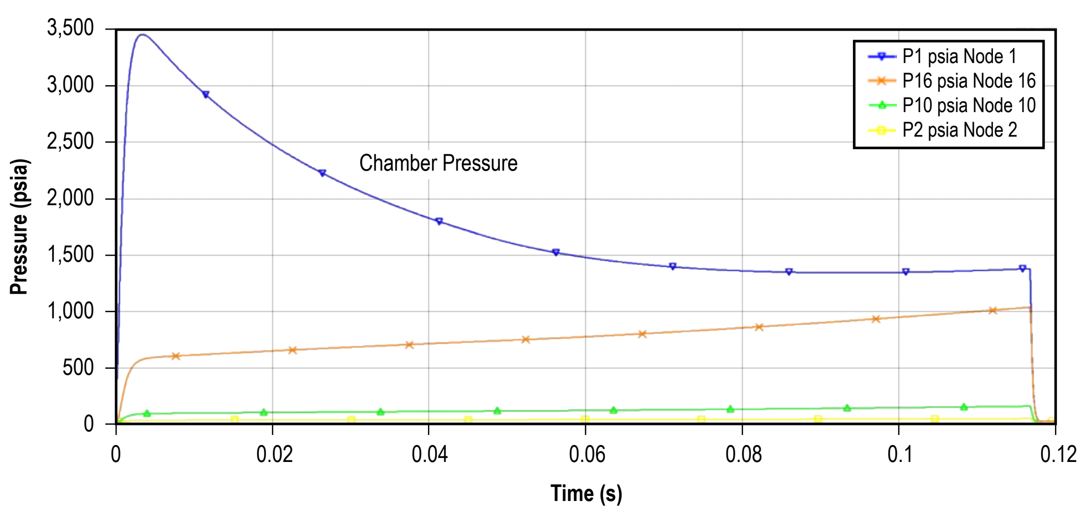

Figure 254. Pressure history during the propellant burn and tail-off.

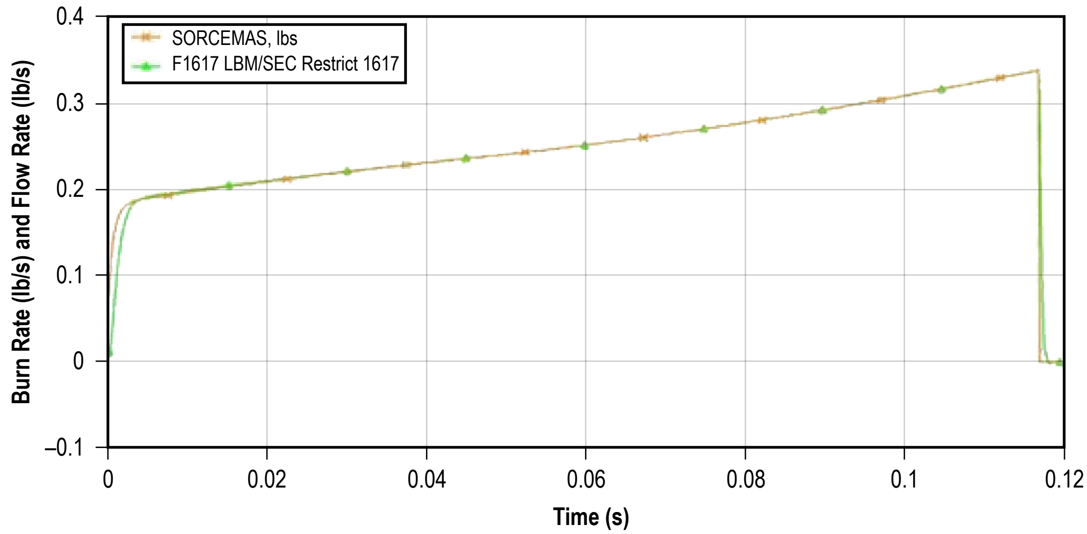

Figure 255. History of burning rate and flow rate at nozzle exit.

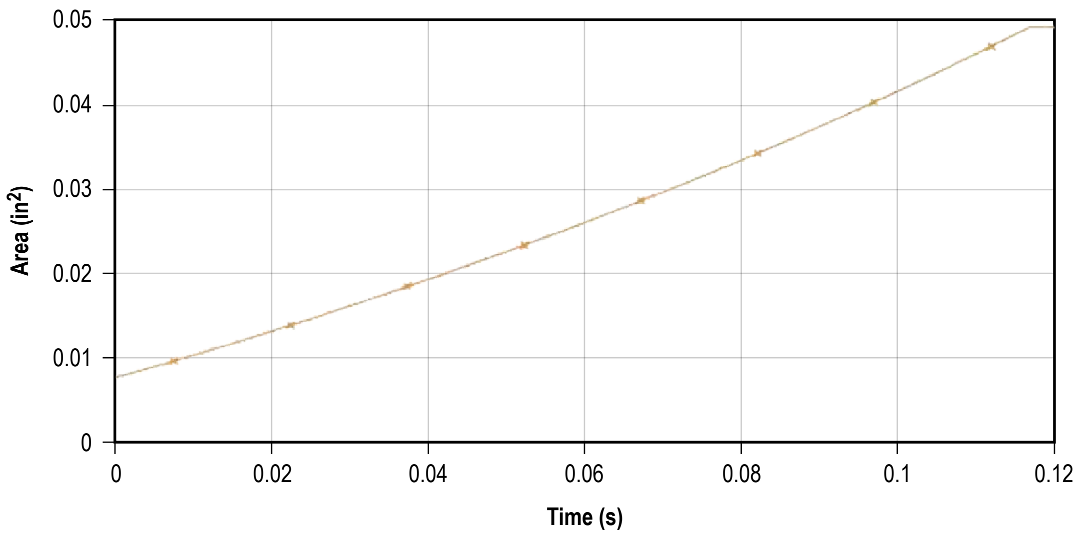

Figure 256. History of area change during propellant burn.

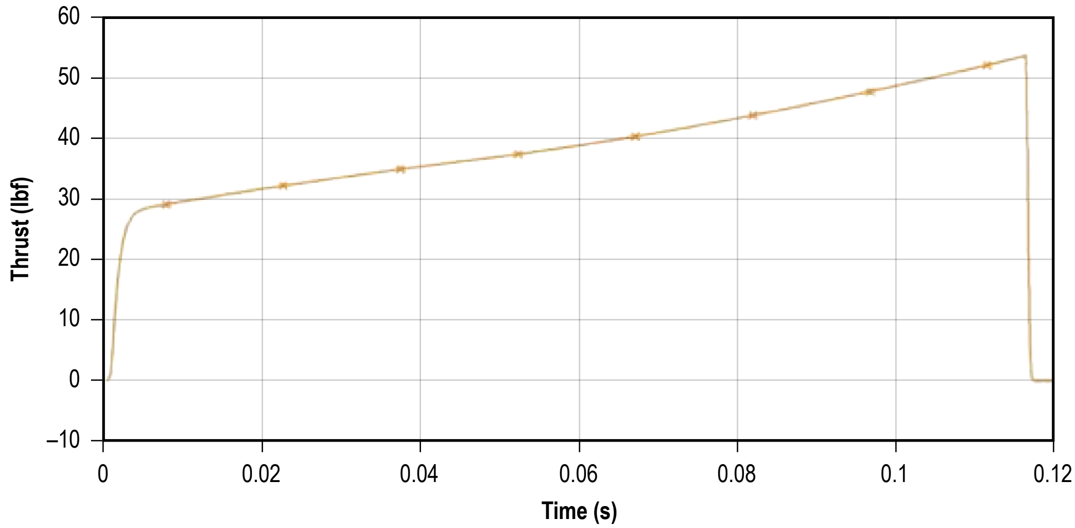

Figure 257. History of thrust during propellant burn and tail-off.

Highlights of this model's control parameters that ensure stable numerical solution are as follows:

- Very small time step (DTAU = 0.0001 s).
- Stringent convergence criterion (CC = 1e-07).
- Heavy under-relaxation on density (RELAXD = 0.05).
- During tail-off, RELAXNR was set to 0.3 in User Subroutine.

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APPENDIX A—DERIVATION OF K_f FOR PIPE FLOW

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

$$P_u - P_d = K_f \dot{m}^2 \ , \tag{143}$$

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:

$$\tau \ \pi \ DL = \left(P_u - P_d\right)\frac{\pi D^2}{4} \ . \tag{144}$$

The Darcy friction factor (f) can be expressed as:

$$f = \frac{8 \ \tau \ g_c}{\rho u^2} \ . \tag{145}$$

From the continuity equation,

$$u = \frac{4\dot{m}}{\rho \ \pi \ D^2} \ . \tag{146}$$

Substituting equations (116) and (117) into equation (115) gives:

$$P_u - P_d = \frac{8 f L \dot{m}^2}{g_c \rho \pi^2 D^5} \ . \tag{147}$$

Therefore,

$$K_f = \frac{8 f L}{g_c \rho \pi^2 D^5} \ . \tag{148}$$

APPENDIX B—SUCCESSIVE SUBSTITUTION METHOD OF SOLVING COUPLED NONLINEAR SYSTEMS OF ALGEBRAIC EQUATIONS

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

(1) Develop the governing equations:

$$x_1 = f_1\left(x_1, x_2, x_3, \ldots, x_n\right)$$

$$x_2 = f_2\left(x_1, x_2, x_3, \ldots, x_n\right)$$

$$\ldots$$

$$x_n = f_n\left(x_1, x_2, x_3, \ldots, x_n\right) \; . \tag{149}$$

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

(2) Guess a solution for the equations. Guess $x_1^*, x_2^*, x_3^*, \ldots, x_n^*$ as an initial solution for the governing equations.

(3) Compute new values of $x_1^*, x_2^*, x_3^*, \ldots, x_n^*$ by substituting $x_1^*, x_2^*, x_3^*, \ldots, x_n^*$ in the right-hand side of equation (124).

(4) Under-relax the computed new value, $x = (1-\alpha)x^* + \alpha x$, where α is the under-relaxation parameter.

(5) Replace $x_1^*, x_2^*, x_3^*, \ldots, x_n^*$ with the computed value of $x_1^*, x_2^*, x_3^*, \ldots, x_n^*$ from step (4).

(6) Repeat steps (3)–(5) until convergence.

APPENDIX C—NEWTON-RAPHSON METHOD OF SOLVING COUPLED NONLINEAR SYSTEMS OF ALGEBRAIC EQUATIONS

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

(1) Develop the governing equations. The equations are expressed in the following form:

$$f_1(x_1, x_2, x_3, \ldots, x_n) = 0$$

$$f_2(x_1, x_2, x_3, \ldots, x_n) = 0$$

$$\ldots$$

$$f_n(x_1, x_2, x_3, \ldots, x_n) = 0 \ . \tag{150}$$

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

(2) Guess a solution for the equations. Guess $x_1^*, x_2^*, x_3^*, \ldots, x_n^*$ as an initial solution for the governing equations.

(3) Calculate the residuals of each equation. When the guessed solutions are substituted into equation (120), the right-hand side of the equation is not zero. The nonzero value is the residual:

$$f_1(x_1^*, x_2^*, x_3^*, \ldots, x_n^*) = R_1$$

$$f_2(x_1^*, x_2^*, x_3^*, \ldots, x_n^*) = R_2$$

$$\ldots$$

$$f_n(x_1^*, x_2^*, x_3^*, \ldots, x_n^*) = R_n \ . \tag{151}$$

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

(4) Develop a set of correction equations for all variables. First construct the matrix of influence coefficients:

$$\begin{matrix} \frac{\partial f_1}{\partial x_1} & \frac{\partial f_1}{\partial x_2} & \frac{\partial f_1}{\partial x_3} & \cdots & \frac{\partial f_1}{\partial x_n} \\ \frac{\partial f_2}{\partial x_1} & \frac{\partial f_2}{\partial x_2} & \frac{\partial f_2}{\partial x_3} & \cdots & \frac{\partial f_2}{\partial x_n} \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ \frac{\partial f_n}{\partial x_1} & \frac{\partial f_n}{\partial x_2} & \frac{\partial f_n}{\partial x_3} & \cdots & \frac{\partial f_n}{\partial x_n} \end{matrix}. \tag{152}$$

Then construct the set of simultaneous equations for corrections:

$$\begin{bmatrix} \frac{\partial f_1}{\partial x_1} & \frac{\partial f_1}{\partial x_2} & \frac{\partial f_1}{\partial x_3} & \cdots & \frac{\partial f_1}{\partial x_n} \\ \frac{\partial f_2}{\partial x_1} & \frac{\partial f_2}{\partial x_2} & \frac{\partial f_2}{\partial x_3} & \cdots & \frac{\partial f_2}{\partial x_n} \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ \frac{\partial f_n}{\partial x_1} & \frac{\partial f_n}{\partial x_2} & \frac{\partial f_n}{\partial x_3} & \cdots & \frac{\partial f_n}{\partial x_n} \end{bmatrix} \begin{bmatrix} x'_1 \\ x'_2 \\ \\ x'_n \end{bmatrix} = \begin{bmatrix} R_1 \\ R_2 \\ \\ R_n \end{bmatrix}. \tag{153}$$

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

(6) Apply correction to each variable.

(7) Iterate until the corrections become very small.

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APPENDIX D—GLOSSARY OF FORTRAN VARIABLES IN THE COMMON BLOCK

GFSSP contains 16 common blocks of variables. The following is a listing of the common blocks and the variables contained within them along with a description of each including units where applicable. Note that the units of several variables described in the common block are different in the input and output files. GFSSP converts the units of the following variables prior to solving the conservation equations:

Variable	Input/Output Unit	GFSSP Unit
Length	inches	feet
Area	$inches^2$	$feet^2$
Volume	$inches^3$	$feet^3$
Angle	degree	radian
Pressure	lb_f/in^2	lb_f/ft^2
Temperature	°F	°R

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

Variable	Description
NERROR	File number for the ERROR.XLS output file
NRP1DAT	File number for the RP-1 property files
NUSR1	User defined file number/integer
NUSR2	User defined file number/integer
NUSR3	User defined file number/integer
NUSR4	User defined file number/integer
NUSR5	User defined file number/integer
NUSR6	User defined file number/integer
NUSR7	User defined file number/integer
NUSR8	User defined file number/integer
NUSR9	User defined file number/integer
NUSR10	User defined file number/integer
NBRPLT	File number for branch results for VTASC post-processing
NBRWINP	File number for branch results for Winplot post-processing
NCOND	File number for thermal conductivity property data
NCP	File number for specific heat property data
NCVHST	File number for control valve history file
NDPLT	File number for node results for VTASC post-processing
NDWINP	File number for node results for Winplot post-processing
NVOPFILE	File number for history file of valve opening/closing
NSLDPLT	File number for solid node results for VTASC post-processing
NSSCPLT	File number for solid to solid conductor results for VTASC post-processing
NSFCPLT	File number for solid to fluid conductor results for VTASC post-processing
NSACPLT	File number for solid to ambient conductor results for VTASC post-processing
NSSRCPLT	File number for solid to solid radiation conductor results for VTASC post-processing
NSLDWIN	File number for solid node results for Winplot post-processing
NSSCWIN	File number for solid to solid conductor results for Winplot post-processing
NSFCWIN	File number for solid to fluid conductor results for Winplot post-processing
NSACWIN	File number for solid to ambient conductor results for Winplot post-processing
NSSCRWIN	File number for solid to solid radiation conductor results for Winplot post-processing
NSAT	File number for reading saturation property table for user-specified fluid

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Variable	Description
NBWPLOT	File number for storing data in binary for Winplot post-processing
NPRGFILE	File number for pressure regulator history data
NFRGFILE	File number for flow regulator history data
NAHSTF	File number for ambient node history data
NSTDERR	File number for writing error information to VTASC
NUVWINP	File number for writing user variables for plotting
NFIXFHST	File number for fixed flow information
NTECPLT	File number for storing 2-D data for Tecplot
2. COMMON/CNODEI/	**Common block for node index information**
NNODES	Total number of nodes
NINT	Total number of internal nodes
NBND	Total number of boundary nodes
NODREF	Reference node number
NODE( )	User assigned node number
INDEX( )	Index number to distinguish between internal and boundary node (1-internal node, 2-boundary node)
INODE( )	Internal node number
IBNODE( )	Boundary node number
NUMBR( )	Number of branches connected to an internal node
NAMEBR(,)	Name of branches connected to an internal node
NMNODE	Number of nodes with moving boundary
NRNODE	Number of nodes with reaction
IVERS	Version number of the code
IBU( )	Not used
IBD( )	Not used
NUMUB( )*	Number of upstream branches of an internal node
NUMDB( )*	Number of downstream branches of an internal node
INDEXUB(,)*	Index number of upstream branches in an internal node
INDEXDB(,)*	Index number of downstream branches in an internal node
3. COMMON/CNODEF/	**Common block for node variable informatio**
P( )	Pressure (lb_f/ft^2)
PM( )	Pressure (lb_f/ft^2) at previous time step
RHO( )	Density (lb_m/ft^3)
RHOM( )	Density (lb_m/ft^3) at previous time step
ZL( )	Not used
H( )	Specific enthalpy (Btu/lb_m)
HM( )	Specific enthalpy (Btu/lb_m) at previous time step
TF( )	Temperature (°R)

*The pointer of these indexing variables refer to internal nodes (1 to NINT) instead of general nodes (1 to NNODES).

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Variable	Description
TM( )	Temperature (°R) at previous time step
CX(,)	Mass specie concentration
CXM(,)	Mass specie concentration at previous time step
CONDF( )	Thermal conductivity (Btu/ft-s-°R)
EMU( )	Absolute viscosity (lb_m/ft-s)
GAMA( )	Ratio of specific heats
CM(,)	Molar specie concentration
RNODE( )	Gas constant (lb_f-ft /lb_m-°R)
RNODEM( )	Gas constant (lb_f-ft /lb_m-°R) at previous time step
XV( )	Mass fraction of vapor in mixture
Z( )	Compressibility factor
ZM( )	Compressibility factor at the previous time step
AREAN( )	Surface area of node (ft^2) for thrust calculation
VOLUME( )	Node volume (ft^3)
VOLUMEM( )	Node volume (ft^3) at previous time step
CVNODE( )	Specific heat at constant volume (Btu/lbm-°R)
EM( )	Mass (lb_m)
EMM( )	Mass (lb_m) at previous time step
U( )	Specific internal energy (Btu/lbm-°R)
UM( )	Specific internal energy (Btu/lbm-°R) at previous time step
EMS( )	Mass source (lb_m/s) at node
HSORCE( )	Heat source (Btu/s or Btu/lb_m) at node
NAMEND(,)	Neighboring nodes of an internal node for conduction calculation
DISTC(,)	Distance between internal and neighboring node (ft)
AREAC(,)	Surface area of heat conduction between internal and neighboring node (ft^2)
NABOR( )	Same as NUMBR(I)
VBOUND( )	Velocity of moving boundary (ft/s), for moving boundary option
HSORCR( )	Heat source (Btu/s) due to chemical reaction
H2( )	Hydrogen concentration in the reaction product
O2( )	Oxygen concentration in the reaction product
H2O( )	Water concentration in the reaction product
ENTROPY( )	Specific entropy (Btu/lb_m-°R)
ENTRPYM( )	Specific entropy (Btu/lb_m-°R) at previous time step
CPNODE( )	Specific heat at constant pressure (Btu/lb_m-°R)
GIBBS( )	Not used.
EXERGY( )	Not used
PR( )	Prandtl Number
SGEN( )	Entropy generation rate (Btu/s-°R)

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Variable	Description
TSORCE( )	Not used
CVNODEM( )	Specific heat at constant volume in previous time step (Btu/lb_m-°R)
HSDENOM( )	Not used
VELIN( )	Average velocity at node inlet (ft/s)
AREAIN( )	Average area at node inlet (ft^2)
TFMAX( )	Not used
HMAX( )	Not used
QDOTSU( )	Not used
QDOTSP( )	Not used
RHOL( )	Liquid density (lb_m/ft^3)
RHOV( )	Vapor density (lb_m/ft^3)
EMUL( )	Liquid viscosity (lb_m/ft-s)
EMUV( )	Vapor viscosity (lb_m/ft-s)
CPNODEL( )	Liquid specific heat (Btu/lb_m-°R)
CPNODEV( )	Vapor specific heat (Btu/lb_m-°R)
CONDFL( )	Liquid thermal conductivity (Btu/ft-s-°R)
CONDFV( )	Vapor thermal conductivity (Btu/ft-s-°R)
RE( )	Node Reynolds number
PMM( )	Pressure at two time steps prior to current period (lb_f/ft^2)
RHOMM( )	Density at two time steps prior to current period (lb_m/ft^3)
HMM( )	Sp. Enthalpy at two time steps prior to current period (Btu/lb_m)
EMMM( )	Mass at two time steps prior to current period (lb_m)
VELINMM( )	Node Velocity at two time steps prior to current period (ft/s)
VELMM( )	Branch Velocity at two time steps prior to current period (ft/s)
TMM( )	Temperature at two time steps prior to current period (°R)
CVNODEMM( )	Sp. heat at two time steps prior to current period (Btu/lb_m-° R)
CXMM( )	Mass specie concentration two time steps prior to current period
HLIQ( )	Specific enthalpy of liquid in two-phase mixture (Btu/lb_m)
HVAP( )	Specific enthalpy of vapor in two-phase mixture (Btu/lb_m)
GAMAL( )	Not used
GAMAV( )	Not used
ELEV( )	Not used
4. COMMON/CBRANCH/	**Common block for branch information**
NBR	Total number of branches in a model
IBRANCH( )	User defined branch number
IBRUN( )	Upstream node number for a given branch
IBRDN( )	Downstream node number for a given branch
FLOWR( )	Mass flow rate (lb_m/s)
FLOWRM( )	Mass flow rate (lb_m/s) at the previous time step
AK( )	Flow resistance coefficient, K_f, (lb_f-s^2/(ft-lb_m)^2) for the branch
AKM( )	Flow resistance coefficient, K_f, (lb_f-s^2/(ft-lb_m)^2) for the branch at the previous time step

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Variable	Description
AREA( )	Branch cross-stional area (ft^2)
AREAM( )	Branch cross-stional area (ft^2) at the previous time step
CLF( )	Not used
EL( )	Not used
D( )	Not used
SR( )	Not used
IOPT( )	Branch resistance option number (1-pipe flow, etc.)
DELP( )	Pressure differential across the branch
AREAUP( )	Not used
AREADN( )	Not used
ANGLE( )	Angle (radians) between branch and the gravity vector. Used when gravity is activated
NONBR( )	Not used
NOUBR( )	Number of upstream branches for a given branch
NODBR( )	Number of downstream branches for a given branch
NMUBR(,)	Name of each upstream branch for a given branch
NMDBR(,)	Name of each downstream branch for a given branch
ANGUBR(,)	Angle (radians) between current branch and each upstream branch. Used in the longitudinal inertia option
ANGDBR(,)	Angle (radians) between current branch and each downstream branch. Used in the longitudinal inertia option
VEL( )	Velocity (ft/s) of the fluid in a given branch
VELM( )	Velocity (ft/s) of the fluid in a given branch at the previous time step
RADU( )	Upstream node radius from axis of rotation (for rotation option)
RADD( )	Downstream node radius from axis of rotation (for rotation option)
RPM( )	Rotational speed (in RPM) for rotation option
AKROT( )	Fluid slip factor, $K_{rotation}$, for rotation (ratio of fluid rotational speed to solid rotational speed)
NRBR	Number of rotating branches
NMBR	Number of branch with momentum source
NIBR	Number of branches with longitudinal inertia
AREAS(,)	Not used
DISTS(,)	Not used
NMNBR(,)	Not used
BRPR1( )	Branch resistance input variable 1 (used in all branch resistance options)
BRPR1M( )	Branch resistance input variable 1 at the previous time step
BRPR2( )	Branch resistance input variable 2
BRPR2M( )	Branch resistance input variable 2
BRPR3( )	Branch resistance input variable 3
BRPR3M( )	Branch resistance input variable 3 at the previous time step

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Variable	Description
BRPR4( )	Branch resistance input variable 4
BRPR4M( )	Branch resistance input variable 4 at the previous time step
BRPR5( )	Branch resistance input variable 5
BRPR5M( )	Branch resistance input variable 5 at the previous time step
BRPR6( )	Branch resistance input variable 6
BRPR6M( )	Branch resistance input variable 6 at the previous time step
SORCE( )	Momentum source (lb_f)
VOLBRN( )	Branch volume (ft^3)
VOLBRNM( )	Branch volume (ft^3) at previous time step
PIPET( )	Not used
EMOD( )	Not used
EMACH( )	Branch Mach number
SOLID( )	Not used
AREASB( )	Not used
DISTSB( )	Not used
VELSB( )	Not used
REYN( )	Reynolds number in a branch
TWOPHM( )	Not used
VIODF( )	Not used
SRATIO( )	Not used
IBRPR1( )	Index to activate X-momentum source in multi-D option
IBRPR2( )	Index to activate Y-momentum source in multi-D option
IBRPR3( )	Not used
MDGEM( )	Not used
5. COMMON/CPROP/	**Common block for property information**
NF	Total number of fluids in a given model
NF1	NF – 1
NFL	Number of fluids available in the library
WM( )	Molecular weights of fluids in the library
RGAS( )	Gas constants (lb_f-ft/ lb_m-°R) of fluids in the library
DELH( )	Reference enthalpy (Btu/ lb_m) of fluids in the library
DELH1( )	Reference enthalpy (Btu/ lb_m) of fluids with respect to 1^{st} reference point
DELH2( )	Reference enthalpy (Btu/ lb_m) of fluids with respect to 2^{nd} reference point
NAMEF( )	Character identifier for fluids in the library
NHREF	Index for specifying reference point for enthalpy calculation for mixture
IFLUID( )	Character identifier for fluid index in a model
NFLUID( )	Character identifier for fluid index in the fluid library
NDATA( )	Not used

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Variable	Description
PREF	Reference pressure (lb_f/ft^2)
TREF	Reference temperature (°R)
RHOREF	Reference density (lb_m/ft^3)
EMUREF	Reference absolute viscosity (lb_m/ft-s)
G	Gravitational acceleration (32.174 ft/s^2)
GC	Force conversion factor (32.174 ft-lb_m/lb_f-s^2)
PI	π (3.1415926)
HEQ	Energy conversion factor (778.16 ft-lb_f/Btu)
GAMREF	Reference ratio of specific heats
RREF	Reference gas constant
CPREF	Reference specific heat at constant pressure (Btu/lb_m-°R)
AKREF	Reference conductivity (Btu/ft-s-°R)
DELHGP( )	Reference enthalpy (Btu/ lb_m) of fluids in the GASPAK library
GSPMIN( )	Minimum allowable pressure for fluids in GASP library
GSPMAX( )	Maximum allowable pressure for fluids in GASP library
GSTMIN( )	Minimum allowable temperature for fluids in GASP library
GSTMAX( )	Maximum allowable temperature for fluids in GASP library
NCVFL( )	Identifier of fluids in GASPAK library that do not have thermophysical properties
GPPMIN( )	Minimum allowable pressure for fluids in GASPAK library
GPPMAX( )	Maximum allowable pressure for fluids in GASPAK library
GPTMIN( )	Minimum allowable temperature for fluids in GASPAK library
GPTMAX( )	Maximum allowable temperature for fluids in GASPAK library
AKNBP	Not used
DNBP	Not used
INDFLCP	Not used
INDFLV	Not used
SIGMAR	Stephan-Boltzman constant = 4.7611E-13 Btu/ft^2-R^4-s
TCRIT	Not used
TNBP	Not used
HREF	Reference enthalpy (Btu/lb_m)
SREF	Reference entropy (Btu/lb_m-°R)
RCONST	Universal Gas Constant = 1545 lb_f-ft/lb_{mol}-°R)
DCRIT	Critical Density (lb_m/ft^3)
EMUNBP	Viscosity at Normal Boiling Point ((lb_m/ft-s)
FRACM	Fraction of Hydrogen Peroxide in aqua mixture
INDFLR	Fluid index in GASPak
PCRIT	Critical Pressure (lb_f/ft^2)
ISATTABL( )	Index variable to determine if user-specified fluid needs saturation property table

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Variable	Description
6. COMMON/CNUM/	**Common block for control variables**
NVAR	Total number of variables to be solved in a model
TLRNCE	Convergence criteria of Newton-Raphson scheme
ITMAX	Maximum allowable number of Newton-Raphson iterations
ITER	Number of outer loop iterations (reset every time step)
ITERNR	Number of Newton-Raphson iterations (reset every time the Newton-Raphson loop is called)
ITERT	Total number of iterations (reset every time step)
ISTEP	Number of time steps
DIFK	Fractional change in flow resistance coefficient between successive iterations
TAU	Time (s)
DTAU	Time step (s)
TIMEF	Start time (s)
TIMEL	End time (s)
AFACT	Not used
GFACT	Not used
V( )	Variable array for Newton-Raphson scheme
NAME( )	Name of variable array for Newton-Raphson scheme
NPSTEP	Interval of printout for an unsteady calculation.
DIFD	Fractional change in density between successive iterations
RELAXK	Under-relaxation parameter for the K-factor, K_f. NOTE: User must specify that 0<RELAXK<1
RELAXD	Under-relaxation parameter for the density. NOTE: User must specify that 0<RELAXD<1
RELAXH	Under-relaxation parameter for the enthalpy/entropy. NOTE: User must specify that 0<RELAXH<1
NITER	Maximum number of outer iterations if SIMULA is false (set in the input deck)
ITERMIN	Minimum number of iterations if SIMULA is false (currently set at 5)
CC	Convergence criteria
DIFMAX	Maximum normalized correction in Newton-Raphson iteration
GREAT	An arbitrary large number (= 10^{25})
TINY	An arbitrary small number (= 10^{-25})
RELAXTS	Under relaxation parameter in solid temperature equation
NPWSTEP	Interval for Winplot data dump for an unsteady calculation
GREAT	Arbitrary large number (=1.E25)
SMALL	Arbitrary small number (=1.E-25)
ALPHA1	1st coefficient for sond-order differencing scheme
ALPHA2	2nd coefficient for sond-order differencing scheme

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Variable	Description
ALPHA3	3rd coefficient for sond-order differencing scheme
IBDF	Index to select 1st or 2nd order differencing scheme
RELAXNR	Under relaxation parameter for Newton-Raphson scheme
RELAXHC	Under relaxation parameter for heat transfer coefficient
ITMAXSLD	Maximum no. of iteration of solid temperature equation
WPLSTEP	Timestep interval of updating Winplot Bianary File
BWFMARGIN	Additional file space allocation for Winplot Binary File
IFRMIX	Index for selecting mixture option
LPP	Not used
AKMIN	Minimum value of K_f (= 1.E-10)
ISOLVE	Index to choose Newton or Broyden Solver
CCMULT	Multiplier for Convergence Criterion (CC)
7. COMMON/CHEX/	**Common block for Heat Exchanger related variables**
NHEX	Number of heat exchangers in a model
NODHIN( )	Upstream node of branch carrying hot fluid
NODHEX( )	Downstream node of branch carrying hot fluid
NODCIN( )	Upstream node of branch carrying cold fluid
NODCEX( )	Downstream node of branch carrying cold fluid
IBRHOT( )	Branch carrying hot fluid
IBRCLD( )	Branch carrying cold fluid
HEXEFF( )	Heat exchanger effectiveness
ITYPHX( )	Index number to describe the type of heat exchanger: 1- Counter flow, 2-Parallel flow
ARHOT( )	Heat transfer area in hot side (ft^2)
ARCOLD( )	Heat transfer area in cold side (ft^2)
UA( )	Product of overall heat transfer coefficient and area (Btu/s-°R)
8. COMMON/CTABLE	
FLAK( )	Filename for thermal conductivity data table
FLRHO( )	Filename for density data table
FLEMU( )	Filename for viscosity data table
FLGAM( )	Filename for specific heat ratio data table
FLH( )	Filename for enthalpy data table
FLS( )	Filename for entropy data table
FLCP( )	Filename for specific heat data table
FLSAT( )	Filename for saturation table
9. COMMON/CTPA/	**Common block for Turbopump related variables**
NTPA	Number of turbopumps in a model
IBRPMP( )	Pump branch number
IBRTRB( )	Turbine branch number

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Variable	Description
NODPMP( )	Node number upstream of pump
NODTRB( )	Node number upstream of turbine
SPEED( )	Operating speed (RPM) of the turbopump
EFFTRB( )	Turbine efficiency
TORQUE( )	Calculated required torque
HPOWER( )	Horsepower of the pump
DIATRB( )	Turbine diameter (ft). Input file uses in
PSITRD( )	Flow coefficient of the turbine at the design point
ETATRB( )	Efficiency of turbine at design point
PSITR( )	Flow coefficient of the turbine at the operating point
10. COMMON/CTVM/	**Common block for Transverse Momentum variables**
NTM	Number of branches for which transverse momentum is calculated
IBRANCHT( )	Name of branch for which transverse momentum will be calculated
NUMBERL( )	Number of parallel branches used to calculate transverse momentum for a given branch
NAMEL(,)	Name of each parallel branch for a given branch
ANGLEL(,)	Angle (radians) between each parallel branch and the current branch. NOTE: If the branches are perfectly parallel and in opposite directions, this angle is π)
NUMBERT(,)	Number of branches connecting each parallel branch and the current branch
NAMELT(, ,)	Name of each connecting branch, corresponding to each parallel branch for the current branch
ANGLELT(, ,)	Angle (radians) between each connecting branch and the current branch
11. COMMON/CSHR/	**Common block for Shear variables**
NSHR	Number of branches for which shear will be calculated
IBRNCHSH( )	Name of branch for which shear will be calculated
NUMBRSH( )	Number of parallel branches, which will contribute to the shear of the current branch
NAMESH(,)	Names of the parallel branches, which will contribute to the shear of the current branch
ANGLESH(,)	Angle (radians) between each parallel branch and the current branch. NOTE: If the branches are perfectly parallel and in opposite directions, this angle is π)
AREASH(,)	Shear area (ft^2) between each parallel branch and the current branch
DISTSH(,)	Distance (ft) between the each parallel branch and the current branch
NSOLID( )	Number of solid wall adjacent to the current branch

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Variable	Description
VSOLID(,)	Velocity (ft/s) of each solid corresponding to the current branch
ANGSOLID(,)	Angle (radians) between each solid walls corresponding to the current branch
AREASOL(,)	Shear area (ft^2) between each solid wall corresponding to the current branch
DISTSOL(,)	Distance (ft) between each solid wall corresponding to the current branch
ENTSHR( )	Entropy generated due to shear for the current branch
NAMELU( )	Name of upstream branch of a branch in multi-D option
NAMELD( )	Name of downstream branch of a branch in multi-D option
NBRMOM	Number of branches with momentum source
IBRMOMS( )	Index of branches with momentum source
IDIR( )	Index to define branch direction
NMUBRMS( )	Upstream branch number that supplies inlet momentum
12. COMMON/CTRANS/	**Common block for Transient variables**
VOLN(,)	Node volume (in^3) - time (s) array used in the input history file for the variable geometry option
VOLB(,)	Branch volume (in^3) - time (s) array used in the input history file for the variable geometry option
AREAB(,)	Branch area (in^2) - time (s) array used in the input history file for the variable geometry option
HEIGHT(,)	Branch height (in) - time (s) array used in the input history file for the variable geometry option. This array is only used for branch resistance option 3 (noncircular duct)
WIDTH(,)	Branch width (in) - time (s) array used in the input history file for the variable geometry option. This array is only used for branch resistance option 3 (noncircular duct)
TIMEG( )	Time (s) array used in history files
NGSTEP	Number of lines of time-data information in a history file
ARNMB(,)	Nodal normal area (in^2) - time (s) array used in the input history file for the variable geometry option when the moving boundary option is used
VELMB(,)	Nodal normal velocity (ft/s) - time (s) array used in the input history file for the variable geometry option when the moving boundary option is used
AREANB( )	Area of the moving boundary (ft^2) of an internal node for the variable geometry option when the moving boundary option is used
TIMER( )	Time (s) used in history file for variable rotation option
RPMT( )	Rotational speed (RPM) used in history file for variable rotation option
NRSTEP	Number of data points in rotational history file

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Variable	Description
13. COMMON/CPRESS/	**Common block for Pressurization variables**
NTANK	Number of pressurization tanks in a model
NODUL( )	Node number representing ullage in a given tank
NODULB( )	Pseudo boundary node representing the interface between ullage and propellant
NODPRP( )	Node number representing propellant tank pressure and temperature
IBRPRP( )	Branch number representing propellant flow rate
TNKAR( )	Tank surface area (ft^2) for heat transfer with ullage gas
TNKTH( )	Tank thickness (ft) for heat conduction calculation in tank wall
TNKRHO( )	Tank density (lb_m/ft^3) for heat conduction calculation in tank wall
TNKCP( )	Tank specific heat (Btu/lb_m-°R) for heat conduction calculation in tank wall
ELHC( )	Length scale (ft) for computing Grashoff number
ARHC( )	Surface area for heat transfer (ft^2) between ullage and propellant
FCTHC( )	Factor controlling the magnitude of heat transfer coefficient (Default value = 1)
TNKTM( )	Tank temperature (°R)
TNKTMM( )	Tank temperature (°R) at the previous time step
QULWAL( )	Heat transfer rate (Btu/s) between ullage and wall
QULPRP( )	Heat transfer rate (Btu/s) between ullage and propellant
EMDPRP( )	Not used
HFG( )	Not used
TSAT( )	Not used
TNKCON( )	Tank conductivity (Btu/ft-s-°R)
QCOND( )	Heat transfer rate (Btu/s) between ullage exposed tank surface and propellant exposed tank surface
ITTYPE( )	Index number to distinguish between type of propellant tank (1 – Cylindrical tank, 2 – Spherical tank)
CIP( )	Constant in the correlation for ullage to propellant heat transfer coefficient
FNIP( )	Power law index in the correlation for ullage to propellant heat transfer coefficient
CIW( )	Constant in the correlation for ullage to wall heat transfer coefficient
FNIW( )	Power law index in the correlation for ullage to wall heat transfer coefficient
ITTYPE( )	Index to define cylindrical or spherical tank
CIP	Constant for heat transfer correlation (ullage to propellant)
FNIP	Index for heat transfer correlation (ullage to propellant)
CIW	Constant for heat transfer correlation (ullage to wall)
FNIW	Index for heat transfer correlation(ullage to wall)

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Variable	Description
14. COMMON/CVALVE/	**Common block for Control Valve variables**
DTAUIN	A temporary variable that stores the data file time step (sec) input by the user. Used by subroutine CTRLVLV when determining minimum time step
NVALVE	Number of control valves in the model
DVTAU( )	User prescribed time step (sec) for each sub-option 2 or 3 control valve
IVOPT( )	Sub-option of each control valve (1=instantaneous, 2=linear, 3=nonlinear
NOVDAT( )	Number of open characteristics data points for suboption 2 and 3 control valves. Used for reading open characteristics data
NCVDAT( )	Number of close characteristics data points for suboption 2 and 3 control valves. Used for reading close characteristics data.
OVTIM(,)	Time schedule (sec) for open valve characteristics for suboption 2 and 3 control valves. Used in calculating transient open valve characteristics
CVTIM(,)	Time schedule (sec) for close valve characteristics for suboption 2 and 3 control valves. Used in calculating transient close valve characteristics
OVCL(,)	Transient opening valve flow coefficient history for suboption 2 and 3 control valves. Used in calculating transient open valve characteristics
CVCL(,)	Transient closing valve flow coefficient history for suboption 2 and 3 control valves. Used in calculating transient close valve characteristics
OVAR(,)	Transient opening valve flow area history (in^2) for suboption 2 and 3 control valves. Used in calculating transient open valve characteristics
CVAR(,)	Transient closing valve flow area history (in^2) for suboption 2 and 3 control valves. Used in calculating transient close valve characteristics
VAREA( )	Flow area (ft^2) calculated in the subroutine CTRLVLV for each control valve. Used for calculating flow resistance for the control valve in subroutine KFACT18
VCL( )	Flow coefficient calculated in the subroutine CTRLVLV for each control valve. Used for calculating flow resistance for the control valve in subroutine KFACT18
TIMEV(,)	Time schedule (sec) for the pressure tolerance files for each control valve. Used for determining the state for each control valve (The states are fully open, fully closed, opening, closing)
PMAXV(,)	Maximum pressure tolerance (psia) history for each control valve. Used for determining the state of each control valve (The states are fully open, fully closed, opening, closing)
PMINV(,)	Minimum pressure tolerance (psia) history for each control valve. Used for determining the state of each control valve (The states are fully open, fully closed, opening, closing)
NVDAT( )	Number of pressure tolerance file data points for each control valve. Used in reading pressure tolerance data

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Variable	Description
15. COMMON/CCONV/	**Common block for conversion factor variables**
FACTP	Conversion factor for pressure (to convert to and from psf and psi, 144)
FACTV	Conversion factor for Volume (to convert to and from in^3 and ft^3, 1728)
FACTA	Conversion factor for area (to convert to and from in^2 and ft^2, 144)
FACTL	Conversion factor for length (to convert to and from in and ft, 12)
FACTT	Conversion factor for area (to convert to and from °F and °R, 459.6)
FACTTH	Conversion factor for angle (to convert to and from degree to radian, 0.01745)
FACTVS	Not used
16. COMMON/CSICONV/	**Common block for SI conversion factor variables**
SIFACTP	Conversion factor for pressure (to convert to and from psf and kpa)
SIFACTV	Conversion factor for Volume (to convert to and from lbm/ft^3 and kgm/m^3)
SIFACTA	Conversion factor for area (to convert to and from m^2 and ft^2)
SIFACTL	Conversion factor for length (to convert to and from m and ft)
SIFACTT	Conversion factor for area (to convert to and from °C and °R)
SIFACTTH	Conversion factor for angle (to convert to and from degree to radian)
SIFACTVS	Not used
17. COMMON/CLOGIC/	**Common block for logical variables. NOTE: a declaration of these variables as logical variables must follow this common block**
STEADY	Logical variable to indicate if the model is steady state, quasi-steady (a series of steady state runs with changing boundary conditions and/or geometry; requires TRANSV to be false), or fully unsteady (requires TRANSV to be true)
DENCON	Logical variable to indicate if the model will use a user defined constant density fluid. NOTE: this option is ONLY valid for steady state and the energy equation will NOT be solved
GRAVITY	Logical variable to indicate if the model will account for gravity in branches where a branch length is associated
ENERGY	Logical variable to indicate if the model will solve one of the two forms of the energy equation within the code. Required for all fluids except when DENCON is true
MIXTURE	Logical variable to indicate if the model is using more than one fluid. NOTE: not valid if DENCON is true
CHOKED	Logical variable to indicate if the model will calculate choked flow
CHOK( )	Logical variable to indicate if an individual branch will have choked flow calculated
THRUST	Logical variable to indicate if the model will calculate thrust (lb_f) using pressure and thrust area (current formulation neglects thrust from linear inertia)

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Variable	Description
RESTART	Not used
TRANSV	Logical variable to indicate if the model will operate in an unsteady mode. NOTE: requires STEADY to be false
INERTIA	Logical variable to indicate if the model will include linear inertia in the calculation of the momentum equation
CONDX	Logical variable to indicate if the model will calculate thermal conduction between nodes
TWOD	Not used
PRINTI	Logical variable to indicate if the main output file will contain the initial guess at the flow field
ROTATION	Logical variable to indicate if the model contains branches where rotation will contribute a momentum source/sink
ROTATE( )	Logical variable indicating if an individual branch will have rotation included as a momentum source/sink. NOTE: requires ROTATION to be true
BUOYANCY	Logical variable to indicate if the model will consider buoyancy (density variation) effects in a gravity field. NOTE: requires GRAVITY to be true
HRATE	Logical variable to indicate if heat sources are in BTU/sec (true) or BTU/lb_m (false)
INVAL	Logical variable to indicate if the model will read in previously saved data from two restart files for node and branch data
SAVER	Logical variable to indicate if the model will write data into two restart files to be used for later restarting of the model
HEX	Logical variable to indicate if the model includes heat exchangers
MSORCE	Logical variable to indicate if the model contains additional momentum sources (in addition to pumps)
MOMSOR( )	Logical variable to indicate which branches have additional momentum sources. NOTE: requires MSORCE to be true
HCOEF	An additional option for heat exchanger calculation; if true UA is alculated, otherwise it must be specified
MOVBND	Logical variable to indicate if the model contains nodes which have a moving boundary
MVBND( )	Logical variable to indicate which nodes contain a moving boundary. NOTE: requires MOVBND to be true
REACTING	Option for activating chemical reaction. NOTE: equilibrium reaction of hydrogen and oxygen is only available
REACTION( )	Logical variable indicating if an individual node will have chemical reaction
TPA	Logical variable to indicate if the model includes turbopump assemblies
TPABR( )	Logical variable indicating if an individual branch represents pump or turbine
ELASTIC	Not used

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Variable	Description
VARGEO	Logical variable to indicate if the model will consider variable geometries (time dependent geometries). NOTE: requires STEADY to be false
TVM	Logical variable to indicate if the model will consider the transverse component of inertia in the momentum equation (transverse momentum)
TRNSM( )	Logical variable to indicate which branches will consider transverse momentum. NOTE: requires TVM to be true
SHEARE	Logical variable to indicate if the model will consider shear stress instead of using a friction factor on at least one branch within the model
SHER( )	Logical variable to indicate which branches will consider shear stress instead of friction. NOTE: requires SHEARE to be true
ADDPROP	Logical variable to indicate if the model will use a fluid thermodynamic/theromphysical property package other than that which is already incorporated into the code. When ADDPROP is false, GASP and WASP are used; when GASPAK is true, the commercially available code GASPak is required (along with a licence)
PRNTIN	Logical variable to indicate if the main output file will contain the input variables
PRNTADD	Logical variable to indicate if the main output file will contain additional thermodynamic output data for each internal node
PRESS	Logical variable to indicate if the model will contain pressurization of a tank. NOTE: requires STEADY to be false and TRANSV to be true
INSUC	Logical variable to activate calculation of initial guess by using a successive substitution method
VARROT	Logical variable to indicate if the model will have time dependent rotation. NOTE: requires ROTATION to be true, ROTATE to be true for at least one branch and STEADY to be false
VOPEN( )	Logical variable that stores the initial position of the valve (T=Open, F=Closed). Used in initializing valve settings
VFLOW( )	A logical variable that indicates whether or not there is flow through a control valve (T=CL & A >0, F=CL & A = 0). Used in flow resistance calculations by subroutine KFACT18
INERT( )	Logical variable to activate longitudinal inertia calculation in a given branch
NORMAL	Logical variable to activate normal stress calculation in a given branch
SIMULA	Logical variable to indicate if the user would like the model to be solved using a totally simultaneous solution scheme or a modified scheme (inner & outer loop for first five iterations of a given time step, then simultaneous)
SIMUL	Logical variable set by SIMULA at the beginning of each time step. See description of SIMULA
SECONDL	Logical variable to indicate if the model will solve the energy equation using the first law of thermodynamics (false, uses enthalpy) or the second law of thermodynamics (true, uses entropy)

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Variable	Description
FRICTBP	Logical variable used to override SIMULA and bypass the simultaneous solution scheme
USETUP	Logical variable to allow the user to customize the input deck. Used in association with the USRSET subroutine (User Subroutine)
LAMINAR	Logical variable used in conjunction with the SHEARE logical variable. When set to false, shear stress is calculated using a modified Prandtl mixing length model for branch to branch interaction and the log-law of the wall for branch to solid interaction. When set to true, shear stress is calculated from the derivative of the velocity and the fluid viscosity
TRANSQ	Logical variable used to identify that heat addition will vary with time using user supplied data in history file(s). Requires TRANSV to be true
TRQ( )	Logical variable used to identify which nodes will have a time variant heat added. Requires TRANSQ to be true
DFLI	Logical variable used to identify between two formulations for longitudinal inertia (requires INERTIA to be active). If set to true in a User Subroutine, the differential form of longitudinal inertia will be active, else the original formulation will be active
CONJUG	Logical variable to indicate if the model will calculate solid to fluid heat transfer
DALTON	Logical variable to indicate if the model will calculate mixture property by Dalton’s law of partial pressure
HYDPOX	Logical variable to indicate if hydrogen peroxide is the working fluid
OPVALVE	Logical variable to indicate if there is any opening or closing of valve
RADIATION	Logical variable to indicate if model needs radiation heat transfer
Winplot	Logical variable to indicate if Winplot will be used to plot data
HSTAG	Logical variable to indicate if the model uses stagnation (TRUE) or static (FALSE) enthalpy
VISCWRK	Logical variable to indicate if viscous work is computed in energy equation
CYCLIC	Logical variable to indicate if cyclic boundary condition is active
REPEAT	Logical variable to indicate if the iterative calculation to be repeated to satisfy adjustable boundary condition
NRSOLVT	Logical variable to indicate if solid temperature equation will be solved by Newton-Raphson method. NRSOLVT=.FALSE. indicates that solid temperature equation is solved by successive substitution method
HCGIVEN	Not used
CHKVAL	Logical variable to indicate if calculated values need to be checked for debugging purpose
SATTABL	Logical variable to indicate that saturation property table has been provided for one of the user-specified fluids
WFILE	Logical variable to indicate if data dump for Winplot is in ASCII(WFILE=.TRUE.) or binary (WFILE=.FALSE.)
UPP	Universal Property Package
NOSTATS	Logical variable to print file open error

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Variable	Description
NOPLT	Logical variable to activate VTASC plotting package
PRESSREG	Not used
FLOWREG	Not used
TRANS_MOM	Logical variable to activate transient momentum term
USRVAR	Logical variable to print user variable in Winplot
ISHT	Logical variable to activate Inter Species Heat Transfer
TRANS_HMIX	Not used
NEWTON_SS	Logical variable to activate Newton-Raphson Solver
BROYDEN_SS	Logical variable to activate Broyden Solver
PSM( )	ogical variable for Phase Separation Model at node
SATURATED( )	Logical variable to indicate saturation state at node
PENERGY	Logical variable to activate potential energy
PSMG	Logical variable for global activation of PSM
RADSA( )	Logical variable for solid to ambient radiation
RADSF( )	Logical variable for solid to fluid radiation
SATMIX(,)	Logical variable to indicate saturation in mixture
PLOTADD	Logical variable to print additional variables
SIUNITS	Logical variable to activate input in SI units
TECPLOT	Logical variable to activate writing data for Tecplot
GRIDGEN	Logical variable to activate grid generation
PRINTD	Logical variable for diagnostic printout
FLUIDMIX( )	Not used
MSORIN	Global logical variable for momentum source
MSORINI( )	Local logical variable for local momentum source
SATTABL	Not used
RLFVLV	Logical variable for Relief Valve
18. COMMON/CUSER/	**Common block for user defined variables. For use in the User Subroutines**
SORCEMAS( )	User defined mass source. Usually defined in the SORCEM User Subroutine
SORCEMOM( )	User defined momentum source. Usually defined in the SORCEF User Subroutine
SORCECON(,)	User defined specie concentration source. Usually defined in the SORCEC User Subroutine
SORCEH( )	User defined heat source. Usually defined in the SORCEH user subroutine
USRVAR1( )	User defined one dimensional variable. Used to pass information between different User Subroutines
USRVAR2( )	User defined one dimensional variable. Used to pass information between different User Subroutines
USRVAR3( )	User defined one dimensional variable. Used to pass information between different User Subroutines
USRVAR4( )	User defined one dimensional variable. Used to pass information between different User Subroutines

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Variable	Description
USRVAR5( )	User defined one dimensional variable. Used to pass information between different User Subroutines
USRVAR6( )	User defined one dimensional variable. Used to pass information between different User Subroutines
USRVAR7( )	User defined one dimensional variable. Used to pass information between different User Subroutines
USRVAR8( )	User defined one dimensional variable. Used to pass information between different User Subroutines
USRVAR9( )	User defined one dimensional variable. Used to pass information between different User Subroutines
USRVAR10( )	User defined one dimensional variable. Used to pass information between different User Subroutines
USRVAR11(,)	User defined two dimensional variable. Used to pass information between different User Subroutines
USRVAR12(,)	User defined two dimensional variable. Used to pass information between different User Subroutines
USRVAR13(,)	User defined two dimensional variable. Used to pass information between different User Subroutines
USRVAR14(, ,)	User defined three dimensional variable. Used to pass information between different User Subroutines
ITERADJU	Iteration counter for adjustable boundary condition iteration loop
19. COMMON/OPVALVE/	**Common block for valve opening or closing**
AREAV(,)	Variable valve area during opening or closing in the valve history file (ft^2)
NVOCBR( )	Branch names that represent variable area valve
NVOPBR	Number of valves in a circuit where valve area changes with time
NVOP( )	Number of data points in valve opening/closing history file
TIMEVOP(,)	Time in valve history file (s)
20. COMMON/CHT/	**Common block for conjugate heat transfer index variables**
NSOLIDX	Number of solid nodes
NAMB	Number of ambient nodes
NSAC	Number of solid to ambient conductors
NSFC	Number of solid to fluid conductors
NSSC	Number of solid to solid conductors
NSSR	Number of solid to solid radiation conductors
21. COMMON/SNODE/	**Common block for solid node properties**
CPSLD( )	Specific heat of solid node (Btu/lb_m-°R)
CPSLDM( )	Specific heat of solid node (Btu/lb_m-°R) at previous time step

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Variable	Description
MATRL( )	Index number to indicate material of solid node
NAMESA(,)	Names of solid to ambient conductors connected to a solid node
NAMESF(,)	Names of solid to fluid conductors connected to a solid node
NAMESS(,)	Names of solid to solid conductors connected to a solid node
NAMESSR(,)	Names of solid to solid radiation conductors connected to a solid node
NODESL( )	Names of the solid node
NUMSA( )	Number of solid to ambient conductors
NUMSF( )	Number of solid to fluid conductors
NUMSS( )	Number of solid to solid conductors
NUMSSR( )	Number of solid to solid radiation conductors
SHSORC( )	External heat source to solid node (Btu/s)
SMASS( )	Mass of solid node (lb_m)
TS( )	Temperature of solid node (°R)
TSM( )	Temperature of solid node (°R) at previous time step
TSMM( )	Temperature of solid node (°R) at two steps prior
CPSLDMM( )	Specific heat of solid node (Btu/lb_m-°R) at two steps prior to current time step
22. COMMON/ANODE/	**Common block for ambient node properties**
NODEAM( )	Name of Ambient node
TAMB( )	Ambient Temperature (ºR)
IHIST( )	Index variable for ambient node has history file
23. COMMON/SSCOND/	**Common block for solid to solid conductor properties**
ARCSIJ( )	Conduction area between neighboring solid nodes (ft^2)
CONDKIJ( )	Conductivity between neighboring solid nodes (Btu/ft-s-°R)
DISTSIJ( )	Distance between neighboring solid nodes (ft)
EFCSIJ( )	Effective conductance between neighboring solid nodes (Btu/s-°R)
ICNSI( )	Upstream solid node of solid to solid conductor
ICNSJ( )	Downstream solid node of solid to solid conductor
ICONSS( )	Name of solid to solid conductor
QDOTSS( )	Heat transfer through a solid conductor (Btu/s)
24. COMMON/SFCOND/	**Common block for solid to fluid conductor properties**
ARSF( )	Heat transfer area between solid and fluid nodes (ft^2)
EFCSF( )	Effective conductance between solid and fluid node (Btu/s-°R)
EMSFF( )	Emissivity of fluid
EMSFS( )	Emissivity of solid
HCSF( )	Heat transfer coefficient between solid and fluid nodes (Btu/ft^2-s-°R)

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Variable	Description
HCSFR( )	Radiation heat transfer coefficient between solid and fluid (Btu/ft^2-s-°R)
ICF( )	Name of connecting fluid nodes
ICONSF( )	Name of solid to fluid conductors
ICS( )	Name of connecting solid nodes
MODEL( )	Index to specify which heat transfer coefficient model to use; MODEL(I)=0 – (User Specified), =1 – (Dittus-Boelter), =2 - Miropolosky
QDOTSF( )	Heat transfer between solid and fluid node (Btu/s)
25. COMMON/SACOND/	**Common block for solid to ambient conductor properties**
ARSA( )	Heat transfer area between solid and ambient nodes (ft^2)
EFCSA( )	Effective conductance between solid and ambient node (Btu/s-°R)
EMSAA( )	Emissivity of ambient
EMSAS( )	Emissivity of solid
HCSA( )	Heat transfer coefficient between solid and ambient nodes (Btu/ft^2-s-°R)
HCSAR( )	Radiation heat transfer coefficient between solid and ambient nodes (Btu/ft^2-s-°R)
ICONSA( )	Name of solid to ambient conductors
ICSAA( )	Name of connecting ambient nodes
ICSAS( )	Name of connecting solid nodes
QDOTSA( )	Heat transfer between solid and ambient node (Btu/s)
26. COMMON/SSRADC/	**Common block for solid to solid radiation conductor properties**
ARRSI( )	Area of ith solid node for radiation calculation (ft^2)
ARRSJ( )	Area of jth solid node for radiation calculation (ft^2)
EFCSSR( )	Effective radiation conductance between solid and ambient node (Btu/s-°R)
EMSSI( )	Emissivity of ith solid node
EMSSJ( )	Emissivity of jth solid node
ICONSSR( )	Name of solid to solid radiation conductors
ICNSRI( )	Name of ith solid node connecting radiation conductor
ICNSRJ( )	Name of jth solid node connecting radiation conductor
QDOTSSR( )	Heat transfer in solid to solid radiation conductor (Btu/s)
27. COMMON/CYCLIC/	**Common block for cyclic boundary condition**
NDCYCLB	Name of cyclic boundary node
NDCYCLU	Name of internal node upstream of cyclic boundary

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Variable	Description
ITERADJC	Integer count for iteration loop for cyclic boundary calculation
DIFTEM	Normalized difference in temperature between upstream and down-stream node of cyclic boundary condition
28. COMMON/PRESSREG/	**Common block for pressure regulator properties**
IBRPRG( )	Branch number representing pressure regulator
IPHIST( )	Index variable to indicate if there is a history file
AREAMAXP( )	Maximum allowable area of pressure regulator
REQPRESS( )	Required pressure downstream of pressure regulator
RELAXPR( )	Relaxation parameter of pressure regulator
CCPRG( )	Convergence criterion of pressure regulator
PRGHIST( )	Name of pressure regulator history file
PREGTIME(,)	Time array in pressure regulator history file
NPRGVALS()	Number of lines in pressure regulator history file
PREGPRESS(,)	Pressure array in pressure regulator history file
IREGTYP	Not used
NUMPREGS	Number of pressure regulators in the circuit
IPRESREG	Index to define the type of pressure regulator
MAXITER( )	Maximum number of allowable iterations
AREAMINP( )	Minimum allowable area of pressure regulator
29. COMMON/FLOWREG/	**Common block for flow regulator properties**
IBRFRG( )	Branch number representing flow regulator
IFHIST( )	Index variable to indicate if there is a history file
AREAMAXF( )	Maximum allowable area of pressure regulator
REQFLOW( )	Required flow rate in flow regulator
RELAXFR( )	Relaxation parameter of flow regulator
CCFRG( )	Convergence criterion of flow regulator
FRGHIST( )	Name of flow regulator history file
FREGTIME(,)	Time array in flow regulator history file
NFRGVALS()	Number of lines in flow regulator history file
FREGFLOW(,)	Flow rate array in flow regulator history file
NUMFREGS	Number of flow regulators in the circuit
IFLOWREG	Index to define the type of flow regulator
30. COMMON/GPATH/	
GPATH( )	Maximum number of allowable iterations
APATH( )	Minimum allowable area of pressure regulator
MODELNAME( )	Name of the model input data file

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Variable	Description
31. COMMON/MATPROPS/	**Common block for material properties**
MAXMATLS	Maximum number of materials allowed
NUMMATLS	Number of materials read from the model
MATL( )	Array of material numbers read from the model
MATLCCT( )	Number of entries (records) in the Conductivity file
MATLCPCT( )	Number of entries (records) in the Specific Heat file
TEMPC(,)	Temperature profile in Conductivity file
TCONDC(,)	Conductance profile in Conductivity file
TEMPS(,)	Temperature profile in Specific Heat file
CPSC(,)	Specific Heat profile in Specific Heat file
32. COMMON/USERPVARS/	**Common block for user specified variables**
USERPVARS	Value of the user variable to be plotted
USRVARSNUM	Number of user variables to be plotted
33. COMMON/USERNVARS/	**Common block for user specified variables**
USRPVARNAME	Name of the user variable to be plotted
USRPVARUNIT	Unit of the user variable to be plotted
34. COMMON/CMIXTURE/	**Common block for mixture properties**
ARFACT	Factor of area calculation for inter-phase heat transfer
CONDUCTX(,)	Thermal conductivity of mixture component
CPX(,)	Sp. Heat at const. pressure of mixture component
CVX(,)	Sp. Heat at const. volume of mixture component
EMX(,)	Mass of mixture component
EMUX(,)	Viscosity of mixture component
GAMAX(,)	Specific heat ratio of mixture component
HSORCEX(,)	Heat source for mixture component
HX(,)	Enthalpy of mixture component
HXM(,)	Enthalpy of mixture component at previous time
QHES(,)	Inter-phase heat transfer between mixture component
HXMM(,)	Enthalpy of mixture component at two time steps prior
PX(,)	Partial Pressure of Mixture Component
RHOX(,)	Density of mixture component
RHOXM(,)	Density of mixture component at previous time step
RHOXMM(,)	Density of mixture component at two time steps prior
SORCEHX(,)	Energy Source for mixture component
SX(,)	Entropy of mixture component
TFX(,)	Temperature of mixture component

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Variable	Description
VOLX(,)	Volume of mixture component
XVX(,)	Vapor quality of mixture component
ZX(,)	Compressibility factor of mixture component
PXM(,)	Partial pressure of mixture component at previous time step
PXMM(,)	Partial pressure of mixture component at two times steps prior
EMXM(,)	Mass of mixture component at previous time step
EMXMM(,)	Mass of mixture component at two time steps prior
NAF(,)	Index variable used for Inter-phase heat transfer
CMV(,)	Not used
CML(,)	Not used
SXM(,)	Not used
SGENX(,)	Not used
SXREF(,)	Not used
TFXM(,)	Not used
RHOLMIX(,)	Not used
RHOVMIX(,)	Not used
EMULMIX(,)	Not used
EMUVMIX(,)	Not used
CPNODEVMIX(,)	Not used
CPNODELMIX(,)	Not used
CONDFVMIX(,)	Not used
CONDFLMIX(,)	Not used
ITEMPMIX	Not used
35. COMMON/CCART/	**Common block for cartesian properties**
NODEX( )	Not used
NODEY( )	Not used
NODEZ( )	Not used
XDIST( )	Not used
YDIST( )	Not used
ZDIST( )	Not used
INDNAB( )	Not used
XU( )	Not used
YV( )	Not used
ZW( )	Not used
IBRVEL( )	Not used
DXU( )	Not used
DYV( )	Not used
DZW( )	Not used

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Variable	Description
NBRNX( )	Not used
NBRNY( )	Not used
NBRNA( )	Not used
NX	Number of nodes in x-direction
NY	Number of nodes in y-direction
NZ	Number of nodes in z-direction
XLEN	Length in x-direction
YLEN	Length in y-direction
ZLEN	Length in z-direction
DXP( )	Not used
DYP( )	Not used
DZP( )	Not used
ANORTH( )	Not used
ASOUTH( )	Not used
AEAST( )	Not used
AWEST( )	Not used
TNORTH( )	Not used
TSOUTH( )	Not used
TEAST( )	Not used
TWEST( )	Not used
36. COMMON/CSPARSE/	**Common block for sparse matrix properties**
MAXL	Not used
MT	Not used
IROW( )	Not used
JCOL(,)	Not used
AS( )	Not used
MTMAXS	Not used
37. COMMON/TECPLOT/	**Common block for tecplot properties**
XDISTFN( )	x-coordinate of node
YDISTFN( )	y-coordinate of node
ZDISTFN( )	z-coordinate of node
XDISTB( )	x-coordinate of branch
YDISTB( )	y-coordinate of branch
ZDISTB( )	z-coordinate of branch
XDISTSN( )	Not used
YDISTSN( )	Not used
ZDISTSN( )	Not used

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Variable	Description
XDISTAN( )	Not used
YDISTAN( )	Not used
ZDISTAN( )	Not used
UVELN( )	u-velocity component of node
VVELN( )	v-velocity component of node
38. COMMON/FIXEDFLOW/	**Common block for fixed flow option**
FFHIST( )	History file name for fixed flow rate option
NFIXFLB	Number of fixed flow branch
AREAFF(,)	Not used
TIMEFF(,)	Time array in fixed flow rate history file
FFLOW(,)	Flow rate in fixed flow rate history file
NDATFF( )	Number of data in fixed flow rate history file
39. COMMON/RLFVLV/	**Common block for relief valve properties**
NRLFVLV	Number of relief valve in the flow circuit
IRLFVLVBR( )	Branch ID number of a relief valve
NRLFVLVVALS( )	Number of A(dP) or Cv(dP) pairs in the relief valve control file
RLFVLVDP(,)	Pressure differential points (dP) in the relief valve control file
RLFVLVACV(,)	Area (A) or Cv points in the relief valve control file
RLFVLVPCRACK( )	Cracking pressure for the relief valve
RLFVLVHIST( )	Filename of the relief valve control file

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APPENDIX E—LISTING OF BLANK USER SUBROUTINES

```
C*************************************************************************
C                                    *
C   ***** GFSSP User SubroutineS *****                  *
C                                    *
C*************************************************************************
C  SUBROUTINE USRINT IS CALLED FROM INIT TO SPECIFY INITIAL VALUES COMPUTED
C       BY USER SPECIFIED THERMODYNAMIC PROPERTY PACKAGE
C
C  SUBROUTINE SORCEM(IPN,TERMU) IS CALLED FROM EQNS FOR MASS SOURCES.
C       IN THIS ROUTINE THE USER DEFINES ANY ADDITIONAL MASS
C       SOURCES TO THE MODEL (MASS SOURCES ARE IN LBM/SEC). USER
C       CAN MODIFY TRANSIENT TERM BY REDEFINING THE ARGUMENT TERMU.
C
C  SUBROUTINE SORCEF(I,TERM0,TERM1,TERM2,TERM3,TERM4,TERM5,TERM6,TERM7,
C       TERM8,TERM9,TERM10,TERM100) IS CALLED FROM EQNS FOR
C       MOMENTUM SOURCES. USER CAN MODIFY INDIVIDUAL TERMS OR
C       DEFINE ADDITIONAL MOMENTUM SOURCES THROUGH TERM100.
C
C  SUBROUTINE SORCEQ IS CALLED FROM EITHER THE ENERGY ROUTINE (EITHER
C       ENTHALPY OR ENTROPY). IN THIS ROUTINE THE USER DEFINES
C       ANY ADDITIONAL HEAT SOURCES TO THE MODEL (HEAT SOURCES
C       ARE IN BTU/SEC)
C
C  SUBROUTINE SORCEC IS CALLED FROM THE SPECIES CONCENTRATION ROUTINE
C       IN THIS ROUTINE THE USER DEFINES ANY ADDITIONAL SPECIES
C       CONCENTRATION SOURCES TO THE MODEL (CONCENTRATION SOURCES
C       ARE IN MASS FRACTIONS SUCH THAT THE SUM OF ALL OF THE
C       CONCENTRATIONS EQUALS 1.0)
C
C  SUBROUTINE KFUSER IS CALLED FROM THE RESIST ROUTINE. IN THIS ROUTINE
C       THE USER DEFINES ANY VARIATION OF THE K-FACTOR OF A BRANCH
C       SUCH THAT THE K-FACTOR IS DEFINED AS THE PRESSURE DROP
C       DIVIDED BY THE MASS FLOW RATE^2 (PRESSURE IS IN PSF, FLOW
C       RATE IS IN LBM/SEC; I.E. THE K-FACTOR IS IN PSF-SEC^2/
C       (LBM-FT)^2)
C
C  SUBROUTINE PRPUSER IS CALLED FROM THE DENSITY ROUTINE. IN THIS
C       ROUTINE THE USER ADDS OR MODIFIES FLUID PROPERTIES (ALLOWS
C       FOR USER SPECIFIED FLUID)
C
C  SUBROUTINE TSTEP IS CALLED FROM THE MAIN ROUTINE. IN THIS ROUTINE
C       THE USER CAN MODIFY THE TIMESTEP, DTAU, FOR AN UNSTEADY
C       MODEL (DTAU IS IN SECONDS)
C
C  SUBROUTINE BNDUSER IS CALLED FROM THE BOUND ROUTINE. IN THIS ROUTINE
C       THE USER CAN MODIFY BOUNDARY CONDITIONS AND GEOMETRY AT
C       EACH TIMESTEP FOR AN UNSTEADY MODEL (PRESSURE IS IN PSF,
C       TEMPERATURE IS IN DEG. R, LENGTH {ETC.} IS IN FT, AREA IS
C       IN FT^2, VOLUME IS IN FT^3)
C
C  SUBROUTINE PRNUSER IS CALLED FROM THE PRINT ROUTINE. IN THIS ROUTINE
C       THE USER CAN MODIFY ADD ADDITIONAL OUTPUT FILES SPECIFIC
C       TO A PARTICULAR MODEL
C
C  SUBROUTINE FILNUM IS CALLED FROM THE MAIN ROUTINE. IN THIS ROUTINE
C       ESTABLISHES THE FILE NUMBERS THAT ARE TO BE OPENED FOR ALL
C       FILES IN GFSSP, AND INCLUDES 10 USER FILE NUMBERS FOR USE
C       IN THE PRNUser Subroutine
C
```

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```
C  SUBROUTINE USRSET IS CALLED FROM THE READIN ROUTINE. IN THIS ROUTINE
C       THE USER SETS UP THE MAJORITY OF THE MODEL; ONLY A DUMMY
C       SEGMENT OF AN INPUT FILE IS NECESSARY TO BE READ, WITH THE
C       REMAINDER OF THE MODEL SETUP IN THIS SUBROUTINE.
C
!  THE FOLLOWING FUNCTIONS ARE AVAILABLE FOR CONVERTING SI UNITS INTO GFSSP INTERNAL (ENGLISH) UNITS.
!
!   FUNCTION rlbmft3_kgm3(rlbmft3)
!   PURPOSE: to convert LBM/FT^3 to KG/M^3

!   FUNCTION PSF_KPA(PSF)
!   PURPOSE: to convert PSF to KPA

!   FUNCTION RLBMS_KGS(RLBMS)
!   PURPOSE: to convert LBM/SEC TO KG/SEC

!   FUNCTION rKGS_LBMS(rKG)
!   PURPOSE: to convert KG/SEC LBM/SEC

!   FUNCTION FT_M(FT)
!   PURPOSE: to convert FT to METERS

!   FUNCTION rM2_FT2(rM2)
!   PURPOSE: to convert METERS^2 to FT^2

!   FUNCTION BTULB_KJKGK(BTU)
!   PURPOSE TO CONVERT BTU/LB TO KJ/KG K

!   FUNCTION BTULBMR_KJKGK(BTU)
!   PURPOSE TO CONVERT BTU/LBM R TO KJKG K

!   FUNCTION rLBMFTS_KGMS(rLBM)
!   PURPOSE TO CONVERT LBM/FT S TO KG/M S

!   FUNCTION BTUFTSR_WMK(BTU)
!   PURPOSE TO CONVERT BTU/FT-S R TO W/M K

!   FUNCTION FTS_MS(FT)
!   PURPOSE TO CONVERT FT/SEC TO M/SEC

!   FUNCTION R_C(T,SIFACTT)
C   PURPOSE: CONVERSION OF UNIT FOR TEMPERATURE

!   FUNCTION C_R(T,SIFACTT)
C   PURPOSE: CONVERSION OF UNIT FOR TEMPERATURE

!   REAL FUNCTION KW_BTUS(KW)
C   PURPOSE: TO CONVERT kW TO BTU/sec (HEAT RATE)

!   REAL FUNCTION KJKG_BTULBM(KJKG)
C   PURPOSE: TO CONVERT kJ/kg to BTU/lbm (HEAT RATE)

!   REAL FUNCTION KGM3_LBMF3(KGM3)
C   PURPOSE: TO CONVERT kg k/m^3 to lbm/ft^3 (DENSITY)

!   REAL FUNCTION NSM2_LBMFS(NSM2)
C   PURPOSE: TO CONVERT ns/m^2 to lbm/f s (VISCOSITY)

!   FUNCTION WMK_BTUFSR(WMK)
C   PURPOSE: TO CONVERT W/m K to BTU/f s R (THERMAL CONDUCTIVITY)

!   FUNCTION WM2K_BTUF2SF(WM2K)
C   PURPOSE: TO CONVERT W/m^2 K to BTU/f^2 s F (HEAT TRANSFER COEFFICIENT)

!   REAL FUNCTION KGS_LBMS(KGS)
C   PURPOSE: TO CONVERT kg/s to lbm/s (MASS)
```

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```
!   REAL FUNCTION M_F(M)
C   PURPOSE: TO CONVERT meters to feet (VELOCITY)

!   FUNCTION W_BTUS(W)
C   PURPOSE: TO CONVERT watts to btu/S ( HEAT RATE)

!   REAL FUNCTION KJ_BTU(KJ)
C   PURPOSE: TO CONVERT kJ to BTU (ENERGY)

!   REAL FUNCTION KJKGK_BTULBMR(KJKGK)
C   PURPOSE: TO CONVERT kJ/kg-K to BTU/lbm-R (SPECIFIC HEAT)

C***********************************************************************
   SUBROUTINE FILENUM
C   PURPOSE: ESTABLISH THE FORTRAN FILE NUMBERS FOR READING &
C       WRITING OF INFORMATION
C***********************************************************************
    INCLUDE 'comblk.for'
C**********************************************************************
C
C    FILES ALREADY WITHIN GFSSP
C
C     NWRTE = FILE # CORRESPONDING TO THE WRITEIN SUBROUTINE
C         (WRITING INPUT DECK FROM COMMAND LINE PREPROCESSOR)
C     NPRNT = FILE # CORRESPONDING TO THE PRINT SUBROUTINE
C         (WRITING THE MAIN OUTPUT FILE)
C     NREAD = FILE # CORRESPONDING TO THE READIN SUBROUTINE
C         (READING IN THE INPUT DECK)
C     NGSPK = FILE # CORRESPONDING TO A NonGASP PROPERTY PACKAGE
C     NFNOD = FILE # CORRESPONDING TO THE FNODE RESTART FILE
C     NGFSOUT = FILE # CORRESPONDING TO THE GFSSP.OUT FILE
C         (DEBUGGING FILE)
C     NFBR = FILE # CORRESPONDING TO THE FBRANCH RESTART FILE
C     NGASP = FILE # CORRESPONDING TO THE GASP.OUT FILE
C         (DEBUGGING FILE)
C     NHSTN = FILE # CORRESPONDING TO THE HISTN.XLS FILE
C     NHSTB = FILE # CORRESPONDING TO THE HISTBR.XLS FILE
C     NHSTF = FILE # CORRESPONDING TO B.C. & VARGEO HISTORY FILES
C     NCVHST = FILE # CORRESPONDING TO THE CONTROL VALVE HISTORY FILE
C     NCVCHR1 = FILE # CORRESPONDING TO THE FIRST OF TWO CONTROL
C         VALVE FILES
C     NCVCHR2 = FILE # CORRESPONDING TO THE SECOND OF TWO CONTROL
C         VALVE FILES
C     NHSTROT = FILE # CORRESPONDING TO THE VARIABLE ROTATION
C         HISTORY FILE
C     NERROR = FILE # CORRESPONDING TO THE ERROR.XLS FILE
C     NRP1DAT = FILE # CORRESPONDING TO THE RP1 PROPERTY DATA FILES
C     NDPLT = FILE # CORRESPONDING TO NODE RESULTS FOR VTASC POST-PROCESSING
C     NBRPLT = FILE # CORRESPONDING TO NODE RESULTS FOR VTASC POST-PROCESSING
C     NDWINP = FILE # CORRESPONDING TO NODE RESULTS FOR Winplot POST-PROCESSING
C     NBRWINP = FILE # CORRESPONDING TO BRANCH RESULTS FOR Winplot POST-PROCESSING
C     NCOND = FILE # CORRESPONDING TO THERMAL CONDUCTIVITY PROPERTY DATA
C     NCP = FILE # CORRESPONDING TO SPECIFIC HEAT PROPERTY DATA
C     NSLDPLT = FILE # CORRESPONDING TO SOLID NODE RESULTS FOR PLOTTING
C     NSSCPLT = FILE # CORRESPONDING TO SOLID TO SOLID CONDUCTOR RESULTS FOR PLOTTING
C     NSFCPLT = FILE # CORRESPONDING TO SOLID TO FLUID CONDUCTOR RESULTS FOR PLOTTING
C     NSACPLT = FILE # CORRESPONDING TO SOLID TO AMBIENT CONDUCTOR RESULTS FOR PLOTTING
C
c THESE ASSIGNMENTS DUPLICATE THOSE FOUND IN GFSSP505.FOR
C       NGSPK=1
C       NPRNT=10
C       NFNOD=11
C       NGFSOUT=12
C       NFBR=13
C       NREAD=15
C       NGASP=17
C       NHSTN=18
C       NHSTB=19
```

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```
C       NWRTE=20
C       NHSTF=21
C       NCVHST=28
C       NCVCHR1=29
C       NCVCHR2=30
C       NHSTROT=35
C              NVOPFILE=36
C              NPRGFILE=37
C              NFRGFILE=38
C       NERROR=55
C       NRP1DAT=51
C     NDPLT=52
C     NBRPLT=53
C     NDWINP=54
C     NBRWINP=56
C     NCOND = 57
C     NCP = 58
C     NSLDPLT = 59
C     NSSCPLT = 60
C     NSFCPLT = 61
C     NSACPLT = 62
C     NSSRCPLT = 67
C        NSSCRWIN = 68
C     NBWPLOT = 70
C        NUVWINP = 71
C     NTECPLT = 72
C     NFIXFHST = 73
C  FILE NUMBERS FOR USER DEFINED FILES (THESE FILES CAN BE USED
C  IN ANY OF THE User SubroutineS; HOWEVER, MOST LIKELY USE IS
C  IN THE PRNUser Subroutine). COMMENT OUT FILE NUMBERS NOT IN USE.
C
C     NUSR1=
C     NUSR2=
C     NUSR3=
C     NUSR4=
C     NUSR5=
C     NUSR6=
C     NUSR7=
C     NUSR8=
C     NUSR9=
C     NUSR10=

   RETURN
   END
C***********************************************************************
   SUBROUTINE USRINT
C   PURPOSE: PROVIDE INITIAL CONDITIONS WHEN ALTERNATE THERMODYNAMIC
C       PROPERTY PACKAGE IS USED
C********************************************************************
    INCLUDE 'comblk.for'
C**********************************************************************
C**********************************************************************
C   ADD CODE HERE
   RETURN
   END
C***********************************************************************
   SUBROUTINE SORCEM(IPN,TERMU)
C   PURPOSE: ADD MASS SOURCES
C   IPN - GFSSP INDEX NUMBER FOR NODE
C   TERMU - UNSTEADY TERM IN MASS CONSERVATION EQUATION
C***********************************************************************
    INCLUDE 'comblk.for'
C**********************************************************************
C   ADD CODE HERE
   RETURN
   END
C***********************************************************************
```

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```
      SUBROUTINE SORCEF(I,TERM0,TERM1,TERM2,TERM3,TERM4,TERM5,TERM6,
     &          TERM7,TERM8,TERM9,TERM10,TERM100)
C     PURPOSE: ADD MOMENTUM SOURCES (LBF)
C     I - GFSSP INDEX NUMBER FOR BRANCH
C     TERM0 - UNSTEADY TERM IN MOMENTUM CONSERVATION EQUATION
C     TERM1 - LONGITUDINAL INERTIA
C     TERM2 - PRESSURE GRADIENT
C     TERM3 - GRAVITY FORCE
C     TERM4 - FRICTION FORCE
C     TERM5 - CENTRIFUGAL FORCE
C     TERM6 - EXTERNAL MOMETUM SOURCE DUE TO PUMP
C     TERM7 - MOMENTUM SOURCE DUE TO TRANSVERSE FLOW(MULTI-DIMENSIONAL MODEL)
C     TERM8 - MOMENTUM SOURCE DUE TO SHEAR(MULTI-DIMENSIONAL MODEL)
C     TERM9 - VARIABLE GEOMETRY UNSTEADY TERM
C     TERM10 - NORMAL STRESS
C     TERM100 - USER SUPPLIED MOMENTUM SOURCE
C**********************************************************************
       INCLUDE ‘comblk.for’
C*********************************************************************
C     ADD CODE HERE

      RETURN
      END
C**********************************************************************
      SUBROUTINE SORCEQ(IPN,TERMD)
C     PURPOSE: ADD HEAT SOURCES
C     IPN - GFSSP INDEX NUMBER FOR NODE
C     TERMD - COMPONENT OF LINEARIZED SOURCE TERM APPEARING IN THE
C         DENOMINATOR OF THE ENTHALPY OR ENTROPY EQUATION
C**********************************************************************
       INCLUDE ‘comblk.for’
C*********************************************************************
C*********************************************************************
C     ADD CODE HERE
      RETURN
      END
C**********************************************************************
      SUBROUTINE SORCEHXQ(IPN,TERMD,K)
C     PURPOSE: ADD HEAT SOURCES
C     IPN - GFSSP INDEX NUMBER FOR NODE
C     TERMD - COMPONENT OF LINEARIZED SOURCE TERM APPEARING IN THE
C         DENOMINATOR OF THE ENTHALPY OR ENTROPY EQUATION
C**********************************************************************
       INCLUDE ‘comblk.for’
C*********************************************************************
C*********************************************************************
C     ADD CODE HERE
      RETURN
      END
C**********************************************************************
      SUBROUTINE SORCEC
C     PURPOSE: ADD CONCENTRATION SOURCES
C**********************************************************************
      INCLUDE ‘comblk.for’
C*********************************************************************
C     ADD CODE HERE
      RETURN
      END
C**********************************************************************
      SUBROUTINE SORCETS(IPSN,TERMD)
C     PURPOSE: ADD SOURCE TERM IN SOLID TEMPERATURE EQUATION
C**********************************************************************
      INCLUDE ‘comblk.for’
C*********************************************************************
C     ADD CODE HERE
      RETURN
      END
```

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```
C***********************************************************************
   SUBROUTINE KFUSER(I,RHOU,EMUU,XVU,RHOUL,EMUUL,AKNEW)
C   PURPOSE: ADD A NEW RESISTANCE OPTION
C***********************************************************************
   INCLUDE 'comblk.for'
C**********************************************************************
C   ADD CODE HERE

   RETURN
   END
C***********************************************************************
   SUBROUTINE KFADJUST(I,RHOU,EMUU,RHOUL,EMUUL,RHOUV,EMUUV,ISATU,
   &          AKNEW)
C   PURPOSE: ADD A NEW RESISTANCE OPTION
C***********************************************************************
   INCLUDE 'comblk.for'
C**********************************************************************
C   ADD CODE HERE
   RETURN
   END
C***********************************************************************
   SUBROUTINE PRPUSER
C   PURPOSE: ADD NEW FLUID PROPERTY
C***********************************************************************
   INCLUDE 'comblk.for'
C**********************************************************************
C   ADD CODE HERE
   RETURN
   END

C***********************************************************************
   SUBROUTINE TSTEP
C   PURPOSE: MODIFY TIME STEP
C***********************************************************************
   INCLUDE 'comblk.for'
C**********************************************************************
C   ADD CODE HERE
   RETURN
   END

C***********************************************************************
   SUBROUTINE BNDUSER
C   PURPOSE: MODIFY BOUNDARY CONDITIONS
C***********************************************************************
   INCLUDE 'comblk.for'
C**********************************************************************
C   ADD CODE HERE
   RETURN
   END
C***********************************************************************
   SUBROUTINE PRNUSER
C   PURPOSE: ADD NEW OUTPUT
C***********************************************************************
   INCLUDE 'comblk.for'
C**********************************************************************
C   ADD CODE HERE
C   write(nprnt,*) '*********** MIXTURE OPTION ************'
C       write (nprnt,*) 'IFRMIX = ', IFRMIX
C       write(nprnt,*) '*********** MIXTURE OPTION ************'
   RETURN
   END
C**********************************************************************
   SUBROUTINE USRSET(FILEIN,TITLE,HISTORY,FNODE,FBRANCH,PCURVE,
   &      HISTGEO,HISTQ,HISTVLV,OVALV,CVALV,ANALYST,FILEOUT)
C   PURPOSE: USER SETS UP THE MAJORITY OF THE MODEL
C***********************************************************************
   INCLUDE 'comblk.for'
C**********************************************************************
```

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```
       CHARACTER*256, FILEIN,FILEOUT,ANALYST
       CHARACTER*80, TITLE
       CHARACTER*20, HISTQ(100),PCURVE(10),HISTGEO,HISTROT
    CHARACTER*256, HISTORY(100)
    CHARACTER*20, HISTVLV(10),OVALV(10),CVALV(10)
    CHARACTER*20, FNODE,FBRANCH
C   ADD CODE HERE
C
C THIS IS THE DEFAULT CODE FOR THIS BLOCK, COMMENT THIS OUT WHEN
C CREATING A MODEL WITHIN THIS SUBROUTINE
C
    WRITE(*,*) ' '
    WRITE(*,*) ' USER ROUTINE USRSET DOES NOT HAVE A MODEL DEVELOPED'
    WRITE(*,*) ' '
    WRITE(*,*) ' OPEN THE User Subroutine FILE AND MODIFY SUBROUTINE'
    WRITE(*,*) ' USRSET TO DEVELOP MODEL OR CHANGE LOGICAL VARIABLE'
    WRITE(*,*) ' USETUP TO FALSE AND DEVELOP MODEL IN INPUT FILE'
    WRITE(*,*) ' '
C    STOP
C
C END OF DEFAULT CODE
C
    RETURN
    END
C***********************************************************************
   SUBROUTINE USRHCF(NUMBER,HCF)
C   PURPOSE: PROVIDE HEAT TRANSFER COEFFICIENT
C************************************************************************
   INCLUDE 'comblk.for'
C***********************************************************************
C   ADD CODE HERE
   RETURN
   END
C***********************************************************************
   SUBROUTINE USRADJUST
C   PURPOSE: ADJUST BOUNDARY CONDITION OR GEOMETRY FOR Steady state MODEL
C************************************************************************
   INCLUDE 'comblk.for'
C***********************************************************************
C   ADD CODE HERE
   RETURN
   END
C***********************************************************************
   SUBROUTINE PRPADJUST
C   PURPOSE: ADJUST THERMODYNAMIC OR THERMOPHYSICAL PROPERTY
C************************************************************************
   INCLUDE 'comblk.for'
C***********************************************************************
C   ADD CODE HERE
   RETURN
   END
C***********************************************************************
   SUBROUTINE TADJUST
C   PURPOSE: ADJUST TEMPERATURE IF NECESSARY
C************************************************************************
   INCLUDE 'comblk.for'
C***********************************************************************
C   ADD CODE HERE
   RETURN
   END

C************************************************************************
   SUBROUTINE PADJUST
C   PURPOSE: ADJUST PRESSURE IF NECESSARY
C************************************************************************
   INCLUDE 'comblk.for'
C***********************************************************************
```

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```
   RETURN
   END
C***********************************************************************
   SUBROUTINE FLADJUST
C   PURPOSE: ADJUST Flow rate IF NECESSARY
C***********************************************************************
   INCLUDE 'comblk.for'
C**********************************************************************
C   ADD CODE HERE
   RETURN
   END
C***********************************************************************
   SUBROUTINE HADJUST
C   PURPOSE: ADJUST ENTHALPY IF NECESSARY
C***********************************************************************
   INCLUDE 'comblk.for'
C**********************************************************************
C   ADD CODE HERE

   RETURN
   END
C***********************************************************************
   SUBROUTINE USRMDG
C   PURPOSE: ADJUST INPUT PARAMETERS FOR MULTI-D FLOW, IF NECESSARY
C***********************************************************************
   INCLUDE 'comblk.for'
C**********************************************************************
C   ADD CODE HERE
   RETURN
   END
C***********************************************************************
C***********************************************************************
C                                    *
C        ***** END OF User SubroutineS *****          *
C                                    *
C**********************************************************************
```

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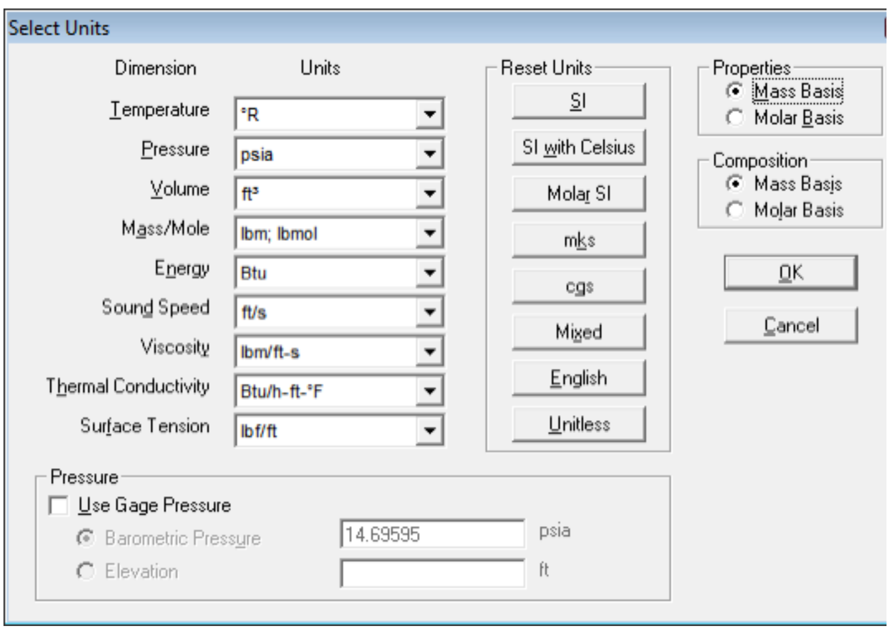
APPENDIX F—INSTRUCTIONS TO CONVERT REFPROP DATA TO GFSSP PROPERTY TABLE

F.1 Fluid Property Data

Appendix F provides instructions for converting fluid property data from the REFPROP program into GFSSP's seven user-defined fluid files.

(1) In REFPROP, select OPTIONS/UNITS. (Note that REFPROP English units set Thermal Conductivity to Btu/h-ft-°F; this will be converted to Btu/s-ft-°F later.)

For English units:



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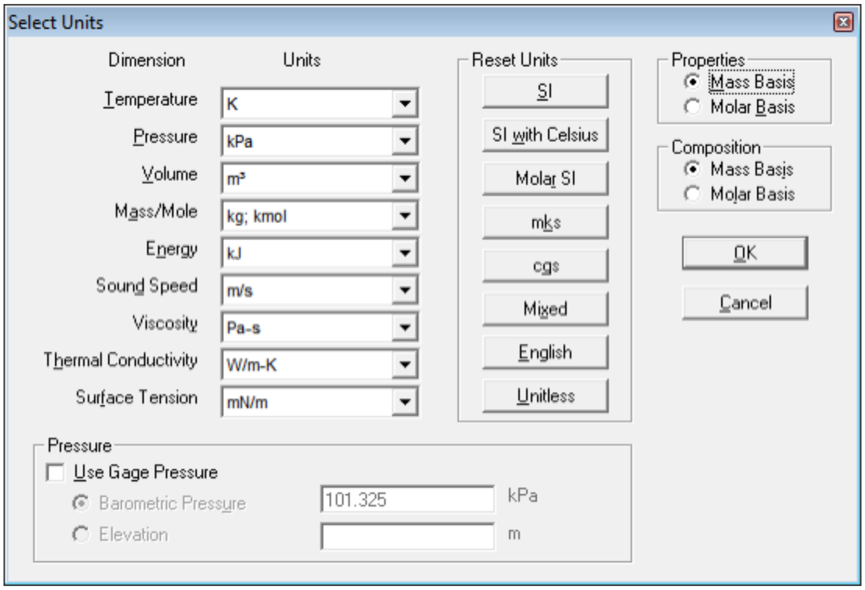
For SI units:



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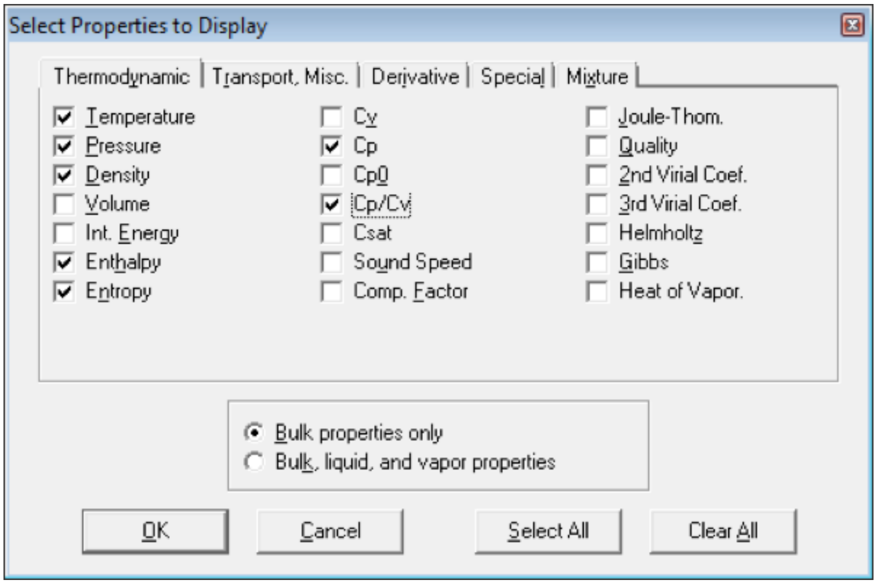
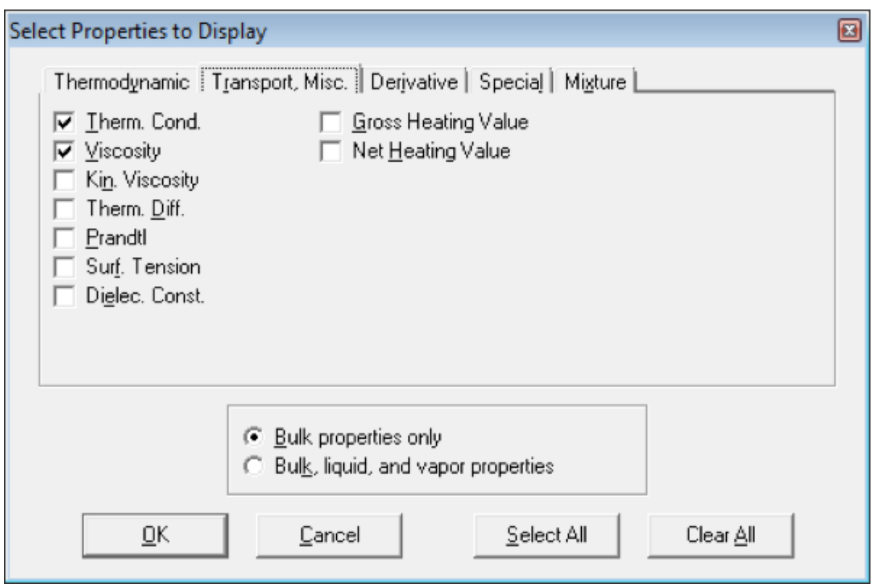
(2) Select OPTIONS/PROPERTIES and select Temperature, Pressure, Density, Enthalpy, Entropy, Cp, Cp/Cv, Thermal Conductivity, and Viscosity:





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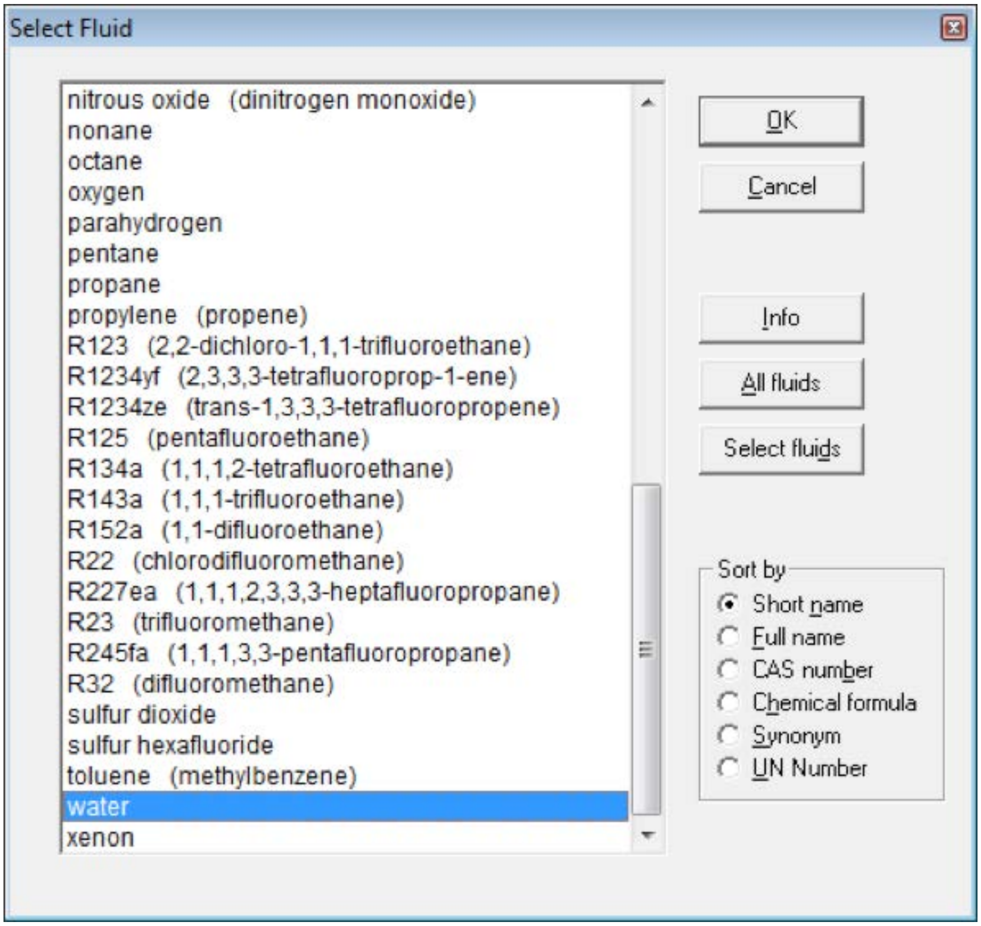
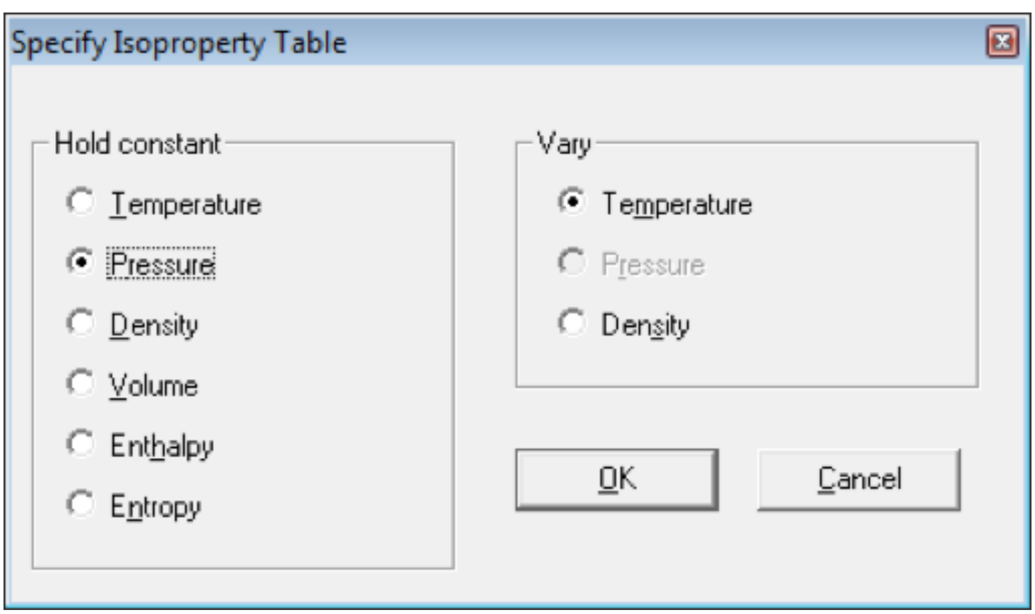
(3) Select SUBSTANCE/PURE FLUID and choose a fluid.



(4) Select CALCULATE/ISOPROPERTY TABLES, then choose to hold Pressure constant while varying temperature:



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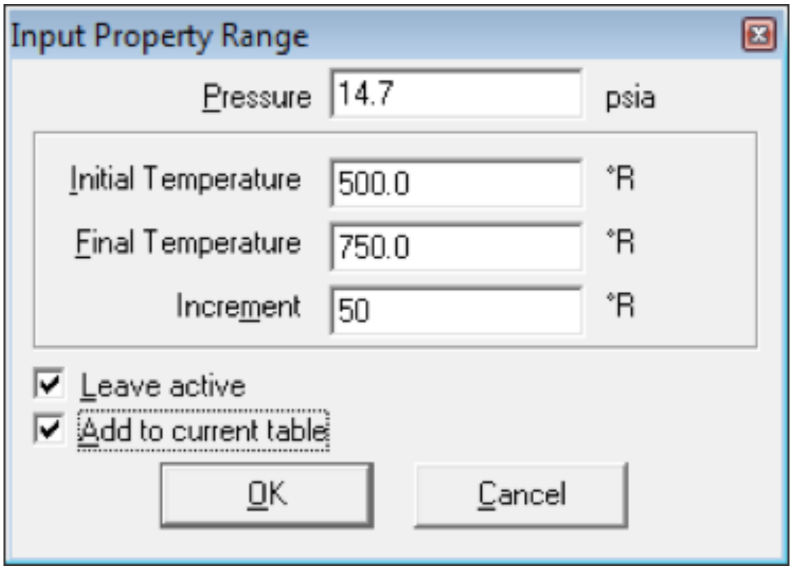
(5) Enter your first pressure and the temperature range and increment. Check the Leave active and a Add to current table boxes to make it easier to assemble a table at multiple pressures.



The example below shows water properties at three pressures and six temperatures (GFSSP's maximum is 301 pressures and 301 temperatures). Note carefully rows 5 and 6. At the given pressure of 14.7 psia, water is saturated at 671.64 ºR (212 ºF), and so REFPROP has added these extra rows. Examine your property data carefully for saturation properties.

1: water: p = 14.7 psia

	Temperature (°R)	Pressure (psia)	Density (lbm/ft³)	Enthalpy (Btu/lbm)	Entropy (Btu/lbm-°R)	Cp (Btu/lbm-°R)	Cp/Cv	Therm. Cond. (Btu/h-ft-°F)	Viscosity (lbm/ft-s)
1	500.00	14.700	62.426	8.4126	0.016879	1.0052	1.0000	0.32948	0.0010323
2	550.00	14.700	62.109	58.456	0.11228	0.99891	1.0176	0.35808	0.00050937
3	600.00	14.700	61.373	108.42	0.19922	1.0002	1.0527	0.37845	0.00031229
4	650.00	14.700	60.347	158.53	0.27944	1.0046	1.0972	0.38988	0.00021614
5	671.64	14.700	59.829	180.30	0.31238	1.0076	1.1187	0.39263	0.00018925
6	671.64	14.700	0.037320	1151.0	1.7577	0.49712	1.3369	0.014509	0.0000082192
7	700.00	14.700	0.035702	1165.0	1.7780	0.48507	1.3338	0.015144	0.0000086294
8	750.00	14.700	0.033204	1188.9	1.8111	0.47573	1.3281	0.016382	0.0000093633
1	500.00	114.70	62.447	8.7082	0.016877	1.0045	1.0000	0.32969	0.0010316
2	550.00	114.70	62.129	58.724	0.11222	0.99848	1.0177	0.35826	0.00050938
3	600.00	114.70	61.392	108.67	0.19914	0.99988	1.0527	0.37864	0.00031241
4	650.00	114.70	60.367	158.76	0.27932	1.0043	1.0971	0.39008	0.00021626
5	700.00	114.70	59.107	209.15	0.35401	1.0122	1.1488	0.39491	0.00016218
6	750.00	114.70	57.633	260.07	0.42426	1.0252	1.2075	0.39502	0.00012873
1	500.00	214.70	62.469	9.0036	0.016875	1.0038	1.0000	0.32989	0.0010309
2	550.00	214.70	62.148	58.993	0.11217	0.99804	1.0178	0.35844	0.00050939
3	600.00	214.70	61.411	108.92	0.19905	0.99952	1.0528	0.37883	0.00031252
4	650.00	214.70	60.386	158.99	0.27921	1.0039	1.0971	0.39029	0.00021639
5	700.00	214.70	59.128	209.37	0.35387	1.0118	1.1486	0.39515	0.00016230
6	750.00	214.70	57.657	260.26	0.42408	1.0247	1.2071	0.39528	0.00012885

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Highlight any lines of saturated data. Then select EDIT/DELETE ROWS.

1: water: p = 14.7 psia

	Temperature (°R)	Pressure (psia)	Density (lbm/ft³)	Enthalpy (Btu/lbm)	Entropy (Btu/lbm-°R)	Cp (Btu/lbm-°R)	Cp/Cv	Therm. Cond. (Btu/h-ft-°F)	Viscosity (lbm/ft-s)
1	500.00	14.700	62.426	8.4126	0.016879	1.0052	1.0000	0.32948	0.0010323
2	550.00	14.700	62.109	58.456	0.11228	0.99891	1.0176	0.35808	0.00050937
3	600.00	14.700	61.373	108.42	0.19922	1.0002	1.0527	0.37845	0.00031229
4	650.00	14.700	60.347	158.53	0.27944	1.0046	1.0972	0.38988	0.00021614
5	671.64	14.700	59.829	180.30	0.31238	1.0076	1.1187	0.39263	0.00018925
6	671.64	14.700	0.037320	1151.0	1.7577	0.49712	1.3369	0.014509	0.0000082192
7	700.00	14.700	0.035702	1165.0	1.7780	0.48507	1.3338	0.015144	0.0000086294
8	750.00	14.700	0.033204	1188.9	1.8111	0.47573	1.3281	0.016382	0.0000093633
1	500.00	114.70	62.447	8.7082	0.016877	1.0045	1.0000	0.32969	0.0010316
2	550.00	114.70	62.129	58.724	0.11222	0.99848	1.0177	0.35826	0.00050938
3	600.00	114.70	61.392	108.67	0.19914	0.99988	1.0527	0.37864	0.00031241
4	650.00	114.70	60.367	158.76	0.27932	1.0043	1.0971	0.39008	0.00021626
5	700.00	114.70	59.107	209.15	0.35401	1.0122	1.1488	0.39491	0.00016218
6	750.00	114.70	57.633	260.07	0.42426	1.0252	1.2075	0.39502	0.00012873
1	500.00	214.70	62.469	9.0036	0.016875	1.0038	1.0000	0.32989	0.0010309
2	550.00	214.70	62.148	58.993	0.11217	0.99804	1.0178	0.35844	0.00050939
3	600.00	214.70	61.411	108.92	0.19905	0.99952	1.0528	0.37883	0.00031252
4	650.00	214.70	60.386	158.99	0.27921	1.0039	1.0971	0.39029	0.00021639
5	700.00	214.70	59.128	209.37	0.35387	1.0118	1.1486	0.39515	0.00016230
6	750.00	214.70	57.657	260.26	0.42408	1.0247	1.2071	0.39528	0.00012885

Your data should now look as below, with the same temperatures at each pressure.

1: water: p = 14.7 psia

	Temperature (°R)	Pressure (psia)	Density (lbm/ft³)	Enthalpy (Btu/lbm)	Entropy (Btu/lbm-°R)	Cp (Btu/lbm-°R)	Cp/Cv	Therm. Cond. (Btu/h-ft-°F)	Viscosity (lbm/ft-s)
1	500.00	14.700	62.426	8.4126	0.016879	1.0052	1.0000	0.32948	0.0010323
2	550.00	14.700	62.109	58.456	0.11228	0.99891	1.0176	0.35808	0.00050937
3	600.00	14.700	61.373	108.42	0.19922	1.0002	1.0527	0.37845	0.00031229
4	650.00	14.700	60.347	158.53	0.27944	1.0046	1.0972	0.38988	0.00021614
7	700.00	14.700	0.035702	1165.0	1.7780	0.48507	1.3338	0.015144	0.0000086294
8	750.00	14.700	0.033204	1188.9	1.8111	0.47573	1.3281	0.016382	0.0000093633
1	500.00	114.70	62.447	8.7082	0.016877	1.0045	1.0000	0.32969	0.0010316
2	550.00	114.70	62.129	58.724	0.11222	0.99848	1.0177	0.35826	0.00050938
3	600.00	114.70	61.392	108.67	0.19914	0.99988	1.0527	0.37864	0.00031241
4	650.00	114.70	60.367	158.76	0.27932	1.0043	1.0971	0.39008	0.00021626
5	700.00	114.70	59.107	209.15	0.35401	1.0122	1.1488	0.39491	0.00016218
6	750.00	114.70	57.633	260.07	0.42426	1.0252	1.2075	0.39502	0.00012873
1	500.00	214.70	62.469	9.0036	0.016875	1.0038	1.0000	0.32989	0.0010309
2	550.00	214.70	62.148	58.993	0.11217	0.99804	1.0178	0.35844	0.00050939
3	600.00	214.70	61.411	108.92	0.19905	0.99952	1.0528	0.37883	0.00031252
4	650.00	214.70	60.386	158.99	0.27921	1.0039	1.0971	0.39029	0.00021639
5	700.00	214.70	59.128	209.37	0.35387	1.0118	1.1486	0.39515	0.00016230
6	750.00	214.70	57.657	260.26	0.42408	1.0247	1.2071	0.39528	0.00012885

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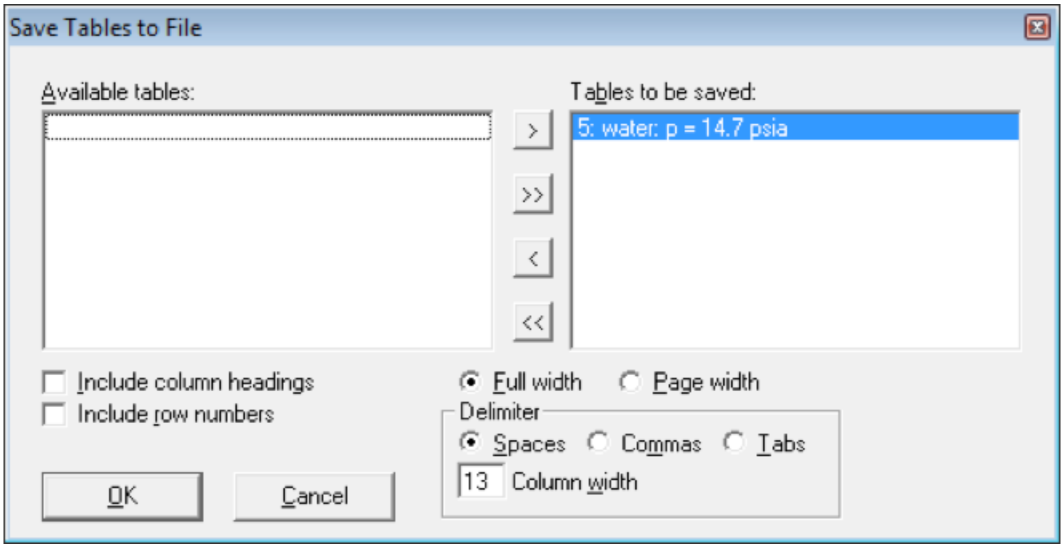
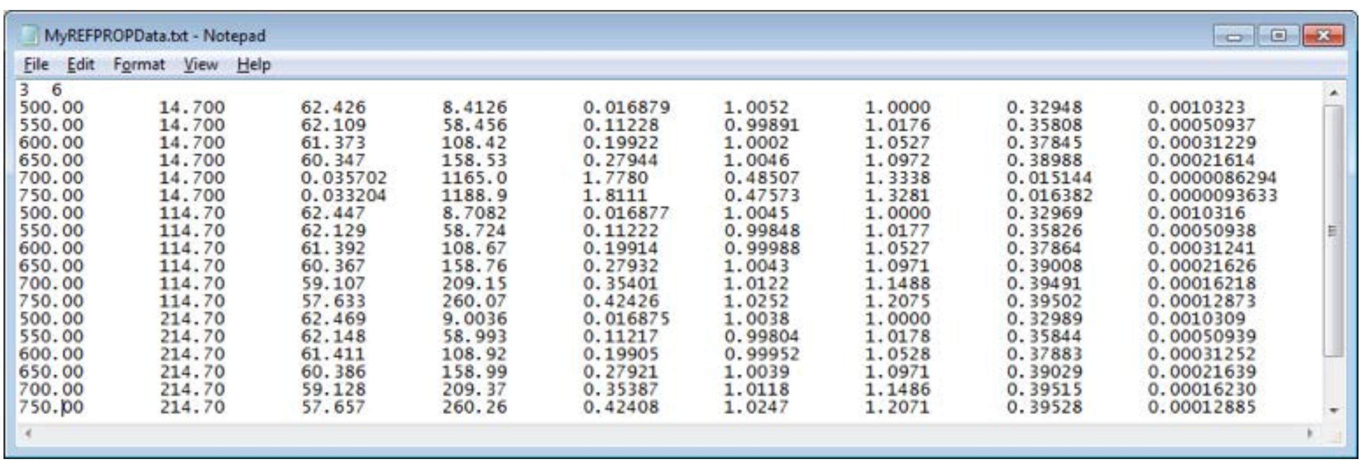
(6) Select FILE/SAVE TABLES. Uncheck the Include Column Headings and Include Row Numbers boxes, and set the Full Width radio button.



(7) Open the file you just saved with a text editor. Edit the file so that the first line gives the number of pressures and number of temperatures. In this example there are three pressures and six temperatures.

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3   6
500.00   14.700   62.426     8.4126   0.016879   1.0052    1.0000   0.32948    0.0010323
550.00   14.700   62.109     58.456   0.11228    0.99891   1.0176   0.35808    0.00050937
600.00   14.700   61.373     108.42   0.19922    1.0002    1.0527   0.37845    0.00031229
650.00   14.700   60.347     158.53   0.27944    1.0046    1.0972   0.38988    0.00021614
700.00   14.700   0.035702   1165.0   1.7780     0.48507   1.3338   0.015144   0.0000086294
750.00   14.700   0.033204   1188.9   1.8111     0.47573   1.3281   0.016382   0.0000093633
500.00   114.70   62.447     8.7082   0.016877   1.0045    1.0000   0.32969    0.0010316
550.00   114.70   62.129     58.724   0.11222    0.99848   1.0177   0.35826    0.00050938
600.00   114.70   61.392     108.67   0.19914    0.99988   1.0527   0.37864    0.00031241
650.00   114.70   60.367     158.76   0.27932    1.0043    1.0971   0.39008    0.00021626
700.00   114.70   59.107     209.15   0.35401    1.0122    1.1488   0.39491    0.00016218
750.00   114.70   57.633     260.07   0.42426    1.0252    1.2075   0.39502    0.00012873
500.00   214.70   62.469     9.0036   0.016875   1.0038    1.0000   0.32989    0.0010309
550.00   214.70   62.148     58.993   0.11217    0.99804   1.0178   0.35844    0.00050939
600.00   214.70   61.411     108.92   0.19905    0.99952   1.0528   0.37883    0.00031252
650.00   214.70   60.386     158.99   0.27921    1.0039    1.0971   0.39029    0.00021639
700.00   214.70   59.128     209.37   0.35387    1.0118    1.1486   0.39515    0.00016230
750.00   214.70   57.657     260.26   0.42408    1.0247    1.2071   0.39528    0.00012885
```

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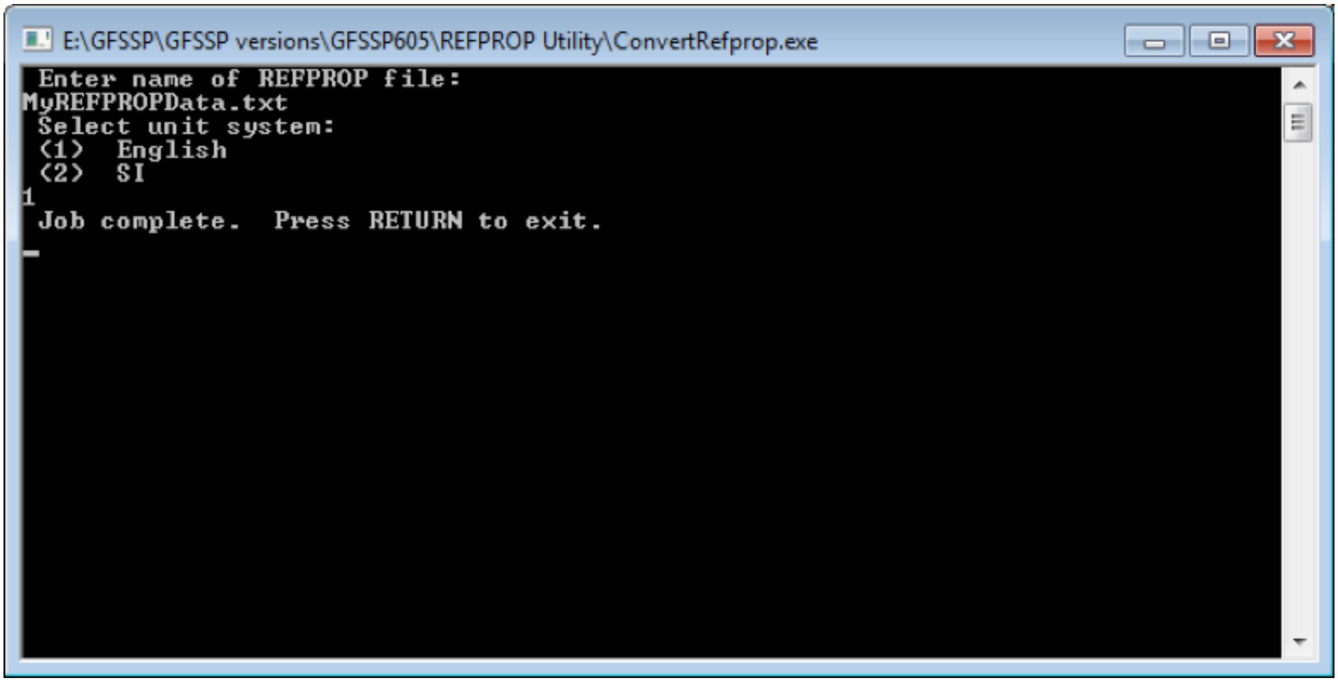
(8) Copy the program ConvertRefprop.exe to your working directory (Windows will not allow it to write output to the GFSSP installation directory.). Run the program and enter the REFPROP data filename. Choose English or SI units (choosing English units converts the units of thermal conductivity from Btu/h-ft-°F to Btu/s-ft-°F). The program will produce the seven user-defined fluid data files in your working directory.



(9) Did you have to remove any lines of saturated data from the pressure/temperature range of your data? Do you expect your fluid will change phase in your GFSSP model? If so, you must also construct an eighth file of saturated properties. Instructions are given below, or consult the file InstructionsToConvertREFPROP-DataToSaturatedFluidFile.pdf, also in the utilities folder

F.2 Saturated Fuid Property Data

This document provides instructions for converting SATURATED fluid property data from the REFPROP program into GFSSP's saturated user-defined fluid input file.

(1) In REFPROP, select OPTIONS/UNITS. (Note that REFPROP English units set Thermal Conductivity to Btu/h-ft-°F; this will be converted to Btu/s-ft-°F later.)

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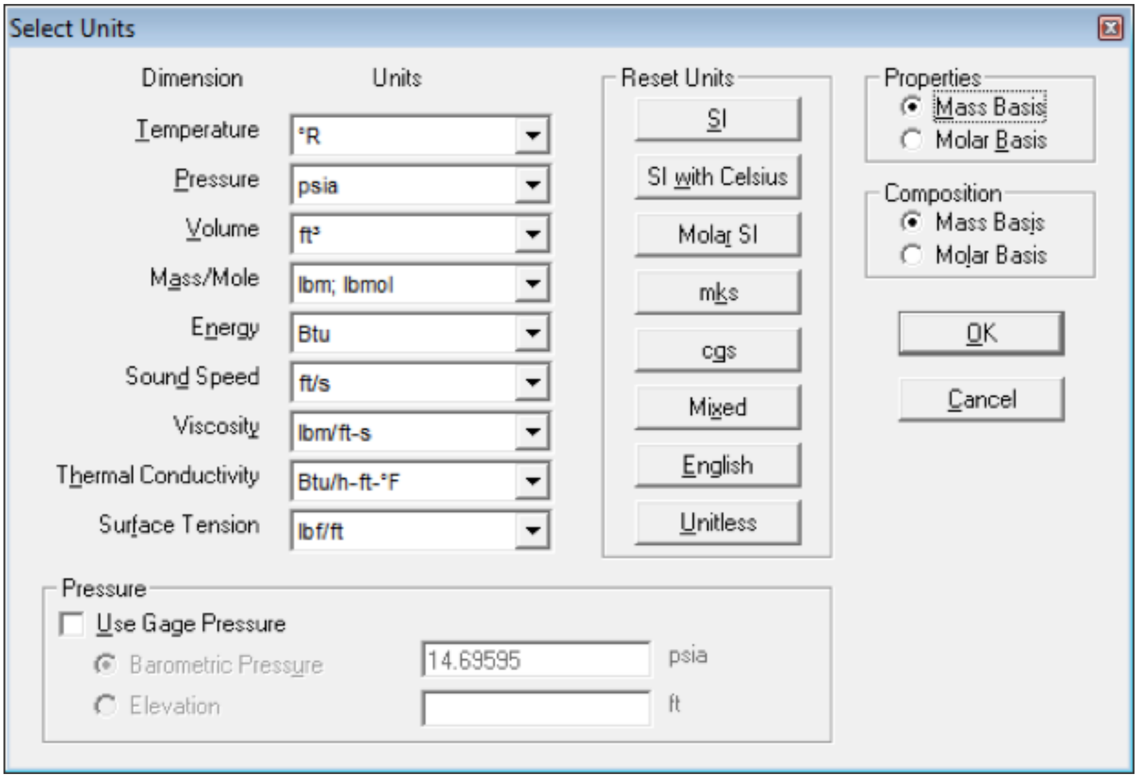
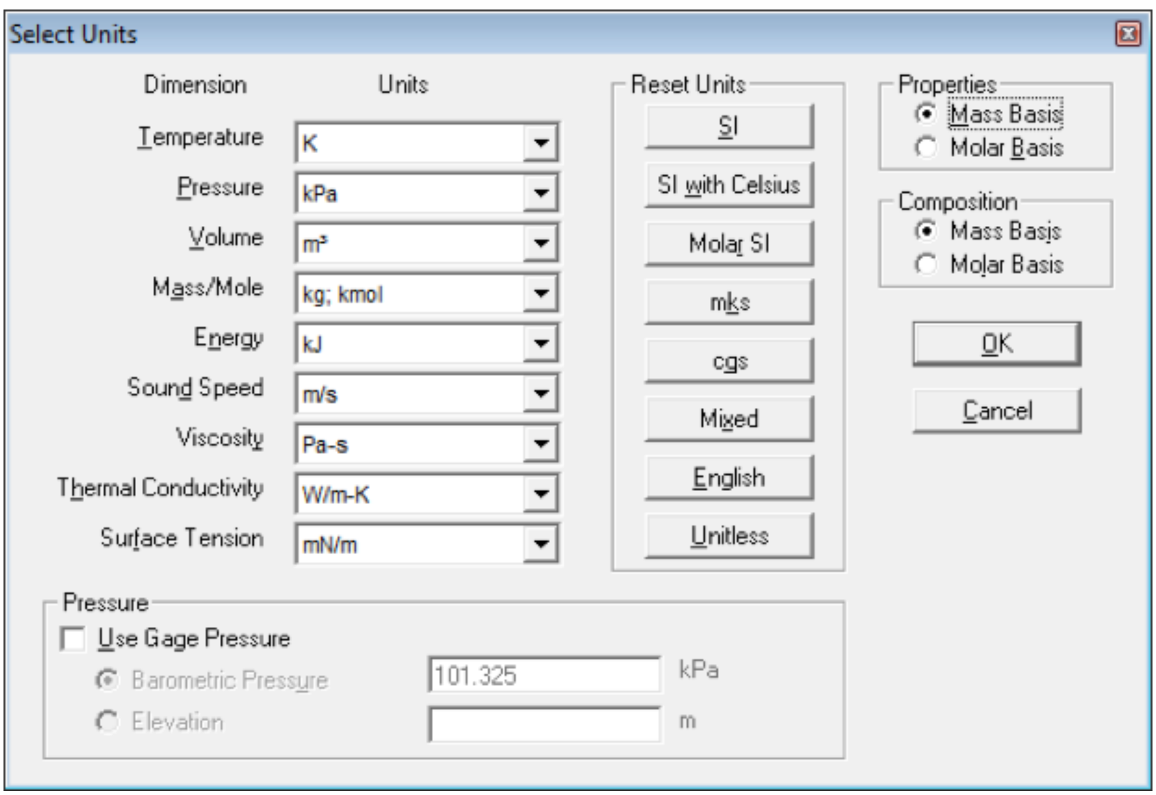
For English units:



For SI units:



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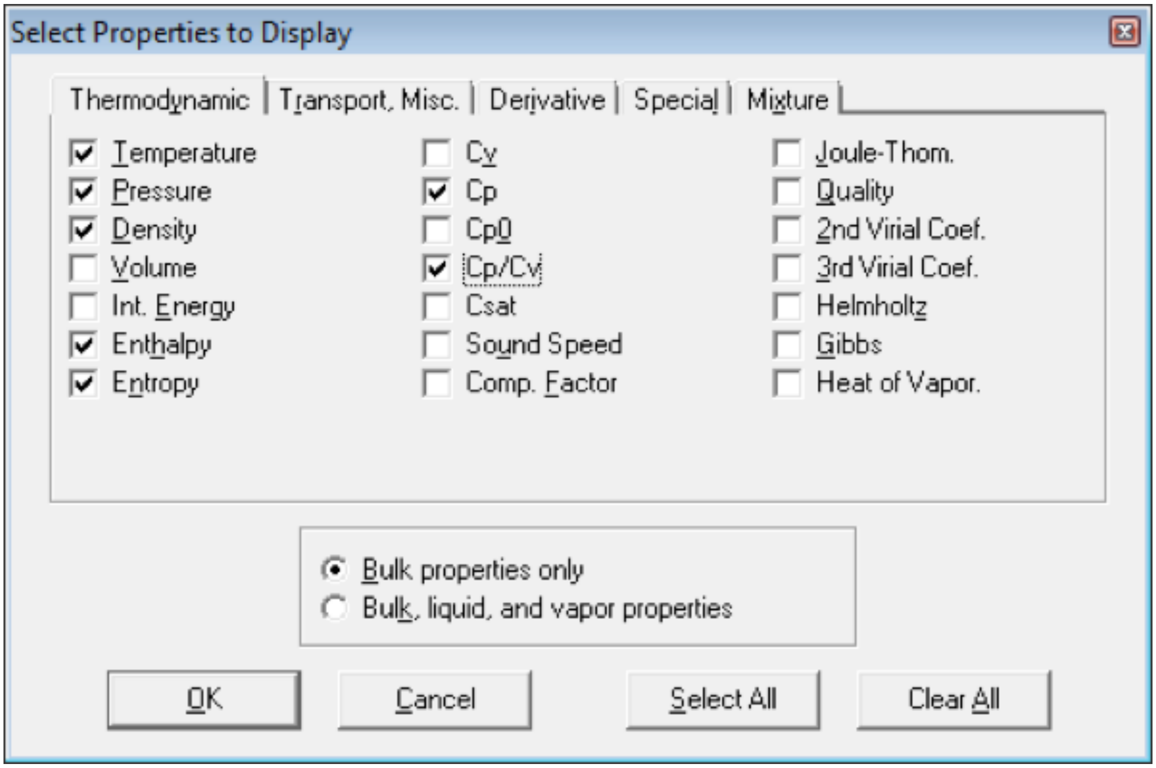
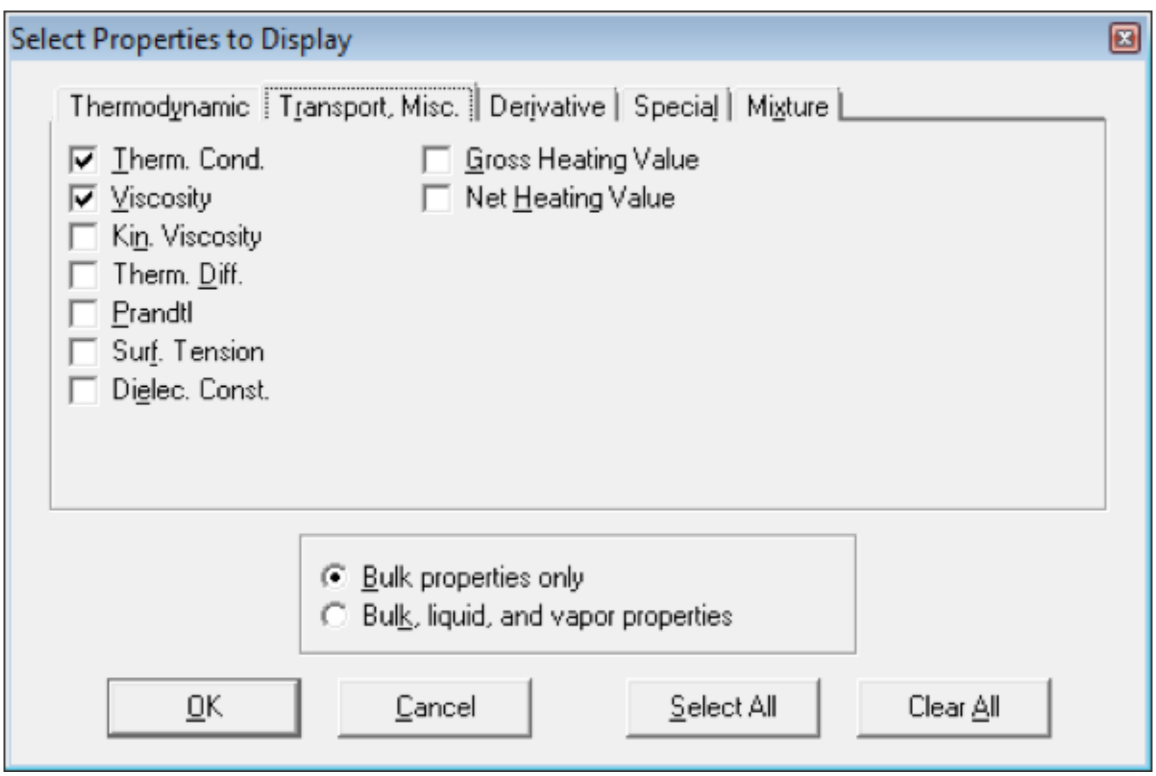
(2) Select OPTIONS/PROPERTIES and select Temperature, Pressure, Density, Enthalpy, Entropy, Cp, Cp/Cv, Thermal Conductivity, and Viscosity:





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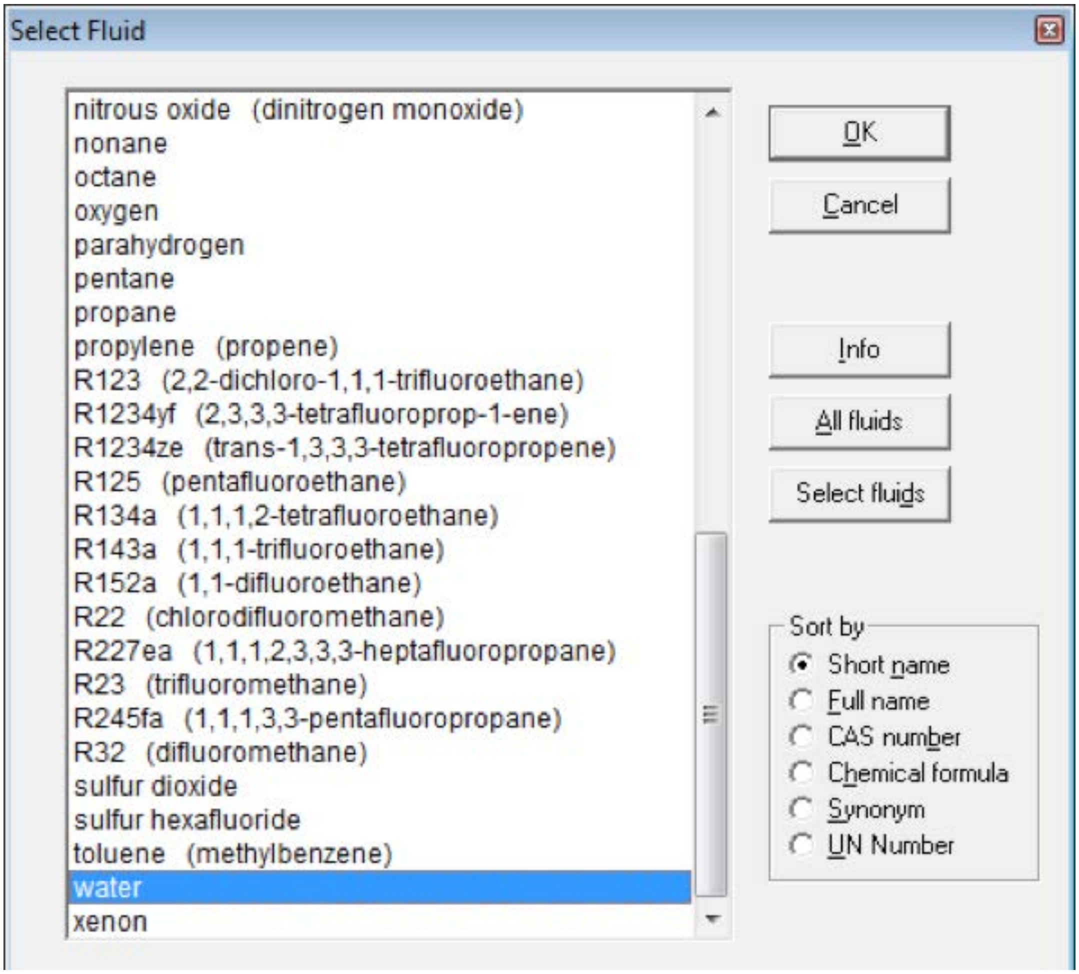
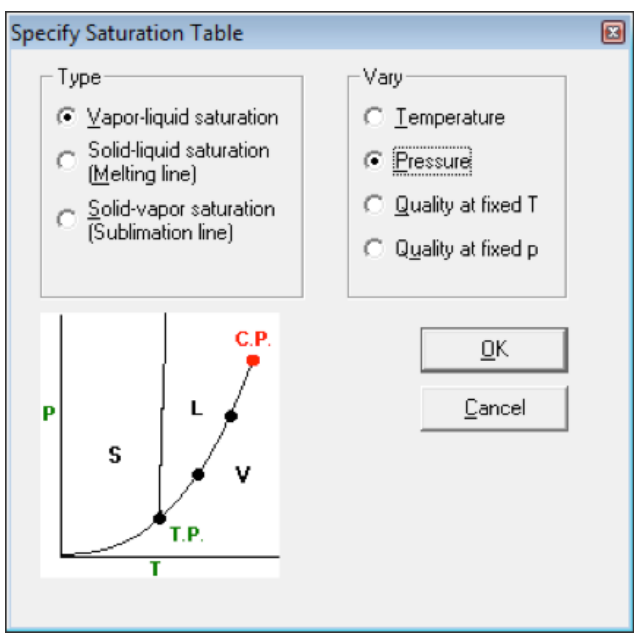
(3) Select SUBSTANCE/PURE FLUID and choose a fluid.



(4) Select CALCULATE/SATURATION TABLES, then choose to vary Pressure:



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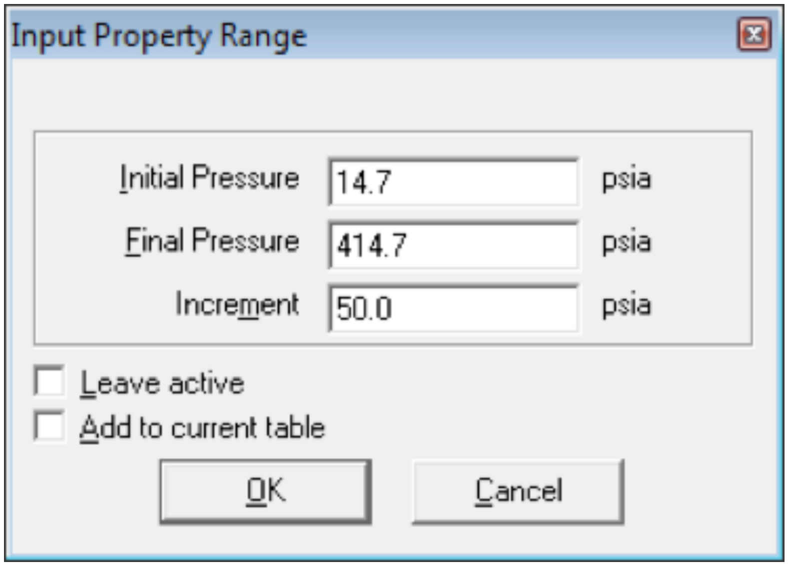
(5) Enter a pressure range and increment.

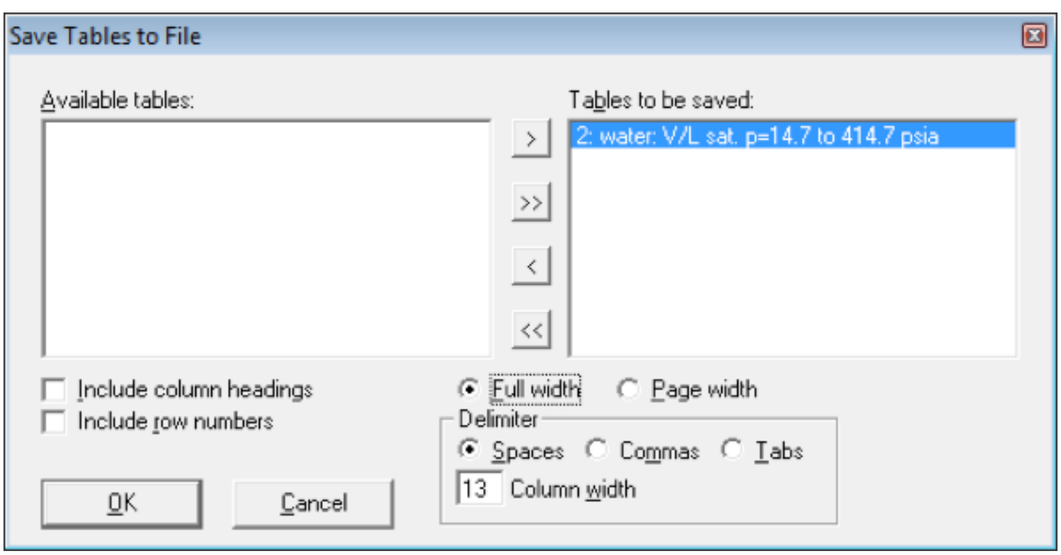


The example below shows saturated water properties at nine pressures.

1: water: V/L sat. p=14.7 to 414.7 psia

	Temperature (°R)	Pressure (psia)	Liquid Density (lbm/ft³)	Vapor Density (lbm/ft³)	Liquid Enthalpy (Btu/lbm)	Vapor Enthalpy (Btu/lbm)	Liquid Entropy (Btu/lbm-°R)	Vapor Entropy (Btu/lbm-°R)	Liquid Cp (Btu/lbm-°R)	Vapor Cp (Btu/lbm-°R)	Liquid Cp/Cv	Vapor Cp/Cv	Liquid Therm. Cond. (Btu/h-ft-°F)	Vapor Therm. Cond. (Btu/h-ft-°F)	Liquid Viscosity (lbm/ft-s)	Vapor Viscosity (lbm/ft-s)
1	671.64	14.700	59.829	0.037320	180.30	1151.0	0.31238	1.7577	1.0076	0.49712	1.1187	1.3369	0.39263	0.014509	0.00018925	0.0000082192
2	757.32	64.700	57.387	0.14960	267.48	1180.1	0.43431	1.6393	1.0279	0.56711	1.2169	1.3658	0.39456	0.018060	0.00012487	0.0000093258
3	797.54	114.70	56.031	0.25692	309.22	1190.7	0.48780	1.5931	1.0439	0.61990	1.2710	1.3917	0.39147	0.020084	0.00010741	0.0000098392
4	825.53	164.70	55.004	0.36269	338.71	1196.8	0.52393	1.5633	1.0582	0.66520	1.3126	1.4167	0.38791	0.021633	0.000097902	0.000010195
5	847.46	214.70	54.148	0.46796	362.13	1200.5	0.55172	1.5410	1.0717	0.70608	1.3479	1.4413	0.38429	0.022934	0.000091561	0.000010474
6	865.70	264.70	53.401	0.57329	381.85	1203.0	0.57455	1.5231	1.0847	0.74413	1.3795	1.4659	0.38070	0.024077	0.000086879	0.000010707
7	881.43	314.70	52.728	0.67901	399.06	1204.5	0.59405	1.5079	1.0974	0.78031	1.4087	1.4906	0.37714	0.025114	0.000083201	0.000010909
8	895.33	364.70	52.110	0.78534	414.44	1205.4	0.61116	1.4946	1.1100	0.81526	1.4362	1.5155	0.37363	0.026072	0.000080190	0.000011089
9	907.83	414.70	51.534	0.89246	428.42	1205.9	0.62647	1.4829	1.1226	0.84945	1.4625	1.5409	0.37016	0.026972	0.000077648	0.000011254

(6) Select FILE/SAVE TABLES. Uncheck the Include Column Headings and Include Row Numbers boxes, and set the Full Width radio button.



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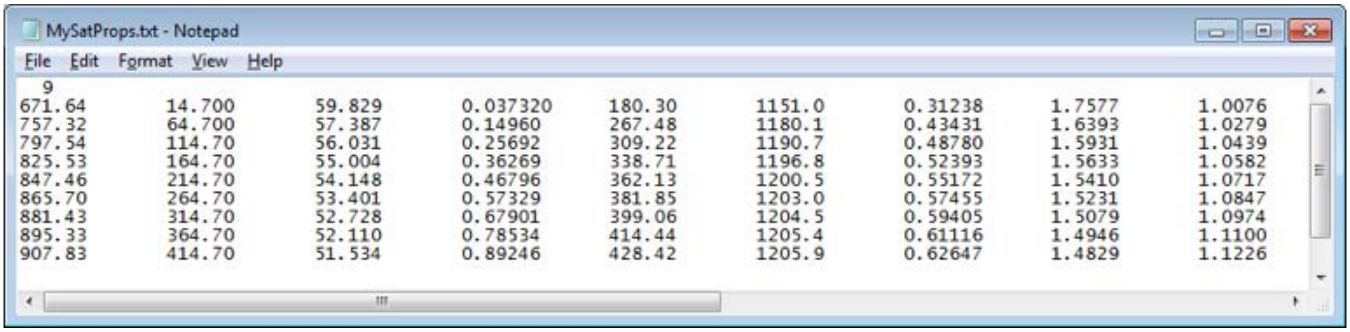
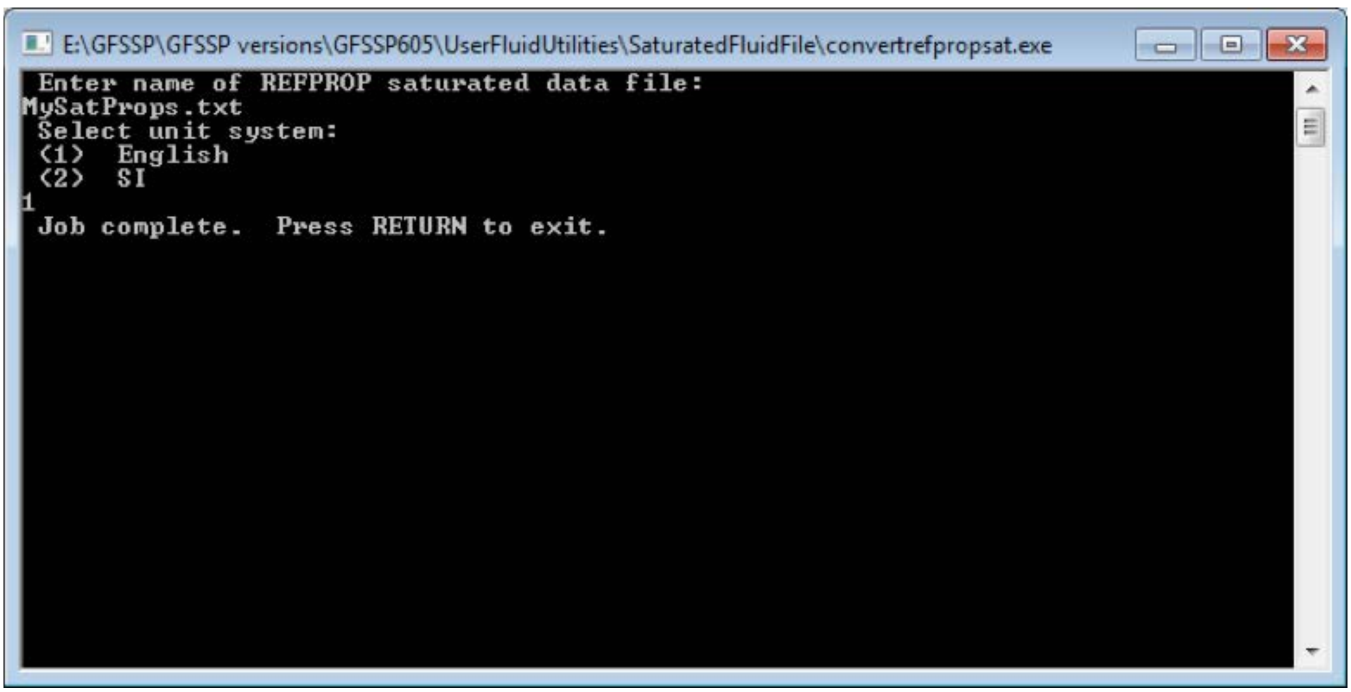
(7) Open the file you just saved with a text editor. Edit the file so that the first line gives the number of saturation pressures. In this example there are nine pressures.



9

671.64	14.700	59.829	0.037320	180.30	1151.0	0.31238	1.7577	1.0076
757.32	64.700	57.387	0.14960	267.48	1180.1	0.43431	1.6393	1.0279
797.54	114.70	56.031	0.25692	309.22	1190.7	0.48780	1.5931	1.0439
825.53	164.70	55.004	0.36269	338.71	1196.8	0.52393	1.5633	1.0582
847.46	214.70	54.148	0.46796	362.13	1200.5	0.55172	1.5410	1.0717
865.70	264.70	53.401	0.57329	381.85	1203.0	0.57455	1.5231	1.0847
881.43	314.70	52.728	0.67901	399.06	1204.5	0.59405	1.5079	1.0974
895.33	364.70	52.110	0.78534	414.44	1205.4	0.61116	1.4946	1.1100
907.83	414.70	51.534	0.89246	428.42	1205.9	0.62647	1.4829	1.1226

(8) Copy the program ConvertRefpropSat.exe to your working directory (Windows will not allow it to write output to the GFSSP installation directory). Run the program and enter the REFPROP data filename. Choose English or SI units (choosing English units converts the units of thermal conductivity from Btu/h-ft-°F to Btu/s-ft-°F). The program will produce the saturated properties data file in your working directory.



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APPENDIX G—LIST OF PUBLICATIONS WHERE GFSSP HAS BEEN USED

		Author(s)	Conference/Journal
1	A General Fluid System Simulation Program to Model Secondary Flows in Turbomachinery	Alok Majumdar Katherine Van Hooser	31st AIAA/ASME/SAE/ASEE Joint Propulsion Conference and Exhibit, San Diego, CA, July 10–12, 1995, AIAA 95-2969
2	Mathematical Modeling of Free Convective Flows for Evaluating Propellant Conditioning Concepts	Alok Majumdar John Bailey Kimberly Holt Susan Turner	32nd AIAA/ASME/SAE/ASEE Joint Propulsion Conference and Exhibit, Lake Buena Vista, FL, July 1–3, 1996, AIAA 96-3117
3	A Generalized Fluid System Simulation Program to Model Flow Distribution in Fluid Networks	Alok Majumdar John Bailey Biplab Sarkar	33rd AIAA/ASME/SAE/ASEE Joint Propulsion Conference and Exhibit, Seattle, WA, July 6–9, 1997, AIAA 97-3225
4	Numerical Prediction of Pressure Distribution Along the Front and Back Face of a Rotating Disc With and Without Blades	Paul Schallhorn Alok Majumdar	33rd AIAA/ASME/SAE/ASEE Joint Propulsion Conference and Exhibit, Seattle, WA, July 6–9, 1997, AIAA 97-3098
5	Flow Network Analyses of Cryogenic Hydrogen Propellant Storage and Feed Systems	Douglas Richards Daniel Vonderwell	33rd AIAA/ASME/SAE/ASEE Joint Propulsion Conference and Exhibit, Seattle, WA, July 6–9, 1997, AIAA 97-3223
6	A Generalized Fluid System Simulation Program to Model Flow Distribution in Fluid Networks	Alok Majumdar John Bailey Paul Schallhorn Todd Steadman	34th AIAA/ASME/SAE/ASEE Joint Propulsion Conference and Exhibit, Cleveland, OH, July 13–15, 1998, AIAA 98-3682
7	Flow Simulation in Secondary Flow Passages of a Rocket Engine Turbopump	Paul Schallhorn Alok Majumdar Katherine Van Hooser Matthew Marsh	34th AIAA/ASME/SAE/ASEE Joint Propulsion Conference and Exhibit, Cleveland, OH, July 13–15, 1998, AIAA 98-3684
8	A Novel Approach for Modeling Long Bearing Squeeze Film Damper Performance	Paul Schallhorn David Elrod David Goggin Alok Majumdar	34th AIAA/ASME/SAE/ASEE Joint Propulsion Conference and Exhibit, Cleveland, OH, July 13–15, 1998, AIAA 98-3684

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		Author(s)	Conference/Journal
9	Unstructured Finite Volume Computational Thermofluid Dynamics Method for Multi-Disciplinary Analysis and Design Optimization	Alok Majumdar Paul Schallhorn	7th AIAA/USAF/NASA/ISSMO Symposium on Multidisciplinary Analysis and Optimization, St. Louis, MO, September 2–4, 1998, AIAA 98-4810
10	***Numerical Modeling of Pressurization of a Propellant Tank***	***Alok Majumdar Todd Steadman***	***Journal of Propulsion and Power, Vol. 17, No. 2, pp. 385–390, 2001; 37th AIAA Aerospace Sciences Meeting Conference and Exhibit, Reno, NV, January 11–14, 1999, AIAA 99-0879***
11	A Second Law Based Unstructured Finite Volume Procedure for Generalized Flow Simulation	Alok Majumdar	37th AIAA Aerospace Sciences Meeting Conference and Exhibit, Reno, NV, January 11–14, 1999, AIAA 99-0934
12	Numerical Prediction of Transient Axial Thrust and Internal Flows in a Rocket Engine Turbopump	Katherine Van Hooser John Bailey Alok Majumdar	35th AIAA/ASME/SAE/ASEE Joint Propulsion Conference and Exhibit, Los Angeles, CA, June 21, 1999, AIAA 99-2189
13	Numerical Modeling of Helium Pressurization System of Propulsion Test Article (PTA)	Todd Steadman Alok Majumdar Kimberly Holt	Thermal & Fluids Analysis Workshop, September 13–17, 1999, Huntsville, AL
14	A Steady State and Quasi-Steady Interface Between the Generalized Fluid System Simulation Program and the SINDA/G Thermal Analysis Program	Paul Schallhorn Alok Majumdar Bruce Tiller	Thermal & Fluids Analysis Workshop, Huntsville, AL, September 13–17, 1999
15	Interfacing a General Purpose Fluid Network Flow Program with the Sinda/G Thermal Analysis Program	Paul Schallhorn Dan Popok	SAE Paper No. 1999-01-2162
16	An Unsteady Long Bearing Squeeze Film Damper Model – Part I: Circular Centered Orbits	Paul Schallhorn David Elrod David Goggin Alok Majumdar	38th AIAA Aerospace Sciences Meeting Conference and Exhibit, Reno, NV, January 11–14, 1999, AIAA 2000-0352

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		Author(s)	Conference/Journal
17	An Unsteady Long Bearing Squeeze Film Damper Model – Part II: Statically Eccentric Operation	Paul Schallhorn David Elrod David Goggin Alok Majumdar	38th AIAA Aerospace Sciences Meeting Conference and Exhibit, Reno, NV, January 11–14, 1999, AIAA 2000-0353
18	***A Fluid Circuit Model for Long Bearing Squeeze Film Damper Rotordynamics***	***Paul Schallhorn David Elrod David Goggin Alok Majumdar***	***AIAA Journal of Propulsion and Power, Vol. 16, No. 5, pp. 777–780, Sept–Oct 2000***
19	Unsteady Analysis of the Fluid Film Forces in a Long Bearing Squeeze Film Damper	Paul Schallhorn	Ph.D. Dissertation, The University of Alabama in Huntsville, 1998
20	Numerical Modeling and Test Data Comparison of Propulsion Test Article Helium Pressurization System	Kimberly Holt Alok Majumdar Todd Steadman Ali Hedayat	36th AIAA/ASME/SAE/ASEE Joint Propulsion Conference and Exhibit, Huntsville, AL, July 16–19, 2000, AIAA 2000-3719
21	Numerical Modeling of Drying Residual RP-1 in Rocket Engines	Alok Majumdar Robert Polsgrove Bruce Tiller	Thermal & Fluids Analysis Workshop, Cleveland, OH, August 21–25, 2000
22	Incorporation of Condensation Heat transfer Model into a Flow Network Code	Miranda Anthony Alok Majumdar	Thermal & Fluids Analysis Workshop, Huntsville, AL, September 10–14, 2001
23	Discharge Characteristics of the International Space Station (Ise) Portable Fire Extinguisher (Pfe) and the effect on Closed Volumes	Charles E Martin Paul Schallhorn Paul Wieland	SAE Paper No. 2001-01-2316
24	*Modeling of Chill Down in Cryogenic Transfer Lines*	*M. Cross A.K. Majumdar J. C. Bennett Jr. R. B. Malla*	***Journal of Spacecraft and Rockets, Vol. 39, No. 2, pp. 284–289, 2002***
25	Design optimization of a nuclear reactor for earth-to-orbit applications	T. Moton D. B Landrum, P. Schallhorn	40th AIAA Aerospace Sciences Meeting and Exhibit, Reno, NV, Jan. 14–17, 2002, AIAA-2002-363
26	Numerical modeling of cavitating venturi—a flow control element of propulsion system	Alok Majumdar	Thermal & Fluids Analysis Workshop, Houston, TX, August 12–16, 2002

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		Author(s)	Conference/Journal
27	Numerical Modeling of Fluid Transient by a Finite Volume Procedure for Rocket Propulsion Systems	Alok Majumdar Robin Flachbart	Proceedings of ASME FEDSM'03, 4th ASME/JSME Joint Fluids Engineering Conference, Paper No. FEDSM2003-45275, Honolulu, HI, July 6–10, 2003
28	Numerical Modeling of Thermofluid Transients During Chilldown of Cryogenic Transfer Lines	Alok Majumdar Todd Steadman	33rd International Conference on Environmental Systems (ICES), Paper No. 2003-01-2662, Vancouver, Canada, July 6–10, 2003
29	Numerical Modeling of Unsteady Thermofluid Dynamics in Cryogenic Systems	Alok Majumdar	Thermal & Fluids Analysis Workshop, Hampton, VA, August 18–22, 2003
30	A Novel Approach for Modeling Chemical Reaction in Generalized Fluid System Simulation Program	Mehmet Sozen Alok Majumdar	39th AIAA/ASME/SAE/ASEE Joint Propulsion Conference and Exhibit, Huntsville, AL, July 20–23, 2003, AIAA 2003-4467
31	Forward Looking Pressure Regulator Algorithm for Improved Modeling Performance Within the Generalized Fluid System Simulation Program http://pdf.aiaa.org/getfile.cfm?urlX=5%3A7I%276D%26X%5B%22%3F%28S0KUWT%5B%5EP%2B%3B%3C4JT%22%0A&urla=%%2ARH%%23PH %0A&urlb=%21%2A %0A&urlc=%21%2A0 %0A&urld=%28%2A%22T%22%21P%22ATA4 %0A&urle=%28%2A%22H%%21%40%2E%40T14 %0A	Paul Schallhorn Neal Hass	40th AIAA/ASME/SAE/ASEE Joint Propulsion Conference and Exhibit, Fort Lauderdale, FL, July 11–14, 2004, AIAA-2004-3667
32	Numerical Modeling of Conjugate Heat Transfer in Fluid Network	Alok Majumdar	Thermal & Fluids Analysis Workshop, Jet Propulsion Laboratory, Pasadena, CA, August 30–September 3, 2004,
33	Numerical Modeling of Flow Distribution in Microfluidics Systems	Alok Majumdar Helen Cole C. P. Chen	Proceedings of Forum on Microfluidics Devices and Systems, ASME Fluids Engineering Conference, Paper No. FEDSM 2005-77378, Houston, TX, June 19–23, 2005

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		Author(s)	Conference/Journal
34	Development and Implementation of NonNewtonian Rheology into the Generalized Fluid System Simulation Program (GFSSP)	Roberto Di Salvo Stelu Deaconn Alok Majumdar	42nd AIAA/ASME/SAE/ASEE Joint Propulsion Conference and Exhibit, Sacramento, CA, July 9–12, 2006,
35	Microfluidic System Simulation including the Electro-Viscous Effect	Eileen Rojas C. P. Chen Alok Majumdar	Integration and Commercialization of Macro and Nano Systems, ASME International Conference, Paper No. MNC2007-21295, Sanya, Hainan China, Jan. 10–13, 2007
36	***Numerical Modeling of Propellant Boil-off in a Cryogenic Storage Tank***	***A K Majumdar*** ***T E Steadman*** ***J L Maroney*** ***J P Sass*** ***J E Fesmire***	***Advances in Cryogenic Engineering, Volume 53 A, American Institute of Physics, pp. 1507–1516, 2008***
37	Computational Model of the Chilldown and Propellant Loading of the Space Shuttle External Tank	André C. LeClair Alok K. Majumdar	46th AIAA/ASME/SAE/ASEE Joint Propulsion Conference and Exhibit, Nashville, TN, July 25–28, 2010
38	***Computational Modeling of Fluid and Thermal Transients for Rocket Propulsion Systems by Fast Nonlinear Network Solver***	*Alok Majumdar* ***S.S. Ravindran***	***International Journal of Numerical Methods for Heat & Fluid Flow, Vol. 20, No. 6, pp. 617–637, 2010***
39	*Numerical Modeling of Conjugate Heat Transfer in Fluid Network*	***Alok Majumdar*** ***S.S. Ravindran***	***AIAA Journal of Propulsion and Power, Vol. 27(3), pp. 620–630, 2011***
40	Network Flow Simulation of Fluid Transients in Rocket Propulsion Systems	Alak Bandyopadhyay Brian Hamill Narayanan Ramachandran Alok Majumdar	JANNAF 8th MSS, 6th LPS. 5th SPS Joint Meeting, Huntsville, AL, December 5–8, 2011
41	Generalized Fluid System Simulation Program (GFSSP) Version 6 – General Purpose Thermo-fluid Network Analysis Software	Alok Majumdar Andre Leclair Ric Moore Paul Schallhorn	Thermal Fluids Analysis Workshop (TFAWS), Newport News, VA , August 15–19, 2011
42	Implementation of Finite Volume based Navier Stokes Algorithm within General Purpose Flow Network Code	Paul Schallhorn Alok Majumdar	50th AIAA Aerospace Sciences Meeting, Nashville, TN, January 9–12, 2012

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APPENDIX H—INPUT AND OUTPUT DATA FILES FROM EXAMPLE 1
Simulation of a Flow System Consisting of a Pump, Valve, and Pipe Line

Content

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```
GFSSP VERSION
    604
GFSSP INSTALLATION PATH

ANALYST
ALOK MAJUMDAR
INPUT DATA FILE NAME
Ex1.dat
OUTPUT FILE NAME
Ex1.out
TITLE
Simulation of a Flow System Consisting of a Pump, Valve and Pipe Line
USETUP
F
DENCON        GRAVITY       ENERGY        MIXTURE       THRUST        STEADY        TRANSV        SAVER
F             T             T             F             F             T             F             F
HEX           HCOEF         REACTING      INERTIA       CONDX         ADDPROP       PRINTI        ROTATION
F             F             F             F             F             F             T             F
BUOYANCY      HRATE         INVAL         MSORCE        MOVBND        TPA           VARGEO        TVM
F             T             F             F             F             F             F             F
SHEAR         PRNTIN        PRNTADD       OPVALVE       TRANSQ        CONJUG        RADIAT        WINPLOT
F             T             T             F             F             F             F             T
PRESS         INSUC         VARROT        CYCLIC        CHKVALS       WINFILE       DALTON        NOSTATS
F             F             F             F             F             T             F             F
NORMAL        SIMUL         SECONDL       NRSOLVT       IBDF          NOPLT         PRESREG       FLOWREG
F             T             T             F             1             T             0             0
TRANS_MOM     USERVARS      PSMG          ISOLVE        PLOTADD       SIUNITS       TECPLOT       MDGEN
F             F             F             1             F             F             F             F
NUM_USER_VARS IFR_MIX       PRINTD        SATTABL       MSORIN        PRELVLV       LAMINAR       HSTAG
1             1             F             F             F             F             T             T
NNODES        NINT          NBR           NF
 4            2            3            1
RELAXK        RELAXD        RELAXH        CC            NITER         RELAXNR       RELAXHC       RELAXTS
 1              0.5              1             0.0001          500 1             1                1
NFLUID(I),  I = 1, NF
 11
NODE          INDEX     DESCRIPTION
 1              2       " Node 1"
 2              1       " Node 2"
 3              1       " Node 3"
 4              2       " Node 4"
 NODE   PRES (PSI)   TEMP(DEGF)   MASS SOURC    HEAT SOURC   THRST AREA   CONCENTRATION
 1      14.7            60                0                  0                  0
 2      14.7            60                0                  0                  0
 3      14.7            60                0                  0                  0
 4      14.7            60                0                  0                  0
```

```
INODE         NUMBR         NAMEBR
 2             2            12   23
 3             2            23   34
BRANCH   UPNODE    DNNODE    OPTION    DESCRIPTION
12         1          2          14      "Pump 12"
23         2          3          13      "Valve 23"
34         3          4          1       "Pipe 34"
BRANCH        OPTION -14    PUMP CONST1   PUMP CONST2  PUMP CONST3    AREA
 12                         30888         0            -0.0008067    201.06
BRANCH        OPTION -13    DIA           K1            K2            AREA
 23                         6             1000         0.1           28.274
BRANCH        OPTION -1     LENGTH        DIA           EPSD          ANGLE         AREA
34   18000   6   0.005   95.74   28.27431
```

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```
 ***************************************************
              G F S S P (Version 604)
      Generalized Fluid System Simulation Program
                    March 2012

     Developed by NASA/Marshall Space Flight Center
     Copyright (C) by Marshall Space Flight Center

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


   RUN DATE:09/12/2012 14:51

 TITLE     :Simulation of a Flow System Consisting of a Pump, Valve and Pipe Line
 ANALYST   :ALOK MAJUMDAR
 FILEIN    :C:\Program Files (x86)\GFSSP604\TestInstalledExamples\EX1\Ex1.dat
 FILEOUT   :Ex1.out

                           OPTION VARIABLES

 ADDPROP   BUOYANCY  CONDX     CONJUG    CYCLIC    DALTON    DENCON    ENERGY
 F         F         F         F         F         F         F         T
 FLOWREG   GRAVITY   HCOEF     HEX       HRATE     IFRMIX    INERTIA   INSUC
 0         T         F         F         T         1         F         F
 INVAL     MIXTURE   MOVBND    MSORCE    NORMAL    NRSOLVT   OPVALVE   PLOTADD
 F         F         F         F         F         F         F         F
 PRESREG   PRESS     PRINTI    PRNTADD   PRNTIN    RADIATION REACTING  ROTATION
 0         F         T         T         T         F         F         F
 SAVER     SECONDL   SHEAR     SIMULA    SIUNITS   STEADY    THRUST    TPA
 F         T         F         T         F         T         F         F
 TRANS_MOM TRANSQ    TRANSV    TVM       TWOD      USRVAR    VARGEO    VARROT
 F         F         F         F         F         F         F         F
 RLFVLV
 F

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


 FLUIDS:  H2O
```

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

  INPUT SPECIFICATIONS FOR INTERNAL NODES
 NODE       AREA         MASS         HEAT
           (IN^2)       (LBM/S)      (BTU/S)
     2    0.0000E+00  0.0000E+00  0.0000E+00
     3    0.0000E+00  0.0000E+00  0.0000E+00

 BRANCH      UPNODE    DNNODE    OPTION
      12         1         2        14
      23         2         3        13
      34         3         4         1
 BRANCH OPTION -14:  PUMP CONS1 PUMP CONS2      PUMP CONS3 AREA
      12             0.309E+05   0.000E+00  -0.807E-03   0.201E+03
 BRANCH OPTION -13:  DIA  K1   K2  AREA
      23             0.600E+01   0.100E+04   0.100E+00   0.283E+02
 BRANCH  OPTION -1:   LENGTH      DIA        EPSD       ANGLE        AREA
      34             0.180E+05   0.600E+01   0.500E-02   0.957E+02   0.283E+02

 INITIAL GUESS FOR INTERNAL NODES

    NODE    P(PSI)   TF(F)      Z(COMP)        RHO       QUALITY
                                             (LBM/FT^3)
     2    0.1470E+02  0.6000E+02  0.7616E-03  0.6237E+02  0.0000E+00
     3    0.1470E+02  0.6000E+02  0.7616E-03  0.6237E+02  0.0000E+00

  TRIAL SOLUTION
   BRANCH    DELP(PSI)   FLOWRATE(LBM/SEC)
      12         0.0000     0.0100
      23         0.0000     0.0100
      34         0.0000     0.0100


 SOLUTION
 INTERNAL NODES
  NODE     P(PSI)      TF(F)        Z           RHO         EM(LBM)     QUALITY
                                              (LBM/FT^3)
     2    0.2290E+03  0.6003E+02  0.1185E-01  0.6241E+02  0.0000E+00  0.0000E+00
     3    0.2288E+03  0.6003E+02  0.1184E-01  0.6241E+02  0.0000E+00  0.0000E+00

    NODE       H          ENTROPY     EMU       COND        CP           GAMA
            BTU/LB       BTU/LB-R  LBM/FT-SEC  BTU/FT-S-R  BTU/LB-R
```

```
    2    0.2876E+02  0.5555E-01  0.7534E-03  0.9524E-04  0.1000E+01  0.1003E+01
    3    0.2876E+02  0.5556E-01  0.7534E-03  0.9524E-04  0.1000E+01  0.1003E+01

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


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

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


  SOLUTION SATISFIED CONVERGENCE CRITERION OF    0.100E-03 IN      5 ITERATIONS
 TAU =    100000000.000000       ISTEP =           1  DTAU =
   100000000.000000

 *************************************************

 TIME OF ANALYSIS WAS   1.562500000000000E-002  SECS

 *************************************************
```

APPENDIX I—INPUT AND OUTPUT DATA FILES FROM EXAMPLE 2

Simulation of a Water Distribution Network

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```
GFSSP VERSION
    604
GFSSP INSTALLATION PATH

ANALYST
Alok Majumdar
INPUT DATA FILE NAME
Ex2.dat
OUTPUT FILE NAME
Ex2.out
TITLE
Simulation of a water distribution network
USETUP
F
DENCON        GRAVITY       ENERGY        MIXTURE       THRUST        STEADY        TRANSV        SAVER
T             F             F             F             F             T             F             F
HEX           HCOEF         REACTING      INERTIA       CONDX         ADDPROP       PRINTI        ROTATION
F             F             F             F             F             F             T             F
BUOYANCY      HRATE         INVAL         MSORCE        MOVBND        TPA           VARGEO        TVM
F             F             F             F             F             F             F             F
SHEAR         PRNTIN        PRNTADD       OPVALVE       TRANSQ        CONJUG        RADIAT        WINPLOT
F             T             T             F             F             F             F             T
PRESS         INSUC         VARROT        CYCLIC        CHKVALS       WINFILE       DALTON        NOSTATS
F             F             F             F             F             T             F             F
NORMAL        SIMUL         SECONDL       NRSOLVT       IBDF          NOPLT         PRESREG       FLOWREG
F             T             T             F             1             T             0             0
TRANS_MOM     USERVARS      PSMG          ISOLVE        PLOTADD       SIUNITS       TECPLOT       MDGEN
F             F             F             1             F             F             F             F
NUM_USER_VARS IFR_MIX       PRINTD        SATTABL       MSORIN        PRELVLV       LAMINAR       HSTAG
1             1             F             F             F             F             T             T
NNODES        NINT          NBR           NF
 9            5            10            0
RELAXK        RELAXD        RELAXH        CC            NITER         RELAXNR       RELAXHC       RELAXTS
 1              0.5            1             0.0001          500 1               1               1
RHOREF        EMUREF
 62.4              0.00066
NODE          INDEX     DESCRIPTION
 1              2       " Node 1"
 2              1       " Node 2"
 3              2       " Node 3"
 4              2       " Node 4"
 5              1       " Node 5"
 6              1       " Node 6"
 7              1       " Node 7"
 8              1       " Node 8"
 9              2       " Node 9"
```

```
NODE  PRES (PSI)  MASS SOURC    HEAT SOURC   THRST AREA
 1      50               0                 0                 0
 2      49.6             0                 0                 0
 3      48               0                 0                 0
 4      45               0                 0                 0
 5      48.4             0                 0                 0
 6      47.4             0                 0                 0
 7      49.2             0                 0                 0
 8      46.4             0                 0                 0
 9      46               0                 0                 0
INODE         NUMBR         NAMEBR
 2             3            12   25   27
 5             4            25   53   57   56
 6             3            56   68   64
 7             3            27   57   78
 8             3            78   68   89
BRANCH   UPNODE    DNNODE    OPTION    DESCRIPTION
12         1          2          1       "Pipe 12"
25         2          5          1       "Pipe 25"
27         2          7          1       "Pipe 27"
53         5          3          1       "Pipe 53"
57         5          7          1       "Pipe 57"
56         5          6          1       "Pipe 56"
78         7          8          1       "Pipe 78"
68         6          8          1       "Pipe 68"
64         6          4          1       "Pipe 64"
89         8          9          1       "Pipe 89"
BRANCH        OPTION -1     LENGTH        DIA           EPSD          ANGLE         AREA
 12                         120               6             0.0018            0                 28.27431
BRANCH        OPTION -1     LENGTH        DIA           EPSD          ANGLE         AREA
 25                         2400              6             0.0018            0                 28.27431
BRANCH        OPTION -1     LENGTH        DIA           EPSD          ANGLE         AREA
 27                         2400              5             0.0018            0                 19.6349375
BRANCH        OPTION -1     LENGTH        DIA           EPSD          ANGLE         AREA
 53                         120               5             0.0018            0                 19.6349375
BRANCH        OPTION -1     LENGTH        DIA           EPSD          ANGLE         AREA
 57                         1440              4             0.0018            0                 12.56636
BRANCH        OPTION -1     LENGTH        DIA           EPSD          ANGLE         AREA
 56                         2400              4             0.0018            0                 12.56636
BRANCH        OPTION -1     LENGTH        DIA           EPSD          ANGLE         AREA
 78                         2400              4             0.0018            0                 12.56636
BRANCH        OPTION -1     LENGTH        DIA           EPSD          ANGLE         AREA
 68                         1440              4             0.0018            0                 12.56636
BRANCH        OPTION -1     LENGTH        DIA           EPSD          ANGLE         AREA
 64                         120               4             0.0018            0                 12.56636
BRANCH        OPTION -1     LENGTH        DIA           EPSD          ANGLE         AREA
             89                         120               5             0.0018            0                 19.6349375
```

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```
 **************************************************
              G F S S P (Version 604)
      Generalized Fluid System Simulation Program
                    March 2012

     Developed by NASA/Marshall Space Flight Center
     Copyright (C) by Marshall Space Flight Center

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


   RUN DATE:09/12/2012 14:53

TITLE     :Simulation of a water distribution network
ANALYST   :Alok Majumdar
FILEIN    :C:\Program Files (x86)\GFSSP604\TestInstalledExamples\EX2\Ex2.dat
FILEOUT   :Ex2.out

                           OPTION VARIABLES

ADDPROP   BUOYANCY  CONDX     CONJUG    CYCLIC    DALTON    DENCON    ENERGY
F         F         F         F         F         F         T         F
FLOWREG   GRAVITY   HCOEF     HEX       HRATE     IFRMIX    INERTIA   INSUC
0         F         F         F         F         1         F         F
INVAL     MIXTURE   MOVBND    MSORCE    NORMAL    NRSOLVT   OPVALVE   PLOTADD
F         F         F         F         F         F         F         F
PRESREG   PRESS     PRINTI    PRNTADD   PRNTIN    RADIATION REACTING  ROTATION
0         F         T         T         T         F         F         F
SAVER     SECONDL   SHEAR     SIMULA    SIUNITS   STEADY    THRUST    TPA
F         T         F         T         F         T         F         F
TRANS_MOM TRANSQ    TRANSV    TVM       TWOD      USRVAR    VARGEO    VARROT
F         F         F         F         F         F         F         F
RLFVLV
F

NNODES    =    9
NINT      =    5
NBR       =   10
NF        =    0
NVAR      =   15
NHREF     =    2

RHOREF    =    62.4000 LBM/FT**3
EMUREF    =   0.6600E-03 LBM/FT-SEC
```

```
 BOUNDARY NODES
  NODE        P        AREA
            (PSI)     (IN^2)
     1    0.5000E+02  0.0000E+00
     3    0.4800E+02  0.0000E+00
     4    0.4500E+02  0.0000E+00
     9    0.4600E+02  0.0000E+00

  INPUT SPECIFICATIONS FOR INTERNAL NODES
 NODE       AREA         MASS         HEAT
           (IN^2)       (LBM/S)     (BTU/LBM)
     2    0.0000E+00  0.0000E+00  0.0000E+00
     5    0.0000E+00  0.0000E+00  0.0000E+00
     6    0.0000E+00  0.0000E+00  0.0000E+00
     7    0.0000E+00  0.0000E+00  0.0000E+00
     8    0.0000E+00  0.0000E+00  0.0000E+00

 BRANCH      UPNODE    DNNODE    OPTION
      12         1         2         1
      25         2         5         1
      27         2         7         1
      53         5         3         1
      57         5         7         1
      56         5         6         1
      78         7         8         1
      68         6         8         1
      64         6         4         1
      89         8         9         1
 BRANCH  OPTION -1:   LENGTH      DIA        EPSD       ANGLE        AREA
      12             0.120E+03   0.600E+01   0.180E-02   0.000E+00   0.283E+02
 BRANCH  OPTION -1:   LENGTH      DIA        EPSD       ANGLE        AREA
      25             0.240E+04   0.600E+01   0.180E-02   0.000E+00   0.283E+02
 BRANCH  OPTION -1:   LENGTH      DIA        EPSD       ANGLE        AREA
      27             0.240E+04   0.500E+01   0.180E-02   0.000E+00   0.196E+02
 BRANCH  OPTION -1:   LENGTH      DIA        EPSD       ANGLE        AREA
      53             0.120E+03   0.500E+01   0.180E-02   0.000E+00   0.196E+02
 BRANCH  OPTION -1:   LENGTH      DIA        EPSD       ANGLE        AREA
      57             0.144E+04   0.400E+01   0.180E-02   0.000E+00   0.126E+02
 BRANCH  OPTION -1:   LENGTH      DIA        EPSD       ANGLE        AREA
      56             0.240E+04   0.400E+01   0.180E-02   0.000E+00   0.126E+02
 BRANCH  OPTION -1:   LENGTH      DIA        EPSD       ANGLE        AREA
      78             0.240E+04   0.400E+01   0.180E-02   0.000E+00   0.126E+02
 BRANCH  OPTION -1:   LENGTH      DIA        EPSD       ANGLE        AREA
      68             0.144E+04   0.400E+01   0.180E-02   0.000E+00   0.126E+02
 BRANCH  OPTION -1:   LENGTH      DIA        EPSD       ANGLE        AREA
      64             0.120E+03   0.400E+01   0.180E-02   0.000E+00   0.126E+02
```

```
BRANCH  OPTION -1:   LENGTH      DIA        EPSD       ANGLE        AREA
      89             0.120E+03   0.500E+01   0.180E-02   0.000E+00   0.196E+02

 INITIAL GUESS FOR INTERNAL NODES

  NODE  P(PSI)
     2    0.4960E+02
     5    0.4840E+02
     6    0.4740E+02
     7    0.4920E+02
     8    0.4640E+02

  TRIAL SOLUTION
   BRANCH    DELP(PSI)   FLOWRATE(LBM/SEC)
      12         0.0000     0.0100
      25         0.0000     0.0100
      27         0.0000     0.0100
      53         0.0000     0.0100
      57         0.0000     0.0100
      56         0.0000     0.0100
      78         0.0000     0.0100
      68         0.0000     0.0100
      64         0.0000     0.0100
      89         0.0000     0.0100


 SOLUTION
 INTERNAL NODES
  NODE     P(PSI)      EM(LBM)
     2    0.4979E+02  0.0000E+00
     5    0.4810E+02  0.0000E+00
     6    0.4535E+02  0.0000E+00
     7    0.4833E+02  0.0000E+00
     8    0.4600E+02  0.0000E+00

 BRANCHES
BRANCH       KFACTOR       DELP        FLOW RATE   VELOCITY    REYN. NO.   MACH NO.   ENTROPY GEN.   LOST WORK
      (LBF-S^2/(LBM-FT)^2)  (PSI)       (LBM/SEC)     (FT/SEC)                            BTU/(R-SEC)   LBF-FT/SEC
      12     0.301E-02     0.210E+00   0.100E+03     0.817E+01   0.386E+06   0.000E+00   0.135E-03   0.484E+02
      25     0.609E-01     0.169E+01   0.631E+02     0.515E+01   0.244E+06   0.000E+00   0.687E-03   0.246E+03
      27     0.154E+00     0.146E+01   0.370E+02     0.435E+01   0.171E+06   0.000E+00   0.349E-03   0.125E+03
      53     0.762E-02     0.104E+00   0.444E+02     0.522E+01   0.206E+06   0.000E+00   0.300E-04   0.107E+02
      57     0.301E+00    -0.224E+00  -0.104E+02    -0.190E+01   0.599E+05   0.000E+00   0.150E-04   0.536E+01
      56     0.469E+00     0.275E+01   0.291E+02     0.534E+01   0.168E+06   0.000E+00   0.516E-03   0.184E+03
      78     0.471E+00     0.232E+01   0.267E+02     0.490E+01   0.154E+06   0.000E+00   0.400E-03   0.143E+03
      68     0.289E+00    -0.650E+00  -0.180E+02    -0.331E+01   0.104E+06   0.000E+00   0.755E-04   0.270E+02
      64     0.230E-01     0.355E+00   0.471E+02     0.864E+01   0.272E+06   0.000E+00   0.108E-03   0.385E+02
```

```
     89     0.858E-02     0.447E-02   0.866E+01     0.102E+01   0.401E+05   0.000E+00   0.249E-06   0.892E-01

         ***** TOTAL ENTROPY GENERATION =    0.232E-02 BTU/(R-SEC) ******

         **** TOTAL WORK LOST =    0.151E+01 HP *****


 SOLUTION SATISFIED CONVERGENCE CRITERION OF    0.100E-03 IN     11 ITERATIONS
TAU =    100000000.000000       ISTEP =           1  DTAU =
  100000000.000000

*************************************************

TIME OF ANALYSIS WAS   0.000000000000000E+000  SECS
*************************************************
```

APPENDIX J—INPUT AND OUTPUT DATA FILES FROM EXAMPLE 3

Simulation of a Compressible Flow in a Converging-Diverging Nozzle

Contents

Back to Appendix J

```
GFSSP VERSION
    604
GFSSP INSTALLATION PATH

ANALYST
jwb
INPUT DATA FILE NAME
Ex3.dat
OUTPUT FILE NAME
Ex3.out
TITLE
Simulation of Compressible Flow in a Converging-Diverging Nozzle
USETUP
F
DENCON        GRAVITY       ENERGY        MIXTURE       THRUST        STEADY        TRANSV        SAVER
F             F             T             F             F             T             F             F
HEX           HCOEF         REACTING      INERTIA       CONDX         ADDPROP       PRINTI        ROTATION
F             F             F             T             F             F             F             F
BUOYANCY      HRATE         INVAL         MSORCE        MOVBND        TPA           VARGEO        TVM
F             F             F             F             F             F             F             F
SHEAR         PRNTIN        PRNTADD       OPVALVE       TRANSQ        CONJUG        RADIAT        WINPLOT
F             F             F             F             F             F             F             T
PRESS         INSUC         VARROT        CYCLIC        CHKVALS       WINFILE       DALTON        NOSTATS
F             F             F             F             F             T             F             F
NORMAL        SIMUL         SECONDL       NRSOLVT       IBDF          NOPLT         PRESREG       FLOWREG
F             T             T             F             1             T             0             0
TRANS_MOM     USERVARS      PSMG          ISOLVE        PLOTADD       SIUNITS       TECPLOT       MDGEN
F             F             F             1             F             F             F             F
NUM_USER_VARS IFR_MIX       PRINTD        SATTABL       MSORIN        PRELVLV       LAMINAR       HSTAG
1             1             F             F             F             F             T             T
NNODES        NINT          NBR           NF
 17            15            16            1
RELAXK        RELAXD        RELAXH        CC            NITER         RELAXNR       RELAXHC       RELAXTS
 1               0.5             1              0.0001         500 1              1                1
NFLUID(I),  I = 1, NF
 11
NODE          INDEX     DESCRIPTION
 1              2       " Node 1"
 2              1       " Node 2"
 3              1       " Node 3"
 4              1       " Node 4"
 5              1       " Node 5"
 6              1       " Node 6"
 7              1       " Node 7"
 8              1       " Node 8"
 9              1       " Node 9"
 10              1       " Node 10"
```

```
 11             1       " Node 11"
 12             1       " Node 12"
 13             1       " Node 13"
 14             1       " Node 14"
 15             1       " Node 15"
 16             1       " Node 16"
 17             2       " Node 17"
 NODE  PRES (PSI)  TEMP(DEGF)  MASS SOURC    HEAT SOURC   THRST AREA   CONCENTRATION
 1     150             1000             0                  0                  0
 2     14.7            60               0                  0                  0
 3     14.7            60               0                  0                  0
 4     14.7            60               0                  0                  0
 5     14.7            60               0                  0                  0
 6     14.7            60               0                  0                  0
 7     14.7            60               0                  0                  0
 8     14.7            60               0                  0                  0
 9     14.7            60               0                  0                  0
 10    14.7            60               0                  0                  0
 11    14.7            60               0                  0                  0
 12    14.7            60               0                  0                  0
 13    14.7            60               0                  0                  0
 14    14.7            60               0                  0                  0
 15    14.7            60               0                  0                  0
 16    14.7            60               0                  0                  0
 17    60              1000             0                  0                  0
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
 16             2             1516   1617
BRANCH   UPNODE    DNNODE    OPTION    DESCRIPTION
12         1         2          2       "Restrict 12"
23         2         3          2       "Restrict 23"
34         3         4          2       "Restrict 34"
45         4         5          2       "Restrict 45"
56         5         6          2       "Restrict 56"
```

```
67         6          7          2       "Restrict 67"
78         7          8          2       "Restrict 78"
89         8          9          2       "Restrict 89"
910        9          10         2       "Restrict 910"
1011       10         11         2       "Restrict 1011"
1112       11         12         2       "Restrict 1112"
1213       12         13         2       "Restrict 1213"
1314       13         14         2       "Restrict 1314"
1415       14         15         2       "Restrict 1415"
1516       15         16         2       "Restrict 1516"
1617       16         17         2       "Restrict 1617"
BRANCH        OPTION -2     FLOW COEFF    AREA
 12                         0             0.3587
BRANCH        OPTION -2     FLOW COEFF    AREA
 23                         0             0.2717
BRANCH        OPTION -2     FLOW COEFF    AREA
 34                         0             0.2243
BRANCH        OPTION -2     FLOW COEFF    AREA
 45                         0             0.2083
BRANCH        OPTION -2     FLOW COEFF    AREA
 56                         0             0.1901
BRANCH        OPTION -2     FLOW COEFF    AREA
 67                         0             0.1949
BRANCH        OPTION -2     FLOW COEFF    AREA
 78                         0             0.2255
BRANCH        OPTION -2     FLOW COEFF    AREA
 89                         0             0.2875
BRANCH        OPTION -2     FLOW COEFF    AREA
 910                        0             0.3948
BRANCH        OPTION -2     FLOW COEFF    AREA
 1011                       0             0.564
BRANCH        OPTION -2     FLOW COEFF    AREA
 1112                       0             0.7633
BRANCH        OPTION -2     FLOW COEFF    AREA
 1213                       0             0.9927
BRANCH        OPTION -2     FLOW COEFF    AREA
 1314                       0             1.252
BRANCH        OPTION -2     FLOW COEFF    AREA
 1415                       0             1.4668
BRANCH        OPTION -2     FLOW COEFF    AREA
 1516                       0             1.5703
BRANCH        OPTION -2     FLOW COEFF    AREA
 1617                       0             1.6286
BRANCH        NOUBR         NMUBR
 12    0
 23    1    12
 34    1    23
```

```
 45    1   34
 56    1   45
 67    1   56
 78    1   67
 89    1   78
 910    1   89
 1011    1   910
 1112    1   1011
 1213    1   1112
 1314    1   1213
 1415    1   1314
 1516    1   1415
 1617    1   1516
BRANCH         NODBR          NMDBR
 12    1   23
 23    1   34
 34    1   45
 45    1   56
 56    1   67
 67    1   78
 78    1   89
 89    1   910
 910    1   1011
 1011    1   1112
 1112    1   1213
 1213    1   1314
 1314    1   1415
 1415    1   1516
 1516    1   1617
 1617    0
BRANCH
 12
  UPSTRM BR.     ANGLE
  DNSTRM BR.     ANGLE
   23     0.00000
BRANCH
 23
  UPSTRM BR.     ANGLE
   12     0.00000
  DNSTRM BR.     ANGLE
   34     0.00000
BRANCH
 34
  UPSTRM BR.     ANGLE
   23     0.00000
  DNSTRM BR.     ANGLE
   45     0.00000
```

```
BRANCH
 45
  UPSTRM BR.     ANGLE
   34     0.00000
  DNSTRM BR.     ANGLE
   56     0.00000
BRANCH
 56
  UPSTRM BR.     ANGLE
   45     0.00000
  DNSTRM BR.     ANGLE
   67     0.00000
BRANCH
 67
  UPSTRM BR.     ANGLE
   56     0.00000
  DNSTRM BR.     ANGLE
   78     0.00000
BRANCH
 78
  UPSTRM BR.     ANGLE
   67     0.00000
  DNSTRM BR.     ANGLE
   89     0.00000
BRANCH
 89
  UPSTRM BR.     ANGLE
   78     0.00000
  DNSTRM BR.     ANGLE
   910     0.00000
BRANCH
 910
  UPSTRM BR.     ANGLE
   89     0.00000
  DNSTRM BR.     ANGLE
   1011     0.00000
BRANCH
 1011
  UPSTRM BR.     ANGLE
   910     0.00000
  DNSTRM BR.     ANGLE
   1112     0.00000
BRANCH
 1112
  UPSTRM BR.     ANGLE
   1011     0.00000
  DNSTRM BR.     ANGLE
```

```
   1213     0.00000
BRANCH
 1213
  UPSTRM BR.     ANGLE
   1112     0.00000
  DNSTRM BR.     ANGLE
   1314     0.00000
BRANCH
 1314
  UPSTRM BR.     ANGLE
   1213     0.00000
  DNSTRM BR.     ANGLE
   1415     0.00000
BRANCH
 1415
  UPSTRM BR.     ANGLE
   1314     0.00000
  DNSTRM BR.     ANGLE
   1516     0.00000
BRANCH
 1516
  UPSTRM BR.     ANGLE
   1415     0.00000
  DNSTRM BR.     ANGLE
   1617     0.00000
BRANCH
 1617
  UPSTRM BR.     ANGLE
   1516     0.00000
  DNSTRM BR.     ANGLE
NUMBER OF BRANCHES WITH INERTIA
 16
 12
 23
 34
 45
 56
 67
 78
 89
 910
 1011
 1112
 1213
 1314
 1415
 1516
 1617
```

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```
            **************************************************
                       G F S S P (Version 604)
               Generalized Fluid System Simulation Program
                             March 2012

              Developed by NASA/Marshall Space Flight Center
              Copyright (C) by Marshall Space Flight Center

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


            RUN DATE:09/12/2012 14:56

TITLE     :Simulation of Compressible Flow in a Converging-Diverging Nozzle
ANALYST   :jwb
FILEIN    :C:\Program Files (x86)\GFSSP604\TestInstalledExamples\EX3\Ex3.dat
FILEOUT   :Ex3.out

                           OPTION VARIABLES

ADDPROP   BUOYANCY  CONDX     CONJUG    CYCLIC    DALTON    DENCON    ENERGY
F         F         F         F         F         F         F         T
FLOWREG   GRAVITY   HCOEF     HEX       HRATE     IFRMIX    INERTIA   INSUC
0         F         F         F         F         1         T         F
INVAL     MIXTURE   MOVBND    MSORCE    NORMAL    NRSOLVT   OPVALVE   PLOTADD
F         F         F         F         F         F         F         F
PRESREG   PRESS     PRINTI    PRNTADD   PRNTIN    RADIATION REACTING  ROTATION
0         F         F         F         F         F         F         F
SAVER     SECONDL   SHEAR     SIMULA    SIUNITS   STEADY    THRUST    TPA
F         T         F         T         F         T         F         F
TRANS_MOM TRANSQ    TRANSV    TVM       TWOD      USRVAR    VARGEO    VARROT
F         F         F         F         F         F         F         F
RLFVLV
F

NNODES   =   17
NINT     =   15
NBR      =   16
NF       =    1
NVAR     =   31
NHREF    =    2


FLUIDS:  H2O
```

BOUNDARY NODES

NODE	P (PSI)	T (F)	RHO (LBM/FT^3)		AREA (IN^2)
1	0.1500E+03	0.1000E+04	0.1736E+00	0.0000E+00	
17	0.6000E+02	0.1000E+04	0.6918E-01	0.0000E+00	

SOLUTION

INTERNAL NODES

NODE	P(PSI)	TF(F)	Z	RHO (LBM/FT^3)	EM(LBM)	QUALITY
2	0.1500E+03	0.1000E+04	0.9939E+00	0.1736E+00	0.0000E+00	0.1000E+01
3	0.1373E+03	0.9725E+03	0.9939E+00	0.1620E+00	0.0000E+00	0.1000E+01
4	0.1197E+03	0.9305E+03	0.9941E+00	0.1455E+00	0.0000E+00	0.1000E+01
5	0.1045E+03	0.8897E+03	0.9942E+00	0.1308E+00	0.0000E+00	0.1000E+01
6	0.8213E+02	0.8199E+03	0.9944E+00	0.1084E+00	0.0000E+00	0.1000E+01
7	0.5974E+02	0.7320E+03	0.9946E+00	0.8463E-01	0.0000E+00	0.1000E+01
8	0.4267E+02	0.6445E+03	0.9948E+00	0.6523E-01	0.0000E+00	0.1000E+01
9	0.3498E+02	0.5953E+03	0.9950E+00	0.5597E-01	0.0000E+00	0.1000E+01
10	0.4116E+02	0.6354E+03	0.9949E+00	0.6344E-01	0.0000E+00	0.1000E+01
11	0.5165E+02	0.6935E+03	0.9947E+00	0.7560E-01	0.0000E+00	0.1000E+01
12	0.5650E+02	0.7172E+03	0.9946E+00	0.8105E-01	0.0000E+00	0.1000E+01
13	0.5839E+02	0.7259E+03	0.9946E+00	0.8315E-01	0.0000E+00	0.1000E+01
14	0.5930E+02	0.7301E+03	0.9946E+00	0.8414E-01	0.0000E+00	0.1000E+01
15	0.5974E+02	0.7320E+03	0.9946E+00	0.8463E-01	0.0000E+00	0.1000E+01
16	0.5991E+02	0.7328E+03	0.9946E+00	0.8482E-01	0.0000E+00	0.1000E+01

BRANCHES

BRANCH	KFACTOR (LBF-S^2/(LBM-FT)^2)	DELP (PSI)	FLOW RATE (LBM/SEC)	VELOCITY (FT/SEC)	REYN. NO.	MACH NO.	ENTROPY GEN. BTU/(R-SEC)	LOST WORK LBF-FT/SEC
12	0.000E+00	0.000E+00	0.336E+00	0.778E+03	0.376E+06	0.342E+00	0.000E+00	0.000E+00
23	0.000E+00	0.127E+02	0.336E+00	0.103E+04	0.432E+06	0.452E+00	0.000E+00	0.000E+00
34	0.000E+00	0.176E+02	0.336E+00	0.133E+04	0.485E+06	0.592E+00	0.000E+00	0.000E+00
45	0.000E+00	0.153E+02	0.336E+00	0.160E+04	0.520E+06	0.720E+00	0.000E+00	0.000E+00
56	0.000E+00	0.223E+02	0.336E+00	0.195E+04	0.563E+06	0.890E+00	0.000E+00	0.000E+00
67	0.000E+00	0.224E+02	0.336E+00	0.229E+04	0.591E+06	0.107E+01	0.000E+00	0.000E+00
78	0.000E+00	0.171E+02	0.336E+00	0.254E+04	0.595E+06	0.123E+01	0.000E+00	0.000E+00
89	0.000E+00	0.769E+01	0.336E+00	0.258E+04	0.576E+06	0.130E+01	0.000E+00	0.000E+00
910	0.000E+00	-0.618E+01	0.336E+00	0.219E+04	0.518E+06	0.112E+01	0.000E+00	0.000E+00
1011	0.000E+00	-0.105E+02	0.336E+00	0.135E+04	0.415E+06	0.682E+00	0.000E+00	0.000E+00
1112	0.000E+00	-0.485E+01	0.336E+00	0.840E+03	0.336E+06	0.413E+00	0.000E+00	0.000E+00
1213	0.000E+00	-0.189E+01	0.336E+00	0.602E+03	0.288E+06	0.293E+00	0.000E+00	0.000E+00
1314	0.000E+00	-0.903E+00	0.336E+00	0.465E+03	0.254E+06	0.226E+00	0.000E+00	0.000E+00
1415	0.000E+00	-0.443E+00	0.336E+00	0.393E+03	0.234E+06	0.190E+00	0.000E+00	0.000E+00
1516	0.000E+00	-0.174E+00	0.336E+00	0.365E+03	0.226E+06	0.177E+00	0.000E+00	0.000E+00
1617	0.000E+00	-0.857E-01	0.336E+00	0.351E+03	0.221E+06	0.170E+00	0.000E+00	0.000E+00

```
         ***** TOTAL ENTROPY GENERATION =    0.000E+00 BTU/(R-SEC) ******

         **** TOTAL WORK LOST =    0.000E+00 HP *****

 ************************************************

 TIME OF ANALYSIS WAS   3.125000000000000E-002  SECS

 ************************************************
```

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APPENDIX K—INPUT AND OUTPUT DATA FILES FROM EXAMPLE 4

Simulation of the Mixing of Combustion Gases and a Cold Gas Stream

Contents

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```
GFSSP VERSION
    604
GFSSP INSTALLATION PATH

ANALYST
ALOK MAJUMDAR
INPUT DATA FILE NAME
Ex4.dat
OUTPUT FILE NAME
Ex4.out
TITLE
Simulation of the Mixing of Combustion Gases and a Cold Gas Stream
USETUP
F
DENCON        GRAVITY       ENERGY        MIXTURE       THRUST        STEADY        TRANSV        SAVER
F             F             T             T             F             T             F             F
HEX           HCOEF         REACTING      INERTIA       CONDX         ADDPROP       PRINTI        ROTATION
F             F             F             F             F             F             T             F
BUOYANCY      HRATE         INVAL         MSORCE        MOVBND        TPA           VARGEO        TVM
F             T             F             F             F             F             F             F
SHEAR         PRNTIN        PRNTADD       OPVALVE       TRANSQ        CONJUG        RADIAT        WINPLOT
F             T             T             F             F             F             F             T
PRESS         INSUC         VARROT        CYCLIC        CHKVALS       WINFILE       DALTON        NOSTATS
F             F             F             F             F             T             F             F
NORMAL        SIMUL         SECONDL       NRSOLVT       IBDF          NOPLT         PRESREG       FLOWREG
F             F             F             F             1             T             0             0
TRANS_MOM     USERVARS      PSMG          ISOLVE        PLOTADD       SIUNITS       TECPLOT       MDGEN
F             F             F             1             F             F             F             F
NUM_USER_VARS IFR_MIX       PRINTD        SATTABL       MSORIN        PRELVLV       LAMINAR       HSTAG
1             1             F             F             F             F             T             T
NNODES        NINT          NBR           NF
 4            1            3            2
RELAXK        RELAXD        RELAXH        CC            NITER         RELAXNR       RELAXHC       RELAXTS
 1               0.5           0.75          0.0001         500 1             1                1
NFLUID(I),  I = 1, NF
 6 11
NODE          INDEX     DESCRIPTION
 1              2       " Node 1"
 2              2       " Node 2"
 3              1       " Node 3"
 4              2       " Node 4"
 NODE   PRES (PSI)  TEMP(DEGF)  MASS SOURC    HEAT SOURC   THRST AREA   CONCENTRATION
 1      500              1500           0                  0                  0                0.1 0.9
 2      500              80             0                  0                  0                1 0
 3      338.2            1500           0                  0                  0                0.1 0.9
 4      14.7             80             0                  0                  0                0.5 0.5
INODE         NUMBR         NAMEBR
```

```
 3             3            13   23   34
BRANCH   UPNODE    DNNODE    OPTION    DESCRIPTION
13         1          3          2       "Restrict 13"
23         2          3          2       "Restrict 23"
34         3          4          22      "Orifice 34"
BRANCH        OPTION -2     FLOW COEFF    AREA
 13                         0.6           1
BRANCH        OPTION -2     FLOW COEFF    AREA
 23                         0.6           1
BRANCH        OPTION -22     AREA       FLOW COEF
 34                         1             0.6
```

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```
**************************************************
             G F S S P (Version 604)
     Generalized Fluid System Simulation Program
                 March 2012

    Developed by NASA/Marshall Space Flight Center
    Copyright (C) by Marshall Space Flight Center

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


  RUN DATE:09/12/2012 14:57

TITLE     :Simulation of the Mixing of Combustion Gases and a Cold Gas Stream
ANALYST   :ALOK MAJUMDAR
FILEIN    :C:\Program Files (x86)\GFSSP604\TestInstalledExamples\EX4\Ex4.dat
FILEOUT   :Ex4.out

                           OPTION VARIABLES

ADDPROP   BUOYANCY  CONDX     CONJUG    CYCLIC    DALTON    DENCON    ENERGY
F         F         F         F         F         F         F         T
FLOWREG   GRAVITY   HCOEF     HEX       HRATE     IFRMIX    INERTIA   INSUC
0         F         F         F         T         1         F         F
INVAL     MIXTURE   MOVBND    MSORCE    NORMAL    NRSOLVT   OPVALVE   PLOTADD
F         T         F         F         F         F         F         F
PRESREG   PRESS     PRINTI    PRNTADD   PRNTIN    RADIATION REACTING  ROTATION
0         F         T         T         T         F         F         F
SAVER     SECONDL   SHEAR     SIMULA    SIUNITS   STEADY    THRUST    TPA
F         F         F         F         F         T         F         F
TRANS_MOM TRANSQ    TRANSV    TVM       TWOD      USRVAR    VARGEO    VARROT
F         F         F         F         F         F         F         F
RLFVLV
F

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


FLUIDS:  O2   H2O
```

```
BOUNDARY NODES
    NODE       P          T          RHO        AREA         CONCENTRATIONS
             (PSI)       (F)      (LBM/FT^3)   (IN^2)
                                                    O2        H2O
    1    0.5000E+03  0.1500E+04  0.4419E+00  0.0000E+00  0.1000E+00  0.9000E+00
    2    0.5000E+03  0.8000E+02  0.2819E+01  0.0000E+00  0.1000E+01  0.0000E+00
    4    0.1470E+02  0.8000E+02  0.4727E+02  0.0000E+00  0.5000E+00  0.5000E+00

 INPUT SPECIFICATIONS FOR INTERNAL NODES
NODE       AREA         MASS         HEAT
          (IN^2)       (LBM/S)      (BTU/S)
    3    0.0000E+00  0.0000E+00  0.0000E+00

BRANCH      UPNODE    DNNODE    OPTION
     13         1         3         2
     23         2         3         2
     34         3         4        22
BRANCH OPTION -2:  FLOW COEF  AREA
     13            0.600E+00   0.100E+01
BRANCH OPTION -2:  FLOW COEF  AREA
     23            0.600E+00   0.100E+01
BRANCH OPTION -22 FLOW COEF   AREA
     34            0.600E+00   0.100E+01

INITIAL GUESS FOR INTERNAL NODES

   NODE    P(PSI)   TF(F)      Z(COMP)    RHO       CONCENTRATIONS
                                         (LBM/FT^3)
                                                              O2        H2O
    3    0.3382E+03  0.1500E+04  0.9968E+00  0.3040E+00  0.1000E+00  0.9000E+00

 TRIAL SOLUTION
  BRANCH    DELP(PSI)   FLOWRATE(LBM/SEC)
     13         0.0000     0.0100
     23         0.0000     0.0100
     34         0.0000     0.0100


SOLUTION
INTERNAL NODES
    NODE     P(PSI)      TF(F)         Z         RHO        EM(LBM)    CONC
                                             (LBM/FT^3)
                                                              O2        H2O
    3    0.4799E+03  0.7045E+03  0.9865E+00  0.1040E+01  0.0000E+00  0.7447E+00  0.2553

   NODE       H          ENTROPY     EMU       COND        CP          GAMA
```

```
           BTU/LB       BTU/LB-R  LBM/FT-SEC  BTU/FT-S-R  BTU/LB-R

    3    0.0000E+00  0.1533E+01  0.2091E-04  0.8265E-05  0.3819E+00  0.1293E+01

 BRANCHES
BRANCH       KFACTOR       DELP        FLOW RATE   VELOCITY    REYN. NO.   MACH NO.   ENTROPY GEN.   LOST WORK
      (LBF-S^2/(LBM-FT)^2) (PSI)       (LBM/SEC)     (FT/SEC)                           BTU/(R-SEC)   LBF-FT/SEC
      13     0.203E+04     0.201E+02   0.120E+01     0.390E+03   0.578E+06   0.152E+00   0.515E-02   0.786E+04
      23     0.318E+03     0.201E+02   0.302E+01     0.154E+03   0.286E+07   0.139E+00   0.741E-02   0.311E+04
      34     0.861E+03     0.465E+03   0.422E+01     0.585E+03   0.273E+07   0.349E+00   0.686E-01   0.622E+05

  WARNING! CHKGASP: T out of fluid property range at node   1

  WARNING! CHKGASP: T out of fluid property range at node   3


  SOLUTION SATISFIED CONVERGENCE CRITERION OF    0.100E-03 IN     27 ITERATIONS
 TAU =    100000000.000000       ISTEP =           1  DTAU =
   100000000.000000

 *************************************************

 TIME OF ANALYSIS WAS   0.000000000000000E+000  SECS

 *************************************************
```

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APPENDIX L—INPUT AND OUTPUT DATA FILES FROM EXAMPLE 5

Simulation of a Flow System Involving a Heat Exchanger

Contents

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```
GFSSP VERSION
    604
GFSSP INSTALLATION PATH

ANALYST
Todd Steadman
INPUT DATA FILE NAME
Ex5.dat
OUTPUT FILE NAME
Ex5.out
TITLE
Simulation of a Flow System Involving a Heat Exchanger
USETUP
F
DENCON        GRAVITY       ENERGY        MIXTURE       THRUST        STEADY        TRANSV        SAVER
F             F             T             F             F             T             F             F
HEX           HCOEF         REACTING      INERTIA       CONDX         ADDPROP       PRINTI        ROTATION
T             T             F             F             F             F             F             F
BUOYANCY      HRATE         INVAL         MSORCE        MOVBND        TPA           VARGEO        TVM
F             T             F             F             F             F             F             F
SHEAR         PRNTIN        PRNTADD       OPVALVE       TRANSQ        CONJUG        RADIAT        WINPLOT
F             T             F             F             F             F             F             T
PRESS         INSUC         VARROT        CYCLIC        CHKVALS       WINFILE       DALTON        NOSTATS
F             F             F             F             F             T             F             F
NORMAL        SIMUL         SECONDL       NRSOLVT       IBDF          NOPLT         PRESREG       FLOWREG
F             T             T             F             1             T             0             0
TRANS_MOM     USERVARS      PSMG          ISOLVE        PLOTADD       SIUNITS       TECPLOT       MDGEN
F             F             F             1             F             F             F             F
NUM_USER_VARS IFR_MIX       PRINTD        SATTABL       MSORIN        PRELVLV       LAMINAR       HSTAG
1             1             F             F             F             F             T             T
NNODES        NINT          NBR           NF
 8            4            6            1
RELAXK        RELAXD        RELAXH        CC            NITER         RELAXNR       RELAXHC       RELAXTS
 1              0.5           1                0.0001          500 1          1               1
NFLUID(I),  I = 1, NF
 11
NODE          INDEX     DESCRIPTION
 1              2       " Node 1"
 2              1       " Node 2"
 3              1       " Node 3"
 4              2       " Node 4"
 5              2       " Node 5"
 6              1       " Node 6"
 7              1       " Node 7"
 8              2       " Node 8"
 NODE   PRES (PSI)   TEMP(DEGF)   MASS SOURC    HEAT SOURC    THRST AREA    CONCENTRATION
 1      50              100              0                  0                  0
```

```
 2     14.7            60               0                 0                 0
 3     14.7            60               0                 0                 0
 4     25              60               0                 0                 0
 5     50              60               0                 0                 0
 6     14.7            60               0                 0                 0
 7     14.7            60               0                 0                 0
 8     25              60               0                 0                 0
INODE         NUMBR         NAMEBR
 2             2            12   23
 3             2            23   34
 6             2            56   67
 7             2            67   78
BRANCH   UPNODE    DNNODE    OPTION    DESCRIPTION
12         1          2         1       "Pipe 12"
23         2          3         1       "Pipe 23"
34         3          4         1       "Pipe 34"
56         5          6         1       "Pipe 56"
67         6          7         1       "Pipe 67"
78         7          8         1       "Pipe 78"
BRANCH        OPTION -1     LENGTH        DIA           EPSD          ANGLE         AREA
 12                         10                0.25            0                 0                 0.04908734375
BRANCH        OPTION -1     LENGTH        DIA           EPSD          ANGLE         AREA
 23                         10                0.25            0                 0                 0.04908734375
BRANCH        OPTION -1     LENGTH        DIA           EPSD          ANGLE         AREA
 34                         10                0.25            0                 0                 0.04908734375
BRANCH        OPTION -1     LENGTH        DIA           EPSD          ANGLE         AREA
 56                         10                0.5             0                 0                 0.196349375
BRANCH        OPTION -1     LENGTH        DIA           EPSD          ANGLE         AREA
 67                         10                0.5             0                 0                 0.196349375
BRANCH        OPTION -1     LENGTH        DIA           EPSD          ANGLE         AREA
 78                         10                0.5             0                 0                 0.196349375
NUMBER OF HEAT EXCHANGERS
1
 IBRHOT   IBRCLD   ITYPHX   ARHOT      ARCOLD      UA     HEXEFF
23     67      1       0         0          1.1038     1.5
```

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```
**************************************************
              G F S S P (Version 604)
     Generalized Fluid System Simulation Program
                  March 2012

    Developed by NASA/Marshall Space Flight Center
    Copyright (C) by Marshall Space Flight Center

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


  RUN DATE:09/12/2012 14:57

TITLE     :Simulation of a Flow System Involving a Heat Exchanger
ANALYST   :Todd Steadman
FILEIN    :C:\Program Files (x86)\GFSSP604\TestInstalledExamples\EX5\Ex5.dat
FILEOUT   :Ex5.out

                           OPTION VARIABLES

ADDPROP   BUOYANCY  CONDX     CONJUG    CYCLIC    DALTON    DENCON    ENERGY
F         F         F         F         F         F         F         T
FLOWREG   GRAVITY   HCOEF     HEX       HRATE     IFRMIX    INERTIA   INSUC
0         F         T         T         T         1         F         F
INVAL     MIXTURE   MOVBND    MSORCE    NORMAL    NRSOLVT   OPVALVE   PLOTADD
F         F         F         F         F         F         F         F
PRESREG   PRESS     PRINTI    PRNTADD   PRNTIN    RADIATION REACTING  ROTATION
0         F         F         F         T         F         F         F
SAVER     SECONDL   SHEAR     SIMULA    SIUNITS   STEADY    THRUST    TPA
F         T         F         T         F         T         F         F
TRANS_MOM TRANSQ    TRANSV    TVM       TWOD      USRVAR    VARGEO    VARROT
F         F         F         F         F         F         F         F
RLFVLV
F

NNODES    =     8
NINT      =     4
NBR       =     6
NF        =     1
NVAR      =    10
NHREF     =     2


FLUIDS:  H2O
```

```
BOUNDARY NODES
   NODE        P           T         RHO                      AREA
             (PSI)        (F)     (LBM/FT^3)                  (IN^2)
    1    0.5000E+02  0.1000E+03  0.6200E+02  0.0000E+00
    4    0.2500E+02  0.6000E+02  0.6237E+02  0.0000E+00
    5    0.5000E+02  0.6000E+02  0.6238E+02  0.0000E+00
    8    0.2500E+02  0.6000E+02  0.6237E+02  0.0000E+00

 INPUT SPECIFICATIONS FOR INTERNAL NODES
NODE       AREA         MASS         HEAT
          (IN^2)       (LBM/S)      (BTU/S)
    2    0.0000E+00  0.0000E+00  0.0000E+00
    3    0.0000E+00  0.0000E+00  0.0000E+00
    6    0.0000E+00  0.0000E+00  0.0000E+00
    7    0.0000E+00  0.0000E+00  0.0000E+00

BRANCH      UPNODE    DNNODE    OPTION
     12         1         2         1
     23         2         3         1
     34         3         4         1
     56         5         6         1
     67         6         7         1
     78         7         8         1
BRANCH  OPTION -1:   LENGTH      DIA         EPSD       ANGLE        AREA
     12             0.100E+02   0.250E+00   0.000E+00   0.000E+00   0.491E-01
BRANCH  OPTION -1:   LENGTH      DIA         EPSD       ANGLE        AREA
     23             0.100E+02   0.250E+00   0.000E+00   0.000E+00   0.491E-01
BRANCH  OPTION -1:   LENGTH      DIA         EPSD       ANGLE        AREA
     34             0.100E+02   0.250E+00   0.000E+00   0.000E+00   0.491E-01
BRANCH  OPTION -1:   LENGTH      DIA         EPSD       ANGLE        AREA
     56             0.100E+02   0.500E+00   0.000E+00   0.000E+00   0.196E+00
BRANCH  OPTION -1:   LENGTH      DIA         EPSD       ANGLE        AREA
     67             0.100E+02   0.500E+00   0.000E+00   0.000E+00   0.196E+00
BRANCH  OPTION -1:   LENGTH      DIA         EPSD       ANGLE        AREA
     78             0.100E+02   0.500E+00   0.000E+00   0.000E+00   0.196E+00


SOLUTION
INTERNAL NODES
 NODE     P(PSI)      TF(F)        Z           RHO         EM(LBM)     QUALITY
                                            (LBM/FT^3)
    2    0.4185E+02  0.1000E+03  0.2025E-02  0.6200E+02  0.0000E+00  0.0000E+00
    3    0.3370E+02  0.7180E+02  0.1709E-02  0.6229E+02  0.0000E+00  0.0000E+00
    6    0.4163E+02  0.6002E+02  0.2157E-02  0.6237E+02  0.0000E+00  0.0000E+00
    7    0.3327E+02  0.6451E+02  0.1709E-02  0.6235E+02  0.0000E+00  0.0000E+00
```

BRANCHES

BRANCH	KFACTOR (LBF-S^2/(LBM-FT)^2)	DELP (PSI)	FLOW RATE (LBM/SEC)	VELOCITY (FT/SEC)	REYN. NO.	MACH NO.	ENTROPY GEN. BTU/(R-SEC)	LOST WORK LBF-FT/SEC
12	0.150E+04	0.815E+01	0.885E+00	0.419E+02	0.118E+06	0.333E-01	0.385E-04	0.167E+02
23	0.150E+04	0.815E+01	0.885E+00	0.419E+02	0.118E+06	0.333E-01	0.385E-04	0.167E+02
34	0.160E+04	0.870E+01	0.885E+00	0.417E+02	0.845E+05	0.343E-01	0.430E-04	0.178E+02
56	0.412E+02	0.837E+01	0.541E+01	0.636E+02	0.219E+06	0.530E-01	0.258E-03	0.104E+03
67	0.412E+02	0.837E+01	0.541E+01	0.636E+02	0.219E+06	0.530E-01	0.258E-03	0.104E+03
78	0.407E+02	0.827E+01	0.541E+01	0.637E+02	0.234E+06	0.528E-01	0.253E-03	0.103E+03

***** TOTAL ENTROPY GENERATION =   0.890E-03 BTU/(R-SEC) ******

**** TOTAL WORK LOST =   0.661E+00 HP *****

****

TIME OF ANALYSIS WAS   0.000000000000000E+000 SECS

****

APPENDIX M—INPUT AND OUTPUT DATA FILES FROM EXAMPLE 6

Radial Flow on a Rotating Disk

Contents

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```
GFSSP VERSION
    604
GFSSP INSTALLATION PATH

ANALYST
Paul Schallhorn
INPUT DATA FILE NAME
Ex6.dat
OUTPUT FILE NAME
Ex6.out
TITLE
Radial Flow on a Rotating Radial Disk
USETUP
F
DENCON        GRAVITY       ENERGY        MIXTURE       THRUST        STEADY        TRANSV        SAVER
F             F             T             F             F             T             F             F
HEX           HCOEF         REACTING      INERTIA       CONDX         ADDPROP       PRINTI        ROTATION
F             F             F             T             F             F             T             T
BUOYANCY      HRATE         INVAL         MSORCE        MOVBND        TPA           VARGEO        TVM
F             T             F             F             F             F             F             F
SHEAR         PRNTIN        PRNTADD       OPVALVE       TRANSQ        CONJUG        RADIAT        WINPLOT
F             F             F             F             F             F             F             T
PRESS         INSUC         VARROT        CYCLIC        CHKVALS       WINFILE       DALTON        NOSTATS
F             F             F             F             F             T             F             F
NORMAL        SIMUL         SECONDL       NRSOLVT       IBDF          NOPLT         PRESREG       FLOWREG
F             T             F             F             1             T             0             0
TRANS_MOM     USERVARS      PSMG          ISOLVE        PLOTADD       SIUNITS       TECPLOT       MDGEN
F             F             F             1             F             F             F             F
NUM_USER_VARS IFR_MIX       PRINTD        SATTABL       MSORIN        PRELVLV       LAMINAR       HSTAG
1             1             F             F             F             F             T             T
NNODES        NINT          NBR           NF
 13            11            12            1
RELAXK        RELAXD        RELAXH        CC            NITER         RELAXNR       RELAXHC       RELAXTS
 1               0.5           1                0.0001          500 1             1                1
NFLUID(I),  I = 1, NF
 11
NODE          INDEX     DESCRIPTION
 1              2       " Node 1"
 2              1       " Node 2"
 3              1       " Node 3"
 4              1       " Node 4"
 5              1       " Node 5"
 6              1       " Node 6"
 7              1       " Node 7"
 8              1       " Node 8"
 9              1       " Node 9"
 10              1       " Node 10"
```

```
 11             1       " Node 11"
 12             1       " Node 12"
 13             2       " Node 13"
 NODE  PRES (PSI)  TEMP(DEGF)  MASS SOURC    HEAT SOURC   THRST AREA   CONCENTRATION
 1     90              80               0                  0                  0
 2     14.7            70               0                  0                  0
 3     14.7            70               0                  0                  0
 4     14.7            70               0                  0                  0
 5     14.7            70               0                  0                  0
 6     14.7            70               0                  0                  0
 7     14.7            70               0                  0                  0
 8     14.7            70               0                  0                  0
 9     14.7            70               0                  0                  0
 10    14.7            70               0                  0                  0
 11    14.7            70               0                  0                  0
 12    14.7            70               0                  0                  0
 13    30              80               0                  0                  0
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    DESCRIPTION
12         1          2         2       "Restrict 12"
23         2          3         2       "Restrict 23"
34         3          4         2       "Restrict 34"
45         4          5         2       "Restrict 45"
56         5          6         2       "Restrict 56"
67         6          7         2       "Restrict 67"
78         7          8         2       "Restrict 78"
89         8          9         2       "Restrict 89"
910        9          10        2       "Restrict 910"
1011       10         11        2       "Restrict 1011"
1112       11         12        2       "Restrict 1112"
1213       12         13        2       "Restrict 1213"
BRANCH        OPTION -2     FLOW COEFF    AREA
 12                         0             3.1416
BRANCH        OPTION -2     FLOW COEFF    AREA
 23                         0             1.8041
BRANCH        OPTION -2     FLOW COEFF    AREA
```

```
 34                           0              3.2218
BRANCH        OPTION -2     FLOW COEFF    AREA
 45                           0              4.6767
BRANCH        OPTION -2     FLOW COEFF    AREA
 56                           0              5.7231
BRANCH        OPTION -2     FLOW COEFF    AREA
 67                           0              6.2062
BRANCH        OPTION -2     FLOW COEFF    AREA
 78                           0              68.33
BRANCH        OPTION -2     FLOW COEFF    AREA
 89                           0              6.2062
BRANCH        OPTION -2     FLOW COEFF    AREA
 910                          0              5.7231
BRANCH        OPTION -2     FLOW COEFF    AREA
 1011                         0              4.6767
BRANCH        OPTION -2     FLOW COEFF    AREA
 1112                         0              3.4605
BRANCH        OPTION -2     FLOW COEFF    AREA
 1213                         0.02189        6.2299
BRANCH        NOUBR         NMUBR
 12    0
 23    1   12
 34    1   23
 45    1   34
 56    1   45
 67    1   56
 78    1   67
 89    1   78
 910    1   89
 1011    1   910
 1112    1   1011
 1213    1   1112
BRANCH        NODBR         NMDBR
 12    1   23
 23    1   34
 34    1   45
 45    1   56
 56    1   67
 67    1   78
 78    1   89
 89    1   910
 910    1   1011
 1011    1   1112
 1112    1   1213
 1213    0
BRANCH
 12
```

```
  UPSTRM BR.     ANGLE
  DNSTRM BR.     ANGLE
   23     0.00000
BRANCH
 23
  UPSTRM BR.     ANGLE
   12     0.00000
  DNSTRM BR.     ANGLE
   34     0.00000
BRANCH
 34
  UPSTRM BR.     ANGLE
   23     0.00000
  DNSTRM BR.     ANGLE
   45     0.00000
BRANCH
 45
  UPSTRM BR.     ANGLE
   34     0.00000
  DNSTRM BR.     ANGLE
   56     0.00000
BRANCH
 56
  UPSTRM BR.     ANGLE
   45     0.00000
  DNSTRM BR.     ANGLE
   67     0.00000
BRANCH
 67
  UPSTRM BR.     ANGLE
   56     0.00000
  DNSTRM BR.     ANGLE
   78     0.00000
BRANCH
 78
  UPSTRM BR.     ANGLE
   67     0.00000
  DNSTRM BR.     ANGLE
   89     0.00000
BRANCH
 89
  UPSTRM BR.     ANGLE
   78     0.00000
  DNSTRM BR.     ANGLE
   910     0.00000
BRANCH
 910
```

```
  UPSTRM BR.     ANGLE
   89     0.00000
  DNSTRM BR.     ANGLE
   1011     0.00000
BRANCH
 1011
  UPSTRM BR.     ANGLE
   910     0.00000
  DNSTRM BR.     ANGLE
   1112     0.00000
BRANCH
 1112
  UPSTRM BR.     ANGLE
   1011     0.00000
  DNSTRM BR.     ANGLE
   1213     0.00000
BRANCH
 1213
  UPSTRM BR.     ANGLE
   1112     0.00000
  DNSTRM BR.     ANGLE
NUMBER OF BRANCHES WITH INERTIA
 12
 12
 23
 34
 45
 56
 67
 78
 89
 910
 1011
 1112
 1213
NUMBER OF ROTATING BRANCHES
 9
BRANCH   UPST RAD    DNST RAD       RPM        K ROT
 23    1.25            2.25            5000              0.8671
 34    2.25            3.625           5000              0.8158
 45    3.625           4.6875          5000              0.763
 56    4.6875          5.375           5000              0.7252
 67    5.375           5.5             5000              0.7076
 89    5.5             5.375           5000              0.7129
 910   5.375           4.6875          5000              0.7349
 1011  4.6875          3.625           5000              0.7824
 1112  3.625           2.65            5000              0.8376
```

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```
 **************************************************
            G F S S P (Version 604)
     Generalized Fluid System Simulation Program
                 March 2012

    Developed by NASA/Marshall Space Flight Center
    Copyright (C) by Marshall Space Flight Center

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


  RUN DATE:09/12/2012 14:58

TITLE     :Radial Flow on a Rotating Radial Disk
ANALYST   :Paul Schallhorn
FILEIN    :C:\Program Files (x86)\GFSSP604\TestInstalledExamples\EX6\Ex6.dat
FILEOUT   :Ex6.out

                           OPTION VARIABLES

ADDPROP   BUOYANCY  CONDX     CONJUG    CYCLIC    DALTON    DENCON    ENERGY
F         F         F         F         F         F         F         T
FLOWREG   GRAVITY   HCOEF     HEX       HRATE     IFRMIX    INERTIA   INSUC
0         F         F         F         T         1         T         F
INVAL     MIXTURE   MOVBND    MSORCE    NORMAL    NRSOLVT   OPVALVE   PLOTADD
F         F         F         F         F         F         F         F
PRESREG   PRESS     PRINTI    PRNTADD   PRNTIN    RADIATION REACTING  ROTATION
0         F         T         F         F         F         F         T
SAVER     SECONDL   SHEAR     SIMULA    SIUNITS   STEADY    THRUST    TPA
F         F         F         T         F         T         F         F
TRANS_MOM TRANSQ    TRANSV    TVM       TWOD      USRVAR    VARGEO    VARROT
F         F         F         F         F         F         F         F
RLFVLV
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    0.9000E+02  0.8000E+02  0.6224E+02  0.0000E+00
    13    0.3000E+02  0.8000E+02  0.6222E+02  0.0000E+00


SOLUTION
INTERNAL NODES
 NODE     P(PSI)      TF(F)        Z           RHO         EM(LBM)     QUALITY
                                             (LBM/FT^3)
     2    0.9000E+02  0.8000E+02  0.4499E-02  0.6224E+02  0.0000E+00  0.0000E+00
     3    0.1237E+03  0.8001E+02  0.6181E-02  0.6224E+02  0.0000E+00  0.0000E+00
     4    0.1924E+03  0.8002E+02  0.9616E-02  0.6226E+02  0.0000E+00  0.0000E+00
     5    0.2582E+03  0.8004E+02  0.1290E-01  0.6227E+02  0.0000E+00  0.0000E+00
     6    0.3048E+03  0.8005E+02  0.1522E-01  0.6228E+02  0.0000E+00  0.0000E+00
     7    0.3135E+03  0.8005E+02  0.1566E-01  0.6228E+02  0.0000E+00  0.0000E+00
     8    0.3135E+03  0.8005E+02  0.1566E-01  0.6228E+02  0.0000E+00  0.0000E+00
     9    0.3046E+03  0.8005E+02  0.1522E-01  0.6228E+02  0.0000E+00  0.0000E+00
    10    0.2568E+03  0.8004E+02  0.1283E-01  0.6227E+02  0.0000E+00  0.0000E+00
    11    0.1877E+03  0.8002E+02  0.9378E-02  0.6226E+02  0.0000E+00  0.0000E+00
    12    0.1328E+03  0.8001E+02  0.6636E-02  0.6225E+02  0.0000E+00  0.0000E+00

BRANCHES
BRANCH      KFACTOR       DELP        FLOW RATE   VELOCITY    REYN. NO.   MACH NO.   ENTROPY GEN.   LOST WORK
      (LBF-S^2/(LBM-FT)^2)  (PSI)      (LBM/SEC)     (FT/SEC)                                BTU/(R-SEC)   LBF-FT/SEC
      12     0.000E+00     0.850E-11   0.729E+01     0.537E+01   0.966E+05   0.437E-02   0.000E+00   0.000E+00
      23     0.000E+00    -0.337E+02   0.729E+01     0.935E+01   0.128E+06   0.762E-02   0.000E+00   0.000E+00
      34     0.000E+00    -0.688E+02   0.729E+01     0.524E+01   0.954E+05   0.426E-02   0.000E+00   0.000E+00
      45     0.000E+00    -0.658E+02   0.729E+01     0.361E+01   0.792E+05   0.294E-02   0.000E+00   0.000E+00
      56     0.000E+00    -0.466E+02   0.729E+01     0.295E+01   0.716E+05   0.240E-02   0.000E+00   0.000E+00
      67     0.000E+00    -0.871E+01   0.729E+01     0.272E+01   0.688E+05   0.221E-02   0.000E+00   0.000E+00
      78     0.000E+00     0.859E-11   0.729E+01     0.247E+00   0.207E+05   0.201E-03   0.000E+00   0.000E+00
      89     0.000E+00     0.884E+01   0.729E+01     0.272E+01   0.688E+05   0.221E-02   0.000E+00   0.000E+00
     910     0.000E+00     0.478E+02   0.729E+01     0.295E+01   0.717E+05   0.240E-02   0.000E+00   0.000E+00
    1011     0.000E+00     0.692E+02   0.729E+01     0.361E+01   0.793E+05   0.294E-02   0.000E+00   0.000E+00
    1112     0.000E+00     0.549E+02   0.729E+01     0.487E+01   0.921E+05   0.397E-02   0.000E+00   0.000E+00
    1213     0.278E+03     0.103E+03   0.729E+01     0.271E+01   0.686E+05   0.221E-02   0.413E-02   0.173E+04


 SOLUTION SATISFIED CONVERGENCE CRITERION OF    0.100E-03 IN      6 ITERATIONS
TAU =    100000000.000000       ISTEP =           1  DTAU =
  100000000.000000

*************************************************

TIME OF ANALYSIS WAS 0.000000000000000E+000 SECS
*************************************************
```

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APPENDIX N—INPUT AND OUTPUT DATA FILES FROM EXAMPLE 7

Flow in a Long Bearing Squeeze Film Damper

Contents

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```
GFSSP VERSION
    604
GFSSP INSTALLATION PATH

ANALYST
Paul Schallhorn
INPUT DATA FILE NAME
Ex7.dat
OUTPUT FILE NAME
Ex7.out
TITLE
Flow in a Long Bearing Squeeze Film Damper
USETUP
F
DENCON        GRAVITY       ENERGY        MIXTURE       THRUST        STEADY        TRANSV        SAVER
T             F             F             F             F             T             F             F
HEX           HCOEF         REACTING      INERTIA       CONDX         ADDPROP       PRINTI        ROTATION
F             F             F             F             F             F             F             F
BUOYANCY      HRATE         INVAL         MSORCE        MOVBND        TPA           VARGEO        TVM
F             T             F             F             T             F             F             F
SHEAR         PRNTIN        PRNTADD       OPVALVE       TRANSQ        CONJUG        RADIAT        WINPLOT
F             F             T             F             F             F             F             F
PRESS         INSUC         VARROT        CYCLIC        CHKVALS       WINFILE       DALTON        NOSTATS
F             F             F             F             F             T             F             F
NORMAL        SIMUL         SECONDL       NRSOLVT       IBDF          NOPLT         PRESREG       FLOWREG
F             T             T             F             1             T             0             0
TRANS_MOM     USERVARS      PSMG          ISOLVE        PLOTADD       SIUNITS       TECPLOT       MDGEN
F             F             F             1             F             F             F             F
NUM_USER_VARS IFR_MIX       PRINTD        SATTABL       MSORIN        PRELVLV       LAMINAR       HSTAG
1             1             F             F             F             F             T             T
NNODES        NINT          NBR           NF
 20            18            19            0
RELAXK        RELAXD        RELAXH        CC            NITER         RELAXNR       RELAXHC       RELAXTS
 1               0.5           1                0.0001          500 1            1                1
RHOREF        EMUREF
 57.806             0.005932
NODE          INDEX    DESCRIPTION
 1              2      " Node 1"
 2              1      " Node 2"
 3              1      " Node 3"
 4              1      " Node 4"
 5              1      " Node 5"
 6              1      " Node 6"
 7              1      " Node 7"
 8              1      " Node 8"
 9              1      " Node 9"
 10              1       " Node 10"
```

11	1	" Node 11"
12	1	" Node 12"
13	1	" Node 13"
14	1	" Node 14"
15	1	" Node 15"
16	1	" Node 16"
17	1	" Node 17"
18	1	" Node 18"
19	1	" Node 19"
20	2	" Node 20"

NODE	PRES (PSI)	MASS SOURC	HEAT SOURC	THRST AREA
1	0	0	0	0
2	0	0	0	0
3	0	0	0	0
4	0	0	0	0
5	0	0	0	0
6	0	0	0	0
7	0	0	0	0
8	0	0	0	0
9	0	0	0	0
10	10	0	0	0
11	0	0	0	0
12	0	0	0	0
13	0	0	0	0
14	0	0	0	0
15	0	0	0	0
16	0	0	0	0
17	0	0	0	0
18	0	0	0	0
19	0	0	0	0
20	0	0	0	0

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
16	2	1516	1617

```
 17            2            1617   1718
 18            2            1718   1819
 19            2            1819   1920
BRANCH   UPNODE    DNNODE    OPTION    DESCRIPTION
12         1          2          3       "Duct 12"
23         2          3          3       "Duct 23"
34         3          4          3       "Duct 34"
45         4          5          3       "Duct 45"
56         5          6          3       "Duct 56"
67         6          7          3       "Duct 67"
78         7          8          3       "Duct 78"
89         8          9          3       "Duct 89"
910        9          10         3       "Duct 910"
1011       10         11         3       "Duct 1011"
1112       11         12         3       "Duct 1112"
1213       12         13         3       "Duct 1213"
1314       13         14         3       "Duct 1314"
1415       14         15         3       "Duct 1415"
1516       15         16         3       "Duct 1516"
1617       16         17         3       "Duct 1617"
1718       17         18         3       "Duct 1718"
1819       18         19         3       "Duct 1819"
1920       19         20         3       "Duct 1920"
BRANCH        OPTION -3     LENGTH        HEIGHT        WIDTH         TYPE          AREA
 12                         0.82673       0.01258       0.94          1             0.0118252
BRANCH        OPTION -3     LENGTH        HEIGHT        WIDTH         TYPE          AREA
 23                         0.8267        0.01799       0.94          1             0.0169106
BRANCH        OPTION -3     LENGTH        HEIGHT        WIDTH         TYPE          AREA
 34                         0.82673       0.02822       0.94          1             0.0265268
BRANCH        OPTION -3     LENGTH        HEIGHT        WIDTH         TYPE          AREA
 45                         0.82673       0.04217       0.94          1             0.0396398
BRANCH        OPTION -3     LENGTH        HEIGHT        WIDTH         TYPE          AREA
 56                         0.82673       0.05832       0.94          1             0.0548208
BRANCH        OPTION -3     LENGTH        HEIGHT        WIDTH         TYPE          AREA
 67                         0.82673       0.07492       0.94          1             0.0704248
BRANCH        OPTION -3     LENGTH        HEIGHT        WIDTH         TYPE          AREA
 78                         0.82673       0.09018       0.94          1             0.0847692
BRANCH        OPTION -3     LENGTH        HEIGHT        WIDTH         TYPE          AREA
 89                         0.82673       0.10244       0.94          1             0.0962936
BRANCH        OPTION -3     LENGTH        HEIGHT        WIDTH         TYPE          AREA
 910                        0.82673       0.11037       0.94          1             0.1037478
BRANCH        OPTION -3     LENGTH        HEIGHT        WIDTH         TYPE          AREA
 1011                       0.82673       0.11311       0.94          1             0.1063234
BRANCH        OPTION -3     LENGTH        HEIGHT        WIDTH         TYPE          AREA
 1112                       0.82673       0.11037       0.94          1             0.1037478
BRANCH        OPTION -3     LENGTH        HEIGHT        WIDTH         TYPE          AREA
 1213                       0.82673       0.10244       0.94          1             0.0962936
```

BRANCH	OPTION -3	LENGTH	HEIGHT	WIDTH	TYPE	AREA
1314		0.82673	0.09018	0.94	1	0.0847692
BRANCH	OPTION -3	LENGTH	HEIGHT	WIDTH	TYPE	AREA
1415		0.82673	0.07492	0.94	1	0.0704248
BRANCH	OPTION -3	LENGTH	HEIGHT	WIDTH	TYPE	AREA
1516		0.82673	0.05832	0.94	1	0.0548208
BRANCH	OPTION -3	LENGTH	HEIGHT	WIDTH	TYPE	AREA
1617		0.82673	0.04217	0.94	1	0.0396398
BRANCH	OPTION -3	LENGTH	HEIGHT	WIDTH	TYPE	AREA
1718		0.82673	0.02822	0.94	1	0.0265268
BRANCH	OPTION -3	LENGTH	HEIGHT	WIDTH	TYPE	AREA
1819		0.82673	0.01799	0.94	1	0.0169106
BRANCH	OPTION -3	LENGTH	HEIGHT	WIDTH	TYPE	AREA
1920		0.82673	0.01258	0.94	1	0.0118252

NUMBER OF NODES WITH MOVING BOUNDARY
18

NODE	AREAN	VBOUND
2	0.77713	0.25618
3	0.77713	0.4846
4	0.77713	0.6605
5	0.77713	0.76483
6	0.77713	0.78628
7	0.77713	0.72252
8	0.77713	0.58047
9	0.77713	0.37551
10	0.77713	0.12986
11	0.77713	-0.12986
12	0.77713	-0.37551
13	0.77713	-0.58047
14	0.77713	-0.72252
15	0.77713	-0.78628
16	0.77713	-0.76483
17	0.77713	-0.6605
18	0.77713	-0.4846
19	0.77713	-0.25618

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```
 **************************************************
           G F S S P (Version 604)
    Generalized Fluid System Simulation Program
                March 2012

   Developed by NASA/Marshall Space Flight Center
   Copyright (C) by Marshall Space Flight Center

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


  RUN DATE:09/12/2012 14:59

TITLE     :Flow in a Long Bearing Squeeze Film Damper
ANALYST   :Paul Schallhorn
FILEIN    :C:\Program Files (x86)\GFSSP604\TestInstalledExamples\EX7\Ex7.dat
FILEOUT   :Ex7.out

                           OPTION VARIABLES

ADDPROP   BUOYANCY  CONDX     CONJUG    CYCLIC    DALTON    DENCON    ENERGY
F         F         F         F         F         F         T         F
FLOWREG   GRAVITY   HCOEF     HEX       HRATE     IFRMIX    INERTIA   INSUC
0         F         F         F         T         1         F         F
INVAL     MIXTURE   MOVBND    MSORCE    NORMAL    NRSOLVT   OPVALVE   PLOTADD
F         F         T         F         F         F         F         F
PRESREG   PRESS     PRINTI    PRNTADD   PRNTIN    RADIATION REACTING  ROTATION
0         F         F         T         F         F         F         F
SAVER     SECONDL   SHEAR     SIMULA    SIUNITS   STEADY    THRUST    TPA
F         T         F         T         F         T         F         F
TRANS_MOM TRANSQ    TRANSV    TVM       TWOD      USRVAR    VARGEO    VARROT
F         F         F         F         F         F         F         F
RLFVLV
F

NNODES   =   20
NINT     =   18
NBR      =   19
NF       =    0
NVAR     =   37
NHREF    =    2

RHOREF   =    57.8060 LBM/FT**3
EMUREF   =   0.5932E-02 LBM/FT-SEC
```

BOUNDARY NODES

NODE	P (PSI)	AREA (IN^2)
1	0.0000E+00	0.0000E+00
20	0.0000E+00	0.0000E+00

SOLUTION

INTERNAL NODES

NODE	P(PSI)	EM(LBM)
2	0.1365E+02	0.0000E+00
3	0.1273E+02	0.0000E+00
4	0.9716E+01	0.0000E+00
5	0.7660E+01	0.0000E+00
6	0.5812E+01	0.0000E+00
7	0.4250E+01	0.0000E+00
8	0.2901E+01	0.0000E+00
9	0.1690E+01	0.0000E+00
10	0.5551E+00	0.0000E+00
11	-0.5551E+00	0.0000E+00
12	-0.1690E+01	0.0000E+00
13	-0.2901E+01	0.0000E+00
14	-0.4250E+01	0.0000E+00
15	-0.5812E+01	0.0000E+00
16	-0.7660E+01	0.0000E+00
17	-0.9716E+01	0.0000E+00
18	-0.1273E+02	0.0000E+00
19	-0.1365E+02	0.0000E+00

BRANCHES

BRANCH	KFACTOR (LBF-S^2/(LBM-FT)^2)	DELP (PSI)	FLOW RATE (LBM/SEC)	VELOCITY (FT/SEC)	REYN. NO.	MACH NO.	ENTROPY GEN. BTU/(R-SEC)	LOST WORK LBF-FT/SEC
12	0.440E+06	-0.136E+02	-0.668E-01	-0.141E+02	0.140E+04	0.000E+00	0.635E-05	0.227E+01
23	0.770E+06	0.920E+00	0.131E-01	0.193E+01	0.230E+03	0.000E+00	0.841E-07	0.301E-01
34	0.161E+05	0.301E+01	0.164E+00	0.154E+02	0.230E+04	0.000E+00	0.345E-05	0.123E+01
45	0.216E+04	0.206E+01	0.370E+00	0.233E+02	0.425E+04	0.000E+00	0.530E-05	0.190E+01
56	0.718E+03	0.185E+01	0.609E+00	0.277E+02	0.594E+04	0.000E+00	0.784E-05	0.280E+01
67	0.308E+03	0.156E+01	0.854E+00	0.302E+02	0.735E+04	0.000E+00	0.929E-05	0.332E+01
78	0.167E+03	0.135E+01	0.108E+01	0.317E+02	0.846E+04	0.000E+00	0.101E-04	0.363E+01
89	0.110E+03	0.121E+01	0.126E+01	0.326E+02	0.927E+04	0.000E+00	0.106E-04	0.380E+01
910	0.861E+02	0.113E+01	0.138E+01	0.331E+02	0.976E+04	0.000E+00	0.109E-04	0.389E+01
1011	0.795E+02	0.111E+01	0.142E+01	0.332E+02	0.993E+04	0.000E+00	0.110E-04	0.392E+01
1112	0.861E+02	0.113E+01	0.138E+01	0.331E+02	0.976E+04	0.000E+00	0.109E-04	0.389E+01
1213	0.110E+03	0.121E+01	0.126E+01	0.326E+02	0.927E+04	0.000E+00	0.106E-04	0.380E+01
1314	0.167E+03	0.135E+01	0.108E+01	0.317E+02	0.846E+04	0.000E+00	0.101E-04	0.363E+01
1415	0.308E+03	0.156E+01	0.854E+00	0.302E+02	0.735E+04	0.000E+00	0.929E-05	0.332E+01

1516	0.718E+03	0.185E+01	0.609E+00	0.277E+02	0.594E+04	0.000E+00	0.784E-05	0.280E+01
1617	0.216E+04	0.206E+01	0.370E+00	0.233E+02	0.425E+04	0.000E+00	0.530E-05	0.190E+01
1718	0.161E+05	0.301E+01	0.164E+00	0.154E+02	0.230E+04	0.000E+00	0.345E-05	0.123E+01
1819	0.770E+06	0.920E+00	0.131E-01	0.193E+01	0.230E+03	0.000E+00	0.841E-07	0.301E-01
1920	0.440E+06	-0.136E+02	-0.668E-01	-0.141E+02	0.140E+04	0.000E+00	0.635E-05	0.227E+01

```
      ***** TOTAL ENTROPY GENERATION =    0.139E-03 BTU/(R-SEC) ******

      **** TOTAL WORK LOST =    0.903E-01 HP *****

*************************************************

TIME OF ANALYSIS WAS   1.562500000000000E-002  SECS

*************************************************
```

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APPENDIX O—INPUT AND OUTPUT DATA FILES FROM EXAMPLE 8

Simulation of the Blow Down of a Pressurized Tank

Contents

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```
GFSSP VERSION
    604
GFSSP INSTALLATION PATH

ANALYST
Alok Majumdar
Ex8.dat
OUTPUT FILE NAME
Ex8.out
TITLE
Simulation of the Blow Down of a Pressurized Tank
USETUP
F
DENCON        GRAVITY       ENERGY        MIXTURE       THRUST        STEADY        TRANSV        SAVER
F             F             T             F             F             F             T             F
HEX           HCOEF         REACTING      INERTIA       CONDX         ADDPROP       PRINTI        ROTATION
F             F             F             F             F             T             T             F
BUOYANCY      HRATE         INVAL         MSORCE        MOVBND        TPA           VARGEO        TVM
F             F             F             F             F             F             F             F
SHEAR         PRNTIN        PRNTADD       OPVALVE       TRANSQ        CONJUG        RADIAT        WINPLOT
F             T             T             F             F             F             F             T
PRESS         INSUC         VARROT        CYCLIC        CHKVALS       WINFILE       DALTON        NOSTATS
F             F             F             F             F             T             F             F
NORMAL        SIMUL         SECONDL       NRSOLVT       IBDF          NOPLT         PRESREG       FLOWREG
F             T             F             F             1             F             0             0
TRANS_MOM     USERVARS      PSMG          ISOLVE        PLOTADD       SIUNITS       TECPLOT       MDGEN
F             F             F             1             F             F             F             F
NUM_USER_VARS IFR_MIX       PRINTD        SATTABL       MSORIN        PRELVLV       LAMINAR       HSTAG
1             1             F             F             F             F             T             T
NNODES        NINT          NBR           NF
 2            1             1             1
RELAXK        RELAXD        RELAXH        CC            NITER         RELAXNR       RELAXHC       RELAXTS
 1            0.5           1             0.0001        500           1             1             1
DTAU          TIMEF         TIMEL         NPSTEP        NPWSTEP       WPLSTEP       WPLBUFF
 1            0             200           25             1             50            1.1
NFLUID(I),  I = 1, NF
 33
RREF         CPREF         GAMREF        EMUREF        AKREF        PREF        TREF        HREF        SREF
 53.34       0.24          1.3999        1.26e-05      4.133e-06    14.7        -459        0           0
NODE          INDEX     DESCRIPTION
 1              1       " Node 1"
 2              2       " Node 2"
 NODE  PRES (PSI)  TEMP(DEGF)  MASS SOURC    HEAT SOURC   THRST AREA   NODE-VOLUME  CONCENTRATION
 1     100         80                0            0            0            17280
 ex8hs2.dat
INODE         NUMBR         NAMEBR
 1             1            12
```

```
BRANCH   UPNODE    DNNODE    OPTION    DESCRIPTION
12         1          2          22      "Orifice 12"

BRANCH        OPTION -22     AREA       FLOW COEF
 12                        0.00785       1
INITIAL FLOWRATES IN BRANCHES FOR UNSTEADY FLOW
 12 0
```

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EXAMPLE 8 HISTORY FILE

EX8HS2.DAT

```
2
0     14.700  80.00  1.00
1000  14.700  80.00  1.00
```

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```
 **************************************************
              G F S S P (Version 604)
     Generalized Fluid System Simulation Program
                    March 2012

    Developed by NASA/Marshall Space Flight Center
    Copyright (C) by Marshall Space Flight Center

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


   RUN DATE:09/12/2012 15:00

TITLE     :Simulation of the Blow Down of a Pressurized Tank
ANALYST   :Alok Majumdar
FILEIN    :C:\Program Files (x86)\GFSSP604\TestInstalledExamples\EX8\Ex8.dat
FILEOUT   :Ex8.out

                           OPTION VARIABLES

ADDPROP   BUOYANCY  CONDX     CONJUG    CYCLIC    DALTON    DENCON    ENERGY
T         F         F         F         F         F         F         T
FLOWREG   GRAVITY   HCOEF     HEX       HRATE     IFRMIX    INERTIA   INSUC
0         F         F         F         F         1         F         F
INVAL     MIXTURE   MOVBND    MSORCE    NORMAL    NRSOLVT   OPVALVE   PLOTADD
F         F         F         F         F         F         F         F
PRESREG   PRESS     PRINTI    PRNTADD   PRNTIN    RADIATION REACTING  ROTATION
0         F         T         T         T         F         F         F
SAVER     SECONDL   SHEAR     SIMULA    SIUNITS   STEADY    THRUST    TPA
F         F         F         T         F         F         F         F
TRANS_MOM TRANSQ    TRANSV    TVM       TWOD      USRVAR    VARGEO    VARROT
F         F         T         F         F         F         F         F
RLFVLV
F

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


FLUIDS:  IDEL
```

```
BOUNDARY NODES
   NODE        P           T         RHO                     AREA
             (PSI)        (F)     (LBM/FT^3)                 (IN^2)
    2    0.1470E+02  0.8000E+02  0.7354E-01  0.0000E+00

 INPUT SPECIFICATIONS FOR INTERNAL NODES
NODE       AREA         MASS         HEAT
          (IN^2)       (LBM/S)     (BTU/LBM)
    1    0.0000E+00  0.0000E+00  0.0000E+00

BRANCH      UPNODE    DNNODE    OPTION
     12        1         2        22
BRANCH OPTION -22 FLOW COEF   AREA
     12            0.100E+01   0.785E-02

INITIAL GUESS FOR INTERNAL NODES

   NODE    P(PSI)   TF(F)      Z(COMP)        RHO       QUALITY
                                           (LBM/FT^3)
    1    0.1000E+03  0.8000E+02  0.1000E+01  0.5002E+00  0.0000E+00

 TRIAL SOLUTION
  BRANCH    DELP(PSI)   FLOWRATE(LBM/SEC)
     12         0.0000     0.0000



 SOLUTION SATISFIED CONVERGENCE CRITERION OF    0.100E-03 IN      9 ITERATIONS
TAU =    1.00000000000000       ISTEP =            1  DTAU =
  1.00000000000000
                             :
                             :
                             :
                             :
```

```
  SOLUTION SATISFIED CONVERGENCE CRITERION OF    0.100E-03 IN      9 ITERATIONS
 TAU =    24.0000000000000       ISTEP =           24  DTAU =
   1.00000000000000


     ISTEP =     25          TAU =  0.25000E+02
 BOUNDARY NODES
    NODE    P(PSI)      TF(F)      Z(COMP)       RHO       QUALITY
                                        (LBM/FT^3)
     2    0.1470E+02  0.8000E+02  0.1000E+01  0.7354E-01  0.0000E+00

 SOLUTION
 INTERNAL NODES
  NODE     P(PSI)      TF(F)        Z           RHO         EM(LBM)     QUALITY
                                                (LBM/FT^3)
     1    0.8834E+02  0.6136E+02  0.1000E+01  0.4577E+00  0.4577E+01  0.0000E+00

    NODE       H          ENTROPY     EMU       COND        CP          GAMA
            BTU/LB       BTU/LB-R  LBM/FT-SEC  BTU/FT-S-R  BTU/LB-R

     1    0.1249E+03  0.1475E+01  0.1260E-04  0.4133E-05  0.2400E+00  0.1400E+01

 BRANCHES
BRANCH       KFACTOR       DELP        FLOW RATE   VELOCITY    REYN. NO.   MACH NO.   ENTROPY GEN.   LOST WORK
      (LBF-S^2/(LBM-FT)^2) (PSI)       (LBM/SEC)     (FT/SEC)                              BTU/(R-SEC)   LBF-FT/SEC
      12     0.114E+08     0.736E+02   0.162E-01     0.647E+03   0.196E+06   0.579E+00   0.260E-03   0.105E+03


  SOLUTION SATISFIED CONVERGENCE CRITERION OF    0.100E-03 IN      9 ITERATIONS
 TAU =    25.0000000000000       ISTEP =           25  DTAU =
   1.00000000000000
                              :
                              :
                              :
                              :

SOLUTION SATISFIED CONVERGENCE CRITERION OF    0.100E-03 IN      9 ITERATIONS
 TAU =    99.0000000000000       ISTEP =           99  DTAU =
   1.00000000000000
```

```
    ISTEP =    100          TAU =  0.10000E+03
 BOUNDARY NODES
    NODE    P(PSI)      TF(F)      Z(COMP)       RHO       QUALITY
                                        (LBM/FT^3)
     2    0.1470E+02  0.8000E+02  0.1000E+01  0.7354E-01  0.0000E+00

 SOLUTION
 INTERNAL NODES
  NODE     P(PSI)      TF(F)        Z           RHO         EM(LBM)     QUALITY
                                                (LBM/FT^3)
     1    0.6167E+02  0.1087E+02  0.1000E+01  0.3538E+00  0.3538E+01  0.0000E+00

    NODE       H          ENTROPY     EMU       COND        CP          GAMA
            BTU/LB       BTU/LB-R  LBM/FT-SEC  BTU/FT-S-R  BTU/LB-R

     1    0.1128E+03  0.1475E+01  0.1260E-04  0.4133E-05  0.2400E+00  0.1400E+01

 BRANCHES
BRANCH       KFACTOR       DELP        FLOW RATE   VELOCITY    REYN. NO.   MACH NO.   ENTROPY GEN.   LOST WORK
      (LBF-S^2/(LBM-FT)^2)  (PSI)       (LBM/SEC)     (FT/SEC)                                 BTU/(R-SEC)   LBF-FT/SEC
      12     0.148E+08     0.470E+02   0.119E-01     0.615E+03   0.144E+06   0.579E+00   0.191E-03   0.698E+02


  SOLUTION SATISFIED CONVERGENCE CRITERION OF    0.100E-03 IN      9 ITERATIONS
 TAU =    100.000000000000       ISTEP =          100  DTAU =
   1.00000000000000
                              :
                              :
                              :
                              :

   SOLUTION SATISFIED CONVERGENCE CRITERION OF    0.100E-03 IN      9 ITERATIONS
 TAU =    199.000000000000       ISTEP =          199  DTAU =
   1.00000000000000


    ISTEP =    200          TAU =  0.20000E+03
 BOUNDARY NODES
    NODE    P(PSI)      TF(F)      Z(COMP)       RHO       QUALITY
                                        (LBM/FT^3)
     2    0.1470E+02  0.8000E+02  0.1000E+01  0.7354E-01  0.0000E+00

 SOLUTION
 INTERNAL NODES
  NODE     P(PSI)      TF(F)        Z           RHO         EM(LBM)     QUALITY
                                                (LBM/FT^3)
     1    0.3922E+02 -0.4580E+02  0.1000E+01  0.2559E+00  0.2559E+01  0.0000E+00
```

```
   NODE       H          ENTROPY     EMU       COND        CP          GAMA
           BTU/LB       BTU/LB-R  LBM/FT-SEC  BTU/FT-S-R  BTU/LB-R

     1    0.9917E+02  0.1475E+01  0.1260E-04  0.4133E-05  0.2400E+00  0.1400E+01

 BRANCHES
BRANCH       KFACTOR       DELP        FLOW RATE   VELOCITY    REYN. NO.   MACH NO.   ENTROPY GEN.   LOST WORK
      (LBF-S^2/(LBM-FT)^2)  (PSI)       (LBM/SEC)     (FT/SEC)                          BTU/(R-SEC)   LBF-FT/SEC
      12     0.204E+08     0.245E+02   0.805E-02     0.577E+03   0.976E+05   0.579E+00   0.129E-03   0.417E+02


  SOLUTION SATISFIED CONVERGENCE CRITERION OF    0.100E-03 IN      9 ITERATIONS
 TAU =    200.000000000000       ISTEP =          200  DTAU =
   1.00000000000000

 *************************************************

 TIME OF ANALYSIS WAS   0.187500000000000       SECS

 *************************************************
```

APPENDIX P—INPUT AND OUTPUT DATA FILES FROM EXAMPLE 9

A Reciprocating Piston-Cylinder

Contents

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```
GFSSP VERSION
    604
GFSSP INSTALLATION PATH

ANALYST
Paul Schallhorn
INPUT DATA FILE NAME
Ex9.dat
OUTPUT FILE NAME
Ex9.out
TITLE
A Reciprocating Piston-Cylinder
USETUP
F
DENCON        GRAVITY       ENERGY        MIXTURE       THRUST        STEADY        TRANSV        SAVER
F             F             T             F             F             F             T             F
HEX           HCOEF         REACTING      INERTIA       CONDX         ADDPROP       PRINTI        ROTATION
F             F             F             F             F             F             F             F
BUOYANCY      HRATE         INVAL         MSORCE        MOVBND        TPA           VARGEO        TVM
F             T             F             F             T             F             T             F
SHEAR         PRNTIN        PRNTADD       OPVALVE       TRANSQ        CONJUG        RADIAT        WINPLOT
F             F             T             F             F             F             F             T
PRESS         INSUC         VARROT        CYCLIC        CHKVALS       WINFILE       DALTON        NOSTATS
F             F             F             F             F             T             F             F
NORMAL        SIMUL         SECONDL       NRSOLVT       IBDF          NOPLT         PRESREG       FLOWREG
F             T             T             F             1             T             0             0
TRANS_MOM     USERVARS      PSMG          ISOLVE        PLOTADD       SIUNITS       TECPLOT       MDGEN
F             F             F             1             F             F             F             F
NUM_USER_VARS IFR_MIX       PRINTD        SATTABL       MSORIN        PRELVLV       LAMINAR       HSTAG
1             1             F             F             F             F             T             T
NNODES        NINT          NBR           NF
 2            2            1            1
RELAXK        RELAXD        RELAXH        CC            NITER         RELAXNR       RELAXHC       RELAXTS
 1               0.5            1              0.0001         500 1             1                1
DTAU          TIMEF         TIMEL         NPSTEP        NPWSTEP       WPLSTEP       WPLBUFF
 0.0001          0                  0.05                 1             1             50            1.1
NFLUID(I),  I = 1, NF
 4
NODE          INDEX     DESCRIPTION
 1              1       " Node 1"
 2              1       " Node 2"
 NODE  PRES (PSI)  TEMP(DEGF)  MASS SOURC    HEAT SOURC   THRST AREA   NODE-VOLUME  CONCENTRATION
 1     14.7            75                 0                   0                   0                   0
 2     14.7            75                 0                   0                   0                   0
ex9vg.dat
INODE         NUMBR         NAMEBR
 1             1            12
```

```
 2             1            12
BRANCH   UPNODE    DNNODE    OPTION    DESCRIPTION
12         1         2          1       "Pipe 12"
BRANCH        OPTION -1     LENGTH        DIA           EPSD          ANGLE         AREA
 12                         7                3                0                 0                  7.0685775
INITIAL FLOWRATES IN BRANCHES FOR UNSTEADY FLOW
 12 0
NUMBER OF NODES WITH MOVING BOUNDARY
2
NODE
 1
 2
```

Back to Appendix P

VARIABLE GEOMETRY HISTORY FILE

```
41
0.000000    0.0000      0.0000    0.0000      0.0000
0.001250    0.0000      0.0000    0.0000      0.0000
0.002500    0.0000      0.0000    0.0000      0.0000
0.003750    0.0000      0.0000    0.0000      0.0000
0.005000    0.0000      0.0000    0.0000      0.0000
0.006250    0.0000      0.0000    0.0000      0.0000
0.007500    0.0000      0.0000    0.0000      0.0000
0.008750    0.0000      0.0000    0.0000      0.0000
0.010000    0.0000      0.0000    0.0000      0.0000
0.011250    0.0000      0.0000    0.0000      0.0000
0.012500    0.0000      0.0000    0.0000      0.0000
0.013750    0.0000      0.0000    0.0000      0.0000
0.015000    0.0000      0.0000    0.0000      0.0000
0.016250    0.0000      0.0000    0.0000      0.0000
0.017500    0.0000      0.0000    0.0000      0.0000
0.018750    0.0000      0.0000    0.0000      0.0000
0.020000    0.0000      0.0000    0.0000      0.0000
0.021250    0.0000      0.0000    0.0000      0.0000
0.022500    0.0000      0.0000    0.0000      0.0000
0.023750    0.0000      0.0000    0.0000      0.0000
0.025000    0.0000      0.0000    0.0000      0.0000
0.026250    0.0000      0.0000    0.0000      0.0000
0.027500    0.0000      0.0000    0.0000      0.0000
0.028750    0.0000      0.0000    0.0000      0.0000
0.030000    0.0000      0.0000    0.0000      0.0000
0.031250    0.0000      0.0000    0.0000      0.0000
0.032500    0.0000      0.0000    0.0000      0.0000
0.033750    0.0000      0.0000    0.0000      0.0000
0.035000    0.0000      0.0000    0.0000      0.0000
0.036250    0.0000      0.0000    0.0000      0.0000
0.037500    0.0000      0.0000    0.0000      0.0000
0.038750    0.0000      0.0000    0.0000      0.0000
0.040000    0.0000      0.0000    0.0000      0.0000
0.041250    0.0000      0.0000    0.0000      0.0000
0.042500    0.0000      0.0000    0.0000      0.0000
0.043750    0.0000      0.0000    0.0000      0.0000
0.045000    0.0000      0.0000    0.0000      0.0000
0.046250    0.0000      0.0000    0.0000      0.0000
0.047500    0.0000      0.0000    0.0000      0.0000
0.048750    0.0000      0.0000    0.0000      0.0000
0.050000    0.0000      0.0000    0.0000      0.0000
BRANCH VOLUME
0.000000    49.48004    0.0000    100.000     0.0000
0.001250    49.21895    0.0000    100.000     0.0000
```

0.002500	48.44213	0.0000	100.000	0.0000
0.003750	47.16871	0.0000	100.000	0.0000
0.005000	45.43005	0.0000	100.000	0.0000
0.006250	43.26896	0.0000	100.000	0.0000
0.007500	40.73865	0.0000	100.000	0.0000
0.008750	37.90143	0.0000	100.000	0.0000
0.010000	34.82716	0.0000	100.000	0.0000
0.011250	31.59153	0.0000	100.000	0.0000
0.012500	28.27423	0.0000	100.000	0.0000
0.013750	24.95692	0.0000	100.000	0.0000
0.015000	21.72130	0.0000	100.000	0.0000
0.016250	18.64704	0.0000	100.000	0.0000
0.017500	15.80983	0.0000	100.000	0.0000
0.018750	13.27954	0.0000	100.000	0.0000
0.020000	11.11847	0.0000	100.000	0.0000
0.021250	9.379835	0.0000	100.000	0.0000
0.022500	8.106441	0.0000	100.000	0.0000
0.023750	7.329646	0.0000	100.000	0.0000
0.025000	7.068578	0.0000	100.000	0.0000
0.026250	7.329646	0.0000	100.000	0.0000
0.027500	8.106441	0.0000	100.000	0.0000
0.028750	9.379835	0.0000	100.000	0.0000
0.030000	11.11847	0.0000	100.000	0.0000
0.031250	13.27954	0.0000	100.000	0.0000
0.032500	15.80983	0.0000	100.000	0.0000
0.033750	18.64704	0.0000	100.000	0.0000
0.035000	21.72130	0.0000	100.000	0.0000
0.036250	24.95692	0.0000	100.000	0.0000
0.037500	28.27423	0.0000	100.000	0.0000
0.038750	31.59153	0.0000	100.000	0.0000
0.040000	34.82716	0.0000	100.000	0.0000
0.041250	37.90143	0.0000	100.000	0.0000
0.042500	40.73865	0.0000	100.000	0.0000
0.043750	43.26896	0.0000	100.000	0.0000
0.045000	45.43005	0.0000	100.000	0.0000
0.046250	47.16871	0.0000	100.000	0.0000
0.047500	48.44213	0.0000	100.000	0.0000
0.048750	49.21895	0.0000	100.000	0.0000
0.050000	49.48004	0.0000	100.000	0.0000
BRANCH AREA				
0.000000	7.06858347	1.0000	1.0000	1.0000
0.001250	7.06858347	1.0000	1.0000	1.0000
0.002500	7.06858347	1.0000	1.0000	1.0000
0.003750	7.06858347	1.0000	1.0000	1.0000
0.005000	7.06858347	1.0000	1.0000	1.0000
0.006250	7.06858347	1.0000	1.0000	1.0000
0.007500	7.06858347	1.0000	1.0000	1.0000

```
0.008750    7.06858347  1.0000    1.0000      1.0000
0.010000    7.06858347  1.0000    1.0000      1.0000
0.011250    7.06858347  1.0000    1.0000      1.0000
0.012500    7.06858347  1.0000    1.0000      1.0000
0.013750    7.06858347  1.0000    1.0000      1.0000
0.015000    7.06858347  1.0000    1.0000      1.0000
0.016250    7.06858347  1.0000    1.0000      1.0000
0.017500    7.06858347  1.0000    1.0000      1.0000
0.018750    7.06858347  1.0000    1.0000      1.0000
0.020000    7.06858347  1.0000    1.0000      1.0000
0.021250    7.06858347  1.0000    1.0000      1.0000
0.022500    7.06858347  1.0000    1.0000      1.0000
0.023750    7.06858347  1.0000    1.0000      1.0000
0.025000    7.06858347  1.0000    1.0000      1.0000
0.026250    7.06858347  1.0000    1.0000      1.0000
0.027500    7.06858347  1.0000    1.0000      1.0000
0.028750    7.06858347  1.0000    1.0000      1.0000
0.030000    7.06858347  1.0000    1.0000      1.0000
0.031250    7.06858347  1.0000    1.0000      1.0000
0.032500    7.06858347  1.0000    1.0000      1.0000
0.033750    7.06858347  1.0000    1.0000      1.0000
0.035000    7.06858347  1.0000    1.0000      1.0000
0.036250    7.06858347  1.0000    1.0000      1.0000
0.037500    7.06858347  1.0000    1.0000      1.0000
0.038750    7.06858347  1.0000    1.0000      1.0000
0.040000    7.06858347  1.0000    1.0000      1.0000
0.041250    7.06858347  1.0000    1.0000      1.0000
0.042500    7.06858347  1.0000    1.0000      1.0000
0.043750    7.06858347  1.0000    1.0000      1.0000
0.045000    7.06858347  1.0000    1.0000      1.0000
0.046250    7.06858347  1.0000    1.0000      1.0000
0.047500    7.06858347  1.0000    1.0000      1.0000
0.048750    7.06858347  1.0000    1.0000      1.0000
0.050000    7.06858347  1.0000    1.0000      1.0000
1
0.000000    7.06858347      0.000000
0.001250    7.06858347      2.457263
0.002500    7.06858347      4.854020
0.003750    7.06858347      7.131254
0.005000    7.06858347      9.232895
0.006250    7.06858347      11.10719
0.007500    7.06858347      12.70799
0.008750    7.06858347      13.99588
0.010000    7.06858347      14.93914
0.011250    7.06858347      15.51456
0.012500    7.06858347      15.70795
0.013750    7.06858347      15.51456
```

```
0.015000    7.06858347      14.93916
0.016250    7.06858347      13.99590
0.017500    7.06858347      12.70802
0.018750    7.06858347      11.10722
0.020000    7.06858347      9.232928
0.021250    7.06858347      7.131292
0.022500    7.06858347      4.854059
0.023750    7.06858347      2.457304
0.025000    7.06858347      0.000000
0.026250    7.06858347     -2.457222
0.027500    7.06858347     -4.853980
0.028750    7.06858347     -7.131217
0.030000    7.06858347     -9.232861
0.031250    7.06858347     -11.10716
0.032500    7.06858347     -12.70797
0.033750    7.06858347     -13.99586
0.035000    7.06858347     -14.93913
0.036250    7.06858347     -15.51455
0.037500    7.06858347     -15.70795
0.038750    7.06858347     -15.51457
0.040000    7.06858347     -14.93917
0.041250    7.06858347     -13.99592
0.042500    7.06858347     -12.70804
0.043750    7.06858347     -11.10725
0.045000    7.06858347     -9.232962
0.046250    7.06858347     -7.131329
0.047500    7.06858347     -4.854099
0.048750    7.06858347     -2.457345
0.050000    7.06858347      0.000000
2
0.000000    7.06858347      0.000000
0.001250    7.06858347      2.457263
0.002500    7.06858347      4.854020
0.003750    7.06858347      7.131254
0.005000    7.06858347      9.232895
0.006250    7.06858347      11.10719
0.007500    7.06858347      12.70799
0.008750    7.06858347      13.99588
0.010000    7.06858347      14.93914
0.011250    7.06858347      15.51456
0.012500    7.06858347      15.70795
0.013750    7.06858347      15.51456
0.015000    7.06858347      14.93916
0.016250    7.06858347      13.99590
0.017500    7.06858347      12.70802
0.018750    7.06858347      11.10722
0.020000    7.06858347      9.232928
```

0.021250	7.06858347	7.131292
0.022500	7.06858347	4.854059
0.023750	7.06858347	2.457304
0.025000	7.06858347	0.000000
0.026250	7.06858347	-2.457222
0.027500	7.06858347	-4.853980
0.028750	7.06858347	-7.131217
0.030000	7.06858347	-9.232861
0.031250	7.06858347	-11.10716
0.032500	7.06858347	-12.70797
0.033750	7.06858347	-13.99586
0.035000	7.06858347	-14.93913
0.036250	7.06858347	-15.51455
0.037500	7.06858347	-15.70795
0.038750	7.06858347	-15.51457
0.040000	7.06858347	-14.93917
0.041250	7.06858347	-13.99592
0.042500	7.06858347	-12.70804
0.043750	7.06858347	-11.10725
0.045000	7.06858347	-9.232962
0.046250	7.06858347	-7.131329
0.047500	7.06858347	-4.854099
0.048750	7.06858347	-2.457345
0.050000	7.06858347	0.000000

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```
          ***************************************************
                    G F S S P (Version 604)
             Generalized Fluid System Simulation Program
                          March 2012

           Developed by NASA/Marshall Space Flight Center
           Copyright (C) by Marshall Space Flight Center

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


          RUN DATE:09/12/2012 15:01

TITLE     :A Reciprocating Piston-Cylinder
ANALYST   :Paul Schallhorn
FILEIN    :C:\Program Files (x86)\GFSSP604\TestInstalledExamples\EX9\Ex9.dat
FILEOUT   :Ex9.out

                           OPTION VARIABLES

ADDPROP   BUOYANCY  CONDX     CONJUG    CYCLIC    DALTON    DENCON    ENERGY
F         F         F         F         F         F         F         T
FLOWREG   GRAVITY   HCOEF     HEX       HRATE     IFRMIX    INERTIA   INSUC
0         F         F         F         T         1         F         F
INVAL     MIXTURE   MOVBND    MSORCE    NORMAL    NRSOLVT   OPVALVE   PLOTADD
F         F         T         F         F         F         F         F
PRESREG   PRESS     PRINTI    PRNTADD   PRNTIN    RADIATION REACTING  ROTATION
0         F         F         T         F         F         F         F
SAVER     SECONDL   SHEAR     SIMULA    SIUNITS   STEADY    THRUST    TPA
F         T         F         T         F         F         F         F
TRANS_MOM TRANSQ    TRANSV    TVM       TWOD      USRVAR    VARGEO    VARROT
F         F         T         F         F         F         T         F
RLFVLV
F

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


FLUIDS:  N2
```

```
    ISTEP =      1          TAU =  0.10000E-03

SOLUTION
INTERNAL NODES
 NODE     P(PSI)      TF(F)        Z           RHO         EM(LBM)     QUALITY
                                             (LBM/FT^3)
    1    0.1471E+02  0.7509E+02  0.1000E+01  0.7181E-01  0.1028E-02  0.1000E+01
    2    0.1471E+02  0.7509E+02  0.1000E+01  0.7181E-01  0.1028E-02  0.1000E+01

   NODE       H          ENTROPY     EMU       COND        CP          GAMA
           BTU/LB       BTU/LB-R  LBM/FT-SEC  BTU/FT-S-R  BTU/LB-R

    1    0.1975E+03  0.1054E+01  0.1199E-04  0.4154E-05  0.2487E+00  0.1401E+01
    2    0.1975E+03  0.1054E+01  0.1199E-04  0.4154E-05  0.2487E+00  0.1401E+01

BRANCHES
BRANCH       KFACTOR       DELP        FLOW RATE   VELOCITY    REYN. NO.   MACH NO.   ENTROPY GEN.   LOST WORK
      (LBF-S^2/(LBM-FT)^2)  (PSI)       (LBM/SEC)     (FT/SEC)                            BTU/(R-SEC)   LBF-FT/SEC
      12     0.000E+00     0.000E+00   0.000E+00     0.000E+00   0.000E+00   0.000E+00   0.000E+00   0.000E+00


         ***** TOTAL ENTROPY GENERATION =    0.000E+00 BTU/(R-SEC) ******

         **** TOTAL WORK LOST =    0.000E+00 HP *****

                             :
                             :
                             :
                             :

   ISTEP =    250          TAU =  0.25000E-01

SOLUTION
INTERNAL NODES
 NODE     P(PSI)      TF(F)        Z           RHO         EM(LBM)     QUALITY
                                             (LBM/FT^3)
    1    0.2235E+03  0.6934E+03  0.1007E+01  0.5023E+00  0.1028E-02  0.1000E+01
    2    0.2235E+03  0.6934E+03  0.1007E+01  0.5023E+00  0.1028E-02  0.1000E+01

   NODE       H          ENTROPY     EMU       COND        CP          GAMA
           BTU/LB       BTU/LB-R  LBM/FT-SEC  BTU/FT-S-R  BTU/LB-R

    1    0.3536E+03  0.1054E+01  0.2052E-04  0.7339E-05  0.2597E+00  0.1382E+01
```

```
     2    0.3536E+03  0.1054E+01  0.2052E-04  0.7339E-05  0.2597E+00  0.1382E+01

 BRANCHES
BRANCH       KFACTOR       DELP        FLOW RATE   VELOCITY    REYN. NO.   MACH NO.   ENTROPY GEN.   LOST WORK
      (LBF-S^2/(LBM-FT)^2)  (PSI)       (LBM/SEC)     (FT/SEC)                          BTU/(R-SEC)   LBF-FT/SEC
      12     0.233E+21     0.000E+00  -0.331E-22    -0.134E-20   0.821E-17   0.798E-24   0.188E-52   0.168E-46


          ***** TOTAL ENTROPY GENERATION =    0.188E-52 BTU/(R-SEC) ******

          **** TOTAL WORK LOST =    0.306E-49 HP *****


  AT ISTEP=    250

  WARNING! CHKGASP: T out of fluid property range at node   1


  AT ISTEP=    250

  WARNING! CHKGASP: T out of fluid property range at node   2
                            :
                            :
                            :
                            :



        ISTEP =    500          TAU =  0.50000E-01

 SOLUTION
 INTERNAL NODES
  NODE     P(PSI)      TF(F)        Z           RHO         EM(LBM)     QUALITY
                                               (LBM/FT^3)
     1    0.1470E+02  0.7501E+02  0.1000E+01  0.7178E-01  0.1028E-02  0.1000E+01
     2    0.1470E+02  0.7501E+02  0.1000E+01  0.7178E-01  0.1028E-02  0.1000E+01

    NODE       H          ENTROPY     EMU       COND        CP          GAMA
            BTU/LB       BTU/LB-R  LBM/FT-SEC  BTU/FT-S-R  BTU/LB-R

     1    0.1975E+03  0.1054E+01  0.1199E-04  0.4154E-05  0.2487E+00  0.1401E+01
     2    0.1975E+03  0.1054E+01  0.1199E-04  0.4154E-05  0.2487E+00  0.1401E+01

 BRANCHES
BRANCH       KFACTOR       DELP        FLOW RATE   VELOCITY    REYN. NO.   MACH NO.   ENTROPY GEN.   LOST WORK
      (LBF-S^2/(LBM-FT)^2)  (PSI)       (LBM/SEC)     (FT/SEC)                          BTU/(R-SEC)   LBF-FT/SEC
      12     0.955E+21     0.000E+00  -0.331E-22    -0.939E-20   0.141E-16   0.814E-23   0.116E-50   0.482E-45
```

```
         ***** TOTAL ENTROPY GENERATION =    0.116E-50 BTU/(R-SEC) ******

         **** TOTAL WORK LOST =    0.876E-48 HP *****

*************************************************

TIME OF ANALYSIS WAS   1.562500000000000E-002  SECS
```

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APPENDIX Q—INPUT AND OUTPUT DATA FILES FROM EXAMPLE 10

Pressurization of a Propellent Tank

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```
GFSSP VERSION
    604
GFSSP INSTALLATION PATH

ANALYST
Todd Steadman
INPUT DATA FILE NAME
EX10.dat
OUTPUT FILE NAME
Ex10.out
TITLE
Pressurization of a Propellant Tank
USETUP
F
DENCON        GRAVITY       ENERGY        MIXTURE       THRUST        STEADY        TRANSV        SAVER
F             F             T             T             F             F             T             F
HEX           HCOEF         REACTING      INERTIA       CONDX         ADDPROP       PRINTI        ROTATION
F             F             F             F             F             F             F             F
BUOYANCY      HRATE         INVAL         MSORCE        MOVBND        TPA           VARGEO        TVM
F             T             F             F             F             F             F             F
SHEAR         PRNTIN        PRNTADD       OPVALVE       TRANSQ        CONJUG        RADIAT        WINPLOT
F             T             T             F             F             F             F             T
PRESS         INSUC         VARROT        CYCLIC        CHKVALS       WINFILE       DALTON        NOSTATS
T             F             F             F             F             T             F             F
NORMAL        SIMUL         SECONDL       NRSOLVT       IBDF          NOPLT         PRESREG       FLOWREG
F             T             F             F             1             T             0             0
TRANS_MOM     USERVARS      PSMG          ISOLVE        PLOTADD       SIUNITS       TECPLOT       MDGEN
F             F             F             1             F             F             F             F
NUM_USER_VARS IFR_MIX       PRINTD        SATTABL       MSORIN        PRELVLV       LAMINAR       HSTAG
1             1             F             F             F             F             T             T
NNODES        NINT          NBR           NF
 5            2            3            2
RELAXK        RELAXD        RELAXH        CC            NITER         RELAXNR       RELAXHC       RELAXTS
 1               0.5           0                0.001          500 1             1               1
DTAU          TIMEF         TIMEL         NPSTEP        NPWSTEP       WPLSTEP       WPLBUFF
 0.1             0                  200                  10            1             50            1.1
NFLUID(I),  I = 1, NF
 1 6
NODE          INDEX     DESCRIPTION
 1              2       " Node 1"
 2              1       " Node 2"
 3              2       " Node 3"
 4              1       " Node 4"
 5              2       " Node 5"
 NODE  PRES (PSI)  TEMP(DEGF)  MASS SOURC    HEAT SOURC   THRST AREA   NODE-VOLUME  CONCENTRATION
 2     67               -264             0                   0                  0               43200           1 0
 4     74.76            -264             0                   0                  0               820800          0 1
```

```
 ex10h1.dat
 ex10h3.dat
 ex10h5.dat
INODE         NUMBR         NAMEBR
 2             1            12
 4             2            34   45
BRANCH   UPNODE    DNNODE    OPTION    DESCRIPTION
12         1          2          2       "Restrict 12"
34         3          4          2       "Restrict 34"
45         4          5          2       "Restrict 45"
BRANCH        OPTION -2     FLOW COEFF    AREA
 12                         0.6           0.785
BRANCH        OPTION -2     FLOW COEFF    AREA
 34                         0             4015
BRANCH        OPTION -2     FLOW COEFF    AREA
 45                         0.3043        14.25
INITIAL FLOWRATES IN BRANCHES FOR UNSTEADY FLOW
 12 1
 34 0.01
 45 0.01
NUMBER OF PRESSURIZATION PROPELLANT TANKS IN CIRCUIT
1
TNKTYPE  NODUL  NODULB  NODPRP  IBRPRP   TNKAR      TNKTH       TNKRHO     TNKCP      TNKCON     ARHC       FCTHC      TNKTM      CIP
FNIP       CIW        FNIW
1        2      3       4       34       6431.9     0.375      170        0.2        0.0362     4015       1          -264       0.27
0.25       0.54       0.25
```

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EXAMPLE 10 HISTORY FILES

EX10H1.DAT

```
2

0.0     95.00   120.00   1.0   0.0

1000    95.00   120.00   1.0   0.0
```

EX10H3.DAT

```
2

0.00      74.76    -264.0   0.0   1.0

1000      74.76    -264.0   0.0   1.0
```

EX10H5.DAT

```
2

0.00     50.00   -264.00   0.00  1.00

1000     50.00   -264.00   0.00  1.00
```

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```
C*********************************************************************
C                                                                     *
C     ***** GFSSP USER SUBROUTINES *****                              *
C                                                                     *
C*********************************************************************
C   SUBROUTINE USRINT IS CALLED FROM INIT TO SPECIFY INITIAL VALUES COMPUTED
C              BY USER SPECIFIED THERMODYNAMIC PROPERTY PACKAGE
C
C   SUBROUTINE SORCEM(IPN,TERMU) IS CALLED FROM EQNS FOR MASS SOURCES.
C              IN THIS ROUTINE THE USER DEFINES ANY ADDITIONAL MASS
C              SOURCES TO THE MODEL (MASS SOURCES ARE IN LBM/SEC).  USER
C              CAN MODIFY TRANSIENT TERM BY REDEFINING THE ARGUMENT TERMU.
C
C   SUBROUTINE SORCEF(I,TERM0,TERM1,TERM2,TERM3,TERM4,TERM5,TERM6,TERM7,
C              TERM8,TERM9,TERM10,TERM100) IS CALLED FROM EQNS FOR
C              MOMENTUM SOURCES.  USER CAN MODIFY INDIVIDUAL TERMS OR
C              DEFINE ADDITIONAL MOMENTUM SOURCES THROUGH TERM100.
C
C   SUBROUTINE SORCEQ IS CALLED FROM EITHER THE ENERGY ROUTINE (EITHER
C              ENTHALPY OR ENTROPY).  IN THIS ROUTINE THE USER DEFINES
C              ANY ADDITIONAL HEAT SOURCES TO THE MODEL (HEAT SOURCES
C              ARE IN BTU/SEC)
C
C   SUBROUTINE SORCEC IS CALLED FROM THE SPECIES CONCENTRATION ROUTINE
C              IN THIS ROUTINE THE USER DEFINES ANY ADDITIONAL SPECIES
C              CONCENTRATION SOURCES TO THE MODEL (CONCENTRATION SOURCES
C              ARE IN MASS FRACTIONS SUCH THAT THE SUM OF ALL OF THE
C              CONCENTRATIONS EQUALS 1.0)
C   SUBROUTINE SORCETS IS CALLED FROM SUROUTINE TSOLID AND TSOLIDNR. IN THIS
C              ROUTINE THE USER DEFINES ANY ADDITIONAL HEAT SOURCES TO ANY
C              SOLID NODE
C
C   SUBROUTINE KFUSER IS CALLED FROM THE RESIST ROUTINE.  IN THIS ROUTINE
C              THE USER DEFINES ANY VARIATION OF THE K-FACTOR OF A BRANCH
C              SUCH THAT THE K-FACTOR IS DEFINED AS THE PRESSURE DROP
C              DIVIDED BY THE MASS FLOW RATE^2 (PRESSURE IS IN PSF, FLOW
C              RATE IS IN LBM/SEC; I.E. THE K-FACTOR IS IN PSF-SEC^2/
C              (LBM-FT)^2)
C
C   SUBROUTINE PRPUSER IS CALLED FROM THE DENSITY ROUTINE.  IN THIS
C              ROUTINE THE USER ADDS OR MODIFIES FLUID PROPERTIES (ALLOWS
C              FOR USER SPECIFIED FLUID)
C
C   SUBROUTINE TSTEP IS CALLED FROM THE MAIN ROUTINE.  IN THIS ROUTINE
C              THE USER CAN MODIFY THE TIMESTEP, DTAU, FOR AN UNSTEADY
C              MODEL (DTAU IS IN SECONDS)
C
```

```
C   SUBROUTINE BNDUSER IS CALLED FROM THE BOUND ROUTINE.  IN THIS ROUTINE
C              THE USER CAN MODIFY BOUNDARY CONDITIONS AND GEOMETRY AT
C              EACH TIMESTEP FOR AN UNSTEADY MODEL (PRESSURE IS IN PSF,
C              TEMPERATURE IS IN DEG. R, LENGTH {ETC.} IS IN FT, AREA IS
C              IN FT^2, VOLUME IS IN FT^3)
C
C   SUBROUTINE PRNUSER IS CALLED FROM THE PRINT ROUTINE.  IN THIS ROUTINE
C              THE USER CAN MODIFY ADD ADDITIONAL OUTPUT FILES SPECIFIC
C              TO A PARTICULAR MODEL
C
C   SUBROUTINE FILNUM IS CALLED FROM THE MAIN ROUTINE.  IN THIS ROUTINE
C              ESTABLISHES THE FILE NUMBERS THAT ARE TO BE OPENED FOR ALL
C              FILES IN GFSSP, AND INCLUDES 10 USER FILE NUMBERS FOR USE
C              IN THE PRNUSER SUBROUTINE
C
C   SUBROUTINE USRSET IS CALLED FROM THE READIN ROUTINE.  IN THIS ROUTINE
C              THE USER SETS UP THE MAJORITY OF THE MODEL; ONLY A DUMMY
C              SEGMENT OF AN INPUT FILE IS NECESSARY TO BE READ, WITH THE
C              REMAINDER OF THE MODEL SETUP IN THIS SUBROUTINE.
C
C   SUBROUTINE USRHCF IS CALLED FROM SUBROUTINE CONVHC.  IN THIS ROUTINE
C              USER SPECIFIES THE HEAT TRANSFER COEFFICIENT.  THE HEAT
C              TRANSFER COEFFICIENT CALCULATED BY GFSSP OR SPECIFIED BY
C              USER IS OVER-WRITTEN
C
C   SUBROUTINE USRADJUST IS CALLED FROM MAIN ROUTINE.  IN THIS ROUTINE
C              USER CAN ADJUST THE BOUNDARY CONDITION OR GEOMETRY UNTIL
C              DESIRED FLOW CONDITION IS ACHIEVED
C*********************************************************************
      SUBROUTINE FILENUM
C     PURPOSE: ESTABLISH THE FORTRAN FILE NUMBERS FOR READING &
C              WRITING OF INFORMATION
C*********************************************************************
       INCLUDE 'COMBLK.FOR'
C********************************************************************
C
C        FILES ALREADY WITHIN GFSSP
C
C          NWRTE = FILE # CORRESPONDING TO THE WRITEIN SUBROUTINE
C                  (WRITING INPUT DECK FROM COMMAND LINE PREPROCESSOR)
C          NPRNT = FILE # CORRESPONDING TO THE PRINT SUBROUTINE
C                  (WRITING THE MAIN OUTPUT FILE)
C          NREAD = FILE # CORRESPONDING TO THE READIN SUBROUTINE
C                  (READING IN THE INPUT DECK)
C          NGSPK = FILE # CORRESPONDING TO A NON-GASP PROPERTY PACKAGE
C          NFNOD = FILE # CORRESPONDING TO THE FNODE RESTART FILE
C          NGFSOUT = FILE # CORRESPONDING TO THE GFSSP.OUT FILE
```

```
C                   (DEBUGGING FILE)
C          NFBR =  FILE # CORRESPONDING TO THE FBRANCH RESTART FILE
C          NGASP = FILE # CORRESPONDING TO THE GASP.OUT FILE
C                   (DEBUGGING FILE)
C          NHSTN = FILE # CORRESPONDING TO THE HISTN.XLS FILE
C          NHSTB = FILE # CORRESPONDING TO THE HISTBR.XLS FILE
C          NHSTF = FILE # CORRESPONDING TO B.C. & VARGEO HISTORY FILES
C          NCVHST = FILE # CORRESPONDING TO THE CONTROL VALVE HISTORY FILE
C          NCVCHR1 = FILE # CORRESPONDING TO THE FIRST OF TWO CONTROL
C                  VALVE FILES
C          NCVCHR2 = FILE # CORRESPONDING TO THE SECOND OF TWO CONTROL
C                  VALVE FILES
C          NHSTROT = FILE # CORRESPONDING TO THE VARIABLE ROTATION
C                  HISTORY FILE
C          NERROR = FILE # CORRESPONDING TO THE ERROR.XLS FILE
C          NRP1DAT = FILE # CORRESPONDING TO THE RP1 PROPERTY DATA FILES
C          NDPLT = FILE # CORRESPONDING TO NODE RESULTS FOR VTASC POST-PROCESSING
C          NBRPLT = FILE # CORRESPONDING TO NODE RESULTS FOR VTASC POST-PROCESSING
C          NDWINP = FILE # CORRESPONDING TO NODE RESULTS FOR WINPLOT POST-PROCESSING
C          NBRWINP = FILE # CORRESPONDING TO BRANCH RESULTS FOR WINPLOT POST-PROCESSING
C          NCOND = FILE # CORRESPONDING TO THERMAL CONDUCTIVITY PROPERTY DATA
C          NCP = FILE # CORRESPONDING TO SPECIFIC HEAT PROPERTY DATA
C          NSLDPLT = FILE # CORRESPONDING TO SOLID NODE RESULTS FOR PLOTTING
C          NSSCPLT = FILE # CORRESPONDING TO SOLID TO SOLID CONDUCTOR RESULTS FOR PLOTTING
C          NSFCPLT = FILE # CORRESPONDING TO SOLID TO FLUID CONDUCTOR RESULTS FOR PLOTTING
C          NSACPLT = FILE # CORRESPONDING TO SOLID TO AMBIENT CONDUCTOR RESULTS FOR PLOTTING
C
        NGSPK=1
         NPRNT=10
         NFNOD=11
        NGFSOUT=12
        NFBR=13
         NREAD=15
        NGASP=17
        NHSTN=18
        NHSTB=19
        NWRTE=20
        NHSTF=21
        NCVHST=28
        NCVCHR1=29
        NCVCHR2=30
        NHSTROT=35
        NERROR=55
        NRP1DAT=51
         NDPLT=52
         NBRPLT=53
         NDWINP=54
```

```
          NBRWINP=56
          NCOND = 57
          NCP = 58
          NSLDPLT = 59
          NSSCPLT = 60
          NSFCPLT = 61
          NSACPLT = 62
          NSSRCPLT = 67
C
C   FILE NUMBERS FOR USER DEFINED FILES (THESE FILES CAN BE USED
C   IN ANY OF THE USER SUBROUTINES; HOWEVER, MOST LIKELY USE IS
C   IN THE PRNUSER SUBROUTINE).  COMMENT OUT FILE NUMBERS NOT IN USE.
C
           NUSR1=14
C          NUSR2=
C          NUSR3=
C          NUSR4=
C          NUSR5=
C          NUSR6=
C          NUSR7=
C          NUSR8=
C          NUSR9=
C          NUSR10=
C
      RETURN
      END
C***********************************************************************
      SUBROUTINE USRINT
C     PURPOSE: PROVIDE INITIAL CONDITIONS WHEN ALTERNATE THERMODYNAMIC
C              PROPERTY PACKAGE IS USED
C*********************************************************************
       INCLUDE 'COMBLK.FOR'
C**********************************************************************
C**********************************************************************
C     ADD CODE HERE
      RETURN
      END
C***********************************************************************
      SUBROUTINE SORCEM(IPN,TERMU)
C     PURPOSE: ADD MASS SOURCES
C     IPN - GFSSP INDEX NUMBER FOR NODE
C     TERMU - UNSTEADY TERM IN MASS CONSERVATION EQUATION
C***********************************************************************
       INCLUDE 'COMBLK.FOR'
C**********************************************************************
C     ADD CODE HERE
      RETURN
```

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

      TERM0=0.0

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

```
C  PURPOSE:  COMPUTE MASS TRANSFER OF PROPELLANT INTO THE ULLAGE
C            DURING TANK PRESSURIZATION
       LOGICAL NOMASS
       CHARACTER*8, FLUID

       IF (PRESS) THEN
          NOMASS=.FALSE.
          IF (NOMASS) THEN
            GO TO 10
          ENDIF
          DO I=1, NTANK
C  FIND NODE INDICES
             DO II=1, NNODES
                NUMBER=NODE(II)
                IF (NUMBER .EQ. NODUL(I))IPUL=II
                IF (NUMBER .EQ. NODPRP(I))IPRP=II
             ENDDO
C  FIND MASS TRANSFER FROM HEAT TRANSFER
             SORCEMAS(IPUL)=0.0
             DO J=1,NF
               DIFFLU=ABS(1.0-CX(IPRP,J))
               IF (DIFFLU .LE. 1.0E-04) THEN
                 NFLU=NFLUID(J)
                 KFLU=J
               ENDIF !(IF (DIFFLU...
             ENDDO !(DO J=1,NF...
             IF (NFLU.EQ.4)FLUID='NITROGEN'
             IF (NFLU.EQ.6)FLUID='OXYGEN'
             IF (NFLU.EQ.10)FLUID='HYDROGEN'
             IF (NFLU.EQ.12)FLUID='RP1'
             CALL SATPRP(FLUID,P(IPUL),TSAT(I),HFG(I))
             SORCECON(IPUL,KFLU)=QULPRP(I)/(HFG(I)+CPNODE(IPRP)
     &          *MAX(TSAT(I)-TF(IPUL),0.0))
             SORCEMAS(IPUL)=SORCEMAS(IPUL)+SORCECON(IPUL,KFLU)
             SORCEMAS(IPRP)=-SORCEMAS(IPUL)
          ENDDO !(DO I=1,NTANK)
       ENDIF !(IF(PRESS))
10    CONTINUE
      RETURN
      END
C*********************************************************************
      SUBROUTINE SORCETS(IPSN,TERMD)
C     PURPOSE: ADD SOURCE TERM IN SOLID TEMPERATURE EQUATION
C*********************************************************************
      INCLUDE 'COMBLK.FOR'
C********************************************************************
C     ADD CODE HERE
```

```
      RETURN
      END
C***********************************************************************
      SUBROUTINE KFUSER(I,RHOU,EMUU,XVU,RHOUL,EMUUL,AKNEW)
C     PURPOSE: ADD A NEW RESISTANCE OPTION
C***********************************************************************
      INCLUDE 'comblk.for'
C**********************************************************************
C     ADD CODE HERE

      RETURN
      END

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

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

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

C***********************************************************************
      SUBROUTINE PRNUSER
```

```
C     PURPOSE: ADD NEW OUTPUT
C**********************************************************************
      INCLUDE 'COMBLK.FOR'
C*********************************************************************
C     ADD CODE HERE
C     GENERATE EXCEL FILE FOR PLOT
      OPEN (NUSR1,FILE = 'EX10.XLS',STATUS = 'UNKNOWN')
      VOLULG=VOLUME(2)
      VOLPRP=VOLUME(4)
      TFTNK1=TNKTM(1)-460.
      WRITE(NUSR1,200) TAU,QULWAL(1),QULPRP(1),
     &      QCOND(1),VOLULG,VOLPRP,TFTNK1,SORCECON(2,2),
     &      CX(2,2)
200   FORMAT (2X,E12.6,100(2X,2E12.6))
      RETURN
      END
C**********************************************************************
      SUBROUTINE USRSET(FILEIN,TITLE,HISTORY,FNODE,FBRANCH,PCURVE,
     &           HISTGEO,HISTQ,HISTVLV,OVALV,CVALV,ANALYST,FILEOUT)
C     PURPOSE: USER SETS UP THE MAJORITY OF THE MODEL
C**********************************************************************
       INCLUDE 'COMBLK.FOR'
C*********************************************************************
       CHARACTER*256, FILEIN,FILEOUT,ANALYST
       CHARACTER*80, TITLE
       CHARACTER*20, HISTQ(100),PCURVE(10),HISTGEO,HISTROT
        CHARACTER*256, HISTORY(100)
        CHARACTER*20, HISTVLV(10),OVALV(10),CVALV(10)
        CHARACTER*20, FNODE,FBRANCH
C
C  THIS IS THE DEFAULT CODE FOR THIS BLOCK, COMMENT THIS OUT WHEN
C  CREATING A MODEL WITHIN THIS SUBROUTINE
C
       WRITE(*,*) ' '
       WRITE(*,*) ' USER ROUTINE USRSET DOES NOT HAVE A MODEL DEVELOPED'
       WRITE(*,*) ' '
       WRITE(*,*) ' OPEN THE USER SUBROUTINE FILE AND MODIFY SUBROUTINE'
       WRITE(*,*) ' USRSET TO DEVELOP MODEL OR CHANGE LOGICAL VARIABLE'
       WRITE(*,*) ' USETUP TO FALSE AND DEVELOP MODEL IN INPUT FILE'
       WRITE(*,*) ' '
C       STOP
C
C  END OF DEFAULT CODE
C
      RETURN
      END
C*********************************************************************
```

```
      SUBROUTINE USRHCF(NUMBER,HCF)
C     PURPOSE: PROVIDE HEAT TRANSFER COEFFICIENT
C***********************************************************************
      INCLUDE 'COMBLK.FOR'
C**********************************************************************
C     ADD CODE HERE

      RETURN
      END
C**********************************************************************
      SUBROUTINE USRADJUST
C     PURPOSE: ADJUST BOUNDARY CONDITION OR GEOMETRY FOR STEADY-STATE MODEL
C***********************************************************************
      INCLUDE 'COMBLK.FOR'
C**********************************************************************
C     ADD CODE HERE
      RETURN
      END
C***********************************************************************
C***********************************************************************
      SUBROUTINE KFADJUST(I,RHOU,EMUU,RHOUL,EMUUL,RHOUV,EMUUV,ISATU,
     &                    AKNEW)
C     PURPOSE: ADD A NEW RESISTANCE OPTION
C***********************************************************************
      INCLUDE 'comblk.for'
C**********************************************************************
C     ADD CODE HERE
      RETURN
      END
C***********************************************************************

      SUBROUTINE PRPADJUST
C     PURPOSE: ADJUST THERMODYNAMIC OR THERMOPHYSICAL PROPERTY
C***********************************************************************
      INCLUDE 'comblk.for'
C**********************************************************************
C     ADD CODE HERE
      RETURN
      END
C**********************************************************************
      SUBROUTINE TADJUST
C     PURPOSE: ADJUST TEMPERATURE IF NECESSARY
C***********************************************************************
      INCLUDE 'comblk.for'
C**********************************************************************
C     ADD CODE HERE
      RETURN
```

```
      END
C**********************************************************************
      SUBROUTINE PADJUST
C     PURPOSE: ADJUST PRESSURE IF NECESSARY
C***********************************************************************
      INCLUDE 'comblk.for'
C**********************************************************************
      RETURN
      END
C***********************************************************************
      SUBROUTINE FLADJUST
C     PURPOSE: ADJUST FLOWRATE IF NECESSARY
C***********************************************************************
      INCLUDE 'comblk.for'
C**********************************************************************
C     ADD CODE HERE
      RETURN
      END
C***********************************************************************
      SUBROUTINE HADJUST
C     PURPOSE: ADJUST ENTHALPY IF NECESSARY
C***********************************************************************
      INCLUDE 'comblk.for'
C**********************************************************************
C     ADD CODE HERE
      RETURN
      END
C***********************************************************************
      SUBROUTINE SORCEHXQ(IPN,TERMD,K)
C     PURPOSE: ADD HEAT SOURCES
C     IPN - GFSSP INDEX NUMBER FOR NODE
C     TERMD - COMPONENT OF LINEARIZED SOURCE TERM APPEARING IN THE
C             DENOMINATOR OF THE ENTHALPY OR ENTROPY EQUATION
C***********************************************************************
       INCLUDE 'comblk.for'
C**********************************************************************
C     ADD CODE HERE
      RETURN
      END
C***********************************************************************
      SUBROUTINE USRMDG
C     PURPOSE: ADJUST INPUT PARAMETERS FOR MULTI-D FLOW, IF NECESSARY
C***********************************************************************
      INCLUDE 'comblk.for'
C**********************************************************************
C     ADD CODE HERE
      RETURN
```

```
      END
C*********************************************************************
C                                                                   *
C                ***** END OF USER SUBROUTINES *****                *
C                                                                   *
C********************************************************************
C**********************************************************
      SUBROUTINE SATPRP(FLUID,PRS,STRT,HTVAP)
C
C     THIS SUBROUTINE CALCULATES
C     **  SATURATION TEMPERATURE FROM VAPOR PRESSURE RELATION **
C     **  ENTHALPY OF EVAPORATION FROM CLAPEYRON EQUATION  *****
C     **  SATPRP UTILIZED ENGLISH UNITS IN CALCULATIONS  *******
C *********************************************************
      CHARACTER*8, FLUID
C  ****   FO(PEOS,TEOS): VAPOR PRESSURE RELATION FOR OXYGEN  ******
C  ****   FN(PEOS,TEOS): VAPOR PRESSURE RELATION FOR NITROGEN *****
C  ****   FH(PEOS,TEOS): VAPOR PRESSURE RELATION FOR HYDROGEN *****
C  ****   FR(PEOS,TEOS): VAPOR PRESSURE RELATION FOR RP-1 *********
C  ****   FDASHO(TEOS): GRADIENT OF VAPOR PRESSURE CURVE FOR OXYGEN **
C  ****   FDASHN(TEOS): GRADIENT OF VAPOR PRESSURE CURVE FOR NITROGEN **
C  ****   FDASHH(TEOS): GRADIENT OF VAPOR PRESSURE CURVE FOR HYDROGEN **
C  ****   FDASHR(TEOS): GRADIENT OF VAPOR PRESSURE CURVE FOR RP-1 ******
C  ****  A,B,C & D ARE CONSTANTS OF VAPOR PRESSURE RELATION *******
      FO(PEOS,TEOS) = ALOG(PEOS) -81.65833 + 2856.85477/TEOS +
     &13.04607*ALOG(TEOS) - 0.03101*TEOS
      FN(PEOS,TEOS) = ALOG(PEOS) + 76.60382 - 117.1873/TEOS - 17.40608
     &*ALOG(TEOS) + 0.05372*TEOS
      FH(PEOS,TEOS)=ALOG(PEOS)-11.403728+211.94778/TEOS+1.22794
     &*ALOG(TEOS)-0.040478*TEOS
      FR(PEOS,TEOS)=ALOG(PEOS) + 3551.8 - 888437.6/TEOS - 68.05
     &*ALOG(TEOS) -2.73183*TEOS
      FDASHO(TEOS) = -2856.85477/(TEOS*TEOS) + 13.04607/TEOS - 0.03101
      FDASHN(TEOS) = 117.1873/(TEOS*TEOS) - 17.4068/TEOS + 0.05372
      FDASHH(TEOS)=-211.94778/(TEOS*TEOS)+1.22794/TEOS-0.040478
      FDASHR(TEOS)=888437.6/(TEOS*TEOS) - 68.05/TEOS - 2.73183
      DATA RLX,CNVRG/0.5,0.001/
      PEOS=PRS/144.
      ITER=0
      IF (FLUID.EQ.'OXYGEN') GO TO 100
      IF (FLUID.EQ.'NITROGEN') GO TO 200
      IF (FLUID.EQ.'HYDROGEN') GO TO 333
      IF (FLUID.EQ.'RP1') GO TO 444
C
100   CONTINUE
C     DATA FOR OXYGEN IN ENGLISH UNITS
C     TEOS IS IN DEG R; PEOS IS IN PSIA
```

```
      A =81.65833
      B = -2856.85477
      C =-13.04607
      D = 0.03101
C     NOTE: TEOS IS A GUESS TEMPERATURE
      TEOS= 135.
      GO TO 1000
C
200   CONTINUE
C     DATA FOR NITROGEN IN ENGLISH UNITS
C     TEOS IS DEG R; PEOS IS IN PSIA
      A = 67.78808
      B = -2156.13382
      C = -10.97167
      D = 0.0327
C     NOTE: TEOS IS A GUESS TEMPERATURE
      TEOS = 209.2
      GO TO 1000
C
333   CONTINUE
C     DATA FOR HYDROGEN IN ENGLISH UNITS
C      TEOS IS IN DEG R ;  PEOS IS IN PSI
          A=11.403728
          B=-211.94778
          C=-1.22794
          D=0.040478
C     NOTE: TEOS IS A GUESS TEMPERATURE
          TEOS=PEOS/2.7586
          GO TO 1000
C
444   CONTINUE
C     DATA FOR RP-1 IN ENGLISH UNITS
C      TEOS IS IN DEG R ; PEOS IS IN PSI
          A=-3551.8
          B=888437.6
          C=68.05
          D=2.73183
C     NOTE:  TEOS IS A GUESS TEMPERATURE
          TEOS=855.
          GO TO 1000
C     THE FOLLOWING LOOP CALCULATES STRT AND HTVAP
C
1000  CONTINUE
      IF (ITER .GT. 1000) THEN
        WRITE(*,*) 'SAT TMP EQN DID NOT CONVERGE'
        GO TO 5000
      ENDIF
```

```
C     CALCULATE TEOS FROM VAPOR-PRESSURE RELATION USING NEWTON-
C     RAPHSON METHOD
C
      IF (FLUID.EQ.'OXYGEN') ANUM =-FO(PEOS,TEOS)
      IF (FLUID.EQ.'NITROGEN') ANUM =-FN(PEOS,TEOS)
      IF (FLUID.EQ.'HYDROGEN') ANUM=-FH(PEOS,TEOS)
      IF (FLUID.EQ.'RP1') ANUM=-FR(PEOS,TEOS)
      IF (FLUID.EQ.'OXYGEN') DENOM = FDASHO(TEOS)
      IF (FLUID.EQ.'NITROGEN') DENOM = FDASHN(TEOS)
      IF (FLUID.EQ.'HYDROGEN') DENOM = FDASHH(TEOS)
      IF (FLUID.EQ.'RP1') DENOM = FDASHR(TEOS)
      TDASH = ANUM/DENOM
      TEOS = TEOS + RLX*TDASH
      IF (FLUID.EQ.'OXYGEN') RES = FO(PEOS,TEOS)
      IF (FLUID.EQ.'NITROGEN') RES = FN(PEOS,TEOS)
      IF (FLUID.EQ.'HYDROGEN') RES=FH(PEOS,TEOS)
      IF (FLUID.EQ.'RP1') RES=FR(PEOS,TEOS)
      ITER = ITER + 1
      IF (ABS(RES).GT.CNVRG) GO TO 1000
      STRT = TEOS
C     VG AND VF ARE IN CUBIC FEET PER POUND-MASS
       CALL BWR(FLUID,PEOS,STRT,VG,VF)
C     HFG IS IN BTU PER POUND-MASS
      DPDT = PEOS*(-B/(STRT**2) + C/STRT + D)
      HTVAP = STRT*(VG-VF)*DPDT*(144.*0.0012849)
5000  CONTINUE
      RETURN
      END
C************************************************************************
       SUBROUTINE BWR(FLUID,PBWR,TBWR,VG,VF)
C
C ************************************************************
       CHARACTER*8,FLUID
       LOGICAL SUCCES
       F(PR,VR,TR,B,C,D,C4,BETA,GAMA)=(PR*VR)/TR-1.-(B/VR)-
     &(C/VR**2)-(D/VR**5)-(C4/(TR**3*VR**2))*(BETA+GAMA/VR**2)*
     &EXP(-GAMA/VR**2)
C  *** LEE-KELSER CONSTANTS FOR SIMPLE FLUID  ****
       DATA B1S,B2S,B3S,B4S/0.1181193,0.265728,0.15479,0.030323/
       DATA C1S,C2S,C3S,C4S/0.0236744,0.0186984,0.0,0.042724/
       DATA D1S,D2S/0.155488E-04,0.623689E-04/
       DATA BETAS,GAMAS/0.65392,0.060167/
C  *** LEE-KELSER CONSTANTS FOR REFERENCE FLUID ***
       DATA B1R,B2R,B3R,B4R/0.2026579,0.331511,0.027655,0.203488/
       DATA C1R,C2R,C3R,C4R/0.0313385,0.0503618,0.016901,0.041577/
       DATA D1R,D2R/0.48736E-04,0.07403361E-04/
       DATA BETAR,GAMAR/1.226,0.03754/
```

```
       DATA OMEGAR/0.3978/
      DATA RCONST,CC/8.31434,0.001/
      DATA RELAX,FACT/0.5,2./
                VG=0.
                VF=0.
C   *****     OBTAIN CRITICAL CONSTANTS  ******
      CALL CONST1(FLUID,PC,TC,TB,WMOL)
C  ***  CONVERT P FROM PSI TO PASCALS
                PK=PBWR/1.45E-04
C ***   CONVERT PK FROM PASCALS TO KILO-PASCALS
                PK=PK/1000.
C ***   CONVERT T FROM DEG R TO DEG K
            TEMPF=TBWR-460.
            TEMPC=(5./9.)*(TEMPF-32.)
            TK=TEMPC+273.16
C *** CALCULATE VG FOR RP-1 ONLY
          IF (FLUID .EQ. 'RP1') THEN
C    GAS CONSTANT FOR RP1 ADJUSTED BY 1000 TO ACCOUNT FOR KPA IN IDEAL GAS EQN
             RRP1=8315/(WMOL*1000)
             VG=(RRP1*TK)/PK
             GO TO 40
          ENDIF
C *** CHECK TO SEE IF STATE POINT FALLS IN INACCURACY WINDOW FOR **
C **  HYDROGEN ONLY                                              **
          PKI=PK
          TKI=TK
          IF(FLUID.EQ.'HYDROGEN')THEN
            CALL INTERPOLE(PKI,TKI,VG)
          ENDIF
          IF(VG.EQ.0.)GO TO 30
          IF(VG.NE.0.)GO TO 40
30       PR=PK/PC
         TR=TK/TC
C  ***  CALCULATE IDEAL REDUCED VOLUME OF A SIMPLE FLUID ***
      B=B1S-(B2S/TR)-(B3S/TR**2)-(B4S/TR**3)
      C=C1S-(C2S/TR)+(C3S/TR**3)
      D=D1S+(D2S/TR)
C     INITIAL GUESS IS FROM IDEAL GAS LAW
      VMOL=RCONST*TK/PK
        VMIDEAL=VMOL
C     DETERMINE THE INITAL RANGE OF VR
        VR1=(VMIDEAL*PC)/(RCONST*TC)
        VR2=10.*VR1
C   **** FIND THRESHOLD FROM ZBRAC  ****
        CALL ZBRAC(PR,VR1,VR2,TR,B,C,D,C4S,BETAS,GAMAS,SUCCES)
C   **** OBTAIN SOLUTION (=VR)  ******
        VRS=RTBIS(PR,VR1,VR2,TR,B,C,D,C4S,BETAS,GAMAS,CC,J1)
```

```
      ZS=(PR*VRS)/TR
C   **** CALCULATE THE IDEAL REDUCED VOLUME OF REFERENCE FLUID ****
     B=B1R-(B2R/TR)-(B3R/TR**2)-(B4R/TR**3)
     C=C1R-(C2R/TR)+(C3R/TR**3)
     D=D1R+(D2R/TR)
C  ****  USE VR FROM SIMPLE FLUID AS FIRST GUESS  ****
C  ***  OBTAIN THRESHOLD                          ****
      VR1=VRS
      VR2=2.*VRS
      CALL ZBRAC(PR,VR1,VR2,TR,B,C,D,C4R,BETAR,GAMAR,SUCCES)
C  **** OBTAIN A SOLUTION (=VR)                     ****
      VRR=RTBIS(PR,VR1,VR2,TR,B,C,D,C4R,BETAR,GAMAR,CC,J2)
      ITER=J1+J2
      ZR=(PR*VRR)/TR
C  ****  CALCULATE THE ACENTRIC FACTOR; OMEGA      ****
C  ** FIRST CONVERT PC FROM KPA TO ATM  ***
         PCA=PC*(0.009867)
         THETA=TB/TC
         ALPHA=-ALOG(PCA)-5.97214+(6.09648/THETA)+1.28862*
    &ALOG(THETA)-0.169347*(THETA**6)
         BETA=15.2518-(15.6875/THETA)-13.4721*ALOG(THETA)+
    &0.43577*(THETA**6)
         OMEGA=ALPHA/BETA
C  *** CALCULATE COMPRESSIBILITY FACTOR FOR THE FLUID OF INTEREST ***
      ZBWR=ZS+(OMEGA/OMEGAR)*(ZR-ZS)
      VR=(ZBWR*TR)/PR
      VMOL=(VR*RCONST*TC)/PC
     VG=VMOL/WMOL
C  *** CONVERT VG FROM M**3/KG TO FT**3/LBM  ****
40     CONTINUE
      VG=VG*16.018067
     IF (FLUID.EQ.'OXYGEN')VF=-0.34614+1.1286E-02*TBWR-1.3837E-04
    &*(TBWR**2)+8.2613E-07*(TBWR**3)-2.4007E-09*(TBWR**4)+
    &2.7247E-12*(TBWR**5)
     IF(FLUID.EQ.'HYDROGEN')VF=-13.132+1.7962*TBWR-9.4964E-02
    &*(TBWR**2)+2.464E-03*(TBWR**3)-3.1377E-05*(TBWR**4)
    &+1.5712E-07*(TBWR**5)
      IF (FLUID.EQ.'NITROGEN')VF=-0.01204 + 0.00061*TBWR
    &-4.23216E-06*TBWR*TBWR +1.06765E-08*TBWR*TBWR*TBWR
C***       CONVERT VF FROM M**3/KG TO FT**3/LBM
C       IF(FLUID.EQ.'NITROGEN')  VF=VF*16.018067
      IF (FLUID .EQ. 'HYDROGEN' .AND. TBWR .GT. 59) VF=0.
      IF (FLUID.EQ.'RP1')VF=0.01923
     RETURN
     END
C  ******************************************************************
     FUNCTION RTBIS(PR,VR1,VR2,TR,B,C,D,C4,BETA,GAMA,CC,J)
```

```
C     USING BISECTION, FIND THE ROOT OF A FUNTCTION F KNOWN TO LIE
C     BETWEEN VR1 AND VR2.  THE ROOT, RETURNED AS RTBIS, WILL BE
C     REFINED UNTIL ITS ACCURACY IS (+/-)CC.
C
C  *******************************************************************
        PARAMETER (JMAX=40)
       F(PR,VR,TR,B,C,D,C4,BETA,GAMA)=PR*VR/TR-1.-B/VR-C/VR**2-D/VR**5
     & -C4/(TR**3*VR**2)*(BETA+GAMA/VR**2)*EXP(-GAMA/VR**2)
        FMID=F(PR,VR2,TR,B,C,D,C4,BETA,GAMA)
        F1=F(PR,VR1,TR,B,C,D,C4,BETA,GAMA)
        IF(F1*FMID.GE.0.) PRINT*,'ROOT MUST BE BRACKETED FOR
     &BISECTION.'
C ** ORIENT THE SEARCH SO THAT F1 > 0 LIES AT VR+DELVR  ***
          IF(F1.LT.0.) THEN
            RTBIS=VR1
            DELVR=VR2-VR1
          ELSE
            RTBIS=VR2
            DELVR=VR1-VR2
          ENDIF
         DO 11 J= 1,JMAX
           DELVR=DELVR*0.5
           XMID=RTBIS+DELVR
           FMID=F(PR,XMID,TR,B,C,D,C4,BETA,GAMA)
           IF(FMID.LE.0.)RTBIS=XMID
           IF(ABS(DELVR/XMID).LT.CC.OR.FMID.EQ.0.)RETURN
11          CONTINUE
            PRINT*,' TOO MANY BISECTIONS'
            END
C *******************************************************
       SUBROUTINE CONST1(FLUID,PC,TC,TB,WMOL)
C
C *******************************************************
       CHARACTER*8,FLUID
       IF(FLUID.EQ.'OXYGEN')THEN
C  *** CRITICAL CONSTANTS ARE IN DEG K AND KPA RESPECTIVELY **
       TC=154.576
       PC=5.0427E03
       WMOL=31.9999
C  *** BOILING PT IS AT 1 ATM IN DEG K  **
       TB=90.2
       ENDIF
       IF(FLUID.EQ.'HYDROGEN')THEN
C  *** CRITICAL CONSTANTS ARE IN DEG K AND KPA RESPECTIVELY **
       TC=33.19
       PC=1315.
       WMOL=2.106
```

```
C  *** BOILING PT IS AT 1 ATM IN DEG K  **
      TB=20.4
      ENDIF
      IF(FLUID.EQ.'NITROGEN') THEN
      TC=126.2
      PC=3390
      WMOL=28.013
      TB=77.347
      ENDIF
      IF (FLUID.EQ.'RP1') THEN
      TC=658.
      PC=1820.
      WMOL=170.33
      TB=489.
      ENDIF
      RETURN
      END
C ********************************************************************
       SUBROUTINE ZBRAC(PR,VR1,VR2,TR,B,C,D,C4,BETA,GAMA,SUCCES)
C    GIVEN A FUNCTION F AND AN INITIAL GUESSED RANGE VR1 TO VR2,
C    THE ROUTINE EXPANDS THE RANGE GEOMETRICALLY UNTIL A ROOT IS
C    BRACKETED BY THE RETURN VALUES VR1 AND VR2 (IN WHICH CASE
C    SUCCES RETURNS AS .TRUE.) OR UNTIL THE RANGE BECOMES
C    UNACCEPTABLY LARGE (IN WHICH CASE SUCCES RETURNS AS .FALSE.).
C
C ********************************************************************
      PARAMETER (FACTOR=1.25,NTRY=50)
      LOGICAL SUCCES
      F(PR,VR,TR,B,C,D,C4,BETA,GAMA)=PR*VR/TR-1.-B/VR-C/VR**2-D/VR**5
     & -C4/(TR**3*VR**2)*(BETA+GAMA/VR**2)*EXP(-GAMA/VR**2)
      IF(VR1.EQ.VR2)PRINT*,'YOU HAVE TO GUESS AN INITIAL RANGE'
      F1=F(PR,VR1,TR,B,C,D,C4,BETA,GAMA)
      F2=F(PR,VR2,TR,B,C,D,C4,BETA,GAMA)
      SUCCES=.TRUE.
       DO 11 J=1,NTRY
          IF(F1*F2.LT.0.)RETURN
          IF(ABS(F1).LT.ABS(F2))THEN
               VR1=VR1+FACTOR*(VR1-VR2)
             VR1=AMAX1(0.001,VR1)
               F1=F(PR,VR1,TR,B,C,D,C4,BETA,GAMA)
          ELSE
               VR2=VR2+FACTOR*(VR2-VR1)
               F2=F(PR,VR2,TR,B,C,D,C4,BETA,GAMA)
               ENDIF
11       CONTINUE
          SUCCES=.FALSE.
          RETURN
```

```
           END
C *******************************************************
C *******************************************************
          SUBROUTINE INTERPOLE(PK,TK,VGP)
C THIS SUBROUTINE CALCULATES THE SPECIFIC VOLUME OF VAPOR OR
C SUPERHEATED VAPOR USING INTERPOLATION IN TWO-DIMENSIONS
C *******************************************************
          LOGICAL SUCCESS
          DIMENSION P(50),T(50),VG(50,50)
      OPEN(UNIT=20,FILE='HYDROGEN.IN',STATUS='OLD')
          DATA NX,NY/5,5/
          READ(20,*)(P(IX),IX=1,NX)
          DO 100 IY=1,NY
          READ(20,*)T(IY),(VG(IX,IY),IX=1,NX)
100       CONTINUE
          CLOSE (20)
C *** DETERMINE THE LOCATION OF PRESSURE AND TEMPERATURE IN THE TABLE
          SUCCESS=.FALSE.
          DO IX=1,NX
          IF(PK.GE.P(IX).AND.PK.LT.P(IX+1)) THEN
          SUCCESS=.TRUE.
          IXP=IX
          ENDIF
          ENDDO
          IF(.NOT.SUCCESS)THEN
C          PRINT*,'GIVEN PRESSURE IS NOT WITHIN THE RANGE'
          GO TO 10
          ENDIF
          SUCCESS=.FALSE.
          DO IY=1,NY
          IF(TK.GE.T(IY).AND.TK.LT.T(IY+1))THEN
          SUCCESS=.TRUE.
          IYP=IY
          ENDIF
          ENDDO
          IF(.NOT.SUCCESS)THEN
C          PRINT*,'GIVEN TEMPERATURE IS NOT WITHIN THE RANGE'
          GO TO 10
          ENDIF
C ** CALCULATE INTERPOLATING FACTOR FACTP=(PK-P(IXP))/(P(IXP+1)-
          P(IXP))
          FACTT=(TK-T(IYP))/(T(IYP+1)-T(IYP))
          VGP=(1.-FACTP)*(1.-FACTT)*VG(IXP,IYP)+FACTP*(1.-FACTT)
     &*VG(IXP+1,IYP)+FACTP*FACTT*VG(IXP+1,IYP+1)+
     &(1.-FACTP)*FACTT*VG(IXP,IYP+1)
           GO TO 3t0
10        VGP=0.
30        RETURN
          END
C***************************************************************************
```

Back to Appendix Q

```
 ***************************************************
            G F S S P (Version 604)
    Generalized Fluid System Simulation Program
                 March 2012

    Developed by NASA/Marshall Space Flight Center
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 A generalized computer program to calculate flow
 rates, pressures, temperatures and concentrations
 in a flow network.
 *************************************************

  RUN DATE:09/12/2012 15:02

TITLE     :Pressurization of a Propellant Tank
ANALYST   :Todd Steadman
FILEIN    :C:\Program Files (x86)\GFSSP604\TestInstalledExamples\EX10\Ex10.dat
FILEOUT   :Ex10.out

                           OPTION VARIABLES

ADDPROP   BUOYANCY  CONDX     CONJUG    CYCLIC    DALTON    DENCON    ENERGY
F         F         F         F         F         F         F         T
FLOWREG   GRAVITY   HCOEF     HEX       HRATE     IFRMIX    INERTIA   INSUC
0         F         F         F         T         1         F         F
INVAL     MIXTURE   MOVBND    MSORCE    NORMAL    NRSOLVT   OPVALVE   PLOTADD
F         T         F         F         F         F         F         F
PRESREG   PRESS     PRINTI    PRNTADD   PRNTIN    RADIATION REACTING  ROTATION
0         T         F         T         T         F         F         F
SAVER     SECONDL   SHEAR     SIMULA    SIUNITS   STEADY    THRUST    TPA
F         F         F         T         F         F         F         F
TRANS_MOM TRANSQ    TRANSV    TVM       TWOD      USRVAR    VARGEO    VARROT
F         F         T         F         F         F         F         F
RLFVLV
F

NNODES   =    5
NINT     =    2
NBR      =    3
NF       =    2
NVAR     =    7
NHREF    =    2


FLUIDS:  HE   O2
```

```
BOUNDARY NODES
    NODE       P          T          RHO        AREA         CONCENTRATIONS
           (PSI)       (F)      (LBM/FT^3)   (IN^2)
                                                     HE        O2
    1    0.9500E+02  0.1200E+03  0.6091E-01  0.0000E+00  0.1000E+01  0.0000E+00
    3    0.7470E+02 -0.2640E+03  0.6509E+02  0.0000E+00  0.0000E+00  0.1000E+01
    5    0.5000E+02 -0.2640E+03  0.8187E+00  0.0000E+00  0.0000E+00  0.1000E+01

 INPUT SPECIFICATIONS FOR INTERNAL NODES
NODE       AREA         MASS         HEAT
          (IN^2)       (LBM/S)      (BTU/S)
    2    0.0000E+00  0.0000E+00  0.0000E+00
    4    0.0000E+00 -0.1000E-01  0.0000E+00

BRANCH      UPNODE    DNNODE    OPTION
     12         1         2         2
     34         3         4         2
     45         4         5         2
BRANCH OPTION -2:  FLOW COEF  AREA
     12            0.600E+00   0.785E+00
BRANCH OPTION -2:  FLOW COEF  AREA
     34            0.000E+00   0.402E+04
BRANCH OPTION -2:  FLOW COEF  AREA
     45            0.304E+00   0.142E+02



  NUMBER OF PRESSURIZATION SYSTEMS =  1
NODUL  NODPRP  QULPRP   QULWAL     QCOND   TNKTM     VOLPROP    VOLULG
               BTU/Sec  BTU/Sec    BTU/Sec   R         Ft^3      Ft^3
    2     4    0.0000    0.0000    0.0000  195.6700  475.0000   25.0000


    ISTEP =     10          TAU =  0.10000E+01
BOUNDARY NODES
   NODE    P(PSI)   TF(F)      Z(COMP)    RHO       CONCENTRATIONS
                                       (LBM/FT^3)
                                                                HE        O2
    1    0.9500E+02  0.1200E+03  0.1004E+01  0.6091E-01  0.1000E+01  0.0000E+00
    3    0.9344E+02 -0.2640E+03  0.1751E-01  0.6509E+02  0.0000E+00  0.1000E+01
    5    0.5000E+02 -0.2640E+03  0.9309E+00  0.8187E+00  0.0000E+00  0.1000E+01

SOLUTION
INTERNAL NODES
    NODE     P(PSI)      TF(F)         Z         RHO        EM(LBM)    CONC
                                             (LBM/FT^3)
```

```
                                                                               HE        O2
     2    0.8665E+02 -0.2105E+03  0.1007E+01  0.1290E+00  0.3472E+01  0.9987E+00  0.0013
     4    0.9344E+02 -0.2640E+03  0.2187E-01  0.6512E+02  0.3081E+05  0.0000E+00  1.0000

    NODE       H          ENTROPY     EMU       COND        CP          GAMA
            BTU/LB       BTU/LB-R  LBM/FT-SEC  BTU/FT-S-R  BTU/LB-R

     2    0.0000E+00  0.5660E+01  0.8122E-05  0.1504E-04  0.1242E+01  0.1669E+01
     4    0.0000E+00  0.7815E+00  0.8476E-04  0.1822E-04  0.4229E+00  0.2029E+01

 BRANCHES
BRANCH       KFACTOR       DELP        FLOW RATE   VELOCITY    REYN. NO.   MACH NO.   ENTROPY GEN.   LOST WORK
      (LBF-S^2/(LBM-FT)^2)  (PSI)       (LBM/SEC)     (FT/SEC)                                BTU/(R-SEC)   LBF-FT/SEC
      12     0.238E+05     0.835E+01   0.224E+00     0.676E+03   0.237E+06   0.195E+00   0.982E-02   0.443E+04
      34     0.000E+00     0.104E-11   0.162E+03     0.893E-01   0.410E+06   0.114E-03   0.000E+00   0.000E+00
      45     0.263E+00     0.434E+02   0.154E+03     0.239E+02   0.652E+07   0.305E-01   0.973E-01   0.148E+05


   NUMBER OF PRESSURIZATION SYSTEMS =  1
 NODUL  NODPRP  QULPRP   QULWAL     QCOND   TNKTM     VOLPROP    VOLULG
               BTU/Sec  BTU/Sec    BTU/Sec   R          Ft^3      Ft^3
     2     4    0.6653    2.1919    0.0000  195.6938  473.0888   26.9112
                             :
                             :
                             :
                             :

     ISTEP =1000          TAU =  0.10000E+03
 BOUNDARY NODES
    NODE    P(PSI)   TF(F)      Z(COMP)    RHO       CONCENTRATIONS
                                       (LBM/FT^3)
                                                                         HE        O2
     1    0.9500E+02  0.1200E+03  0.0000E+00  0.6091E-01  0.1000E+01  0.0000E+00
     3    0.9321E+02 -0.2640E+03  0.0000E+00  0.6510E+02  0.0000E+00  0.1000E+01
     5    0.5000E+02 -0.2640E+03  0.0000E+00  0.8191E+00  0.0000E+00  0.1000E+01

 SOLUTION
 INTERNAL NODES
     NODE     P(PSI)      TF(F)         Z         RHO        EM(LBM)    CONC
                                               (LBM/FT^3)
                                                                         HE        O2
     2    0.8944E+02 -0.7853E+02  0.1005E+01  0.1002E+00  0.2378E+02  0.8515E+00  0.1485
     4    0.9321E+02 -0.2640E+03  0.2182E-01  0.6513E+02  0.1512E+05  0.0000E+00  1.0000

    NODE       H          ENTROPY     EMU       COND        CP          GAMA
            BTU/LB       BTU/LB-R  LBM/FT-SEC  BTU/FT-S-R  BTU/LB-R
```

```
     2    0.2495E+03  0.5460E+01  0.1076E-04  0.1961E-04  0.1091E+01  0.1662E+01
     4    0.7491E+02  0.7814E+00  0.8483E-04  0.1822E-04  0.4228E+00  0.2029E+01

 BRANCHES
BRANCH       KFACTOR       DELP        FLOW RATE   VELOCITY    REYN. NO.   MACH NO.   ENTROPY GEN.   LOST WORK
      (LBF-S^2/(LBM-FT)^2)  (PSI)       (LBM/SEC)     (FT/SEC)                              BTU/(R-SEC)   LBF-FT/SEC
    12       0.238E+05     0.556E+01   0.183E+00     0.552E+03   0.194E+06   0.159E+00   0.534E-02   0.241E+04
    34       0.000E+00     0.000E+00   0.154E+03     0.847E-01   0.388E+06   0.108E-03   0.000E+00   0.000E+00
    45       0.263E+00     0.432E+02   0.154E+03     0.239E+02   0.650E+07   0.304E-01   0.965E-01   0.147E+05


   NUMBER OF PRESSURIZATION SYSTEMS =  1
 NODUL  NODPRP  QULPRP   QULWAL     QCOND   TNKTM     VOLPROP    VOLULG
     2     4    2.9585   38.9020    0.0901  213.2504  232.1752  267.8248

                               :
                               :
                               :
                               :

    ISTEP =   2000          TAU =  0.20000E+03
 BOUNDARY NODES
    NODE    P(PSI)   TF(F)      Z(COMP)    RHO       CONCENTRATIONS
                                        (LBM/FT^3)
                                                               HE        O2
     1    0.9500E+02  0.1200E+03  0.1004E+01  0.6091E-01  0.1000E+01  0.0000E+00
     3    0.8799E+02 -0.2640E+03  0.1751E-01  0.6509E+02  0.0000E+00  0.1000E+01
     5    0.5000E+02 -0.2640E+03  0.9309E+00  0.8187E+00  0.0000E+00  0.1000E+01

 SOLUTION
 INTERNAL NODES
     NODE     P(PSI)      TF(F)         Z         RHO        EM(LBM)    CONC
                                                (LBM/FT^3)
                                                               HE        O2
     2    0.8788E+02 -0.8244E+02  0.1005E+01  0.1002E+00  0.4943E+02  0.8444E+00  0.1556
     4    0.8799E+02 -0.2640E+03  0.2060E-01  0.6511E+02  0.4230E+03  0.0000E+00  1.0000

    NODE       H          ENTROPY     EMU       COND        CP          GAMA
            BTU/LB       BTU/LB-R  LBM/FT-SEC  BTU/FT-S-R  BTU/LB-R

     2    0.0000E+00  0.5422E+01  0.1068E-04  0.1945E-04  0.1083E+01  0.1662E+01
     4    0.0000E+00  0.7816E+00  0.8470E-04  0.1821E-04  0.4230E+00  0.2030E+01

 BRANCHES
BRANCH       KFACTOR       DELP        FLOW RATE   VELOCITY    REYN. NO.   MACH NO.   ENTROPY GEN.   LOST WORK
      (LBF-S^2/(LBM-FT)^2)  (PSI)       (LBM/SEC)     (FT/SEC)                              BTU/(R-SEC)   LBF-FT/SEC
      12     0.238E+05     0.712E+01   0.207E+00     0.624E+03   0.219E+06   0.180E+00   0.773E-02   0.349E+04
```

34	0.000E+00	0.000E+00	0.144E+03	0.795E-01	0.364E+06	0.101E-03	0.000E+00	0.000E+00
45	0.263E+00	0.380E+02	0.144E+03	0.224E+02	0.611E+07	0.285E-01	0.796E-01	0.121E+05

NUMBER OF PRESSURIZATION SYSTEMS = 1

NODUL	NODPRP	QULPRP	QULWAL	QCOND	TNKTM	VOLPROP	VOLULG
		BTU/Sec	BTU/Sec	BTU/Sec	R	Ft^3	Ft^3
2	4	2.8710	56.1603	6.5609	231.6004	6.4972	493.5028

```
*************************************************

TIME OF ANALYSIS WAS    1.60937500000000       SECS
```

APPENDIX R—INPUT AND OUTPUT DATA FILES FROM EXAMPLE 11

Power Balancing of a Turbopump Assembly

Contents

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```
GFSSP VERSION
    604
GFSSP INSTALLATION PATH

ANALYST
PS
INPUT DATA FILE NAME
Ex11.dat
OUTPUT FILE NAME
Ex11.out
TITLE
Power Balancing of a Turbopump Assembly
USETUP
F
DENCON        GRAVITY       ENERGY        MIXTURE       THRUST        STEADY        TRANSV        SAVER
F             F             T             F             F             T             F             F
HEX           HCOEF         REACTING      INERTIA       CONDX         ADDPROP       PRINTI        ROTATION
T             T             F             F             F             F             F             F
BUOYANCY      HRATE         INVAL         MSORCE        MOVBND        TPA           VARGEO        TVM
F             T             F             F             F             T             F             F
SHEAR         PRNTIN        PRNTADD       OPVALVE       TRANSQ        CONJUG        RADIAT        WINPLOT
F             F             T             F             F             F             F             T
PRESS         INSUC         VARROT        CYCLIC        CHKVALS       WINFILE       DALTON        NOSTATS
F             F             F             F             F             T             F             F
NORMAL        SIMUL         SECONDL       NRSOLVT       IBDF          NOPLT         PRESREG       FLOWREG
F             T             F             F             1             T             0             0
TRANS_MOM     USERVARS      PSMG          ISOLVE        PLOTADD       SIUNITS       TECPLOT       MDGEN
F             F             F             1             F             F             F             F
NUM_USER_VARS IFR_MIX       PRINTD        SATTABL       MSORIN        PRELVLV       LAMINAR       HSTAG
1             1             F             F             F             F             T             T
NNODES        NINT          NBR           NF
 20            17            20            1
RELAXK        RELAXD        RELAXH        CC            NITER         RELAXNR       RELAXHC       RELAXTS
 1               0.5           1                0.0001          500 1              1                1
NFLUID(I),  I = 1, NF
 10
NODE          INDEX     DESCRIPTION
 1              2       " Node 1"
 2              1       " Node 2"
 3              1       " Node 3"
 4              1       " Node 4"
 5              1       " Node 5"
 6              1       " Node 6"
 7              1       " Node 7"
 8              1       " Node 8"
 9              1       " Node 9"
 10              1       " Node 10"
```

11	1	" Node 11"
12	1	" Node 12"
13	1	" Node 13"
14	1	" Node 14"
15	1	" Node 15"
16	1	" Node 16"
17	2	" Node 17"
18	1	" Node 18"
19	1	" Node 19"
20	2	" Node 20"

NODE	PRES (PSI)	TEMP(DEGF)	MASS SOURC	HEAT SOURC	THRST AREA	CONCENTRATION
1	60	-419	0	0		0
2	25	-419	0	0		0
3	25	-419	0	0		0
4	25	-419	0	0		0
5	25	-419	0	0		0
6	25	-419	0	0		0
7	25	-419	0	0		0
8	25	-419	0	0		0
9	25	-419	0	0		0
10	25	-419	0	0		0
11	25	-419	0	0		0
12	25	-419	0	0		0
13	25	-419	0	0		0
14	25	-419	0	0		0
15	25	-419	0	0		0
16	25	-419	0	0		0
17	14.7	80	0	0		0
18	25	-419	0		200	0
19	25	-419	0	0		0
20	14.7	80	0	0		0

INODE	NUMBR	NAMEBR		
2	2	12	23	
3	2	23	34	
4	3	34	45	46
5	2	45	57	
6	2	46	68	
7	2	57	78	
8	3	78	68	89
9	2	89	910	
10	2	910	1011	
11	2	1011	1112	
12	2	1112	1213	
13	2	1213	1314	
14	2	1314	1415	
15	2	1415	1516	
16	3	1516	1617	1618

```
 18           2           1618   1819
 19           2           1819   1920
BRANCH   UPNODE    DNNODE    OPTION    DESCRIPTION
12         1          2          16      "CV 12"
23         2          3          15      "Pump 23"
34         3          4          1       "Pipe 34"
45         4          5          1       "Pipe 45"
57         5          7          1       "Pipe 57"
78         7          8          1       "Pipe 78"
46         4          6          1       "Pipe 46"
68         6          8          1       "Pipe 68"
89         8          9          16      "CV 89"
910        9          10         1       "Pipe 910"
1011       10         11         1       "Pipe 1011"
1112       11         12         16      "CV 1112"
1213       12         13         15      "Pump 1213"
1314       13         14         1       "Pipe 1314"
1415       14         15         1       "Pipe 1415"
1516       15         16         1       "Pipe 1516"
1617       16         17         16      "CV 1617"
1618       16         18         16      "CV 1618"
1819       18         19         1       "Pipe 1819"
1920       19         20         1       "Pipe 1920"
BRANCH        OPTION -16    CV            AREA
 12                         2.877         0.19635
BRANCH        OPTION -15    HORSEPOWER    EFFICIENCY    AREA
 23                         0             0.8          0.12112
BRANCH        OPTION -1     LENGTH        DIA           EPSD          ANGLE         AREA
 34                         100              0.3927        0.0025          0                0.12111873243
BRANCH        OPTION -1     LENGTH        DIA           EPSD          ANGLE         AREA
 45                         100              0.3927        0.0025          0                0.12111873243
BRANCH        OPTION -1     LENGTH        DIA           EPSD          ANGLE         AREA
 57                         100              0.3927        0.0025          0                0.12111873243
BRANCH        OPTION -1     LENGTH        DIA           EPSD          ANGLE         AREA
 78                         100              0.3927        0.0025          0                0.12111873243
BRANCH        OPTION -1     LENGTH        DIA           EPSD          ANGLE         AREA
 46                         100              0.3927        0.0025          0                0.12111873243
BRANCH        OPTION -1     LENGTH        DIA           EPSD          ANGLE         AREA
 68                         100              0.3927        0.0025          0                0.12111873243
BRANCH        OPTION -16    CV            AREA
 89                         3.554         0.19635
BRANCH        OPTION -1     LENGTH        DIA           EPSD          ANGLE         AREA
 910                        100              0.3927        0.0025          0                0.12111873243
BRANCH        OPTION -1     LENGTH        DIA           EPSD          ANGLE         AREA
 1011                       100              0.3927        0.0025          0                0.12111873243
BRANCH        OPTION -16    CV            AREA
 1112                       3.554         0.19635
```

```
BRANCH        OPTION -15    HORSEPOWER    EFFICIENCY    AREA
 1213                       0             1            0.019635
BRANCH        OPTION -1     LENGTH        DIA           EPSD          ANGLE         AREA
 1314                       100              0.3927         0.0025            0                 0.12111873243
BRANCH        OPTION -1     LENGTH        DIA           EPSD          ANGLE         AREA
 1415                       100              0.3927         0.0025            0                 0.12111873243
BRANCH        OPTION -1     LENGTH        DIA           EPSD          ANGLE         AREA
 1516                       100              0.3927         0.0025            0                 0.12111873243
BRANCH        OPTION -16    CV            AREA
 1617                       0.00354       0.01
BRANCH        OPTION -16    CV            AREA
 1618                       3.554         0.19635
BRANCH        OPTION -1     LENGTH        DIA           EPSD          ANGLE         AREA
 1819                       100              0.3927         0.0025            0                 0.12111873243
BRANCH        OPTION -1     LENGTH        DIA           EPSD          ANGLE         AREA
 1920                       100              0.3927         0.0025            0                 0.12111873243
NUMBER OF HEAT EXCHANGERS
2
 IBRHOT   IBRCLD   ITYPHX   ARHOT      ARCOLD      UA     HEXEFF
1415   57      2       0          0          0          0.8
1819   910     2       0          0          0          0.9
NUMBER OF TURBOPUMP ASSEMBLY IN THE CIRCUIT
1
IBRPMP   IBRTRB    SPEED(RPM)      EFFTURB     DIATRB    PSITRD
23     1213   80000       0.5         3.435       0.4
PUMP CHARACTERISTICS CURVE DATA FILE
ex11pmp23.dat
```

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Example 11 Pump Characteristic Data File

EX11PMP23.DAT

```
18
0.000      8.680E-06  0.000
3.035E-05  8.971E-06  8.8724E-10
6.071E-05  9.190E-06  9.7065E-10
9.106E-05  9.341E-06  1.0804E-09
1.214E-04  9.436E-06  1.2166E-09
1.518E-04  9.486E-06  1.3393E-09
1.821E-04  9.486E-06  1.4570E-09
2.125E-04  9.445E-06  1.5644E-09
2.428E-04  9.372E-06  1.6733E-09
2.732E-04  9.263E-06  1.7872E-09
3.035E-04  9.117E-06  1.9105E-09
3.339E-04  8.935E-06  2.0558E-09
3.643E-04  8.753E-06  2.2161E-09
3.718E-04  8.689E-06  2.2698E-09
3.749E-04  8.625E-06  2.2869E-09
3.794E-04  8.479E-06  2.3215E-09
3.807E-04  8.388E-06  2.3281E-09
3.810E-04  0.000E+00  0.000
```

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```
 ***************************************************
           G F S S P (Version 604)
    Generalized Fluid System Simulation Program
                 March 2012

   Developed by NASA/Marshall Space Flight Center
   Copyright (C) by Marshall Space Flight Center

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

 RUN DATE:09/12/2012 15:04

TITLE     :Power Balancing of a Turbopump Assembly
ANALYST   :PS
FILEIN    :C:\Program Files (x86)\GFSSP604\TestInstalledExamples\EX11\Ex11.dat
FILEOUT   :Ex11.out

                           OPTION VARIABLES

ADDPROP   BUOYANCY  CONDX     CONJUG    CYCLIC    DALTON    DENCON    ENERGY
F         F         F         F         F         F         F         T
FLOWREG   GRAVITY   HCOEF     HEX       HRATE     IFRMIX    INERTIA   INSUC
0         F         T         T         T         1         F         F
INVAL     MIXTURE   MOVBND    MSORCE    NORMAL    NRSOLVT   OPVALVE   PLOTADD
F         F         F         F         F         F         F         F
PRESREG   PRESS     PRINTI    PRNTADD   PRNTIN    RADIATION REACTING  ROTATION
0         F         F         T         F         F         F         F
SAVER     SECONDL   SHEAR     SIMULA    SIUNITS   STEADY    THRUST    TPA
F         F         F         T         F         T         F         T
TRANS_MOM TRANSQ    TRANSV    TVM       TWOD      USRVAR    VARGEO    VARROT
F         F         F         F         F         F         F         F
RLFVLV
F

NNODES   =   20
NINT     =   17
NBR      =   20
NF       =    1
NVAR     =   37
NHREF    =    2


FLUIDS:  H2
```

BOUNDARY NODES

NODE	P (PSI)	T (F)	RHO (LBM/FT^3)		AREA (IN^2)
1	0.6000E+02	-0.4190E+03	0.4264E+01	0.0000E+00	
17	0.1470E+02	0.8000E+02	0.5112E-02	0.0000E+00	
20	0.1470E+02	0.8000E+02	0.5112E-02	0.0000E+00	

1

IBRPMP	IBRTRB	SPEED(RPM)	ETATRB	PSITR	TORQUE(LB-IN)	HPOWER
23	1213	0.800E+05	0.000E+00	0.000E+00	0.000E+00	0.000E+00

SOLUTION

INTERNAL NODES

NODE	P(PSI)	TF(F)	Z	RHO (LBM/FT^3)	EM(LBM)	QUALITY
2	0.5542E+02	-0.4190E+03	0.6007E-01	0.4258E+01	0.0000E+00	0.0000E+00
3	0.1789E+04	-0.4073E+03	0.1368E+01	0.4697E+01	0.0000E+00	0.0000E+00
4	0.1779E+04	-0.4072E+03	0.1358E+01	0.4690E+01	0.0000E+00	0.0000E+00
5	0.1777E+04	-0.4072E+03	0.1357E+01	0.4690E+01	0.0000E+00	0.0000E+00
6	0.1774E+04	-0.4072E+03	0.1355E+01	0.4688E+01	0.0000E+00	0.0000E+00
7	0.1776E+04	-0.1455E+03	0.1091E+01	0.9734E+00	0.0000E+00	0.1000E+01
8	0.1770E+04	-0.3064E+03	0.1063E+01	0.2041E+01	0.0000E+00	0.1000E+01
9	0.1764E+04	-0.3064E+03	0.1062E+01	0.2035E+01	0.0000E+00	0.1000E+01
10	0.1740E+04	0.1482E+03	0.1065E+01	0.5050E+00	0.0000E+00	0.1000E+01
11	0.1644E+04	0.1486E+03	0.1061E+01	0.4783E+00	0.0000E+00	0.1000E+01
12	0.1617E+04	0.1487E+03	0.1060E+01	0.4709E+00	0.0000E+00	0.1000E+01
13	0.1078E+04	0.9107E+02	0.1043E+01	0.3525E+00	0.0000E+00	0.1000E+01
14	0.9399E+03	0.9153E+02	0.1038E+01	0.3087E+00	0.0000E+00	0.1000E+01
15	0.7827E+03	-0.3345E+01	0.1034E+01	0.3115E+00	0.0000E+00	0.1000E+01
16	0.6269E+03	-0.3025E+01	0.1028E+01	0.2509E+00	0.0000E+00	0.1000E+01
18	0.5763E+03	0.2498E+03	0.1020E+01	0.1496E+00	0.0000E+00	0.1000E+01
19	0.2537E+03	-0.2248E+03	0.1008E+01	0.2013E+00	0.0000E+00	0.1000E+01

NODE	H BTU/LB	ENTROPY BTU/LB-R	EMU LBM/FT-SEC	COND BTU/FT-S-R	CP BTU/LB-R	GAMA
2	-0.9806E+02	0.6873E+01	0.7613E-05	0.1636E-04	0.2569E+01	0.1939E+01
3	-0.2274E+02	0.6873E+01	0.9957E-05	0.2254E-04	0.2465E+01	0.1537E+01
4	-0.2274E+02	0.6873E+01	0.9900E-05	0.2252E-04	0.2472E+01	0.1541E+01
5	-0.2274E+02	0.6873E+01	0.9893E-05	0.2251E-04	0.2473E+01	0.1541E+01
6	-0.2274E+02	0.6873E+01	0.9876E-05	0.2250E-04	0.2475E+01	0.1542E+01
7	0.9641E+03	0.6873E+01	0.4454E-05	0.2583E-04	0.4050E+01	0.1393E+01
8	0.3238E+03	0.6873E+01	0.3648E-05	0.1630E-04	0.3731E+01	0.1811E+01
9	0.3238E+03	0.6873E+01	0.3643E-05	0.1628E-04	0.3731E+01	0.1811E+01
10	0.2069E+04	0.6873E+01	0.6574E-05	0.3411E-04	0.3538E+01	0.1411E+01
11	0.2069E+04	0.6873E+01	0.6566E-05	0.3408E-04	0.3536E+01	0.1410E+01

12	0.2069E+04	0.6873E+01	0.6564E-05	0.3407E-04	0.3535E+01	0.1410E+01
13	0.1857E+04	0.6873E+01	0.6099E-05	0.3195E-04	0.3575E+01	0.1401E+01
14	0.1857E+04	0.6873E+01	0.6087E-05	0.3192E-04	0.3570E+01	0.1399E+01
15	0.1510E+04	0.6873E+01	0.5363E-05	0.2854E-04	0.3714E+01	0.1382E+01
16	0.1510E+04	0.6873E+01	0.5344E-05	0.2850E-04	0.3705E+01	0.1379E+01
18	0.2408E+04	0.6873E+01	0.7157E-05	0.3684E-04	0.3497E+01	0.1400E+01
19	0.6568E+03	0.6873E+01	0.3405E-05	0.1810E-04	0.3796E+01	0.1381E+01

BRANCHES

BRANCH	KFACTOR (LBF-S^2/(LBM-FT)^2)	DELP (PSI)	FLOW RATE (LBM/SEC)	VELOCITY (FT/SEC)	REYN. NO.	MACH NO.	ENTROPY GEN. BTU/(R-SEC)	LOST WORK LBF-FT/SEC
12	0.132E+05	0.457E+01	0.224E+00	0.385E+02	0.894E+06	0.276E-01	0.109E-02	0.346E+02
23	0.000E+00	-0.173E+04	0.224E+00	0.624E+02	0.114E+07	0.447E-01	0.000E+00	0.000E+00
34	0.298E+05	0.104E+02	0.224E+00	0.566E+02	0.874E+06	0.402E-01	0.175E-02	0.711E+02
45	0.303E+05	0.130E+01	0.785E-01	0.199E+02	0.309E+06	0.141E-01	0.767E-04	0.313E+01
57	0.303E+05	0.130E+01	0.785E-01	0.199E+02	0.309E+06	0.141E-01	0.767E-04	0.313E+01
78	0.144E+06	0.618E+01	0.785E-01	0.959E+02	0.686E+06	0.292E-01	0.294E-03	0.718E+02
46	0.300E+05	0.438E+01	0.145E+00	0.368E+02	0.570E+06	0.261E-01	0.479E-03	0.195E+02
68	0.300E+05	0.439E+01	0.145E+00	0.368E+02	0.572E+06	0.260E-01	0.479E-03	0.196E+02
89	0.180E+05	0.626E+01	0.224E+00	0.804E+02	0.187E+07	0.307E-01	0.829E-03	0.988E+02
910	0.685E+05	0.238E+02	0.224E+00	0.131E+03	0.239E+07	0.499E-01	0.316E-02	0.377E+03
1011	0.277E+06	0.962E+02	0.224E+00	0.527E+03	0.132E+07	0.114E+00	0.130E-01	0.613E+04
1112	0.770E+05	0.267E+02	0.224E+00	0.343E+03	0.104E+07	0.746E-01	0.380E-02	0.180E+04
1213	0.000E+00	0.539E+03	0.224E+00	0.348E+04	0.329E+07	0.757E+00	0.000E+00	0.000E+00
1314	0.397E+06	0.138E+03	0.224E+00	0.754E+03	0.143E+07	0.173E+00	0.294E-01	0.126E+05
1415	0.453E+06	0.157E+03	0.224E+00	0.861E+03	0.143E+07	0.197E+00	0.382E-01	0.164E+05
1516	0.448E+06	0.156E+03	0.224E+00	0.854E+03	0.162E+07	0.216E+00	0.454E-01	0.161E+05
1617	0.148E+12	0.612E+03	0.772E-03	0.443E+02	0.196E+05	0.112E-01	0.763E-03	0.271E+03
1618	0.147E+06	0.506E+02	0.223E+00	0.651E+03	0.127E+07	0.165E+00	0.182E-01	0.647E+04
1819	0.935E+06	0.323E+03	0.223E+00	0.177E+04	0.121E+07	0.358E+00	0.125E+00	0.692E+05
1920	0.693E+06	0.239E+03	0.223E+00	0.132E+04	0.255E+07	0.466E+00	0.209E+00	0.381E+05

1

IBRPMP	IBRTRB	SPEED(RPM)	ETATRB	PSITR	TORQUE(LB-IN)	HPOWER
23	1213	0.800E+05	0.578E+00	0.269E+00	0.511E+02	0.649E+02

****

TIME OF ANALYSIS WAS 0.453125000000000 SECS

****

APPENDIX S—INPUT AND OUTPUT DATA FILES FROM EXAMPLE 12

Helium Pressurization of LOX and RP-1 Propellent Tanks

Contents

Back to Appendix S

```
GFSSP VERSION
    604
GFSSP INSTALLATION PATH

ANALYST
Todd Steadman
INPUT DATA FILE NAME
Ex12.dat
OUTPUT FILE NAME
Ex12.out
TITLE
Helium Pressurization of LOX and RP-1 Propellant Tanks
USETUP
F
DENCON        GRAVITY       ENERGY        MIXTURE       THRUST        STEADY        TRANSV        SAVER
F             F             T             T             F             F             T             F
HEX           HCOEF         REACTING      INERTIA       CONDX         ADDPROP       PRINTI        ROTATION
F             F             F             T             F             F             F             F
BUOYANCY      HRATE         INVAL         MSORCE        MOVBND        TPA           VARGEO        TVM
F             T             F             F             F             F             F             F
SHEAR         PRNTIN        PRNTADD       OPVALVE       TRANSQ        CONJUG        RADIAT        WINPLOT
F             T             T             F             F             F             F             T
PRESS         INSUC         VARROT        CYCLIC        CHKVALS       WINFILE       DALTON        NOSTATS
T             F             F             F             F             T             F             F
NORMAL        SIMUL         SECONDL       NRSOLVT       IBDF          NOPLT         PRESREG       FLOWREG
F             F             F             F             1             T             0             0
TRANS_MOM     USERVARS      PSMG          ISOLVE        PLOTADD       SIUNITS       TECPLOT       MDGEN
F             F             F             1             F             F             F             F
NUM_USER_VARS IFR_MIX       PRINTD        SATTABL       MSORIN        PRELVLV       LAMINAR       HSTAG
1             1             F             F             F             F             T             T
NNODES        NINT          NBR           NF
 65            59            64            3
RELAXK        RELAXD        RELAXH        CC            NITER         RELAXNR       RELAXHC       RELAXTS
 1              0.5              0.01          0.001           50 1             1               1
DTAU          TIMEF         TIMEL         NPSTEP        NPWSTEP       WPLSTEP       WPLBUFF
 0.1              0                  60                  1             1             50            1.5
NFLUID(I),  I = 1, NF
 1 6 12
NODE          INDEX     DESCRIPTION
 1              2       " Node 1"
 2              1       " Node 2"
 3              1       " Node 3"
 4              1       " Node 4"
 5              1       " Node 5"
 6              1       " Node 6"
 7              1       " Node 7"
 8              1       " Node 8"
```

9	1	" Node 9"
10	1	" Node 10"
11	1	" Node 11"
12	1	" Node 12"
13	1	" Node 13"
14	1	" Node 14"
15	1	" Node 15"
16	1	" Node 16"
17	1	" Node 17"
18	1	" Node 18"
19	1	" Node 19"
20	1	" Node 20"
21	1	" Node 21"
22	1	" Node 22"
23	1	" Node 23"
24	1	" Node 24"
25	1	" Node 25"
26	1	" Node 26"
27	1	" Node 27"
28	1	" Node 28"
29	1	" Node 29"
30	2	" Node 30"
31	1	" Node 31"
32	1	" Node 32"
33	1	" Node 33"
34	2	" Node 34"
35	1	" Node 35"
36	1	" Node 36"
37	1	" Node 37"
38	1	" Node 38"
39	1	" Node 39"
40	1	" Node 40"
41	1	" Node 41"
42	1	" Node 42"
43	1	" Node 43"
44	1	" Node 44"
45	1	" Node 45"
46	1	" Node 46"
47	1	" Node 47"
48	1	" Node 48"
49	1	" Node 49"
50	1	" Node 50"
51	1	" Node 51"
52	1	" Node 52"
53	1	" Node 53"
54	1	" Node 54"
55	2	" Node 55"

56	1	" Node 56"
57	1	" Node 57"
58	1	" Node 58"
59	2	" Node 59"
60	1	" Node 60"
61	1	" Node 61"
62	1	" Node 62"
63	1	" Node 63"
64	1	" Node 64"
65	2	" Node 65"

NODE	PRES (PSI)	TEMP(DEGF)	MASS SOURC	HEAT SOURC	THRST AREA	NODE-VOLUME	CONCENTRATION
2	762	120	0	0	0	0	1 0 0
3	741.3	120.1	0	0	0	0	1 0 0
4	741.2	120.1	0	0	0	0	1 0 0
5	741.1	120.1	0	0	0	0	1 0 0
6	735.2	120.3	0	0	0	0	1 0 0
7	733.2	120.3	0	0	0	0	1 0 0
8	733.2	120.3	0	0	0	0	1 0 0
9	732.8	120.3	0	0	0	0	1 0 0
10	726.4	120.3	0	0	0	0	1 0 0
11	725.3	120.3	0	0	0	0	1 0 0
12	724.9	120.3	0	0	0	0	1 0 0
13	724.9	120.3	0	0	0	0	1 0 0
14	724.9	120.3	0	0	0	0	1 0 0
15	91.37	125.4	0	0	0	0	1 0 0
16	91.37	125.4	0	0	0	0	1 0 0
17	723.5	120.3	0	0	0	0	1 0 0
18	723.3	120.3	0	0	0	0	1 0 0
19	722.2	120.3	0	0	0	0	1 0 0
20	721.9	120.3	0	0	0	0	1 0 0
21	91.36	125.4	0	0	0	0	1 0 0
22	80.61	125.5	0	0	0	0	1 0 0
23	72.25	125.6	0	0	0	0	1 0 0
24	68.17	125.7	0	0	0	0	1 0 0
25	62.67	125.6	0	0	0	0	1 0 0
26	57.96	125.7	0	0	0	0	1 0 0
27	49.99	125.8	0	0	0	0	1 0 0
28	50	125.8	0	0	0	0	1 0 0
29	50	70	0	0	0	25920	1 0 0
31	53.57	70	0	0	0	492500	0 0 1
32	27.13	70	0	0	0	0	0 0 1
33	959	70	0	0	0	0	0 0 1
35	733.1	120.3	0	0	0	0	1 0 0
36	732.2	120.3	0	0	0	0	1 0 0
37	728.3	120.3	0	0	0	0	1 0 0
38	728.3	120.3	0	0	0	0	1 0 0
39	728.3	120.3	0	0	0	0	1 0 0

40	152.8	124.9	0	0	0	0	1 0 0
41	152.8	124.9	0	0	0	0	1 0 0
42	724.3	120.4	0	0	0	0	1 0 0
43	722.5	120.4	0	0	0	0	1 0 0
44	718.6	120.3	0	0	0	0	1 0 0
45	717.6	120.3	0	0	0	0	1 0 0
46	152.8	124.9	0	0	0	0	1 0 0
47	134	125	0	0	0	0	1 0 0
48	117.4	125.2	0	0	0	0	1 0 0
49	112.2	125.2	0	0	0	0	1 0 0
50	95.73	125.4	0	0	0	0	1 0 0
51	85.44	125.5	0	0	0	0	1 0 0
52	67.01	125.6	0	0	0	0	1 0 0
53	67.01	125.6	0	0	0	0	1 0 0
54	67	-260	0	0	0	43200	1 0 0
56	75.55	-300	0	0	0	820800	0 1 0
57	43	-300	0	0	0	0	0 1 0
58	919	-300	0	0	0	0	0 1 0
60	741.2	120.1	0	0	0	0	1 0 0
61	741.1	120.1	0	0	0	0	1 0 0
62	736.4	120.3	0	0	0	0	1 0 0
63	729.1	120.3	0	0	0	0	1 0 0
64	643	121	0	0	0	0	1 0 0

ex12hs1.dat
ex12hs2.dat
ex12hs3.dat
ex12hs4.dat
ex12hs5.dat
ex12hs6.dat

INODE	NUMBR	NAMEBR		
2	2	1001	1002	
3	3	1002	1003	1059
4	2	1003	1004	
5	2	1004	1005	
6	2	1005	1006	
7	3	1006	1007	1034
8	2	1007	1008	
9	2	1008	1009	
10	2	1009	1010	
11	2	1010	1011	
12	3	1011	1012	1016
13	2	1012	1013	
14	2	1013	1014	
15	2	1014	1015	
16	2	1015	1021	
17	2	1016	1017	
18	2	1017	1018	

```
 19            2            1018   1019
 20            2            1019   1020
 21            3            1021   1020   1022
 22            2            1022   1023
 23            2            1023   1024
 24            2            1024   1025
 25            2            1025   1026
 26            2            1026   1027
 27            2            1027   1028
 28            2            1028   1029
 29            1            1029
 31            2            1030   1031
 32            2            1031   1032
 33            2            1032   1033
 35            2            1034   1035
 36            2            1035   1036
 37            3            1036   1037   1041
 38            2            1037   1038
 39            2            1038   1039
 40            2            1039   1040
 41            2            1040   1046
 42            2            1041   1042
 43            2            1042   1043
 44            2            1043   1044
 45            2            1044   1045
 46            3            1046   1045   1047
 47            2            1047   1048
 48            2            1048   1049
 49            2            1049   1050
 50            2            1050   1051
 51            2            1051   1052
 52            2            1052   1053
 53            2            1053   1054
 54            1            1054
 56            2            1055   1056
 57            2            1056   1057
 58            2            1057   1058
 60            2            1059   1060
 61            2            1060   1061
 62            2            1061   1062
 63            2            1062   1063
 64            2            1063   1064
BRANCH   UPNODE    DNNODE    OPTION    DESCRIPTION
1001       1          2         1       "Pipe 1001"
1002       2          3         2       "Restrict 1002"
1003       3          4         13      "Valve 1003"
1004       4          5         1       "Pipe 1004"
```

1005	5	6	2	"Restrict 1005"
1006	6	7	1	"Pipe 1006"
1007	7	8	13	"Valve 1007"
1008	8	9	7	"Reduct 1008"
1009	9	10	1	"Pipe 1009"
1010	10	11	2	"Restrict 1010"
1011	11	12	1	"Pipe 1011"
1012	12	13	13	"Valve 1012"
1013	13	14	1	"Pipe 1013"
1014	14	15	2	"Restrict 1014"
1015	15	16	1	"Pipe 1015"
1021	16	21	2	"Restrict 1021"
1016	12	17	13	"Valve 1016"
1017	17	18	1	"Pipe 1017"
1018	18	19	18	"Valve 1018"
1019	19	20	1	"Pipe 1019"
1020	20	21	2	"Restrict 1020"
1022	21	22	13	"Valve 1022"
1023	22	23	2	"Restrict 1023"
1024	23	24	1	"Pipe 1024"
1025	24	25	2	"Restrict 1025"
1026	25	26	1	"Pipe 1026"
1027	26	27	8	"Expan 1027"
1028	27	28	2	"Restrict 1028"
1029	28	29	2	"Restrict 1029"
1030	30	31	2	"Restrict 1030"
1031	31	32	2	"Restrict 1031"
1032	32	33	14	"Pump 1032"
1033	33	34	2	"Restrict 1033"
1034	7	35	13	"Valve 1034"
1035	35	36	7	"Reduct 1035"
1036	36	37	2	"Restrict 1036"
1037	37	38	13	"Valve 1037"
1038	38	39	1	"Pipe 1038"
1039	39	40	2	"Restrict 1039"
1040	40	41	1	"Pipe 1040"
1046	41	46	2	"Restrict 1046"
1041	37	42	13	"Valve 1041"
1042	42	43	1	"Pipe 1042"
1043	43	44	18	"Valve 1043"
1044	44	45	1	"Pipe 1044"
1045	45	46	2	"Restrict 1045"
1047	46	47	13	"Valve 1047"
1048	47	48	2	"Restrict 1048"
1049	48	49	1	"Pipe 1049"
1050	49	50	2	"Restrict 1050"
1051	50	51	1	"Pipe 1051"

```
1052       51         52         8       "Expan 1052"
1055       55         56         2       "Restrict 1055"
1056       56         57         2       "Restrict 1056"
1057       57         58         14      "Pump 1057"
1058       58         59         2       "Restrict 1058"
1059       3          60         13      "Valve 1059"
1060       60         61         1       "Pipe 1060"
1061       61         62         2       "Restrict 1061"
1062       62         63         7       "Reduct 1062"
1063       63         64         1       "Pipe 1063"
1064       64         65         1       "Pipe 1064"
1053       52         53         2       "Restrict 1053"
1054       53         54         2       "Restrict 1054"
BRANCH        OPTION -1     LENGTH        DIA           EPSD          ANGLE         AREA
 1001                       128               1.3              0.00061538461538    0                  1.327321775
BRANCH        OPTION -2     FLOW COEFF    AREA
 1002                       0.6           0.63617
BRANCH        OPTION -13    DIA           K1            K2            AREA
 1003                       1.3           200          0.1           1.3273
BRANCH        OPTION -1     LENGTH        DIA           EPSD          ANGLE         AREA
 1004                       17                1.3              0.00061538461538    0                  1.327321775
BRANCH        OPTION -2     FLOW COEFF    AREA
 1005                       0.6           0.63617
BRANCH        OPTION -1     LENGTH        DIA           EPSD          ANGLE         AREA
 1006                       288               1.3              0.00061538461538    0                  1.327321775
BRANCH        OPTION -13    DIA           K1            K2            AREA
 1007                       1.3           200          0.1           1.3273
BRANCH        OPTION -7     PIPE DIA      RED. DIA      AREA
 1008                       1.3           0.53          1.3273
BRANCH        OPTION -1     LENGTH        DIA           EPSD          ANGLE         AREA
 1009                       221               0.53             0.0015094339623    0                  0.22061815775
BRANCH        OPTION -2     FLOW COEFF    AREA
 1010                       0.6           0.2827
BRANCH        OPTION -1     LENGTH        DIA           EPSD          ANGLE         AREA
 1011                       12                0.53             0.0015094339623    0                  0.22061815775
BRANCH        OPTION -13    DIA           K1            K2            AREA
 1012                       0.53          500          0.7           0.22062
BRANCH        OPTION -1     LENGTH        DIA           EPSD          ANGLE         AREA
 1013                       14                0.53             0.0015094339623    0                  0.22061815775
BRANCH        OPTION -2     FLOW COEFF    AREA
 1014                       0.6           1e-05
BRANCH        OPTION -1     LENGTH        DIA           EPSD          ANGLE         AREA
 1015                       14                0.53             0.0015094339623    0                  0.22061815775
BRANCH        OPTION -2     FLOW COEFF    AREA
 1021                       0.6           0.00785
BRANCH        OPTION -13    DIA           K1            K2            AREA
 1016                       0.53          500          0.7           0.22062
```

```
BRANCH        OPTION -1     LENGTH        DIA           EPSD          ANGLE         AREA
 1017                       7.5               0.53             0.0015094339623    0                  0.22061815775
BRANCH        OPTION -18-2  VALVE OPTION  CL            AREA          CONTROL NODE  INITIAL VALVE POSITION
 1018                       2             0.6          0.2827        29             T
VALVE CYCLE TIME            NUMBER OF CYCLES            PRESSURE FILE HISTORY FILE NAME
 0.05                      5
ex12rp1.dat
BRANCH        OPTION -1     LENGTH        DIA           EPSD          ANGLE         AREA
 1019                       9                 0.53             0.0015094339623    0                  0.22061815775
BRANCH        OPTION -2     FLOW COEFF    AREA
 1020                       0.6           0.02895
BRANCH        OPTION -13    DIA           K1            K2            AREA
 1022                       0.53          500          0.7           0.22062
BRANCH        OPTION -2     FLOW COEFF    AREA
 1023                       0.83056       0.2255
BRANCH        OPTION -1     LENGTH        DIA           EPSD          ANGLE         AREA
 1024                       14                0.53             0.0015094339623    0                  0.22061815775
BRANCH        OPTION -2     FLOW COEFF    AREA
 1025                       0.6           0.4185
BRANCH        OPTION -1     LENGTH        DIA           EPSD          ANGLE         AREA
 1026                       14                0.53             0.0015094339623    0                  0.22061815775
BRANCH        OPTION -8     PIPE DIA      EXP DIA       AREA
 1027                       0.53          3             0.22062
BRANCH        OPTION -2     FLOW COEFF    AREA
 1028                       0             7.0686
BRANCH        OPTION -2     FLOW COEFF    AREA
 1029                       0.6           37.699
BRANCH        OPTION -2     FLOW COEFF    AREA
 1030                       0             3987
BRANCH        OPTION -2     FLOW COEFF    AREA
 1031                       0.181         14.25
BRANCH        OPTION -14    PUMP CONST1   PUMP CONST2  PUMP CONST3    AREA
 1032                       1.6876e+05    0            -4.9362       14.25
BRANCH        OPTION -2     FLOW COEFF    AREA
 1033                       0.0464        14.25
BRANCH        OPTION -13    DIA           K1            K2            AREA
 1034                       1.3           200          0.1           1.3273
BRANCH        OPTION -7     PIPE DIA      RED. DIA      AREA
 1035                       1.3           0.78          1.3273
BRANCH        OPTION -2     FLOW COEFF    AREA
 1036                       0.6           0.63617
BRANCH        OPTION -13    DIA           K1            K2            AREA
 1037                       0.78          500          0.7           0.47784
BRANCH        OPTION -1     LENGTH        DIA           EPSD          ANGLE         AREA
 1038                       11                0.78             0.0010256410256    0                  0.477835839
BRANCH        OPTION -2     FLOW COEFF    AREA
 1039                       0.6           1e-05
```

```
BRANCH        OPTION -1     LENGTH        DIA           EPSD          ANGLE         AREA
 1040                       18                0.78            0.0010256410256   0                 0.477835839
BRANCH        OPTION -2     FLOW COEFF    AREA
 1046                       0.6           0.01767
BRANCH        OPTION -13    DIA           K1            K2            AREA
 1041                       0.78          500          0.7           0.47784
BRANCH        OPTION -1     LENGTH        DIA           EPSD          ANGLE         AREA
 1042                       28                0.78            0.0010256410256   0                 0.477835839
BRANCH        OPTION -18-2  VALVE OPTION  CL            AREA          CONTROL NODE  INITIAL VALVE POSITION
 1043                       2             0.6          0.63617       54            T
VALVE CYCLE TIME            NUMBER OF CYCLES            PRESSURE FILE HISTORY FILE NAME
 0.05                      5
ex12lox.dat
BRANCH        OPTION -1     LENGTH        DIA           EPSD          ANGLE         AREA
 1044                       15                0.78            0.0010256410256   0                 0.477835839
BRANCH        OPTION -2     FLOW COEFF    AREA
 1045                       0.6           0.10179
BRANCH        OPTION -13    DIA           K1            K2            AREA
 1047                       0.78          500          0.7           0.47784
BRANCH        OPTION -2     FLOW COEFF    AREA
 1048                       0.77371       0.55351
BRANCH        OPTION -1     LENGTH        DIA           EPSD          ANGLE         AREA
 1049                       13                0.78            0.0010256410256   0                 0.477835839
BRANCH        OPTION -2     FLOW COEFF    AREA
 1050                       0.6           0.7854
BRANCH        OPTION -1     LENGTH        DIA           EPSD          ANGLE         AREA
 1051                       21                0.78            0.0010256410256   0                 0.477835839
BRANCH        OPTION -8     PIPE DIA      EXP DIA       AREA
 1052                       0.78          3             0.47784
BRANCH        OPTION -2     FLOW COEFF    AREA
 1055                       0             4015
BRANCH        OPTION -2     FLOW COEFF    AREA
 1056                       0.304         14.25
BRANCH        OPTION -14    PUMP CONST1   PUMP CONST2  PUMP CONST3    AREA
 1057                       1.7603e+05    0            -2.5799       14.25
BRANCH        OPTION -2     FLOW COEFF    AREA
 1058                       0.105         14.25
BRANCH        OPTION -13    DIA           K1            K2            AREA
 1059                       1.3           200          0.1           1.3273
BRANCH        OPTION -1     LENGTH        DIA           EPSD          ANGLE         AREA
 1060                       19                1.3             0.00061538461538   0                 1.327321775
BRANCH        OPTION -2     FLOW COEFF    AREA
 1061                       0.6           0.63617
BRANCH        OPTION -7     PIPE DIA      RED. DIA      AREA
 1062                       1.3           0.53          1.3273
BRANCH        OPTION -1     LENGTH        DIA           EPSD          ANGLE         AREA
 1063                       143               0.53            0.0015094339623   0                 0.22061815775
```

```
BRANCH        OPTION -1     LENGTH        DIA           EPSD          ANGLE         AREA
 1064                       28               0.53             0.0060377358491    0                  0.22061815775
BRANCH        OPTION -2     FLOW COEFF    AREA
 1053                       0             7.0686
BRANCH        OPTION -2     FLOW COEFF    AREA
 1054                       0.6           37.699
INITIAL FLOWRATES IN BRANCHES FOR UNSTEADY FLOW
 1001 0.803
 1002 0.803
 1003 0.423
 1004 0.423
 1005 0.423
 1006 0.423
 1007 0.082
 1008 0.082
 1009 0.082
 1010 0.082
 1011 0.082
 1012 0.0001
 1013 0.0001
 1014 0.0001
 1015 0.0001
 1021 0.0001
 1016 0.0819
 1017 0.0819
 1018 0.0819
 1019 0.0819
 1020 0.0819
 1022 0.0819
 1023 0.0819
 1024 0.0819
 1025 0.0819
 1026 0.0819
 1027 0.0819
 1028 0.0819
 1029 0.0819
 1030 64
 1031 64
 1032 64
 1033 64
 1034 0.341
 1035 0.341
 1036 0.341
 1037 0.0001
 1038 0.0001
 1039 0.0001
 1040 0.0001
```

```
 1046 0.0001
 1041 0.3409
 1042 0.3409
 1043 0.3409
 1044 0.3409
 1045 0.3409
 1047 0.3409
 1048 0.3409
 1049 0.3409
 1050 0.3409
 1051 0.3409
 1052 0.3409
 1055 140
 1056 140
 1057 140
 1058 140
 1059 0.38
 1060 0.38
 1061 0.38
 1062 0.38
 1063 0.38
 1064 0.38
 1053 0.3409
 1054 0.3409
BRANCH        NOUBR         NMUBR
 1001    0
 1002    1   1001
 1003    2   1002   1059
 1004    1   1003
 1005    1   1004
 1006    1   1005
 1007    2   1006   1034
 1008    1   1007
 1009    1   1008
 1010    1   1009
 1011    1   1010
 1012    2   1011   1016
 1013    1   1012
 1014    1   1013
 1015    1   1014
 1021    1   1015
 1016    2   1011   1012
 1017    1   1016
 1018    1   1017
 1019    1   1018
 1020    1   1019
 1022    2   1021   1020
```

```
 1023    1   1022
 1024    1   1023
 1025    1   1024
 1026    1   1025
 1027    1   1026
 1028    1   1027
 1029    1   1028
 1030    0
 1031    1   1030
 1032    1   1031
 1033    1   1032
 1034    2   1006   1007
 1035    1   1034
 1036    1   1035
 1037    2   1036   1041
 1038    1   1037
 1039    1   1038
 1040    1   1039
 1046    1   1040
 1041    2   1036   1037
 1042    1   1041
 1043    1   1042
 1044    1   1043
 1045    1   1044
 1047    2   1046   1045
 1048    1   1047
 1049    1   1048
 1050    1   1049
 1051    1   1050
 1052    1   1051
 1055    0
 1056    1   1055
 1057    1   1056
 1058    1   1057
 1059    2   1002   1003
 1060    1   1059
 1061    1   1060
 1062    1   1061
 1063    1   1062
 1064    1   1063
 1053    1   1052
 1054    1   1053
BRANCH         NODBR          NMDBR
 1001    1   1002
 1002    2   1003   1059
 1003    1   1004
 1004    1   1005
```

1005	1	1006	
1006	2	1007	1034
1007	1	1008	
1008	1	1009	
1009	1	1010	
1010	1	1011	
1011	2	1012	1016
1012	1	1013	
1013	1	1014	
1014	1	1015	
1015	1	1021	
1021	2	1020	1022
1016	1	1017	
1017	1	1018	
1018	1	1019	
1019	1	1020	
1020	2	1021	1022
1022	1	1023	
1023	1	1024	
1024	1	1025	
1025	1	1026	
1026	1	1027	
1027	1	1028	
1028	1	1029	
1029	0		
1030	1	1031	
1031	1	1032	
1032	1	1033	
1033	0		
1034	1	1035	
1035	1	1036	
1036	2	1037	1041
1037	1	1038	
1038	1	1039	
1039	1	1040	
1040	1	1046	
1046	2	1045	1047
1041	1	1042	
1042	1	1043	
1043	1	1044	
1044	1	1045	
1045	2	1046	1047
1047	1	1048	
1048	1	1049	
1049	1	1050	
1050	1	1051	
1051	1	1052	

```
 1052    1   1053
 1055    1   1056
 1056    1   1057
 1057    1   1058
 1058    0
 1059    1   1060
 1060    1   1061
 1061    1   1062
 1062    1   1063
 1063    1   1064
 1064    0
 1053    1   1054
 1054    0
BRANCH
 1001
  UPSTRM BR.     ANGLE
  DNSTRM BR.     ANGLE
   1002     0.00000
BRANCH
 1002
  UPSTRM BR.     ANGLE
   1001     0.00000
  DNSTRM BR.     ANGLE
   1003     0.00000
   1059     0.00000
BRANCH
 1003
  UPSTRM BR.     ANGLE
   1002     0.00000
   1059     0.00000
  DNSTRM BR.     ANGLE
   1004     0.00000
BRANCH
 1004
  UPSTRM BR.     ANGLE
   1003     0.00000
  DNSTRM BR.     ANGLE
   1005     0.00000
BRANCH
 1005
  UPSTRM BR.     ANGLE
   1004     0.00000
  DNSTRM BR.     ANGLE
   1006     0.00000
BRANCH
 1006
  UPSTRM BR.     ANGLE
```

```
   1005     0.00000
  DNSTRM BR.     ANGLE
   1007     0.00000
   1034     0.00000
BRANCH
 1007
  UPSTRM BR.     ANGLE
   1006     0.00000
   1034     0.00000
  DNSTRM BR.     ANGLE
   1008     0.00000
BRANCH
 1008
  UPSTRM BR.     ANGLE
   1007     0.00000
  DNSTRM BR.     ANGLE
   1009     0.00000
BRANCH
 1009
  UPSTRM BR.     ANGLE
   1008     0.00000
  DNSTRM BR.     ANGLE
   1010     0.00000
BRANCH
 1010
  UPSTRM BR.     ANGLE
   1009     0.00000
  DNSTRM BR.     ANGLE
   1011     0.00000
BRANCH
 1011
  UPSTRM BR.     ANGLE
   1010     0.00000
  DNSTRM BR.     ANGLE
   1012     0.00000
   1016     0.00000
BRANCH
 1012
  UPSTRM BR.     ANGLE
   1011     0.00000
   1016     0.00000
  DNSTRM BR.     ANGLE
   1013     0.00000
BRANCH
 1013
  UPSTRM BR.     ANGLE
   1012     0.00000
```

```
  DNSTRM BR.     ANGLE
   1014     0.00000
BRANCH
 1014
  UPSTRM BR.     ANGLE
   1013     0.00000
  DNSTRM BR.     ANGLE
   1015     0.00000
BRANCH
 1015
  UPSTRM BR.     ANGLE
   1014     0.00000
  DNSTRM BR.     ANGLE
   1021     0.00000
BRANCH
 1021
  UPSTRM BR.     ANGLE
   1015     0.00000
  DNSTRM BR.     ANGLE
   1020     0.00000
   1022     0.00000
BRANCH
 1016
  UPSTRM BR.     ANGLE
   1011     0.00000
   1012     0.00000
  DNSTRM BR.     ANGLE
   1017     0.00000
BRANCH
 1017
  UPSTRM BR.     ANGLE
   1016     0.00000
  DNSTRM BR.     ANGLE
   1018     0.00000
BRANCH
 1018
  UPSTRM BR.     ANGLE
   1017     0.00000
  DNSTRM BR.     ANGLE
   1019     0.00000
BRANCH
 1019
  UPSTRM BR.     ANGLE
   1018     0.00000
  DNSTRM BR.     ANGLE
   1020     0.00000
BRANCH
```

```
 1020
  UPSTRM BR.     ANGLE
   1019     0.00000
  DNSTRM BR.     ANGLE
   1021     0.00000
   1022     0.00000
BRANCH
 1022
  UPSTRM BR.     ANGLE
   1021     0.00000
   1020     0.00000
  DNSTRM BR.     ANGLE
   1023     0.00000
BRANCH
 1023
  UPSTRM BR.     ANGLE
   1022     0.00000
  DNSTRM BR.     ANGLE
   1024     0.00000
BRANCH
 1024
  UPSTRM BR.     ANGLE
   1023     0.00000
  DNSTRM BR.     ANGLE
   1025     0.00000
BRANCH
 1025
  UPSTRM BR.     ANGLE
   1024     0.00000
  DNSTRM BR.     ANGLE
   1026     0.00000
BRANCH
 1026
  UPSTRM BR.     ANGLE
   1025     0.00000
  DNSTRM BR.     ANGLE
   1027     0.00000
BRANCH
 1027
  UPSTRM BR.     ANGLE
   1026     0.00000
  DNSTRM BR.     ANGLE
   1028     0.00000
BRANCH
 1028
  UPSTRM BR.     ANGLE
   1027     0.00000
```

```
  DNSTRM BR.     ANGLE
   1029     0.00000
BRANCH
 1029
  UPSTRM BR.     ANGLE
   1028     0.00000
  DNSTRM BR.     ANGLE
BRANCH
 1030
  UPSTRM BR.     ANGLE
  DNSTRM BR.     ANGLE
   1031     0.00000
BRANCH
 1031
  UPSTRM BR.     ANGLE
   1030     0.00000
  DNSTRM BR.     ANGLE
   1032     0.00000
BRANCH
 1032
  UPSTRM BR.     ANGLE
   1031     0.00000
  DNSTRM BR.     ANGLE
   1033     0.00000
BRANCH
 1033
  UPSTRM BR.     ANGLE
   1032     0.00000
  DNSTRM BR.     ANGLE
BRANCH
 1034
  UPSTRM BR.     ANGLE
   1006     0.00000
   1007     0.00000
  DNSTRM BR.     ANGLE
   1035     0.00000
BRANCH
 1035
  UPSTRM BR.     ANGLE
   1034     0.00000
  DNSTRM BR.     ANGLE
   1036     0.00000
BRANCH
 1036
  UPSTRM BR.     ANGLE
   1035     0.00000
  DNSTRM BR.     ANGLE
```

```
   1037     0.00000
   1041     0.00000
BRANCH
 1037
  UPSTRM BR.     ANGLE
   1036     0.00000
   1041     0.00000
  DNSTRM BR.     ANGLE
   1038     0.00000
BRANCH
 1038
  UPSTRM BR.     ANGLE
   1037     0.00000
  DNSTRM BR.     ANGLE
   1039     0.00000
BRANCH
 1039
  UPSTRM BR.     ANGLE
   1038     0.00000
  DNSTRM BR.     ANGLE
   1040     0.00000
BRANCH
 1040
  UPSTRM BR.     ANGLE
   1039     0.00000
  DNSTRM BR.     ANGLE
   1046     0.00000
BRANCH
 1046
  UPSTRM BR.     ANGLE
   1040     0.00000
  DNSTRM BR.     ANGLE
   1045     0.00000
   1047     0.00000
BRANCH
 1041
  UPSTRM BR.     ANGLE
   1036     0.00000
   1037     0.00000
  DNSTRM BR.     ANGLE
   1042     0.00000
BRANCH
 1042
  UPSTRM BR.     ANGLE
   1041     0.00000
  DNSTRM BR.     ANGLE
   1043     0.00000
```

```
BRANCH
 1043
  UPSTRM BR.     ANGLE
   1042     0.00000
  DNSTRM BR.     ANGLE
   1044     0.00000
BRANCH
 1044
  UPSTRM BR.     ANGLE
   1043     0.00000
  DNSTRM BR.     ANGLE
   1045     0.00000
BRANCH
 1045
  UPSTRM BR.     ANGLE
   1044     0.00000
  DNSTRM BR.     ANGLE
   1046     0.00000
   1047     0.00000
BRANCH
 1047
  UPSTRM BR.     ANGLE
   1046     0.00000
   1045     0.00000
  DNSTRM BR.     ANGLE
   1048     0.00000
BRANCH
 1048
  UPSTRM BR.     ANGLE
   1047     0.00000
  DNSTRM BR.     ANGLE
   1049     0.00000
BRANCH
 1049
  UPSTRM BR.     ANGLE
   1048     0.00000
  DNSTRM BR.     ANGLE
   1050     0.00000
BRANCH
 1050
  UPSTRM BR.     ANGLE
   1049     0.00000
  DNSTRM BR.     ANGLE
   1051     0.00000
BRANCH
 1051
  UPSTRM BR.     ANGLE
```

```
   1050     0.00000
  DNSTRM BR.     ANGLE
   1052     0.00000
BRANCH
 1052
  UPSTRM BR.     ANGLE
   1051     0.00000
  DNSTRM BR.     ANGLE
   1053     0.00000
BRANCH
 1055
  UPSTRM BR.     ANGLE
  DNSTRM BR.     ANGLE
   1056     0.00000
BRANCH
 1056
  UPSTRM BR.     ANGLE
   1055     0.00000
  DNSTRM BR.     ANGLE
   1057     0.00000
BRANCH
 1057
  UPSTRM BR.     ANGLE
   1056     0.00000
  DNSTRM BR.     ANGLE
   1058     0.00000
BRANCH
 1058
  UPSTRM BR.     ANGLE
   1057     0.00000
  DNSTRM BR.     ANGLE
BRANCH
 1059
  UPSTRM BR.     ANGLE
   1002     0.00000
   1003     0.00000
  DNSTRM BR.     ANGLE
   1060     0.00000
BRANCH
 1060
  UPSTRM BR.     ANGLE
   1059     0.00000
  DNSTRM BR.     ANGLE
   1061     0.00000
BRANCH
 1061
  UPSTRM BR.     ANGLE
```

```
   1060     0.00000
  DNSTRM BR.     ANGLE
   1062     0.00000
BRANCH
 1062
  UPSTRM BR.     ANGLE
   1061     0.00000
  DNSTRM BR.     ANGLE
   1063     0.00000
BRANCH
 1063
  UPSTRM BR.     ANGLE
   1062     0.00000
  DNSTRM BR.     ANGLE
   1064     0.00000
BRANCH
 1064
  UPSTRM BR.     ANGLE
   1063     0.00000
  DNSTRM BR.     ANGLE
BRANCH
 1053
  UPSTRM BR.     ANGLE
   1052     0.00000
  DNSTRM BR.     ANGLE
   1054     0.00000
BRANCH
 1054
  UPSTRM BR.     ANGLE
   1053     0.00000
  DNSTRM BR.     ANGLE
NUMBER OF BRANCHES WITH INERTIA
 7
 1008
 1020
 1027
 1035
 1045
 1052
 1062
NUMBER OF PRESSURIZATION PROPELLANT TANKS IN CIRCUIT
2
TNKTYPE  NODUL  NODULB  NODPRP  IBRPRP   TNKAR      TNKTH        TNKRHO     TNKCP      TNKCON     ARHC       FCTHC      TNKTM      CIP
FNIP       CIW        FNIW
1        29     30      31      1030     5442       0.38       170        0.2        0.03622    3987       1          70         0.27
0.25       0.54       0.25
```

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```
1        54     55      56      1055      6431.9     0.375      170        0.2        0.03622    4015       1          -300       0.27
0.25       0.54       0.25
```

EXAMPLE 12 HISTORY FILES

EX12HS1.DAT

```
 3
-500  765.00  120.0  1.00  0.00  0.00
0     765.00  120.0  1.00  0.00  0.00
300   765.00  120.0  1.00  0.00  0.00
```

EX12HS2.DAT

```
6
-500. 14.700  70.00  0.00  0.00  1.00
-499. 20.000  70.00  0.00  0.00  1.00
-420. 20.000  70.00  0.00  0.00  1.00
-419. 50.000  70.00  0.00  0.00  1.00
0     50.000  70.00  0.00  0.00  1.00
300   50.000  70.00  0.00  0.00  1.00
```

EX12HS3.DAT

```
5
-500    14.700  70.00  0.00  0.00  1.00
-420    14.700  70.00  0.00  0.00  1.00
-418    652.00  70.00  0.00  0.00  1.00
0       652.00  70.00  0.00  0.00  1.00
300     652.00  70.00  0.00  0.00  1.00
```

EX12HS4.DAT

```
6
-500. 14.700  -300.  0.00  1.00  0.00
-499. 20.000  -300.  0.00  1.00  0.00
-420. 20.000  -300.  0.00  1.00  0.00
-419. 67.000  -300.  0.00  1.00  0.00
0     67.000  -300.  0.00  1.00  0.00
300   67.000  -300.  0.00  1.00  0.00
```

EX12HS5.DAT

```
5
-500    14.700  -300.  0.00  1.00  0.00
```

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```
-420    14.700  -300.  0.00  1.00  0.00
-419    652.00  -300.  0.00  1.00  0.00
0       652.00  -300.  0.00  1.00  0.00
300     652.00  -300.  0.00  1.00  0.00
```

EX12HS6.DAT

```
3
-500. 615.00  120.0  1.00  0.00  0.00
0     615.00  120.0  1.00  0.00  0.00
300   615.00  120.0  1.00  0.00  0.00
```

```
C***********************************************************************

C                                                                      *

C     ***** GFSSP USER SUBROUTINES *****                               *
C                                                                      *
C***********************************************************************
                              :
                              :
                              :
                              :

C***********************************************************************
      SUBROUTINE PRNUSER
C     PURPOSE: ADD NEW OUTPUT
C***********************************************************************
      INCLUDE 'COMBLK.FOR'
C**********************************************************************
C     ADD CODE HERE
C     GENERATE EXCEL FILE FOR PLOT
      OPEN (NUSR1,FILE = 'EX12.XLS',STATUS = 'UNKNOWN')
      VOLUL1=VOLUME(29)
      VOLUL2=VOLUME(54)
      TFTNK1=TNKTM(1)-460.
      TFTNK2=TNKTM(2)-460.
      WRITE(NUSR1,200) TAU,QULWAL(1),QULWAL(2),QULPRP(1),QULPRP(2),
     &      QCOND(1),QCOND(2),VOLUL1,VOLUL2,TFTNK1,TFTNK2,
     &      SORCECON(29,3),SORCECON(54,2),CX(29,3),CX(54,2)
200   FORMAT (2X,E12.6,100(2X,2E12.6))
      RETURN
      END
```

NOTE: All other user subroutines are identical with Example 10 (Appendix 5)

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```
 ***************************************************
            G F S S P (Version 604)
    Generalized Fluid System Simulation Program
                  March 2012

   Developed by NASA/Marshall Space Flight Center
   Copyright (C) by Marshall Space Flight Center

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


  RUN DATE:09/12/2012 15:10

TITLE     :Helium Pressurization of LOX and RP-1 Propellant Tanks
ANALYST   :Todd Steadman
FILEIN    :C:\Program Files (x86)\GFSSP604\TestInstalledExamples\EX12\Ex12.dat
FILEOUT   :Ex12.out

                           OPTION VARIABLES

ADDPROP   BUOYANCY  CONDX     CONJUG    CYCLIC    DALTON    DENCON    ENERGY
F         F         F         F         F         F         F         T
FLOWREG   GRAVITY   HCOEF     HEX       HRATE     IFRMIX    INERTIA   INSUC
0         F         F         F         T         1         T         F
INVAL     MIXTURE   MOVBND    MSORCE    NORMAL    NRSOLVT   OPVALVE   PLOTADD
F         T         F         F         F         F         F         F
PRESREG   PRESS     PRINTI    PRNTADD   PRNTIN    RADIATION REACTING  ROTATION
0         T         F         T         T         F         F         F
SAVER     SECONDL   SHEAR     SIMULA    SIUNITS   STEADY    THRUST    TPA
F         F         F         F         F         F         F         F
TRANS_MOM TRANSQ    TRANSV    TVM       TWOD      USRVAR    VARGEO    VARROT
F         F         T         F         F         F         F         F
RLFVLV
F

NNODES    =   65
NINT      =   59
NBR       =   64
NF        =    3
NVAR      =  182
NHREF     =    2


FLUIDS:  HE    O2    RP1
```

BOUNDARY NODES

NODE	P (PSI)	T (F)	RHO (LBM/FT^3)	AREA (IN^2)	CONCENTRATIONS		
				HE	O2	RP1	
1	0.7650E+03	0.1200E+03	0.4783E+00	0.0000E+00	0.1000E+01	0.0000E+00	0.0000
30	0.5368E+02	0.7000E+02	0.5151E+02	0.0000E+00	0.0000E+00	0.0000E+00	1.0000
34	0.6520E+03	0.7000E+02	0.5170E+02	0.0000E+00	0.0000E+00	0.0000E+00	1.0000
55	0.7548E+02	-0.3000E+03	0.7172E+02	0.0000E+00	0.0000E+00	0.1000E+01	0.0000
59	0.6520E+03	-0.3000E+03	0.7226E+02	0.0000E+00	0.0000E+00	0.1000E+01	0.0000
65	0.6150E+03	0.1200E+03	0.3867E+00	0.0000E+00	0.1000E+01	0.0000E+00	0.0000

INPUT SPECIFICATIONS FOR INTERNAL NODES

NODE	AREA (IN^2)	MASS (LBM/S)	HEAT (BTU/S)
2	0.0000E+00	0.0000E+00	0.0000E+00
3	0.0000E+00	0.0000E+00	0.0000E+00
4	0.0000E+00	0.0000E+00	0.0000E+00
5	0.0000E+00	0.0000E+00	0.0000E+00
6	0.0000E+00	0.0000E+00	0.0000E+00
7	0.0000E+00	0.0000E+00	0.0000E+00
8	0.0000E+00	0.0000E+00	0.0000E+00
9	0.0000E+00	0.0000E+00	0.0000E+00
10	0.0000E+00	0.0000E+00	0.0000E+00
11	0.0000E+00	0.0000E+00	0.0000E+00
12	0.0000E+00	0.0000E+00	0.0000E+00
13	0.0000E+00	0.0000E+00	0.0000E+00
14	0.0000E+00	0.0000E+00	0.0000E+00
15	0.0000E+00	0.0000E+00	0.0000E+00
16	0.0000E+00	0.0000E+00	0.0000E+00
17	0.0000E+00	0.0000E+00	0.0000E+00
18	0.0000E+00	0.0000E+00	0.0000E+00
19	0.0000E+00	0.0000E+00	0.0000E+00
20	0.0000E+00	0.0000E+00	0.0000E+00
21	0.0000E+00	0.0000E+00	0.0000E+00
22	0.0000E+00	0.0000E+00	0.0000E+00
23	0.0000E+00	0.0000E+00	0.0000E+00
24	0.0000E+00	0.0000E+00	0.0000E+00
25	0.0000E+00	0.0000E+00	0.0000E+00
26	0.0000E+00	0.0000E+00	0.0000E+00
27	0.0000E+00	0.0000E+00	0.0000E+00
28	0.0000E+00	0.0000E+00	0.0000E+00
29	0.0000E+00	0.0000E+00	0.0000E+00
31	0.0000E+00	-0.6400E+02	0.0000E+00
32	0.0000E+00	0.0000E+00	0.0000E+00
33	0.0000E+00	0.0000E+00	0.0000E+00
35	0.0000E+00	0.0000E+00	0.0000E+00

36	0.0000E+00	0.0000E+00	0.0000E+00
37	0.0000E+00	0.0000E+00	0.0000E+00
38	0.0000E+00	0.0000E+00	0.0000E+00
39	0.0000E+00	0.0000E+00	0.0000E+00
40	0.0000E+00	0.0000E+00	0.0000E+00
41	0.0000E+00	0.0000E+00	0.0000E+00
42	0.0000E+00	0.0000E+00	0.0000E+00
43	0.0000E+00	0.0000E+00	0.0000E+00
44	0.0000E+00	0.0000E+00	0.0000E+00
45	0.0000E+00	0.0000E+00	0.0000E+00
46	0.0000E+00	0.0000E+00	0.0000E+00
47	0.0000E+00	0.0000E+00	0.0000E+00
48	0.0000E+00	0.0000E+00	0.0000E+00
49	0.0000E+00	0.0000E+00	0.0000E+00
50	0.0000E+00	0.0000E+00	0.0000E+00
51	0.0000E+00	0.0000E+00	0.0000E+00
52	0.0000E+00	0.0000E+00	0.0000E+00
53	0.0000E+00	0.0000E+00	0.0000E+00
54	0.0000E+00	0.0000E+00	0.0000E+00
56	0.0000E+00	-0.1400E+03	0.0000E+00
57	0.0000E+00	0.0000E+00	0.0000E+00
58	0.0000E+00	0.0000E+00	0.0000E+00
60	0.0000E+00	0.0000E+00	0.0000E+00
61	0.0000E+00	0.0000E+00	0.0000E+00
62	0.0000E+00	0.0000E+00	0.0000E+00
63	0.0000E+00	0.0000E+00	0.0000E+00
64	0.0000E+00	0.0000E+00	0.0000E+00

BRANCH	UPNODE	DNNODE	OPTION
1001	1	2	1
1002	2	3	2
1003	3	4	13
1004	4	5	1
1005	5	6	2
1006	6	7	1
1007	7	8	13
1008	8	9	7
1009	9	10	1
1010	10	11	2
1011	11	12	1
1012	12	13	13
1013	13	14	1
1014	14	15	2
1015	15	16	1
1021	16	21	2
1016	12	17	13
1017	17	18	1

1018	18	19	18
1019	19	20	1
1020	20	21	2
1022	21	22	13
1023	22	23	2
1024	23	24	1
1025	24	25	2
1026	25	26	1
1027	26	27	8
1028	27	28	2
1029	28	29	2
1030	30	31	2
1031	31	32	2
1032	32	33	14
1033	33	34	2
1034	7	35	13
1035	35	36	7
1036	36	37	2
1037	37	38	13
1038	38	39	1
1039	39	40	2
1040	40	41	1
1046	41	46	2
1041	37	42	13
1042	42	43	1
1043	43	44	18
1044	44	45	1
1045	45	46	2
1047	46	47	13
1048	47	48	2
1049	48	49	1
1050	49	50	2
1051	50	51	1
1052	51	52	8
1055	55	56	2
1056	56	57	2
1057	57	58	14
1058	58	59	2
1059	3	60	13
1060	60	61	1
1061	61	62	2
1062	62	63	7
1063	63	64	1
1064	64	65	1
1053	52	53	2
1054	53	54	2

BRANCH OPTION -1: LENGTH DIA EPSD ANGLE AREA

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   1001             0.128E+03   0.130E+01   0.615E-03   0.000E+00   0.133E+01
BRANCH OPTION -2:  FLOW COEF  AREA
   1002             0.600E+00   0.636E+00
BRANCH OPTION -13:  DIA  K1   K2  AREA
   1003             0.130E+01   0.200E+03   0.100E+00   0.133E+01
BRANCH  OPTION -1:   LENGTH      DIA        EPSD       ANGLE        AREA
   1004             0.170E+02   0.130E+01   0.615E-03   0.000E+00   0.133E+01
BRANCH OPTION -2:  FLOW COEF  AREA
   1005             0.600E+00   0.636E+00
BRANCH  OPTION -1:   LENGTH      DIA        EPSD       ANGLE        AREA
   1006             0.288E+03   0.130E+01   0.615E-03   0.000E+00   0.133E+01
BRANCH OPTION -13:  DIA  K1   K2  AREA
   1007             0.130E+01   0.200E+03   0.100E+00   0.133E+01
BRANCH OPTION -7:   PIPE DIA   REDUCED DIA AREA
   1008             0.130E+01   0.530E+00   0.133E+01
BRANCH  OPTION -1:   LENGTH      DIA        EPSD       ANGLE        AREA
   1009             0.221E+03   0.530E+00   0.151E-02   0.000E+00   0.221E+00
BRANCH OPTION -2:  FLOW COEF  AREA
   1010             0.600E+00   0.283E+00
BRANCH  OPTION -1:   LENGTH      DIA        EPSD       ANGLE        AREA
   1011             0.120E+02   0.530E+00   0.151E-02   0.000E+00   0.221E+00
BRANCH OPTION -13:  DIA  K1   K2  AREA
   1012             0.530E+00   0.500E+03   0.700E+00   0.221E+00
BRANCH  OPTION -1:   LENGTH      DIA        EPSD       ANGLE        AREA
   1013             0.140E+02   0.530E+00   0.151E-02   0.000E+00   0.221E+00
BRANCH OPTION -2:  FLOW COEF  AREA
   1014             0.600E+00   0.100E-04
BRANCH  OPTION -1:   LENGTH      DIA        EPSD       ANGLE        AREA
   1015             0.140E+02   0.530E+00   0.151E-02   0.000E+00   0.221E+00
BRANCH OPTION -2:  FLOW COEF  AREA
   1021             0.600E+00   0.785E-02
BRANCH OPTION -13:  DIA  K1   K2  AREA
   1016             0.530E+00   0.500E+03   0.700E+00   0.221E+00
BRANCH  OPTION -1:   LENGTH      DIA        EPSD       ANGLE        AREA
   1017             0.750E+01   0.530E+00   0.151E-02   0.000E+00   0.221E+00
BR OPT-> 18-2  SUBOPT  FLOW COEF, AREA, CTRL NODE, INIT POS
 1018          2     0.60000     0.28270    29.00000   T
BR OPT-> 18-2(continued), CYCLE TIME, CYCLE STEPS, PR TOL FILE
                           0.05000     5.00000   ex12rp1.dat
BRANCH  OPTION -1:   LENGTH      DIA        EPSD       ANGLE        AREA
   1019             0.900E+01   0.530E+00   0.151E-02   0.000E+00   0.221E+00
BRANCH OPTION -2:  FLOW COEF  AREA
   1020             0.600E+00   0.290E-01
BRANCH OPTION -13:  DIA  K1   K2  AREA
   1022             0.530E+00   0.500E+03   0.700E+00   0.221E+00
BRANCH OPTION -2:  FLOW COEF  AREA
   1023             0.831E+00   0.226E+00
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BRANCH  OPTION -1:   LENGTH      DIA        EPSD       ANGLE        AREA
   1024            0.140E+02   0.530E+00   0.151E-02   0.000E+00   0.221E+00
BRANCH OPTION -2:  FLOW COEF  AREA
   1025            0.600E+00   0.418E+00
BRANCH  OPTION -1:   LENGTH      DIA        EPSD       ANGLE        AREA
   1026            0.140E+02   0.530E+00   0.151E-02   0.000E+00   0.221E+00
BRANCH OPTION -8:  PIPE DIA      EXP DIA     AREA
   1027            0.530E+00   0.300E+01   0.221E+00
BRANCH OPTION -2:  FLOW COEF  AREA
   1028            0.000E+00   0.707E+01
BRANCH OPTION -2:  FLOW COEF  AREA
   1029            0.600E+00   0.377E+02
BRANCH OPTION -2:  FLOW COEF  AREA
   1030            0.000E+00   0.399E+04
BRANCH OPTION -2:  FLOW COEF  AREA
   1031            0.181E+00   0.142E+02
BRANCH OPTION -14:  PUMP CONS1 PUMP CONS2      PUMP CONS3 AREA
   1032            0.169E+06   0.000E+00  -0.494E+01   0.142E+02
BRANCH OPTION -2:  FLOW COEF  AREA
   1033            0.464E-01   0.142E+02
BRANCH OPTION -13:  DIA  K1   K2  AREA
   1034            0.130E+01   0.200E+03   0.100E+00   0.133E+01
BRANCH OPTION -7:   PIPE DIA   REDUCED DIA AREA
   1035            0.130E+01   0.780E+00   0.133E+01
BRANCH OPTION -2:  FLOW COEF  AREA
   1036            0.600E+00   0.636E+00
BRANCH OPTION -13:  DIA  K1   K2  AREA
   1037            0.780E+00   0.500E+03   0.700E+00   0.478E+00
BRANCH  OPTION -1:   LENGTH      DIA        EPSD       ANGLE        AREA
   1038            0.110E+02   0.780E+00   0.103E-02   0.000E+00   0.478E+00
BRANCH OPTION -2:  FLOW COEF  AREA
   1039            0.600E+00   0.100E-04
BRANCH  OPTION -1:   LENGTH      DIA        EPSD       ANGLE        AREA
   1040            0.180E+02   0.780E+00   0.103E-02   0.000E+00   0.478E+00
BRANCH OPTION -2:  FLOW COEF  AREA
   1046            0.600E+00   0.177E-01
BRANCH OPTION -13:  DIA  K1   K2  AREA
   1041            0.780E+00   0.500E+03   0.700E+00   0.478E+00
BRANCH  OPTION -1:   LENGTH      DIA        EPSD       ANGLE        AREA
   1042            0.280E+02   0.780E+00   0.103E-02   0.000E+00   0.478E+00
BR OPT-> 18-2  SUBOPT  FLOW COEF, AREA, CTRL NODE, INIT POS
 1043           2     0.60000     0.63617    54.00000   T
BR OPT-> 18-2(continued), CYCLE TIME, CYCLE STEPS, PR TOL FILE
                          0.05000     5.00000   ex12lox.dat
BRANCH  OPTION -1:   LENGTH      DIA        EPSD       ANGLE        AREA
   1044            0.150E+02   0.780E+00   0.103E-02   0.000E+00   0.478E+00
BRANCH OPTION -2:  FLOW COEF  AREA
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   1045             0.600E+00   0.102E+00
BRANCH OPTION -13:  DIA  K1   K2  AREA
   1047             0.780E+00   0.500E+03   0.700E+00   0.478E+00
BRANCH OPTION -2:  FLOW COEF  AREA
   1048             0.774E+00   0.554E+00
BRANCH  OPTION -1:   LENGTH      DIA        EPSD       ANGLE        AREA
   1049             0.130E+02   0.780E+00   0.103E-02   0.000E+00   0.478E+00
BRANCH OPTION -2:  FLOW COEF  AREA
   1050             0.600E+00   0.785E+00
BRANCH  OPTION -1:   LENGTH      DIA        EPSD       ANGLE        AREA
   1051             0.210E+02   0.780E+00   0.103E-02   0.000E+00   0.478E+00
BRANCH OPTION -8:  PIPE DIA      EXP DIA     AREA
   1052             0.780E+00   0.300E+01   0.478E+00
BRANCH OPTION -2:  FLOW COEF  AREA
   1055             0.000E+00   0.402E+04
BRANCH OPTION -2:  FLOW COEF  AREA
   1056             0.304E+00   0.142E+02
BRANCH OPTION -14:  PUMP CONS1 PUMP CONS2      PUMP CONS3 AREA
   1057             0.176E+06   0.000E+00  -0.258E+01   0.142E+02
BRANCH OPTION -2:  FLOW COEF  AREA
   1058             0.105E+00   0.142E+02
BRANCH OPTION -13:  DIA  K1   K2  AREA
   1059             0.130E+01   0.200E+03   0.100E+00   0.133E+01
BRANCH  OPTION -1:   LENGTH      DIA        EPSD       ANGLE        AREA
   1060             0.190E+02   0.130E+01   0.615E-03   0.000E+00   0.133E+01
BRANCH OPTION -2:  FLOW COEF  AREA
   1061             0.600E+00   0.636E+00
BRANCH OPTION -7:   PIPE DIA   REDUCED DIA AREA
   1062             0.130E+01   0.530E+00   0.133E+01
BRANCH  OPTION -1:   LENGTH      DIA        EPSD       ANGLE        AREA
   1063             0.143E+03   0.530E+00   0.151E-02   0.000E+00   0.221E+00
BRANCH  OPTION -1:   LENGTH      DIA        EPSD       ANGLE        AREA
   1064             0.280E+02   0.530E+00   0.604E-02   0.000E+00   0.221E+00
BRANCH OPTION -2:  FLOW COEF  AREA
   1053             0.000E+00   0.707E+01
BRANCH OPTION -2:  FLOW COEF  AREA
   1054             0.600E+00   0.377E+02


  NUMBER OF PRESSURIZATION SYSTEMS =  2
NODUL  NODPRP  QULPRP   QULWAL     QCOND   TNKTM     VOLPROP    VOLULG
               BTU/Sec  BTU/Sec    BTU/Sec   R         Ft^3      Ft^3
   29    31    0.0000    0.0000    0.0000  529.6700  284.8873   15.1242
   54    56    0.0000    0.0000    0.0000  159.6700  474.8048   25.1952
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    ISTEP =       1          TAU =  0.10000E+00
BOUNDARY NODES
   NODE    P(PSI)   TF(F)       Z(COMP)    RHO       CONCENTRATIONS
                                       (LBM/FT^3)
                                                          HE        O2        RP1
    1    0.7650E+03  0.1200E+03  0.1029E+01  0.4783E+00  0.1000E+01  0.0000E+00  0.0000
   30    0.5368E+02  0.7000E+02  0.2938E-01  0.5151E+02  0.0000E+00  0.0000E+00  1.0000
   34    0.6520E+03  0.7000E+02  0.3817E+00  0.5170E+02  0.0000E+00  0.0000E+00  1.0000
   55    0.7548E+02 -0.3000E+03  0.1745E-01  0.7172E+02  0.0000E+00  0.1000E+01  0.0000
   59    0.6520E+03 -0.3000E+03  0.1686E+00  0.7226E+02  0.0000E+00  0.1000E+01  0.0000
   65    0.6150E+03  0.1200E+03  0.1024E+01  0.3867E+00  0.1000E+01  0.0000E+00  0.0000

SOLUTION
INTERNAL NODES
    NODE     P(PSI)       TF(F)         Z         RHO        EM(LBM)    CONC
                                                (LBM/FT^3)
                                                          HE        O2        RP1
    2    0.7619E+03  0.1200E+03  0.1029E+01  0.4765E+00  0.4685E-01  0.1000E+01  0.0000  0.0000
    3    0.7412E+03  0.1200E+03  0.1028E+01  0.4638E+00  0.0000E+00  0.1000E+01  0.0000  0.0000
    4    0.7411E+03  0.1200E+03  0.1028E+01  0.4637E+00  0.3028E-02  0.1000E+01  0.0000  0.0000
    5    0.7409E+03  0.1200E+03  0.1028E+01  0.4637E+00  0.3027E-02  0.1000E+01  0.0000  0.0000
    6    0.7350E+03  0.1201E+03  0.1028E+01  0.4600E+00  0.5088E-01  0.1000E+01  0.0000  0.0000
    7    0.7329E+03  0.1202E+03  0.1028E+01  0.4587E+00  0.5073E-01  0.1000E+01  0.0000  0.0000
    8    0.7329E+03  0.1201E+03  0.1028E+01  0.4587E+00 -0.1472E-18  0.1000E+01  0.0000  0.0000
    9    0.7326E+03  0.1205E+03  0.1028E+01  0.4582E+00  0.6464E-02  0.1000E+01  0.0000  0.0000
   10    0.7258E+03  0.1209E+03  0.1028E+01  0.4537E+00  0.6401E-02  0.1000E+01  0.0000  0.0000
   11    0.7246E+03  0.1233E+03  0.1028E+01  0.4512E+00  0.3456E-03  0.1000E+01  0.0000  0.0000
   12    0.7242E+03  0.1251E+03  0.1028E+01  0.4496E+00  0.3444E-03  0.1000E+01  0.0000  0.0000
   13    0.7242E+03  0.6684E+02  0.1030E+01  0.4982E+00  0.4452E-03  0.1000E+01  0.0000  0.0000
   14    0.7242E+03  0.6473E+02  0.1030E+01  0.5001E+00  0.4469E-03  0.1000E+01  0.0000  0.0000
   15    0.8981E+02  0.5712E+02  0.1004E+01  0.6458E-01  0.5772E-04  0.1000E+01  0.0000  0.0000
   16    0.8981E+02  0.5785E+02  0.1004E+01  0.6449E-01  0.5763E-04  0.1000E+01  0.0000  0.0000
   17    0.7228E+03  0.1242E+03  0.1028E+01  0.4495E+00  0.2152E-03  0.1000E+01  0.0000  0.0000
   18    0.7226E+03  0.1197E+03  0.1028E+01  0.4529E+00  0.2168E-03  0.1000E+01  0.0000  0.0000
   19    0.7214E+03  0.1121E+03  0.1028E+01  0.4581E+00  0.2631E-03  0.1000E+01  0.0000  0.0000
   20    0.7211E+03  0.1028E+03  0.1028E+01  0.4654E+00  0.2673E-03  0.1000E+01  0.0000  0.0000
   21    0.8981E+02  0.9315E+02  0.1004E+01  0.6044E-01 -0.8307E-19  0.1000E+01  0.0000  0.0000
   22    0.7923E+02  0.8313E+02  0.1003E+01  0.5432E-01  0.9231E-19  0.1000E+01  0.0000  0.0000
   23    0.7115E+02  0.7488E+02  0.1003E+01  0.4954E-01  0.4426E-04  0.1000E+01  0.0000  0.0000
   24    0.6728E+02  0.6846E+02  0.1003E+01  0.4742E-01  0.4237E-04  0.1000E+01  0.0000  0.0000
   25    0.6215E+02  0.6376E+02  0.1003E+01  0.4419E-01  0.3949E-04  0.1000E+01  0.0000  0.0000
   26    0.5782E+02  0.6047E+02  0.1003E+01  0.4138E-01  0.3697E-04  0.1000E+01  0.0000  0.0000
   27    0.5058E+02  0.5805E+02  0.1002E+01  0.3637E-01  0.2810E-19  0.1000E+01  0.0000  0.0000
   28    0.5058E+02  0.5642E+02  0.1002E+01  0.3648E-01  0.6338E-20  0.1000E+01  0.0000  0.0000
   29    0.5058E+02  0.7220E+02  0.1002E+01  0.3540E-01  0.5354E+00  0.1000E+01  0.0000  0.0000
   31    0.5368E+02  0.7000E+02  0.3154E-01  0.5151E+02  0.1468E+05  0.0000E+00  0.0000  1.0000
   32    0.2686E+02  0.6997E+02  0.1578E-01  0.5151E+02  0.0000E+00  0.0000E+00  0.0000  1.0000
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33	0.1058E+04	0.7104E+02	0.6171E+00	0.5179E+02	0.0000E+00	0.0000E+00	0.0000	1.0000
35	0.7329E+03	0.1201E+03	0.1028E+01	0.4587E+00	0.0000E+00	0.1000E+01	0.0000	0.0000
36	0.7319E+03	0.1198E+03	0.1028E+01	0.4584E+00	0.0000E+00	0.1000E+01	0.0000	0.0000
37	0.7280E+03	0.1193E+03	0.1028E+01	0.4565E+00	0.0000E+00	0.1000E+01	0.0000	0.0000
38	0.7280E+03	0.8366E+02	0.1030E+01	0.4857E+00	0.7385E-03	0.1000E+01	0.0000	0.0000
39	0.7280E+03	0.8082E+02	0.1030E+01	0.4881E+00	0.7423E-03	0.1000E+01	0.0000	0.0000
40	0.1536E+03	0.7999E+02	0.1006E+01	0.1055E+00	0.2625E-03	0.1000E+01	0.0000	0.0000
41	0.1536E+03	0.8431E+02	0.1006E+01	0.1047E+00	0.2604E-03	0.1000E+01	0.0000	0.0000
42	0.7241E+03	0.1189E+03	0.1028E+01	0.4543E+00	0.1759E-02	0.1000E+01	0.0000	0.0000
43	0.7223E+03	0.1189E+03	0.1028E+01	0.4531E+00	0.1754E-02	0.1000E+01	0.0000	0.0000
44	0.7183E+03	0.1194E+03	0.1028E+01	0.4503E+00	0.9340E-03	0.1000E+01	0.0000	0.0000
45	0.7174E+03	0.1204E+03	0.1028E+01	0.4489E+00	0.9311E-03	0.1000E+01	0.0000	0.0000
46	0.1536E+03	0.1226E+03	0.1006E+01	0.9777E-01	0.9983E-20	0.1000E+01	0.0000	0.0000
47	0.1352E+03	0.1242E+03	0.1005E+01	0.8586E-01	-0.1018E-19	0.1000E+01	0.0000	0.0000
48	0.1188E+03	0.1258E+03	0.1005E+01	0.7533E-01	0.1354E-03	0.1000E+01	0.0000	0.0000
49	0.1137E+03	0.1271E+03	0.1005E+01	0.7195E-01	0.1294E-03	0.1000E+01	0.0000	0.0000
50	0.9764E+02	0.1284E+03	0.1004E+01	0.6169E-01	0.1791E-03	0.1000E+01	0.0000	0.0000
51	0.8761E+02	0.1293E+03	0.1004E+01	0.5528E-01	0.1605E-03	0.1000E+01	0.0000	0.0000
52	0.6971E+02	0.1301E+03	0.1003E+01	0.4396E-01	0.1000E-21	0.1000E+01	0.0000	0.0000
53	0.6971E+02	0.1306E+03	0.1003E+01	0.4393E-01	-0.3219E-20	0.1000E+01	0.0000	0.0000
54	0.6970E+02	-0.2526E+03	0.1006E+01	0.1248E+00	0.3144E+01	0.1000E+01	0.0000	0.0000
56	0.7548E+02	-0.3000E+03	0.1966E-01	0.7173E+02	0.3406E+05	0.0000E+00	1.0000	0.0000
57	0.4337E+02	-0.3001E+03	0.1130E-01	0.7171E+02	0.0000E+00	0.0000E+00	1.0000	0.0000
58	0.9197E+03	-0.2977E+03	0.2349E+00	0.7213E+02	0.0000E+00	0.0000E+00	1.0000	0.0000
60	0.7411E+03	0.1200E+03	0.1028E+01	0.4638E+00	0.3384E-02	0.1000E+01	0.0000	0.0000
61	0.7410E+03	0.1200E+03	0.1028E+01	0.4637E+00	0.3384E-02	0.1000E+01	0.0000	0.0000
62	0.7362E+03	0.1200E+03	0.1028E+01	0.4608E+00	0.0000E+00	0.1000E+01	0.0000	0.0000
63	0.7290E+03	0.1200E+03	0.1028E+01	0.4564E+00	0.4166E-02	0.1000E+01	0.0000	0.0000
64	0.6429E+03	0.1202E+03	0.1025E+01	0.4037E+00	0.5128E-02	0.1000E+01	0.0000	0.0000

NODE	H BTU/LB	ENTROPY BTU/LB-R	EMU LBM/FT-SEC	COND BTU/FT-S-R	CP BTU/LB-R	GAMA
2	0.0000E+00	0.5634E+01	0.1455E-04	0.2672E-04	0.1244E+01	0.1670E+01
3	0.0000E+00	0.5648E+01	0.1454E-04	0.2671E-04	0.1244E+01	0.1670E+01
4	0.0000E+00	0.5648E+01	0.1454E-04	0.2671E-04	0.1244E+01	0.1670E+01
5	0.0000E+00	0.5648E+01	0.1454E-04	0.2671E-04	0.1244E+01	0.1670E+01
6	0.0000E+00	0.5652E+01	0.1454E-04	0.2671E-04	0.1244E+01	0.1670E+01
7	0.0000E+00	0.5654E+01	0.1454E-04	0.2671E-04	0.1244E+01	0.1670E+01
8	0.0000E+00	0.5653E+01	0.1454E-04	0.2671E-04	0.1244E+01	0.1670E+01
9	0.0000E+00	0.5655E+01	0.1455E-04	0.2672E-04	0.1244E+01	0.1670E+01
10	0.0000E+00	0.5660E+01	0.1456E-04	0.2674E-04	0.1244E+01	0.1670E+01
11	0.0000E+00	0.5666E+01	0.1460E-04	0.2681E-04	0.1244E+01	0.1670E+01
12	0.0000E+00	0.5670E+01	0.1463E-04	0.2687E-04	0.1244E+01	0.1670E+01
13	0.0000E+00	0.5539E+01	0.1359E-04	0.2502E-04	0.1244E+01	0.1671E+01
14	0.0000E+00	0.5534E+01	0.1356E-04	0.2495E-04	0.1244E+01	0.1671E+01
15	0.0000E+00	0.6554E+01	0.1331E-04	0.2452E-04	0.1242E+01	0.1667E+01

16	0.0000E+00	0.6556E+01	0.1332E-04	0.2454E-04	0.1242E+01	0.1667E+01
17	0.0000E+00	0.5669E+01	0.1461E-04	0.2684E-04	0.1244E+01	0.1670E+01
18	0.0000E+00	0.5659E+01	0.1453E-04	0.2669E-04	0.1244E+01	0.1670E+01
19	0.0000E+00	0.5644E+01	0.1440E-04	0.2645E-04	0.1244E+01	0.1670E+01
20	0.0000E+00	0.5623E+01	0.1423E-04	0.2615E-04	0.1244E+01	0.1670E+01
21	0.0000E+00	0.6637E+01	0.1397E-04	0.2566E-04	0.1242E+01	0.1667E+01
22	0.0000E+00	0.6677E+01	0.1378E-04	0.2533E-04	0.1241E+01	0.1667E+01
23	0.0000E+00	0.6711E+01	0.1363E-04	0.2507E-04	0.1241E+01	0.1667E+01
24	0.0000E+00	0.6724E+01	0.1351E-04	0.2487E-04	0.1241E+01	0.1667E+01
25	0.0000E+00	0.6752E+01	0.1343E-04	0.2472E-04	0.1241E+01	0.1667E+01
26	0.0000E+00	0.6781E+01	0.1336E-04	0.2462E-04	0.1241E+01	0.1667E+01
27	0.0000E+00	0.6841E+01	0.1332E-04	0.2453E-04	0.1241E+01	0.1667E+01
28	0.0000E+00	0.6837E+01	0.1329E-04	0.2448E-04	0.1241E+01	0.1667E+01
29	0.0000E+00	0.6875E+01	0.1358E-04	0.2499E-04	0.1241E+01	0.1667E+01
31	0.0000E+00	0.0000E+00	0.1251E-02	0.2352E-04	0.4437E+00	0.1381E+01
32	0.0000E+00	0.0000E+00	0.1249E-02	0.2351E-04	0.4438E+00	0.1381E+01
33	0.0000E+00	0.0000E+00	0.1346E-02	0.2392E-04	0.4429E+00	0.1375E+01
35	0.0000E+00	0.5653E+01	0.1454E-04	0.2671E-04	0.1244E+01	0.1670E+01
36	0.0000E+00	0.5653E+01	0.1454E-04	0.2670E-04	0.1244E+01	0.1670E+01
37	0.0000E+00	0.5655E+01	0.1453E-04	0.2668E-04	0.1244E+01	0.1670E+01
38	0.0000E+00	0.5576E+01	0.1389E-04	0.2554E-04	0.1244E+01	0.1670E+01
39	0.0000E+00	0.5569E+01	0.1384E-04	0.2545E-04	0.1244E+01	0.1670E+01
40	0.0000E+00	0.6341E+01	0.1374E-04	0.2526E-04	0.1242E+01	0.1668E+01
41	0.0000E+00	0.6351E+01	0.1382E-04	0.2540E-04	0.1242E+01	0.1667E+01
42	0.0000E+00	0.5657E+01	0.1452E-04	0.2667E-04	0.1244E+01	0.1670E+01
43	0.0000E+00	0.5658E+01	0.1452E-04	0.2667E-04	0.1244E+01	0.1670E+01
44	0.0000E+00	0.5662E+01	0.1453E-04	0.2669E-04	0.1244E+01	0.1670E+01
45	0.0000E+00	0.5665E+01	0.1455E-04	0.2672E-04	0.1244E+01	0.1670E+01
46	0.0000E+00	0.6436E+01	0.1452E-04	0.2664E-04	0.1242E+01	0.1667E+01
47	0.0000E+00	0.6503E+01	0.1455E-04	0.2668E-04	0.1242E+01	0.1667E+01
48	0.0000E+00	0.6570E+01	0.1458E-04	0.2673E-04	0.1242E+01	0.1667E+01
49	0.0000E+00	0.6595E+01	0.1460E-04	0.2677E-04	0.1242E+01	0.1667E+01
50	0.0000E+00	0.6673E+01	0.1462E-04	0.2681E-04	0.1242E+01	0.1667E+01
51	0.0000E+00	0.6729E+01	0.1464E-04	0.2684E-04	0.1241E+01	0.1667E+01
52	0.0000E+00	0.6844E+01	0.1465E-04	0.2686E-04	0.1241E+01	0.1667E+01
53	0.0000E+00	0.6845E+01	0.1466E-04	0.2687E-04	0.1241E+01	0.1667E+01
54	0.0000E+00	0.5544E+01	0.7210E-05	0.1331E-04	0.1243E+01	0.1669E+01
56	0.0000E+00	0.6963E+00	0.1416E-03	0.2073E-04	0.4202E+00	0.1730E+01
57	0.0000E+00	0.6962E+00	0.1414E-03	0.2072E-04	0.4204E+00	0.1731E+01
58	0.0000E+00	0.6971E+00	0.1468E-03	0.2093E-04	0.4143E+00	0.1705E+01
60	0.0000E+00	0.5648E+01	0.1454E-04	0.2671E-04	0.1244E+01	0.1670E+01
61	0.0000E+00	0.5648E+01	0.1454E-04	0.2671E-04	0.1244E+01	0.1670E+01
62	0.0000E+00	0.5651E+01	0.1454E-04	0.2671E-04	0.1244E+01	0.1670E+01
63	0.0000E+00	0.5656E+01	0.1454E-04	0.2671E-04	0.1244E+01	0.1670E+01
64	0.0000E+00	0.5719E+01	0.1453E-04	0.2669E-04	0.1243E+01	0.1670E+01

BRANCHES

BRANCH	KFACTOR (LBF-S^2/(LBM-FT)^2)	DELP (PSI)	FLOW RATE (LBM/SEC)	VELOCITY (FT/SEC)	REYN. NO.	MACH NO.	ENTROPY GEN. BTU/(R-SEC)	LOST WORK LBF-FT/SEC
1001	0.684E+03	0.306E+01	0.803E+00	0.182E+03	0.649E+06	0.525E-01	0.164E-02	0.740E+03
1002	0.464E+04	0.208E+02	0.803E+00	0.381E+03	0.937E+06	0.110E+00	0.112E-01	0.504E+04
1003	0.700E+02	0.874E-01	0.424E+00	0.992E+02	0.343E+06	0.286E-01	0.255E-04	0.115E+02
1004	0.964E+02	0.120E+00	0.424E+00	0.992E+02	0.343E+06	0.286E-01	0.351E-04	0.159E+02
1005	0.477E+04	0.596E+01	0.424E+00	0.207E+03	0.495E+06	0.597E-01	0.174E-02	0.785E+03
1006	0.165E+04	0.206E+01	0.424E+00	0.100E+03	0.343E+06	0.288E-01	0.605E-03	0.273E+03
1007	0.717E+02	0.349E-02	0.837E-01	0.198E+02	0.677E+05	0.571E-02	0.204E-06	0.919E-01
1008	0.733E+04	0.357E+00	0.837E-01	0.198E+02	0.677E+05	0.571E-02	0.208E-04	0.939E+01
1009	0.139E+06	0.677E+01	0.838E-01	0.119E+03	0.166E+06	0.344E-01	0.395E-03	0.178E+03
1010	0.247E+05	0.121E+01	0.839E-01	0.942E+02	0.147E+06	0.272E-01	0.712E-04	0.321E+02
1011	0.765E+04	0.375E+00	0.839E-01	0.121E+03	0.166E+06	0.349E-01	0.221E-04	0.100E+02
1012	0.340E+05	0.185E-03	0.883E-03	0.128E+01	0.174E+04	0.369E-03	0.115E-09	0.521E-04
1013	0.218E+05	0.357E-04	0.486E-03	0.637E+00	0.103E+04	0.193E-03	0.123E-10	0.502E-05
1014	0.179E+14	0.634E+03	0.714E-04	0.206E+04	0.226E+05	0.624E+00	0.320E-04	0.131E+02
1015	0.610E+07	0.729E-05	0.131E-04	0.132E+00	0.284E+02	0.405E-04	0.530E-12	0.213E-06
1021	0.240E+09	-0.329E-02	-0.444E-04	-0.135E+02	0.486E+03	0.412E-02	0.810E-09	0.348E-03
1016	0.298E+05	0.143E+01	0.831E-01	0.121E+03	0.164E+06	0.346E-01	0.836E-04	0.380E+02
1017	0.480E+04	0.230E+00	0.831E-01	0.121E+03	0.164E+06	0.347E-01	0.135E-04	0.613E+01
1018	0.247E+05	0.119E+01	0.831E-01	0.935E+02	0.146E+06	0.270E-01	0.695E-04	0.313E+02
1019	0.565E+04	0.271E+00	0.831E-01	0.118E+03	0.166E+06	0.344E-01	0.159E-04	0.707E+01
1020	0.229E+07	0.631E+03	0.830E-01	0.887E+03	0.464E+06	0.260E+00	0.644E-02	0.282E+04
1022	0.222E+06	0.106E+02	0.829E-01	0.895E+03	0.171E+06	0.265E+00	0.487E-02	0.209E+04
1023	0.169E+06	0.808E+01	0.829E-01	0.975E+03	0.172E+06	0.291E+00	0.421E-02	0.178E+04
1024	0.811E+05	0.387E+01	0.829E-01	0.109E+04	0.175E+06	0.328E+00	0.224E-02	0.933E+03
1025	0.108E+06	0.514E+01	0.829E-01	0.601E+03	0.128E+06	0.182E+00	0.315E-02	0.129E+04
1026	0.908E+05	0.433E+01	0.828E-01	0.122E+04	0.178E+06	0.372E+00	0.287E-02	0.117E+04
1027	0.152E+06	0.724E+01	0.828E-01	0.131E+04	0.179E+06	0.398E+00	0.515E-02	0.209E+04
1028	0.000E+00	0.000E+00	0.828E-01	0.464E+02	0.317E+05	0.142E-01	0.000E+00	0.000E+00
1029	0.173E+02	0.822E-03	0.828E-01	0.867E+01	0.137E+05	0.265E-02	0.669E-06	0.269E+00
1030	0.000E+00	0.000E+00	0.641E+02	0.450E-01	0.110E+05	0.978E-04	0.000E+00	0.000E+00
1031	0.940E+00	0.268E+02	0.641E+02	0.126E+02	0.184E+06	0.273E-01	0.117E-01	0.481E+04
1032	0.000E+00	-0.103E+04	0.641E+02	0.126E+02	0.184E+06	0.274E-01	0.000E+00	0.000E+00
1033	0.142E+02	0.406E+03	0.641E+02	0.125E+02	0.171E+06	0.272E-01	0.175E+00	0.724E+05
1034	0.708E+02	0.570E-01	0.340E+00	0.805E+02	0.275E+06	0.232E-01	0.135E-04	0.609E+01
1035	0.120E+04	0.962E+00	0.340E+00	0.805E+02	0.275E+06	0.232E-01	0.228E-03	0.103E+03
1036	0.482E+04	0.388E+01	0.340E+00	0.168E+03	0.398E+06	0.485E-01	0.921E-03	0.415E+03
1037	0.607E+04	0.433E-04	0.101E-02	0.670E+00	0.136E+04	0.193E-03	0.306E-10	0.138E-04
1038	0.333E+04	0.721E-05	0.559E-03	0.347E+00	0.787E+03	0.103E-03	0.283E-11	0.120E-05
1039	0.183E+14	0.574E+03	0.672E-04	0.198E+04	0.208E+05	0.592E+00	0.271E-04	0.114E+02
1040	0.966E+05	-0.142E-04	-0.145E-03	-0.419E+00	0.206E+03	0.125E-03	0.671E-11	0.284E-05
1046	0.293E+08	-0.232E-01	-0.337E-03	-0.282E+02	0.237E+04	0.839E-02	0.254E-07	0.115E-01
1041	0.494E+04	0.395E+01	0.339E+00	0.224E+03	0.458E+06	0.647E-01	0.940E-03	0.423E+03
1042	0.227E+04	0.182E+01	0.339E+00	0.225E+03	0.458E+06	0.650E-01	0.435E-03	0.196E+03
1043	0.488E+04	0.390E+01	0.339E+00	0.169E+03	0.397E+06	0.489E-01	0.935E-03	0.421E+03
1044	0.123E+04	0.983E+00	0.339E+00	0.227E+03	0.457E+06	0.655E-01	0.237E-03	0.107E+03

1045	0.192E+06	0.564E+03	0.339E+00	0.107E+04	0.990E+06	0.308E+00	0.371E-01	0.168E+05
1047	0.231E+05	0.184E+02	0.339E+00	0.105E+04	0.457E+06	0.301E+00	0.203E-01	0.920E+04
1048	0.205E+05	0.163E+02	0.339E+00	0.103E+04	0.424E+06	0.295E+00	0.204E-01	0.929E+04
1049	0.637E+04	0.509E+01	0.339E+00	0.136E+04	0.456E+06	0.390E+00	0.723E-02	0.329E+04
1050	0.202E+05	0.161E+02	0.339E+00	0.864E+03	0.355E+06	0.248E+00	0.239E-01	0.109E+05
1051	0.126E+05	0.100E+02	0.339E+00	0.166E+04	0.454E+06	0.475E+00	0.173E-01	0.794E+04
1052	0.224E+05	0.179E+02	0.339E+00	0.185E+04	0.454E+06	0.529E+00	0.345E-01	0.158E+05
1055	0.000E+00	0.000E+00	0.139E+03	0.693E-01	0.209E+06	0.106E-03	0.000E+00	0.000E+00
1056	0.239E+00	0.321E+02	0.139E+03	0.196E+02	0.352E+07	0.299E-01	0.722E-01	0.896E+04
1057	0.000E+00	-0.876E+03	0.139E+03	0.196E+02	0.353E+07	0.299E-01	0.000E+00	0.000E+00
1058	0.200E+01	0.268E+03	0.139E+03	0.195E+02	0.340E+07	0.297E-01	0.590E+00	0.743E+05
1059	0.700E+02	0.698E-01	0.379E+00	0.886E+02	0.306E+06	0.256E-01	0.182E-04	0.821E+01
1060	0.108E+03	0.108E+00	0.379E+00	0.886E+02	0.306E+06	0.256E-01	0.282E-04	0.127E+02
1061	0.477E+04	0.476E+01	0.379E+00	0.185E+03	0.442E+06	0.533E-01	0.124E-02	0.560E+03
1062	0.727E+04	0.725E+01	0.379E+00	0.892E+02	0.306E+06	0.257E-01	0.190E-02	0.858E+03
1063	0.864E+05	0.861E+02	0.379E+00	0.542E+03	0.751E+06	0.156E+00	0.228E-01	0.103E+05
1064	0.280E+05	0.279E+02	0.379E+00	0.613E+03	0.751E+06	0.177E+00	0.835E-02	0.377E+04
1053	0.000E+00	0.000E+00	0.339E+00	0.157E+03	0.118E+06	0.449E-01	0.000E+00	0.000E+00
1054	0.143E+02	0.114E-01	0.339E+00	0.295E+02	0.510E+05	0.843E-02	0.277E-04	0.127E+02

NUMBER OF PRESSURIZATION SYSTEMS = 2

NODUL	NODPRP	QULPRP	QULWAL	QCOND	TNKTM	VOLPROP	VOLULG
		BTU/Sec	BTU/Sec	BTU/Sec	R	Ft^3	Ft^3
29	31	0.0000	0.0000	0.0000	529.6700	284.8873	15.1242
54	56	0.0000	0.0000	0.0000	159.6700	474.8048	25.1952

SOLUTION DID NOT SATISFY CONVERGENCE CRITERION 0.100E-02 IN 91 ITERATIONS
DIFMAX IN SUCCESSIVE ITERATION = 0.212E-02

:
:
:
:

ISTEP = 856 TAU = 0.60040E+02

BOUNDARY NODES

NODE	P(PSI)	TF(F)	Z(COMP)	RHO (LBM/FT^3)	CONCENTRATIONS		
					HE	O2	RP1
1	0.7650E+03	0.1200E+03	0.1029E+01	0.4783E+00	0.1000E+01	0.0000E+00	0.0000
30	0.5490E+02	0.7000E+02	0.2938E-01	0.5151E+02	0.0000E+00	0.0000E+00	1.0000
34	0.6520E+03	0.7000E+02	0.3817E+00	0.5170E+02	0.0000E+00	0.0000E+00	1.0000
55	0.7194E+02	-0.3000E+03	0.1745E-01	0.7172E+02	0.0000E+00	0.1000E+01	0.0000
59	0.6520E+03	-0.3000E+03	0.1686E+00	0.7226E+02	0.0000E+00	0.1000E+01	0.0000
65	0.6150E+03	0.1200E+03	0.1024E+01	0.3867E+00	0.1000E+01	0.0000E+00	0.0000

SOLUTION

INTERNAL NODES

NODE	P(PSI)	TF(F)	Z	RHO (LBM/FT^3)	EM(LBM)	CONC		
					HE	O2	RP1	
2	0.7638E+03	0.1200E+03	0.1029E+01	0.4776E+00	0.4696E-01	0.1000E+01	0.0000	0.0000
3	0.7562E+03	0.1200E+03	0.1029E+01	0.4730E+00	-0.2202E-19	0.1000E+01	0.0000	0.0000
4	0.7562E+03	0.1199E+03	0.1029E+01	0.4730E+00	0.3088E-02	0.1000E+01	0.0000	0.0000
5	0.7562E+03	0.1198E+03	0.1029E+01	0.4731E+00	0.3089E-02	0.1000E+01	0.0000	0.0000
6	0.7559E+03	0.1181E+03	0.1029E+01	0.4743E+00	0.5246E-01	0.1000E+01	0.0000	0.0000
7	0.7558E+03	0.1156E+03	0.1029E+01	0.4762E+00	0.5268E-01	0.1000E+01	0.0000	0.0000
8	0.7558E+03	0.1160E+03	0.1029E+01	0.4760E+00	-0.3793E-20	0.1000E+01	0.0000	0.0000
9	0.7555E+03	0.1161E+03	0.1029E+01	0.4757E+00	0.6711E-02	0.1000E+01	0.0000	0.0000
10	0.7489E+03	0.1148E+03	0.1029E+01	0.4727E+00	0.6668E-02	0.1000E+01	0.0000	0.0000
11	0.7477E+03	0.1164E+03	0.1029E+01	0.4706E+00	0.3605E-03	0.1000E+01	0.0000	0.0000
12	0.7473E+03	0.1185E+03	0.1029E+01	0.4688E+00	0.3591E-03	0.1000E+01	0.0000	0.0000
13	0.7473E+03	0.6647E+02	0.1031E+01	0.5138E+00	0.4592E-03	0.1000E+01	0.0000	0.0000
14	0.7473E+03	0.6411E+02	0.1031E+01	0.5161E+00	0.4612E-03	0.1000E+01	0.0000	0.0000
15	0.9315E+02	0.5830E+02	0.1004E+01	0.6682E-01	0.5971E-04	0.1000E+01	0.0000	0.0000
16	0.9315E+02	0.5958E+02	0.1004E+01	0.6665E-01	0.5957E-04	0.1000E+01	0.0000	0.0000
17	0.7459E+03	0.1206E+03	0.1029E+01	0.4662E+00	0.2232E-03	0.1000E+01	0.0000	0.0000
18	0.7457E+03	0.1219E+03	0.1029E+01	0.4651E+00	0.2227E-03	0.1000E+01	0.0000	0.0000
19	0.7445E+03	0.1210E+03	0.1029E+01	0.4651E+00	0.2672E-03	0.1000E+01	0.0000	0.0000
20	0.7442E+03	0.1178E+03	0.1029E+01	0.4674E+00	0.2686E-03	0.1000E+01	0.0000	0.0000
21	0.9314E+02	0.1137E+03	0.1004E+01	0.6037E-01	-0.1286E-19	0.1000E+01	0.0000	0.0000
22	0.8215E+02	0.1068E+03	0.1003E+01	0.5392E-01	0.4135E-19	0.1000E+01	0.0000	0.0000
23	0.7371E+02	0.9884E+02	0.1003E+01	0.4909E-01	0.4387E-04	0.1000E+01	0.0000	0.0000
24	0.6965E+02	0.9032E+02	0.1003E+01	0.4711E-01	0.4210E-04	0.1000E+01	0.0000	0.0000
25	0.6428E+02	0.8212E+02	0.1003E+01	0.4414E-01	0.3945E-04	0.1000E+01	0.0000	0.0000
26	0.5977E+02	0.7489E+02	0.1003E+01	0.4161E-01	0.3718E-04	0.1000E+01	0.0000	0.0000
27	0.5228E+02	0.6889E+02	0.1002E+01	0.3682E-01	0.1032E-19	0.1000E+01	0.0000	0.0000
28	0.5228E+02	0.6425E+02	0.1002E+01	0.3714E-01	-0.7869E-20	0.1000E+01	0.0000	0.0000
29	0.5228E+02	0.8373E+02	0.1002E+01	0.3583E-01	0.3213E+01	0.9996E+00	0.0000	0.0004
31	0.5490E+02	0.7004E+02	0.3226E-01	0.5151E+02	0.1083E+05	0.0000E+00	0.0000	1.0000
32	0.2803E+02	0.7001E+02	0.1647E-01	0.5150E+02	0.0000E+00	0.0000E+00	0.0000	1.0000
33	0.1059E+04	0.7108E+02	0.6176E+00	0.5178E+02	0.0000E+00	0.0000E+00	0.0000	1.0000
35	0.7558E+03	0.1149E+03	0.1029E+01	0.4768E+00	0.2752E-19	0.1000E+01	0.0000	0.0000
36	0.7558E+03	0.1152E+03	0.1029E+01	0.4766E+00	0.2581E-19	0.1000E+01	0.0000	0.0000
37	0.7558E+03	0.1155E+03	0.1029E+01	0.4764E+00	0.3904E-20	0.1000E+01	0.0000	0.0000
38	0.7558E+03	0.8336E+02	0.1031E+01	0.5038E+00	0.7662E-03	0.1000E+01	0.0000	0.0000
39	0.7558E+03	0.8031E+02	0.1031E+01	0.5066E+00	0.7704E-03	0.1000E+01	0.0000	0.0000
40	0.6533E+02	0.8264E+02	0.1003E+01	0.4482E-01	0.1115E-03	0.1000E+01	0.0000	0.0000
41	0.6533E+02	0.8823E+02	0.1003E+01	0.4436E-01	0.1104E-03	0.1000E+01	0.0000	0.0000
42	0.7558E+03	0.1157E+03	0.1029E+01	0.4762E+00	0.1844E-02	0.1000E+01	0.0000	0.0000
43	0.7558E+03	0.1160E+03	0.1029E+01	0.4759E+00	0.1843E-02	0.1000E+01	0.0000	0.0000
44	0.6533E+02	0.1147E+03	0.1003E+01	0.4232E-01	0.8776E-04	0.1000E+01	0.0000	0.0000
45	0.6533E+02	0.1141E+03	0.1003E+01	0.4237E-01	0.8786E-04	0.1000E+01	0.0000	0.0000

46	0.6533E+02	0.1160E+03	0.1003E+01	0.4222E-01	0.1215E-18	0.1000E+01	0.0000	0.0000
47	0.6533E+02	0.1168E+03	0.1003E+01	0.4217E-01	-0.1698E-19	0.1000E+01	0.0000	0.0000
48	0.6533E+02	0.1178E+03	0.1003E+01	0.4209E-01	0.7566E-04	0.1000E+01	0.0000	0.0000
49	0.6533E+02	0.1189E+03	0.1003E+01	0.4202E-01	0.7552E-04	0.1000E+01	0.0000	0.0000
50	0.6533E+02	0.1201E+03	0.1003E+01	0.4192E-01	0.1217E-03	0.1000E+01	0.0000	0.0000
51	0.6533E+02	0.1214E+03	0.1003E+01	0.4183E-01	0.1215E-03	0.1000E+01	0.0000	0.0000
52	0.6533E+02	0.1227E+03	0.1003E+01	0.4174E-01	0.7260E-20	0.1000E+01	0.0000	0.0000
53	0.6533E+02	0.1239E+03	0.1003E+01	0.4165E-01	-0.6819E-22	0.1000E+01	0.0000	0.0000
54	0.6533E+02	-0.1054E+03	0.1004E+01	0.7903E-01	0.1117E+02	0.8484E+00	0.1516	0.0000
56	0.7194E+02	-0.3000E+03	0.1874E-01	0.7172E+02	0.2573E+05	0.0000E+00	1.0000	0.0000
57	0.4000E+02	-0.3001E+03	0.1043E-01	0.7170E+02	0.0000E+00	0.0000E+00	1.0000	0.0000
58	0.9183E+03	-0.2977E+03	0.2345E+00	0.7212E+02	0.0000E+00	0.0000E+00	1.0000	0.0000
60	0.7561E+03	0.1199E+03	0.1029E+01	0.4730E+00	0.3451E-02	0.1000E+01	0.0000	0.0000
61	0.7560E+03	0.1199E+03	0.1029E+01	0.4729E+00	0.3451E-02	0.1000E+01	0.0000	0.0000
62	0.7507E+03	0.1199E+03	0.1029E+01	0.4697E+00	0.0000E+00	0.1000E+01	0.0000	0.0000
63	0.7426E+03	0.1199E+03	0.1029E+01	0.4648E+00	0.4243E-02	0.1000E+01	0.0000	0.0000
64	0.6465E+03	0.1200E+03	0.1025E+01	0.4060E+00	0.5158E-02	0.1000E+01	0.0000	0.0000

NODE	H BTU/LB	ENTROPY BTU/LB-R	EMU LBM/FT-SEC	COND BTU/FT-S-R	CP BTU/LB-R	GAMA
2	0.0000E+00	0.5633E+01	0.1454E-04	0.2672E-04	0.1244E+01	0.1670E+01
3	0.0000E+00	0.5638E+01	0.1454E-04	0.2671E-04	0.1244E+01	0.1670E+01
4	0.0000E+00	0.5637E+01	0.1454E-04	0.2671E-04	0.1244E+01	0.1670E+01
5	0.0000E+00	0.5637E+01	0.1454E-04	0.2671E-04	0.1244E+01	0.1670E+01
6	0.0000E+00	0.5634E+01	0.1451E-04	0.2665E-04	0.1244E+01	0.1670E+01
7	0.0000E+00	0.5628E+01	0.1447E-04	0.2657E-04	0.1244E+01	0.1670E+01
8	0.0000E+00	0.5629E+01	0.1447E-04	0.2659E-04	0.1244E+01	0.1670E+01
9	0.0000E+00	0.5630E+01	0.1448E-04	0.2659E-04	0.1244E+01	0.1670E+01
10	0.0000E+00	0.5631E+01	0.1445E-04	0.2654E-04	0.1244E+01	0.1670E+01
11	0.0000E+00	0.5636E+01	0.1448E-04	0.2660E-04	0.1244E+01	0.1670E+01
12	0.0000E+00	0.5640E+01	0.1452E-04	0.2666E-04	0.1244E+01	0.1670E+01
13	0.0000E+00	0.5523E+01	0.1359E-04	0.2502E-04	0.1244E+01	0.1671E+01
14	0.0000E+00	0.5517E+01	0.1355E-04	0.2494E-04	0.1244E+01	0.1671E+01
15	0.0000E+00	0.6539E+01	0.1333E-04	0.2456E-04	0.1242E+01	0.1667E+01
16	0.0000E+00	0.6542E+01	0.1336E-04	0.2460E-04	0.1242E+01	0.1667E+01
17	0.0000E+00	0.5646E+01	0.1455E-04	0.2673E-04	0.1244E+01	0.1670E+01
18	0.0000E+00	0.5649E+01	0.1458E-04	0.2677E-04	0.1244E+01	0.1670E+01
19	0.0000E+00	0.5647E+01	0.1456E-04	0.2674E-04	0.1244E+01	0.1670E+01
20	0.0000E+00	0.5641E+01	0.1450E-04	0.2664E-04	0.1244E+01	0.1670E+01
21	0.0000E+00	0.6665E+01	0.1435E-04	0.2633E-04	0.1242E+01	0.1667E+01
22	0.0000E+00	0.6712E+01	0.1422E-04	0.2610E-04	0.1241E+01	0.1667E+01
23	0.0000E+00	0.6748E+01	0.1408E-04	0.2585E-04	0.1241E+01	0.1667E+01
24	0.0000E+00	0.6757E+01	0.1392E-04	0.2557E-04	0.1241E+01	0.1667E+01
25	0.0000E+00	0.6779E+01	0.1377E-04	0.2530E-04	0.1241E+01	0.1667E+01
26	0.0000E+00	0.6798E+01	0.1363E-04	0.2507E-04	0.1241E+01	0.1667E+01
27	0.0000E+00	0.6851E+01	0.1352E-04	0.2488E-04	0.1241E+01	0.1667E+01

28	0.0000E+00	0.6840E+01	0.1344E-04	0.2474E-04	0.1241E+01	0.1667E+01
29	0.0000E+00	0.6882E+01	0.1380E-04	0.2535E-04	0.1241E+01	0.1667E+01
31	0.0000E+00	0.0000E+00	0.1251E-02	0.2352E-04	0.4438E+00	0.1381E+01
32	0.0000E+00	0.0000E+00	0.1248E-02	0.2351E-04	0.4438E+00	0.1381E+01
33	0.0000E+00	0.0000E+00	0.1345E-02	0.2392E-04	0.4429E+00	0.1375E+01
35	0.0000E+00	0.5627E+01	0.1445E-04	0.2655E-04	0.1244E+01	0.1670E+01
36	0.0000E+00	0.5627E+01	0.1446E-04	0.2656E-04	0.1244E+01	0.1670E+01
37	0.0000E+00	0.5628E+01	0.1446E-04	0.2657E-04	0.1244E+01	0.1670E+01
38	0.0000E+00	0.5557E+01	0.1389E-04	0.2554E-04	0.1244E+01	0.1670E+01
39	0.0000E+00	0.5550E+01	0.1384E-04	0.2545E-04	0.1244E+01	0.1671E+01
40	0.0000E+00	0.6772E+01	0.1378E-04	0.2532E-04	0.1241E+01	0.1667E+01
41	0.0000E+00	0.6785E+01	0.1388E-04	0.2550E-04	0.1241E+01	0.1667E+01
42	0.0000E+00	0.5629E+01	0.1447E-04	0.2658E-04	0.1244E+01	0.1670E+01
43	0.0000E+00	0.5629E+01	0.1447E-04	0.2659E-04	0.1244E+01	0.1670E+01
44	0.0000E+00	0.6843E+01	0.1437E-04	0.2636E-04	0.1241E+01	0.1667E+01
45	0.0000E+00	0.6842E+01	0.1435E-04	0.2634E-04	0.1241E+01	0.1667E+01
46	0.0000E+00	0.6846E+01	0.1439E-04	0.2640E-04	0.1241E+01	0.1667E+01
47	0.0000E+00	0.6848E+01	0.1440E-04	0.2642E-04	0.1241E+01	0.1667E+01
48	0.0000E+00	0.6850E+01	0.1442E-04	0.2645E-04	0.1241E+01	0.1667E+01
49	0.0000E+00	0.6852E+01	0.1444E-04	0.2649E-04	0.1241E+01	0.1667E+01
50	0.0000E+00	0.6855E+01	0.1446E-04	0.2653E-04	0.1241E+01	0.1667E+01
51	0.0000E+00	0.6858E+01	0.1449E-04	0.2657E-04	0.1241E+01	0.1667E+01
52	0.0000E+00	0.6860E+01	0.1451E-04	0.2661E-04	0.1241E+01	0.1667E+01
53	0.0000E+00	0.6863E+01	0.1453E-04	0.2665E-04	0.1241E+01	0.1667E+01
54	0.0000E+00	0.5501E+01	0.1023E-04	0.1865E-04	0.1087E+01	0.1662E+01
56	0.0000E+00	0.6964E+00	0.1415E-03	0.2073E-04	0.4202E+00	0.1731E+01
57	0.0000E+00	0.6963E+00	0.1413E-03	0.2072E-04	0.4204E+00	0.1732E+01
58	0.0000E+00	0.6972E+00	0.1468E-03	0.2092E-04	0.4143E+00	0.1705E+01
60	0.0000E+00	0.5638E+01	0.1454E-04	0.2671E-04	0.1244E+01	0.1670E+01
61	0.0000E+00	0.5638E+01	0.1454E-04	0.2671E-04	0.1244E+01	0.1670E+01
62	0.0000E+00	0.5641E+01	0.1454E-04	0.2671E-04	0.1244E+01	0.1670E+01
63	0.0000E+00	0.5646E+01	0.1454E-04	0.2671E-04	0.1244E+01	0.1670E+01
64	0.0000E+00	0.5716E+01	0.1453E-04	0.2668E-04	0.1243E+01	0.1670E+01

BRANCHES

BRANCH	KFACTOR (LBF-S^2/(LBM-FT)^2)	DELP (PSI)	FLOW RATE (LBM/SEC)	VELOCITY (FT/SEC)	REYN. NO.	MACH NO.	ENTROPY GEN. BTU/(R-SEC)	LOST WORK LBF-FT/SEC
1001	0.698E+03	0.116E+01	0.489E+00	0.111E+03	0.395E+06	0.320E-01	0.377E-03	0.170E+03
1002	0.463E+04	0.768E+01	0.489E+00	0.232E+03	0.570E+06	0.668E-01	0.251E-02	0.113E+04
1003	0.696E+02	0.345E-02	0.845E-01	0.194E+02	0.683E+05	0.559E-02	0.197E-06	0.888E-01
1004	0.111E+03	0.548E-02	0.845E-01	0.194E+02	0.683E+05	0.559E-02	0.313E-06	0.141E+00
1005	0.468E+04	0.232E+00	0.845E-01	0.404E+02	0.987E+05	0.117E-01	0.132E-04	0.597E+01
1006	0.187E+04	0.926E-01	0.845E-01	0.193E+02	0.685E+05	0.559E-02	0.529E-05	0.238E+01
1007	0.691E+02	0.342E-02	0.845E-01	0.192E+02	0.686E+05	0.557E-02	0.195E-06	0.874E-01
1008	0.707E+04	0.350E+00	0.845E-01	0.193E+02	0.686E+05	0.557E-02	0.200E-04	0.894E+01
1009	0.134E+06	0.662E+01	0.845E-01	0.116E+03	0.168E+06	0.335E-01	0.378E-03	0.169E+03
1010	0.237E+05	0.117E+01	0.845E-01	0.910E+02	0.149E+06	0.264E-01	0.676E-04	0.302E+02

1011	0.733E+04	0.363E+00	0.845E-01	0.117E+03	0.168E+06	0.339E-01	0.209E-04	0.938E+01
1012	0.768E+05	0.290E-05	0.737E-04	0.103E+00	0.146E+03	0.296E-04	0.146E-12	0.656E-07
1013	0.139E+06	0.526E-05	0.737E-04	0.936E-01	0.156E+03	0.283E-04	0.265E-12	0.109E-06
1014	0.173E+14	0.654E+03	0.737E-04	0.206E+04	0.233E+05	0.624E+00	0.330E-04	0.135E+02
1015	0.106E+07	0.395E-04	0.734E-04	0.717E+00	0.159E+03	0.219E-03	0.155E-10	0.624E-05
1021	0.218E+09	0.807E-02	0.730E-04	0.201E+02	0.835E+03	0.613E-02	0.315E-08	0.127E-02
1016	0.286E+05	0.141E+01	0.844E-01	0.117E+03	0.168E+06	0.339E-01	0.814E-04	0.366E+02
1017	0.463E+04	0.229E+00	0.844E-01	0.118E+03	0.167E+06	0.341E-01	0.132E-04	0.596E+01
1018	0.241E+05	0.119E+01	0.844E-01	0.924E+02	0.147E+06	0.266E-01	0.687E-04	0.311E+02
1019	0.557E+04	0.275E+00	0.844E-01	0.118E+03	0.167E+06	0.341E-01	0.159E-04	0.719E+01
1020	0.228E+07	0.651E+03	0.844E-01	0.898E+03	0.463E+06	0.259E+00	0.654E-02	0.294E+04
1022	0.222E+06	0.110E+02	0.845E-01	0.913E+03	0.170E+06	0.265E+00	0.496E-02	0.221E+04
1023	0.170E+06	0.844E+01	0.845E-01	0.100E+04	0.169E+06	0.292E+00	0.432E-02	0.190E+04
1024	0.819E+05	0.406E+01	0.845E-01	0.112E+04	0.173E+06	0.330E+00	0.231E-02	0.100E+04
1025	0.108E+06	0.537E+01	0.845E-01	0.617E+03	0.127E+06	0.183E+00	0.324E-02	0.139E+04
1026	0.910E+05	0.451E+01	0.845E-01	0.125E+04	0.177E+06	0.373E+00	0.294E-02	0.124E+04
1027	0.151E+06	0.749E+01	0.844E-01	0.132E+04	0.179E+06	0.398E+00	0.526E-02	0.219E+04
1028	0.000E+00	0.000E+00	0.844E-01	0.467E+02	0.318E+05	0.141E-01	0.000E+00	0.000E+00
1029	0.170E+02	0.840E-03	0.844E-01	0.869E+01	0.139E+05	0.264E-02	0.675E-06	0.275E+00
1030	0.000E+00	0.000E+00	0.642E+02	0.450E-01	0.110E+05	0.979E-04	0.000E+00	0.000E+00
1031	0.940E+00	0.269E+02	0.642E+02	0.126E+02	0.184E+06	0.274E-01	0.117E-01	0.482E+04
1032	0.000E+00	-0.103E+04	0.642E+02	0.126E+02	0.184E+06	0.274E-01	0.000E+00	0.000E+00
1033	0.142E+02	0.407E+03	0.642E+02	0.125E+02	0.171E+06	0.273E-01	0.176E+00	0.726E+05
1034	0.128E+04	0.542E-07	0.782E-04	0.178E-01	0.635E+02	0.516E-05	0.286E-14	0.128E-08
1035	0.958E+04	0.407E-06	0.782E-04	0.178E-01	0.636E+02	0.515E-05	0.215E-13	0.960E-08
1036	0.464E+04	0.197E-06	0.782E-04	0.371E-01	0.918E+02	0.108E-04	0.104E-13	0.465E-08
1037	0.193E+05	0.755E-06	0.750E-04	0.475E-01	0.102E+03	0.137E-04	0.382E-13	0.171E-07
1038	0.239E+05	0.934E-06	0.750E-04	0.449E-01	0.106E+03	0.134E-04	0.474E-13	0.200E-07
1039	0.177E+14	0.691E+03	0.750E-04	0.213E+04	0.232E+05	0.637E+00	0.350E-04	0.147E+02
1040	0.416E+06	0.179E-04	0.786E-04	0.529E+00	0.112E+03	0.158E-03	0.107E-10	0.451E-05
1046	0.646E+08	0.303E-02	0.822E-04	0.151E+02	0.603E+03	0.448E-02	0.190E-08	0.809E-03
1041	0.349E+06	0.244E-07	0.317E-05	0.201E-02	0.430E+01	0.581E-06	0.524E-16	0.235E-10
1042	0.159E+07	0.111E-06	0.316E-05	0.200E-02	0.428E+01	0.580E-06	0.236E-15	0.106E-09
1043	0.100E+17	0.691E+03	0.315E-05	0.150E-02	0.370E+01	0.434E-06	0.147E-05	0.659E+00
1044	0.502E+07	0.125E-05	0.599E-05	0.427E-01	0.817E+01	0.124E-04	0.572E-13	0.256E-07
1045	0.204E+07	0.430E-05	0.884E-05	0.295E+00	0.261E+02	0.856E-04	0.744E-13	0.332E-07
1047	0.188E+06	0.108E-04	0.910E-04	0.650E+00	0.124E+03	0.188E-03	0.751E-11	0.336E-05
1048	0.417E+05	0.240E-05	0.910E-04	0.562E+00	0.115E+03	0.163E-03	0.166E-11	0.746E-06
1049	0.282E+06	0.171E-04	0.935E-04	0.669E+00	0.127E+03	0.194E-03	0.122E-10	0.547E-05
1050	0.345E+05	0.221E-05	0.959E-04	0.418E+00	0.101E+03	0.121E-03	0.161E-11	0.726E-06
1051	0.429E+06	0.297E-04	0.999E-04	0.718E+00	0.135E+03	0.207E-03	0.226E-10	0.102E-04
1052	0.672E+05	0.502E-05	0.104E-03	0.748E+00	0.140E+03	0.216E-03	0.397E-11	0.180E-05
1055	0.000E+00	0.000E+00	0.138E+03	0.690E-01	0.208E+06	0.105E-03	0.000E+00	0.000E+00
1056	0.239E+00	0.319E+02	0.139E+03	0.195E+02	0.351E+07	0.298E-01	0.716E-01	0.889E+04
1057	0.000E+00	-0.878E+03	0.139E+03	0.195E+02	0.352E+07	0.298E-01	0.000E+00	0.000E+00
1058	0.200E+01	0.266E+03	0.139E+03	0.194E+02	0.339E+07	0.296E-01	0.585E+00	0.737E+05
1059	0.687E+02	0.778E-01	0.404E+00	0.927E+02	0.326E+06	0.267E-01	0.212E-04	0.957E+01

1060	0.106E+03	0.120E+00	0.404E+00	0.927E+02	0.327E+06	0.267E-01	0.327E-04	0.148E+02
1061	0.468E+04	0.530E+01	0.404E+00	0.193E+03	0.472E+06	0.558E-01	0.145E-02	0.652E+03
1062	0.713E+04	0.809E+01	0.404E+00	0.933E+02	0.327E+06	0.269E-01	0.222E-02	0.100E+04
1063	0.847E+05	0.961E+02	0.404E+00	0.567E+03	0.801E+06	0.164E+00	0.267E-01	0.120E+05
1064	0.278E+05	0.315E+02	0.404E+00	0.650E+03	0.802E+06	0.187E+00	0.100E-01	0.452E+04
1053	0.000E+00	0.000E+00	0.104E-03	0.506E-01	0.364E+02	0.146E-04	0.000E+00	0.000E+00
1054	0.151E+02	0.113E-08	0.104E-03	0.952E-02	0.158E+02	0.274E-05	0.894E-15	0.406E-09

NUMBER OF PRESSURIZATION SYSTEMS = 2

NODUL	NODPRP	QULPRP	QULWAL	QCOND	TNKTM	VOLPROP	VOLULG
		BTU/Sec	BTU/Sec	BTU/Sec	R	Ft^3	Ft^3
29	31	0.0709	0.4474	0.0005	529.7980	210.3289	89.6826
54	56	2.7834	23.1030	0.0298	168.7120	358.6981	141.3019

****

TIME OF ANALYSIS WAS 713.750000000000 SECS

****

APPENDIX T—INPUT AND OUTPUT DATA FILES FROM EXAMPLE 13

Steady State & Transient Conduction Through a Circular Rod, with Convection

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```
GFSSP VERSION
    604
GFSSP INSTALLATION PATH

ANALYST
Alok Majumdar
INPUT DATA FILE NAME
Ex13.dat
OUTPUT FILE NAME
Ex13.out
TITLE
Steady State & Transient Conduction Through a Circular Rod, With Convection
USETUP
F
DENCON        GRAVITY       ENERGY        MIXTURE       THRUST        STEADY        TRANSV        SAVER
F             F             T             F             F             T             F             F
HEX           HCOEF         REACTING      INERTIA       CONDX         ADDPROP       PRINTI        ROTATION
F             F             F             F             F             F             T             F
BUOYANCY      HRATE         INVAL         MSORCE        MOVBND        TPA           VARGEO        TVM
F             T             F             F             F             F             F             F
SHEAR         PRNTIN        PRNTADD       OPVALVE       TRANSQ        CONJUG        RADIAT        WINPLOT
F             T             T             F             F             T             F             T
PRESS         INSUC         VARROT        CYCLIC        CHKVALS       WINFILE       DALTON        NOSTATS
F             F             F             F             F             F             F             F
NORMAL        SIMUL         SECONDL       NRSOLVT       IBDF          NOPLT         PRESREG       FLOWREG
F             T             F             F             1             T             0             0
TRANS_MOM     USERVARS      PSMG          ISOLVE        PLOTADD       SIUNITS       TECPLOT       MDGEN
F             F             F             1             F             F             F             F
NUM_USER_VARS IFR_MIX       PRINTD        SATTABL       MSORIN        PRELVLV       LAMINAR       HSTAG
1             1             F             F             F             F             T             T
NNODES        NINT          NBR           NF
 4            2            3             1
RELAXK        RELAXD        RELAXH        CC            NITER         RELAXNR       RELAXHC       RELAXTS
 1              0.5           1             0.0001         500 1              1               1
NFLUID(I),  I = 1, NF
 11
NODE          INDEX     DESCRIPTION
 11              2       " Node 11"
 12              1       " Node 12"
 13              1       " Node 13"
 14              2       " Node 14"
 NODE   PRES (PSI)   TEMP(DEGF)   MASS SOURC    HEAT SOURC    THRST AREA    CONCENTRATION
 11     50              70            0                 0                  0
 12     14.7            60            0                 0                  0
 13     14.7            60            0                 0                  0
 14     45              70            0                 0                  0
INODE         NUMBR         NAMEBR
```

```
 12            2            1112   1213
 13            2            1213   1314
BRANCH   UPNODE    DNNODE    OPTION    DESCRIPTION
1112       11        12         1       "Pipe 1112"
1213       12        13         1       "Pipe 1213"
1314       13        14         1       "Pipe 1314"
BRANCH        OPTION -1     LENGTH        DIA           EPSD          ANGLE         AREA
 1112                       0.1               1.73             0                 0                 2.3506161778
BRANCH        OPTION -1     LENGTH        DIA           EPSD          ANGLE         AREA
 1213                       12                1.73             0                 0                 2.3506161778
BRANCH        OPTION -1     LENGTH        DIA           EPSD          ANGLE         AREA
 1314                       12                1.73             0                 0                 2.3506161778
NSOLID   NAMB   NSSC   NSFC   NSAC   NSSR
  8       2      7      8      2      0
NODESL  MATRL    SMASS         TS              HtSrc    NUMSS  NUMSF  NUMSA  NUMSSR  DESCRIPTION
 2        41     1.0000000     70.0000000    0.0000000        1      1      1       0     "S Node 2"
NAMESS
   23
NAMESF
   122
NAMESA
   12
 3        41     1.0000000     70.0000000    0.0000000        2      1      0       0     "S Node 3"
NAMESS
   23   34
NAMESF
   123
 4        41     1.0000000     70.0000000    0.0000000        2      1      0       0     "S Node 4"
NAMESS
   34   45
NAMESF
   124
 5        41     1.0000000     70.0000000    0.0000000        2      1      0       0     "S Node 5"
NAMESS
   45   56
NAMESF
   125
 6        41     1.0000000     70.0000000    0.0000000        2      1      0       0     "S Node 6"
NAMESS
   56   67
NAMESF
   136
 7        41     1.0000000     70.0000000    0.0000000        2      1      0       0     "S Node 7"
NAMESS
   67   78
NAMESF
   137
```

```
 8        41     1.0000000     70.0000000    0.0000000         2      1      0       0     "S Node 8"
NAMESS
   78   89
NAMESF
   138
 9        41     1.0000000     70.0000000    0.0000000         1      1      1       0     "S Node 9"
NAMESS
   89
NAMESF
   139
NAMESA
   910
NODEAM  TAMB        DESCRIPTION
 1      32.00000      "A Node 1"    0
 10     212.00000     "A Node 10"    0
ICONSS  ICNSI  ICNSJ  ARCSIJ     DISTSIJ    DESCRIPTION
 23     2      3     3.14159     3.00000     "Conductor 23"
 34     3      4     3.14159     3.00000     "Conductor 34"
 45     4      5     3.14159     3.00000     "Conductor 45"
 56     5      6     3.14159     3.00000     "Conductor 56"
 67     6      7     3.14159     3.00000     "Conductor 67"
 78     7      8     3.14159     3.00000     "Conductor 78"
 89     8      9     3.14159     3.00000     "Conductor 89"
ICONSF  ICS  ICF   MODEL   ARSF         HCSF     RADSF    EMSFS        EMSFF     DESCRIPTION
 122    2      12    0  1.88500e+01  3.17000e-04   F   0.00000e+00  0.00000e+00 "Convection 122"
 123    3      12    0  1.88500e+01  3.17000e-04   F   0.00000e+00  0.00000e+00 "Convection 123"
 124    4      12    0  1.88500e+01  3.17000e-04   F   0.00000e+00  0.00000e+00 "Convection 124"
 125    5      12    0  1.88500e+01  3.17000e-04   F   0.00000e+00  0.00000e+00 "Convection 125"
 136    6      13    0  1.88500e+01  3.17000e-04   F   0.00000e+00  0.00000e+00 "Convection 136"
 137    7      13    0  1.88500e+01  3.17000e-04   F   0.00000e+00  0.00000e+00 "Convection 137"
 138    8      13    0  1.88500e+01  3.17000e-04   F   0.00000e+00  0.00000e+00 "Convection 138"
 139    9      13    0  1.88500e+01  3.17000e-04   F   0.00000e+00  0.00000e+00 "Convection 139"
ICONSA  ICSAS  ICSAA  ARSA          HCSA      RADSA   EMSAS        EMSAA     DESCRIPTION
 12     2      1     3.14159e+00  2.00000e-02   F   0.00000e+00  0.00000e+00 "Convection 12"
 910    9      10    3.14159e+00  2.00000e-02   F   0.00000e+00  0.00000e+00 "Convection 910"
```

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EXAMPLE 13 PROPERTY FILES

USER1CP.PRP

```
2
0       0.1981
1000    0.1981
```

USER1K.PRP

```
2
0       0.002611
1000    0.002611
```

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```
 **************************************************
            G F S S P (Version 604)
    Generalized Fluid System Simulation Program
                 March 2012

   Developed by NASA/Marshall Space Flight Center
   Copyright (C) by Marshall Space Flight Center

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

  RUN DATE:09/12/2012 15:25

TITLE     :Steady State & Transient Conduction Through a Circular Rod, With Convection
ANALYST   :Alok Majumdar
FILEIN    :C:\Program Files (x86)\GFSSP604\TestInstalledExamples\EX13\Ex13.dat
FILEOUT   :Ex13.out

                    OPTION VARIABLES

ADDPROP   BUOYANCY  CONDX     CONJUG    CYCLIC    DALTON    DENCON    ENERGY
F         F         F         T         F         F         F         T
FLOWREG   GRAVITY   HCOEF     HEX       HRATE     IFRMIX    INERTIA   INSUC
0         F         F         F         T         1         F         F
INVAL     MIXTURE   MOVBND    MSORCE    NORMAL    NRSOLVT   OPVALVE   PLOTADD
F         F         F         F         F         F         F         F
PRESREG   PRESS     PRINTI    PRNTADD   PRNTIN    RADIATION REACTING  ROTATION
0         F         T         T         T         F         F         F
SAVER     SECONDL   SHEAR     SIMULA    SIUNITS   STEADY    THRUST    TPA
F         F         F         T         F         T         F         F
TRANS_MOM TRANSQ    TRANSV    TVM       TWOD      USRVAR    VARGEO    VARROT
F         F         F         F         F         F         F         F
RLFVLV
F

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

FLUIDS:  H2O
```

```
BOUNDARY NODES
   NODE        P           T         RHO                     AREA
             (PSI)        (F)     (LBM/FT^3)                 (IN^2)
   11    0.5000E+02  0.7000E+02  0.6231E+02  0.0000E+00
   14    0.4500E+02  0.7000E+02  0.6231E+02  0.0000E+00

 INPUT SPECIFICATIONS FOR INTERNAL NODES
NODE       AREA         MASS         HEAT
          (IN^2)       (LBM/S)      (BTU/S)
   12    0.0000E+00  0.0000E+00  0.0000E+00
   13    0.0000E+00  0.0000E+00  0.0000E+00

BRANCH      UPNODE    DNNODE    OPTION
   1112        11        12         1
   1213        12        13         1
   1314        13        14         1
BRANCH  OPTION -1:   LENGTH      DIA        EPSD       ANGLE        AREA
   1112            0.100E+00   0.173E+01   0.000E+00   0.000E+00   0.235E+01
BRANCH  OPTION -1:   LENGTH      DIA        EPSD       ANGLE        AREA
   1213            0.120E+02   0.173E+01   0.000E+00   0.000E+00   0.235E+01
BRANCH  OPTION -1:   LENGTH      DIA        EPSD       ANGLE        AREA
   1314            0.120E+02   0.173E+01   0.000E+00   0.000E+00   0.235E+01

INITIAL GUESS FOR INTERNAL NODES

   NODE    P(PSI)   TF(F)      Z(COMP)        RHO       QUALITY
                                           (LBM/FT^3)
   12    0.1470E+02  0.6000E+02  0.7616E-03  0.6237E+02  0.0000E+00
   13    0.1470E+02  0.6000E+02  0.7616E-03  0.6237E+02  0.0000E+00

 TRIAL SOLUTION
  BRANCH    DELP(PSI)   FLOWRATE(LBM/SEC)
   1112         0.0000     0.0100
   1213         0.0000     0.0100
   1314         0.0000     0.0100


 CONJUGATE HEAT TRANSFER
 NSOLIDX =    8
 NAMB    =    2
 NSSC    =    7
 NSFC    =    8
 NSAC    =    2
 NSSR    =    0
NODESL  MATRL    SMASS        TS          NUMSS  NUMSF  NUMSA
     2    41      1.0000     70.0000          1     1     1
```

```
 NAMESS
    23
 NAMESF
   122
 NAMESA
    12
NODESL  MATRL    SMASS        TS          NUMSS  NUMSF  NUMSA
     3    41      1.0000     70.0000          2      1      0
 NAMESS
    23    34
 NAMESF
   123
NODESL  MATRL    SMASS        TS          NUMSS  NUMSF  NUMSA
     4    41      1.0000     70.0000          2      1      0
 NAMESS
    34    45
 NAMESF
   124
NODESL  MATRL    SMASS        TS          NUMSS  NUMSF  NUMSA
     5    41      1.0000     70.0000          2      1      0
 NAMESS
    45    56
 NAMESF
   125
NODESL  MATRL    SMASS        TS          NUMSS  NUMSF  NUMSA
     6    41      1.0000     70.0000          2      1      0
 NAMESS
    56    67
 NAMESF
   136
NODESL  MATRL    SMASS        TS          NUMSS  NUMSF  NUMSA
     7    41      1.0000     70.0000          2      1      0
 NAMESS
    67    78
 NAMESF
   137
NODESL  MATRL    SMASS        TS          NUMSS  NUMSF  NUMSA
     8    41      1.0000     70.0000          2      1      0
 NAMESS
    78    89
 NAMESF
   138
NODESL  MATRL    SMASS        TS          NUMSS  NUMSF  NUMSA
     9    41      1.0000     70.0000          1      1      1
 NAMESS
    89
 NAMESF
```

```
   139
 NAMESA
   910
NODEAM  TAMB
   1        32.0000
  10       212.0000
ICONSS    ICNSI  ICNSJ    ARCSIJ      DISTSIJ
      23     2     3      3.1416      3.0000
      34     3     4      3.1416      3.0000
      45     4     5      3.1416      3.0000
      56     5     6      3.1416      3.0000
      67     6     7      3.1416      3.0000
      78     7     8      3.1416      3.0000
      89     8     9      3.1416      3.0000
ICONSF    ICS   ICF      ARSF       EMSFS       EMSFF
   122     2    12     18.8500      0.0000      0.0000
   123     3    12     18.8500      0.0000      0.0000
   124     4    12     18.8500      0.0000      0.0000
   125     5    12     18.8500      0.0000      0.0000
   136     6    13     18.8500      0.0000      0.0000
   137     7    13     18.8500      0.0000      0.0000
   138     8    13     18.8500      0.0000      0.0000
   139     9    13     18.8500      0.0000      0.0000
ICONSA  ICSAS  ICSAA  ARSA      HCSA       EMSAS       EMSAA
      12     2     1  0.3142E+01  0.2000E-01  0.0000E+00  0.0000E+00
     910     9    10  0.3142E+01  0.2000E-01  0.0000E+00  0.0000E+00

 SOLUTION
 INTERNAL NODES
  NODE     P(PSI)      TF(F)        Z           RHO         EM(LBM)     QUALITY
                                               (LBM/FT^3)
    12    0.4998E+02  0.7000E+02  0.2543E-02  0.6231E+02  0.0000E+00  0.0000E+00
    13    0.4749E+02  0.7001E+02  0.2416E-02  0.6231E+02  0.0000E+00  0.0000E+00

    NODE       H          ENTROPY     EMU       COND        CP          GAMA
            BTU/LB       BTU/LB-R  LBM/FT-SEC  BTU/FT-S-R  BTU/LB-R

    12    0.3823E+02  0.5555E-01  0.6557E-03  0.9663E-04  0.9998E+00  0.1007E+01
    13    0.3823E+02  0.5555E-01  0.6557E-03  0.9663E-04  0.9998E+00  0.1007E+01

 BRANCHES
BRANCH       KFACTOR       DELP        FLOW RATE   VELOCITY    REYN. NO.   MACH NO.   ENTROPY GEN.   LOST WORK
      (LBF-S^2/(LBM-FT)^2)  (PSI)       (LBM/SEC)     (FT/SEC)                                BTU/(R-SEC)   LBF-FT/SEC
    1112     0.639E-03     0.207E-01   0.684E+02     0.672E+02   0.921E+06   0.554E-01   0.795E-05   0.328E+01
    1213     0.767E-01     0.249E+01   0.684E+02     0.672E+02   0.921E+06   0.554E-01   0.955E-03   0.393E+03
    1314     0.767E-01     0.249E+01   0.684E+02     0.673E+02   0.921E+06   0.555E-01   0.955E-03   0.393E+03
```

SOLID NODES

NODESL	CPSLD	TS
	BTU/LB F	F
2	0.000E+00	0.423E+02
3	0.000E+00	0.569E+02
4	0.000E+00	0.691E+02
5	0.000E+00	0.812E+02
6	0.000E+00	0.954E+02
7	0.000E+00	0.114E+03
8	0.000E+00	0.141E+03
9	0.000E+00	0.181E+03

SOLID TO SOLID CONDUCTOR

ICONSS	CONDKIJ	QDOTSS
	BTU/S FT F	BTU/S
23	0.261E-02	-0.333E-02
34	0.261E-02	-0.279E-02
45	0.261E-02	-0.276E-02
56	0.261E-02	-0.322E-02
67	0.261E-02	-0.428E-02
78	0.261E-02	-0.611E-02
89	0.261E-02	-0.906E-02

SOLID TO FLUID CONDUCTOR

ICONSF	QDOTSF	HCSF	HCSFR
	BTU/S	BTU/S FT**2 F	
122	-0.115E-02	0.317E-03	0.000E+00
123	-0.544E-03	0.317E-03	0.000E+00
124	-0.356E-04	0.317E-03	0.000E+00
125	0.466E-03	0.317E-03	0.000E+00
136	0.105E-02	0.317E-03	0.000E+00
137	0.183E-02	0.317E-03	0.000E+00
138	0.294E-02	0.317E-03	0.000E+00
139	0.459E-02	0.317E-03	0.000E+00

SOLID TO AMBIENT CONDUCTOR

ICONSA	QDOTSA	HCSA	HCSAR
	BTU/S	BTU/S FT**2 F	BTU/S FT**2 F
12	0.448E-02	0.200E-01	0.000E+00
910	-0.136E-01	0.200E-01	0.000E+00

SOLUTION SATISFIED CONVERGENCE CRITERION OF 0.100E-03 IN 10 ITERATIONS
TAU = 100000000.000000 ISTEP = 1 DTAU =
100000000.000000

****

TIME OF ANALYSIS WAS 1.562500000000000E-002 SECS

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APPENDIX U—INPUT AND OUTPUT DATA FILES FROM EXAMPLE 14

Liquid Hydrogen Transfer Line Chilldown With Heat Transfer

Contents

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```
GFSSP VERSION
    605
GFSSP INSTALLATION PATH

ANALYST
Todd Steadman
INPUT DATA FILE NAME
Ex14.dat
OUTPUT FILE NAME
Ex14.out
TITLE
Liquid Hydrogen Transfer Line Chilldown with Heat Transfer (30 Nodes)
USETUP
F
DENCON         GRAVITY       ENERGY       MIXTURE       THRUST       STEADY        TRANSV       SAVER
F              F             T            F             F            F             T            F
HEX            HCOEF         REACTING     INERTIA       CONDX        ADDPROP       PRINTI       ROTATION
F              F             F            F             F            F             F            F
BUOYANCY       HRATE         INVAL        MSORCE        MOVBND       TPA           VARGEO       TVM
F              T             F            F             F            F             F            F
SHEAR          PRNTIN        PRNTADD      OPVALVE       TRANSQ       CONJUG        RADIAT       WINPLOT
F              F             F            T             F            T             F            T
PRESS          INSUC         VARROT       CYCLIC        CHKVALS      WINFILE       DALTON       NOSTATS
F              F             F            F             F            F             F            T
NORMAL         SIMUL         SECONDL      NRSOLVT       IBDF         NOPLT         PRESREG      FLOWREG
F              T             F            F             1            T             0            0
TRANS_MOM      USERVARS      PSMG         ISOLVE        PLOTADD      SIUNITS       TECPLOT      MDGEN
T              F             F            1             F            F             F            F
NUM_USER_VARS  IFR_MIX       PRINTD       SATTABL       MSORIN       PRELVLV       LAMINAR      HSTAG
1              1             F            F             F            F             T            T
DFLI
T
NNODES      NINT     NBR      NF
 33         31       32       1
RELAXK      RELAXD   RELAXH   CC        NITER     RELAXNR   RELAXHC   RELAXTS
 0.5        0.5      0.5      0.0001    500 1     1         1
DTAU        TIMEF    TIMEL    NPSTEP    NPWSTEP   WPLSTEP   WPLBUFF
 0.005      0        80       200       20        50        1.1
NFLUID(I),  I = 1, NF
 10
NODE     INDEX    DESCRIPTION
 1       2        "Node 1"
 2       1        " "
 3       1        " "
 4       1        " "
 5       1        " "
 6       1        " "
 7       1        " "
 8       1        " "
 9       1        " "
 10      1        " "
 11      1        " "
 12      1        " "
 13      1        " "
 14      1        " "
```

```
 15      1        " "
 16      1        " "
 17      1        " "
 18      1        " "
 19      1        " "
 20      1        " "
 21      1        " "
 22      1        " "
 23      1        " "
 24      1        "Node 24"
 25      1        " "
 26      1        " "
 27      1        " "
 28      1        " "
 29      1        " "
 30      1        " "
 31      1        " "
 32      1        " "
 33      2        "Node 33"

NODE   PRES (PSI)   TEMP(DEGF)   MASS SOURC   HEAT SOURC   THRST AREA   NODE-VOLUME   CONCENTRATION
 2     12.05        44.334                0              0            0             0
 3     12.05        44.334                0              0            0             0
 4     12.05        44.334                0              0            0             0
 5     12.05        44.334                0              0            0             0
 6     12.05        44.334                0              0            0             0
 7     12.05        44.334                0              0            0             0
 8     12.05        44.334                0              0            0             0
 9     12.05        44.334                0              0            0             0
 10    12.05        44.334                0              0            0             0
 11    12.05        44.334                0              0            0             0
 12    12.05        44.334                0              0            0             0
 13    12.05        44.334                0              0            0             0
 14    12.05        44.334                0              0            0             0
 15    12.05        44.334                0              0            0             0
 16    12.05        44.334                0              0            0             0
 17    12.05        44.334                0              0            0             0
 18    12.05        44.334                0              0            0             0
 19    12.05        44.334                0              0            0             0
 20    12.05        44.334                0              0            0             0
 21    12.05        44.334                0              0            0             0
 22    12.05        44.334                0              0            0             0
 23    12.05        44.334                0              0            0             0
 24    12.05        44.334                0              0            0             0
 25    12.05        44.334                0              0            0             0
 26    12.05        44.334                0              0            0             0
 27    12.05        44.334                0              0            0             0
 28    12.05        44.334                0              0            0             0
 29    12.05        44.334                0              0            0             0
 30    12.05        44.334                0              0            0             0
 31    12.05        44.334                0              0            0             0
 32    12.05        44.334                0              0            0             0
 EX14Hist1.dat
 EX14Hist33.dat
```

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
16	2	1516	1617
17	2	1617	1718
18	2	1718	1819
19	2	1819	1920
20	2	1920	2021
21	2	2021	2122
22	2	2122	2223
23	2	2223	2324
24	2	2324	2425
25	2	2425	2526
26	2	2526	2627
27	2	2627	2728
28	2	2728	2829
29	2	2829	2930
30	2	2930	3031
31	2	3031	3132
32	2	3132	3233

BRANCH	UPNODE	DNNODE	OPTION	DESCRIPTION
12	1	2	2	" "
23	2	3	1	"Pipe 23"
34	3	4	1	" "
45	4	5	1	" "
56	5	6	1	" "
67	6	7	1	" "
78	7	8	1	" "
89	8	9	1	" "
910	9	10	1	" "
1011	10	11	1	" "
1112	11	12	1	" "
1213	12	13	1	" "
1314	13	14	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	" "
2021	20	21	1	" "
2122	21	22	1	" "

```
 2223     22        23        1        "     "
 2324     23        24        1        "     "
 2425     24        25        1        "     "
 2526     25        26        1        "     "
 2627     26        27        1        "     "
 2728     27        28        1        "     "
 2829     28        29        1        "     "
 2930     29        30        1        "     "
 3031     30        31        1        "     "
 3132     31        32        1        "     "
 3233     32        33        2        "     "
BRANCH   OPTION -2   LOW COEFF   AREA
 12                  0.6         0.3068
BRANCH   OPTION -1   LENGTH      DIA       EPSD    ANGLE    AREA
 23                  80          0.625     0       0        0.30679589844
BRANCH   OPTION -1   LENGTH      DIA       EPSD    ANGLE    AREA
 34                  80          0.625     0       0        0.30679589844
BRANCH   OPTION -1   LENGTH      DIA       EPSD    ANGLE    AREA
 45                  80          0.625     0       0        0.30679589844
BRANCH   OPTION -1   LENGTH      DIA       EPSD    ANGLE    AREA
 56                  80          0.625     0       0        0.30679589844
BRANCH   OPTION -1   LENGTH      DIA       EPSD    ANGLE    AREA
 67                  80          0.625     0       0        0.30679589844
BRANCH   OPTION -1   LENGTH      DIA       EPSD    ANGLE    AREA
 78                  80          0.625     0       0        0.30679589844
BRANCH   OPTION -1   LENGTH      DIA       EPSD    ANGLE    AREA
 89                  80          0.625     0       0        0.30679589844
BRANCH   OPTION -1   LENGTH      DIA       EPSD    ANGLE    AREA
 910                 80          0.625     0       0        0.30679589844
BRANCH   OPTION -1   LENGTH      DIA       EPSD    ANGLE    AREA
 1011                80          0.625     0       0        0.30679589844
BRANCH   OPTION -1   LENGTH      DIA       EPSD    ANGLE    AREA
 1112                80          0.625     0       0        0.30679589844
BRANCH   OPTION -1   LENGTH      DIA       EPSD    ANGLE    AREA
 1213                80          0.625     0       0        0.30679589844
BRANCH   OPTION -1   LENGTH      DIA       EPSD    ANGLE    AREA
 1314                80          0.625     0       0        0.30679589844
BRANCH   OPTION -1   LENGTH      DIA       EPSD    ANGLE    AREA
 1415                80          0.625     0       0        0.30679589844
BRANCH   OPTION -1   LENGTH      DIA       EPSD    ANGLE    AREA
 1516                80          0.625     0       0        0.30679589844
BRANCH   OPTION -1   LENGTH      DIA       EPSD    ANGLE    AREA
 1617                80          0.625     0       0        0.30679589844
BRANCH   OPTION -1   LENGTH      DIA       EPSD    ANGLE    AREA
 1718                80          0.625     0       0        0.30679589844
BRANCH   OPTION -1   LENGTH      DIA       EPSD    ANGLE    AREA
 1819                80          0.625     0       0        0.30679589844
BRANCH   OPTION -1   LENGTH      DIA       EPSD    ANGLE    AREA
 1920                80          0.625     0       0        0.30679589844
BRANCH   OPTION -1   LENGTH      DIA       EPSD    ANGLE    AREA
 2021                80          0.625     0       0        0.30679589844
BRANCH   OPTION -1   LENGTH      DIA       EPSD    ANGLE    AREA
 2122                80          0.625     0       0        0.30679589844
BRANCH   OPTION -1   LENGTH      DIA       EPSD    ANGLE    AREA
 2223                80          0.625     0       0        0.30679589844
```

```
BRANCH   OPTION -1   LENGTH      DIA       EPSD    ANGLE    AREA
 2324                80          0.625     0       0        0.30679589844
BRANCH   OPTION -1   LENGTH      DIA       EPSD    ANGLE    AREA
 2425                80          0.625     0       0        0.30679589844
BRANCH   OPTION -1   LENGTH      DIA       EPSD    ANGLE    AREA
 2526                80          0.625     0       0        0.30679589844
BRANCH   OPTION -1   LENGTH      DIA       EPSD    ANGLE    AREA
 2627                80          0.625     0       0        0.30679589844
BRANCH   OPTION -1   LENGTH      DIA       EPSD    ANGLE    AREA
 2728                80          0.625     0       0        0.30679589844
BRANCH   OPTION -1   LENGTH      DIA       EPSD    ANGLE    AREA
 2829                80          0.625     0       0        0.30679589844
BRANCH   OPTION -1   LENGTH      DIA       EPSD    ANGLE    AREA
 2930                80          0.625     0       0        0.30679589844
BRANCH   OPTION -1   LENGTH      DIA       EPSD    ANGLE    AREA
 3031                80          0.625     0       0        0.30679589844
BRANCH   OPTION -1   LENGTH      DIA       EPSD    ANGLE    AREA
 3132                80          0.625     0       0        0.30679589844
BRANCH   OPTION -2   FLOW COEFF  AREA
 3233                1           0.3068
INITIAL FLOWRATES IN BRANCHES FOR UNSTEADY FLOW
 12    0.0001
 23    0.0001
 34    0.0001
 45    0.0001
 56    0.0001
 67    0.0001
 78    0.0001
 89    0.0001
 910   0.0001
 1011  0.0001
 1112  0.0001
 1213  0.0001
 1314  0.0001
 1415  0.0001
 1516  0.0001
 1617  0.0001
 1718  0.0001
 1819  0.0001
 1920  0.0001
 2021  0.0001
 2122  0.0001
 2223  0.0001
 2324  0.0001
 2425  0.0001
 2526  0.0001
 2627  0.0001
 2728  0.0001
 2829  0.0001
 2930  0.0001
 3031  0.0001
 3132  0.0001
 3233  0.0001
```

```
NUMBER OF CLOSING/OPENING VALVES IN THE CIRCUIT
 1
BRANCH
12
FILE NAME
vlv7c.dat

NSOLID    NAMB    NSSC         NSFC         NSAC          NSSR
 31       0       30           31           0             0
NODESL    MATRL   SMASS        TS           HtSrc         NUMSS   NUMSF   NUMSA   NUMSSR   DESCRIPTION
 34       12      1.7380000    44.3340000   0.0000000     1       1       0       0        "S Node 34"
NAMESS
 3435
NAMESF
 234
 35       12      3.4750000    44.3340000   0.0000000     2       1       0       0        "S Node 35"
NAMESS
 3435     3536
NAMESF
 335
 36       12      3.4750000    44.3340000   0.0000000     2       1       0       0        "S Node 36"
NAMESS
 3536     3637
NAMESF
 436
 37       12      3.4750000    44.3340000   0.0000000     2       1       0       0        "S Node 37"
NAMESS
 3637     3738
NAMESF
 537
 38       12      3.4750000    44.3340000   0.0000000     2       1       0       0        "S Node 38"
NAMESS
 3738     3839
NAMESF
 638
 39       12      3.4750000    44.3340000   0.0000000     2       1       0       0        "S Node 39"
NAMESS
 3839     3940
NAMESF
 739
 40       12      3.4750000    44.3340000   0.0000000     2       1       0       0        "S Node 40"
NAMESS
 3940     4041
NAMESF
 840
 41       12      3.4750000    44.3340000   0.0000000     2       1       0       0        "S Node 41"
NAMESS
 4041     4142
NAMESF
 941
 42       12      3.4750000    44.3340000   0.0000000     2       1       0       0        "S Node 42"
NAMESS
   4142   4243
```

```
NAMESF
 1042
 43       12     3.4750000     44.3340000    0.0000000         2      1      0       0     "S Node 43"
NAMESS
 4243     4344
NAMESF
 1143
 44       12     3.4750000     44.3340000    0.0000000         2      1      0       0     "S Node 44"
NAMESS
 4344     4445
NAMESF
 1244
 45       12     3.4750000     44.3340000    0.0000000         2      1      0       0     "S Node 45"
NAMESS
 4445     4546
NAMESF
 1345
 46       12     3.4750000     44.3340000    0.0000000         2      1      0       0     "S Node 46"
NAMESS
 4546     4647
NAMESF
   1446
 47       12     3.4750000     44.3340000    0.0000000         2      1      0       0     "S Node 47"
NAMESS
 4647     4748
NAMESF
   1547
 48       12     3.4750000     44.3340000    0.0000000         2      1      0       0     "S Node 48"
NAMESS
 4748     4849
NAMESF
 1648
 49       12     3.4750000     44.3340000    0.0000000         2      1      0       0     "S Node 49"
NAMESS
   4849   4950
NAMESF
   1749
 50       12     3.4750000     44.3340000    0.0000000         2      1      0       0     "S Node 50"
NAMESS
 4950     5051
NAMESF
 1850
 51       12     3.4750000     44.3340000    0.0000000         2      1      0       0     "S Node 51"
NAMESS
   5051   5152
NAMESF
 1951
 52       12     3.4750000     44.3340000    0.0000000         2      1      0       0     "S Node 52"
NAMESS
 5152     5253
NAMESF
 2052
 53       12     3.4750000     44.3340000    0.0000000         2      1      0       0     "S Node 53"
NAMESS
 5253     5354
```

```
NAMESF
 2153
 54       12     3.4750000     44.3340000    0.0000000         2      1      0       0     "S Node 54"
NAMESS
 5354     5455
NAMESF
 2254
 55       12     3.4750000     44.3340000    0.0000000         2      1      0       0     "S Node 55"
NAMESS
 5455     5556
NAMESF
 2355
 56       12     3.4750000     44.3340000    0.0000000         2      1      0       0     "S Node 56"
NAMESS
 5556     5657
NAMESF
 2456
 57       12     3.4750000     44.3340000    0.0000000         2      1      0       0     "S Node 57"
NAMESS
 5657     5758
NAMESF
 2557
 58       12     3.4750000     44.3340000    0.0000000         2      1      0       0     "S Node 58"
NAMESS
 5758     5859
NAMESF
 2658
 59       12     3.4750000     44.3340000    0.0000000         2      1      0       0     "S Node 59"
NAMESS
 5859     5960
NAMESF
 2759
 60       12     3.4750000     44.3340000    0.0000000         2      1      0       0     "S Node 60"
NAMESS
 5960     6061
NAMESF
 2860
 61       12     3.4750000     44.3340000    0.0000000         2      1      0       0     "S Node 61"
NAMESS
 6061     6162
NAMESF
 2961
 62       12     3.4750000     44.3340000    0.0000000         2      1      0       0     "S Node 62"
NAMESS
 6162     6263
NAMESF
 3062
 63       12     3.4750000     44.3340000    0.0000000         2      1      0       0     "S Node 63"
NAMESS
 6263     6364
NAMESF
 3163
 64       12     1.7380000     44.3340000    0.0000000         1      1      0       0     "S Node 64"
NAMESS
 6364
```

NAMESF
3264

ICONSS	ICNSI	ICNSJ	ARCSIJ	DISTSIJ	DESCRIPTION
3435	34	35	0.13500	80.00000	"Conductor 3435"
3536	35	36	0.13500	80.00000	"Conductor 3536"
3637	36	37	0.13500	80.00000	"Conductor 3637"
3738	37	38	0.13500	80.00000	"Conductor 3738"
3839	38	39	0.13500	80.00000	"Conductor 3839"
3940	39	40	0.13500	80.00000	"Conductor 3940"
4041	40	41	0.13500	80.00000	"Conductor 4041"
4142	41	42	0.13500	80.00000	"Conductor 4142"
4243	42	43	0.13500	80.00000	"Conductor 4243"
4344	43	44	0.13500	80.00000	"Conductor 4344"
4445	44	45	0.13500	80.00000	"Conductor 4445"
4546	45	46	0.13500	80.00000	"Conductor 4546"
4647	46	47	0.13500	80.00000	"Conductor 4647"
4748	47	48	0.13500	80.00000	"Conductor 4748"
4849	48	49	0.13500	80.00000	"Conductor 4849"
4950	49	50	0.13500	80.00000	"Conductor 4950"
5051	50	51	0.13500	80.00000	"Conductor 5051"
5152	51	52	0.13500	80.00000	"Conductor 5152"
5253	52	53	0.13500	80.00000	"Conductor 5253"
5354	53	54	0.13500	80.00000	"Conductor 5354"
5455	54	55	0.13500	80.00000	"Conductor 5455"
5556	55	56	0.13500	80.00000	"Conductor 5556"
5657	56	57	0.13500	80.00000	"Conductor 5657"
5758	57	58	0.13500	80.00000	"Conductor 5758"
5859	58	59	0.13500	80.00000	"Conductor 5859"
5960	59	60	0.13500	80.00000	"Conductor 5960"
6061	60	61	0.13500	80.00000	"Conductor 6061"
6162	61	62	0.13500	80.00000	"Conductor 6162"
6263	62	63	0.13500	80.00000	"Conductor 6263"
6364	63	64	0.13500	80.00000	"Conductor 6364"

ICONSF	ICS	ICF	MODEL	ARSF	HCSF	RADSF	EMSFS	EMSFF	DESCRIPTION
234	34	2	2	7.85400e+01	0.00000e+00	F	0.00000e+00	0.00000e+00	" "
335	35	3	2	1.57070e+02	0.00000e+00	F	0.00000e+00	0.00000e+00	" "
436	36	4	2	1.57070e+02	0.00000e+00	F	0.00000e+00	0.00000e+00	" "
537	37	5	2	1.57070e+02	0.00000e+00	F	0.00000e+00	0.00000e+00	" "
638	38	6	2	1.57070e+02	0.00000e+00	F	0.00000e+00	0.00000e+00	" "
739	39	7	2	1.57070e+02	0.00000e+00	F	0.00000e+00	0.00000e+00	" "
840	40	8	2	1.57070e+02	0.00000e+00	F	0.00000e+00	0.00000e+00	" "
941	41	9	2	1.57070e+02	0.00000e+00	F	0.00000e+00	0.00000e+00	" "
1042	42	10	2	1.57070e+02	0.00000e+00	F	0.00000e+00	0.00000e+00	" "
1143	43	11	2	1.57070e+02	0.00000e+00	F	0.00000e+00	0.00000e+00	" "
1244	44	12	2	1.57070e+02	0.00000e+00	F	0.00000e+00	0.00000e+00	" "
1345	45	13	2	1.57070e+02	0.00000e+00	F	0.00000e+00	0.00000e+00	" "
1446	46	14	2	1.57070e+02	0.00000e+00	F	0.00000e+00	0.00000e+00	" "
1547	47	15	2	1.57070e+02	0.00000e+00	F	0.00000e+00	0.00000e+00	" "
1648	48	16	2	1.57070e+02	0.00000e+00	F	0.00000e+00	0.00000e+00	" "
1749	49	17	2	1.57070e+02	0.00000e+00	F	0.00000e+00	0.00000e+00	" "
1850	50	18	2	1.57070e+02	0.00000e+00	F	0.00000e+00	0.00000e+00	" "
1951	51	19	2	1.57070e+02	0.00000e+00	F	0.00000e+00	0.00000e+00	" "

2052	52	20	2	1.57070e+02	0.00000e+00	F	0.00000e+00	0.00000e+00	"	"
2153	53	21	2	1.57070e+02	0.00000e+00	F	0.00000e+00	0.00000e+00	"	"
2254	54	22	2	1.57070e+02	0.00000e+00	F	0.00000e+00	0.00000e+00	"	"
2355	55	23	2	1.57070e+02	0.00000e+00	F	0.00000e+00	0.00000e+00	"	"
2456	56	24	2	1.57070e+02	0.00000e+00	F	0.00000e+00	0.00000e+00	"	"
2557	57	25	2	1.57070e+02	0.00000e+00	F	0.00000e+00	0.00000e+00	"	"
2658	58	26	2	1.57070e+02	0.00000e+00	F	0.00000e+00	0.00000e+00	"	"
2759	59	27	2	1.57070e+02	0.00000e+00	F	0.00000e+00	0.00000e+00	"	"
2860	60	28	2	1.57070e+02	0.00000e+00	F	0.00000e+00	0.00000e+00	"	"
2961	61	29	2	1.57070e+02	0.00000e+00	F	0.00000e+00	0.00000e+00	"	"
3062	62	30	2	1.57070e+02	0.00000e+00	F	0.00000e+00	0.00000e+00	"	"
3163	63	31	2	1.57070e+02	0.00000e+00	F	0.00000e+00	0.00000e+00	"	"
3264	64	32	2	7.85400e+01	0.00000e+00	F	0.00000e+00	0.00000e+00	"	"

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EXAMPLE 14 HISTORY FILES

EX14Hist1.DAT

```
 2
 0      74.97  -411.066  1.0000
 500.  74.97  -411.066  1.0000
```

EX14Hist33.DAT

```
 2
 0      12.05  70.000  1.00000
 500.  12.05  70.000  1.00000
```

Vlv7c.DAT

```
 0.00    1.E-16
 0.01    6.1355E-02
 0.02    0.1227
 0.03    0.1841
 0.04    0.2454
 0.05    0.3068
 1000    0.3068
```

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```
 ***************************************************
               G F S S P (Version 605)
        Generalized Fluid System Simulation Program
                      May 2014

       Developed by NASA/Marshall Space Flight Center
       Copyright (C) by Marshall Space Flight Center

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


   RUN DATE:06/25/2014 10:42

 TITLE     :Liquid Hydrogen Transfer Line Chilldown with Heat Transfer (30 Nodes)
 ANALYST   :Todd Steadman
 FILEIN    :C:\GFSSP605InstallTest\EXAMPLES\Ex14\Ex14.dat
 FILEOUT   :Ex14.out

OPTION VARIABLES
ADDPROP    BUOYANCY   CONDX    CONJUG    CYCLIC    DALTON     DENCON     ENERGY
 F          F          F        T         F         F          F          T
FLOWREG    GRAVITY    HCOEF    HEX       HRATE     IFRMIX     INERTIA    INSUC
 0          F          F        F         T         1          F          F
INVAL      MIXTURE    MOVBND   MSORCE    NORMAL    NRSOLVT    OPVALVE    PLOTADD
 F          F          F        F         F         F          T          F
PRESREG    PRESS      PRINTI   PRNTADD   PRNTIN    RADIATION  REACTING   ROTATION
 0          F          F        F         F         F          F          F
SAVER      SECONDL    SHEAR    SIMULA    SIUNITS   STEADY     THRUST     TPA
 F          F          F        T         F         F          F          F
TRANS_MOM  TRANSQ     TRANSV   TVM       TWOD      USRVAR     VARGEO     VARROT
 T          F          T        F         F         F          F          F
RLFVLV     DFLI
 F          T

NNOES   =  33
NINT    =  31
NBR     =  32
NF      =   1
NVAR    =  94
NHREF   =   2


FLUIDS:  H2

BOUNDARY NODES
NODE   P             T             RHO          AREA
       (PSI)         (F)           (LBM/FT^3)   (IN^2)
 1     7.4970E+01   -4.1107E+02   3.8133E+00   0.0000E+00
 33    1.2050E+01    7.0000E+01   4.2697E-03   0.0000E+00
```

CONJUGATE HEAT TRANSFER

```
 NSOLIDX =   31
 NAMB    =    0
 NSSC    =   30
 NSFC    =   31
 NSAC    =    0
 NSSR    =    0
```

ISTEP = 200 TAU = 0.10000E+01

BOUNDARY NODES

NODE	P(PSI)	TF(F)	Z(COMP)	RHO (LBM/FT^3)	QUALITY
1	7.4970E+01	-4.1107E+02	7.6001E-02	3.8133E+00	0.0000E+00
33	1.2050E+01	7.0000E+01	1.0011E+00	4.2697E-03	1.0000E+00

SOLUTION

INTERNAL NODES

NODE	P(PSI)	TF(F)	Z	RHO (LBM/FT^3)	EM(LBM)	QUALITY
2	8.8241E+01	-4.0365E+02	7.8587E-01	3.7661E-01	2.6746E-03	1.0000E+00
3	7.8060E+01	-2.3576E+02	1.0026E+00	6.5332E-02	9.2797E-04	1.0000E+00
4	7.3346E+01	-9.9163E+01	1.0041E+00	3.8071E-02	5.4074E-04	1.0000E+00
5	7.1244E+01	-2.0329E+01	1.0039E+00	3.0350E-02	4.3108E-04	1.0000E+00
6	7.0060E+01	1.2524E+01	1.0038E+00	2.7773E-02	3.9447E-04	1.0000E+00
7	6.9266E+01	2.7105E+01	1.0037E+00	2.6637E-02	3.7834E-04	1.0000E+00
8	6.8599E+01	3.4417E+01	1.0037E+00	2.5992E-02	3.6917E-04	1.0000E+00
9	6.7901E+01	3.8446E+01	1.0036E+00	2.5520E-02	3.6248E-04	1.0000E+00
10	6.7083E+01	4.0832E+01	1.0036E+00	2.5094E-02	3.5642E-04	1.0000E+00
11	6.6103E+01	4.2329E+01	1.0035E+00	2.4654E-02	3.5017E-04	1.0000E+00
12	6.4949E+01	4.3306E+01	1.0035E+00	2.4178E-02	3.4341E-04	1.0000E+00
13	6.3631E+01	4.3952E+01	1.0034E+00	2.3658E-02	3.3603E-04	1.0000E+00
14	6.2167E+01	4.4374E+01	1.0034E+00	2.3096E-02	3.2805E-04	1.0000E+00
15	6.0581E+01	4.4635E+01	1.0033E+00	2.2497E-02	3.1953E-04	1.0000E+00
16	5.8890E+01	4.4782E+01	1.0032E+00	2.1864E-02	3.1055E-04	1.0000E+00
17	5.7113E+01	4.4847E+01	1.0032E+00	2.1203E-02	3.0115E-04	1.0000E+00
18	5.5258E+01	4.4858E+01	1.0031E+00	2.0516E-02	2.9139E-04	1.0000E+00
19	5.3334E+01	4.4835E+01	1.0030E+00	1.9804E-02	2.8128E-04	1.0000E+00
20	5.1339E+01	4.4794E+01	1.0029E+00	1.9066E-02	2.7081E-04	1.0000E+00
21	4.9272E+01	4.4746E+01	1.0028E+00	1.8302E-02	2.5995E-04	1.0000E+00
22	4.7124E+01	4.4697E+01	1.0027E+00	1.7507E-02	2.4866E-04	1.0000E+00
23	4.4884E+01	4.4652E+01	1.0026E+00	1.6678E-02	2.3689E-04	1.0000E+00
24	4.2539E+01	4.4613E+01	1.0025E+00	1.5809E-02	2.2455E-04	1.0000E+00
25	4.0068E+01	4.4579E+01	1.0024E+00	1.4894E-02	2.1154E-04	1.0000E+00
26	3.7448E+01	4.4550E+01	1.0023E+00	1.3922E-02	1.9774E-04	1.0000E+00
27	3.4646E+01	4.4525E+01	1.0022E+00	1.2882E-02	1.8298E-04	1.0000E+00
28	3.1617E+01	4.4502E+01	1.0021E+00	1.1759E-02	1.6701E-04	1.0000E+00
29	2.8299E+01	4.4481E+01	1.0019E+00	1.0526E-02	1.4951E-04	1.0000E+00
30	2.4591E+01	4.4459E+01	1.0018E+00	9.1490E-03	1.2995E-04	1.0000E+00
31	2.0324E+01	4.4435E+01	1.0016E+00	7.5631E-03	1.0742E-04	1.0000E+00
32	1.5161E+01	4.4426E+01	1.0014E+00	5.6430E-03	4.0075E-05	1.0000E+00

BRANCHES

BRANCH	KFACTOR (LBF-S^2/ (LBM-FT)^2)	DELP (PSI)	FLOW RATE (LBM/SEC)	VELOCITY (FT/SEC)	REYN. NO.	MACH NO.	ENTROPY GEN. (BTU/(R-SEC))	LOST WORK (LBF-FT/SEC)
12	2.525E+04	-1.327E+01	-1.595E-01	-1.987E+02	3.199E+06	1.141E-01	6.243E-03	2.718E+02
23	1.189E+04	1.018E+01	1.096E-01	1.366E+02	2.199E+06	7.508E-02	9.542E-04	4.154E+01
34	9.707E+04	4.715E+00	3.981E-02	2.860E+02	2.993E+05	1.037E-01	5.383E-04	9.376E+01
45	1.977E+05	2.102E+00	2.300E-02	2.835E+02	1.253E+05	8.185E-02	2.251E-04	6.315E+01
56	2.637E+05	1.184E+00	1.952E-02	3.019E+02	9.299E+04	7.850E-02	1.891E-04	6.463E+01
67	2.913E+05	7.941E-01	1.949E-02	3.294E+02	8.842E+04	8.241E-02	2.114E-04	7.768E+01
78	3.017E+05	6.671E-01	2.055E-02	3.621E+02	9.129E+04	8.910E-02	2.594E-04	9.824E+01
89	3.056E+05	6.975E-01	2.193E-02	3.960E+02	9.646E+04	9.669E-02	3.226E-04	1.240E+02
910	3.077E+05	8.180E-01	2.331E-02	4.287E+02	1.020E+05	1.042E-01	3.941E-04	1.527E+02
1011	3.098E+05	9.809E-01	2.453E-02	4.587E+02	1.069E+05	1.112E-01	4.677E-04	1.821E+02
1112	3.129E+05	1.154E+00	2.550E-02	4.855E+02	1.110E+05	1.175E-01	5.391E-04	2.105E+02
1213	3.173E+05	1.318E+00	2.623E-02	5.093E+02	1.140E+05	1.231E-01	6.055E-04	2.370E+02
1314	3.231E+05	1.463E+00	2.674E-02	5.305E+02	1.161E+05	1.282E-01	6.663E-04	2.611E+02
1415	3.302E+05	1.587E+00	2.706E-02	5.499E+02	1.174E+05	1.328E-01	7.222E-04	2.832E+02
1516	3.385E+05	1.690E+00	2.724E-02	5.683E+02	1.182E+05	1.372E-01	7.750E-04	3.041E+02
1617	3.481E+05	1.778E+00	2.732E-02	5.864E+02	1.185E+05	1.416E-01	8.270E-04	3.246E+02
1718	3.590E+05	1.854E+00	2.733E-02	6.051E+02	1.185E+05	1.461E-01	8.806E-04	3.457E+02
1819	3.710E+05	1.925E+00	2.731E-02	6.249E+02	1.185E+05	1.509E-01	9.386E-04	3.685E+02
1920	3.845E+05	1.994E+00	2.728E-02	6.465E+02	1.183E+05	1.561E-01	1.004E-03	3.940E+02
2021	3.994E+05	2.067E+00	2.724E-02	6.705E+02	1.182E+05	1.619E-01	1.078E-03	4.233E+02
2122	4.162E+05	2.148E+00	2.720E-02	6.976E+02	1.180E+05	1.685E-01	1.166E-03	4.578E+02
2223	4.352E+05	2.239E+00	2.718E-02	7.286E+02	1.179E+05	1.759E-01	1.271E-03	4.989E+02
2324	4.569E+05	2.346E+00	2.716E-02	7.643E+02	1.179E+05	1.846E-01	1.399E-03	5.488E+02
2425	4.820E+05	2.471E+00	2.715E-02	8.061E+02	1.178E+05	1.947E-01	1.555E-03	6.102E+02
2526	5.116E+05	2.620E+00	2.715E-02	8.555E+02	1.178E+05	2.066E-01	1.752E-03	6.873E+02
2627	5.473E+05	2.802E+00	2.715E-02	9.153E+02	1.178E+05	2.211E-01	2.005E-03	7.867E+02
2728	5.915E+05	3.028E+00	2.715E-02	9.893E+02	1.179E+05	2.390E-01	2.343E-03	9.191E+02
2829	6.480E+05	3.318E+00	2.716E-02	1.084E+03	1.179E+05	2.619E-01	2.814E-03	1.104E+03
2930	7.238E+05	3.708E+00	2.716E-02	1.211E+03	1.179E+05	2.926E-01	3.513E-03	1.378E+03
3031	8.327E+05	4.267E+00	2.717E-02	1.394E+03	1.180E+05	3.367E-01	4.653E-03	1.825E+03
3132	1.007E+06	5.164E+00	2.717E-02	1.686E+03	1.180E+05	4.074E-01	6.812E-03	2.672E+03
3233	6.067E+05	3.111E+00	2.717E-02	2.260E+03	1.180E+05	5.460E-01	5.500E-03	2.157E+03

SOLID NODES

NODESL	CPSLD BTU/LB F	TS F
34	7.812E-02	-1.635E+02
35	8.735E-02	-2.282E+01
36	8.901E-02	1.012E+01
37	8.993E-02	2.833E+01
38	9.034E-02	3.684E+01
39	9.046E-02	4.125E+01
40	9.051E-02	4.328E+01
41	9.053E-02	4.418E+01
42	9.054E-02	4.456E+01
43	9.054E-02	4.471E+01
44	9.054E-02	4.476E+01
45	9.054E-02	4.477E+01
46	9.054E-02	4.476E+01
47	9.054E-02	4.474E+01
48	9.054E-02	4.473E+01

49	9.054E-02	4.471E+01
50	9.054E-02	4.469E+01
51	9.054E-02	4.468E+01
52	9.054E-02	4.466E+01
53	9.054E-02	4.464E+01
54	9.054E-02	4.462E+01
55	9.054E-02	4.461E+01
56	9.054E-02	4.459E+01
57	9.054E-02	4.457E+01
58	9.054E-02	4.455E+01
59	9.054E-02	4.453E+01
60	9.054E-02	4.451E+01
61	9.054E-02	4.448E+01
62	9.054E-02	4.446E+01
63	9.054E-02	4.442E+01
64	9.053E-02	4.440E+01

SOLID TO SOLID CONDUCTOR

ICONSS	CONDKIJ	QDOTSS
	BTU/S FT F	BTU/S
3435	6.936E-02	-1.372E-03
3536	6.642E-02	-3.077E-04
3637	6.571E-02	-1.682E-04
3738	6.534E-02	-7.820E-05
3839	6.519E-02	-4.045E-05
3940	6.515E-02	-1.854E-05
4041	6.513E-02	-8.240E-06
4142	6.512E-02	-3.510E-06
4243	6.511E-02	-1.388E-06
4344	6.511E-02	-4.624E-07
4445	6.511E-02	-7.236E-08
4546	6.511E-02	8.331E-08
4647	6.511E-02	1.401E-07
4748	6.511E-02	1.573E-07
4849	6.511E-02	1.600E-07
4950	6.511E-02	1.584E-07
5051	6.511E-02	1.563E-07
5152	6.511E-02	1.553E-07
5253	6.511E-02	1.558E-07
5354	6.511E-02	1.580E-07
5455	6.511E-02	1.616E-07
5556	6.511E-02	1.668E-07
5657	6.511E-02	1.736E-07
5758	6.511E-02	1.820E-07
5859	6.511E-02	1.925E-07
5960	6.511E-02	2.053E-07
6061	6.512E-02	2.221E-07
6162	6.512E-02	2.466E-07
6263	6.512E-02	2.768E-07
6364	6.512E-02	2.084E-07

SOLID TO FLUID CONDUCTOR

ICONSF	QDOTSF	HCSF	HCSFR
	BTU/S	BTU/S FT**2	F
234	7.131E+01	5.257E-01	0.000E+00
335	6.435E+00	4.793E-02	0.000E+00
436	2.507E+00	3.426E-02	0.000E+00
537	2.715E+00	6.264E-02	0.000E+00
638	2.108E+00	8.215E-02	0.000E+00
739	1.487E+00	9.759E-02	0.000E+00
840	9.594E-01	1.095E-01	0.000E+00
941	5.644E-01	1.182E-01	0.000E+00
1042	2.924E-01	1.242E-01	0.000E+00
1143	1.176E-01	1.280E-01	0.000E+00
1244	1.356E-02	1.302E-01	0.000E+00
1345	-4.171E-02	1.313E-01	0.000E+00
1446	-6.503E-02	1.315E-01	0.000E+00
1547	-6.873E-02	1.313E-01	0.000E+00
1648	-6.157E-02	1.309E-01	0.000E+00
1749	-4.949E-02	1.304E-01	0.000E+00
1850	-3.627E-02	1.299E-01	0.000E+00
1951	-2.412E-02	1.295E-01	0.000E+00
2052	-1.411E-02	1.292E-01	0.000E+00
2153	-6.564E-03	1.290E-01	0.000E+00
2254	-1.371E-03	1.289E-01	0.000E+00
2355	1.820E-03	1.288E-01	0.000E+00
2456	3.448E-03	1.288E-01	0.000E+00
2557	3.948E-03	1.289E-01	0.000E+00
2658	3.696E-03	1.289E-01	0.000E+00
2759	2.992E-03	1.289E-01	0.000E+00
2860	2.050E-03	1.290E-01	0.000E+00
2961	1.013E-03	1.290E-01	0.000E+00
3062	-8.002E-05	1.291E-01	0.000E+00
3163	-1.493E-03	1.291E-01	0.000E+00
3264	-1.868E-03	1.291E-01	0.000E+00

:
:
:
:

ISTEP = 16000 TAU = 0.80000E+02

BOUNDARY NODES

NODE	P(PSI)	TF(F)	Z(COMP)	RHO	QUALITY
				(LBM/FT^3)	
1	7.4970E+01	-4.1107E+02	7.6001E-02	3.8133E+00	0.0000E+00
33	1.2050E+01	7.0000E+01	1.0011E+00	4.2697E-03	1.0000E+00

SOLUTION

INTERNAL NODES

NODE	P(PSI)	TF(F)	Z	RHO	EM(LBM)	QUALITY
				(LBM/FT^3)		
2	7.3021E+01	-4.1107E+02	7.4083E-02	3.8103E+00	2.7060E-02	0.0000E+00
3	7.2060E+01	-4.1106E+02	7.3136E-02	3.8088E+00	5.4102E-02	0.0000E+00
4	7.1092E+01	-4.1106E+02	7.2181E-02	3.8073E+00	5.4081E-02	0.0000E+00
5	7.0090E+01	-4.1119E+02	7.3213E-02	3.7101E+00	5.2697E-02	3.0263E-03

6	6.9091E+01	-4.1133E+02	7.4478E-02	3.6054E+00	5.1209E-02	6.3610E-03
7	6.8061E+01	-4.1147E+02	7.5802E-02	3.4999E+00	4.9711E-02	9.7897E-03
8	6.7002E+01	-4.1162E+02	7.7186E-02	3.3941E+00	4.8209E-02	1.3309E-02
9	6.5911E+01	-4.1177E+02	7.8636E-02	3.2879E+00	4.6700E-02	1.6925E-02
10	6.4786E+01	-4.1193E+02	8.0164E-02	3.1809E+00	4.5180E-02	2.0657E-02
11	6.3626E+01	-4.1210E+02	8.1768E-02	3.0735E+00	4.3655E-02	2.4499E-02
12	6.2427E+01	-4.1228E+02	8.3454E-02	2.9657E+00	4.2124E-02	2.8460E-02
13	6.1187E+01	-4.1246E+02	8.5229E-02	2.8574E+00	4.0585E-02	3.2548E-02
14	5.9903E+01	-4.1266E+02	8.7101E-02	2.7486E+00	3.9040E-02	3.6773E-02
15	5.8570E+01	-4.1286E+02	8.9080E-02	2.6393E+00	3.7487E-02	4.1146E-02
16	5.7185E+01	-4.1308E+02	9.1176E-02	2.5293E+00	3.5925E-02	4.5680E-02
17	5.5743E+01	-4.1331E+02	9.3402E-02	2.4187E+00	3.4354E-02	5.0391E-02
18	5.4239E+01	-4.1355E+02	9.5772E-02	2.3073E+00	3.2772E-02	5.5295E-02
19	5.2667E+01	-4.1381E+02	9.8304E-02	2.1951E+00	3.1178E-02	6.0414E-02
20	5.1018E+01	-4.1409E+02	1.0102E-01	2.0819E+00	2.9570E-02	6.5771E-02
21	4.9285E+01	-4.1439E+02	1.0394E-01	1.9675E+00	2.7946E-02	7.1396E-02
22	4.7458E+01	-4.1471E+02	1.0710E-01	1.8519E+00	2.6303E-02	7.7324E-02
23	4.5522E+01	-4.1507E+02	1.1055E-01	1.7346E+00	2.4638E-02	8.3603E-02
24	4.3463E+01	-4.1545E+02	1.1432E-01	1.6155E+00	2.2946E-02	9.0290E-02
25	4.1261E+01	-4.1588E+02	1.1850E-01	1.4940E+00	2.1221E-02	9.7461E-02
26	3.8890E+01	-4.1636E+02	1.2318E-01	1.3698E+00	1.9455E-02	1.0522E-01
27	3.6315E+01	-4.1691E+02	1.2848E-01	1.2419E+00	1.7639E-02	1.1371E-01
28	3.3490E+01	-4.1754E+02	1.3461E-01	1.1095E+00	1.5758E-02	1.2314E-01
29	3.0345E+01	-4.1829E+02	1.4189E-01	9.7097E-01	1.3791E-02	1.3385E-01
30	2.6775E+01	-4.1921E+02	1.5085E-01	8.2419E-01	1.1706E-02	1.4637E-01
31	2.2602E+01	-4.2040E+02	1.6253E-01	6.6536E-01	9.4505E-03	1.6176E-01
32	1.7484E+01	-4.2210E+02	1.7919E-01	4.8798E-01	3.4655E-03	1.8219E-01

BRANCHES

BRANCH	KFACTOR (LBF-S^2/ (LBM-FT)^2)	DELP (PSI)	FLOW RATE (LBM/SEC)	VELOCITY (FT/SEC)	REYN. NO.	MACH NO.	ENTROPY GEN. BTU/(R-SEC)	LOST WORK LBF-FT/SEC
12	2.494E+03	1.950E+00	3.358E-01	4.133E+01	1.490E+06	2.373E-02	6.556E-04	2.476E+01
23	1.252E+03	9.641E-01	3.356E-01	4.135E+01	1.492E+06	2.370E-02	3.289E-04	1.242E+01
34	1.253E+03	9.687E-01	3.351E-01	4.129E+01	1.491E+06	2.365E-02	3.276E-04	1.237E+01
45	1.253E+03	9.977E-01	3.346E-01	4.125E+01	1.490E+06	2.360E-02	3.266E-04	1.233E+01
56	1.284E+03	9.988E-01	3.352E-01	4.240E+01	1.504E+06	2.436E-02	3.459E-04	1.303E+01
67	1.319E+03	1.030E+00	3.352E-01	4.364E+01	1.517E+06	2.519E-02	3.669E-04	1.378E+01
78	1.357E+03	1.059E+00	3.352E-01	4.495E+01	1.530E+06	2.607E-02	3.900E-04	1.461E+01
89	1.397E+03	1.091E+00	3.352E-01	4.636E+01	1.544E+06	2.701E-02	4.153E-04	1.551E+01
910	1.440E+03	1.124E+00	3.352E-01	4.786E+01	1.558E+06	2.803E-02	4.434E-04	1.650E+01
1011	1.486E+03	1.160E+00	3.352E-01	4.946E+01	1.574E+06	2.912E-02	4.746E-04	1.760E+01
1112	1.536E+03	1.199E+00	3.352E-01	5.119E+01	1.590E+06	3.029E-02	5.092E-04	1.882E+01
1213	1.589E+03	1.240E+00	3.352E-01	5.305E+01	1.606E+06	3.156E-02	5.480E-04	2.018E+01
1314	1.646E+03	1.285E+00	3.352E-01	5.506E+01	1.624E+06	3.294E-02	5.914E-04	2.169E+01
1415	1.708E+03	1.333E+00	3.352E-01	5.723E+01	1.643E+06	3.444E-02	6.405E-04	2.340E+01
1516	1.775E+03	1.385E+00	3.351E-01	5.960E+01	1.663E+06	3.608E-02	6.961E-04	2.532E+01
1617	1.849E+03	1.442E+00	3.351E-01	6.218E+01	1.683E+06	3.788E-02	7.596E-04	2.750E+01
1718	1.929E+03	1.504E+00	3.350E-01	6.502E+01	1.706E+06	3.986E-02	8.327E-04	3.000E+01
1819	2.018E+03	1.573E+00	3.350E-01	6.815E+01	1.729E+06	4.206E-02	9.173E-04	3.287E+01
1920	2.116E+03	1.648E+00	3.349E-01	7.162E+01	1.755E+06	4.452E-02	1.016E-03	3.621E+01
2021	2.225E+03	1.733E+00	3.349E-01	7.549E+01	1.782E+06	4.729E-02	1.133E-03	4.013E+01
2122	2.348E+03	1.828E+00	3.348E-01	7.986E+01	1.811E+06	5.043E-02	1.273E-03	4.478E+01
2223	2.487E+03	1.936E+00	3.347E-01	8.483E+01	1.844E+06	5.402E-02	1.442E-03	5.036E+01
2324	2.647E+03	2.059E+00	3.346E-01	9.054E+01	1.879E+06	5.819E-02	1.650E-03	5.718E+01

2425	2.833E+03	2.202E+00	3.345E-01	9.720E+01	1.918E+06	6.309E-02	1.911E-03	6.566E+01
2526	3.052E+03	2.371E+00	3.344E-01	1.051E+02	1.961E+06	6.896E-02	2.246E-03	7.643E+01
2627	3.316E+03	2.575E+00	3.344E-01	1.146E+02	2.011E+06	7.612E-02	2.689E-03	9.049E+01
2728	3.641E+03	2.825E+00	3.343E-01	1.263E+02	2.068E+06	8.510E-02	3.296E-03	1.095E+02
2829	4.054E+03	3.145E+00	3.342E-01	1.414E+02	2.135E+06	9.677E-02	4.167E-03	1.364E+02
2930	4.604E+03	3.570E+00	3.341E-01	1.615E+02	2.216E+06	1.127E-01	5.501E-03	1.769E+02
3031	5.385E+03	4.173E+00	3.340E-01	1.902E+02	2.320E+06	1.359E-01	7.747E-03	2.435E+02
3132	6.607E+03	5.118E+00	3.340E-01	2.356E+02	2.462E+06	1.737E-01	1.213E-02	3.699E+02
3233	7.016E+03	5.434E+00	3.340E-01	3.212E+02	2.678E+06	2.481E-01	1.835E-02	5.355E+02

SOLID NODES

NODESL	CPSLD BTU/LB F	TS F
34	6.774E-02	-4.111E+02
35	6.774E-02	-4.111E+02
36	6.774E-02	-4.111E+02
37	6.774E-02	-4.112E+02
38	6.774E-02	-4.113E+02
39	6.774E-02	-4.114E+02
40	6.774E-02	-4.116E+02
41	6.774E-02	-4.117E+02
42	6.774E-02	-4.119E+02
43	6.774E-02	-4.120E+02
44	6.774E-02	-4.122E+02
45	6.774E-02	-4.124E+02
46	6.774E-02	-4.126E+02
47	6.774E-02	-4.128E+02
48	6.774E-02	-4.130E+02
49	6.774E-02	-4.132E+02
50	6.774E-02	-4.134E+02
51	6.774E-02	-4.137E+02
52	6.774E-02	-4.140E+02
53	6.774E-02	-4.143E+02
54	6.774E-02	-4.146E+02
55	6.774E-02	-4.149E+02
56	6.774E-02	-4.153E+02
57	6.774E-02	-4.157E+02
58	6.774E-02	-4.162E+02
59	6.774E-02	-4.167E+02
60	6.774E-02	-4.173E+02
61	6.774E-02	-4.181E+02
62	6.774E-02	-4.190E+02
63	6.774E-02	-4.201E+02
64	6.774E-02	-4.218E+02

SOLID TO SOLID CONDUCTOR

ICONSS	CONDKIJ (BTU/S FT F)	QDOTSS (BTU/S)
3435	7.778E-02	-2.640E-09
3536	7.778E-02	-2.363E-09
3637	7.778E-02	1.173E-06
3738	7.778E-02	1.429E-06
3839	7.778E-02	1.491E-06
3940	7.778E-02	1.553E-06
4041	7.778E-02	1.610E-06

4142	7.778E-02	1.599E-06
4243	7.778E-02	1.774E-06
4344	7.778E-02	1.859E-06
4445	7.778E-02	1.952E-06
4546	7.778E-02	2.054E-06
4647	7.778E-02	2.167E-06
4748	7.778E-02	2.292E-06
4849	7.778E-02	2.431E-06
4950	7.778E-02	2.587E-06
5051	7.778E-02	2.763E-06
5152	7.778E-02	2.965E-06
5253	7.778E-02	3.196E-06
5354	7.778E-02	3.462E-06
5455	7.778E-02	3.774E-06
5556	7.778E-02	4.144E-06
5657	7.778E-02	4.591E-06
5758	7.778E-02	5.144E-06
5859	7.778E-02	5.844E-06
5960	7.778E-02	6.761E-06
6061	7.778E-02	8.017E-06
6162	7.778E-02	9.838E-06
6263	7.778E-02	1.274E-05
6364	7.778E-02	1.798E-05

SOLID TO FLUID CONDUCTOR

ICONSF	QDOTSF	HCSF	HCSFR
	BTU/S	(BTU/S FT**2)	(F)
234	1.073E-04	6.799E-01	0.000E+00
335	5.826E-04	6.802E-01	0.000E+00
436	5.455E-04	6.796E-01	0.000E+00
537	1.175E-03	6.893E-02	0.000E+00
638	1.698E-03	6.936E-02	0.000E+00
739	2.206E-03	6.968E-02	0.000E+00
840	2.720E-03	7.000E-02	0.000E+00
941	3.308E-03	7.033E-02	0.000E+00
1042	4.492E-03	7.068E-02	0.000E+00
1143	5.008E-03	7.103E-02	0.000E+00
1244	5.538E-03	7.138E-02	0.000E+00
1345	6.082E-03	7.175E-02	0.000E+00
1446	6.641E-03	7.211E-02	0.000E+00
1547	7.210E-03	7.248E-02	0.000E+00
1648	7.793E-03	7.285E-02	0.000E+00
1749	8.392E-03	7.323E-02	0.000E+00
1850	9.008E-03	7.360E-02	0.000E+00
1951	9.638E-03	7.398E-02	0.000E+00
2052	1.027E-02	7.435E-02	0.000E+00
2153	1.092E-02	7.472E-02	0.000E+00
2254	1.158E-02	7.507E-02	0.000E+00
2355	1.228E-02	7.542E-02	0.000E+00
2456	1.302E-02	7.574E-02	0.000E+00
2557	1.381E-02	7.603E-02	0.000E+00
2658	1.467E-02	7.628E-02	0.000E+00
2759	1.562E-02	7.646E-02	0.000E+00
2860	1.670E-02	7.656E-02	0.000E+00

```
 2961    1.797E-02   7.650E-02      0.000E+00
 3062    1.956E-02   7.617E-02      0.000E+00
 3163    2.171E-02   7.534E-02      0.000E+00
 3264    1.289E-02   7.324E-02      0.000E+00

*******************************************

TIME OF ANALYSIS WAS 470.779817800000 SECS

*******************************************
```

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APPENDIX V—INPUT AND OUTPUT DATA FILES FROM EXAMPLE 15

Simulation of Fluid Transient Following Sudden Valve Closure

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```
GFSSP VERSION
    604
GFSSP INSTALLATION PATH

ANALYST
Alok Majumdar
INPUT DATA FILE NAME
Ex15.dat
OUTPUT FILE NAME
Ex15.out
TITLE
Simulation of Fluid Transient Following Sudden Valve Closure
USETUP
F
DENCON        GRAVITY       ENERGY        MIXTURE       THRUST        STEADY        TRANSV        SAVER
F             F             T             F             F             F             T             F
HEX           HCOEF         REACTING      INERTIA       CONDX         ADDPROP       PRINTI        ROTATION
F             F             F             F             F             F             T             F
BUOYANCY      HRATE         INVAL         MSORCE        MOVBND        TPA           VARGEO        TVM
F             T             T             F             F             F             F             F
SHEAR         PRNTIN        PRNTADD       OPVALVE       TRANSQ        CONJUG        RADIAT        WINPLOT
F             T             T             T             F             F             F             T
PRESS         INSUC         VARROT        CYCLIC        CHKVALS       WINFILE       DALTON        NOSTATS
F             F             F             F             F             F             F             F
NORMAL        SIMUL         SECONDL       NRSOLVT       IBDF          NOPLT         PRESREG       FLOWREG
F             T             F             F             1             T             0             0
TRANS_MOM     USERVARS      PSMG          ISOLVE        PLOTADD       SIUNITS       TECPLOT       MDGEN
T             F             F             1             F             F             F             F
NUM_USER_VARS IFR_MIX       PRINTD        SATTABL       MSORIN        PRELVLV       LAMINAR       HSTAG
1             1             F             F             F             F             T             T
NNODES        NINT          NBR           NF
 7            5            6            1
RELAXK        RELAXD        RELAXH        CC            NITER         RELAXNR       RELAXHC       RELAXTS
 1               0.5            1              0.0001         500 1              1               1
DTAU          TIMEF         TIMEL         NPSTEP        NPWSTEP       WPLSTEP       WPLBUFF
 0.02              0                 1                 1             1             50             1.1
NFLUID(I),  I = 1, NF
 6
NODE          INDEX     DESCRIPTION
 1              2       " Node 1"
 2              1       " Node 2"
 3              1       " Node 3"
 4              1       " Node 4"
 5              1       " Node 5"
 6              1       " Node 6"
 7              2       " Node 7"
 NODE   PRES (PSI)   TEMP(DEGF)   MASS SOURC    HEAT SOURC   THRST AREA   NODE-VOLUME  CONCENTRATION
```

```
 2     14.7            60               0                  0                  0                  0
 3     14.7            60               0                  0                  0                  0
 4     14.7            60               0                  0                  0                  0
 5     14.7            60               0                  0                  0                  0
 6     14.7            60               0                  0                  0                  0
 ex15hs1.dat
 ex15hs7.dat
INODE         NUMBR         NAMEBR
 2             2            12   23
 3             2            23   34
 4             2            34   45
 5             2            45   56
 6             2            56   67
BRANCH   UPNODE    DNNODE    OPTION    DESCRIPTION
12        1         2         1       "Pipe 12"
23        2         3         1       "Pipe 23"
34        3         4         1       "Pipe 34"
45        4         5         1       "Pipe 45"
56        5         6         1       "Pipe 56"
67        6         7         2       "Restrict 67"
BRANCH        OPTION -1     LENGTH        DIA           EPSD          ANGLE         AREA
 12                         960               0.25            0                 0                 0.04908734375
BRANCH        OPTION -1     LENGTH        DIA           EPSD          ANGLE         AREA
 23                         960               0.25            0                 0                 0.04908734375
BRANCH        OPTION -1     LENGTH        DIA           EPSD          ANGLE         AREA
 34                         960               0.25            0                 0                 0.04908734375
BRANCH        OPTION -1     LENGTH        DIA           EPSD          ANGLE         AREA
 45                         960               0.25            0                 0                 0.04908734375
BRANCH        OPTION -1     LENGTH        DIA           EPSD          ANGLE         AREA
 56                         960               0.25            0                 0                 0.04908734375
BRANCH        OPTION -2     FLOW COEFF    AREA
 67                         0.6           0.0491
INITIAL FLOWRATES IN BRANCHES FOR UNSTEADY FLOW
 12 0
 23 0
 34 0
 45 0
 56 0
 67 0
NUMBER OF CLOSING/OPENING VALVES IN THE CIRCUIT
 1
BRANCH
67
FILE NAME
ex15vlv.dat
RESTART NODE INFORMATION FILE
FNDEX15.DAT
```

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```
RESTART BRANCH INFORMATION FILE
FBREX15.DAT
```

EXAMPLE 15 HISTORY AND RESTART FILES

EX15HS1.DAT

```
2
0     500.0  -260.0  0.0
1000  500.0  -260.0  0.0
```

EX15HS7.DAT

```
2
0     450.0  -260.0  0.0
1000  450.0  -260.0  0.0
```

EX15VLV.DAT

```
7
0.00      0.0491
0.02      0.0164
0.04      0.00545
0.06      0.00182
0.08      0.00061
0.1       1.E-16
100       1.E-16
```

FNDEX15.DAT

```
NODE P(PSF) TF(R) H(BTU/LB) CONC RHO(LB/FT^3)
  EMU(LB/FT-S) Z R(LBF-FT/LB-R) EM(LB) CP(BTU/LB-R) ENTROPY(BTU/LB-R)
           2   70570.99       199.6258       77.07056       1.000000
   64.96349      8.4011677E-05  0.1126991       48.28000      0.0000000E+00
  0.4173057       1.524868
           3   69141.62       199.6527       77.07056       1.000000
   64.94235      8.3891122E-05  0.1104375       48.28000      0.0000000E+00
  0.4175506       1.524851
           4   67712.23       199.6797       77.07058       1.000000
   64.92119      8.3770668E-05  0.1081750       48.28000      0.0000000E+00
  0.4178011       1.524851
           5   66282.80       199.7065       77.07059       1.000000
   64.90001      8.3650339E-05  0.1059117       48.28000      0.0000000E+00
```

```
  0.4180055       1.524851
           6   64853.37       199.7332       77.07063       1.000000
   64.87878      8.3530074E-05  0.1036477       48.28000      0.0000000E+00
  0.4182283       1.524851
```

FBREX15.DAT

```
BRANCH AK FLOWR(LB/S) VEL(FT/S)
          12   153259.8      9.6560813E-02   4.358272
          23   153280.5      9.6560813E-02   4.360718
          34   153282.9      9.6560813E-02   4.362138
          45   153285.4      9.6560813E-02   4.363560
          56   153287.8      9.6560813E-02   4.364984
          67   5722.974      9.6560813E-02   4.369652
```

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```
          **************************************************
                       G F S S P (Version 604)
               Generalized Fluid System Simulation Program
                            January 2013

              Developed by NASA/Marshall Space Flight Center
              Copyright (C) by Marshall Space Flight Center

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


            RUN DATE:01/25/2013 15:35

TITLE     :Simulation of Fluid Transient Following Sudden Valve Closure
ANALYST   :Alok Majumdar
FILEIN    :D:\GFSSP604Intel\ExamplesJan25\EX15\Ex15.dat
FILEOUT   :Ex15.out

                           OPTION VARIABLES

ADDPROP   BUOYANCY  CONDX     CONJUG    CYCLIC    DALTON    DENCON    ENERGY
F         F         F         F         F         F         F         T
FLOWREG   GRAVITY   HCOEF     HEX       HRATE     IFRMIX    INERTIA   INSUC
0         F         F         F         T         1         F         F
INVAL     MIXTURE   MOVBND    MSORCE    NORMAL    NRSOLVT   OPVALVE   PLOTADD
T         F         F         F         F         F         T         F
PRESREG   PRESS     PRINTI    PRNTADD   PRNTIN    RADIATION REACTING  ROTATION
0         F         T         T         T         F         F         F
SAVER     SECONDL   SHEAR     SIMULA    SIUNITS   STEADY    THRUST    TPA
F         F         F         T         F         F         F         F
TRANS_MOM TRANSQ    TRANSV    TVM       TWOD      USRVAR    VARGEO    VARROT
T         F         T         F         F         F         F         F
RLFVLV
F

NNODES   =    7
NINT     =    5
NBR      =    6
NF       =    1
NVAR     =   16
NHREF    =    2


FLUIDS:  O2
```

```
BOUNDARY NODES
   NODE        P           T         RHO                    AREA
             (PSI)        (F)     (LBM/FT^3)                (IN^2)
    1    0.5000E+03 -0.2600E+03  0.6498E+02  0.0000E+00
    7    0.4500E+03 -0.2600E+03  0.6490E+02  0.0000E+00

 INPUT SPECIFICATIONS FOR INTERNAL NODES
NODE       AREA         MASS         HEAT
          (IN^2)       (LBM/S)      (BTU/S)
    2    0.0000E+00  0.0000E+00  0.0000E+00
    3    0.0000E+00  0.0000E+00  0.0000E+00
    4    0.0000E+00  0.0000E+00  0.0000E+00
    5    0.0000E+00  0.0000E+00  0.0000E+00
    6    0.0000E+00  0.0000E+00  0.0000E+00

BRANCH      UPNODE    DNNODE    OPTION
     12         1         2         1
     23         2         3         1
     34         3         4         1
     45         4         5         1
     56         5         6         1
     67         6         7         2
BRANCH  OPTION -1:   LENGTH      DIA        EPSD       ANGLE        AREA
     12             0.960E+03   0.250E+00   0.000E+00   0.000E+00   0.491E-01
BRANCH  OPTION -1:   LENGTH      DIA        EPSD       ANGLE        AREA
     23             0.960E+03   0.250E+00   0.000E+00   0.000E+00   0.491E-01
BRANCH  OPTION -1:   LENGTH      DIA        EPSD       ANGLE        AREA
     34             0.960E+03   0.250E+00   0.000E+00   0.000E+00   0.491E-01
BRANCH  OPTION -1:   LENGTH      DIA        EPSD       ANGLE        AREA
     45             0.960E+03   0.250E+00   0.000E+00   0.000E+00   0.491E-01
BRANCH  OPTION -1:   LENGTH      DIA        EPSD       ANGLE        AREA
     56             0.960E+03   0.250E+00   0.000E+00   0.000E+00   0.491E-01
BRANCH OPTION -2:  FLOW COEF  AREA
     67             0.600E+00   0.164E-01

INITIAL GUESS FOR INTERNAL NODES

   NODE    P(PSI)   TF(F)      Z(COMP)        RHO       QUALITY
                                           (LBM/FT^3)
    2    0.4901E+03 -0.2600E+03  0.1127E+00  0.6496E+02  0.0000E+00
    3    0.4802E+03 -0.2600E+03  0.1104E+00  0.6494E+02  0.0000E+00
    4    0.4702E+03 -0.2600E+03  0.1082E+00  0.6492E+02  0.0000E+00
    5    0.4603E+03 -0.2600E+03  0.1059E+00  0.6490E+02  0.0000E+00
    6    0.4504E+03 -0.2599E+03  0.1036E+00  0.6488E+02  0.0000E+00

 TRIAL SOLUTION
```

BRANCH	DELP(PSI)	FLOWRATE(LBM/SEC)
12	0.0000	0.0966
23	0.0000	0.0966
34	0.0000	0.0966
45	0.0000	0.0966
56	0.0000	0.0966
67	0.0000	0.0966

ISTEP = 1 TAU = 0.20000E-01

BOUNDARY NODES

NODE	P(PSI)	TF(F)	Z(COMP)	RHO (LBM/FT^3)	QUALITY
1	0.5000E+03	-0.2600E+03	0.0000E+00	0.6498E+02	0.0000E+00
7	0.4500E+03	-0.2600E+03	0.0000E+00	0.6490E+02	0.0000E+00

SOLUTION

INTERNAL NODES

NODE	P(PSI)	TF(F)	Z	RHO (LBM/FT^3)	EM(LBM)	QUALITY
2	0.4832E+03	-0.2601E+03	0.1111E+00	0.6497E+02	0.2657E+01	0.0000E+00
3	0.4725E+03	-0.2600E+03	0.1087E+00	0.6494E+02	0.1771E+01	0.0000E+00
4	0.4640E+03	-0.2600E+03	0.1068E+00	0.6492E+02	0.1771E+01	0.0000E+00
5	0.4645E+03	-0.2599E+03	0.1069E+00	0.6491E+02	0.1770E+01	0.0000E+00
6	0.4995E+03	-0.2597E+03	0.1148E+00	0.6493E+02	0.8853E+00	0.0000E+00

NODE	H BTU/LB	ENTROPY BTU/LB-R	EMU LBM/FT-SEC	COND BTU/FT-S-R	CP BTU/LB-R	GAMA
2	0.7705E+02	0.1525E+01	0.8398E-04	0.1819E-04	0.4174E+00	0.2026E+01
3	0.7705E+02	0.1525E+01	0.8386E-04	0.1818E-04	0.4177E+00	0.2028E+01
4	0.7705E+02	0.1525E+01	0.8374E-04	0.1817E-04	0.4179E+00	0.2029E+01
5	0.7708E+02	0.1525E+01	0.8367E-04	0.1816E-04	0.4179E+00	0.2030E+01
6	0.7721E+02	0.1525E+01	0.8376E-04	0.1817E-04	0.4174E+00	0.2028E+01

BRANCHES

BRANCH	KFACTOR (LBF-S^2/(LBM-FT)^2)	DELP (PSI)	FLOW RATE (LBM/SEC)	VELOCITY (FT/SEC)	REYN. NO.	MACH NO.	ENTROPY GEN. BTU/(R-SEC)	LOST WORK LBF-FT/SEC
12	0.152E+06	0.168E+02	0.998E-01	0.451E+01	0.726E+05	0.569E-02	0.150E-04	0.233E+01
23	0.153E+06	0.107E+02	0.968E-01	0.437E+01	0.705E+05	0.552E-02	0.138E-04	0.214E+01
34	0.153E+06	0.847E+01	0.960E-01	0.434E+01	0.700E+05	0.547E-02	0.135E-04	0.209E+01
45	0.155E+06	-0.482E+00	0.927E-01	0.419E+01	0.677E+05	0.528E-02	0.122E-04	0.190E+01
56	0.162E+06	-0.350E+02	0.748E-01	0.338E+01	0.547E+05	0.426E-02	0.673E-05	0.105E+01
67	0.513E+05	0.495E+02	0.409E-01	0.553E+01	0.516E+05	0.697E-02	0.347E-06	0.540E-01

```
 SOLUTION SATISFIED CONVERGENCE CRITERION OF    0.100E-03 IN    284 ITERATIONS
TAU =   2.000000000000000E-002  ISTEP =           1  DTAU =
 2.000000000000000E-002                            :
                            :
                            :
                            :

   ISTEP =     25          TAU =  0.50000E+00
 BOUNDARY NODES
   NODE    P(PSI)      TF(F)      Z(COMP)       RHO       QUALITY
                                          (LBM/FT^3)
    1    0.5000E+03 -0.2600E+03  0.0000E+00  0.6498E+02  0.0000E+00
    7    0.4500E+03 -0.2600E+03  0.0000E+00  0.6490E+02  0.0000E+00

 SOLUTION
 INTERNAL NODES
  NODE     P(PSI)      TF(F)        Z           RHO         EM(LBM)     QUALITY
                                              (LBM/FT^3)
    2    0.4828E+03 -0.2601E+03  0.1110E+00  0.6497E+02  0.2657E+01  0.0000E+00
    3    0.4544E+03 -0.2601E+03  0.1046E+00  0.6493E+02  0.1771E+01  0.0000E+00
    4    0.4348E+03 -0.2601E+03  0.1001E+00  0.6490E+02  0.1770E+01  0.0000E+00
    5    0.4211E+03 -0.2601E+03  0.9702E-01  0.6488E+02  0.1769E+01  0.0000E+00
    6    0.4175E+03 -0.2601E+03  0.9618E-01  0.6486E+02  0.8843E+00  0.0000E+00

   NODE       H          ENTROPY     EMU       COND        CP          GAMA
           BTU/LB       BTU/LB-R  LBM/FT-SEC  BTU/FT-S-R  BTU/LB-R

    2    0.7705E+02  0.1525E+01  0.8398E-04  0.1819E-04  0.4174E+00  0.2026E+01
    3    0.7700E+02  0.1525E+01  0.8377E-04  0.1817E-04  0.4180E+00  0.2029E+01
    4    0.7697E+02  0.1525E+01  0.8361E-04  0.1816E-04  0.4184E+00  0.2031E+01
    5    0.7696E+02  0.1525E+01  0.8347E-04  0.1815E-04  0.4187E+00  0.2033E+01
    6    0.7698E+02  0.1525E+01  0.8338E-04  0.1814E-04  0.4188E+00  0.2034E+01

 BRANCHES
BRANCH       KFACTOR       DELP        FLOW RATE   VELOCITY    REYN. NO.   MACH NO.   ENTROPY GEN.   LOST WORK
      (LBF-S^2/(LBM-FT)^2) (PSI)       (LBM/SEC)     (FT/SEC)                                BTU/(R-SEC)   LBF-FT/SEC
      12     0.201E+06     0.172E+02  -0.295E-01    -0.133E+01   0.215E+05   0.168E-02   0.511E-06   0.793E-01
      23     0.214E+06     0.283E+02  -0.230E-01    -0.104E+01   0.168E+05   0.131E-02   0.258E-06   0.401E-01
      34     0.234E+06     0.196E+02  -0.162E-01    -0.733E+00   0.119E+05   0.924E-03   0.989E-07   0.153E-01
      45     0.272E+06     0.137E+02  -0.927E-02    -0.419E+00   0.679E+04   0.528E-03   0.215E-07   0.334E-02
      56     0.230E+06     0.365E+01  -0.301E-02    -0.136E+00   0.220E+04   0.171E-03   0.621E-09   0.964E-04
      67     0.138E+34    -0.325E+02  -0.111E-11    -0.246E+05   0.180E+02   0.310E+02   0.187E-09   0.290E-04

 SOLUTION SATISFIED CONVERGENCE CRITERION OF    0.100E-03 IN    102 ITERATIONS
TAU =   0.500000000000000       ISTEP =          25  DTAU =
 2.000000000000000E-002                            :
```

```
                              :
                              :

   ISTEP =     50          TAU =  0.10000E+01
 BOUNDARY NODES
   NODE    P(PSI)      TF(F)      Z(COMP)       RHO       QUALITY
                                          (LBM/FT^3)
     1    0.5000E+03 -0.2600E+03  0.0000E+00  0.6498E+02  0.0000E+00
     7    0.4500E+03 -0.2600E+03  0.0000E+00  0.6490E+02  0.0000E+00

 SOLUTION
 INTERNAL NODES
  NODE     P(PSI)      TF(F)        Z           RHO         EM(LBM)     QUALITY
                                              (LBM/FT^3)
     2    0.5083E+03 -0.2600E+03  0.1168E+00  0.6499E+02  0.2658E+01  0.0000E+00
     3    0.5192E+03 -0.2599E+03  0.1193E+00  0.6498E+02  0.1772E+01  0.0000E+00
     4    0.5261E+03 -0.2598E+03  0.1208E+00  0.6497E+02  0.1772E+01  0.0000E+00
     5    0.5304E+03 -0.2597E+03  0.1218E+00  0.6496E+02  0.1771E+01  0.0000E+00
     6    0.5314E+03 -0.2596E+03  0.1220E+00  0.6495E+02  0.8855E+00  0.0000E+00

   NODE       H          ENTROPY     EMU       COND        CP          GAMA
           BTU/LB       BTU/LB-R  LBM/FT-SEC  BTU/FT-S-R  BTU/LB-R

     2    0.7712E+02  0.1525E+01  0.8410E-04  0.1820E-04  0.4170E+00  0.2025E+01
     3    0.7718E+02  0.1525E+01  0.8407E-04  0.1819E-04  0.4169E+00  0.2025E+01
     4    0.7723E+02  0.1525E+01  0.8403E-04  0.1819E-04  0.4168E+00  0.2025E+01
     5    0.7727E+02  0.1525E+01  0.8398E-04  0.1819E-04  0.4168E+00  0.2025E+01
     6    0.7730E+02  0.1525E+01  0.8391E-04  0.1818E-04  0.4168E+00  0.2026E+01

 BRANCHES
BRANCH       KFACTOR       DELP        FLOW RATE   VELOCITY    REYN. NO.   MACH NO.   ENTROPY GEN.   LOST WORK
      (LBF-S^2/(LBM-FT)^2)  (PSI)       (LBM/SEC)     (FT/SEC)                                BTU/(R-SEC)   LBF-FT/SEC
      12     0.188E+06    -0.833E+01  -0.387E-01    -0.175E+01   0.281E+05   0.221E-02   0.108E-05   0.168E+00
      23     0.194E+06    -0.109E+02  -0.342E-01    -0.154E+01   0.248E+05   0.195E-02   0.766E-06   0.119E+00
      34     0.206E+06    -0.696E+01  -0.269E-01    -0.121E+01   0.195E+05   0.153E-02   0.394E-06   0.613E-01
      45     0.231E+06    -0.426E+01  -0.171E-01    -0.771E+00   0.124E+05   0.972E-03   0.113E-06   0.176E-01
      56     0.310E+06    -0.105E+01  -0.581E-02    -0.262E+00   0.423E+04   0.331E-03   0.602E-08   0.937E-03
      67     0.138E+34     0.815E+02  -0.111E-11    -0.246E+05   0.180E+02   0.310E+02   0.186E-09   0.290E-04

  SOLUTION SATISFIED CONVERGENCE CRITERION OF    0.100E-03 IN    129 ITERATIONS
 TAU =    1.00000000000000       ISTEP =           50  DTAU =
  2.000000000000000E-002
 ************************************************

 TIME OF ANALYSIS WAS    1.98437500000000       SECS

 ************************************************
```

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APPENDIX W—INPUT AND OUTPUT DATA FILES FROM EXAMPLE 16

Simulation of a Pressure Regulator Downstream of a Pressurized Tank

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```
GFSSP VERSION
    604
GFSSP INSTALLATION PATH
C:\Program Files (x86)\GFSSP604\
ANALYST
Alok Majumdar
INPUT DATA FILE NAME
D:\GFSSP604Intel\Examples\Ex16\EX16.dat
OUTPUT FILE NAME
EX16.out
TITLE
Simulation of a pressure regulator downstream of a Pressurized Tank
USETUP
F
DENCON        GRAVITY       ENERGY        MIXTURE       THRUST        STEADY        TRANSV        SAVER
F             F             T             F             F             F             T             F
HEX           HCOEF         REACTING      INERTIA       CONDX         ADDPROP       PRINTI        ROTATION
F             F             F             F             F             T             T             F
BUOYANCY      HRATE         INVAL         MSORCE        MOVBND        TPA           VARGEO        TVM
F             T             F             F             F             F             F             F
SHEAR         PRNTIN        PRNTADD       OPVALVE       TRANSQ        CONJUG        RADIAT        WINPLOT
F             T             T             F             F             F             F             T
PRESS         INSUC         VARROT        CYCLIC        CHKVALS       WINFILE       DALTON        NOSTATS
F             F             F             F             F             T             F             F
NORMAL        SIMUL         SECONDL       NRSOLVT       IBDF          NOPLT         PRESREG       FLOWREG
F             T             T             F             1             T             1             0
TRANS_MOM     USERVARS      PSMG          ISOLVE        PLOTADD       SIUNITS       TECPLOT       MDGEN
F             F             F             1             F             F             F             F
NUM_USER_VARS IFR_MIX       PRINTD        SATTABL       MSORIN        PRELVLV       LAMINAR       HSTAG
1             1             F             F             F             F             T             T
NNODES        NINT          NBR           NF
 3            2             2             1
RELAXK        RELAXD        RELAXH        CC            NITER         RELAXNR       RELAXHC       RELAXTS
 1               0.5             1               1e-05           500 1             1              1
DTAU          TIMEF         TIMEL         NPSTEP        NPWSTEP       WPLSTEP       WPLBUFF
 0.1          0             15            5             1             50            1.1
NFLUID(I),  I = 1, NF
 33
RREF         CPREF         GAMREF        EMUREF        AKREF        PREF        TREF        HREF        SREF
 53.34       0.24          1.3999        1.26e-05      4.133e-06    14.7        -459        0           0
NODE          INDEX     DESCRIPTION
 1              1       " Node 1"
 3              2       " Node 3"
 2              1       " Node 2"
```

```
NODE  PRES (PSI)  TEMP(DEGF)  MASS SOURC    HEAT SOURC   THRST AREA   NODE-VOLUME  CONCENTRATION
 1     100             80         0             0             0           17280
 2     14.7            60         0             0             0           100
 ex16hs3.dat
INODE         NUMBR         NAMEBR
 1             1            12
 2             2            12   23
BRANCH   UPNODE    DNNODE    OPTION    DESCRIPTION
12         1          2          2       "Restrict 12"
23         2          3          2       "Restrict 23"
BRANCH        OPTION -2     FLOW COEFF    AREA
 12                         1             0.04
BRANCH        OPTION -2     FLOW COEFF    AREA
 23                         1             0.00785
INITIAL FLOWRATES IN BRANCHES FOR UNSTEADY FLOW
 12 0
 23 0
NUMBER OF PRESSURE REGULATOR ASSEMBLY IN THE CIRCUIT
1
PRESS REG BR   HIST FILE  MAX_AREA   PRESSURE   RELAXATION   CONVERGENCE  MAX_ITERATIONS MIN_AREA
12             1          1.44       40          0.3          0.0001       50            1e-16
PRESSURE REGULATOR HISTORY FILE
preg_hist.dat
```

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EXAMPLE 16 HISTORY FILES

EX16HS3.DAT

```
2
0     14.700  80.00  1.00
1000  14.700  80.00  1.00
```

PREG_HIST.DAT

```
4
0       35.00
10      35.00
10.01   40.00
1000   40.00
```

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```
 ***************************************************
             G F S S P (Version 604)
     Generalized Fluid System Simulation Program
                  March 2012

    Developed by NASA/Marshall Space Flight Center
    Copyright (C) by Marshall Space Flight Center

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

  RUN DATE:09/28/2012 08:54

TITLE     :Simulation of a pressure regulator downstream of a Pressurized Tank
ANALYST   :Alok Majumdar
FILEIN    :D:\GFSSP604Intel\Examples\Ex16\EX16.dat
FILEOUT   :EX16.out

                 OPTION VARIABLES

ADDPROP   BUOYANCY  CONDX     CONJUG    CYCLIC    DALTON    DENCON    ENERGY
T         F         F         F         F         F         F         T
FLOWREG   GRAVITY   HCOEF     HEX       HRATE     IFRMIX    INERTIA   INSUC
0         F         F         F         T         1         F         F
INVAL     MIXTURE   MOVBND    MSORCE    NORMAL    NRSOLVT   OPVALVE   PLOTADD
F         F         F         F         F         F         F         F
PRESREG   PRESS     PRINTI    PRNTADD   PRNTIN    RADIATION REACTING  ROTATION
1         F         T         T         T         F         F         F
SAVER     SECONDL   SHEAR     SIMULA    SIUNITS   STEADY    THRUST    TPA
F         T         F         T         F         F         F         F
TRANS_MOM TRANSQ    TRANSV    TVM       TWOD      USRVAR    VARGEO    VARROT
F         F         T         F         F         F         F         F
RLFVLV
F

NNODES   =     3
NINT     =     2
NBR      =     2
NF       =     1
NVAR     =     6
NHREF    =     2


FLUIDS:  IDEL
```

```
BOUNDARY NODES
   NODE        P           T         RHO                     AREA
            (PSI)        (F)     (LBM/FT^3)                  (IN^2)
    3    0.1470E+02  0.8000E+02  0.7354E-01  0.0000E+00

 INPUT SPECIFICATIONS FOR INTERNAL NODES
NODE       AREA         MASS         HEAT
          (IN^2)       (LBM/S)      (BTU/S)
    1    0.0000E+00  0.0000E+00  0.0000E+00
    2    0.0000E+00  0.0000E+00  0.0000E+00

BRANCH      UPNODE    DNNODE    OPTION
     12        1         2         2
     23        2         3         2
BRANCH OPTION -2:  FLOW COEF  AREA
     12             0.100E+01   0.400E-01
BRANCH OPTION -2:  FLOW COEF  AREA
     23             0.100E+01   0.785E-02

INITIAL GUESS FOR INTERNAL NODES

   NODE    P(PSI)   TF(F)      Z(COMP)        RHO       QUALITY
                                            (LBM/FT^3)
    1    0.1000E+03  0.8000E+02  0.1000E+01  0.5002E+00  0.0000E+00
    2    0.1470E+02  0.6000E+02  0.1000E+01  0.7637E-01  0.0000E+00

 TRIAL SOLUTION
  BRANCH    DELP(PSI)   FLOWRATE(LBM/SEC)
     12         0.0000     0.0000
     23         0.0000     0.0000



 SOLUTION SATISFIED CONVERGENCE CRITERION OF    0.100E-04 IN    501 ITERATIONS
TAU =   0.100000000000000       ISTEP =           1  DTAU =
 0.100000000000000


 SOLUTION SATISFIED CONVERGENCE CRITERION OF    0.100E-04 IN    505 ITERATIONS
TAU =   0.200000000000000       ISTEP =           2  DTAU =
 0.100000000000000


 SOLUTION SATISFIED CONVERGENCE CRITERION OF    0.100E-04 IN    409 ITERATIONS
TAU =   0.300000000000000       ISTEP =           3  DTAU =
 0.100000000000000
```

```
 SOLUTION SATISFIED CONVERGENCE CRITERION OF    0.100E-04 IN    294 ITERATIONS
 TAU =   0.400000000000000       ISTEP =            4  DTAU =
 0.100000000000000


    ISTEP =      5          TAU =  0.50000E+00
 BOUNDARY NODES
   NODE    P(PSI)      TF(F)      Z(COMP)       RHO       QUALITY
                                        (LBM/FT^3)
    3    0.1470E+02  0.8000E+02  0.1000E+01  0.7354E-01  0.0000E+00

 SOLUTION
 INTERNAL NODES
  NODE     P(PSI)      TF(F)        Z           RHO         EM(LBM)     QUALITY
                                              (LBM/FT^3)
    1    0.9969E+02  0.7952E+02  0.1000E+01  0.4991E+00  0.4991E+01  0.0000E+00
    2    0.3477E+02  0.6359E+02  0.1000E+01  0.1794E+00  0.1038E-01  0.0000E+00

   NODE       H          ENTROPY     EMU       COND        CP          GAMA
           BTU/LB       BTU/LB-R  LBM/FT-SEC  BTU/FT-S-R  BTU/LB-R

    1    0.1294E+03  0.1475E+01  0.1260E-04  0.4133E-05  0.2400E+00  0.1400E+01
    2    0.1246E+03  0.1540E+01  0.1260E-04  0.4133E-05  0.2400E+00  0.1400E+01

 BRANCHES
BRANCH       KFACTOR       DELP        FLOW RATE   VELOCITY    REYN. NO.   MACH NO.   ENTROPY GEN.   LOST WORK
      (LBF-S^2/(LBM-FT)^2)  (PSI)       (LBM/SEC)     (FT/SEC)                           BTU/(R-SEC)   LBF-FT/SEC
      12     0.997E+08     0.649E+02   0.968E-02     0.110E+04   0.206E+06   0.965E+00   0.432E-03   0.181E+03
      23     0.292E+08     0.201E+02   0.996E-02     0.102E+04   0.121E+06   0.908E+00   0.394E-03   0.160E+03


         ***** TOTAL ENTROPY GENERATION =    0.826E-03 BTU/(R-SEC) ******

         **** TOTAL WORK LOST =    0.621E+00 HP *****


 SOLUTION SATISFIED CONVERGENCE CRITERION OF    0.100E-04 IN    287 ITERATIONS
 TAU =   0.500000000000000       ISTEP =            5  DTAU =
 0.100000000000000


 SOLUTION SATISFIED CONVERGENCE CRITERION OF    0.100E-04 IN    299 ITERATIONS
 TAU =   0.600000000000000       ISTEP =            6  DTAU =
 0.100000000000000
```

```
 SOLUTION SATISFIED CONVERGENCE CRITERION OF    0.100E-04 IN    254 ITERATIONS
TAU =   0.700000000000000       ISTEP =            7  DTAU =
 0.100000000000000


 SOLUTION SATISFIED CONVERGENCE CRITERION OF    0.100E-04 IN    253 ITERATIONS
TAU =   0.800000000000000       ISTEP =            8  DTAU =
 0.100000000000000


 SOLUTION SATISFIED CONVERGENCE CRITERION OF    0.100E-04 IN    253 ITERATIONS
TAU =   0.900000000000000       ISTEP =            9  DTAU =
 0.100000000000000
                                    .
                                    .
                                    .
                                    .


     ISTEP =     70          TAU =  0.70000E+01
BOUNDARY NODES
   NODE    P(PSI)      TF(F)      Z(COMP)       RHO       QUALITY
                                        (LBM/FT^3)
    3    0.1470E+02  0.8000E+02  0.1000E+01  0.7354E-01  0.0000E+00

SOLUTION
INTERNAL NODES
 NODE     P(PSI)      TF(F)        Z           RHO         EM(LBM)     QUALITY
                                             (LBM/FT^3)
    1    0.9778E+02  0.7655E+02  0.1000E+01  0.4923E+00  0.4923E+01  0.0000E+00
    2    0.3500E+02  0.2094E+02  0.1000E+01  0.1966E+00  0.1138E-01  0.0000E+00

   NODE       H          ENTROPY     EMU       COND        CP          GAMA
           BTU/LB       BTU/LB-R  LBM/FT-SEC  BTU/FT-S-R  BTU/LB-R

    1    0.1294E+03  0.1475E+01  0.1260E-04  0.4133E-05  0.2400E+00  0.1400E+01
    2    0.1246E+03  0.1519E+01  0.1260E-04  0.4133E-05  0.2400E+00  0.1400E+01

BRANCHES
BRANCH       KFACTOR       DELP        FLOW RATE   VELOCITY    REYN. NO.   MACH NO.   ENTROPY GEN.   LOST WORK
      (LBF-S^2/(LBM-FT)^2)  (PSI)       (LBM/SEC)     (FT/SEC)                            BTU/(R-SEC)   LBF-FT/SEC
      12     0.822E+08     0.628E+02   0.105E-01     0.109E+04   0.212E+06   0.958E+00   0.462E-03   0.193E+03
      23     0.266E+08     0.203E+02   0.105E-01     0.978E+03   0.127E+06   0.910E+00   0.417E-03   0.156E+03
```

```
     ***** TOTAL ENTROPY GENERATION =    0.878E-03 BTU/(R-SEC) ******

     **** TOTAL WORK LOST =    0.634E+00 HP *****

                                   .
                                   .
                                   .
                                   .



      ISTEP =    150          TAU =  0.15000E+02
 BOUNDARY NODES
    NODE    P(PSI)      TF(F)      Z(COMP)       RHO       QUALITY
                                            (LBM/FT^3)
     3    0.1470E+02  0.8000E+02  0.1000E+01  0.7354E-01  0.0000E+00

 SOLUTION
 INTERNAL NODES
  NODE     P(PSI)      TF(F)        Z           RHO         EM(LBM)     QUALITY
                                              (LBM/FT^3)
     1    0.9516E+02  0.7240E+02  0.1000E+01  0.4828E+00  0.4828E+01  0.0000E+00
     2    0.4000E+02  0.3080E+02  0.1000E+01  0.2201E+00  0.1274E-01  0.0000E+00

    NODE       H          ENTROPY     EMU       COND        CP          GAMA
            BTU/LB       BTU/LB-R  LBM/FT-SEC  BTU/FT-S-R  BTU/LB-R

     1    0.1294E+03  0.1475E+01  0.1260E-04  0.4133E-05  0.2400E+00  0.1400E+01
     2    0.1246E+03  0.1514E+01  0.1260E-04  0.4133E-05  0.2400E+00  0.1400E+01

 BRANCHES
BRANCH       KFACTOR       DELP        FLOW RATE   VELOCITY    REYN. NO.   MACH NO.   ENTROPY GEN.   LOST WORK
      (LBF-S^2/(LBM-FT)^2)  (PSI)       (LBM/SEC)     (FT/SEC)                            BTU/(R-SEC)   LBF-FT/SEC
      12     0.517E+08     0.552E+02   0.124E-01     0.103E+04   0.222E+06   0.910E+00   0.492E-03   0.204E+03
      23     0.238E+08     0.253E+02   0.124E-01     0.103E+04   0.150E+06   0.951E+00   0.537E-03   0.205E+03


     ***** TOTAL ENTROPY GENERATION =    0.103E-02 BTU/(R-SEC) ******

     **** TOTAL WORK LOST =    0.743E+00 HP *****


  SOLUTION SATISFIED CONVERGENCE CRITERION OF    0.100E-04 IN     92 ITERATIONS
 TAU =    15.0000000000000       ISTEP =          150  DTAU =
  0.100000000000000
```

```
 SOLUTION SATISFIED CONVERGENCE CRITERION OF    0.100E-04 IN     92 ITERATIONS
TAU =    15.1000000000000       ISTEP =          151  DTAU =
 0.100000000000000

**************************************************

TIME OF ANALYSIS WAS   0.109375000000000       SECS

**************************************************
```

APPENDIX X—INPUT AND OUTPUT DATA FILES FROM EXAMPLE 17

Simulation of a Flow Regulator Downstream of a Pressurized Tank

Contents

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```
GFSSP VERSION
    604
GFSSP INSTALLATION PATH
C:\Program Files (x86)\GFSSP604\
ANALYST
Alok Majumdar
INPUT DATA FILE NAME
D:\GFSSP604Intel\Examples\Ex17\Ex17.dat
OUTPUT FILE NAME
Ex17.out
TITLE
Simulation of a flow regulator downstream of a Pressurized Tank
USETUP
F
DENCON        GRAVITY       ENERGY        MIXTURE       THRUST        STEADY        TRANSV        SAVER
F             F             T             F             F             F             T             F
HEX           HCOEF         REACTING      INERTIA       CONDX         ADDPROP       PRINTI        ROTATION
F             F             F             F             F             T             T             F
BUOYANCY      HRATE         INVAL         MSORCE        MOVBND        TPA           VARGEO        TVM
F             F             F             F             F             F             F             F
SHEAR         PRNTIN        PRNTADD       OPVALVE       TRANSQ        CONJUG        RADIAT        WINPLOT
F             T             T             F             F             F             F             T
PRESS         INSUC         VARROT        CYCLIC        CHKVALS       WINFILE       DALTON        NOSTATS
F             F             F             F             F             F             F             F
NORMAL        SIMUL         SECONDL       NRSOLVT       IBDF          NOPLT         PRESREG       FLOWREG
F             T             F             F             1             F             0             1
TRANS_MOM     USERVARS      PSMG          ISOLVE        PLOTADD       SIUNITS       TECPLOT       MDGEN
F             F             F             1             F             F             F             F
NUM_USER_VARS IFR_MIX       PRINTD        SATTABL       MSORIN        PRELVLV       LAMINAR       HSTAG
1             1             F             F             F             F             T             T
NNODES        NINT          NBR           NF
 2            1            1            1
RELAXK        RELAXD        RELAXH        CC            NITER         RELAXNR       RELAXHC       RELAXTS
 1            0.5           1             0.0001        500            1             1              1
DTAU          TIMEF         TIMEL         NPSTEP        NPWSTEP       WPLSTEP       WPLBUFF
 0.5          0             20            5             1             50            1.1
NFLUID(I),  I = 1, NF
 33
RREF         CPREF        GAMREF       EMUREF       AKREF        PREF        TREF        HREF        SREF
 53.34       0.24         1.3999       1.26e-05     4.133e-06    14.7        -459        0           0
NODE          INDEX     DESCRIPTION
 1              1       " Node 1"
 2              2       " Node 2"
 NODE  PRES (PSI)  TEMP(DEGF)  MASS SOURC    HEAT SOURC    THRST AREA    NODE-VOLUME  CONCENTRATION
 1     100              80        0              0             0           17280
 Ex17hs3.dat
```

```
INODE         NUMBR         NAMEBR
 1             1            12
BRANCH   UPNODE    DNNODE    OPTION    DESCRIPTION
12         1          2          22      "Orifice 12"
BRANCH        OPTION -22     AREA       FLOW COEF
 12                         0.00785       1
INITIAL FLOWRATES IN BRANCHES FOR UNSTEADY FLOW
 12 0
NUMBER OF FLOW REGULATOR ASSEMBLY IN THE CIRCUIT
1
FLOW REG BR   HIST FILE  AREA    REGULATOR FLOW   RELAXATION   CONVERGENCE
12             1          0.3         0.012         1            0.001
FLOW REGULATOR HISTORY FILE
freg_hist.dat
```

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EXAMPLE 17 HISTORY FILES

Ex17hs3.dat

```
2
0     14.700  80.00  1.00
1000  14.700  80.00  1.00
```

FREQ_HIST.DAT

```
4
0        35.00
10       35.00
10.01    40.00
1000    40.00
```

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```
 **************************************************
              G F S S P (Version 604)
      Generalized Fluid System Simulation Program
                   March 2012

     Developed by NASA/Marshall Space Flight Center
     Copyright (C) by Marshall Space Flight Center

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


   RUN DATE:09/28/2012 10:00

TITLE     :Simulation of a flow regulator downstream of a Pressurized Tank
ANALYST   :Alok Majumdar
FILEIN    :D:\GFSSP604Intel\Examples\Ex17\Ex17.dat
FILEOUT   :Ex17.out

                     OPTION VARIABLES

ADDPROP   BUOYANCY  CONDX     CONJUG    CYCLIC    DALTON    DENCON    ENERGY
T         F         F         F         F         F         F         T
FLOWREG   GRAVITY   HCOEF     HEX       HRATE     IFRMIX    INERTIA   INSUC
1         F         F         F         F         1         F         F
INVAL     MIXTURE   MOVBND    MSORCE    NORMAL    NRSOLVT   OPVALVE   PLOTADD
F         F         F         F         F         F         F         F
PRESREG   PRESS     PRINTI    PRNTADD   PRNTIN    RADIATION REACTING  ROTATION
0         F         T         T         T         F         F         F
SAVER     SECONDL   SHEAR     SIMULA    SIUNITS   STEADY    THRUST    TPA
F         F         F         T         F         F         F         F
TRANS_MOM TRANSQ    TRANSV    TVM       TWOD      USRVAR    VARGEO    VARROT
F         F         T         F         F         F         F         F
RLFVLV
F

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


FLUIDS:  IDEL
```

```
BOUNDARY NODES
   NODE        P           T         RHO                    AREA
             (PSI)        (F)     (LBM/FT^3)                (IN^2)
    2    0.1470E+02  0.8000E+02  0.7354E-01  0.0000E+00

 INPUT SPECIFICATIONS FOR INTERNAL NODES
NODE       AREA         MASS         HEAT
          (IN^2)       (LBM/S)     (BTU/LBM)
    1    0.0000E+00  0.0000E+00  0.0000E+00

BRANCH      UPNODE    DNNODE    OPTION
     12         1         2        22
BRANCH OPTION -22 FLOW COEF   AREA
     12             0.100E+01   0.785E-02

INITIAL GUESS FOR INTERNAL NODES

   NODE    P(PSI)   TF(F)      Z(COMP)        RHO       QUALITY
                                           (LBM/FT^3)
    1    0.1000E+03  0.8000E+02  0.1000E+01  0.5002E+00  0.0000E+00

 TRIAL SOLUTION
  BRANCH    DELP(PSI)   FLOWRATE(LBM/SEC)
     12         0.0000     0.0000


 SOLUTION SATISFIED CONVERGENCE CRITERION OF    0.100E-03 IN    108 ITERATIONS
TAU =   0.500000000000000       ISTEP =           1  DTAU =
 0.500000000000000


 SOLUTION SATISFIED CONVERGENCE CRITERION OF    0.100E-03 IN      7 ITERATIONS
TAU =    1.00000000000000       ISTEP =           2  DTAU =
 0.500000000000000


 SOLUTION SATISFIED CONVERGENCE CRITERION OF    0.100E-03 IN     22 ITERATIONS
TAU =    1.50000000000000       ISTEP =           3  DTAU =
 0.500000000000000


 SOLUTION SATISFIED CONVERGENCE CRITERION OF    0.100E-03 IN     22 ITERATIONS
TAU =    2.00000000000000       ISTEP =           4  DTAU =
 0.500000000000000
```

```
                                      .
                                      .
                                      .
                                      .
   ISTEP =     20          TAU =  0.10000E+02
 BOUNDARY NODES
   NODE    P(PSI)      TF(F)      Z(COMP)       RHO       QUALITY
                                              (LBM/FT^3)
    2    0.1470E+02  0.8000E+02  0.1000E+01  0.7354E-01  0.0000E+00

 SOLUTION
 INTERNAL NODES
  NODE     P(PSI)      TF(F)        Z           RHO         EM(LBM)     QUALITY
                                              (LBM/FT^3)
    1    0.9666E+02  0.7479E+02  0.1000E+01  0.4883E+00  0.4883E+01  0.0000E+00

   NODE       H          ENTROPY     EMU       COND        CP          GAMA
           BTU/LB       BTU/LB-R  LBM/FT-SEC  BTU/FT-S-R  BTU/LB-R

    1    0.1281E+03  0.1475E+01  0.1260E-04  0.4133E-05  0.2400E+00  0.1400E+01

 BRANCHES
BRANCH       KFACTOR       DELP        FLOW RATE   VELOCITY    REYN. NO.   MACH NO.   ENTROPY GEN.   LOST WORK
      (LBF-S^2/(LBM-FT)^2)  (PSI)       (LBM/SEC)     (FT/SEC)                          BTU/(R-SEC)   LBF-FT/SEC
      12     0.227E+08     0.820E+02   0.120E-01     0.656E+03   0.175E+06   0.579E+00   0.193E-03   0.801E+02


  SOLUTION SATISFIED CONVERGENCE CRITERION OF    0.100E-03 IN     22 ITERATIONS
 TAU =    10.0000000000000       ISTEP =           20  DTAU =
  0.500000000000000


  SOLUTION SATISFIED CONVERGENCE CRITERION OF    0.100E-03 IN    122 ITERATIONS
 TAU =    10.5000000000000       ISTEP =           21  DTAU =
  0.500000000000000


  SOLUTION SATISFIED CONVERGENCE CRITERION OF    0.100E-03 IN     28 ITERATIONS
 TAU =    11.0000000000000       ISTEP =           22  DTAU =
  0.500000000000000


  SOLUTION SATISFIED CONVERGENCE CRITERION OF    0.100E-03 IN     28 ITERATIONS
 TAU =    11.5000000000000       ISTEP =           23  DTAU =
  0.500000000000000
```

```
 SOLUTION SATISFIED CONVERGENCE CRITERION OF    0.100E-03 IN     28 ITERATIONS
TAU =    12.0000000000000       ISTEP =           24  DTAU =
 0.500000000000000


                                   .
                                   .
                                   .
                                   .


    ISTEP =     40          TAU =  0.20000E+02
BOUNDARY NODES
   NODE    P(PSI)      TF(F)      Z(COMP)       RHO       QUALITY
                                          (LBM/FT^3)
    2    0.1470E+02  0.8000E+02  0.1000E+01  0.7354E-01  0.0000E+00

SOLUTION
INTERNAL NODES
 NODE     P(PSI)      TF(F)        Z           RHO         EM(LBM)     QUALITY
                                              (LBM/FT^3)
    1    0.9117E+02  0.6595E+02  0.1000E+01  0.4683E+00  0.4683E+01  0.0000E+00

   NODE       H          ENTROPY     EMU       COND        CP          GAMA
           BTU/LB       BTU/LB-R  LBM/FT-SEC  BTU/FT-S-R  BTU/LB-R

    1    0.1260E+03  0.1475E+01  0.1260E-04  0.4133E-05  0.2400E+00  0.1400E+01

BRANCHES
BRANCH       KFACTOR       DELP        FLOW RATE   VELOCITY    REYN. NO.   MACH NO.   ENTROPY GEN.   LOST WORK
      (LBF-S^2/(LBM-FT)^2)  (PSI)       (LBM/SEC)     (FT/SEC)                           BTU/(R-SEC)   LBF-FT/SEC
      12     0.771E+07     0.765E+02   0.200E-01     0.650E+03   0.221E+06   0.579E+00   0.321E-03   0.131E+03


 SOLUTION SATISFIED CONVERGENCE CRITERION OF    0.100E-03 IN     28 ITERATIONS
TAU =    20.0000000000000       ISTEP =           40  DTAU =
 0.500000000000000

************************************************

TIME OF ANALYSIS WAS   1.562500000000000E-002  SECS
```

APPENDIX Y—INPUT AND OUTPUT DATA FILES FROM EXAMPLE 18

Subsonic Fanno Flow

Contents

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```
GFSSP VERSION
    604
GFSSP INSTALLATION PATH
C:\Program Files (x86)\GFSSP604\
ANALYST
Dr. Alok Majumdar
INPUT DATA FILE NAME
D:\GFSSP604Intel\Examples\Ex18\Ex18.dat
OUTPUT FILE NAME
Fanno_Flow.out
TITLE
Subsonic Fanno Flow
USETUP
F
DENCON        GRAVITY       ENERGY        MIXTURE       THRUST        STEADY        TRANSV        SAVER
F             F             T             F             F             T             F             F
HEX           HCOEF         REACTING      INERTIA       CONDX         ADDPROP       PRINTI        ROTATION
F             F             F             T             F             F             T             F
BUOYANCY      HRATE         INVAL         MSORCE        MOVBND        TPA           VARGEO        TVM
F             T             F             F             F             F             F             F
SHEAR         PRNTIN        PRNTADD       OPVALVE       TRANSQ        CONJUG        RADIAT        WINPLOT
F             T             T             F             F             F             F             F
PRESS         INSUC         VARROT        CYCLIC        CHKVALS       WINFILE       DALTON        NOSTATS
F             F             F             F             F             T             T             F
NORMAL        SIMUL         SECONDL       NRSOLVT       IBDF          NOPLT         PRESREG       FLOWREG
F             T             T             F             1             T             0             0
TRANS_MOM     USERVARS      PSMG          ISOLVE        PLOTADD       SIUNITS       TECPLOT       MDGEN
F             F             F             1             F             F             F             F
NUM_USER_VARS IFR_MIX       PRINTD        SATTABL       MSORIN        PRELVLV       LAMINAR       HSTAG
1             1             F             F             F             F             T             T
NNODES        NINT          NBR           NF
 21            19            20            1
RELAXK        RELAXD        RELAXH        CC            NITER         RELAXNR       RELAXHC       RELAXTS
 1               0.5             1              0.0001          500 1              1                1
NFLUID(I),  I = 1, NF
 4
NODE          INDEX     DESCRIPTION
 1              2       " Node 1"
 2              1       " "
 3              1       " "
 4              1       " "
 5              1       " "
 6              1       " "
 7              1       " "
 8              1       " "
 9              1       " "
```

```
 10             1       " "
 11             1       " "
 12             1       " "
 13             1       " "
 14             1       " "
 15             1       " "
 16             1       " "
 17             1       " "
 18             1       " "
 19             1       " "
 20             1       " "
 21             2       " Node 21"
 NODE  PRES (PSI)  TEMP(DEGF)  MASS SOURC    HEAT SOURC   THRST AREA   CONCENTRATION
 1     50              80                0                  0                  0
 2     14.7            60                0                  0                  0
 3     14.7            60                0                  0                  0
 4     14.7            60                0                  0                  0
 5     14.7            60                0                  0                  0
 6     14.7            60                0                  0                  0
 7     14.7            60                0                  0                  0
 8     14.7            60                0                  0                  0
 9     14.7            60                0                  0                  0
 10    14.7            60                0                  0                  0
 11    14.7            60                0                  0                  0
 12    14.7            60                0                  0                  0
 13    14.7            60                0                  0                  0
 14    14.7            60                0                  0                  0
 15    14.7            60                0                  0                  0
 16    14.7            60                0                  0                  0
 17    14.7            60                0                  0                  0
 18    14.7            60                0                  0                  0
 19    14.7            60                0                  0                  0
 20    14.7            60                0                  0                  0
 21    23.4            60                0                  0                  0
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
 16           2           1516   1617
 17           2           1617   1718
 18           2           1718   1819
 19           2           1819   1920
 20           2           1920   2021
BRANCH   UPNODE    DNNODE    OPTION    DESCRIPTION
12        1         2          1       "Pipe 12"
23        2         3          1       "Pipe 23"
34        3         4          1       "Pipe 34"
45        4         5          1       "Pipe 45"
56        5         6          1       "Pipe 56"
67        6         7          1       "Pipe 67"
78        7         8          1       "Pipe 78"
89        8         9          1       "Pipe 89"
910       9         10         1       "Pipe 910"
1011      10        11         1       "Pipe 1011"
1112      11        12         1       "Pipe 1112"
1213      12        13         1       "Pipe 1213"
1314      13        14         1       "Pipe 1314"
1415      14        15         1       "Pipe 1415"
1516      15        16         1       "Pipe 1516"
1617      16        17         1       "Pipe 1617"
1718      17        18         1       "Pipe 1718"
1819      18        19         1       "Pipe 1819"
1920      19        20         1       "Pipe 1920"
2021      20        21         1       "Pipe 2021"
BRANCH       OPTION -1     LENGTH        DIA          EPSD         ANGLE        AREA
 12                        62                6              0                 0                  28.27431
BRANCH       OPTION -1     LENGTH        DIA          EPSD         ANGLE        AREA
 23                        74                6              0                 0                  28.27431
BRANCH       OPTION -1     LENGTH        DIA          EPSD         ANGLE        AREA
 34                        89                6              0                 0                  28.27431
BRANCH       OPTION -1     LENGTH        DIA          EPSD         ANGLE        AREA
 45                        107               6              0                 0                  28.27431
BRANCH       OPTION -1     LENGTH        DIA          EPSD         ANGLE        AREA
 56                        128               6              0                 0                  28.27431
BRANCH       OPTION -1     LENGTH        DIA          EPSD         ANGLE        AREA
 67                        154               6              0                 0                  28.27431
BRANCH       OPTION -1     LENGTH        DIA          EPSD         ANGLE        AREA
 78                        184               6              0                 0                  28.27431
BRANCH       OPTION -1     LENGTH        DIA          EPSD         ANGLE        AREA
 89                        221               6              0                 0                  28.27431
BRANCH       OPTION -1     LENGTH        DIA          EPSD         ANGLE        AREA
 910                       266               6              0                 0                  28.27431
BRANCH       OPTION -1     LENGTH        DIA          EPSD         ANGLE        AREA
```

```
 1011                      319             6                0                  0                   28.27431
BRANCH        OPTION -1    LENGTH        DIA           EPSD          ANGLE         AREA
 1112                      318             6                0                  0                   28.27431
BRANCH        OPTION -1    LENGTH        DIA           EPSD          ANGLE         AREA
 1213                      266             6                0                  0                   28.27431
BRANCH        OPTION -1    LENGTH        DIA           EPSD          ANGLE         AREA
 1314                      221             6                0                  0                   28.27431
BRANCH        OPTION -1    LENGTH        DIA           EPSD          ANGLE         AREA
 1415                      184             6                0                  0                   28.27431
BRANCH        OPTION -1    LENGTH        DIA           EPSD          ANGLE         AREA
 1516                      154             6                0                  0                   28.27431
BRANCH        OPTION -1    LENGTH        DIA           EPSD          ANGLE         AREA
 1617                      128             6                0                  0                   28.27431
BRANCH        OPTION -1    LENGTH        DIA           EPSD          ANGLE         AREA
 1718                      107             6                0                  0                   28.27431
BRANCH        OPTION -1    LENGTH        DIA           EPSD          ANGLE         AREA
 1819                      89              6                0                  0                   28.27431
BRANCH        OPTION -1    LENGTH        DIA           EPSD          ANGLE         AREA
 1920                      74              6                0                  0                   28.27431
BRANCH        OPTION -1    LENGTH        DIA           EPSD          ANGLE         AREA
 2021                      62              6                0                  0                   28.27431
BRANCH        NOUBR        NMUBR
 12    0
 23    1   12
 34    1   23
 45    1   34
 56    1   45
 67    1   56
 78    1   67
 89    1   78
 910    1   89
 1011    1   910
 1112    1   1011
 1213    1   1112
 1314    1   1213
 1415    1   1314
 1516    1   1415
 1617    1   1516
 1718    1   1617
 1819    1   1718
 1920    1   1819
 2021    1   1920
BRANCH        NODBR        NMDBR
 12    1   23
 23    1   34
 34    1   45
 45    1   56
```

```
 56    1   67
 67    1   78
 78    1   89
 89    1   910
 910    1   1011
 1011    1   1112
 1112    1   1213
 1213    1   1314
 1314    1   1415
 1415    1   1516
 1516    1   1617
 1617    1   1718
 1718    1   1819
 1819    1   1920
 1920    1   2021
 2021    0
BRANCH
 12
  UPSTRM BR.     ANGLE
  DNSTRM BR.     ANGLE
   23     0.00000
BRANCH
 23
  UPSTRM BR.     ANGLE
   12     0.00000
  DNSTRM BR.     ANGLE
   34     0.00000
BRANCH
 34
  UPSTRM BR.     ANGLE
   23     0.00000
  DNSTRM BR.     ANGLE
   45     0.00000
BRANCH
 45
  UPSTRM BR.     ANGLE
   34     0.00000
  DNSTRM BR.     ANGLE
   56     0.00000
BRANCH
 56
  UPSTRM BR.     ANGLE
   45     0.00000
  DNSTRM BR.     ANGLE
   67     0.00000
BRANCH
 67
```

```
  UPSTRM BR.     ANGLE
    56     0.00000
  DNSTRM BR.     ANGLE
    78     0.00000
BRANCH
 78
  UPSTRM BR.     ANGLE
    67     0.00000
  DNSTRM BR.     ANGLE
    89     0.00000
BRANCH
 89
  UPSTRM BR.     ANGLE
    78     0.00000
  DNSTRM BR.     ANGLE
    910     0.00000
BRANCH
 910
  UPSTRM BR.     ANGLE
    89     0.00000
  DNSTRM BR.     ANGLE
    1011     0.00000
BRANCH
 1011
  UPSTRM BR.     ANGLE
    910     0.00000
  DNSTRM BR.     ANGLE
    1112     0.00000
BRANCH
 1112
  UPSTRM BR.     ANGLE
    1011     0.00000
  DNSTRM BR.     ANGLE
    1213     0.00000
BRANCH
 1213
  UPSTRM BR.     ANGLE
    1112     0.00000
  DNSTRM BR.     ANGLE
    1314     0.00000
BRANCH
 1314
  UPSTRM BR.     ANGLE
    1213     0.00000
  DNSTRM BR.     ANGLE
    1415     0.00000
BRANCH
```

```
 1415
  UPSTRM BR.     ANGLE
   1314     0.00000
  DNSTRM BR.     ANGLE
   1516     0.00000
BRANCH
 1516
  UPSTRM BR.     ANGLE
   1415     0.00000
  DNSTRM BR.     ANGLE
   1617     0.00000
BRANCH
 1617
  UPSTRM BR.     ANGLE
   1516     0.00000
  DNSTRM BR.     ANGLE
   1718     0.00000
BRANCH
 1718
  UPSTRM BR.     ANGLE
   1617     0.00000
  DNSTRM BR.     ANGLE
   1819     0.00000
BRANCH
 1819
  UPSTRM BR.     ANGLE
   1718     0.00000
  DNSTRM BR.     ANGLE
   1920     0.00000
BRANCH
 1920
  UPSTRM BR.     ANGLE
   1819     0.00000
  DNSTRM BR.     ANGLE
   2021     0.00000
BRANCH
 2021
  UPSTRM BR.     ANGLE
   1920     0.00000
  DNSTRM BR.     ANGLE
NUMBER OF BRANCHES WITH INERTIA
 20
 12
 23
 34
 45
 56
```

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Example 18 User Subroutines

```
C                                                                     *

C     ***** GFSSP USER SUBROUTINES *****                              *
C                                                                     *
C**********************************************************************
                              :
                              :
                              :
                              :

*********************************************************************
      SUBROUTINE KFADJUST(I,RHOU,EMUU,RHOUL,EMUUL,RHOUV,EMUUV,ISATU,
     &                    AKNEW)
C     PURPOSE: ADJUST RESISTANCE IN A BRANCH
C**********************************************************************
      INCLUDE 'COMBLK.FOR'
C*********************************************************************
C     ADD CODE HERE
      IF(IOPT(I).EQ.1) THEN
       PIPEL=BRPR1(I)
       PIPED=BRPR2(I)
       F=0.002
       AKNEW=8.*F*PIPEL/(RHOU*GC*PI*PI*PIPED**5)
      ENDIF
      RETURN
      END
C**********************************************************************
```

NOTE: All other user subroutines are not used in Example 18

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```
 ***************************************************
              G F S S P (Version 604)
      Generalized Fluid System Simulation Program
                   March 2012

     Developed by NASA/Marshall Space Flight Center
     Copyright (C) by Marshall Space Flight Center

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


   RUN DATE:09/28/2012 10:38

TITLE      :Subsonic Fanno Flow
ANALYST    :Dr. Alok Majumdar
FILEIN     :D:\GFSSP604Intel\Examples\Ex18\Ex18.dat
FILEOUT    :Fanno_Flow.out

                           OPTION VARIABLES

ADDPROP   BUOYANCY  CONDX     CONJUG    CYCLIC    DALTON    DENCON    ENERGY
F         F         F         F         F         T         F         T
FLOWREG   GRAVITY   HCOEF     HEX       HRATE     IFRMIX    INERTIA   INSUC
0         F         F         F         T         1         T         F
INVAL     MIXTURE   MOVBND    MSORCE    NORMAL    NRSOLVT   OPVALVE   PLOTADD
F         F         F         F         F         F         F         F
PRESREG   PRESS     PRINTI    PRNTADD   PRNTIN    RADIATION REACTING  ROTATION
0         F         F         T         F         F         F         F
SAVER     SECONDL   SHEAR     SIMULA    SIUNITS   STEADY    THRUST    TPA
F         T         F         T         F         T         F         F
TRANS_MOM TRANSQ    TRANSV    TVM       TWOD      USRVAR    VARGEO    VARROT
F         F         F         F         F         F         F         F
RLFVLV
F

NNODES    =   21
NINT      =   19
NBR       =   20
NF        =    1
NVAR      =   39
NHREF     =    2
```

FLUIDS: N2

BOUNDARY NODES

NODE	P (PSI)	T (F)	RHO (LBM/FT^3)		AREA (IN^2)
1	0.5000E+02	0.8000E+02	0.2420E+00	0.0000E+00	
21	0.2340E+02	0.6000E+02	0.1176E+00	0.0000E+00	

SOLUTION
INTERNAL NODES

NODE	P(PSI)	TF(F)	Z	RHO (LBM/FT^3)	EM(LBM)	QUALITY
2	0.4981E+02	0.7998E+02	0.9999E+00	0.2410E+00	0.0000E+00	0.1000E+01
3	0.4950E+02	0.7974E+02	0.9999E+00	0.2396E+00	0.0000E+00	0.1000E+01
4	0.4911E+02	0.7939E+02	0.9999E+00	0.2379E+00	0.0000E+00	0.1000E+01
5	0.4863E+02	0.7894E+02	0.9999E+00	0.2358E+00	0.0000E+00	0.1000E+01
6	0.4805E+02	0.7837E+02	0.9999E+00	0.2332E+00	0.0000E+00	0.1000E+01
7	0.4734E+02	0.7765E+02	0.9999E+00	0.2301E+00	0.0000E+00	0.1000E+01
8	0.4646E+02	0.7673E+02	0.9999E+00	0.2262E+00	0.0000E+00	0.1000E+01
9	0.4538E+02	0.7554E+02	0.9999E+00	0.2214E+00	0.0000E+00	0.1000E+01
10	0.4404E+02	0.7396E+02	0.9999E+00	0.2155E+00	0.0000E+00	0.1000E+01
11	0.4234E+02	0.7182E+02	0.9999E+00	0.2080E+00	0.0000E+00	0.1000E+01
12	0.4041E+02	0.6883E+02	0.9999E+00	0.1997E+00	0.0000E+00	0.1000E+01
13	0.3845E+02	0.6506E+02	0.9998E+00	0.1913E+00	0.0000E+00	0.1000E+01
14	0.3655E+02	0.6086E+02	0.9998E+00	0.1834E+00	0.0000E+00	0.1000E+01
15	0.3472E+02	0.5629E+02	0.9998E+00	0.1757E+00	0.0000E+00	0.1000E+01
16	0.3294E+02	0.5133E+02	0.9997E+00	0.1684E+00	0.0000E+00	0.1000E+01
17	0.3119E+02	0.4590E+02	0.9997E+00	0.1611E+00	0.0000E+00	0.1000E+01
18	0.2942E+02	0.3983E+02	0.9997E+00	0.1539E+00	0.0000E+00	0.1000E+01
19	0.2760E+02	0.3284E+02	0.9996E+00	0.1464E+00	0.0000E+00	0.1000E+01
20	0.2564E+02	0.2447E+02	0.9996E+00	0.1384E+00	0.0000E+00	0.1000E+01

NODE	H BTU/LB	ENTROPY BTU/LB-R	EMU LBM/FT-SEC	COND BTU/FT-S-R	CP BTU/LB-R	GAMA
2	0.1986E+03	0.9697E+00	0.1209E-04	0.4190E-05	0.2496E+00	0.1405E+01
3	0.1985E+03	0.9700E+00	0.1208E-04	0.4188E-05	0.2496E+00	0.1405E+01
4	0.1984E+03	0.9704E+00	0.1208E-04	0.4185E-05	0.2496E+00	0.1405E+01
5	0.1983E+03	0.9709E+00	0.1207E-04	0.4182E-05	0.2496E+00	0.1405E+01
6	0.1982E+03	0.9715E+00	0.1206E-04	0.4178E-05	0.2496E+00	0.1405E+01
7	0.1980E+03	0.9722E+00	0.1205E-04	0.4173E-05	0.2496E+00	0.1405E+01
8	0.1978E+03	0.9732E+00	0.1203E-04	0.4166E-05	0.2495E+00	0.1405E+01
9	0.1975E+03	0.9743E+00	0.1201E-04	0.4158E-05	0.2495E+00	0.1405E+01
10	0.1971E+03	0.9757E+00	0.1199E-04	0.4146E-05	0.2495E+00	0.1405E+01
11	0.1966E+03	0.9775E+00	0.1195E-04	0.4131E-05	0.2494E+00	0.1405E+01
12	0.1958E+03	0.9794E+00	0.1190E-04	0.4109E-05	0.2494E+00	0.1405E+01

13	0.1949E+03	0.9812E+00	0.1184E-04	0.4082E-05	0.2494E+00	0.1404E+01
14	0.1939E+03	0.9828E+00	0.1176E-04	0.4051E-05	0.2493E+00	0.1404E+01
15	0.1927E+03	0.9843E+00	0.1169E-04	0.4017E-05	0.2493E+00	0.1404E+01
16	0.1915E+03	0.9856E+00	0.1160E-04	0.3981E-05	0.2492E+00	0.1404E+01
17	0.1902E+03	0.9868E+00	0.1151E-04	0.3941E-05	0.2492E+00	0.1404E+01
18	0.1887E+03	0.9880E+00	0.1141E-04	0.3896E-05	0.2491E+00	0.1404E+01
19	0.1869E+03	0.9890E+00	0.1129E-04	0.3844E-05	0.2491E+00	0.1404E+01
20	0.1849E+03	0.9900E+00	0.1114E-04	0.3781E-05	0.2491E+00	0.1404E+01

BRANCHES

BRANCH	KFACTOR (LBF-S^2/(LBM-FT)^2)	DELP (PSI)	FLOW RATE (LBM/SEC)	VELOCITY (FT/SEC)	REYN. NO.	MACH NO.	ENTROPY GEN. BTU/(R-SEC)	LOST WORK LBF-FT/SEC
12	0.344E-01	0.193E+00	0.284E+02	0.599E+03	0.599E+07	0.516E+00	0.780E-02	0.327E+04
23	0.413E-01	0.306E+00	0.284E+02	0.601E+03	0.599E+07	0.518E+00	0.938E-02	0.394E+04
34	0.499E-01	0.389E+00	0.284E+02	0.605E+03	0.599E+07	0.521E+00	0.114E-01	0.479E+04
45	0.604E-01	0.478E+00	0.284E+02	0.609E+03	0.600E+07	0.525E+00	0.139E-01	0.584E+04
56	0.729E-01	0.583E+00	0.284E+02	0.614E+03	0.600E+07	0.530E+00	0.170E-01	0.712E+04
67	0.887E-01	0.714E+00	0.284E+02	0.621E+03	0.601E+07	0.536E+00	0.209E-01	0.875E+04
78	0.107E+00	0.874E+00	0.284E+02	0.630E+03	0.601E+07	0.544E+00	0.257E-01	0.107E+05
89	0.131E+00	0.108E+01	0.284E+02	0.640E+03	0.602E+07	0.554E+00	0.320E-01	0.134E+05
910	0.161E+00	0.135E+01	0.284E+02	0.654E+03	0.603E+07	0.566E+00	0.403E-01	0.168E+05
1011	0.199E+00	0.170E+01	0.284E+02	0.672E+03	0.604E+07	0.583E+00	0.512E-01	0.212E+05
1112	0.205E+00	0.194E+01	0.284E+02	0.696E+03	0.606E+07	0.605E+00	0.549E-01	0.227E+05
1213	0.179E+00	0.196E+01	0.284E+02	0.726E+03	0.609E+07	0.632E+00	0.502E-01	0.206E+05
1314	0.155E+00	0.190E+01	0.284E+02	0.757E+03	0.612E+07	0.662E+00	0.457E-01	0.187E+05
1415	0.135E+00	0.183E+01	0.284E+02	0.790E+03	0.616E+07	0.694E+00	0.418E-01	0.169E+05
1516	0.118E+00	0.178E+01	0.284E+02	0.824E+03	0.620E+07	0.727E+00	0.384E-01	0.154E+05
1617	0.102E+00	0.175E+01	0.284E+02	0.860E+03	0.624E+07	0.763E+00	0.351E-01	0.140E+05
1718	0.892E-01	0.176E+01	0.284E+02	0.899E+03	0.629E+07	0.801E+00	0.324E-01	0.127E+05
1819	0.777E-01	0.182E+01	0.284E+02	0.941E+03	0.635E+07	0.844E+00	0.299E-01	0.116E+05
1920	0.679E-01	0.196E+01	0.284E+02	0.989E+03	0.642E+07	0.893E+00	0.279E-01	0.107E+05
2021	0.602E-01	0.224E+01	0.284E+02	0.105E+04	0.650E+07	0.954E+00	0.266E-01	0.100E+05

```
     ***** TOTAL ENTROPY GENERATION =    0.612E+00 BTU/(R-SEC) ******

     **** TOTAL WORK LOST =    0.453E+03 HP *****

*************************************************

TIME OF ANALYSIS WAS   1.562500000000000E-002  SECS

*************************************************
```

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APPENDIX Z—INPUT AND OUTPUT DATA FILES FROM EXAMPLE 19

Subsonic Rayleigh Flow

Contents

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```
GFSSP VERSION
    604
GFSSP INSTALLATION PATH
C:\Program Files (x86)\GFSSP604\
ANALYST
Dr. Alok Majumdar
INPUT DATA FILE NAME
D:\GFSSP604Intel\Examples\Ex19\Ex19.dat
OUTPUT FILE NAME
Ex19.out
TITLE
Subsonic Rayleigh Flow
USETUP
F
DENCON        GRAVITY       ENERGY        MIXTURE       THRUST        STEADY        TRANSV        SAVER
F             F             T             F             F             T             F             F
HEX           HCOEF         REACTING      INERTIA       CONDX         ADDPROP       PRINTI        ROTATION
F             F             F             T             F             F             T             F
BUOYANCY      HRATE         INVAL         MSORCE        MOVBND        TPA           VARGEO        TVM
F             T             F             F             F             F             F             F
SHEAR         PRNTIN        PRNTADD       OPVALVE       TRANSQ        CONJUG        RADIAT        WINPLOT
F             T             T             F             F             F             F             F
PRESS         INSUC         VARROT        CYCLIC        CHKVALS       WINFILE       DALTON        NOSTATS
F             F             F             F             F             T             F             F
NORMAL        SIMUL         SECONDL       NRSOLVT       IBDF          NOPLT         PRESREG       FLOWREG
F             T             T             F             1             T             0             0
TRANS_MOM     USERVARS      PSMG          ISOLVE        PLOTADD       SIUNITS       TECPLOT       MDGEN
F             F             F             1             F             F             F             F
NUM_USER_VARS IFR_MIX       PRINTD        SATTABL       MSORIN        PRELVLV       LAMINAR       HSTAG
1             1             F             F             F             F             T             T
NNODES        NINT          NBR           NF
 21            19            20            1
RELAXK        RELAXD        RELAXH        CC            NITER         RELAXNR       RELAXHC       RELAXTS
 1               0.5            1              0.0001          500 1             1                1
NFLUID(I),  I = 1, NF
 4
NODE          INDEX     DESCRIPTION
 1              2       " Node 1"
 2              1       " Node 2"
 3              1       " Node 3"
 4              1       " Node 4"
 5              1       " Node 5"
 6              1       " Node 6"
 7              1       " Node 7"
 8              1       " Node 8"
 9              1       " Node 9"
```

```
 10             1       " Node 10"
 11             1       " Node 11"
 12             1       " Node 12"
 13             1       " Node 13"
 14             1       " Node 14"
 15             1       " Node 15"
 16             1       " Node 16"
 17             1       " Node 17"
 18             1       " Node 18"
 19             1       " Node 19"
 20             1       " Node 20"
 21             2       " Node 21"
 NODE  PRES (PSI)  TEMP(DEGF)  MASS SOURC    HEAT SOURC   THRST AREA   CONCENTRATION
 1     50              80        0            0                  0
 2     14.7            60        0            55.6               0
 3     14.7            60        0            45.7               0
 4     14.7            60        0            55                 0
 5     14.7            60        0            65.9               0
 6     14.7            60        0            79.1               0
 7     14.7            60        0            94.9               0
 8     14.7            60        0            113.7              0
 9     14.7            60        0            136.7              0
 10    14.7            60        0            164.2              0
 11    14.7            60        0            178.8              0
 12    14.7            60        0            163.9              0
 13    14.7            60        0            136.7              0
 14    14.7            60        0            113.7              0
 15    14.7            60        0            94.9               0
 16    14.7            60        0            79.1               0
 17    14.7            60        0            65.9               0
 18    14.7            60        0            55                 0
 19    14.7            60        0            45.7               0
 20    14.7            60        0            55.6               0
 21    35              40        0            0                  0
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
 16            2             1516   1617
 17            2             1617   1718
 18            2             1718   1819
 19            2             1819   1920
 20            2             1920   2021
BRANCH   UPNODE    DNNODE    OPTION    DESCRIPTION
12         1          2         1       "Pipe 12"
23         2          3         1       "Pipe 23"
34         3          4         1       "Pipe 34"
45         4          5         1       "Pipe 45"
56         5          6         1       "Pipe 56"
67         6          7         1       "Pipe 67"
78         7          8         1       "Pipe 78"
89         8          9         1       "Pipe 89"
910        9          10        1       "Pipe 910"
1011       10         11        1       "Pipe 1011"
1112       11         12        1       "Pipe 1112"
1213       12         13        1       "Pipe 1213"
1314       13         14        1       "Pipe 1314"
1415       14         15        1       "Pipe 1415"
1516       15         16        1       "Pipe 1516"
1617       16         17        1       "Pipe 1617"
1718       17         18        1       "Pipe 1718"
1819       18         19        1       "Pipe 1819"
1920       19         20        1       "Pipe 1920"
2021       20         21        1       "Pipe 2021"
BRANCH        OPTION -1     LENGTH        DIA          EPSD          ANGLE         AREA
 12                         62            6            0                 0         28.27431
BRANCH        OPTION -1     LENGTH        DIA          EPSD          ANGLE         AREA
 23                         74            6            0                 0         28.27431
BRANCH        OPTION -1     LENGTH        DIA          EPSD          ANGLE         AREA
 34                         89            6            0                 0         28.27431
BRANCH        OPTION -1     LENGTH        DIA          EPSD          ANGLE         AREA
 45                         107           6            0                 0         28.27431
BRANCH        OPTION -1     LENGTH        DIA          EPSD          ANGLE         AREA
 56                         128           6            0                 0         28.27431
BRANCH        OPTION -1     LENGTH        DIA          EPSD          ANGLE         AREA
 67                         154           6            0                 0         28.27431
BRANCH        OPTION -1     LENGTH        DIA          EPSD          ANGLE         AREA
 78                         184           6            0                 0         28.27431
BRANCH        OPTION -1     LENGTH        DIA          EPSD          ANGLE         AREA
 89                         221           6            0                 0         28.27431
BRANCH        OPTION -1     LENGTH        DIA          EPSD          ANGLE         AREA
 910                        266           6            0                 0         28.27431
BRANCH        OPTION -1     LENGTH        DIA          EPSD          ANGLE         AREA
```

```
 1011                  319        6          0          0        28.27431
BRANCH       OPTION -1 LENGTH     DIA        EPSD       ANGLE    AREA
 1112                  318        6          0          0        28.27431
BRANCH       OPTION -1 LENGTH     DIA        EPSD       ANGLE    AREA
 1213                  266        6          0          0        28.27431
BRANCH       OPTION -1 LENGTH     DIA        EPSD       ANGLE    AREA
 1314                  221        6          0          0        28.27431
BRANCH       OPTION -1 LENGTH     DIA        EPSD       ANGLE    AREA
 1415                  184        6          0          0        28.27431
BRANCH       OPTION -1 LENGTH     DIA        EPSD       ANGLE    AREA
 1516                  154        6          0          0        28.27431
BRANCH       OPTION -1 LENGTH     DIA        EPSD       ANGLE    AREA
 1617                  128        6          0          0        28.27431
BRANCH       OPTION -1 LENGTH     DIA        EPSD       ANGLE    AREA
 1718                  107        6          0          0        28.27431
BRANCH       OPTION -1 LENGTH     DIA        EPSD       ANGLE    AREA
 1819                  89         6          0          0        28.27431
BRANCH       OPTION -1 LENGTH     DIA        EPSD       ANGLE    AREA
 1920                  74         6          0          0        28.27431
BRANCH       OPTION -1 LENGTH     DIA        EPSD       ANGLE    AREA
 2021                  62         6          0          0        28.27431
BRANCH       NOUBR     NMUBR
 12   0
 23   1   12
 34   1   23
 45   1   34
 56   1   45
 67   1   56
 78   1   67
 89   1   78
 910   1   89
 1011   1   910
 1112   1   1011
 1213   1   1112
 1314   1   1213
 1415   1   1314
 1516   1   1415
 1617   1   1516
 1718   1   1617
 1819   1   1718
 1920   1   1819
 2021   1   1920
BRANCH       NODBR     NMDBR
 12   1   23
 23   1   34
 34   1   45
 45   1   56
```

```
 56    1   67
 67    1   78
 78    1   89
 89    1   910
 910    1   1011
 1011    1   1112
 1112    1   1213
 1213    1   1314
 1314    1   1415
 1415    1   1516
 1516    1   1617
 1617    1   1718
 1718    1   1819
 1819    1   1920
 1920    1   2021
 2021    0
BRANCH
 12
  UPSTRM BR.     ANGLE
  DNSTRM BR.     ANGLE
   23     0.00000
BRANCH
 23
  UPSTRM BR.     ANGLE
   12     0.00000
  DNSTRM BR.     ANGLE
   34     0.00000
BRANCH
 34
  UPSTRM BR.     ANGLE
   23     0.00000
  DNSTRM BR.     ANGLE
   45     0.00000
BRANCH
 45
  UPSTRM BR.     ANGLE
   34     0.00000
  DNSTRM BR.     ANGLE
   56     0.00000
BRANCH
 56
  UPSTRM BR.     ANGLE
   45     0.00000
  DNSTRM BR.     ANGLE
   67     0.00000
BRANCH
 67
```

```
  UPSTRM BR.     ANGLE
   56     0.00000
  DNSTRM BR.     ANGLE
   78     0.00000
BRANCH
 78
  UPSTRM BR.     ANGLE
   67     0.00000
  DNSTRM BR.     ANGLE
   89     0.00000
BRANCH
 89
  UPSTRM BR.     ANGLE
   78     0.00000
  DNSTRM BR.     ANGLE
   910     0.00000
BRANCH
 910
  UPSTRM BR.     ANGLE
   89     0.00000
  DNSTRM BR.     ANGLE
   1011     0.00000
BRANCH
 1011
  UPSTRM BR.     ANGLE
   910     0.00000
  DNSTRM BR.     ANGLE
   1112     0.00000
BRANCH
 1112
  UPSTRM BR.     ANGLE
   1011     0.00000
  DNSTRM BR.     ANGLE
   1213     0.00000
BRANCH
 1213
  UPSTRM BR.     ANGLE
   1112     0.00000
  DNSTRM BR.     ANGLE
   1314     0.00000
BRANCH
 1314
  UPSTRM BR.     ANGLE
   1213     0.00000
  DNSTRM BR.     ANGLE
   1415     0.00000
BRANCH
```

```
 1415
  UPSTRM BR.     ANGLE
   1314     0.00000
  DNSTRM BR.     ANGLE
   1516     0.00000
BRANCH
 1516
  UPSTRM BR.     ANGLE
   1415     0.00000
  DNSTRM BR.     ANGLE
   1617     0.00000
BRANCH
 1617
  UPSTRM BR.     ANGLE
   1516     0.00000
  DNSTRM BR.     ANGLE
   1718     0.00000
BRANCH
 1718
  UPSTRM BR.     ANGLE
   1617     0.00000
  DNSTRM BR.     ANGLE
   1819     0.00000
BRANCH
 1819
  UPSTRM BR.     ANGLE
   1718     0.00000
  DNSTRM BR.     ANGLE
   1920     0.00000
BRANCH
 1920
  UPSTRM BR.     ANGLE
   1819     0.00000
  DNSTRM BR.     ANGLE
   2021     0.00000
BRANCH
 2021
  UPSTRM BR.     ANGLE
   1920     0.00000
  DNSTRM BR.     ANGLE
NUMBER OF BRANCHES WITH INERTIA
 20
 12
 23
 34
 45
 56
```

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Example 19 User Subroutines

```
C                                                                       *

C     ***** GFSSP USER SUBROUTINES *****                                *
C                                                                       *
C************************************************************************
                              :
                              :
                              :
                              :

***********************************************************************
      SUBROUTINE KFADJUST(I,RHOU,EMUU,RHOUL,EMUUL,RHOUV,EMUUV,ISATU,
     &                   AKNEW)
C     PURPOSE: ADJUST RESISTANCE IN A BRANCH
C************************************************************************
      INCLUDE 'COMBLK.FOR'
C***********************************************************************
C     ADD CODE HERE
      IF(IOPT(I).EQ.1) THEN
       PIPEL=BRPR1(I)
       PIPED=BRPR2(I)
       F=0.000000001
       AKNEW=8.*F*PIPEL/(RHOU*GC*PI*PI*PIPED**5)
      ENDIF
      RETURN
      ENDC***********************************************************************
```

NOTE: All other user subroutines are not used in Example 19

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```
              **************************************************
                           G F S S P (Version 604)
                   Generalized Fluid System Simulation Program
                                 March 2012

                  Developed by NASA/Marshall Space Flight Center
                  Copyright (C) by Marshall Space Flight Center

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


                RUN DATE:09/28/2012 12:57

    TITLE      :Subsonic Rayleigh Flow
    ANALYST    :Dr. Alok Majumdar
    FILEIN     :D:\GFSSP604Intel\Examples\Ex19\Ex19.dat
    FILEOUT    :Ex19.out

                                 OPTION VARIABLES

    ADDPROP   BUOYANCY  CONDX     CONJUG    CYCLIC    DALTON    DENCON    ENERGY
    F         F         F         F         F         F         F         T
    FLOWREG   GRAVITY   HCOEF     HEX       HRATE     IFRMIX    INERTIA   INSUC
    0         F         F         F         T         1         T         F
    INVAL     MIXTURE   MOVBND    MSORCE    NORMAL    NRSOLVT   OPVALVE   PLOTADD
    F         F         F         F         F         F         F         F
    PRESREG   PRESS     PRINTI    PRNTADD   PRNTIN    RADIATION REACTING  ROTATION
    0         F         F         T         F         F         F         F
    SAVER     SECONDL   SHEAR     SIMULA    SIUNITS   STEADY    THRUST    TPA
    F         T         F         T         F         T         F         F
    TRANS_MOM TRANSQ    TRANSV    TVM       TWOD      USRVAR    VARGEO    VARROT
    F         F         F         F         F         F         F         F
    RLFVLV
    F

    NNODES    =   21
    NINT      =   19
    NBR       =   20
    NF        =    1
    NVAR      =   39
    NHREF     =    2
```

FLUIDS: N2

BOUNDARY NODES

NODE	P (PSI)	T (F)	RHO (LBM/FT^3)		AREA (IN^2)
1	0.5000E+02	0.8000E+02	0.2420E+00	0.0000E+00	
21	0.3500E+02	0.4000E+02	0.1830E+00	0.0000E+00	

SOLUTION

INTERNAL NODES

NODE	P(PSI)	TF(F)	Z	RHO (LBM/FT^3)	EM(LBM)	QUALITY
2	0.5000E+02	0.8862E+02	0.1000E+01	0.2381E+00	0.0000E+00	0.1000E+01
3	0.4975E+02	0.9494E+02	0.1000E+01	0.2342E+00	0.0000E+00	0.1000E+01
4	0.4949E+02	0.1027E+03	0.1000E+01	0.2297E+00	0.0000E+00	0.1000E+01
5	0.4918E+02	0.1119E+03	0.1000E+01	0.2246E+00	0.0000E+00	0.1000E+01
6	0.4881E+02	0.1229E+03	0.1000E+01	0.2187E+00	0.0000E+00	0.1000E+01
7	0.4835E+02	0.1360E+03	0.1001E+01	0.2118E+00	0.0000E+00	0.1000E+01
8	0.4779E+02	0.1516E+03	0.1001E+01	0.2040E+00	0.0000E+00	0.1000E+01
9	0.4710E+02	0.1701E+03	0.1001E+01	0.1951E+00	0.0000E+00	0.1000E+01
10	0.4625E+02	0.1920E+03	0.1001E+01	0.1851E+00	0.0000E+00	0.1000E+01
11	0.4518E+02	0.2150E+03	0.1001E+01	0.1746E+00	0.0000E+00	0.1000E+01
12	0.4392E+02	0.2348E+03	0.1001E+01	0.1649E+00	0.0000E+00	0.1000E+01
13	0.4261E+02	0.2498E+03	0.1001E+01	0.1566E+00	0.0000E+00	0.1000E+01
14	0.4136E+02	0.2614E+03	0.1001E+01	0.1496E+00	0.0000E+00	0.1000E+01
15	0.4021E+02	0.2703E+03	0.1001E+01	0.1436E+00	0.0000E+00	0.1000E+01
16	0.3916E+02	0.2771E+03	0.1001E+01	0.1386E+00	0.0000E+00	0.1000E+01
17	0.3819E+02	0.2821E+03	0.1001E+01	0.1343E+00	0.0000E+00	0.1000E+01
18	0.3731E+02	0.2857E+03	0.1001E+01	0.1305E+00	0.0000E+00	0.1000E+01
19	0.3651E+02	0.2882E+03	0.1001E+01	0.1273E+00	0.0000E+00	0.1000E+01
20	0.3578E+02	0.2926E+03	0.1001E+01	0.1240E+00	0.0000E+00	0.1000E+01

NODE	H BTU/LB	ENTROPY BTU/LB-R	EMU LBM/FT-SEC	COND BTU/FT-S-R	CP BTU/LB-R	GAMA
2	0.2007E+03	0.9734E+00	0.1223E-04	0.4251E-05	0.2496E+00	0.1405E+01
3	0.2023E+03	0.9766E+00	0.1233E-04	0.4296E-05	0.2496E+00	0.1405E+01
4	0.2042E+03	0.9804E+00	0.1246E-04	0.4351E-05	0.2496E+00	0.1405E+01
5	0.2065E+03	0.9849E+00	0.1261E-04	0.4400E-05	0.2496E+00	0.1404E+01
6	0.2093E+03	0.9902E+00	0.1279E-04	0.4461E-05	0.2496E+00	0.1404E+01
7	0.2125E+03	0.9965E+00	0.1300E-04	0.4534E-05	0.2496E+00	0.1403E+01
8	0.2164E+03	0.1004E+01	0.1325E-04	0.4620E-05	0.2496E+00	0.1403E+01
9	0.2211E+03	0.1012E+01	0.1355E-04	0.4722E-05	0.2497E+00	0.1402E+01
10	0.2265E+03	0.1022E+01	0.1390E-04	0.4841E-05	0.2498E+00	0.1402E+01
11	0.2323E+03	0.1032E+01	0.1419E-04	0.4965E-05	0.2499E+00	0.1401E+01
12	0.2372E+03	0.1042E+01	0.1448E-04	0.5071E-05	0.2500E+00	0.1400E+01

13	0.2410E+03	0.1049E+01	0.1470E-04	0.5151E-05	0.2502E+00	0.1400E+01
14	0.2439E+03	0.1055E+01	0.1486E-04	0.5212E-05	0.2503E+00	0.1399E+01
15	0.2461E+03	0.1060E+01	0.1499E-04	0.5259E-05	0.2503E+00	0.1399E+01
16	0.2478E+03	0.1065E+01	0.1509E-04	0.5294E-05	0.2504E+00	0.1399E+01
17	0.2491E+03	0.1068E+01	0.1516E-04	0.5320E-05	0.2504E+00	0.1398E+01
18	0.2500E+03	0.1071E+01	0.1521E-04	0.5339E-05	0.2505E+00	0.1398E+01
19	0.2506E+03	0.1073E+01	0.1525E-04	0.5353E-05	0.2505E+00	0.1398E+01
20	0.2517E+03	0.1076E+01	0.1531E-04	0.5375E-05	0.2505E+00	0.1398E+01

BRANCHES

BRANCH	KFACTOR (LBF-S^2/(LBM-FT)^2)	DELP (PSI)	FLOW RATE (LBM/SEC)	VELOCITY (FT/SEC)	REYN. NO.	MACH NO.	ENTROPY GEN. BTU/(R-SEC)	LOST WORK LBF-FT/SEC
12	0.172E-07	0.783E-07	0.256E+02	0.539E+03	0.539E+07	0.464E+00	0.284E-08	0.119E-02
23	0.209E-07	0.250E+00	0.256E+02	0.547E+03	0.533E+07	0.468E+00	0.345E-08	0.147E-02
34	0.255E-07	0.262E+00	0.256E+02	0.557E+03	0.528E+07	0.473E+00	0.423E-08	0.183E-02
45	0.313E-07	0.309E+00	0.256E+02	0.567E+03	0.523E+07	0.479E+00	0.522E-08	0.228E-02
56	0.383E-07	0.374E+00	0.256E+02	0.580E+03	0.517E+07	0.486E+00	0.643E-08	0.286E-02
67	0.473E-07	0.456E+00	0.256E+02	0.596E+03	0.510E+07	0.495E+00	0.800E-08	0.363E-02
78	0.584E-07	0.559E+00	0.256E+02	0.615E+03	0.501E+07	0.505E+00	0.996E-08	0.462E-02
89	0.728E-07	0.688E+00	0.256E+02	0.639E+03	0.492E+07	0.518E+00	0.126E-07	0.598E-02
910	0.916E-07	0.855E+00	0.256E+02	0.668E+03	0.481E+07	0.534E+00	0.161E-07	0.787E-02
1011	0.116E-06	0.107E+01	0.256E+02	0.704E+03	0.469E+07	0.553E+00	0.207E-07	0.105E-01
1112	0.122E-06	0.126E+01	0.256E+02	0.746E+03	0.459E+07	0.576E+00	0.224E-07	0.117E-01
1213	0.108E-06	0.131E+01	0.256E+02	0.790E+03	0.450E+07	0.602E+00	0.204E-07	0.110E-01
1314	0.948E-07	0.125E+01	0.256E+02	0.832E+03	0.443E+07	0.627E+00	0.184E-07	0.101E-01
1415	0.826E-07	0.115E+01	0.256E+02	0.871E+03	0.438E+07	0.651E+00	0.165E-07	0.926E-02
1516	0.720E-07	0.105E+01	0.256E+02	0.907E+03	0.435E+07	0.674E+00	0.148E-07	0.840E-02
1617	0.620E-07	0.963E+00	0.256E+02	0.940E+03	0.432E+07	0.695E+00	0.131E-07	0.750E-02
1718	0.535E-07	0.878E+00	0.256E+02	0.971E+03	0.430E+07	0.716E+00	0.116E-07	0.668E-02
1819	0.458E-07	0.802E+00	0.256E+02	0.998E+03	0.428E+07	0.734E+00	0.101E-07	0.588E-02
1920	0.390E-07	0.731E+00	0.256E+02	0.102E+04	0.427E+07	0.752E+00	0.883E-08	0.514E-02
2021	0.336E-07	0.780E+00	0.256E+02	0.105E+04	0.426E+07	0.770E+00	0.775E-08	0.454E-02

***** TOTAL ENTROPY GENERATION = 0.233E-06 BTU/(R-SEC) ******

**** TOTAL WORK LOST = 0.223E-03 HP *****

****

TIME OF ANALYSIS WAS 3.125000000000000E-002 SECS

****

APPENDIX AA—INPUT AND OUTPUT DATA FILES FROM EXAMPLE 20

Lithium Loop Model

Contents

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```
GFSSP VERSION
    604
GFSSP INSTALLATION PATH
C:\Program Files (x86)\GFSSP604\
ANALYST
Alok Majumdar
INPUT DATA FILE NAME
D:\GFSSP604Intel\Examples\Ex20\Ex20.dat
OUTPUT FILE NAME
Ex20.out
TITLE
Lithium Loop Model
USETUP
F
DENCON        GRAVITY       ENERGY        MIXTURE       THRUST        STEADY        TRANSV        SAVER
F             F             T             T             F             T             F             F
HEX           HCOEF         REACTING      INERTIA       CONDX         ADDPROP       PRINTI        ROTATION
T             F             F             T             F             F             T             F
BUOYANCY      HRATE         INVAL         MSORCE        MOVBND        TPA           VARGEO        TVM
F             T             F             F             F             F             F             F
SHEAR         PRNTIN        PRNTADD       OPVALVE       TRANSQ        CONJUG        RADIAT        WINPLOT
F             T             T             F             F             F             F             T
PRESS         INSUC         VARROT        CYCLIC        CHKVALS       WINFILE       DALTON        NOSTATS
F             F             F             T             F             T             F             F
NORMAL        SIMUL         SECONDL       NRSOLVT       IBDF          NOPLT         PRESREG       FLOWREG
F             T             F             F             1             T             0             0
TRANS_MOM     USERVARS      PSMG          ISOLVE        PLOTADD       SIUNITS       TECPLOT       MDGEN
F             F             F             1             F             F             F             F
NUM_USER_VARS IFR_MIX       PRINTD        SATTABL       MSORIN        PRELVLV       LAMINAR       HSTAG
1             1             F             F             F             F             T             T
NNODES        NINT          NBR           NF
 28            25            27            2
RELAXK        RELAXD        RELAXH        CC            NITER         RELAXNR       RELAXHC       RELAXTS
 1               0.5           0.01          1e-06          500 1             1                1
NFLUID(I),  I = 1, NF
 37 4
FLUID 1 PROPERTY FILES
23
AKNAK.DAT
RHONAK.DAT
EMUNAK.DAT
GAMNAK.DAT
HNAK.DAT
SNAK.DAT
CPNAK.DAT
NODE          INDEX     DESCRIPTION
```

```
1             2       " Node 1"
2             1       " Node 2"
6             1       " Node 6"
7             1       " "
8             1       " "
9             1       " "
10             1       " "
11             1       " "
12             1       " "
13             1       " "
14             1       " "
15             1       " "
16             1       " "
17             1       " "
18             1       " "
19             1       " "
20             1       " "
21             1       " "
22             1       " Node 22"
3             1       " "
4             1       " Node 4"
5             1       " Node 5"
30             2       " Node 30"
35             2       " Node 35"
31             1       " Node 31"
32             1       " Node 32"
33             1       " Node 33"
34             1       " Node 34"
NODE  PRES (PSI)  TEMP(DEGF)  MASS SOURC    HEAT SOURC   THRST AREA   CONCENTRATION
1     7            932             0                  0                  0               1 0
2     7.02         932             0                  0                  0               1 0
6     7.02         932             0                  0                  0               1 0
7     7.02         932             0                  0                  0               1 0
8     7.02         932             0                  0                  0               1 0
9     7.02         932             0                  0                  0               1 0
10    7.02         932             0                  0                  0               1 0
11    7.02         932             0                  0                  0               1 0
12    7.02         932             0                  0                  0               1 0
13    7.02         932             0                  0                  0               1 0
14    7.02         932             0                  0                  0               1 0
15    7.02         932             0                  0                  0               1 0
16    7.02         932             0                  0                  0               1 0
17    7.02         932             0                  0                  0               1 0
18    7.02         932             0                  0                  0               1 0
19    7.02         932             0                  0                  0               1 0
20    7.02         932             0                  0                  0               1 0
21    7.02         932             0                  0                  0               1 0
```

22	7.02	932	0	0	0	1	0
3	7.02	932	0	0	0	1	0
4	7.02	932	0	0	0	1	0
5	7.02	930	0	5	0	1	0
30	200	477	0	0	0	0	1
35	14.7	60	0	0	0	0	1
31	7.02	932	0	0	0	0	1
32	7.02	932	0	0	0	0	1
33	7.02	932	0	0	0	0	1
34	7.02	932	0	0	0	0	1

INODE	NUMBR	NAMEBR	
2	2	12	23
6	2	67	56
7	2	78	67
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	1516	1415
16	2	1516	1617
17	2	1617	1718
18	2	1718	1819
19	2	1920	1819
20	2	2021	1920
21	2	2122	2021
22	2	2122	221
3	2	34	23
4	2	34	45
5	2	56	45
31	2	3031	3132
32	2	3132	3233
33	2	3334	3233
34	2	3334	3435

BRANCH	UPNODE	DNNODE	OPTION	DESCRIPTION	
12	1	2	8	"	"
78	7	8	7	"	"
2122	21	22	1	"	"
67	6	7	1	"	"
89	8	9	1	"	"
910	9	10	13	"	"
1011	10	11	1	"	"
1516	15	16	13	"	"
2021	20	21	1	"	"
34	3	4	3	"	"

```
56          5           6           3        "      "
23          2           3           1        "      "
45          4           5           1        "      "
1112        11          12          13       "      "
1213        12          13          1        "      "
1314        13          14          3        "      "
1415        14          15          1        "      "
1617        16          17          1        "      "
1718        17          18          2        "      "
1920        19          20          13       "      "
3334        33          34          1        "      "
3435        34          35          22       "Orifice 3435"
3031        30          31          1        "      "
3132        31          32          1        "      "
3233        32          33          1        "      "
221         22          1           1        "      "
1819        18          19          1        "      "
BRANCH         OPTION -8      PIPE DIA       EXP DIA        AREA
 12                           0.83           6.625          0.54106
BRANCH         OPTION -7      PIPE DIA       RED. DIA       AREA
 78                           6.375          0.87           31.919
BRANCH         OPTION -1      LENGTH         DIA            EPSD           ANGLE          AREA
 2122                         12                 0.81              7.4074074074e-05    0                  0.51529929975
BRANCH         OPTION -1      LENGTH         DIA            EPSD           ANGLE          AREA
 67                           2                  6.375             1.4745098039e-06    0                  31.919045273
BRANCH         OPTION -1      LENGTH         DIA            EPSD           ANGLE          AREA
 89                           2                  0.81              7.4074074074e-05    0                  0.51529929975
BRANCH         OPTION -13     DIA            K1             K2             AREA
 910                          0.87           800           0.2            0.59447
BRANCH         OPTION -1      LENGTH         DIA            EPSD           ANGLE          AREA
 1011                         18                 0.81              7.4074074074e-05    0                  0.51529929975
BRANCH         OPTION -13     DIA            K1             K2             AREA
 1516                         0.87           800           0.2            0.59447
BRANCH         OPTION -1      LENGTH         DIA            EPSD           ANGLE          AREA
 2021                         9                  0.81              7.4074074074e-05    0                  0.51529929975
BRANCH         OPTION -3      LENGTH         HEIGHT         WIDTH          TYPE           AREA
 34                           25             6.357          6.625          3              10.9301445298
BRANCH         OPTION -3      LENGTH         HEIGHT         WIDTH          TYPE           AREA
 56                           0.018          0.5            0.68           3              0.667273716
BRANCH         OPTION -1      LENGTH         DIA            EPSD           ANGLE          AREA
 23                           6.5                6                 1.6666666667e-06    0                  28.27431
BRANCH         OPTION -1      LENGTH         DIA            EPSD           ANGLE          AREA
 45                           1                  6.625             1.5094339623e-06    0                  34.471587148
BRANCH         OPTION -13     DIA            K1             K2             AREA
 1112                         0.87           800           0.2            0.59447
BRANCH         OPTION -1      LENGTH         DIA            EPSD           ANGLE          AREA
 1213                         2                  0.81              7.4074074074e-05    0                  0.51529929975
```

```
BRANCH        OPTION -3     LENGTH        HEIGHT        WIDTH         TYPE          AREA
 1314                       46.56         2.8           5             3             53.9096844
BRANCH        OPTION -1     LENGTH        DIA           EPSD          ANGLE         AREA
 1415                       27                0.81          7.4074074074e-05    0                 0.51529929975
BRANCH        OPTION -1     LENGTH        DIA           EPSD          ANGLE         AREA
 1617                       30.25             0.81          7.4074074074e-05    0                 0.51529929975
BRANCH        OPTION -2     FLOW COEFF    AREA
 1718                       0             0.5944
BRANCH        OPTION -13    DIA           K1            K2            AREA
 1920                       1             800          0.2          0.7854
BRANCH        OPTION -1     LENGTH        DIA           EPSD          ANGLE         AREA
 3334                       5                 5.292         1.8896447468e-06    0                 21.995264332
BRANCH        OPTION -22     AREA       FLOW COEF
 3435                       0.13          1
BRANCH        OPTION -1     LENGTH        DIA           EPSD          ANGLE         AREA
 3031                       13                3.26          6.1349693252e-06    0                 8.346890471
BRANCH        OPTION -1     LENGTH        DIA           EPSD          ANGLE         AREA
 3132                       5                 5.292         1.8896447468e-06    0                 21.995264332
BRANCH        OPTION -1     LENGTH        DIA           EPSD          ANGLE         AREA
 3233                       0.17              0.1875        0.0017066666667    0                 0.027611630859
BRANCH        OPTION -1     LENGTH        DIA           EPSD          ANGLE         AREA
 221                        9                 0.81          7.4074074074e-05    0                 0.51529929975
BRANCH        OPTION -1     LENGTH        DIA           EPSD          ANGLE         AREA
 1819                       37                0.81          0                  0                 0.51529929975
BRANCH        NOUBR         NMUBR
 12    1   221
 78    1   67
 2122    1   2021
 67    1   56
 89    1   78
 910    1   89
 1011    1   910
 1516    1   1415
 2021    1   1920
 34    1   23
 56    1   45
 23    1   12
 45    1   34
 1112    1   1011
 1213    1   1112
 1314    1   1213
 1415    1   1314
 1617    1   1516
 1718    1   1617
 1920    1   1819
 3334    1   3233
 3435    1   3334
```

```
 3031    0
 3132    1   3031
 3233    1   3132
 221    1   2122
 1819    1   1718
BRANCH         NODBR          NMDBR
 12    1   23
 78    1   89
 2122    1   221
 67    1   78
 89    1   910
 910    1   1011
 1011    1   1112
 1516    1   1617
 2021    1   2122
 34    1   45
 56    1   67
 23    1   34
 45    1   56
 1112    1   1213
 1213    1   1314
 1314    1   1415
 1415    1   1516
 1617    1   1718
 1718    1   1819
 1920    1   2021
 3334    1   3435
 3435    0
 3031    1   3132
 3132    1   3233
 3233    1   3334
 221    1   12
 1819    1   1920
BRANCH
 12
  UPSTRM BR.     ANGLE
   221     0.00000
  DNSTRM BR.     ANGLE
   23     0.00000
BRANCH
 78
  UPSTRM BR.     ANGLE
   67     0.00000
  DNSTRM BR.     ANGLE
   89     0.00000
BRANCH
 2122
```

```
  UPSTRM BR.     ANGLE
   2021     0.00000
  DNSTRM BR.     ANGLE
   221     0.00000
BRANCH
 67
  UPSTRM BR.     ANGLE
   56     0.00000
  DNSTRM BR.     ANGLE
   78     0.00000
BRANCH
 89
  UPSTRM BR.     ANGLE
   78     0.00000
  DNSTRM BR.     ANGLE
   910     0.00000
BRANCH
 910
  UPSTRM BR.     ANGLE
   89     0.00000
  DNSTRM BR.     ANGLE
   1011     0.00000
BRANCH
 1011
  UPSTRM BR.     ANGLE
   910     0.00000
  DNSTRM BR.     ANGLE
   1112     0.00000
BRANCH
 1516
  UPSTRM BR.     ANGLE
   1415     0.00000
  DNSTRM BR.     ANGLE
   1617     0.00000
BRANCH
 2021
  UPSTRM BR.     ANGLE
   1920     0.00000
  DNSTRM BR.     ANGLE
   2122     0.00000
BRANCH
 34
  UPSTRM BR.     ANGLE
   23     0.00000
  DNSTRM BR.     ANGLE
   45     0.00000
BRANCH
```

```
 56
  UPSTRM BR.     ANGLE
   45     0.00000
  DNSTRM BR.     ANGLE
   67     0.00000
BRANCH
 23
  UPSTRM BR.     ANGLE
   12     0.00000
  DNSTRM BR.     ANGLE
   34     0.00000
BRANCH
 45
  UPSTRM BR.     ANGLE
   34     0.00000
  DNSTRM BR.     ANGLE
   56     0.00000
BRANCH
 1112
  UPSTRM BR.     ANGLE
   1011     0.00000
  DNSTRM BR.     ANGLE
   1213     0.00000
BRANCH
 1213
  UPSTRM BR.     ANGLE
   1112     0.00000
  DNSTRM BR.     ANGLE
   1314     0.00000
BRANCH
 1314
  UPSTRM BR.     ANGLE
   1213     0.00000
  DNSTRM BR.     ANGLE
   1415     0.00000
BRANCH
 1415
  UPSTRM BR.     ANGLE
   1314     0.00000
  DNSTRM BR.     ANGLE
   1516     0.00000
BRANCH
 1617
  UPSTRM BR.     ANGLE
   1516     0.00000
  DNSTRM BR.     ANGLE
   1718     0.00000
```

```
BRANCH
 1718
  UPSTRM BR.     ANGLE
   1617     0.00000
  DNSTRM BR.     ANGLE
   1819     0.00000
BRANCH
 1920
  UPSTRM BR.     ANGLE
   1819     0.00000
  DNSTRM BR.     ANGLE
   2021     0.00000
BRANCH
 3334
  UPSTRM BR.     ANGLE
   3233     0.00000
  DNSTRM BR.     ANGLE
   3435     0.00000
BRANCH
 3435
  UPSTRM BR.     ANGLE
   3334     0.00000
  DNSTRM BR.     ANGLE
BRANCH
 3031
  UPSTRM BR.     ANGLE
  DNSTRM BR.     ANGLE
   3132     0.00000
BRANCH
 3132
  UPSTRM BR.     ANGLE
   3031     0.00000
  DNSTRM BR.     ANGLE
   3233     0.00000
BRANCH
 3233
  UPSTRM BR.     ANGLE
   3132     0.00000
  DNSTRM BR.     ANGLE
   3334     0.00000
BRANCH
 221
  UPSTRM BR.     ANGLE
   2122     0.00000
  DNSTRM BR.     ANGLE
   12     0.00000
BRANCH
```

```
 1819
  UPSTRM BR.     ANGLE
   1718     0.00000
  DNSTRM BR.     ANGLE
   1920     0.00000
NUMBER OF BRANCHES WITH INERTIA
 0
NUMBER OF HEAT EXCHANGERS
1
 IBRHOT   IBRCLD   ITYPHX   ARHOT      ARCOLD      UA     HEXEFF
1314   3233    1       0          0          0          0.9
CYCLIC BNDARY NODE    UPSTREAM NODE
1          22
```

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Example 20 User Subroutines

```
C                                                                       *
                                                                                
C     ***** GFSSP USER SUBROUTINES *****                                *
C                                                                       *
C************************************************************************
                              :
                              :
                              :
                              :

***********************************************************************
      SUBROUTINE SORCEF(I,TERM0,TERM1,TERM2,TERM3,TERM4,TERM5,TERM6,
     &                  TERM7,TERM8,TERM9,TERM10,TERM100)
C     PURPOSE: ADD MOMENTUM SOURCES (LBF)
C     I - GFSSP INDEX NUMBER FOR BRANCH
C     TERM0 - UNSTEADY TERM IN MOMENTUM CONSERVATION EQUATION
C     TERM1 - LONGITUDINAL INERTIA
C     TERM2 - PRESSURE GRADIENT
C     TERM3 - GRAVITY FORCE
C     TERM4 - FRICTION FORCE
C     TERM5 - CENTRIFUGAL FORCE
C     TERM6 - EXTERNAL MOMETUM SOURCE DUE TO PUMP
C     TERM7 - MOMENTUM SOURCE DUE TO TRANSVERSE FLOW(MULTI-DIMENSIONAL MODEL)
C     TERM8 - MOMENTUM SOURCE DUE TO SHEAR(MULTI-DIMENSIONAL MODEL)
C     TERM9 - VARIABLE GEOMETRY UNSTEADY TERM
C     TERM10 - NORMAL STRESS
C     TERM100 - USER SUPPLIED MOMENTUM SOURCE
C************************************************************************
       INCLUDE 'COMBLK.FOR'
C***********************************************************************
C     ADD CODE HERE
C     MODELING OF THERMO-ELECTRIC PUMP
      DIMENSION VOLT(50),FLWTE(50),DPTE(50,50)
       LOGICAL UNREAD
      DATA VOLTIN/170/
C     READ PUMP CHARACTERISTIC DATA FROM FILE
      IF (ITER.EQ.1.AND. (.NOT. UNREAD)) THEN
       OPEN (NUSR1,FILE='Ex20_pump.dat',STATUS='UNKNOWN')
       READ(NUSR1,*) NFLW,NVOLT
       READ(NUSR1,*)  (VOLT(JJ),JJ=1,NVOLT)
       DO II = 1,NFLW
        READ(NUSR1,*) FLWTE(II),(DPTE(II,JJ),JJ=1,NVOLT)
       ENDDO
       UNREAD = .TRUE.
      ENDIF ! IF (ITER.EQ.0)..
```

```
      IF (IBRANCH(I) .EQ. 1718) THEN
C     BRACKET THE FLOWRATE
      IR=0
      DO II =2,NFLW
        IF (FLOWR(I).GE.FLWTE(II-1).AND.FLOWR(I).LE.FLWTE(II)) THEN
         IR=II
         GO TO 100
        ENDIF
      ENDDO
100   IF (IR.EQ.0) THEN
       IF (FLOWR(I).GT.FLWTE(NFLW)) IR=NFLW
       IF (FLOWR(I).LT.FLWTE(1)) IR=2
      ENDIF
C     BRACKET THE VOLT
      JR=0
      DO JJ = 2,NVOLT
        IF (VOLTIN.GE.VOLT(JJ-1).AND.VOLTIN.LE.VOLT(JJ)) THEN
         JR=JJ
         GO TO 200
        ENDIF
      ENDDO
200   IF (JR.EQ.0) THEN
        IF(VOLTIN.GT.VOLT(NVOLT)) JR=NVOLT
        IF(VOLTIN.LT.VOLT(1)) JR=2
      ENDIF
C     CALCULATE DELPTE
      FACTFLW=(FLOWR(I)-FLWTE(IR-1))/(FLWTE(IR)-FLWTE(IR-1))
      FACTV=(VOLTIN-VOLT(JR-1))/(VOLT(JR)-VOLT(JR-1))
      DELPTE=(1.-FACTFLW)*(1.-FACTV)*DPTE(IR-1,JR-1)
     &       +FACTFLW*(1.-FACTV)*DPTE(IR,JR-1)
     &       +FACTFLW*FACTV*DPTE(IR,JR)
     &       +(1.-FACTFLW)*FACTV*DPTE(IR-1,JR)
      TERM100=144*DELPTE*AREA(I)


      ENDIF ! IF (IBRANCH(I).EQ...)


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

```
C*********************************************************************
       INCLUDE 'COMBLK.FOR'
C********************************************************************
C********************************************************************
C     ADD CODE HERE
      DATA TCINLET/1512.6/
      IF (NODE(IPN).EQ.19) THEN
        SORCEH(IPN)=1.E20*TCINLET
        TERMD=1.E20
      ENDIF
      RETURN
      END
C*********************************************************************
```

NOTE: All other user subroutines are not used in Example 20

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```
**************************************************
              G F S S P (Version 604)
      Generalized Fluid System Simulation Program
                    March 2012

     Developed by NASA/Marshall Space Flight Center
     Copyright (C) by Marshall Space Flight Center

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

   RUN DATE:03/27/2012 08:54

TITLE     :Lithium Loop Model
ANALYST   :Alok Majumdar
FILEIN    :D:\GFSSP604Intel\Examples\Ex20\Ex20.dat
FILEOUT   :Ex20.out

                          OPTION VARIABLES

ADDPROP   BUOYANCY  CONDX     CONJUG    CYCLIC    DALTON    DENCON    ENERGY
F         F         F         F         T         F         F         T
FLOWREG   GRAVITY   HCOEF     HEX       HRATE     IFRMIX    INERTIA   INSUC
0         F         F         T         T         1         T         F
INVAL     MIXTURE   MOVBND    MSORCE    NORMAL    NRSOLVT   OPVALVE   PLOTADD
F         T         F         F         F         F         F         F
PRESREG   PRESS     PRINTI    PRNTADD   PRNTIN    RADIATION REACTING  ROTATION
0         F         T         T         T         F         F         F
SAVER     SECONDL   SHEAR     SIMULA    SIUNITS   STEADY    THRUST    TPA
F         F         F         T         F         T         F         F
TRANS_MOM TRANSQ    TRANSV    TVM       TWOD      USRVAR    VARGEO    VARROT
F         F         F         F         F         F         F         F
RLFVLV
F

NNODES   =   28
NINT     =   25
NBR      =   27
NF       =    2
NVAR     =   52
NHREF    =    2
```

FLUIDS: FLD1 N2

BOUNDARY NODES

NODE	P (PSI)	T (F)	RHO (LBM/FT^3)	AREA (IN^2)	CONCENTRATIONS FLD1	N2
1	0.7000E+01	0.9320E+03	0.4716E+02	0.0000E+00	0.1000E+01	0.0000E+00
30	0.2000E+03	0.4770E+03	0.5541E+00	0.0000E+00	0.0000E+00	0.1000E+01
35	0.1470E+02	0.6000E+02	0.7386E-01	0.0000E+00	0.0000E+00	0.1000E+01

INPUT SPECIFICATIONS FOR INTERNAL NODES

NODE	AREA (IN^2)	MASS (LBM/S)	HEAT (BTU/S)
2	0.0000E+00	0.0000E+00	0.0000E+00
6	0.0000E+00	0.0000E+00	0.0000E+00
7	0.0000E+00	0.0000E+00	0.0000E+00
8	0.0000E+00	0.0000E+00	0.0000E+00
9	0.0000E+00	0.0000E+00	0.0000E+00
10	0.0000E+00	0.0000E+00	0.0000E+00
11	0.0000E+00	0.0000E+00	0.0000E+00
12	0.0000E+00	0.0000E+00	0.0000E+00
13	0.0000E+00	0.0000E+00	0.0000E+00
14	0.0000E+00	0.0000E+00	0.0000E+00
15	0.0000E+00	0.0000E+00	0.0000E+00
16	0.0000E+00	0.0000E+00	0.0000E+00
17	0.0000E+00	0.0000E+00	0.0000E+00
18	0.0000E+00	0.0000E+00	0.0000E+00
19	0.0000E+00	0.0000E+00	0.0000E+00
20	0.0000E+00	0.0000E+00	0.0000E+00
21	0.0000E+00	0.0000E+00	0.0000E+00
22	0.0000E+00	0.0000E+00	0.0000E+00
3	0.0000E+00	0.0000E+00	0.0000E+00
4	0.0000E+00	0.0000E+00	0.0000E+00
5	0.0000E+00	0.0000E+00	0.5000E+01
31	0.0000E+00	0.0000E+00	0.0000E+00
32	0.0000E+00	0.0000E+00	0.0000E+00
33	0.0000E+00	0.0000E+00	0.0000E+00
34	0.0000E+00	0.0000E+00	0.0000E+00

BRANCH	UPNODE	DNNODE	OPTION
12	1	2	8
78	7	8	7
2122	21	22	1
67	6	7	1
89	8	9	1
910	9	10	13
1011	10	11	1

```
   1516        15        16        13
   2021        20        21         1
     34         3         4         3
     56         5         6         3
     23         2         3         1
     45         4         5         1
   1112        11        12        13
   1213        12        13         1
   1314        13        14         3
   1415        14        15         1
   1617        16        17         1
   1718        17        18         2
   1920        19        20        13
   3334        33        34         1
   3435        34        35        22
   3031        30        31         1
   3132        31        32         1
   3233        32        33         1
    221        22         1         1
   1819        18        19         1
BRANCH OPTION -8:  PIPE DIA      EXP DIA     AREA
     12            0.830E+00   0.662E+01   0.541E+00
BRANCH OPTION -7:   PIPE DIA   REDUCED DIA AREA
     78            0.638E+01   0.870E+00   0.319E+02
BRANCH  OPTION -1:   LENGTH      DIA        EPSD       ANGLE        AREA
   2122            0.120E+02   0.810E+00   0.741E-04   0.000E+00   0.515E+00
BRANCH  OPTION -1:   LENGTH      DIA        EPSD       ANGLE        AREA
     67            0.200E+01   0.638E+01   0.147E-05   0.000E+00   0.319E+02
BRANCH  OPTION -1:   LENGTH      DIA        EPSD       ANGLE        AREA
     89            0.200E+01   0.810E+00   0.741E-04   0.000E+00   0.515E+00
BRANCH OPTION -13:  DIA  K1   K2  AREA
    910            0.870E+00   0.800E+03   0.200E+00   0.594E+00
BRANCH  OPTION -1:   LENGTH      DIA        EPSD       ANGLE        AREA
   1011            0.180E+02   0.810E+00   0.741E-04   0.000E+00   0.515E+00
BRANCH OPTION -13:  DIA  K1   K2  AREA
   1516            0.870E+00   0.800E+03   0.200E+00   0.594E+00
BRANCH  OPTION -1:   LENGTH      DIA        EPSD       ANGLE        AREA
   2021            0.900E+01   0.810E+00   0.741E-04   0.000E+00   0.515E+00
BR OPT -> 3-3 LENGTH   INNER RAD   OUTER RAD   TYPE        AREA
     34            0.250E+02   0.636E+01   0.662E+01   0.300E+01   0.109E+02
BR OPT -> 3-3 LENGTH   INNER RAD   OUTER RAD   TYPE        AREA
     56            0.180E-01   0.500E+00   0.680E+00   0.300E+01   0.667E+00
BRANCH  OPTION -1:   LENGTH      DIA        EPSD       ANGLE        AREA
     23            0.650E+01   0.600E+01   0.167E-05   0.000E+00   0.283E+02
BRANCH  OPTION -1:   LENGTH      DIA        EPSD       ANGLE        AREA
     45            0.100E+01   0.662E+01   0.151E-05   0.000E+00   0.345E+02
BRANCH OPTION -13:  DIA  K1   K2  AREA
```

```
   1112             0.870E+00   0.800E+03   0.200E+00   0.594E+00
BRANCH  OPTION -1:   LENGTH      DIA         EPSD       ANGLE         AREA
   1213             0.200E+01   0.810E+00   0.741E-04   0.000E+00   0.515E+00
BR OPT -> 3-3 LENGTH   INNER RAD   OUTER RAD   TYPE        AREA
   1314             0.466E+02   0.280E+01   0.500E+01   0.300E+01   0.539E+02
BRANCH  OPTION -1:   LENGTH      DIA         EPSD       ANGLE         AREA
   1415             0.270E+02   0.810E+00   0.741E-04   0.000E+00   0.515E+00
BRANCH  OPTION -1:   LENGTH      DIA         EPSD       ANGLE         AREA
   1617             0.302E+02   0.810E+00   0.741E-04   0.000E+00   0.515E+00
BRANCH OPTION -2:  FLOW COEF  AREA
   1718             0.000E+00   0.594E+00
BRANCH OPTION -13:  DIA  K1   K2  AREA
   1920             0.100E+01   0.800E+03   0.200E+00   0.785E+00
BRANCH  OPTION -1:   LENGTH      DIA         EPSD       ANGLE         AREA
   3334             0.500E+01   0.529E+01   0.189E-05   0.000E+00   0.220E+02
BRANCH OPTION -22 FLOW COEF   AREA
   3435             0.100E+01   0.130E+00
BRANCH  OPTION -1:   LENGTH      DIA         EPSD       ANGLE         AREA
   3031             0.130E+02   0.326E+01   0.613E-05   0.000E+00   0.835E+01
BRANCH  OPTION -1:   LENGTH      DIA         EPSD       ANGLE         AREA
   3132             0.500E+01   0.529E+01   0.189E-05   0.000E+00   0.220E+02
BRANCH  OPTION -1:   LENGTH      DIA         EPSD       ANGLE         AREA
   3233             0.170E+00   0.188E+00   0.171E-02   0.000E+00   0.276E-01
BRANCH  OPTION -1:   LENGTH      DIA         EPSD       ANGLE         AREA
    221             0.900E+01   0.810E+00   0.741E-04   0.000E+00   0.515E+00
BRANCH  OPTION -1:   LENGTH      DIA         EPSD       ANGLE         AREA
   1819             0.370E+02   0.810E+00   0.000E+00   0.000E+00   0.515E+00

INITIAL GUESS FOR INTERNAL NODES

   NODE    P(PSI)   TF(F)      Z(COMP)    RHO       CONCENTRATIONS
                                         (LBM/FT^3)
                                                             FLD1      N2
     2    0.7020E+01  0.9320E+03  0.2293E-03  0.4716E+02  0.1000E+01  0.0000E+00
     6    0.7020E+01  0.9320E+03  0.2293E-03  0.4716E+02  0.1000E+01  0.0000E+00
     7    0.7020E+01  0.9320E+03  0.2293E-03  0.4716E+02  0.1000E+01  0.0000E+00
     8    0.7020E+01  0.9320E+03  0.2293E-03  0.4716E+02  0.1000E+01  0.0000E+00
     9    0.7020E+01  0.9320E+03  0.2293E-03  0.4716E+02  0.1000E+01  0.0000E+00
    10    0.7020E+01  0.9320E+03  0.2293E-03  0.4716E+02  0.1000E+01  0.0000E+00
    11    0.7020E+01  0.9320E+03  0.2293E-03  0.4716E+02  0.1000E+01  0.0000E+00
    12    0.7020E+01  0.9320E+03  0.2293E-03  0.4716E+02  0.1000E+01  0.0000E+00
    13    0.7020E+01  0.9320E+03  0.2293E-03  0.4716E+02  0.1000E+01  0.0000E+00
    14    0.7020E+01  0.9320E+03  0.2293E-03  0.4716E+02  0.1000E+01  0.0000E+00
    15    0.7020E+01  0.9320E+03  0.2293E-03  0.4716E+02  0.1000E+01  0.0000E+00
    16    0.7020E+01  0.9320E+03  0.2293E-03  0.4716E+02  0.1000E+01  0.0000E+00
    17    0.7020E+01  0.9320E+03  0.2293E-03  0.4716E+02  0.1000E+01  0.0000E+00
    18    0.7020E+01  0.9320E+03  0.2293E-03  0.4716E+02  0.1000E+01  0.0000E+00
```

19	0.7020E+01	0.9320E+03	0.2293E-03	0.4716E+02	0.1000E+01	0.0000E+00
20	0.7020E+01	0.9320E+03	0.2293E-03	0.4716E+02	0.1000E+01	0.0000E+00
21	0.7020E+01	0.9320E+03	0.2293E-03	0.4716E+02	0.1000E+01	0.0000E+00
22	0.7020E+01	0.9320E+03	0.2293E-03	0.4716E+02	0.1000E+01	0.0000E+00
3	0.7020E+01	0.9320E+03	0.2293E-03	0.4716E+02	0.1000E+01	0.0000E+00
4	0.7020E+01	0.9320E+03	0.2293E-03	0.4716E+02	0.1000E+01	0.0000E+00
5	0.7020E+01	0.9300E+03	0.2296E-03	0.4717E+02	0.1000E+01	0.0000E+00
31	0.7020E+01	0.9320E+03	0.1000E+01	0.1317E-01	0.0000E+00	0.1000E+01
32	0.7020E+01	0.9320E+03	0.1000E+01	0.1317E-01	0.0000E+00	0.1000E+01
33	0.7020E+01	0.9320E+03	0.1000E+01	0.1317E-01	0.0000E+00	0.1000E+01
34	0.7020E+01	0.9320E+03	0.1000E+01	0.1317E-01	0.0000E+00	0.1000E+01

TRIAL SOLUTION

BRANCH	DELP(PSI)	FLOWRATE(LBM/SEC)
12	0.0000	0.0100
78	0.0000	0.0100
2122	0.0000	0.0100
67	0.0000	0.0100
89	0.0000	0.0100
910	0.0000	0.0100
1011	0.0000	0.0100
1516	0.0000	0.0100
2021	0.0000	0.0100
34	0.0000	0.0100
56	0.0000	0.0100
23	0.0000	0.0100
45	0.0000	0.0100
1112	0.0000	0.0100
1213	0.0000	0.0100
1314	0.0000	0.0100
1415	0.0000	0.0100
1617	0.0000	0.0100
1718	0.0000	0.0100
1920	0.0000	0.0100
3334	0.0000	0.0100
3435	0.0000	0.0100
3031	0.0000	0.0100
3132	0.0000	0.0100
3233	0.0000	0.0100
221	0.0000	0.0100
1819	0.0000	0.0100

SOLUTION

INTERNAL NODES

NODE	P(PSI)	TF(F)	Z	RHO (LBM/FT^3)	EM(LBM)	CONC

					FLD1	N2	
2	0.5707E+01	0.9320E+03	0.1864E-03	0.4716E+02	0.0000E+00	0.1000E+01	0.0000
6	0.5701E+01	0.9398E+03	0.1854E-03	0.4709E+02	0.0000E+00	0.1000E+01	0.0000
7	0.5701E+01	0.9398E+03	0.1854E-03	0.4709E+02	0.0000E+00	0.1000E+01	0.0000
8	0.5045E+01	0.9398E+03	0.1641E-03	0.4709E+02	0.0000E+00	0.1000E+01	0.0000
9	0.4994E+01	0.9398E+03	0.1624E-03	0.4709E+02	0.0000E+00	0.1000E+01	0.0000
10	0.4521E+01	0.9398E+03	0.1470E-03	0.4709E+02	0.0000E+00	0.1000E+01	0.0000
11	0.4057E+01	0.9398E+03	0.1320E-03	0.4709E+02	0.0000E+00	0.1000E+01	0.0000
12	0.3584E+01	0.9398E+03	0.1166E-03	0.4709E+02	0.0000E+00	0.1000E+01	0.0000
13	0.3533E+01	0.9398E+03	0.1149E-03	0.4709E+02	0.0000E+00	0.1000E+01	0.0000
14	0.3533E+01	0.8829E+03	0.1186E-03	0.4756E+02	0.0000E+00	0.1000E+01	0.0000
15	0.2838E+01	0.8829E+03	0.9527E-04	0.4756E+02	0.0000E+00	0.1000E+01	0.0000
16	0.2369E+01	0.8829E+03	0.7954E-04	0.4756E+02	0.0000E+00	0.1000E+01	0.0000
17	0.1591E+01	0.8829E+03	0.5341E-04	0.4756E+02	0.0000E+00	0.1000E+01	0.0000
18	0.8918E+01	0.8829E+03	0.2994E-03	0.4756E+02	0.0000E+00	0.1000E+01	0.0000
19	0.8025E+01	0.9320E+03	0.2621E-03	0.4716E+02	0.0000E+00	0.1000E+01	0.0000
20	0.7773E+01	0.9320E+03	0.2539E-03	0.4716E+02	0.0000E+00	0.1000E+01	0.0000
21	0.7541E+01	0.9320E+03	0.2463E-03	0.4716E+02	0.0000E+00	0.1000E+01	0.0000
22	0.7232E+01	0.9320E+03	0.2362E-03	0.4716E+02	0.0000E+00	0.1000E+01	0.0000
3	0.5707E+01	0.9320E+03	0.1864E-03	0.4716E+02	0.0000E+00	0.1000E+01	0.0000
4	0.5702E+01	0.9320E+03	0.1862E-03	0.4716E+02	0.0000E+00	0.1000E+01	0.0000
5	0.5702E+01	0.9398E+03	0.1855E-03	0.4709E+02	0.0000E+00	0.1000E+01	0.0000
31	0.2000E+03	0.4770E+03	0.1006E+01	0.5542E+00	0.0000E+00	0.0000E+00	1.0000
32	0.2000E+03	0.4770E+03	0.1006E+01	0.5542E+00	0.0000E+00	0.0000E+00	1.0000
33	0.1868E+03	0.8443E+03	0.1006E+01	0.3720E+00	0.0000E+00	0.0000E+00	1.0000
34	0.1868E+03	0.8443E+03	0.1006E+01	0.3720E+00	0.0000E+00	0.0000E+00	1.0000

NODE	H BTU/LB	ENTROPY BTU/LB-R	EMU LBM/FT-SEC	COND BTU/FT-S-R	CP BTU/LB-R	GAMA
2	0.0000E+00	0.0000E+00	0.1197E-03	0.2588E+00	0.2088E+00	0.1000E+01
6	0.0000E+00	0.0000E+00	0.1184E-03	0.2609E+00	0.2089E+00	0.1000E+01
7	0.0000E+00	0.0000E+00	0.1184E-03	0.2609E+00	0.2089E+00	0.1000E+01
8	0.0000E+00	0.0000E+00	0.1184E-03	0.2609E+00	0.2089E+00	0.1000E+01
9	0.0000E+00	0.0000E+00	0.1184E-03	0.2609E+00	0.2089E+00	0.1000E+01
10	0.0000E+00	0.0000E+00	0.1184E-03	0.2609E+00	0.2089E+00	0.1000E+01
11	0.0000E+00	0.0000E+00	0.1184E-03	0.2609E+00	0.2089E+00	0.1000E+01
12	0.0000E+00	0.0000E+00	0.1184E-03	0.2609E+00	0.2089E+00	0.1000E+01
13	0.0000E+00	0.0000E+00	0.1184E-03	0.2609E+00	0.2089E+00	0.1000E+01
14	0.0000E+00	0.0000E+00	0.1261E-03	0.2451E+00	0.2081E+00	0.1000E+01
15	0.0000E+00	0.0000E+00	0.1261E-03	0.2451E+00	0.2081E+00	0.1000E+01
16	0.0000E+00	0.0000E+00	0.1261E-03	0.2451E+00	0.2081E+00	0.1000E+01
17	0.0000E+00	0.0000E+00	0.1261E-03	0.2451E+00	0.2081E+00	0.1000E+01
18	0.0000E+00	0.0000E+00	0.1261E-03	0.2451E+00	0.2081E+00	0.1000E+01
19	0.0000E+00	0.0000E+00	0.1197E-03	0.2588E+00	0.2088E+00	0.1000E+01
20	0.0000E+00	0.0000E+00	0.1197E-03	0.2588E+00	0.2088E+00	0.1000E+01
21	0.0000E+00	0.0000E+00	0.1197E-03	0.2588E+00	0.2088E+00	0.1000E+01

22	0.0000E+00	0.0000E+00	0.1197E-03	0.2588E+00	0.2088E+00	0.1000E+01
3	0.0000E+00	0.0000E+00	0.1197E-03	0.2588E+00	0.2088E+00	0.1000E+01
4	0.0000E+00	0.0000E+00	0.1197E-03	0.2588E+00	0.2088E+00	0.1000E+01
5	0.0000E+00	0.0000E+00	0.1184E-03	0.2609E+00	0.2089E+00	0.1000E+01
31	0.0000E+00	0.1009E+01	0.1784E-04	0.6307E-05	0.2546E+00	0.1396E+01
32	0.0000E+00	0.1009E+01	0.1784E-04	0.6307E-05	0.2546E+00	0.1396E+01
33	0.0000E+00	0.1099E+01	0.2226E-04	0.8027E-05	0.2642E+00	0.1371E+01
34	0.0000E+00	0.1099E+01	0.2226E-04	0.8027E-05	0.2642E+00	0.1371E+01

BRANCHES

BRANCH	KFACTOR (LBF-S^2/(LBM-FT)^2)	DELP (PSI)	FLOW RATE (LBM/SEC)	VELOCITY (FT/SEC)	REYN. NO.	MACH NO.	ENTROPY GEN. BTU/(R-SEC)	LOST WORK LBF-FT/SEC
12	0.229E+02	0.129E+01	0.285E+01	0.161E+02	0.439E+06	0.929E-02	0.104E-04	0.113E+02
78	0.116E+02	0.656E+00	0.285E+01	0.273E+00	0.578E+05	0.157E-03	0.525E-05	0.572E+01
2122	0.546E+01	0.309E+00	0.285E+01	0.169E+02	0.450E+06	0.975E-02	0.249E-05	0.270E+01
67	0.426E-04	0.241E-05	0.285E+01	0.273E+00	0.578E+05	0.157E-03	0.193E-10	0.211E-04
89	0.911E+00	0.515E-01	0.285E+01	0.169E+02	0.455E+06	0.974E-02	0.413E-06	0.450E+00
910	0.836E+01	0.473E+00	0.285E+01	0.147E+02	0.423E+06	0.844E-02	0.379E-05	0.413E+01
1011	0.820E+01	0.464E+00	0.285E+01	0.169E+02	0.455E+06	0.974E-02	0.372E-05	0.405E+01
1516	0.828E+01	0.469E+00	0.285E+01	0.145E+02	0.397E+06	0.853E-02	0.388E-05	0.405E+01
2021	0.410E+01	0.232E+00	0.285E+01	0.169E+02	0.450E+06	0.975E-02	0.187E-05	0.202E+01
34	0.838E-01	0.474E-02	0.285E+01	0.797E+00	0.977E+05	0.460E-03	0.382E-07	0.413E-01
56	0.137E-01	0.775E-03	0.285E+01	0.131E+02	0.400E+06	0.752E-02	0.621E-08	0.677E-02
23	0.185E-03	0.105E-04	0.285E+01	0.308E+00	0.607E+05	0.178E-03	0.844E-10	0.914E-04
45	0.178E-04	0.100E-05	0.285E+01	0.253E+00	0.550E+05	0.146E-03	0.809E-11	0.876E-05
1112	0.836E+01	0.473E+00	0.285E+01	0.147E+02	0.423E+06	0.844E-02	0.379E-05	0.413E+01
1213	0.911E+00	0.515E-01	0.285E+01	0.169E+02	0.455E+06	0.974E-02	0.413E-06	0.450E+00
1314	0.683E-03	0.387E-04	0.285E+01	0.162E+00	0.444E+05	0.931E-04	0.310E-09	0.337E-03
1415	0.123E+02	0.695E+00	0.285E+01	0.168E+02	0.427E+06	0.985E-02	0.575E-05	0.600E+01
1617	0.138E+02	0.778E+00	0.285E+01	0.168E+02	0.427E+06	0.985E-02	0.644E-05	0.673E+01
1718	0.000E+00	-0.733E+01	0.285E+01	0.145E+02	0.398E+06	0.854E-02	0.000E+00	0.000E+00
1920	0.446E+01	0.252E+00	0.285E+01	0.111E+02	0.364E+06	0.640E-02	0.203E-05	0.220E+01
3334	0.362E-01	0.305E-04	0.348E+00	0.613E+01	0.452E+05	0.344E-02	0.405E-08	0.411E-02
3435	0.513E+05	0.172E+03	0.348E+00	0.104E+04	0.588E+06	0.582E+00	0.574E-02	0.582E+04
3031	0.611E+00	0.515E-03	0.348E+00	0.108E+02	0.915E+05	0.712E-02	0.639E-07	0.466E-01
3132	0.231E-01	0.195E-04	0.348E+00	0.411E+01	0.564E+05	0.270E-02	0.242E-08	0.176E-02
3233	0.156E+05	0.132E+02	0.348E+00	0.328E+04	0.159E+07	0.215E+01	0.163E-02	0.119E+04
221	0.410E+01	0.232E+00	0.285E+01	0.169E+02	0.450E+06	0.975E-02	0.187E-05	0.202E+01
1819	0.158E+02	0.893E+00	0.285E+01	0.168E+02	0.427E+06	0.986E-02	0.739E-05	0.772E+01

SOLUTION SATISFIED CONVERGENCE CRITERION OF 0.100E-05 IN 36 ITERATIONS

ITERADJC = 3 DIFTEM = 0.000E+00
TAU = 100000000.000000 ISTEP = 1 DTAU =
100000000.000000

```
**************************************************

TIME OF ANALYSIS WAS   6.250000000000000E-002  SECS

**************************************************
```

```
GFSSP VERSION
    604
GFSSP INSTALLATION PATH
C:\Program Files (x86)\GFSSP604\
ANALYST
Alok Majumdar
INPUT DATA FILE NAME
D:\GFSSP604Intel\Examples\Ex20\Ex20.dat
OUTPUT FILE NAME
Ex20.out
TITLE
Lithium Loop Model
USETUP
F
DENCON        GRAVITY       ENERGY        MIXTURE       THRUST        STEADY        TRANSV        SAVER
F             F             T             T             F             T             F             F
HEX           HCOEF         REACTING      INERTIA       CONDX         ADDPROP       PRINTI        ROTATION
T             F             F             T             F             F             T             F
BUOYANCY      HRATE         INVAL         MSORCE        MOVBND        TPA           VARGEO        TVM
F             T             F             F             F             F             F             F
SHEAR         PRNTIN        PRNTADD       OPVALVE       TRANSQ        CONJUG        RADIAT        WINPLOT
F             T             T             F             F             F             F             T
PRESS         INSUC         VARROT        CYCLIC        CHKVALS       WINFILE       DALTON        NOSTATS
F             F             F             T             F             T             F             F
NORMAL        SIMUL         SECONDL       NRSOLVT       IBDF          NOPLT         PRESREG       FLOWREG
F             T             F             F             1             T             0             0
TRANS_MOM     USERVARS      PSMG          ISOLVE        PLOTADD       SIUNITS       TECPLOT       MDGEN
F             F             F             1             F             F             F             F
NUM_USER_VARS IFR_MIX       PRINTD        SATTABL       MSORIN        PRELVLV       LAMINAR       HSTAG
1             1             F             F             F             F             T             T
NNODES        NINT          NBR           NF
 28            25            27            2
RELAXK        RELAXD        RELAXH        CC            NITER         RELAXNR       RELAXHC       RELAXTS
 1               0.5           0.01          1e-06         500 1             1                1
NFLUID(I),  I = 1, NF
 37 4
FLUID 1 PROPERTY FILES
23
AKNAK.DAT
RHONAK.DAT
EMUNAK.DAT
GAMNAK.DAT
HNAK.DAT
SNAK.DAT
CPNAK.DAT
NODE          INDEX     DESCRIPTION
```

```
1              2       " Node 1"
2              1       " Node 2"
6              1       " Node 6"
7              1       " "
8              1       " "
9              1       " "
10             1       " "
11             1       " "
12             1       " "
13             1       " "
14             1       " "
15             1       " "
16             1       " "
17             1       " "
18             1       " "
19             1       " "
20             1       " "
21             1       " "
22             1       " Node 22"
3              1       " "
4              1       " Node 4"
5              1       " Node 5"
30             2       " Node 30"
35             2       " Node 35"
31             1       " Node 31"
32             1       " Node 32"
33             1       " Node 33"
34             1       " Node 34"
NODE  PRES (PSI)  TEMP(DEGF)  MASS SOURC    HEAT SOURC   THRST AREA   CONCENTRATION
1     7              932               0                  0                  0               1 0
2     7.02           932               0                  0                  0               1 0
6     7.02           932               0                  0                  0               1 0
7     7.02           932               0                  0                  0               1 0
8     7.02           932               0                  0                  0               1 0
9     7.02           932               0                  0                  0               1 0
10    7.02           932               0                  0                  0               1 0
11    7.02           932               0                  0                  0               1 0
12    7.02           932               0                  0                  0               1 0
13    7.02           932               0                  0                  0               1 0
14    7.02           932               0                  0                  0               1 0
15    7.02           932               0                  0                  0               1 0
16    7.02           932               0                  0                  0               1 0
17    7.02           932               0                  0                  0               1 0
18    7.02           932               0                  0                  0               1 0
19    7.02           932               0                  0                  0               1 0
20    7.02           932               0                  0                  0               1 0
21    7.02           932               0                  0                  0               1 0
```

22	7.02	932	0	0	0	1	0
3	7.02	932	0	0	0	1	0
4	7.02	932	0	0	0	1	0
5	7.02	930	0	5	0	1	0
30	200	477	0	0	0	0	1
35	14.7	60	0	0	0	0	1
31	7.02	932	0	0	0	0	1
32	7.02	932	0	0	0	0	1
33	7.02	932	0	0	0	0	1
34	7.02	932	0	0	0	0	1

INODE	NUMBR	NAMEBR	
2	2	12	23
6	2	67	56
7	2	78	67
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	1516	1415
16	2	1516	1617
17	2	1617	1718
18	2	1718	1819
19	2	1920	1819
20	2	2021	1920
21	2	2122	2021
22	2	2122	221
3	2	34	23
4	2	34	45
5	2	56	45
31	2	3031	3132
32	2	3132	3233
33	2	3334	3233
34	2	3334	3435

BRANCH	UPNODE	DNNODE	OPTION	DESCRIPTION
12	1	2	8	" "
78	7	8	7	" "
2122	21	22	1	" "
67	6	7	1	" "
89	8	9	1	" "
910	9	10	13	" "
1011	10	11	1	" "
1516	15	16	13	" "
2021	20	21	1	" "
34	3	4	3	" "

```
56        5         6         3       "     "
23        2         3         1       "     "
45        4         5         1       "     "
1112      11        12        13      "     "
1213      12        13        1       "     "
1314      13        14        3       "     "
1415      14        15        1       "     "
1617      16        17        1       "     "
1718      17        18        2       "     "
1920      19        20        13      "     "
3334      33        34        1       "     "
3435      34        35        22      "Orifice 3435"
3031      30        31        1       "     "
3132      31        32        1       "     "
3233      32        33        1       "     "
221       22        1         1       "     "
1819      18        19        1       "     "
BRANCH       OPTION -8     PIPE DIA      EXP DIA       AREA
 12                        0.83          6.625         0.54106
BRANCH       OPTION -7     PIPE DIA      RED. DIA      AREA
 78                        6.375         0.87          31.919
BRANCH       OPTION -1     LENGTH        DIA           EPSD          ANGLE         AREA
 2122                      12                0.81          7.4074074074e-05    0                  0.51529929975
BRANCH       OPTION -1     LENGTH        DIA           EPSD          ANGLE         AREA
 67                        2                 6.375         1.4745098039e-06    0                  31.919045273
BRANCH       OPTION -1     LENGTH        DIA           EPSD          ANGLE         AREA
 89                        2                 0.81          7.4074074074e-05    0                  0.51529929975
BRANCH       OPTION -13    DIA           K1            K2            AREA
 910                       0.87          800          0.2          0.59447
BRANCH       OPTION -1     LENGTH        DIA           EPSD          ANGLE         AREA
 1011                      18                0.81          7.4074074074e-05    0                  0.51529929975
BRANCH       OPTION -13    DIA           K1            K2            AREA
 1516                      0.87          800          0.2          0.59447
BRANCH       OPTION -1     LENGTH        DIA           EPSD          ANGLE         AREA
 2021                      9                 0.81          7.4074074074e-05    0                  0.51529929975
BRANCH       OPTION -3     LENGTH        HEIGHT        WIDTH         TYPE          AREA
 34                        25            6.357         6.625         3             10.9301445298
BRANCH       OPTION -3     LENGTH        HEIGHT        WIDTH         TYPE          AREA
 56                        0.018         0.5           0.68          3             0.667273716
BRANCH       OPTION -1     LENGTH        DIA           EPSD          ANGLE         AREA
 23                        6.5               6             1.6666666667e-06    0                  28.27431
BRANCH       OPTION -1     LENGTH        DIA           EPSD          ANGLE         AREA
 45                        1                 6.625         1.5094339623e-06    0                  34.471587148
BRANCH       OPTION -13    DIA           K1            K2            AREA
 1112                      0.87          800          0.2          0.59447
BRANCH       OPTION -1     LENGTH        DIA           EPSD          ANGLE         AREA
 1213                      2                 0.81          7.4074074074e-05    0                  0.51529929975
```

```
BRANCH        OPTION -3     LENGTH        HEIGHT        WIDTH         TYPE          AREA
 1314                       46.56         2.8           5             3             53.9096844
BRANCH        OPTION -1     LENGTH        DIA           EPSD          ANGLE         AREA
 1415                       27                0.81             7.4074074074e-05    0                  0.51529929975
BRANCH        OPTION -1     LENGTH        DIA           EPSD          ANGLE         AREA
 1617                       30.25             0.81             7.4074074074e-05    0                  0.51529929975
BRANCH        OPTION -2     FLOW COEFF    AREA
 1718                       0             0.5944
BRANCH        OPTION -13    DIA           K1            K2            AREA
 1920                       1             800          0.2           0.7854
BRANCH        OPTION -1     LENGTH        DIA           EPSD          ANGLE         AREA
 3334                       5                 5.292            1.8896447468e-06    0                  21.995264332
BRANCH        OPTION -22     AREA       FLOW COEF
 3435                       0.13          1
BRANCH        OPTION -1     LENGTH        DIA           EPSD          ANGLE         AREA
 3031                       13                3.26             6.1349693252e-06    0                  8.346890471
BRANCH        OPTION -1     LENGTH        DIA           EPSD          ANGLE         AREA
 3132                       5                 5.292            1.8896447468e-06    0                  21.995264332
BRANCH        OPTION -1     LENGTH        DIA           EPSD          ANGLE         AREA
 3233                       0.17              0.1875           0.0017066666667    0                  0.027611630859
BRANCH        OPTION -1     LENGTH        DIA           EPSD          ANGLE         AREA
 221                        9                 0.81             7.4074074074e-05    0                  0.51529929975
BRANCH        OPTION -1     LENGTH        DIA           EPSD          ANGLE         AREA
 1819                       37                0.81             0                 0                  0.51529929975
BRANCH        NOUBR         NMUBR
 12    1   221
 78    1   67
 2122    1   2021
 67    1   56
 89    1   78
 910    1   89
 1011    1   910
 1516    1   1415
 2021    1   1920
 34    1   23
 56    1   45
 23    1   12
 45    1   34
 1112    1   1011
 1213    1   1112
 1314    1   1213
 1415    1   1314
 1617    1   1516
 1718    1   1617
 1920    1   1819
 3334    1   3233
 3435    1   3334
```

```
 3031    0
 3132    1   3031
 3233    1   3132
 221    1   2122
 1819    1   1718
BRANCH         NODBR          NMDBR
 12    1   23
 78    1   89
 2122    1   221
 67    1   78
 89    1   910
 910    1   1011
 1011    1   1112
 1516    1   1617
 2021    1   2122
 34    1   45
 56    1   67
 23    1   34
 45    1   56
 1112    1   1213
 1213    1   1314
 1314    1   1415
 1415    1   1516
 1617    1   1718
 1718    1   1819
 1920    1   2021
 3334    1   3435
 3435    0
 3031    1   3132
 3132    1   3233
 3233    1   3334
 221    1   12
 1819    1   1920
BRANCH
 12
  UPSTRM BR.     ANGLE
   221     0.00000
  DNSTRM BR.     ANGLE
   23     0.00000
BRANCH
 78
  UPSTRM BR.     ANGLE
   67     0.00000
  DNSTRM BR.     ANGLE
   89     0.00000
BRANCH
 2122
```

```
  UPSTRM BR.     ANGLE
   2021     0.00000
  DNSTRM BR.     ANGLE
   221     0.00000
BRANCH
 67
  UPSTRM BR.     ANGLE
   56     0.00000
  DNSTRM BR.     ANGLE
   78     0.00000
BRANCH
 89
  UPSTRM BR.     ANGLE
   78     0.00000
  DNSTRM BR.     ANGLE
   910     0.00000
BRANCH
 910
  UPSTRM BR.     ANGLE
   89     0.00000
  DNSTRM BR.     ANGLE
   1011     0.00000
BRANCH
 1011
  UPSTRM BR.     ANGLE
   910     0.00000
  DNSTRM BR.     ANGLE
   1112     0.00000
BRANCH
 1516
  UPSTRM BR.     ANGLE
   1415     0.00000
  DNSTRM BR.     ANGLE
   1617     0.00000
BRANCH
 2021
  UPSTRM BR.     ANGLE
   1920     0.00000
  DNSTRM BR.     ANGLE
   2122     0.00000
BRANCH
 34
  UPSTRM BR.     ANGLE
   23     0.00000
  DNSTRM BR.     ANGLE
   45     0.00000
BRANCH
```

```
 56
  UPSTRM BR.     ANGLE
   45     0.00000
  DNSTRM BR.     ANGLE
   67     0.00000
BRANCH
 23
  UPSTRM BR.     ANGLE
   12     0.00000
  DNSTRM BR.     ANGLE
   34     0.00000
BRANCH
 45
  UPSTRM BR.     ANGLE
   34     0.00000
  DNSTRM BR.     ANGLE
   56     0.00000
BRANCH
 1112
  UPSTRM BR.     ANGLE
   1011     0.00000
  DNSTRM BR.     ANGLE
   1213     0.00000
BRANCH
 1213
  UPSTRM BR.     ANGLE
   1112     0.00000
  DNSTRM BR.     ANGLE
   1314     0.00000
BRANCH
 1314
  UPSTRM BR.     ANGLE
   1213     0.00000
  DNSTRM BR.     ANGLE
   1415     0.00000
BRANCH
 1415
  UPSTRM BR.     ANGLE
   1314     0.00000
  DNSTRM BR.     ANGLE
   1516     0.00000
BRANCH
 1617
  UPSTRM BR.     ANGLE
   1516     0.00000
  DNSTRM BR.     ANGLE
   1718     0.00000
```

```
BRANCH
 1718
  UPSTRM BR.     ANGLE
   1617     0.00000
  DNSTRM BR.     ANGLE
   1819     0.00000
BRANCH
 1920
  UPSTRM BR.     ANGLE
   1819     0.00000
  DNSTRM BR.     ANGLE
   2021     0.00000
BRANCH
 3334
  UPSTRM BR.     ANGLE
   3233     0.00000
  DNSTRM BR.     ANGLE
   3435     0.00000
BRANCH
 3435
  UPSTRM BR.     ANGLE
   3334     0.00000
  DNSTRM BR.     ANGLE
BRANCH
 3031
  UPSTRM BR.     ANGLE
  DNSTRM BR.     ANGLE
   3132     0.00000
BRANCH
 3132
  UPSTRM BR.     ANGLE
   3031     0.00000
  DNSTRM BR.     ANGLE
   3233     0.00000
BRANCH
 3233
  UPSTRM BR.     ANGLE
   3132     0.00000
  DNSTRM BR.     ANGLE
   3334     0.00000
BRANCH
 221
  UPSTRM BR.     ANGLE
   2122     0.00000
  DNSTRM BR.     ANGLE
   12     0.00000
BRANCH
```

```
 1819
  UPSTRM BR.     ANGLE
   1718     0.00000
  DNSTRM BR.     ANGLE
   1920     0.00000
NUMBER OF BRANCHES WITH INERTIA
 0
NUMBER OF HEAT EXCHANGERS
1
 IBRHOT   IBRCLD   ITYPHX   ARHOT      ARCOLD      UA     HEXEFF
1314   3233    1       0          0          0          0.9
CYCLIC BNDARY NODE    UPSTREAM NODE
1          22
```

Example 20 User Subroutines

```
C                                                                         *

C     ***** GFSSP USER SUBROUTINES *****                                  *
C                                                                         *
C**************************************************************************
                              :
                              :
                              :
                              :

************************************************************************
      SUBROUTINE SORCEF(I,TERM0,TERM1,TERM2,TERM3,TERM4,TERM5,TERM6,
     &                  TERM7,TERM8,TERM9,TERM10,TERM100)
C     PURPOSE: ADD MOMENTUM SOURCES (LBF)
C     I - GFSSP INDEX NUMBER FOR BRANCH
C     TERM0 - UNSTEADY TERM IN MOMENTUM CONSERVATION EQUATION
C     TERM1 - LONGITUDINAL INERTIA
C     TERM2 - PRESSURE GRADIENT
C     TERM3 - GRAVITY FORCE
C     TERM4 - FRICTION FORCE
C     TERM5 - CENTRIFUGAL FORCE
C     TERM6 - EXTERNAL MOMETUM SOURCE DUE TO PUMP
C     TERM7 - MOMENTUM SOURCE DUE TO TRANSVERSE FLOW(MULTI-DIMENSIONAL MODEL)
C     TERM8 - MOMENTUM SOURCE DUE TO SHEAR(MULTI-DIMENSIONAL MODEL)
C     TERM9 - VARIABLE GEOMETRY UNSTEADY TERM
C     TERM10 - NORMAL STRESS
C     TERM100 - USER SUPPLIED MOMENTUM SOURCE
C**************************************************************************
       INCLUDE 'COMBLK.FOR'
C*************************************************************************
C     ADD CODE HERE
C     MODELING OF THERMO-ELECTRIC PUMP
      DIMENSION VOLT(50),FLWTE(50),DPTE(50,50)
       LOGICAL UNREAD
      DATA VOLTIN/170/
C     READ PUMP CHARACTERISTIC DATA FROM FILE
      IF (ITER.EQ.1.AND. (.NOT. UNREAD)) THEN
       OPEN (NUSR1,FILE='Ex20_pump.dat',STATUS='UNKNOWN')
       READ(NUSR1,*) NFLW,NVOLT
       READ(NUSR1,*) (VOLT(JJ),JJ=1,NVOLT)
       DO II = 1,NFLW
        READ(NUSR1,*) FLWTE(II),(DPTE(II,JJ),JJ=1,NVOLT)
       ENDDO
       UNREAD = .TRUE.
      ENDIF ! IF (ITER.EQ.0)..
```

```
      IF (IBRANCH(I) .EQ. 1718) THEN
C     BRACKET THE FLOWRATE
      IR=0
      DO II =2,NFLW
        IF (FLOWR(I).GE.FLWTE(II-1).AND.FLOWR(I).LE.FLWTE(II)) THEN
         IR=II
         GO TO 100
        ENDIF
      ENDDO
100   IF (IR.EQ.0) THEN
       IF (FLOWR(I).GT.FLWTE(NFLW)) IR=NFLW
       IF (FLOWR(I).LT.FLWTE(1)) IR=2
      ENDIF
C     BRACKET THE VOLT
      JR=0
      DO JJ = 2,NVOLT
        IF (VOLTIN.GE.VOLT(JJ-1).AND.VOLTIN.LE.VOLT(JJ)) THEN
         JR=JJ
         GO TO 200
        ENDIF
      ENDDO
200   IF (JR.EQ.0) THEN
        IF(VOLTIN.GT.VOLT(NVOLT)) JR=NVOLT
        IF(VOLTIN.LT.VOLT(1)) JR=2
      ENDIF
C     CALCULATE DELPTE
      FACTFLW=(FLOWR(I)-FLWTE(IR-1))/(FLWTE(IR)-FLWTE(IR-1))
      FACTV=(VOLTIN-VOLT(JR-1))/(VOLT(JR)-VOLT(JR-1))
      DELPTE=(1.-FACTFLW)*(1.-FACTV)*DPTE(IR-1,JR-1)
     &       +FACTFLW*(1.-FACTV)*DPTE(IR,JR-1)
     &       +FACTFLW*FACTV*DPTE(IR,JR)
     &       +(1.-FACTFLW)*FACTV*DPTE(IR-1,JR)
      TERM100=144*DELPTE*AREA(I)


      ENDIF ! IF (IBRANCH(I).EQ...)


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

```
C***********************************************************************
       INCLUDE 'COMBLK.FOR'
C**********************************************************************
C**********************************************************************
C     ADD CODE HERE
      DATA TCINLET/1512.6/
      IF (NODE(IPN).EQ.19) THEN
        SORCEH(IPN)=1.E20*TCINLET
        TERMD=1.E20
      ENDIF
      RETURN
      END
C***********************************************************************
```

NOTE: All other user subroutines are not used in Example 20

```
 **************************************************
              G F S S P (Version 604)
        Generalized Fluid System Simulation Program
                    March 2012

        Developed by NASA/Marshall Space Flight Center
        Copyright (C) by Marshall Space Flight Center

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


       RUN DATE:03/27/2012 08:54

TITLE     :Lithium Loop Model
ANALYST   :Alok Majumdar
FILEIN    :D:\GFSSP604Intel\Examples\Ex20\Ex20.dat
FILEOUT   :Ex20.out

                           OPTION VARIABLES

ADDPROP   BUOYANCY  CONDX     CONJUG    CYCLIC    DALTON    DENCON    ENERGY
F         F         F         F         T         F         F         T
FLOWREG   GRAVITY   HCOEF     HEX       HRATE     IFRMIX    INERTIA   INSUC
0         F         F         T         T         1         T         F
INVAL     MIXTURE   MOVBND    MSORCE    NORMAL    NRSOLVT   OPVALVE   PLOTADD
F         T         F         F         F         F         F         F
PRESREG   PRESS     PRINTI    PRNTADD   PRNTIN    RADIATION REACTING  ROTATION
0         F         T         T         T         F         F         F
SAVER     SECONDL   SHEAR     SIMULA    SIUNITS   STEADY    THRUST    TPA
F         F         F         T         F         T         F         F
TRANS_MOM TRANSQ    TRANSV    TVM       TWOD      USRVAR    VARGEO    VARROT
F         F         F         F         F         F         F         F
RLFVLV
F

NNODES   =   28
NINT     =   25
NBR      =   27
NF       =    2
NVAR     =   52
NHREF    =    2
```

FLUIDS: FLD1 N2

BOUNDARY NODES

NODE	P (PSI)	T (F)	RHO (LBM/FT^3)	AREA (IN^2)	CONCENTRATIONS FLD1	N2
1	0.7000E+01	0.9320E+03	0.4716E+02	0.0000E+00	0.1000E+01	0.0000E+00
30	0.2000E+03	0.4770E+03	0.5541E+00	0.0000E+00	0.0000E+00	0.1000E+01
35	0.1470E+02	0.6000E+02	0.7386E-01	0.0000E+00	0.0000E+00	0.1000E+01

INPUT SPECIFICATIONS FOR INTERNAL NODES

NODE	AREA (IN^2)	MASS (LBM/S)	HEAT (BTU/S)
2	0.0000E+00	0.0000E+00	0.0000E+00
6	0.0000E+00	0.0000E+00	0.0000E+00
7	0.0000E+00	0.0000E+00	0.0000E+00
8	0.0000E+00	0.0000E+00	0.0000E+00
9	0.0000E+00	0.0000E+00	0.0000E+00
10	0.0000E+00	0.0000E+00	0.0000E+00
11	0.0000E+00	0.0000E+00	0.0000E+00
12	0.0000E+00	0.0000E+00	0.0000E+00
13	0.0000E+00	0.0000E+00	0.0000E+00
14	0.0000E+00	0.0000E+00	0.0000E+00
15	0.0000E+00	0.0000E+00	0.0000E+00
16	0.0000E+00	0.0000E+00	0.0000E+00
17	0.0000E+00	0.0000E+00	0.0000E+00
18	0.0000E+00	0.0000E+00	0.0000E+00
19	0.0000E+00	0.0000E+00	0.0000E+00
20	0.0000E+00	0.0000E+00	0.0000E+00
21	0.0000E+00	0.0000E+00	0.0000E+00
22	0.0000E+00	0.0000E+00	0.0000E+00
3	0.0000E+00	0.0000E+00	0.0000E+00
4	0.0000E+00	0.0000E+00	0.0000E+00
5	0.0000E+00	0.0000E+00	0.5000E+01
31	0.0000E+00	0.0000E+00	0.0000E+00
32	0.0000E+00	0.0000E+00	0.0000E+00
33	0.0000E+00	0.0000E+00	0.0000E+00
34	0.0000E+00	0.0000E+00	0.0000E+00

BRANCH	UPNODE	DNNODE	OPTION
12	1	2	8
78	7	8	7
2122	21	22	1
67	6	7	1
89	8	9	1
910	9	10	13
1011	10	11	1

```
   1516        15        16        13
   2021        20        21         1
     34         3         4         3
     56         5         6         3
     23         2         3         1
     45         4         5         1
   1112        11        12        13
   1213        12        13         1
   1314        13        14         3
   1415        14        15         1
   1617        16        17         1
   1718        17        18         2
   1920        19        20        13
   3334        33        34         1
   3435        34        35        22
   3031        30        31         1
   3132        31        32         1
   3233        32        33         1
    221        22         1         1
   1819        18        19         1
BRANCH OPTION -8:  PIPE DIA      EXP DIA     AREA
     12             0.830E+00   0.662E+01   0.541E+00
BRANCH OPTION -7:   PIPE DIA   REDUCED DIA AREA
     78             0.638E+01   0.870E+00   0.319E+02
BRANCH  OPTION -1:   LENGTH      DIA        EPSD       ANGLE        AREA
   2122             0.120E+02   0.810E+00   0.741E-04   0.000E+00   0.515E+00
BRANCH  OPTION -1:   LENGTH      DIA        EPSD       ANGLE        AREA
     67             0.200E+01   0.638E+01   0.147E-05   0.000E+00   0.319E+02
BRANCH  OPTION -1:   LENGTH      DIA        EPSD       ANGLE        AREA
     89             0.200E+01   0.810E+00   0.741E-04   0.000E+00   0.515E+00
BRANCH OPTION -13:  DIA  K1   K2  AREA
    910             0.870E+00   0.800E+03   0.200E+00   0.594E+00
BRANCH  OPTION -1:   LENGTH      DIA        EPSD       ANGLE        AREA
   1011             0.180E+02   0.810E+00   0.741E-04   0.000E+00   0.515E+00
BRANCH OPTION -13:  DIA  K1   K2  AREA
   1516             0.870E+00   0.800E+03   0.200E+00   0.594E+00
BRANCH  OPTION -1:   LENGTH      DIA        EPSD       ANGLE        AREA
   2021             0.900E+01   0.810E+00   0.741E-04   0.000E+00   0.515E+00
BR OPT -> 3-3 LENGTH   INNER RAD   OUTER RAD   TYPE        AREA
     34             0.250E+02   0.636E+01   0.662E+01   0.300E+01   0.109E+02
BR OPT -> 3-3 LENGTH   INNER RAD   OUTER RAD   TYPE        AREA
     56             0.180E-01   0.500E+00   0.680E+00   0.300E+01   0.667E+00
BRANCH  OPTION -1:   LENGTH      DIA        EPSD       ANGLE        AREA
     23             0.650E+01   0.600E+01   0.167E-05   0.000E+00   0.283E+02
BRANCH  OPTION -1:   LENGTH      DIA        EPSD       ANGLE        AREA
     45             0.100E+01   0.662E+01   0.151E-05   0.000E+00   0.345E+02
BRANCH OPTION -13:  DIA  K1   K2  AREA
```

```
   1112            0.870E+00   0.800E+03   0.200E+00   0.594E+00
BRANCH  OPTION -1:   LENGTH      DIA        EPSD       ANGLE        AREA
   1213            0.200E+01   0.810E+00   0.741E-04   0.000E+00   0.515E+00
BR OPT -> 3-3 LENGTH   INNER RAD   OUTER RAD   TYPE        AREA
   1314            0.466E+02   0.280E+01   0.500E+01   0.300E+01   0.539E+02
BRANCH  OPTION -1:   LENGTH      DIA        EPSD       ANGLE        AREA
   1415            0.270E+02   0.810E+00   0.741E-04   0.000E+00   0.515E+00
BRANCH  OPTION -1:   LENGTH      DIA        EPSD       ANGLE        AREA
   1617            0.302E+02   0.810E+00   0.741E-04   0.000E+00   0.515E+00
BRANCH OPTION -2:  FLOW COEF  AREA
   1718            0.000E+00   0.594E+00
BRANCH OPTION -13:  DIA  K1   K2  AREA
   1920            0.100E+01   0.800E+03   0.200E+00   0.785E+00
BRANCH  OPTION -1:   LENGTH      DIA        EPSD       ANGLE        AREA
   3334            0.500E+01   0.529E+01   0.189E-05   0.000E+00   0.220E+02
BRANCH OPTION -22 FLOW COEF   AREA
   3435            0.100E+01   0.130E+00
BRANCH  OPTION -1:   LENGTH      DIA        EPSD       ANGLE        AREA
   3031            0.130E+02   0.326E+01   0.613E-05   0.000E+00   0.835E+01
BRANCH  OPTION -1:   LENGTH      DIA        EPSD       ANGLE        AREA
   3132            0.500E+01   0.529E+01   0.189E-05   0.000E+00   0.220E+02
BRANCH  OPTION -1:   LENGTH      DIA        EPSD       ANGLE        AREA
   3233            0.170E+00   0.188E+00   0.171E-02   0.000E+00   0.276E-01
BRANCH  OPTION -1:   LENGTH      DIA        EPSD       ANGLE        AREA
    221            0.900E+01   0.810E+00   0.741E-04   0.000E+00   0.515E+00
BRANCH  OPTION -1:   LENGTH      DIA        EPSD       ANGLE        AREA
   1819            0.370E+02   0.810E+00   0.000E+00   0.000E+00   0.515E+00

INITIAL GUESS FOR INTERNAL NODES

   NODE    P(PSI)   TF(F)      Z(COMP)    RHO       CONCENTRATIONS
                                          (LBM/FT^3)
                                                              FLD1      N2
    2    0.7020E+01  0.9320E+03  0.2293E-03  0.4716E+02  0.1000E+01  0.0000E+00
    6    0.7020E+01  0.9320E+03  0.2293E-03  0.4716E+02  0.1000E+01  0.0000E+00
    7    0.7020E+01  0.9320E+03  0.2293E-03  0.4716E+02  0.1000E+01  0.0000E+00
    8    0.7020E+01  0.9320E+03  0.2293E-03  0.4716E+02  0.1000E+01  0.0000E+00
    9    0.7020E+01  0.9320E+03  0.2293E-03  0.4716E+02  0.1000E+01  0.0000E+00
   10    0.7020E+01  0.9320E+03  0.2293E-03  0.4716E+02  0.1000E+01  0.0000E+00
   11    0.7020E+01  0.9320E+03  0.2293E-03  0.4716E+02  0.1000E+01  0.0000E+00
   12    0.7020E+01  0.9320E+03  0.2293E-03  0.4716E+02  0.1000E+01  0.0000E+00
   13    0.7020E+01  0.9320E+03  0.2293E-03  0.4716E+02  0.1000E+01  0.0000E+00
   14    0.7020E+01  0.9320E+03  0.2293E-03  0.4716E+02  0.1000E+01  0.0000E+00
   15    0.7020E+01  0.9320E+03  0.2293E-03  0.4716E+02  0.1000E+01  0.0000E+00
   16    0.7020E+01  0.9320E+03  0.2293E-03  0.4716E+02  0.1000E+01  0.0000E+00
   17    0.7020E+01  0.9320E+03  0.2293E-03  0.4716E+02  0.1000E+01  0.0000E+00
   18    0.7020E+01  0.9320E+03  0.2293E-03  0.4716E+02  0.1000E+01  0.0000E+00
```

19	0.7020E+01	0.9320E+03	0.2293E-03	0.4716E+02	0.1000E+01	0.0000E+00
20	0.7020E+01	0.9320E+03	0.2293E-03	0.4716E+02	0.1000E+01	0.0000E+00
21	0.7020E+01	0.9320E+03	0.2293E-03	0.4716E+02	0.1000E+01	0.0000E+00
22	0.7020E+01	0.9320E+03	0.2293E-03	0.4716E+02	0.1000E+01	0.0000E+00
3	0.7020E+01	0.9320E+03	0.2293E-03	0.4716E+02	0.1000E+01	0.0000E+00
4	0.7020E+01	0.9320E+03	0.2293E-03	0.4716E+02	0.1000E+01	0.0000E+00
5	0.7020E+01	0.9300E+03	0.2296E-03	0.4717E+02	0.1000E+01	0.0000E+00
31	0.7020E+01	0.9320E+03	0.1000E+01	0.1317E-01	0.0000E+00	0.1000E+01
32	0.7020E+01	0.9320E+03	0.1000E+01	0.1317E-01	0.0000E+00	0.1000E+01
33	0.7020E+01	0.9320E+03	0.1000E+01	0.1317E-01	0.0000E+00	0.1000E+01
34	0.7020E+01	0.9320E+03	0.1000E+01	0.1317E-01	0.0000E+00	0.1000E+01

TRIAL SOLUTION

BRANCH	DELP(PSI)	FLOWRATE(LBM/SEC)
12	0.0000	0.0100
78	0.0000	0.0100
2122	0.0000	0.0100
67	0.0000	0.0100
89	0.0000	0.0100
910	0.0000	0.0100
1011	0.0000	0.0100
1516	0.0000	0.0100
2021	0.0000	0.0100
34	0.0000	0.0100
56	0.0000	0.0100
23	0.0000	0.0100
45	0.0000	0.0100
1112	0.0000	0.0100
1213	0.0000	0.0100
1314	0.0000	0.0100
1415	0.0000	0.0100
1617	0.0000	0.0100
1718	0.0000	0.0100
1920	0.0000	0.0100
3334	0.0000	0.0100
3435	0.0000	0.0100
3031	0.0000	0.0100
3132	0.0000	0.0100
3233	0.0000	0.0100
221	0.0000	0.0100
1819	0.0000	0.0100

SOLUTION

INTERNAL NODES

NODE	P(PSI)	TF(F)	Z	RHO (LBM/FT^3)	EM(LBM)	CONC

					FLD1	N2	
2	0.5707E+01	0.9320E+03	0.1864E-03	0.4716E+02	0.0000E+00	0.1000E+01	0.0000
6	0.5701E+01	0.9398E+03	0.1854E-03	0.4709E+02	0.0000E+00	0.1000E+01	0.0000
7	0.5701E+01	0.9398E+03	0.1854E-03	0.4709E+02	0.0000E+00	0.1000E+01	0.0000
8	0.5045E+01	0.9398E+03	0.1641E-03	0.4709E+02	0.0000E+00	0.1000E+01	0.0000
9	0.4994E+01	0.9398E+03	0.1624E-03	0.4709E+02	0.0000E+00	0.1000E+01	0.0000
10	0.4521E+01	0.9398E+03	0.1470E-03	0.4709E+02	0.0000E+00	0.1000E+01	0.0000
11	0.4057E+01	0.9398E+03	0.1320E-03	0.4709E+02	0.0000E+00	0.1000E+01	0.0000
12	0.3584E+01	0.9398E+03	0.1166E-03	0.4709E+02	0.0000E+00	0.1000E+01	0.0000
13	0.3533E+01	0.9398E+03	0.1149E-03	0.4709E+02	0.0000E+00	0.1000E+01	0.0000
14	0.3533E+01	0.8829E+03	0.1186E-03	0.4756E+02	0.0000E+00	0.1000E+01	0.0000
15	0.2838E+01	0.8829E+03	0.9527E-04	0.4756E+02	0.0000E+00	0.1000E+01	0.0000
16	0.2369E+01	0.8829E+03	0.7954E-04	0.4756E+02	0.0000E+00	0.1000E+01	0.0000
17	0.1591E+01	0.8829E+03	0.5341E-04	0.4756E+02	0.0000E+00	0.1000E+01	0.0000
18	0.8918E+01	0.8829E+03	0.2994E-03	0.4756E+02	0.0000E+00	0.1000E+01	0.0000
19	0.8025E+01	0.9320E+03	0.2621E-03	0.4716E+02	0.0000E+00	0.1000E+01	0.0000
20	0.7773E+01	0.9320E+03	0.2539E-03	0.4716E+02	0.0000E+00	0.1000E+01	0.0000
21	0.7541E+01	0.9320E+03	0.2463E-03	0.4716E+02	0.0000E+00	0.1000E+01	0.0000
22	0.7232E+01	0.9320E+03	0.2362E-03	0.4716E+02	0.0000E+00	0.1000E+01	0.0000
3	0.5707E+01	0.9320E+03	0.1864E-03	0.4716E+02	0.0000E+00	0.1000E+01	0.0000
4	0.5702E+01	0.9320E+03	0.1862E-03	0.4716E+02	0.0000E+00	0.1000E+01	0.0000
5	0.5702E+01	0.9398E+03	0.1855E-03	0.4709E+02	0.0000E+00	0.1000E+01	0.0000
31	0.2000E+03	0.4770E+03	0.1006E+01	0.5542E+00	0.0000E+00	0.0000E+00	1.0000
32	0.2000E+03	0.4770E+03	0.1006E+01	0.5542E+00	0.0000E+00	0.0000E+00	1.0000
33	0.1868E+03	0.8443E+03	0.1006E+01	0.3720E+00	0.0000E+00	0.0000E+00	1.0000
34	0.1868E+03	0.8443E+03	0.1006E+01	0.3720E+00	0.0000E+00	0.0000E+00	1.0000

NODE	H	ENTROPY	EMU	COND	CP	GAMA
	BTU/LB	BTU/LB-R	LBM/FT-SEC	BTU/FT-S-R	BTU/LB-R	
2	0.0000E+00	0.0000E+00	0.1197E-03	0.2588E+00	0.2088E+00	0.1000E+01
6	0.0000E+00	0.0000E+00	0.1184E-03	0.2609E+00	0.2089E+00	0.1000E+01
7	0.0000E+00	0.0000E+00	0.1184E-03	0.2609E+00	0.2089E+00	0.1000E+01
8	0.0000E+00	0.0000E+00	0.1184E-03	0.2609E+00	0.2089E+00	0.1000E+01
9	0.0000E+00	0.0000E+00	0.1184E-03	0.2609E+00	0.2089E+00	0.1000E+01
10	0.0000E+00	0.0000E+00	0.1184E-03	0.2609E+00	0.2089E+00	0.1000E+01
11	0.0000E+00	0.0000E+00	0.1184E-03	0.2609E+00	0.2089E+00	0.1000E+01
12	0.0000E+00	0.0000E+00	0.1184E-03	0.2609E+00	0.2089E+00	0.1000E+01
13	0.0000E+00	0.0000E+00	0.1184E-03	0.2609E+00	0.2089E+00	0.1000E+01
14	0.0000E+00	0.0000E+00	0.1261E-03	0.2451E+00	0.2081E+00	0.1000E+01
15	0.0000E+00	0.0000E+00	0.1261E-03	0.2451E+00	0.2081E+00	0.1000E+01
16	0.0000E+00	0.0000E+00	0.1261E-03	0.2451E+00	0.2081E+00	0.1000E+01
17	0.0000E+00	0.0000E+00	0.1261E-03	0.2451E+00	0.2081E+00	0.1000E+01
18	0.0000E+00	0.0000E+00	0.1261E-03	0.2451E+00	0.2081E+00	0.1000E+01
19	0.0000E+00	0.0000E+00	0.1197E-03	0.2588E+00	0.2088E+00	0.1000E+01
20	0.0000E+00	0.0000E+00	0.1197E-03	0.2588E+00	0.2088E+00	0.1000E+01
21	0.0000E+00	0.0000E+00	0.1197E-03	0.2588E+00	0.2088E+00	0.1000E+01

22	0.0000E+00	0.0000E+00	0.1197E-03	0.2588E+00	0.2088E+00	0.1000E+01
3	0.0000E+00	0.0000E+00	0.1197E-03	0.2588E+00	0.2088E+00	0.1000E+01
4	0.0000E+00	0.0000E+00	0.1197E-03	0.2588E+00	0.2088E+00	0.1000E+01
5	0.0000E+00	0.0000E+00	0.1184E-03	0.2609E+00	0.2089E+00	0.1000E+01
31	0.0000E+00	0.1009E+01	0.1784E-04	0.6307E-05	0.2546E+00	0.1396E+01
32	0.0000E+00	0.1009E+01	0.1784E-04	0.6307E-05	0.2546E+00	0.1396E+01
33	0.0000E+00	0.1099E+01	0.2226E-04	0.8027E-05	0.2642E+00	0.1371E+01
34	0.0000E+00	0.1099E+01	0.2226E-04	0.8027E-05	0.2642E+00	0.1371E+01

BRANCHES

BRANCH	KFACTOR (LBF-S^2/(LBM-FT)^2)	DELP (PSI)	FLOW RATE (LBM/SEC)	VELOCITY (FT/SEC)	REYN. NO.	MACH NO.	ENTROPY GEN. BTU/(R-SEC)	LOST WORK LBF-FT/SEC
12	0.229E+02	0.129E+01	0.285E+01	0.161E+02	0.439E+06	0.929E-02	0.104E-04	0.113E+02
78	0.116E+02	0.656E+00	0.285E+01	0.273E+00	0.578E+05	0.157E-03	0.525E-05	0.572E+01
2122	0.546E+01	0.309E+00	0.285E+01	0.169E+02	0.450E+06	0.975E-02	0.249E-05	0.270E+01
67	0.426E-04	0.241E-05	0.285E+01	0.273E+00	0.578E+05	0.157E-03	0.193E-10	0.211E-04
89	0.911E+00	0.515E-01	0.285E+01	0.169E+02	0.455E+06	0.974E-02	0.413E-06	0.450E+00
910	0.836E+01	0.473E+00	0.285E+01	0.147E+02	0.423E+06	0.844E-02	0.379E-05	0.413E+01
1011	0.820E+01	0.464E+00	0.285E+01	0.169E+02	0.455E+06	0.974E-02	0.372E-05	0.405E+01
1516	0.828E+01	0.469E+00	0.285E+01	0.145E+02	0.397E+06	0.853E-02	0.388E-05	0.405E+01
2021	0.410E+01	0.232E+00	0.285E+01	0.169E+02	0.450E+06	0.975E-02	0.187E-05	0.202E+01
34	0.838E-01	0.474E-02	0.285E+01	0.797E+00	0.977E+05	0.460E-03	0.382E-07	0.413E-01
56	0.137E-01	0.775E-03	0.285E+01	0.131E+02	0.400E+06	0.752E-02	0.621E-08	0.677E-02
23	0.185E-03	0.105E-04	0.285E+01	0.308E+00	0.607E+05	0.178E-03	0.844E-10	0.914E-04
45	0.178E-04	0.100E-05	0.285E+01	0.253E+00	0.550E+05	0.146E-03	0.809E-11	0.876E-05
1112	0.836E+01	0.473E+00	0.285E+01	0.147E+02	0.423E+06	0.844E-02	0.379E-05	0.413E+01
1213	0.911E+00	0.515E-01	0.285E+01	0.169E+02	0.455E+06	0.974E-02	0.413E-06	0.450E+00
1314	0.683E-03	0.387E-04	0.285E+01	0.162E+00	0.444E+05	0.931E-04	0.310E-09	0.337E-03
1415	0.123E+02	0.695E+00	0.285E+01	0.168E+02	0.427E+06	0.985E-02	0.575E-05	0.600E+01
1617	0.138E+02	0.778E+00	0.285E+01	0.168E+02	0.427E+06	0.985E-02	0.644E-05	0.673E+01
1718	0.000E+00	-0.733E+01	0.285E+01	0.145E+02	0.398E+06	0.854E-02	0.000E+00	0.000E+00
1920	0.446E+01	0.252E+00	0.285E+01	0.111E+02	0.364E+06	0.640E-02	0.203E-05	0.220E+01
3334	0.362E-01	0.305E-04	0.348E+00	0.613E+01	0.452E+05	0.344E-02	0.405E-08	0.411E-02
3435	0.513E+05	0.172E+03	0.348E+00	0.104E+04	0.588E+06	0.582E+00	0.574E-02	0.582E+04
3031	0.611E+00	0.515E-03	0.348E+00	0.108E+02	0.915E+05	0.712E-02	0.639E-07	0.466E-01
3132	0.231E-01	0.195E-04	0.348E+00	0.411E+01	0.564E+05	0.270E-02	0.242E-08	0.176E-02
3233	0.156E+05	0.132E+02	0.348E+00	0.328E+04	0.159E+07	0.215E+01	0.163E-02	0.119E+04
221	0.410E+01	0.232E+00	0.285E+01	0.169E+02	0.450E+06	0.975E-02	0.187E-05	0.202E+01
1819	0.158E+02	0.893E+00	0.285E+01	0.168E+02	0.427E+06	0.986E-02	0.739E-05	0.772E+01

SOLUTION SATISFIED CONVERGENCE CRITERION OF 0.100E-05 IN 36 ITERATIONS

ITERADJC = 3 DIFTEM = 0.000E+00
TAU = 100000000.000000 ISTEP = 1 DTAU =
100000000.000000

```
************************************************

TIME OF ANALYSIS WAS   6.250000000000000E-002  SECS

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```

APPENDIX BB—INPUT AND OUTPUT DATA FILES FROM EXAMPLE 21

Expanded LOX-Simplex Model: 25,000 RPM, w/ All Branches & Nodes (& Axial Thrust)

Contents

Back to Appendix BB

```
GFSSP VERSION
    604
GFSSP INSTALLATION PATH
C:\Program Files (x86)\GFSSP604\
ANALYST
Paul Schallhorn (updated to GFSSP v6 by Andre LeClair)
INPUT DATA FILE NAME
D:\GFSSP604Compaq\Examples\EX21\Ex21.dat
OUTPUT FILE NAME
Ex21.out
TITLE
Expanded LOx-Simplex Model:  25,000 RPM, w/ All Branches & Nodes (& Axial Thrust)
USETUP
F
DENCON        GRAVITY       ENERGY        MIXTURE       THRUST        STEADY        TRANSV        SAVER
F             F             T             F             T             T             F             F
HEX           HCOEF         REACTING      INERTIA       CONDX         ADDPROP       PRINTI        ROTATION
F             F             F             F             F             F             F             T
BUOYANCY      HRATE         INVAL         MSORCE        MOVBND        TPA           VARGEO        TVM
F             F             F             F             F             F             F             F
SHEAR         PRNTIN        PRNTADD       OPVALVE       TRANSQ        CONJUG        RADIAT        WINPLOT
F             T             T             F             F             F             F             F
PRESS         INSUC         VARROT        CYCLIC        CHKVALS       WINFILE       DALTON        NOSTATS
F             F             F             F             F             F             F             F
NORMAL        SIMUL         SECONDL       NRSOLVT       IBDF          NOPLT         PRESREG       FLOWREG
F             T             F             T             1             T             0             0
TRANS_MOM     USERVARS      PSMG          ISOLVE        PLOTADD       SIUNITS       TECPLOT       MDGEN
F             F             F             1             F             F             F             F
NUM_USER_VARS IFR_MIX       PRINTD        SATTABL       MSORIN        PRELVLV       LAMINAR       HSTAG
1             1             F             F             F             F             T             T
NNODES        NINT          NBR           NF
 35            27            36            1
RELAXK        RELAXD        RELAXH        CC            NITER         RELAXNR       RELAXHC       RELAXTS
 0.5             0.25          0.5           0.0001          500 0.5           1               1
NFLUID(I),  I = 1, NF
 6
NODE          INDEX     DESCRIPTION
 100              2       " Impeller Discharge"
 101              1       " Node 101"
 102              2       " Node 102"
 103              1       " Node 103"
 104              1       " Node 104"
 105              2       " Impeller Inlet"
 106              1       " Node 106"
 107              2       " Node 107"
 108              1       " Node 108"
 109              1       " Node 109"
```

```
110             1       " Node 110"
111             1       " Node 111"
112             1       " Node 112"
114             1       " Node 114"
115             1       " Node 115"
116             2       " Turbine Disc Front Face"
170             1       " Node 170"
180             2       " Turbine Disc Back Face"
1181             1       " Node 1181"
118             1       " Node 118"
121             1       " Node 121"
122             1       " Node 122"
123             1       " Node 123"
124             1       " Node 124"
130             2       " Atmosphere"
1131             1       " Node 1131"
113             1       " Node 113"
131             1       " Node 131"
132             1       " Node 132"
133             1       " Node 133"
134             1       " Node 134"
135             1       " Node 135"
136             1       " Node 136"
138             1       " Node 138"
140             2       " Inducer Inlet"
NODE  PRES (PSI)  TEMP(DEGF)  MASS SOURC    HEAT SOURC   THRST AREA   CONCENTRATION
100   1100             -286.6          0                  0                  0
101   1035             -286.6          0                  0                  -3.479
102   1025             -286.6          0                  0                  -3.479
103   330.4            -286.6          0                  0                  0
104   187.2            -286.6          0                  0                  -0.9388
105   346.2            -286.6          0                  0                  -0.9388
106   1059             -286.6          0                  0                  2.792
107   1078             -286.6          0                  0                  2.792
108   330.4            -286.6          0                  0                  3.387
109   307.8            -286.6          0                  5.3                3.387
110   285.3            -286.6          0                  0.932              0
111   499.2            -286.6          0                  0                  0
112   489.2            -286.6          0                  0.932              -0.8837
114   97.25            -286.6          0                  0                  0
115   46.25            -286.6          0                  0                  -12.28
116   62.6             -265.6          0                  0                  -28.48
170   34.7             -286            0                  0                  0
180   14.7             -286            0                  0                  45.66
1181  35               -286            0                  0                  0
118   35               -286            0                  0                  0
121   30               -286            0                  0                  0
```

122	30	-286	0	0	0
123	25	-286	0	0	0
124	25	-286	0	0	0
130	14.7	-286.6	0	0	0
1131	150	-286	0	0	0
113	150	-286	0	0	0
131	140	-286	0	0	0
132	140	-286	0	0	0
133	130	-286	0	0	0
134	130	-286	0	0	0
135	120	-286	0	0	0
136	120	-286	0	0	0
138	100	-286	0	0	0
140	93.7	-286.6	0	0	-8.442

INODE	NUMBR	NAMEBR		
101	2	201	202	
103	2	203	204	
104	2	204	205	
106	2	206	207	
108	2	208	209	
109	2	209	210	
110	2	210	211	
111	2	211	212	
112	3	212	214	2131
114	3	214	215	2801
115	2	215	216	
170	2	270	280	
1181	2	2801	2802	
118	3	2802	221	222
121	2	221	223	
122	2	222	224	
123	2	223	2301	
124	2	224	2302	
1131	2	2131	2132	
113	3	2132	231	232
131	2	231	233	
132	2	232	234	
133	2	233	235	
134	2	234	236	
135	2	235	2381	
136	2	236	2382	
138	3	2381	2382	2401

BRANCH	UPNODE	DNNODE	OPTION	DESCRIPTION
201	100	101	9	"Duct 201"
202	101	102	3	"Duct 202"
203	102	103	9	"Duct 203"
204	103	104	11	"Seal 204"

```
205        104        105        2       "Restrict 205"
206        100        106        9       "Duct 206"
207        106        107        3       "Duct 207"
208        107        108        11      "Seal 208"
209        108        109        2       "Restrict 209"
210        109        110        2       "Ball Bearing Branch"
211        110        111        9       "Duct 211"
212        111        112        2       "Ball Bearing Branch"
214        112        114        11      "Seal 214"
215        114        115        11      "Seal 215"
216        115        116        3       "Duct 216"
270        116        170        2       "Restrict 270"
280        170        180        22      "Restrict 280"
2801       114        1181       21      "Tube 2801"
2802       1181       118        21      "Tube 2802 Exit Equiv Length"
221        118        121        4       "Pipe L 221"
222        118        122        4       "Pipe L 222"
223        121        123        1       "Pipe 223"
224        122        124        1       "Pipe 224"
2301       123        130        4       "Pipe L 2301"
2302       124        130        4       "Pipe L 2302"
2131       112        1131       21      "Tube 2131"
2132       1131       113        21      "Tube 2132 Inlet & Exit Equiv Length"
231        113        131        4       "Pipe L 231"
232        113        132        4       "Pipe L 232"
233        131        133        1       "Pipe 233"
234        132        134        1       "Pipe 234"
235        133        135        1       "Pipe 235"
236        134        136        1       "Pipe 236"
2381       135        138        1       "Pipe 2381"
2382       136        138        1       "Pipe 2382"
2401       138        140        21      "Tube 2401"
BRANCH        OPTION -9     LENGTH        OUTER RAD     INNER RAD     RPM           AREA
 201                        0.125         2.3125       2.25          25000          0.89584
BRANCH        OPTION -3     LENGTH        HEIGHT        WIDTH         TYPE          AREA
 202                        0.5625        0.03125       12.37         1             0.3865625
BRANCH        OPTION -9     LENGTH        OUTER RAD     INNER RAD     RPM           AREA
 203                        0.3125        1.75         1.6875        25000          0.67495
BRANCH        OPTION -11    RAD           CLEARANCE     PITCH         No. OF TEETH  MULTIPLIER    Area
 204                        1.6875        0.007        0.03          5             1                  0.07422
BRANCH        OPTION -2     FLOW COEFF    AREA
 205                        1             0.31293
BRANCH        OPTION -9     LENGTH        OUTER RAD     INNER RAD     RPM           AREA
 206                        0.125         2.3125       2.25          25000          0.89584
BRANCH        OPTION -3     LENGTH        HEIGHT        WIDTH         TYPE          AREA
 207                        0.4375        0.0625        12.763        1             0.79767
BRANCH        OPTION -11    RAD           CLEARANCE     PITCH         No. OF TEETH  MULTIPLIER    Area
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 208                  1.8125        0.01         0.03          4             1                 0.11388
BRANCH        OPTION -2     FLOW COEFF    AREA
 209                  0             2.8225
BRANCH        OPTION -2     FLOW COEFF    AREA
 210                  0.057         1.4363
BRANCH        OPTION -9     LENGTH        OUTER RAD     INNER RAD     RPM           AREA
 211                  6.0625        1.4375       1.0625        25000         2.9452
BRANCH        OPTION -2     FLOW COEFF    AREA
 212                  0.057         1.4364
BRANCH        OPTION -11    RAD           CLEARANCE     PITCH         No. OF TEETH  MULTIPLIER    Area
 214                  1.2188        0.005        0.03          5             0.85              0.038288
BRANCH        OPTION -11    RAD           CLEARANCE     PITCH         No. OF TEETH  MULTIPLIER    Area
 215                  1.25          0.005        0.03          4             1                 0.03927
BRANCH        OPTION -3     LENGTH        HEIGHT        WIDTH         TYPE          AREA
 216                  1.8125        0.14063       13.548        1             1.9052707093
BRANCH        OPTION -2     FLOW COEFF    AREA
 270                  1             0.38656
BRANCH        OPTION -22     AREA       FLOW COEF
 280                  0.38656       1
BRANCH        OPTION -21    LENGTH    DIAMETER    ABS ROUGHNESS    NUMBER TUBES
 2801                 1.25          0.0625        0             22
BRANCH        OPTION -21    LENGTH    DIAMETER    ABS ROUGHNESS    NUMBER TUBES
 2802                 3.91          0.0625        0             22
BRANCH        OPTION -4     LENGTH        DIA           ESPD          KI            KE            ANGLE         AREA
 221                  1.4           0.25          0             0.5           0             0             0.049087
BRANCH        OPTION -4     LENGTH        DIA           ESPD          KI            KE            ANGLE         AREA
 222                  1.4           0.25          0             0.5           0             0             0.049087
BRANCH        OPTION -1     LENGTH        DIA           EPSD          ANGLE         AREA
 223                  3.5625           0.3125           0                0                 0.076698974609
BRANCH        OPTION -1     LENGTH        DIA           EPSD          ANGLE         AREA
 224                  3.5625           0.3125           0                0                 0.076698974609
BRANCH        OPTION -4     LENGTH        DIA           ESPD          KI            KE            ANGLE         AREA
 2301                 120           0.375         0             0             1             0             0.11045
BRANCH        OPTION -4     LENGTH        DIA           ESPD          KI            KE            ANGLE         AREA
 2302                 120           0.375         0             0             1             0             0.11045
BRANCH        OPTION -21    LENGTH    DIAMETER    ABS ROUGHNESS    NUMBER TUBES
 2131                 0.25          0.0625        0             8
BRANCH        OPTION -21    LENGTH    DIAMETER    ABS ROUGHNESS    NUMBER TUBES
 2132                 7.825         0.0625        0             8
BRANCH        OPTION -4     LENGTH        DIA           ESPD          KI            KE            ANGLE         AREA
 231                  1.5           0.25          0             0.5           0             0             0.049087
BRANCH        OPTION -4     LENGTH        DIA           ESPD          KI            KE            ANGLE         AREA
 232                  1.5           0.25          0             0.5           0             0             0.049087
BRANCH        OPTION -1     LENGTH        DIA           EPSD          ANGLE         AREA
 233                  3.625            0.25             0                0                 0.04908734375
BRANCH        OPTION -1     LENGTH        DIA           EPSD          ANGLE         AREA
 234                  3.625            0.25             0                0                 0.04908734375
```

```
BRANCH        OPTION -1     LENGTH        DIA           EPSD          ANGLE         AREA
 235                        0.3               0.45962         0                 0                   0.16591564945
BRANCH        OPTION -1     LENGTH        DIA           EPSD          ANGLE         AREA
 236                        0.3               0.45962         0                 0                   0.16591564945
BRANCH        OPTION -1     LENGTH        DIA           EPSD          ANGLE         AREA
 2381                       24.5              0.6             0                 0                   0.2827431
BRANCH        OPTION -1     LENGTH        DIA           EPSD          ANGLE         AREA
 2382                       24.5              0.6             0                 0                   0.2827431
BRANCH        OPTION -21    LENGTH    DIAMETER    ABS ROUGHNESS    NUMBER TUBES
 2401                       0.375         0.375         0             8
NUMBER OF ROTATING BRANCHES
 4
BRANCH   UPST RAD    DNST RAD       RPM        K ROT
 202   2.25            1.688            25000             0.3038
 205   1.688           1.5              25000             0.1235
 207   2.25            1.813            25000             0.184
 209   1.813           1.063            25000             0.1122
```

Back to Appendix BB

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************************************************
            G F S S P (Version 604)
     Generalized Fluid System Simulation Program
                  March 2012

     Developed by NASA/Marshall Space Flight Center
     Copyright (C) by Marshall Space Flight Center

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


   RUN DATE:09/14/2012 08:31

TITLE      :Expanded LOx-Simplex Model:  25,000 RPM, w/ All Branches & Nodes (& Axial Thrust
ANALYST    :Paul Schallhorn (updated to GFSSP v6 by Andre LeClair)
FILEIN     :D:\GFSSP604Compaq\Examples\EX21\Ex21.dat
FILEOUT    :Ex21.out

                         OPTION VARIABLES

ADDPROP    BUOYANCY   CONDX      CONJUG     CYCLIC     DALTON     DENCON     ENERGY
F          F          F          F          F          F          F          T
FLOWREG    GRAVITY    HCOEF      HEX        HRATE      IFRMIX     INERTIA    INSUC
0          F          F          F          F          1          F          F
INVAL      MIXTURE    MOVBND     MSORCE     NORMAL     NRSOLVT    OPVALVE    PLOTADD
F          F          F          F          F          T          F          F
PRESREG    PRESS      PRINTI     PRNTADD    PRNTIN     RADIATION  REACTING   ROTATION
0          F          F          T          T          F          F          T
SAVER      SECONDL    SHEAR      SIMULA     SIUNITS    STEADY     THRUST     TPA
F          F          F          T          F          T          T          F
TRANS_MOM  TRANSQ     TRANSV     TVM        TWOD       USRVAR     VARGEO     VARROT
F          F          F          F          F          F          F          F
RLFVLV
F

NNODES    =   35
NINT      =   27
NBR       =   36
NF        =    1
NVAR      =   63
NHREF     =    2


FLUIDS:   O2
```

BOUNDARY NODES

NODE	P (PSI)	T (F)	RHO (LBM/FT^3)		AREA (IN^2)
100	0.1100E+04	-0.2866E+03	0.7047E+02	0.0000E+00	
102	0.1025E+04	-0.2866E+03	0.7040E+02	-0.3479E+01	
105	0.3462E+03	-0.2866E+03	0.6968E+02	-0.9388E+00	
107	0.1078E+04	-0.2866E+03	0.7045E+02	0.2792E+01	
116	0.6260E+02	-0.2656E+03	0.1058E+01	-0.2848E+02	
180	0.1470E+02	-0.2860E+03	0.2596E+00	0.4566E+02	
130	0.1470E+02	-0.2866E+03	0.2606E+00	0.0000E+00	
140	0.9370E+02	-0.2866E+03	0.6940E+02	-0.8442E+01	

INPUT SPECIFICATIONS FOR INTERNAL NODES

NODE	AREA (IN^2)	MASS (LBM/S)	HEAT (BTU/LBM)
101	-0.3479E+01	0.0000E+00	0.0000E+00
103	0.0000E+00	0.0000E+00	0.0000E+00
104	-0.9388E+00	0.0000E+00	0.0000E+00
106	0.2792E+01	0.0000E+00	0.0000E+00
108	0.3387E+01	0.0000E+00	0.0000E+00
109	0.3387E+01	0.0000E+00	0.5300E+01
110	0.0000E+00	0.0000E+00	0.9320E+00
111	0.0000E+00	0.0000E+00	0.0000E+00
112	-0.8837E+00	0.0000E+00	0.9320E+00
114	0.0000E+00	0.0000E+00	0.0000E+00
115	-0.1228E+02	0.0000E+00	0.0000E+00
170	0.0000E+00	0.0000E+00	0.0000E+00
1181	0.0000E+00	0.0000E+00	0.0000E+00
118	0.0000E+00	0.0000E+00	0.0000E+00
121	0.0000E+00	0.0000E+00	0.0000E+00
122	0.0000E+00	0.0000E+00	0.0000E+00
123	0.0000E+00	0.0000E+00	0.0000E+00
124	0.0000E+00	0.0000E+00	0.0000E+00
1131	0.0000E+00	0.0000E+00	0.0000E+00
113	0.0000E+00	0.0000E+00	0.0000E+00
131	0.0000E+00	0.0000E+00	0.0000E+00
132	0.0000E+00	0.0000E+00	0.0000E+00
133	0.0000E+00	0.0000E+00	0.0000E+00
134	0.0000E+00	0.0000E+00	0.0000E+00
135	0.0000E+00	0.0000E+00	0.0000E+00
136	0.0000E+00	0.0000E+00	0.0000E+00
138	0.0000E+00	0.0000E+00	0.0000E+00

BRANCH	UPNODE	DNNODE	OPTION
201	100	101	9
202	101	102	3

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     203       102       103         9
     204       103       104        11
     205       104       105         2
     206       100       106         9
     207       106       107         3
     208       107       108        11
     209       108       109         2
     210       109       110         2
     211       110       111         9
     212       111       112         2
     214       112       114        11
     215       114       115        11
     216       115       116         3
     270       116       170         2
     280       170       180        22
    2801       114      1181        21
    2802      1181       118        21
     221       118       121         4
     222       118       122         4
     223       121       123         1
     224       122       124         1
    2301       123       130         4
    2302       124       130         4
    2131       112      1131        21
    2132      1131       113        21
     231       113       131         4
     232       113       132         4
     233       131       133         1
     234       132       134         1
     235       133       135         1
     236       134       136         1
    2381       135       138         1
    2382       136       138         1
    2401       138       140        21
BRANCH OPTION -9:   LENGTH,     OUTER RAD,  INNER RAD,   RPM,        AREA
     201            0.125E+00   0.231E+01   0.225E+01   0.250E+05   0.896E+00
BR OPT -> 3-1       LENGTH      HEIGHT      WIDTH       TYPE        AREA
     202            0.562E+00   0.312E-01   0.124E+02   0.100E+01   0.387E+00
BRANCH OPTION -9:   LENGTH,     OUTER RAD,  INNER RAD,  RPM,        AREA
     203            0.312E+00   0.175E+01   0.169E+01   0.250E+05   0.675E+00
BRANCH OPTION -11:  IN RAD      PIPE DIA    ORIFICE DIA  AREA
     204            0.169E+01   0.700E-02   0.300E-01   0.500E+01   0.100E+01   0.742E-01
BRANCH OPTION -2:  FLOW COEF    AREA
     205            0.100E+01   0.313E+00
BRANCH OPTION -9:   LENGTH,     OUTER RAD,  INNER RAD,  RPM,        AREA
     206            0.125E+00   0.231E+01   0.225E+01   0.250E+05   0.896E+00
BR OPT -> 3-1 LENGTH   HEIGHT      WIDTH     TYPE        AREA
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    207             0.438E+00   0.625E-01   0.128E+02   0.100E+01   0.798E+00
BRANCH OPTION -11:  IN RAD      PIPE DIA    ORIFICE DIA  AREA
    208             0.181E+01   0.100E-01   0.300E-01   0.400E+01   0.100E+01   0.114E+00
BRANCH OPTION -2:   FLOW COEF    AREA
    209              0.000E+00   0.282E+01
BRANCH OPTION -2:   FLOW COEF    AREA
    210             0.570E-01   0.144E+01
BRANCH OPTION -9:   LENGTH,      OUTER RAD,  INNER RAD,  RPM,        AREA
    211             0.606E+01   0.144E+01   0.106E+01   0.250E+05   0.295E+01
BRANCH OPTION -2:   FLOW COEF    AREA
    212             0.570E-01   0.144E+01
BRANCH OPTION -11:  IN RAD      PIPE DIA    ORIFICE DIA   AREA
    214             0.122E+01   0.500E-02   0.300E-01   0.500E+01   0.850E+00   0.383E-01
BRANCH OPTION -11:  IN RAD      PIPE DIA    ORIFICE DIA  AREA
    215             0.125E+01   0.500E-02   0.300E-01   0.400E+01   0.100E+01   0.393E-01
BR OPT -> 3-1       LENGTH      HEIGHT      WIDTH       TYPE        AREA
    216             0.181E+01   0.141E+00   0.135E+02   0.100E+01   0.191E+01
BRANCH OPTION -2:  FLOW COEF    AREA
    270             0.100E+01   0.387E+00
BRANCH OPTION -22 FLOW COEF     AREA
    280             0.100E+01   0.387E+00
BRANCH OPTION -21:(PARALLEL TUBES)LENGTH,   DIA         EPSD,      NO. OF TUBES  AREA
   2801                          .125E+01   0.625E-01   0.000E+00   0.220E+02   0.675E-01
BRANCH OPTION -21:(PARALLEL TUBES)LENGTH,    DIA        EPSD,       NO. OF TUBES  AREA
   2802                          0.391E+01   0.625E-01   0.000E+00   0.220E+02   0.675E-01
BRANCH  OPTION -4:  LENGTH,     DIA         EPSD        ANGLE,      AREA
    221             0.140E+01   0.250E+00   0.000E+00   0.500E+00   0.000E+00   0.000E+00   0.491E-01
BRANCH  OPTION -4:  LENGTH,     DIA         EPSD        ANGLE,      AREA
    222             0.140E+01   0.250E+00   0.000E+00   0.500E+00   0.000E+00   0.000E+00   0.491E-01
BRANCH  OPTION -1:  LENGTH      DIA         EPSD       ANGLE        AREA
    223             0.356E+01   0.312E+00   0.000E+00   0.000E+00   0.767E-01
BRANCH  OPTION -1:   LENGTH      DIA        EPSD       ANGLE        AREA
    224             0.356E+01   0.312E+00   0.000E+00   0.000E+00   0.767E-01
BRANCH  OPTION -4:  LENGTH,     DIA         EPSD       ANGLE,      AREA
   2301             0.120E+03   0.375E+00   0.000E+00   0.000E+00   0.100E+01   0.000E+00   0.110E+00
BRANCH  OPTION -4:  LENGTH, DIA  EPSD        ANGLE,      AREA
   2302             0.120E+03   0.375E+00   0.000E+00   0.000E+00   0.100E+01   0.000E+00   0.110E+00
BRANCH OPTION -21:(PARALLEL TUBES)LENGTH,   DIA         EPSD,      NO. OF TUBES  AREA
   2131                          0.250E+00   0.625E-01   0.000E+00   0.800E+01   0.245E-01
BRANCH OPTION -21:(PARALLEL TUBES)LENGTH,   DIA         EPSD,      NO. OF TUBES  AREA
   2132                          0.783E+01  0.625E-01   0.000E+00   0.800E+01   0.245E-01
BRANCH  OPTION -4:  LENGTH,     DIA         EPSD       ANGLE,       AREA
    231             0.150E+01   0.250E+00   0.000E+00   0.500E+00   0.000E+00   0.000E+00   0.491E-01
BRANCH  OPTION -4:  LENGTH,     DIA         EPSD       ANGLE,       AREA
    232             0.150E+01   0.250E+00   0.000E+00   0.500E+00   0.000E+00   0.000E+00   0.491E-01
BRANCH  OPTION -1:   LENGTH      DIA        EPSD       ANGLE        AREA
    233             0.362E+01   0.250E+00   0.000E+00   0.000E+00   0.491E-01
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BRANCH  OPTION -1:   LENGTH      DIA         EPSD       ANGLE        AREA
    234             0.362E+01   0.250E+00   0.000E+00   0.000E+00   0.491E-01
BRANCH  OPTION -1:   LENGTH      DIA         EPSD       ANGLE        AREA
    235             0.300E+00   0.460E+00   0.000E+00   0.000E+00   0.166E+00
BRANCH  OPTION -1:   LENGTH      DIA         EPSD       ANGLE        AREA
    236             0.300E+00   0.460E+00   0.000E+00   0.000E+00   0.166E+00
BRANCH  OPTION -1:   LENGTH      DIA         EPSD       ANGLE        AREA
   2381             0.245E+02   0.600E+00   0.000E+00   0.000E+00   0.283E+00
BRANCH  OPTION -1:   LENGTH      DIA         EPSD       ANGLE        AREA
   2382             0.245E+02   0.600E+00   0.000E+00   0.000E+00   0.283E+00
BRANCH OPTION -21:(PARALLEL TUBES)LENGTH,    DIA        EPSD,       NO. OF TUBES  AREA
   2401                         0.375E+00  0.375E+00   0.000E+00   0.800E+01   0.884E+00


SOLUTION
INTERNAL NODES
 NODE     P(PSI)       TF(F)          Z           RHO          EM(LBM)      QUALITY
                                              (LBM/FT^3)
  101    0.1100E+04 -0.2866E+03  0.2690E+00  0.7047E+02  0.0000E+00  0.0000E+00
  103    0.1025E+04 -0.2866E+03  0.2508E+00  0.7040E+02  0.0000E+00  0.0000E+00
  104    0.3566E+03 -0.2841E+03  0.8749E-01  0.6926E+02  0.0000E+00  0.0000E+00
  106    0.1100E+04 -0.2866E+03  0.2690E+00  0.7047E+02  0.0000E+00  0.0000E+00
  108    0.8603E+03 -0.2858E+03  0.2105E+00  0.7009E+02  0.0000E+00  0.0000E+00
  109    0.8507E+03 -0.2729E+03  0.2002E+00  0.6785E+02  0.0000E+00  0.0000E+00
  110    0.7571E+03 -0.2703E+03  0.1772E+00  0.6727E+02  0.0000E+00  0.0000E+00
  111    0.7569E+03 -0.2703E+03  0.1772E+00  0.6727E+02  0.0000E+00  0.0000E+00
  112    0.6625E+03 -0.2677E+03  0.1544E+00  0.6668E+02  0.0000E+00  0.0000E+00
  114    0.7873E+02 -0.2660E+03  0.1851E-01  0.6549E+02  0.0000E+00  0.0000E+00
  115    0.6260E+02 -0.2675E+03  0.2198E-01  0.4421E+02  0.0000E+00  0.8084E-02
  170    0.5196E+02 -0.2680E+03  0.9231E+00  0.8760E+00  0.0000E+00  0.1000E+01
 1181    0.7370E+02 -0.2659E+03  0.1733E-01  0.6548E+02  0.0000E+00  0.0000E+00
  118    0.5796E+02 -0.2694E+03  0.2946E-01  0.3084E+02  0.0000E+00  0.1752E-01
  121    0.4887E+02 -0.2734E+03  0.4559E-01  0.1716E+02  0.0000E+00  0.3728E-01
  122    0.4887E+02 -0.2734E+03  0.4559E-01  0.1716E+02  0.0000E+00  0.3728E-01
  123    0.4717E+02 -0.2742E+03  0.4888E-01  0.1552E+02  0.0000E+00  0.4121E-01
  124    0.4717E+02 -0.2742E+03  0.4888E-01  0.1552E+02  0.0000E+00  0.4121E-01
 1131    0.6454E+03 -0.2676E+03  0.1504E+00  0.6664E+02  0.0000E+00  0.0000E+00
  113    0.1108E+03 -0.2660E+03  0.2604E-01  0.6556E+02  0.0000E+00  0.0000E+00
  131    0.9799E+02 -0.2660E+03  0.2303E-01  0.6553E+02  0.0000E+00  0.0000E+00
  132    0.9799E+02 -0.2660E+03  0.2303E-01  0.6553E+02  0.0000E+00  0.0000E+00
  133    0.9411E+02 -0.2660E+03  0.2212E-01  0.6552E+02  0.0000E+00  0.0000E+00
  134    0.9411E+02 -0.2660E+03  0.2212E-01  0.6552E+02  0.0000E+00  0.0000E+00
  135    0.9409E+02 -0.2660E+03  0.2211E-01  0.6552E+02  0.0000E+00  0.0000E+00
  136    0.9409E+02 -0.2660E+03  0.2211E-01  0.6552E+02  0.0000E+00  0.0000E+00
  138    0.9370E+02 -0.2660E+03  0.2202E-01  0.6552E+02  0.0000E+00  0.0000E+00

   NODE       H          ENTROPY      EMU        COND         CP          GAMA
```

	BTU/LB	BTU/LB-R	LBM/FT-SEC	BTU/FT-S-R	BTU/LB-R	
101	0.6701E+02	0.7239E+00	0.1272E-03	0.2029E-04	0.4098E+00	0.1761E+01
103	0.6690E+02	0.7284E+00	0.1264E-03	0.2026E-04	0.4104E+00	0.1764E+01
104	0.6690E+02	0.7294E+00	0.1151E-03	0.1979E-04	0.4158E+00	0.1817E+01
106	0.6701E+02	0.7237E+00	0.1272E-03	0.2029E-04	0.4098E+00	0.1761E+01
108	0.6698E+02	0.7284E+00	0.1232E-03	0.2013E-04	0.4114E+00	0.1778E+01
109	0.7225E+02	0.7286E+00	0.1032E-03	0.1928E-04	0.4079E+00	0.1880E+01
110	0.7319E+02	0.7287E+00	0.9879E-04	0.1906E-04	0.4090E+00	0.1909E+01
111	0.7319E+02	0.7273E+00	0.9879E-04	0.1906E-04	0.4090E+00	0.1909E+01
112	0.7412E+02	0.7274E+00	0.9458E-04	0.1883E-04	0.4107E+00	0.1939E+01
114	0.7412E+02	0.7300E+00	0.8690E-04	0.1835E-04	0.4218E+00	0.2010E+01
115	0.7412E+02	0.7303E+00	0.7956E-04	0.1832E-04	0.4199E+00	0.1992E+01
170	0.1571E+03	0.7319E+00	0.5844E-05	0.1653E-05	0.2502E+00	0.1514E+01
1181	0.7412E+02	0.7319E+00	0.8684E-04	0.1835E-04	0.4219E+00	0.2011E+01
118	0.7412E+02	0.7319E+00	0.7234E-04	0.1829E-04	0.4176E+00	0.1968E+01
121	0.7412E+02	0.7319E+00	0.6029E-04	0.1823E-04	0.4131E+00	0.1920E+01
122	0.7412E+02	0.7319E+00	0.6029E-04	0.1823E-04	0.4131E+00	0.1920E+01
123	0.7412E+02	0.1247E+01	0.5828E-04	0.1822E-04	0.4123E+00	0.1911E+01
124	0.7412E+02	0.1247E+01	0.5828E-04	0.1822E-04	0.4123E+00	0.1911E+01
1131	0.7412E+02	0.7311E+00	0.9435E-04	0.1882E-04	0.4110E+00	0.1941E+01
113	0.7412E+02	0.7311E+00	0.8732E-04	0.1838E-04	0.4211E+00	0.2006E+01
131	0.7412E+02	0.7311E+00	0.8715E-04	0.1837E-04	0.4214E+00	0.2007E+01
132	0.7412E+02	0.7311E+00	0.8715E-04	0.1837E-04	0.4214E+00	0.2007E+01
133	0.7412E+02	0.7312E+00	0.8710E-04	0.1837E-04	0.4215E+00	0.2008E+01
134	0.7412E+02	0.7312E+00	0.8710E-04	0.1837E-04	0.4215E+00	0.2008E+01
135	0.7412E+02	0.7313E+00	0.8710E-04	0.1837E-04	0.4215E+00	0.2008E+01
136	0.7412E+02	0.7313E+00	0.8710E-04	0.1837E-04	0.4215E+00	0.2008E+01
138	0.7412E+02	0.7314E+00	0.8710E-04	0.1837E-04	0.4215E+00	0.2008E+01

BRANCHES

BRANCH	KFACTOR	DELP	FLOW RATE	VELOCITY	REYN. NO.	MACH NO.	ENTROPY GEN.	LOST WORK
	(LBF-S^2/(LBM-FT)^2)	(PSI)	(LBM/SEC)	(FT/SEC)			BTU/(R-SEC)	LBF-FT/SEC
201	0.120E+01	0.188E+00	0.475E+01	0.108E+02	0.535E+06	0.158E-01	0.136E-04	0.183E+01
202	0.581E+01	0.748E+02	0.475E+01	0.251E+02	0.814E+06	0.365E-01	0.658E-04	0.885E+01
203	0.326E+01	0.493E+00	0.467E+01	0.141E+02	0.608E+06	0.205E-01	0.350E-04	0.471E+01
204	0.442E+04	0.668E+03	0.467E+01	0.129E+03	0.183E+07	0.187E+00	0.473E-01	0.637E+04
205	0.475E+02	0.104E+02	0.467E+01	0.310E+02	0.982E+06	0.440E-01	0.510E-03	0.697E+02
206	0.131E+01	0.172E+00	0.434E+01	0.991E+01	0.489E+06	0.144E-01	0.113E-04	0.153E+01
207	0.546E+00	0.218E+02	0.434E+01	0.111E+02	0.518E+06	0.162E-01	0.472E-05	0.635E+00
208	0.165E+04	0.218E+03	0.436E+01	0.783E+02	0.138E+07	0.114E+00	0.144E-01	0.194E+04
209	0.000E+00	0.962E+01	0.436E+01	0.318E+01	0.285E+06	0.458E-02	0.000E+00	0.000E+00
210	0.709E+03	0.936E+02	0.436E+01	0.645E+01	0.478E+06	0.873E-02	0.597E-02	0.867E+03
211	0.112E+01	0.149E+00	0.436E+01	0.317E+01	0.348E+06	0.423E-02	0.942E-05	0.139E+01
212	0.715E+03	0.944E+02	0.436E+01	0.650E+01	0.499E+06	0.867E-02	0.599E-02	0.882E+03
214	0.248E+05	0.584E+03	0.184E+01	0.104E+03	0.135E+07	0.137E+00	0.156E-01	0.232E+04
215	0.154E+05	0.161E+02	0.388E+00	0.218E+02	0.305E+06	0.280E-01	0.914E-04	0.138E+02

216	0.469E+00	0.491E-03	0.388E+00	0.664E+00	0.479E+05	0.861E-03	0.416E-08	0.622E-03
270	0.204E+04	0.106E+02	0.867E+00	0.305E+03	0.318E+07	0.448E+00	0.831E-02	0.126E+04
280	0.246E+04	0.373E+02	0.867E+00	0.369E+03	0.323E+07	0.549E+00	0.123E-01	0.183E+04
2801	0.343E+03	0.503E+01	0.145E+01	0.474E+02	0.872E+06	0.609E-01	0.107E-03	0.161E+02
2802	0.107E+04	0.157E+02	0.145E+01	0.474E+02	0.873E+06	0.609E-01	0.334E-03	0.503E+02
221	0.248E+04	0.909E+01	0.727E+00	0.692E+02	0.614E+06	0.907E-01	0.208E-03	0.308E+02
222	0.248E+04	0.909E+01	0.727E+00	0.692E+02	0.614E+06	0.907E-01	0.208E-03	0.308E+02
223	0.465E+03	0.171E+01	0.727E+00	0.795E+02	0.589E+06	0.107E+00	0.718E-04	0.104E+02
224	0.465E+03	0.171E+01	0.727E+00	0.795E+02	0.589E+06	0.107E+00	0.718E-04	0.104E+02
2301	0.885E+04	0.325E+02	0.727E+00	0.611E+02	0.508E+06	0.823E-01	0.152E-02	0.219E+03
2302	0.885E+04	0.325E+02	0.727E+00	0.611E+02	0.508E+06	0.823E-01	0.152E-02	0.219E+03
2131	0.387E+03	0.171E+02	0.252E+01	0.222E+03	0.230E+07	0.292E+00	0.622E-03	0.929E+02
2132	0.121E+05	0.535E+03	0.252E+01	0.222E+03	0.231E+07	0.292E+00	0.195E-01	0.291E+04
231	0.117E+04	0.129E+02	0.126E+01	0.564E+02	0.882E+06	0.726E-01	0.236E-03	0.356E+02
232	0.117E+04	0.129E+02	0.126E+01	0.564E+02	0.882E+06	0.726E-01	0.236E-03	0.356E+02
233	0.352E+03	0.388E+01	0.126E+01	0.564E+02	0.884E+06	0.726E-01	0.713E-04	0.107E+02
234	0.352E+03	0.388E+01	0.126E+01	0.564E+02	0.884E+06	0.726E-01	0.713E-04	0.107E+02
235	0.155E+01	0.170E-01	0.126E+01	0.167E+02	0.481E+06	0.215E-01	0.313E-06	0.472E-01
236	0.155E+01	0.170E-01	0.126E+01	0.167E+02	0.481E+06	0.215E-01	0.313E-06	0.472E-01
2381	0.350E+02	0.385E+00	0.126E+01	0.979E+01	0.368E+06	0.126E-01	0.709E-05	0.107E+01
2382	0.350E+02	0.385E+00	0.126E+01	0.979E+01	0.368E+06	0.126E-01	0.709E-05	0.107E+01
2401	0.105E+00	0.462E-02	0.252E+01	0.627E+01	0.417E+06	0.807E-02	0.170E-06	0.256E-01

AXIAL THRUST = 566.95967 LBF

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TIME OF ANALYSIS WAS 9.375000000000000E-002 SECS

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APPENDIX CC—INPUT AND OUTPUT DATA FILES FROM EXAMPLE 22ss

Simulation of a Fluid Network with Fixed Flowrate Option

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```
GFSSP VERSION
    604
GFSSP INSTALLATION PATH
C:\Program Files (x86)\GFSSP604\
ANALYST

INPUT DATA FILE NAME
F:\GFSSP\Revised User Manual\EX22\EX22ss.dat
OUTPUT FILE NAME
EX22ss.out
TITLE
Example 22 -- Simulation of a Fluid Network with Fixed Flowrate Option
USETUP
F
DENCON        GRAVITY       ENERGY        MIXTURE       THRUST        STEADY        TRANSV        SAVER
F             F             T             F             F             T             F             F
HEX           HCOEF         REACTING      INERTIA       CONDX         ADDPROP       PRINTI        ROTATION
F             F             F             F             F             F             F             F
BUOYANCY      HRATE         INVAL         MSORCE        MOVBND        TPA           VARGEO        TVM
F             T             F             F             F             F             F             F
SHEAR         PRNTIN        PRNTADD       OPVALVE       TRANSQ        CONJUG        RADIAT        WINPLOT
F             T             T             F             F             F             F             F
PRESS         INSUC         VARROT        CYCLIC        CHKVALS       WINFILE       DALTON        NOSTATS
F             F             F             F             F             F             F             F
NORMAL        SIMUL         SECONDL       NRSOLVT       IBDF          NOPLT         PRESREG       FLOWREG
F             T             F             T             1             T             0             0
TRANS_MOM     USERVARS      PSMG          ISOLVE        PLOTADD       SIUNITS       TECPLOT       MDGEN
F             F             F             1             F             F             F             F
NUM_USER_VARS IFR_MIX       PRINTD        SATTABL       MSORIN        PRELVLV       LAMINAR       HSTAG
1             1             F             F             F             F             T             T
NNODES        NINT          NBR           NF
 5            2           4            1
RELAXK        RELAXD        RELAXH        CC            NITER         RELAXNR       RELAXHC       RELAXTS
 1               0.5           1              0.0001          500 1              1               1
NFLUID(I),  I = 1, NF
 11
NODE          INDEX     DESCRIPTION
 1              2       " Node 1"
 2              1       " Node 2"
 3              1       " Node 3"
 4              2       " Node 4"
 5              2       " Node 5"
 NODE   PRES (PSI)  TEMP(DEGF)  MASS SOURC    HEAT SOURC   THRST AREA   CONCENTRATION
 1      14.7             60               0                  0                  0
 2      14.7             60               0                  0                  0
 3      14.7             60               0                  0                  0
 4      14.7             60               0                  0                  0
```

```
 5     14.7            60                0                  0                  0
INODE         NUMBR         NAMEBR
 2             3            12   23   52
 3             2            23   34
BRANCH   UPNODE    DNNODE    OPTION    DESCRIPTION
12         1         2          24      "FixedFlow 12"
23         2         3          13      "Valve 23"
34         3         4          1       "Pipe 34"
52         5         2          24      "FixedFlow 52"
BRANCH        OPTION -24    FLOW_RATE     AREA          HISTORY
 12                         100           200           0
BRANCH        OPTION -13    DIA           K1            K2            AREA
 23                         6             300          0.1           28.274
BRANCH        OPTION -1     LENGTH        DIA           EPSD          ANGLE         AREA
 34                         18000             6                1.6666666667e-05    0                  28.27431
BRANCH        OPTION -24    FLOW_RATE     AREA          HISTORY
 52                         -10           200           0
```

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```
            ***************************************************
                         G F S S P (Version 604)
                    Generalized Fluid System Simulation Program
                                March 2012

                   Developed by NASA/Marshall Space Flight Center
                   Copyright (C) by Marshall Space Flight Center

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


              RUN DATE:09/17/2012 13:22

  TITLE      :Example 22 -- Simulation of a Fluid Network with Fixed Flowrate Option
  ANALYST    :
  FILEIN     :F:\GFSSP\Revised User Manual\EX22\EX22ss.dat
  FILEOUT    :EX22ss.out

                               OPTION VARIABLES

  ADDPROP    BUOYANCY   CONDX      CONJUG     CYCLIC     DALTON     DENCON     ENERGY
  F          F          F          F          F          F          F          T
  FLOWREG    GRAVITY    HCOEF      HEX        HRATE      IFRMIX     INERTIA    INSUC
  0          F          F          F          T          1          F          F
  INVAL      MIXTURE    MOVBND     MSORCE     NORMAL     NRSOLVT    OPVALVE    PLOTADD
  F          F          F          F          F          T          F          F
  PRESREG    PRESS      PRINTI     PRNTADD    PRNTIN     RADIATION  REACTING   ROTATION
  0          F          F          T          T          F          F          F
  SAVER      SECONDL    SHEAR      SIMULA     SIUNITS    STEADY     THRUST     TPA
  F          F          F          T          F          T          F          F
  TRANS_MOM  TRANSQ     TRANSV     TVM        TWOD       USRVAR     VARGEO     VARROT
  F          F          F          F          F          F          F          F
  RLFVLV
  F

  NNODES    =     5
  NINT      =     2
  NBR       =     4
  NF        =     1
  NVAR      =     6
  NHREF     =     2


  FLUIDS:   H2O
```

```
 BOUNDARY NODES
    NODE        P           T         RHO                     AREA
             (PSI)         (F)     (LBM/FT^3)                 (IN^2)
     1    0.1470E+02  0.6000E+02  0.6237E+02  0.0000E+00
     4    0.1470E+02  0.6000E+02  0.6237E+02  0.0000E+00
     5    0.1470E+02  0.6000E+02  0.6237E+02  0.0000E+00

  INPUT SPECIFICATIONS FOR INTERNAL NODES
 NODE        AREA         MASS         HEAT
           (IN^2)       (LBM/S)       (BTU/S)
     2    0.0000E+00  0.0000E+00  0.0000E+00
     3    0.0000E+00  0.0000E+00  0.0000E+00

 BRANCH      UPNODE    DNNODE    OPTION
      12         1         2        24
      23         2         3        13
      34         3         4         1
      52         5         2        24
 BRANCH OPTION -13:  DIA  K1   K2  AREA
      23            0.600E+01   0.300E+03   0.100E+00   0.283E+02
 BRANCH  OPTION -1:   LENGTH      DIA        EPSD       ANGLE        AREA
      34            0.180E+05   0.600E+01   0.167E-04   0.000E+00   0.283E+02


 SOLUTION
 INTERNAL NODES
  NODE     P(PSI)      TF(F)        Z           RHO         EM(LBM)     QUALITY
                                             (LBM/FT^3)
     2    0.3067E+02  0.5995E+02  0.1589E-02  0.6237E+02  0.0000E+00  0.0000E+00
     3    0.3063E+02  0.5995E+02  0.1587E-02  0.6237E+02  0.0000E+00  0.0000E+00

    NODE       H          ENTROPY     EMU       COND        CP          GAMA
           BTU/LB       BTU/LB-R  LBM/FT-SEC  BTU/FT-S-R  BTU/LB-R

     2    0.2813E+02  0.5555E-01  0.7548E-03  0.9511E-04  0.1002E+01  0.1003E+01
     3    0.2813E+02  0.5555E-01  0.7548E-03  0.9511E-04  0.1002E+01  0.1003E+01

 BRANCHES
BRANCH       KFACTOR       DELP        FLOW RATE   VELOCITY    REYN. NO.   MACH NO.   ENTROPY GEN.   LOST WORK
      (LBF-S^2/(LBM-FT)^2)  (PSI)       (LBM/SEC)     (FT/SEC)                            BTU/(R-SEC)   LBF-FT/SEC
      12     0.000E+00    -0.160E+02   0.100E+03     0.115E+01   0.127E+06   0.962E-03   0.000E+00   0.000E+00
      23     0.760E-03     0.428E-01   0.900E+02     0.735E+01   0.304E+06   0.613E-02   0.220E-04   0.889E+01
      34     0.283E+00     0.159E+02   0.900E+02     0.735E+01   0.304E+06   0.613E-02   0.819E-02   0.331E+04
      52     0.000E+00    -0.160E+02  -0.100E+02    -0.116E+00   0.127E+05   0.963E-04   0.000E+00   0.000E+00

 *************************************************
```

BOUNDARY NODES

NODE	P (PSI)	T (F)	RHO (LBM/FT^3)		AREA (IN^2)
1	0.1470E+02	0.6000E+02	0.6237E+02	0.0000E+00	
4	0.1470E+02	0.6000E+02	0.6237E+02	0.0000E+00	
5	0.1470E+02	0.6000E+02	0.6237E+02	0.0000E+00	

INPUT SPECIFICATIONS FOR INTERNAL NODES

NODE	AREA (IN^2)	MASS (LBM/S)	HEAT (BTU/S)
2	0.0000E+00	0.0000E+00	0.0000E+00
3	0.0000E+00	0.0000E+00	0.0000E+00

BRANCH	UPNODE	DNNODE	OPTION
12	1	2	24
23	2	3	13
34	3	4	1
52	5	2	24

BRANCH OPTION -13:	DIA	K1	K2	AREA
23	0.600E+01	0.300E+03	0.100E+00	0.283E+02

BRANCH OPTION -1:	LENGTH	DIA	EPSD	ANGLE	AREA
34	0.180E+05	0.600E+01	0.167E-04	0.000E+00	0.283E+02

SOLUTION

INTERNAL NODES

NODE	P(PSI)	TF(F)	Z	RHO (LBM/FT^3)	EM(LBM)	QUALITY
2	0.3067E+02	0.5995E+02	0.1589E-02	0.6237E+02	0.0000E+00	0.0000E+00
3	0.3063E+02	0.5995E+02	0.1587E-02	0.6237E+02	0.0000E+00	0.0000E+00

NODE	H BTU/LB	ENTROPY BTU/LB-R	EMU LBM/FT-SEC	COND BTU/FT-S-R	CP BTU/LB-R	GAMA
2	0.2813E+02	0.5555E-01	0.7548E-03	0.9511E-04	0.1002E+01	0.1003E+01
3	0.2813E+02	0.5555E-01	0.7548E-03	0.9511E-04	0.1002E+01	0.1003E+01

BRANCHES

BRANCH	KFACTOR (LBF-S^2/(LBM-FT)^2)	DELP (PSI)	FLOW RATE (LBM/SEC)	VELOCITY (FT/SEC)	REYN. NO.	MACH NO.	ENTROPY GEN. BTU/(R-SEC)	LOST WORK LBF-FT/SEC
12	0.000E+00	-0.160E+02	0.100E+03	0.115E+01	0.127E+06	0.962E-03	0.000E+00	0.000E+00
23	0.760E-03	0.428E-01	0.900E+02	0.735E+01	0.304E+06	0.613E-02	0.220E-04	0.889E+01
34	0.283E+00	0.159E+02	0.900E+02	0.735E+01	0.304E+06	0.613E-02	0.819E-02	0.331E+04
52	0.000E+00	-0.160E+02	-0.100E+02	-0.116E+00	0.127E+05	0.963E-04	0.000E+00	0.000E+00

****

TIME OF ANALYSIS WAS 0.000000000000000E+000 SECS

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APPENDIX DD—INPUT AND OUTPUT DATA FILES FROM EXAMPLE 22tr

Simulation of a Fluid Network with Fixed Flowrate Option

Contents

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```
GFSSP VERSION
    604
GFSSP INSTALLATION PATH
C:\Program Files (x86)\GFSSP604\
ANALYST

INPUT DATA FILE NAME
F:\GFSSP\Revised User Manual\EX22\EX22tr.dat
OUTPUT FILE NAME
EX22tr.out
TITLE
Example 22 -- Simulation of a Fluid Network with Fixed Flowrate Option
USETUP
F
DENCON        GRAVITY       ENERGY        MIXTURE       THRUST        STEADY        TRANSV        SAVER
F             F             T             F             F             F             T             F
HEX           HCOEF         REACTING      INERTIA       CONDX         ADDPROP       PRINTI        ROTATION
F             F             F             F             F             F             F             F
BUOYANCY      HRATE         INVAL         MSORCE        MOVBND        TPA           VARGEO        TVM
F             T             F             F             F             F             F             F
SHEAR         PRNTIN        PRNTADD       OPVALVE       TRANSQ        CONJUG        RADIAT        WINPLOT
F             T             T             F             F             F             F             T
PRESS         INSUC         VARROT        CYCLIC        CHKVALS       WINFILE       DALTON        NOSTATS
F             F             F             F             F             F             F             F
NORMAL        SIMUL         SECONDL       NRSOLVT       IBDF          NOPLT         PRESREG       FLOWREG
F             T             F             T             1             T             0             0
TRANS_MOM     USERVARS      PSMG          ISOLVE        PLOTADD       SIUNITS       TECPLOT       MDGEN
F             F             F             1             F             F             F             F
NUM_USER_VARS IFR_MIX       PRINTD        SATTABL       MSORIN        PRELVLV       LAMINAR       HSTAG
1             1             F             F             F             F             T             T
NNODES        NINT          NBR           NF
 5            2            4             1
RELAXK        RELAXD        RELAXH        CC            NITER         RELAXNR       RELAXHC       RELAXTS
 1               0.5            1             1e-05          2000 1              1               1
DTAU          TIMEF         TIMEL         NPSTEP        NPWSTEP       WPLSTEP       WPLBUFF
 1               0                  20                   1             1             50            1.1
NFLUID(I),  I = 1, NF
 11
NODE          INDEX     DESCRIPTION
 1              2       " Node 1"
 2              1       " Node 2"
 3              1       " Node 3"
 4              2       " Node 4"
 5              2       " Node 5"
 NODE   PRES (PSI)  TEMP(DEGF)  MASS SOURC    HEAT SOURC   THRST AREA   NODE-VOLUME  CONCENTRATION
 2      14.7             60                0                  0                  0                  0
 3      14.7             60                0                  0                  0                  0
```

```
 Hist1.dat
 Hist4.dat
 Hist5.dat
INODE         NUMBR         NAMEBR
 2             3            12   23   52
 3             2            23   34
BRANCH   UPNODE    DNNODE    OPTION    DESCRIPTION
12         1          2          24      "FixedFlow 12"
23         2          3          13      "Valve 23"
34         3          4          1       "Pipe 34"
52         5          2          24      "FixedFlow 52"
BRANCH        OPTION -24    FLOW_RATE     AREA          HISTORY
 12                         0             200           1
mdot12.dat
BRANCH        OPTION -13    DIA           K1            K2            AREA
 23                         6             300          0.1           28.274
BRANCH        OPTION -1     LENGTH        DIA           EPSD          ANGLE         AREA
 34                         18000             6                1.6666666667e-05    0                  28.27431
BRANCH        OPTION -24    FLOW_RATE     AREA          HISTORY
 52                         0             200           1
mdot52.dat
INITIAL FLOWRATES IN BRANCHES FOR UNSTEADY FLOW
 12 0
 23 0
 34 0
 52 0
```

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EXAMPLE 22tr HISTORY FILES

Hist1.dat

```
2
 0.0  14.7  60.0  1.0
20.0  14.7  60.0  1.0
```

Hist4.dat

```
2
 0.0  14.7  60.0  1.0
20.0  14.7  60.0  1.0
```

Hist5.dat

```
2
 0.0  14.7  60.0  1.0
20.0  14.7  60.0  1.0
```

Mdot12.dat

```
3
 0.0  100.0  200.0
10.0   50.0  200.0
20.0   50.0  200.0
```

Mdot52.dat

```
4
 0.0  -10.0  200.0
10.0  -10.0  200.0
10.1   10.0  200.0
20.0   10.0  200.0
```

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```
 ***************************************************
              G F S S P (Version 604)
      Generalized Fluid System Simulation Program
                    March 2012

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

   RUN DATE:09/17/2012 13:14

TITLE      :Example 22 -- Simulation of a Fluid Network with Fixed Flowrate Option
ANALYST    :
FILEIN     :F:\GFSSP\Revised User Manual\EX22\EX22tr.dat
FILEOUT    :EX22tr.out

                   OPTION VARIABLES

ADDPROP   BUOYANCY  CONDX     CONJUG    CYCLIC    DALTON    DENCON    ENERGY
F         F         F         F         F         F         F         T
FLOWREG   GRAVITY   HCOEF     HEX       HRATE     IFRMIX    INERTIA   INSUC
0         F         F         F         T         1         F         F
INVAL     MIXTURE   MOVBND    MSORCE    NORMAL    NRSOLVT   OPVALVE   PLOTADD
F         F         F         F         F         T         F         F
PRESREG   PRESS     PRINTI    PRNTADD   PRNTIN    RADIATION REACTING  ROTATION
0         F         F         T         T         F         F         F
SAVER     SECONDL   SHEAR     SIMULA    SIUNITS   STEADY    THRUST    TPA
F         F         F         T         F         F         F         F
TRANS_MOM TRANSQ    TRANSV    TVM       TWOD      USRVAR    VARGEO    VARROT
F         F         T         F         F         F         F         F
RLFVLV
F

NNODES    =     5
NINT      =     2
NBR       =     4
NF        =     1
NVAR      =     8
NHREF     =     2


FLUIDS:   H2O
```

```
BOUNDARY NODES
   NODE        P           T         RHO                     AREA
             (PSI)        (F)     (LBM/FT^3)                 (IN^2)
     1    0.1470E+02  0.6000E+02  0.6237E+02  0.0000E+00
     4    0.1470E+02  0.6000E+02  0.6237E+02  0.0000E+00
     5    0.1470E+02  0.6000E+02  0.6237E+02  0.0000E+00

 INPUT SPECIFICATIONS FOR INTERNAL NODES
NODE       AREA         MASS         HEAT
          (IN^2)       (LBM/S)      (BTU/S)
     2    0.0000E+00  0.0000E+00  0.0000E+00
     3    0.0000E+00  0.0000E+00  0.0000E+00

BRANCH      UPNODE    DNNODE    OPTION
     12         1         2        24
     23         2         3        13
     34         3         4         1
     52         5         2        24
BRANCH OPTION -13:  DIA  K1   K2  AREA
     23             0.600E+01   0.300E+03   0.100E+00   0.283E+02
BRANCH  OPTION -1:   LENGTH      DIA         EPSD       ANGLE        AREA
     34             0.180E+05   0.600E+01   0.167E-04   0.000E+00   0.283E+02



    ISTEP =      1          TAU =  0.10000E+01
BOUNDARY NODES
   NODE    P(PSI)      TF(F)      Z(COMP)       RHO       QUALITY
                                       (LBM/FT^3)
     1    0.1470E+02  0.6000E+02  0.0000E+00  0.6237E+02  0.0000E+00
     4    0.1470E+02  0.6000E+02  0.0000E+00  0.6237E+02  0.0000E+00
     5    0.1470E+02  0.6000E+02  0.0000E+00  0.6237E+02  0.0000E+00

SOLUTION
INTERNAL NODES
 NODE     P(PSI)      TF(F)        Z           RHO         EM(LBM)     QUALITY
                                              (LBM/FT^3)
     2    0.2888E+02  0.5996E+02  0.1496E-02  0.6237E+02  0.5218E-15  0.0000E+00
     3    0.2885E+02  0.6000E+02  0.1494E-02  0.6237E+02  0.1837E+05  0.0000E+00

   NODE       H          ENTROPY      EMU        COND        CP          GAMA
           BTU/LB       BTU/LB-R  LBM/FT-SEC  BTU/FT-S-R  BTU/LB-R

     2    0.2813E+02  0.5555E-01  0.7547E-03  0.9511E-04  0.1002E+01  0.1003E+01
     3    0.2817E+02  0.5555E-01  0.7542E-03  0.9511E-04  0.1002E+01  0.1003E+01
```

```
 BRANCHES
BRANCH       KFACTOR       DELP         FLOW RATE   VELOCITY    REYN. NO.   MACH NO.   ENTROPY GEN.   LOST WORK
      (LBF-S^2/(LBM-FT)^2)  (PSI)        (LBM/SEC)     (FT/SEC)                          BTU/(R-SEC)   LBF-FT/SEC
      12     0.000E+00    -0.142E+02   0.950E+02     0.762E-02   0.100E+05   0.635E-05   0.000E+00   0.000E+00
      23     0.761E-03     0.382E-01   0.850E+02     0.694E+01   0.287E+06   0.579E-02   0.185E-04   0.749E+01
      34     0.286E+00     0.141E+02   0.843E+02     0.689E+01   0.285E+06   0.574E-02   0.681E-02   0.275E+04
      52     0.000E+00    -0.142E+02  -0.100E+02    -0.802E-03   0.106E+04   0.668E-06   0.000E+00   0.000E+00

                                                                .
                                                                .
                                                                .

SOLUTION
 INTERNAL NODES
  NODE      P(PSI)       TF(F)         Z           RHO          EM(LBM)      QUALITY
                                                 (LBM/FT^3)
     2    0.2235E+02  0.5998E+02  0.1158E-02  0.6237E+02 -0.5422E-16  0.0000E+00
     3    0.2233E+02  0.6000E+02  0.1157E-02  0.6237E+02  0.1837E+05  0.0000E+00

    NODE        H          ENTROPY      EMU         COND         CP           GAMA
            BTU/LB       BTU/LB-R  LBM/FT-SEC  BTU/FT-S-R  BTU/LB-R

     2    0.2813E+02  0.5555E-01  0.7545E-03  0.9511E-04  0.1002E+01  0.1003E+01
     3    0.2815E+02  0.5555E-01  0.7543E-03  0.9511E-04  0.1002E+01  0.1003E+01

 BRANCHES
BRANCH       KFACTOR       DELP         FLOW RATE   VELOCITY    REYN. NO.   MACH NO.   ENTROPY GEN.   LOST WORK
      (LBF-S^2/(LBM-FT)^2)  (PSI)        (LBM/SEC)     (FT/SEC)                          BTU/(R-SEC)   LBF-FT/SEC
      12     0.000E+00    -0.765E+01   0.500E+02     0.401E-02   0.529E+04   0.334E-05   0.000E+00   0.000E+00
      23     0.764E-03     0.191E-01   0.600E+02     0.490E+01   0.202E+06   0.408E-02   0.654E-05   0.264E+01
      34     0.305E+00     0.763E+01   0.600E+02     0.490E+01   0.203E+06   0.409E-02   0.261E-02   0.106E+04
      52     0.000E+00    -0.765E+01   0.100E+02     0.802E-03   0.106E+04   0.668E-06   0.000E+00   0.000E+00

 **************************************************

 TIME OF ANALYSIS WAS   0.562500000000000       SECS

 **************************************************
```

APPENDIX EE—INPUT AND OUTPUT DATA FILES FROM EXAMPLE 23A

Oxygen Recirculation Line with Deliberate Heat Leak

Contents

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```
GFSSP VERSION
    604
GFSSP INSTALLATION PATH
C:\Program Files (x86)\GFSSP604\
ANALYST

INPUT DATA FILE NAME
F:\GFSSP\Revised User Manual\EX23\EX23A.dat
OUTPUT FILE NAME
EX23A.out
TITLE
Oxygen Recirculation Line with Deliberate Heat Leak
USETUP
F
DENCON        GRAVITY       ENERGY        MIXTURE       THRUST        STEADY        TRANSV        SAVER
F             T             T             F             F             T             F             F
HEX           HCOEF         REACTING      INERTIA       CONDX         ADDPROP       PRINTI        ROTATION
F             F             F             F             F             F             F             F
BUOYANCY      HRATE         INVAL         MSORCE        MOVBND        TPA           VARGEO        TVM
F             T             F             F             F             F             F             F
SHEAR         PRNTIN        PRNTADD       OPVALVE       TRANSQ        CONJUG        RADIAT        WINPLOT
F             T             T             F             F             T             F             F
PRESS         INSUC         VARROT        CYCLIC        CHKVALS       WINFILE       DALTON        NOSTATS
F             F             F             F             F             F             F             F
NORMAL        SIMUL         SECONDL       NRSOLVT       IBDF          NOPLT         PRESREG       FLOWREG
F             T             F             T             1             T             0             0
TRANS_MOM     USERVARS      PSMG          ISOLVE        PLOTADD       SIUNITS       TECPLOT       MDGEN
F             F             F             1             F             F             F             F
NUM_USER_VARS IFR_MIX       PRINTD        SATTABL       MSORIN        PRELVLV       LAMINAR       HSTAG
1             1             F             F             F             F             T             T
NNODES        NINT          NBR           NF
 8            6            7            1
RELAXK        RELAXD        RELAXH        CC            NITER         RELAXNR       RELAXHC       RELAXTS
 1              0.5            1             0.0001          500 1             1               1
NFLUID(I),  I = 1, NF
 6
NODE          INDEX     DESCRIPTION
 1              2       " Node 1"
 2              1       " Node 2"
 3              1       " Node 3"
 4              1       " Node 4"
 5              1       " Node 5"
 6              1       " Node 6"
 7              1       " Node 7"
 8              2       " Node 8"
 NODE  PRES (PSI)  TEMP(DEGF)  MASS SOURC    HEAT SOURC   THRST AREA   CONCENTRATION
 1     55.78           -272.5           0                  0                  0
```

```
 2     14.7            60              0                0                0
 3     14.7            60              0                0                0
 4     14.7            60              0                0                0
 5     14.7            60              0                0                0
 6     14.7            60              0                0                0
 7     14.7            60              0                0                0
 8     53              -272.5          0                0                0
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
BRANCH   UPNODE    DNNODE    OPTION    DESCRIPTION
12         1          2         2        "Restrict 12"
23         2          3         1        "Pipe 23"
34         3          4         1        "Pipe 34"
45         4          5         1        "Pipe 45"
56         5          6         1        "Pipe 56"
67         6          7         1        "Pipe 67"
78         7          8         1        "Pipe 78"
BRANCH        OPTION -2     FLOW COEFF    AREA
 12                         0.424         0.639
BRANCH        OPTION -1     LENGTH        DIA           EPSD          ANGLE         AREA
 23                         12                1.87            0               180               2.7464565178
BRANCH        OPTION -1     LENGTH        DIA           EPSD          ANGLE         AREA
 34                         12                1.87            0               180               2.7464565178
BRANCH        OPTION -1     LENGTH        DIA           EPSD          ANGLE         AREA
 45                         12                1.87            0               180               2.7464565178
BRANCH        OPTION -1     LENGTH        DIA           EPSD          ANGLE         AREA
 56                         12                1.87            0               180               2.7464565178
BRANCH        OPTION -1     LENGTH        DIA           EPSD          ANGLE         AREA
 67                         12                1.87            0               180               2.7464565178
BRANCH        OPTION -1     LENGTH        DIA           EPSD          ANGLE         AREA
 78                         12                1.87            0               180               2.7464565178
NSOLID   NAMB   NSSC   NSFC   NSAC   NSSR
  2       1      1      1      1      0
NODESL  MATRL    SMASS        TS              HtSrc    NUMSS  NUMSF  NUMSA  NUMSSR  DESCRIPTION
 9       17     2.6300000     70.0000000    0.0000000        1      1      0       0     "Node 9"
NAMESS
   910
NAMESF
   49
 10      17     2.6300000     70.0000000    0.0000000        1      0      1       0     "Node 10"
NAMESS
   910
```

```
NAMESA
   1011
NODEAM  TAMB        DESCRIPTION
 11     70.00000      "Node 11"    0
ICONSS  ICNSI  ICNSJ  ARCSIJ     DISTSIJ    DESCRIPTION
 910    9      10    79.00000    0.22500     "Conductor 910"
ICONSF  ICS  ICF   MODEL   ARSF         HCSF      RADSF    EMSFS        EMSFF     DESCRIPTION
 49     9      4     1  7.05000e+01  0.00000e+00   F   0.00000e+00  0.00000e+00 "Convection 49"
ICONSA  ICSAS  ICSAA  ARSA          HCSA      RADSA   EMSAS        EMSAA     DESCRIPTION
 1011   10     11    8.75000e+01  5.56000e-04   F   0.00000e+00  0.00000e+00 "Convection 1011"
```

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```
 ***************************************************
              G F S S P (Version 604)
      Generalized Fluid System Simulation Program
                   March 2012

     Developed by NASA/Marshall Space Flight Center
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  A generalized computer program to calculate flow
  rates, pressures, temperatures and concentrations
  in a flow network.
 **************************************************

   RUN DATE:09/20/2012 10:13

TITLE     :Oxygen Recirculation Line with Deliberate Heat Leak
ANALYST   :
FILEIN    :F:\GFSSP\Revised User Manual\EX23\EX23A.dat
FILEOUT   :EX23A.out

                         OPTION VARIABLES

ADDPROP   BUOYANCY  CONDX     CONJUG    CYCLIC    DALTON    DENCON    ENERGY
F         F         F         T         F         F         F         T
FLOWREG   GRAVITY   HCOEF     HEX       HRATE     IFRMIX    INERTIA   INSUC
0         T         F         F         T         1         F         F
INVAL     MIXTURE   MOVBND    MSORCE    NORMAL    NRSOLVT   OPVALVE   PLOTADD
F         F         F         F         F         T         F         F
PRESREG   PRESS     PRINTI    PRNTADD   PRNTIN    RADIATION REACTING  ROTATION
0         F         F         T         T         F         F         F
SAVER     SECONDL   SHEAR     SIMULA    SIUNITS   STEADY    THRUST    TPA
F         F         F         T         F         T         F         F
TRANS_MOM TRANSQ    TRANSV    TVM       TWOD      USRVAR    VARGEO    VARROT
F         F         F         F         F         F         F         F
RLFVLV
F

NNODES    =     8
NINT      =     6
NBR       =     7
NF        =     1
NVAR      =    13
NHREF     =     2


FLUIDS:   O2
```

```
BOUNDARY NODES
   NODE        P           T         RHO                    AREA
            (PSI)         (F)     (LBM/FT^3)                (IN^2)
    1    0.5578E+02 -0.2725E+03  0.6674E+02  0.0000E+00
    8    0.5300E+02 -0.2725E+03  0.6674E+02  0.0000E+00

 INPUT SPECIFICATIONS FOR INTERNAL NODES
NODE       AREA         MASS         HEAT
          (IN^2)       (LBM/S)      (BTU/S)
    2    0.0000E+00  0.0000E+00  0.0000E+00
    3    0.0000E+00  0.0000E+00  0.0000E+00
    4    0.0000E+00  0.0000E+00  0.0000E+00
    5    0.0000E+00  0.0000E+00  0.0000E+00
    6    0.0000E+00  0.0000E+00  0.0000E+00
    7    0.0000E+00  0.0000E+00  0.0000E+00

BRANCH      UPNODE    DNNODE    OPTION
     12         1         2         2
     23         2         3         1
     34         3         4         1
     45         4         5         1
     56         5         6         1
     67         6         7         1
     78         7         8         1
BRANCH OPTION -2:  FLOW COEF  AREA
     12             0.424E+00   0.639E+00
BRANCH  OPTION -1:   LENGTH      DIA        EPSD       ANGLE        AREA
     23             0.120E+02   0.187E+01   0.000E+00   0.180E+03   0.275E+01
BRANCH  OPTION -1:   LENGTH      DIA        EPSD       ANGLE        AREA
     34             0.120E+02   0.187E+01   0.000E+00   0.180E+03   0.275E+01
BRANCH  OPTION -1:   LENGTH      DIA        EPSD       ANGLE        AREA
     45             0.120E+02   0.187E+01   0.000E+00   0.180E+03   0.275E+01
BRANCH  OPTION -1:   LENGTH      DIA        EPSD       ANGLE        AREA
     56             0.120E+02   0.187E+01   0.000E+00   0.180E+03   0.275E+01
BRANCH  OPTION -1:   LENGTH      DIA        EPSD       ANGLE        AREA
     67             0.120E+02   0.187E+01   0.000E+00   0.180E+03   0.275E+01
BRANCH  OPTION -1:   LENGTH      DIA        EPSD       ANGLE        AREA
     78             0.120E+02   0.187E+01   0.000E+00   0.180E+03   0.275E+01


 CONJUGATE HEAT TRANSFER
 NSOLIDX =    2
 NAMB    =    1
 NSSC    =    1
 NSFC    =    1
 NSAC    =    1
```

```
  NSSR    =    0
NODESL  MATRL    SMASS        TS          NUMSS  NUMSF  NUMSA
     9    17      2.6300     70.0000          1      1      0
 NAMESS
   910
 NAMESF
    49
NODESL  MATRL    SMASS        TS          NUMSS  NUMSF  NUMSA
    10    17      2.6300     70.0000          1      0      1
 NAMESS
   910
 NAMESA
  1011
NODEAM  TAMB
  11         70.0000
ICONSS    ICNSI  ICNSJ    ARCSIJ      DISTSIJ
     910     9    10     79.0000      0.2250
ICONSF    ICS    ICF      ARSF       EMSFS       EMSFF
    49     9     4     70.5000      0.0000      0.0000
ICONSA  ICSAS  ICSAA  ARSA       HCSA       EMSAS        EMSAA
    1011    10    11  0.8750E+02  0.5560E-03  0.0000E+00  0.0000E+00

 SOLUTION
 INTERNAL NODES
  NODE     P(PSI)      TF(F)        Z           RHO          EM(LBM)     QUALITY
                                              (LBM/FT^3)
     2    0.5577E+02 -0.2725E+03  0.1332E-01  0.6667E+02  0.0000E+00  0.0000E+00
     3    0.5530E+02 -0.2725E+03  0.1321E-01  0.6667E+02  0.0000E+00  0.0000E+00
     4    0.5484E+02 -0.2710E+03  0.1305E-01  0.6639E+02  0.0000E+00  0.0000E+00
     5    0.5438E+02 -0.2710E+03  0.1294E-01  0.6639E+02  0.0000E+00  0.0000E+00
     6    0.5392E+02 -0.2711E+03  0.1320E-01  0.6546E+02  0.0000E+00  0.4101E-03
     7    0.5346E+02 -0.2713E+03  0.1402E-01  0.6331E+02  0.0000E+00  0.1425E-02

    NODE       H          ENTROPY     EMU        COND        CP          GAMA
             BTU/LB       BTU/LB-R  LBM/FT-SEC  BTU/FT-S-R  BTU/LB-R

     2    0.7134E+02  0.1525E+01  0.9487E-04  0.1882E-04  0.4194E+00  0.1944E+01
     3    0.7134E+02  0.1525E+01  0.9486E-04  0.1882E-04  0.4194E+00  0.1944E+01
     4    0.7196E+02  0.1525E+01  0.9294E-04  0.1871E-04  0.4199E+00  0.1959E+01
     5    0.7196E+02  0.1525E+01  0.9293E-04  0.1871E-04  0.4199E+00  0.1959E+01
     6    0.7196E+02  0.1525E+01  0.9246E-04  0.1871E-04  0.4198E+00  0.1959E+01
     7    0.7196E+02  0.1525E+01  0.9131E-04  0.1870E-04  0.4196E+00  0.1956E+01

 BRANCHES
BRANCH       KFACTOR        DELP         FLOW RATE    VELOCITY    REYN. NO.   MACH NO.   ENTROPY GEN.   LOST WORK
      (LBF-S^2/(LBM-FT)^2)  (PSI)        (LBM/SEC)      (FT/SEC)                            BTU/(R-SEC)   LBF-FT/SEC
      12     0.658E+02     0.185E-01   0.172E+00     0.727E+00   0.308E+05   0.966E-03   0.346E-07   0.504E-02
```

23	0.115E+00	0.462E+00	0.172E+00	0.169E+00	0.148E+05	0.225E-03	0.604E-10	0.880E-05
34	0.115E+00	0.461E+00	0.172E+00	0.169E+00	0.148E+05	0.225E-03	0.604E-10	0.880E-05
45	0.115E+00	0.459E+00	0.172E+00	0.170E+00	0.151E+05	0.225E-03	0.602E-10	0.883E-05
56	0.115E+00	0.459E+00	0.172E+00	0.170E+00	0.151E+05	0.225E-03	0.602E-10	0.883E-05
67	0.116E+00	0.459E+00	0.172E+00	0.170E+00	0.152E+05	0.225E-03	0.618E-10	0.907E-05
78	0.120E+00	0.461E+00	0.172E+00	0.171E+00	0.154E+05	0.225E-03	0.660E-10	0.966E-05

```
 SOLID NODES
  NODESL     CPSLD       TS
           BTU/LB F      F
     9   0.000E+00  -0.248E+03
    10   0.000E+00  -0.245E+03

 SOLID TO SOLID CONDUCTOR
  ICONSS    CONDKIJ     QDOTSS
        BTU/S FT F    BTU/S
   910   0.135E-02  -0.106E+00

 SOLID TO FLUID CONDUCTOR
 ICONSF  QDOTSF      HCSF          HCSFR
        BTU/S     BTU/S FT**2 F
    49   0.106E+00   0.925E-02   0.000E+00

 SOLID TO AMBIENT CONDUCTOR
ICONSA  QDOTSA        HCSA        HCSAR
        BTU/S     BTU/S FT**2 F  BTU/S FT**2 F
  1011  -0.106E+00   0.556E-03   0.000E+00

 *************************************************

 TIME OF ANALYSIS WAS   1.562500000000000E-002  SECS

 *************************************************
```

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APPENDIX FF—INPUT AND OUTPUT DATA FILES FROM EXAMPLE 23B

Helium Injector

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```
GFSSP VERSION
    604
GFSSP INSTALLATION PATH
C:\Program Files (x86)\GFSSP604\
ANALYST

INPUT DATA FILE NAME
F:\GFSSP\Revised User Manual\EX23\EX23B.dat
OUTPUT FILE NAME
EX23B.out
TITLE
Helium Injector
USETUP
F
DENCON        GRAVITY       ENERGY        MIXTURE       THRUST        STEADY        TRANSV        SAVER
F             F             T             F             F             T             F             F
HEX           HCOEF         REACTING      INERTIA       CONDX         ADDPROP       PRINTI        ROTATION
F             F             F             T             F             F             F             F
BUOYANCY      HRATE         INVAL         MSORCE        MOVBND        TPA           VARGEO        TVM
F             T             F             F             F             F             F             F
SHEAR         PRNTIN        PRNTADD       OPVALVE       TRANSQ        CONJUG        RADIAT        WINPLOT
F             T             T             F             F             F             F             F
PRESS         INSUC         VARROT        CYCLIC        CHKVALS       WINFILE       DALTON        NOSTATS
F             F             F             F             F             F             F             F
NORMAL        SIMUL         SECONDL       NRSOLVT       IBDF          NOPLT         PRESREG       FLOWREG
F             T             F             T             1             T             0             0
TRANS_MOM     USERVARS      PSMG          ISOLVE        PLOTADD       SIUNITS       TECPLOT       MDGEN
F             F             F             1             F             F             F             F
NUM_USER_VARS IFR_MIX       PRINTD        SATTABL       MSORIN        PRELVLV       LAMINAR       HSTAG
1             1             F             F             F             F             T             T
NNODES        NINT          NBR           NF
 4            2            3            1
RELAXK        RELAXD        RELAXH        CC            NITER         RELAXNR       RELAXHC       RELAXTS
 1               0.5           1             0.0001          500 1              1               1
NFLUID(I),  I = 1, NF
 1
NODE          INDEX     DESCRIPTION
 1              2       " Node 1"
 2              1       " Node 2"
 3              1       " Node 3"
 4              2       " Node 4"
 NODE   PRES (PSI)   TEMP(DEGF)  MASS SOURC    HEAT SOURC   THRST AREA   CONCENTRATION
 1      425               100           0                  0                  0
 2      14.7              60            0                  0                  0
 3      14.7              60            0                  0                  0
 4      14.7              60            0                  0                  0
INODE         NUMBR         NAMEBR
```

```
 2             2            12   23
 3             2            23   34
BRANCH   UPNODE    DNNODE    OPTION    DESCRIPTION
12         1          2         1       "Pipe 12"
23         2          3         2       "Restrict 23"
34         3          4         1       "Pipe 34"
BRANCH        OPTION -1     LENGTH        DIA           EPSD          ANGLE         AREA
 12                         12                0.152            0                 0                  0.01814582384
BRANCH        OPTION -2     FLOW COEFF    AREA
 23                         0.6           0.0012566
BRANCH        OPTION -1     LENGTH        DIA           EPSD          ANGLE         AREA
 34                         28                0.152            0                 0                  0.01814582384
BRANCH        NOUBR         NMUBR
 12    0
 23    1   12
 34    1   23
BRANCH        NODBR         NMDBR
 12    1   23
 23    1   34
 34    0
BRANCH
 12
  UPSTRM BR.     ANGLE
  DNSTRM BR.     ANGLE
   23     0.00000
BRANCH
 23
  UPSTRM BR.     ANGLE
   12     0.00000
  DNSTRM BR.     ANGLE
   34     0.00000
BRANCH
 34
  UPSTRM BR.     ANGLE
   23     0.00000
  DNSTRM BR.     ANGLE
NUMBER OF BRANCHES WITH INERTIA
 1
 23
```

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```
 ***************************************************
              G F S S P (Version 604)
      Generalized Fluid System Simulation Program
                    March 2012

     Developed by NASA/Marshall Space Flight Center
     Copyright (C) by Marshall Space Flight Center

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


   RUN DATE:09/21/2012 08:43

TITLE     :Helium Injector
ANALYST   :
FILEIN    :F:\GFSSP\Revised User Manual\EX23\EX23B.dat
FILEOUT   :EX23B.out

                 OPTION VARIABLES

ADDPROP   BUOYANCY  CONDX     CONJUG    CYCLIC    DALTON    DENCON    ENERGY
F         F         F         F         F         F         F         T
FLOWREG   GRAVITY   HCOEF     HEX       HRATE     IFRMIX    INERTIA   INSUC
0         F         F         F         T         1         T         F
INVAL     MIXTURE   MOVBND    MSORCE    NORMAL    NRSOLVT   OPVALVE   PLOTADD
F         F         F         F         F         T         F         F
PRESREG   PRESS     PRINTI    PRNTADD   PRNTIN    RADIATION REACTING  ROTATION
0         F         F         T         T         F         F         F
SAVER     SECONDL   SHEAR     SIMULA    SIUNITS   STEADY    THRUST    TPA
F         F         F         T         F         T         F         F
TRANS_MOM TRANSQ    TRANSV    TVM       TWOD      USRVAR    VARGEO    VARROT
F         F         F         F         F         F         F         F
RLFVLV
F

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


FLUIDS:  HE
```

BOUNDARY NODES

NODE	P (PSI)	T (F)	RHO (LBM/FT^3)		AREA (IN^2)
1	0.4250E+03	0.1000E+03	0.2786E+00	0.0000E+00	
4	0.1470E+02	0.6000E+02	0.1054E-01	0.0000E+00	

INPUT SPECIFICATIONS FOR INTERNAL NODES

NODE	AREA (IN^2)	MASS (LBM/S)	HEAT (BTU/S)
2	0.0000E+00	0.0000E+00	0.0000E+00
3	0.0000E+00	0.0000E+00	0.0000E+00

BRANCH	UPNODE	DNNODE	OPTION
12	1	2	1
23	2	3	2
34	3	4	1

BRANCH OPTION -1:	LENGTH	DIA	EPSD	ANGLE	AREA
12	0.120E+02	0.152E+00	0.000E+00	0.000E+00	0.181E-01

BRANCH OPTION -2:	FLOW COEF	AREA
23	0.600E+00	0.126E-02

BRANCH OPTION -1:	LENGTH	DIA	EPSD	ANGLE	AREA
34	0.280E+02	0.152E+00	0.000E+00	0.000E+00	0.181E-01

SOLUTION

INTERNAL NODES

NODE	P(PSI)	TF(F)	Z	RHO (LBM/FT^3)	EM(LBM)	QUALITY
2	0.4248E+03	0.1000E+03	0.1017E+01	0.2785E+00	0.0000E+00	0.1000E+01
3	0.2164E+02	0.1032E+03	0.1001E+01	0.1432E-01	0.0000E+00	0.1000E+01

NODE	H BTU/LB	ENTROPY BTU/LB-R	EMU LBM/FT-SEC	COND BTU/FT-S-R	CP BTU/LB-R	GAMA
2	0.7052E+03	0.7460E+01	0.1415E-04	0.2598E-04	0.1243E+01	0.1669E+01
3	0.7052E+03	0.7460E+01	0.1415E-04	0.2597E-04	0.1241E+01	0.1667E+01

BRANCHES

BRANCH	KFACTOR (LBF-S^2/(LBM-FT)^2)	DELP (PSI)	FLOW RATE (LBM/SEC)	VELOCITY (FT/SEC)	REYN. NO.	MACH NO.	ENTROPY GEN. BTU/(R-SEC)	LOST WORK LBF-FT/SEC
12	0.824E+07	0.153E+00	0.163E-02	0.466E+02	0.116E+05	0.137E-01	0.296E-06	0.129E+00
23	0.204E+10	0.403E+03	0.163E-02	0.673E+03	0.441E+05	0.197E+00	0.733E-04	0.319E+02
34	0.374E+09	0.694E+01	0.163E-02	0.907E+03	0.116E+05	0.266E+00	0.260E-03	0.114E+03

****

TIME OF ANALYSIS WAS 0.000000000000000E+000 SECS

****

APPENDIX GG—INPUT AND OUTPUT DATA FILES FROM EXAMPLE 23C

Helium Injector

Contents

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```
GFSSP VERSION
    604
GFSSP INSTALLATION PATH
C:\Program Files (x86)\GFSSP604\
ANALYST

INPUT DATA FILE NAME
F:\GFSSP\Revised User Manual\EX23\EX23C.dat
OUTPUT FILE NAME
EX23C.out
TITLE
LOx Recirculation Line with Helium Injection
USETUP
F
DENCON        GRAVITY       ENERGY        MIXTURE       THRUST        STEADY        TRANSV        SAVER
F             T             T             T             F             F             T             F
HEX           HCOEF         REACTING      INERTIA       CONDX         ADDPROP       PRINTI        ROTATION
F             F             F             T             F             F             F             F
BUOYANCY      HRATE         INVAL         MSORCE        MOVBND        TPA           VARGEO        TVM
F             T             F             F             F             F             F             F
SHEAR         PRNTIN        PRNTADD       OPVALVE       TRANSQ        CONJUG        RADIAT        WINPLOT
F             T             T             F             F             T             F             T
PRESS         INSUC         VARROT        CYCLIC        CHKVALS       WINFILE       DALTON        NOSTATS
F             F             F             F             F             F             F             F
NORMAL        SIMUL         SECONDL       NRSOLVT       IBDF          NOPLT         PRESREG       FLOWREG
F             T             F             T             1             T             0             0
TRANS_MOM     USERVARS      PSMG          ISOLVE        PLOTADD       SIUNITS       TECPLOT       MDGEN
F             F             F             1             F             F             F             F
NUM_USER_VARS IFR_MIX       PRINTD        SATTABL       MSORIN        PRELVLV       LAMINAR       HSTAG
1             3             F             F             F             F             T             T
NNODES        NINT          NBR           NF
 11            8            10            2
RELAXK        RELAXD        RELAXH        CC            NITER         RELAXNR       RELAXHC       RELAXTS
 1               0.5             1             0.0001           500 1           1             1
DTAU          TIMEF         TIMEL         NPSTEP        NPWSTEP       WPLSTEP       WPLBUFF
 0.1             0                  250                10             1             50            1.1
NFLUID(I),  I = 1, NF
 1 6
NODE          INDEX     DESCRIPTION
 1              2       " Node 1"
 2              1       " Node 2"
 3              1       " Node 3"
 101              2       " Node 1"
 102              1       " Node 2"
 103              1       " Node 3"
 104              1       " Node 4"
 5              1       " Node 5"
```

```
 6              1       " Node 6"
 7              1       " Node 7"
 8              2       " Node 8"
 NODE  PRES (PSI)  TEMP(DEGF)  MASS SOURC    HEAT SOURC   THRST AREA   NODE-VOLUME  CONCENTRATION
 2     14.7             60               0                  0                  0                  0                1 0
 3     14.7             60               0                  0                  0                  0                1 0
 102   14.7             60               0                  0                  0                  0                0 1
 103   14.7             60               0                  0                  0                  0                0 1
 104   14.7             60               0                  0                  0                  0                0 1
 5     14.7             60               0                  0                  0                  0                0 1
 6     14.7             60               0                  0                  0                  0                0 1
 7     14.7             60               0                  0                  0                  0                0 1
 Hist1.dat
 Hist101.dat
 Hist8.dat
INODE         NUMBR         NAMEBR
 2             2            12   23
 3             2            23   34
 102             2            112   123
 103             3            123   134   34
 104             2            134   45
 5             2            45   56
 6             2            56   67
 7             2            67   78
BRANCH   UPNODE    DNNODE    OPTION    DESCRIPTION
12         1          2          1       "Pipe 12"
23         2          3          2       "Restrict 23"
34         3          103        1       "Pipe 34"
112        101        102        2       "Restrict 12"
123        102        103        1       "Pipe 23"
134        103        104        1       "Pipe 34"
45         104        5          1       "Pipe 45"
56         5          6          1       "Pipe 56"
67         6          7          1       "Pipe 67"
78         7          8          1       "Pipe 78"
BRANCH        OPTION -1     LENGTH        DIA           EPSD          ANGLE         AREA
 12                         12                0.152            0                 90                 0.01814582384
BRANCH        OPTION -2     FLOW COEFF    AREA
 23                         0.6           0.0012566
BRANCH        OPTION -1     LENGTH        DIA           EPSD          ANGLE         AREA
 34                         28                0.152            0                 90                 0.01814582384
BRANCH        OPTION -2     FLOW COEFF    AREA
 112                        0.424         0.639
BRANCH        OPTION -1     LENGTH        DIA           EPSD          ANGLE         AREA
 123                        12                1.87             0                 180                2.7464565178
BRANCH        OPTION -1     LENGTH        DIA           EPSD          ANGLE         AREA
 134                        12                1.87             0                 180                2.7464565178
```

```
BRANCH        OPTION -1     LENGTH        DIA           EPSD          ANGLE         AREA
 45                         12                1.87              0                 180                2.7464565178
BRANCH        OPTION -1     LENGTH        DIA           EPSD          ANGLE         AREA
 56                         12                1.87              0                 180                2.7464565178
BRANCH        OPTION -1     LENGTH        DIA           EPSD          ANGLE         AREA
 67                         12                1.87              0                 180                2.7464565178
BRANCH        OPTION -1     LENGTH        DIA           EPSD          ANGLE         AREA
 78                         12                1.87              0                 180                2.7464565178
INITIAL FLOWRATES IN BRANCHES FOR UNSTEADY FLOW
 12 0
 23 0
 34 0
 112 0
 123 0
 134 0
 45 0
 56 0
 67 0
 78 0
BRANCH        NOUBR         NMUBR
 12    0
 23    1   12
 34    1   23
 112    0
 123    1   112
 134    2   123   34
 45    1   134
 56    1   45
 67    1   56
 78    1   67
BRANCH        NODBR         NMDBR
 12    1   23
 23    1   34
 34    2   123   134
 112    1   123
 123    2   134   34
 134    1   45
 45    1   56
 56    1   67
 67    1   78
 78    0
BRANCH
 12
  UPSTRM BR.     ANGLE
  DNSTRM BR.     ANGLE
   23     0.00000
BRANCH
```

```
 23
  UPSTRM BR.     ANGLE
   12     0.00000
  DNSTRM BR.     ANGLE
   34     0.00000
BRANCH
 34
  UPSTRM BR.     ANGLE
   23     0.00000
  DNSTRM BR.     ANGLE
   123     0.00000
   134     0.00000
BRANCH
 112
  UPSTRM BR.     ANGLE
  DNSTRM BR.     ANGLE
   123     0.00000
BRANCH
 123
  UPSTRM BR.     ANGLE
   112     0.00000
  DNSTRM BR.     ANGLE
   134     0.00000
   34     0.00000
BRANCH
 134
  UPSTRM BR.     ANGLE
   123     0.00000
   34     0.00000
  DNSTRM BR.     ANGLE
   45     0.00000
BRANCH
 45
  UPSTRM BR.     ANGLE
   134     0.00000
  DNSTRM BR.     ANGLE
   56     0.00000
BRANCH
 56
  UPSTRM BR.     ANGLE
   45     0.00000
  DNSTRM BR.     ANGLE
   67     0.00000
BRANCH
 67
  UPSTRM BR.     ANGLE
   56     0.00000
```

```
  DNSTRM BR.     ANGLE
   78     0.00000
BRANCH
 78
  UPSTRM BR.     ANGLE
   67     0.00000
  DNSTRM BR.     ANGLE
NUMBER OF BRANCHES WITH INERTIA
 1
 23
NSOLID   NAMB   NSSC   NSFC   NSAC   NSSR
  2       1      1      1      1      0
NODESL  MATRL    SMASS        TS              HtSrc    NUMSS  NUMSF  NUMSA  NUMSSR  DESCRIPTION
 9        17     2.6300000     70.0000000    0.0000000         1      1      0       0     "Node 9"
NAMESS
   910
NAMESF
   49
 10       17     2.6300000     70.0000000    0.0000000         1      0      1       0     "Node 10"
NAMESS
   910
NAMESA
   1011
NODEAM  TAMB        DESCRIPTION
 11     70.00000      "Node 11"    0
ICONSS  ICNSI  ICNSJ  ARCSIJ     DISTSIJ    DESCRIPTION
 910    9      10    79.00000    0.22500     "Conductor 910"
ICONSF  ICS  ICF   MODEL   ARSF         HCSF     RADSF    EMSFS        EMSFF     DESCRIPTION
 49     9      104   1  7.05000e+01  0.00000e+00   F   0.00000e+00  0.00000e+00 "Convection 49"
ICONSA  ICSAS  ICSAA  ARSA          HCSA      RADSA   EMSAS        EMSAA     DESCRIPTION
 1011   10     11    8.75000e+01  5.56000e-04   F   0.00000e+00  0.00000e+00 "Convection 1011"
```

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EXAMPLE 23C HISTORY FILES

Hist1.dat

```
2
  0.0  425.0  100.0  1.0  0.0
100.0  425.0  100.0  1.0  0.0
```

Hist8.dat

```
2
   0.0  53.0  -272.5  0.0  1.0
1000.0  53.0  -272.5  0.0  1.0
```

Hist101.dat

```
2
   0.0  55.78  -272.5  0.0  1.0
1000.0  55.78  -272.5  0.0  1.0
```

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```
 ***************************************************
              G F S S P (Version 604)
      Generalized Fluid System Simulation Program
                   March 2012

     Developed by NASA/Marshall Space Flight Center
     Copyright (C) by Marshall Space Flight Center

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


  RUN DATE:09/21/2012 11:09

TITLE      :LOx Recirculation Line with Helium Injection
ANALYST    :
FILEIN     :F:\GFSSP\Revised User Manual\EX23\EX23C.dat
FILEOUT    :EX23C.out

                   OPTION VARIABLES

ADDPROP   BUOYANCY  CONDX     CONJUG    CYCLIC    DALTON    DENCON    ENERGY
F         F         F         T         F         F         F         T
FLOWREG   GRAVITY   HCOEF     HEX       HRATE     IFRMIX    INERTIA   INSUC
0         T         F         F         T         3         T         F
INVAL     MIXTURE   MOVBND    MSORCE    NORMAL    NRSOLVT   OPVALVE   PLOTADD
F         T         F         F         F         T         F         F
PRESREG   PRESS     PRINTI    PRNTADD   PRNTIN    RADIATION REACTING  ROTATION
0         F         F         T         T         F         F         F
SAVER     SECONDL   SHEAR     SIMULA    SIUNITS   STEADY    THRUST    TPA
F         F         F         T         F         F         F         F
TRANS_MOM TRANSQ    TRANSV    TVM       TWOD      USRVAR    VARGEO    VARROT
F         F         T         F         F         F         F         F
RLFVLV
F

NNODES   =    11
NINT     =     8
NBR      =    10
NF       =     2
NVAR     =    26
NHREF    =     2


FLUIDS:  HE   O2
```

```
BOUNDARY NODES
    NODE       P          T          RHO        AREA         CONCENTRATIONS
             (PSI)       (F)      (LBM/FT^3)   (IN^2)
                                                  HE        O2
     1    0.4250E+03  0.1000E+03  0.2786E+00  0.0000E+00  0.1000E+01  0.0000E+00
   101    0.5578E+02 -0.2725E+03  0.6674E+02  0.0000E+00  0.0000E+00  0.1000E+01
     8    0.5300E+02 -0.2725E+03  0.6673E+02  0.0000E+00  0.0000E+00  0.1000E+01

 INPUT SPECIFICATIONS FOR INTERNAL NODES
NODE       AREA        MASS        HEAT
          (IN^2)      (LBM/S)     (BTU/S)
     2    0.0000E+00  0.0000E+00  0.0000E+00
     3    0.0000E+00  0.0000E+00  0.0000E+00
   102    0.0000E+00  0.0000E+00  0.0000E+00
   103    0.0000E+00  0.0000E+00  0.0000E+00
   104    0.0000E+00  0.0000E+00  0.0000E+00
     5    0.0000E+00  0.0000E+00  0.0000E+00
     6    0.0000E+00  0.0000E+00  0.0000E+00
     7    0.0000E+00  0.0000E+00  0.0000E+00

BRANCH      UPNODE    DNNODE    OPTION
     12         1         2         1
     23         2         3         2
     34         3       103         1
    112       101       102         2
    123       102       103         1
    134       103       104         1
     45       104         5         1
     56         5         6         1
     67         6         7         1
     78         7         8         1
BRANCH  OPTION -1:   LENGTH      DIA        EPSD       ANGLE        AREA
     12             0.120E+02   0.152E+00   0.000E+00   0.900E+02   0.181E-01
BRANCH OPTION -2:  FLOW COEF  AREA
     23             0.600E+00   0.126E-02
BRANCH  OPTION -1:   LENGTH      DIA        EPSD       ANGLE        AREA
     34             0.280E+02   0.152E+00   0.000E+00   0.900E+02   0.181E-01
BRANCH OPTION -2:  FLOW COEF  AREA
    112             0.424E+00   0.639E+00
BRANCH  OPTION -1:   LENGTH      DIA        EPSD       ANGLE        AREA
    123             0.120E+02   0.187E+01   0.000E+00   0.180E+03   0.275E+01
BRANCH  OPTION -1:   LENGTH      DIA        EPSD       ANGLE        AREA
    134             0.120E+02   0.187E+01   0.000E+00   0.180E+03   0.275E+01
BRANCH  OPTION -1:   LENGTH      DIA        EPSD       ANGLE        AREA
     45             0.120E+02   0.187E+01   0.000E+00   0.180E+03   0.275E+01
BRANCH  OPTION -1:   LENGTH      DIA        EPSD       ANGLE        AREA
```

```
      56             0.120E+02   0.187E+01   0.000E+00   0.180E+03   0.275E+01
 BRANCH  OPTION -1:   LENGTH      DIA        EPSD       ANGLE        AREA
      67             0.120E+02   0.187E+01   0.000E+00   0.180E+03   0.275E+01
 BRANCH  OPTION -1:   LENGTH      DIA        EPSD       ANGLE        AREA
      78             0.120E+02   0.187E+01   0.000E+00   0.180E+03   0.275E+01


  CONJUGATE HEAT TRANSFER
  NSOLIDX =    2
  NAMB    =    1
  NSSC    =    1
  NSFC    =    1
  NSAC    =    1
  NSSR    =    0
NODESL  MATRL    SMASS        TS          NUMSS  NUMSF  NUMSA
     9    17      2.6300     70.0000          1      1      0
 NAMESS
   910
 NAMESF
    49
NODESL  MATRL    SMASS        TS          NUMSS  NUMSF  NUMSA
    10    17      2.6300     70.0000          1      0      1
 NAMESS
   910
 NAMESA
  1011
NODEAM  TAMB
  11         70.0000
ICONSS    ICNSI  ICNSJ    ARCSIJ      DISTSIJ
     910     9    10     79.0000      0.2250
ICONSF    ICS    ICF      ARSF       EMSFS       EMSFF
    49     9   104     70.5000      0.0000      0.0000
ICONSA  ICSAS  ICSAA  ARSA      HCSA       EMSAS       EMSAA
    1011    10    11  0.8750E+02  0.5560E-03  0.0000E+00  0.0000E+00


     ISTEP =     10          TAU =  0.10000E+01
 BOUNDARY NODES
    NODE    P(PSI)    TF(F)      Z(COMP)    RHO       CONCENTRATIONS
                                           (LBM/FT^3)
                                                                 HE        O2
     1    0.4250E+03  0.1000E+03  0.1017E+01  0.2786E+00  0.1000E+01  0.0000E+00
   101    0.5578E+02 -0.2725E+03  0.1332E-01  0.6674E+02  0.0000E+00  0.1000E+01
     8    0.5300E+02 -0.2725E+03  0.1266E-01  0.6673E+02  0.0000E+00  0.1000E+01

 SOLUTION
 INTERNAL NODES
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NODE	P(PSI)	TF(F)	Z	RHO (LBM/FT^3)	EM(LBM)	CONC	
					HE	O2	
2	0.4239E+03	0.1000E+03	0.1017E+01	0.2779E+00	0.3502E-04	0.1000E+01	0.0000
3	0.6911E+02	0.1028E+03	0.1003E+01	0.4569E-01	0.6719E-05	0.1000E+01	0.0000
102	0.5399E+02	-0.2718E+03	0.1290E-01	0.6660E+02	0.6337E+00	0.3931E-05	1.0000
103	0.5362E+02	-0.2708E+03	0.4427E-01	0.3905E+02	0.3599E+00	0.3027E-02	0.9970
104	0.5344E+02	-0.2706E+03	0.9193E-01	0.1229E+02	0.1705E+00	0.3468E-02	0.9965
5	0.5336E+02	-0.2703E+03	0.1121E+00	0.9689E+01	0.1390E+00	0.3983E-02	0.9960
6	0.5330E+02	-0.2699E+03	0.1373E+00	0.7621E+01	0.1131E+00	0.4579E-02	0.9954
7	0.5325E+02	-0.2691E+03	0.1800E+00	0.5564E+01	0.1292E+00	0.5553E-02	0.9944

NODE	H BTU/LB	ENTROPY BTU/LB-R	EMU LBM/FT-SEC	COND BTU/FT-S-R	CP BTU/LB-R	GAMA
2	0.0000E+00	0.5882E+01	0.1415E-04	0.2598E-04	0.1243E+01	0.1669E+01
3	0.0000E+00	0.6789E+01	0.1414E-04	0.2597E-04	0.1241E+01	0.1667E+01
102	0.0000E+00	0.7646E+00	0.9398E-04	0.1877E-04	0.4196E+00	0.1951E+01
103	0.0000E+00	0.7853E+00	0.6652E-04	0.1847E-04	0.4208E+00	0.1947E+01
104	0.0000E+00	0.8103E+00	0.2521E-04	0.1765E-04	0.4128E+00	0.1924E+01
5	0.0000E+00	0.8217E+00	0.2181E-04	0.1735E-04	0.4101E+00	0.1915E+01
6	0.0000E+00	0.8360E+00	0.1907E-04	0.1697E-04	0.4066E+00	0.1903E+01
7	0.0000E+00	0.8602E+00	0.1635E-04	0.1633E-04	0.4005E+00	0.1884E+01

MIXTURE FLUID HE (AMAGAT MODEL)

NODE	TFX(F)	HX BTU/LB	XVX	RHOX LBM/FT^3	EMUX LBM/FT-SEC	CONDUCTX BTU/FT-S-R	ENTROPY BTU/LB-R
1	0.1000E+03	0.7052E+03	0.0000E+00	0.2786E+00	0.1415E-04	0.2598E-04	0.5881E+01
2	0.1000E+03	0.7052E+03	0.1000E+01	0.2779E+00	0.1415E-04	0.2598E-04	0.5882E+01
3	0.1028E+03	0.7052E+03	0.1000E+01	0.4570E-01	0.1415E-04	0.2597E-04	0.6789E+01
101	-0.2725E+03	0.2389E+03	0.0000E+00	0.1106E+00	0.6758E-05	0.0000E+00	0.0000E+00
102	-0.2576E+03	0.2575E+03	0.1000E+01	0.9915E-01	0.7092E-05	0.1309E-04	0.5641E+01
103	-0.2241E+03	0.2991E+03	0.1000E+01	0.8454E-01	0.7819E-05	0.1448E-04	0.5834E+01
104	-0.2024E+03	0.3260E+03	0.1000E+01	0.7718E-01	0.8276E-05	0.1535E-04	0.5945E+01
5	-0.1809E+03	0.3527E+03	0.1000E+01	0.7114E-01	0.8720E-05	0.1619E-04	0.6046E+01
6	-0.1623E+03	0.3758E+03	0.1000E+01	0.6662E-01	0.9098E-05	0.1691E-04	0.6127E+01
7	-0.1403E+03	0.4032E+03	0.1000E+01	0.6198E-01	0.9540E-05	0.1774E-04	0.6216E+01
8	-0.2725E+03	0.2389E+03	0.0000E+00	0.1051E+00	0.6757E-05	0.0000E+00	0.0000E+00

NODE	CM MOL CONC	CX MASS CONC	PX PSIA	VOLX FT^3	GAMAX	CPX BTU/LB-R	CVX BTU/LB-R	QHES BTU/S
1	0.1000E+01	0.1000E+01	0.4250E+03	0.0000E+00	0.1669E+01	0.1243E+01	0.0000E+00	0.0000E+00
2	0.1000E+01	0.1000E+01	0.4239E+03	0.1260E-03	0.1669E+01	0.1243E+01	0.7447E+00	0.0000E+00
3	0.1000E+01	0.1000E+01	0.6911E+02	0.1470E-03	0.1667E+01	0.1241E+01	0.7447E+00	0.0000E+00
101	0.0000E+00	0.0000E+00	0.5578E+02	0.0000E+00	0.1669E+01	0.0000E+00	0.0000E+00	0.0000E+00
102	0.3143E-04	0.3931E-05	0.5399E+02	0.2997E-06	0.1669E+01	0.1243E+01	0.7447E+00	0.0000E+00
103	0.2370E-01	0.3027E-02	0.5362E+02	0.4555E-03	0.1668E+01	0.1242E+01	0.7447E+00	0.0000E+00

104	0.2706E-01	0.3468E-02	0.5344E+02	0.5162E-03	0.1668E+01	0.1242E+01	0.7447E+00	0.0000E+00
5	0.3098E-01	0.3983E-02	0.5336E+02	0.5908E-03	0.1668E+01	0.1242E+01	0.7447E+00	0.0000E+00
6	0.3547E-01	0.4579E-02	0.5330E+02	0.6765E-03	0.1668E+01	0.1242E+01	0.7447E+00	0.0000E+00
7	0.4273E-01	0.5553E-02	0.5325E+02	0.1222E-02	0.1667E+01	0.1242E+01	0.7447E+00	0.0000E+00
8	0.0000E+00	0.0000E+00	0.5300E+02	0.0000E+00	0.1669E+01	0.0000E+00	0.0000E+00	0.0000E+00

MIXTURE FLUID O2 (AMAGAT MODEL)

NODE	TFX(F)	HX BTU/LB	XVX	RHOX LBM/FT^3	EMUX LBM/FT-SEC	CONDUCTX BTU/FT-S-R	ENTROPY BTU/LB-R
1	0.1000E+03	0.2371E+03	0.0000E+00	0.2297E+01	0.1461E-04	0.0000E+00	0.0000E+00
2	0.9997E+02	0.2371E+03	0.1000E+01	0.2291E+01	0.1461E-04	0.4613E-05	0.1328E+01
3	0.8912E+02	0.2371E+03	0.1000E+01	0.3765E+00	0.1420E-04	0.4335E-05	0.1440E+01
101	-0.2725E+03	0.7134E+02	0.0000E+00	0.6674E+02	0.9487E-04	0.1882E-04	0.7631E+00
102	-0.2718E+03	0.7162E+02	0.0000E+00	0.6661E+02	0.9398E-04	0.1877E-04	0.7646E+00
103	-0.2712E+03	0.7263E+02	0.9078E-02	0.4049E+02	0.5852E-04	0.1857E-04	0.7700E+00
104	-0.2713E+03	0.7686E+02	0.5960E-01	0.1272E+02	0.2149E-04	0.1771E-04	0.7925E+00
5	-0.2714E+03	0.7843E+02	0.7848E-01	0.1011E+02	0.1802E-04	0.1739E-04	0.8008E+00
6	-0.2714E+03	0.8046E+02	0.1027E+00	0.8008E+01	0.1522E-04	0.1698E-04	0.8116E+00
7	-0.2714E+03	0.8398E+02	0.1445E+00	0.5891E+01	0.1239E-04	0.1626E-04	0.8303E+00
8	-0.2725E+03	0.7133E+02	0.0000E+00	0.6674E+02	0.9484E-04	0.1881E-04	0.7631E+00

NODE	CM MOL CONC	CX MASS CONC	PX PSIA	VOLX FT^3	GAMAX	CPX BTU/LB-R	CVX BTU/LB-R	QHES BTU/S
1	0.0000E+00	0.0000E+00	0.4250E+03	0.0000E+00	0.1446E+01	0.0000E+00	0.0000E+00	0.0000E+00
2	0.1389E-16	0.1110E-15	0.4239E+03	0.1750E-20	0.1446E+01	0.2299E+00	0.1590E+00	0.0000E+00
3	0.2778E-16	0.2220E-15	0.6911E+02	0.4084E-20	0.1403E+01	0.2214E+00	0.1579E+00	0.0000E+00
101	0.1000E+01	0.1000E+01	0.5578E+02	0.0000E+00	0.1944E+01	0.4194E+00	0.0000E+00	0.0000E+00
102	0.1000E+01	0.1000E+01	0.5399E+02	0.9536E-02	0.1951E+01	0.4196E+00	0.2151E+00	0.0000E+00
103	0.9763E+00	0.9970E+00	0.5362E+02	0.1876E-01	0.1953E+01	0.4183E+00	0.2140E+00	0.0000E+00
104	0.9729E+00	0.9965E+00	0.5344E+02	0.1856E-01	0.1931E+01	0.4099E+00	0.2117E+00	0.0000E+00
5	0.9690E+00	0.9960E+00	0.5336E+02	0.1848E-01	0.1922E+01	0.4068E+00	0.2108E+00	0.0000E+00
6	0.9645E+00	0.9954E+00	0.5330E+02	0.1840E-01	0.1912E+01	0.4027E+00	0.2097E+00	0.0000E+00
7	0.9573E+00	0.9944E+00	0.5325E+02	0.2739E-01	0.1894E+01	0.3958E+00	0.2077E+00	0.0000E+00
8	0.1000E+01	0.1000E+01	0.5300E+02	0.0000E+00	0.1945E+01	0.4195E+00	0.0000E+00	0.0000E+00

BRANCHES

BRANCH	KFACTOR (LBF-S^2/(LBM-FT)^2)	DELP (PSI)	FLOW RATE (LBM/SEC)	VELOCITY (FT/SEC)	REYN. NO.	MACH NO.	ENTROPY GEN. BTU/(R-SEC)	LOST WORK LBF-FT/SEC
12	0.626E+07	0.109E+01	0.500E-02	0.143E+03	0.356E+05	0.419E-01	0.647E-05	0.282E+01
23	0.204E+10	0.355E+03	0.500E-02	0.206E+04	0.135E+06	0.606E+00	0.211E-02	0.920E+03
34	0.891E+08	0.155E+02	0.500E-02	0.869E+03	0.356E+05	0.255E+00	0.558E-03	0.244E+03
112	0.658E+02	0.180E+01	0.198E+01	0.670E+01	0.353E+06	0.891E-02	0.525E-04	0.764E+01
123	0.664E-01	0.365E+00	0.197E+01	0.155E+01	0.171E+06	0.206E-02	0.522E-07	0.763E-02
134	0.111E+00	0.176E+00	0.154E+01	0.207E+01	0.189E+06	0.271E-02	0.701E-07	0.103E-01
45	0.302E+00	0.791E-01	0.131E+01	0.557E+01	0.425E+06	0.732E-02	0.377E-06	0.555E-01
56	0.386E+00	0.623E-01	0.110E+01	0.603E+01	0.411E+06	0.792E-02	0.357E-06	0.526E-01
67	0.495E+00	0.476E-01	0.918E+00	0.673E+01	0.393E+06	0.884E-02	0.340E-06	0.502E-01

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     78     0.689E+00     0.252E+00   0.720E+00     0.828E+01   0.360E+06   0.109E-01   0.311E-06   0.461E-01

 SOLID NODES
  NODESL     CPSLD       TS
           BTU/LB F     F
     9   0.104E+00   0.579E+02
    10   0.104E+00   0.691E+02

 SOLID TO SOLID CONDUCTOR
  ICONSS    CONDKIJ     QDOTSS
        BTU/S FT F    BTU/S
   910   0.177E-02  -0.579E+00

 SOLID TO FLUID CONDUCTOR
 ICONSF  QDOTSF      HCSF           HCSFR
        BTU/S     BTU/S FT**2 F
    49   0.502E+01   0.312E-01   0.000E+00

 SOLID TO AMBIENT CONDUCTOR
ICONSA  QDOTSA        HCSA         HCSAR
        BTU/S     BTU/S FT**2 F  BTU/S FT**2 F
  1011  -0.137E-03   0.556E-03   0.000E+00


                                        .
                                        .
                                        .


    ISTEP =   1250          TAU =  0.12500E+03
 BOUNDARY NODES
   NODE    P(PSI)   TF(F)      Z(COMP)    RHO       CONCENTRATIONS
                                       (LBM/FT^3)
                                                          HE        O2
    1    0.4250E+03  0.1000E+03  0.1017E+01  0.2786E+00  0.1000E+01  0.0000E+00
  101    0.5578E+02 -0.2725E+03  0.1332E-01  0.6674E+02  0.0000E+00  0.1000E+01
    8    0.5300E+02 -0.2725E+03  0.1266E-01  0.6673E+02  0.0000E+00  0.1000E+01

 SOLUTION
 INTERNAL NODES
    NODE     P(PSI)      TF(F)         Z         RHO        EM(LBM)    CONC
                                             (LBM/FT^3)
                                                          HE        O2
    2    0.4239E+03  0.1000E+03  0.1017E+01  0.2779E+00  0.3502E-04  0.1000E+01  0.0000
    3    0.7002E+02  0.1028E+03  0.1003E+01  0.4630E-01  0.6808E-05  0.1000E+01  0.0000
  102    0.5523E+02 -0.2725E+03  0.1319E-01  0.6674E+02  0.6364E+00  0.2449-108  1.0000
  103    0.5477E+02 -0.2707E+03  0.4790E-01  0.6357E+02  0.3363E+00  0.4522E-02  0.9955
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104	0.5438E+02	-0.2709E+03	0.5111E-01	0.5034E+02	0.3108E+00	0.4520E-02	0.9955
5	0.5404E+02	-0.2711E+03	0.5168E-01	0.4828E+02	0.3057E+00	0.4518E-02	0.9955
6	0.5371E+02	-0.2712E+03	0.5223E-01	0.4642E+02	0.3008E+00	0.4516E-02	0.9955
7	0.5339E+02	-0.2713E+03	0.5276E-01	0.4474E+02	0.4444E+00	0.4514E-02	0.9955

NODE	H	ENTROPY	EMU	COND	CP	GAMA
	BTU/LB	BTU/LB-R	LBM/FT-SEC	BTU/FT-S-R	BTU/LB-R	
2	0.0000E+00	0.5882E+01	0.1415E-04	0.2598E-04	0.1243E+01	0.1669E+01
3	0.0000E+00	0.6783E+01	0.1415E-04	0.2597E-04	0.1241E+01	0.1667E+01
102	0.0000E+00	0.7631E+00	0.9486E-04	0.1882E-04	0.4194E+00	0.1944E+01
103	0.0000E+00	0.7887E+00	0.1064E-03	0.1847E-04	0.4237E+00	0.1952E+01
104	0.0000E+00	0.7901E+00	0.8539E-04	0.1842E-04	0.4230E+00	0.1949E+01
5	0.0000E+00	0.7901E+00	0.8226E-04	0.1842E-04	0.4228E+00	0.1947E+01
6	0.0000E+00	0.7901E+00	0.7945E-04	0.1841E-04	0.4227E+00	0.1945E+01
7	0.0000E+00	0.7901E+00	0.7688E-04	0.1841E-04	0.4225E+00	0.1944E+01

MIXTURE FLUID HE (AMAGAT MODEL)

NODE	TFX(F)	HX	XVX	RHOX	EMUX	CONDUCTX	ENTROPY
		BTU/LB		LBM/FT^3	LBM/FT-SEC	BTU/FT-S-R	BTU/LB-R
1	0.1000E+03	0.7052E+03	0.0000E+00	0.2786E+00	0.1415E-04	0.2598E-04	0.5881E+01
2	0.1000E+03	0.7052E+03	0.1000E+01	0.2779E+00	0.1415E-04	0.2598E-04	0.5882E+01
3	0.1028E+03	0.7052E+03	0.1000E+01	0.4630E-01	0.1415E-04	0.2597E-04	0.6783E+01
101	-0.2725E+03	0.2389E+03	0.0000E+00	0.1106E+00	0.6758E-05	0.0000E+00	0.0000E+00
102	-0.2725E+03	0.2389E+03	0.1000E+01	0.1095E+00	0.6758E-05	0.1246E-04	0.5534E+01
103	-0.2708E+03	0.2410E+03	0.1000E+01	0.1076E+00	0.6796E-05	0.1253E-04	0.5549E+01
104	-0.2708E+03	0.2410E+03	0.1000E+01	0.1068E+00	0.6795E-05	0.1253E-04	0.5553E+01
5	-0.2708E+03	0.2410E+03	0.1000E+01	0.1062E+00	0.6795E-05	0.1253E-04	0.5556E+01
6	-0.2708E+03	0.2410E+03	0.1000E+01	0.1055E+00	0.6795E-05	0.1253E-04	0.5559E+01
7	-0.2709E+03	0.2410E+03	0.1000E+01	0.1049E+00	0.6794E-05	0.1252E-04	0.5562E+01
8	-0.2725E+03	0.2389E+03	0.0000E+00	0.1051E+00	0.6757E-05	0.0000E+00	0.0000E+00

NODE	CM	CX	PX	VOLX	GAMAX	CPX	CVX	QHES
	MOL CONC	MASS CONC	PSIA	FT^3		BTU/LB-R	BTU/LB-R	BTU/S
1	0.1000E+01	0.1000E+01	0.4250E+03	0.0000E+00	0.1669E+01	0.1243E+01	0.0000E+00	0.0000E+00
2	0.1000E+01	0.1000E+01	0.4239E+03	0.1260E-03	0.1669E+01	0.1243E+01	0.7447E+00	0.0000E+00
3	0.1000E+01	0.1000E+01	0.7002E+02	0.1470E-03	0.1667E+01	0.1241E+01	0.7447E+00	0.0000E+00
101	0.0000E+00	0.0000E+00	0.5578E+02	0.0000E+00	0.1669E+01	0.0000E+00	0.0000E+00	0.0000E+00
102	0.1958-107	0.2449-108	0.5523E+02	0.1867-109	0.1669E+01	0.1243E+01	0.7447E+00	0.0000E+00
103	0.3504E-01	0.4522E-02	0.5477E+02	0.6735E-03	0.1669E+01	0.1243E+01	0.7447E+00	0.0000E+00
104	0.3503E-01	0.4520E-02	0.5438E+02	0.6680E-03	0.1669E+01	0.1243E+01	0.7447E+00	0.0000E+00
5	0.3501E-01	0.4518E-02	0.5404E+02	0.6678E-03	0.1669E+01	0.1243E+01	0.7447E+00	0.0000E+00
6	0.3500E-01	0.4516E-02	0.5371E+02	0.6675E-03	0.1669E+01	0.1243E+01	0.7447E+00	0.0000E+00
7	0.3498E-01	0.4514E-02	0.5339E+02	0.1001E-02	0.1669E+01	0.1243E+01	0.7447E+00	0.0000E+00
8	0.0000E+00	0.0000E+00	0.5300E+02	0.0000E+00	0.1669E+01	0.0000E+00	0.0000E+00	0.0000E+00

MIXTURE FLUID O2 (AMAGAT MODEL)

NODE	TFX(F)	HX BTU/LB	XVX	RHOX LBM/FT^3	EMUX LBM/FT-SEC	CONDUCTX BTU/FT-S-R	ENTROPY BTU/LB-R
1	0.1000E+03	0.2371E+03	0.0000E+00	0.2297E+01	0.1461E-04	0.0000E+00	0.0000E+00
2	0.9997E+02	0.2371E+03	0.1000E+01	0.2291E+01	0.1461E-04	0.4613E-05	0.1328E+01
3	0.8915E+02	0.2371E+03	0.1000E+01	0.3815E+00	0.1420E-04	0.4335E-05	0.1439E+01
101	-0.2725E+03	0.7134E+02	0.0000E+00	0.6674E+02	0.9487E-04	0.1882E-04	0.7631E+00
102	-0.2725E+03	0.7134E+02	0.0000E+00	0.6674E+02	0.9486E-04	0.1882E-04	0.7631E+00
103	-0.2707E+03	0.7209E+02	0.1139E-03	0.6588E+02	0.9188E-04	0.1869E-04	0.7671E+00
104	-0.2709E+03	0.7234E+02	0.3923E-02	0.5216E+02	0.7382E-04	0.1863E-04	0.7684E+00
5	-0.2711E+03	0.7234E+02	0.4680E-02	0.5003E+02	0.7110E-04	0.1863E-04	0.7684E+00
6	-0.2712E+03	0.7234E+02	0.5410E-02	0.4810E+02	0.6865E-04	0.1863E-04	0.7685E+00
7	-0.2713E+03	0.7234E+02	0.6118E-02	0.4636E+02	0.6642E-04	0.1863E-04	0.7685E+00
8	-0.2725E+03	0.7133E+02	0.0000E+00	0.6674E+02	0.9484E-04	0.1881E-04	0.7631E+00

NODE	CM MOL CONC	CX MASS CONC	PX PSIA	VOLX FT^3	GAMAX	CPX BTU/LB-R	CVX BTU/LB-R	QHES BTU/S
1	0.0000E+00	0.0000E+00	0.4250E+03	0.0000E+00	0.1446E+01	0.0000E+00	0.0000E+00	0.0000E+00
2	0.0000E+00	0.0000E+00	0.4239E+03	0.1260E-03	0.1446E+01	0.2299E+00	0.1590E+00	0.0000E+00
3	0.0000E+00	0.0000E+00	0.7002E+02	0.1470E-03	0.1403E+01	0.2215E+00	0.1579E+00	0.0000E+00
101	0.1000E+01	0.1000E+01	0.5578E+02	0.0000E+00	0.1944E+01	0.4194E+00	0.0000E+00	0.0000E+00
102	0.1000E+01	0.1000E+01	0.5523E+02	0.9536E-02	0.1944E+01	0.4194E+00	0.2157E+00	0.0000E+00
103	0.9650E+00	0.9955E+00	0.5477E+02	0.1855E-01	0.1962E+01	0.4199E+00	0.2140E+00	0.0000E+00
104	0.9650E+00	0.9955E+00	0.5438E+02	0.1840E-01	0.1959E+01	0.4193E+00	0.2140E+00	0.0000E+00
5	0.9650E+00	0.9955E+00	0.5404E+02	0.1840E-01	0.1957E+01	0.4191E+00	0.2141E+00	0.0000E+00
6	0.9650E+00	0.9955E+00	0.5371E+02	0.1841E-01	0.1955E+01	0.4189E+00	0.2142E+00	0.0000E+00
7	0.9650E+00	0.9955E+00	0.5339E+02	0.2761E-01	0.1954E+01	0.4188E+00	0.2143E+00	0.0000E+00
8	0.1000E+01	0.1000E+01	0.5300E+02	0.0000E+00	0.1945E+01	0.4195E+00	0.0000E+00	0.0000E+00

BRANCHES

BRANCH	KFACTOR (LBF-S^2/(LBM-FT)^2)	DELP (PSI)	FLOW RATE (LBM/SEC)	VELOCITY (FT/SEC)	REYN. NO.	MACH NO.	ENTROPY GEN. BTU/(R-SEC)	LOST WORK LBF-FT/SEC
12	0.626E+07	0.109E+01	0.500E-02	0.142E+03	0.355E+05	0.418E-01	0.644E-05	0.281E+01
23	0.204E+10	0.354E+03	0.500E-02	0.206E+04	0.135E+06	0.605E+00	0.210E-02	0.917E+03
34	0.879E+08	0.152E+02	0.500E-02	0.857E+03	0.355E+05	0.251E+00	0.542E-03	0.237E+03
112	0.658E+02	0.553E+00	0.110E+01	0.371E+01	0.196E+06	0.494E-02	0.900E-05	0.131E+01
123	0.747E-01	0.453E+00	0.110E+01	0.864E+00	0.947E+05	0.115E-02	0.102E-07	0.149E-02
134	0.803E-01	0.396E+00	0.111E+01	0.911E+00	0.849E+05	0.119E-02	0.116E-07	0.171E-02
45	0.968E-01	0.343E+00	0.111E+01	0.115E+01	0.106E+06	0.150E-02	0.177E-07	0.260E-02
56	0.100E+00	0.330E+00	0.111E+01	0.120E+01	0.110E+06	0.157E-02	0.191E-07	0.280E-02
67	0.103E+00	0.317E+00	0.111E+01	0.125E+01	0.114E+06	0.163E-02	0.205E-07	0.301E-02
78	0.107E+00	0.388E+00	0.111E+01	0.130E+01	0.118E+06	0.169E-02	0.220E-07	0.322E-02

SOLID NODES

NODESL	CPSLD BTU/LB F	TS F
9	0.104E+00	-0.251E+03
10	0.104E+00	-0.246E+03

```
 SOLID TO SOLID CONDUCTOR
  ICONSS    CONDKIJ     QDOTSS
        BTU/S FT F    BTU/S
   910   0.135E-02  -0.203E+00

 SOLID TO FLUID CONDUCTOR
 ICONSF  QDOTSF      HCSF           HCSFR
        BTU/S     BTU/S FT**2 F
    49   0.283E+00   0.295E-01   0.000E+00

 SOLID TO AMBIENT CONDUCTOR
ICONSA  QDOTSA        HCSA        HCSAR
        BTU/S     BTU/S FT**2 F  BTU/S FT**2 F
  1011  -0.107E+00   0.556E-03   0.000E+00

                                            .
                                            .
                                            .

     ISTEP =   2500          TAU =  0.25000E+03
 BOUNDARY NODES
    NODE    P(PSI)   TF(F)      Z(COMP)    RHO       CONCENTRATIONS
                                       (LBM/FT^3)
                                                           HE        O2
     1    0.4250E+03  0.1000E+03  0.1017E+01  0.2786E+00  0.1000E+01  0.0000E+00
   101    0.5578E+02 -0.2725E+03  0.1332E-01  0.6674E+02  0.0000E+00  0.1000E+01
     8    0.5300E+02 -0.2725E+03  0.1266E-01  0.6673E+02  0.0000E+00  0.1000E+01

 SOLUTION
 INTERNAL NODES
     NODE     P(PSI)      TF(F)         Z         RHO        EM(LBM)    CONC
                                             (LBM/FT^3)
                                                           HE        O2
     2    0.4239E+03  0.1000E+03  0.1017E+01  0.2779E+00  0.3502E-04  0.1000E+01  0.0000
     3    0.7008E+02  0.1028E+03  0.1003E+01  0.4634E-01  0.6813E-05  0.1000E+01  0.0000
   102    0.5529E+02 -0.2725E+03  0.1320E-01  0.6674E+02  0.6364E+00  0.2448-191  1.0000
   103    0.5485E+02 -0.2707E+03  0.5048E-01  0.6162E+02  0.3188E+00  0.4818E-02  0.9952
   104    0.5445E+02 -0.2709E+03  0.5230E-01  0.5373E+02  0.3034E+00  0.4818E-02  0.9952
     5    0.5408E+02 -0.2710E+03  0.5291E-01  0.5128E+02  0.2982E+00  0.4818E-02  0.9952
     6    0.5373E+02 -0.2712E+03  0.5350E-01  0.4911E+02  0.2932E+00  0.4818E-02  0.9952
     7    0.5340E+02 -0.2713E+03  0.5407E-01  0.4716E+02  0.4328E+00  0.4818E-02  0.9952

    NODE       H          ENTROPY      EMU        COND        CP           GAMA
           BTU/LB       BTU/LB-R  LBM/FT-SEC  BTU/FT-S-R  BTU/LB-R

     2    0.0000E+00  0.5882E+01  0.1415E-04  0.2598E-04  0.1243E+01  0.1669E+01
```

3	0.0000E+00	0.6782E+01	0.1415E-04	0.2597E-04	0.1241E+01	0.1667E+01
102	0.0000E+00	0.7631E+00	0.9486E-04	0.1882E-04	0.4194E+00	0.1944E+01
103	0.0000E+00	0.7904E+00	0.1044E-03	0.1845E-04	0.4239E+00	0.1952E+01
104	0.0000E+00	0.7910E+00	0.9182E-04	0.1842E-04	0.4234E+00	0.1949E+01
5	0.0000E+00	0.7910E+00	0.8806E-04	0.1842E-04	0.4233E+00	0.1947E+01
6	0.0000E+00	0.7911E+00	0.8472E-04	0.1842E-04	0.4231E+00	0.1945E+01
7	0.0000E+00	0.7911E+00	0.8173E-04	0.1842E-04	0.4229E+00	0.1944E+01

MIXTURE FLUID HE (AMAGAT MODEL)

NODE	TFX(F)	HX BTU/LB	XVX	RHOX LBM/FT^3	EMUX LBM/FT-SEC	CONDUCTX BTU/FT-S-R	ENTROPY BTU/LB-R
1	0.1000E+03	0.7052E+03	0.0000E+00	0.2786E+00	0.1415E-04	0.2598E-04	0.5881E+01
2	0.1000E+03	0.7052E+03	0.1000E+01	0.2779E+00	0.1415E-04	0.2598E-04	0.5882E+01
3	0.1028E+03	0.7052E+03	0.1000E+01	0.4634E-01	0.1415E-04	0.2597E-04	0.6782E+01
101	-0.2725E+03	0.2389E+03	0.0000E+00	0.1106E+00	0.6758E-05	0.0000E+00	0.0000E+00
102	-0.2725E+03	0.2389E+03	0.1000E+01	0.1096E+00	0.6758E-05	0.1246E-04	0.5533E+01
103	-0.2707E+03	0.2412E+03	0.1000E+01	0.1077E+00	0.6799E-05	0.1253E-04	0.5549E+01
104	-0.2707E+03	0.2412E+03	0.1000E+01	0.1069E+00	0.6799E-05	0.1253E-04	0.5553E+01
5	-0.2707E+03	0.2412E+03	0.1000E+01	0.1062E+00	0.6798E-05	0.1253E-04	0.5557E+01
6	-0.2707E+03	0.2412E+03	0.1000E+01	0.1055E+00	0.6798E-05	0.1253E-04	0.5560E+01
7	-0.2707E+03	0.2412E+03	0.1000E+01	0.1048E+00	0.6798E-05	0.1253E-04	0.5563E+01
8	-0.2725E+03	0.2389E+03	0.0000E+00	0.1051E+00	0.6757E-05	0.0000E+00	0.0000E+00

NODE	CM MOL CONC	CX MASS CONC	PX PSIA	VOLX FT^3	GAMAX	CPX BTU/LB-R	CVX BTU/LB-R	QHES BTU/S
1	0.1000E+01	0.1000E+01	0.4250E+03	0.0000E+00	0.1669E+01	0.1243E+01	0.0000E+00	0.0000E+00
2	0.1000E+01	0.1000E+01	0.4239E+03	0.1260E-03	0.1669E+01	0.1243E+01	0.7447E+00	0.0000E+00
3	0.1000E+01	0.1000E+01	0.7008E+02	0.1470E-03	0.1667E+01	0.1241E+01	0.7447E+00	0.0000E+00
101	0.0000E+00	0.0000E+00	0.5578E+02	0.0000E+00	0.1669E+01	0.0000E+00	0.0000E+00	0.0000E+00
102	0.1957-190	0.2448-191	0.5529E+02	0.1867-192	0.1669E+01	0.1243E+01	0.7447E+00	0.0000E+00
103	0.3726E-01	0.4818E-02	0.5485E+02	0.7161E-03	0.1669E+01	0.1243E+01	0.7447E+00	0.0000E+00
104	0.3726E-01	0.4818E-02	0.5445E+02	0.7106E-03	0.1669E+01	0.1243E+01	0.7447E+00	0.0000E+00
5	0.3726E-01	0.4818E-02	0.5408E+02	0.7106E-03	0.1669E+01	0.1243E+01	0.7447E+00	0.0000E+00
6	0.3726E-01	0.4818E-02	0.5373E+02	0.7106E-03	0.1669E+01	0.1243E+01	0.7447E+00	0.0000E+00
7	0.3726E-01	0.4818E-02	0.5340E+02	0.1066E-02	0.1669E+01	0.1243E+01	0.7447E+00	0.0000E+00
8	0.0000E+00	0.0000E+00	0.5300E+02	0.0000E+00	0.1669E+01	0.0000E+00	0.0000E+00	0.0000E+00

MIXTURE FLUID O2 (AMAGAT MODEL)

NODE	TFX(F)	HX BTU/LB	XVX	RHOX LBM/FT^3	EMUX LBM/FT-SEC	CONDUCTX BTU/FT-S-R	ENTROPY BTU/LB-R
1	0.1000E+03	0.2371E+03	0.0000E+00	0.2297E+01	0.1461E-04	0.0000E+00	0.0000E+00
2	0.9997E+02	0.2371E+03	0.1000E+01	0.2291E+01	0.1461E-04	0.4613E-05	0.1328E+01
3	0.8915E+02	0.2371E+03	0.1000E+01	0.3818E+00	0.1420E-04	0.4335E-05	0.1439E+01
101	-0.2725E+03	0.7134E+02	0.0000E+00	0.6674E+02	0.9487E-04	0.1882E-04	0.7631E+00
102	-0.2725E+03	0.7134E+02	0.0000E+00	0.6674E+02	0.9486E-04	0.1882E-04	0.7631E+00
103	-0.2707E+03	0.7214E+02	0.5398E-03	0.6400E+02	0.8936E-04	0.1868E-04	0.7674E+00
104	-0.2709E+03	0.7225E+02	0.2730E-02	0.5581E+02	0.7865E-04	0.1865E-04	0.7680E+00

5	-0.2710E+03	0.7225E+02	0.3530E-02	0.5327E+02	0.7540E-04	0.1865E-04	0.7680E+00
6	-0.2712E+03	0.7225E+02	0.4297E-02	0.5101E+02	0.7251E-04	0.1865E-04	0.7680E+00
7	-0.2713E+03	0.7225E+02	0.5036E-02	0.4898E+02	0.6992E-04	0.1864E-04	0.7680E+00
8	-0.2725E+03	0.7133E+02	0.0000E+00	0.6674E+02	0.9484E-04	0.1881E-04	0.7631E+00

NODE	CM MOL CONC	CX MASS CONC	PX PSIA	VOLX FT^3	GAMAX	CPX BTU/LB-R	CVX BTU/LB-R	QHES BTU/S
1	0.0000E+00	0.0000E+00	0.4250E+03	0.0000E+00	0.1446E+01	0.0000E+00	0.0000E+00	0.0000E+00
2	0.0000E+00	0.0000E+00	0.4239E+03	0.1260E-03	0.1446E+01	0.2299E+00	0.1590E+00	0.0000E+00
3	0.0000E+00	0.0000E+00	0.7008E+02	0.1470E-03	0.1403E+01	0.2215E+00	0.1579E+00	0.0000E+00
101	0.1000E+01	0.1000E+01	0.5578E+02	0.0000E+00	0.1944E+01	0.4194E+00	0.0000E+00	0.0000E+00
102	0.1000E+01	0.1000E+01	0.5529E+02	0.9536E-02	0.1944E+01	0.4194E+00	0.2157E+00	0.0000E+00
103	0.9627E+00	0.9952E+00	0.5485E+02	0.1850E-01	0.1963E+01	0.4199E+00	0.2139E+00	0.0000E+00
104	0.9627E+00	0.9952E+00	0.5445E+02	0.1836E-01	0.1960E+01	0.4195E+00	0.2140E+00	0.0000E+00
5	0.9627E+00	0.9952E+00	0.5408E+02	0.1836E-01	0.1958E+01	0.4193E+00	0.2141E+00	0.0000E+00
6	0.9627E+00	0.9952E+00	0.5373E+02	0.1836E-01	0.1956E+01	0.4191E+00	0.2142E+00	0.0000E+00
7	0.9627E+00	0.9952E+00	0.5340E+02	0.2754E-01	0.1954E+01	0.4190E+00	0.2143E+00	0.0000E+00
8	0.1000E+01	0.1000E+01	0.5300E+02	0.0000E+00	0.1945E+01	0.4195E+00	0.0000E+00	0.0000E+00

BRANCHES

BRANCH	KFACTOR (LBF-S^2/(LBM-FT)^2)	DELP (PSI)	FLOW RATE (LBM/SEC)	VELOCITY (FT/SEC)	REYN. NO.	MACH NO.	ENTROPY GEN. BTU/(R-SEC)	LOST WORK LBF-FT/SEC
12	0.626E+07	0.109E+01	0.500E-02	0.142E+03	0.355E+05	0.418E-01	0.644E-05	0.281E+01
23	0.204E+10	0.354E+03	0.500E-02	0.206E+04	0.135E+06	0.605E+00	0.210E-02	0.916E+03
34	0.878E+08	0.152E+02	0.500E-02	0.856E+03	0.355E+05	0.251E+00	0.541E-03	0.237E+03
112	0.658E+02	0.487E+00	0.103E+01	0.349E+01	0.184E+06	0.464E-02	0.744E-05	0.108E+01
123	0.757E-01	0.446E+00	0.103E+01	0.811E+00	0.889E+05	0.108E-02	0.857E-08	0.125E-02
134	0.836E-01	0.401E+00	0.104E+01	0.883E+00	0.812E+05	0.115E-02	0.103E-07	0.151E-02
45	0.933E-01	0.365E+00	0.104E+01	0.101E+01	0.923E+05	0.132E-02	0.132E-07	0.194E-02
56	0.969E-01	0.349E+00	0.104E+01	0.106E+01	0.962E+05	0.138E-02	0.144E-07	0.211E-02
67	0.100E+00	0.335E+00	0.104E+01	0.111E+01	0.100E+06	0.144E-02	0.156E-07	0.228E-02
78	0.104E+00	0.396E+00	0.104E+01	0.115E+01	0.104E+06	0.150E-02	0.168E-07	0.246E-02

SOLID NODES

NODESL	CPSLD BTU/LB F	TS F
9	0.104E+00	-0.263E+03
10	0.104E+00	-0.260E+03

SOLID TO SOLID CONDUCTOR

ICONSS	CONDKIJ BTU/S FT F	QDOTSS BTU/S
910	0.133E-02	-0.116E+00

SOLID TO FLUID CONDUCTOR

ICONSF	QDOTSF BTU/S	HCSF BTU/S FT**2 F	HCSFR

```
    49   0.119E+00   0.292E-01   0.000E+00

 SOLID TO AMBIENT CONDUCTOR
ICONSA  QDOTSA        HCSA        HCSAR
         BTU/S     BTU/S FT**2 F  BTU/S FT**2 F
  1011  -0.111E+00   0.556E-03   0.000E+00

 *************************************************

 TIME OF ANALYSIS WAS    8.54687500000000       SECS

 *************************************************
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APPENDIX HH—INPUT AND OUTPUT DATA FILES FROM EXAMPLE 24

Simulation of Relief Valve in a Pressurized Tank

Contents

Back to Appendix HH

```
GFSSP VERSION
    604
GFSSP INSTALLATION PATH

ANALYST

INPUT DATA FILE NAME
EX24.dat
OUTPUT FILE NAME
EX24.out
TITLE
Simulation of Relief Valve in a Pressurized Tank
USETUP
F
DENCON        GRAVITY       ENERGY        MIXTURE       THRUST        STEADY        TRANSV        SAVER
F             F             T             F             F             F             T             F
HEX           HCOEF         REACTING      INERTIA       CONDX         ADDPROP       PRINTI        ROTATION
F             F             F             F             F             T             F             F
BUOYANCY      HRATE         INVAL         MSORCE        MOVBND        TPA           VARGEO        TVM
F             T             F             F             F             F             F             F
SHEAR         PRNTIN        PRNTADD       OPVALVE       TRANSQ        CONJUG        RADIAT        WINPLOT
F             T             T             F             F             F             F             T
PRESS         INSUC         VARROT        CYCLIC        CHKVALS       WINFILE       DALTON        NOSTATS
F             F             F             F             F             F             F             F
NORMAL        SIMUL         SECONDL       NRSOLVT       IBDF          NOPLT         PRESREG       FLOWREG
F             T             F             T             1             T             0             0
TRANS_MOM     USERVARS      PSMG          ISOLVE        PLOTADD       SIUNITS       TECPLOT       MDGEN
F             F             F             1             F             F             F             F
NUM_USER_VARS IFR_MIX       PRINTD        SATTABL       MSORIN        PRELVLV       LAMINAR       HSTAG
1             1             F             F             F             T             T             T
NNODES        NINT          NBR           NF
 3            1            2             1
RELAXK        RELAXD        RELAXH        CC            NITER         RELAXNR       RELAXHC       RELAXTS
 1               0.5             1             0.0001          500 1            1               1
DTAU          TIMEF         TIMEL         NPSTEP        NPWSTEP       WPLSTEP       WPLBUFF
 0.5             0                  50                 10            1            50             1.1
NFLUID(I),  I = 1, NF
 33
RREF         CPREF         GAMREF        EMUREF        AKREF         PREF         TREF         HREF         SREF
 53.34           0.24             1.3999      1.26e-05         4.133e-06        14.7              80                0
0
NODE          INDEX     DESCRIPTION
 1              2       " Node 1"
 2              1       " Node 2"
 3              2       " Node 3"
 NODE  PRES (PSI)  TEMP(DEGF)  MASS SOURC    HEAT SOURC   THRST AREA   NODE-VOLUME  CONCENTRATION
 2     14.7          60                0                  0                  0                 17280
```

```
 Hist1.dat
 Hist3.dat
INODE         NUMBR         NAMEBR
 2             2            12   23
BRANCH   UPNODE    DNNODE    OPTION    DESCRIPTION
12        1          2          22      "Orifice 12"
23        2          3          22      "Orifice 23"
BRANCH        OPTION -22     AREA       FLOW COEF
 12                         0.0785        1
BRANCH        OPTION -22     AREA       FLOW COEF
 23                         1e-16         1
INITIAL FLOWRATES IN BRANCHES FOR UNSTEADY FLOW
 12 0
 23 0
NUMBER OF PRESSURE RELIEF ASSEMBLIES IN THE CIRCUIT
1
RELIEF VALVE BR    CRACKING PRESSURE (psid)
23 9.5
CORRESPONDING CONTROL FILE
RLFVLV23Area.DAT
```

Back to Appendix HH

EXAMPLE 24 HISTORY FILES

Hist1.dat

```
2
  0.0  35.0  70.0  1.0
100.0  35.0  70.0  1.0
```

Hist3.dat

```
2
  0.0  14.7  70.0  1.0
100.0  14.7  70.0  1.0
```

RLFVLV23.DAT

```
4              NUMBER OF DELTA-P VS AREA POINTS IN INTERPOLATION TABLE (MAX = 20)
7.0 1.0E-16    DELTA-P (psi), A (in2)   (FIRST POINT SHOULD BE RESEAT PRESSURE WITH VERY SMALL AREA)
8.0 0.24
9.0 0.48
10. 0.72       (LAST POINT SHOULD BE MAX POSSIBLE AREA FOR FULLY OPEN VALVE)
```

```
      ^
      |
      |            3**********
AREA  |           *
      |          *
      |         2
      |        *
      |*******1
      L_______________________>

               dP
```

Area remains close to zero until pressure is greater than the cracking pressure (point 2). Then area is interpolated from the curve. If pressure is greater than the max pressure (point 3), then the valve is fully open at its maximum area. If pressure falls below reseat pressure (point 1), then area returns to nearly zero until pressure once again is greater than the cracking pressure (point 2).

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```
 ****************************************************
              G F S S P (Version 604)
      Generalized Fluid System Simulation Program
                     March 2012

     Developed by NASA/Marshall Space Flight Center
     Copyright (C) by Marshall Space Flight Center

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

   RUN DATE:09/24/2012 15:34

TITLE      :Simulation of Relief Valve in a Pressurized Tank
ANALYST    :
FILEIN     :F:\GFSSP\Revised User Manual\EX24\EX24.dat
FILEOUT    :EX24.out

                          OPTION VARIABLES

ADDPROP   BUOYANCY  CONDX     CONJUG    CYCLIC    DALTON    DENCON    ENERGY
T         F         F         F         F         F         F         T
FLOWREG   GRAVITY   HCOEF     HEX       HRATE     IFRMIX    INERTIA   INSUC
0         F         F         F         T         1         F         F
INVAL     MIXTURE   MOVBND    MSORCE    NORMAL    NRSOLVT   OPVALVE   PLOTADD
F         F         F         F         F         T         F         F
PRESREG   PRESS     PRINTI    PRNTADD   PRNTIN    RADIATION REACTING  ROTATION
0         F         F         T         T         F         F         F
SAVER     SECONDL   SHEAR     SIMULA    SIUNITS   STEADY    THRUST    TPA
F         F         F         T         F         F         F         F
TRANS_MOM TRANSQ    TRANSV    TVM       TWOD      USRVAR    VARGEO    VARROT
F         F         T         F         F         F         F         F
RLFVLV
T

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


FLUIDS:   IDEL
```

```
 BOUNDARY NODES
    NODE        P           T         RHO                      AREA
             (PSI)         (F)     (LBM/FT^3)                  (IN^2)
     1    0.3500E+02  0.7000E+02  0.1784E+00  0.0000E+00
     3    0.1470E+02  0.7000E+02  0.7492E-01  0.0000E+00

  INPUT SPECIFICATIONS FOR INTERNAL NODES
 NODE       AREA         MASS         HEAT
          (IN^2)       (LBM/S)      (BTU/S)
     2    0.0000E+00  0.0000E+00  0.0000E+00

 BRANCH      UPNODE    DNNODE    OPTION
      12         1         2        22
      23         2         3        22
 BRANCH OPTION -22 FLOW COEF   AREA
      12            0.100E+01   0.785E-01
 BRANCH OPTION -22 FLOW COEF   AREA
      23            0.100E+01   0.100E-15



     ISTEP =     10          TAU =  0.50000E+01
 BOUNDARY NODES
    NODE    P(PSI)      TF(F)      Z(COMP)       RHO       QUALITY
                                       (LBM/FT^3)
     1    0.3500E+02  0.7000E+02  0.1000E+01  0.1784E+00  0.0000E+00
     3    0.1470E+02  0.7000E+02  0.1000E+01  0.7492E-01  0.0000E+00

 SOLUTION
 INTERNAL NODES
  NODE     P(PSI)      TF(F)        Z           RHO         EM(LBM)     QUALITY
                                               (LBM/FT^3)
     2    0.2331E+02  0.1242E+03  0.1000E+01  0.1078E+00  0.1078E+01  0.0000E+00

    NODE       H          ENTROPY     EMU       COND        CP          GAMA
            BTU/LB       BTU/LB-R  LBM/FT-SEC  BTU/FT-S-R  BTU/LB-R

     2    0.1062E+02 -0.9063E-02  0.1260E-04  0.4133E-05  0.2400E+00  0.1400E+01

 BRANCHES
BRANCH       KFACTOR       DELP        FLOW RATE   VELOCITY    REYN. NO.   MACH NO.   ENTROPY GEN.   LOST WORK
      (LBF-S^2/(LBM-FT)^2)  (PSI)       (LBM/SEC)     (FT/SEC)                          BTU/(R-SEC)    LBF-FT/SEC
      12     0.293E+06     0.117E+02   0.608E-01     0.625E+03   0.233E+06   0.554E+00   0.894E-03   0.369E+03
      23     0.299E+36     0.861E+01   0.359E-17     0.474E+02   0.386E-03   0.400E-01   0.284E-21   0.129E-15
```

```
    ISTEP =     20          TAU =  0.10000E+02
 BOUNDARY NODES
   NODE    P(PSI)      TF(F)      Z(COMP)       RHO       QUALITY
                                       (LBM/FT^3)
    1    0.3500E+02  0.7000E+02  0.1000E+01  0.1784E+00  0.0000E+00
    3    0.1470E+02  0.7000E+02  0.1000E+01  0.7492E-01  0.0000E+00

 SOLUTION
 INTERNAL NODES
 NODE     P(PSI)      TF(F)        Z           RHO         EM(LBM)     QUALITY
                                             (LBM/FT^3)
    2    0.2276E+02  0.1108E+03  0.1000E+01  0.1077E+00  0.1077E+01  0.0000E+00

   NODE       H          ENTROPY     EMU       COND        CP          GAMA
          BTU/LB       BTU/LB-R  LBM/FT-SEC  BTU/FT-S-R  BTU/LB-R

    2    0.7381E+01 -0.9063E-02  0.1260E-04  0.4133E-05  0.2400E+00  0.1400E+01

 BRANCHES
BRANCH       KFACTOR       DELP        FLOW RATE   VELOCITY    REYN. NO.   MACH NO.   ENTROPY GEN.   LOST WORK
      (LBF-S^2/(LBM-FT)^2)  (PSI)       (LBM/SEC)     (FT/SEC)                               BTU/(R-SEC)   LBF-FT/SEC
      12     0.293E+06     0.122E+02   0.614E-01     0.631E+03   0.235E+06   0.559E+00   0.921E-03   0.380E+03
      23     0.299E+36     0.806E+01   0.288E-12     0.385E+07   0.310E+02   0.329E+04   0.150E-06   0.664E-01


    ISTEP =     30          TAU =  0.15000E+02
 BOUNDARY NODES
   NODE    P(PSI)      TF(F)      Z(COMP)       RHO       QUALITY
                                       (LBM/FT^3)
    1    0.3500E+02  0.7000E+02  0.1000E+01  0.1784E+00  0.0000E+00
    3    0.1470E+02  0.7000E+02  0.1000E+01  0.7492E-01  0.0000E+00

 SOLUTION
 INTERNAL NODES
 NODE     P(PSI)      TF(F)        Z           RHO         EM(LBM)     QUALITY
                                             (LBM/FT^3)
    2    0.2279E+02  0.1036E+03  0.1000E+01  0.1092E+00  0.1092E+01  0.0000E+00

   NODE       H          ENTROPY     EMU       COND        CP          GAMA
          BTU/LB       BTU/LB-R  LBM/FT-SEC  BTU/FT-S-R  BTU/LB-R

    2    0.5669E+01 -0.9063E-02  0.1260E-04  0.4133E-05  0.2400E+00  0.1400E+01

 BRANCHES
BRANCH       KFACTOR       DELP        FLOW RATE   VELOCITY    REYN. NO.   MACH NO.   ENTROPY GEN.   LOST WORK
      (LBF-S^2/(LBM-FT)^2)  (PSI)       (LBM/SEC)     (FT/SEC)                               BTU/(R-SEC)   LBF-FT/SEC
      12     0.293E+06     0.122E+02   0.613E-01     0.631E+03   0.235E+06   0.559E+00   0.920E-03   0.379E+03
```

23	0.295E+36	0.809E+01	0.288E-12	0.380E+07	0.310E+02	0.327E+04	0.148E-06	0.647E-01

ISTEP = 40 TAU = 0.20000E+02

BOUNDARY NODES

NODE	P(PSI)	TF(F)	Z(COMP)	RHO (LBM/FT^3)	QUALITY
1	0.3500E+02	0.7000E+02	0.1000E+01	0.1784E+00	0.0000E+00
3	0.1470E+02	0.7000E+02	0.1000E+01	0.7492E-01	0.0000E+00

SOLUTION

INTERNAL NODES

NODE	P(PSI)	TF(F)	Z	RHO (LBM/FT^3)	EM(LBM)	QUALITY
2	0.2280E+02	0.9819E+02	0.1000E+01	0.1104E+00	0.1104E+01	0.0000E+00

NODE	H BTU/LB	ENTROPY BTU/LB-R	EMU LBM/FT-SEC	COND BTU/FT-S-R	CP BTU/LB-R	GAMA
2	0.4367E+01	-0.9063E-02	0.1260E-04	0.4133E-05	0.2400E+00	0.1400E+01

BRANCHES

BRANCH	KFACTOR (LBF-S^2/(LBM-FT)^2)	DELP (PSI)	FLOW RATE (LBM/SEC)	VELOCITY (FT/SEC)	REYN. NO.	MACH NO.	ENTROPY GEN. BTU/(R-SEC)	LOST WORK LBF-FT/SEC
12	0.293E+06	0.122E+02	0.613E-01	0.630E+03	0.235E+06	0.559E+00	0.919E-03	0.379E+03
23	0.292E+36	0.811E+01	0.291E-12	0.380E+07	0.312E+02	0.328E+04	0.150E-06	0.650E-01

ISTEP = 50 TAU = 0.25000E+02

BOUNDARY NODES

NODE	P(PSI)	TF(F)	Z(COMP)	RHO (LBM/FT^3)	QUALITY
1	0.3500E+02	0.7000E+02	0.1000E+01	0.1784E+00	0.0000E+00
3	0.1470E+02	0.7000E+02	0.1000E+01	0.7492E-01	0.0000E+00

SOLUTION

INTERNAL NODES

NODE	P(PSI)	TF(F)	Z	RHO (LBM/FT^3)	EM(LBM)	QUALITY
2	0.2281E+02	0.9408E+02	0.1000E+01	0.1112E+00	0.1112E+01	0.0000E+00

NODE	H BTU/LB	ENTROPY BTU/LB-R	EMU LBM/FT-SEC	COND BTU/FT-S-R	CP BTU/LB-R	GAMA
2	0.3380E+01	-0.9063E-02	0.1260E-04	0.4133E-05	0.2400E+00	0.1400E+01

BRANCHES

```
BRANCH       KFACTOR        DELP         FLOW RATE   VELOCITY    REYN. NO.   MACH NO.   ENTROPY GEN.   LOST WORK
      (LBF-S^2/(LBM-FT)^2)  (PSI)        (LBM/SEC)     (FT/SEC)                           BTU/(R-SEC)   LBF-FT/SEC
      12     0.293E+06     0.122E+02   0.613E-01     0.630E+03   0.235E+06   0.559E+00   0.919E-03   0.379E+03
      23     0.290E+36     0.811E+01   0.293E-12     0.380E+07   0.315E+02   0.329E+04   0.152E-06   0.655E-01


     ISTEP =     60          TAU =  0.30000E+02
 BOUNDARY NODES
    NODE    P(PSI)      TF(F)      Z(COMP)       RHO       QUALITY
                                       (LBM/FT^3)
     1    0.3500E+02  0.7000E+02  0.1000E+01  0.1784E+00  0.0000E+00
     3    0.1470E+02  0.7000E+02  0.1000E+01  0.7492E-01  0.0000E+00

 SOLUTION
 INTERNAL NODES
  NODE     P(PSI)      TF(F)        Z           RHO          EM(LBM)     QUALITY
                                              (LBM/FT^3)
     2    0.2282E+02  0.9096E+02  0.1000E+01  0.1119E+00  0.1119E+01  0.0000E+00

    NODE       H          ENTROPY      EMU        COND         CP          GAMA
            BTU/LB       BTU/LB-R  LBM/FT-SEC  BTU/FT-S-R  BTU/LB-R

     2    0.2631E+01 -0.9063E-02  0.1260E-04  0.4133E-05  0.2400E+00  0.1400E+01

 BRANCHES
BRANCH       KFACTOR        DELP         FLOW RATE   VELOCITY    REYN. NO.   MACH NO.   ENTROPY GEN.   LOST WORK
      (LBF-S^2/(LBM-FT)^2)  (PSI)        (LBM/SEC)     (FT/SEC)                           BTU/(R-SEC)   LBF-FT/SEC
      12     0.293E+06     0.122E+02   0.613E-01     0.630E+03   0.235E+06   0.559E+00   0.918E-03   0.378E+03
      23     0.288E+36     0.812E+01   0.295E-12     0.380E+07   0.317E+02   0.330E+04   0.154E-06   0.659E-01


     ISTEP =     70          TAU =  0.35000E+02
 BOUNDARY NODES
    NODE    P(PSI)      TF(F)      Z(COMP)       RHO       QUALITY
                                       (LBM/FT^3)
     1    0.3500E+02  0.7000E+02  0.1000E+01  0.1784E+00  0.0000E+00
     3    0.1470E+02  0.7000E+02  0.1000E+01  0.7492E-01  0.0000E+00

 SOLUTION
 INTERNAL NODES
  NODE     P(PSI)      TF(F)        Z           RHO          EM(LBM)     QUALITY
                                              (LBM/FT^3)
     2    0.2282E+02  0.8858E+02  0.1000E+01  0.1124E+00  0.1124E+01  0.0000E+00

    NODE       H          ENTROPY      EMU        COND         CP          GAMA
            BTU/LB       BTU/LB-R  LBM/FT-SEC  BTU/FT-S-R  BTU/LB-R
```

```
    2    0.2060E+01 -0.9063E-02  0.1260E-04  0.4133E-05  0.2400E+00  0.1400E+01

 BRANCHES
BRANCH       KFACTOR       DELP        FLOW RATE   VELOCITY    REYN. NO.   MACH NO.   ENTROPY GEN.   LOST WORK
      (LBF-S^2/(LBM-FT)^2)  (PSI)       (LBM/SEC)     (FT/SEC)                            BTU/(R-SEC)   LBF-FT/SEC
      12     0.293E+06     0.122E+02   0.613E-01     0.630E+03   0.235E+06   0.559E+00   0.918E-03   0.378E+03
      23     0.287E+36     0.813E+01   0.296E-12     0.380E+07   0.318E+02   0.331E+04   0.155E-06   0.662E-01


    ISTEP =     80          TAU =  0.40000E+02
 BOUNDARY NODES
   NODE    P(PSI)      TF(F)      Z(COMP)       RHO       QUALITY
                                          (LBM/FT^3)
    1    0.3500E+02  0.7000E+02  0.1000E+01  0.1784E+00  0.0000E+00
    3    0.1470E+02  0.7000E+02  0.1000E+01  0.7492E-01  0.0000E+00

 SOLUTION
 INTERNAL NODES
  NODE     P(PSI)      TF(F)        Z           RHO         EM(LBM)     QUALITY
                                                (LBM/FT^3)
    2    0.2283E+02  0.8677E+02  0.1000E+01  0.1128E+00  0.1128E+01  0.0000E+00

   NODE       H           ENTROPY     EMU       COND        CP          GAMA
          BTU/LB       BTU/LB-R  LBM/FT-SEC  BTU/FT-S-R  BTU/LB-R

    2    0.1624E+01 -0.9063E-02  0.1260E-04  0.4133E-05  0.2400E+00  0.1400E+01

 BRANCHES
BRANCH       KFACTOR       DELP        FLOW RATE   VELOCITY    REYN. NO.   MACH NO.   ENTROPY GEN.   LOST WORK
      (LBF-S^2/(LBM-FT)^2)  (PSI)       (LBM/SEC)     (FT/SEC)                            BTU/(R-SEC)   LBF-FT/SEC
      12     0.293E+06     0.122E+02   0.613E-01     0.630E+03   0.235E+06   0.559E+00   0.918E-03   0.378E+03
      23     0.286E+36     0.813E+01   0.297E-12     0.380E+07   0.319E+02   0.331E+04   0.156E-06   0.665E-01


    ISTEP =     90          TAU =  0.45000E+02
 BOUNDARY NODES
   NODE    P(PSI)      TF(F)      Z(COMP)       RHO       QUALITY
                                          (LBM/FT^3)
    1    0.3500E+02  0.7000E+02  0.1000E+01  0.1784E+00  0.0000E+00
    3    0.1470E+02  0.7000E+02  0.1000E+01  0.7492E-01  0.0000E+00

 SOLUTION
 INTERNAL NODES
  NODE     P(PSI)      TF(F)        Z           RHO         EM(LBM)     QUALITY
                                                (LBM/FT^3)
    2    0.2283E+02  0.8538E+02  0.1000E+01  0.1131E+00  0.1131E+01  0.0000E+00
```

NODE	H	ENTROPY	EMU	COND	CP	GAMA
	BTU/LB	BTU/LB-R	LBM/FT-SEC	BTU/FT-S-R	BTU/LB-R	
2	0.1290E+01	-0.9063E-02	0.1260E-04	0.4133E-05	0.2400E+00	0.1400E+01

BRANCHES

BRANCH	KFACTOR	DELP	FLOW RATE	VELOCITY	REYN. NO.	MACH NO.	ENTROPY GEN.	LOST WORK
	(LBF-S^2/(LBM-FT)^2)	(PSI)	(LBM/SEC)	(FT/SEC)			BTU/(R-SEC)	LBF-FT/SEC
12	0.293E+06	0.122E+02	0.613E-01	0.630E+03	0.235E+06	0.559E+00	0.918E-03	0.378E+03
23	0.285E+36	0.813E+01	0.298E-12	0.380E+07	0.320E+02	0.332E+04	0.157E-06	0.667E-01

ISTEP = 100 TAU = 0.50000E+02

BOUNDARY NODES

NODE	P(PSI)	TF(F)	Z(COMP)	RHO	QUALITY
				(LBM/FT^3)	
1	0.3500E+02	0.7000E+02	0.1000E+01	0.1784E+00	0.0000E+00
3	0.1470E+02	0.7000E+02	0.1000E+01	0.7492E-01	0.0000E+00

SOLUTION

INTERNAL NODES

NODE	P(PSI)	TF(F)	Z	RHO	EM(LBM)	QUALITY
				(LBM/FT^3)		
2	0.2283E+02	0.8431E+02	0.1000E+01	0.1133E+00	0.1133E+01	0.0000E+00

NODE	H	ENTROPY	EMU	COND	CP	GAMA
	BTU/LB	BTU/LB-R	LBM/FT-SEC	BTU/FT-S-R	BTU/LB-R	
2	0.1034E+01	-0.9063E-02	0.1260E-04	0.4133E-05	0.2400E+00	0.1400E+01

BRANCHES

BRANCH	KFACTOR	DELP	FLOW RATE	VELOCITY	REYN. NO.	MACH NO.	ENTROPY GEN.	LOST WORK
	(LBF-S^2/(LBM-FT)^2)	(PSI)	(LBM/SEC)	(FT/SEC)			BTU/(R-SEC)	LBF-FT/SEC
12	0.293E+06	0.122E+02	0.613E-01	0.630E+03	0.235E+06	0.559E+00	0.918E-03	0.378E+03
23	0.284E+36	0.814E+01	0.299E-12	0.380E+07	0.321E+02	0.332E+04	0.158E-06	0.668E-01

****

TIME OF ANALYSIS WAS 3.125000000000000E-002 SECS

****

APPENDIX II—INPUT AND OUTPUT DATA FILES FROM EXAMPLE 25

Driven Cavity

Contents

Back to Appendix II

```
GFSSP VERSION
    604
GFSSP INSTALLATION PATH
C:\Program Files (x86)\GFSSP604\
ANALYST
akm
INPUT DATA FILE NAME
D:\GFSSP604Intel\Examples\EX25\Ex25.dat
OUTPUT FILE NAME
Ex25.out
TITLE
Driven_Cavity
USETUP
F
DENCON        GRAVITY       ENERGY        MIXTURE       THRUST        STEADY        TRANSV        SAVER
T             F             F             F             F             T             F             F
HEX           HCOEF         REACTING      INERTIA       CONDX         ADDPROP       PRINTI        ROTATION
F             F             F             T             F             F             F             F
BUOYANCY      HRATE         INVAL         MSORCE        MOVBND        TPA           VARGEO        TVM
F             T             F             F             F             F             F             T
SHEAR         PRNTIN        PRNTADD       OPVALVE       TRANSQ        CONJUG        RADIAT        WINPLOT
T             T             T             F             F             F             F             F
PRESS         INSUC         VARROT        CYCLIC        CHKVALS       WINFILE       DALTON        NOSTATS
F             F             F             F             F             F             F             F
NORMAL        SIMUL         SECONDL       NRSOLVT       IBDF          NOPLT         PRESREG       FLOWREG
F             F             F             T             1             T             0             0
TRANS_MOM     USERVARS      PSMG          ISOLVE        PLOTADD       SIUNITS       TECPLOT       MDGEN
F             F             F             1             F             F             T             T
NUM_USER_VARS IFR_MIX       PRINTD        SATTABL       MSORIN        PRELVLV       LAMINAR       HSTAG
1             1             F             F             F             F             T             T
NNODES     NINT       NBR       NF        NX         NY         NZ         LX            LY            LZ
50         49          85        0        7          7          1          12            12             1
RELAXK        RELAXD        RELAXH        CC            NITER         RELAXNR       RELAXHC       RELAXTS
 1               0.5             1             1e-10          500 1                 1                1
RHOREF        EMUREF
 1                 1
NODE          INDEX     DESCRIPTION        XCOORD      YCOORD       ZCOORD
2               2       "Node 2"           0           0            0
3               1       "Node 3"           0.85714     0.85714      1
4               1       "Node 4"           2.5714      0.85714      1
5               1       "Node 5"           4.2857      0.85714      1
6               1       "Node 6"           6           0.85714      1
7               1       "Node 7"           7.7143      0.85714      1
8               1       "Node 8"           9.4286      0.85714      1
9               1       "Node 9"           11.143      0.85714      1
10              1       "Node 10"           0.85714     2.5714       1
11              1       "Node 11"           2.5714      2.5714       1
```

12	1	"Node 12"	4.2857	2.5714	1
13	1	"Node 13"	6	2.5714	1
14	1	"Node 14"	7.7143	2.5714	1
15	1	"Node 15"	9.4286	2.5714	1
16	1	"Node 16"	11.143	2.5714	1
17	1	"Node 17"	0.85714	4.2857	1
18	1	"Node 18"	2.5714	4.2857	1
19	1	"Node 19"	4.2857	4.2857	1
20	1	"Node 20"	6	4.2857	1
21	1	"Node 21"	7.7143	4.2857	1
22	1	"Node 22"	9.4286	4.2857	1
23	1	"Node 23"	11.143	4.2857	1
24	1	"Node 24"	0.85714	6	1
25	1	"Node 25"	2.5714	6	1
26	1	"Node 26"	4.2857	6	1
27	1	"Node 27"	6	6	1
28	1	"Node 28"	7.7143	6	1
29	1	"Node 29"	9.4286	6	1
30	1	"Node 30"	11.143	6	1
31	1	"Node 31"	0.85714	7.7143	1
32	1	"Node 32"	2.5714	7.7143	1
33	1	"Node 33"	4.2857	7.7143	1
34	1	"Node 34"	6	7.7143	1
35	1	"Node 35"	7.7143	7.7143	1
36	1	"Node 36"	9.4286	7.7143	1
37	1	"Node 37"	11.143	7.7143	1
38	1	"Node 38"	0.85714	9.4286	1
39	1	"Node 39"	2.5714	9.4286	1
40	1	"Node 40"	4.2857	9.4286	1
41	1	"Node 41"	6	9.4286	1
42	1	"Node 42"	7.7143	9.4286	1
43	1	"Node 43"	9.4286	9.4286	1
44	1	"Node 44"	11.143	9.4286	1
45	1	"Node 45"	0.85714	11.143	1
46	1	"Node 46"	2.5714	11.143	1
47	1	"Node 47"	4.2857	11.143	1
48	1	"Node 48"	6	11.143	1
49	1	"Node 49"	7.7143	11.143	1
50	1	"Node 50"	9.4286	11.143	1
51	1	"Node 51"	11.143	11.143	1

NODE	PRES (PSI)	MASS SOURC	HEAT SOURC	THRST AREA
2	14.7	0	0	0
3	14.7	0	0	0
4	14.7	0	0	0
5	14.7	0	0	0
6	14.7	0	0	0
7	14.7	0	0	0

8	14.7	0	0	0
9	14.7	0	0	0
10	14.7	0	0	0
11	14.7	0	0	0
12	14.7	0	0	0
13	14.7	0	0	0
14	14.7	0	0	0
15	14.7	0	0	0
16	14.7	0	0	0
17	14.7	0	0	0
18	14.7	0	0	0
19	14.7	0	0	0
20	14.7	0	0	0
21	14.7	0	0	0
22	14.7	0	0	0
23	14.7	0	0	0
24	14.7	0	0	0
25	14.7	0	0	0
26	14.7	0	0	0
27	14.7	0	0	0
28	14.7	0	0	0
29	14.7	0	0	0
30	14.7	0	0	0
31	14.7	0	0	0
32	14.7	0	0	0
33	14.7	0	0	0
34	14.7	0	0	0
35	14.7	0	0	0
36	14.7	0	0	0
37	14.7	0	0	0
38	14.7	0	0	0
39	14.7	0	0	0
40	14.7	0	0	0
41	14.7	0	0	0
42	14.7	0	0	0
43	14.7	0	0	0
44	14.7	0	0	0
45	14.7	0	0	0
46	14.7	0	0	0
47	14.7	0	0	0
48	14.7	0	0	0
49	14.7	0	0	0
50	14.7	0	0	0
51	14.7	0	0	0

INODE	NUMBR	NAMEBR		
3	2	34	310	
4	3	34	45	411

5	3	45	56	512	
6	3	56	67	613	
7	3	67	78	714	
8	3	78	89	815	
9	2	89	916		
10	3	1011	310	1017	
11	4	1011	1112	411	1118
12	4	1112	1213	512	1219
13	4	1213	1314	613	1320
14	4	1314	1415	714	1421
15	4	1415	1516	815	1522
16	3	1516	916	1623	
17	3	1718	1017	1724	
18	4	1718	1819	1118	1825
19	4	1819	1920	1219	1926
20	4	1920	2021	1320	2027
21	4	2021	2122	1421	2128
22	4	2122	2223	1522	2229
23	3	2223	1623	2330	
24	3	2425	1724	2431	
25	4	2425	2526	1825	2532
26	4	2526	2627	1926	2633
27	4	2627	2728	2027	2734
28	4	2728	2829	2128	2835
29	4	2829	2930	2229	2936
30	3	2930	2330	3037	
31	3	3132	2431	3138	
32	4	3132	3233	2532	3239
33	4	3233	3334	2633	3340
34	4	3334	3435	2734	3441
35	4	3435	3536	2835	3542
36	4	3536	3637	2936	3643
37	3	3637	3037	3744	
38	3	3839	3138	3845	
39	4	3839	3940	3239	3946
40	4	3940	4041	3340	4047
41	4	4041	4142	3441	4148
42	4	4142	4243	3542	4249
43	4	4243	4344	3643	4350
44	3	4344	3744	4451	
45	2	4546	3845		
46	3	4546	4647	3946	
47	3	4647	4748	4047	
48	3	4748	4849	4148	
49	3	4849	4950	4249	
50	3	4950	5051	4350	
51	3	12	5051	4451	

BRANCH	UPNODE	DNNODE	OPTION	DESCRIPTION	MDGEN	XCOORD	YCOORD	ZCOORD
12	51	2	2	"Restrict 12"	0 0	0 0		
34	3	4	25	"Cartesian 34"	1	1.7143	0.85714	1
45	4	5	25	"Cartesian 45"	1	3.4286	0.85714	1
56	5	6	25	"Cartesian 56"	1	5.1429	0.85714	1
67	6	7	25	"Cartesian 67"	1	6.8571	0.85714	1
78	7	8	25	"Cartesian 78"	1	8.5714	0.85714	1
89	8	9	25	"Cartesian 89"	1	10.286	0.85714	1
1011	10	11	25	"Cartesian 1011"	1	1.7143	2.5714	1
1112	11	12	25	"Cartesian 1112"	1	3.4286	2.5714	1
1213	12	13	25	"Cartesian 1213"	1	5.1429	2.5714	1
1314	13	14	25	"Cartesian 1314"	1	6.8571	2.5714	1
1415	14	15	25	"Cartesian 1415"	1	8.5714	2.5714	1
1516	15	16	25	"Cartesian 1516"	1	10.286	2.5714	1
1718	17	18	25	"Cartesian 1718"	1	1.7143	4.2857	1
1819	18	19	25	"Cartesian 1819"	1	3.4286	4.2857	1
1920	19	20	25	"Cartesian 1920"	1	5.1429	4.2857	1
2021	20	21	25	"Cartesian 2021"	1	6.8571	4.2857	1
2122	21	22	25	"Cartesian 2122"	1	8.5714	4.2857	1
2223	22	23	25	"Cartesian 2223"	1	10.286	4.2857	1
2425	24	25	25	"Cartesian 2425"	1	1.7143	6	1
2526	25	26	25	"Cartesian 2526"	1	3.4286	6	1
2627	26	27	25	"Cartesian 2627"	1	5.1429	6	1
2728	27	28	25	"Cartesian 2728"	1	6.8571	6	1
2829	28	29	25	"Cartesian 2829"	1	8.5714	6	1
2930	29	30	25	"Cartesian 2930"	1	10.286	6	1
3132	31	32	25	"Cartesian 3132"	1	1.7143	7.7143	1
3233	32	33	25	"Cartesian 3233"	1	3.4286	7.7143	1
3334	33	34	25	"Cartesian 3334"	1	5.1429	7.7143	1
3435	34	35	25	"Cartesian 3435"	1	6.8571	7.7143	1
3536	35	36	25	"Cartesian 3536"	1	8.5714	7.7143	1
3637	36	37	25	"Cartesian 3637"	1	10.286	7.7143	1
3839	38	39	25	"Cartesian 3839"	1	1.7143	9.4286	1
3940	39	40	25	"Cartesian 3940"	1	3.4286	9.4286	1
4041	40	41	25	"Cartesian 4041"	1	5.1429	9.4286	1
4142	41	42	25	"Cartesian 4142"	1	6.8571	9.4286	1
4243	42	43	25	"Cartesian 4243"	1	8.5714	9.4286	1
4344	43	44	25	"Cartesian 4344"	1	10.286	9.4286	1
4546	45	46	25	"Cartesian 4546"	1	1.7143	11.143	1
4647	46	47	25	"Cartesian 4647"	1	3.4286	11.143	1
4748	47	48	25	"Cartesian 4748"	1	5.1429	11.143	1
4849	48	49	25	"Cartesian 4849"	1	6.8571	11.143	1
4950	49	50	25	"Cartesian 4950"	1	8.5714	11.143	1
5051	50	51	25	"Cartesian 5051"	1	10.286	11.143	1
310	3	10	25	"Cartesian 310"	1	0.85714	1.7143	1
411	4	11	25	"Cartesian 411"	1	2.5714	1.7143	1
512	5	12	25	"Cartesian 512"	1	4.2857	1.7143	1

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613        6          13         25     "Cartesian 613"     1     6           1.7143       1
714        7          14         25     "Cartesian 714"     1     7.7143      1.7143       1
815        8          15         25     "Cartesian 815"     1     9.4286      1.7143       1
916        9          16         25     "Cartesian 916"     1     11.143      1.7143       1
1017       10         17         25     "Cartesian 1017"     1     0.85714     3.4286       1
1118       11         18         25     "Cartesian 1118"     1     2.5714      3.4286       1
1219       12         19         25     "Cartesian 1219"     1     4.2857      3.4286       1
1320       13         20         25     "Cartesian 1320"     1     6           3.4286       1
1421       14         21         25     "Cartesian 1421"     1     7.7143      3.4286       1
1522       15         22         25     "Cartesian 1522"     1     9.4286      3.4286       1
1623       16         23         25     "Cartesian 1623"     1     11.143      3.4286       1
1724       17         24         25     "Cartesian 1724"     1     0.85714     5.1429       1
1825       18         25         25     "Cartesian 1825"     1     2.5714      5.1429       1
1926       19         26         25     "Cartesian 1926"     1     4.2857      5.1429       1
2027       20         27         25     "Cartesian 2027"     1     6           5.1429       1
2128       21         28         25     "Cartesian 2128"     1     7.7143      5.1429       1
2229       22         29         25     "Cartesian 2229"     1     9.4286      5.1429       1
2330       23         30         25     "Cartesian 2330"     1     11.143      5.1429       1
2431       24         31         25     "Cartesian 2431"     1     0.85714     6.8571       1
2532       25         32         25     "Cartesian 2532"     1     2.5714      6.8571       1
2633       26         33         25     "Cartesian 2633"     1     4.2857      6.8571       1
2734       27         34         25     "Cartesian 2734"     1     6           6.8571       1
2835       28         35         25     "Cartesian 2835"     1     7.7143      6.8571       1
2936       29         36         25     "Cartesian 2936"     1     9.4286      6.8571       1
3037       30         37         25     "Cartesian 3037"     1     11.143      6.8571       1
3138       31         38         25     "Cartesian 3138"     1     0.85714     8.5714       1
3239       32         39         25     "Cartesian 3239"     1     2.5714      8.5714       1
3340       33         40         25     "Cartesian 3340"     1     4.2857      8.5714       1
3441       34         41         25     "Cartesian 3441"     1     6           8.5714       1
3542       35         42         25     "Cartesian 3542"     1     7.7143      8.5714       1
3643       36         43         25     "Cartesian 3643"     1     9.4286      8.5714       1
3744       37         44         25     "Cartesian 3744"     1     11.143      8.5714       1
3845       38         45         25     "Cartesian 3845"     1     0.85714     10.286       1
3946       39         46         25     "Cartesian 3946"     1     2.5714      10.286       1
4047       40         47         25     "Cartesian 4047"     1     4.2857      10.286       1
4148       41         48         25     "Cartesian 4148"     1     6           10.286       1
4249       42         49         25     "Cartesian 4249"     1     7.7143      10.286       1
4350       43         50         25     "Cartesian 4350"     1     9.4286      10.286       1
4451       44         51         25     "Cartesian 4451"     1     11.143      10.286       1
BRANCH        OPTION -2     FLOW COEFF    AREA
 12                         1             1e-06
BRANCH        OPTION -24     AREA          VOLUME      DIRECTION      WALL      VELOCITY  DIRINDEX
 34                         1.7143        4.4082        1             4          0            1
BRANCH        OPTION -24     AREA          VOLUME      DIRECTION      WALL      VELOCITY  DIRINDEX
 45                         1.7143        2.9388       1             4          0            2
BRANCH        OPTION -24     AREA          VOLUME      DIRECTION      WALL      VELOCITY  DIRINDEX
 56                         1.7143        2.9388       1             4          0            3
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BRANCH        OPTION -24    AREA          VOLUME      DIRECTION     WALL     VELOCITY  DIRINDEX
 67                        1.7143        2.9388        1            4         0             4
BRANCH        OPTION -24    AREA          VOLUME      DIRECTION     WALL     VELOCITY  DIRINDEX
 78                        1.7143        2.9388        1            4         0             5
BRANCH        OPTION -24    AREA          VOLUME      DIRECTION     WALL     VELOCITY  DIRINDEX
 89                        1.7143        4.4082         1            4         0             6
BRANCH        OPTION -24    AREA          VOLUME      DIRECTION     WALL     VELOCITY  DIRINDEX
 1011                      1.7143        4. BRANCH        OPTION -2     FLOW COEFF    AREA
 12                        1             1e-06
BRANCH        OPTION -25    AREA          VOLUME      DIRECTION     WALL     VELOCITY  DIRINDEX
 34                        1.7143        4.4082        1            0         0             1
BRANCH        OPTION -25    AREA          VOLUME      DIRECTION     WALL     VELOCITY  DIRINDEX
 45                        1.7143        2.9388        1            0         0             2
BRANCH        OPTION -25    AREA          VOLUME      DIRECTION     WALL     VELOCITY  DIRINDEX
 56                        1.7143        2.9388        1            0         0             3
BRANCH        OPTION -25    AREA          VOLUME      DIRECTION     WALL     VELOCITY  DIRINDEX
 67                        1.7143        2.9388        1            0         0             4
BRANCH        OPTION -25    AREA          VOLUME      DIRECTION     WALL     VELOCITY  DIRINDEX
 78                        1.7143        2.9388        1            0         0             5
BRANCH        OPTION -25    AREA          VOLUME      DIRECTION     WALL     VELOCITY  DIRINDEX
 89                        1.7143        4.4082        1            0         0             6
BRANCH        OPTION -25    AREA          VOLUME      DIRECTION     WALL     VELOCITY  DIRINDEX
 1011                      1.7143        4.4082        1            0         0             1
BRANCH        OPTION -25    AREA          VOLUME      DIRECTION     WALL     VELOCITY  DIRINDEX
 1112                      1.7143        2.9388        1            0         0             2
BRANCH        OPTION -25    AREA          VOLUME      DIRECTION     WALL     VELOCITY  DIRINDEX
 1213                      1.7143        2.9388        1            0         0             3
BRANCH        OPTION -25    AREA          VOLUME      DIRECTION     WALL     VELOCITY  DIRINDEX
 1314                      1.7143        2.9388        1            0         0             4
BRANCH        OPTION -25    AREA          VOLUME      DIRECTION     WALL     VELOCITY  DIRINDEX
 1415                      1.7143        2.9388        1            0         0             5
BRANCH        OPTION -25    AREA          VOLUME      DIRECTION     WALL     VELOCITY  DIRINDEX
 1516                      1.7143        4.4082        1            0         0             6
BRANCH        OPTION -25    AREA          VOLUME      DIRECTION     WALL     VELOCITY  DIRINDEX
 1718                      1.7143        4.4082        1            0         0             1
BRANCH        OPTION -25    AREA          VOLUME      DIRECTION     WALL     VELOCITY  DIRINDEX
 1819                      1.7143        2.9388        1            0         0             2
BRANCH        OPTION -25    AREA          VOLUME      DIRECTION     WALL     VELOCITY  DIRINDEX
 1920                      1.7143        2.9388        1            0         0             3
BRANCH        OPTION -25    AREA          VOLUME      DIRECTION     WALL     VELOCITY  DIRINDEX
 2021                      1.7143        2.9388        1            0         0             4
BRANCH        OPTION -25    AREA          VOLUME      DIRECTION     WALL     VELOCITY  DIRINDEX
 2122                      1.7143        2.9388        1            0         0             5
BRANCH        OPTION -25    AREA          VOLUME      DIRECTION     WALL     VELOCITY  DIRINDEX
 2223                      1.7143        4.4082        1            0         0             6
BRANCH        OPTION -25    AREA          VOLUME      DIRECTION     WALL     VELOCITY  DIRINDEX
 2425                      1.7143        4.4082        1            0         0             1
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BRANCH        OPTION -25    AREA          VOLUME     DIRECTION      WALL     VELOCITY  DIRINDEX
 2526                      1.7143        2.9388       1              0        0               2
BRANCH        OPTION -25    AREA          VOLUME     DIRECTION      WALL     VELOCITY  DIRINDEX
 2627                      1.7143        2.9388       1              0        0               3
BRANCH        OPTION -25    AREA          VOLUME     DIRECTION      WALL     VELOCITY  DIRINDEX
 2728                      1.7143        2.9388       1              0        0               4
BRANCH        OPTION -25    AREA          VOLUME     DIRECTION      WALL     VELOCITY  DIRINDEX
 2829                      1.7143        2.9388       1              0        0               5
BRANCH        OPTION -25    AREA          VOLUME     DIRECTION      WALL     VELOCITY  DIRINDEX
 2930                      1.7143        4.4082       1              0        0               6
BRANCH        OPTION -25    AREA          VOLUME     DIRECTION      WALL     VELOCITY  DIRINDEX
 3132                      1.7143        4.4082       1              0        0               1
BRANCH        OPTION -25    AREA          VOLUME     DIRECTION      WALL     VELOCITY  DIRINDEX
 3233                      1.7143        2.9388       1              0        0               2
BRANCH        OPTION -25    AREA          VOLUME     DIRECTION      WALL     VELOCITY  DIRINDEX
 3334                      1.7143        2.9388       1              0        0               3
BRANCH        OPTION -25    AREA          VOLUME     DIRECTION      WALL     VELOCITY  DIRINDEX
 3435                      1.7143        2.9388       1              0        0               4
BRANCH        OPTION -25    AREA          VOLUME     DIRECTION      WALL     VELOCITY  DIRINDEX
 3536                      1.7143        2.9388       1              0        0               5
BRANCH        OPTION -25    AREA          VOLUME     DIRECTION      WALL     VELOCITY  DIRINDEX
 3637                      1.7143        4.4082       1              0        0               6
BRANCH        OPTION -25    AREA          VOLUME     DIRECTION      WALL     VELOCITY  DIRINDEX
 3839                      1.7143        4.4082       1              0        0               1
BRANCH        OPTION -25    AREA          VOLUME     DIRECTION      WALL     VELOCITY  DIRINDEX
 3940                      1.7143        2.9388       1              0        0               2
BRANCH        OPTION -25    AREA          VOLUME     DIRECTION      WALL     VELOCITY  DIRINDEX
 4041                      1.7143        2.9388       1              0        0               3
BRANCH        OPTION -25    AREA          VOLUME     DIRECTION      WALL     VELOCITY  DIRINDEX
 4142                      1.7143        2.9388       1              0        0               4
BRANCH        OPTION -25    AREA          VOLUME     DIRECTION      WALL     VELOCITY  DIRINDEX
 4243                      1.7143        2.9388       1              0        0               5
BRANCH        OPTION -25    AREA          VOLUME     DIRECTION      WALL     VELOCITY  DIRINDEX
 4344                      1.7143        4.4082       1              0        0               6
BRANCH        OPTION -25    AREA          VOLUME     DIRECTION      WALL     VELOCITY  DIRINDEX
 4546                      1.7143        4.4082       1              2        100             1
BRANCH        OPTION -25    AREA          VOLUME     DIRECTION      WALL     VELOCITY  DIRINDEX
 4647                      1.7143        2.9388       1              2        100             2
BRANCH        OPTION -25    AREA          VOLUME     DIRECTION      WALL     VELOCITY  DIRINDEX
 4748                      1.7143        2.9388       1              2        100             3
BRANCH        OPTION -25    AREA          VOLUME     DIRECTION      WALL     VELOCITY  DIRINDEX
 4849                      1.7143        2.9388       1              2        100             4
BRANCH        OPTION -25    AREA          VOLUME     DIRECTION      WALL     VELOCITY  DIRINDEX
 4950                      1.7143        2.9388       1              2        100             5
BRANCH        OPTION -25    AREA          VOLUME     DIRECTION      WALL     VELOCITY  DIRINDEX
 5051                      1.7143        4.4082       1              2        100             6
BRANCH        OPTION -25    AREA          VOLUME     DIRECTION      WALL     VELOCITY  DIRINDEX
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310		1.7143	4.4082	2	0	0	1
BRANCH	OPTION -25	AREA	VOLUME	DIRECTION	WALL	VELOCITY	DIRINDEX
411		1.7143	4.4082	2	0	0	1
BRANCH	OPTION -25	AREA	VOLUME	DIRECTION	WALL	VELOCITY	DIRINDEX
512		1.7143	4.4082	2	0	0	1
BRANCH	OPTION -25	AREA	VOLUME	DIRECTION	WALL	VELOCITY	DIRINDEX
613		1.7143	4.4082	2	0	0	1
BRANCH	OPTION -25	AREA	VOLUME	DIRECTION	WALL	VELOCITY	DIRINDEX
714		1.7143	4.4082	2	0	0	1
BRANCH	OPTION -25	AREA	VOLUME	DIRECTION	WALL	VELOCITY	DIRINDEX
815		1.7143	4.4082	2	0	0	1
BRANCH	OPTION -25	AREA	VOLUME	DIRECTION	WALL	VELOCITY	DIRINDEX
916		1.7143	4.4082	2	0	0	1
BRANCH	OPTION -25	AREA	VOLUME	DIRECTION	WALL	VELOCITY	DIRINDEX
1017		1.7143	2.9388	2	0	0	2
BRANCH	OPTION -25	AREA	VOLUME	DIRECTION	WALL	VELOCITY	DIRINDEX
1118		1.7143	2.9388	2	0	0	2
BRANCH	OPTION -25	AREA	VOLUME	DIRECTION	WALL	VELOCITY	DIRINDEX
1219		1.7143	2.9388	2	0	0	2
BRANCH	OPTION -25	AREA	VOLUME	DIRECTION	WALL	VELOCITY	DIRINDEX
1320		1.7143	2.9388	2	0	0	2
BRANCH	OPTION -25	AREA	VOLUME	DIRECTION	WALL	VELOCITY	DIRINDEX
1421		1.7143	2.9388	2	0	0	2
BRANCH	OPTION -25	AREA	VOLUME	DIRECTION	WALL	VELOCITY	DIRINDEX
1522		1.7143	2.9388	2	0	0	2
BRANCH	OPTION -25	AREA	VOLUME	DIRECTION	WALL	VELOCITY	DIRINDEX
1623		1.7143	2.9388	2	0	0	2
BRANCH	OPTION -25	AREA	VOLUME	DIRECTION	WALL	VELOCITY	DIRINDEX
1724		1.7143	2.9388	2	0	0	3
BRANCH	OPTION -25	AREA	VOLUME	DIRECTION	WALL	VELOCITY	DIRINDEX
1825		1.7143	2.9388	2	0	0	3
BRANCH	OPTION -25	AREA	VOLUME	DIRECTION	WALL	VELOCITY	DIRINDEX
1926		1.7143	2.9388	2	0	0	3
BRANCH	OPTION -25	AREA	VOLUME	DIRECTION	WALL	VELOCITY	DIRINDEX
2027		1.7143	2.9388	2	0	0	3
BRANCH	OPTION -25	AREA	VOLUME	DIRECTION	WALL	VELOCITY	DIRINDEX
2128		1.7143	2.9388	2	0	0	3
BRANCH	OPTION -25	AREA	VOLUME	DIRECTION	WALL	VELOCITY	DIRINDEX
2229		1.7143	2.9388	2	0	0	3
BRANCH	OPTION -25	AREA	VOLUME	DIRECTION	WALL	VELOCITY	DIRINDEX
2330		1.7143	2.9388	2	0	0	3
BRANCH	OPTION -25	AREA	VOLUME	DIRECTION	WALL	VELOCITY	DIRINDEX
2431		1.7143	2.9388	2	0	0	4
BRANCH	OPTION -25	AREA	VOLUME	DIRECTION	WALL	VELOCITY	DIRINDEX
2532		1.7143	2.9388	2	0	0	4
BRANCH	OPTION -25	AREA	VOLUME	DIRECTION	WALL	VELOCITY	DIRINDEX
2633		1.7143	2.9388	2	0	0	4

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BRANCH        OPTION -25     AREA          VOLUME      DIRECTION      WALL      VELOCITY  DIRINDEX
 2734                       1.7143        2.9388        2            0         0            4
BRANCH        OPTION -25     AREA          VOLUME      DIRECTION      WALL      VELOCITY  DIRINDEX
 2835                       1.7143        2.9388        2            0         0            4
BRANCH        OPTION -25     AREA          VOLUME      DIRECTION      WALL      VELOCITY  DIRINDEX
 2936                       1.7143        2.9388        2            0         0            4
BRANCH        OPTION -25     AREA          VOLUME      DIRECTION      WALL      VELOCITY  DIRINDEX
 3037                       1.7143        2.9388        2            0         0            4
BRANCH        OPTION -25     AREA          VOLUME      DIRECTION      WALL      VELOCITY  DIRINDEX
 3138                       1.7143        2.9388        2            0         0            5
BRANCH        OPTION -25     AREA          VOLUME      DIRECTION      WALL      VELOCITY  DIRINDEX
 3239                       1.7143        2.9388        2            0         0            5
BRANCH        OPTION -25     AREA          VOLUME      DIRECTION      WALL      VELOCITY  DIRINDEX
 3340                       1.7143        2.9388        2            0         0            5
BRANCH        OPTION -25     AREA          VOLUME      DIRECTION      WALL      VELOCITY  DIRINDEX
 3441                       1.7143        2.9388        2            0         0            5
BRANCH        OPTION -25     AREA          VOLUME      DIRECTION      WALL      VELOCITY  DIRINDEX
 3542                       1.7143        2.9388        2            0         0            5
BRANCH        OPTION -25     AREA          VOLUME      DIRECTION      WALL      VELOCITY  DIRINDEX
 3643                       1.7143        2.9388        2            0         0            5
BRANCH        OPTION -25     AREA          VOLUME      DIRECTION      WALL      VELOCITY  DIRINDEX
 3744                       1.7143        2.9388        2            0         0            5
BRANCH        OPTION -25     AREA          VOLUME      DIRECTION      WALL      VELOCITY  DIRINDEX
 3845                       1.7143        4.4082        2            0         0            6
BRANCH        OPTION -25     AREA          VOLUME      DIRECTION      WALL      VELOCITY  DIRINDEX
 3946                       1.7143        4.4082        2            0         0            6
BRANCH        OPTION -25     AREA          VOLUME      DIRECTION      WALL      VELOCITY  DIRINDEX
 4047                       1.7143        4.4082        2            0         0            6
BRANCH        OPTION -25     AREA          VOLUME      DIRECTION      WALL      VELOCITY  DIRINDEX
 4148                       1.7143        4.4082        2            0         0            6
BRANCH        OPTION -25     AREA          VOLUME      DIRECTION      WALL      VELOCITY  DIRINDEX
 4249                       1.7143        4.4082        2            0         0            6
BRANCH        OPTION -25     AREA          VOLUME      DIRECTION      WALL      VELOCITY  DIRINDEX
 4350                       1.7143        4.4082        2            0         0            6
BRANCH        OPTION -25     AREA          VOLUME      DIRECTION      WALL      VELOCITY  DIRINDEX
 4451                       1.7143        4.4082        2            0         0            6
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 45    2   34   411
 56    2   45   512
 67    2   56   613
 78    2   67   714
 89    2   78   815
 1011    2   310   1017
 1112    3   1011   411   1118
 1213    3   1112   512   1219
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1516	3	1415	815	1522
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1920	3	1819	1219	1926
2021	3	1920	1320	2027
2122	3	2021	1421	2128
2223	3	2122	1522	2229
2425	2	1724	2431	
2526	3	2425	1825	2532
2627	3	2526	1926	2633
2728	3	2627	2027	2734
2829	3	2728	2128	2835
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3637	3	3536	2936	3643
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4041	3	3940	3340	4047
4142	3	4041	3441	4148
4243	3	4142	3542	4249
4344	3	4243	3643	4350
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4748	2	4647	4047	
4849	2	4748	4148	
4950	2	4849	4249	
5051	2	4950	4350	
310	1	34		
411	2	34	45	
512	2	45	56	
613	2	56	67	
714	2	67	78	
815	2	78	89	
916	1	89		
1017	2	1011	310	
1118	3	1011	1112	411
1219	3	1112	1213	512
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1421	3	1314	1415	714
1522	3	1415	1516	815
1623	2	1516	916	

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 2431    2   2425   1724
 2532    3   2425   2526   1825
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 2734    3   2627   2728   2027
 2835    3   2728   2829   2128
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 3037    2   2930   2330
 3138    2   3132   2431
 3239    3   3132   3233   2532
 3340    3   3233   3334   2633
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 3542    3   3435   3536   2835
 3643    3   3536   3637   2936
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 45    2   56   512
 56    2   67   613
 67    2   78   714
 78    2   89   815
 89    1   916
 1011    3   1112   411   1118
 1112    3   1213   512   1219
 1213    3   1314   613   1320
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 1415    3   1516   815   1522
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 1920    3   2021   1320   2027
 2021    3   2122   1421   2128
 2122    3   2223   1522   2229
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2627	3	2728	2027	2734
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2829	3	2930	2229	2936
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 3542    3   4142   4243   4249
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   1213     0.00000
   1314     0.00000
   613     0.00000
  DNSTRM BR.     ANGLE
   1920     0.00000
   2021     0.00000
   2027     0.00000
BRANCH
 1421
  UPSTRM BR.     ANGLE
   1314     0.00000
   1415     0.00000
   714     0.00000
  DNSTRM BR.     ANGLE
   2021     0.00000
   2122     0.00000
   2128     0.00000
BRANCH
```

```
 1522
  UPSTRM BR.     ANGLE
   1415     0.00000
   1516     0.00000
   815     0.00000
  DNSTRM BR.     ANGLE
   2122     0.00000
   2223     0.00000
   2229     0.00000
BRANCH
 1623
  UPSTRM BR.     ANGLE
   1516     0.00000
   916     0.00000
  DNSTRM BR.     ANGLE
   2223     0.00000
   2330     0.00000
BRANCH
 1724
  UPSTRM BR.     ANGLE
   1718     0.00000
   1017     0.00000
  DNSTRM BR.     ANGLE
   2425     0.00000
   2431     0.00000
BRANCH
 1825
  UPSTRM BR.     ANGLE
   1718     0.00000
   1819     0.00000
   1118     0.00000
  DNSTRM BR.     ANGLE
   2425     0.00000
   2526     0.00000
   2532     0.00000
BRANCH
 1926
  UPSTRM BR.     ANGLE
   1819     0.00000
   1920     0.00000
   1219     0.00000
  DNSTRM BR.     ANGLE
   2526     0.00000
   2627     0.00000
   2633     0.00000
BRANCH
 2027
```

```
  UPSTRM BR.     ANGLE
   1920     0.00000
   2021     0.00000
   1320     0.00000
  DNSTRM BR.     ANGLE
   2627     0.00000
   2728     0.00000
   2734     0.00000
BRANCH
 2128
  UPSTRM BR.     ANGLE
   2021     0.00000
   2122     0.00000
   1421     0.00000
  DNSTRM BR.     ANGLE
   2728     0.00000
   2829     0.00000
   2835     0.00000
BRANCH
 2229
  UPSTRM BR.     ANGLE
   2122     0.00000
   2223     0.00000
   1522     0.00000
  DNSTRM BR.     ANGLE
   2829     0.00000
   2930     0.00000
   2936     0.00000
BRANCH
 2330
  UPSTRM BR.     ANGLE
   2223     0.00000
   1623     0.00000
  DNSTRM BR.     ANGLE
   2930     0.00000
   3037     0.00000
BRANCH
 2431
  UPSTRM BR.     ANGLE
   2425     0.00000
   1724     0.00000
  DNSTRM BR.     ANGLE
   3132     0.00000
   3138     0.00000
BRANCH
 2532
  UPSTRM BR.     ANGLE
```

```
   2425     0.00000
   2526     0.00000
   1825     0.00000
  DNSTRM BR.     ANGLE
   3132     0.00000
   3233     0.00000
   3239     0.00000
BRANCH
 2633
  UPSTRM BR.     ANGLE
   2526     0.00000
   2627     0.00000
   1926     0.00000
  DNSTRM BR.     ANGLE
   3233     0.00000
   3334     0.00000
   3340     0.00000
BRANCH
 2734
  UPSTRM BR.     ANGLE
   2627     0.00000
   2728     0.00000
   2027     0.00000
  DNSTRM BR.     ANGLE
   3334     0.00000
   3435     0.00000
   3441     0.00000
BRANCH
 2835
  UPSTRM BR.     ANGLE
   2728     0.00000
   2829     0.00000
   2128     0.00000
  DNSTRM BR.     ANGLE
   3435     0.00000
   3536     0.00000
   3542     0.00000
BRANCH
 2936
  UPSTRM BR.     ANGLE
   2829     0.00000
   2930     0.00000
   2229     0.00000
  DNSTRM BR.     ANGLE
   3536     0.00000
   3637     0.00000
   3643     0.00000
```

```
BRANCH
 3037
  UPSTRM BR.     ANGLE
   2930     0.00000
   2330     0.00000
  DNSTRM BR.     ANGLE
   3637     0.00000
   3744     0.00000
BRANCH
 3138
  UPSTRM BR.     ANGLE
   3132     0.00000
   2431     0.00000
  DNSTRM BR.     ANGLE
   3839     0.00000
   3845     0.00000
BRANCH
 3239
  UPSTRM BR.     ANGLE
   3132     0.00000
   3233     0.00000
   2532     0.00000
  DNSTRM BR.     ANGLE
   3839     0.00000
   3940     0.00000
   3946     0.00000
BRANCH
 3340
  UPSTRM BR.     ANGLE
   3233     0.00000
   3334     0.00000
   2633     0.00000
  DNSTRM BR.     ANGLE
   3940     0.00000
   4041     0.00000
   4047     0.00000
BRANCH
 3441
  UPSTRM BR.     ANGLE
   3334     0.00000
   3435     0.00000
   2734     0.00000
  DNSTRM BR.     ANGLE
   4041     0.00000
   4142     0.00000
   4148     0.00000
BRANCH
```

```
 3542
  UPSTRM BR.     ANGLE
   3435     0.00000
   3536     0.00000
   2835     0.00000
  DNSTRM BR.     ANGLE
   4142     0.00000
   4243     0.00000
   4249     0.00000
BRANCH
 3643
  UPSTRM BR.     ANGLE
   3536     0.00000
   3637     0.00000
   2936     0.00000
  DNSTRM BR.     ANGLE
   4243     0.00000
   4344     0.00000
   4350     0.00000
BRANCH
 3744
  UPSTRM BR.     ANGLE
   3637     0.00000
   3037     0.00000
  DNSTRM BR.     ANGLE
   4344     0.00000
   4451     0.00000
BRANCH
 3845
  UPSTRM BR.     ANGLE
   3839     0.00000
   3138     0.00000
  DNSTRM BR.     ANGLE
   4546     0.00000
BRANCH
 3946
  UPSTRM BR.     ANGLE
   3839     0.00000
   3940     0.00000
   3239     0.00000
  DNSTRM BR.     ANGLE
   4546     0.00000
   4647     0.00000
BRANCH
 4047
  UPSTRM BR.     ANGLE
   3940     0.00000
```

```
   4041     0.00000
   3340     0.00000
  DNSTRM BR.     ANGLE
   4647     0.00000
   4748     0.00000
BRANCH
 4148
  UPSTRM BR.     ANGLE
   4041     0.00000
   4142     0.00000
   3441     0.00000
  DNSTRM BR.     ANGLE
   4748     0.00000
   4849     0.00000
BRANCH
 4249
  UPSTRM BR.     ANGLE
   4142     0.00000
   4243     0.00000
   3542     0.00000
  DNSTRM BR.     ANGLE
   4849     0.00000
   4950     0.00000
BRANCH
 4350
  UPSTRM BR.     ANGLE
   4243     0.00000
   4344     0.00000
   3643     0.00000
  DNSTRM BR.     ANGLE
   4950     0.00000
   5051     0.00000
BRANCH
 4451
  UPSTRM BR.     ANGLE
   4344     0.00000
   3744     0.00000
  DNSTRM BR.     ANGLE
   12     0.00000
   5051     0.00000
NUMBER OF BRANCHES WITH INERTIA
 84
 34
 45
 56
 67
 78
```

Back to Appendix II

```
**************************************************
            G F S S P (Version 604)
     Generalized Fluid System Simulation Program
                  March 2012

    Developed by NASA/Marshall Space Flight Center
    Copyright (C) by Marshall Space Flight Center

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

  RUN DATE:10/15/2012 15:56

TITLE     :Driven_Cavity
ANALYST   :akm
FILEIN    :D:\GFSSP604Intel\Examples\EX25\Ex25Oct15.dat
FILEOUT   :Ex25Oct15.out

                   OPTION VARIABLES

ADDPROP   BUOYANCY  CONDX     CONJUG    CYCLIC    DALTON    DENCON    ENERGY
F         F         F         F         F         F         T         F
FLOWREG   GRAVITY   HCOEF     HEX       HRATE     IFRMIX    INERTIA   INSUC
0         F         F         F         T         1         T         F
INVAL     MIXTURE   MOVBND    MSORCE    NORMAL    NRSOLVT   OPVALVE   PLOTADD
F         F         F         F         F         T         F         F
PRESREG   PRESS     PRINTI    PRNTADD   PRNTIN    RADIATION REACTING  ROTATION
0         F         F         T         T         F         F         F
SAVER     SECONDL   SHEAR     SIMULA    SIUNITS   STEADY    THRUST    TPA
F         F         T         F         F         T         F         F
TRANS_MOM TRANSQ    TRANSV    TVM       TWOD      USRVAR    VARGEO    VARROT
F         F         F         T         F         F         F         F
RLFVLV
F

NNODES    =   50
NINT      =   49
NBR       =   85
NF        =    0
NVAR      =  134
NHREF     =    2

RHOREF    =     1.0000 LBM/FT**3
EMUREF    =   0.1000E+01 LBM/FT-SEC
```

BOUNDARY NODES

NODE	P (PSI)	AREA (IN^2)
2	0.1470E+02	0.0000E+00

INPUT SPECIFICATIONS FOR INTERNAL NODES

NODE	AREA (IN^2)	MASS (LBM/S)	HEAT (BTU/S)
3	0.0000E+00	0.0000E+00	0.0000E+00
4	0.0000E+00	0.0000E+00	0.0000E+00
5	0.0000E+00	0.0000E+00	0.0000E+00
6	0.0000E+00	0.0000E+00	0.0000E+00
7	0.0000E+00	0.0000E+00	0.0000E+00
8	0.0000E+00	0.0000E+00	0.0000E+00
9	0.0000E+00	0.0000E+00	0.0000E+00
10	0.0000E+00	0.0000E+00	0.0000E+00
11	0.0000E+00	0.0000E+00	0.0000E+00
12	0.0000E+00	0.0000E+00	0.0000E+00
13	0.0000E+00	0.0000E+00	0.0000E+00
14	0.0000E+00	0.0000E+00	0.0000E+00
15	0.0000E+00	0.0000E+00	0.0000E+00
16	0.0000E+00	0.0000E+00	0.0000E+00
17	0.0000E+00	0.0000E+00	0.0000E+00
18	0.0000E+00	0.0000E+00	0.0000E+00
19	0.0000E+00	0.0000E+00	0.0000E+00
20	0.0000E+00	0.0000E+00	0.0000E+00
21	0.0000E+00	0.0000E+00	0.0000E+00
22	0.0000E+00	0.0000E+00	0.0000E+00
23	0.0000E+00	0.0000E+00	0.0000E+00
24	0.0000E+00	0.0000E+00	0.0000E+00
25	0.0000E+00	0.0000E+00	0.0000E+00
26	0.0000E+00	0.0000E+00	0.0000E+00
27	0.0000E+00	0.0000E+00	0.0000E+00
28	0.0000E+00	0.0000E+00	0.0000E+00
29	0.0000E+00	0.0000E+00	0.0000E+00
30	0.0000E+00	0.0000E+00	0.0000E+00
31	0.0000E+00	0.0000E+00	0.0000E+00
32	0.0000E+00	0.0000E+00	0.0000E+00
33	0.0000E+00	0.0000E+00	0.0000E+00
34	0.0000E+00	0.0000E+00	0.0000E+00
35	0.0000E+00	0.0000E+00	0.0000E+00
36	0.0000E+00	0.0000E+00	0.0000E+00
37	0.0000E+00	0.0000E+00	0.0000E+00
38	0.0000E+00	0.0000E+00	0.0000E+00
39	0.0000E+00	0.0000E+00	0.0000E+00
40	0.0000E+00	0.0000E+00	0.0000E+00

41	0.0000E+00	0.0000E+00	0.0000E+00
42	0.0000E+00	0.0000E+00	0.0000E+00
43	0.0000E+00	0.0000E+00	0.0000E+00
44	0.0000E+00	0.0000E+00	0.0000E+00
45	0.0000E+00	0.0000E+00	0.0000E+00
46	0.0000E+00	0.0000E+00	0.0000E+00
47	0.0000E+00	0.0000E+00	0.0000E+00
48	0.0000E+00	0.0000E+00	0.0000E+00
49	0.0000E+00	0.0000E+00	0.0000E+00
50	0.0000E+00	0.0000E+00	0.0000E+00
51	0.0000E+00	0.0000E+00	0.0000E+00

BRANCH	UPNODE	DNNODE	OPTION
12	51	2	2
34	3	4	25
45	4	5	25
56	5	6	25
67	6	7	25
78	7	8	25
89	8	9	25
1011	10	11	25
1112	11	12	25
1213	12	13	25
1314	13	14	25
1415	14	15	25
1516	15	16	25
1718	17	18	25
1819	18	19	25
1920	19	20	25
2021	20	21	25
2122	21	22	25
2223	22	23	25
2425	24	25	25
2526	25	26	25
2627	26	27	25
2728	27	28	25
2829	28	29	25
2930	29	30	25
3132	31	32	25
3233	32	33	25
3334	33	34	25
3435	34	35	25
3536	35	36	25
3637	36	37	25
3839	38	39	25
3940	39	40	25
4041	40	41	25

4142	41	42	25
4243	42	43	25
4344	43	44	25
4546	45	46	25
4647	46	47	25
4748	47	48	25
4849	48	49	25
4950	49	50	25
5051	50	51	25
310	3	10	25
411	4	11	25
512	5	12	25
613	6	13	25
714	7	14	25
815	8	15	25
916	9	16	25
1017	10	17	25
1118	11	18	25
1219	12	19	25
1320	13	20	25
1421	14	21	25
1522	15	22	25
1623	16	23	25
1724	17	24	25
1825	18	25	25
1926	19	26	25
2027	20	27	25
2128	21	28	25
2229	22	29	25
2330	23	30	25
2431	24	31	25
2532	25	32	25
2633	26	33	25
2734	27	34	25
2835	28	35	25
2936	29	36	25
3037	30	37	25
3138	31	38	25
3239	32	39	25
3340	33	40	25
3441	34	41	25
3542	35	42	25
3643	36	43	25
3744	37	44	25
3845	38	45	25
3946	39	46	25
4047	40	47	25

```
   4148        41        48        25
   4249        42        49        25
   4350        43        50        25
   4451        44        51        25
BRANCH OPTION -2:  FLOW COEF  AREA
     12             0.100E+01   0.100E-05


SOLUTION
INTERNAL NODES
 NODE     P(PSI)      EM(LBM)
    3    0.1456E+02  0.0000E+00
    4    0.1462E+02  0.0000E+00
    5    0.1467E+02  0.0000E+00
    6    0.1467E+02  0.0000E+00
    7    0.1464E+02  0.0000E+00
    8    0.1460E+02  0.0000E+00
    9    0.1457E+02  0.0000E+00
   10    0.1458E+02  0.0000E+00
   11    0.1460E+02  0.0000E+00
   12    0.1463E+02  0.0000E+00
   13    0.1465E+02  0.0000E+00
   14    0.1464E+02  0.0000E+00
   15    0.1462E+02  0.0000E+00
   16    0.1460E+02  0.0000E+00
   17    0.1460E+02  0.0000E+00
   18    0.1459E+02  0.0000E+00
   19    0.1459E+02  0.0000E+00
   20    0.1461E+02  0.0000E+00
   21    0.1463E+02  0.0000E+00
   22    0.1465E+02  0.0000E+00
   23    0.1466E+02  0.0000E+00
   24    0.1462E+02  0.0000E+00
   25    0.1458E+02  0.0000E+00
   26    0.1455E+02  0.0000E+00
   27    0.1455E+02  0.0000E+00
   28    0.1460E+02  0.0000E+00
   29    0.1468E+02  0.0000E+00
   30    0.1474E+02  0.0000E+00
   31    0.1461E+02  0.0000E+00
   32    0.1458E+02  0.0000E+00
   33    0.1454E+02  0.0000E+00
   34    0.1453E+02  0.0000E+00
   35    0.1459E+02  0.0000E+00
   36    0.1469E+02  0.0000E+00
   37    0.1478E+02  0.0000E+00
   38    0.1455E+02  0.0000E+00
```

39	0.1455E+02	0.0000E+00
40	0.1455E+02	0.0000E+00
41	0.1458E+02	0.0000E+00
42	0.1464E+02	0.0000E+00
43	0.1468E+02	0.0000E+00
44	0.1476E+02	0.0000E+00
45	0.1436E+02	0.0000E+00
46	0.1455E+02	0.0000E+00
47	0.1466E+02	0.0000E+00
48	0.1471E+02	0.0000E+00
49	0.1468E+02	0.0000E+00
50	0.1466E+02	0.0000E+00
51	0.1470E+02	0.0000E+00

BRANCHES

BRANCH	KFACTOR (LBF-S^2/(LBM-FT)^2)	DELP (PSI)	FLOW RATE (LBM/SEC)	VELOCITY (FT/SEC)	REYN. NO.	MACH NO.	ENTROPY GEN. BTU/(R-SEC)	LOST WORK LBF-FT/SEC
12	0.322E+15	-0.316E-13	-0.115E-10	-0.165E-02	0.155E-06	0.000E+00	0.136E-23	0.486E-18
34	0.322E+15	-0.634E-01	-0.220E+00	-0.185E+02	0.228E+01	0.000E+00	0.962E+07	0.344E+13
45	0.322E+15	-0.456E-01	-0.338E+00	-0.284E+02	0.349E+01	0.000E+00	0.347E+08	0.124E+14
56	0.322E+15	-0.344E-02	-0.369E+00	-0.310E+02	0.381E+01	0.000E+00	0.451E+08	0.161E+14
67	0.322E+15	0.286E-01	-0.331E+00	-0.278E+02	0.342E+01	0.000E+00	0.327E+08	0.117E+14
78	0.322E+15	0.410E-01	-0.244E+00	-0.205E+02	0.252E+01	0.000E+00	0.131E+08	0.467E+13
89	0.322E+15	0.289E-01	-0.128E+00	-0.107E+02	0.132E+01	0.000E+00	0.189E+07	0.675E+12
1011	0.322E+15	-0.237E-01	-0.167E+00	-0.140E+02	0.172E+01	0.000E+00	0.418E+07	0.149E+13
1112	0.322E+15	-0.317E-01	-0.279E+00	-0.234E+02	0.289E+01	0.000E+00	0.196E+08	0.700E+13
1213	0.322E+15	-0.146E-01	-0.328E+00	-0.276E+02	0.340E+01	0.000E+00	0.319E+08	0.114E+14
1314	0.322E+15	0.599E-02	-0.318E+00	-0.267E+02	0.329E+01	0.000E+00	0.290E+08	0.104E+14
1415	0.322E+15	0.231E-01	-0.256E+00	-0.215E+02	0.264E+01	0.000E+00	0.151E+08	0.538E+13
1516	0.322E+15	0.205E-01	-0.144E+00	-0.121E+02	0.149E+01	0.000E+00	0.271E+07	0.971E+12
1718	0.322E+15	0.195E-01	-0.976E-01	-0.820E+01	0.101E+01	0.000E+00	0.838E+06	0.300E+12
1819	0.322E+15	-0.190E-02	-0.189E+00	-0.158E+02	0.195E+01	0.000E+00	0.604E+07	0.216E+13
1920	0.322E+15	-0.185E-01	-0.250E+00	-0.210E+02	0.258E+01	0.000E+00	0.140E+08	0.502E+13
2021	0.322E+15	-0.224E-01	-0.270E+00	-0.227E+02	0.279E+01	0.000E+00	0.178E+08	0.636E+13
2122	0.322E+15	-0.223E-01	-0.233E+00	-0.196E+02	0.241E+01	0.000E+00	0.114E+08	0.409E+13
2223	0.322E+15	-0.119E-01	-0.134E+00	-0.112E+02	0.138E+01	0.000E+00	0.215E+07	0.768E+12
2425	0.322E+15	0.368E-01	-0.367E-01	-0.308E+01	0.380E+00	0.000E+00	0.446E+05	0.160E+11
2526	0.322E+15	0.289E-01	-0.870E-01	-0.731E+01	0.900E+00	0.000E+00	0.594E+06	0.212E+12
2627	0.322E+15	-0.241E-02	-0.132E+00	-0.111E+02	0.137E+01	0.000E+00	0.209E+07	0.748E+12
2728	0.322E+15	-0.457E-01	-0.160E+00	-0.135E+02	0.166E+01	0.000E+00	0.371E+07	0.133E+13
2829	0.322E+15	-0.855E-01	-0.138E+00	-0.116E+02	0.143E+01	0.000E+00	0.237E+07	0.846E+12
2930	0.322E+15	-0.535E-01	-0.796E-01	-0.668E+01	0.823E+00	0.000E+00	0.454E+06	0.162E+12
3132	0.322E+15	0.279E-01	0.921E-02	0.773E+00	0.952E-01	0.000E+00	0.703E+03	0.252E+09
3233	0.322E+15	0.364E-01	0.183E-01	0.153E+01	0.189E+00	0.000E+00	0.550E+04	0.197E+10
3334	0.322E+15	0.892E-02	0.258E-01	0.217E+01	0.267E+00	0.000E+00	0.155E+05	0.556E+10
3435	0.322E+15	-0.620E-01	0.465E-01	0.390E+01	0.481E+00	0.000E+00	0.904E+05	0.323E+11
3536	0.322E+15	-0.101E+00	0.451E-01	0.378E+01	0.466E+00	0.000E+00	0.824E+05	0.295E+11

3637	0.322E+15	-0.826E-01	0.738E-02	0.620E+00	0.763E-01	0.000E+00	0.361E+03	0.129E+09
3839	0.322E+15	0.126E-03	0.801E-01	0.673E+01	0.829E+00	0.000E+00	0.464E+06	0.166E+12
3940	0.322E+15	-0.178E-02	0.187E+00	0.157E+02	0.194E+01	0.000E+00	0.593E+07	0.212E+13
4041	0.322E+15	-0.289E-01	0.287E+00	0.241E+02	0.297E+01	0.000E+00	0.213E+08	0.763E+13
4142	0.322E+15	-0.625E-01	0.338E+00	0.284E+02	0.350E+01	0.000E+00	0.349E+08	0.125E+14
4243	0.322E+15	-0.380E-01	0.273E+00	0.229E+02	0.282E+01	0.000E+00	0.183E+08	0.655E+13
4344	0.322E+15	-0.746E-01	0.132E+00	0.111E+02	0.136E+01	0.000E+00	0.206E+07	0.735E+12
4546	0.322E+15	-0.190E+00	0.432E+00	0.363E+02	0.447E+01	0.000E+00	0.726E+08	0.260E+14
4647	0.322E+15	-0.112E+00	0.687E+00	0.577E+02	0.710E+01	0.000E+00	0.292E+09	0.104E+15
4748	0.322E+15	-0.488E-01	0.766E+00	0.643E+02	0.792E+01	0.000E+00	0.405E+09	0.145E+15
4849	0.322E+15	0.323E-01	0.695E+00	0.584E+02	0.719E+01	0.000E+00	0.303E+09	0.108E+15
4950	0.322E+15	0.204E-01	0.553E+00	0.464E+02	0.572E+01	0.000E+00	0.152E+09	0.545E+14
5051	0.322E+15	-0.411E-01	0.346E+00	0.291E+02	0.358E+01	0.000E+00	0.375E+08	0.134E+14
310	0.322E+15	-0.216E-01	0.220E+00	0.185E+02	0.228E+01	0.000E+00	0.962E+07	0.344E+13
411	0.322E+15	0.181E-01	0.118E+00	0.987E+01	0.122E+01	0.000E+00	0.146E+07	0.523E+12
512	0.322E+15	0.320E-01	0.308E-01	0.259E+01	0.319E+00	0.000E+00	0.263E+05	0.942E+10
613	0.322E+15	0.209E-01	-0.375E-01	-0.315E+01	0.388E+00	0.000E+00	0.475E+05	0.170E+11
714	0.322E+15	-0.171E-02	-0.872E-01	-0.733E+01	0.902E+00	0.000E+00	0.598E+06	0.214E+12
815	0.322E+15	-0.197E-01	-0.116E+00	-0.974E+01	0.120E+01	0.000E+00	0.140E+07	0.502E+12
916	0.322E+15	-0.281E-01	-0.128E+00	-0.107E+02	0.132E+01	0.000E+00	0.189E+07	0.675E+12
1017	0.322E+15	-0.263E-01	0.387E+00	0.325E+02	0.400E+01	0.000E+00	0.522E+08	0.187E+14
1118	0.322E+15	0.169E-01	0.230E+00	0.193E+02	0.238E+01	0.000E+00	0.109E+08	0.391E+13
1219	0.322E+15	0.467E-01	0.800E-01	0.672E+01	0.828E+00	0.000E+00	0.462E+06	0.165E+12
1320	0.322E+15	0.428E-01	-0.477E-01	-0.401E+01	0.493E+00	0.000E+00	0.979E+05	0.350E+11
1421	0.322E+15	0.144E-01	-0.150E+00	-0.126E+02	0.155E+01	0.000E+00	0.302E+07	0.108E+13
1522	0.322E+15	-0.310E-01	-0.227E+00	-0.191E+02	0.235E+01	0.000E+00	0.106E+08	0.378E+13
1623	0.322E+15	-0.634E-01	-0.272E+00	-0.229E+02	0.282E+01	0.000E+00	0.182E+08	0.651E+13
1724	0.322E+15	-0.120E-01	0.485E+00	0.407E+02	0.501E+01	0.000E+00	0.103E+09	0.367E+14
1825	0.322E+15	0.524E-02	0.321E+00	0.270E+02	0.332E+01	0.000E+00	0.298E+08	0.106E+14
1926	0.322E+15	0.361E-01	0.141E+00	0.119E+02	0.146E+01	0.000E+00	0.253E+07	0.905E+12
2027	0.322E+15	0.521E-01	-0.272E-01	-0.228E+01	0.281E+00	0.000E+00	0.180E+05	0.645E+10
2128	0.322E+15	0.288E-01	-0.187E+00	-0.157E+02	0.193E+01	0.000E+00	0.585E+07	0.209E+13
2229	0.322E+15	-0.343E-01	-0.327E+00	-0.275E+02	0.338E+01	0.000E+00	0.315E+08	0.113E+14
2330	0.322E+15	-0.759E-01	-0.406E+00	-0.341E+02	0.420E+01	0.000E+00	0.603E+08	0.216E+14
2431	0.322E+15	0.113E-01	0.521E+00	0.438E+02	0.539E+01	0.000E+00	0.128E+09	0.457E+14
2532	0.322E+15	0.239E-02	0.371E+00	0.312E+02	0.384E+01	0.000E+00	0.461E+08	0.165E+14
2633	0.322E+15	0.985E-02	0.187E+00	0.157E+02	0.193E+01	0.000E+00	0.585E+07	0.209E+13
2734	0.322E+15	0.212E-01	0.713E-03	0.599E-01	0.737E-02	0.000E+00	0.326E+00	0.117E+06
2835	0.322E+15	0.494E-02	-0.209E+00	-0.175E+02	0.216E+01	0.000E+00	0.821E+07	0.294E+13
2936	0.322E+15	-0.102E-01	-0.385E+00	-0.324E+02	0.398E+01	0.000E+00	0.515E+08	0.184E+14
3037	0.322E+15	-0.394E-01	-0.485E+00	-0.408E+02	0.502E+01	0.000E+00	0.103E+09	0.369E+14
3138	0.322E+15	0.539E-01	0.512E+00	0.430E+02	0.530E+01	0.000E+00	0.121E+09	0.433E+14
3239	0.322E+15	0.261E-01	0.362E+00	0.304E+02	0.374E+01	0.000E+00	0.428E+08	0.153E+14
3340	0.322E+15	-0.121E-01	0.179E+00	0.150E+02	0.185E+01	0.000E+00	0.516E+07	0.185E+13
3441	0.322E+15	-0.499E-01	-0.199E-01	-0.167E+01	0.206E+00	0.000E+00	0.711E+04	0.254E+10
3542	0.322E+15	-0.504E-01	-0.207E+00	-0.174E+02	0.215E+01	0.000E+00	0.805E+07	0.288E+13
3643	0.322E+15	0.122E-01	-0.348E+00	-0.292E+02	0.360E+01	0.000E+00	0.378E+08	0.135E+14

3744	0.322E+15	0.202E-01	-0.478E+00	-0.402E+02	0.494E+01	0.000E+00	0.985E+08	0.352E+14
3845	0.322E+15	0.191E+00	0.432E+00	0.363E+02	0.447E+01	0.000E+00	0.726E+08	0.260E+14
3946	0.322E+15	0.991E-03	0.255E+00	0.214E+02	0.264E+01	0.000E+00	0.149E+08	0.533E+13
4047	0.322E+15	-0.109E+00	0.792E-01	0.665E+01	0.819E+00	0.000E+00	0.447E+06	0.160E+12
4148	0.322E+15	-0.129E+00	-0.709E-01	-0.596E+01	0.733E+00	0.000E+00	0.321E+06	0.115E+12
4249	0.322E+15	-0.345E-01	-0.142E+00	-0.119E+02	0.147E+01	0.000E+00	0.259E+07	0.926E+12
4350	0.322E+15	0.239E-01	-0.206E+00	-0.173E+02	0.213E+01	0.000E+00	0.792E+07	0.283E+13
4451	0.322E+15	0.574E-01	-0.346E+00	-0.291E+02	0.358E+01	0.000E+00	0.375E+08	0.134E+14

****

TIME OF ANALYSIS WAS 4.28125000000000 SECS

****

APPENDIX JJ—INPUT AND OUTPUT DATA FILES FROM EXAMPLE 26

Simulation of Fluid Transient Following Sudden Valve Opening

Contents

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```
GFSSP VERSION
     605
 GFSSP INSTALLATION PATH
 C:\Program Files (x86)\GFSSP605\
 ANALYST
 Alak Bandyopadhyay
 INPUT DATA FILE NAME
 C:\GFSSP605InstallTest\EXAMPLES\EX26\EX26.dat
 OUTPUT FILE NAME
 Ex26.out
 TITLE
 Simulation of Fluid Transient Following Sudden Valve Opening
 USETUP
 F
 DENCON        GRAVITY       ENERGY        MIXTURE       THRUST        STEADY        TRANSV        SAVER
 F             F             T             F             F             F             T             F
 HEX           HCOEF         REACTING      INERTIA       CONDX         ADDPROP       PRINTI        ROTATION
 F             F             F             F             F             F             T             F
 BUOYANCY      HRATE         INVAL         MSORCE        MOVBND        TPA           VARGEO        TVM
 F             T             F             F             F             F             F             F
 SHEAR         PRNTIN        PRNTADD       OPVALVE       TRANSQ        CONJUG        RADIAT        WINPLOT
 F             T             T             T             F             F             F             T
 PRESS         INSUC         VARROT        CYCLIC        CHKVALS       WINFILE       DALTON        NOSTATS
 F             F             F             F             F             F             F             F
 NORMAL        SIMUL         SECONDL       NRSOLVT       IBDF          NOPLT         PRESREG       FLOWREG
 F             T             T             T             2             T             0             0
 TRANS_MOM     USERVARS      PSMG          ISOLVE        PLOTADD       SIUNITS       TECPLOT       MDGEN
 T             T             F             1             F             F             F             F
 NUM_USER_VARS IFR_MIX       PRINTD        SATTABL       MSORIN        PRELVLV       LAMINAR       HSTAG
 2             1             F             F             F             F             T             T
 DFLI
 T
 NNODES       NINT          NBR           NF
  12          11            11            1
 RELAXK       RELAXD        RELAXH        CC            NITER         RELAXNR       RELAXHC       RELAXTS
  1           0.5           0.5           1e-05         2000          1             1             1
 DTAU         TIMEF         TIMEL         NPSTEP        NPWSTEP       WPLSTEP       WPLBUFF
  0.005       0             4             10            1             1             1.1
 NFLUID(I),  I = 1, NF
  11
 NODE     INDEX    DESCRIPTION
  1       2        "Node 1"
  2       1        "Node 2"
  3       1        "Node 3"
  4       1        "Node 4"
  5       1        "Node 5"
  6       1        "Node 6"
  7       1        " "
  8       1        " "
  9       1        "Node 9"
  10      1        " "
  11      1        " "
  12      1        "Node 12"
```

```
NODE    PRES (PSI)    TEMP(DEGF)    MASS SOURC   HEAT SOURC      THRST AREA      NODE-VOLUME     CONCENTRATION
 2      14.7          60                       0                 0               0               0
 3      14.7          60                       0                 0               0               0
 4      14.7          60                       0                 0               0               0
 5      14.7          60                       0                 0               0               0
 6      14.7          60                       0                 0               0               0
 7      14.7          60                       0                 0               0               0
 8      14.7          60                       0                 0               0               0
 9      14.7          60                       0                 0               0               0
 10     14.7          60                       0                 0               0               0
 11     14.7          60                       0                 0               0               0
 12     14.7          60                       0                 0               0               0
Ex26hs1.DAT
INODE       NUMBR        NAMEBR
 2          2            23     12
 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         1            1112
BRANCH      UPNODE       DNNODE       OPTION      DESCRIPTION
 23         2            3            1           "Pipe 23"
 34         3            4            1           "Pipe 34"
 45         4            5            1           "Pipe 45"
 56         5            6            1           "Pipe 56"
 12         1            2            2           "Restrict 12"
 67         6            7            1           "Pipe 67"
 78         7            8            1           "Pipe 78"
 89         8            9            1           "Pipe 89"
 910        9            10           1           "Pipe 910"
 1011       10           11           1           "Pipe 1011"
 1112       11           12           1           "Pipe 1112"
BRANCH  OPTION -1    LENGTH        DIA         EPSD     ANGLE    AREA
 23                  24            1.025       0        0        0.82515824844
BRANCH  OPTION -1    LENGTH        DIA         EPSD     ANGLE    AREA
 34                  24            1.025       0        0        0.82515824844
BRANCH  OPTION -1    LENGTH        DIA         EPSD     ANGLE    AREA
 45                  24            1.025       0        0        0.82515824844
BRANCH  OPTION -1    LENGTH        DIA         EPSD     ANGLE    AREA
 56                  24            1.025       0        0        0.82515824844
BRANCH  OPTION -2    FLOW COEFF    AREA
 12                  0.6           0.82516
BRANCH  OPTION -1    LENGTH        DIA         EPSD     ANGLE    AREA
 67                  24            1.025       0        0        0.82515824844
BRANCH  OPTION -1    LENGTH        DIA         EPSD     ANGLE    AREA
 78                  24            1.025       0        0        0.82515824844
BRANCH  OPTION -1    LENGTH        DIA         EPSD     ANGLE    AREA
 89                  24            1.025       0        0        0.82515824844
BRANCH  OPTION -1    LENGTH        DIA         EPSD     ANGLE    AREA
 910                 24            1.025       0        0        0.82515824844
```

```
BRANCH  OPTION -1    LENGTH        DIA         EPSD     ANGLE    AREA
 1011                24            1.025       0        0        0.82515824844
BRANCH  OPTION -1    LENGTH        DIA         EPSD     ANGLE    AREA
 1112                24            1.025       0        0        0.82515824844
INITIAL FLOWRATES IN BRANCHES FOR UNSTEADY FLOW
 23    0
 34    0
 45    0
 56    0
 12    0
 67    0
 78    0
 89    0
 910   0
 1011  0
 1112  0
NUMBER OF CLOSING/OPENING VALVES IN THE CIRCUIT
 1
BRANCH
 12
FILE NAME
Ex26vlv.dat
```

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EXAMPLE 26 USER SUBROUTINE AND HISTORY FILES

EX26hs1.DAT

```
2
0     102.9   60.00   1.0
100   102.9   60.00   1.0
```

EX26vlv.DAT

```
13
0.00E+00       1.e-5
4.64E-02       1.e-5
1.11E-01       1.e-5
1.51E-01       1.e-3
1.92E-01       1.e-2
2.04E-01       9.58E-02
2.33E-01       4.16E-01
2.76E-01       7.07E-01
3.20E-01       8.16E-01
3.93E-01       8.25E-01
5.02E-01       8.25E-01
1.0            8.2515E-01
10.0           8.2515E-01
```

EX26.for

```
C***********************************************************************
C                                                                      *
C      ***** GFSSP USER SUBROUTINES *****                              *
C                                                                      *
C***********************************************************************
                       :
                       :
                       :
                       :
C***********************************************************************
      SUBROUTINE SORCEM(IPN,TERMU)
C     PURPOSE: ADD MASS SOURCES
C     IPN - GFSSP INDEX NUMBER FOR NODE
C     TERMU - UNSTEADY TERM IN MASS CONSERVATION EQUATION
C***********************************************************************
       INCLUDE 'comblk.for'
C***********************************************************************
C     ADD CODE HERE
        EQUIVALENCE (VOLAIRM, USRVAR1(1))
        EQUIVALENCE (VOLAIR, USRVAR1(2))

        EQUIVALENCE (PGASM, USRVAR1(3))
        EQUIVALENCE (PGAS, USRVAR1(4))
        EQUIVALENCE (DVOLUME, USRVAR1(7))
        DATA alpha_g/0.448/
```

```
      DATA RAIR, GAMAAIR/53.3, 1.4/
      DATA RELAXVOL,RELAXPGAS/1,1/
      DATA RELAXV/0.8/
      DATA p0air, T0air/14.7, 60/
      DATA xWater/20.0/
c Initial property calculations
c Temperature in Rankine
      t0airR = t0air + 459.67  ! converting into R
c Density: (using ideal gas law)
      rhoair0 = 144.0 * p0air /(RAIR * t0airR) ! in lbmass/cuft
c Air col length:
      xair = alpha_g * xWater/(1.0 - alpha_g)
c Initial volume and mass of air entrapped in the pipe:
      DPipe = 1.025/12.0    ! in ft
      volAir0 = 3.1415927 * DPipe*DPipe*xair/4.0
      AirMass0 = volAir0 * rhoAir0  ! initial air mass
      EMGAS = AirMass0
      NUMBER = 12                   ! Last Node
      CALL INDEXI(NUMBER,NODE,NNODES,IPN)
      IF(ISTEP.EQ.1) then
      PGAS = P(IPN)
      PGASM = PM(IPN)
      vwat0 = volume(ipn)
      vtot0 = vwat0 + volair0
      endif
      VOLOLD = VOLUME(IPN)
C     Using real gas law (for Water)
c     Z = compressibility factor
c     EM = mass
c     RNODE = gas constant for the gas
c     TF = fluid temp, is it automatically in Rankin?
c     PGAS = air pressure
c     VOLNEW = volume at current time step, computed using the thermo
c     dynamic relations
c     DVOLUME = change in volume of node 12 from the previous time step
c     VOLNEW = Z(IPN) * EM(IPN) * RNODE(IPN)*TF(IPN)/PGAS
      FACTVOL = AirMass0*RAIR/(Z(IPN)*EM(IPN)*RNODE(IPN))
c
      VOLNEW = vtot0/(1.0+FACTVOL)
      VOLUME(IPN) = (1.-RELAXV)*VOLOLD + RELAXV*VOLNEW
      DVOLUME = VOLUME(IPN) - VOLUMEM(IPN)
c     air volume change (DVOLAIR) is same in mag but opposite sign than
c     water volume.
      DVOLAIR = - DVOLUME
      IF(ISTEP.EQ.1) then
      VOLAIR = volair0
      ELSE
      VOLAIROLD = VOLAIR
c     volairm is being updated in BNDUSER
      VOLAIRNEW = VOLAIRM + DVOLAIR
      VOLAIR = (1-RELAXVOL)*VOLAIROLD + RELAXVOL * VOLAIRNEW
      ENDIF
      IF (VOLAIR .GT. 0.0) THEN
c      Pressure and Temperature Calculation
       PGAS = EMGAS*RAIR*TF(IPN)/(Vtot0-VOLUME(IPN))
```

```
        TGAS = PGAS * (Vtot0-VOLUME(IPN))/(EMGAS * RAIR)
      ELSE
        PRINT *, " ***AIR VOLUME IS 0 or NEGATIVE, and = ", VOLAIR
      ENDIF
      PGASPSI = PGAS/144.0
      TGASF = TGAS - 460
      USRPVAR(2) = TGASF
      USRPVARNAME(2) = 'TGAS'
      USRPVARUNIT(2) = 'F'
      USRPVAR(1) = PGASPSI
      USRPVARNAME(1) = 'PGAS'
      USRPVARUNIT(1) = 'psi'
      RETURN
      END
C***********************************************************************
      SUBROUTINE SORCEF(I,TERM0,TERM1,TERM2,TERM3,TERM4,TERM5,TERM6,
     &                  TERM7,TERM8,TERM9,TERM10,TERM100)
C     PURPOSE: ADD MOMENTUM SOURCES (LBF)
C     I - GFSSP INDEX NUMBER FOR BRANCH
C     TERM0 - UNSTEADY TERM IN MOMENTUM CONSERVATION EQUATION
C     TERM1 - LONGITUDINAL INERTIA
C     TERM2 - PRESSURE GRADIENT
C     TERM3 - GRAVITY FORCE
C     TERM4 - FRICTION FORCE
C     TERM5 - CENTRIFUGAL FORCE
C     TERM6 - EXTERNAL MOMETUM SOURCE DUE TO PUMP
C     TERM7 - MOMENTUM SOURCE DUE TO TRANSVERSE FLOW(MULTI-DIMENSIONAL MODEL)
C     TERM8 - MOMENTUM SOURCE DUE TO SHEAR(MULTI-DIMENSIONAL MODEL)
C     TERM9 - VARIABLE GEOMETRY UNSTEADY TERM
C     TERM10 - NORMAL STRESS
C     TERM100 - USER SUPPLIED MOMENTUM SOURCE
C**********************************************************************
       INCLUDE 'comblk.for'
C**********************************************************************
C     ADD CODE HERE
      IF(IBRANCH(I).EQ.1112)then
        NUMBER = 12
        CALL INDEXI(NUMBER,NODE,NNODES,IPN)
c Momentum Source term for the Last Branch
        TERM100 = -RHO(IPN)*(VOLUME(IPN)-VOLUMEM(IPN))*VEL(I)/(GC*DTAU)
      ELSE                 ! For all other branches
        TERM100 = 0.0
      ENDIF
      RETURN
      END
C**********************************************************************
      SUBROUTINE BNDUSER
C     PURPOSE: MODIFY BOUNDARY CONDITIONS
C**********************************************************************
      INCLUDE 'comblk.for'
C**********************************************************************
C     ADD CODE HERE
      EQUIVALENCE (VOLAIRM, USRVAR1(1) )
      EQUIVALENCE (VOLAIR,  USRVAR1(2) )
```

```
       EQUIVALENCE (PGASM,    USRVAR1(3))
       EQUIVALENCE (PGAS, USRVAR1(4) )
       EQUIVALENCE (DVOLUME, USRVAR1(7))
c      print *, "TAU = " , tau
c      print *, PGAsM, PGAS, VOLAIRM, VOLAIR, DVOLUME

       VOLAIRM = VOLAIR
       PGASM = PGAS
c        print *, 'pasm = ', pgasm, 'pgas = ', pgas

      RETURN
      END
C***********************************************************************
```

NOTE: All other user subroutines are not used in Example 26

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EX26 OUTPUT

```
          **************************************************
                       G F S S P (Version 605)
               Generalized Fluid System Simulation Program
                               May 2014

             Developed by NASA/Marshall Space Flight Center
             Copyright (C) by Marshall Space Flight Center

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


            RUN DATE:06/25/2014 11:10

  TITLE     :Simulation of Fluid Transient Following Sudden Valve Opening
  ANALYST   :Alak Bandyopadhyay
  FILEIN    :C:\GFSSP605InstallTest\EXAMPLES\EX26\EX26.dat
  FILEOUT   :Ex26.out

                                  OPTION VARIABLES

  ADDPROP   BUOYANCY  CONDX     CONJUG    CYCLIC    DALTON    DENCON    ENERGY
  F         F         F         F         F         F         F         T
  FLOWREG   GRAVITY   HCOEF     HEX       HRATE     IFRMIX    INERTIA   INSUC
  0         F         F         F         T         1         F         F
  INVAL     MIXTURE   MOVBND    MSORCE    NORMAL    NRSOLVT   OPVALVE   PLOTADD
  F         F         F         F         F         T         T         F
  PRESREG   PRESS     PRINTI    PRNTADD   PRNTIN    RADIATION REACTING  ROTATION
  0         F         T         T         T         F         F         F
  SAVER     SECONDL   SHEAR     SIMULA    SIUNITS   STEADY    THRUST    TPA
  F         T         F         T         F         F         F         F
  TRANS_MOM TRANSQ    TRANSV    TVM       TWOD      USRVAR    VARGEO    VARROT
  T         F         T         F         F         T         F         F
  RLFVLV    DFLI
  F         T

  NNODES    =   12
  NINT      =   11
  NBR       =   11
  NF        =    1
  NVAR      =   33
  NHREF     =    2


  FLUIDS:  H2O
```

BOUNDARY NODES

NODE	P (PSI)	T (F)	RHO (LBM/FT^3)	AREA (IN^2)
1	1.0290E+02	6.0000E+01	6.2387E+01	0.0000E+00

INPUT SPECIFICATIONS FOR INTERNAL NODES

NODE	AREA (IN^2)	MASS (LBM/S)	HEAT (BTU/S)
2	0.0000E+00	0.0000E+00	0.0000E+00
3	0.0000E+00	0.0000E+00	0.0000E+00
4	0.0000E+00	0.0000E+00	0.0000E+00
5	0.0000E+00	0.0000E+00	0.0000E+00
6	0.0000E+00	0.0000E+00	0.0000E+00
7	0.0000E+00	0.0000E+00	0.0000E+00
8	0.0000E+00	0.0000E+00	0.0000E+00
9	0.0000E+00	0.0000E+00	0.0000E+00
10	0.0000E+00	0.0000E+00	0.0000E+00
11	0.0000E+00	0.0000E+00	0.0000E+00
12	0.0000E+00	0.0000E+00	0.0000E+00

BRANCH	UPNODE	DNNODE	OPTION
23	2	3	1
34	3	4	1
45	4	5	1
56	5	6	1
12	1	2	2
67	6	7	1
78	7	8	1
89	8	9	1
910	9	10	1
1011	10	11	1
1112	11	12	1

```
BRANCH  OPTION -1:   LENGTH      DIA         EPSD        ANGLE        AREA
 23                  0.240E+02   0.102E+01   0.000E+00   0.000E+00    0.825E+00
BRANCH  OPTION -1:   LENGTH      DIA         EPSD        ANGLE        AREA
 34                  0.240E+02   0.102E+01   0.000E+00   0.000E+00    0.825E+00
BRANCH  OPTION -1:   LENGTH      DIA         EPSD        ANGLE        AREA
 45                  0.240E+02   0.102E+01   0.000E+00   0.000E+00    0.825E+00
BRANCH  OPTION -1:   LENGTH      DIA         EPSD        ANGLE        AREA
 56                  0.240E+02   0.102E+01   0.000E+00   0.000E+00    0.825E+00
BRANCH  OPTION -2:   FLOW COEF   AREA
 12                  0.600E+00   0.100E-04
BRANCH  OPTION -1:   LENGTH      DIA         EPSD        ANGLE        AREA
 67                  0.240E+02   0.102E+01   0.000E+00   0.000E+00    0.825E+00
BRANCH  OPTION -1:   LENGTH      DIA         EPSD        ANGLE        AREA
 78                  0.240E+02   0.102E+01   0.000E+00   0.000E+00    0.825E+00
BRANCH  OPTION -1:   LENGTH      DIA         EPSD        ANGLE        AREA
 89                  0.240E+02   0.102E+01   0.000E+00   0.000E+00    0.825E+00
BRANCH  OPTION -1:   LENGTH      DIA         EPSD        ANGLE        AREA
 910                 0.240E+02   0.102E+01   0.000E+00   0.000E+00    0.825E+00
BRANCH  OPTION -1:   LENGTH      DIA         EPSD        ANGLE        AREA
 1011                0.240E+02   0.102E+01   0.000E+00   0.000E+00    0.825E+00
BRANCH  OPTION -1:   LENGTH      DIA         EPSD        ANGLE        AREA
 1112                0.240E+02   0.102E+01   0.000E+00   0.000E+00    0.825E+00
```

INITIAL GUESS FOR INTERNAL NODES

NODE	P(PSI)	TF(F)	Z(COMP)	RHO (LBM/FT^3)	QUALITY
2	1.4700E+01	6.0000E+01	7.6155E-04	6.2369E+01	0.0000E+00
3	1.4700E+01	6.0000E+01	7.6155E-04	6.2369E+01	0.0000E+00
4	1.4700E+01	6.0000E+01	7.6155E-04	6.2369E+01	0.0000E+00
5	1.4700E+01	6.0000E+01	7.6155E-04	6.2369E+01	0.0000E+00
6	1.4700E+01	6.0000E+01	7.6155E-04	6.2369E+01	0.0000E+00
7	1.4700E+01	6.0000E+01	7.6155E-04	6.2369E+01	0.0000E+00
8	1.4700E+01	6.0000E+01	7.6155E-04	6.2369E+01	0.0000E+00
9	1.4700E+01	6.0000E+01	7.6155E-04	6.2369E+01	0.0000E+00
10	1.4700E+01	6.0000E+01	7.6155E-04	6.2369E+01	0.0000E+00
11	1.4700E+01	6.0000E+01	7.6155E-04	6.2369E+01	0.0000E+00
12	1.4700E+01	6.0000E+01	7.6155E-04	6.2369E+01	0.0000E+00

TRIAL SOLUTION

BRANCH	DELP(PSI)	FLOWRATE(LBM/SEC)
23	0.0000	0.0000
34	0.0000	0.0000
45	0.0000	0.0000
56	0.0000	0.0000
12	0.0000	0.0000
67	0.0000	0.0000
78	0.0000	0.0000
89	0.0000	0.0000
910	0.0000	0.0000
1011	0.0000	0.0000
1112	0.0000	0.0000

```
 SOLUTION SATISFIED CONVERGENCE CRITERION OF    0.100E-04 IN    5 ITERATIONS
 TAU =   5.000000000000000E-003  ISTEP =           1  DTAU =   5.000000000000000E-003

 SOLUTION SATISFIED CONVERGENCE CRITERION OF    0.100E-04 IN    5 ITERATIONS
 TAU =   1.000000000000000E-002  ISTEP =           2  DTAU =   5.000000000000000E-003

 SOLUTION SATISFIED CONVERGENCE CRITERION OF    0.100E-04 IN    5 ITERATIONS
 TAU =   1.500000000000000E-002  ISTEP =           3  DTAU =   5.000000000000000E-003

 SOLUTION SATISFIED CONVERGENCE CRITERION OF    0.100E-04 IN    5 ITERATIONS
 TAU =   2.000000000000000E-002  ISTEP =           4  DTAU =   5.000000000000000E-003

 SOLUTION SATISFIED CONVERGENCE CRITERION OF    0.100E-04 IN    5 ITERATIONS
 TAU =   2.500000000000000E-002  ISTEP =           5  DTAU =   5.000000000000000E-003

 SOLUTION SATISFIED CONVERGENCE CRITERION OF    0.100E-04 IN    5 ITERATIONS
 TAU =   3.000000000000000E-002  ISTEP =           6  DTAU =   5.000000000000000E-003
```

```
SOLUTION SATISFIED CONVERGENCE CRITERION OF    0.100E-04 IN    5 ITERATIONS
TAU =   3.500000000000000E-002  ISTEP =           7  DTAU =   5.000000000000000E-003


SOLUTION SATISFIED CONVERGENCE CRITERION OF    0.100E-04 IN    5 ITERATIONS
TAU =   4.000000000000000E-002  ISTEP =           8  DTAU =   5.000000000000000E-003


SOLUTION SATISFIED CONVERGENCE CRITERION OF    0.100E-04 IN    5 ITERATIONS
TAU =   4.500000000000000E-002  ISTEP =           9  DTAU =   5.000000000000000E-003


ISTEP = 10          TAU = 0.50000E-01
```

BOUNDARY NODES

NODE	P(PSI)	TF(F)	Z(COMP)	RHO (LBM/FT^3)	QUALITY
1	1.0290E+02	6.0000E+01	5.3293E-03	6.2387E+01	0.0000E+00

SOLUTION
INTERNAL NODES

NODE	P(PSI)	TF(F)	Z	RHO (LBM/FT^3)	EM(LBM)	QUALITY
2	1.4700E+01	6.0000E+01	7.6155E-04	6.2369E+01	3.5739E-01	0.0000E+00
3	1.4700E+01	6.0000E+01	7.6155E-04	6.2369E+01	7.1478E-01	0.0000E+00
4	1.4700E+01	6.0000E+01	7.6155E-04	6.2369E+01	7.1478E-01	0.0000E+00
5	1.4700E+01	6.0000E+01	7.6155E-04	6.2369E+01	7.1478E-01	0.0000E+00
6	1.4700E+01	6.0000E+01	7.6155E-04	6.2369E+01	7.1478E-01	0.0000E+00
7	1.4700E+01	6.0000E+01	7.6155E-04	6.2369E+01	7.1478E-01	0.0000E+00
8	1.4700E+01	6.0000E+01	7.6155E-04	6.2369E+01	7.1478E-01	0.0000E+00
9	1.4700E+01	6.0000E+01	7.6155E-04	6.2369E+01	7.1478E-01	0.0000E+00
10	1.4700E+01	6.0000E+01	7.6155E-04	6.2369E+01	7.1478E-01	0.0000E+00
11	1.4700E+01	6.0000E+01	7.6155E-04	6.2369E+01	7.1478E-01	0.0000E+00
12	1.4699E+01	6.0000E+01	7.6150E-04	6.2369E+01	3.5739E-01	0.0000E+00

NODE	H BTU/LB	ENTROPY BTU/LB-R	EMU LBM/FT-SEC	COND BTU/FT-S-R	CP BTU/LB-R	GAMA
2	2.8128E+01	5.5555E-02	7.5430E-04	9.5104E-05	1.0017E+00	1.0033E+00
3	2.8128E+01	5.5555E-02	7.5430E-04	9.5104E-05	1.0017E+00	1.0033E+00
4	2.8128E+01	5.5555E-02	7.5430E-04	9.5104E-05	1.0017E+00	1.0033E+00
5	2.8128E+01	5.5555E-02	7.5430E-04	9.5104E-05	1.0017E+00	1.0033E+00
6	2.8128E+01	5.5555E-02	7.5430E-04	9.5104E-05	1.0017E+00	1.0033E+00
7	2.8128E+01	5.5555E-02	7.5430E-04	9.5104E-05	1.0017E+00	1.0033E+00
8	2.8128E+01	5.5555E-02	7.5430E-04	9.5104E-05	1.0017E+00	1.0033E+00
9	2.8128E+01	5.5555E-02	7.5430E-04	9.5104E-05	1.0017E+00	1.0033E+00
10	2.8128E+01	5.5555E-02	7.5430E-04	9.5104E-05	1.0017E+00	1.0033E+00
11	2.8128E+01	5.5555E-02	7.5430E-04	9.5104E-05	1.0017E+00	1.0033E+00
12	2.8128E+01	5.5555E-02	7.5430E-04	9.5104E-05	1.0017E+00	1.0033E+00

BRANCHES

BRANCH	KFACTOR (LBF-S^2/ (LBM-FT)^2)	DELP (PSI)	FLOW RATE (LBM/SEC)	VELOCITY (FT/SEC)	REYN. NO.	MACH NO.	ENTROPY GEN. BTU/(R-SEC)	LOST WORK LBF-FT/SEC
23	3.145E+13	9.145E-08	1.830E-14	5.120E-14	3.616E-10	4.269E-17	7.640E-36	3.089E-30
34	1.045E+16	-4.295E-13	5.506E-17	1.541E-16	1.088E-12	1.285E-19	6.919E-41	2.797E-35
45	3.471E+18	8.400E-13	1.658E-19	4.638E-19	3.276E-15	3.867E-22	6.270E-46	2.535E-40
56	1.153E+21	0.000E+00	4.990E-22	1.396E-21	9.862E-18	1.164E-24	5.682E-51	2.298E-45
12	1.435E+11	8.820E+01	2.398E-09	5.535E-04	1.362E-02	4.614E-07	7.843E-23	3.171E-17
67	3.830E+23	0.000E+00	1.502E-24	4.203E-24	2.969E-20	3.505E-27	5.150E-56	2.082E-50
78	1.273E+26	0.000E+00	4.519E-27	1.264E-26	8.930E-23	1.054E-29	4.659E-61	1.884E-55
89	4.779E+26	0.000E+00	-1.204E-27	-3.369E-27	2.379E-23	2.809E-30	3.308E-62	1.337E-56
910	1.423E+24	0.000E+00	-4.045E-25	-1.132E-24	7.993E-21	9.435E-28	3.733E-57	1.509E-51
1011	4.283E+21	0.000E+00	-1.344E-22	-3.759E-22	2.655E-18	3.134E-25	4.119E-52	1.665E-46

**** TOTAL ENTROPY GENERATION = 0.784E-22 BTU/(R-SEC) ******

**** TOTAL WORK LOST = 0.577E-19 HP ***** :

:

:

:

:

ISTEP = 800 TAU = 0.40000E+01

BOUNDARY NODES

NODE	P(PSI)	TF(F)	Z(COMP)	RHO (LBM/FT^3)	QUALITY
1	1.0290E+02	6.0000E+01	5.3293E-03	6.2387E+01	0.0000E+00

SOLUTION

INTERNAL NODES

NODE	P(PSI)	TF(F)	Z	RHO (LBM/FT^3)	EM(LBM)	QUALITY
2	1.0243E+02	6.0023E+01	5.3049E-03	6.2387E+01	3.5749E-01	0.0000E+00
3	1.0158E+02	6.0039E+01	5.2608E-03	6.2386E+01	7.1498E-01	0.0000E+00
4	1.0050E+02	6.0054E+01	5.2043E-03	6.2386E+01	7.1497E-01	0.0000E+00
5	9.9462E+01	6.0065E+01	5.1507E-03	6.2386E+01	7.1497E-01	0.0000E+00
6	9.8507E+01	6.0070E+01	5.1012E-03	6.2386E+01	7.1497E-01	0.0000E+00
7	9.7643E+01	6.0070E+01	5.0565E-03	6.2385E+01	7.1496E-01	0.0000E+00
8	9.6867E+01	6.0065E+01	5.0163E-03	6.2385E+01	7.1496E-01	0.0000E+00
9	9.6161E+01	6.0058E+01	4.9799E-03	6.2385E+01	7.1496E-01	0.0000E+00
10	9.5509E+01	6.0050E+01	4.9462E-03	6.2385E+01	7.1496E-01	0.0000E+00
11	9.4903E+01	6.0044E+01	4.9149E-03	6.2385E+01	7.1496E-01	0.0000E+00
12	9.2508E+01	6.0075E+01	4.7906E-03	6.2384E+01	5.2382E+00	0.0000E+00

NODE	H BTU/LB	ENTROPY BTU/LB-R	EMU LBM/FT-SEC	COND BTU/FT-S-R	CP BTU/LB-R	GAMA
2	2.8400E+01	5.5577E-02	7.5380E-04	9.5162E-05	1.0012E+00	1.0034E+00
3	2.8414E+01	5.5609E-02	7.5362E-04	9.5164E-05	1.0012E+00	1.0034E+00
4	2.8426E+01	5.5638E-02	7.5346E-04	9.5165E-05	1.0012E+00	1.0034E+00
5	2.8433E+01	5.5658E-02	7.5335E-04	9.5166E-05	1.0012E+00	1.0034E+00
6	2.8436E+01	5.5668E-02	7.5330E-04	9.5166E-05	1.0012E+00	1.0034E+00
7	2.8433E+01	5.5669E-02	7.5330E-04	9.5166E-05	1.0012E+00	1.0034E+00
8	2.8427E+01	5.5660E-02	7.5335E-04	9.5165E-05	1.0012E+00	1.0034E+00

9	2.8417E+01	5.5646E-02	7.5343E-04	9.5163E-05	1.0012E+00	1.0034E+00
10	2.8408E+01	5.5631E-02	7.5352E-04	9.5162E-05	1.0012E+00	1.0034E+00
11	2.8400E+01	5.5620E-02	7.5359E-04	9.5160E-05	1.0012E+00	1.0034E+00
12	2.8424E+01	5.5680E-02	7.5326E-04	9.5164E-05	1.0012E+00	1.0034E+00

BRANCHES

BRANCH	KFACTOR (LBF-S^2/) (LBM-FT)^2	DELP (PSI)	FLOW RATE (LBM/SEC)	VELOCITY (FT/SEC)	REYN. NO.	MACH NO.	ENTROPY GEN. BTU/(R-SEC)	LOST WORK LBF-FT/SEC
23	4.444E+00	8.477E-01	1.163E+00	3.254E+00	2.300E+04	2.712E-03	2.772E-07	1.121E-01
34	4.444E+00	1.089E+00	1.163E+00	3.253E+00	2.300E+04	2.712E-03	2.771E-07	1.121E-01
45	4.444E+00	1.033E+00	1.163E+00	3.253E+00	2.300E+04	2.712E-03	2.769E-07	1.120E-01
56	4.444E+00	9.547E-01	1.162E+00	3.251E+00	2.300E+04	2.710E-03	2.766E-07	1.119E-01
12	2.107E+01	4.675E-01	1.163E+00	3.254E+00	2.299E+04	2.713E-03	1.315E-06	5.316E-01
67	4.445E+00	8.640E-01	1.162E+00	3.249E+00	2.298E+04	2.709E-03	2.761E-07	1.116E-01
78	4.446E+00	7.767E-01	1.161E+00	3.246E+00	2.296E+04	2.706E-03	2.754E-07	1.114E-01
89	4.447E+00	7.056E-01	1.159E+00	3.243E+00	2.294E+04	2.703E-03	2.746E-07	1.111E-01
910	4.448E+00	6.519E-01	1.158E+00	3.239E+00	2.291E+04	2.700E-03	2.737E-07	1.107E-01
1011	4.450E+00	6.059E-01	1.156E+00	3.235E+00	2.288E+04	2.697E-03	2.728E-07	1.103E-01
1112	4.451E+00	2.396E+00	1.155E+00	3.231E+00	2.285E+04	2.694E-03	2.719E-07	1.099E-01

```
***** TOTAL ENTROPY GENERATION = 0.407E-05 BTU/(R-SEC) ******

***** TOTAL WORK LOST = 0.299E-02 HP *****


SOLUTION SATISFIED CONVERGENCE CRITERION OF 0.100E-04 IN 421 ITERATIONS
TAU = 3.99999999999994    ISTEP = 800    DTAU = 5.000000000000000E-003


SOLUTION SATISFIED CONVERGENCE CRITERION OF 0.100E-04 IN 558 ITERATIONS
TAU = 4.00499999999994    ISTEP = 801    DTAU = 5.000000000000000E-003

*******************************************

TIME OF ANALYSIS WAS 130.978439600000 SECS

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APPENDIX KK—INPUT AND OUTPUT DATA FILES FROM EXAMPLE 27 TABLE

Boiling of Water in a Vertical Pipe

Contents

Back to Appendix KK

```
GFSSP VERSION
    605
GFSSP INSTALLATION PATH
C:\Program Files (x86)\GFSSP605\
ANALYST
akm
INPUT DATA FILE NAME
C:\GFSSP605InstallTest\EXAMPLES\EX27\Table\EX27Table.dat
OUTPUT FILE NAME
EX27Table.out
TITLE
Boiling of water in a vertical pipe
USETUP
F
DENCON        GRAVITY       ENERGY        MIXTURE       THRUST        STEADY        TRANSV        SAVER
F             T             T             F             F             T             F             F
HEX           HCOEF         REACTING      INERTIA       CONDX         ADDPROP       PRINTI        ROTATION
F             F             F             T             F             F             F             F
BUOYANCY      HRATE         INVAL         MSORCE        MOVBND        TPA           VARGEO        TVM
F             F             F             F             F             F             F             F
SHEAR         PRNTIN        PRNTADD       OPVALVE       TRANSQ        CONJUG        RADIAT        WINPLOT
F             T             T             F             F             F             F             F
PRESS         INSUC         VARROT        CYCLIC        CHKVALS       WINFILE       DALTON        NOSTATS
F             F             F             F             F             F             F             F
NORMAL        SIMUL         SECONDL       NRSOLVT       IBDF          NOPLT         PRESREG       FLOWREG
F             T             F             T             1             T             0             0
TRANS_MOM     USERVARS      PSMG          ISOLVE        PLOTADD       SIUNITS       TECPLOT       MDGEN
F             F             F             1             F             F             F             F
NUM_USER_VARS IFR_MIX       PRINTD        SATTABL       MSORIN        PRELVLV       LAMINAR       HSTAG
1             1             F             T             F             F             T             T
DFLI
T
NNODES        NINT          NBR           NF
 11           9             10            1
RELAXK        RELAXD        RELAXH        CC            NITER         RELAXNR       RELAXHC       RELAXTS
 1            0.5           1             1e-05         500 1         1             1
NFLUID(I),  I = 1, NF
 37
FLUID 1 PROPERTY FILES
 18  1
aakwater2.dat
rhowater2.dat
emuwater2.dat
gammawater2.dat
hwater2.dat
swater2.dat
cpwater2.dat
satwater2.dat
NODE     NDEX    DESCRIPTION
 1       2       "Node 1"
 2       1       "Node 2"
 3       1       "Node 3"
 4       1       "Node 4"
 5       1       "Node 5"
 6       1       "Node 6"
```

```
 7       1       "Node 7"
 8       1       "Node 8"
 9       1       "Node 9"
 10      1       "Node 10"
 11      2       "Node 11"
NODE   PRES (PSI)   TEMP(DEGF)   MASS SOURC   HEAT SOURC   THRST AREA   CONCENTRATION
 1     30           80                     0             0            0
 2     14.7         80                     0             130          0
 3     14.7         80                     0             130          0
 4     14.7         80                     0             130          0
 5     14.7         80                     0             130          0
 6     14.7         80                     0             130          0
 7     14.7         80                     0             130          0
 8     14.7         80                     0             130          0
 9     14.7         80                     0             130          0
 10    14.7         80                     0             130          0
 11    14.7         60                     0             0            0
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
BRANCH    UPNODE    DNNODE    OPTION    DESCRIPTION
 12       1         2         1         "Pipe 12"
 23       2         3         1         "Pipe 23"
 34       3         4         1         "Pipe 34"
 45       4         5         1         "Pipe 45"
 56       5         6         1         "Pipe 56"
 67       6         7         1         "Pipe 67"
 78       7         8         1         "Pipe 78"
 89       8         9         1         "Pipe 89"
 910      9         10        1         "Pipe 910"
 1011     10        11        1         "Pipe 1011"
BRANCH    OPTION -1     LENGTH     DIA     EPSD     ANGLE     AREA
 12                     7.2        1       0        180       0.7853975
BRANCH    OPTION -1     LENGTH     DIA     EPSD     ANGLE     AREA
 23                     7.2        1       0        180       0.7853975
BRANCH    OPTION -1     LENGTH     DIA     EPSD     ANGLE     AREA
 34                     7.2        1       0        180       0.7853975
BRANCH    OPTION -1     LENGTH     DIA     EPSD     ANGLE     AREA
 45                     7.2        1       0        180       0.7853975
BRANCH    OPTION -1     LENGTH     DIA     EPSD     ANGLE     AREA
 56                     7.2        1       0        180       0.7853975
BRANCH    OPTION -1     LENGTH     DIA     EPSD     ANGLE     AREA
 67                     7.2        1       0        180       0.7853975
BRANCH    OPTION -1     LENGTH     DIA     EPSD     ANGLE     AREA
 78                     7.2        1       0        180       0.7853975
BRANCH    OPTION -1     LENGTH     DIA     EPSD     ANGLE     AREA
 89                     7.2        1       0        180       0.7853975
BRANCH    OPTION -1     LENGTH     DIA     EPSD     ANGLE     AREA
```

```
 910                   7.2        1       0        180       0.7853975
BRANCH    OPTION -1    LENGTH     DIA     EPSD     ANGLE     AREA
 1011                  7.2        1       0        180       0.7853975
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
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     0
BRANCH
 12
  UPSTRM BR.    ANGLE
  DNSTRM BR.    ANGLE
  23            0.00000
BRANCH
 23
  UPSTRM BR.    ANGLE
  12            0.00000
  DNSTRM BR.    ANGLE
  34            0.00000
BRANCH
 34
  UPSTRM BR.    ANGLE
  23            0.00000
  DNSTRM BR.    ANGLE
  45            0.00000
BRANCH
 45
  UPSTRM BR.    ANGLE
  34            0.00000
  DNSTRM BR.    ANGLE
  56            0.00000
BRANCH
 56
  UPSTRM BR.    ANGLE
  45            0.00000
  DNSTRM BR.    ANGLE
  67            0.00000
```

```
BRANCH
 67
  UPSTRM BR.    ANGLE
  56            0.00000
  DNSTRM BR.    ANGLE
  78            0.00000
BRANCH
 78
  UPSTRM BR.    ANGLE
  67            0.00000
  DNSTRM BR.    ANGLE
  89            0.00000
BRANCH
 89
  UPSTRM BR.    ANGLE
  78            0.00000
  DNSTRM BR.    ANGLE
  910           0.00000
BRANCH
 910
  UPSTRM BR.    ANGLE
  89            0.00000
  DNSTRM BR.    ANGLE
  1011          0.00000
BRANCH
 1011
  UPSTRM BR.    ANGLE
  910           0.00000
  DNSTRM BR.    ANGLE
NUMBER OF BRANCHES WITH INERTIA
 10
 12
 23
 34
 45
 56
 67
 78
 89
 910
 1011
```

Back to Appendix KK

```
          **************************************************
                       G F S S P (Version 605)
                Generalized Fluid System Simulation Program
                               May 2014

              Developed by NASA/Marshall Space Flight Center
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             A generalized computer program to calculate flow
             rates, pressures, temperatures and concentrations
             in a flow network.
          **************************************************


              RUN DATE:06/25/2014 12:57

  TITLE      :Boiling of water in a vertical pipe
  ANALYST    :akm
  FILEIN     :C:\GFSSP605InstallTest\EXAMPLES\EX27\Table\EX27Table.dat
  FILEOUT    :EX27Table.out

                               OPTION VARIABLES

  ADDPROP    BUOYANCY  CONDX   CONJUG   CYCLIC   DALTON     DENCON     ENERGY
  F          F         F       F        F        F          F          T
  FLOWREG    GRAVITY   HCOEF   HEX      HRATE    IFRMIX     INERTIA    INSUC
  0          T         F       F        F        1          T          F
  INVAL      MIXTURE   MOVBND  MSORCE   NORMAL   NRSOLVT    OPVALVE    PLOTADD
  F          F         F       F        F        T          F          F
  PRESREG    PRESS     PRINTI  PRNTADD  PRNTIN   RADIATION  REACTING   ROTATION
  0          F         F       T        T        F          F          F
  SAVER      SECONDL   SHEAR   SIMULA   SIUNITS  STEADY     THRUST     TPA
  F          F         F       T        F        T          F          F
  TRANS_MOM  TRANSQ    TRANSV  TVM      TWOD     USRVAR     VARGEO     VARROT
  F          F         F       F        F        F          F          F
  RLFVLV     DFLI
  F          T

  NNODES   =  11
  NINT     =   9
  NBR      =  10
  NF       =   1
  NVAR     =  19
  NHREF    =   2


FLUIDS:  FLD1

BOUNDARY NODES
NODE     P              T              RHO            AREA
         (PSI)          (F)            (LBM/FT^3)     (IN^2)
  1      3.0000E+01     8.0000E+01     6.2219E+01     0.0000E+00
  11     1.4700E+01     6.0000E+01     6.2366E+01     0.0000E+00
```

INPUT SPECIFICATIONS FOR INTERNAL NODES

NODE	AREA (IN^2)	MASS (LBM/S)	HEAT (BTU/LBM)
2	0.0000E+00	0.0000E+00	1.3000E+02
3	0.0000E+00	0.0000E+00	1.3000E+02
4	0.0000E+00	0.0000E+00	1.3000E+02
5	0.0000E+00	0.0000E+00	1.3000E+02
6	0.0000E+00	0.0000E+00	1.3000E+02
7	0.0000E+00	0.0000E+00	1.3000E+02
8	0.0000E+00	0.0000E+00	1.3000E+02
9	0.0000E+00	0.0000E+00	1.3000E+02
10	0.0000E+00	0.0000E+00	1.3000E+02

BRANCH	UPNODE	DNNODE	OPTION
12	1	2	1
23	2	3	1
34	3	4	1
45	4	5	1
56	5	6	1
67	6	7	1
78	7	8	1
89	8	9	1
910	9	10	1
1011	10	11	1

BRANCH	OPTION -1:	LENGTH	DIA	EPSD	ANGLE	AREA
12		0.720E+01	0.100E+01	0.000E+00	0.180E+03	0.785E+00
BRANCH	OPTION -1:	LENGTH	DIA	EPSD	ANGLE	AREA
23		0.720E+01	0.100E+01	0.000E+00	0.180E+03	0.785E+00
BRANCH	OPTION -1:	LENGTH	DIA	EPSD	ANGLE	AREA
34		0.720E+01	0.100E+01	0.000E+00	0.180E+03	0.785E+00
BRANCH	OPTION -1:	LENGTH	DIA	EPSD	ANGLE	AREA
45		0.720E+01	0.100E+01	0.000E+00	0.180E+03	0.785E+00
BRANCH	OPTION -1:	LENGTH	DIA	EPSD	ANGLE	AREA
56		0.720E+01	0.100E+01	0.000E+00	0.180E+03	0.785E+00
BRANCH	OPTION -1:	LENGTH	DIA	EPSD	ANGLE	AREA
67		0.720E+01	0.100E+01	0.000E+00	0.180E+03	0.785E+00
BRANCH	OPTION -1:	LENGTH	DIA	EPSD	ANGLE	AREA
78		0.720E+01	0.100E+01	0.000E+00	0.180E+03	0.785E+00
BRANCH	OPTION -1:	LENGTH	DIA	EPSD	ANGLE	AREA
89		0.720E+01	0.100E+01	0.000E+00	0.180E+03	0.785E+00
BRANCH	OPTION -1:	LENGTH	DIA	EPSD	ANGLE	AREA
910		0.720E+01	0.100E+01	0.000E+00	0.180E+03	0.785E+00
BRANCH	OPTION -1:	LENGTH	DIA	EPSD	ANGLE	AREA
1011		0.720E+01	0.100E+01	0.000E+00	0.180E+03	0.785E+00

SOLUTION

INTERNAL NODES

NODE	P(PSI)	TF(F)	Z	RHO (LBM/FT^3)	EM(LBM)	QUALITY
2	2.9747E+01	2.0959E+02	1.2610E-03	5.9133E+01	0.0000E+00	0.0000E+00
3	2.9622E+01	2.4947E+02	9.3740E-02	7.4759E-01	0.0000E+00	9.5035E-02
4	1.9911E+01	2.2690E+02	2.4881E-01	1.9554E-01	0.0000E+00	2.5260E-01
5	1.8536E+01	2.2302E+02	3.8505E-01	1.1830E-01	0.0000E+00	3.9092E-01
6	1.7971E+01	2.2142E+02	5.1890E-01	8.5304E-02	0.0000E+00	5.2693E-01
7	1.7481E+01	2.2004E+02	6.5236E-01	6.6138E-02	0.0000E+00	6.6252E-01
8	1.6989E+01	2.1865E+02	7.8554E-01	5.3489E-02	0.0000E+00	7.9786E-01
9	1.6477E+01	2.1721E+02	9.1843E-01	4.4466E-02	0.0000E+00	9.3298E-01
10	1.5935E+01	3.5255E+02	9.9005E-01	3.3245E-02	0.0000E+00	1.0000E+00

NODE	H BTU/LB	ENTROPY BTU/LB-R	EMU LBM/FT-SEC	COND BTU/FT-S-R	CP BTU/LB-R	GAMA
2	1.7818E+02	3.2765E-01	1.8976E-04	1.0767E-04	1.0005E+00	1.1190E+00
3	3.0818E+02	4.9410E-01	5.9751E-05	9.9725E-05	9.6772E-01	1.1769E+00
4	4.3818E+02	6.8822E-01	2.9216E-05	8.2818E-05	8.8279E-01	1.1865E+00
5	5.6818E+02	8.8074E-01	1.9987E-05	6.8200E-05	8.1176E-01	1.2121E+00
6	6.9818E+02	1.0730E+00	1.5239E-05	5.3871E-05	7.4234E-01	1.2395E+00
7	8.2818E+02	1.2658E+00	1.2311E-05	3.9594E-05	6.7304E-01	1.2673E+00
8	9.5818E+02	1.4594E+00	1.0321E-05	2.5347E-05	6.0370E-01	1.2954E+00
9	1.0882E+03	1.6539E+00	8.8794E-06	1.1128E-05	5.3428E-01	1.3237E+00
10	1.2182E+03	1.8552E+00	1.0276E-05	5.0319E-06	4.7343E-01	1.3224E+00

BRANCHES

BRANCH	KFACTOR (LBF-S^2/ (LBM-FT)^2)	DELP (PSI)	FLOW RATE (LBM/SEC)	VELOCITY (FT/SEC)	REYN. NO.	MACH NO.	ENTROPY GEN. BTU/(R-SEC)	LOST WORK LBF-FT/SEC
12	2.631E+00	2.530E-01	1.131E-01	3.333E-01	2.999E+03	2.714E-04	1.458E-10	6.120E-05
23	2.014E+00	1.250E-01	1.131E-01	3.507E-01	9.108E+03	2.439E-04	9.466E-11	4.929E-05
34	1.192E+02	9.711E+00	1.131E-01	2.774E+01	2.892E+04	1.827E-02	4.181E-07	2.307E-01
45	3.872E+02	1.375E+00	1.131E-01	1.061E+02	5.915E+04	7.071E-02	5.364E-06	2.866E+00
56	5.897E+02	5.653E-01	1.131E-01	1.753E+02	8.647E+04	1.160E-01	1.358E-05	7.215E+00
67	7.728E+02	4.900E-01	1.131E-01	2.431E+02	1.134E+05	1.592E-01	2.474E-05	1.311E+01
78	9.542E+02	4.918E-01	1.131E-01	3.136E+02	1.404E+05	2.033E-01	3.948E-05	2.088E+01
89	1.139E+03	5.119E-01	1.131E-01	3.877E+02	1.675E+05	2.489E-01	5.838E-05	3.082E+01
910	1.330E+03	5.420E-01	1.131E-01	4.664E+02	1.946E+05	2.965E-01	8.218E-05	4.328E+01
1011	1.831E+03	1.235E+00	1.131E-01	6.245E+02	1.682E+05	3.626E-01	1.261E-04	7.970E+01

****

TIME OF ANALYSIS WAS 3.120020000000000E-002 SECS

****

APPENDIX LL—INPUT AND OUTPUT DATA FILES FROM EXAMPLE 27 WASP

Boiling of Water in a Vertical Pipe

Contents

Back to Appendix LL

```
GFSSP VERSION
    605
GFSSP INSTALLATION PATH
C:\Program Files (x86)\GFSSP605\
ANALYST
akm
INPUT DATA FILE NAME
C:\GFSSP605InstallTest\EXAMPLESOct-14\EX27\WASP\EX27WASP.dat
OUTPUT FILE NAME
EX27WASP.out
TITLE
Boiling of water in a vertical pipe
USETUP
F
DENCON        GRAVITY       ENERGY        MIXTURE       THRUST        STEADY        TRANSV        SAVER
F             T             T             F             F             T             F             F
HEX           HCOEF         REACTING      INERTIA       CONDX         ADDPROP       PRINTI        ROTATION
F             F             F             T             F             F             F             F
BUOYANCY      HRATE         INVAL         MSORCE        MOVBND        TPA           VARGEO        TVM
F             F             F             F             F             F             F             F
SHEAR         PRNTIN        PRNTADD       OPVALVE       TRANSQ        CONJUG        RADIAT        WINPLOT
F             T             T             F             F             F             F             F
PRESS         INSUC         VARROT        CYCLIC        CHKVALS       WINFILE       DALTON        NOSTATS
F             F             F             F             F             F             F             F
NORMAL        SIMUL         SECONDL       NRSOLVT       IBDF          NOPLT         PRESREG       FLOWREG
F             T             F             T             1             T             0             0
TRANS_MOM     USERVARS      PSMG          ISOLVE        PLOTADD       SIUNITS       TECPLOT       MDGEN
F             F             F             1             F             F             F             F
NUM_USER_VARS IFR_MIX       PRINTD        SATTABL       MSORIN        PRELVLV       LAMINAR       HSTAG
1             1             F             F             F             F             T             T
DFLI
T
NNODES        NINT          NBR           NF
 11           9             10            1
RELAXK        RELAXD        RELAXH        CC            NITER         RELAXNR       RELAXHC       RELAXTS
 1            0.5           1             1e-05         500 1         1             1
NFLUID(I),  I = 1, NF
 11
```

```
NODE   INDEX   DESCRIPTION
 1     2       "Node 1"
 2     1       "Node 2"
 3     1       "Node 3"
 4     1       "Node 4"
 5     1       "Node 5"
 6     1       "Node 6"
 7     1       "Node 7"
 8     1       "Node 8"
 9     1       "Node 9"
 10    1       "Node 10"
 11    2       "Node 11"
NODE    PRES (PSI)   TEMP(DEGF)   MASS SOURC   HEAT SOURC   THRST AREA   CONCENTRATION
 1      30           80                       0             0            0
 2      14.7         80                       0             130          0
 3      14.7         80                       0             130          0
 4      14.7         80                       0             130          0
 5      14.7         80                       0             130          0
 6      14.7         80                       0             130          0
 7      14.7         80                       0             130          0
 8      14.7         80                       0             130          0
 9      14.7         80                       0             130          0
 10     14.7         80                       0             130          0
 11     14.7         60                       0             0            0
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
BRANCH        UPNODE    DNNODE    OPTION   DESCRIPTION
 12           1         2         1        "Pipe 12"
 23           2         3         1        "Pipe 23"
 34           3         4         1        "Pipe 34"
 45           4         5         1        "Pipe 45"
 56           5         6         1        "Pipe 56"
 67           6         7         1        "Pipe 67"
 78           7         8         1        "Pipe 78"
```

```
 89         8         9         1        "Pipe 89"
 910        9         10        1        "Pipe 910"
 1011       10        11        1        "Pipe 1011"
BRANCH   OPTION -1   LENGTH   DIA   EPSD   ANGLE   AREA
 12                  7.2      1     0      180     0.7853975
BRANCH   OPTION -1   LENGTH   DIA   EPSD   ANGLE   AREA
 23                  7.2      1     0      180     0.7853975
BRANCH   OPTION -1   LENGTH   DIA   EPSD   ANGLE   AREA
 34                  7.2      1     0      180     0.7853975
BRANCH   OPTION -1   LENGTH   DIA   EPSD   ANGLE   AREA
 45                  7.2      1     0      180     0.7853975
BRANCH   OPTION -1   LENGTH   DIA   EPSD   ANGLE   AREA
 56                  7.2      1     0      180     0.7853975
BRANCH   OPTION -1   LENGTH   DIA   EPSD   ANGLE   AREA
 67                  7.2      1     0      180     0.7853975
BRANCH   OPTION -1   LENGTH   DIA   EPSD   ANGLE   AREA
 78                  7.2      1     0      180     0.7853975
BRANCH   OPTION -1   LENGTH   DIA   EPSD   ANGLE   AREA
 89                  7.2      1     0      180     0.7853975
BRANCH   OPTION -1   LENGTH   DIA   EPSD   ANGLE   AREA
 910                 7.2      1     0      180     0.7853975
BRANCH   OPTION -1   LENGTH   DIA   EPSD   ANGLE   AREA
 1011                7.2      1     0      180     0.7853975
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
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    0
BRANCH
 12
  UPSTRM BR.   ANGLE
  DNSTRM BR.   ANGLE
   23          0.00000
BRANCH
 23
  UPSTRM BR.   ANGLE
   12          0.00000
  DNSTRM BR.   ANGLE
   34          0.00000
BRANCH
 34
  UPSTRM BR.   ANGLE
   23          0.00000
  DNSTRM BR.   ANGLE
   45          0.00000
BRANCH
 45
  UPSTRM BR.   ANGLE
   34          0.00000
  DNSTRM BR.   ANGLE
   56          0.00000
BRANCH
 56
  UPSTRM BR.   ANGLE
   45          0.00000
  DNSTRM BR.   ANGLE
   67          0.00000
BRANCH
 67
  UPSTRM BR.   ANGLE
   56          0.00000
  DNSTRM BR.   ANGLE
   78          0.00000
BRANCH
 78
  UPSTRM BR.   ANGLE
   67          0.00000
```

```
  DNSTRM BR.   ANGLE
   89          0.00000
BRANCH
 89
  UPSTRM BR.   ANGLE
   78          0.00000
  DNSTRM BR.   ANGLE
   910         0.00000
BRANCH
 910
  UPSTRM BR.   ANGLE
   89          0.00000
  DNSTRM BR.   ANGLE
   1011        0.00000
BRANCH
 1011
  UPSTRM BR.   ANGLE
   910         0.00000
  DNSTRM BR.   ANGLE
NUMBER OF BRANCHES WITH INERTIA
 10
 12
 23
 34
 45
 56
 67
 78
 89
 910
 1011
```

Back to Appendix LL

```
 *************************************************
              G F S S P (Version 605)
      Generalized Fluid System Simulation Program
                    May 2014

    Developed by NASA/Marshall Space Flight Center
    Copyright (C) by Marshall Space Flight Center

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


   RUN DATE:10/14/2014 13:28

TITLE      :Boiling of water in a vertical pipe
ANALYST    :akm
FILEIN     :C:\GFSSP605InstallTest\EXAMPLESOct-14\EX27\WASP\EX27WASP.dat
FILEOUT    :EX27WASP.out

                    OPTION VARIABLES

ADDPROP    BUOYANCY   CONDX      CONJUG     CYCLIC     DALTON     DENCON     ENERGY
F          F          F          F          F          F          F          T
FLOWREG    GRAVITY    HCOEF      HEX        HRATE      IFRMIX     INERTIA    INSUC
0          T          F          F          F          1          T          F
INVAL      MIXTURE    MOVBND     MSORCE     NORMAL     NRSOLVT    OPVALVE    PLOTADD
F          F          F          F          F          T          F          F
PRESREG    PRESS      PRINTI     PRNTADD    PRNTIN     RADIATION  REACTING   ROTATION
0          F          F          T          T          F          F          F
SAVER      SECONDL    SHEAR      SIMULA     SIUNITS    STEADY     THRUST     TPA
F          F          F          T          F          T          F          F
TRANS_MOM  TRANSQ     TRANSV     TVM        TWOD       USRVAR     VARGEO     VARROT
F          F          F          F          F          F          F          F
RLFVLV     DFLI
F          T
```

```
 NNODES   =   11
 NINT     =    9
 NBR      =   10
 NF       =    1
 NVAR     =   19
 NHREF    =    2

 FLUIDS:  H2O
```

BOUNDARY NODES

NODE	P	T	RHO	AREA
	(PSI)	(F)	(LBM/FT^3	(IN^2)
1	3.0000E+01	8.0000E+01	6.2224E+01	0.0000E+00
11	1.4700E+01	6.0000E+01	6.2369E+01	0.0000E+00

INPUT SPECIFICATIONS FOR INTERNAL NODES

NODE	AREA	MASS	HEAT
	(IN^2)	(LBM/S)	(BTU/LBM)
2	0.0000E+00	0.0000E+00	1.3000E+02
3	0.0000E+00	0.0000E+00	1.3000E+02
4	0.0000E+00	0.0000E+00	1.3000E+02
5	0.0000E+00	0.0000E+00	1.3000E+02
6	0.0000E+00	0.0000E+00	1.3000E+02
7	0.0000E+00	0.0000E+00	1.3000E+02
8	0.0000E+00	0.0000E+00	1.3000E+02
9	0.0000E+00	0.0000E+00	1.3000E+02
10	0.0000E+00	0.0000E+00	1.3000E+02

BRANCH	UPNODE	DNNODE	OPTION
12	1	2	1
23	2	3	1
34	3	4	1
45	4	5	1
56	5	6	1
67	6	7	1
78	7	8	1
89	8	9	1
910	9	10	1
1011	10	11	1

```
BRANCH  OPTION -1:   LENGTH      DIA         EPSD        ANGLE        AREA
12                   0.720E+01   0.100E+01   0.000E+00   0.180E+03    0.785E+00
BRANCH  OPTION -1:   LENGTH      DIA         EPSD        ANGLE        AREA
23                   0.720E+01   0.100E+01   0.000E+00   0.180E+03    0.785E+00
BRANCH  OPTION -1:   LENGTH      DIA         EPSD        ANGLE        AREA
34                   0.720E+01   0.100E+01   0.000E+00   0.180E+03    0.785E+00
BRANCH  OPTION -1:   LENGTH      DIA         EPSD        ANGLE        AREA
45                   0.720E+01   0.100E+01   0.000E+00   0.180E+03    0.785E+00
BRANCH  OPTION -1:   LENGTH      DIA         EPSD        ANGLE        AREA
56                   0.720E+01   0.100E+01   0.000E+00   0.180E+03    0.785E+00
BRANCH  OPTION -1:   LENGTH      DIA         EPSD        ANGLE        AREA
67                   0.720E+01   0.100E+01   0.000E+00   0.180E+03    0.785E+00
BRANCH  OPTION -1:   LENGTH      DIA         EPSD        ANGLE        AREA
78                   0.720E+01   0.100E+01   0.000E+00   0.180E+03    0.785E+00
BRANCH  OPTION -1:   LENGTH      DIA         EPSD        ANGLE        AREA
89                   0.720E+01   0.100E+01   0.000E+00   0.180E+03    0.785E+00
BRANCH  OPTION -1:   LENGTH      DIA         EPSD        ANGLE        AREA
910                  0.720E+01   0.100E+01   0.000E+00   0.180E+03    0.785E+00
BRANCH  OPTION -1:   LENGTH      DIA         EPSD        ANGLE        AREA
1011                 0.720E+01   0.100E+01   0.000E+00   0.180E+03    0.785E+00


SOLUTION
INTERNAL NODES
 NODE   P(PSI)       TF(F)       Z           RHO          EM(LBM)      QUALITY
                                             (LBM/FT^3)
 2      2.9745E+01  2.0999E+02  1.2456E-03  5.9878E+01  0.0000E+00  0.0000E+00
 3      2.9619E+01  2.4961E+02  9.3880E-02  7.4689E-01  0.0000E+00  9.5127E-02
 4      1.9873E+01  2.2761E+02  2.4814E-01  1.9566E-01  0.0000E+00  2.5226E-01
 5      1.8517E+01  2.2388E+02  3.8406E-01  1.1843E-01  0.0000E+00  3.9057E-01
 6      1.7959E+01  2.2227E+02  5.1784E-01  8.5388E-02  0.0000E+00  5.2672E-01
 7      1.7474E+01  2.2085E+02  6.5132E-01  6.6197E-02  0.0000E+00  6.6246E-01
 8      1.6988E+01  2.1939E+02  7.8465E-01  5.3534E-02  0.0000E+00  7.9797E-01
 9      1.6482E+01  2.1782E+02  9.1788E-01  4.4503E-02  0.0000E+00  9.3326E-01
 10     1.5946E+01  3.5439E+02  9.9336E-01  3.3110E-02  0.0000E+00  1.0000E+00
```

NODE	H BTU/LB	ENTROPY BTU/LB-R	EMU LBM/FT-SEC	COND BTU/FT-S-R	CP BTU/LB-R	GAMA
2	1.7817E+02	3.0911E-01	1.9195E-04	1.0880E-04	1.0065E+00	1.1148E+00
3	3.0817E+02	4.9402E-01	5.9750E-05	9.9804E-05	9.6628E-01	1.1746E+00
4	4.3817E+02	6.8776E-01	2.9274E-05	8.2823E-05	8.7962E-01	1.1862E+00
5	5.6817E+02	8.7987E-01	2.0030E-05	6.8187E-05	8.0702E-01	1.2130E+00
6	6.9817E+02	1.0718E+00	1.5269E-05	5.3837E-05	7.3600E-01	1.2414E+00
7	8.2817E+02	1.2644E+00	1.2332E-05	3.9541E-05	6.6512E-01	1.2702E+00
8	9.5817E+02	1.4578E+00	1.0336E-05	2.5278E-05	5.9420E-01	1.2992E+00
9	1.0882E+03	1.6523E+00	8.8900E-06	1.1046E-05	5.2320E-01	1.3285E+00
10	1.2182E+03	1.8392E+00	1.0306E-05	5.0489E-06	4.7320E-01	1.3224E+00

BRANCHES

BRANCH	KFACTOR (LBF-S^2/ (LBM-FT)^2)	DELP (PSI)	FLOW RATE LBM/SEC)	VELOCITY (FT/SEC)	REYN. NO.	MACH NO.	ENTROPY GEN. BTU/(R-SEC)	LOST WORK LBF-FT/SEC
12	2.636E+00	2.546E-01	1.125E-01	3.315E-01	2.982E+03	2.700E-04	1.436E-10	6.030E-05
23	1.998E+00	1.265E-01	1.125E-01	3.445E-01	8.955E+03	2.400E-04	9.116E-11	4.750E-05
34	1.194E+02	9.746E+00	1.125E-01	2.762E+01	2.877E+04	1.821E-02	4.125E-07	2.277E-01
45	3.876E+02	1.357E+00	1.125E-01	1.054E+02	5.871E+04	7.028E-02	5.273E-06	2.820E+00
56	5.900E+02	5.579E-01	1.125E-01	1.742E+02	8.581E+04	1.151E-01	1.334E-05	7.093E+00
67	7.732E+02	4.845E-01	1.125E-01	2.416E+02	1.126E+05	1.580E-01	2.430E-05	1.289E+01
78	9.548E+02	4.863E-01	1.125E-01	3.116E+02	1.394E+05	2.018E-01	3.878E-05	2.053E+01
89	1.139E+03	5.061E-01	1.125E-01	3.853E+02	1.663E+05	2.469E-01	5.735E-05	3.030E+01
910	1.330E+03	5.358E-01	1.125E-01	4.635E+02	1.933E+05	2.941E-01	8.074E-05	4.256E+01
1011	1.841E+03	1.246E+00	1.125E-01	6.236E+02	1.668E+05	3.618E-01	1.250E-04	7.917E+01

****

TIME OF ANALYSIS WAS   1.560010000000000E-002 SECS

****

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APPENDIX MM—INPUT AND OUTPUT DATA FILES FROM EXAMPLE 28

K-site Tank Facility

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```
GFSSP VERSION
    605
GFSSP INSTALLATION PATH
C:\Program Files (x86)\GFSSP605\
ANALYST
akm
INPUT DATA FILE NAME
C:\GFSSP605InstallTest\EXAMPLES\EX28\EX28.dat
OUTPUT FILE NAME
EX28.out
TITLE
K-site Tank Facility
USETUP
F
DENCON        GRAVITY       ENERGY        MIXTURE       THRUST        STEADY        TRANSV        SAVER
F             T             T             F             F             F             T             F
HEX           HCOEF         REACTING      INERTIA       CONDX         ADDPROP       PRINTI        ROTATION
F             F             F             F             F             F             F             F
BUOYANCY      HRATE         INVAL         MSORCE        MOVBND        TPA           VARGEO        TVM
F             T             F             F             F             F             F             F
SHEAR         PRNTIN        PRNTADD       OPVALVE       TRANSQ        CONJUG        RADIAT        WINPLOT
F             T             T             T             F             T             F             T
PRESS         INSUC         VARROT        CYCLIC        CHKVALS       WINFILE       DALTON        NOSTATS
F             F             F             F             F             F             F             T
NORMAL        SIMUL         SECONDL       NRSOLVT       IBDF          NOPLT         PRESREG       FLOWREG
F             T             F             T             1             T             0             0
TRANS_MOM     USERVARS      PSMG          ISOLVE        PLOTADD       SIUNITS       TECPLOT       MDGEN
F             F             F             1             F             F             F             F
NUM_USER_VARS IFR_MIX       PRINTD        SATTABL       MSORIN        PRELVLV       LAMINAR       HSTAG
1             1             F             F             F             F             T             T
DFLI
T
NNODES        NINT          NBR           NF
 13           11            20            1
RELAXK        RELAXD        RELAXH        CC            NITER         RELAXNR       RELAXHC       RELAXTS
 1            0.5           1             0.0001        300           0.5           1             1
DTAU          TIMEF         TIMEL         NPSTEP        NPWSTEP       WPLSTEP       WPLBUFF
 0.1          0             8467          100           10            50            1.1
NFLUID(I),  I = 1, NF
 10
NODE          INDEX     DESCRIPTION
 1            1         "Node 1"
 2            1         "Node 2"
 3            1         "Node 3"
 4            1         "Node 4"
 5            1         "Node 5"
 6            1         "Node 6"
 7            1         "Node 7"
 8            1         "Node 8"
 9            1         "Node 9"
 10           1         "Node 10"
 11           1         "Node 11"
 12           2         "Node 12"
 13           2         "Node 13"
```

NODE	PRES (PSI)	TEMP(DEGF)	MASS SOURC	HEAT SOURC	THRST AREA	NODE-VOLUME	CONCENTRATION
1	1.97	-19.57	0		0	0	0
2	1.97	-19.57	0		0	0	0
3	1.97	-19.57	0		0	0	0
4	1.97	-19.57	0		0	0	0
5	1.97	-19.57	0		0	0	0
6	1.97	-19.57	0		0	0	0
7	1.97	-19.57	0		0	0	0
8	1.97	-19.57	0		0	0	0
9	1.97	-19.57	0		0	0	0
10	1.97	-19.57	0		0	0	0
11	1.97	-19.57	0		0	0	0

Hist12.dat
Hist13_1.dat

INODE	NUMBR	NAMEBR		
1	2	12	131	
2	3	12	23	132
3	3	23	34	133
4	3	34	45	134
5	3	45	56	135
6	3	56	67	136
7	3	67	78	137
8	3	78	89	138
9	3	89	910	139
10	2	910	1011	
11	2	1011	1112	

BRANCH	UPNODE	DNNODE	OPTION	DESCRIPTION
12	1	2	1	"Pipe 12"
23	2	3	1	"Pipe 23"
34	3	4	1	"Pipe 34"
45	4	5	1	"Pipe 45"
56	5	6	1	"Pipe 56"
67	6	7	1	"Pipe 67"
78	7	8	1	"Pipe 78"
89	8	9	1	"Pipe 89"
910	9	10	2	"Restrict 910"
1011	10	11	1	"Pipe 1011"
1112	11	12	2	"Restrict 1112"
135	13	5	24	"FixedFlow 135"
139	13	9	24	"FixedFlow 139"
138	13	8	24	"FixedFlow 138"
137	13	7	24	"FixedFlow 137"
136	13	6	24	"FixedFlow 136"
134	13	4	24	"FixedFlow 134"
133	13	3	24	"FixedFlow 133"
132	13	2	24	"FixedFlow 132"
131	13	1	24	"FixedFlow 131"

BRANCH	OPTION -1	LENGTH	DIA	EPSD	ANGLE	AREA
12		11.063	38.59	0	180	1169.6046108
BRANCH	OPTION -1	LENGTH	DIA	EPSD	ANGLE	AREA
23		11.063	62.71	0	180	3088.6103048

```
BRANCH  OPTION -1    LENGTH    DIA      EPSD    ANGLE    AREA
  34                 11.063    74.61    0       180      4372.0346427
BRANCH  OPTION -1    LENGTH    DIA      EPSD    ANGLE    AREA
  45                 11.063    79.88    0       180      5011.4756777
BRANCH  OPTION -1    LENGTH    DIA      EPSD    ANGLE    AREA
 56                  11.063    79.88    0       180      5011.4756777
BRANCH  OPTION -1    LENGTH    DIA      EPSD    ANGLE    AREA
 67                  11.063    74.61    0       180      4372.0346427
BRANCH  OPTION -1    LENGTH    DIA      EPSD    ANGLE    AREA
 78                  11.063    62.71    0       180      3088.6103048
BRANCH  OPTION -1    LENGTH    DIA      EPSD    ANGLE    AREA
 89                  11.063    38.59    0       180      1169.6046108
BRANCH  OPTION -2    FLOW COEFF    AREA
 910                 1             3.14
BRANCH  OPTION -1    LENGTH    DIA      EPSD    ANGLE    AREA
 1011                100       2        0       90       3.14159
BRANCH  OPTION -2    FLOW COEFF    AREA
 1112                0.6           0.0491
BRANCH  OPTION -24   FLOW_RATE     AREA     HISTORY
 135                 0             1        1

flow_hist_chill_spray_5.dat
BRANCH  OPTION -24   FLOW_RATE     AREA     HISTORY
 139                 0             1        1
flow_hist_chill_spray_9.dat
BRANCH  OPTION -24   FLOW_RATE     AREA     HISTORY
 138                 0             1        1
flow_hist_chill_spray_8.dat
BRANCH  OPTION -24   FLOW_RATE     AREA     HISTORY
 137                 0             1        1
flow_hist_chill_spray_7.dat
BRANCH  OPTION -24   FLOW_RATE     AREA     HISTORY
 136                 0             1        1
flow_hist_chill_spray_6.dat
BRANCH  OPTION -24   FLOW_RATE     AREA     HISTORY
 134                 0             1        1
flow_hist_chill_spray_4.dat
BRANCH  OPTION -24   FLOW_RATE     AREA     HISTORY
 133                 0             1        1
flow_hist_chill_spray_3.dat
BRANCH  OPTION -24   FLOW_RATE     AREA     HISTORY
 132                 0             1        1
flow_hist_chill_spray_2.dat
BRANCH  OPTION -24   FLOW_RATE     AREA     HISTORY
 131                 0             1        1
flow_hist_chill_spray_1.dat

INITIAL FLOWRATES IN BRANCHES FOR UNSTEADY FLOW
 12   0
 23   0
 34   0
 45   0
 56   0
 67   0
 78   0
```

```
 89   0
 910   0
 1011  0
 1112  0
 135   0
 139   0
 138   0
 137   0
 136   0
 134   0
 133   0
 132   0
 131   0

NUMBER OF CLOSING/OPENING VALVES IN THE CIRCUIT
 1
BRANCH
 1112
FILE NAME
Valve_Hist_Chill.dat
NSOLID    NAMB    NSSC   NSFC   NSAC   NSSR
 9        0       0      9      0      0
NODESL    MATRL   SMASS          TS            HtSrc        NUMSS   NUMSF   NUMSA   NUMSSR   DESCRIPTION
 14       2       7.0460000    -19.5700000    0.0000000    0       1       0       0        "Node 14"
NAMESF
 149
 15       2       25.6830000   -19.5700000    0.0000000    0       1       0       0        "Node 15"
NAMESF
 158
 16       2       45.0130000   -19.5700000    0.0000000    0       1       0       0        "Node 16"
NAMESF
 167
 17       2       56.6360000   -19.5700000    0.0000000    0       1       0       0        "Node 17"
NAMESF
 176
 18       2       60.4910000   -19.5700000    0.0000000    0       1       0       0        "Node 18"
NAMESF
 185
 19       2       56.6360000   -19.5700000    0.0000000    0       1       0       0        "Node 19"
NAMESF
 194
 20       2       45.0130000   -19.5700000    0.0000000    0       1       0       0        "Node 20"
NAMESF
 203
 21       2       25.6830000   -19.5700000    0.0000000    0       1       0       0        "Node 21"
NAMESF
 212
 22       2       7.0460000    -19.5700000    0.0000000    0       1       0       0        "Node 22"
NAMESF
 221
ICONSF  ICS  ICF   MODEL            ARSF          HCSF  RADSF          EMSFS          EMSFF DESCRIPTION
 149    14   9     0  4.62270e+02   1.00000e-03   F     0.00000e+00   0.00000e+00   "Convection 149"
 158    15   8     0  1.68492e+03   1.00000e-03   F     0.00000e+00   0.00000e+00   "Convection 158"
 167    16   7     0  2.95294e+03   1.00000e-03   F     0.00000e+00   0.00000e+00   "Convection 167"
 176    17   6     0  3.71548e+03   1.00000e-03   F     0.00000e+00   0.00000e+00   "Convection 176"
```

185	18	5	0	3.96821e+03	1.00000e-03	F	0.00000e+00	0.00000e+00	"Convection 185"
194	19	4	0	3.71548e+03	1.00000e-03	F	0.00000e+00	0.00000e+00	"Convection 194"
203	20	3	0	2.95294e+03	1.00000e-03	F	0.00000e+00	0.00000e+00	"Convection 203"
212	21	2	0	1.68492e+03	1.00000e-03	F	0.00000e+00	0.00000e+00	"Convection 212"
221	22	1	0	4.62270e+02	1.00000e-03	F	0.00000e+00	0.00000e+00	"Convection 221"

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Example 28 User Subroutines

```
C*********************************************************************
C                                                                    *
C     ***** GFSSP USER SUBROUTINES *****                             *
C                                                                    *
C*********************************************************************
                       :
                       :
                       :
                       :
C*********************************************************************
      SUBROUTINE BNDUSER
C     PURPOSE: MODIFY BOUNDARY CONDITIONS
C*********************************************************************
      INCLUDE 'comblk.for'
C*********************************************************************
C     ADD CODE HERE
      IF (TAU.GT.6300.) RELAXNR = 0.1
      RETURN
      END
C*********************************************************************
      SUBROUTINE USRHCF(NUMBER,HCF)
C     PURPOSE: PROVIDE HEAT TRANSFER COEFFICIENT
C*********************************************************************
      INCLUDE 'comblk.for'
C*********************************************************************
C     ADD CODE HERE
      DATA TANKDIA/7.25/
      DATA CON1,FN1/0.27,0.50/
      DATA FACTHC/1.0/
C     OBTAIN INDICES OF THE FLUID NODE
      NUM2=ICF(NUMBER)
      CALL INDEXI(NUM2,NODE,NNODES,IPN)
      NUM1=ICS(NUMBER)
      CALL INDEXS(NUM1,NODESL,NSOLIDX,IPSN)

C     COMPUTE HEAT TRANSFER BETWEEN WALL AND PROPELLANT
      BETA=1./TF(IPN)
      DELTAT=ABS(TS(IPSN)-TF(IPN))
      IF(DELTAT .NE. 0.0) THEN
        GR=TANKDIA**3*RHO(IPN)**2*G*BETA*DELTAT/(EMU(IPN)**2)
        PRNDTL=CPNODE(IPN)*EMU(IPN)/CONDF(IPN)
        HCF=FACTHC*CON1*CONDF(IPN)*(GR*PRNDTL)**FN1/TANKDIA
        ENDIF
      RETURN
      END
C********************************************************************
C                                                                   *
C               ***** END OF USER SUBROUTINES *****                 *
C                                                                   *
C********************************************************************
```

NOTE: All other user subroutines are not used in Example 18

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Example 28 History Files (9 identical)
Flow_hist_chill_spray_1.dat

26

0	2.22e-03	1.0
74.88	2.22e-03	1.0
74.89	1.E-16	1.0
884.88	1.E-16	1.0
884.89	8.31e-03	1.0
945.00	8.31e-03	1.0
945.01	1.e-16	1.0
1898.9	1.e-16	1.0
1899	1.80e-02	1.0
1944	1.80e-02	1.0
1944.01	1.e-16	1.0
2946.14	1.e-16	1.0
2946.24	7.76e-03	1.0
2991.24	7.76e-03	1.0
2991.34	1.e-16	1.0
4113.26	1.e-16	1.0
4113.36	1.22e-02	1.0
4158.36	1.22e-02	1.0
4158.46	1.e-16	1.0
5244.38	1.e-16	1.0
5244.48	1.81e-02	1.0
5319.36	1.81e-02	1.0
5319.37	1.e-16	1.0
6306.48	1.e-16	1.0
6306.49	3.51e-02	1.0
8467.00	3.51e-02	1.0

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```
 **************************************************
              G F S S P (Version 605)
      Generalized Fluid System Simulation Program
                     May 2014

    Developed by NASA/Marshall Space Flight Center
    Copyright (C) by Marshall Space Flight Center

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


   RUN DATE:06/25/2014 13:01

 TITLE     :K-site Tank Facility
 ANALYST   :akm
 FILEIN    :C:\GFSSP605InstallTest\EXAMPLES\EX28\EX28.dat
 FILEOUT   :EX28.out

                  OPTION VARIABLES

 ADDPROP   BUOYANCY  CONDX     CONJUG    CYCLIC    DALTON    DENCON    ENERGY
 F         F         F         T         F         F         F         T
 FLOWREG   GRAVITY   HCOEF     HEX       HRATE     IFRMIX    INERTIA   INSUC
 0         T         F         F         T         1         F         F
 INVAL     MIXTURE   MOVBND    MSORCE    NORMAL    NRSOLVT   OPVALVE   PLOTADD
 F         F         F         F         F         T         T         F
 PRESREG   PRESS     PRINTI    PRNTADD   PRNTIN    RADIATION REACTING  ROTATION
 0         F         F         T         T         F         F         F
 SAVER     SECONDL   SHEAR     SIMULA    SIUNITS   STEADY    THRUST    TPA
 F         F         F         T         F         F         F         F
 TRANS_MOM TRANSQ    TRANSV    TVM       TWOD      USRVAR    VARGEO    VARROT
 F         F         T         F         F         F         F         F
 RLFVLV    DFLI
 F         T

 NNODES  =  13
 NINT    =  11
 NBR     =  20
 NF      =   1
 NVAR    =  42
 NHREF   =   2


 FLUIDS:  H2

BOUNDARY NODES
 NODE   P             T            RHO           AREA
        (PSI)        (F)           (LBM/FT^3)    (IN^2)
 12     1.0000E+00    8.0000E+01   3.4793E-04    0.0000E+00
 13     3.2700E+00   -4.2000E+02   1.5734E-02    0.0000E+00
```

```
INPUT SPECIFICATIONS FOR INTERNAL NODES
NODE    AREA         MASS         HEAT
        (IN^2)       (LBM/S)      (BTU/S)
 1      0.0000E+00   0.0000E+00   0.0000E+00
 2      0.0000E+00   0.0000E+00   0.0000E+00
 3      0.0000E+00   0.0000E+00   0.0000E+00
 4      0.0000E+00   0.0000E+00   0.0000E+00
 5      0.0000E+00   0.0000E+00   0.0000E+00
 6      0.0000E+00   0.0000E+00   0.0000E+00
 7      0.0000E+00   0.0000E+00   0.0000E+00
 8      0.0000E+00   0.0000E+00   0.0000E+00
 9      0.0000E+00   0.0000E+00   0.0000E+00
 10     0.0000E+00   0.0000E+00   0.0000E+00
 11     0.0000E+00   0.0000E+00   0.0000E+00

BRANCH      UPNODE    DNNODE    OPTION
 12         1         2         1
 23         2         3         1
 34         3         4         1
 45         4         5         1
 56         5         6         1
 67         6         7         1
 78         7         8         1
 89         8         9         1
 910        9         10        2
 1011       10        11        1
 1112       11        12        2
 135        13        5         24
 139        13        9         24
 138        13        8         24
 137        13        7         24
 136        13        6         24
 134        13        4         24
 133        13        3         24
 132        13        2         24
 131        13        1         24
BRANCH OPTION -1:   LENGTH       DIA          EPSD         ANGLE        AREA
 12                 0.111E+02    0.386E+02    0.000E+00    0.180E+03    0.117E+04
BRANCH OPTION -1:   LENGTH       DIA          EPSD         ANGLE        AREA
 23                 0.111E+02    0.627E+02    0.000E+00    0.180E+03    0.309E+04
BRANCH OPTION -1:   LENGTH       DIA          EPSD         ANGLE        AREA
 34                 0.111E+02    0.746E+02    0.000E+00    0.180E+03    0.437E+04
BRANCH OPTION -1:   LENGTH       DIA          EPSD         ANGLE        AREA
 45                 0.111E+02    0.799E+02    0.000E+00    0.180E+03    0.501E+04
BRANCH OPTION -1:   LENGTH       DIA          EPSD         ANGLE        AREA
 56                 0.111E+02    0.799E+02    0.000E+00    0.180E+03    0.501E+04
BRANCH OPTION -1:   LENGTH       DIA          EPSD         ANGLE        AREA
 67                 0.111E+02    0.746E+02    0.000E+00    0.180E+03    0.437E+04
BRANCH OPTION -1:   LENGTH       DIA          EPSD         ANGLE        AREA
 78                 0.111E+02    0.627E+02    0.000E+00    0.180E+03    0.309E+04
BRANCH OPTION -1:   LENGTH       DIA          EPSD         ANGLE        AREA
 89                 0.111E+02    0.386E+02    0.000E+00    0.180E+03    0.117E+04
BRANCH OPTION -2:   FLOW COEF    AREA
 910                0.100E+01    0.314E+01
```

```
 BRANCH OPTION -1:    LENGTH       DIA          EPSD        ANGLE        AREA
  1011                0.100E+03    0.200E+01    0.000E+00   0.900E+02    0.314E+01
 BRANCH OPTION -2:    FLOW COEF    AREA
  1112                0.600E+00    0.100E-15


CONJUGATE HEAT TRANSFER
  NSOLIDX =  9
  NAMB    =  0
  NSSC    =  0
  NSFC    =  9
  NSAC    =  0
  NSSR    =  0

NODESL  MATRL  SMASS    TS         NUMSS  NUMSF  NUMSA
  14    2      7.0460   -19.5700   0      1      0
 NAMESF
 149
NODESL  MATRL  SMASS    TS         NUMSS  NUMSF  NUMSA
  15    2      25.6830  -19.5700   0      1      0
 NAMESF
 158
NODESL  MATRL  SMASS    TS         NUMSS  NUMSF  NUMSA
  16    2      45.0130  -19.5700   0      1      0
 NAMESF
 167
NODESL  MATRL  SMASS    TS         NUMSS  NUMSF  NUMSA
  17    2      56.6360  -19.5700   0      1      0
 NAMESF
 176
NODESL  MATRL  SMASS    TS         NUMSS  NUMSF  NUMSA
  18    2      60.4910  -19.5700   0      1      0
 NAMESF
 185
NODESL  MATRL  SMASS    TS         NUMSS  NUMSF  NUMSA
  19    2      56.6360  -19.5700   0      1      0
 NAMESF
 194
NODESL  MATRL  SMASS    TS         NUMSS  NUMSF  NUMSA
  20    2      45.0130  -19.5700   0      1      0
 NAMESF
 203
NODESL  MATRL  SMASS    TS         NUMSS  NUMSF  NUMSA
  21    2      25.6830  -19.5700   0      1      0
 NAMESF
 212
NODESL  MATRL  SMASS    TS         NUMSS  NUMSF  NUMSA
  22    2      7.0460   -19.5700   0      1      0
 NAMESF
 221
ICONSF  ICS   ICF  ARSF        EMSFS    EMSFF
 149    14    9     462.2700   0.0000   0.0000
 158    15    8    1684.9200   0.0000   0.0000
 167    16    7    2952.9400   0.0000   0.0000
 176    17    6    3715.4800   0.0000   0.0000
```

```
 185    18    5    3968.2100   0.0000   0.0000
 194    19    4    3715.4800   0.0000   0.0000
 203    20    3    2952.9400   0.0000   0.0000
 212    21    2    1684.9200   0.0000   0.0000
 221    22    1     462.2700   0.0000   0.0000


  AT ISTEP = 1

  WARNING! CHKGASP: P out of fluid property range at node 12


  AT ISTEP = 2

  WARNING! CHKGASP: P out of fluid property range at node 12
                            :
                            :
                            :
                            :


   ISTEP = 100     TAU = 0.10000E+02
BOUNDARY NODES
 NODE    P(PSI)      TF(F)         Z(COMP)      RHO          QUALITY
                                              (LBM/FT^3)
 12      1.0000E+00   8.0000E+01   1.0007E+00   3.4793E-04   1.0000E+00
 13      6.4559E+00  -4.2000E+02   9.6812E-01   3.1585E-02   1.0000E+00

SOLUTION
INTERNAL NODES
 NODE    P(PSI)      TF(F)         Z            RHO          EM(LBM)      QUALITY
                                               (LBM/FT^3)
 1       4.4650E+00  -8.2348E+01   1.0009E+00   2.2213E-03   8.3165E-03   1.0000E+00
 2       4.4649E+00  -4.6676E+01   1.0009E+00   2.0294E-03   2.7663E-02   1.0000E+00
 3       4.4649E+00  -3.5260E+01   1.0009E+00   1.9748E-03   4.7163E-02   1.0000E+00
 4       4.4649E+00  -3.1297E+01   1.0009E+00   1.9565E-03   5.8770E-02   1.0000E+00
 5       4.4649E+00  -3.0217E+01   1.0009E+00   1.9516E-03   6.2617E-02   1.0000E+00
 6       4.4649E+00  -3.1296E+01   1.0009E+00   1.9565E-03   5.8769E-02   1.0000E+00
 7       4.4649E+00  -3.5256E+01   1.0009E+00   1.9748E-03   4.7162E-02   1.0000E+00
 8       4.4649E+00  -4.6660E+01   1.0009E+00   2.0293E-03   2.7661E-02   1.0000E+00
 9       4.4649E+00  -8.2349E+01   1.0009E+00   2.2212E-03   8.3163E-03   1.0000E+00
 10      4.4649E+00  -1.8951E+01   1.0009E+00   1.9017E-03   1.7287E-04   1.0000E+00
 11      4.4649E+00   5.8544E+01   1.0009E+00   1.6173E-03   1.4702E-04   1.0000E+00
```

NODE	H	ENTROPY	EMU	COND	CP	GAMA
	BTU/LB	BTU/LB-R	LBM/FT-SEC	BTU/FT-S-R	BTU/LB-R	
1	1.2094E+03	1.5350E+01	4.6163E-06	2.6199E-05	3.8010E+00	1.3505E+00
2	1.3440E+03	1.5691E+01	4.9103E-06	2.7333E-05	3.7438E+00	1.3578E+00
3	1.3866E+03	1.5793E+01	5.0026E-06	2.7590E-05	3.7245E+00	1.3603E+00
4	1.4014E+03	1.5828E+01	5.0345E-06	2.7667E-05	3.7177E+00	1.3612E+00
5	1.4054E+03	1.5837E+01	5.0431E-06	2.7687E-05	3.7159E+00	1.3614E+00
6	1.4014E+03	1.5828E+01	5.0345E-06	2.7667E-05	3.7177E+00	1.3612E+00
7	1.3866E+03	1.5793E+01	5.0026E-06	2.7590E-05	3.7245E+00	1.3603E+00
8	1.3440E+03	1.5691E+01	4.9104E-06	2.7334E-05	3.7438E+00	1.3578E+00
9	1.2094E+03	1.5350E+01	4.6163E-06	2.6199E-05	3.8010E+00	1.3505E+00
10	1.4471E+03	1.5933E+01	5.1332E-06	2.7866E-05	3.6966E+00	1.3640E+00
11	1.7287E+03	1.6522E+01	5.7340E-06	3.0440E-05	3.5751E+00	1.3810E+00

BRANCHES

BRANCH	KFACTOR	DELP	FLOW RATE	VELOCITY	REYN. NO.	MACH NO.	ENTROPY GEN.	LOST WORK
	(LBF-S^2)/ (LBM-FT)^2	(PSI)	(LBM/SEC)	(FT/SEC)			BTU/(R-SEC)	LBF-FT/SEC
12	1.304E-02	1.361E-05	1.740E-03	9.646E-02	1.493E+02	2.721E-05	1.054E-13	3.093E-08
23	1.596E-03	1.282E-05	2.374E-03	5.454E-02	1.178E+02	1.467E-05	3.273E-14	1.052E-08
34	1.053E-03	1.258E-05	1.879E-03	3.133E-02	7.690E+01	8.305E-06	1.071E-14	3.537E-09
45	2.164E-03	1.251E-05	7.069E-04	1.038E-02	2.686E+01	2.738E-06	1.172E-15	3.907E-10
56	2.218E-03	1.251E-05	-6.898E-04	-1.013E-02	2.621E+01	2.668E-06	1.116E-15	3.721E-10
67	1.063E-03	1.258E-05	-1.862E-03	-3.105E-02	7.620E+01	8.188E-06	1.052E-14	3.473E-09
78	1.607E-03	1.282E-05	-2.357E-03	-5.415E-02	1.169E+02	1.435E-05	3.226E-14	1.037E-08
89	1.317E-02	1.361E-05	-1.723E-03	-9.551E-02	1.478E+02	2.568E-05	1.033E-13	3.033E-08
910	1.471E+04	3.038E-08	1.724E-05	3.560E-01	2.854E+01	1.004E-04	1.157E-13	3.395E-08
1011	5.038E+06	1.848E-06	7.328E-06	1.766E-01	1.091E+01	4.588E-05	3.040E-12	1.042E-06
1112	5.535E+37	3.465E+00	7.565E-11	6.735E+10	1.786E+04	1.603E+07	3.674E+04	1.481E+10
135	0.000E+00	1.991E+00	2.220E-03	1.012E+01	3.709E+04	7.781E-03	0.000E+00	0.000E+00
139	0.000E+00	1.991E+00	2.220E-03	1.012E+01	3.709E+04	7.781E-03	0.000E+00	0.000E+00
138	0.000E+00	1.991E+00	2.220E-03	1.012E+01	3.709E+04	7.781E-03	0.000E+00	0.000E+00
137	0.000E+00	1.991E+00	2.220E-03	1.012E+01	3.709E+04	7.781E-03	0.000E+00	0.000E+00
136	0.000E+00	1.991E+00	2.220E-03	1.012E+01	3.709E+04	7.781E-03	0.000E+00	0.000E+00
134	0.000E+00	1.991E+00	2.220E-03	1.012E+01	3.709E+04	7.781E-03	0.000E+00	0.000E+00
133	0.000E+00	1.991E+00	2.220E-03	1.012E+01	3.709E+04	7.781E-03	0.000E+00	0.000E+00
132	0.000E+00	1.991E+00	2.220E-03	1.012E+01	3.709E+04	7.781E-03	0.000E+00	0.000E+00
131	0.000E+00	1.991E+00	2.220E-03	1.012E+01	3.709E+04	7.781E-03	0.000E+00	0.000E+00

SOLID NODES

NODESL	CPSLD	TS
	BTU/LB F	F
14	2.060E-01	-3.468E+01
15	2.060E-01	-2.381E+01
16	2.060E-01	-2.146E+01
17	2.060E-01	-2.080E+01
18	2.060E-01	-2.064E+01
19	2.060E-01	-2.080E+01
20	2.060E-01	-2.146E+01
21	2.060E-01	-2.382E+01
22	2.060E-01	-3.468E+01

SOLID TO FLUID CONDUCTOR

ICONSF	QDOTSF	HCSF	HCSFR
	BTU/S	BTU/S	FT**2 F
149	2.303E+00	1.504E-02	0.000E+00
158	2.395E+00	8.942E-03	0.000E+00
167	1.879E+00	6.625E-03	0.000E+00
176	1.543E+00	5.683E-03	0.000E+00
185	1.431E+00	5.405E-03	0.000E+00
194	1.544E+00	5.684E-03	0.000E+00
203	1.880E+00	6.626E-03	0.000E+00
212	2.397E+00	8.945E-03	0.000E+00
221	2.303E+00	1.504E-02	0.000E+00

:
:
:
:

ISTEP = 84600 TAU = 0.84600E+04

BOUNDARY NODES

NODE	P(PSI)	TF(F)	Z(COMP)	RHO	QUALITY
				(LBM/FT^3)	
12	1.0000E+00	8.0000E+01	1.0007E+00	3.4793E-04	1.0000E+00
13	2.7991E+01	-4.2000E+02	3.0925E-02	4.2870E+00	0.0000E+00

SOLUTION

INTERNAL NODES

NODE	P(PSI)	TF(F)	Z	RHO	EM(LBM)	QUALITY
				(LBM/FT^3)		
1	4.7450E+01	-4.2003E+02	5.2275E-02	4.3025E+00	1.6109E+01	0.0000E+00
2	4.7422E+01	-4.1874E+02	5.1321E-02	4.2419E+00	5.7821E+01	0.0000E+00
3	4.7396E+01	-4.1666E+02	5.0066E-02	4.1360E+00	9.8777E+01	0.0000E+00
4	4.7369E+01	-4.1483E+02	4.9232E-02	4.0319E+00	1.2111E+02	0.0000E+00
5	4.7347E+01	-4.1473E+02	6.5256E-02	3.0337E+00	9.7335E+01	2.1495E-02
6	4.7324E+01	-4.1474E+02	4.9959E-02	3.9611E+00	1.1898E+02	1.0785E-03
7	4.7299E+01	-4.1652E+02	4.9893E-02	4.1284E+00	9.8595E+01	0.0000E+00
8	4.7272E+01	-4.1866E+02	5.1106E-02	4.2378E+00	5.7765E+01	0.0000E+00
9	4.7244E+01	-4.2002E+02	5.2042E-02	4.3018E+00	1.6106E+01	0.0000E+00
10	4.7244E+01	-4.1598E+02	4.9575E-02	4.0982E+00	3.7253E-01	0.0000E+00
11	4.7244E+01	-4.1475E+02	2.8238E-01	6.9984E-01	6.3617E-02	3.1165E-01

NODE	H	ENTROPY	EMU	COND	CP	GAMA
	BTU/LB	BTU/LB-R	LBM/FT-SEC	BTU/FT-S-R	BTU/LB-R	
1	-1.0096E+02	2.1207E+00	7.9334E-06	1.6301E-05	2.4737E+00	1.8854E+00
2	-9.7688E+01	2.2020E+00	7.5094E-06	1.6322E-05	2.6036E+00	1.9596E+00
3	-9.2026E+01	2.3369E+00	6.8803E-06	1.6239E-05	2.8689E+00	2.0834E+00
4	-8.6514E+01	2.4624E+00	6.3659E-06	1.6047E-05	3.1706E+00	2.2096E+00
5	-8.2445E+01	2.5530E+00	5.6652E-06	1.5763E-05	3.1947E+00	2.2189E+00
6	-8.6026E+01	2.4733E+00	6.3023E-06	1.6020E-05	3.1886E+00	2.2171E+00
7	-9.1627E+01	2.3462E+00	6.8395E-06	1.6228E-05	2.8897E+00	2.0923E+00
8	-9.7478E+01	2.2072E+00	7.4829E-06	1.6321E-05	2.6129E+00	1.9645E+00
9	-1.0093E+02	2.1216E+00	7.9284E-06	1.6301E-05	2.4751E+00	1.8863E+00
10	-9.0026E+01	2.3832E+00	6.6831E-06	1.6179E-05	2.9742E+00	2.1280E+00
11	-3.1774E+01	3.6812E+00	2.3264E-06	1.2117E-05	3.2680E+00	2.2390E+00

BRANCH	KFACTOR (LBF-S^2)/ (LBM-FT)^2)	DELP (PSI)	FLOW RATE (LBM/SEC)	VELOCITY (FT/SEC)	REYN. NO.	MACH NO.	ENTROPY GEN. BTU/(R-SEC)	LOST WORK LBF-FT/SEC
12	5.748E-07	2.735E-02	3.502E-02	1.002E-03	1.748E+03	7.382E-07	1.863E-16	5.738E-12
23	4.015E-08	2.682E-02	6.901E-02	7.585E-04	2.239E+03	5.394E-07	9.787E-17	3.112E-12
34	2.630E-08	2.615E-02	1.008E-01	8.029E-04	3.001E+03	5.402E-07	1.951E-16	6.517E-12
45	1.768E-08	2.262E-02	1.308E-01	9.323E-04	3.931E+03	5.965E-07	2.818E-16	9.818E-12
56	3.608E-08	2.239E-02	3.077E-02	2.915E-04	1.039E+03	1.859E-07	9.928E-18	3.466E-13
67	2.633E-08	2.590E-02	-1.005E-01	-8.016E-04	3.008E+03	5.114E-07	1.930E-16	6.468E-12
78	4.019E-08	2.678E-02	-6.878E-02	-7.567E-04	2.240E+03	5.072E-07	9.686E-17	3.086E-12
89	5.774E-07	2.734E-02	-3.484E-02	-9.973E-04	1.740E+03	7.076E-07	1.844E-16	5.679E-12
910	7.598E+00	1.551E-09	1.715E-04	1.828E-03	1.653E+02	1.346E-06	2.893E-16	8.911E-12
1011	1.374E+02	-4.111E-05	1.623E-04	1.815E-03	1.855E+02	1.198E-06	4.223E-15	1.434E-10
1112	1.279E+35	4.624E+01	9.909E-11	2.039E+08	5.768E+04	1.295E+05	5.095E+00	1.778E+05
135	0.000E+00	-1.936E+01	3.510E-02	1.179E+00	6.064E+04	8.637E-04	0.000E+00	0.000E+00
139	0.000E+00	-1.925E+01	3.510E-02	1.179E+00	6.064E+04	8.637E-04	0.000E+00	0.000E+00
138	0.000E+00	-1.928E+01	3.510E-02	1.179E+00	6.064E+04	8.637E-04	0.000E+00	0.000E+00
137	0.000E+00	-1.931E+01	3.510E-02	1.179E+00	6.064E+04	8.637E-04	0.000E+00	0.000E+00
136	0.000E+00	-1.933E+01	3.510E-02	1.179E+00	6.064E+04	8.637E-04	0.000E+00	0.000E+00
134	0.000E+00	-1.938E+01	3.510E-02	1.179E+00	6.064E+04	8.637E-04	0.000E+00	0.000E+00
133	0.000E+00	-1.940E+01	3.510E-02	1.179E+00	6.064E+04	8.637E-04	0.000E+00	0.000E+00
132	0.000E+00	-1.943E+01	3.510E-02	1.179E+00	6.064E+04	8.637E-04	0.000E+00	0.000E+00
131	0.000E+00	-1.946E+01	3.510E-02	1.179E+00	6.064E+04	8.637E-04	0.000E+00	0.000E+00

SOLID NODES

NODESL	CPSLD BTU/LB F	TS F
14	2.060E-01	-4.200E+02
15	2.060E-01	-4.187E+02
16	2.060E-01	-4.165E+02
17	2.060E-01	-4.147E+02
18	2.060E-01	-4.147E+02
19	2.060E-01	-4.148E+02
20	2.060E-01	-4.167E+02
21	2.060E-01	-4.187E+02
22	2.060E-01	-4.200E+02

SOLID TO FLUID CONDUCTOR

ICONSF	QDOTSF BTU/S	HCSF BTU/S	HCSFR FT**2 F
149	4.606E-04	1.796E-01	0.000E+00
158	9.684E-03	3.275E-01	0.000E+00
167	2.678E-02	3.918E-01	0.000E+00
176	-3.609E-02	4.068E-01	0.000E+00
185	-3.729E-02	3.473E-01	0.000E+00
194	3.657E-02	4.118E-01	0.000E+00
203	2.594E-02	3.870E-01	0.000E+00
212	9.177E-03	3.213E-01	0.000E+00
221	4.239E-04	1.747E-01	0.000E+00

AT ISTEP = 84600
WARNING! CHKGASP: P out of fluid property range at node 12

SOLUTION DID NOT SATISFY CONVERGENCE CRITERION 0.100E-03 IN 300 ITERATIONS
DIFMAX IN SUCCESSIVE ITERATION = 0.342E-02

```
*******************************************

TIME OF ANALYSIS WAS 2092.23861170000 SECS

*******************************************
```

APPENDIX NN—INPUT AND OUTPUT DATA FILES FROM EXAMPLE 29

Self-Pressurization of a Propellant Tank

Contents

Back to Appendix NN

```
GFSSP VERSION
    605
GFSSP INSTALLATION PATH
C:\Program Files (x86)\GFSSP605\
ANALYST
Juan Valenzuela
INPUT DATA FILE NAME
C:\GFSSP605InstallTest\EXAMPLES\EX29\Ex29.dat
OUTPUT FILE NAME
Ex29.out
TITLE
Self Pressurization of a Propellant Tank
USETUP
F
DENCON          GRAVITY     ENERGY      MIXTURE     THRUST      STEADY      TRANSV      SAVER
F               T           T           F           F           F           T           F
HEX             HCOEF       REACTING    INERTIA     CONDX       ADDPROP     PRINTI      ROTATION
F               F           F           F           F           F           F           F
BUOYANCY        HRATE       INVAL       MSORCE      MOVBND      TPA         VARGEO      TVM
F               T           F           F           F           F           F           F
SHEAR           PRNTIN      PRNTADD     OPVALVE     TRANSQ      CONJUG      RADIAT      WINPLOT
F               T           T           F           T           T           F           T
PRESS           INSUC       VARROT      CYCLIC      CHKVALS     WINFILE     DALTON      NOSTATS
F               F           F           F           F           F           F           T
NORMAL          SIMUL       SECONDL     NRSOLVT     IBDF        NOPLT       PRESREG     FLOWREG
F               T           F           F           1           T           0           0
TRANS_MOM       USERVARS    PSMG        ISOLVE      PLOTADD     SIUNITS     TECPLOT     MDGEN
T               F           F           1           T           F           F           F
NUM_USER_VARS   IFR_MIX     PRINTD      SATTABL     MSORIN      PRELVLV     LAMINAR     HSTAG
1               1           F           F           F           F           T           T
DFLI
F
NNODES        NINT         NBR           NF
 10           6            13            1
RELAXK        RELAXD       RELAXH        CC           NITER       RELAXNR    RELAXHC     RELAXTS
 0.5          0.5          1             1e-07        1000 0.5    1          0.3
DTAU          TIMEF        TIMEL         NPSTEP       NPWSTEP     WPLSTEP    WPLBUFF
 0.1          127110       177000        500          100         1          1.1
NFLUID(I),  I = 1, NF
 10
NODE     INDEX    DESCRIPTION
 1       2        " Node 1"
 2       1        " Node 2"
 3       2        " Node 3"
 4       1        " Node 4"
 5       2        " Node 5"
 8       1        " Node 8"
 9       1        " Node 9"
 10      1        " Node 10"
 11      1        " Node 11"
 16      2        " Node 16"
```

```
NODE   PRES (PSI)   TEMP(DEGF)   MASS SOURC   HEAT SOURC   THRST AREA   NODE-VOLUME   CONCENTRATION
 2     16.18        -421.15                0            0            0             133464
 4     16.18        -422.6                 0            0            0             552124
 8     16.18        -418.72                0            0            0             133464
 9     16.18        -416.79                0            0            0             132435
 10    16.18        -413                   0            0            0             109017
 11    16.18        -410.37                0            0            0             43067
 MHTBex10h1_multiple node.dat
 MHTBex10h5_multiple node.dat
 MHTBex10h5_multiple node.dat
 Hist16.dat
TRANSIENT HEAT LOAD INFORMATION
NUMBER OF NODES WITH TRANSIENT HEAT LOADS
 0
INODE    NUMBR    NAMEBR
 2       2        82     162
 4       3        34     164    45
 8       3        98     82     168
 9       3        109    98     169
 10      3        1110   109    1610
 11      3        111    1110   1611
BRANCH   UPNODE   DNNODE   OPTION   DESCRIPTION
 111     1        11       2        "Restrict 12"
 34      3        4        2        "Restrict 34"
 1110    10       11       1        "Pipe 1110"
 109     9        10       1        "Pipe 109"
 98      8        9        1        "Pipe 98"
 82      2        8        1        "Pipe 82"
 164     16       4        2        "FixedFlow 164"
 1610    16       10       2        "FixedFlow 1610"
 169     16       9        2        "FixedFlow 169"
 168     16       8        2        "FixedFlow 168"
 162     16       2        2        "FixedFlow 162"
 45      4        5        2        "Restrict 45"
 1611    16       11       2        "Restrict 1611"
BRANCH   OPTION -2   FLOW COEFF   AREA
 111                 0.6          1e-16
BRANCH   OPTION -2   FLOW COEFF   AREA
 34                  1            1e-10
BRANCH   OPTION -1   LENGTH       DIA     EPSD                 ANGLE   AREA
 1110                15           77      7.7922077922e-07     180     4656.6217775
BRANCH   OPTION -1   LENGTH       DIA     EPSD                 ANGLE   AREA
 109                 15           112     5.3571428571e-07     180     9852.02624
BRANCH   OPTION -1   LENGTH       DIA     EPSD                 ANGLE   AREA
 98                  15           119     5.0420168067e-07     180     11122.013997
BRANCH   OPTION -1   LENGTH       DIA     EPSD                 ANGLE   AREA
 82                  15           119     5.0420168067e-07     180     11122.013997
BRANCH   OPTION -2   FLOW COEFF   AREA
 164                 0.6          1e-10
BRANCH   OPTION -2   FLOW COEFF   AREA
 1610                0.6          1e-10
BRANCH   OPTION -2   FLOW COEFF   AREA
 169                 0.6          1e-10
BRANCH   OPTION -2   FLOW COEFF   AREA
 168                 0.6          1e-10
```

```
BRANCH   OPTION -2   FLOW COEFF   AREA
 162                 0.6          1e-10
BRANCH   OPTION -2   FLOW COEFF   AREA
 45                  0.6          1e-10
BRANCH   OPTION -2   FLOW COEFF   AREA
 1611                0.6          1e-10
INITIAL FLOWRATES IN BRANCHES FOR UNSTEADY FLOW
 111     1
 34      0
 1110    0
 109     0
 98      0
 82      0
 164     0
 1610    0
 169     0
 168     0
 162     0
 45      0
 1611    0
NSOLID   NAMB   NSSC   NSFC   NSAC   NSSR
 6       0      5      6      0      0
NODESL   MATRL   SMASS          TS             HtSrc        NUMSS   NUMSF   NUMSA   NUMSSR   DESCRIPTION
 6       41      214.7000000    -421.8000000   0.0000000    2       1       0       0        "Node 6"
NAMESS
 67      126
NAMESF
 62
 7       41      1392.5000000   -422.6000000   0.0000000    1       1       0       0        "Node 7"
NAMESS
 67
NAMESF
 74
 12      41      214.7000000    -419.8000000   0.0000000    2       1       0       0        "Node 12"
NAMESS
 1312    126
NAMESF
 128
 13      41      216.6000000    -417.0100000   0.0000000    2       1       0       0        "Node 13"
NAMESS
 1413    1312
NAMESF
 139
 14      41      266.3000000    -414.5900000   0.0000000    2       1       0       0        "Node 14"
NAMESS
 1514    1413
NAMESF
 1410
 15      41      347.9000000    -411.6500000   0.0000000    1       1       0       0        "Node 15"
NAMESS
 1514
NAMESF
 1511
```

ICONSS	ICNSI	ICNSJ	ARCSIJ	DISTSIJ	DESCRIPTION
67	6	7	186.00000	60.00000	"Conductor 67"
1514	15	14	150.00000	12.00000	"Conductor 1514"
1413	14	13	179.00000	12.00000	"Conductor 1413"
1312	13	12	186.00000	12.00000	"Conductor 1312"
126	12	6	186.00000	12.00000	"Conductor 126"

ICONSF	ICS	ICF	MODEL	ARSF	HCSF	RADSF	EMSFS	EMSFF	DESCRIPTION
62	6	2	0	4.48600e+03	7.50000e-01	F	0.00000e+00	0.00000e+00	"Convection 62"
74	7	4	0	2.69190e+04	7.50000e-01	F	0.00000e+00	0.00000e+00	"Convection 74"
1511	15	11	0	7.43500e+03	7.50000e-01	F	0.00000e+00	0.00000e+00	"Convection 1511"
1410	14	10	0	5.57600e+03	7.50000e-01	F	0.00000e+00	0.00000e+00	"Convection 1410"
139	13	9	0	4.53600e+03	7.50000e-01	F	0.00000e+00	0.00000e+00	"Convection 139"
128	12	8	0	4.48600e+03	7.50000e-01	F	0.00000e+00	0.00000e+00	"Convection 128"

Back to Appendix NN

Example 29 User Subroutines

```
C***********************************************************************
C                                                                      *
C                                                                      *
C      ***** GFSSP USER SUBROUTINES *****                              *
C                                                                      *
C***********************************************************************
                              :
                              :
                              :
                              :
      SUBROUTINE SORCEM(IPN,TERMU)
C     PURPOSE: ADD MASS SOURCES
C     IPN - GFSSP INDEX NUMBER FOR NODE
C     TERMU - UNSTEADY TERM IN MASS CONSERVATION EQUATION
C**********************************************************************
      INCLUDE 'comblk.for'
C**********************************************************************
C     ADD CODE HERE
      DATA TIL,HFGLH2/38.07,191.30/
      DATA HAREA,HL/ 78.5,5.0/
      DATA C1, C2 /0.1, 0.25/
      NUMUL=2
      NUMPRP = 4
      CALL INDEXI(NUMUL,NODE,NNODES,IPUL)
      CALL INDEXI(NUMPRP,NODE,NNODES,IPPRP)
C     ESTIMATE MASS TRANSFER FROM PROPELLANT TO ULLAGE

C     CALCULATE ULLAGE TO INTERFACE HEAT TRANSFER COEFFICIENT
c     BETA = 1.0 / TF(IPUL)
c     DELTAT = ABS(TF(IPUL) - TIL)
c     GR = HL**3 * RHO(IPUL)**2 * G * BETA * DELTAT / (EMU(IPUL)**2)
c     PRNDTL = CPNODE(IPUL) * EMU(IPUL) / CONDF(IPUL)
c     XNU = C1 * (GR * PRNDTL)**C2
      HUL =  CONDF(IPUL) / HL
      HLP = CONDF(IPPRP) / HL
      QDOTUL = HUL*HAREA*(TF(IPUL)-TIL)
      QDOTLP = HLP*HAREA*(TIL-TF(IPPRP))
      EMDOTGH2 = (QDOTUL-QDOTLP)/HFGLH2
      IF (NODE(IPN).EQ. 2) EMS(IPN) = EMDOTGH2
      IF (NODE(IPN).EQ. 4) EMS(IPN) = -EMDOTGH2

C     EXTRACT MASS FROM LIQUID NODE

      CALL INDEXI(164,IBRANCH,NBR,IB164)
      CALL INDEXI(4,NODE,NNODES,IP2)
      SORCEMAS(IP2) = -FLOWR(IB164)

c     WRITE(*,100) TAU,TF(IPUL),TF(IPPRP),QDOTUL,QDOTLP,EMDOTGH2

c100  FORMAT (6E12.3)


      RETURN
      END
```

```
C*********************************************************************
      SUBROUTINE SORCETS(IPSN,TERMD)
C     PURPOSE: ADD SOURCE TERM IN SOLID TEMPERATURE EQUATION
C*********************************************************************
      INCLUDE 'comblk.for'
C*********************************************************************
C     ADD CODE HERE
C***  COMMON BLOCK FOR MLI SUBROUTINE
      COMMON/CMLI/FNSTAR(10),FNLAYER(10),QFLUX(10),SAREA(10),
     &       TC,TH,PTORR,FMLIEMISS,SHRDEMISS,CR,CS,CG,DF

C    MLI Layer Density per section (layer/cm)
      DATA FNSTAR(1),FNSTAR(2),FNSTAR(3)/8,12,16/

C    Number of layers per section
      DATA FNLAYER(1),FNLAYER(2),FNLAYER(3)/10,15,20/

      DATA SAREA(1),SAREA(2),SAREA(3),SAREA(4)/4*1.0/
      DATA PTORR/5.0E-6/
      DATA FMLIEMISS/0.031/
      DATA SHRDEMISS/0.04/

      DATA THR/522./
C***  Determine with nodes are to be MLI nodes
      DIMENSION MLINODE(6)
      DATA (MLINODE(I),I = 1,6)/7,6,12,13,14,15/

      DF=2.9
      CS=2.4E-4
      CR=4.944E-10
      CG=14600.0

      NLAYER = 3

C     DEFINE SOLID NODE NUMBERS CONNECTED TO MLI


      TH = THR/1.8

      DO I = 1,6
        IF(NODESL(IPSN).EQ.MLINODE(I)) THEN
          TC = TS(IPSN)/1.8
          CALL MLI_HEAT_RATE(NLAYER,QAVG)
C     CONVERT THE HEAT RATE FROM WATT/MT**2 TO BTU/SEC-FT**2
          QAVGBTUSEC = QAVG*0.0009486608/10.7631
C     GET THE CONDUCTOR AREA
          NUMBER = NAMESF(IPSN,1)
          CALL INDEXSFC(NUMBER,ICONSF,NSFC,ICSF)
          SHSORC(IPSN) = QAVGBTUSEC*ARSF(ICSF)
        ENDIF
      ENDDO
      RETURN
      END
```

```
C*********************************************************************
      SUBROUTINE BNDUSER
C     PURPOSE: MODIFY BOUNDARY CONDITIONS
C*********************************************************************
      INCLUDE 'comblk.for'
C********************************************************************
C     ADD CODE HERE
C     PLOT MLI HEAT LEAK
      DIMENSION MLINODE(6)
      DATA (MLINODE(I),I = 1,6)/7,6,12,13,14,15/

C     UPDATE PRESSURE OF THE PSEUDO-BOUNDARY NODE

      DATA TIL,HFGLH2/38.07,191.30/
      DATA HAREA/ 27.882/
      PULMAX = 20*144
      PULMIN = 19*144
      OPENARU = 0.003526
      OPENARL = 0.003526
      CLAREA = 1.E-16
      NUMUL=2
      NUMPSN = 3
      NUMPRP = 4
      USRVAR = .TRUE.
      USRVARSNUM=7
      USRPVARNAME(1)='QMLI7'
      USRPVARNAME(2)='QMLI6'
      USRPVARNAME(3)='QMLI12'
      USRPVARNAME(4)='QMLI13'
      USRPVARNAME(5)='QMLI14'
      USRPVARNAME(6)='QMLI15'
      USRPVARNAME(7)='SQMLI'

      USRPVARUNIT(1)='BTU/SEC'
      USRPVARUNIT(2)='BTU/SEC'
      USRPVARUNIT(3)='BTU/SEC'
      USRPVARUNIT(4)='BTU/SEC'
      USRPVARUNIT(5)='BTU/SEC'
      USRPVARUNIT(6)='BTU/SEC'
      USRPVARUNIT(7)='BTU/SEC'

      SUMQMLI = 0.0
      DO I = 1,6
        NUMBER = MLINODE(I)
        CALL INDEXS(NUMBER,NODESL,NSOLIDX,IPSN)
        USRPVAR(I) = SHSORC(IPSN)
        SUMQMLI = SUMQMLI + SHSORC(IPSN)
      ENDDO

      USRPVAR(7) = SUMQMLI

      CALL INDEXI(NUMUL,NODE,NNODES,IPUL)
      CALL INDEXI(NUMPSN,NODE,NNODES,IPPSN)
      CALL INDEXI(NUMPRP,NODE,NNODES,IPPRP)
      P(IPPSN) = P(IPUL)
```

```
      IF (ISTEP.EQ.1) TANKVOL = VOLUME(IPUL)+VOLUME(IPPRP)
C     CALCULATE PROPELLANT AND ULLAGE VOLUME
      VOLUME(IPPRP) = EM(IPPRP)*Z(IPPRP)*RNODE(IPPRP)*TF(IPPRP)/P(IPPRP)
      VOLUME(IPUL) = TANKVOL-VOLUME(IPPRP)

C     TVS VALVE OPENING & CLOSING SEQUENCE
C     ULLAGE BRANCHES (162,168,169,1610,1611)

      CALL INDEXI(162,IBRANCH,NBR,IB162)
      CALL INDEXI(168,IBRANCH,NBR,IB168)
      CALL INDEXI(169,IBRANCH,NBR,IB169)
      CALL INDEXI(1610,IBRANCH,NBR,IB1610)
      CALL INDEXI(1611,IBRANCH,NBR,IB1611)

C     NODE 2 IS PRESSURE MONITORING NODE
      CALL INDEXI(2,NODE,NNODES,IP2)
      IF (P(IP2).GE.PULMAX) THEN
        AREA(IB162) = OPENARU
        AREA(IB168) = OPENARU
        AREA(IB169) = OPENARU
        AREA(IB1610) = OPENARU
        AREA(IB1611) = OPENARU
      ENDIF
      IF (P(IP2).LE.PULMIN) THEN
        AREA(IB162) = CLAREA
        AREA(IB168) = CLAREA
        AREA(IB169) = CLAREA
        AREA(IB1610) = CLAREA
        AREA(IB1611) = CLAREA
      ENDIF
C     LIQUID
      NUMBER = 164
      CALL INDEXI(NUMBER,IBRANCH,NBR,IB164)
C     NODE 2 IS PRESSURE MONITORING NODE
      IF (P(IP2).GE.PULMAX) AREA(IB164) = OPENARL
      IF (P(IP2).LE.PULMIN) AREA(IB164) = CLAREA

C     PRESSURE AT BOUNDARY NODE 16 IS FIXED TO BE 0.1 PSI
C     HIGHER THAN PRESSURE AT INTERNAL NODE 2.

      CALL INDEXI(2, NODE, NNODES, IPN2)
      CALL INDEXI(16, NODE, NNODES, IPN16)
      P(IPN16) = (P(IPN2) / 144.0 + 0.268) * 144


      RETURN
      END
C*********************************************************************
      SUBROUTINE USRHCF(NUMBER,HCF)
C     PURPOSE: PROVIDE HEAT TRANSFER COEFFICIENT
C*********************************************************************
      INCLUDE 'comblk.for'
C********************************************************************
```

```
C     ADD CODE HERE
      DATA HL /5.0/
c      return ! heat transfer coefficient specified in VTASC

C     IF(ICONSF(NUMBER).NE.62) RETURN

      NUMF = ICF(NUMBER)
      CALL INDEXI(NUMF, NODE, NNODES, IPN)
      NUMS = ICS(NUMBER)
      CALL INDEXS(NUMS, NODESL, NSOLIDX, IPSN)

      BETA = 1.0 / TF(IPN)
      DELTAT = ABS(TF(IPN) - TS(IPSN))
      IF(DELTAT .LT. 1.0E-6)DELTAT = 1.E-6
      GR = HL**3 * RHO(IPN)**2 * G * BETA * DELTAT / (EMU(IPN)**2)
      PRNDTL = CPNODE(IPN) * EMU(IPN) / CONDF(IPN)
      RA = GR*PRNDTL
      CVT = (0.13*PRNDTL**0.22)/(1.0+0.61*PRNDTL**0.81)**0.42
      CLBAR = 0.671/(1+(0.492/PRNDTL)**(9.0/16.0))**(4.0/9.0)
      ANUUT = CLBAR*RA**0.25
      ANUL = 2.0/LOG(1.0+2.0/ANUUT)
      ANUT = CVT*RA**0.33/(1.0+1.4E09*PRNDTL/RA)
      ANU = (ANUL**6+ANUT**6)**(1.0/6.0)
      HCF = 10 * ANU * CONDF(IPN) / HL

      RETURN
      END
C*********************************************************************
C                                                                    *
C               ***** END OF USER SUBROUTINES *****                  *
C                                                                    *
C*********************************************************************
!*****************************************************************************
!
      SUBROUTINE MLI_HEAT_RATE(NLAYER,QAVG)
!
!  PURPOSE:  Determine MLI heat leak of variable density MLI with the Modified Lockeed Equation
!
!*****************************************************************************
        DIMENSION RMLI(10), MLICORR(10), PDMLI(10,10),TMLI(10),
     &            TMLICORR(10), FTMLICORR(10)
!=================================================================================================
      COMMON/CMLI/FNSTAR(10),FNLAYER(10),QFLUX(10),SAREA(10),
     &       TC,TH,PTORR,FMLIEMISS,SHRDEMISS,CR,CS,CG,DF
        LOGICAL PRINTI
!        OPEN (14,FILE = 'MLI_OUT',STATUS = 'UNKNOWN')

        DATA CCMULT/0.1/
        DATA RELAXMLI/0.5/
        DATA CCMLI/1.0E-6/
        DATA ITMAX/500/
        DATA PRINTI/.TRUE./
!       DATA DF/1.0/
       F=(TH-TC)/4
      TMLI(1)=TC+F
```

```
      TMLI(2)=TMLI(1)+F
      TMLI(3)=TH-F

! Define number of equations
      NVARMLI= NLAYER

!Start interation counter
      ITERMLI= 0

!Call subroutines to calculate values of residuals, partial derivatives and changes in values of varialbes

30    CAll MLIEQNS(RMLI,TMLI,NVARMLI)

      ITERMLI= ITERMLI + 1

      CALL MLICOEF(RMLI, PDMLI,TMLI,NVARMLI)

      CALL GAUSSY(PDMLI, RMLI, TMLICORR, NVARMLI, MESSAGE)

!      IF (MESSAGE .EQ. 1) THEN
!        WRITE (14,*) ITERMLI
!      END IF

C   Correcting values of the variables

      DO L=1, NVARMLI
        TMLI(L)= TMLI(L)- TMLICORR(L)* RELAXMLI
      END DO

C    CAlculate Fractional Change

      DIFMAX=0
      IF (ITERMLI .GT. 20)  RELAXMLI = 0.9

      DO I= 1, NVARMLI

       IF (TMLI(I) .GT. 1.E-6) THEN
        FTMLICORR(I)= ABS(TMLICORR(I)/ TMLI(I))
        DIFMAX= MAX(FTMLICORR(I), DIFMAX)!sdd
       END IF
      END DO

       IF (DIFMAX .GT. CCMLI .AND. ITERMLI .LT. ITMAX) GO TO 30
       IF (DIFMAX .GT. CCMLI .AND. ITERMLI .GT. ITMAX) THEN
       WRITE (*,*) 'MLI equation did not converge -- DIFMAX=', DIFMAX

      END IF

      SUMQFLX = 0.0
      NLAYERP1 = NLAYER+1
      DO I = 1, NLAYER+1
        IF (I.EQ.1) CALL QFLUXMLI(TMLI(1),TC,CR,CS,CG,FNSTAR(1),
     &                          FNLAYER(1),FMLIEMISS,PTORR,DF,QFLUX(1))
       IF (I.EQ.NLAYERP1) CALL QFLUXRAD(TH,TMLI(NVARMLI),FMLIEMISS,
     &                                  SHRDEMISS,QFLUX(NLAYERP1))
```

```
       IF (I.NE.1.AND.I.NE.NLAYERP1) CALL QFLUXMLI(TMLI(I),TMLI(I-1),
     &  CR,CS,CG,FNSTAR(I),FNLAYER(I),FMLIEMISS,PTORR,DF,QFLUX(I))
        SUMQFLX = SUMQFLX + QFLUX(I)
      ENDDO
      QAVG = SUMQFLX/FLOAT(NLAYERP1)

      RETURN
      END
  !=======================================================================================

      SUBROUTINE MLICOEF(RMLI, PDMLI,TMLI,NVARMLI)

! Calculates numerical differentiation of Modified Lockheed equation
      DIMENSION  TMLI(10),TMLID(10), RMLI(10), RMLID(10), PDMLI(10,10)

      DELTA = 0.001

      DO I= 1, NVARMLI
        TMLID(I)= TMLI(I)
      END DO

! CAlculate Partial Derivatives

      DO J=1, NVARMLI
        IF (ABS(TMLI(J)) .LT. 1.E-10) THEN
            TMLI(J)= TMLI(J)+ DELTA
            ELSE
                TMLI(J)=  (1.+ DELTA)* TMLI(J)
        END IF

        CALL MLIEQNS(RMLID,TMLI,NVARMLI)

! Calculate Partial Derivatives
      DO I=1, NVARMLI
        ANUM= RMLID(I)- RMLI(I)
        IF (ABS(TMLI(J)) .LT. 1.E-10) THEN
            PDMLI(I,J)= ANUM/DELTA
            ELSE
            PDMLI(I,J)= ANUM/(TMLI(J) *DELTA)
        END IF
      END DO
! Restore variables to original values
      TMLI(J)= TMLID(J)
      END DO
      RETURN
      END

!==========================================================================================

      SUBROUTINE MLIEQNS(RMLI,TMLI,NVARMLI)

! Calculates residuals of the MLI Modified Lockheed Equation

      DIMENSION TMLI(10),RMLI(10)
```

```
      COMMON/CMLI/FNSTAR(10),FNLAYER(10),QFLUX(10),SAREA(10),
     &       TC,TH,PTORR,FMLIEMISS,SHRDEMISS,CR,CS,CG,DF

      NLAYERP1 = NVARMLI + 1

C     CALCULATE HEAT FLUX THROUGH EACH LAYER AND RADIATIVE HEAT FLUX FROM AMBIENT
      DO I = 1, NLAYERP1
       IF (I.EQ.1) CALL QFLUXMLI(TMLI(1),TC,CR,CS,CG,FNSTAR(1),
     &                          FNLAYER(1),FMLIEMISS,PTORR,DF,QFLUX(1))
       IF (I.EQ.NLAYERP1) CALL QFLUXRAD(TH,TMLI(NVARMLI),FMLIEMISS,
     &                                  SHRDEMISS,QFLUX(NLAYERP1))
       IF (I.NE.1.AND.I.NE.NLAYERP1)CALL QFLUXMLI(TMLI(I),TMLI(I-1),CR,
     &  CS,CG,FNSTAR(I),FNLAYER(I),FMLIEMISS,PTORR,DF,QFLUX(I))
      ENDDO
C     CALCULATE RESIDUAL
      DO I=1, NVARMLI
        RMLI(I)= QFLUX(I+1)*SAREA(I+1)- QFLUX(I)*SAREA(I)
      END DO
      RETURN
      END

!=====================================================================================================

      SUBROUTINE QFLUXMLI(T2,T1,CR,CS,CG,FNST,FNLR,FMLIEMISS,PTORR,
     &                    DF,QFLX)


! Constant for Modified Lockheed equation for 0.25mil Myler with Dacron Spacer layer

      TAVG=(T2+T1)/2
! Modified Lockheed Equation

       QFLX = DF*((((CS * (0.017+7.0E-6 * (800-TAVG) + 2.28E-2 *
     & log(TAVG)) * (FNST**2.68) * (T2-T1)))/FNLR)+((CR*FMLIEMISS*
     & ((T2**4.67)-(T1**4.67)))/FNLR)+(((CG*PTORR*
     & ((T2**0.52)-(T1**0.52))))/FNLR))

      RETURN
      END

C*********************************************************************
      SUBROUTINE QFLUXRAD(T2,T1,FMLIEMISS,SHRDEMISS,QFLX)
C     PURPOSE: CALCULATE RADIATIVE HEAT FLUX FROM AMBIENT
C*********************************************************************
      DATA SIGMA/5.67037E-08/

      ANUM = SIGMA*(T2**4 - T1**4)
      DENOM = 1./FMLIEMISS + 1./SHRDEMISS - 1.0
      QFLX = ANUM/DENOM

      RETURN
      END
C*********************************************************************
```

NOTE: All other user subroutines are not used in Example 29

Back to Appendix NN

```
EX29 HISTORY FILES

Hist16.dat
 2
 127110   20.22   -422.6   1.00
 177000   20.22   -422.6   1.00

MHTBex10h1_multiplenode.dat
 2
 0.0      16.18   -418.54   1.0
 50000    16.18   -418.54   1.0

MHTBex10h3_multiplenode.dat
 2
 0.00     16.18   -422.6    1.0
 50000    16.18   -422.6    1.0

MHTBex10h5_multiplenode.dat
 2
 0.00     16.18   -422.7   1.00
 50000    16.18   -422.7   1.00
```

Back to Appendix NN

```
            ***************************************************
                         G F S S P (Version 605)
                     Generalized Fluid System Simulation Program
                                May 2014

                   Developed by NASA/Marshall Space Flight Center
                   Copyright (C) by Marshall Space Flight Center

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


                  RUN DATE:06/25/2014 13:02

  TITLE      :Self Pressurization of a Propellant Tank
  ANALYST    :Juan Valenzuela
  FILEIN     :C:\GFSSP605InstallTest\EXAMPLES\EX29\Ex29.dat
  FILEOUT    :Ex29.out

OPTION VARIABLES

  ADDPROP      BUOYANCY  CONDX      CONJUG     CYCLIC     DALTON     DENCON     ENERGY
  F            F         F          T          F          F          F          T
  FLOWREG      GRAVITY   HCOEF      HEX        HRATE      IFRMIX     INERTIA    INSUC
  0            T         F          F          T          1          F          F
  INVAL        MIXTURE   MOVBND     MSORCE     NORMAL     NRSOLVT    OPVALVE    PLOTADD
  F            F         F          F          F          F          F          T
  PRESREG      PRESS     PRINTI     PRNTADD    PRNTIN     RADIATION  REACTING   ROTATION
  0            F         F          T          T          F          F          F
  SAVER        SECONDL   SHEAR      SIMULA     SIUNITS    STEADY     THRUST     TPA
  F            F         F          T          F          F          F          F
  TRANS_MOM    TRANSQ    TRANSV     TVM        TWOD       USRVAR     VARGEO     VARROT
  T            T         T          F          F          T          F          F
  RLFVLV       DFLI
  F            F

  NNODES   =  10
  NINT     =   6
  NBR      =  13
  NF       =   1
  NVAR     =  25
  NHREF    =   2


FLUIDS:  H2

BOUNDARY NODES
NODE   P            T             RHO           AREA
       (PSI)        (F)           (LBM/FT^3)    (IN^2)
1      1.6180E+01   -4.1854E+02   8.0053E-02    0.0000E+00
3      1.6180E+01   -4.2270E+02   4.3983E+00    0.0000E+00
5      1.6180E+01   -4.2270E+02   4.3983E+00    0.0000E+00
16     1.6448E+01   -4.2260E+02   4.3943E+00    0.0000E+00
```

```
INPUT SPECIFICATIONS FOR INTERNAL NODES
NODE    AREA         MASS         HEAT
        (IN^2)       (LBM/S)      (BTU/S)
 2      0.0000E+00   0.0000E+00   0.0000E+00
 4      0.0000E+00   0.0000E+00   0.0000E+00
 8      0.0000E+00   0.0000E+00   0.0000E+00
 9      0.0000E+00   0.0000E+00   0.0000E+00
 10     0.0000E+00   0.0000E+00   0.0000E+00
 11     0.0000E+00   0.0000E+00   0.0000E+00

BRANCH   UPNODE   DNNODE   OPTION
 111     1        11       2
 34      3        4        2
 1110    10       11       1
 109     9        10       1
 98      8        9        1
 82      2        8        1
 164     16       4        2
 1610    16       10       2
 169     16       9        2
 168     16       8        2
 162     16       2        2
 45      4        5        2
 1611    16       11       2
BRANCH  OPTION -2:   FLOW COEF   AREA
 111                0.600E+00   0.100E-15
BRANCH  OPTION -2:   FLOW COEF   AREA
 34                 0.100E+01   0.100E-09
BRANCH  OPTION -1:  LENGTH      DIA         EPSD        ANGLE       AREA
 1110               0.150E+02   0.770E+02   0.779E-06   0.180E+03   0.466E+04
BRANCH  OPTION -1:  LENGTH      DIA         EPSD        ANGLE       AREA
 109                0.150E+02   0.112E+03   0.536E-06   0.180E+03   0.985E+04
BRANCH  OPTION -1:  LENGTH      DIA         EPSD        ANGLE       AREA
 98                 0.150E+02   0.119E+03   0.504E-06   0.180E+03   0.111E+05
BRANCH  OPTION -1:  LENGTH      DIA         EPSD        ANGLE       AREA
 82                 0.150E+02   0.119E+03   0.504E-06   0.180E+03   0.111E+05
BRANCH  OPTION -2:   FLOW COEF   AREA
 164                0.600E+00   0.144E-13
BRANCH  OPTION -2:   FLOW COEF   AREA
 1610               0.600E+00   0.144E-13
BRANCH  OPTION -2:   FLOW COEF   AREA
 169                0.600E+00   0.144E-13
BRANCH  OPTION -2:   FLOW COEF   AREA
 168                0.600E+00   0.144E-13
BRANCH  OPTION -2:   FLOW COEF   AREA
 162                0.600E+00   0.144E-13
BRANCH  OPTION -2:   FLOW COEF   AREA
 45                 0.600E+00   0.100E-09
BRANCH  OPTION -2:   FLOW COEF   AREA
 1611               0.600E+00   0.144E-13
```

```
CONJUGATE HEAT TRANSFER
 NSOLIDX =  6
 NAMB    =  0
 NSSC    =  5
 NSFC    =  6
 NSAC    =  0
 NSSR    =  0
NODESL   MATRL   SMASS       TS          NUMSS   NUMSF   NUMSA
 6       41      214.7000    -421.7945   2       1       0
NAMESS
 67      126
NAMESF
 62
NODESL   MATRL   SMASS       TS          NUMSS   NUMSF   NUMSA
 7       41      1392.5000   -422.5998   1       1       0
NAMESS
 67
NAMESF
 74
NODESL   MATRL   SMASS       TS          NUMSS   NUMSF   NUMSA
 12      41      214.7000    -419.7932   2       1       0
NAMESS
 1312    126
NAMESF
 128
NODESL   MATRL   SMASS       TS          NUMSS   NUMSF   NUMSA
 13      41      216.6000    -417.0093   2       1       0
NAMESS
 1413    1312
 NAMESF
 139
NODESL   MATRL   SMASS       TS          NUMSS   NUMSF   NUMSA
 14      41      266.3000    -414.5837   2       1       0
 NAMESS
 1514    1413
NAMESF
 1410
NODESL   MATRL   SMASS       TS          NUMSS   NUMSF   NUMSA
 15      41      347.9000    -411.6464   1       1       0
NAMESS
 1514
NAMESF
 1511
ICONSS   ICNSI   ICNSJ   ARCSIJ     DISTSIJ
 67      6       7       186.0000   60.0000
 1514    15      14      150.0000   12.0000
 1413    14      13      179.0000   12.0000
 1312    13      12      186.0000   12.0000
 126     12      6       186.0000   12.0000
ICONSF   ICS   ICF   ARSF         EMSFS    EMSFF
 62      6     2     4486.0000    0.0000   0.0000
 74      7     4     26919.0000   0.0000   0.0000
 1511    15    11    7435.0000    0.0000   0.0000
 1410    14    10    5576.0000    0.0000   0.0000
 139     13    9     4536.0000    0.0000   0.0000
```

128 12 8 4486.0000 0.0000 0.0000

SOLUTION DID NOT SATISFY CONVERGENCE CRITERION 0.100E-06 IN 1000 ITERATIONS
DIFMAX IN SUCCESSIVE ITERATION = 0.236E-06

ISTEP = 500 TAU = 0.12716E+06

BOUNDARY NODES

NODE	P(PSI)	TF(F)	Z(COMP)	RHO (LBM/FT^3)	QUALITY
1	1.6180E+01	-4.1854E+02	9.2331E-01	8.0053E-02	1.0000E+00
3	1.6113E+01	-4.2270E+02	1.8619E-02	4.3983E+00	0.0000E+00
5	1.6180E+01	-4.2270E+02	1.8696E-02	4.3983E+00	0.0000E+00
16	1.6381E+01	-4.2260E+02	1.8895E-02	4.3942E+00	0.0000E+00

SOLUTION

INTERNAL NODES

NODE	P(PSI)	TF(F)	Z	RHO (LBM/FT^3)	EM(LBM)	QUALITY
2	1.6113E+01	-4.2124E+02	9.0876E-01	8.6682E-02	1.0879E+01	1.0000E+00
4	1.6178E+01	-4.2260E+02	1.8661E-02	4.3941E+00	1.4040E+03	0.0000E+00
8	1.6112E+01	-4.1885E+02	9.2224E-01	8.0417E-02	1.3975E+01	1.0000E+00
9	1.6112E+01	-4.1687E+02	9.3139E-01	7.5949E-02	1.2735E+01	1.0000E+00
10	1.6111E+01	-4.1333E+02	9.4446E-01	6.9167E-02	8.7191E+00	1.0000E+00
11	1.6110E+01	-4.1102E+02	9.5123E-01	6.5411E-02	2.9523E+00	1.0000E+00

NODE	H BTU/LB	ENTROPY BTU/LB-R	EMU LBM/FT-SEC	COND BTU/FT-S-R	CP BTU/LB-R	GAMA
2	8.6695E+01	7.2246E+00	7.9907E-07	2.7596E-06	2.7847E+00	1.8682E+00
4	-1.0792E+02	1.9741E+00	8.7338E-06	1.5966E-05	2.3107E+00	1.7600E+00
8	9.3284E+01	7.3909E+00	8.4553E-07	2.9254E-06	2.7378E+00	1.8360E+00
9	9.8660E+01	7.5196E+00	8.8352E-07	3.0631E-06	2.7069E+00	1.8149E+00
10	1.0817E+02	7.7332E+00	9.5068E-07	3.3099E-06	2.6636E+00	1.7858E+00
11	1.1430E+02	7.8623E+00	9.9373E-07	3.4698E-06	2.6415E+00	1.7713E+00

BRANCHES

BRANCH	KFACTOR (LBF-S^2/ (LBM-FT)^2)	DELP (PSI)	FLOW RATE (LBM/SEC)	VELOCITY (FT/SEC)	REYN. NO.	MACH NO.	ENTROPY GEN. BTU/(R-SEC)	LOST WORK (LBF-FT/SEC)
111	1.118E+36	6.952E-02	3.693E-11	6.643E+08	5.872E+04	4.872E+05	2.202E+01	7.034E+05
34	7.334E+21	-6.518E-02	-5.686E-25	-1.863E-13	8.816E-14	1.473E-16	1.066E-56	3.069E-52
1110	9.858E-05	5.841E-04	1.302E-04	5.821E-05	2.717E+01	4.075E-08	8.735E-20	3.145E-15
109	7.138E-06	6.298E-04	3.399E-04	6.542E-05	5.249E+01	4.727E-08	1.111E-19	3.692E-15
98	7.822E-06	6.787E-04	2.200E-04	3.543E-05	3.341E+01	2.606E-08	3.267E-20	1.036E-15
82	8.705E-06	7.253E-04	1.733E-04	2.589E-05	2.785E+01	1.946E-08	1.752E-20	5.230E-16
164	9.824E+29	2.028E-01	6.136E-32	1.396E-16	7.927E-19	1.101E-19	1.794E-69	5.165E-65
1610	9.824E+29	2.701E-01	1.188E-29	2.703E-14	1.535E-16	2.131E-17	1.302E-62	3.748E-58
169	9.824E+29	2.694E-01	8.099E-30	1.843E-14	1.046E-16	1.453E-17	4.125E-63	1.188E-58
168	9.824E+29	2.687E-01	7.365E-30	1.676E-14	9.514E-17	1.321E-17	3.102E-63	8.931E-59
162	9.824E+29	2.680E-01	9.431E-30	2.146E-14	1.218E-16	1.692E-17	6.513E-63	1.875E-58
45	2.035E+22	-1.698E-03	-2.899E-26	-9.490E-15	4.474E-15	7.482E-18	3.925E-60	1.127E-55
1611	9.824E+29	2.706E-01	3.523E-29	8.016E-14	4.551E-16	6.320E-17	3.394E-61	9.773E-57

SOLID NODES

NODESL	CPSLD	TS
	BTU/LB F	F
6	2.653E-03	-4.211E+02
7	2.419E-03	-4.226E+02
12	3.146E-03	-4.189E+02
13	3.710E-03	-4.168E+02
14	4.729E-03	-4.136E+02
15	5.606E-03	-4.112E+02

SOLID TO SOLID CONDUCTOR

ICONSS	CONDKIJ	QDOTSS
	BTU/S FT F	BTU/S
67	2.897E-03	1.081E-03
1514	3.603E-03	9.065E-03
1413	3.393E-03	1.373E-02
1312	3.198E-03	8.668E-03
126	3.035E-03	8.674E-03

SOLID TO FLUID CONDUCTOR

ICONSF	QDOTSF	HCSF	HCSFR
	BTU/S	BTU/S	FT**2 F
62	6.580E-03	2.365E-03	0.000E+00
74	2.603E-02	1.987E-02	0.000E+00
1511	-1.688E-02	2.248E-03	0.000E+00
1410	-2.734E-02	2.816E-03	0.000E+00
139	1.967E-03	1.602E-03	0.000E+00
128	-5.800E-03	2.193E-03	0.000E+00

:
:
:
:

ISTEP = 498500   TAU = 0.17696E+06

BOUNDARY NODES

NODE	P(PSI)	TF(F)	Z(COMP)	RHO	QUALITY
				(LBM/FT^3)	
1	1.6180E+01	-4.1854E+02	9.2331E-01	8.0053E-02	1.0000E+00
3	1.9636E+01	-4.2270E+02	2.2678E-02	4.4005E+00	0.0000E+00
5	1.6180E+01	-4.2270E+02	1.8696E-02	4.3983E+00	0.0000E+00
16	1.9904E+01	-4.2260E+02	2.2947E-02	4.3965E+00	0.0000E+00

SOLUTION

INTERNAL NODES

NODE	P(PSI)	TF(F)	Z	RHO	EM(LBM)	QUALITY
				(LBM/FT^3)		
2	1.9636E+01	-4.1306E+02	9.3251E-01	8.4887E-02	1.0533E+01	1.0000E+00
4	1.7480E+01	-4.2212E+02	1.9994E-02	4.3745E+00	1.4039E+03	0.0000E+00
8	1.9635E+01	-4.1076E+02	9.4073E-01	8.0190E-02	1.3936E+01	1.0000E+00
9	1.9635E+01	-4.0952E+02	9.4462E-01	7.7879E-02	1.3058E+01	1.0000E+00
10	1.9634E+01	-4.0940E+02	9.4497E-01	7.7664E-02	9.7903E+00	1.0000E+00
11	1.9633E+01	-4.1278E+02	9.3359E-01	8.4276E-02	3.8037E+00	1.0000E+00

NODE	H BTU/LB	ENTROPY BTU/LB-R	EMU LBM/FT-SEC	COND BTU/FT-S-R	CP BTU/LB-R	GAMA
2	1.0741E+02	7.5338E+00	9.5991E-07	3.3515E-06	2.7120E+00	1.8151E+00
4	-1.0676E+02	2.0036E+00	8.5523E-06	1.6028E-05	2.3407E+00	1.7874E+00
8	1.1361E+02	7.6636E+00	1.0024E-06	3.5096E-06	2.6838E+00	1.7965E+00
9	1.1693E+02	7.7308E+00	1.0252E-06	3.5953E-06	2.6706E+00	1.7878E+00
10	1.1725E+02	7.7371E+00	1.0274E-06	3.6035E-06	2.6694E+00	1.7871E+00
11	1.0816E+02	7.5500E+00	9.6507E-07	3.3705E-06	2.7083E+00	1.8127E+00

BRANCHES

BRANCH	KFACTOR (LBF-S^2/ (LBM-FT)^2)	DELP (PSI)	FLOW RATE (LBM/SEC)	VELOCITY (FT/SEC)	REYN. NO.	MACH NO.	ENTROPY GEN. BTU/(R-SEC)	LOST WORK LBF-FT/SEC
111	1.118E+36	-3.453E+00	3.557E-11	6.398E+08	5.656E+04	4.692E+05	1.967E+01	6.286E+05
34	7.323E+21	2.156E+00	1.902E-20	6.224E-09	2.930E-09	4.925E-12	3.989E-43	1.145E-38
1110	1.102E-04	7.029E-04	-9.700E-05	-3.559E-05	1.994E+01	2.392E-08	3.277E-20	1.194E-15
109	1.404E-04	6.751E-04	-1.966E-05	-3.700E-06	2.610E+00	2.488E-09	3.515E-22	1.373E-17
98	1.536E-04	6.861E-04	1.332E-05	2.151E-06	1.706E+00	1.462E-09	1.192E-22	4.530E-18
82	4.446E-05	7.165E-04	4.163E-05	6.350E-06	5.568E+00	4.396E-09	1.043E-21	3.779E-17
164	9.819E+29	2.424E+00	8.498E-11	1.933E+05	1.096E+03	1.525E+02	4.760E-06	1.371E-01
1610	9.819E+29	2.701E-01	8.604E-11	1.957E+05	1.109E+03	1.544E+02	4.941E-06	1.423E-01
169	9.819E+29	2.694E-01	6.622E-11	1.506E+05	8.539E+02	1.188E+02	2.253E-06	6.486E-02
168	9.819E+29	2.687E-01	6.222E-11	1.415E+05	8.023E+02	1.117E+02	1.869E-06	5.380E-02
162	9.819E+29	2.680E-01	7.982E-11	1.816E+05	1.029E+03	1.433E+02	3.945E-06	1.136E-01
45	2.046E+22	1.300E+00	7.870E-21	2.591E-09	1.246E-09	2.014E-12	7.817E-44	2.280E-39
1611	9.819E+29	2.708E-01	3.453E-10	7.853E+05	4.452E+03	6.196E+02	3.192E-04	9.192E+00

SOLID NODES

NODESL	CPSLD BTU/LB F	TS F
6	4.939E-03	-4.130E+02
7	2.497E-03	-4.221E+02
12	5.755E-03	-4.108E+02
13	6.248E-03	-4.096E+02
14	6.277E-03	-4.095E+02
15	5.038E-03	-4.127E+02

SOLID TO SOLID CONDUCTOR

ICONSS	CONDKIJ BTU/S FT F	QDOTSS BTU/S
67	3.184E-03	7.511E-03
1514	3.693E-03	-1.235E-02
1413	3.810E-03	3.281E-04
1312	3.763E-03	5.954E-03
126	3.639E-03	1.035E-02

SOLID TO FLUID CONDUCTOR

ICONSF	QDOTSF	HCSF	HCSFR
	BTU/S	BTU/S	FT**2 F
62	5.860E-03	2.255E-03	0.000E+00
74	3.243E-02	2.108E-02	0.000E+00
1511	1.100E-02	2.318E-03	0.000E+00
1410	-6.260E-03	2.059E-03	0.000E+00
139	-1.346E-03	1.452E-03	0.000E+00
128	-4.034E-04	1.072E-03	0.000E+00

****

TIME OF ANALYSIS WAS 2213.17058690000 SECS

****

APPENDIX OO—INPUT AND OUTPUT DATA FILES FROM EXAMPLE 30

Solid Propellant Burning and Thruster Model

Contents

Back to Appendix OO

```
GFSSP VERSION
 605
GFSSP INSTALLATION PATH
C:\Program Files (x86)\GFSSP605\
ANALYST
AKM
INPUT DATA FILE NAME
C:\GFSSP605InstallTest\EXAMPLES\EX30\EX30.dat
OUTPUT FILE NAME
EX30.out
TITLE
Solid Propellant Burning & Thruster Model
USETUP
F
DENCON          GRAVITY        ENERGY         MIXTURE        THRUST         STEADY         TRANSV         SAVER
F               F              T              F              F              F              T              F
HEX             HCOEF          REACTING       INERTIA        CONDX          ADDPROP        PRINTI         ROTATION
F               F              F              T              F              T              F              F
BUOYANCY        HRATE          INVAL          MSORCE         MOVBND         TPA            VARGEO         TVM
F               T              F              F              F              F              F              F
SHEAR           PRNTIN         PRNTADD        OPVALVE        TRANSQ         CONJUG         RADIAT         WINPLOT
F               F              T              F              F              F              F              T
PRESS           INSUC          VARROT         CYCLIC         CHKVALS        WINFILE        DALTON         NOSTATS
F               F              F              F              F              F              F              F
NORMAL          SIMUL          SECONDL        NRSOLVT        IBDF           NOPLT          PRESREG        FLOWREG
F               F              F              F              2              T              0              0
TRANS_MOM       USERVARS       PSMG           ISOLVE         PLOTADD        SIUNITS        TECPLOT        MDGEN
F               T              F              1              T              F              F              F
NUM_USER_VARS   IFR_MIX        PRINTD         SATTABL        MSORIN         PRELVLV        LAMINAR        HSTAG
3               1              F              F              F              F              T              T
DFLI
T
NNODES        NINT          NBR           NF
 22           21            21            1
RELAXK        RELAXD        RELAXH        CC            NITER         RELAXNR       RELAXHC       RELAXTS
 1            0.05          1             1e-07         3000 1        1             1
DTAU          TIMEF         TIMEL         NPSTEP        NPWSTEP       WPLSTEP       WPLBUFF
 0.0001       0             0.12          100           1             1             1.1
NFLUID(I),  I = 1, NF
 33
RREF      CPREF    GAMREF   EMUREF     AKREF       PREF    TREF    HREF    SREF
 66.35    0.4729   1.22     1.26e-05   4.133e-06   14.7    80      0       0
NODE      INDEX    DESCRIPTION
 2        1        "Node 2"
 3        1        "Node 3"
 4        1        "Node 4"
 5        1        "Node 5"
 6        1        "Node 6"
 7        1        "Node 7"
 8        1        "Node 8"
 9        1        "Node 9"
 10       1        "Node 10"
 11       1        "Node 11"
 12       1        "Node 12"
 13       1        "Node 13"
```

```
 14       1        "Node 14"
 15       1        "Node 15"
 16       1        "Node 16"
 17       2        "Node 17"
 1        1        "Node 1"
 18       1        "Node 18"
 19       1        "Node 19"
 20       1        "Node 20"
 21       1        "Node 21"
 22       1        "Node 22"
NODE   PRES (PSI)   TEMP(DEGF)   MASS SOURC   HEAT SOURC   THRST AREA   NODE-VOLUME   CONCENTRATION
 2     14.7         4000                    0              0            0              0
 3     14.7         4000                    0              0            0              0
 4     14.7         4000                    0              0            0              0
 5     14.7         4000                    0              0            0              0
 6     14.7         4000                    0              0            0              0
 7     14.7         4000                    0              0            0              0
 8     14.7         4000                    0              0            0              0
 9     14.7         4000                    0              0            0              0
 10    14.7         4000                    0              0            0              0
 11    14.7         4000                    0              0            0              0
 12    14.7         4000                    0              0            0              0
 13    14.7         4000                    0              0            0              0
 14    14.7         4000                    0              0            0              0
 15    14.7         4000                    0              0            0              0
 16    14.7         4000                    0              0            0              0
 1     200          4000                    0              0            0              0
 18    14.7         4000                    0              0            0              0
 19    14.7         4000                    0              0            0              0
 20    14.7         4000                    0              0            0              0
 21    14.7         4000                    0              0            0              0
 22    14.7         4000                    0              0            0              0
 Hist17.dat
INODE     NUMBR     NAMEBR
 2        2         23     222
 3        2         23     34
 4        2         34     45
 5        2         45     56
 6        2         56     67
 7        2         67     78
 8        2         78     89
 9        2         89     910
 10       2         910    1011
 11       2         1011   1112
 12       2         1112   1213
 13       2         1213   1314
 14       2         1314   1415
 15       2         1415   1516
 16       2         1516   1617
 1        1         118
 18       2         118    1819
 19       2         1819   1920
 20       2         1920   2021
 21       2         2021   2122
 22       2         2122   222
```

```
BRANCH      UPNODE     DNNODE     OPTION    DESCRIPTION
 23         2          3          1         "Restrict 23"
 34         3          4          1         "Restrict 34"
 45         4          5          1         "Restrict 45"
 56         5          6          1         "Restrict 56"
 67         6          7          1         "Restrict 67"
 78         7          8          1         "Restrict 78"
 89         8          9          1         "Restrict 89"
 910        9          10         1         "Restrict 910"
 1011       10         11         1         "Restrict 1011"
 1112       11         12         1         "Restrict 1112"
 1213       12         13         1         "Restrict 1213"
 1314       13         14         1         "Restrict 1314"
 1415       14         15         1         "Restrict 1415"
 1516       15         16         1         "Restrict 1516"
 1617       16         17         1         "Restrict 1617"
 118        1          18         1         "Pipe 118"
 1819       18         19         22        "Expan 1819"
 1920       19         20         1         "Pipe 1920"
 2021       20         21         8         "Expan 2021"
 2122       21         22         1         "Pipe 2122"
 222        22         2          1         "Restrict 222"
BRANCH   OPTION -1     LENGTH      DIA          EPSD      ANGLE     AREA
 23                    0.02        0.3          0         0         0.070685775
BRANCH   OPTION -1     LENGTH      DIA          EPSD      ANGLE     AREA
 34                    0.02        0.268        0         0         0.05641039004
BRANCH   OPTION -1     LENGTH      DIA          EPSD      ANGLE     AREA
 45                    0.02        0.258        0         0         0.05227919919
BRANCH   OPTION -1     LENGTH      DIA          EPSD      ANGLE     AREA
 56                    0.02        0.246        0         0         0.04752911511
BRANCH   OPTION -1     LENGTH      DIA          EPSD      ANGLE     AREA
 67                    0.02        0.25         0         0         0.04908734375
BRANCH   OPTION -1     LENGTH      DIA          EPSD      ANGLE     AREA
 78                    0.2212      0.268        0         0         0.05641039004
BRANCH   OPTION -1     LENGTH      DIA          EPSD      ANGLE     AREA
 89                    0.22        0.302        0         0         0.07163139359
BRANCH   OPTION -1     LENGTH      DIA          EPSD      ANGLE     AREA
 910                   0.44        0.354        0         0         0.09842287311
BRANCH   OPTION -1     LENGTH      DIA          EPSD      ANGLE     AREA
 1011                  0.44        0.424        0         0         0.14119562096
BRANCH   OPTION -1     LENGTH      DIA          EPSD      ANGLE     AREA
 1112                  0.44        0.494        0         0         0.19166526431
BRANCH   OPTION -1     LENGTH      DIA          EPSD      ANGLE     AREA
 1213                  0.44        0.562        0         0         0.24806308799
BRANCH   OPTION -1     LENGTH      DIA          EPSD      ANGLE     AREA
 1314                  0.44        0.632        0         0         0.31370661104
BRANCH   OPTION -1     LENGTH      DIA          EPSD      ANGLE     AREA
 1415                  0.22        0.684        0         0         0.36745293276
BRANCH   OPTION -1     LENGTH      DIA          EPSD      ANGLE     AREA
 1516                  0.084       0.708        0         0         0.39369149244
BRANCH   OPTION -1     LENGTH      DIA          EPSD      ANGLE     AREA
 1617                  0.084       0.72         0         0         0.407150064
BRANCH   OPTION -1     LENGTH      DIA          EPSD      ANGLE     AREA
 118                   12          0.1          0         0         0.007853975
```

```
BRANCH   OPTION -22    AREA        FLOW COEF
 1819                  0.0079      1
BRANC    OPTION -1     LENGTH      DIA          EPSD      ANGLE     AREA
 1920                  0.5         0.25         0         0         0.04908734375
BRA      OPTION -8     PIPE DIA    EXP DIA      AREA
 2021                  0.25        0.5          0.049087
BR       OPTION -1     LENGTH      DIA          EPSD      ANGLE     AREA
 2122                  0.5         0.5          0         0         0.196349375
BRA      OPTION -1     LENGTH      DIA          EPSD      ANGLE     AREA
 222                   0.02        0.4          0         0         0.1256636
INITIAL FLOWRATES IN BRANCHES FOR UNSTEADY FLOW
 23     0
 34     0
 45     0
 56     0
 67     0
 78     0
 89     0
 910    0
 1011   0
 1112   0
 1213   0
 1314   0
 1415   0
 1516   0
 1617   0
 118    0
 1819   0
 1920   0
 2021   0
 2122   0
 222    0
BRANCH    NOUBR    NMUBR
 23        1        222
 34        1        23
 45        1        34
 56        1        45
 67        1        56
 78        1        67
 89        1        78
 910       1        89
 1011      1        910
 1112      1        1011
 1213      1        1112
 1314      1        1213
 1415      1        1314
 1516      1        1415
 1617      1        1516
 118       0
 1819      1        118
 1920      1        1819
 2021      1        1920
 2122      1        2021
 222       1        2122
```

```
BRANCH    NODBR    NMDBR
 23       1        34
 34       1        45
 45       1        56
 56       1        67
 67       1        78
 78       1        89
 89       1        910
 910      1        1011
 1011     1        1112
 1112     1        1213
 1213     1        1314
 1314     1        1415
 1415     1        1516
 1516     1        1617
 1617     0
 118      1        1819
 1819     1        1920
 1920     1        2021
 2021     1        2122
 2122     1        222
 222      1        23
BRANCH
 23
  UPSTRM BR.   ANGLE
  222          0.00000
  DNSTRM BR.   ANGLE
  34           0.00000
BRANCH
 34
  UPSTRM BR.   ANGLE
  23           0.00000
  DNSTRM BR.   ANGLE
  45           0.00000
BRANCH
 45
  UPSTRM BR.   ANGLE
  34           0.00000
  DNSTRM BR.   ANGLE
  56           0.00000
BRANCH
 56
  UPSTRM BR.   ANGLE
  45           0.00000
  DNSTRM BR.   ANGLE
  67           0.00000
BRANCH
 67
  UPSTRM BR.   ANGLE
  56           0.00000
  DNSTRM BR.   ANGLE
  78           0.00000
```

```
BRANCH
 78
  UPSTRM BR.   ANGLE
  67           0.00000
  DNSTRM BR.   ANGLE
  89           0.00000
BRANCH
 89
  UPSTRM BR.   ANGLE
  78           0.00000
  DNSTRM BR.   ANGLE
  910          0.00000
BRANCH
 910
  UPSTRM BR.   ANGLE
  89           0.00000
  DNSTRM BR.   ANGLE
  1011         0.00000
BRANCH
 1011
  UPSTRM BR.   ANGLE
  910          0.00000
  DNSTRM BR.   ANGLE
  1112         0.00000
BRANCH
 1112
  UPSTRM BR.   ANGLE
  1011         0.00000
  DNSTRM BR.   ANGLE
  1213         0.00000
BRANCH
 1213
  UPSTRM BR.   ANGLE
  1112         0.00000
  DNSTRM BR.   ANGLE
  1314         0.00000
BRANCH
 1314
  UPSTRM BR.   ANGLE
  1213         0.00000
  DNSTRM BR.   ANGLE
  1415         0.00000
BRANCH
 1415
  UPSTRM BR.   ANGLE
  1314         0.00000
  DNSTRM BR.   ANGLE
  1516         0.00000
BRANCH
 1516
  UPSTRM BR.   ANGLE
  1415         0.00000
  DNSTRM BR.   ANGLE
  1617         0.00000
```

```
BRANCH
 1617
  UPSTRM BR.    ANGLE
  1516          0.00000
  DNSTRM BR.    ANGLE
BRANCH
 118
  UPSTRM BR.    ANGLE
  DNSTRM BR.    ANGLE
  1819          0.00000
BRANCH
 1819
  UPSTRM BR.    ANGLE
  118           0.00000
  DNSTRM BR.    ANGLE
  1920          0.00000
BRANCH
 1920
  UPSTRM BR.    ANGLE
  1819          0.00000
  DNSTRM BR.    ANGLE
  2021          0.00000
BRANCH
 2021
  UPSTRM BR.    ANGLE
  1920          0.00000
  DNSTRM BR.    ANGLE
  2122          0.00000
BRANCH
 2122
  UPSTRM BR.    ANGLE
  2021          0.00000
  DNSTRM BR.    ANGLE
  222           0.00000
BRANCH
 222
  UPSTRM BR.    ANGLE
  2122          0.00000
  DNSTRM BR.    ANGLE
  23            0.00000
NUMBER OF BRANCHES WITH INERTIA
 16
 23
 34
 45
 56
 67
 78
 89
 910
 1011
 1112
 1213
 1314
 1415
```

1516
1617
222

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Example 30 User Subroutines

```
C***********************************************************************
C                                                                      *
C     ***** GFSSP USER SUBROUTINES *****                               *
C                                                                      *
C***********************************************************************
                              :
                              :
                              :
                              :

      SUBROUTINE FILENUM
C     PURPOSE: ESTABLISH THE FORTRAN FILE NUMBERS FOR READING &
C              WRITING OF INFORMATION
C***********************************************************************
       INCLUDE 'comblk.for'
C***********************************************************************
C   FILE NUMBERS FOR USER DEFINED FILES (THESE FILES CAN BE USED
C   IN ANY OF THE USER SUBROUTINES; HOWEVER, MOST LIKELY USE IS
C   IN THE PRNUSER SUBROUTINE).  COMMENT OUT FILE NUMBERS NOT IN USE.
C
          NUSR1= 41
C          NUSR2=
C          NUSR3=
      RETURN
      END
C***********************************************************************
      SUBROUTINE SORCEQ(IPN,TERMD)
C     PURPOSE: ADD HEAT SOURCES
C     IPN - GFSSP INDEX NUMBER FOR NODE
C     TERMD - COMPONENT OF LINEARIZED SOURCE TERM APPEARING IN THE
C             DENOMINATOR OF THE ENTHALPY OR ENTROPY EQUATION
C***********************************************************************
       INCLUDE 'comblk.for'
C***********************************************************************
C     ADD CODE HERE
      DATA TPROP /4460.0/

C  SET TEMPERATURE OF NODE TO PROPELLANT TEMPERATURE

      IF (NODE(IPN).EQ.1) THEN
         SORCEH(IPN) = SORCEMAS(IPN) * CPNODE(IPN) * TPROP
         TERMD = SORCEMAS(IPN) * CPNODE(IPN)
      END IF

      RETURN
      END
C***********************************************************************
      SUBROUTINE BNDUSER
C     PURPOSE: MODIFY BOUNDARY CONDITIONS
C***********************************************************************
      INCLUDE 'comblk.for'
C***********************************************************************
C     ADD CODE HERE
```

```
C     DATA OF SOLID PROPELLANT BURN RATE
      DATA ABR,CNBR/0.0687,0.30/
      DATA PROPDEN/0.06/ ! LBM/IN**3
      DATA PROPOD/0.25/ ! INCH
      LOGICAL LBURN
      DATA LBURN/.TRUE./

C     OBTAIN INDICES FOR NODE AND BRANCHES

      CALL INDEXI(1,NODE,NNODES,IP1)
      CALL INDEXI(118,IBRANCH,NBR,IB118)
      CALL INDEXI(1819,IBRANCH,NBR,IB1819)

      if( lburn ) then

C        CALCULATE BURNING RATE, based on pressure at node 1
         PC = P(IP1)/144.
         RINCH = ABR*(PC**CNBR)

C        ESTIMATE NEW DIAMETER, Original Diameter set in VTASC
         ELPROP = BRPR1(IB118)*12. ! PROPELLANT LENGTH IN INCH
         RPROPM = BRPR2M(IB118)*12./2. ! PROPELLANT RADIUS IN PREVIOUS TIME STEP
         RPROP = RPROPM + RINCH*DTAU ! PROPELLANT RADIUS IN CURRENT TIME STEP
         BRPR2(IB118) = 2.*RPROP/12. ! PROPELLANT DIAMETER IN CURRENT TIME STEP

C        ESTIMATE MASS SOURCE FROM BURNING RATE
         VDOT = 2.*PI*RPROPM*ELPROP*RINCH
         SORCEMAS(IP1) = PROPDEN*VDOT

C        ADJUST AREA OF COMPRESSIBLE ORIFICE
         AREA(IB1819) = PI*BRPR2(IB118)**2/4.

      else

         SORCEMAS(IP1) = 0.

      end if

C  WHEN DIAMETER EXCEEDS PROPELLANT OUTER DIAMETER, STOP BURNING

      IF (BRPR2(IB118) .GE. PROPOD/12. ) then

         lburn = .false.
         RELAXNR = 0.3

      end if

C  CALCULATE THRUST IN LBF

      CALL INDEXI(1617, IBRANCH, NBR, IB1617)
      FORCE = FLOWR(IB1617) * VEL(IB1617) / GC

C  PLOT VARIABLES IN WINPLOT

      USRVAR = .TRUE.
```

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```
      USRVARSNUM = 3
      USRPVARNAME(1) = 'RINCH'
      USRPVARUNIT(1) = 'in/s'
      USRPVARNAME(2) = 'SORCEMAS'
      USRPVARUNIT(2) = 'lb/s'
   USRPVARNAME(3) = 'Thrust'
   USRPVARUNIT(3) = 'lbf'

   USRPVAR(1) = RINCH
   USRPVAR(2) = SORCEMAS(IP1)
   USRPVAR(3) = FORCE

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

NOTE: All other user subroutines are not used in Example 30

```
EX30 HISTORY FILE
Hist17.dat
2
0.0     14.7    60.0    1.0    0
100.0   14.7    60.0    1.0    0
```

```
       ************************************************
       G F S S P (Version 605)
       Generalized Fluid System Simulation Program
                           May 2014

       Developed by NASA/Marshall Space Flight Center
       Copyright (C) by Marshall Space Flight Center

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


              RUN DATE:06/25/2014 13:37

        TITLE     :Solid Propellant Burning & Thruster Model
        ANALYST   :AKM
        FILEIN    :C:\GFSSP605InstallTest\EXAMPLES\EX30\EX30.dat
        FILEOUT   :EX30.out
```

```
OPTION VARIABLES

  ADDPROP     BUOYANCY  CONDX     CONJUG    CYCLIC    DALTON    DENCON    ENERGY
  T           F         F         F         F         F         F         T
  FLOWREG     GRAVITY   HCOEF     HEX       HRATE     IFRMIX    INERTIA   INSUC
  0           F         F         F         T         1         T         F
  INVAL       MIXTURE   MOVBND    MSORCE    NORMAL    NRSOLVT   OPVALVE   PLOTADD
  F           F         F         F         F         F         F         T
  PRESREG     PRESS     PRINTI    PRNTADD   PRNTIN    RADIATION REACTING  ROTATION
  0           F         F         T         F         F         F         F
  SAVER       SECONDL   SHEAR     SIMULA    SIUNITS   STEADY    THRUST    TPA
  F           F         F         F         F         F         F         F
  TRANS_MOM   TRANSQ    TRANSV    TVM       TWOD      USRVAR    VARGEO    VARROT
  F           F         T         F         F         T         F         F
RLFVLV    DFLI
  F       T

  NNODES   =   22
  NINT     =   21
  NBR      =   21
  NF       =    1
  NVAR     =   63
  NHREF    =    2


FLUIDS:  IDEL

BOUNDARY NODES
NODE   P            T            RHO          AREA
       (PSI)        (F)          (LBM/FT^3)   (IN^2)
 17    1.4700E+01   6.0000E+01   6.1392E-02   0.0000E+00

ISTEP = 100          TAU = 0.10000E-01
BOUNDARY NODES
NODE   P(PSI)       TF(F)        Z(COMP)      RHO          QUALITY
                                              (LBM/FT^3)
 17    1.4700E+01   6.0000E+01   1.0000E+00   6.1392E-02   0.0000E+00

SOLUTION
INTERNAL NODES
 NODE   P(PSI)       TF(F)        Z            RHO          EM(LBM)      QUALITY
                                               (LBM/FT^3)
 2      6.0273E+02   3.1034E+03   1.0000E+00   3.6713E-01   4.1716E-07   0.0000E+00
 3      5.2483E+02   3.1034E+03   1.0000E+00   3.1968E-01   2.3513E-07   0.0000E+00
 4      4.5478E+02   3.1034E+03   1.0000E+00   2.7701E-01   1.7424E-07   0.0000E+00
 5      4.0009E+02   3.1034E+03   1.0000E+00   2.4370E-01   1.4076E-07   0.0000E+00
 6      3.2374E+02   3.1034E+03   1.0000E+00   1.9720E-01   1.1026E-07   0.0000E+00
 7      2.4742E+02   3.1034E+03   1.0000E+00   1.5071E-01   5.8694E-07   0.0000E+00
 8      1.7956E+02   3.1034E+03   1.0000E+00   1.0937E-01   8.9361E-07   0.0000E+00
 9      1.2592E+02   3.1034E+03   1.0000E+00   7.6698E-02   1.3108E-06   0.0000E+00
 10     8.7389E+01   3.1035E+03   1.0000E+00   5.3229E-02   1.6238E-06   0.0000E+00
 11     6.3236E+01   3.1035E+03   1.0000E+00   3.8517E-02   1.6323E-06   0.0000E+00
 12     4.7645E+01   3.1035E+03   1.0000E+00   2.9020E-02   1.6247E-06   0.0000E+00
 13     3.7213E+01   3.1036E+03   1.0000E+00   2.2666E-02   1.6211E-06   0.0000E+00
 14     3.1187E+01   3.1036E+03   1.0000E+00   1.8995E-02   1.2030E-06   0.0000E+00
```

15	2.7789E+01	3.1036E+03	1.0000E+00	1.6926E-02	5.5787E-07	0.0000E+00
16	2.3977E+01	3.1036E+03	1.0000E+00	1.4604E-02	4.2878E-07	0.0000E+00
1	2.9963E+03	3.1056E+03	1.0000E+00	1.8239E+00	4.9740E-05	0.0000E+00
18	2.5168E+03	3.1028E+03	1.0000E+00	1.5333E+00	4.1814E-05	0.0000E+00
19	6.7285E+02	3.1029E+03	1.0000E+00	4.0990E-01	2.9110E-06	0.0000E+00
20	6.7074E+02	3.1030E+03	1.0000E+00	4.0861E-01	2.9018E-06	0.0000E+00
21	6.1955E+02	3.1032E+03	1.0000E+00	3.7740E-01	1.0721E-05	0.0000E+00
22	6.1947E+02	3.1034E+03	1.0000E+00	3.7733E-01	1.0993E-05	0.0000E+00

NODE	H (TU/LB)	ENTROPY (BTU/LB-R)	EMU (LBM/FT-SEC)	COND (BTU/FT-S-R)	CP (BTU/LB-R)	GAMA
2	1.4298E+03	9.9870E-01	1.2600E-05	4.1330E-06	4.7290E-01	1.2200E+00
3	1.4298E+03	9.9870E-01	1.2600E-05	4.1330E-06	4.7290E-01	1.2200E+00
4	1.4298E+03	9.9870E-01	1.2600E-05	4.1330E-06	4.7290E-01	1.2200E+00
5	1.4298E+03	9.9870E-01	1.2600E-05	4.1330E-06	4.7290E-01	1.2200E+00
6	1.4298E+03	9.9870E-01	1.2600E-05	4.1330E-06	4.7290E-01	1.2200E+00
7	1.4298E+03	9.9870E-01	1.2600E-05	4.1330E-06	4.7290E-01	1.2200E+00
8	1.4298E+03	9.9870E-01	1.2600E-05	4.1330E-06	4.7290E-01	1.2200E+00
9	1.4298E+03	9.9870E-01	1.2600E-05	4.1330E-06	4.7290E-01	1.2200E+00
10	1.4298E+03	9.9870E-01	1.2600E-05	4.1330E-06	4.7290E-01	1.2200E+00
11	1.4298E+03	9.9870E-01	1.2600E-05	4.1330E-06	4.7290E-01	1.2200E+00
12	1.4298E+03	9.9870E-01	1.2600E-05	4.1330E-06	4.7290E-01	1.2200E+00
13	1.4298E+03	9.9870E-01	1.2600E-05	4.1330E-06	4.7290E-01	1.2200E+00
14	1.4299E+03	9.9870E-01	1.2600E-05	4.1330E-06	4.7290E-01	1.2200E+00
15	1.4299E+03	9.9870E-01	1.2600E-05	4.1330E-06	4.7290E-01	1.2200E+00
16	1.4299E+03	9.9870E-01	1.2600E-05	4.1330E-06	4.7290E-01	1.2200E+00
1	1.4308E+03	7.7612E-01	1.2600E-05	4.1330E-06	4.7290E-01	1.2200E+00
18	1.4295E+03	9.9870E-01	1.2600E-05	4.1330E-06	4.7290E-01	1.2200E+00
19	1.4295E+03	9.9870E-01	1.2600E-05	4.1330E-06	4.7290E-01	1.2200E+00
20	1.4296E+03	9.9870E-01	1.2600E-05	4.1330E-06	4.7290E-01	1.2200E+00
21	1.4296E+03	9.9870E-01	1.2600E-05	4.1330E-06	4.7290E-01	1.2200E+00
22	1.4297E+03	9.9870E-01	1.2600E-05	4.1330E-06	4.7290E-01	1.2200E+00

BRANCHES

BRANCH	KFACTOR (LBF-S^2/ (LBM-FT)^2)	DELP (PSI)	FLOW RATE (LBM/SEC)	VELOCITY (FT/SEC)	REYN. NO.	MACH NO.	ENTROPY GEN. BTU/(R-SEC)	LOST WORK (LBF-FT/SEC)
23	1.416E+02	7.790E+01	1.990E-01	1.104E+03	8.045E+05	3.626E-01	1.097E-06	3.041E+00
34	2.803E+02	7.005E+01	1.990E-01	1.589E+03	9.006E+05	5.217E-01	2.493E-06	6.913E+00
45	3.887E+02	5.468E+01	1.990E-01	1.979E+03	9.355E+05	6.497E-01	3.990E-06	1.106E+01
56	5.560E+02	7.635E+01	1.990E-01	2.474E+03	9.811E+05	8.123E-01	6.487E-06	1.799E+01
67	6.356E+02	7.633E+01	1.990E-01	2.961E+03	9.654E+05	9.720E-01	9.166E-06	2.541E+01
78	6.576E+03	6.786E+01	1.990E-01	3.371E+03	9.005E+05	1.107E+00	1.241E-04	3.440E+02
89	5.064E+03	5.364E+01	1.990E-01	3.658E+03	7.991E+05	1.201E+00	1.316E-04	3.650E+02
910	6.711E+03	3.853E+01	1.990E-01	3.796E+03	6.817E+05	1.246E+00	2.487E-04	6.896E+02
1011	4.051E+03	2.415E+01	1.990E-01	3.813E+03	5.691E+05	1.252E+00	2.163E-04	5.997E+02
1112	2.680E+03	1.559E+01	1.990E-01	3.882E+03	4.885E+05	1.274E+00	1.978E-04	5.484E+02
1213	1.911E+03	1.043E+01	1.990E-01	3.980E+03	4.293E+05	1.307E+00	1.871E-04	5.189E+02
1314	1.390E+03	6.026E+00	1.990E-01	4.030E+03	3.818E+05	1.323E+00	1.743E-04	4.832E+02
1415	5.670E+02	3.398E+00	1.990E-01	4.105E+03	3.527E+05	1.347E+00	8.479E-05	2.351E+02
1516	2.058E+02	3.812E+00	1.990E-01	4.300E+03	3.408E+05	1.411E+00	3.454E-05	9.576E+01
1617	2.200E+02	9.277E+00	1.990E-01	4.818E+03	3.351E+05	1.582E+00	4.279E-05	1.186E+02
118	1.755E+06	4.795E+02	1.984E-01	1.994E+03	2.405E+06	6.544E-01	2.706E-03	7.509E+03
1819	1.944E+06	1.844E+03	1.992E-01	1.799E+03	2.099E+06	5.906E-01	3.615E-03	1.002E+04

1920	7.644E+03	2.106E+00	1.992E-01	1.426E+03	9.661E+05	4.680E-01	5.316E-05	1.474E+02
2021	1.858E+05	5.119E+01	1.992E-01	1.430E+03	9.661E+05	4.694E-01	1.296E-03	3.593E+03
2122	2.933E+02	8.073E-02	1.991E-01	3.869E+02	4.829E+05	1.270E-01	2.212E-06	6.133E+00
222	3.440E+01	1.674E+01	1.990E-01	6.045E+02	6.034E+05	1.984E-01	2.592E-07	7.188E-01

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ISTEP = 1200   TAU = 0.12000E+00

BOUNDARY NODES

NODE	P(PSI)	TF(F)	Z(COMP)	RHO (LBM/FT^3)	QUALITY
17	1.4700E+01	6.0000E+01	1.0000E+00	6.1392E-02	0.0000E+00

SOLUTION

INTERNAL NODES

NODE	P(PSI)	TF(F)	Z	RHO (LBM/FT^3)	EM(LBM)	QUALITY
2	1.4700E+01	1.0407E+03	1.0000E+00	2.1264E-02	2.4162E-08	0.0000E+00
3	1.4700E+01	1.0546E+03	1.0000E+00	2.1069E-02	1.5497E-08	0.0000E+00
4	1.4700E+01	1.0596E+03	1.0000E+00	2.0999E-02	1.3208E-08	0.0000E+00
5	1.4700E+01	1.0623E+03	1.0000E+00	2.0962E-02	1.2107E-08	0.0000E+00
6	1.4700E+01	1.0645E+03	1.0000E+00	2.0932E-02	1.1703E-08	0.0000E+00
7	1.4700E+01	1.0678E+03	1.0000E+00	2.0886E-02	8.1343E-08	0.0000E+00
8	1.4700E+01	1.0870E+03	1.0000E+00	2.0627E-02	1.6853E-07	0.0000E+00
9	1.4700E+01	1.1226E+03	1.0000E+00	2.0164E-02	3.4461E-07	0.0000E+00
10	1.4700E+01	1.1793E+03	1.0000E+00	1.9466E-02	5.9385E-07	0.0000E+00
11	1.4700E+01	1.2506E+03	1.0000E+00	1.8654E-02	7.9052E-07	0.0000E+00
12	1.4700E+01	1.3304E+03	1.0000E+00	1.7822E-02	9.9776E-07	0.0000E+00
13	1.4700E+01	1.4145E+03	1.0000E+00	1.7023E-02	1.2175E-06	0.0000E+00
14	1.4700E+01	1.4737E+03	1.0000E+00	1.6502E-02	1.0451E-06	0.0000E+00
15	1.4700E+01	1.3728E+03	1.0000E+00	1.7410E-02	5.7383E-07	0.0000E+00
16	1.4700E+01	7.3638E+02	1.0000E+00	2.6674E-02	7.8318E-07	0.0000E+00
1	1.4700E+01	9.7124E+02	1.0000E+00	2.2296E-02	6.0804E-07	0.0000E+00
18	1.4700E+01	9.7373E+02	1.0000E+00	2.2258E-02	6.0699E-07	0.0000E+00
19	1.4700E+01	9.7924E+02	1.0000E+00	2.2172E-02	1.5746E-07	0.0000E+00
20	1.4700E+01	9.8318E+02	1.0000E+00	2.2112E-02	1.5703E-07	0.0000E+00
21	1.4700E+01	9.8730E+02	1.0000E+00	2.2049E-02	6.2633E-07	0.0000E+00
22	1.4700E+01	9.9609E+02	1.0000E+00	2.1915E-02	6.3849E-07	0.0000E+00

NODE	H (BTU/LB)	ENTROPY (BTU/LB-R)	EMU (LBM/FT-SEC)	COND (BTU/FT-S-R)	CP (BTU/LB-R)	GAMA
2	4.5432E+02	9.9870E-01	1.2600E-05	4.1330E-06	4.7290E-01	1.2200E+00
3	4.6087E+02	9.9870E-01	1.2600E-05	4.1330E-06	4.7290E-01	1.2200E+00
4	4.6326E+02	9.9870E-01	1.2600E-05	4.1330E-06	4.7290E-01	1.2200E+00
5	4.6454E+02	9.9870E-01	1.2600E-05	4.1330E-06	4.7290E-01	1.2200E+00
6	4.6557E+02	9.9870E-01	1.2600E-05	4.1330E-06	4.7290E-01	1.2200E+00
7	4.6715E+02	9.9870E-01	1.2600E-05	4.1330E-06	4.7290E-01	1.2200E+00
8	4.7621E+02	9.9870E-01	1.2600E-05	4.1330E-06	4.7290E-01	1.2200E+00
9	4.9302E+02	9.9870E-01	1.2600E-05	4.1330E-06	4.7290E-01	1.2200E+00
10	5.1984E+02	9.9870E-01	1.2600E-05	4.1330E-06	4.7290E-01	1.2200E+00
11	5.5359E+02	9.9870E-01	1.2600E-05	4.1330E-06	4.7290E-01	1.2200E+00
12	5.9133E+02	9.9870E-01	1.2600E-05	4.1330E-06	4.7290E-01	1.2200E+00
13	6.3106E+02	9.9870E-01	1.2600E-05	4.1330E-06	4.7290E-01	1.2200E+00
14	6.5907E+02	9.9870E-01	1.2600E-05	4.1330E-06	4.7290E-01	1.2200E+00

15	6.1138E+02	9.9870E-01	1.2600E-05	4.1330E-06	4.7290E-01	1.2200E+00
16	3.1040E+02	9.9870E-01	1.2600E-05	4.1330E-06	4.7290E-01	1.2200E+00
1	4.2147E+02	7.7612E-01	1.2600E-05	4.1330E-06	4.7290E-01	1.2200E+00
18	4.2264E+02	9.9870E-01	1.2600E-05	4.1330E-06	4.7290E-01	1.2200E+00
19	4.2525E+02	9.9870E-01	1.2600E-05	4.1330E-06	4.7290E-01	1.2200E+00
20	4.2711E+02	9.9870E-01	1.2600E-05	4.1330E-06	4.7290E-01	1.2200E+00
21	4.2906E+02	9.9870E-01	1.2600E-05	4.1330E-06	4.7290E-01	1.2200E+00
22	4.3322E+02	9.9870E-01	1.2600E-05	4.1330E-06	4.7290E-01	1.2200E+00

BRANCHES

BRANCH	KFACTOR (LBF-S^2/ (LBM-FT)^2)	DELP (PSI)	FLOW RATE (LBM/SEC)	VELOCITY (FT/SEC)	REYN. NO.	MACH NO.	ENTROPY GEN. BTU/(R-SEC)	LOST WORK (LBF-FT/SEC)
23	5.659E+07	6.576E-09	-5.710E-08	4.410E-02	2.308E-01	2.231E-05	4.243E-19	5.000E-13
34	9.268E+07	3.133E-08	-5.493E-08	5.594E-02	2.485E-01	2.817E-05	6.186E-19	7.313E-13
45	1.096E+08	4.408E-08	-5.418E-08	6.053E-02	2.546E-01	3.043E-05	7.020E-19	8.314E-13
56	1.337E+08	5.341E-08	-5.381E-08	6.659E-02	2.653E-01	3.345E-05	8.391E-19	9.952E-13
67	1.263E+08	5.765E-08	-5.350E-08	6.447E-02	2.595E-01	3.236E-05	7.794E-19	9.264E-13
78	1.075E+09	3.255E-07	-5.333E-08	5.527E-02	2.413E-01	2.771E-05	6.567E-18	7.903E-12
89	7.085E+08	2.037E-07	-5.105E-08	4.275E-02	2.050E-01	2.130E-05	3.796E-18	4.674E-12
910	8.429E+08	2.052E-07	-4.708E-08	2.974E-02	1.613E-01	1.465E-05	3.543E-18	4.519E-12
1011	4.930E+08	9.186E-08	-4.082E-08	1.881E-02	1.167E-01	9.106E-06	1.350E-18	1.797E-12
1112	3.559E+08	4.214E-08	-3.211E-08	1.173E-02	7.882E-02	5.557E-06	4.748E-19	6.613E-13
1213	3.380E+08	1.831E-08	-2.114E-08	6.653E-03	4.561E-02	3.081E-06	1.286E-19	1.875E-13
1314	5.432E+08	5.384E-09	-8.483E-09	2.592E-03	1.628E-02	1.173E-06	1.336E-20	2.010E-14
1415	8.072E+12	1.145E-04	-1.972E-13	-4.416E-09	3.496E-07	1.968E-12	2.493E-30	3.555E-24
1516	6.180E+06	-1.912E-10	-5.592E-08	-7.667E-04	9.577E-02	3.510E-07	4.352E-20	4.051E-14
1617	1.586E+05	-8.627E-10	-8.850E-07	-5.098E-03	1.490E+00	2.889E-06	4.429E-18	1.791E-12
118	1.400E+11	1.327E-05	-2.713E-08	2.513E-01	3.290E-01	1.302E-04	1.126E-16	1.256E-10
1819	6.021E+06	-3.632E-04	-5.385E-08	8.215E-02	2.611E-01	4.252E-05	3.787E-20	4.240E-14
1920	2.891E+09	1.108E-06	-5.522E-08	8.021E-02	2.678E-01	4.143E-05	1.960E-17	2.201E-11
2021	6.629E+09	6.441E-06	-5.665E-08	7.811E-02	2.748E-01	4.029E-05	4.854E-17	5.466E-11
2122	1.646E+08	6.091E-08	-6.113E-08	1.732E-02	1.483E-01	8.920E-06	1.515E-18	1.716E-12
222	1.575E+07	5.022E-09	-6.430E-08	2.369E-02	1.949E-01	1.217E-05	1.687E-19	1.970E-13

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14. ABSTRACT
The Generalized Fluid System Simulation Program (GFSSP) is a finite-volume based general-purpose computer program for analyzing steady state and time-dependant flow rates, pressures, temperatures, and concentrations in a complex flow network. The program is capable of modeling real fluids with phase changes, compressibility, mixture thermodynamics, conjugate heat transfer between solid and fluid, fluid transients, pumps, compressors and external body forces such as gravity and centrifugal. The thermofluid system to be analyzed is discretized into nodes, branches, and conductors. The scalar properties such as pressure, temperature, and concentrations are calculated at nodes. Mass flow rates and heat transfer rates are computed in branches and conductors. The graphical user interface allows users to build their models using the 'point, drag, and click' method; the users can also run their models and post-process the results in the same environment. The integrated fluid library supplies thermodynamic and thermophysical properties of 36 fluids, and 24 different resistance/source options are provided for modeling momentum sources or sinks in the branches. This Technical Publication illustrates the application and verification of the code through 30 demonstrated example problems.

15. SUBJECT TERMS
network flow, finite volume method, thermofluid system, two-phase, conjugate heat transfer

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