Generalized Fluid System Simulation Program (GFSSP)
Version 6 – General Purpose Thermo-Fluid Network Analysis Software

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Content

• Introduction

• Additional Capabilities of Version 6
  – Fluid Mixture Option with Phase Change
  – Pressure Regulator Model with Forward Looking Algorithm
  – Prescribed Flow Option
  – Two-dimensional Navier-Stokes Solver
  – SI Option

• Concluding Remarks
Introduction

- GFSSP stands for Generalized Fluid System Simulation Program
- It is a general-purpose computer program to compute pressure, temperature and flow distribution in a flow network
- It was primarily developed to analyze
  - Internal Flow Analysis of a Turbopump
  - Transient Flow Analysis of a Propulsion System
- GFSSP development started in 1994 with an objective to provide a generalized and easy to use flow analysis tool for thermo-fluid systems
Development History

• Version 1.4 (Steady State) was released in 1996
• Version 2.01 (Thermodynamic Transient) was released in 1998
• Version 3.0 (User Subroutine) was released in 1999
• Graphical User Interface, VTASC was developed in 2000
• Selected for NASA Software of the Year Award in 2001
• Version 4.0 (Fluid Transient and post-processing capability) is released in 2003
• Version 5 (Conjugate Heat Transfer) is released in 2007
Network Definition

GFSSP calculates pressure, temperature, and concentrations at nodes and calculates flow rates through branches.
Graphical User Interface (VTASC)

Input Data File
- Creates Flow Circuit
- Runs GFSSP
- Displays results graphically

Solver & Property Module
- Equation Generator
- Equation Solver
- Fluid Property Program

Output Data File

User Subroutines
- New Physics
  - Time dependent process
  - Non-linear boundary conditions
  - External source term
  - Customized output
  - New resistance / fluid option
## Mathematical Closure

<table>
<thead>
<tr>
<th>Unknown Variables</th>
<th>Available Equations to Solve</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Pressure</td>
<td>1. Mass Conservation Equation</td>
</tr>
<tr>
<td>2. Flowrate</td>
<td>2. Momentum Conservation Equation</td>
</tr>
<tr>
<td>5. Specie Concentrations</td>
<td>5. Conservation Equations for Mass Fraction of Species</td>
</tr>
</tbody>
</table>
Capabilities

- Steady or unsteady flow
- Compressible or incompressible flow
- Single fluid or mixture
- 25 flow resistance and 33 fluid options
- Options for new components and physics through User Subroutine
- Options for new fluid through table look-up
- Conjugate Heat Transfer
- Interface with Thermal Analysis Code, SINDA-G/PATRAN
- Translator of SINDA/Fluint Model
Additional Capabilities of Version 6

• Fluid Mixture Option with Phase Change
• Pressure Regulator Model with Forward Looking Algorithm
• Prescribed Flow Option
• Two-dimensional Navier-Stokes Solver
• SI Option
Fluid Mixture Option with Phase Change

- The mixture capability in earlier versions of GFSSP does not allow phase change in any constituent of the mixture.
- In liquid propulsion applications, there are situations where one of the constituents is saturated, i.e. mixture of liquid and vapor in equilibrium.
  - For example during purging of liquid oxygen by ambient helium, a mixture of helium, LO2 and GO2 exist.
- Why is there such a limitation?
  - Because the energy conservation equation of the mixture is solved in terms of temperature.
  - For calculating phase change, energy equation for each species must be solved in terms of enthalpy or entropy.
Mathematical Formulation

- **Mass Conservation**
  - Mixture Mass
  - Concentration of Species
- **Momentum Conservation**
  - Mixture Momentum
- **Energy Conservation**
  - Temperature option
    - Energy Conservation is formulated in terms of temperature
    - Applicable for gas mixture
  - Enthalpy option – 1
    - Temperature is calculated by an iterative Newton-Raphson method
  - Enthalpy option - 2
    - Separate Energy Equations are solved for Individual Species
    - Applicable for liquid-gas mixture with phase change
Enthalpy Option - 1

Mixture Enthalpy Equation

\[
h_{i,\tau+\Delta\tau} = \frac{\sum_{j=1}^{n} \sum_{k=1}^{n_f} x_{j,k} h_{j,k,\text{MAX}} \left[ -m_{ij},0 \right] + \frac{(m h_i)_\tau}{\Delta \tau} + Q_i}{\sum_{j=1}^{n} \sum_{k=1}^{n_f} x_{j,k} \text{MAX} \left[ m_{ij},0 \right] + \frac{m_{\tau}}{\Delta \tau}}
\]

Temperature Equation

\[
\sum_{k=1}^{n_f} x_{i,k} h_{i,k} \left( p_i, T_i \right) - h_i = 0
\]

Temperature equation is solved iteratively adjusting \( T_i \) until right hand side of Temperature equation becomes zero.
Separate Energy Equation for Individual Species (SEEIS) – Enthalpy Option - 2

\[
\begin{align*}
\Delta \tau & \frac{m_i h_{ik} - \frac{p}{\rho_k \cdot J}}{\tau + \Delta \tau} - \frac{m_i h_{ik}}{\rho_k \cdot J} \\
\text{Transient Term} & \\
\sum_{j=1}^{j=n} & \left\{ \text{MAX} \left[ -m_{ij} , 0 \right] h_{jk} - \text{MAX} \left[ m_{ij} , 0 \right] h_{ik} \right\} + \dot{Q}_{ik} + \left\{ \pm \dot{Q}_{1 \rightarrow 2}^{HES} \right\} \\
\text{Advection Term} & \\
\text{Source Term} &
\end{align*}
\]
Thermodynamic Properties

• Temperature and other properties of individual species are calculated from node pressure and enthalpy of the species:

\[ T_{ik} = f(p_i, h_{ik}) \]
\[ \rho_{ik} = f(p_i, h_{ik}) \]
\[ \mu_{ik} = f(p_i, h_{ik}) \]
\[ K_{ik} = f(p_i, h_{ik}) \]
\[ C_{p_{ik}} = f(p_i, h_{ik}) \]

• The nodal properties are calculated by averaging the properties of species:

\[ \rho_i = \sum_{k=1}^{n_f} c_{ik} \rho_{ik} \]
\[ \mu_i = \sum_{k=1}^{n_f} c_{ik} \mu_{ik} \]

• Temperature is currently calculated by averaging based on molar concentration of species
• Alternate method of temperature calculation based on Vapor Liquid Equilibrium for multi-component, multi-phase mixture is in progress
Pogo Accumulator with Charge Line and Dump line
GFSSP Model of Pogo Accumulator & Drain Line

Helium Charge System

Segment 1 Accumulator (Nodes 1 to 10)

Segment

Dip Tube Orifice Array

Dip Tube

Communication Ports

Feed Line Pressure

Seg. 3  Seg. 2

Seg. 5  Seg. 6

Dump Port

Deep Space

Drain Valve Assembly
Charging of helium & draining of He-LO2 mixture

Displacement of Oxygen from the Accumulator during charging

Concentrations of Helium and Oxygen in the Dip Tube
Pressure Regulator Model with Forward Looking Algorithm

- In Marching Algorithm, area is guessed and adjusted only once in each time step
- Adjustment of area is calculated based on difference between calculated and desired pressure
- Area adjustment can be done by backward differencing algorithm (Schallhorn-Majumdar) or forward looking algorithm (Schallhorn-Hass)
- Schallhorn-Hass Algorithm has been implemented in GFSSP Version 602
Backward & Forward Differencing Algorithm

\[ A_{\text{new}} = A_\tau - \frac{\partial A}{\partial p} (p_\tau - p_{\text{reg}}) \]

\[ \eta_{\text{relax}} = \text{relaxation factor/reaction lag} \]

\[ \frac{\partial A}{\partial p} \approx \left| \frac{A_\tau - A_{\tau-\Delta\tau}}{p_\tau - p_{\tau-\Delta\tau}} \right|, \]

**Backward Differencing Scheme**

\[ A^{*}_{\tau+\Delta\tau} = \begin{cases} 
\min (\left[A_\tau + \eta_{\text{relax}} (A_{\text{new}} - A_\tau)\right]A_{\text{max}}), \\
\max (\left[A_\tau + \eta_{\text{relax}} (A_{\text{new}} - A_\tau)\right]0) 
\end{cases} \]

where,

\[ A_{\text{new}} = A_\tau \left( \frac{p_{\text{reg}}}{p_\tau} \right)^3 \left( e^{\left( \frac{p_{\text{reg}}}{p_\tau} - 1 \right)} \right) \]

**Forward Differencing Scheme**
Application of Forward Looking Algorithm

Pressure History
(Schallhorn & Haas Algorithm)

Note oscillations over time

Pressure downstream of regulator

Tank Pressure
Fixed Flow Option

• A new branch option has been introduced to fix flowrate in a given branch
• The fixed flow branch can only be located adjacent to a Boundary Node
• For unsteady option, a history file will be needed to specify flowrate and area at all timesteps
• With this new option a user can prescribe either pressure or flowrate as boundary condition
• Flow Regulator option is also available in unsteady mode to fix flowrate in an internal branch
Algorithm for Fixed Flow Option (Schallhorn)

\[ \Delta p = A + C \dot{m} \]

where \( A = \alpha \dot{m} \); \( C = -\alpha \); where \( \alpha = 1 \times 10^{25} \)

Substituting \( A \) and \( C \), one gets:

\[ \dot{m} = \frac{\dot{m}}{m} \]
New Resistance Option – Fixed Flow
Properties of Fixed Flow Option

Flowrate
Area
Results of Fixed Flow Option
Two-dimensional Navier-Stokes Solver

- Higher fidelity solutions are often needed that are not within the capacity of system level codes.
- GFSSP's momentum equation has been extended to perform multi-dimensional calculation.
Shear Driven Square Cavity Centerline Velocity Distribution

Velocity Field and Pressure Contours

Predicted Stream Traces
S I Option

- SI Option is for input/output
- GFSSP solver works in Engineering Unit
- User Subroutine must be in Engineering Unit
Concluding Remarks

- GFSSP Version 6 will have additional capabilities to model:
  - Fluid Mixture Option with Phase Change
  - Pressure Regulator Model with Forward Looking Algorithm
  - Prescribed Flow Option
  - Two-dimensional Navier-Stokes Solver
  - SI Option

- GFSSP is available (with no cost) to all Federal Government Organizations and their Contractors

- Concepts/NREC has the license for commercial distribution to domestic and international Companies or Universities

- A process is in work to make an educational version available to all Accredited US Universities for teaching and research
Acknowledgement

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1. Generalized Fluid System Simulation Program - Majumdar; Alok Kumar, Bailey; John W.; Schallhorn; Paul Alan; Steadman; Todd E. , United States Patent No. 6,748,349, June 8, 2004


