GFSSP Software Demo

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Outline

- Introduction & Overview
- Mathematical Formulation
- Resistance Options
- Fluid Options
- Demonstration Models

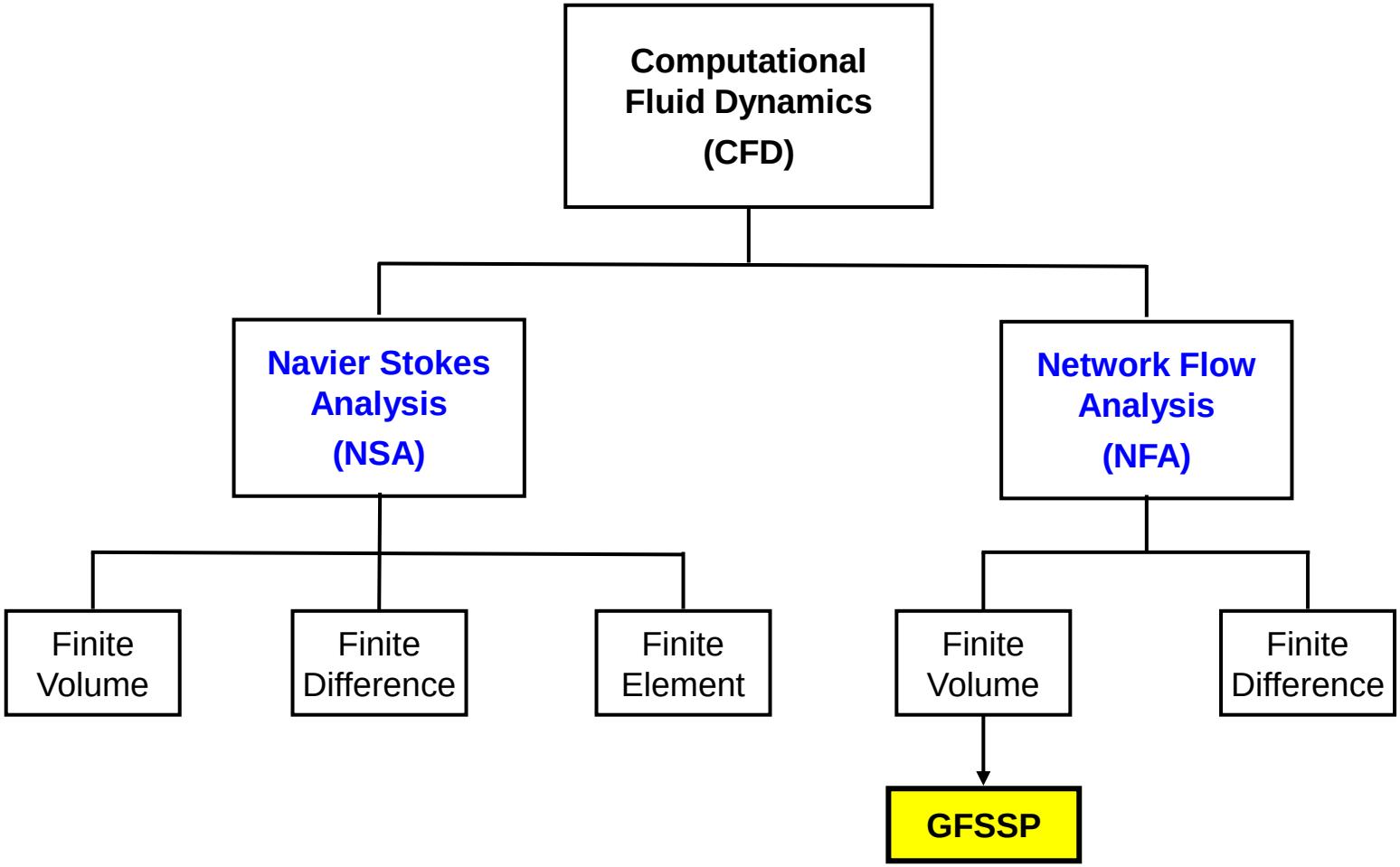
Background

- 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 to provide a generalized and easy to use flow analysis tool
- Selected for NASA Software of the Year award in 2001

Availability

- GFSSP is free for NASA civil servants and on-site contractors. Contact:
  - andre.c.leclair@nasa.gov
  - alok.k.majumdar@nasa.gov
- GFSSP is also free for other civil servants and for contractors with federal contracts
  - Request at software.nasa.gov
- An Educational Version, without user subroutine capability, is available for universities
- More information is available at the website:
  - www.nasa.gov/gfssp

NETWORK FLOW OR NAVIER-STOKES ANALYSIS (1/2)



NETWORK FLOW OR NAVIER-STOKES ANALYSIS (2/2)

Navier Stokes Analysis

- Suitable for detailed flow analysis within a component
- Requires fine grid resolution to accurately model transport processes
- Used after preliminary design

Network Flow Analysis

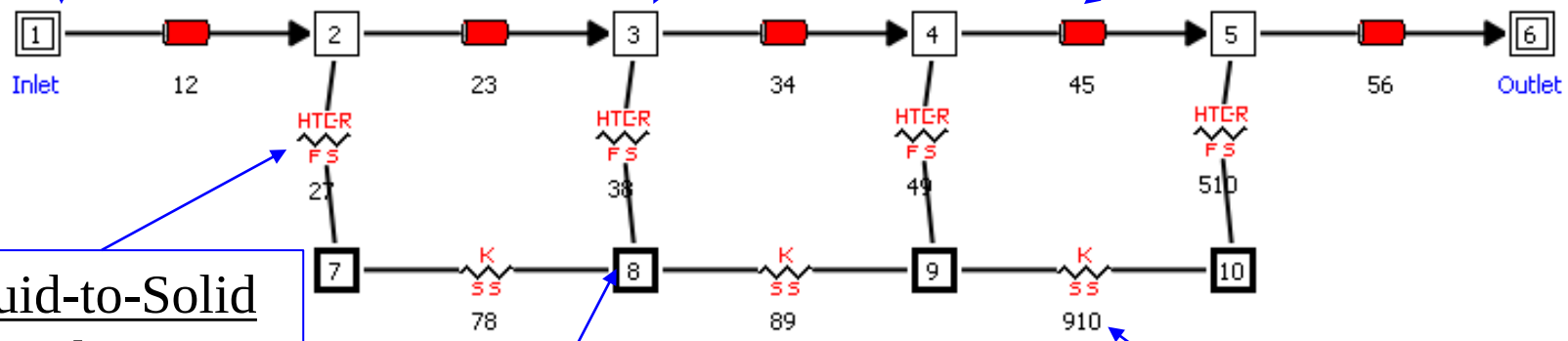
- Suitable for flow analysis of a system consisting of several components
- Uses empirical laws of transport process
- Used during preliminary design

Network Definition

Fluid Boundary Nodes Set boundary P/T

Fluid Nodes: **mass** and **energy** equations are solved for pressures and enthalpies

Fluid Branches: **momentum** equation is solved for flowrates



Fluid-to-Solid Conductors: Convection

Solid Nodes: Solve solid energy equation for wall temperatures

Solid-to-Solid Conductors Conduction

UNITS AND SIGN CONVENTIONS

- Units

	External (input/output)	**Internal** (inside GFSSP)
– Length	- in, ft, m, cm	- feet
– Area	- in^2, ft^2, m^2, cm^2	- $feet^2$
– Pressure	- psia, kPa	- psf
– Temperature	- °F, °R, °C, K	- °R
– Mass injection	- lbm/s, kg/s	- lbm/s
– Heat Source	- Btu/s, W	- Btu/s

- Sign Convention
  - Mass input to node = positive
  - Mass output from node = negative
  - Heat input to node = positive
  - Heat output from node = negative

MATHEMATICAL FORMULATION

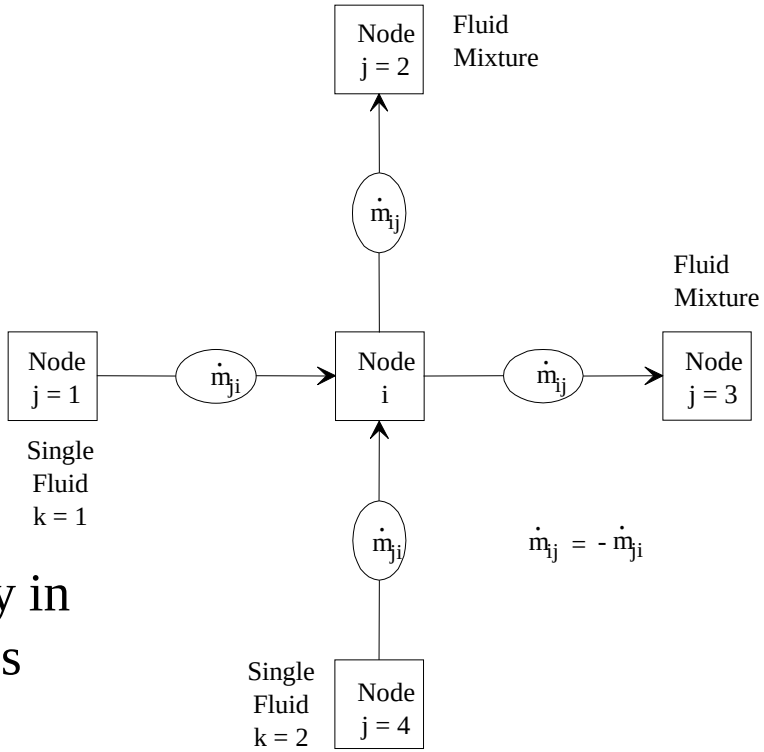
- Principal Variables

Unknown Variables	Available Equations to Solve
1. Pressure	1. Mass Conservation Equation
2. Flowrate	2. Momentum Conservation Equation
3. Fluid Temperature	3. Energy Conservation Equation of Fluid
4. Solid Temperature	4. Energy Conservation Equation of Solid
5. Species Concentration	5. Conservation Equations for Mass Fraction of Species
6. Mass	6. Thermodynamic Equation of State

GOVERNING EQUATIONS

MASS CONSERVATION EQUATION

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



Note : Pressure does not appear explicitly in Mass Conservation Equation although it is earmarked for calculating pressures

GOVERNING EQUATIONS

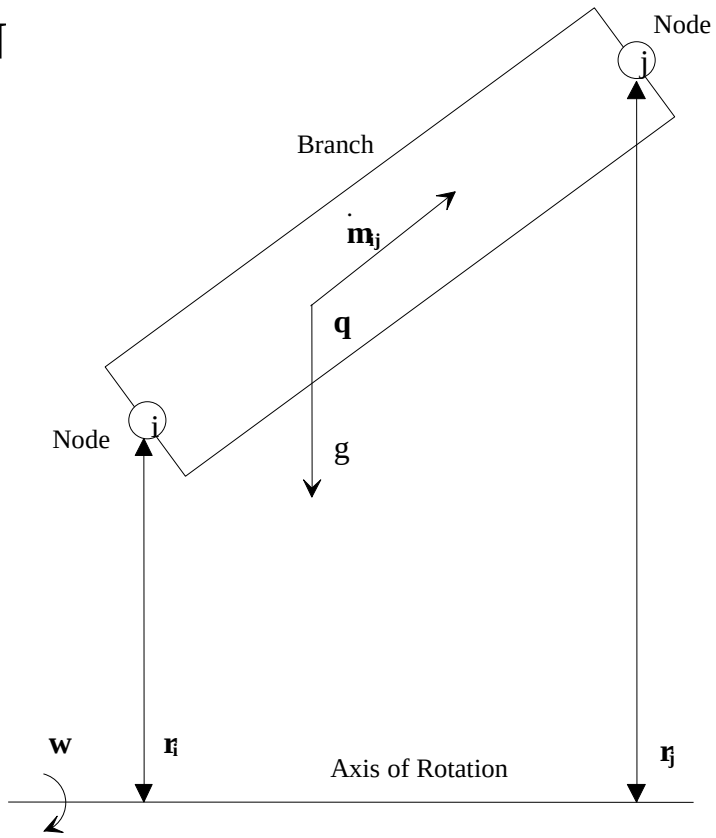
MOMENTUM CONSERVATION EQUATION

- Represents Newton's Second Law of Motion

Mass x Acceleration = Forces

- Unsteady
- Longitudinal Inertia
- Transverse Inertia

- <u>Pressure</u>
- Gravity
- <u>Friction</u>
- Centrifugal
- Shear Stress
- Moving Boundary
- Normal Stress
- External Force



GOVERNING EQUATIONS

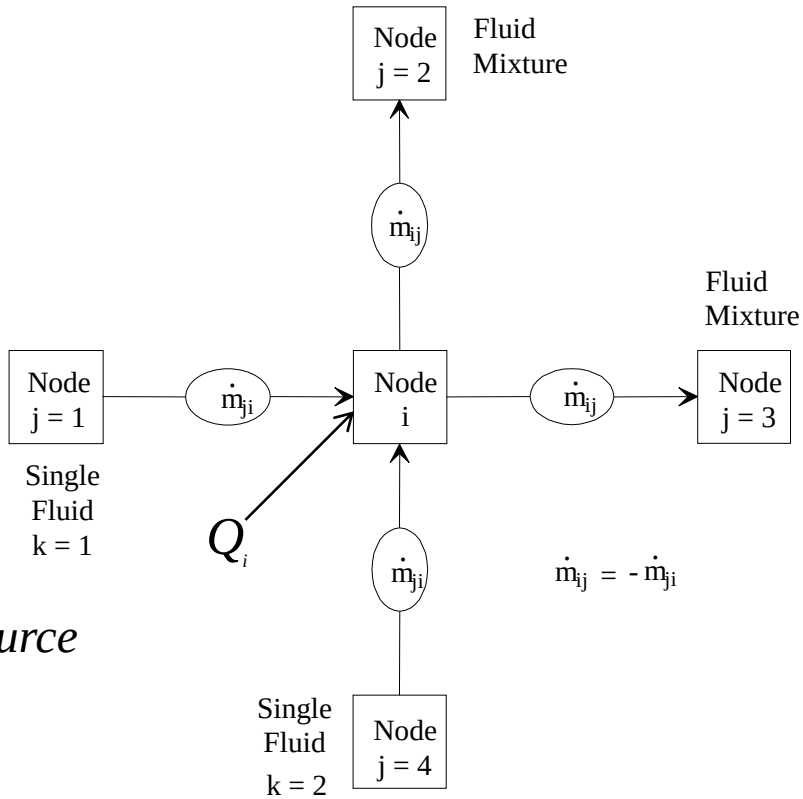
ENERGY CONSERVATION EQUATION

- Energy Conservation Equation can be written in Enthalpy or Entropy
- Based on Upwind Scheme

<u>Enthalpy Equation</u>

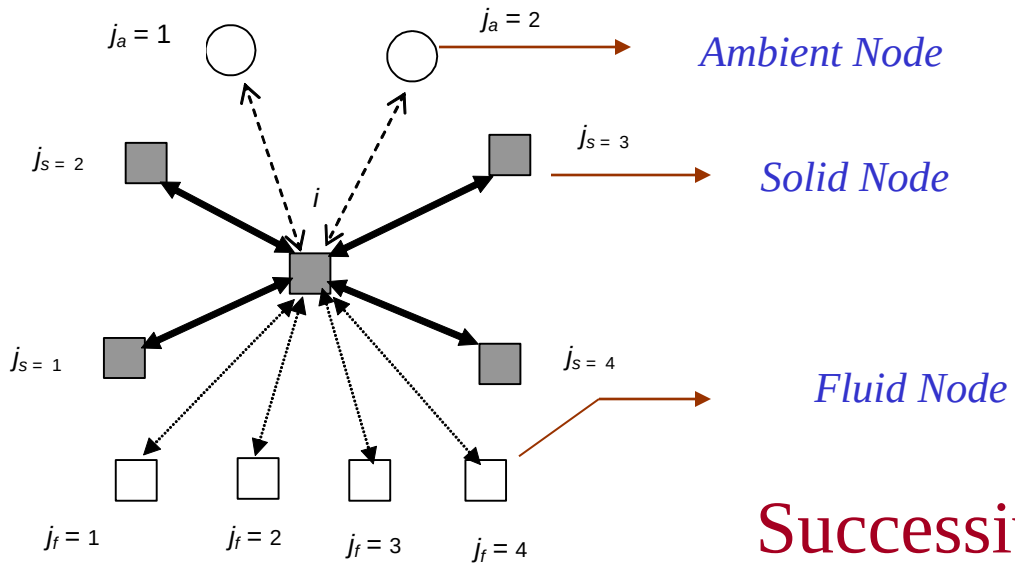
Rate of Increase of Internal Energy =

Enthalpy Inflow - Enthalpy Outflow + Heat Source



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

GOVERNING EQUATIONS



SOLID ENERGY CONSERVATION EQUATION

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

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

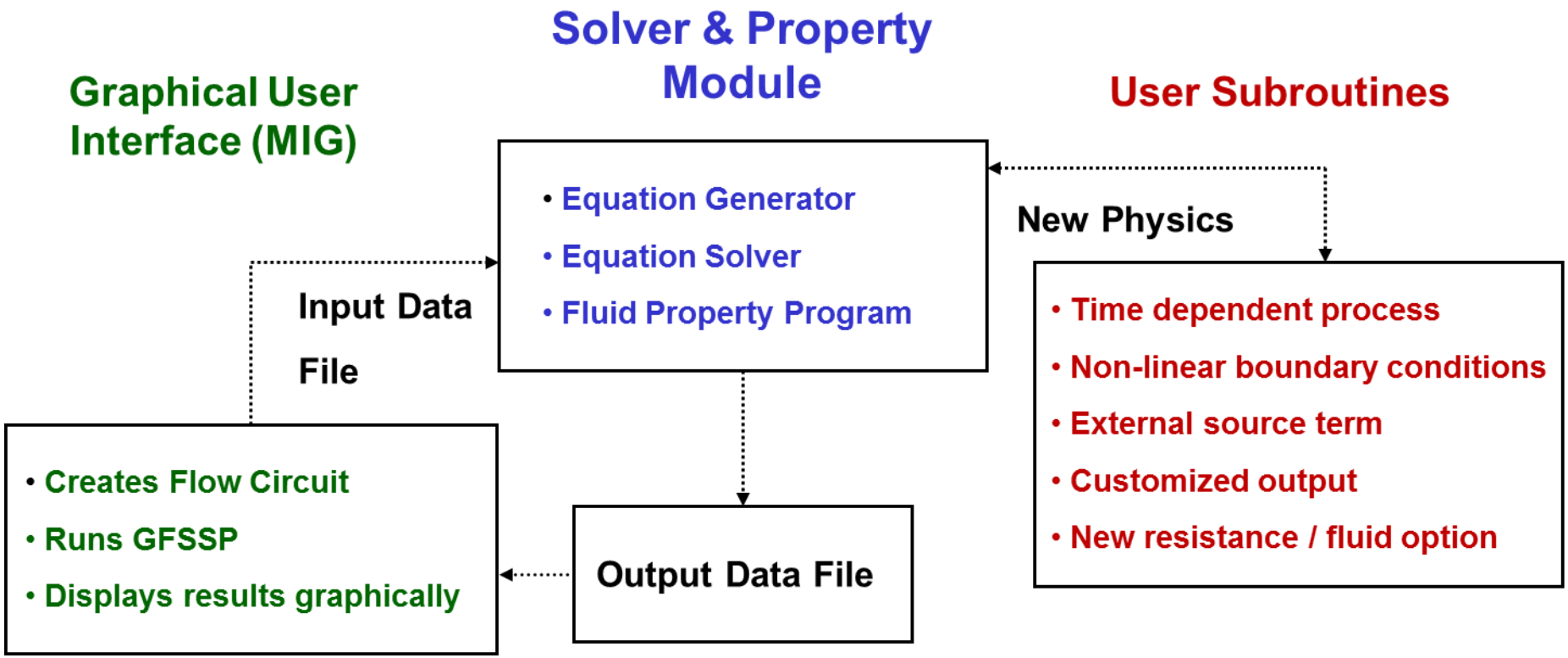
$$\dot{q}_{sf} = h_{ij_f} A_{ij_f}\left(T_f^{j_f} - T_s^i\right)$$

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

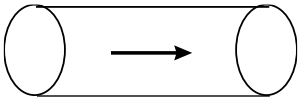
Successive Substitution Form

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

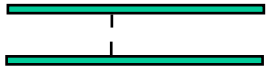
PROGRAM STRUCTURE



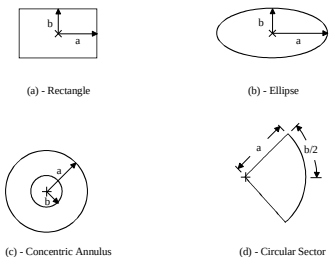
RESISTANCE OPTIONS



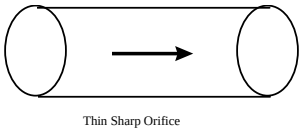
1. Pipe Flow



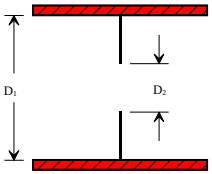
2. Flow Through a Restriction



3. Non-Circular Duct

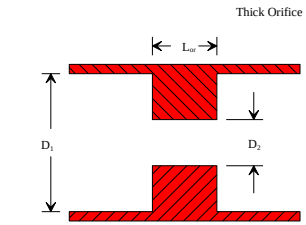


4. Pipe Flow with Entrance & Exit Losses



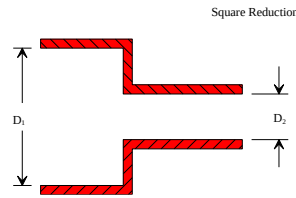
Where:
D_1 = Pipe Diameter
D_2 = Orifice Throat Diameter

5. Thin, Sharp Orifice



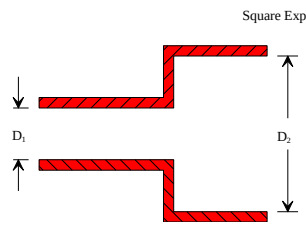
Where:
D_1 = Pipe Diameter
D_2 = Orifice Throat Diameter
L_{or} = Orifice Length

6. Thick Orifice



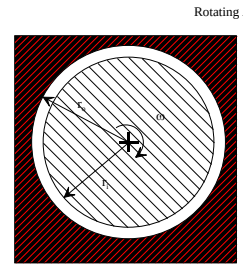
Where:
D_1 = Upstream Pipe Diameter
D_2 = Downstream Pipe Diameter

7. Square Reduction



Where:
D_1 = Upstream Pipe Diameter
D_2 = Downstream Pipe Diameter

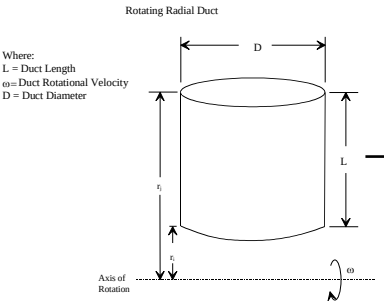
8. Square Expansion



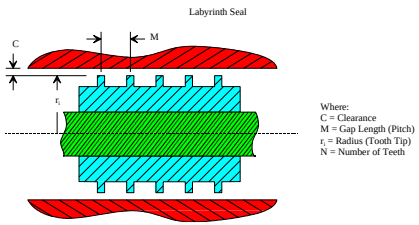
Where:
L = Duct Length (Perpendicular to Page)
b = Duct Wall Thickness ($b = r_o - r_i$)
ω = Duct Rotational Velocity
r_i = Duct Inner Radius
r_o = Duct Outer Radius

9. Rotating Annular Duct

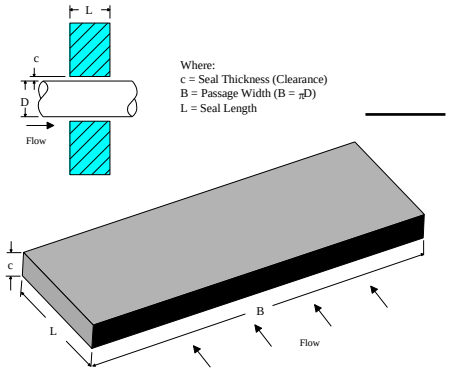
RESISTANCE OPTIONS



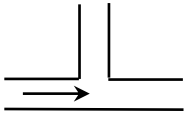
10. Rotating Radial Duct



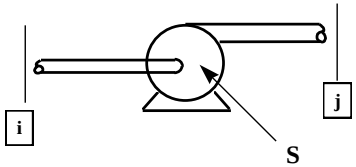
11. Labyrinth Seal



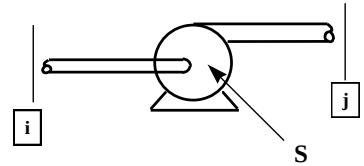
12. Face Seal



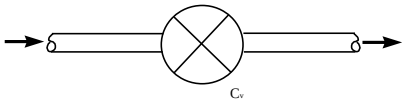
13. Common Fittings & Valves



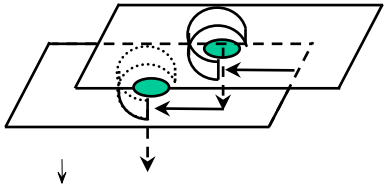
14. Pump Characteristics



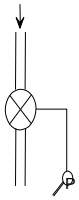
15. Pump Power



16. Valve with Given Cv



17. Viscojet



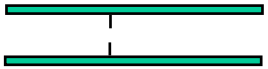
18. Control Valve

RESISTANCE OPTIONS

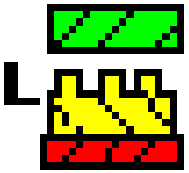
19. User Defined

20. Heat Exchanger Core

21. Parallel Tube



22. Compressible Orifice



23. Labyrinth Seal (Egli Correlation

24. Fixed Flowrate

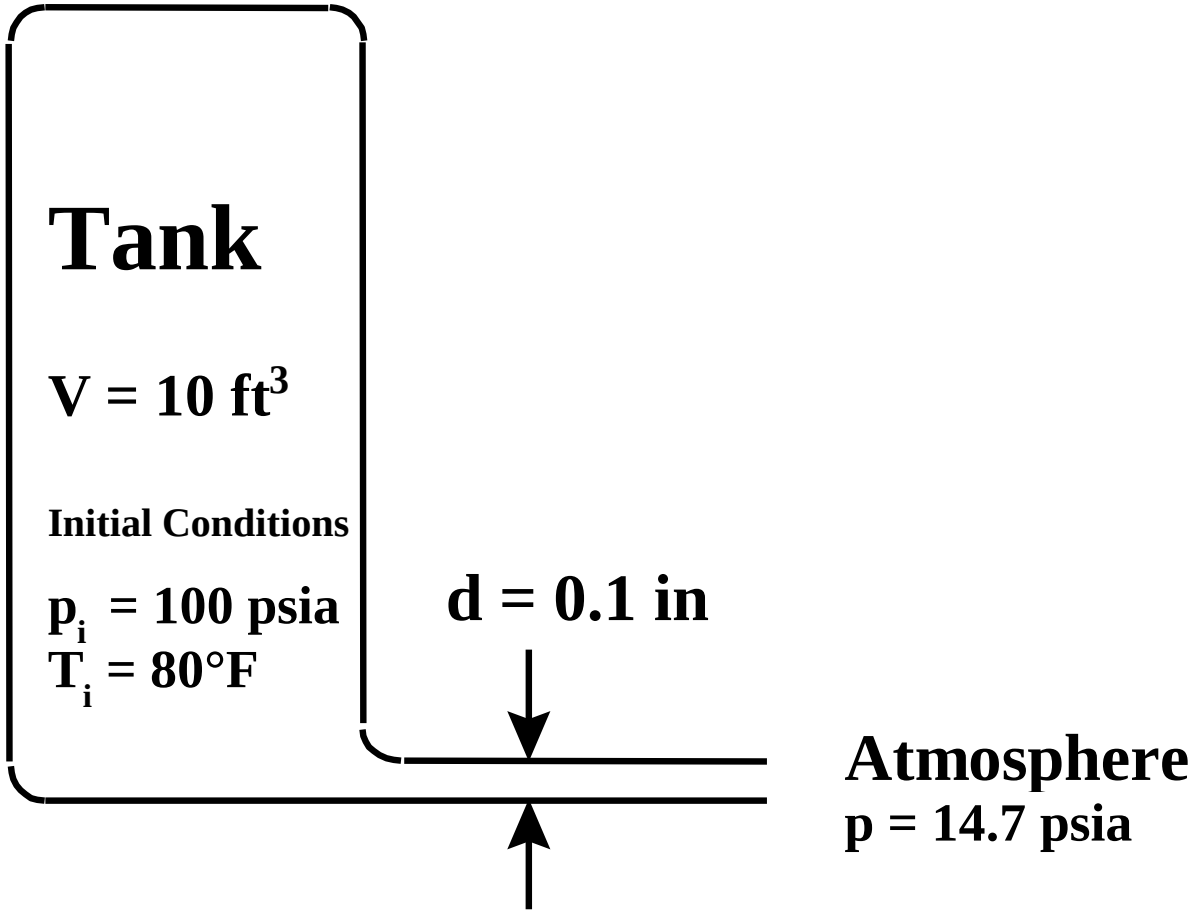
25. Cartesian Grid

FLUID OPTIONS

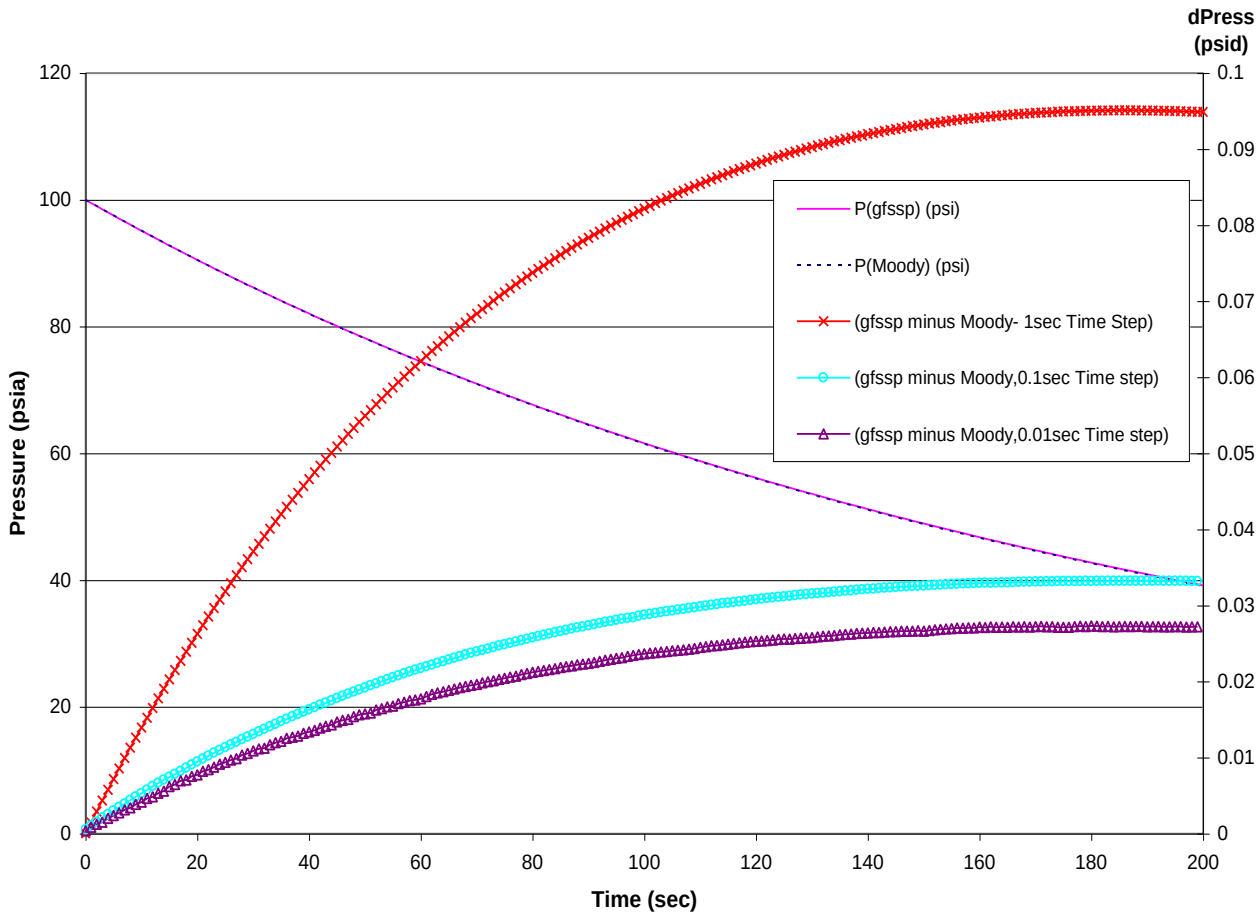
ID Number	SOURCE / FLUID	ID Number	SOURCE / FLUID	ID Number	SOURCE / FLUID
1	GASP He	51	GASPAK He	69	GASPAK Kr
2	GASP CH_4	52	GASPAK CH_4	70	GASPAK Propane
3	GASP Ne	53	GASPAK Ne	71	GASPAK Xe
4	GASP N_2	54	GASPAK N_2	72	GASPAK R-11
5	GASP CO	55	GASPAK CO	73	GASPAK R-12
6	GASP O_2	56	GASPAK O_2	74	GASPAK R-22
7	GASP Ar	57	GASPAK Ar	75	GASPAK R-32
8	GASP CO_2	58	GASPAK CO_2	76	GASPAK R-123
9	GASP F_2	59	GASPAK H_2 (para)	77	GASPAK R-124
10	GASP H_2 (para)	60	GASPAK H_2 (normal)	78	GASPAK R-125
11	WASP H_2O	61	GASPAK H_2O	79	GASPAK R-134A
12	RP-1 Tables	62	GASPAK RP-1 (liq)	80	GASPAK R-152A
		63	GASPAK Isobutane	81	GASPAK N_2F_3
33	Ideal Gas	64	GASPAK Butane	82	GASPAK NH_3
		65	GASPAK Deuterium	84	GASPAK H_2O_2
37	User Fluid 1	66	GASPAK Ethane	86	GASPAK Air
38	User Fluid 2	67	GASPAK Ethylene		
39	User Fluid 3	68	GASPAK H_2S		

Demonstration Models

1. Blow Down of Pressurized Tank



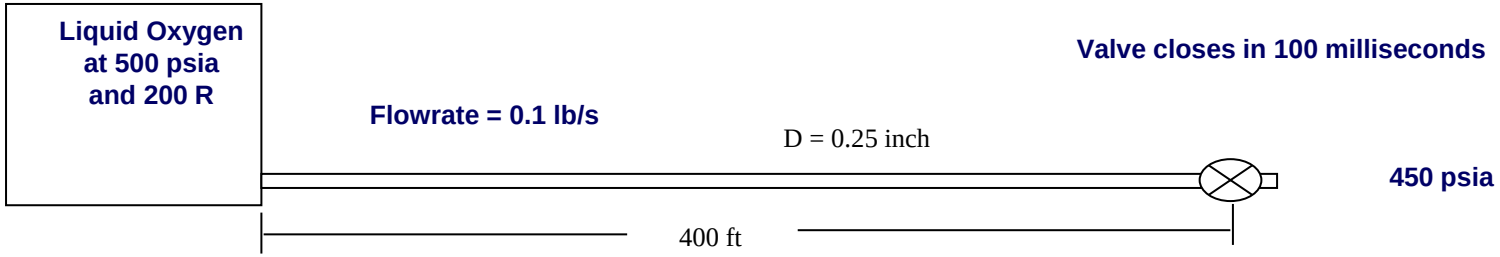
1. Blow Down of Pressurized Tank



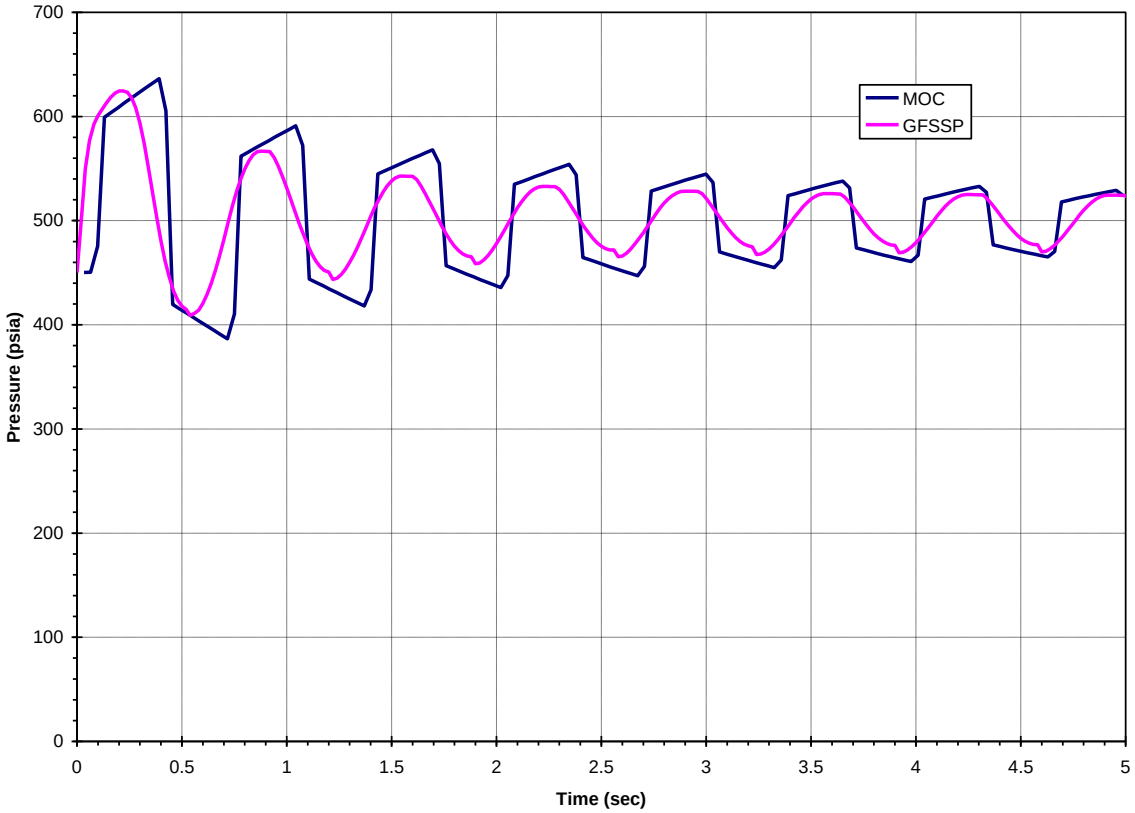
Analytical Solution:

$$\frac{p}{p_i} = \left[1 + \left(\frac{\gamma - 1}{2}\right)\left(\frac{2}{\gamma + 1}\right)^{(\gamma+1)/2(\gamma-1)} \sqrt{\frac{\gamma\, g_c\, p_i}{\rho_i}}\, \frac{A\tau}{V}\right]^{-2\gamma/(\gamma-1)}$$

2. Waterhammer

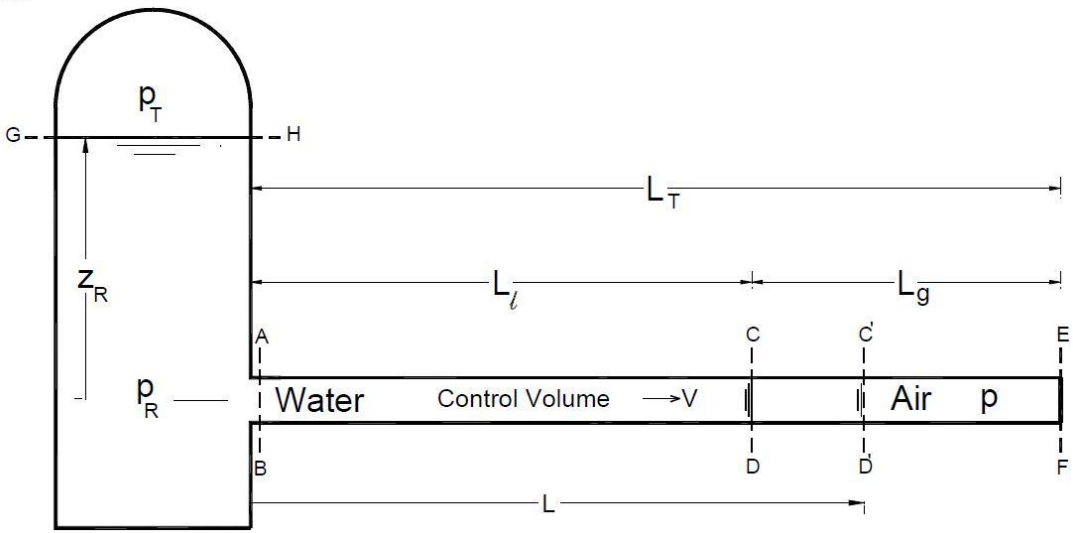


2. Waterhammer



GFSSP results compared to Method of Characteristics

3. Sudden Valve Opening / Priming

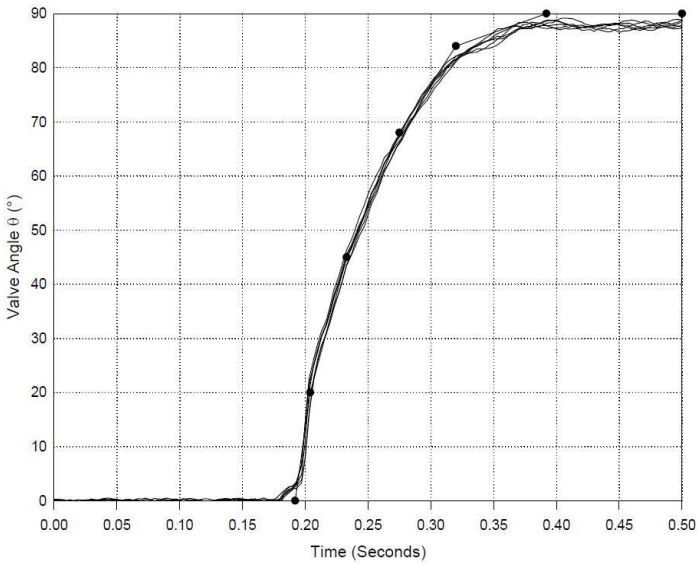


Top: Schematic of the Pipeline System with ball-valve location.

Side: Ball-Valve Opening History

Parameters: $\alpha = L_g/L_T$

$P_R = p_R/p_0$



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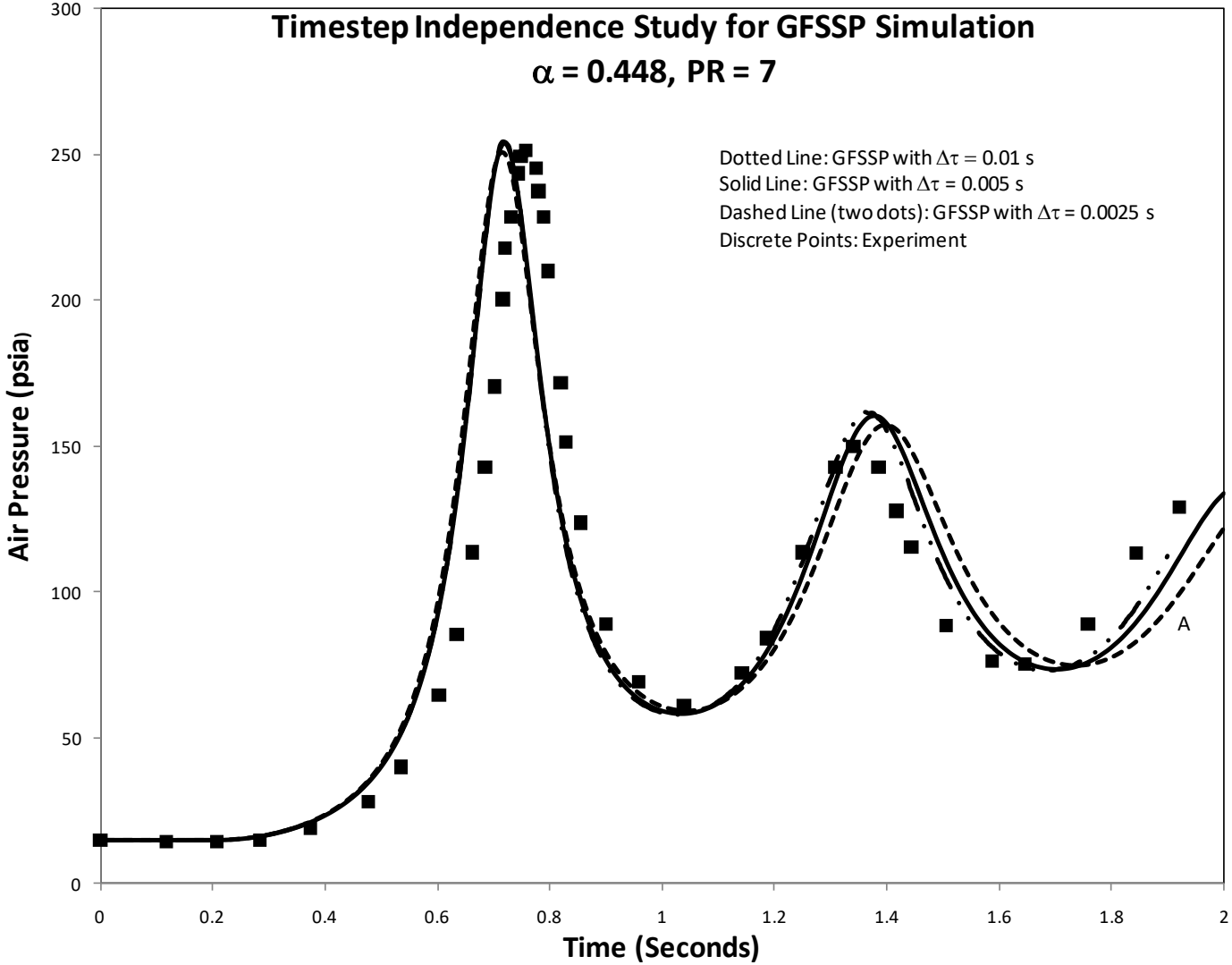
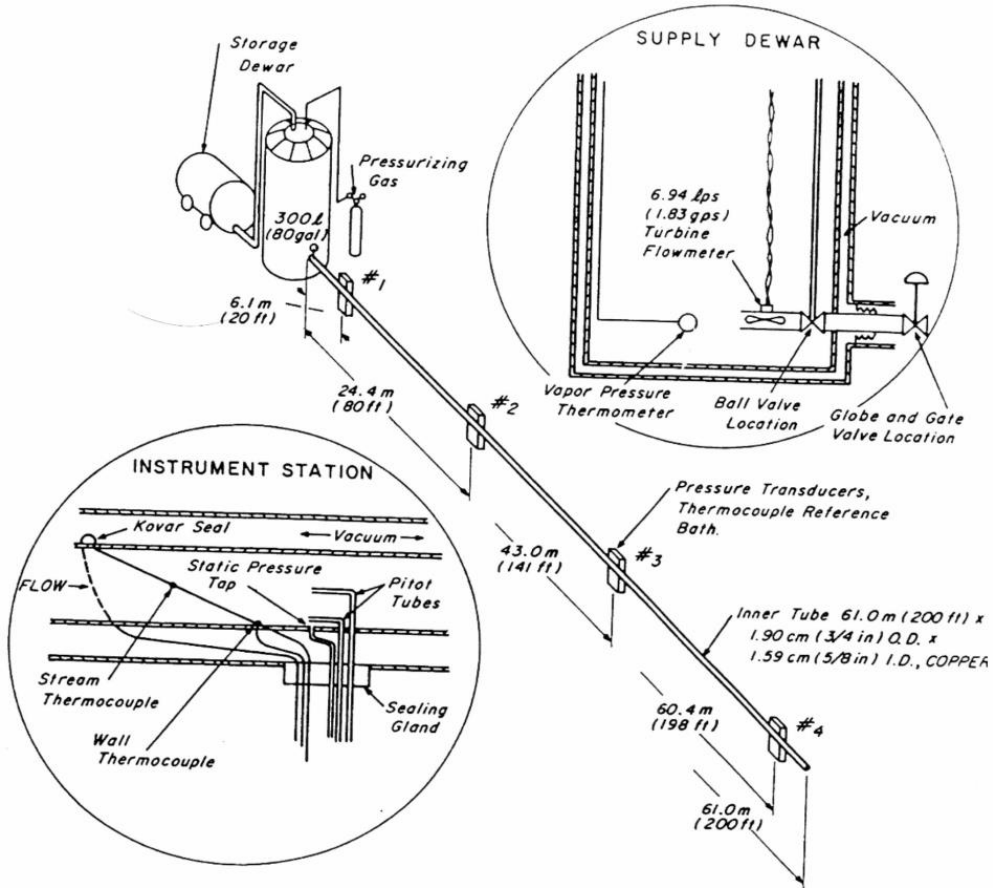


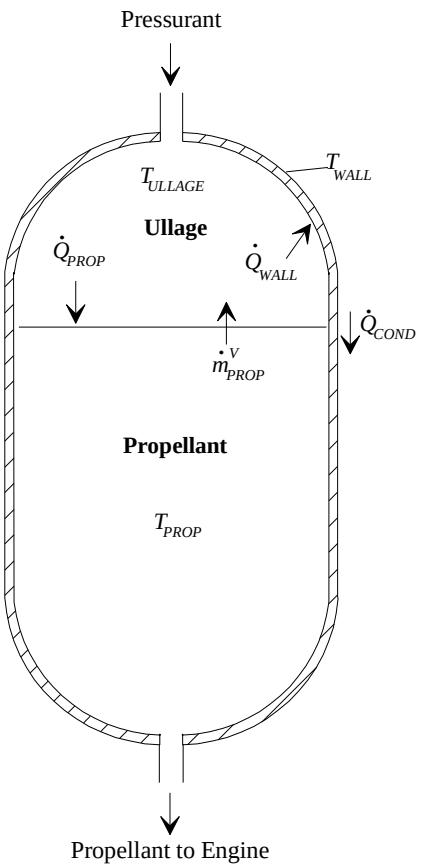
4. Transfer Line Chilldown



NBS Chilldown Experiment

5. Tank Pressurization

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



Questions?

- For more information:
  - www.nasa.gov/gfssp
- Or contact:
  - alok.k.majumdar@nasa.gov
  - andre.c.leclair@nasa.gov