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Use of Generalized Fluid System Simulation Program (GFSSP) for Teaching and Performing Senior Design Projects at Educational Institutions

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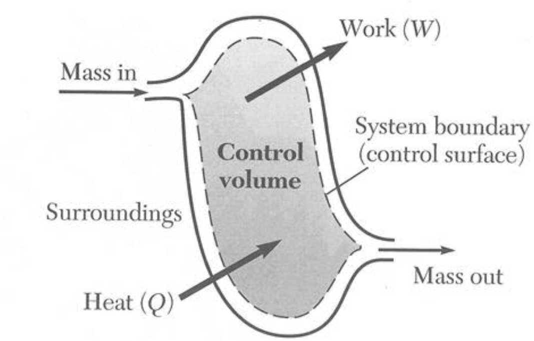
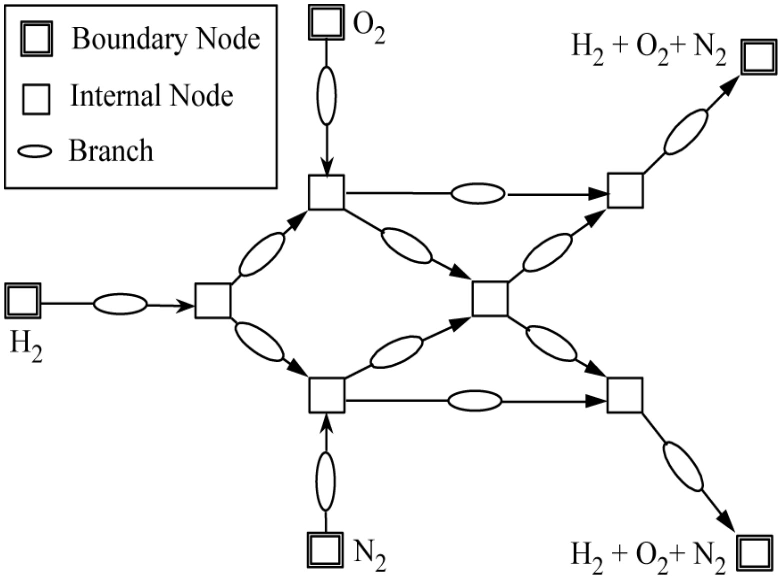
Finite Volume Procedure
Basics

The Finite Volume Procedure for a fluid network is an extension of single control volume analysis of mass and energy conservation in classical thermodynamics.

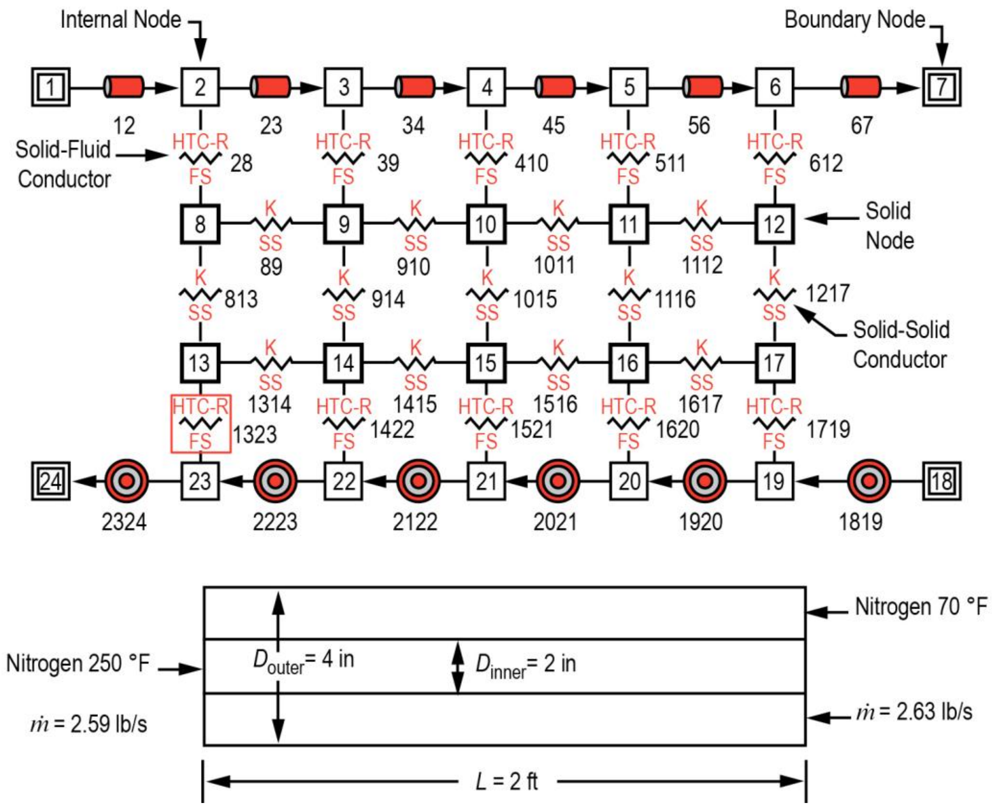


Control Volume Analysis
in Classical Thermodynamics



Finite Volume Analysis in
Fluid Network

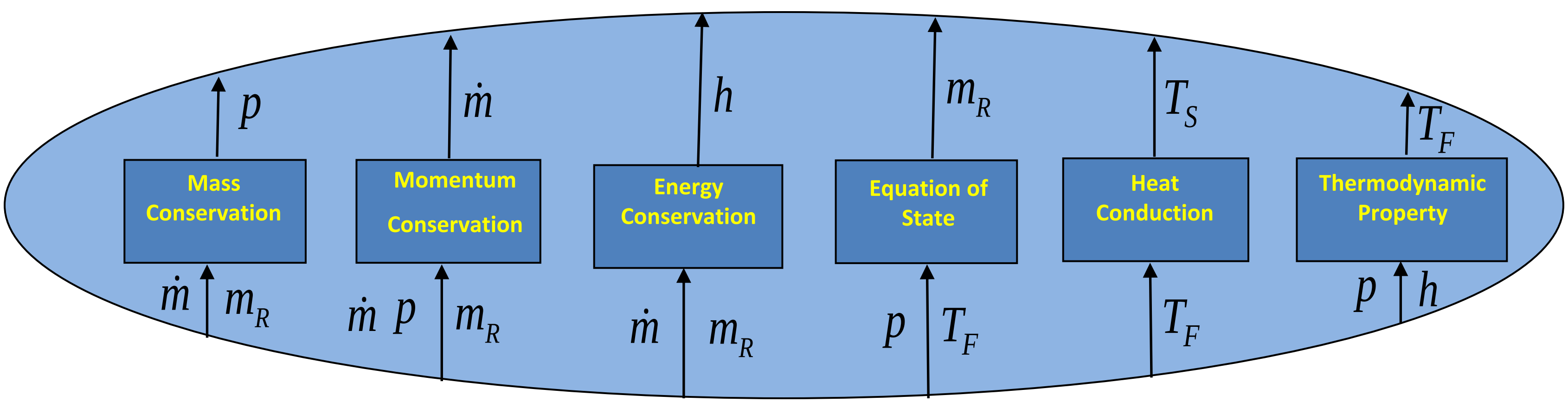
Network Definition & Main Characteristics



- **Data Structure for Generalized Flow Network**
- **Pressure Based Finite Volume Method**
- **Conjugate Heat Transfer**
- **Fluid Transient**

Mathematical Formulation

<u>**Unknown Variables**</u>	<u>**Governing Equations to Solve**</u>
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. Mass	5. Thermodynamic Equation of State



Program Structure

Solver & Property Module

- Equation Generator
- Equation Solver
- Fluid Property Program

Graphical User Interface (VTASC)

- Creates Flow Circuit
- Runs GFSSP
- Displays results graphically

User Subroutines

- Time dependent process
- non-linear boundary conditions
- External source term
- Customized output
- New resistance / fluid option

Input Data File

New Physics

Output Data File

Fluid Option

Two Thermo-dynamic Property Programs are integrated with GFSSP

GASP & WASP

Index	Fluid	Index	Fluid
1	Helium	7	Argon
2	Methane	8	Carbon dioxide
3	Neon	9	Fluorine
4	Nitrogen	10	Hydrogen
5	Carbon monoxide	11	Water
6	Oxygen	12	RP-1

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		

Additional Fluid can be added as Property Table Lookup

Resistance Option

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.

Additional Resistance Option can be added through User Subroutine

Modeling Options

- Pressurization
- Heat Exchanger
- Turbopump
- Valve open/close
- Pressure Regulator
- Flow Regulator
- Cyclic Boundary
- Moving Boundary
- Fluid Mixture
- Rotation

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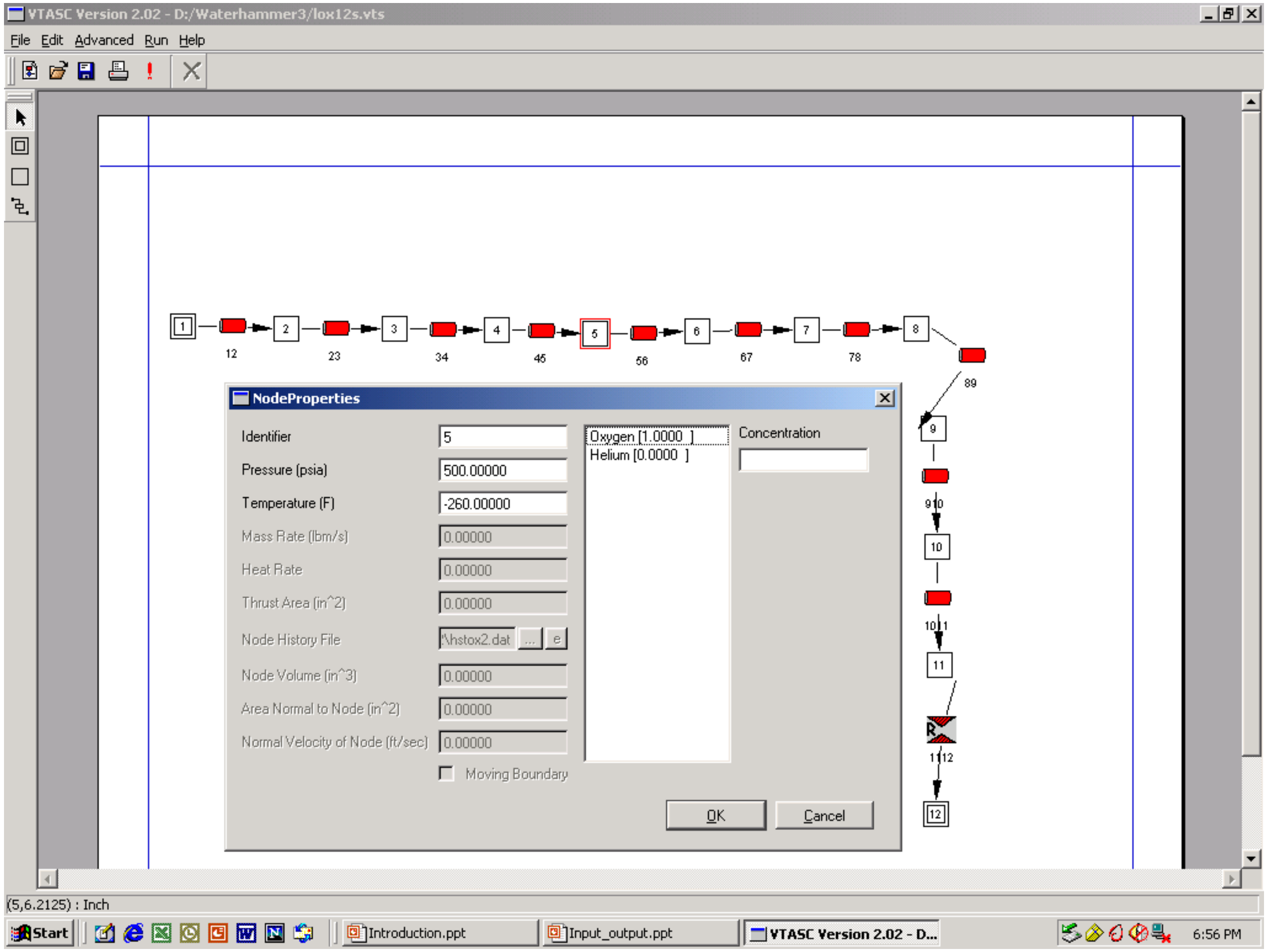
GRAPHICAL USER INTERFACE

MODEL BUILDING

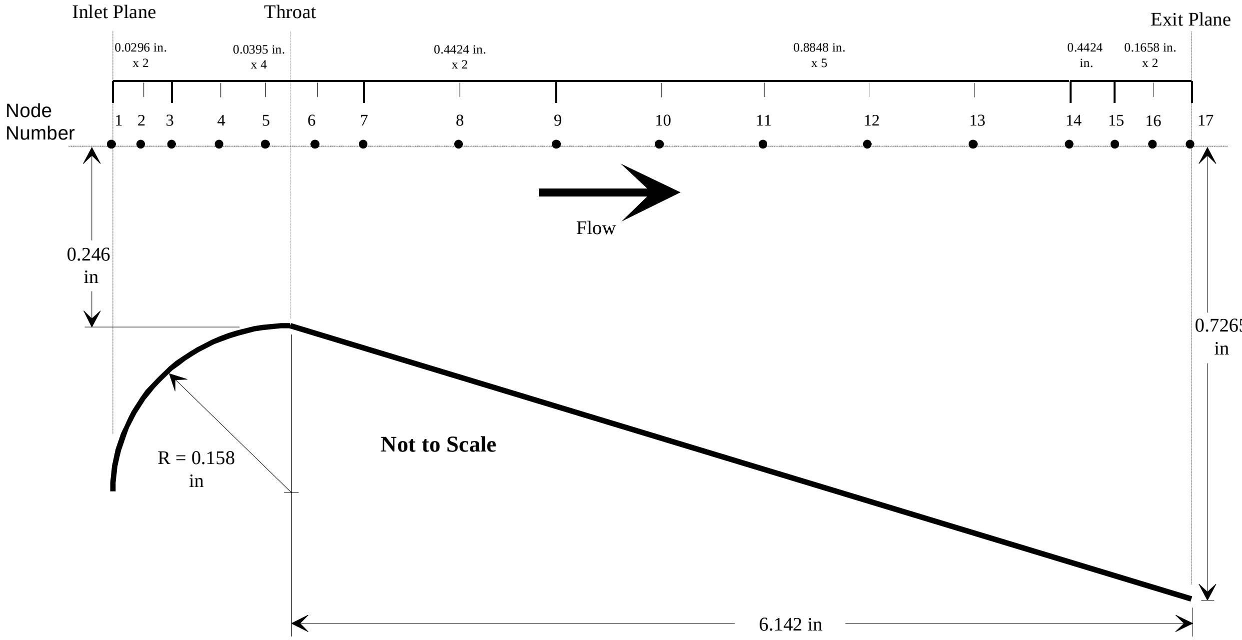
MODEL RUNNING

MODEL RESULTS

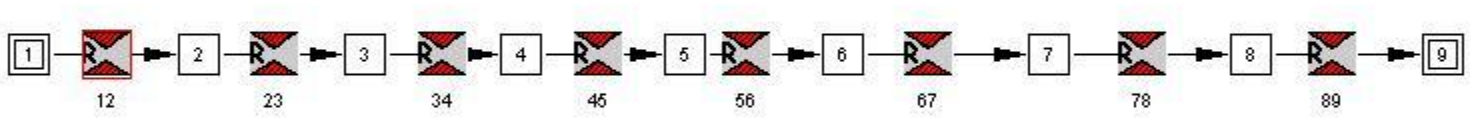


Tutorial 1: Compressible flow in a Converging-Diverging Nozzle

Detailed Schematic



VTASC Model



Results of Parametric Computations

Run five cases, gradually decreasing the exit pressure.

P_{exit} (psia)	$\dot{m}$ (lbm/s)
134	0.279
100	0.329
60	0.336
50	0.337
45	0.337

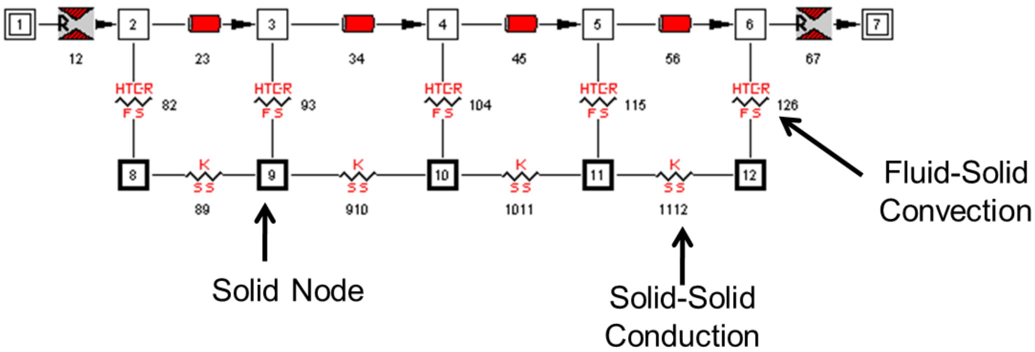
- How does the choked flowrate compare to the hand-calculated value of 0.327 lb_m/s?

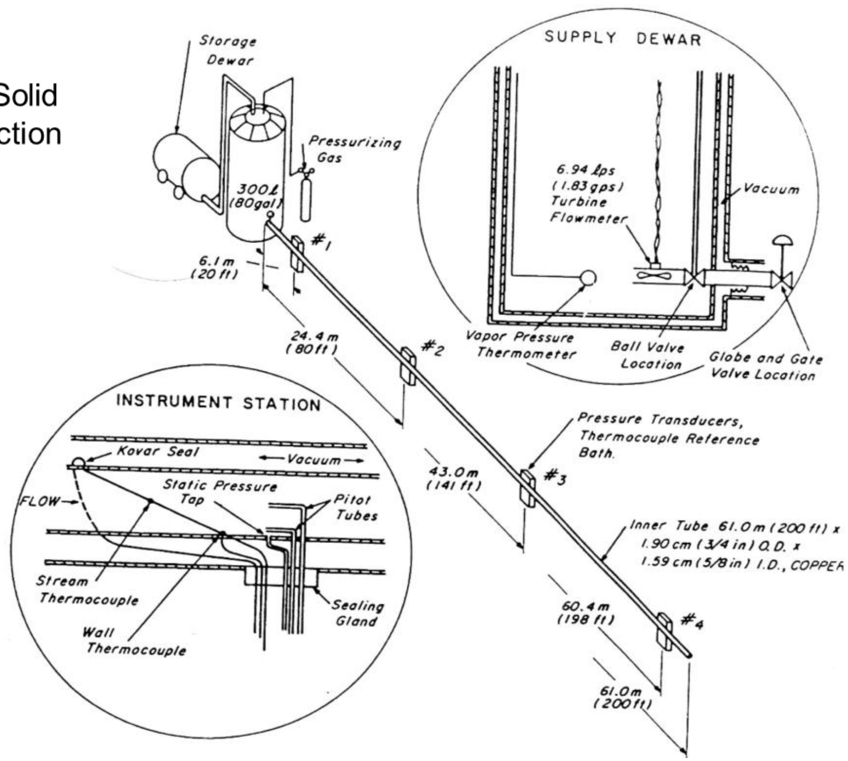
$$\dot{m} = A_{throat} P_{inlet} \sqrt{\frac{g_c \gamma}{R\, T_{inlet}} \left(\frac{2}{\gamma + 1} \right)^{\left(\frac{\gamma+1}{\gamma-1} \right)}} = \left(0.19012\, in^2\right)\left(161.6\, \frac{lbf}{in^2}\right) \sqrt{\frac{32.174 \frac{lbm-ft}{lbf-s^2}(1.281)}{85.83 \frac{lbf-ft}{lbm-{}^0R} 1460^0 R} \left(\frac{2}{1.281+1} \right)^{\frac{2.281}{0.281}}} = 0.327 \frac{lbm}{s}$$

Tutorial 2: CHILLDOWN OF TRANSFER LINE

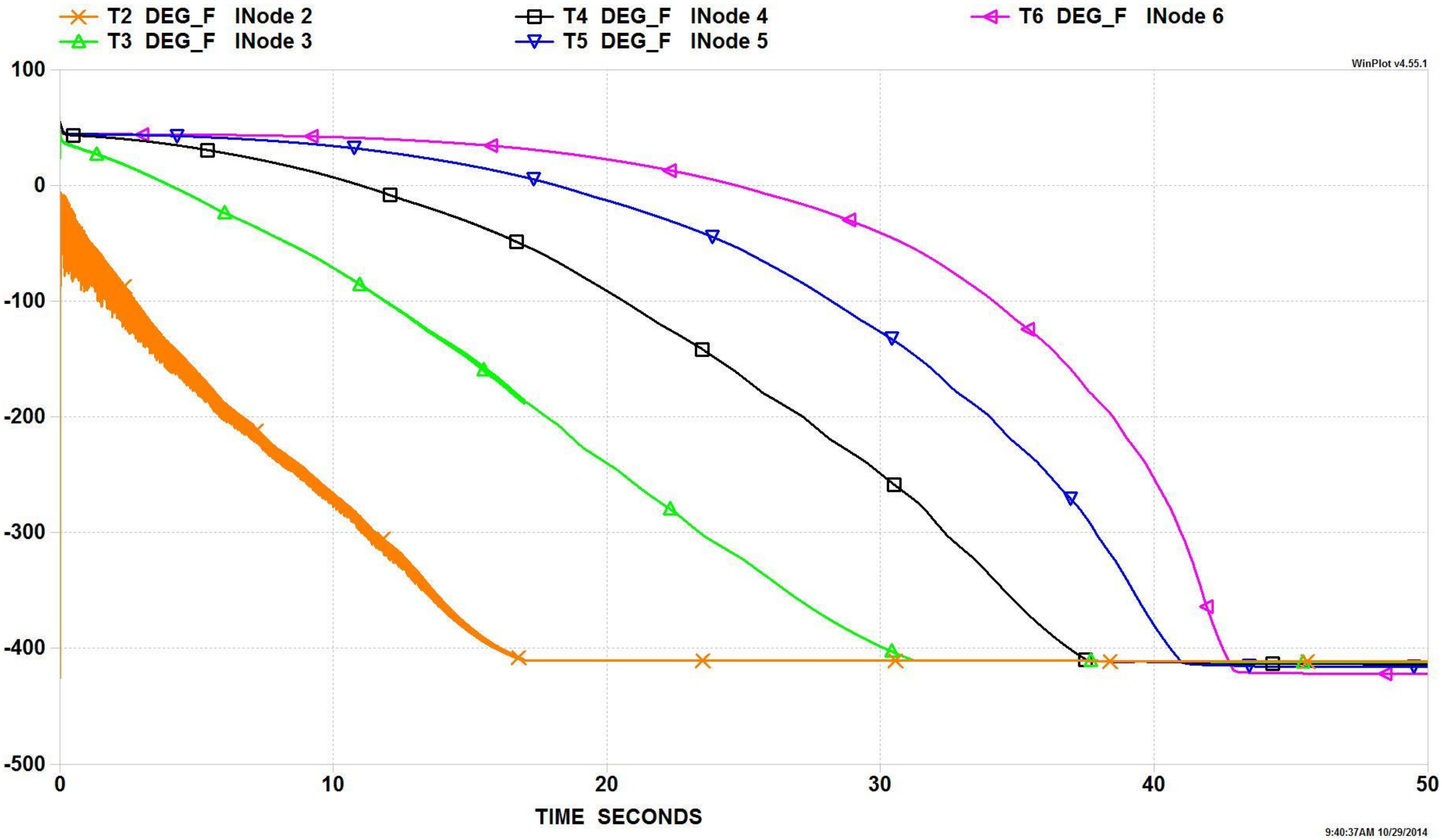
Problem Considered:

•Time dependent Pressure, Temperature and Flow Rate history during chilldown





Fluid Temperature



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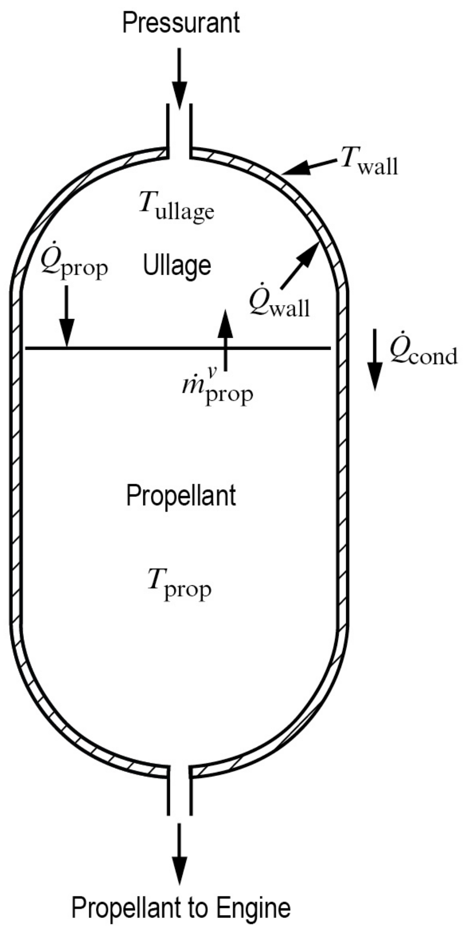
Tutorial – 3

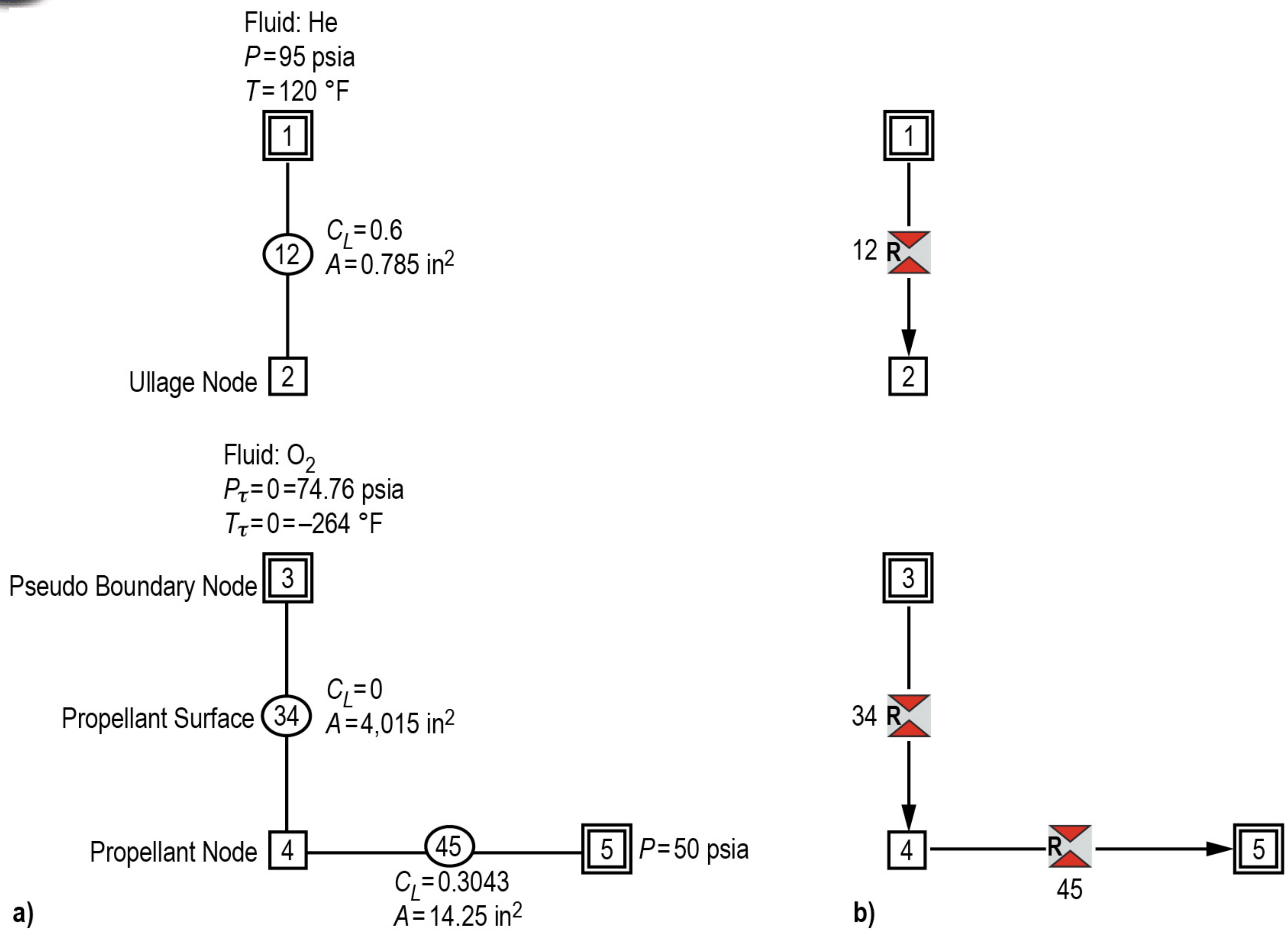
Pressurization of a Propellant Tank



- Predict the ullage conditions considering heat and mass transfer between the propellant and the tank wall

- Predict the propellant conditions leaving the tank

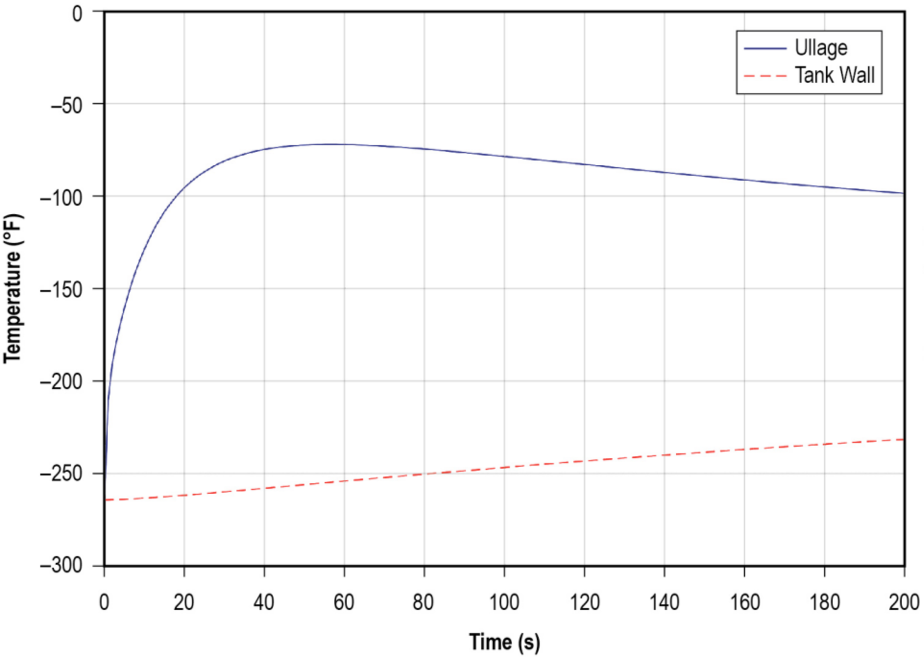
GFSSP Model



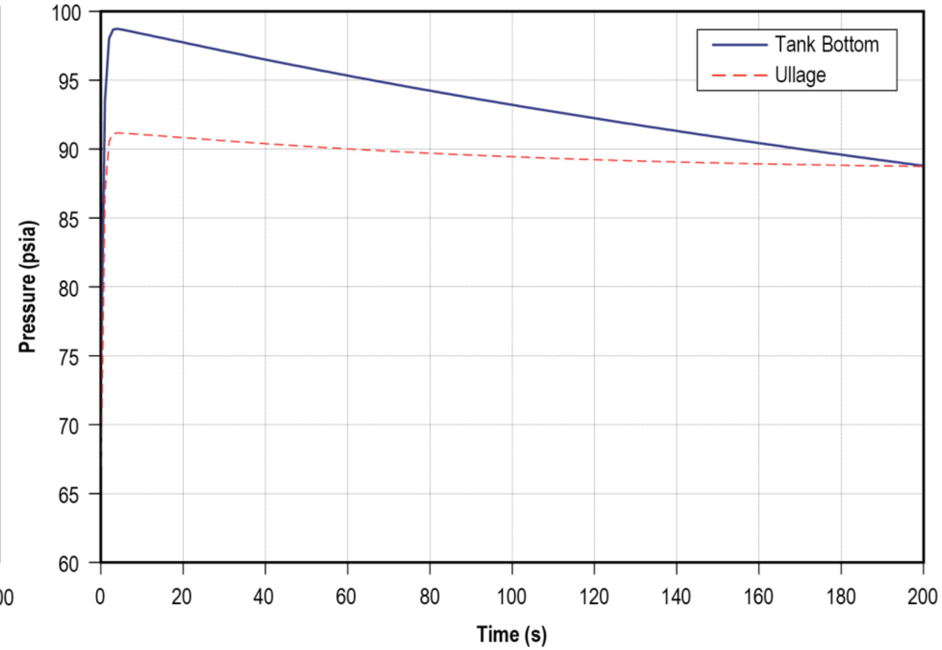
Fluid: He
P=95 psia
T=120 °F
1
12
C_L=0.6
A=0.785 in2
Ullage Node
2
Fluid: O2
P_τ=0=74.76 psia
T_τ=0=–264 °F
Pseudo Boundary Node
3
Propellant Surface
34
C_L=0
A=4,015 in2
Propellant Node
4
45
C_L=0.3043
A=14.25 in2
5
P=50 psia
a)
1
12 R
2
3
34 R
4
R
45
5
b)

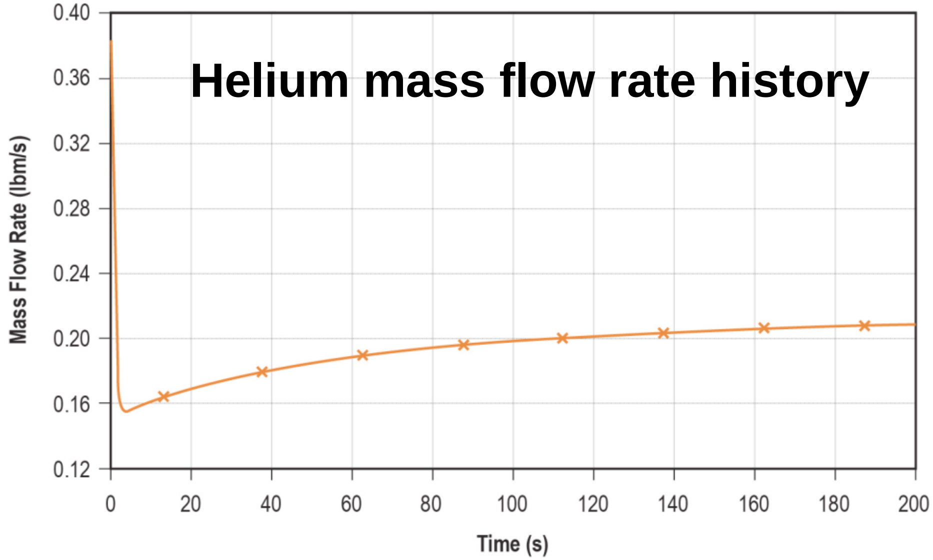
Model Results

Ullage and tank wall temperature history

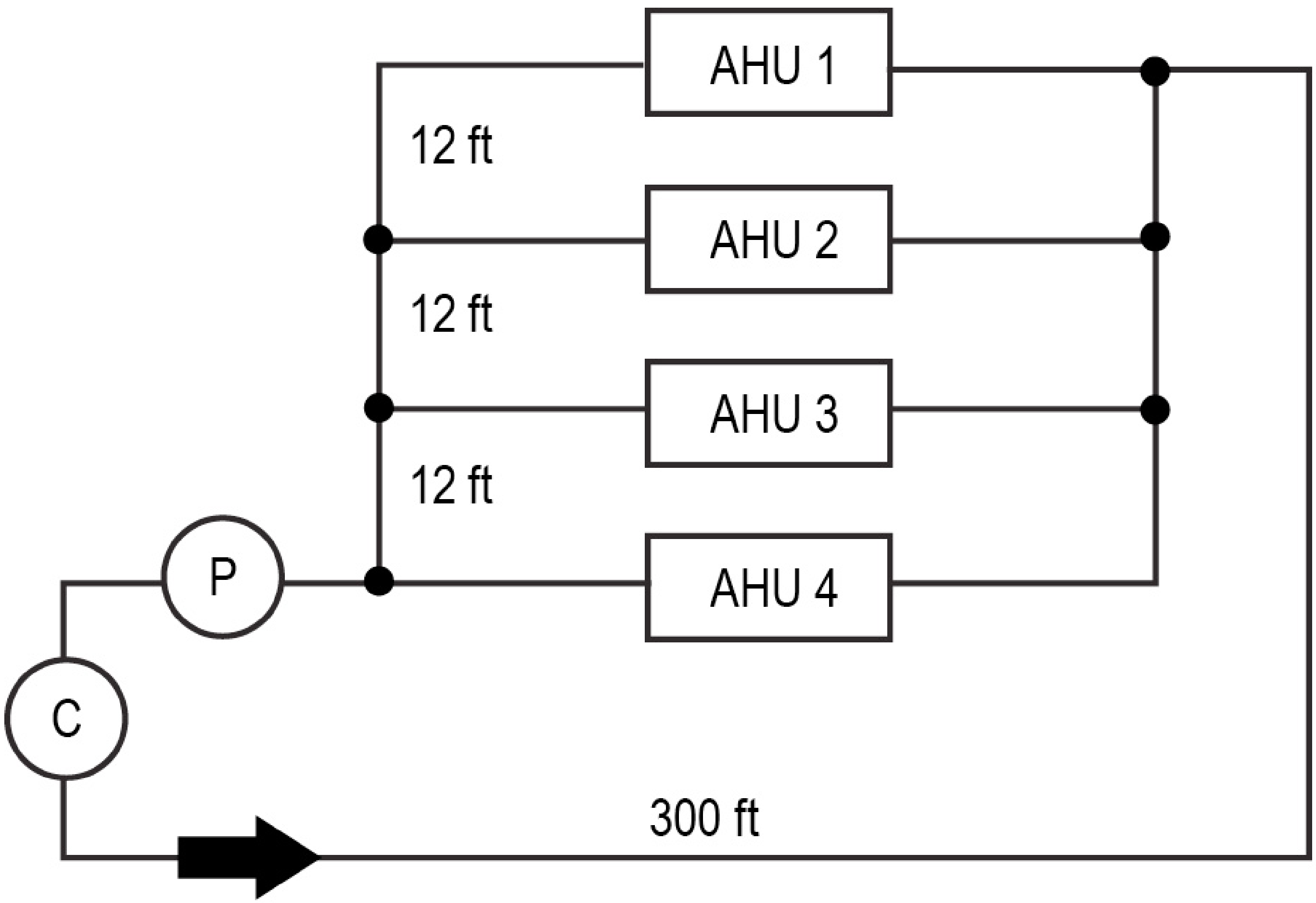


Ullage and tank bottom pressure history





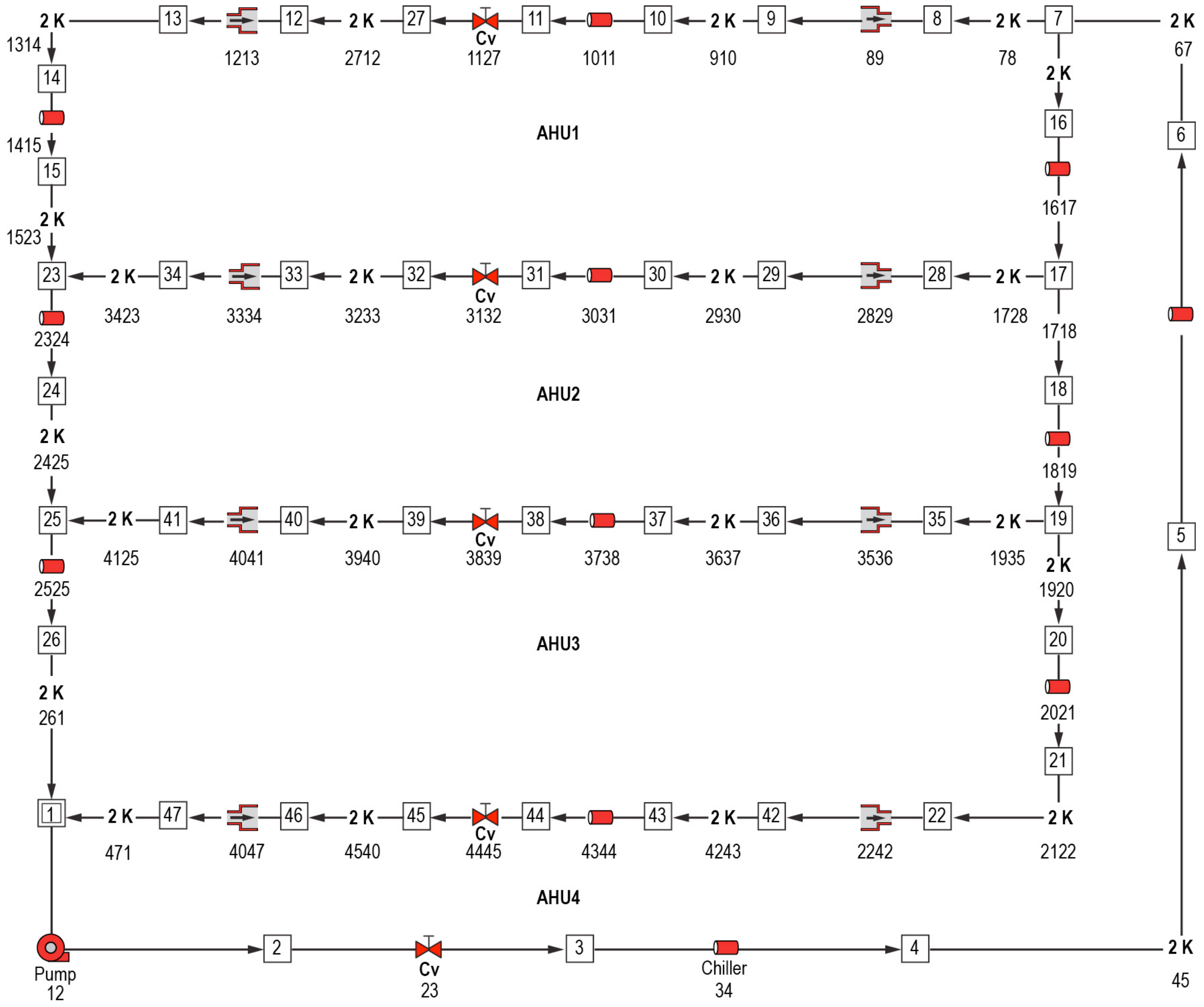
Design Project Assignment



Air conditioning system requirements

Requirement Number	Title	Description
1	Flow rate	Each floor requires a chilled-water flow rate of 18,000 lbm/hr.
2	Flow velocities	All flow velocities are not to exceed 5 ft/s.
3	Floor spacing	Each floor is 12 ft higher than the one below.
4	Supply and return pipe sizing	The supply and return pipes must all be the same diameter (Schedule 80).
5	Supply pipe length	The total length of supply pipe running from the exit of the bottom floor, through the pump and chiller, and up to the entrance of the top floor is 300 ft (See Fig. 11).
6	Floor pipe sizing	The floor pipes must all be the same diameter (Schedule 80).
7	Floor pipe length	Each floor must have 100 ft of pipe.
8	Floor valves	Each floor must have two gate valves.
9	AHU pressure drop	The pressure drop across each AHU must be 50 psi.
10	Chiller pressure drop	The pressure drop across the chiller must be 100 psi.

GFSSP Model


AHU1
AHU2
AHU3
AHU4
2 K
Cv
Pump
12
Cv
23
Chiller
34
45
67
1314
1415
1523
1213
2712
1127
1011
910
89
78
1617
1718
1819
1920
2021
2122
2324
2425
2525
261
3423
3334
3233
3132
3031
2930
2829
1728
4125
4041
3940
3839
3738
3637
3536
1935
471
4047
4540
4445
4344
4243
2242

Project design results

	GFSSP Value	Requirements Value	Notes
Supply and return pipe size (Schedule 80)	3.826 in		
Floor pipe size (Schedule 80)	1.939 in		
Pressure rise across pump	154.0 psi		
Pump power required	23.5 hp (17.5 kW)		At 55% efficiency
Cost of operation (per 24 hr)	$42		$0.10 per kW-hr for 24 hr
Mass flow rate in pipe 1011 (4th floor)	18,036 lbm/hr	18,000 lbm/hr	% Difference: 0.2%
Mass flow rate in pipe 3031 (3rd floor)	18,018 lbm/hr	18,000 lbm/hr	% Difference: 0.1%
Mass flow rate in pipe 3738 (2nd floor)	18,018 lbm/hr	18,000 lbm/hr	% Difference: 0.1%
Mass flow rate in pipe 4344 (1st floor)	18,040 lbm/hr	18,000 lbm/hr	% Difference: 0.22%
Mass flow rate in 300-ft supply pipe	72,108 lbm/hr	72,000 lbm/hr	% Difference: 0.15%
AHU 4 pressure drop	49.96 psi	50 psi	% Difference: 0.08%
AHU 3 pressure drop	49.86 psi	50 psi	% Difference: 0.28%
AHU 2 pressure drop	49.86 psi	50 psi	% Difference: 0.28%
AHU 1 pressure drop	49.96 psi	50 psi	% Difference: 0.08%
Chiller pressure drop	100.1 psi	100 psi	% Difference: 0.1%
Fluid velocity in pipe 1011 (4th floor)	3.917 ft/s	<5 ft/s	Meets requirement
Fluid velocity in pipe 3031 (3rd floor)	3.913 ft/s	<5 ft/s	Meets requirement
Fluid velocity in pipe 3738 (2nd floor)	3.913 ft/s	<5 ft/s	Meets requirement
Fluid velocity in pipe 4344 (1st floor)	3.917 ft/s	<5 ft/s	Meets requirement
Velocity in 300-ft supply line	4.022 ft/s	<5 ft/s	Meets requirement

Summary

- This paper demonstrates how a system level, user-friendly network flow analysis code can be integrated in a senior level thermal design class.
- The intent was to introduce a state-of-the-art computational tool to perform a real world technical task
- The introduction of GFSSP was done through lectures, tutorials, and a senior design project.
- The authors' experience of using GFSSP in the class was very positive from students'feedback
- GFSSP is available free of cost to all universities in the United States from MSFC's Technology Transfer Office

Acknowledgement

- GFSSP Development was supported by:
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  - Launch Service Program (LSP) at Kennedy Space Center
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