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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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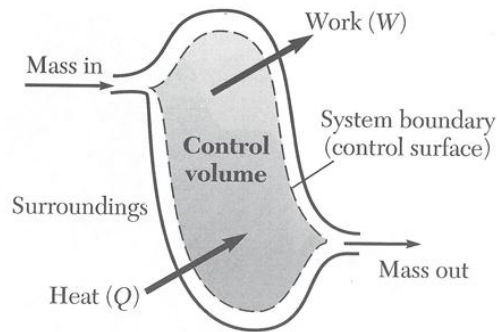
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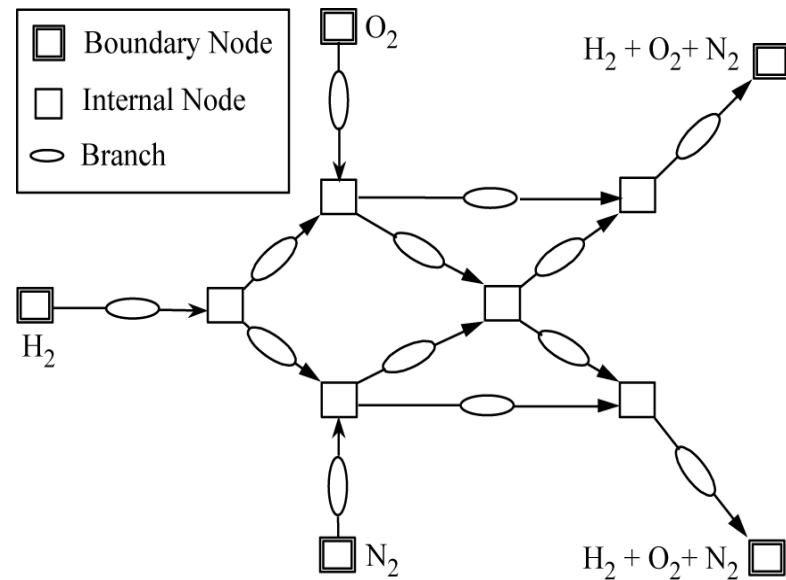


# Finite Volume Procedure Basics

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



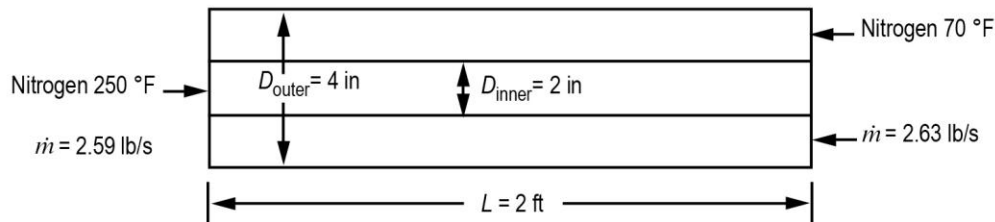
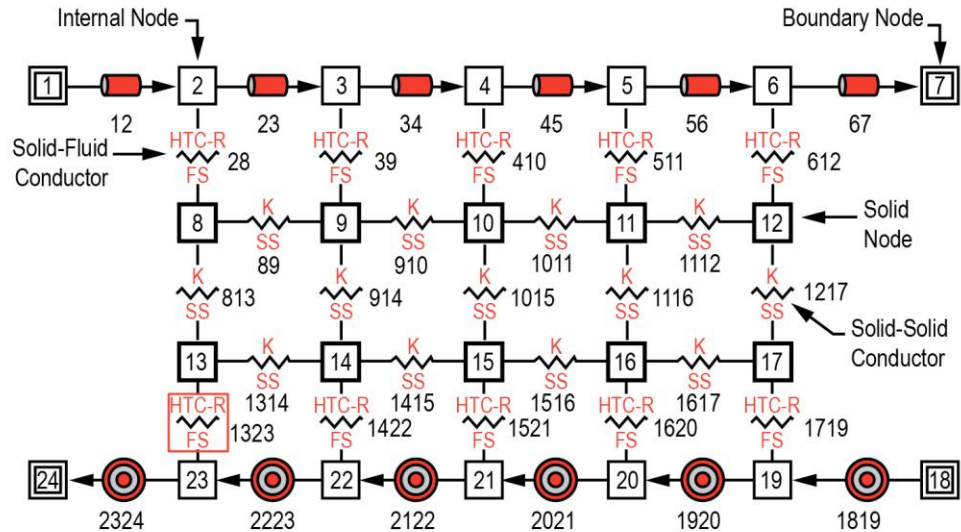
Control Volume Analysis  
in Classical Thermodynamics



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



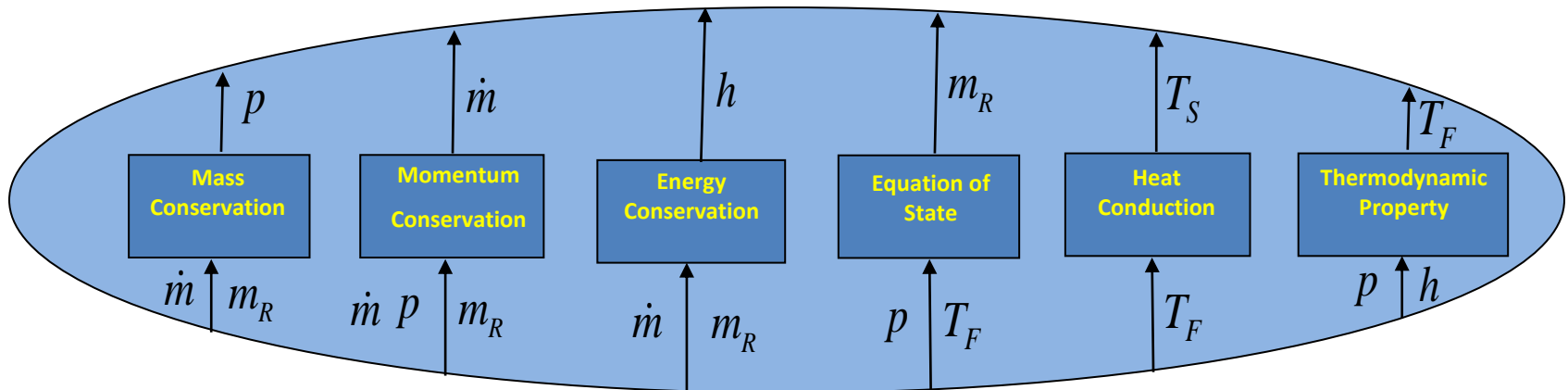
# Mathematical Formulation

## Unknown Variables

1. Pressure
2. Flowrate
3. Fluid Temperature
4. Solid Temperature
5. Mass

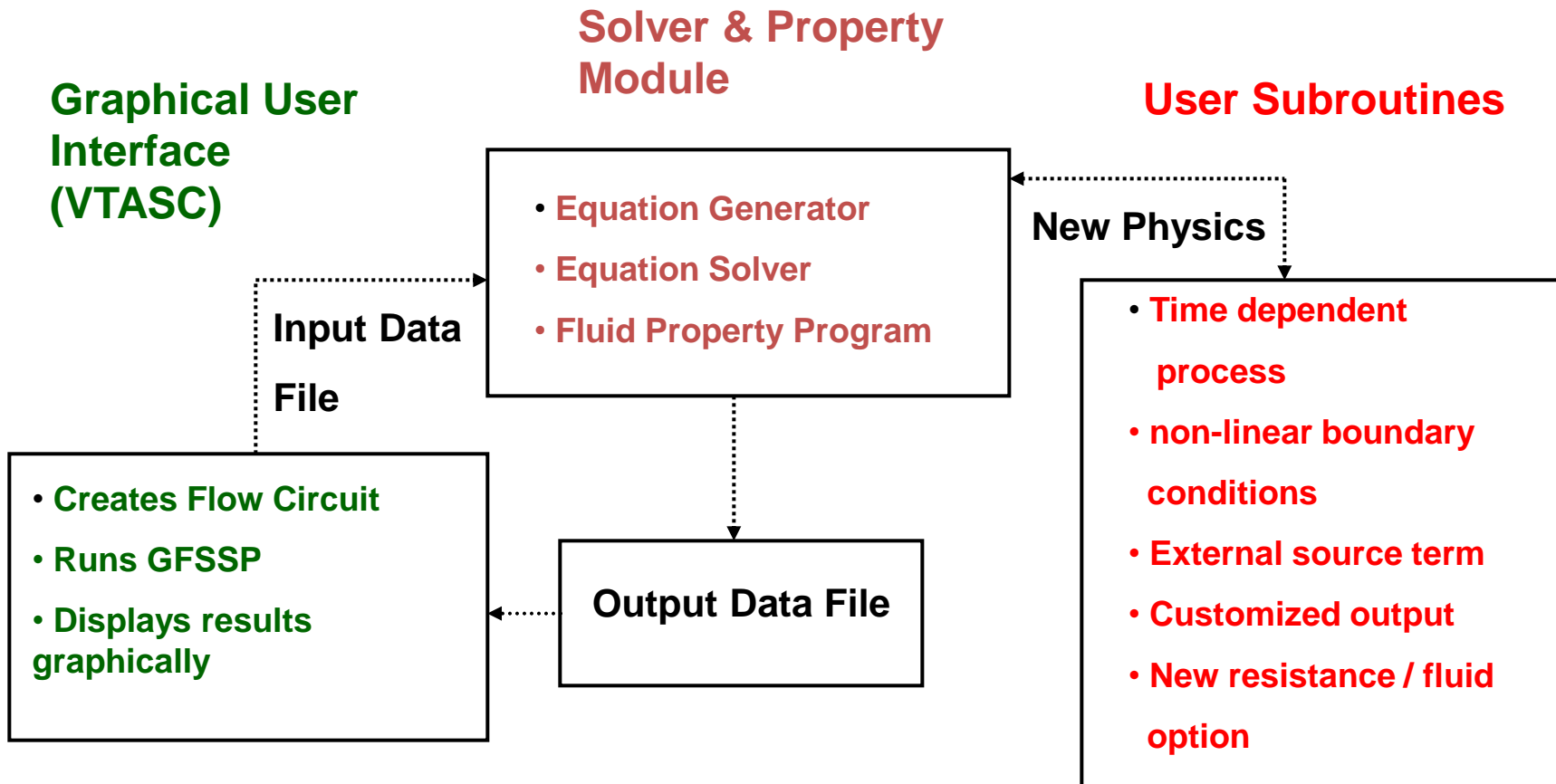
## Governing Equations to Solve

1. Mass Conservation Equation
2. Momentum Conservation Equation
3. Energy Conservation Equation of Fluid
4. Energy Conservation Equation of Solid
5. Thermodynamic Equation of State





# Program Structure





# Fluid Option

Two Thermo-dynamic Property Programs are integrated with GFSSP

## GASPAK

### 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

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 trifluoride
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), $\epsilon/D$	13	Common fittings and valves (two K method)	$D$ (in), $K_1$ , $K_2$
2	Flow-through restriction	$C_L$ , $A$ (in <sup>2</sup> )	14	Pump characteristics*	$A_0$ , $B_0$ , $C_0$ , $A$ (in <sup>2</sup> )
3	Noncircular duct	$a$ (in), $b$ (in)	15	Pump power	$P$ (hp), $\eta$ , $A$ (in <sup>2</sup> )
4	Pipe with entrance and exit loss	$L$ (in), $D$ (in), $\epsilon/D$ , $K_f$ , $K_e$	16	Valve with given $C_v$	$C_v$ , $A$
5	Thin, sharp orifice	$D_1$ (in), $D_2$ (in)	17	Joule-Thompson device	$L_{\Omega}$ , $V_p$ , $k_v$ , $A$
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 <sup>2</sup> )
8	Square expansion	$D_1$ (in), $D_2$ (in)	20	Heat exchanger core	$A_f$ (in <sup>2</sup> ), $A_s$ (in <sup>2</sup> ), $A_c$ (in <sup>2</sup> ), $L$ (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), $\epsilon/D$ , $n$
10	Rotating radial duct	$L$ (in), $D$ (in), $N$ (rpm)	22	Compressible orifice	$C_L$ , $A$ (in <sup>2</sup> )
11	Labyrinth seal	$r_i$ (in), $c$ (in), $m$ (in), $n$ , $\alpha$	23	Labyrinth seal, Egli correlation	$r_i$ (in), $c$ (in), $m$ (in), $n$ , $\alpha$
12	Flow between parallel plates	$r_i$ (in), $c$ (in), $L$ (in)	24	Fixed flow	Flow (lb <sub>m</sub> /s), $A$ (in <sup>2</sup> )

\* Pump characteristics are expressed as  $\Delta p = A_0 + B_0 \dot{m} + C_0 \dot{m}^2$ ,  $\Delta p$  – Pressure rise, lbf/ft<sup>2</sup>,  $\dot{m}$  – 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**



# GRAPHICAL USER INTERFACE

MODEL BUILDING

MODEL RUNNING

MODEL RESULTS

The screenshot displays the VTASC Version 2.02 graphical user interface. The main window shows a flow diagram with nodes 1 through 12. Node 5 is highlighted with a red box. A 'NodeProperties' dialog box is open, showing the following data:

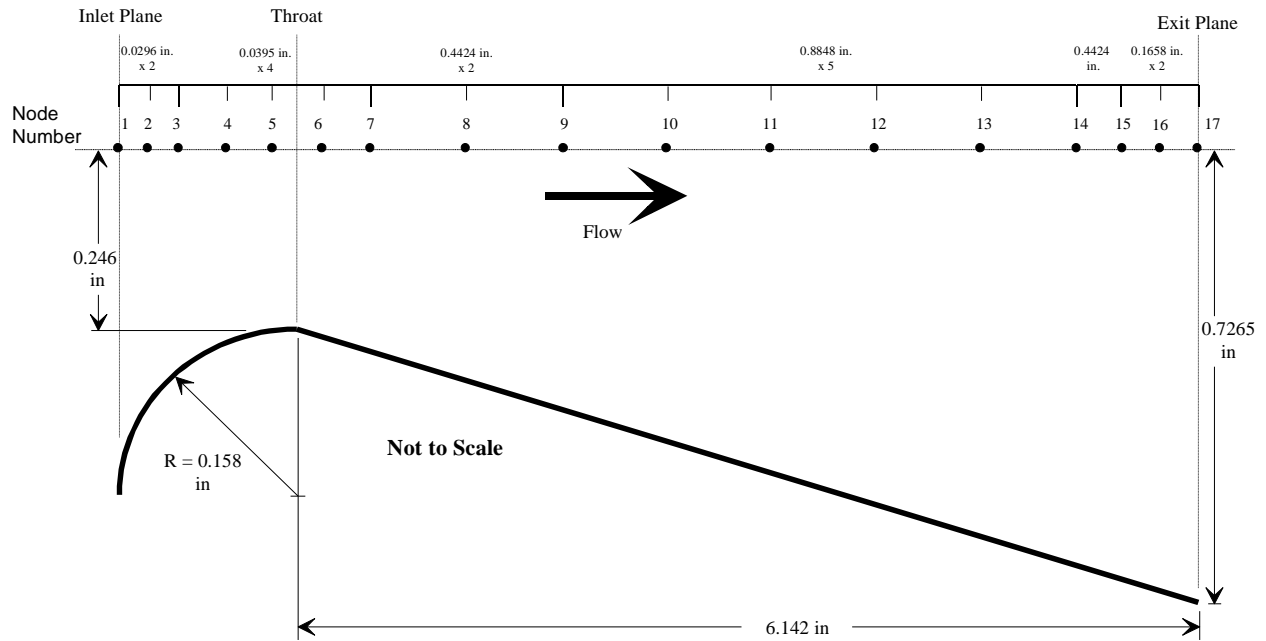
Property	Value
Identifier	5
Pressure (psia)	500.00000
Temperature (F)	-260.00000
Mass Rate (lbm/s)	0.00000
Heat Rate	0.00000
Thrust Area (in <sup>2</sup> )	0.00000
Node History File	\\hstox2.dat
Node Volume (in <sup>3</sup> )	0.00000
Area Normal to Node (in <sup>2</sup> )	0.00000
Normal Velocity of Node (ft/sec)	0.00000

The dialog box also includes a 'Concentration' section with a list of components: Oxygen [1.0000] and Helium [0.0000]. The 'Moving Boundary' checkbox is unchecked. The 'OK' and 'Cancel' buttons are visible at the bottom of the dialog.

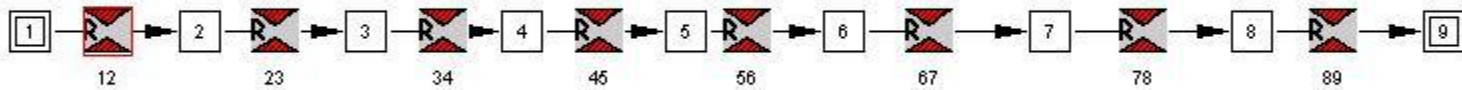


# Tutorial 1: Compressible flow in a Converging-Diverging Nozzle

## Detailed Schematic



## VTASC Model





## Results of Parametric Computations

Run five cases, gradually decreasing the exit pressure.

$P_{\text{exit}}$ (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<sub>m</sub>/s?

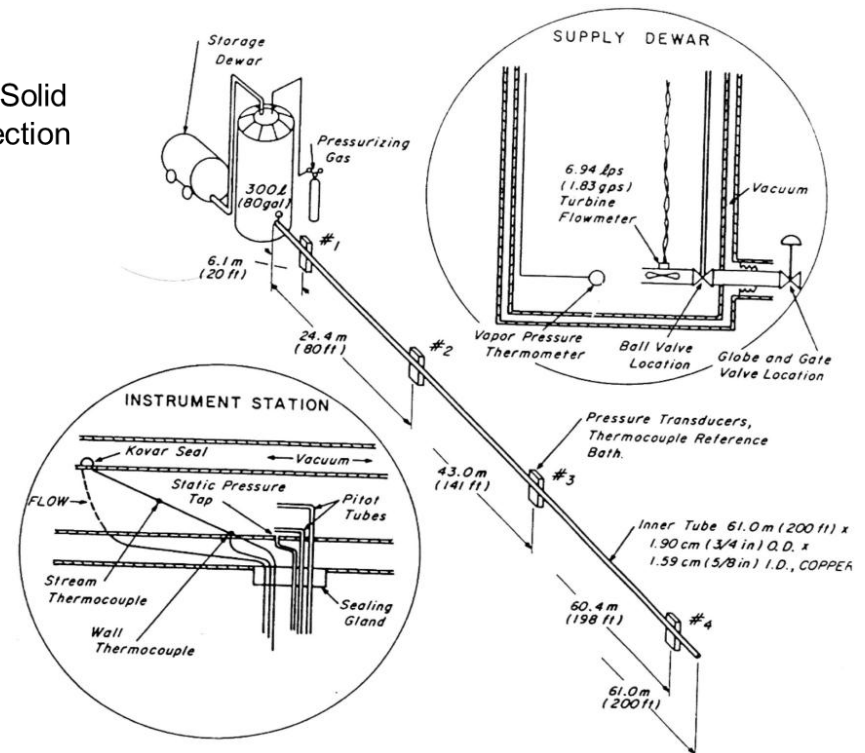
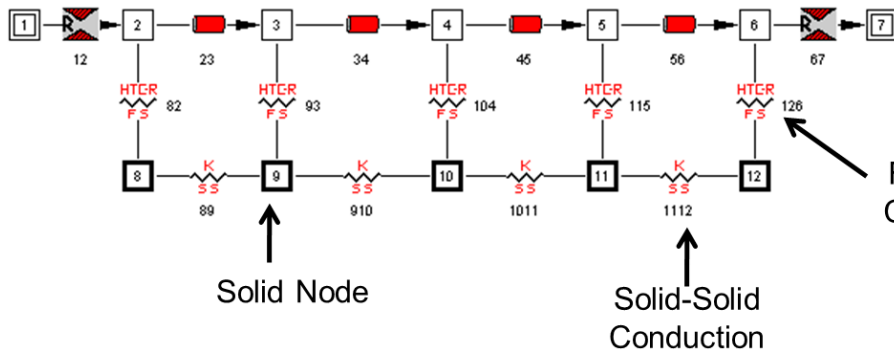
$$\dot{m} = A_{\text{throat}} P_{\text{inlet}} \sqrt{\frac{g_c \gamma}{R T_{\text{inlet}}} \left( \frac{2}{\gamma + 1} \right)^{\frac{\gamma + 1}{\gamma - 1}}} = (0.19012 \text{ in}^2) \left( 161.6 \frac{\text{lbf}}{\text{in}^2} \right) \sqrt{\frac{32.174 \frac{\text{lbm} - \text{ft}}{\text{lbf} - \text{s}^2}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



# Tutorial 2: CHILLDOWN OF TRANSFER LINE

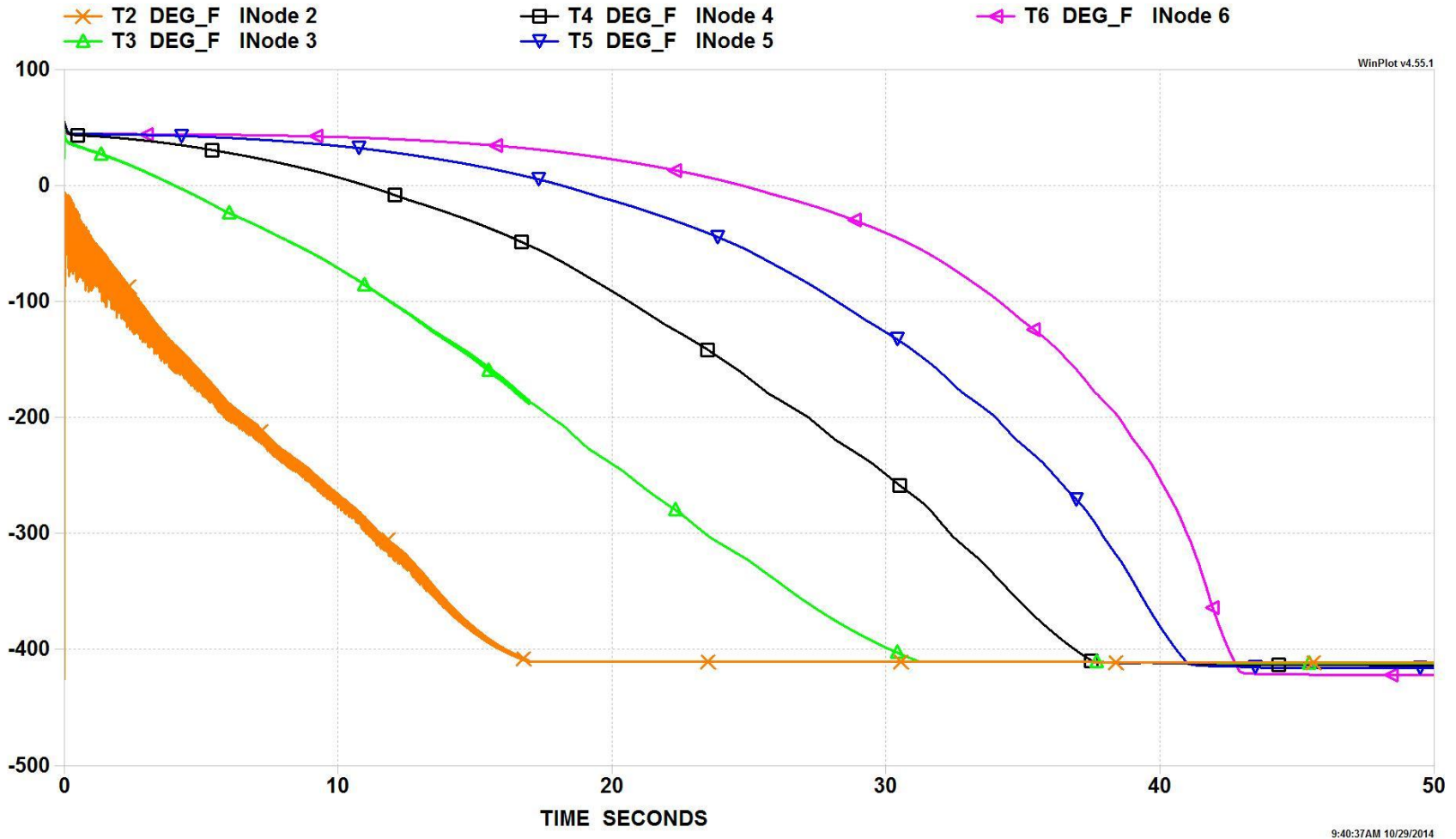
Problem Considered:

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





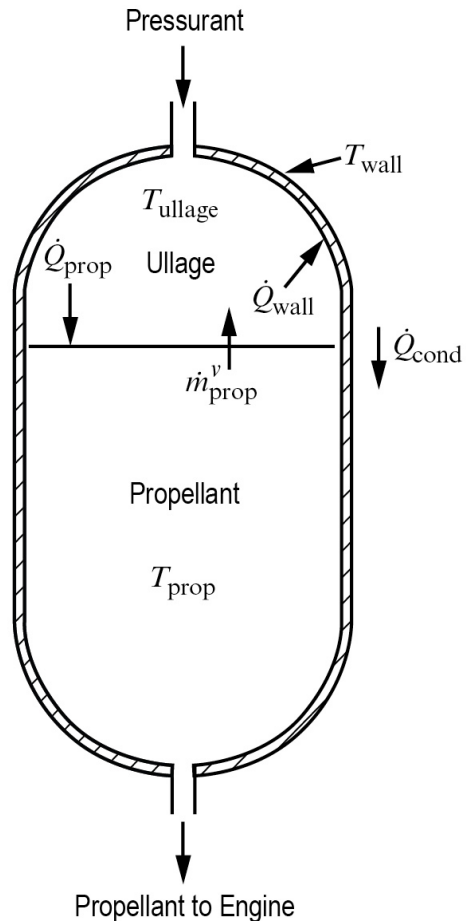
# Fluid Temperature





## Tutorial – 3

# Pressurization of a Propellant Tank

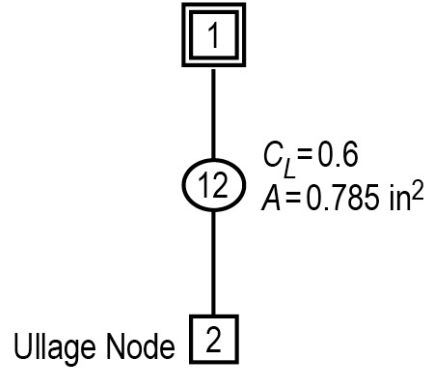


- Predict the ullage conditions considering heat and mass transfer between the propellant and the tank wall
- Predict the propellant conditions leaving the tank

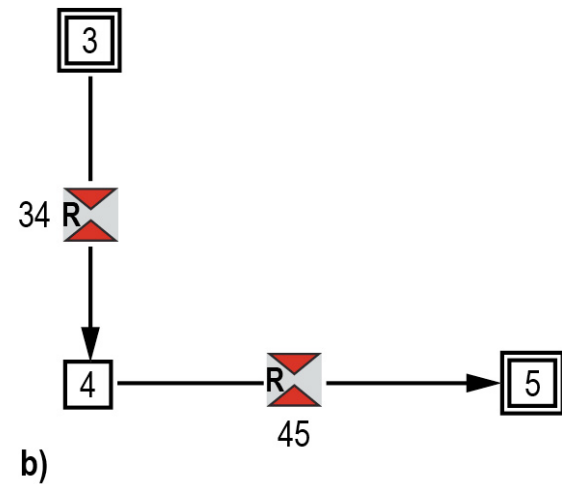
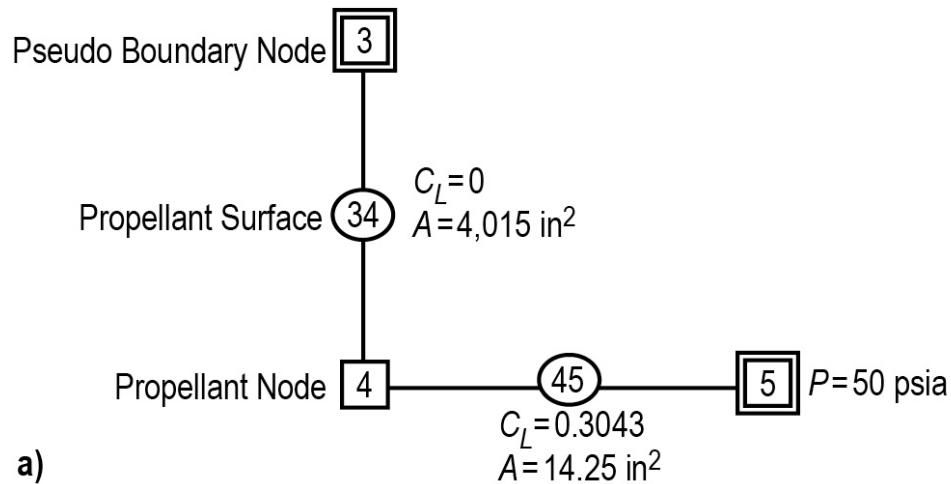


# GFSSP Model

Fluid: He  
 $P=95$  psia  
 $T=120$  °F



Fluid: O<sub>2</sub>  
 $P_{\tau=0}=74.76$  psia  
 $T_{\tau=0}=-264$  °F



a)

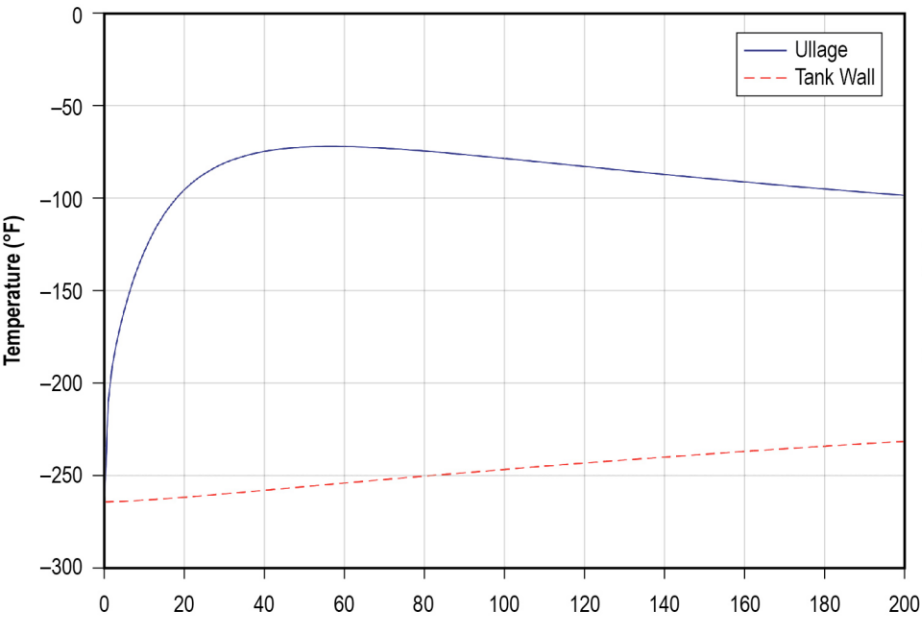
b)



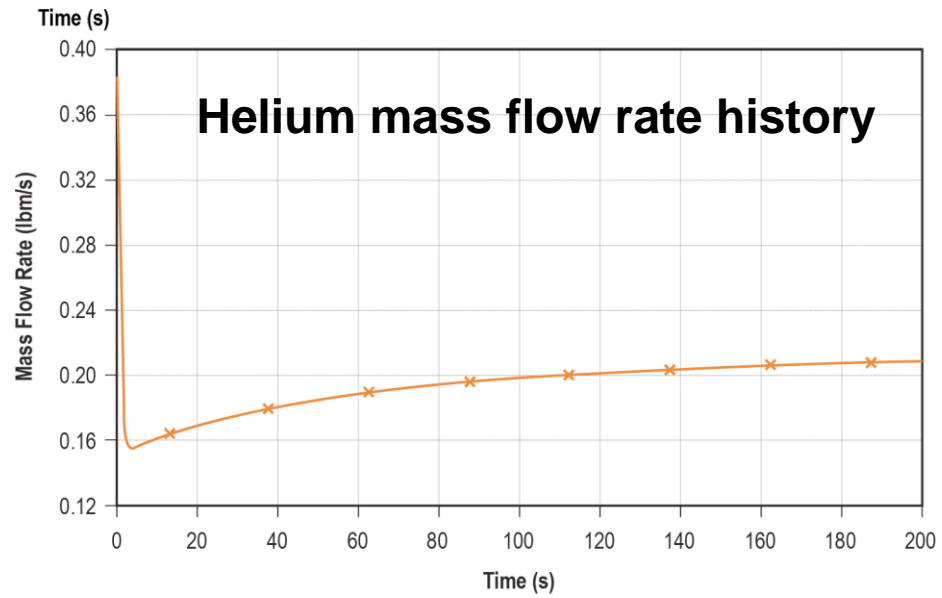
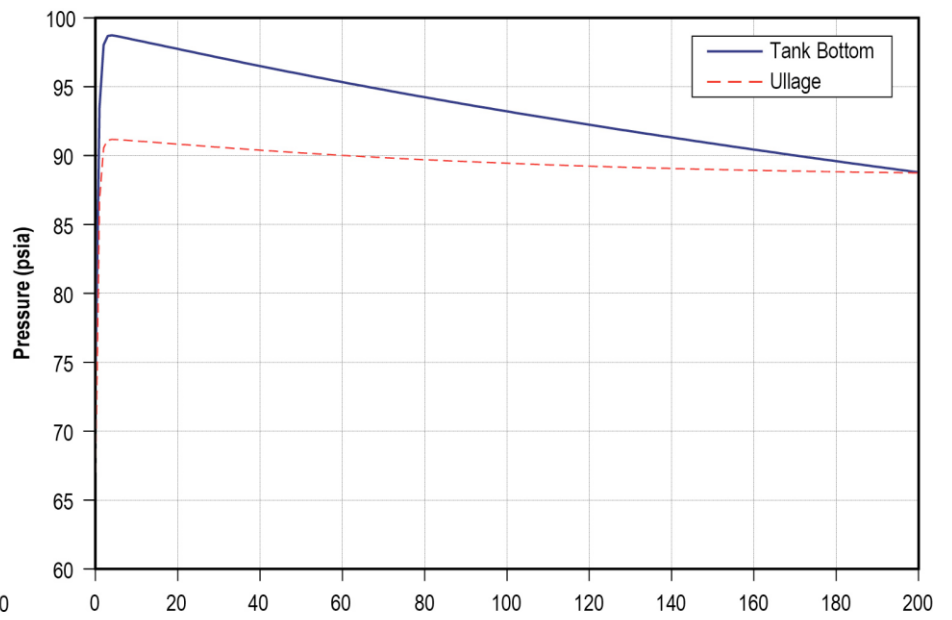


# Model Results

## Ullage and tank wall temperature history

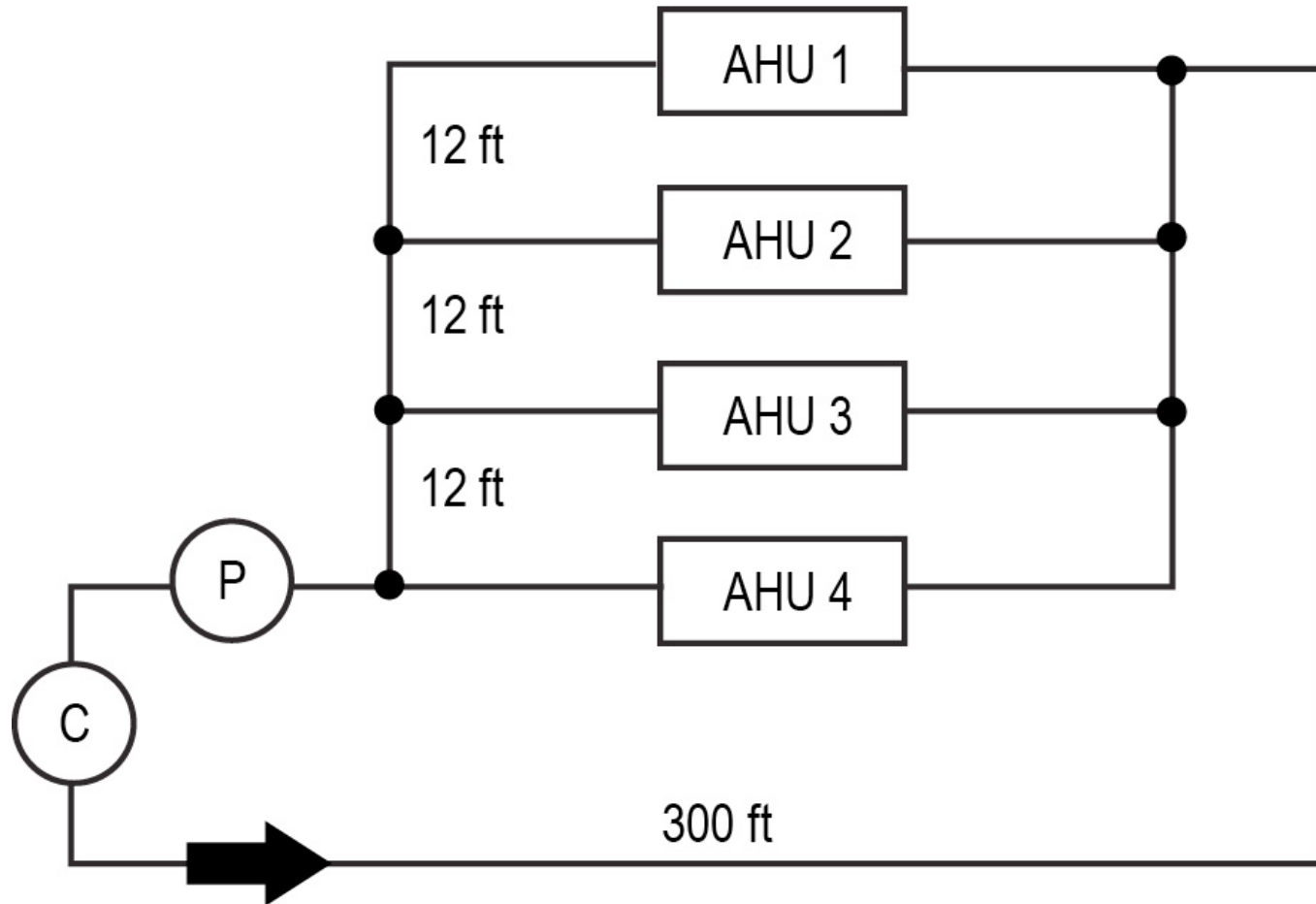


## Ullage and tank bottom pressure history





# Design Project Assignment



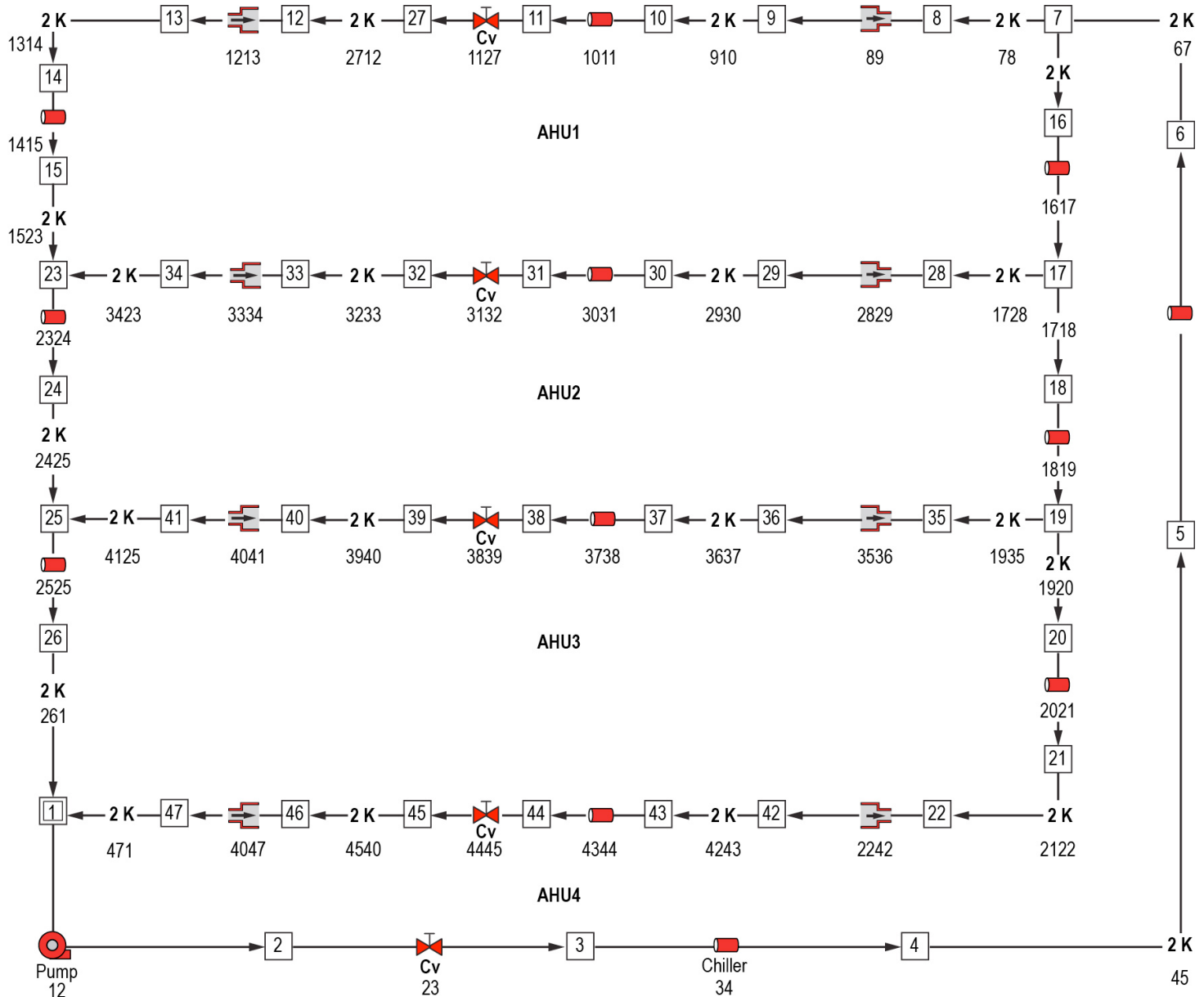


# Air conditioning system requirements

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





# 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

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  - National Institute of Rocket Propulsion (NIRPS) at Marshall Space Flight Center
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