NO VENT TANK FILL AND TRANSFER LINE CHILLDOWN ANALYSIS BY GENERALIZED FLUID SYSTEM SIMULATION PROGRAM (GFSSP)

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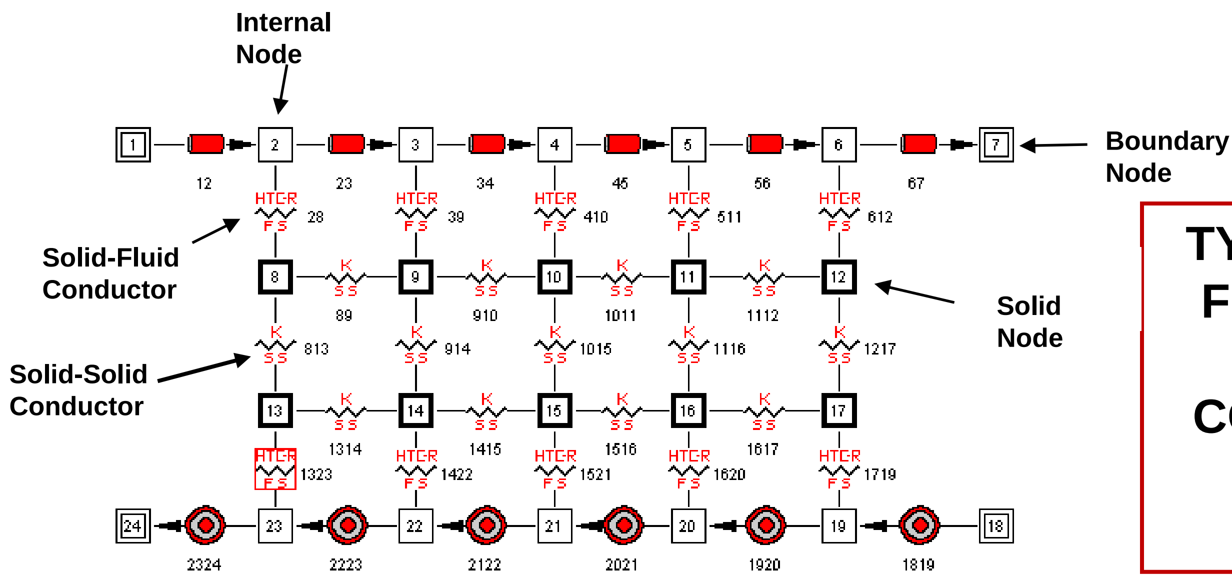
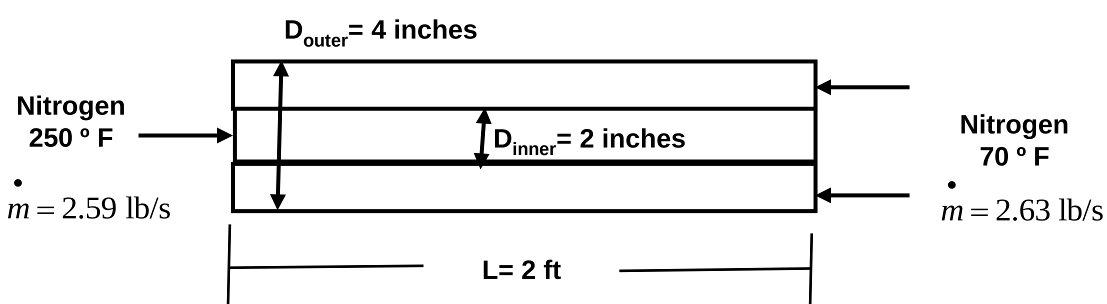
Introduction

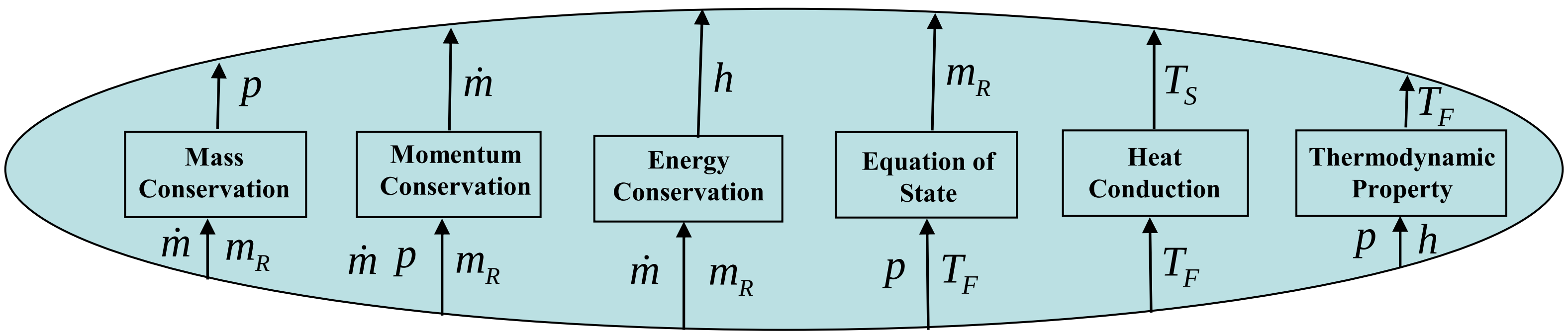
GFSSP is a finite volume based Thermo-fluid system analysis program developed at NASA



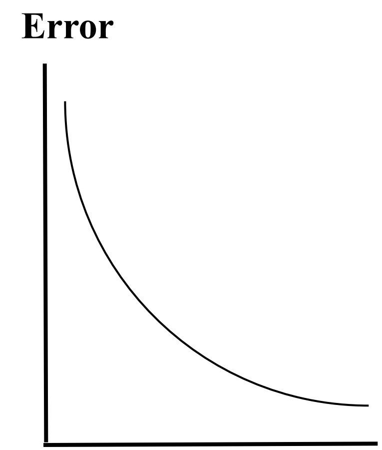
TYPICAL GFSSP FLOW CIRCUIT FOR A COUNTERFLOW HEAT EXCHANGER



- GFSSP uses a pressure based method
- GFSSP's solver uses a combination of simultaneous and successive substitution method



GFSSP Iteration Cycle



p	- **Pressure**	$\dot{m}$	- **Flowrate**	T_F	- **Fluid Temperature**
m_R	- **Resident Mass**	h	- **Enthalpy**	T_S	- **Solid Temperature**

PROGRAM STRUCTURE

Graphical User Interface (VTASC)

- Creates Flow Circuit
- Runs GFSSP
- Displays results graphically

Input Data File

Solver & Property Module

- Equation Generator
- Equation Solver
- Fluid Property Program

Output Data File

New Physics

User Subroutines

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

- GFSSP has integrated two Thermo-dynamic Property Programs, GASP/WASP & GASPAK

Capabilities

- Steady and unsteady flow
- Compressible and incompressible flow
- Single fluid and mixture
- 25 flow resistance 33 fluid options
- Options for new components through User Subroutine
- Options Pressure Regulator, Flow Regulator, Control Valve
- Fluid Transients (e.g. Water hammer)
- Conjugate Heat Transfer
- Options for Model Enhancement through User Subroutine
- Multi-Dimensional Flow Model in Fluid Network System

No Vent Chill & Fill Model of Cryogenic Tank

- Tank Chilldown in micro-gravity environment is different than ground based tank chilldown
- During normal gravity chilldown, a vent on top of the tank is kept open to vent the vapor generated during chill process and maintain a low tank pressure
- In micro-gravity environment, due to absence of stratification, such practice may result in dumping large amount of liquid overboard
- The intent of no-vent chill & fill method is to minimize the loss of propellant during chilldown of propellant tank in micro-gravity environment
- No-vent chill & fill method consists of repeated cyclic process of charge, hold and vent
- The purpose of this presentation is to report the progress of an analytical effort to develop a simulation model of no-vent chill & Fill method for loading a cryogenic tank in space

K-site Test Tank(GRC) - The LH2 chilldown test

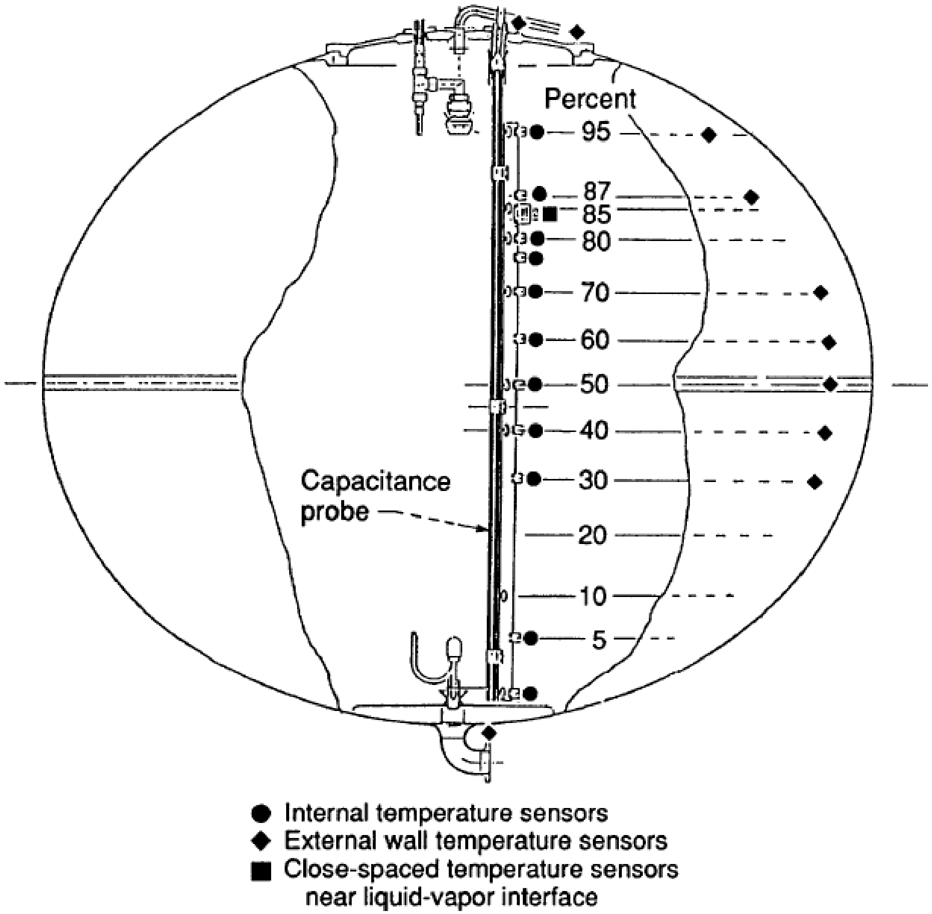


Figure 6.—Tank instrumentation.

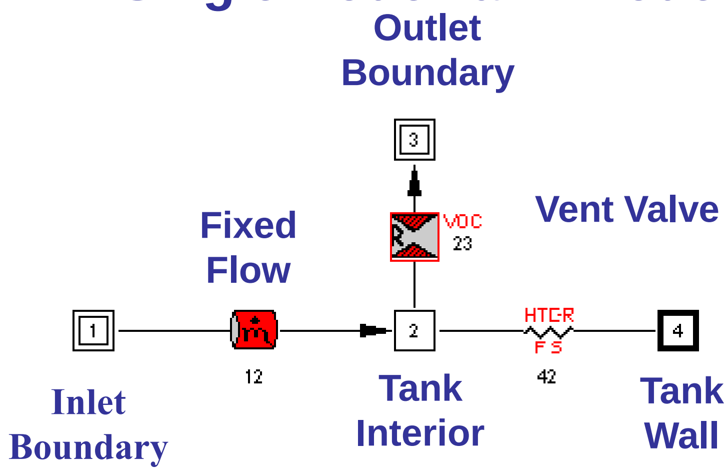
Tank Material – 2219 Aluminum
Tank Volume = 175 ft^3 (87 x 72.5 inch)
Tank Weight = 329.25 lbs
Tank Insulation – 34 layers of MLI

<u>Chilldown Method:</u>

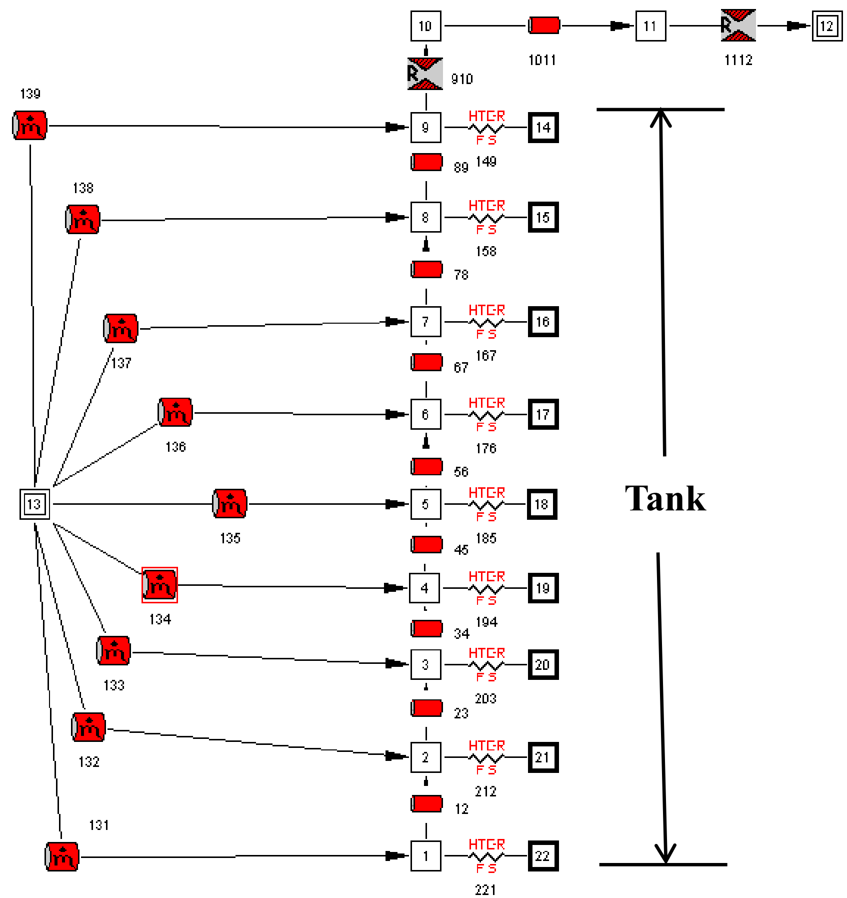
- **6 Cycles of Charge-Hold-Vent Process**
- **Injection rates were measured**
- **714.35 lbs of LH2 was injected in 2.35 hrs**
- **Tank was filled to 94%**
- **Fluid and wall temperatures measured**
- **Estimated consumption of LH2 = 32 lbs**

GFSSP Model

Single Node Tank Model



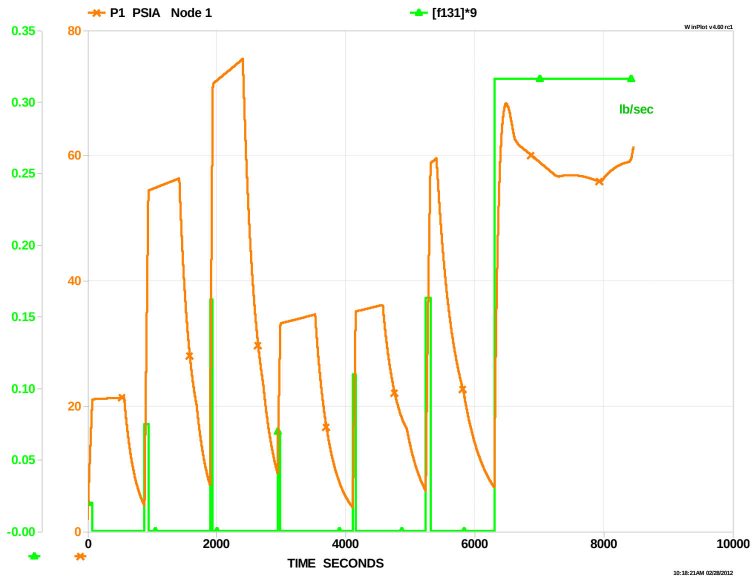
Nine Node Tank Model



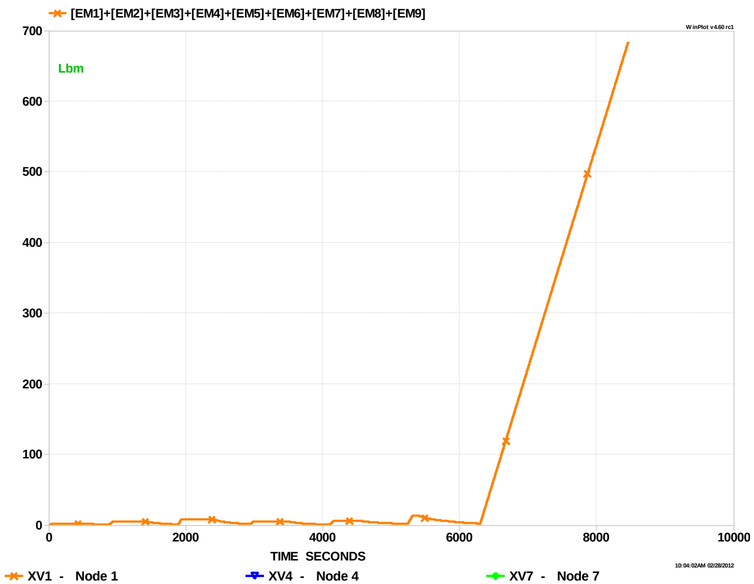
- No heat leak was assumed
- Initial Tank Pressure = 2 psia
- Initial Tank Temperature = -20 º F

GFSSP Model Results

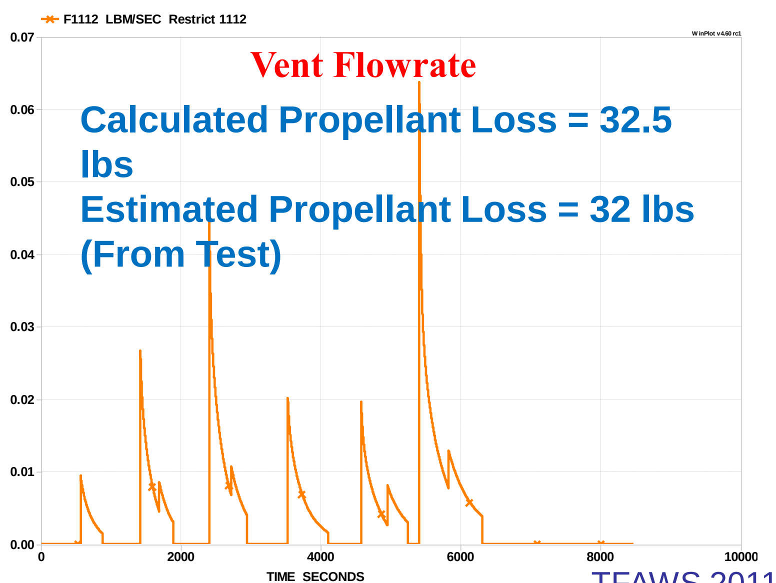
Pressure & Inlet Flowrate



LH2 Mass in Tank

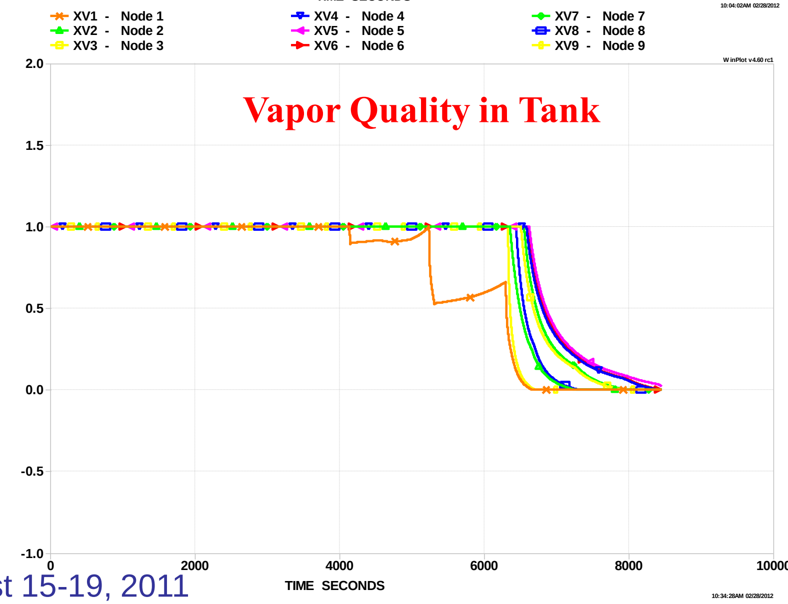


Vent Flowrate

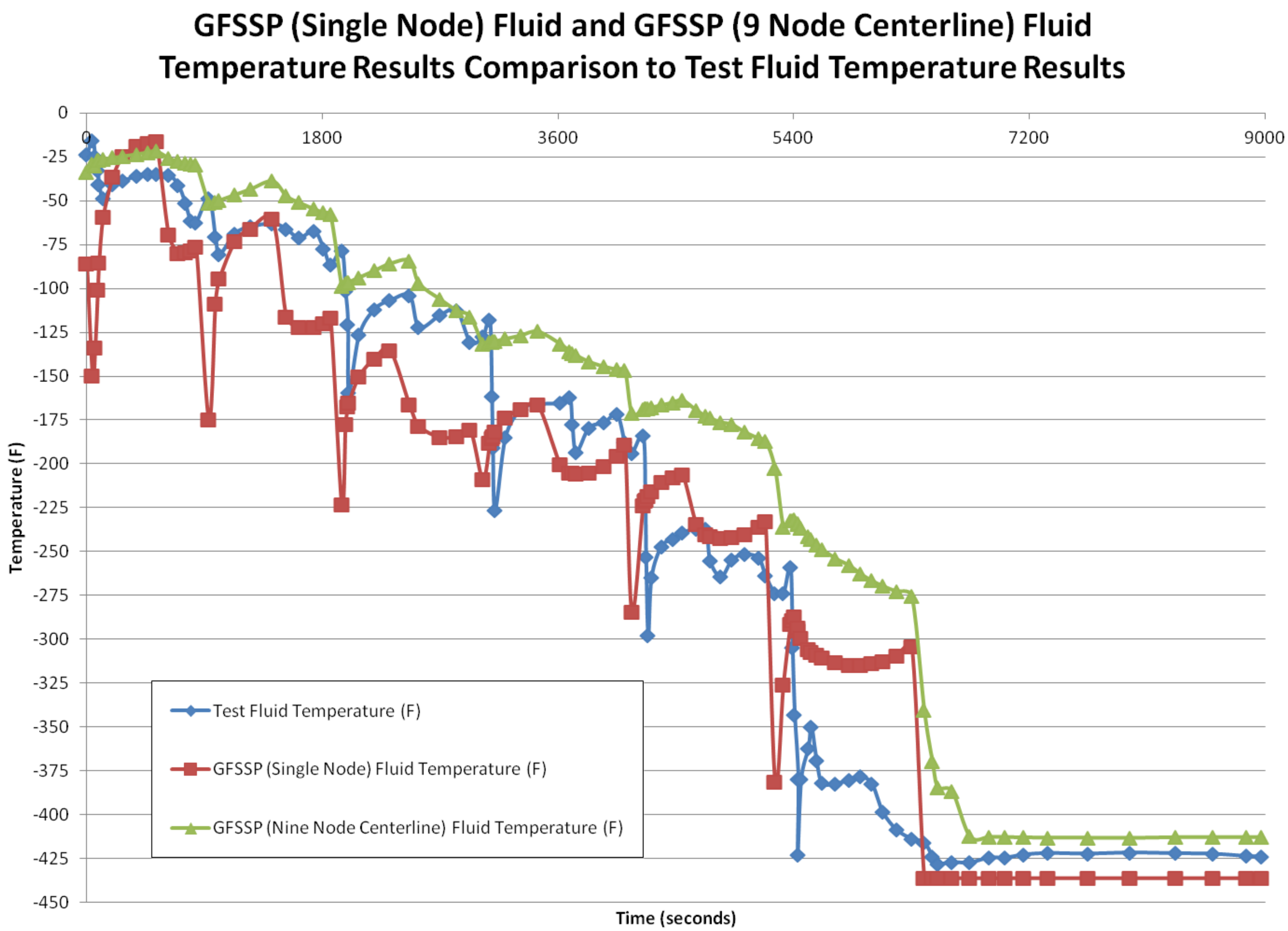


Calculated Propellant Loss = 32.5 lbs
Estimated Propellant Loss = 32 lbs (From Test)

Vapor Quality in Tank



COMPARISON WITH TEST DATA



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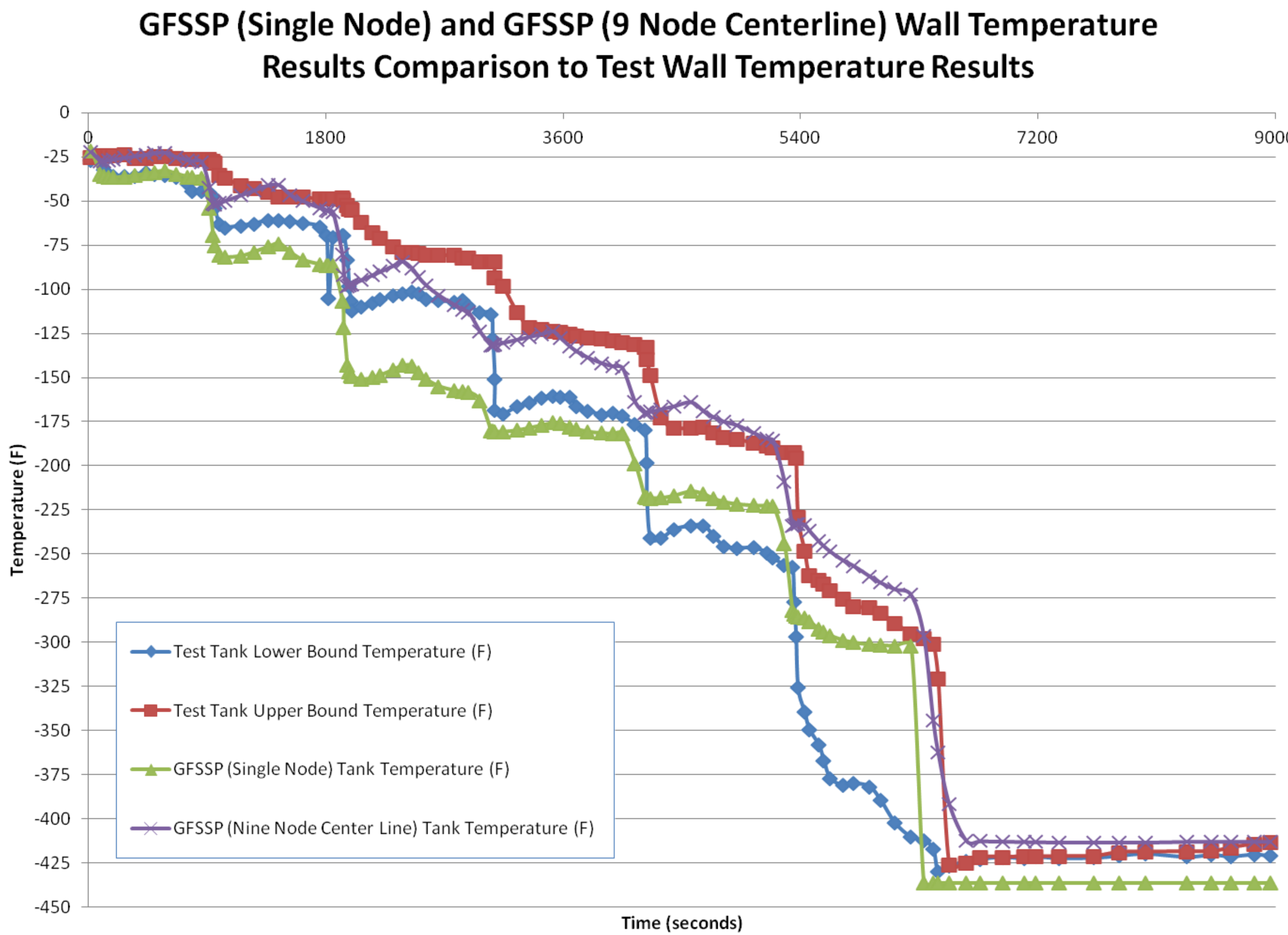
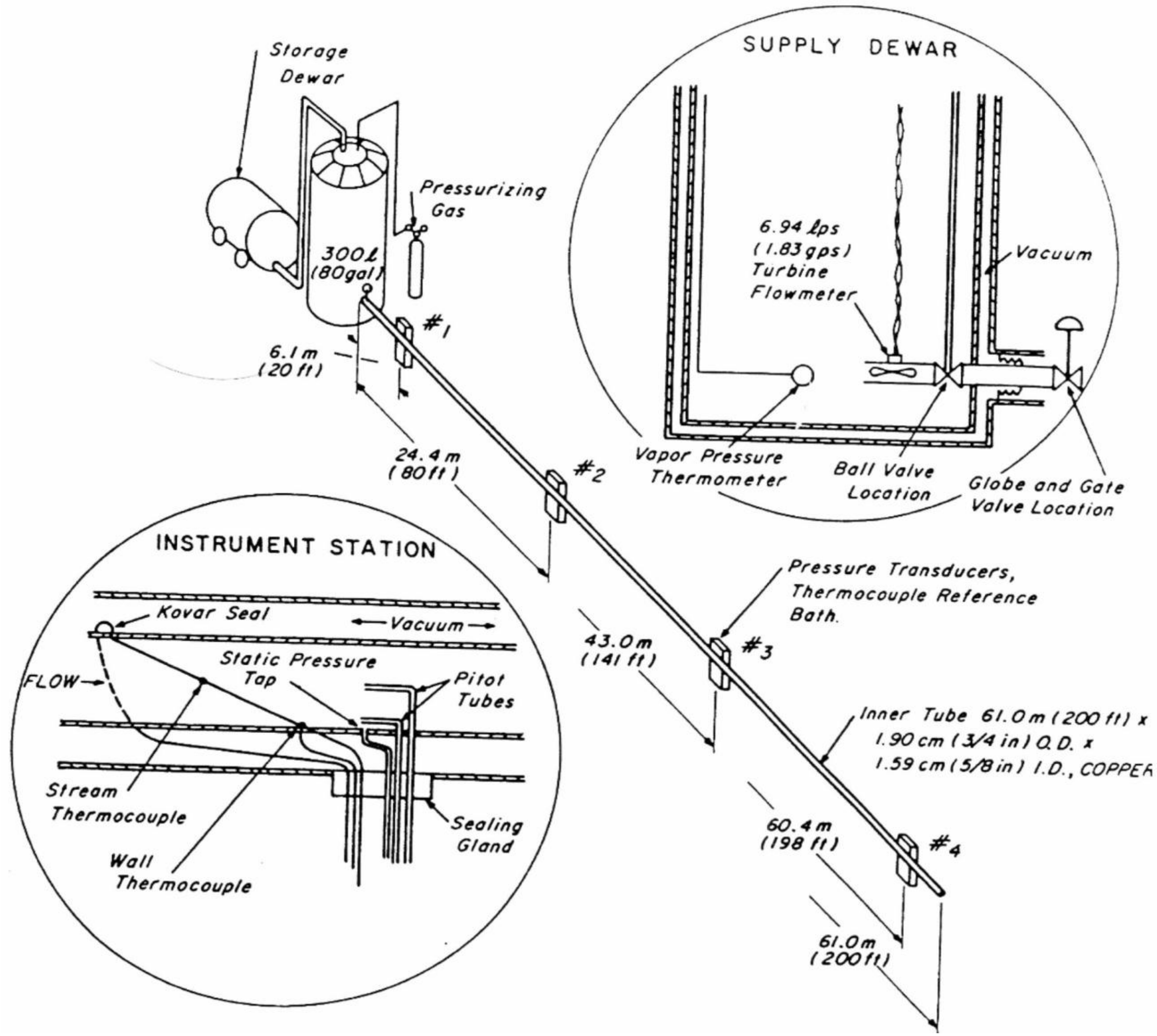


Discussion of Results

- Predicted propellant loss agrees extremely well with estimated propellant loss during the test:
  - Predicted – 32.5 lbs (9-node model) & 33.5 lbs (1-node model)
  - Test – 32 lbs
- Pressure Predictions, however, are inaccurate due to use of fixed flowrate boundary condition at inlet
  - GFSSP's preferable option is to employ pressure boundary condition and calculate flowrate
  - K-site test report does not have enough information to model transfer line upstream of the tank where pressure is measured
- Future validation effort should be directed towards the development of integrated transfer line and tank model to simulate the entire chilldown process which includes both transfer line and tank
- Improved pressure prediction will also improve temperature prediction

NBS Test Set-up of Cryogenic Transfer Line



GFSSP Model of Cryogenic Transfer Line

Saturated LH_2 chilldown time for various driving pressures

Driving Pressure (psia)	Saturation Temperature (°F)	Experimental Chilldown Time (s)	Predicted Chilldown Time (s)
74.97	–411.06	68	70
86.73	–409.08	62	69
111.72	–406.4	42	50
161.72	–402.13	30	33

Subcooled LH_2 chilldown time for various driving pressures. LH_2 is subcooled at –424.57 °F

Driving Pressure (psia)	Experimental Chilldown Time (s)	Predicted Chilldown Time (s)
36.75	148	150
61.74	75	80
86.73	62	60
111.72	41	45
136.72	32	35
161.7	28	30

Saturated LN_2 chilldown time for various driving pressures

Driving Pressure (psia)	Saturation Temperature (°F)	Experimental Chilldown Time (s)	Predicted Chilldown Time (s)
61.74	–294.09	165	185
74.97	–289.71	150	160
86.73	–286.24	130	140

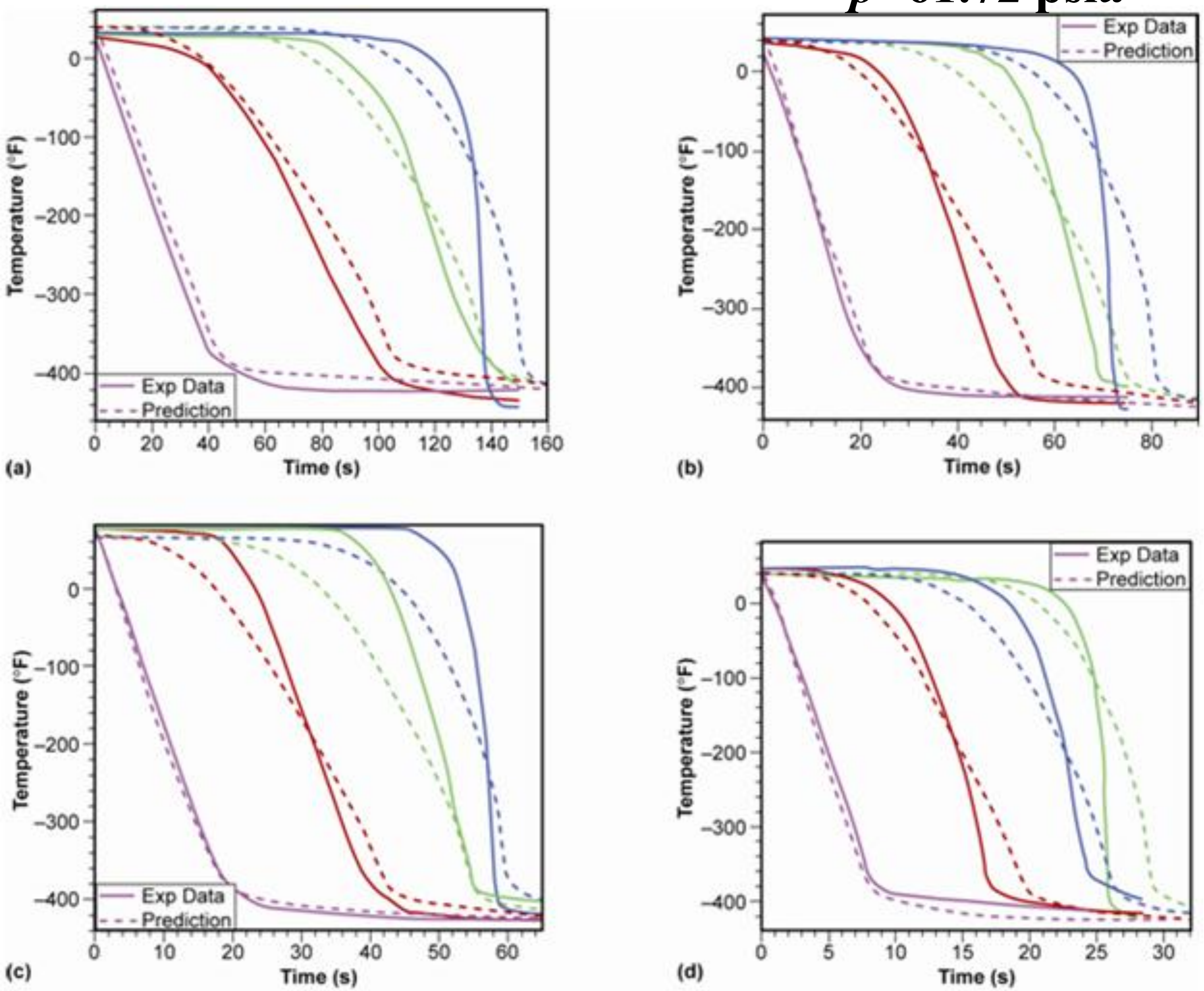
Subcooled LN_2 chilldown time for various driving pressures. LN_2 is subcooled at –322.87 °F

Driving Pressure (psia)	Experimental Chilldown Time (s)	Predicted Chilldown Time (s)
36.75	222	250
49.97	170	175
61.74	129	140
74.97	100	100
86.73	85	90

Comparison of temperature histories for subcooled LH_2

p=36.74 psia

p=61.72 psia



p=86.7 psia

p=161 psia

Station #1 (violet) — 20 ft from tank inlet

Station #2 (red) — 80 ft from tank inlet

Station #3 (green) — 141 ft from tank inlet

Station #4 (blue) — 198 ft from tank inlet

Discussion of Transfer Line Chilldown Results

- Good agreement between test and prediction has been observed for chilldown time for different test conditions
- The model correctly predicts the effects of varying the inlet driving pressure on chilldown time for both subcooled and saturated conditions
- There is, however, discrepancy in temperature history between test and predictions
- The observed discrepancy may be attributed to the inaccuracy in heat transfer coefficient correlation
- An implementation of complete boiling curve that include the regimes of film boiling, transitional region and nucleate boiling may reduce or eliminate the observed discrepancies

CONCLUDING REMARKS

- GFSSP is a general-purpose finite-volume based multi-node (flow network) code for steady and time-dependent flows, including modeling phase changes, conjugate heat transfer, compressibility, mixture thermodynamics, and external body forces such as gravity and centrifugal.
- Twenty-one different resistance/source options are provided for modeling momentum sources or sinks in the branches.
- Two thermodynamic property programs (GASP/WASP and GASPAK) provide required thermodynamic and thermo-physical properties for thirty six fluids
- This paper presents an application and partial verification of no-vent fill modeling of cryogenic tank and transfer line chilldown
- More experimental data are needed for further verification and validation of the code to model these processes
- Boiling heat transfer correlations for all regimes need to be incorporated
- GFSSP is available free of cost for Government use from MSFC Tech Transfer Office after completing the necessary paperwork
- 3-day Training Class is offered at MSFC & KSC; a shorter version is offered at TFAWS