Simulation of Propellant Loading using GFSSP

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Objective

Simulation and Optimization of Propellant using GFSSP

- Optimal Time line for Pre-chill, Slow fill, Fast fill , Topping and Replenishment
- Parametric study to evaluate Temperature, Pressure, Vent Flow Rate, Surface Temperature
- Modification of Existing Algorithm to reduce the Computation Time.
- Implementation of the work into the Senior Design Course at Alabama A & M University.

Analytical Tool: Generalized Fluid System Simulation Program (GFSSP)

Model Features: Transient, Conjugate Heat Transfer and Homogeneous 2- Phase (Boiling and Condensation)

Boundary Conditions & Assumptions:

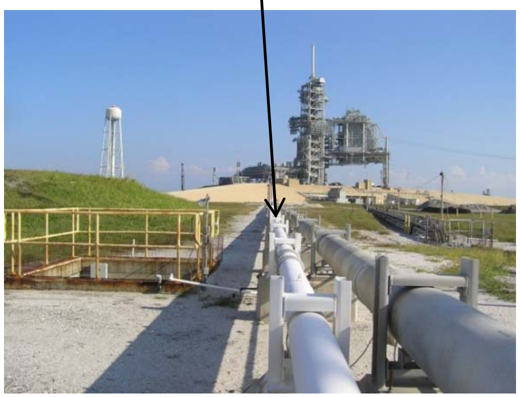
- Base Model is developed by NASA MSFC [1]
- Miropolskii's correlation of Boiling Heat Transfer Coefficient was used for Transfer Line Chilldown
- Heat Transfer Coefficient correlation for Propellant Tanks was developed from Test Data obtained from KSC's Cryogenic Laboratory
- Phase Separation Model has been developed to maintain separation of liquid and vapor in the ullage using a Homogeneous Two-Phase Model.

Propellant Loading in Launch Complex 39B

LO2 Storage Tank

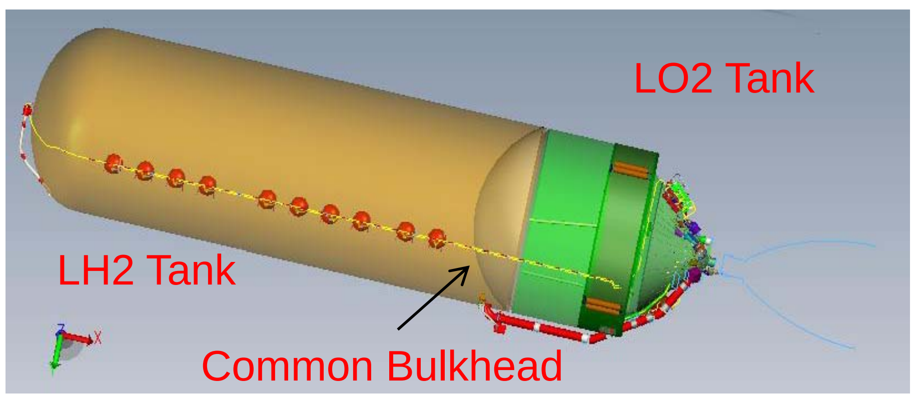
LH2 Storage Tank

Cross Country Pipe



Flare Stack

Upper Stage Propellant Tank

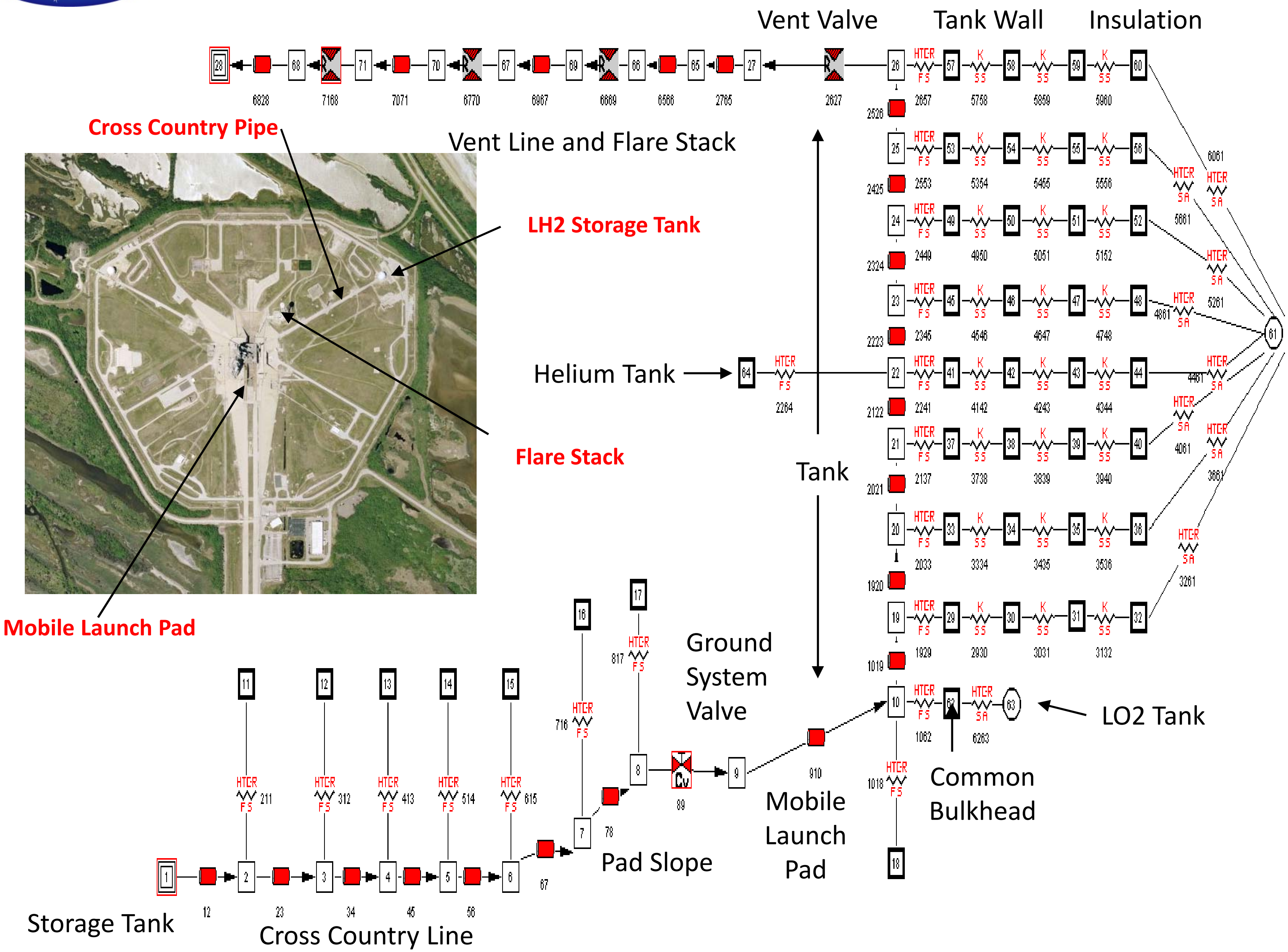


Requirements for Propellant Loading

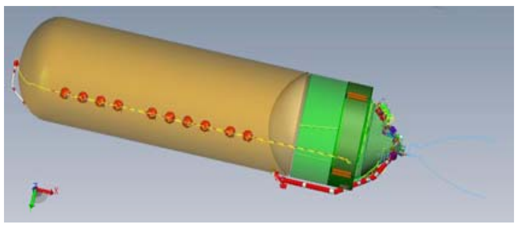
- LH2 Loading
  - Slow fill – 2 lb/sec until Tank is 5% full
  - Fast fill – 15 lb/sec until Tank is 95% full
  - Topping – 2 lb/sec until Tank is 100% full
  - Replenish – 1 lb/sec to allow replenishment due to boil-off
- Pre-chill
  - Chilling of both tanks should start simultaneously to maintain a favorable thermal gradient across Common Bulkhead
  - LH2 loading can only start after completion of LO2 loading followed by 15 minutes of pressure test
  - Tank pressure must not exceed 10 psig during loading

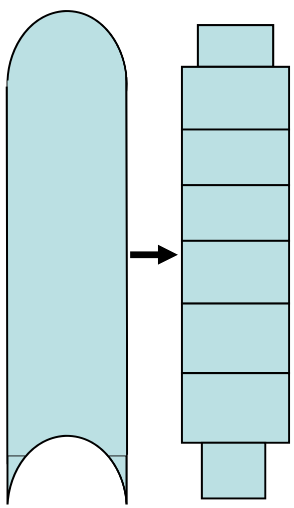
Only LH2 Loading has been considered in this work.
LO2 Modeling will be similar and not simulated in this work.

GFSSP Model of LH2 Tank Loading of Ares I Upper Stage



Input Data for Integrated Ground System, LH_2 Tank and Flare Stack Model of Propellant Loading





LH2 Storage Tank Pressure	46.3 psia
Ambient Temperature	85 ° F
LH2 Propellant Load	48593 lb
Pre-Chill Valve C_v	16
Slow Fill & Topping Valve C_v	12
Fast Fill Valve C_v	140
Replenish Valve C_v	5.64
Vent Valve Area	20.94 in^2
Vent Valve C_d	0.552
Ground System Pipe Length and Volume	1910 ft / 879 ft^3
Flare Stack Pipe Length and Volume	1305 ft /1605 ft^3
Tank Volume	11,620 ft^3
Ground System Pipe Mass	29314 lb
Tank Mass	8742 lb
Foam Mass	673 lb
Metal (Al-Li) thickness	0.1934 in
Foam (BX-265) thickness (Tank Barrel)	1 in
Foam (BX-265) thickness (Dome)	0.5 in
Common Bulkhead Conductance	0.045 Btu/hr-ft^2-F

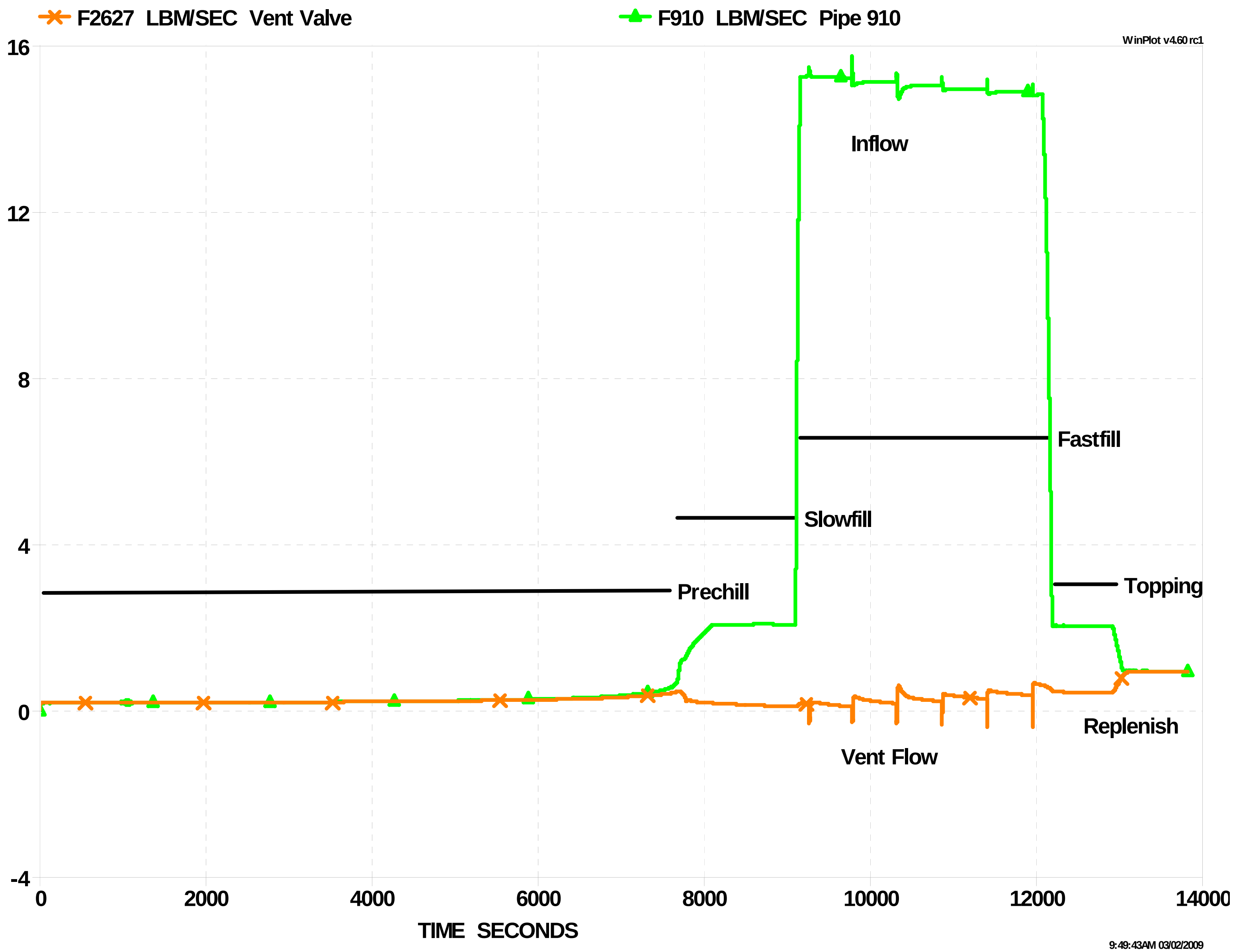
Summary Result for LH2 Loading

Design Parameters	Ground Supply Vapor Quality = 50%	Ground Supply Vapor Quality = 2%
Pre-chill Time (after start)	129 Minutes	129 Minutes
5% Tank Fill Time (after pre-chill)	23 Minutes	23 Minutes
95% Tank Fill Time (after pre-chill)	73 Minutes	73 Minutes
100% Tank Fill Time (after pre-chill)	87 Minutes	87 Minutes
Tank Chill-down Time (after start)	194 Minutes	194 Minutes
Maximum Tank Pressure (pre-chill)	15.94 psia	15.94 psia
Maximum Ullage Pressure (Replenish)	15.5 psia	14.85 psia
Maximum Vent Flowrate	0.95 lb/sec	0.67 lb/sec
Amount of GH2 Vented	4069 lb	3681 lb
Minimum Foam Surface Temperature	6.5 F	6.2 F

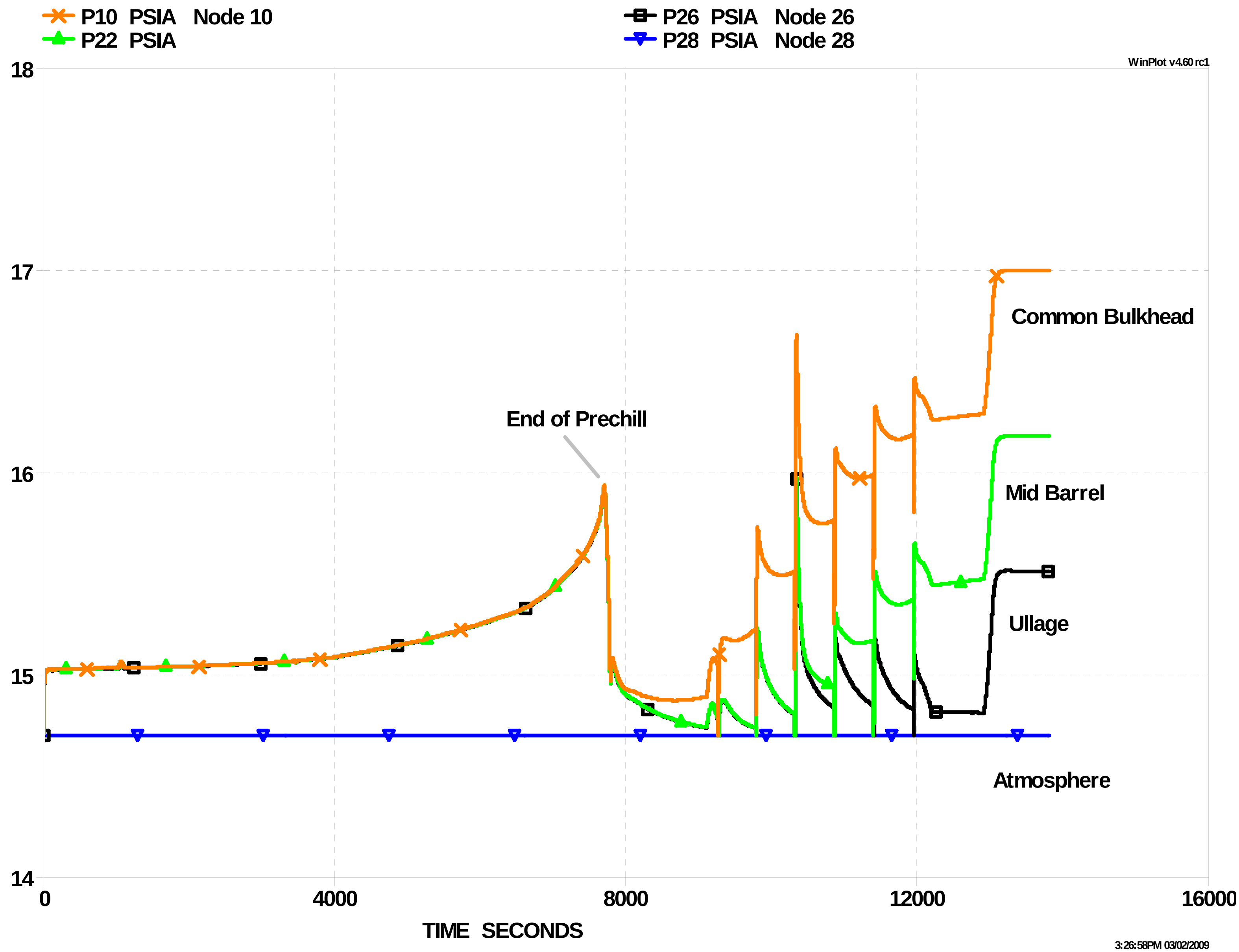
Time Step Study and Effect of CPU TIME

Derived Parameters from Simulation	Base Run (Time step = 0.1 s)	Run1 (Time step = 0.05 s)	Run 2(Time step = 0.2 s)
Pre-chilled Time (min)	128	138	117
Time taken for 5% Fill (min)	23.2	22.8	23.4
Time taken for 98% Fill (min)	72.7	72.5	72.9
Time taken for 100% Fill (min)	86.8	86.6	87.0
Computational Time needed for Simulation	11 hours 26 mins	23 hours 16 mins	6 hours 17 mins

Tank Inflow rate and Vent flow rate

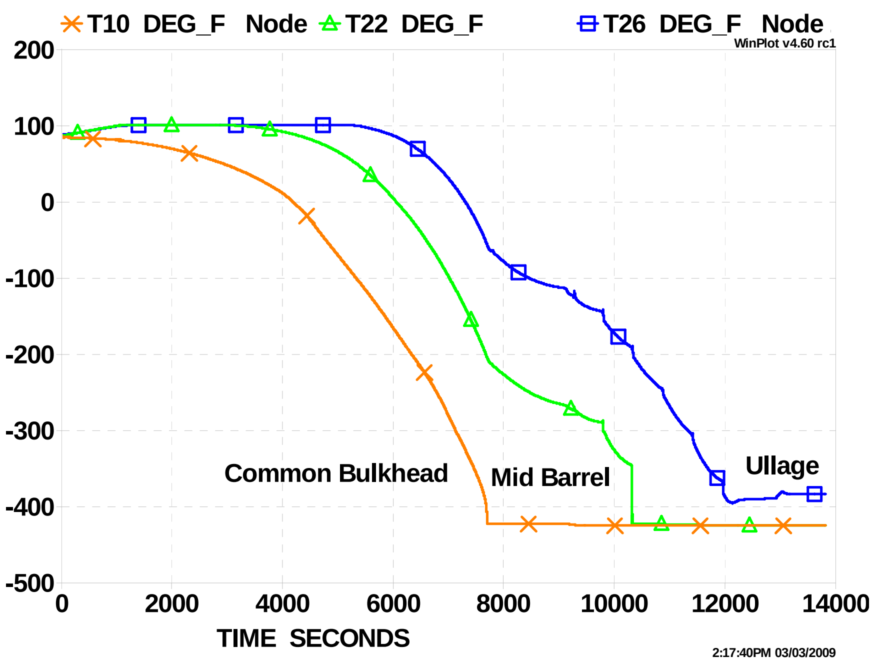


Pressure in LH2 Tank

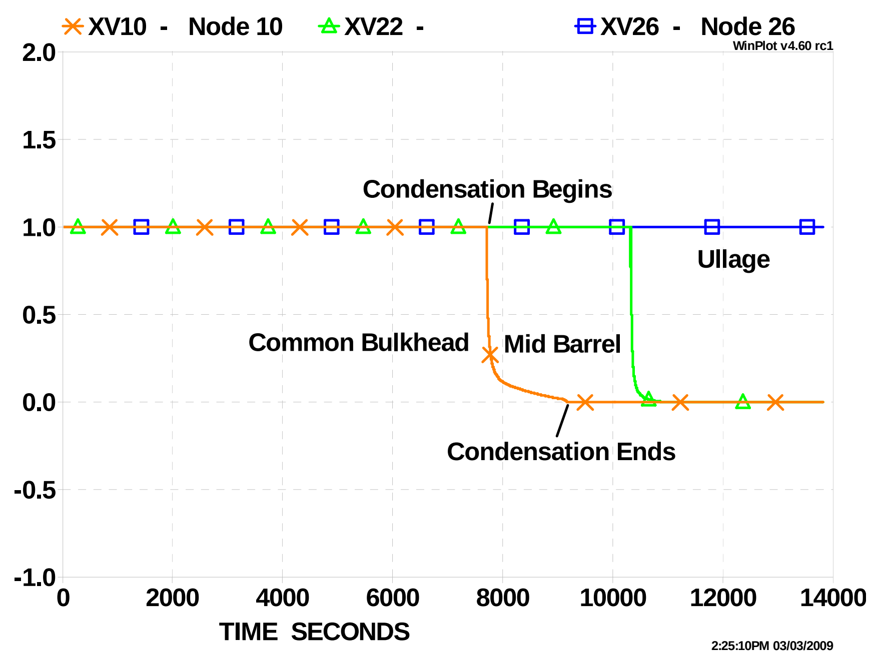


Propellant Temperature and Quality in LH2 Tank

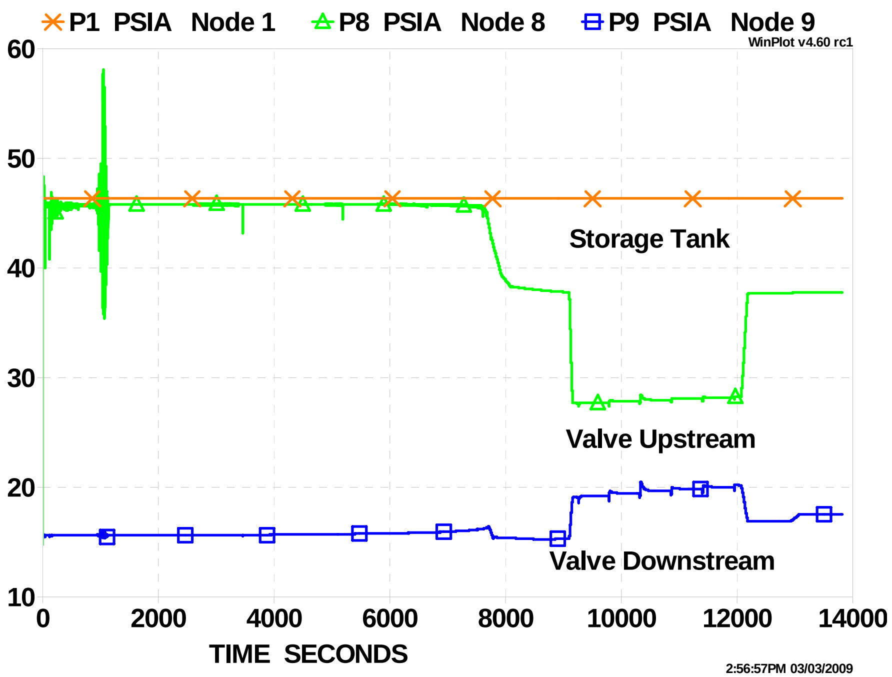
Hydrogen Temperature

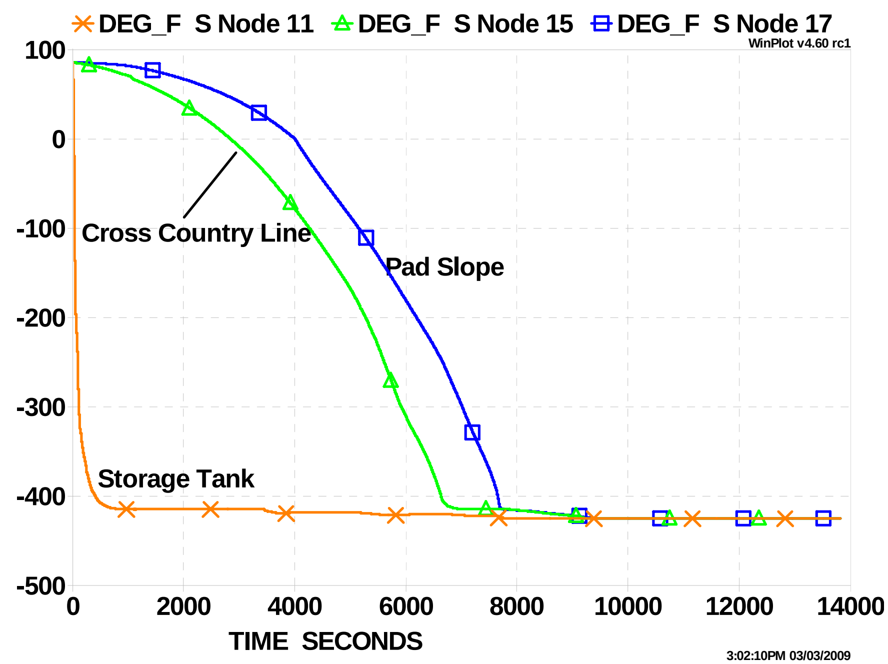


Quality (Vapor Fraction)

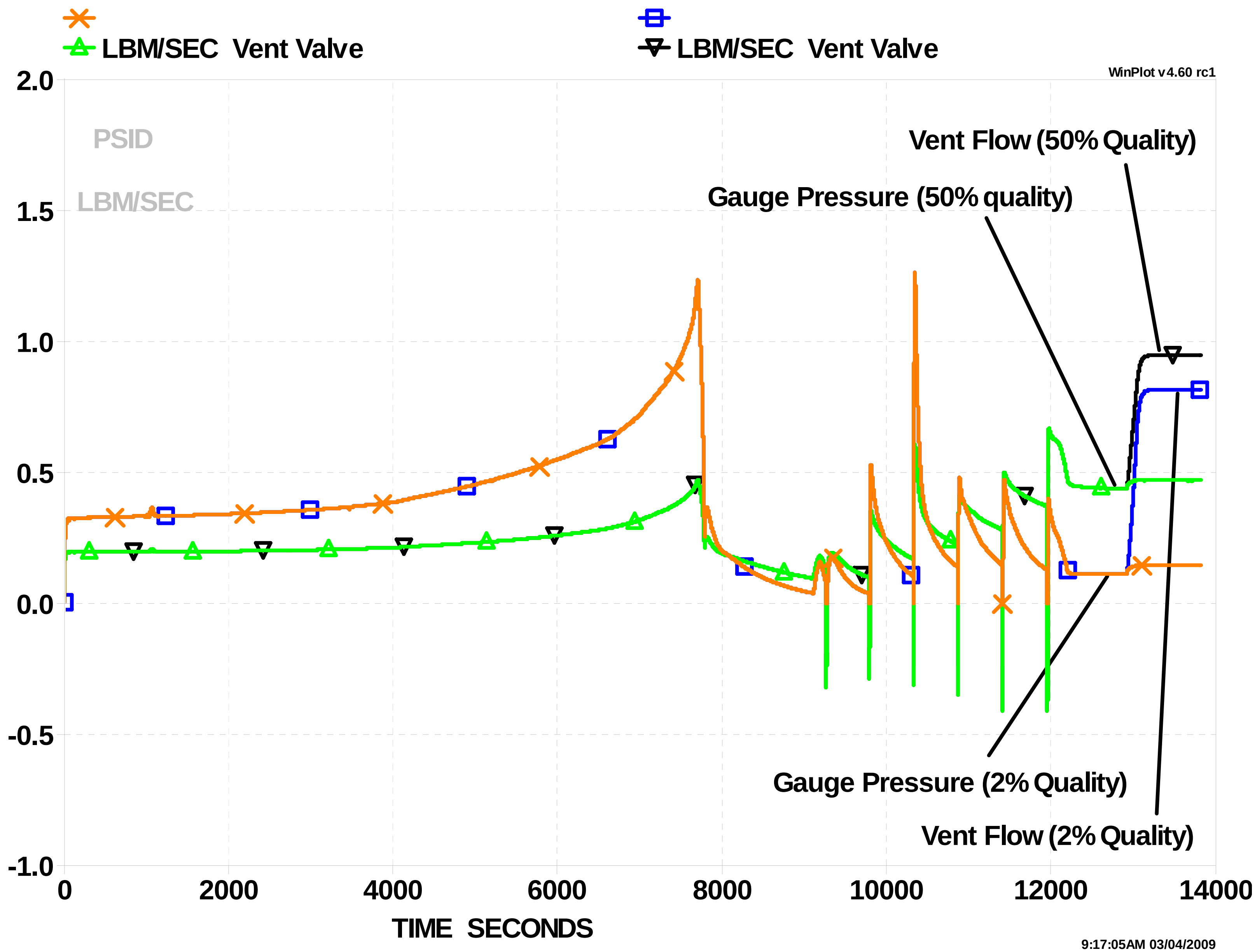


Pressure and Facility Temperature in the Ground System





Ullage Pressure & Flowrate in Vent Line



CONCLUSION

- The Simulation Model will be carried on at Alabama A & M University by the students in the senior design students for further optimization and parametric study.
- The model simulates all phases of loading: Pre-chill, Slow fill, Fast fill, Topping and Replenish
- A new solver technique developed at MSFC will be implemented and tested in the senior design course.
- The computation time is cut by 50% by optimizing the time step. However, further study is needed to optimize further.

- STUDENTS WORK
  - Improve computational efficiency of numerical simulation by introducing fast solver and using fast compiler
  - PARAMETRIC STUDY
  - TEST WITH BROYDEN SOLVER (replacing the existing Newton Raphson).

REFERENCES and ACKNOWLEDGEMENT

REFERENCES:

1. Majumdar, Aloke and LeClair Andre, “LO2 and LH2 Tank Loading and Boil-Off Analysis Report”, report no. MPS-PR-08, NASA MSFC, March 21, 2008

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