Simulation of Propellant Loading using GFSSP

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ESMD SPACE GRANT EDUCATION PROJECT
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

Cross Country Pipe

LH2 Storage Tank

Upper Stage Propellant Tank

Flare Stack

LO2 Tank

LH2 Tank

Common Bulkhead
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

Cross Country Pipe

Vent Line and Flare Stack

LH2 Storage Tank

Helium Tank

Flare Stack

Mobile Launch Pad

Ground System Valve

Pad Slope

Mobile Launch Pad

LO2 Tank

Common Bulkhead

Storage Tank

Cross Country Line
## Input Data for Integrated Ground System, LH₂ Tank and Flare Stack Model of Propellant Loading

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>LH₂ Storage Tank Pressure</td>
<td>46.3 psia</td>
</tr>
<tr>
<td>Ambient Temperature</td>
<td>85 ° F</td>
</tr>
<tr>
<td>LH₂ Propellant Load</td>
<td>48593 lb</td>
</tr>
<tr>
<td>Pre-Chill Valve $C_v$</td>
<td>16</td>
</tr>
<tr>
<td>Slow Fill &amp; Topping Valve $C_v$</td>
<td>12</td>
</tr>
<tr>
<td>Fast Fill Valve $C_v$</td>
<td>140</td>
</tr>
<tr>
<td>Replenish Valve $C_v$</td>
<td>5.64</td>
</tr>
<tr>
<td>Vent Valve Area</td>
<td>20.94 in²</td>
</tr>
<tr>
<td>Vent Valve $C_d$</td>
<td>0.552</td>
</tr>
<tr>
<td>Ground System Pipe Length and Volume</td>
<td>1910 ft / 879 ft³</td>
</tr>
<tr>
<td>Flare Stack Pipe Length and Volume</td>
<td>1305 ft / 1605 ft³</td>
</tr>
<tr>
<td>Tank Volume</td>
<td>11,620 ft³</td>
</tr>
<tr>
<td>Ground System Pipe Mass</td>
<td>29314 lb</td>
</tr>
<tr>
<td>Tank Mass</td>
<td>8742 lb</td>
</tr>
<tr>
<td>Foam Mass</td>
<td>673 lb</td>
</tr>
<tr>
<td>Metal (Al-Li) thickness</td>
<td>0.1934 in</td>
</tr>
<tr>
<td>Foam (BX-265) thickness (Tank Barrel)</td>
<td>1 in</td>
</tr>
<tr>
<td>Foam (BX-265) thickness (Dome)</td>
<td>0.5 in</td>
</tr>
<tr>
<td>Common Bulkhead Conductance</td>
<td>0.045 Btu/hr-ft²-F</td>
</tr>
</tbody>
</table>
## Summary Result for LH2 Loading

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

<table>
<thead>
<tr>
<th>Derived Parameters from Simulation</th>
<th>Base Run (Time step = 0.1 s)</th>
<th>Run1 (Time step = 0.05 s)</th>
<th>Run2 (Time step = 0.2 s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-chilled Time (min)</td>
<td>128</td>
<td>138</td>
<td>117</td>
</tr>
<tr>
<td>Time taken for 5% Fill (min)</td>
<td>23.2</td>
<td>22.8</td>
<td>23.4</td>
</tr>
<tr>
<td>Time taken for 98% Fill (min)</td>
<td>72.7</td>
<td>72.5</td>
<td>72.9</td>
</tr>
<tr>
<td>Time taken for 100% Fill (min)</td>
<td>86.8</td>
<td>86.6</td>
<td>87.0</td>
</tr>
<tr>
<td>Computational Time needed for Simulation</td>
<td>11 hours 26 mins</td>
<td>23 hours 16 mins</td>
<td>6 hours 17 mins</td>
</tr>
</tbody>
</table>
Tank Inflow rate and Vent flow rate

WinPlot v4.60 rc1

F2627 LBM/SEC Vent Valve
F910 LBM/SEC Pipe 910

Inflow
Fastfill
Slowfill
Prechill

Vent Flow
Replenish

TIME SECONDS
0 2000 4000 6000 8000 10000 12000 14000
0 4 8 12 16

9:49:43AM 03/02/2009
9-40-43AM 03/02/2009
Propellant Temperature and Quality in LH2 Tank

Hydrogen Temperature

Quality (Vapor Fraction)

Condensation Begins

Condensation Ends

Common Bulkhead

Mid Barrel

Ullage
Ullage Pressure & Flowrate in Vent Line

- Vent Flow (50% Quality)
- Gauge Pressure (50% quality)
- Vent Flow (2% Quality)
- Gauge Pressure (2% Quality)

TIME SECONDS

PSID

LBM/SEC

LBM/SEC Vent Valve

LBM/SEC Vent Valve

WinPlot v4.60 rc1

9:17:05AM 03/04/2009
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:


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