Evolvable Cryogenics (eCryo) Project
Technology Workshop with Industry

Engineering Development Unit (EDU) Workshop

EDU Tank LH2 Chill/Fill Analysis

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EDU LH2 Tank Chill/Fill Analysis

Objectives

• Utilize Generalized Fluid Simulation Systems Program (GFSSP) to develop EDU fluid/thermal model for:
  
  – **Pretest**
    • Predict/Estimate maximum ullage pressure in EDU tank during Fill process
    • Evaluate vent system capacity
    • Predict/Estimate Chill-down/Fill time
  
  – **Post-test**
    • Incorporate test conditions into GFSSP model
    • Correlate/anchor the model
• GFSSP model was developed for EDU configuration by applying modeling methodology used in:
  – Ares LO2 and LH2 Tank Loading and Chill down Model, reported in:
  – Propellant Loading of the Space Shuttle External Tank Model, published in:

• Model contains:
  – LH2 supply source
  – EDU tank divided into five equal segments
  – Fill/Vent lines and components
EDU LH2 Tank Chill/Fill Analysis
GFSSP Model

Feed Lines
LH2 Supply $P_s$

Tank

Vent Lines
Atm. 14.7 psia
• Lines dimensions are based on actual measurement
• Valve CVs provided by testing personnel
• EDU Tank is divided into 5 equal segments (100 lb/segment)
• Tank maximum heat leak = 3 kW
• Fill/Vent lines heat leak is neglected
Table 1. Component representations used in GFSSP Model

<table>
<thead>
<tr>
<th>Branch #</th>
<th>Component representation</th>
<th>Dimension (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>8079</td>
<td>Pipe</td>
<td>$D = 2$ in., $L = 39$ in., $\varepsilon = 6 \times 10^{-5}$ in.</td>
</tr>
<tr>
<td>7978</td>
<td>Valve</td>
<td>$C_v = 50$</td>
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<tr>
<td>7873</td>
<td>Pipe</td>
<td>$D = 2$ in., $L = 295$ in., $\varepsilon = 6 \times 10^{-5}$ in.</td>
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<tr>
<td>7372</td>
<td>Valve</td>
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<tr>
<td>7271</td>
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<td>$D = 2$ in., $L = 80$ in., $\varepsilon = 6 \times 10^{-5}$ in.</td>
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<tr>
<td>7170</td>
<td>Valve</td>
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<td>702</td>
<td>Pipe</td>
<td>$D = 2$ in., $L = 180$ in., $\varepsilon = 6 \times 10^{-5}$ in.</td>
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<tr>
<td>23</td>
<td>Valve</td>
<td>$C_v = 1.12$</td>
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<tr>
<td>34</td>
<td>Pipe</td>
<td>$D = 2$ in., $L = 36$ in., $\varepsilon = 6 \times 10^{-5}$ in.</td>
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<td>45</td>
<td>Tank</td>
<td>$D = 66.9$ in., $L = 14.21$ in., $\varepsilon = 6 \times 10^{-5}$ in.</td>
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<tr>
<td>56</td>
<td>Tank</td>
<td>$D = 66.9$ in., $L = 14.21$ in., $\varepsilon = 6 \times 10^{-5}$ in.</td>
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<tr>
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<tr>
<td>78</td>
<td>Tank</td>
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</tr>
<tr>
<td>89</td>
<td>Tank</td>
<td>$D = 66.9$ in., $L = 14.21$ in., $\varepsilon = 6 \times 10^{-5}$ in.</td>
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<tr>
<td>910</td>
<td>Reduction</td>
<td>$D_1 = 66.9$ in., $D_2 = 1.5$ in.</td>
</tr>
<tr>
<td>1011</td>
<td>Pipe</td>
<td>$D = 2$ in., $L = 174$ in., $\varepsilon = 6 \times 10^{-5}$ in.</td>
</tr>
<tr>
<td>1112</td>
<td>Valve</td>
<td>$C_v = 46$</td>
</tr>
<tr>
<td>1213</td>
<td>Pipe</td>
<td>$D = 1.5$ in., $L = 71$ in., $\varepsilon = 6 \times 10^{-5}$ in.</td>
</tr>
<tr>
<td>1314</td>
<td>Valve</td>
<td>$C_v = 39.5$</td>
</tr>
<tr>
<td>1415</td>
<td>Pipe</td>
<td>$D = 1.5$ in., $L = 18$ in., $\varepsilon = 6 \times 10^{-5}$ in.</td>
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<tr>
<td>1516</td>
<td>Expansion</td>
<td>$D_1 = 1.5$ in., $D_2 = 2$ in.</td>
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<td>Pipe</td>
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<td>Expansion</td>
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<td>1819</td>
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<td>$D = 3$ in., $L = 2183$ in., $\varepsilon = 6 \times 10^{-5}$ in.</td>
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<td>1920</td>
<td>Check valve</td>
<td>$C_v = 50$</td>
</tr>
<tr>
<td>2021</td>
<td>Pipe</td>
<td>$D = 3$ in., $L = 12$ in., $\varepsilon = 6 \times 10^{-5}$ in.</td>
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</table>

$D =$ diameter, $L =$ length, $\varepsilon =$ pipe roughness, $C_v =$ Valve flow coefficient
• Criteria given to Team to implement the test:
  – LH2 Source pressure $P_s = 39$ psia
  – Maximum ullage pressure $P_{\text{max}_{\text{Ullage}}} = 24$ psia
  – Chill/Fill duration $t_{\text{C/F}} = 3.75$ hours
• Observations based on initial results:
  – Due to long duration of model simulation (time step = $10^{-5}$ s), the chill/fill was estimated based on chill-down slope in early stage of cool-down predicted by the model.
  – Values for $P_{\text{max}_{\text{Ullage}}}$ and $t_{\text{C/F}}$ included:
    • Addition of 6 psi (i.e., $18 + 6 = 24$ psi)
    • Addition of 30% margin (i.e. $2.88 \times 1.3 = 3.75$ hours)
EDU LH2 Tank Chill/Fill Analysis: Pre-test Results

Ullage Pressure: Comparison Pre-test Estimates & Test Data

Facility Line Chilldown

Tank Fill Begins

Truck Pressure with 14.7 psia adjustment

EDU Tank Pressure does not exceed 5 psid with environment during fill. Large Pressure drop across system

Estimated 24 psia
EDU LH2 Tank Chill/Fill Analysis: Pre-test Results

Chill/Fill Time: Comparison Pre-test Estimates & Test Data

Temperature Rake Incorrect Wet/Dry Readings During initial fill. Relied on temp mode to declare tank full

Presumed Tank Full at 1.5 hrs after fill started using temperature mode and RFMG

Estimated 3.75 hrs
• To speed up model simulation time, worked with Alok Majumdar/ER43. Per his suggestions, time step selection has been modified (no changes in model configurations and physics). This modification lead to a significant reduction in model simulation run time.

• Correlated and anchored the model by incorporating the EDU chill/fill conditions into GFSSP model.
EDU LH2 Chill/Fill Tank Analysis: Post-test Results
Tank Wall temperature History, 10% Fill Level

Wall Temperature (Deg. F) vs. Time (s)

Model Test
EDU LH2 Chill/Fill Tank Analysis: Post-test Results

EDU Tank Wall temperature History, 50% Fill Level

Wall Temperature (Deg. F) vs Time (s) for Model and Test.
EDU LH2 Chill/Fill Tank Analysis: Post-test Results
Tank Wall temperature History, 80% Fill Level

Model Test

Wall Temperature (Deg. F)

Time (s)
EDU Tank LH2 Chill/Fill Tank Analysis: Post-test Results

Accumulated LH2 Mass History

- **Cap_probe** ~ 461.65 lb
- **RFMG** ~ 469.65 lb
- **Model** ~ 453.5 lb

![Graph showing accumulated LH2 mass history](image-url)
• Utilized GFSSP to thermal/fluid model for EDU tank during chill/fill
• In Pre-test, provided EDU testing team following criteria to implement the testing:
  – LH2 source pressure
  – Maximum ullage pressure estimate
  – Chill/Fill duration estimate
• In Post-test, correlated GFSSP model by Incorporating EDU fill/chill test initial and boundary conditions.
  – Comparison of model predictions with test data, provided good agreements for:
    • Tank wall temperature at 10%, 50%, and 80% fill levels
    • Accumulated LH2 mass in EDU tank during fill/chill process