Evolvable Cryogenics (eCryo) Project
Technology Workshop with Industry

Engineering Development Unit (EDU) Workshop

EDU Tank LH2 Chill/Fill Analysis

Ali Hedayat/MSFC-ER22

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

EDU LH2 Tank Chill/Fill Analysis

Approach

- 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:**

  "LO2 and LH2 Tank Loading and Boil-Off Analysis Report," Report No. MPS-CDR-AE-01 Prepared by Alok Majumdar & André LeClair ER43/Thermal and Combustion Analysis Branch, Summer, 2010

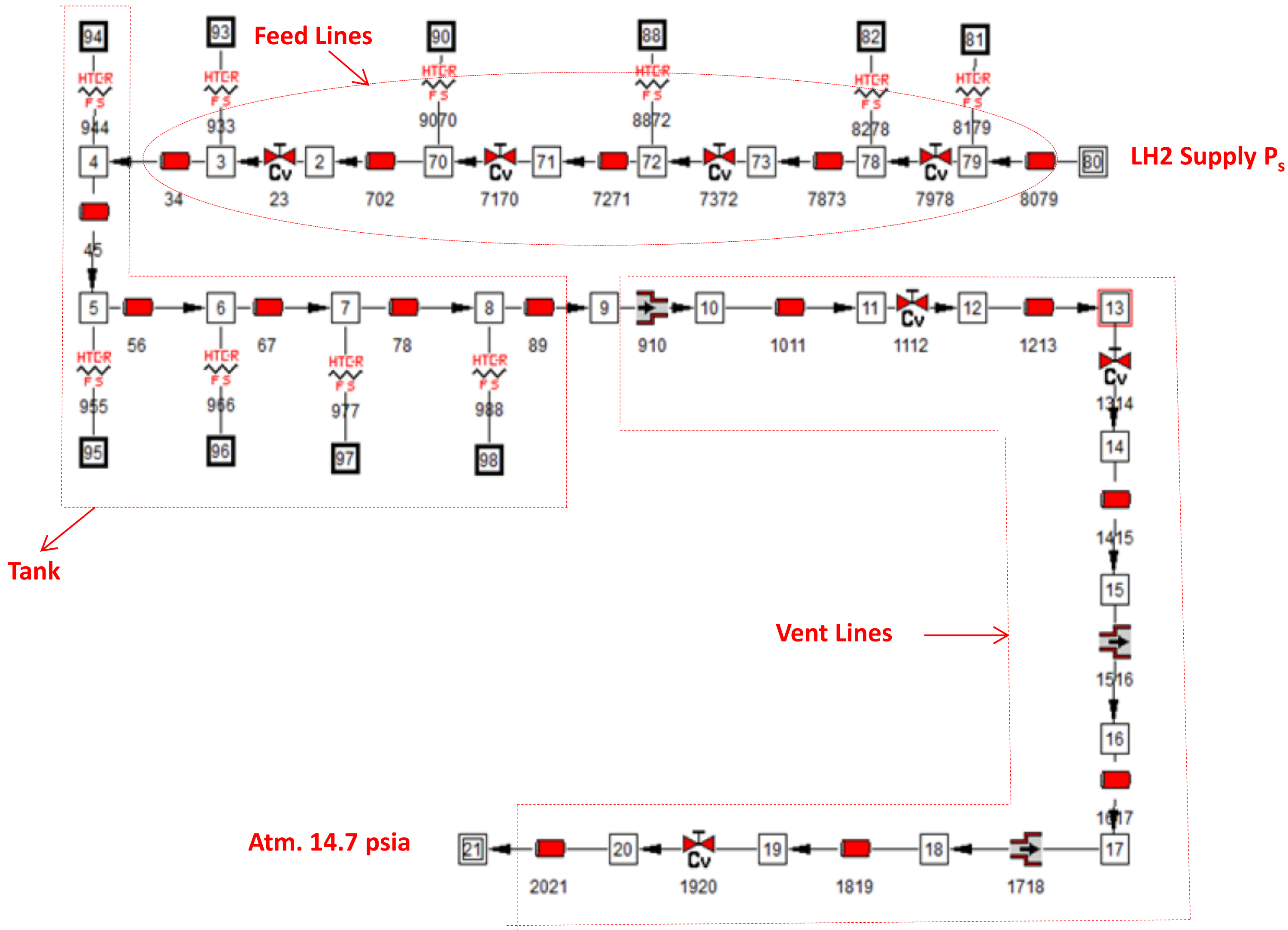
  - **Propellant Loading of the Space Shuttle External Tank Model, published in:**

    "Computational Model of the Chilldown and Propellant Loading of the Space Shuttle External Tank," André C. LeClair and Alok K. Majumdar, AIAA 2010-6561, 46th AIAA/ASME/SAE/ASEE Joint Propulsion Conference & Exhibit 25 - 28 July 2010, Nashville, TN

- 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



EDU LH2 Tank Chill/Fill Analysis:
Assumptions

- 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

EDU LH2 Tank Chill/Fill Analysis

Table 1. Component representations used in GFSSP Model

Branch #	Component representation	Dimension (s)
8079	Pipe	D = 2 in., L = 39 in., ε = 6x10-5 in.
7978	Valve	Cv = 50
7873	Pipe	D = 2 in., L = 295 in., ε = 6x10-5 in.
7372	Valve	Cv = 50
7271	Pipe	D = 2 in., L = 80 in., ε = 6x10-5 in.
7170	valve	Cv = 50
702	Pipe	D = 2 in., L = 180 in., ε = 6x10-5 in.
23	Valve	Cv = 1.12
34	Pipe	D = 2 in., L = 36 in., ε = 6x10-5 in.
45	Tank	D = 66.9 in., L = 14.21 in., ε = 6x10-5 in.
56	Tank	D = 66.9 in., L = 14.21 in. , ε = 6x10-5 in.
67	Tank	D = 66.9 in., L = 14.21 in., ε = 6x10-5 in.
78	Tank	D = 66.9 in., L = 14.21 in. , ε = 6x10-5 in.
89	Tank	D = 66.9 in., L = 14.21 in., ε = 6x10-5 in.
910	Reduction	D1 = 66.9 in., D2 = 1.5 in.
1011	Pipe	D = 2 in., L = 174 in., ε = 6x10-5 in.
1112	Valve	Cv = 46
1213	Pipe	D = 1.5 in., L = 71 in., ε = 6x10-5 in.
1314	Valve	Cv = 39.5
1415	Pipe	D = 1.5 in., L = 18 in., ε = 6x10-5 in.
1516	Expansion	D1 = 1.5 in., D2 = 2 in.
1617	Pipe	D = 2 in., L = 126 in., ε = 6x10-5 in.
1718	Expansion	D1 = 2 in, D2 = 3 in.
1819	Pipe	D = 3 in., L = 2183 in., ε = 6x10-5 in.
1920	Check valve	Cv = 50
2021	Pipe	D = 3. in., L = 12 in. , ε = 6x10-5 in.

D = diameter, L = length, ε = pipe roughness, Cv = Valve flow coefficient

EDU LH2 Tank Chill/Fill Analysis

Pre-test Results

- Criteria given to Team to implement the test:
  - LH2 Source pressure P_s = 39 psia
  - Maximum ullage pressure $P_{max})_{Ullage}$ = 24 psia
  - Chill/Fill duration = $t_{C/F}$ = 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 $P_{max})_{Ullage}$ and $t_{C/F}$ included:
    - Addition of 6 psi (i.e., 18 + 6 = 24 psi)
    - Addition of 30% margin (i.e. 2.88 *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

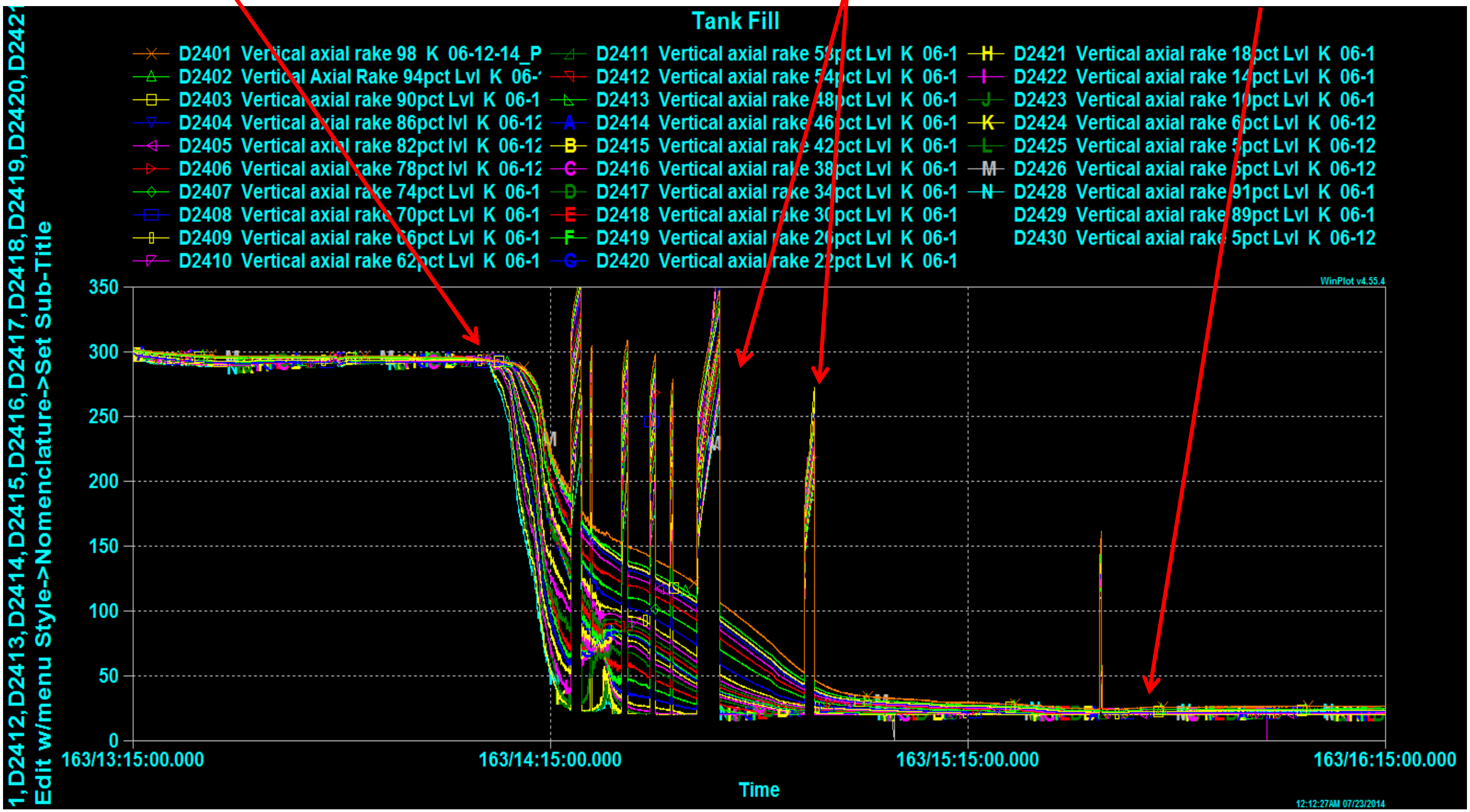
EDU LH2 Tank Chill/Fill Analysis: Pre-test Results

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

Tank Loading Begins

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**

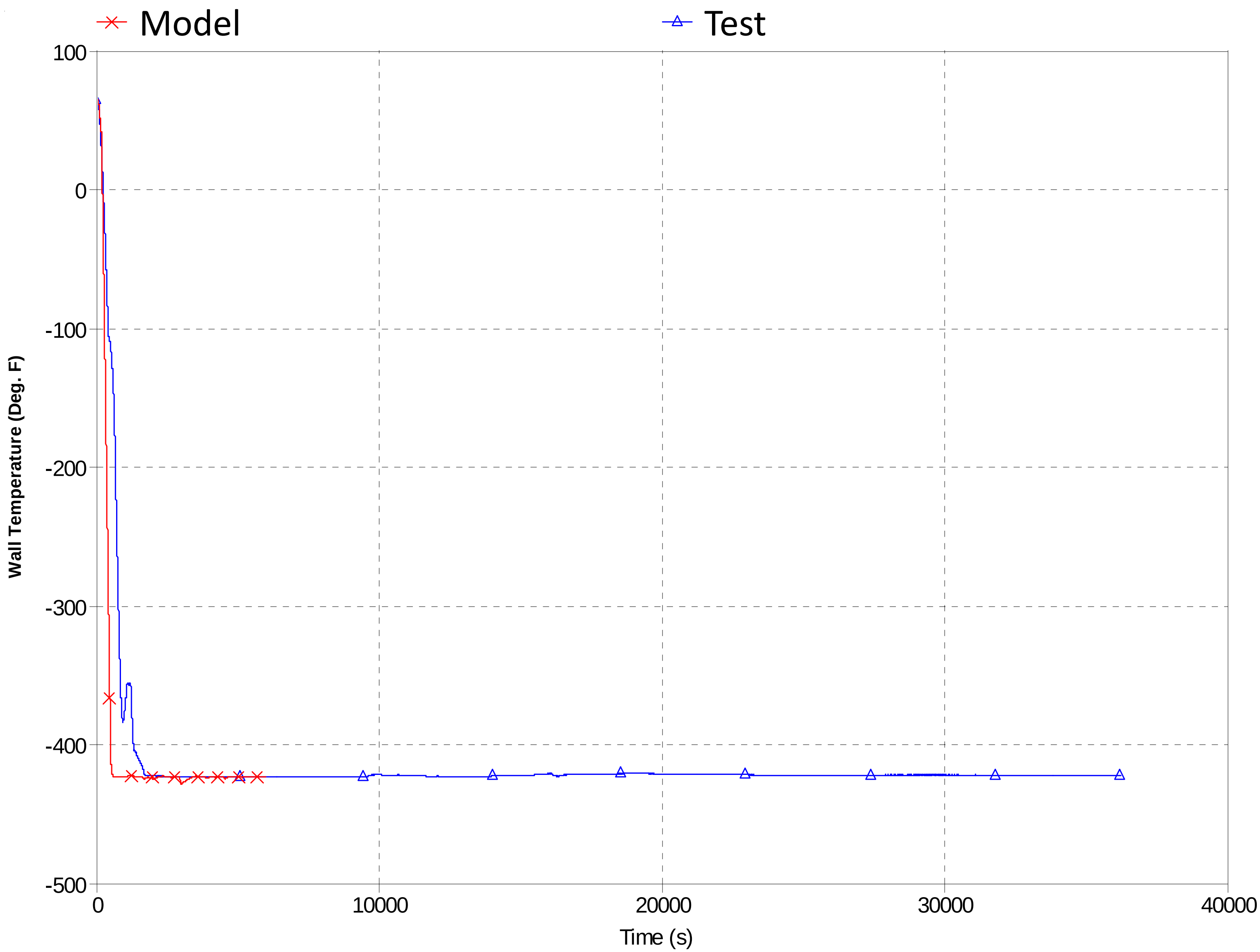


EDU LH2 Tank Chill/Fill Analysis
Post-Test

- 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.

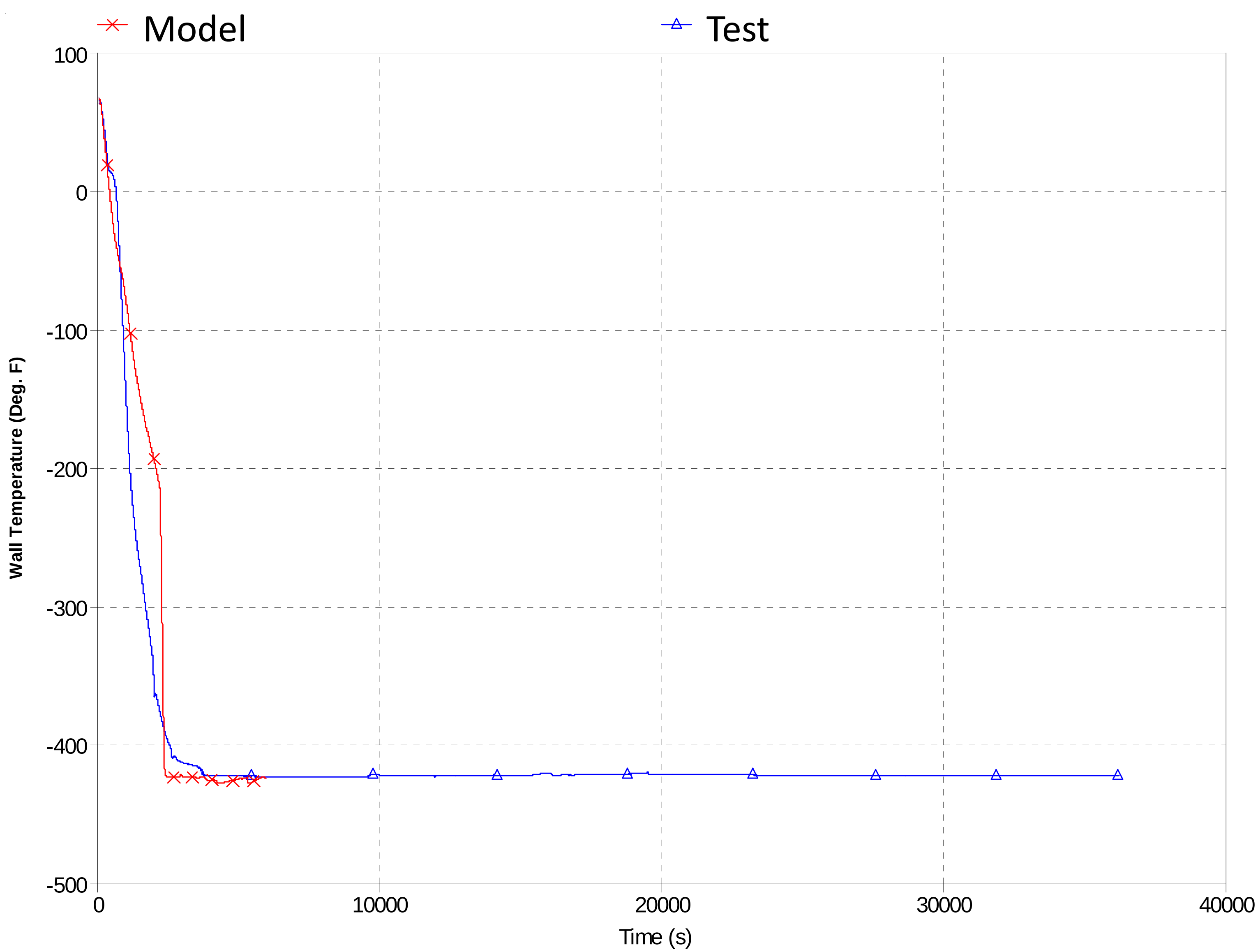
EDU LH2 Chill/Fill Tank Analysis: Post-test Results

Tank Wall temperature History, 10% Fill Level



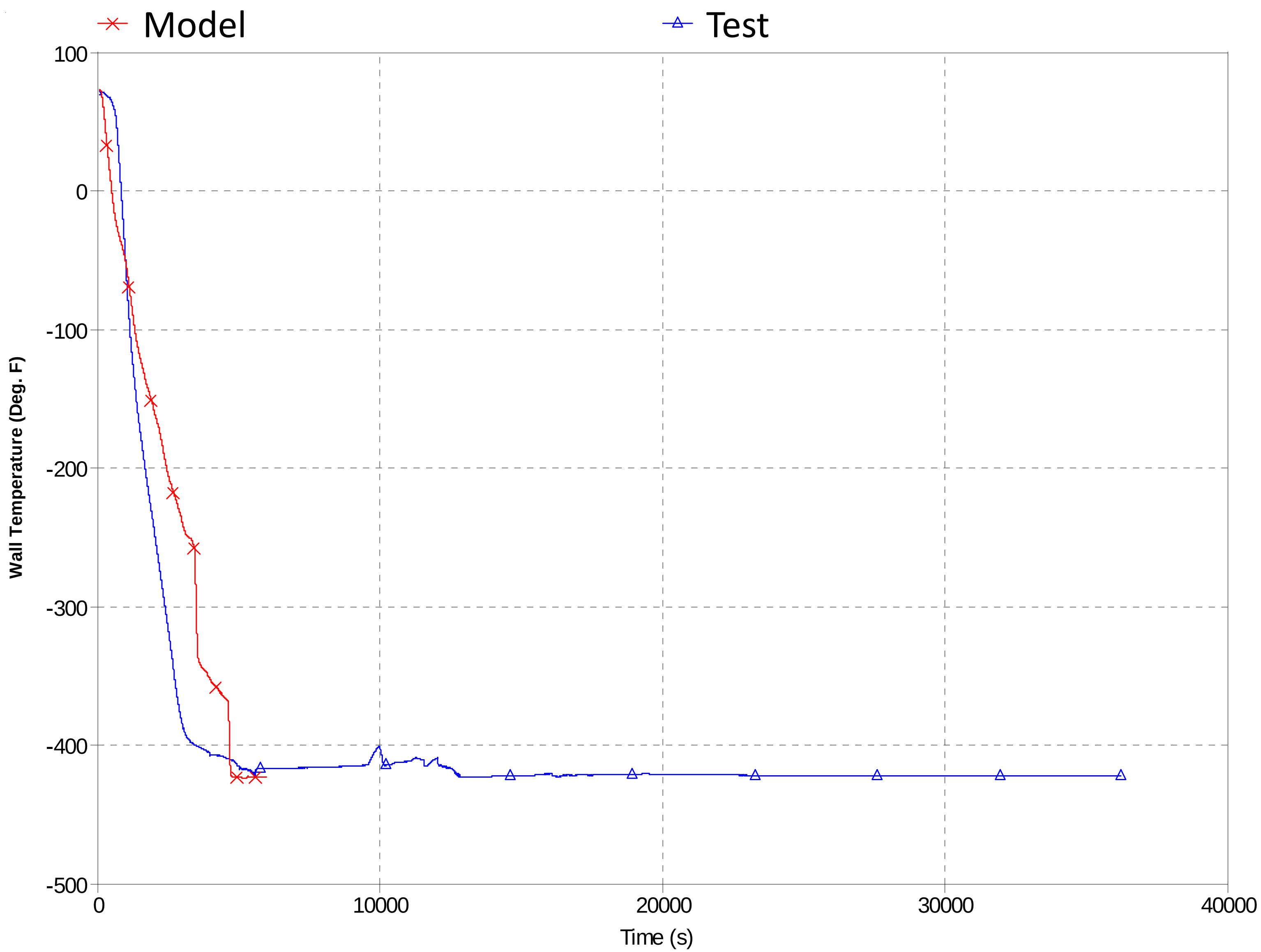
EDU LH2 Chill/Fill Tank Analysis: Post-test Results

EDU Tank Wall temperature History, 50% Fill Level



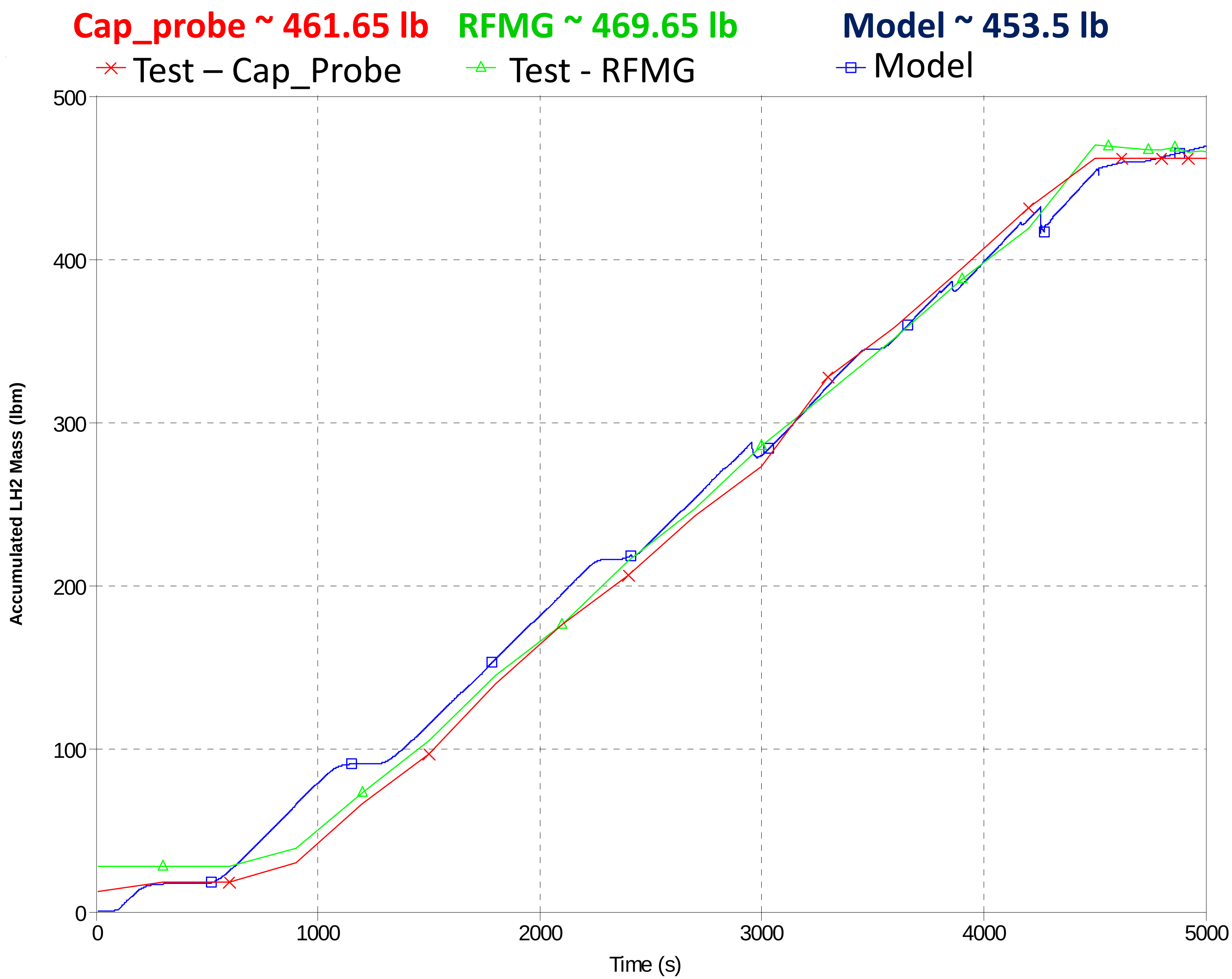
EDU LH2 Chill/Fill Tank Analysis: Post-test Results

Tank Wall temperature History, 80% Fill Level



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

Accumulated LH2 Mass History



EDU Tank LH2 Chill/Fill Analysis
Summary

- 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