Evolvable Cryogenics (eCryo) Project
Technology Workshop with Industry

Engineering Development Unit (EDU) Workshop

Welcome and Introductions

NASA Marshall Space Flight Center

November 18-19, 2014

Agenda – Day 1

November 18, 2014 (Day 1)		
Time (CST)	**Topic**	**Presenter**
8:00-8:30 am	Registration, Welcome and Introductions	
8:30 – 9:15 am	History & Manufacture of EDU	Arthur Werkheiser
9:15 – 10:00 am	Multi-Layer Insulation (MLI)	Jessica Wood
10:00 – 10:15 am	BREAK	
10:15 – 11:30 am	Thermal Analysis of EDU	Tim Page
11:30 – 1:00 pm	LUNCH	
1:00 – 1:45 pm	Radio Frequency Mass Gauge (RFMG)	Greg Zimmerli
1:45 – 2:45 pm	Pressurization test results	Jonathan Stevens
2:45 – 3:15 pm	Fill model	Ali Hedyat
3:15 – 4:00 pm	Cryo Valves	Becky Crownover
4:00 – 4:20 pm	Liquid Acquisition Device (LADs)	Arthur Werkheiser
4:20 – 4:45 pm	TVS	Joe Zoeckler
4:45 – 5:00 pm	Success criteria & Wrap up	Arthur Werkheiser
	Adjourn to the Firehouse Pub	

Agenda – Day 2

November 19, 2014 (Day 2) ** Meet in the parking lot at 8:00 at same location (The Overlook)		
Time (CST)	**Topic**	**Presenter**
8:00 – 8:30 am	Meet in the parking lot of the Overlook	
8:30 – 9:30 am	SOFI Booth	Arthur Werkheiser
9:30 – 11:00 am	TS300	Arthur Werkheiser
11:00 am	ADJOURN	

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History & Manufacture of Engineering Development Unit (EDU)

CPST – Cryogenic Propellant Storage and Transfer Project
(which has become)
eCryo – evolvable Cryogenics Project

Arthur Werkheiser

October 2014

What is eCryo and EDU?

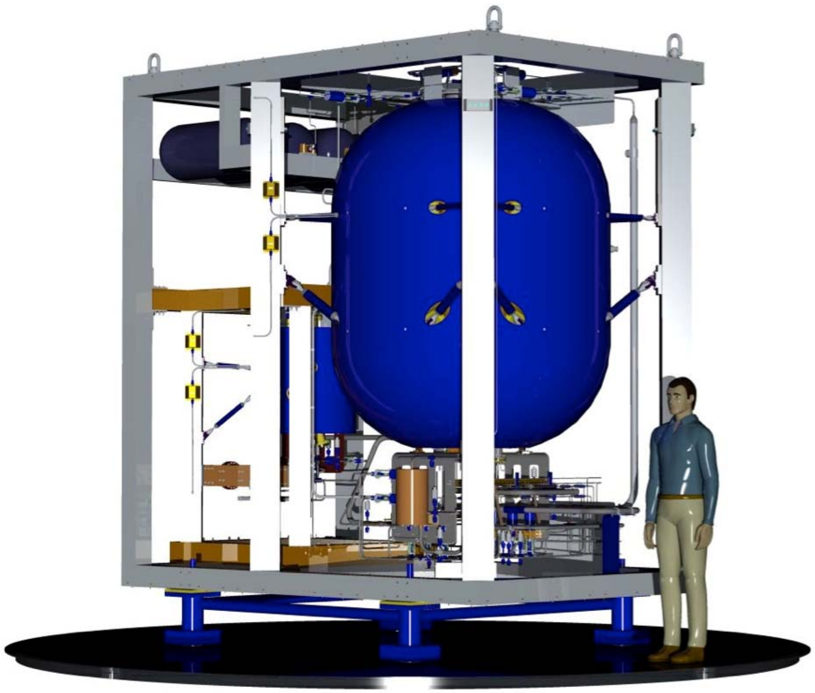
- eCryo (evolvable Cryogenics) is a Ground based (non-flight) Project under the sponsorship of NASA's STMD – Science and Technology Mission Directorate
- eCryo (and CPST) are Multi Center efforts to advance Cryogenics for Space Flight
  - Glenn Research Center and Marshall Space Flight Center are on eCryo (and CPST)
  - Langley Research Center was on CPST project only
- eCryo is continuing the effort to "invest in" and investigate Cryogenic Technologies that will benefit NASA's goals (short term and long term).
  - In Particular the long term storage and general handling of cryogenic fluids.
  - Liquid Hydrogen is probably one of the most difficult of cryogens
- This tank was initiated under the CPST project: It was called the Ground Test Article (GTA) and was planned to provide ground based knowledge to develop the actual flight article. The flight article was not built due to reformulation of the project at the direction of the STMD office. The GTA was also lost to reformulation and cost/schedule overruns.
- The Engineering Develop Unit was an effort to take the hardware generated under GTA and provide a "Proof of Manufacturability" for the Flight Article.

Why GTA? – A Historical Perspective

- GTA was proposed in June 2011 and given ATP August 2011
- Proposed as a lean engineering effort to help address the following gaps:
  - Need for integrated “flight-like” CFS Storage Tank Assembly
    - Manufacturing flight weight tank
    - Integration concerns with hardware internal and external on flight weight tank.
    - Flight similar LADs integrated within assembly
  - Need for understanding of performance interactions
    - Interactions between thermal system, TVS, LADs, instrumentation, and quantity gauging within Storage Tank Assembly
    - Interactions between Storage Tank assembly, transfer system, and transfer tank assembly for heat leaks / propellant losses.
    - Orientation / fluid location effect on acquisition and pressurization performance
  - Need for data from an integrated flight scale system to anchor mathematical models
    - Overall heat loads, transfer performance, pressurization performance, etc.
  - Need for early software sequence development / evaluation for autonomous flight operations
  - Need for flight system development / pathfinder design /build / test activity feeding into critical design phase.

Ground Test Article (GTA) Overview

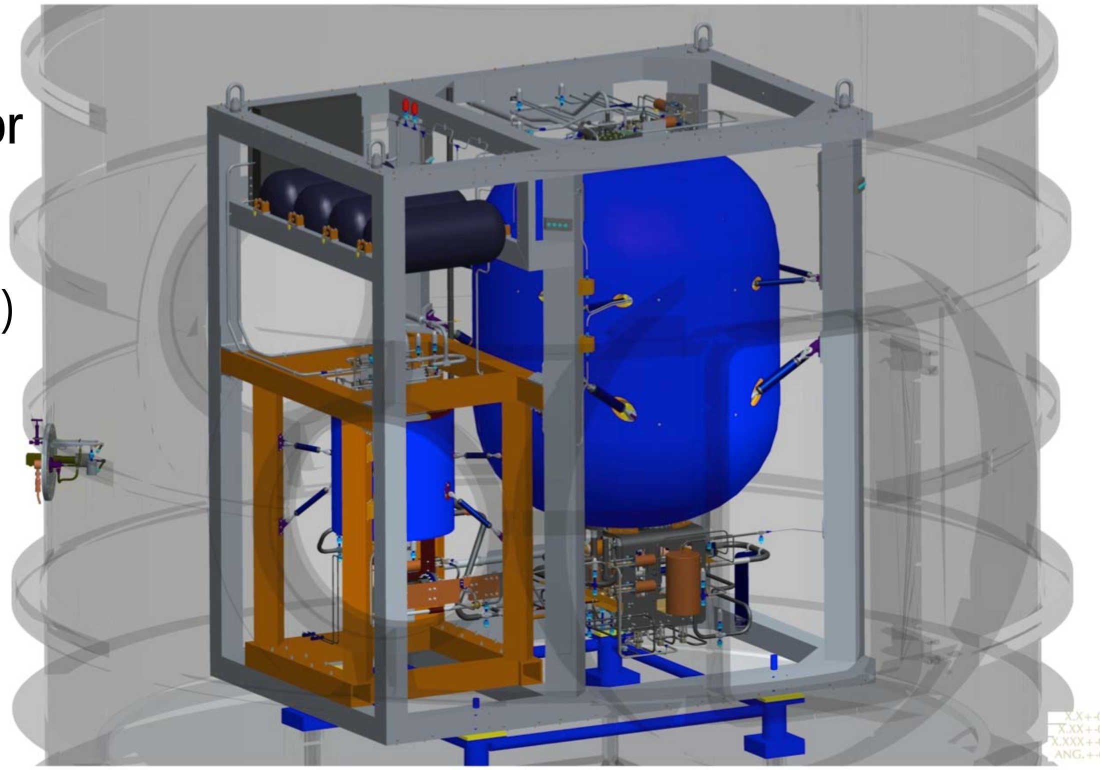
- GTA Description
  - A technology development version of the CPST CFM Payload with all CPST functionality (Pre-Phase A)
  - GTA consists of flight-like:
    - Storage and Transfer Tanks
    - LADs (channel and vane)
    - Passive Thermal features and interfaces
    - Transfer and Pressurization Systems
    - Instrumentation
  - Designed to perform integrated passive and active thermal, storage and transfer during LN2 functional testing and LH2 performance testing in vacuum environment



- GTA Scope:
  - Demonstrate thermal vacuum performance for a simulated mission environment
  - Perform Integrated System Performance for all modes of operation to allow for correlation of math models to help anchor Flight Payload design
  - Mature and evaluate flight-like design interface details for manufacturability
  - Demonstrate flight tank prototype manufacturing and streamlined engineering
  - Demonstrate flight-like LAD manufacture and integration
  - Overall assembly and integration

GTA Description

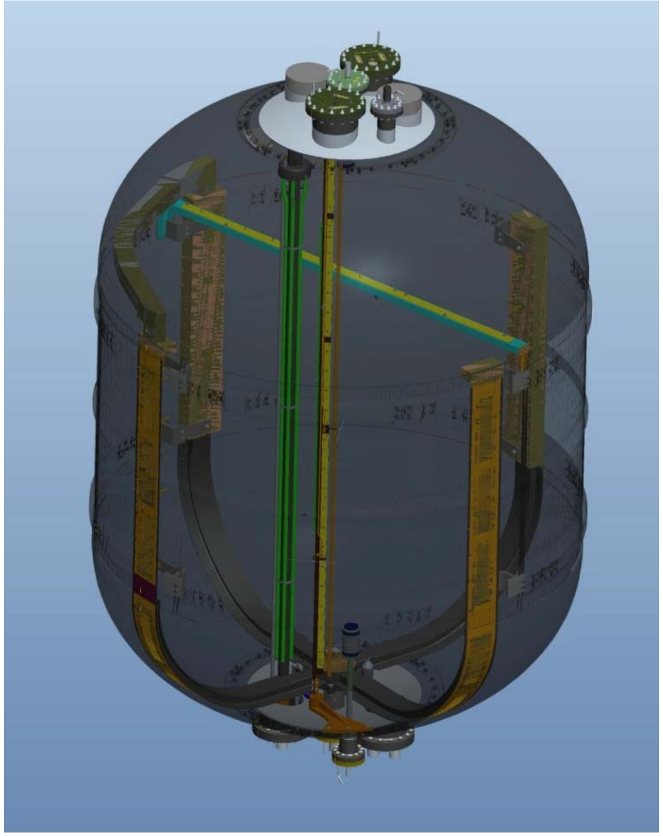
- GTA Side-by-Side Configuration:
  - Accessibility to Components
- Government Pre-Phase A basis for Design
  - LH2 Only
  - Storage Tank LH2 Capacity (260kg)
  - ANTARES Launch Vehicle
  - Technology Demonstration Capabilities
- Major subsystems:
  - Pressurization System*
  - Storage Tank Assembly*
  - Transfer Tank Assembly*
  - Transfer System*
- Designed to be tested at MSFC TS300



*Subassemblies include all of the passive thermal, fluid and structural features and interfaces.

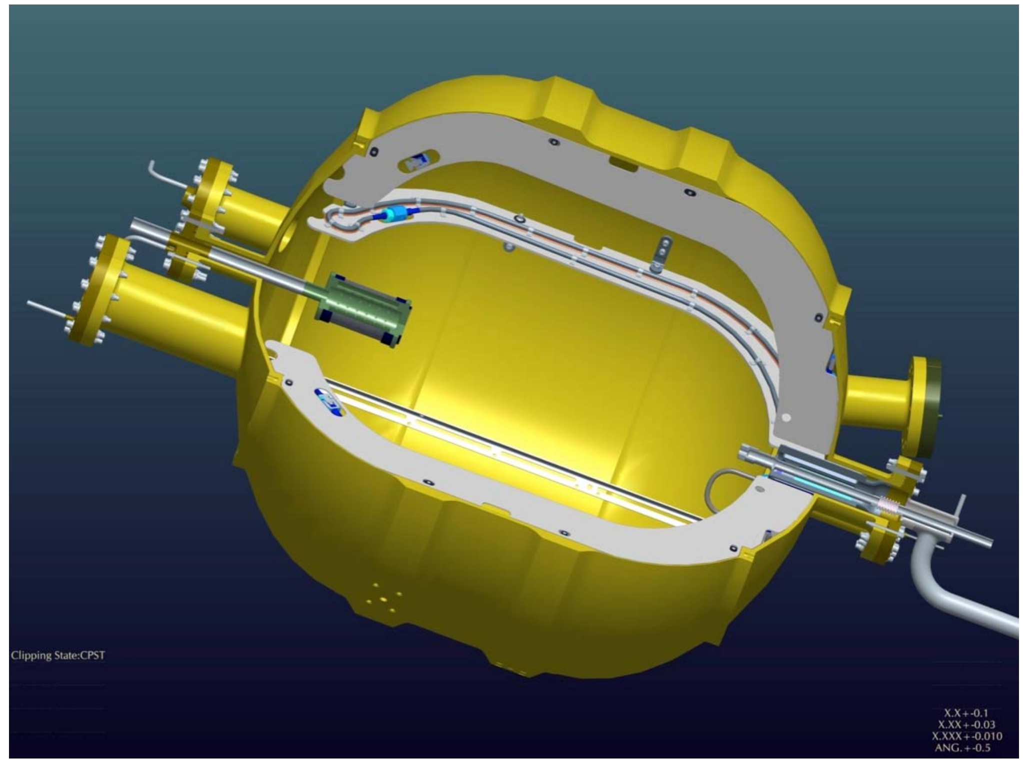
Flight Representative Capabilities to be Demonstrated on GTA

- LH2 Cryogenic Fluid Storage
  - Low Conductivity Structures
    - Storage and Transfer Tanks: Composite Struts
  - Insulation
    - Storage Tank: MLI and SOFI
    - Transfer Tank: MLI
    - Lines, COPVs, Components
  - Pressure Control
    - Storage Tank: Spray Bar and Axial Jet Mixing /TVS Systems
    - Transfer Tank: TVS
  - Active Thermal Control
    - Storage Tank: BAC/Cryocooler system
- LH2 Cryogenic Fluid Acquisition
  - Liquid Acquisition Devices (LADs)
    - Storage Tank: Screen gallery arms with TVS cooling
    - Transfer Tank: Vanes



Flight Representative Capabilities to be Demonstrated on GTA

- LH2 Cryogenic Fluid Transfer
  - Transfer Line Chilldown
  - Tank Pressurization
  - Transfer Tank Chilldown
  - Pressure-fed Transfer



- LH2 Cryogenic Fluid Quantity Gauging
  - Mass Gauging in the Storage Tank
    - RFMG
    - Temperature Rake (Wet/Dry)
    - Cryotracker
    - Capacitance Probe
  - Mass Gauging in the Transfer Tank
    - RFMG
    - Temperature Rake (Wet/Dry)
- Automated Software Sequences
  - Development / demonstration of automated programs

Subset of Manufacturing / Development Activities (In-work / Accomplished)

C-Seal Test Set-up

Strut Development

Cryovalve Development

Subset of Manufacturing / Development Activities (In-work / Accomplished)

Pressurant Diffusers

MLI Layup Table

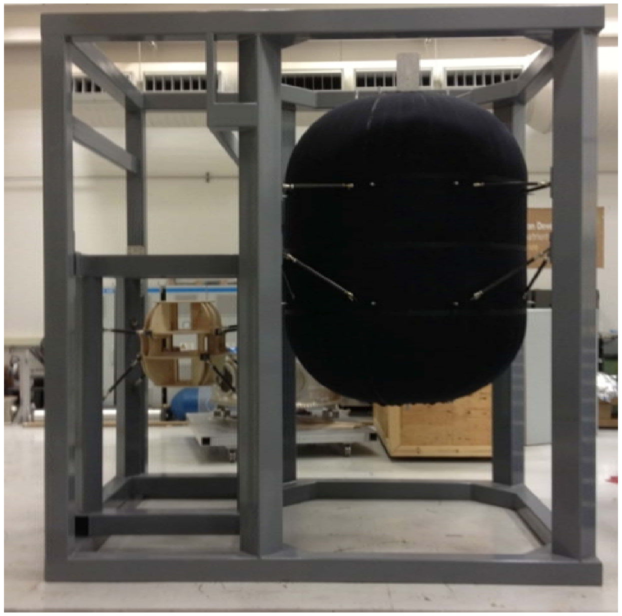
Transfer Tank TVS Tubes

Storage Tank Dome

Storage Tank LADs

Welding Pathfinder

Subset of Manufacturing / Development Activities (In-work / Accomplished)



GTA Mock-up and MLI Test-Fit Tool

Internal Fluid Line Silicon Diode Mounting

Pressurization Panel Testing

Reduced Gravity CryoTracker

Low Temperature Calibration Set-up

GTA Cancelled - EDU Begins

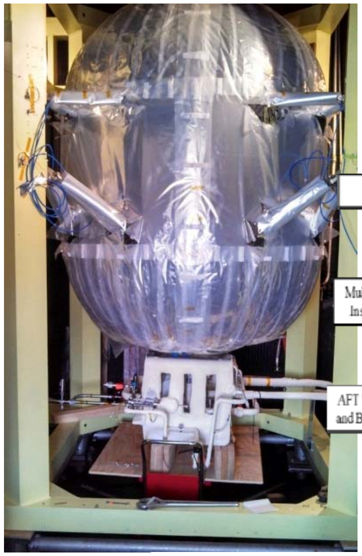
- This effort Originally started life as CPST Ground Test Article - GTA
  - Included small transfer tank and four LAD arms (as opposed to three LAD arms)
- GTA was terminated for several reasons on Feb 14, 2013
  - CPST as a whole was reformulated; GTA was over budget
- In spring of 2013, EDU was given the ATP with strict guidelines
  - GTA derivative, Fixed budget, Fixed schedule, test complete by July 31, 2014.
- The “Contract” with EDU was the “EDU White Paper”
  - CPST Engineering Development Unit (EDU) Processing & Test Objectives, Document No: CPST-RPT-0099. Also known as, the EDU White paper
- The purpose of the EDU was a “proof of manufacturing” for CPST Payload
- The Contractual Objectives are from the White paper (1 – 10)
  - The Contractual Objectives are quantifiable and more “operational” in nature.
  - Reproduced in the Test Plan section 1.3
- As we approached the test, additional “data-centered” objectives were identified (A-N)
  - The data-centered Objectives are in priority order and are not as much “pass/fail” from a “rapid, success-measurement” standpoint.
  - These are Documented as Appendix “I” in the Test Plan

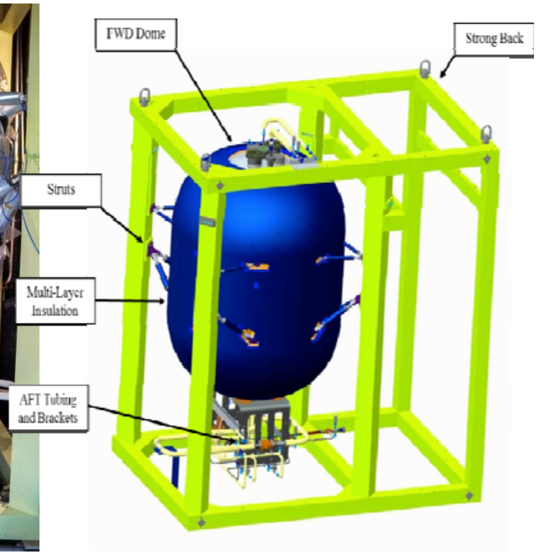
EDU

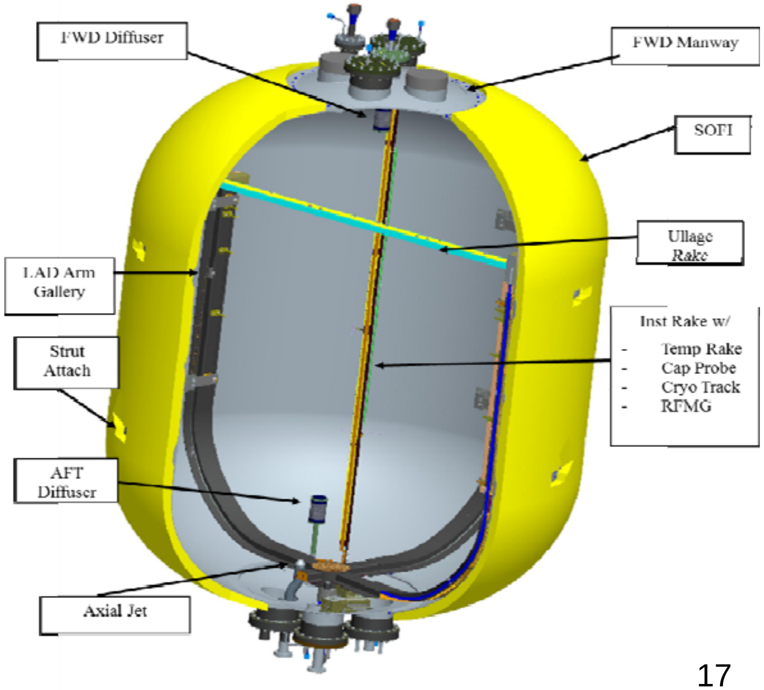
- EDU was given Authority To Proceed (ATP) June 2013
- Fixed cost and Schedule was enforced (GTA spent about 3.5 M so far, EDU had 1.5M to complete)
- The Scope of EDU was reduced from the GTA goals.
- These items deleted:
    - Transfer Tank and Support Structure,
    - “On-Board” Helium bottles,
    - “On-Board” Pressurization panel,
    - Only 3 of 4 planned LADs completed,
    - Internal Camera & Light Source
    - EDU was given 10 Specific Goals
    - “Cold Walls” were deleted
- The LH2 Test was performed from June 12 to July 1 of 2014
- 24 x 7 Operations with a planning meeting every day at 9 AM.
- The EDU Tank is still in TS300 (You will see it tomorrow)

CPST EDU

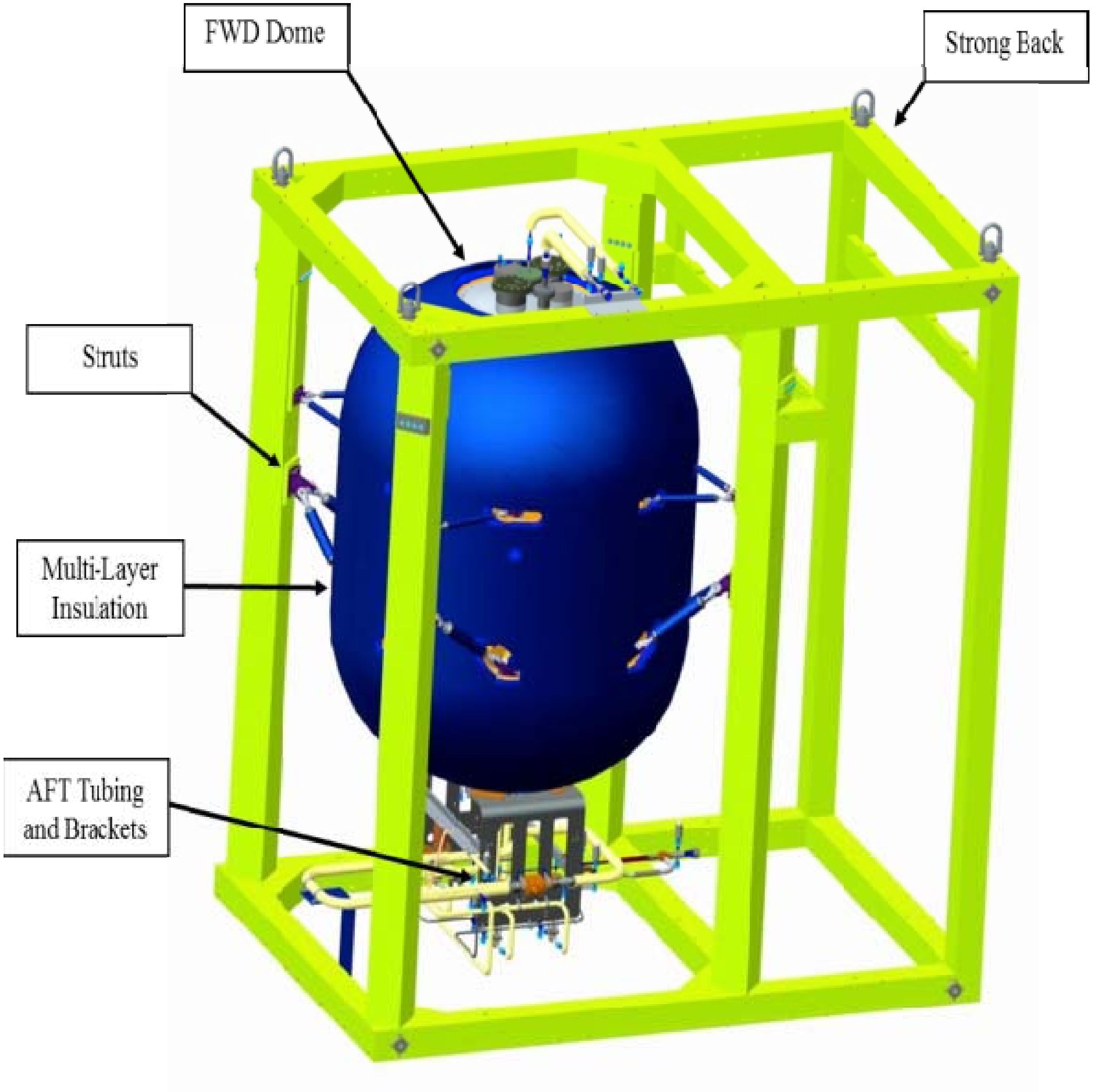
- Integrated Mass Gauging (X4)
  - Temp Rake, Cryo Tracker, Cap Probe, RFMG
- Passive LH2 Storage
  - Mixing pump with adjustable flow rates
  - Axial Jet TVS
  - Foam/MLI
- Ullage and Submerged GHe pressurization
- Gallery LAD Arms (X3)
  - Built with seam welding technique
  - Mass gauging and temperature instruments
  - TVS cooling capability and foam insulation
- Lightweight Struts (X16). Each are temperature Instrumented and purge capable
- Calibrated Heat Load capability
- Heavily instrumented tank skin, SOFI, and MLI to assess thermal profile
- GHe purge aft tubing enclosure. Does not need to be at vacuum in order to cryo load the tank



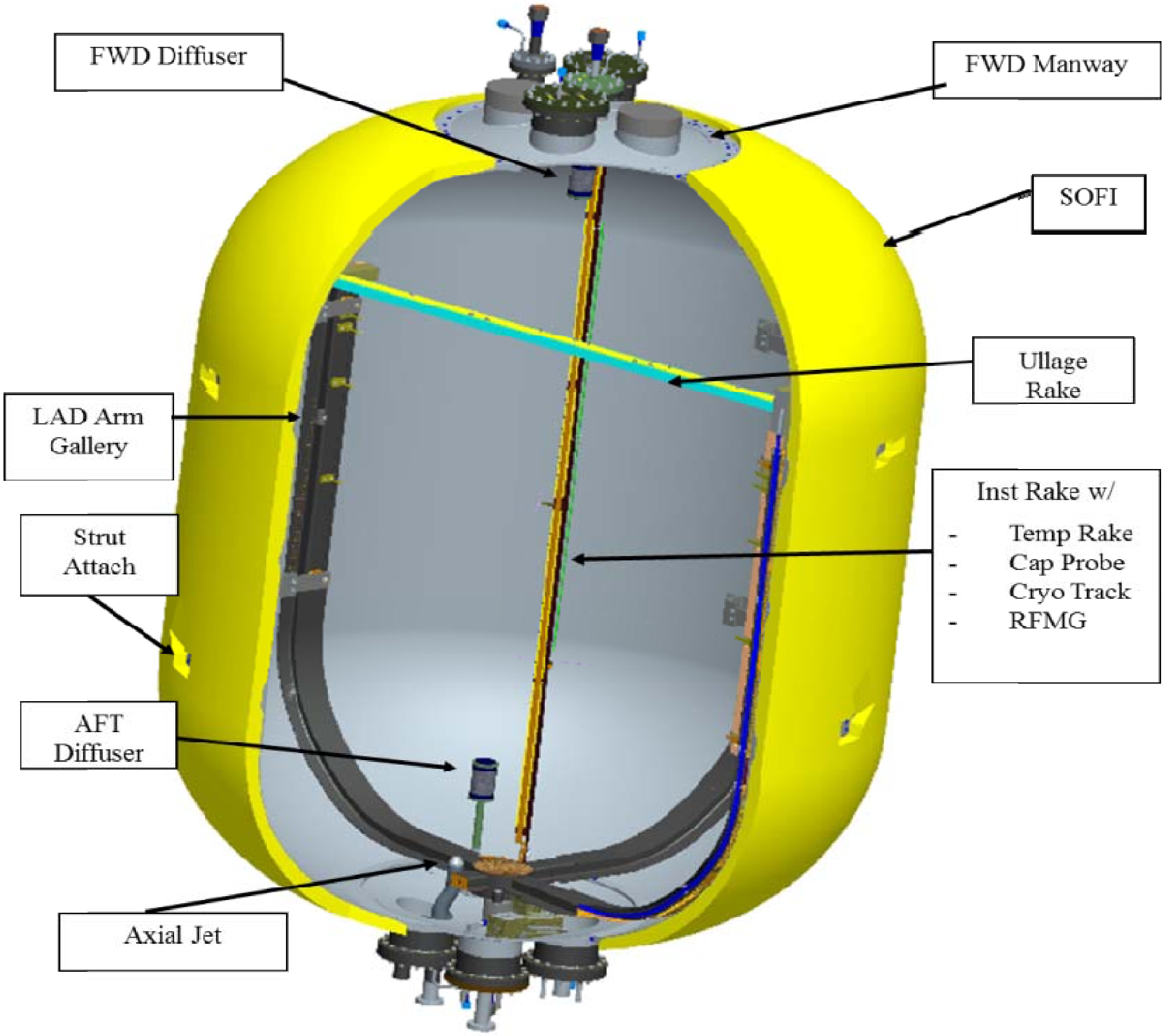




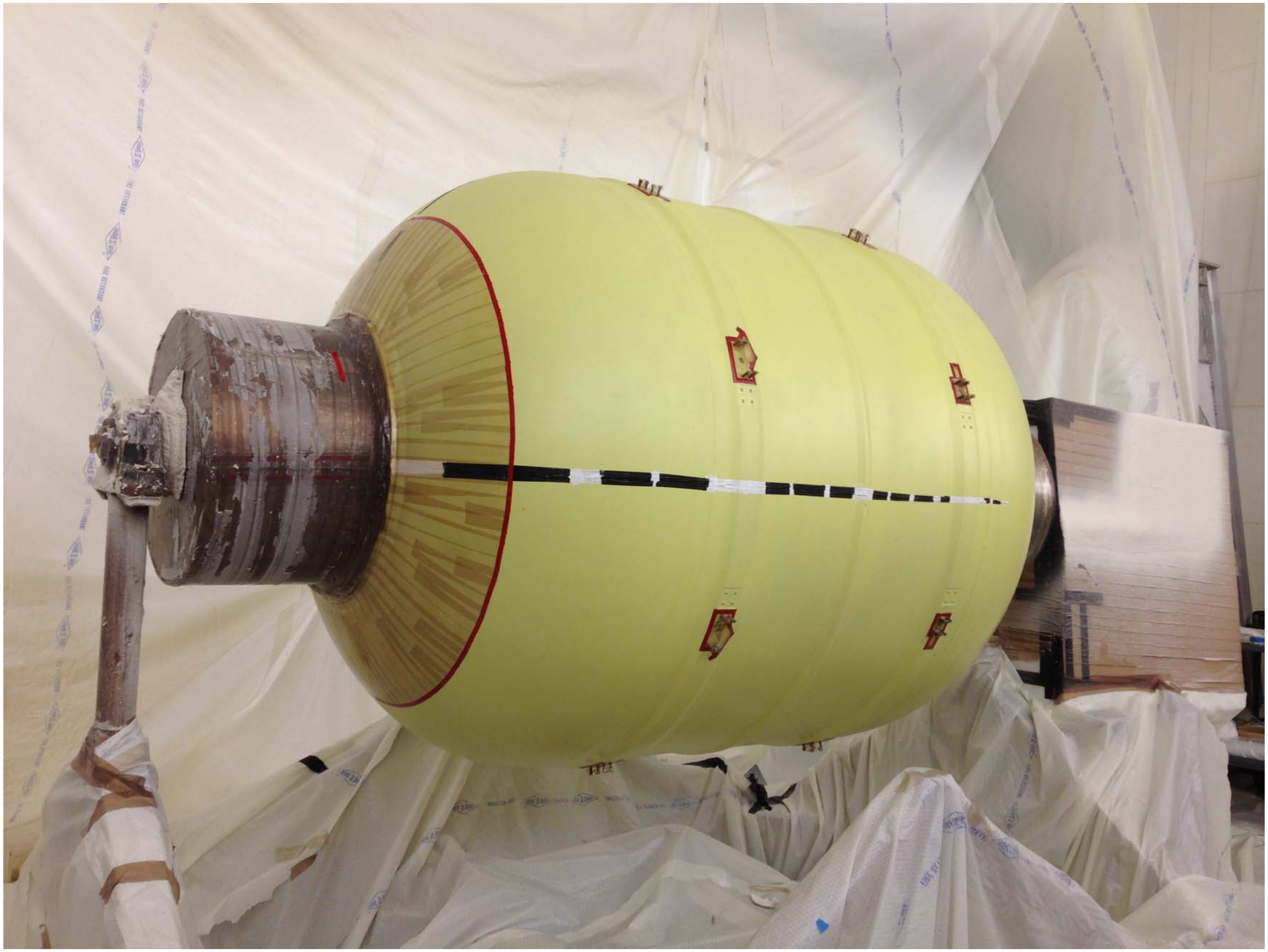
CPST EDU External Model View



CPST EDU Internal Model View



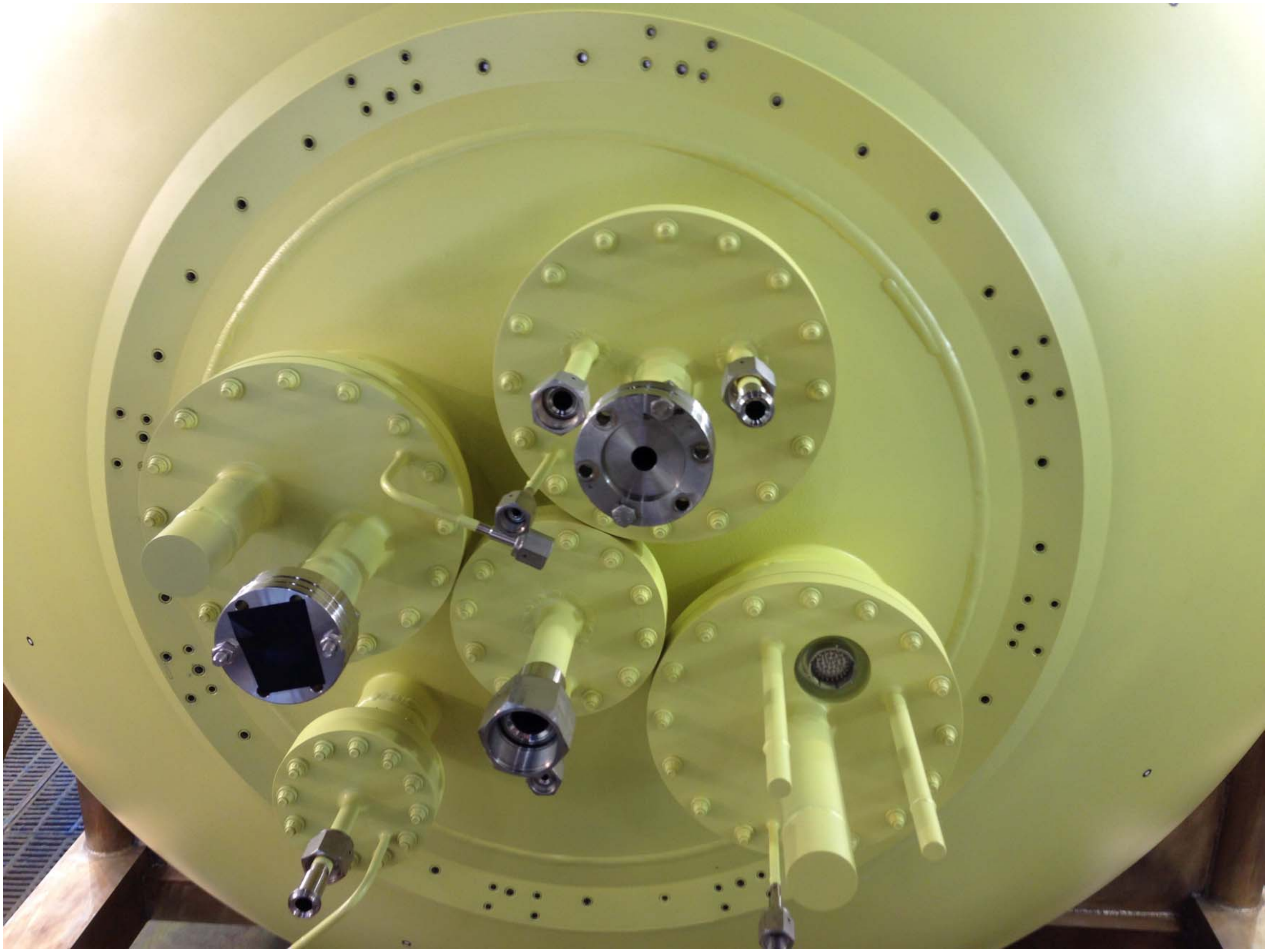
CPST EDU Pre-SOFI



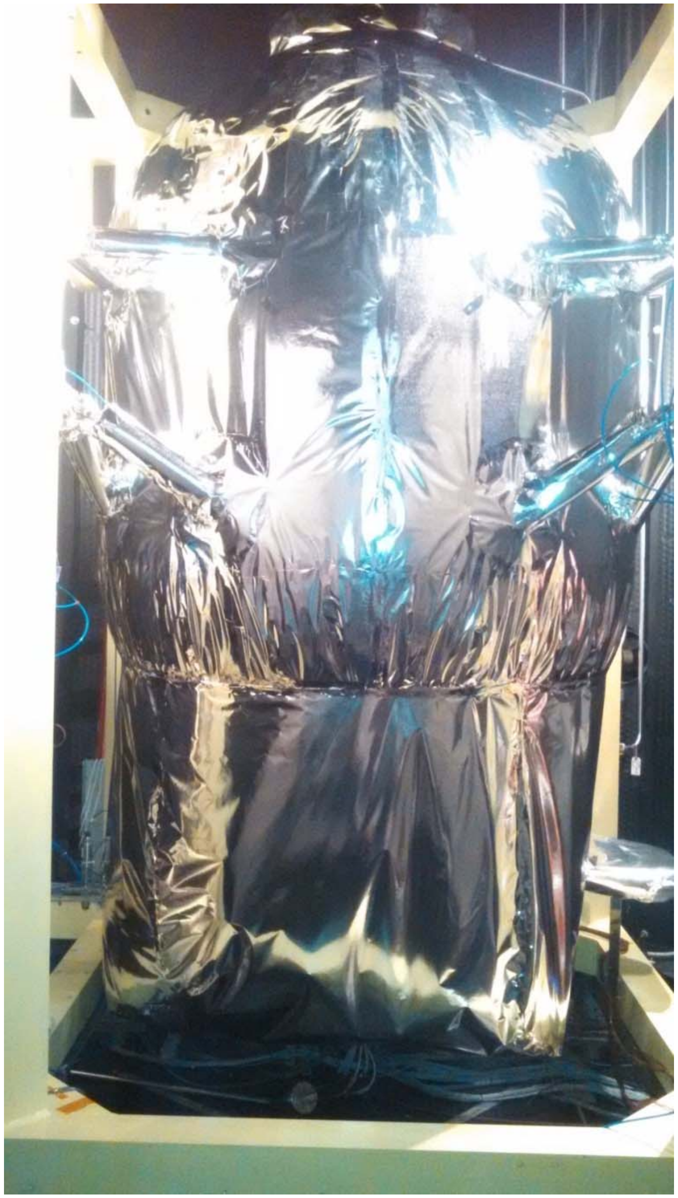
CPST EDU Post SOFI Pre MLI

CPST EDU Post MLI

CPST EDU Close up AFT



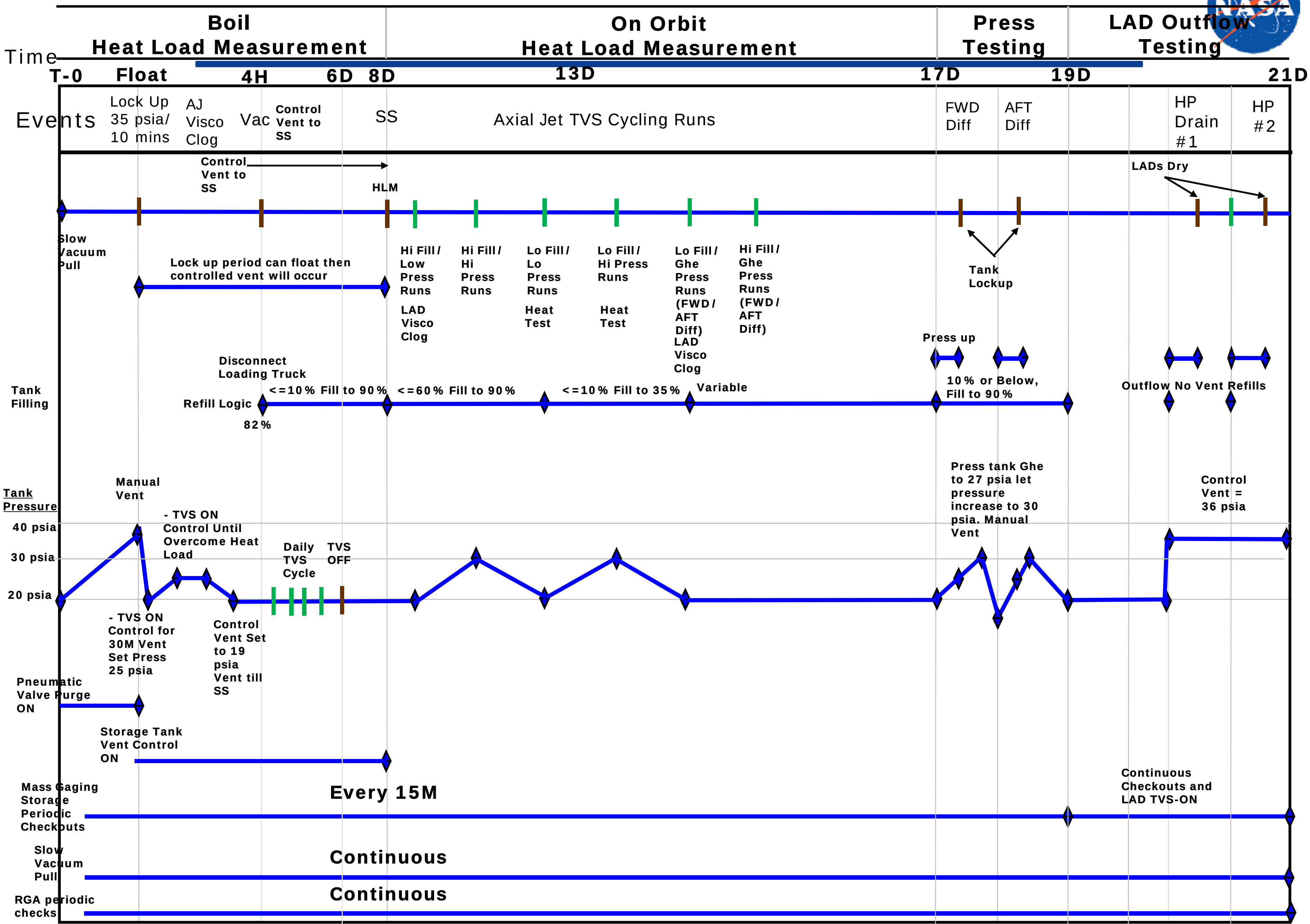
EDU and The Test Team



EDU Planned Testing

- Load the EDU under a simulated atmospheric pressure (14.7 PSI – 100% Nitrogen) to determine heat load (boil off)
- Pull a Vacuum on the chamber to simulate ascent (Ascent profile time was not realistic however)
- Measure boil off after “ascent”
- Allow the Tank to reach Steady State conditions (6+ days) and measure boil-off
- Perform several days of TVS testing at different fill levels and pressures
- Perform submerged diffuser pressurization testing (and non-submerged)
- Perform LAD outflow testing

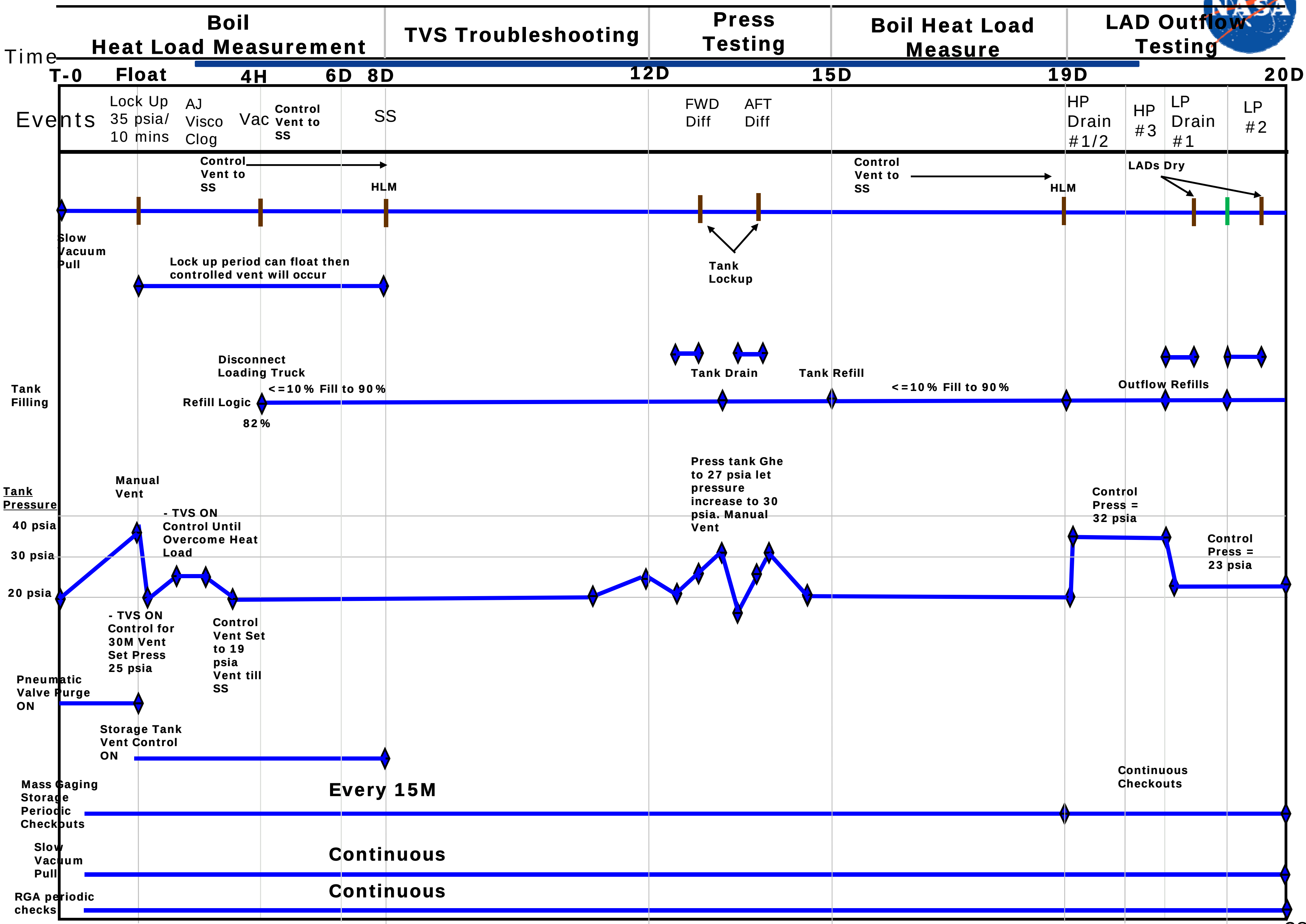
EDU LH2 Test Run Timeline



EDU ACTUAL Testing

- Load the EDU under a simulated atmospheric Pressure to determine Heat load
- Pull a Vacuum on the chamber to simulate ascent
- Measure boil off
- Allow the Tank to reach Steady State conditions and measure boil-off
- Inadvertent Tank Venting to Ambient Pressure on Day 7. (We claim Steady State)
- ~~Perform several days of TVS testing at different Fill levels and pressures~~
- TVS system is blocked despite heroic efforts to unclog
- Spent 3 days troubleshooting Axial Jet Pump. Finally functional with Old controller
- Aborted TVS testing due to blockage.
- Proceeded to run Pressurization tests with Submerged and non-submerged Diffuser. Ran more tests than were in original test plan.
- Back to Steady State Boil-off for 5 more days
- Perform LAD outflow testing

EDU LH2 Test As-Run Timeline



EDU LH2 Test Scorecard (Spoiler Alert)

- EDU Operational Objectives (from Whitepaper)
- 9.2 out of 10

- EDU Data-centric objectives
- 10 out of 14