The Structural Heat Intercept-Insulation-Vibration Evaluation Rig (SHIIVER)

W.L. Johnson, J.G. Zoeckler, and L.M. Best-Ameen
NASA Glenn Research Center

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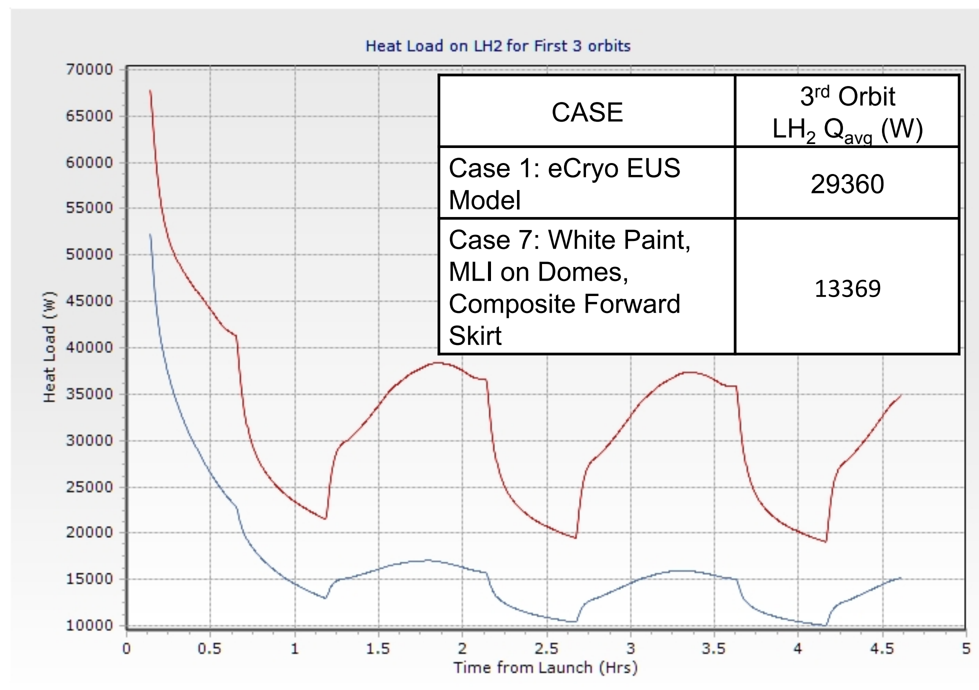
SHIIVER Introduction

- In 2014, NASA approved the formulation of the Evolvable Cryogenics (eCryo) Project as ground-based project to develop, integrate and validate cryogenic fluid management (CFM) technologies at a scale relevant to and meeting the mission needs for Space Launch Systems (SLS) Stages and Exploration systems.
- SHIIVER is one element of the eCryo Project
- SHIIVER is intended to result in a test asset available for future CFM technology testing
- Under the eCryo Project, the SHIIVER asset will demonstrate passive heat intercept technologies in an integrated fashion
    - Thick, large scale MLI blankets
    - Vapor Cooled Structure

eCryo Rationale for SHIIVER

- The current upper stage of record (EUS) has thermal heat load “challenges”
- Recent analysis has suggested that even by just painting the surface, insulating the domes of the hydrogen tank and reducing the conductivity of the skirt, the heat load can be reduced over 50% by the third orbit.
  - The mass of the modifications are less than the boil-off mass saved
  - Just putting MLI on the stage is not enough to enable long durations
  - Some methodology of reducing the heat load on the structure is required
- Vapor cooling is an often mentioned method of reducing structural heat load
  - Limited data exists for hydrogen on conical structures
- It appears that the use of MLI and vapor cooling can go a long way to solving challenges with current upper stages
- **Current funding is focused on the Demonstration of passive “heat intercept” at an integrated tank level**
- Expand past large tank testing to include representative structure



Why a tank?

Multiple methods for general testing of large scale systems were investigated:

- Large tank boiling
  - Simple straight forward method
  - Looks like end application
- Cluster of small tanks attached by plenum and conduction panels
  - Still required hydrogen, quantity of hydrogen not a huge safety driver
  - Could be useful for full scale testing
- Use cryocooler to directly cool the walls of a structure
  - Route working fluid of a large reverse brayton cycle engine around a tank-like structure
  - Similar to recent Tube-On-Tank oxygen testing, but tube is inside structure instead of outside
  - For non-tank shape, requires edge-guarding (proportional to size)
- Use boil-off vapor from bath to cool the walls of a structure
  - Similar to how most thermal vacuum cold walls operate
  - For non-tank shape, requires edge guarding

Why a tank?

Capabilities	CBTs		Tests						Max Size Transportable	Test Experience ?
	20 K	90 K	Acoustic	Orbit	Transfer	TVS/ Mixing	Ground	Vapor Cooling		
Cryocooler Shield	Y	Y	Y?	Y	N	N	N	N	10 m	ZBO?
Vapor Shield	Y	Y	Y?	Y	N	N	N	?	10 m	N
Cryogenic Tank	Y	Y	Y	Y	Y	Y	Y	Y	4.25 m	Y

Test Design	Vessel Construct	Hazardous Fluids?	Test Experience?	Finned Heat Transfer	Break-up for Easy Transport	Fluid Consumption	Cooler/Heater Power Usage
Cryocooler Shield	B31.3	N	ZBO?	Y	Y	Low	10s kW
Vapor Shield	B31.3	Y	N	Y	Y	High	1s kW
Cryogenic Tank	Section VIII	Y	Y	N	N	Med	100s Ws

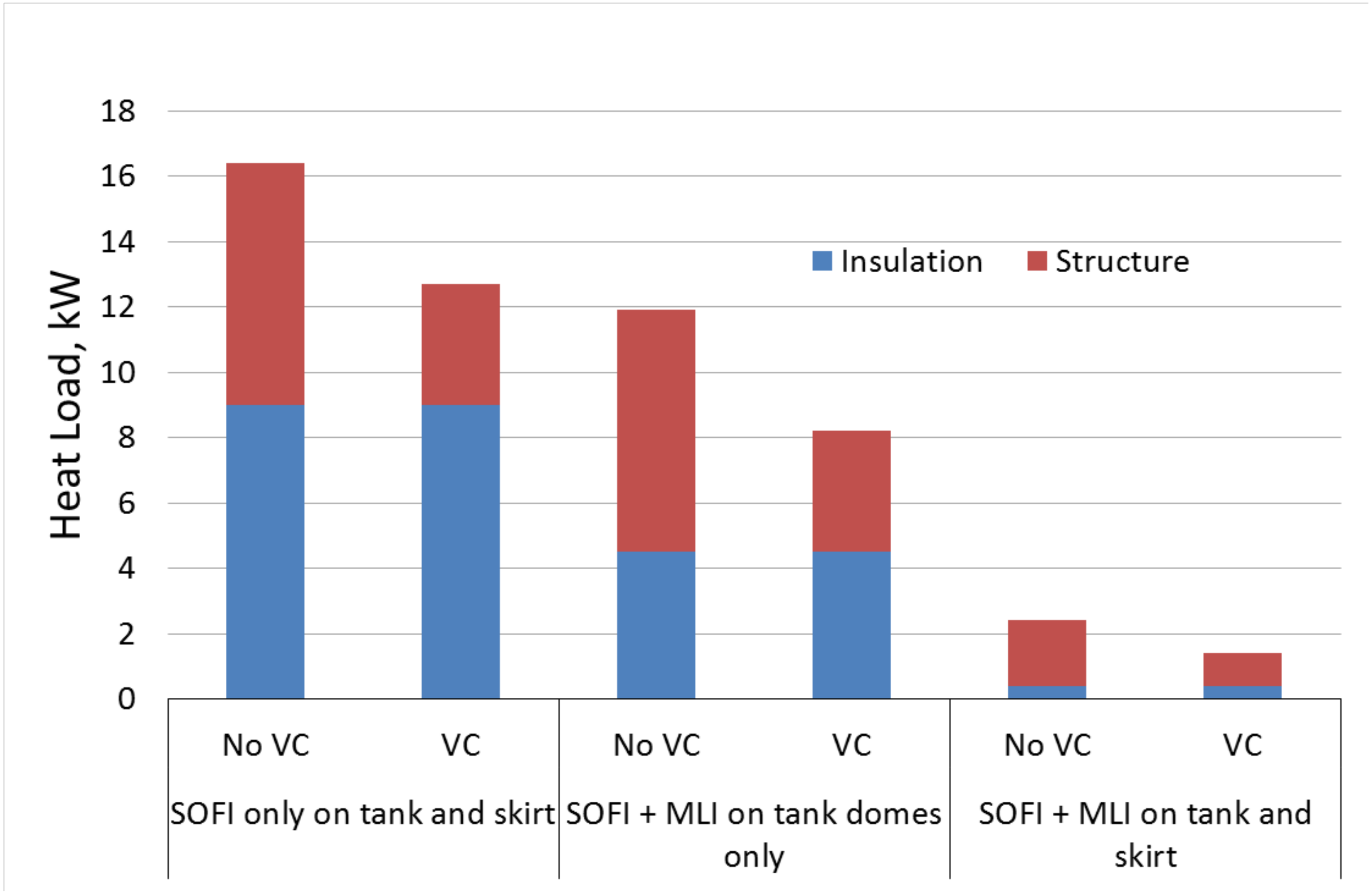
Limitations on Scale

- How big is big enough?
  - Material widths and application
  - Transportation
  - Existing test data
  - Test facility size and access
    - Facility determined to be Plum Brook: B2 for thermal vacuum; SPF for acoustic
  - Representative of possible applications
- The biggest driver in maximizing size was transportation
  - Shipping a vessel bigger than ~4 m diameter requires expensive transportation methods
    - Boat transportation through St. Lawrence River (also takes several months)
    - Air transportation on Super-Guppy or equivalent
- Current concept is a 4 m diameter

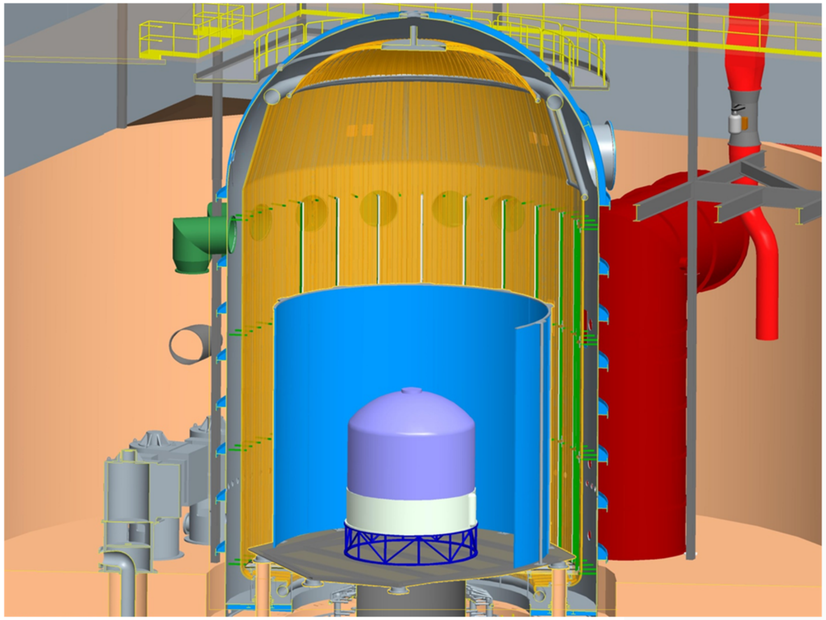
Initial Testing Technologies

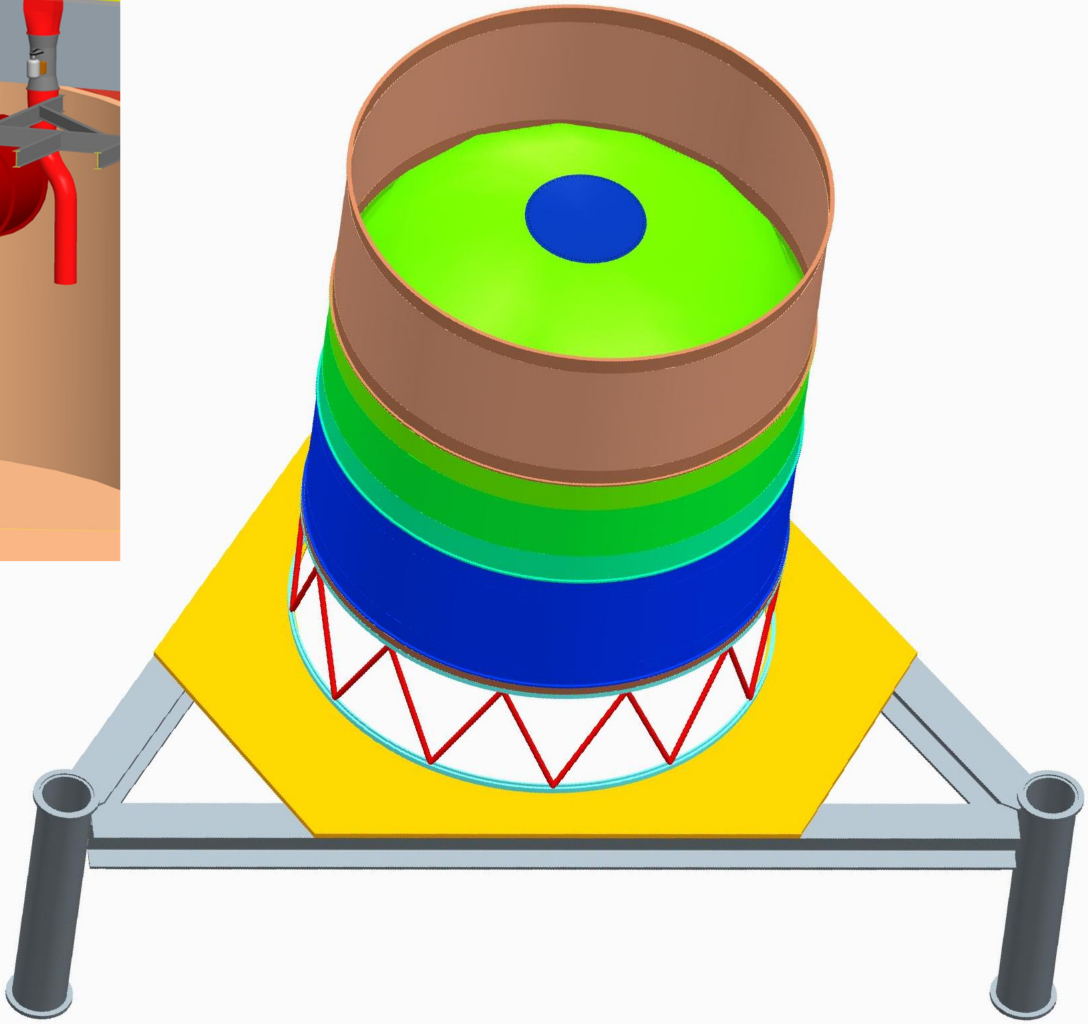
- **Selected based on initial needs:**
  - Multilayer Insulation
  - Vapor Cooling of Structure
  - Thermodynamic Model Verification

Benefits of Technology

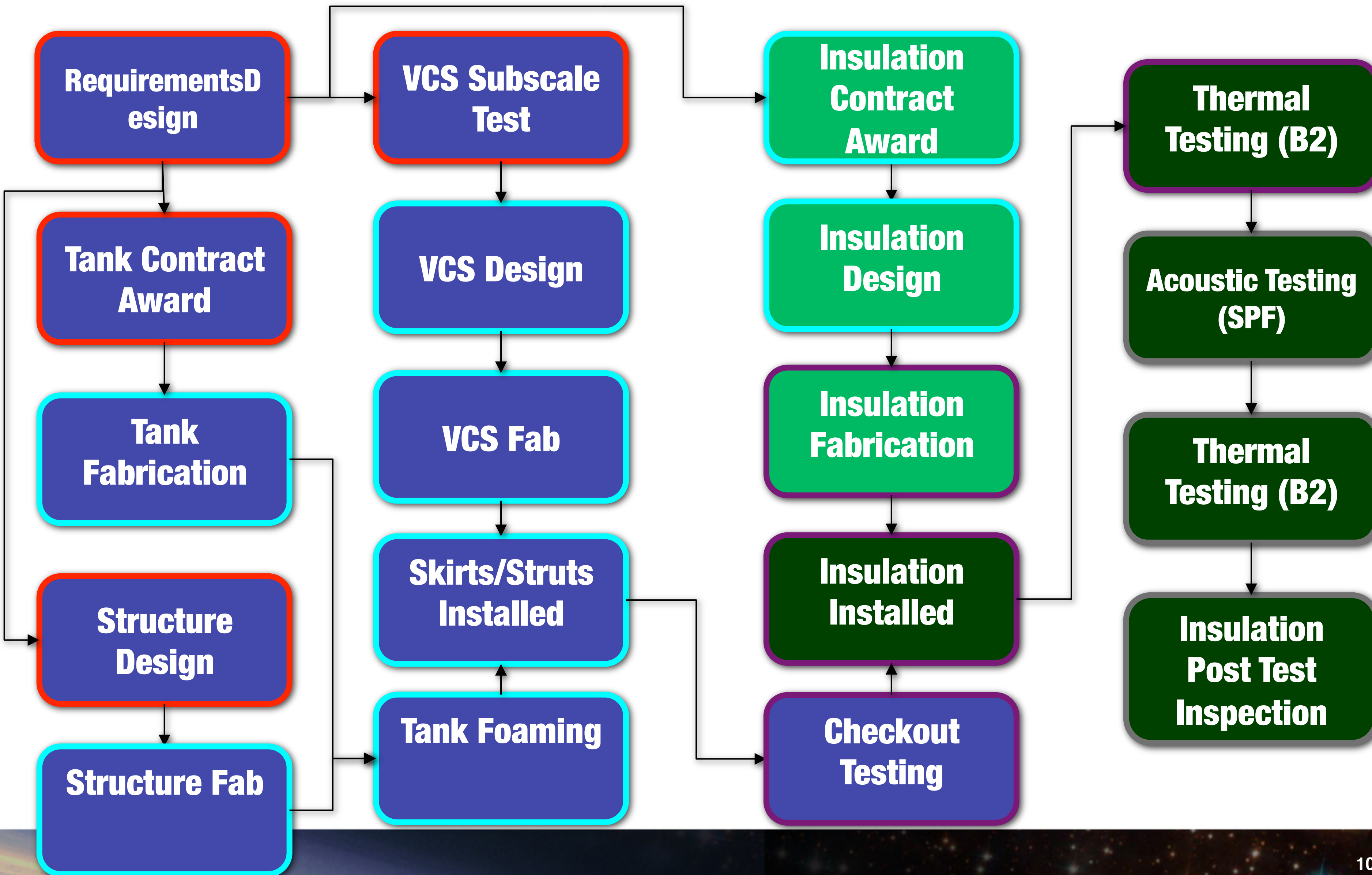


Hardware Concept





Test Flow



RequirementsD esign
VCS Subscale Test
Insulation Contract Award
Thermal Testing (B2)
Tank Contract Award
VCS Design
Insulation Design
Acoustic Testing (SPF)
Tank Fabrication
VCS Fab
Insulation Fabrication
Thermal Testing (B2)
Structure Design
Skirts/Struts Installed
Insulation Installed
Insulation Post Test Inspection
Structure Fab
Tank Foaming
Checkout Testing

Test Plan

- Initial/Checkout Thermal Vacuum testing
  - Foam insulation only thermal performance
  - Possibly use vapor cooled skirt
- Thermal Vacuum Testing
  - Foam + MLI thermal performance
  - Strain on MLI blanket due to venting
  - Vapor Cooling On and Off
  - Pressure Rise testing for stratification/heat buildup
- Acoustic Testing
  - Foam + MLI survivability
  - Strain on MLI blanket/dynamic envelope
  - Vapor cooling survivability
- Thermal Vacuum Testing
  - Foam + MLI thermal performance (change from 1st thermal vac?)
  - Strain on MLI blanket due to venting
  - Vapor Cooling On and Off

Multilayer Insulation

- The application of a multilayer insulation system to the test tank has multiple goals:
  - Understand the thermal performance of a MLI system applied to a large tank
  - Understand the acoustic survivability of a MLI system applied to a large tank
  - Understand the application and attachment issue with MLI applied to a large tank
  - Understand the cost factors of MLI applied to a large tank
- Coupon level testing is planned as a part of the MLI development strategy and will be a part of the MLI procurement
- Testing is currently being done in-house to measure effects of design details
- Uncertain how low temperatures (~90 K) would affect acoustic-vibe testing, so testing with LN2 in the tank being considered
- Vendor visits will be conducted in the July – September time frame

Vapor Cooled Structure/Skirt

- The use of vapor to cool structural skirts and reduce structural heat load has several objectives:
  - Understand the possible thermal benefits of cooling structural skirts
  - Understand the possible limitations of cooling structural skirts
  - Understand the impact of fill level on cooling structural skirts
  - Understand the impact of pressurant gas (helium) on cooling structural skirts
- Design and build planned to be done by NASA
- Sub-scale vapor cooling efforts are getting underway
  - Focusing on attachment methods and efficiencies onto real systems
  - Results will inform large scale design
- The use of MLI on the skirt is still being considered
  - There may be MLI blankets that can be removed during thermal vacuum testing to understand the effects of having MLI on the skirt
  - There is uncertainty regarding if MLI could be used on the exterior of the structure in a real flight environment
- There are no expected acoustic-vibe issues with the attachment methods
  - Attachment methods may be verified in subscale testing

Model Verification

- eCryo is making a concerted effort for data to be available for model verification both internally and externally to NASA
  - Data will probably be subject to export control regulations
- Discussions on sensor location and quantities for model verification will be conducted at industry workshops sponsored by the Project
- Pressure rise testing has currently been identified as a key test that is needed for model verification as tank sizes grow

Test Schedule

- Tank Procurement – ETA of RFP: Oct 2015
- MLI Procurement – ETA of RFP: March 2016
- Design Reviews: July 2015, May 2016, February 2017
- Thermal Vacuum Testing #1: December 2017 – April 2018
- Acoustic Testing: May 2018
- Thermal Vacuum Testing #2: Sept 2018 – Nov 2018

Note: The eCryo Project is currently planning annual industry workshops in the July time frame, starting in 2016. SHIIVER status and plan updates may be briefed at those workshops.

Future Testing

- It is NASA's desire that the SHIIVER effort result in a test-bed type asset
  - Discussions with industry on possible testing configurations subsequent to the currently planned testing within the eCryo Project will occur and are highly encouraged
- Tank scarring for future testing is currently being considered as a part of the SHIIVER design effort