Structural Heat Intercept, Insulation, and Vibration Evaluation Rig (SHIIVER)

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Space Cryogenics Workshop
Structural Heat Intercept, Insulation, and Vibration Evaluation Rig (SHIIVER)

SLS

EUS

SHIIVER

Boil-off vapor cooling on forward skirt

Curtain that can be lowered to simulate external MLI solution thermal benefit

Forward and Aft structural skirts
- Baseline for EUS

Traditional MLI on top and bottom domes

Spray on Foam Insulation on barrel and top and bottom domes
- Baseline for EUS

Test Flow

Baseline Test (SOFI Only) ➔ Install MLI on domes ➔ Pre Acoustic Thermal Test ➔ Acoustic Test ➔ Post Acoustic Thermal Test

B2

SPF
Structural Heat Intercept, Insulation, and Vibration Evaluation Rig (SHIIVER)

Objectives:
- Perform sub-scale engineering development to ensure that the heat intercept approaches for the large-scale rig are stage-representative.
- Build a large stage-representative rig capable of testing cryogenic fluid management technologies.
- Perform an initial test of the large rig under mission-representative environmental conditions using one configuration of a possible stage-like heat intercept system (vapor cooling and multilayer insulation).

Status:
- Tank Engineering Design Approved: Dec 2016
- MLI Preliminary Design Review: Feb 2017
- Stakeholders Reviews: June 2015, July 2016
- SHIIVER Concept Review: August 2015

Schedule:
- Receive Tank at MSFC: July 2017
- Finish Sub-scale Vapor Cooling Testing: Aug 2017
- SOFI Installation completed: October 2017
- Testing Starting: August 2018
- Testing Completed: May 2019
- Final Report: April 2020

<table>
<thead>
<tr>
<th>KPP</th>
<th>State of the Art</th>
<th>Project Goal</th>
</tr>
</thead>
<tbody>
<tr>
<td>MLI Thermal Performance on a 4 m tank</td>
<td>SOFI baseline testing done by eCryo</td>
<td>40% boil-off reduction after exposure to acoustic vibration loads</td>
</tr>
<tr>
<td>MLI Mass on a 4 m tank</td>
<td>Thick MLI has not been demonstrated in</td>
<td>MLI added mass of not more than 2% of tank fluid mass</td>
</tr>
<tr>
<td></td>
<td>a manner representative of an upper</td>
<td></td>
</tr>
<tr>
<td></td>
<td>stage flight application.</td>
<td></td>
</tr>
<tr>
<td>Vapor Based Heat Intercept Thermal</td>
<td>Small flight helium dewars (&lt;2 m). CRYOTE testing (0.75 m)</td>
<td>15% boil-off reduction on 4 m tank at 50% full</td>
</tr>
<tr>
<td>Performance on a 4 m tank</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vapor Based Heat Intercept Mass on a 4 m</td>
<td>CRYOTE testing (.75 m tank) 9% of tank fluid mass (using LH2 density)</td>
<td>Not more than 5% of tank fluid mass</td>
</tr>
<tr>
<td>tank</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

SHIIVER is developing the baseline for thermal performance both of existing upper stages and technology enhancements.
Sub-scale Vapor Cooling Testing

- **Looking at two different flow channels:**
  - Welded, with flow directly on skirt surface
  - Bolted channel assembly
- **Preliminary results from welded flow channel** shows a 50%+ reduction in heat load through the skirt. Heat load appears to be more strongly correlated to the inlet coolant temperature.
- **Remaining tests:**
  - Bolted channel assembly – July 2017
Multilayer Insulation

- **Design, Fabrication, and Install by Aerospace Fabrication and Materials**
  - Three pieces:
    - MLI for domes – needed for pre-acoustic thermal vacuum testing
    - MLI for curtains – needed for baseline testing
    - MLI for interior of skirts – needed for baseline testing
  - Coupon Testing Feb – June 2017 to verify performance and help scale/analyze data

- **Specifications**
  - 30 layers
  - Attached at outer diameter on skirts
  - Attached near inner manway
  - Expected heat flux less than 1 W/m²

- **Current projected mass: 40 kg**
SHIIVER Components

Forward Skirt:
- Design in progress (dependent on SLICE activity)
- Fabrication planned at GRC
- Anticipated Delivery: 12/17

Test Tank:
- Includes manways & “shipping skirts”
- Awarded to Didion on 10/16
- Fabrication completed
- Cold shock completed
- Cleaning/leak test prior to shipment
- Anticipated Delivery to MSFC: 7/17

Aft skirt:
- Design complete
- Fabrication at MSFC/Votaw
- Anticipated Delivery: 9/17

Support structures (3 – 1 for B2, 1 for RATF, 1 for transportation):
- B2 support structure design complete
  - Fabrication in progress @ GRC
  - Anticipated Delivery: 9/17
- Transportation Support Stand
  - Anticipated Delivery: 2/18
- RATF Support Stand
  - Initial requirements evaluated
  - Design not started
  - Anticipated Delivery: 2/18
### Predicted Benefits from Heat Intercept Technology

The graph illustrates the predicted heat load in kilowatts (kW) for different configurations of heat intercept technology. The configurations include:

- **No VC**
  - SOFI only
  - SOFI + MLI on tank domes only

- **VC**
  - SOFI + MLI on tank and skirt

The bars are color-coded as follows:

- AFT skirt
- FWD skirt
- MLI
- SOFI

#### Heat Load, kW

<table>
<thead>
<tr>
<th>Configuration</th>
<th>SOFI only</th>
<th>SOFI + MLI on tank domes only</th>
<th>SOFI + MLI on tank and skirt</th>
</tr>
</thead>
<tbody>
<tr>
<td>No VC</td>
<td><img src="chart.png" alt="Heat Load Chart" /></td>
<td><img src="chart.png" alt="Heat Load Chart" /></td>
<td><img src="chart.png" alt="Heat Load Chart" /></td>
</tr>
<tr>
<td>VC</td>
<td><img src="chart.png" alt="Heat Load Chart" /></td>
<td><img src="chart.png" alt="Heat Load Chart" /></td>
<td><img src="chart.png" alt="Heat Load Chart" /></td>
</tr>
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</table>
Hardware & Testing

SHIIVER Tank During Cold Shock

Machining Tank Flanges
TEST PLAN
SHIIVER Instrumentation

• **Temperature**
  – 190 silicon diodes ordered and delivered in FY16
    • +/- 0.1 K: 4 K < T < 30 K
    • +/- 0.5 K: 30 K < T < 400 K
  – Ordered with ~13 ft leads to minimize extensions needed
  – Locations for 146 assigned diodes on test system have been identified and assigned by SN to P&ID

• **Liquid Level**
  – Capacitance probe ordered and delivered in FY16
  – RFMG installed to demonstrate scaling of hardware
  – Will also have diode rake every 5%

• **Heat Flux Sensors**
  – Heat flux sensors have been identified and purchased for comparative testing
  – Calibration to 20 K this summer

• **Accelerometers**
  – Accelerometers ordered and delivered in FY16
  – Locations still being worked by SHIIVER team

• **Boil-off and Vapor flow**
  – Flow meters have been identified and ordered
  – Covers range of expected heat loads on SHIIVER

• **Pressure**
  – Pressure transducers have been spec’d and identified
  – Quantity and locations on P&ID identified
  – Procurement and placement in B2 in progress
Tank & SOFI

- Tank wall sensor, temperature
- SOFI surface sensor, temp
- Heat Flux Sensor

See FWD Skirt

Also on tank backside
FWD Skirt/Vapor Cooling Temperatures

- FWD skirt sensor, temperature
Test Plan

Testing split into four distinct categories

– Baseline Testing:
  • Show system performance with SOFI only (sprayed to EUS dimensions and tolerances)
  • Demonstrate vapor cooling performance benefits with SOFI only

– Pre-Acoustic Testing:
  • Demonstrate performance benefits with MLI compared to baseline
  • Demonstrate vapor cooling performance benefits in conjunction with MLI

– Acoustic Testing:
  • Demonstrate that MLI survives SLS/EUS anticipated acoustic loads
  • Demonstrate that MLI survives transportation between facilities

– Post-Acoustic Testing:
  • Demonstrate performance losses due to acoustic loads on MLI system
Tests required to meet KPPs:
- Insulation performance at 90% full
- Vapor cooling performance at 50% full

<table>
<thead>
<tr>
<th>Test Name</th>
<th>Vapor Cooling (On/Off)</th>
<th>Liquid Level (%)</th>
<th>Curtain (Up/Down)</th>
<th>Baseline Testing (SOFI)</th>
<th>Pre-Acoustic Testing</th>
<th>Post-Acoustic Testing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fill of warm tank (in Vacuum)</td>
<td>Off</td>
<td>0 – 90</td>
<td>Up</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Boil-off/Heat Load High Fill</td>
<td>Off</td>
<td>90</td>
<td>Up</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Boil-off/Heat Load Med Fill</td>
<td>Off</td>
<td>50</td>
<td>Up</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Vapor Cooling max flow</td>
<td>On</td>
<td>50</td>
<td>Up</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Vapor Cooling – Nominal</td>
<td>On (partial flow)</td>
<td>50</td>
<td>Up</td>
<td>X</td>
<td>X</td>
<td>?</td>
</tr>
</tbody>
</table>
**Thermal Vacuum Testing Priorities - Needed**

Without these tests SHIIVER may be programmatically successful, but leave infusion targets partially satisfied.

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<tr>
<th>Test Name</th>
<th>Vapor Cooling (On/Off)</th>
<th>Liquid Level (%)</th>
<th>Curtain (Up/Down)</th>
<th>Baseline Testing (SOFI)</th>
<th>Pre-Acoustic Testing</th>
<th>Post-Acoustic Testing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boil-off/Heat Load High Fill w/curtain</td>
<td>Off</td>
<td>90</td>
<td>Down</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Vapor Cooling/High fill</td>
<td>On</td>
<td>90</td>
<td>Up</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Pressure Rise, High Fill</td>
<td>Off</td>
<td>90</td>
<td>Up</td>
<td>?</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Vapor Cooling-Nominal/Curt</td>
<td>On</td>
<td>50</td>
<td>Down</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Transient Vapor Cooling</td>
<td>On</td>
<td>70</td>
<td>Up</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Transient No Vapor Cooling</td>
<td>Off</td>
<td>70</td>
<td>Up</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Fill of warm tank (in Vacuum) with cooling</td>
<td>On (partial flow)</td>
<td>0 – 90</td>
<td>Up</td>
<td></td>
<td></td>
<td>X</td>
</tr>
</tbody>
</table>
## Thermal Vacuum Testing Priorities - Other

<table>
<thead>
<tr>
<th>Test Name</th>
<th>Vapor Cooling (On/Off)</th>
<th>Liquid Level (%)</th>
<th>Curtain (Up/Down)</th>
<th>Baseline Testing (SOFI)</th>
<th>Pre-Acoustic Testing</th>
<th>Post-Acoustic Testing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cycling Flow</td>
<td>On</td>
<td>50</td>
<td>Up</td>
<td></td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Boil-off Low Fill</td>
<td>Off</td>
<td>25</td>
<td>Up</td>
<td>X</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Vapor Cooling – Low Fill</td>
<td>On</td>
<td>25</td>
<td>Up</td>
<td>X</td>
<td></td>
<td>X</td>
</tr>
</tbody>
</table>
## Acoustic Test Matrix

<table>
<thead>
<tr>
<th>Test Name</th>
<th>Profile</th>
<th>Duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Launch</td>
<td>EUS</td>
<td>40 s</td>
</tr>
<tr>
<td>Aero acoustics</td>
<td>EUS</td>
<td>20 s</td>
</tr>
</tbody>
</table>
SHIIVER Conclusions

- The SHIIVER test articles are making progress in development including the beginning of fabrication
- Performance goals and targets are show with projected performance meeting all performance goals
- A prioritized test matrix is laid out to meet all project and performance needs
- Testing should begin in late 2018