Tank Applied Testing of Load Bearing Multilayer Insulation (LB-MLI)

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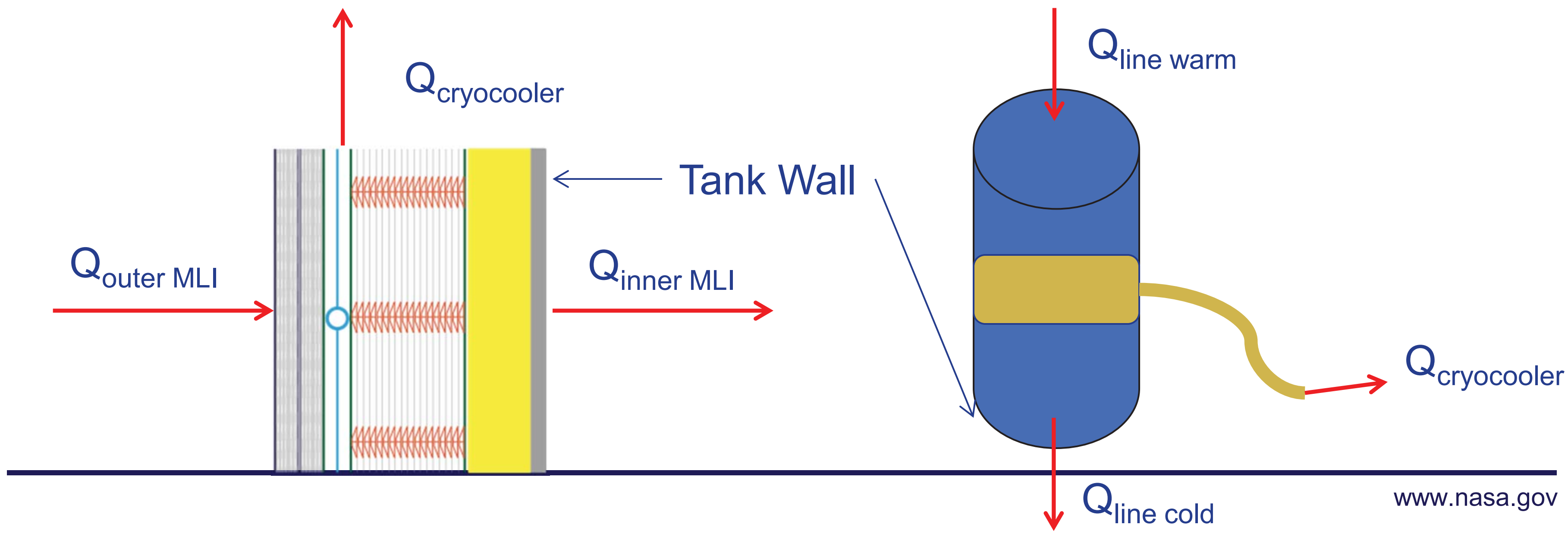
Reduced Boil-Off

- For long duration storage of cryogenic propellants on orbit, boil-off is a significant problem
  - Reducing the boil-off through active refrigeration may be required if passive insulation systems cannot be built to meet mission requirements
- Lack of large scale 20 K class cryocoolers limits our current availability to do zero boil-off for liquid hydrogen
- Incorporating existing 90 K cryocoolers could still lower heat load by as much as 70% (theoretical)
  - Use a Broad Area Cooling (BAC) shield, similar to a vapor cooled shield, but attached to a cryocooler
  - Cool struts and plumbing in addition to insulation system



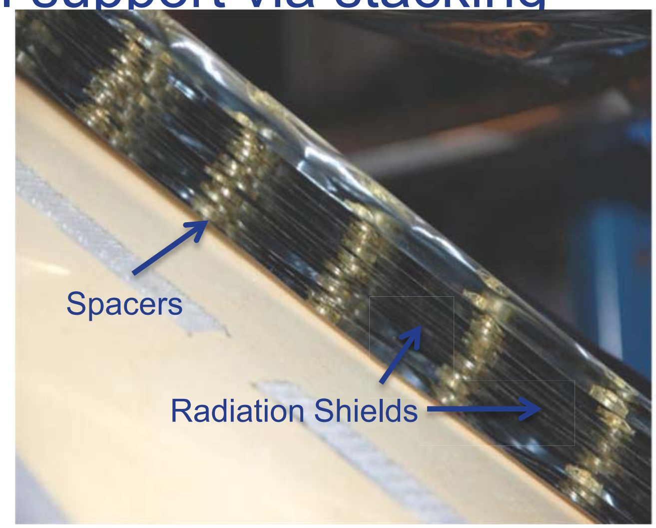
Problem Statement

- Demonstrate a system that can:
  - Support a Broad Area Cooling shield in the middle of an MLI blanket
  - Survive launch loads
  - Provide high thermal performance on orbit
  - Survive rapid depressurization

- Solution:
  - Load-Bearing Multilayer Insulation
    - Built by Quest Products & Ball Aerospace
    - Developed through several SBIR contracts

Load Bearing Multilayer Insulation

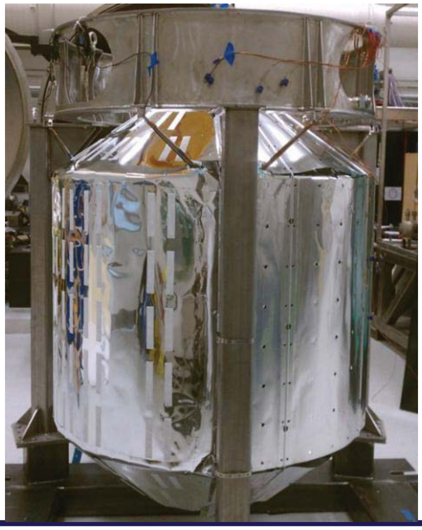
- Uses polymer based stand-offs to separate the layers as opposed to netting
  - Creates a simpler conduction heat transfer network for modeling
  - Allows for more accurate modeling of MLI system
- Can be arranged to provide structural support via stacking spacers
  - Previous testing used plastic stand-offs to support BAC shield
  - No stand-offs required with LB-MLI
- Currently at low (5 layer/cm) layer density
  - Based on current MLI theory, about optimum for 90 – 100 K warm boundary
  - Replaced 30 layer traditional blanket with 19 layer LB-MLI blanket



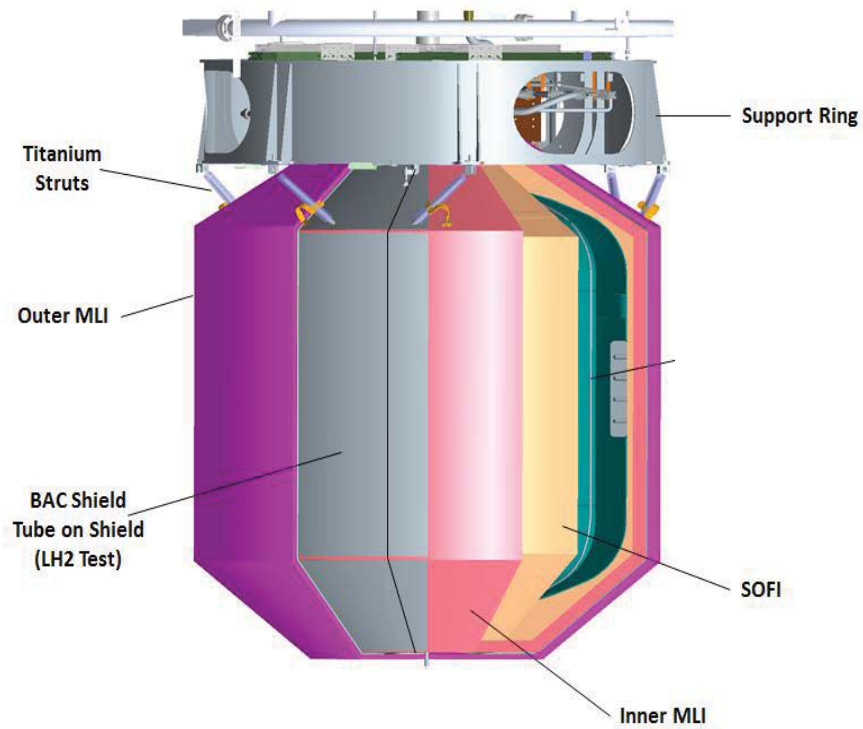
Test Program

Two tanks were fabricated to be as close to identical as possible

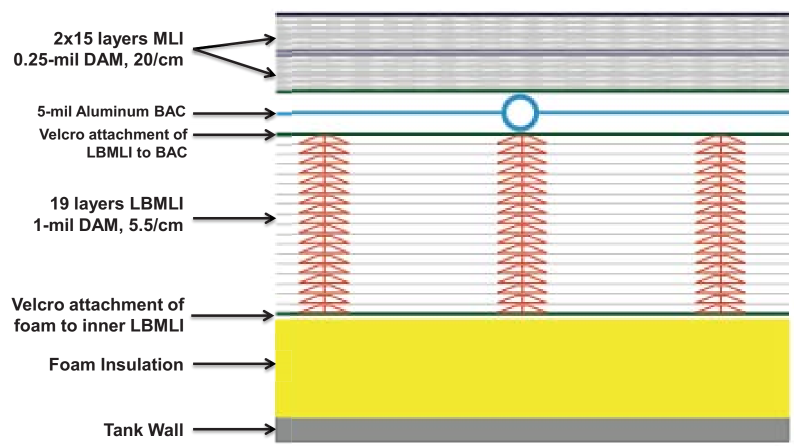
- Nearly identical insulation systems were installed on each tank
- One tank was tested with liquid hydrogen for thermal performance
- The other was tested with liquid nitrogen to determine the acoustic environmental effects on the cooled shield/MLI.



Test Configuration



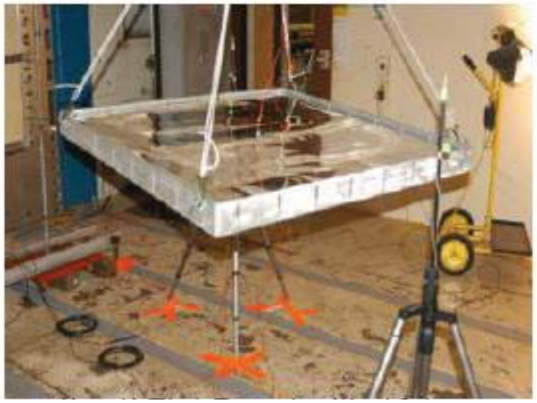
Layered cut-away view



Cross-Sectional View

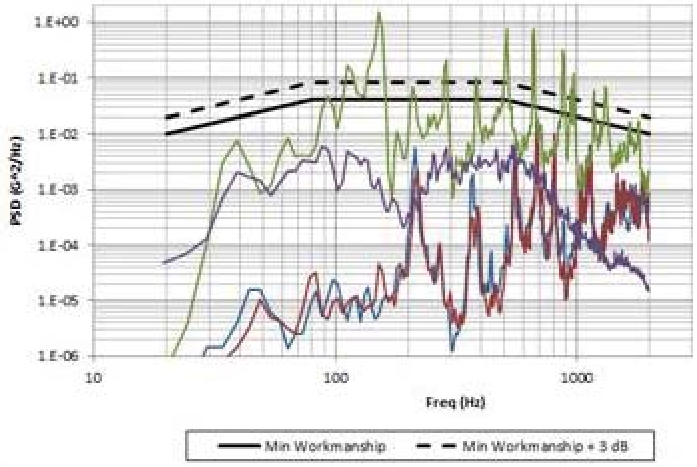
Structural Testing

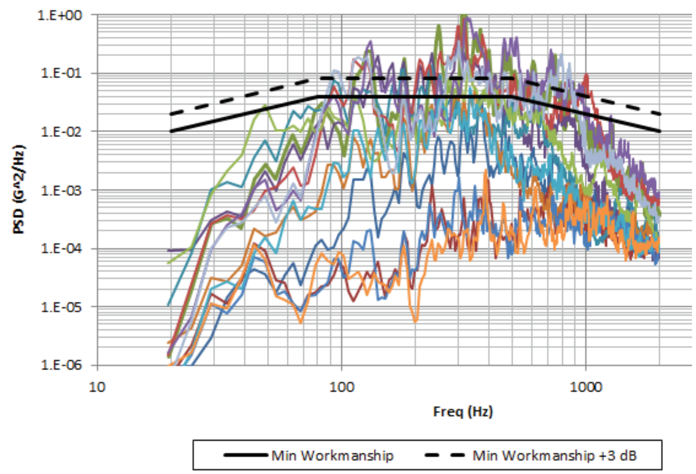
- In order to demonstrate structural integrity of the blanket, acoustic testing was selected over vibration testing
  - Insulation systems are large area, lightweight systems that respond more to acoustically input energy than vibrationally input energy
- Testing on coupons
  - Unloaded flat panel
  - Loaded curved panel
  - Post test examination for changes (damage)
- Testing on a Tank
  - Thermal testing before and after
  - Post test examination for changes (damage)
- All actual acoustic testing done when system was a room temperature



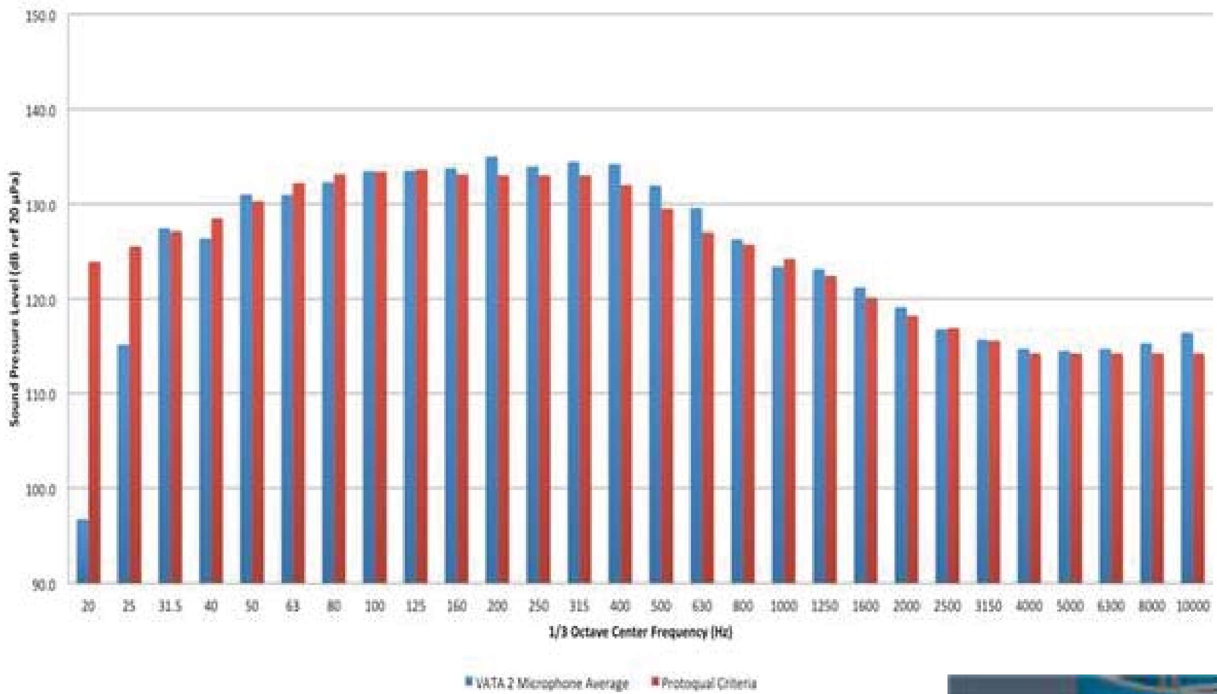
Coupon Test Results

- The dotted black line indicates input levels
- Colored squiggly lines indicate response
- Flat panel test (top)
  - Just LB-MLI, no load attached(i.e. BAC shield, other MLI)
  - Post test inspection revealed no issues (debonding, tearing, etc)
  - Indicated that LB-MLI can survive launch & ascent with no external load
- Curved panel test (bottom)
  - Included BAC shield mass simulator and outer MLI
  - Post test inspection revealed no issues
  - Indicated that LB-MLI can survive launch & ascent with load attached
- Both tests combined indicated that LB-MLI was ready to proceed with tank applied testing

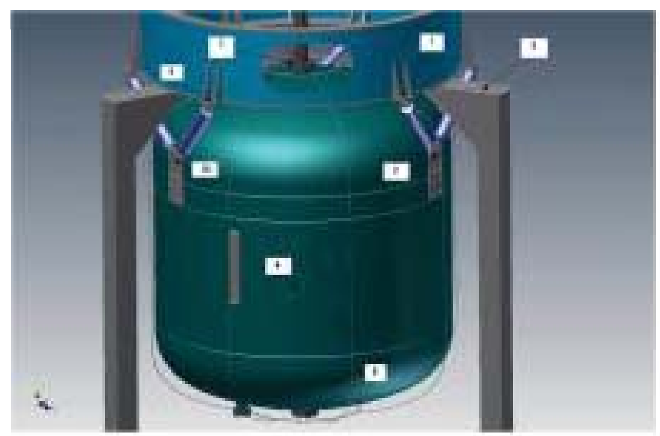




Tank Applied Test Setup



Accel #	Description	Type
1	On gusset, near strut attach point	Triax
2	On tank, near strut attach point	Triax
3	On support column, top surface	Triax
4	On tank surface, mid-barrel section	Uniaxial
5	Same as #4, clocked 120 degrees around tank	Uniaxial
7	On top of tank	Uniaxial
8	On bottom of tank	Uniaxial
9	On gusset, near strut attach point	Triax
10	On tank, near strut attach point	Triax

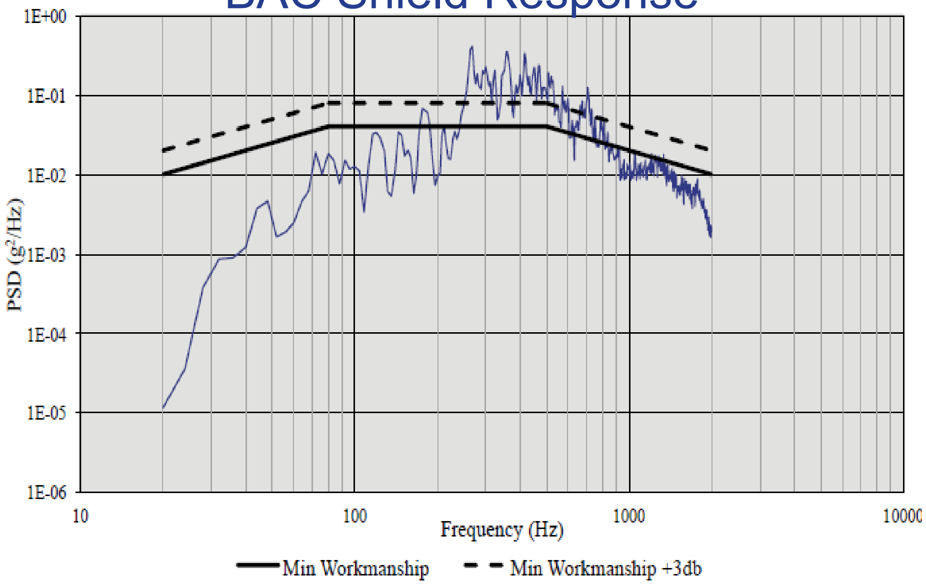


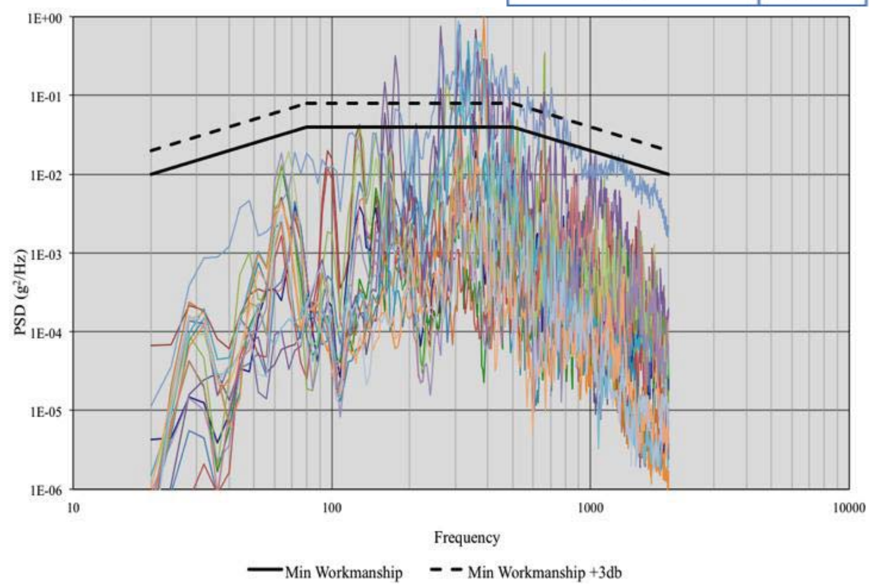
Tank Applied Acoustic Testing Results

- Pre and Post Test Thermal testing using LN2
  - Heat load of 7.5 W on both tests
  - When running chilled GN2 through BAC shield tubing, heat load of 4.5 W on both tests
    - No gas leaks in tubing degrading performance
- Post test inspection found no issues
  - No debonding of spacers, no tears of MLI, no warping of MLI blanket
- Maximum acceleration level on BAC shield: 8.7 G_{RMS}
  - Original level for concern was 6 G_{RMS}
  - After no damage found, at 8.7G_{RMS}, level of concern was upped to 10 G_{RMS}

VATA 2 Full Scale Tank Test	
Accelerometer	GRMS
R1R	1.498
R1L	1.551
R1T	0.867
R2R	4.709
R2L	1.31
R2T	0.728
R3R	1.24
R3L	1.089
R3T	2.982
R4R	6.407
R5R	3.041
R7L	3.061
R8L	8.697
R9R	2.051
R9L	1.576
R9T	0.991
R10R	5.22
R10L	1.046
R10T	0.769

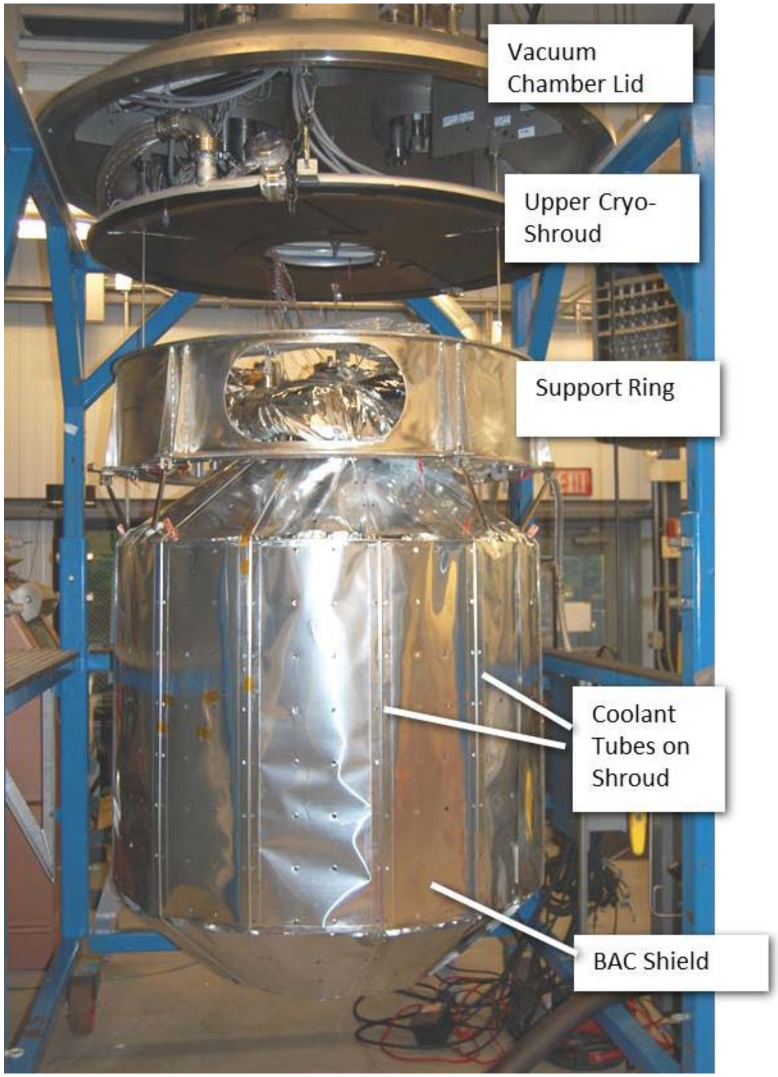
BAC Shield Response





Thermal Testing

- In order to demonstrate thermal viability, a thermal vacuum test was run using liquid hydrogen
  - Broad Area Cooled (BAC) Shield was integrated on top of the blanket
  - BAC shield was coupled to a cryocooler
  - Testing with and without cryocooler operational
- Pre-test coupons were tested using liquid nitrogen



Thermal Coupon Results

	layers	Tc, K	Th, K	Measured Q, W/m^2	Model Q, W/m^2	% difference	SF
Ball	10	76	296	0.95	0.91	-4.3%	1.05
KSC	20	77	292	0.41	0.43	5.6%	0.95
KSC	20	77	305	0.57	0.51	-11%	1.12
Ball	3	76	296	3.62	3.02	-16%	1.20
KSC	9	78	293	0.92	0.97	5.2%	0.95
	9	78	325	1.36	1.41	4.0%	0.96
	9	78	316	1.23	1.28	3.5%	0.97
KSC	5	78	293	1.77	1.75	-1.3%	1.01
	5	78	305	1.99	2.02	1.5%	0.99
	5	78	325	2.61	2.54	-2.6%	1.03
KSC	19	78	293	0.55	0.46	-16%	1.18
	19	78	305	0.77	0.51	-34%	1.51
	19	78	327.8	0.85	0.69	-19%	1.23
FSU	4	20	85	0.18	0.11	-42%	1.71
	9	20	85	0.13	0.048	-63%	2.71

$$Scale\ Factor = \frac{Q_{MLI,test}}{Q_{MLI,predict}}$$

Tank Applied Thermal Test Matrix

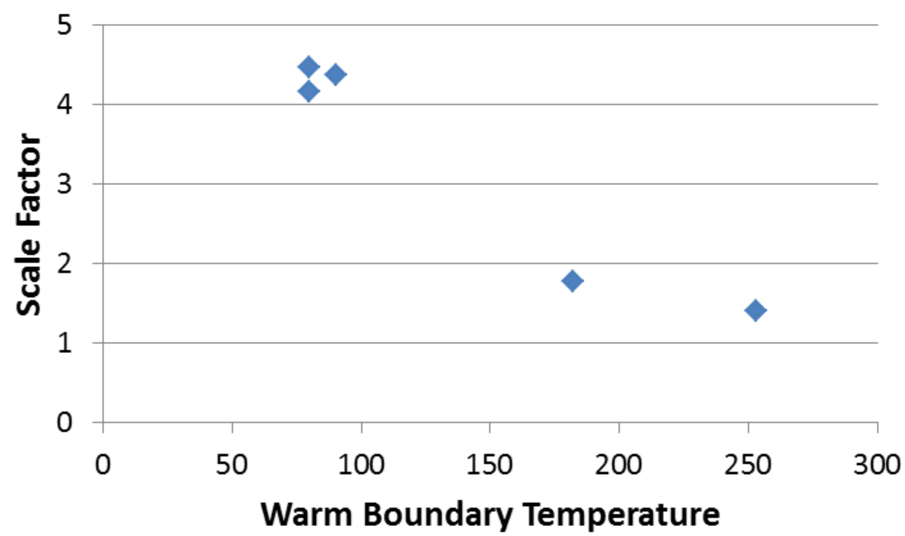
Test #	BAC Shield Set Point (K)	Bypass Valve (open/closed)	Fill Level (%)	Environmental Temperature (K)	Test Type
1	80 K	Open	90	220	Steady State
2	80 K	Open	25	220	Steady State
3	N/A	Open	90	220	Steady State
4	N/A	Closed	90	220	Steady State
5	90 K	Open	90	220	Steady State
6	90 K	Closed	90	220	Steady State
7	N/A	Open	90	300	Rapid Evacuation
8	N/A	Open	90	300	Steady State

Note: Bypass Valve was to allow for testing with and without Thermo-Acoustic Oscillations (TAO)

Tank Applied Thermal Test Results

Test #	Heat Load to Tank (W)	Conduction Heat Loads (W)	Net Remainder (W)	MLI Penetrations (W)	MLI Heat Load (W)	MLI Heat Flux (mW/m²)	Predicted MLI Heat Flux (mW/m²)
1	1.67	0.94	0.73	0.17	0.56	79	19
2	1.68	0.97	0.71	0.17	0.54	76	17
3	3.32	1.69	1.63	0.17	1.46	207	116
5	1.83	1.01	0.82	0.17	0.64	92	21
8	6.12	2.77	3.35	0.28	3.07	436	310

$$Scale\ Factor = \frac{Q_{MLI,test}}{Q_{MLI,predict}}$$

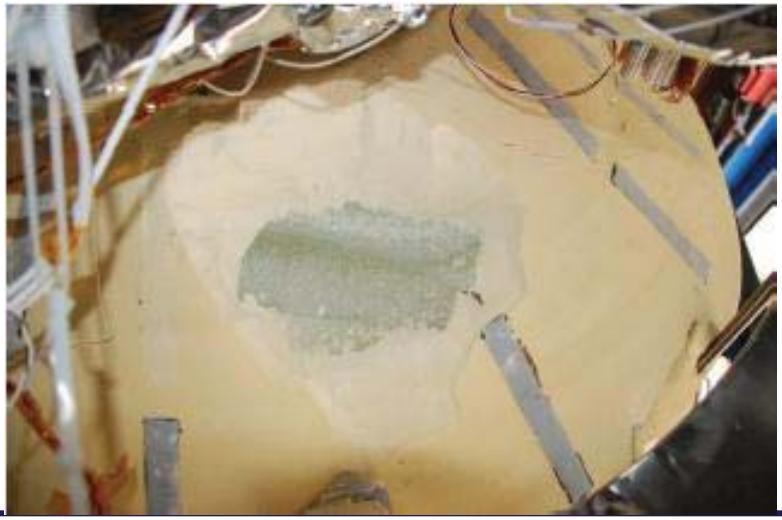


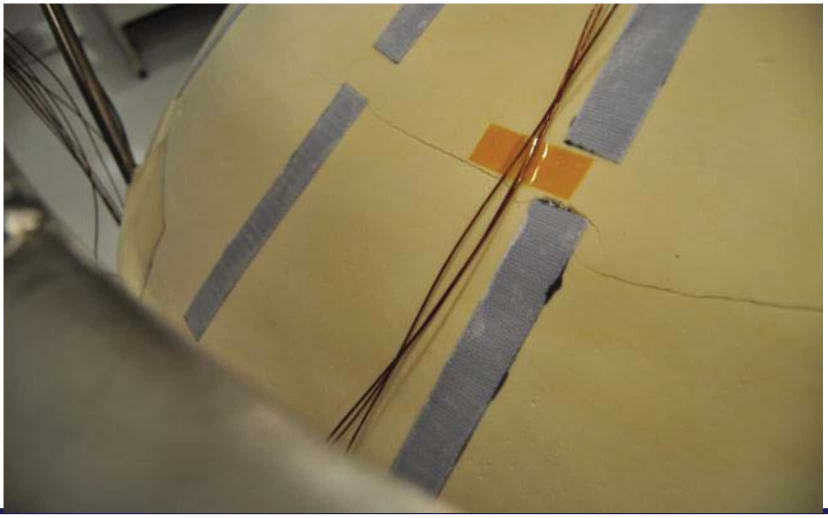
Rapid Depressurization

- Rapid Depressurization was performed
  - Simulates the first few minutes to hours of mission
  - Attempted twice, both times got through the rough pumping portion but had trouble switching to turbo/diffusion pumps
    - Issues with gaseous nitrogen evacuation due to the formation of solid nitrogen at the bottom on the MLI blanket
  - Attempted with helium gas and was fully successful

Post Test Evaluation

- Post test evaluation showed divoting and cracking of the SOFI, further investigation yielded:
  - Tank was stainless steel, not aluminum, SOFI shrinkage optimized for aluminum
  - SOFI was up to 4” thick in some places, recommend not greater than 1.5” to 2” thick in future
  - Velcro may have added extra stresses to cause more cracking





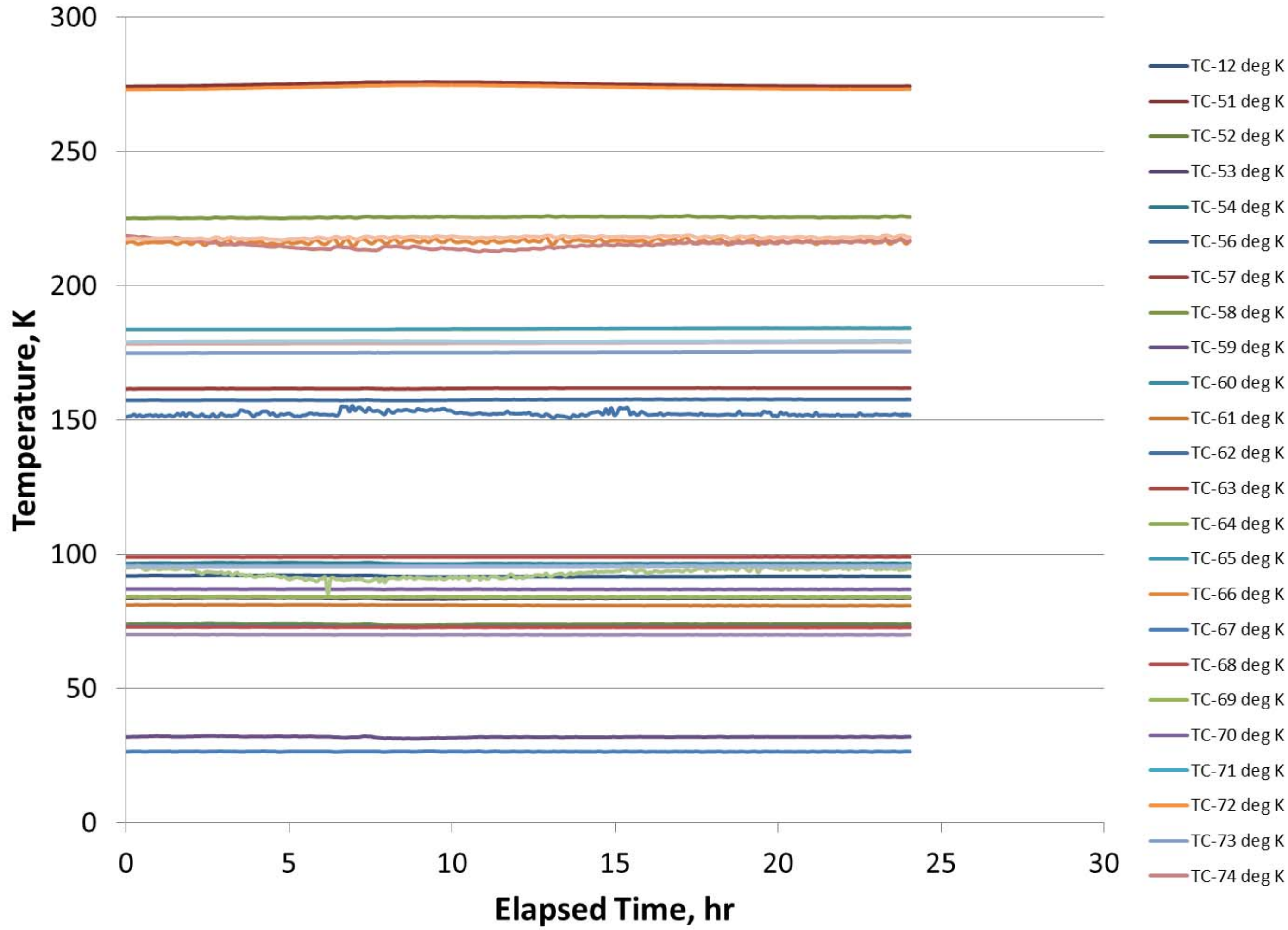
Conclusion

- Demonstrated a system (LB-MLI) that can:
  - Support a Broad Area Cooling shield in the middle of an MLI blanket
  - Survive launch loads
  - Heat load of less than 0.1 W/m^2 through the MLI with the cryocooler on and 0.2 W/m^2 with the cryocooler off.
  - Survive rapid depressurization
- Noticed increasing scale factor with decreasing temperature, first cut analysis indicates it is a radiation issue
  - This is not an LB-MLI specific problem
  - Was worse on previous traditional MLI blanket testing
- SOFI had issues handling combined loads during rapid depressurization
  - partially a design issue
  - more investigation needed to fully understand

Acknowledgments

- The Small Multipurpose Research Facility Test Team (Glenn Research Center – Tank Applied Thermal Testing)
- Bldg 4619 Acoustic Chamber Test Team (Marshall Space Flight Center – Acoustic testing)
- Environmental Systems Test Facility Test Team (Marshall Space Flight Center – Pre/Post-Acoustic Thermal Testing).
- Funding was provided by both the:
  - Cryogenic Propellant Storage and Transfer Technology Demonstration Mission
  - Self-Supporting Multilayer Insulation Project (STMD Game Changing Division)

Questions?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Temperature, K
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25
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Elapsed Time, hr
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