Development Path for Cryogenic Insulation Systems Supporting NASA Exploration

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Outline

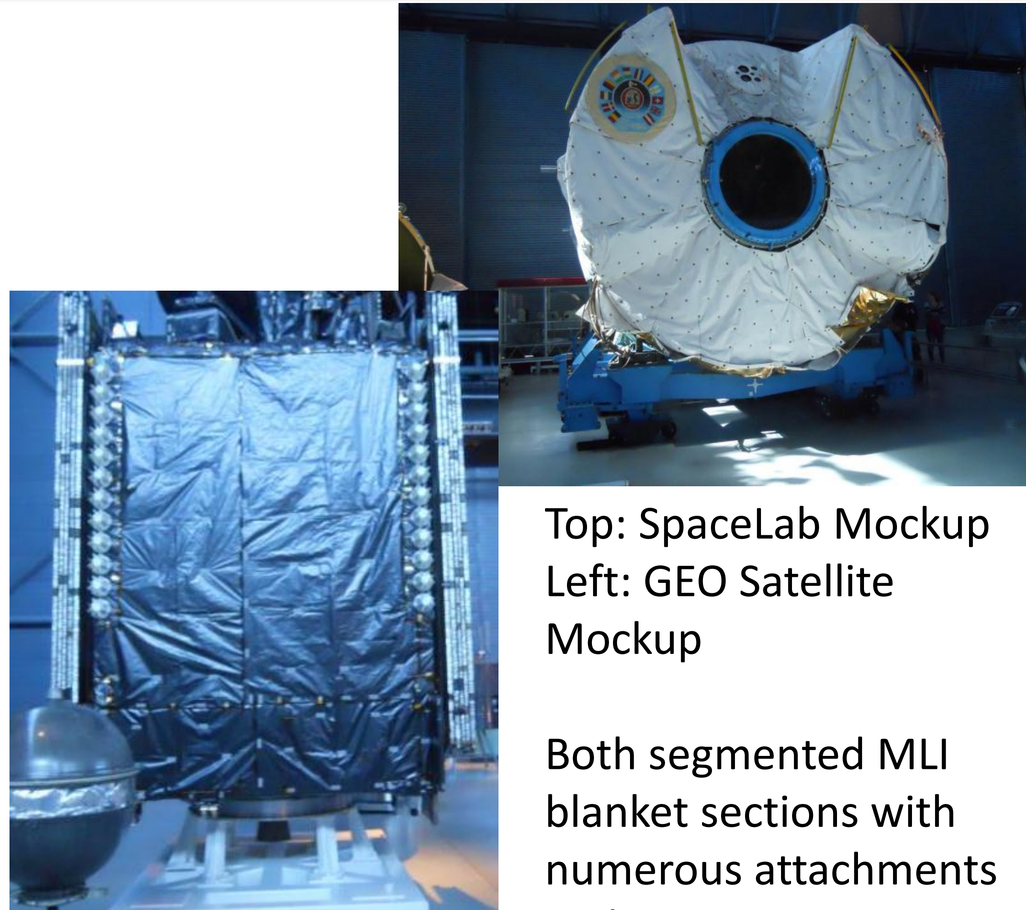
- Introduction
- Current Flight State of the Art
- Recent Research Activities
- Current Research Activities
- Needed Research Activities
- Path to Usage

Introduction

- Insulation is the basic materials that reduce heat flow into something
  - It is also the complex system that has many other requirements (structural, fluid, electrical)
  - The details in how a system is put together will determine performance
  - Communication from the design engineer to the fabrication engineer to the installation technicians are needed to ensure that details are uniformly understood through all parties
    - Multiple test programs have encountered difficulty because the design engineer didn't know the details going on the fabrication floor
- Multilayer Insulation for cryogenic applications has been around for ~ 60 years in a very similar state
  - Multiple different companies (Lockheed, General Dynamics, Boeing, Douglas, Goodyear, NASA internal, etc) ready to produce cryogenic flight MLI for large scale applications on Mars Nuclear Vehicle in 1970's
    - Several of the companies did on tank demonstrations on 1-2 m diameter tanks
  - Recent NASA interest in exploring beyond Earth orbit has caused researchers and engineers to need to relearn many of the lessons lost in the interim.
- Recently, multiple novel solutions have been developed focusing on unique mission timelines.

State of the Art in Flight – Large Scale

Space Shuttle External Tank
Spray on Foam Insulation



Top: SpaceLab Mockup
Left: GEO Satellite Mockup

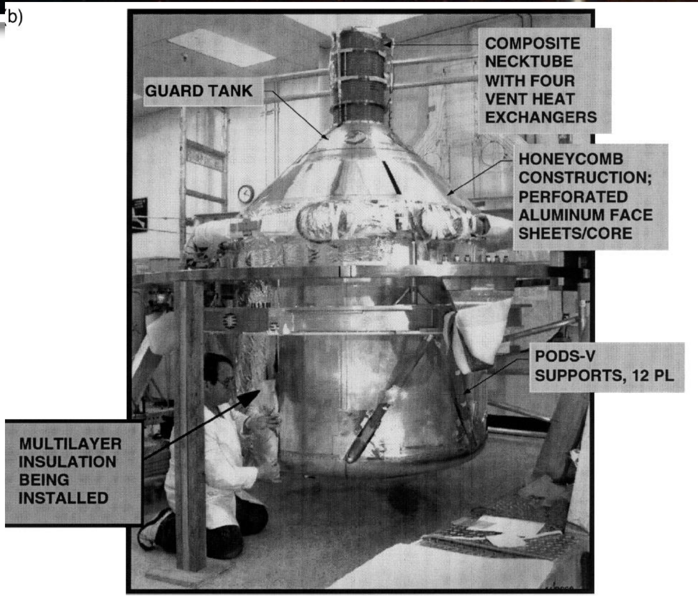
Both segmented MLI blanket sections with numerous attachments and seams.

ULA has flown up to 3 layers of MLI on a Centaur upper stage side wall

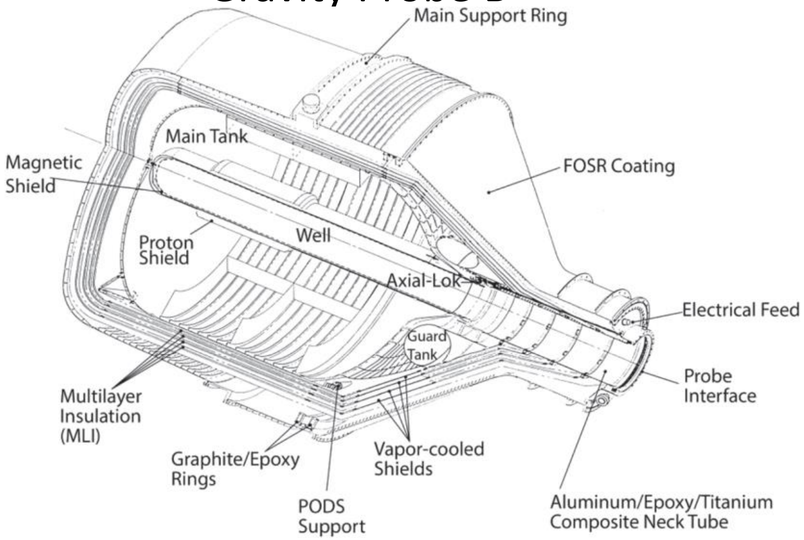
State of the Art in Flight – Small Scale

Cryogenic Flight Dewar MLI is:

- Laid out layer by layer by technicians in a temperature/humidity controlled (quasi-clean) room.
- Enclosed in a second wall that is evacuated very slowly and prior to launch.
- Isolated from all launch structural and thermal loading by being inside vacuum dewar.



Gravity Probe B[1]

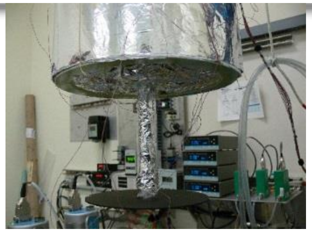


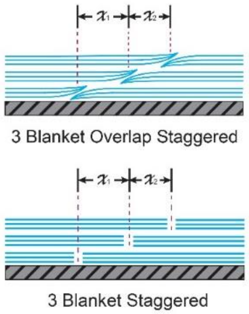
1. Read, D.C., Parmley, R.T., et. al. Cryogenics, vol. 39, pp. 369 – 379.

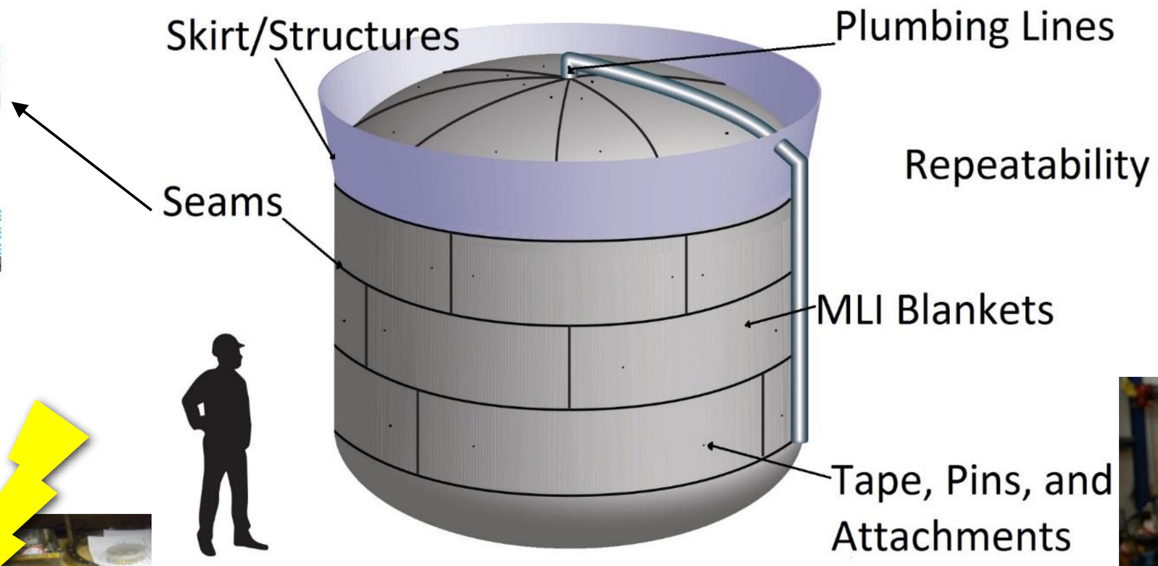
Key Thoughts

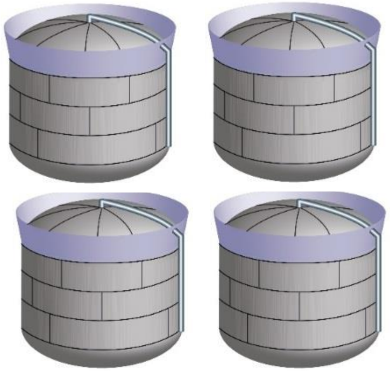
- For spacecraft MLI, the required blanket performance is usually equivalent of 1 – 2 layers of ideal MLI. However, 10 -15 actual layers are used due to degradations of various sorts (seams, penetrations, grounding, structure, ease of installation, etc.)
- For cryogenic dewars, great pains are taken to hide the MLI from the various environments during launch to minimize these degradations
  - Dewar eliminates need for grounding and acoustic survival
  - Instruments are often vibration isolated
  - Layer by layer assembly eliminates seams
  - Small size makes installation easy to manage in quasi-clean room and all parts within width of procurable materials
  - Penetrations are small and can be integrated into the MLI design
- Without the capability of hiding the MLI in a vacuum jacket – what can be done to improve MLI performance?

Current Research Activities

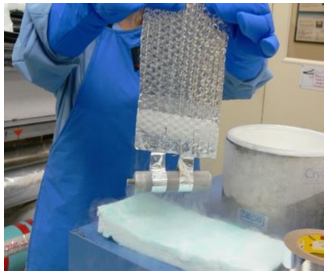


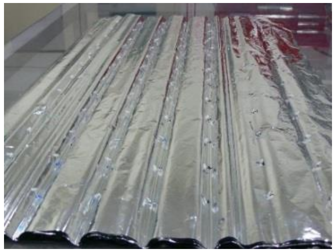






Grounding





Transmissivity Calorimeter Results & Calculations

Test Coupon	Vacuum Pressure (Torr)	Warm Boundary (K)	Cold Boundary (K)	SD-31 (K)	SD-34 (K)	Calculated Heat Load (mW)
Aluminum Foil	2.2 $\times 10^{-8}$	87.1	20.1	16.77	19.80	281
Aluminum Foil	2.2 $\times 10^{-8}$	107.2	20.4	16.80	20.07	306
Aluminized Mylar	1.8 $\times 10^{-8}$	87.8	19.9	18.07	20.04	190
Aluminized Mylar	1.2 $\times 10^{-8}$	107.8	20.2	18.08	20.21	207

Test Coupon	Warm Boundary (K)	Qnet (mW)	Heat Flux (mW/m^2)	Effective emissivity
Aluminum Foil	87.1	132	93	0.028
Aluminum Foil	107.2	152	107	0.014
Aluminized Mylar	87.8	66	46	0.014
Aluminized Mylar	107.8	81	57	0.007

Transmissivity Summary

- Appears that there is minimal transmission through reflector layers, even at wavelengths associated with temperatures < 10 K
  - Aluminum showed slightly worse emmissivities at low temperatures
  - Consistent with measurements by Laman & Grischkowsky (Applied Physics Letters, 93, 051105, 2008)
  - Inconsistent with observations by the cryogenic community over the years
- There does appear to be a “degradation” in emissivity
  - Linearized assuming constant parasitic load and constant emissivity yields 82.2 mW/m^2 (foil) and 37.4 mW/m^2 (DAM) parasitic loads and 0.33% (foil) and 0.26% (DAM) emissivities
  - Consistent with aluminum foil being slightly worse from an emissivity perspective
  - Easiest answer is a small parasitic load; will know more details when calibration completed
- Will publish the data when calibration issue resolved

Repeatability Overview

Two phases of Testing:

- Phase 1: Directed work via Grant to Florida State University (FSU)
  - GRC provided test coupons (5)
    - 25 reflective layers
  - Two Temperature Ranges:
    - 20 K and 300 K (first series - completed)
    - 20 K and 100 K (second series)
  - Two types of repeatability
    - Between coupons
    - With same coupon
- Phase 2: Competed testing (awarded to Yetispace)
  - Fabrication of minimum 5 coupons, up to 10 via options (options have been exercised)
    - 10 reflective layers
    - 2 Thermocouples within each blanket
  - Temperature boundaries: 77 K to 300 K
  - Calorimeter selected by proposer (Yetispace working with FSU)
  - Testing each blanket once
  - All 10 coupon testing completed

Repeatability Summary

- Phase 1A showed initial repeatability of +/- 8.4 %
  - Five coupons between 300 K and 20 K (25 layers)
  - Statistics line up with standard errors associated with small sample sizes, suggests that data is meaningful (see ASTM E 2586)
  - This only dropped to +/- 8.0% when same coupon tested multiple times (note there was no apparent degradation trend over these multiple tests)
- Phase 2 Testing showed initial repeatability of +/- 20%
  - 10 layers of MLI (between 300 K and 77 K)
  - Data still being analyzed
  - Data is statistically significant
- Repeatability appears to be:
  - Driven by installation, not fabrication
  - A function of the number of layers

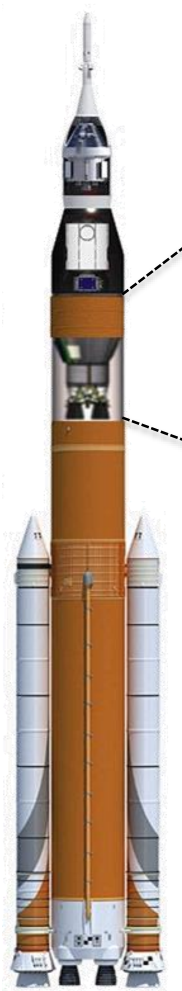
Key Questions for Large Flight Cryogenic MLI Blankets

- How are they held onto the tank?
- How long does installation take?
- How many penetrations are needed coming through the blankets (can the function of several be combined)?
- Should the structures (skirts or struts) be insulated as well?
- How well are the blankets evacuated?
- What are the actual grounding requirements on the blanket (the tank is mostly just a big dumb hydrogen tank, no electronics)?
- What actual thermal margins need to be accounted for and how can they be reduced (reduced thermal margin is reduced mass)?

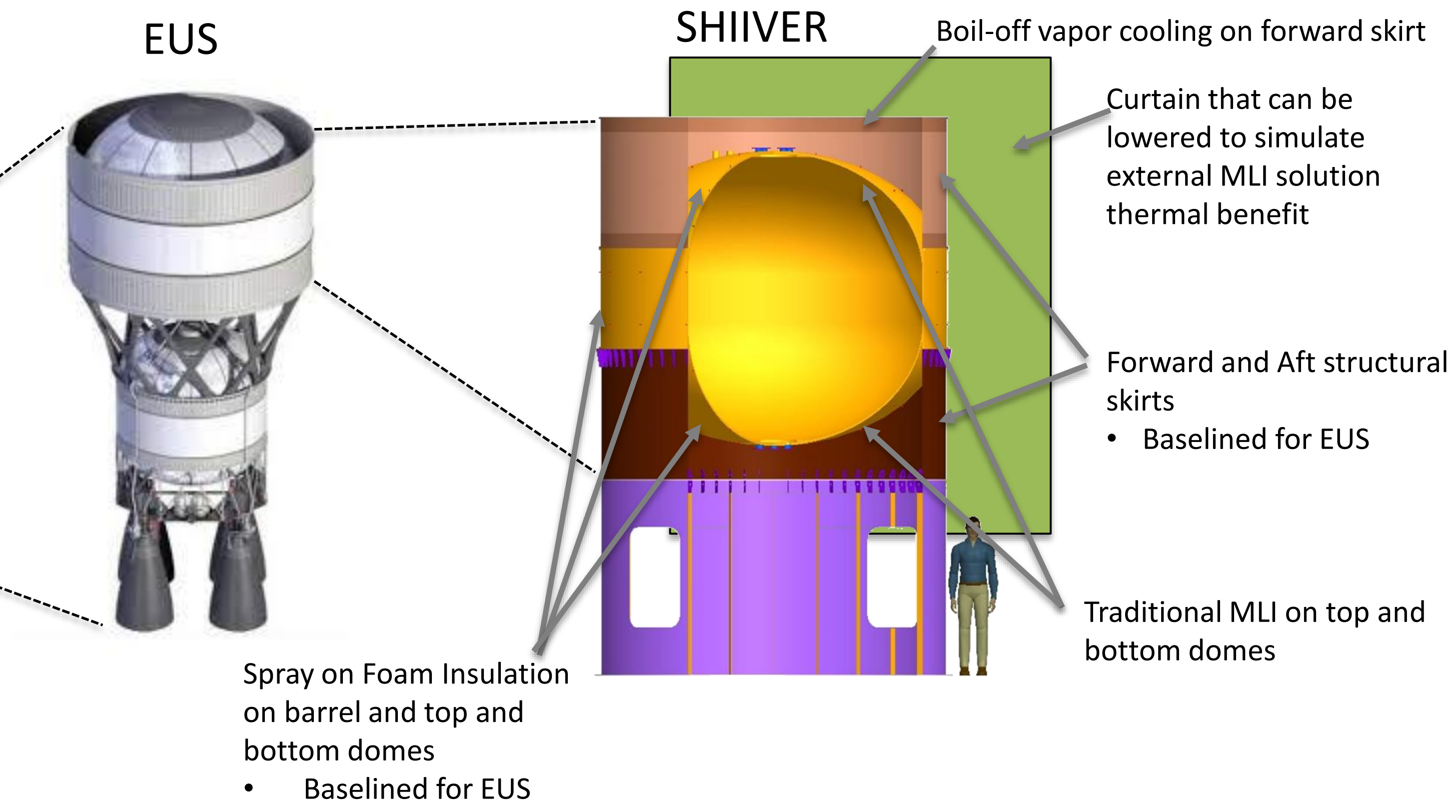
- The Evolvable Cryogenics project (SHIIVER & IFUSI) is answering these and many more questions for a "traditional" MLI blanket

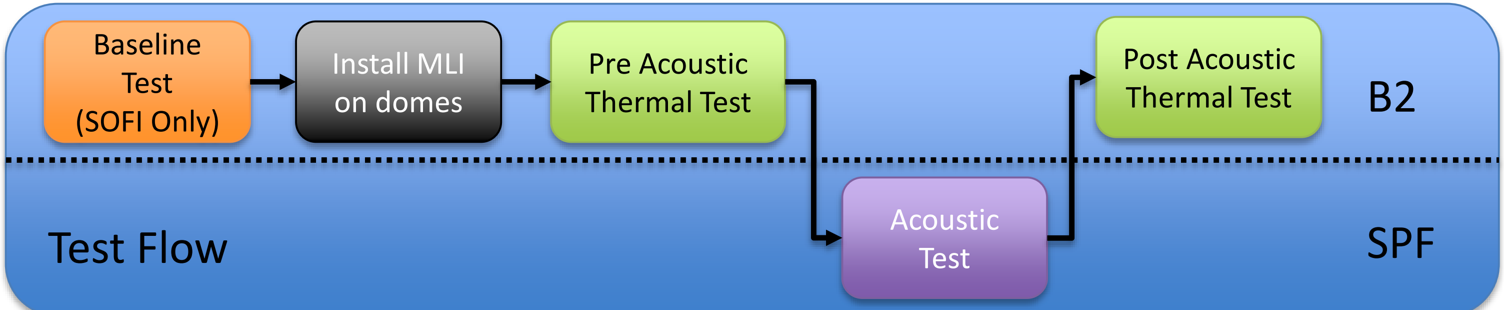
Structural Heat Intercept, Insulation, and Vibration Evaluation Rig

SLS



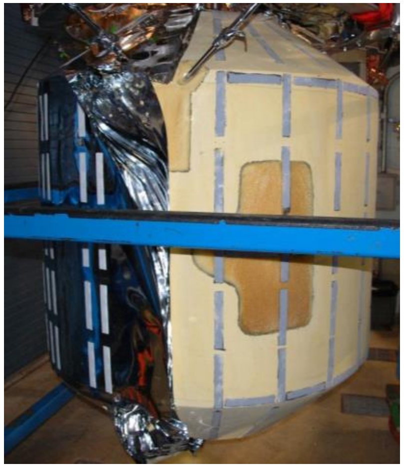
EUS





Advanced MLI options

- Multiple innovative MLI systems have been developed over the years via SBIR and other procurement set asides.
- Testing these to compare to the SHIIVER baseline should be considered and would show scaling of the advanced MLI.
- x-MLI systems (Quest)
  - IMLI flying on GPIM and RRM3 (launching warm in both cases)
  - LB-MLI demonstration on 4’ diameter tank
  - VC-MLI possible SOFI replacement
- CELCIUS (Paragon)
  - Survive launch/ascent outside launch vehicle



LB-MLI on 4’ diameter tank

IMLI on GPIM

Needed Insulation Development

- Mars Surface
  - Lander ascent stage cryogenic propellant tanks need to survive full of liquid or be refilled with liquid during stay on surface.
  - The Mars atmosphere is 5 torr, which is just enough pressure to cause MLI performance to significantly degrade
  - Some notional investment in vacuum jacketed concepts
  - There has been development in soft vacuum insulation systems, however, these systems may leave performance to be desired during in-space cruise
  - Currently doing trade study evaluations for prioritization
- External to Vehicle
  - No existing MLI can survive launch on the outside of the vehicle, require being inside of a fairing
  - A few concepts with notional investment have been made
  - Need to prove out concepts and address scaling issues

Path to Usage

- Defining the architecture and thermal requirements of each stage in that architecture is key to enabling technology trades to occur that define what technologies are actually needed.
- The initial SHIIVER testing should give great insight to what performance is actually manufacturable (along with costs and timelines for doing so) for large stages. This also gives advanced MLI concepts a baseline to target for improvement.
- Depending on the environments of the selected architectures, there may be some technology development needed
  - Soft vacuum on Mars surface
  - High performance insulation systems outside fairings during launch

Questions?