Demonstration of Hybrid Multilayer Insulation for Fixed Thickness Applications

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Background

• Recent testing has shown a benefit to variable density multilayer insulation.
• LB-MLI and IMLI provide a layer density of ~5 layer/cm, well below what is possible in traditional lay-ups.
• Combining LB-MLI with a traditionally made blanket (similar to RBO II and VATA II) may produce a blanket with better performance.
  – Theoretical improvement of ~30% over all traditional MLI and ~20% over all LB-MLI
• Originally planned to occur under CPST payload, but delayed due to cancellation.
Test Purpose and Objectives

• Test Purpose
  – Determine the design space surrounding hybrid MLI with a foam substrate.
  – Gain more experience with LB-MLI.

• Test Objectives
  – Understand the thickness trade between traditional MLI and LB-MLI.
  – Complete performance testing of a flight like insulation specimen.
  – Increase the understanding of LB-MLI by increasing the amount of thermal test data on it.
Test Article Configuration

- Traditional MLI
- Load Bearing MLI
- SOFI/Cryolite
**Theory**

**Model Definitions & Assumptions:**
- **tMLI:**
  - New Equation (based off of Lockheed and Modified Lockheed)
  - Accounts for Dacron netting (Modified Lockheed)
  - Accounts for perforation pattern (Lockheed)
- **LB-MLI:**
  - Layer by layer approach using discrete spacer locations
- **Integration:**
  - Solve for constant heat flux
  - Vary interface temperature
- **Variables:**
  - Warm Boundary (293 K)
  - Cold Boundary (78 K)
  - Vacuum Pressure ($1 \times 10^{-6}$ Torr)
Test Approach

- SOFI sprayed at MSFC and shipped to KSC
  - Target thickness half inch
- Procure 4 LB-MLI blankets from Quest through Phase III SBIR
  - 12, 14, 16, and 20 layers
  - ID designed for half inch SOFI substrate
- Make tMLI blankets in house
  - Perforated double aluminized mylar
  - Dacron netting
| Test Series | Substrate Material | Substrate Thickness (mm) | # layers, LB-MLI | # layers, tMLI | Layer Density, tMLI (layers/mm) | MLI Total Thickness (mm) | WBT (K) |
|-------------|--------------------|--------------------------|------------------|----------------|---------------------------------|--------------------------|---------|
| A174        | None               | 0                        | 10               | 50             | 2.0                             | 36.8                     | 293     |
| A175        | None               | 0                        | 10               | 40             | 2.3                             | 38.4                     | 293     |
| A181        | None               | 0                        | 10               | 40             | 2.7                             | 34.0                     | 293, 325|
| A182        | None               | 0                        | 10               | 30             | 3.5                             | 22.9                     | 293, 325|
| A183        | SOFI               | 14.7                     | 12               | 50             | 5.6                             | 27.4                     | 293, 325|
| A184        | CryoLite           | 12.5                     | 12               | 40             | 3.1                             | 31.2                     | 293, 325|
| A185        | CryoLite           | 12.5                     | 14               | 40             | 4.2                             | 42.2                     | 293     |
| A187        | CryoLite           | 12.5                     | 16               | 40             | 3.0                             | 38.4                     | 293, 325|
| A188        | CryoLite           | 12.5                     | 16               | 30             | 2.8                             | 35.6                     | 293, 325|
| A189        | CryoLite           | 12.5                     | 20               | 30             | 2.2                             | 46.0                     | 293, 325|
| A190        | SOFI               | 14.7                     | 14               | 40             | 2.1                             | 40.4                     | 293, 325|
| Test Series | # layers, LB-MLI | Layer Density, LB-MLI (layers/mm) | Area, LB-MLI (m²) | # layers, tMLI | Layer Density, tMLI (layers/mm) | Area, t-MLI (m²) |
|-------------|------------------|-----------------------------------|-------------------|--------------|----------------------------------|-----------------|
| A174        | 10               | 0.52                              | 0.334             | 50           | 2.0                              | 0.400           |
| A175        | 10               | 0.52                              | 0.334             | 40           | 2.3                              | 0.403           |
| A181        | 10               | 0.52                              | 0.338             | 40           | 2.7                              | 0.401           |
| A182        | 10               | 0.52                              | 0.330             | 30           | 3.5                              | 0.372           |
| A183        | 12               | 0.70                              | 0.391             | 50           | 5.6                              | 0.441           |
| A184        | 12               | 0.70                              | 0.382             | 40           | 3.1                              | 0.439           |
| A185        | 14               | 0.66                              | 0.393             | 40           | 2.1                              | 0.467           |
| A187        | 16               | 0.64                              | 0.393             | 40           | 3.0                              | 0.464           |
| A188        | 16               | 0.64                              | 0.394             | 30           | 2.8                              | 0.461           |
| A189        | 20               | 0.62                              | 0.406             | 30           | 2.2                              | 0.491           |
| A190        | 14               | 0.66                              | 0.393             | 40           | 2.1                              | 0.467           |
Installation
TEST DATA AND RESULTS
### Results

| Test | Substrate (W/m²) | LB-MLI (W/m²) | tMLI (W/m²) | Heat Load (W) | Interface Temperature (K) | Cold Vacuum Pressure (mTorr) |
|------|------------------|---------------|-------------|---------------|---------------------------|-----------------------------|
| A174 | 0.410            | 0.343         | 0.137       | 181           |                           | 2.0E-03                     |
| A175 | 0.395            | 0.328         | 0.132       | 178           |                           | 5.0E-03                     |
| A181 | 0.376            | 0.317         | 0.127       | 194           |                           | 2.6E-03                     |
| A182 | 0.552            | 0.489         | 0.182       | 194           |                           | 6.7E-02                     |
| A183 | 0.976            | 0.824         | 0.730       | 228           |                           | 7.5E-02                     |
| A184 | 0.635            | 0.542         | 0.472       | 219           |                           | 4.2E-02                     |
| A185 | 1.239            | 1.028         | 0.865       | 215           |                           | 5.8E-01                     |
| A187 | 1.046            | 0.868         | 0.735       | 261           |                           | 4.8E-03                     |
| A188 | 1.046            | 0.868         | 0.742       | 268           |                           | 3.5E-03                     |
| A189 | 1.031            | 0.828         | 0.684       | 265           |                           | 2.8E-03                     |
| A190 | 0.970            | 0.814         | 0.685       | 254           |                           | 3.4E-03                     |

**WBT = 293 K**

| Test | Substrate (W/m²) | LB-MLI (W/m²) | tMLI (W/m²) | Heat Load (W) | Interface Temperature (K) | Cold Vacuum Pressure (mTorr) |
|------|------------------|---------------|-------------|---------------|---------------------------|-----------------------------|
| A181 | 0.420            | 0.354         | 0.142       | 199           |                           | 2.6E-03                     |
| A182 | 0.673            | 0.597         | 0.222       | 210           |                           | 5.6E-02                     |
| A183 | 1.255            | 1.059         | 0.939       | 247           |                           | 5.9E-02                     |
| A184 | 0.859            | 0.733         | 0.638       | 240           |                           | 3.8E-02                     |
| A185 | Not Attempted due to Poor Vacuum Conditions |               |             |               |                           |                             |
| A187 | 1.331            | 1.104         | 0.935       | 280           |                           | 5.9E-03                     |
| A188 | 1.355            | 1.124         | 0.961       | 290           |                           | 6.4E-03                     |
| A189 | 1.340            | 1.076         | 0.890       | 289           |                           | 4.5E-03                     |
| A190 | 1.330            | 1.117         | 0.940       | 275           |                           | 1.0E-02                     |

**WBT = 325 K**
tMLI Performance

- 293 K W boundary
- 325 K W boundary
Heat Flux vs LB-MLI layers

Constant thickness ~ 38 mm (1.5 inches)
Data from A139 (60 layers tMLI) and A142 (20 layers LB-MLI) for 0 and 20 layer LB-MLI
Mass Comparison

Hybrid MLI Masses

- SOFI Mass (g)
- Cryolite Mass (g)
- LB-MLI Mass (g)
- tMLI Mass (g)

Density, g/cc

- A174
- A175
- A181
- A182
- A183
- A184
- A185
- A187
- A188
- A189
- A190

Mass, g

- A174
- A175
- A181
- A182
- A183
- A184
- A185
- A187
- A188
- A189
- A190
Conclusions

• Testing completed on hybrid MLI blankets between 293 K and 78 K.
  – Substrate (SOFI or CryoLite) on the cold side
  – Load Bearing MLI in middle
  – Traditional MLI on warm side

• Issues
  – Vacuum systems – were resolved and testing repeated
  – Constant layer density tMLI
    • Noticed that performance tailed off with blanket reuse
  – LB-MLI had higher heat flux than expected
    • Varied between 1.5 and 2.5 times expected
    • Had discussions with vendor

• Heat fluxes greater than expected
  – Due to degradation of traditional MLI over time
  – Tests A174 and A175 showed sensitivity of blankets about as expected with similar results

• System mass density decreased with increasing LB-MLI layers
  – Lower layer density of LB-MLI

• Demonstrates the sensitivities in optimizing a blanket design, even just for building on a calorimeter