Heat Loads Due to Small Penetrations in Multilayer Insulation Blankets

W L Johnson¹, K W Heckle², and J E Fesmire³
¹Glenn Research Center, Cleveland, OH, 44135 USA
²Sierra Lobo, Cryogenics Test Laboratory, Kennedy Space Center, FL 32899 USA
³Cryogenics Test Laboratory, Kennedy Space Center, FL 32899 USA

July 10, 2017
Cryogenic Engineering Conference
By accounting for each item separately, LOX ZBO testing accurately predicted total MLI performance. More information is provided in the following:

- NASA-TP-2012-216315

**Seams**

- MLI Blankets
  - Traditional
  - SS-MLI
  - Hybrid

**Tape, Pins & Attachments**

**Skirt Integration**

**Penetration Integration:**

**Repeatability**
ATV 1 (Joules Verne) incident

- During launch, more power draw required than expected, was traced to blanket disengagement.
- Root causes came down to improper structural attachment
- AIAA-2010-6197
Nylon Tag Testing

- Nylon tags have long been used to hold MLI together
- Installed 56 pins into an existing 10 layer LB-MLI blanket
  - Individual pins have a really small heat load (~0.9 mW each)
  - Needed repeatable MLI coupon to do initial test and pinned test
  - Pin spacing ~ 3 inch
- **Blanket Heat flux (KSC – Cryostat 100):**
  - A164 July 2012\(^1\): 0.92 W/m\(^2\)
  - A191 March 2015: 1.04 W/m\(^2\)
  - Was also used in Hybrid MLI testing\(^2\) (A174, A175, A181, A182)
- **Predicted disturbance:**
  - Variable tag geometry
  - 20 node conduction model (NIST nylon props):
    - 0.5 mW/tag
  - Direct radiation through hole: 8 µW/tag

---


## Test matrix

<table>
<thead>
<tr>
<th>Test Series</th>
<th># layers [n]</th>
<th>Thickness [x] (mm)</th>
<th>Layer Density [z] (layers/mm)*</th>
<th>Effective Area [A_e] (m²)</th>
<th>CVP Tested (torr)</th>
<th>Warm Boundary Temperature (K)</th>
<th># pins</th>
</tr>
</thead>
<tbody>
<tr>
<td>A164</td>
<td>10</td>
<td>16.5</td>
<td>0.54</td>
<td>0.334</td>
<td>~10⁻⁶</td>
<td>~293</td>
<td>0</td>
</tr>
<tr>
<td>A191</td>
<td>10</td>
<td>15.2</td>
<td>0.59</td>
<td>0.331</td>
<td>~10⁻⁶</td>
<td>~293</td>
<td>0</td>
</tr>
<tr>
<td>A192</td>
<td>10</td>
<td>15.1</td>
<td>0.60</td>
<td>0.331</td>
<td>~10⁻⁶</td>
<td>~293</td>
<td>56</td>
</tr>
</tbody>
</table>
## Results

![Graph showing heat flux for different test series.](image)

<table>
<thead>
<tr>
<th>Test Series (Data Time)</th>
<th>CVP (Torr)</th>
<th>WBT (K)</th>
<th>Q (W)</th>
<th>$k_e$ (mW/m/K)</th>
<th>q (W/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A164</td>
<td>5x10⁻⁶</td>
<td>291.7</td>
<td>0.31</td>
<td>0.072</td>
<td>0.92</td>
</tr>
<tr>
<td>A191 (20 hrs)</td>
<td>2x10⁻⁵</td>
<td>292.4</td>
<td>0.37</td>
<td>0.078</td>
<td>1.11</td>
</tr>
<tr>
<td>A191 (50 hrs)</td>
<td>2x10⁻⁵</td>
<td>293.0</td>
<td>0.35</td>
<td>0.074</td>
<td>1.04</td>
</tr>
<tr>
<td>A192 (20 hrs)</td>
<td>7x10⁻⁶</td>
<td>293.3</td>
<td>0.47</td>
<td>0.099</td>
<td>1.41</td>
</tr>
<tr>
<td>A192 (50 hrs)</td>
<td>7x10⁻⁶</td>
<td>292.4</td>
<td>0.51</td>
<td>0.106</td>
<td>1.51</td>
</tr>
</tbody>
</table>
Test Results Analysis

- **Total heat to the blanket (with 56 tags): 0.51 W**
  - 0.35 W through blanket
  - 0.16 W (+/- 0.025) residual (i.e. through tags)
- **Predicted load: 45 mW**
- **Measured heat load is 3.5 x predicted heat load**

- **Similar to Arthur D. Little, Inc results from 1966**
  - Single 0.8 mm nylon pin through 10 layers MLI (1.0 mm diameter hole)
  - Predicted heat load of 0.3 mW
  - Measured change in heat load of ~ 3 mW, which was the experimental error

- **Need revised model**

---

Revised model

- Based on perforations model developed for MHTB large perforations, the radiation through a perforation is not limited to direct radiation\(^4\).
- Instead the effective radiation area is defined by a 10 deg angle.
- Using layer density as the spacing for LB-MLI, this can be extrapolated to a tag hole.

\[
\theta = 10 \text{ deg} = 0.175 \text{ rad}
\]

\[
r_{\text{eff}} = \frac{1}{z \cos \theta} + r_{\text{perf}}
\]

\[
A_{\text{eff}} = \pi r_{\text{eff}}^2
\]

\[
\dot{Q} = A_{\text{eff}} \varepsilon_{\text{layer}} \sigma (T_h^4 - T_c^4) + \int \frac{A}{dx} \int k dT
\]

- Revised model estimates 3.6 mW per tag on recent testing (~30% more than actual).
- Revised model estimates 3.6 mW heat load for tag & hole in ADL test

Conclusions

• Completed testing on an MLI blanket with multiple small penetrations.
• Results show that heat load much more than conduction only.
• Analytical approach with combined radiation and conduction shows uncertainty less than 30%.
  – Change in vacuum level may account for difference

<table>
<thead>
<tr>
<th>Test Series</th>
<th>Hole Radius (mm)</th>
<th># layers</th>
<th>Layer Density (lay/mm)</th>
<th>$Q_{\text{hole}}$ (mW)</th>
<th>$Q_{\text{pin}}$ (mW)</th>
<th>$Q_{\text{total}}$ (mW)</th>
<th>$Q_{\text{meas}}$ (mW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A192</td>
<td>0.5</td>
<td>10</td>
<td>0.6</td>
<td>3.1</td>
<td>0.52</td>
<td>3.6</td>
<td>2.0-2.8</td>
</tr>
<tr>
<td>Black [9]</td>
<td>0.5</td>
<td>10</td>
<td>1.3</td>
<td>3.3</td>
<td>0.3</td>
<td>3.6</td>
<td>~3</td>
</tr>
</tbody>
</table>