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

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By accounting for each item separately, LOX ZBO testing accurately predicted total MLI performance. More information is

Seams

Skirt Integration

Penetration Integration:
- NASA-TP-2012-216315

MLI Blankets
- Traditional
  - SS-MLI
  - Hybrid

Tape, Pins & Attachments

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 \(\mu\)W/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

<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**

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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.

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

\[
\begin{align*}
\frac{1}{z} & \quad \text{Reflectors} \\
10^\circ & \quad \text{Hole/Perforation, } R_{\text{perf}} \\
\text{Radiation Source} & \\
R_{\text{eff}} &
\end{align*}
\]

\[
\begin{align*}
\dot{Q} &= A_{\text{eff}} \varepsilon_{\text{layer}} \sigma (T_h^4 - T_c^4) + \int \frac{A}{dx} \int k dT \\
A_{\text{eff}} &= \pi r_{\text{eff}}^2 \\
r_{\text{eff}} &= \frac{1}{z \cos \theta} + r_{\text{perf}}
\end{align*}
\]

- 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>