Heat Loads Due to Small Penetrations in Multilayer Insulation Blankets

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July 10, 2017
Cryogenic Engineering Conference
By accounting for each item separately, LOX ZBO testing accurately predicted total MLI performance. More information is available in NASA-TP-2012-216315.

Seams

Penetration Integration:
- NASA-TP-2012-216315

Repeatability

Skirt Integration

MLI Blankets
- Traditional
- SS-MLI
- Hybrid

Tape, Pins & Attachments
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

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## 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 vs time for different test series and data times.]

<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.

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

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

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

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

- 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>