SWOT Mission Background

- Surface Water Ocean Topography (SWOT) will map oceans, lakes, and rivers to increase understanding of the global water cycle
Primary Instrument is Ka-Band Radar Interferometer (KaRIn)
- 1100W dissipation split across four thermal pallets
- The main thermal path for each pallet is first through parallel constant conductance heat pipes (CCHPs) and then through a loop heat pipe (LHP) to the radiator
- Lowering thermal resistance at each interface on the path reduces radiator size, required survival power, and cost
• Characterize thermal conductance of a key thermal interface on SWOT Payload using three candidate materials:
  • Dry bolted interface
  • Graphite foil (eGraf 1220)
  • RTV (CV-2948)

• Rate potential options with the following criteria:
  • Heat transport
  • Integration issues (shedding, deformation)
  • Other issues (outgassing, thermal cycling issues, etc.)

• Baseline interface materials for each flat plate interface on the spacecraft
Test Article

- Test article mimics half of the 12” LHP evaporator that is a key interface in the conductive path of the interferometer power dissipation
- Bolt pattern, type, and preload same as in flight (12 #8 bolts)
Test Article

* Top Calorimeter was removed for later stages of testing
* Bottom Calorimeter switched for stainless steel version

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Test Architecture

• Heat exchanger was routed to a chiller and controlled at a temperature necessary to keep interface within desired range (-10°C to 50°C)

• Test article was placed in a bell-jar style vacuum chamber at ≤7x10^{-5} Torr

• Aluminum foil shielded thermocouple wire from electromagnetic interference from the vacuum pump

• 1x6” strip heater applied up to 70W of power to top interface
Two methods were used to calculate interface conductance:

- **Method 1**: Uses applied power, interface $\Delta T$, and interface area
  - Pros: Simple, requires fewer temperature sensors
  - Cons: High $Q_{in}$ uncertainty due to radiation and electrical losses
  
  \[ h_{I/F} = \frac{Q_{in}}{A_{I/F} \times \Delta T_{I/F}} \]

- **Method 2**: Uses stainless steel calorimeter plate
  - Pros: Uses well quantified calorimeter properties
  - Cons: Requires more temperature readings
  
  \[ h_{I/F} = \frac{k_{cal} \times A_{cal} \times \Delta T_{cal}}{t_{cal} \times A_{I/F} \times \Delta T_{I/F}} \]

Method 1 was used to compare between different interface materials, and Method 2 was used as verification.
Material Comparison

- Ideal interface material fills gaps between plates with minimum thickness and high conductivity
- Theoretical limit of interface conductance
  \[ h_{\text{theo}} = \frac{k_{I/F}}{t_{I/F}} \]

<table>
<thead>
<tr>
<th>Material</th>
<th>Type</th>
<th>Thickness [mil]</th>
<th>k [W/m-K]</th>
<th>( h_{\text{theo}} ) [W/m²-K]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry</td>
<td>No interface material</td>
<td>N/A</td>
<td>N/A</td>
<td>infinite</td>
</tr>
<tr>
<td>eGraf 1220</td>
<td>graphite foil</td>
<td>20</td>
<td>10</td>
<td>20,000</td>
</tr>
<tr>
<td>CV-2948</td>
<td>Silicone</td>
<td>7</td>
<td>1.95</td>
<td>11,000</td>
</tr>
</tbody>
</table>

- Moving from dry to Grafoil to CV-2948
  - Decreases voids when properly installed
  - Can get closer to theoretical interface conductance
Each interface was tested at various power levels and temperatures

Observed trend: higher power $\rightarrow$ higher $h$

- Not accounted for by terms included in uncertainty analysis

### Approach and Results

<table>
<thead>
<tr>
<th>Run</th>
<th>$Q_{in}$ [W]</th>
<th>$T_{int}$ [°C]</th>
<th>$h_{int}$ [W/m²-K]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>17.5</td>
<td>34</td>
<td>640</td>
</tr>
<tr>
<td>2</td>
<td>28.6</td>
<td>27</td>
<td>740</td>
</tr>
<tr>
<td></td>
<td></td>
<td>690</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>38.8</td>
<td>18</td>
<td>6100</td>
</tr>
<tr>
<td>2</td>
<td>49.0</td>
<td>44</td>
<td>7600</td>
</tr>
<tr>
<td>3</td>
<td>54.1</td>
<td>43</td>
<td>8700</td>
</tr>
</tbody>
</table>

*Results calculated using calorimeter method were within uncertainty of this value*
Uncertainty Analysis

• Uncertainty in the interface conductance value due to each of the following sources was calculated:

<table>
<thead>
<tr>
<th>Quantity</th>
<th>Sources of Uncertainty</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heat flow across interface</td>
<td>Radiation from top interface, power supply resistance</td>
</tr>
<tr>
<td>Interface Area</td>
<td>Manufacturing tolerance</td>
</tr>
<tr>
<td>Interface ΔT</td>
<td>Thermocouple error, electromagnetic interference</td>
</tr>
</tbody>
</table>

• To be conservative, all uncertainty was calculated based on lowest power run for each material

<table>
<thead>
<tr>
<th>Uncertainty due to</th>
<th>Dry [W/m²-K]</th>
<th>Grafoil [W/m²-K]</th>
<th>CV-2948 [W/m²-K]</th>
</tr>
</thead>
<tbody>
<tr>
<td>( Q_{in} )</td>
<td>70</td>
<td>360</td>
<td>440</td>
</tr>
<tr>
<td>( A_{int} )</td>
<td>10</td>
<td>240</td>
<td>120</td>
</tr>
<tr>
<td>( T_{top} )</td>
<td>10</td>
<td>1050</td>
<td>670</td>
</tr>
<tr>
<td>( T_{bot} )</td>
<td>10</td>
<td>1050</td>
<td>670</td>
</tr>
<tr>
<td>Total</td>
<td><strong>100</strong></td>
<td><strong>2700</strong></td>
<td><strong>1900</strong></td>
</tr>
</tbody>
</table>
Results/Recommendations

- **Dry**: 690 ± 100 W/m²-K
- **Grafoil**: 7400 ± 2700 W/m²-K
- **CV-2948**: 6100 ± 1900 W/m²-K

<table>
<thead>
<tr>
<th>Option</th>
<th>Thermal Performance</th>
<th>Integration/Removal</th>
<th>Contamination</th>
<th>Suitable for:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry</td>
<td>Poor</td>
<td>Simplest</td>
<td>None</td>
<td>Low power density interfaces</td>
</tr>
<tr>
<td>Grafoil</td>
<td>Excellent</td>
<td>Relatively Simple</td>
<td>Shedding Concerns</td>
<td>LHP evaporator, other thermally critical interfaces. Seal edges to reduce shedding concerns</td>
</tr>
<tr>
<td>CV-2948</td>
<td>Excellent</td>
<td>Potential Voids, Difficult Removal</td>
<td>No Concerns</td>
<td>Thermally critical interfaces for payloads where Grafoil shedding is unacceptable</td>
</tr>
</tbody>
</table>

- Baseline: Grafoil with sealed edges on critical thermal paths, dry bolted interface elsewhere
- Using measured Grafoil I/F conductances yields acceptable predicted on-orbit thermal performance
Issues/Lessons Learned

• CTE mismatch on calorimeter/interface plate and heat exchanger
  • Original calorimeter was G10
  • Repeated temperature cycles caused debonding of Stycast

• Excessive vibration from motor on test cart

• Ice in chiller fluid
  • Water condensation formed in the chiller fluid, which froze and stalled the motor at sub-0°C temperatures

• Motor caused unacceptable instability of thermocouple (TC) readings
  • Largely solved by adding aluminum foil shielding to TC wires
Issues/Lessons Learned

- Multiple heater installations led to bubbles and eventual burnout

- Could not replicate the 200W that the half of the LHP evaporator will see in flight.
  - 1x6” heater strip provided up to 70W
  - Lower ΔT across interface meant higher uncertainty in conductance results
  - Retest only if uncertainty level is deemed unacceptable in the future
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