Thermal Vacuum Tests of GLAS Propylene Loop Heat Pipe Development Model
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Flight LHP System (Laser)

- Three Lasers Linked to Three Al-NH3 HPs
- Three HPs linked to Propylene LHP
- LHP Condenser embedded into two-sided radiator panel
Flight LHP System (Laser)
Test Design and Objectives

- **Test Design**
  - Conductively isolate all components from the Test Stand (G10 spacers, minimize the Temperature Difference by Heating Stand)
  - Radiatively isolate all components from each other with MLI
  - Use heater plates to control sink for both sides of radiator

- **Test Objectives for Both Hot and Cold Cases**
  - Demonstrate LHP system startup and operation with propylene
  - Demonstrate LHP Temperature Control
  - Measure Control Heater Power with On/Off Controller and Liquid-Vapor Line Coupling blocks
  - Compare Adverse to Reflux Orientation Operation
DM LHP Test Design

- Two Mass Simulators linked to Two Al-NH3 HPs
  - Single Mass Simulator (15 Kg) is actively powered to resemble 1 laser
  - Double Mass Simulator (30 Kg) resembles 2 unpowered lasers
- Two HPs linked to Propylene LHP
- LHP Condenser flange bolted into two-sided radiator panel
Starter Heater and Coupling Blocks

- Ten Al Blocks (1” long) couple Liquid and Vapor Lines
- Starter Htr is a Dale NHG-25 50 Ohm resistor footprint 0.56” x 1.1”
  - Heater was located 1” from end of evaporator (away from CC)
  - Startups were performed with 0, 15 and 20 W on heater
CC Control Heaters and PRT

- Heaters were circumferentially wrapped around the middle of the CC
- PRT was used for control and placed along the centerline of the CC
- On/Off Controller setpoint was +/-0.1°C
- Survival Thermostat had a setpoint from 0 to 5°C

Circumferential Control Heaters
Heater Plates (Shown in Reflux Mode)

- Two Heater Plates which viewed the radiator panel on one side and the -170°C TV shroud on the other side were used to simulate the Flight Environment
- Plates were temperature controlled with large Kapton Heaters and painted black
- Plate Setpoints were correlated with Flight predicts
- Reflux mode (as shown) was defined as the majority of the vertical condenser above the evaporator (adverse is the opposite)
- Adverse height could be as high as 44”
Startup Tests

• 17 Startups were performed with the following parameters:
  • Reflux versus Adverse Orientation (+44° vs -44°)
  • 0 W, 15 W, 20 W of Starter Heater Power
  • Hot and Cold Survival Sink Conditions (-100 to -45°C Teff)
  • Various initial Evaporator and CC temperatures (0 to 25°C)
• All startups were preceded by pre-heating the CC 3-5°C above the evaporator temperature
• Verified need for starter heater for startup
Startups: Effect of Orientation and Sink

- Orientation (Adverse versus Reflux)
  - 6 Startups performed in Reflux
  - 11 Startups performed in Adverse
  - Startups were similar in both orientations for
    - Time for Startup
    - Superheat at Startup (Max Evap Temp - CC Temp)
    - Maximum Evaporator Temperature
- Sink (Hot and Cold)
  - No significant difference was seen between the Hot and Cold Sinks
- Startup to Startup, the above parameters varied greatly
Startups: Effect of Starter Heater Power

• Starter Heater Power
  • No Starter Heater Power
    • Even with 100 W on the Mass Simulator the LHP would not start without a starter heater (test stopped when 30°C reached)
  • 15 W vs 20 W of Starter Heater Power
    • The LHP started at similar evaporator temperature for either starter heater power on average (16.5°C)
    • The LHP required slightly higher superheat prior to startup for 20 W of Starter Heater Power on average (4.2 vs 3.5°C for 15 W)
    • The LHP required a longer startup time for 15 W of Starter Heater Power on average (18.5 vs 13.5 hours for 20 W)
Startups: Effect of Initial Evap Temp

- Effect of Initial Evap Temp
  - All startups require the elapse of time and the evaporator reaching a high enough temperature
  - A high initial evaporator temperature still required time prior to startup, but less overall time than a cold initial evaporator temperature
  - The LHP always started before reaching 20°C as long as the evaporator was below 15°C initially
Startups: Repeatability

- Repeatability
  - 5 Similar Tests were conducted with 15 W on Starter Heater
  - 12 other tests had a variety of conditions (varied initial evaporator temperatures)

<table>
<thead>
<tr>
<th>Startup Tests</th>
<th># of Tests</th>
<th>Avg of Max TC1 Temps</th>
<th>Std Dev of Max TC1 Temps</th>
<th>Avg of Max Overall Evap Temps</th>
<th>Std Dev of Max Overall Evap Temps</th>
<th>Time for Startup (hours)</th>
<th>Std Dev of Time for Startup</th>
<th>Avg Superheat</th>
<th>Std Dev of Avg Superheat</th>
</tr>
</thead>
<tbody>
<tr>
<td>All with Starter Heater (T0&lt;20°C)</td>
<td>17</td>
<td>18.1°C</td>
<td>3.6°C</td>
<td>15.7°C</td>
<td>3.7°C</td>
<td>12:20</td>
<td>7:07</td>
<td>4.0°C</td>
<td>0.7°C</td>
</tr>
<tr>
<td>20 W Starter Heater Only</td>
<td>12</td>
<td>17.7°C</td>
<td>4.3°C</td>
<td>15.1°C</td>
<td>4.3°C</td>
<td>8:30</td>
<td>5:06</td>
<td>4.2°C</td>
<td>0.7°C</td>
</tr>
<tr>
<td>15 W Starter Heater Only</td>
<td>5</td>
<td>18.9°C</td>
<td>2.5°C</td>
<td>16.6°C</td>
<td>2.5°C</td>
<td>18:28</td>
<td>5:31</td>
<td>3.5°C</td>
<td>0.4°C</td>
</tr>
</tbody>
</table>
CC Control Heater Power Tests for CC Temperature Control

- Control Heater power can only be accurately measured in TV
  - GLAS DM LHP may be the first control heater power measurements in TV
- 20 Control Heater Power Test measurements were performed with the following parameters:
  - Reflux versus Adverse Orientation
  - Hot and Cold Survival Sink Conditions and control setpoint
  - Mass Simulator Power (100 W, 120 W, 200 W)
  - Liquid-vapor Coupling blocks (8 vs 10 blocks)
  - Changing control setpoint (increasing and decreasing)
  - Measured temperature stability at mass simulator
- All control heater power measurements were verified electronically and with a strip chart recorder
Heater Power: Effect of Orientation

<table>
<thead>
<tr>
<th>Test #</th>
<th>Power Required (W)</th>
<th>TC31</th>
<th>TC32</th>
<th>Test #</th>
<th>Power Required (W)</th>
<th>TC31</th>
<th>TC32</th>
</tr>
</thead>
<tbody>
<tr>
<td>9</td>
<td>2.6</td>
<td>-66.</td>
<td>1.</td>
<td>14</td>
<td>2.7</td>
<td>-51.</td>
<td>1.</td>
</tr>
<tr>
<td>12</td>
<td>1.9</td>
<td>-20.</td>
<td>-3.</td>
<td>17</td>
<td>1.5</td>
<td>-18.</td>
<td>-1.</td>
</tr>
<tr>
<td>13</td>
<td>2.4</td>
<td>-27.</td>
<td>3.</td>
<td>18</td>
<td>2.1</td>
<td>-22.</td>
<td>5.</td>
</tr>
</tbody>
</table>

- Three comparable tests were performed in both the reflux and adverse orientations.
- Cold case Test 9 and Test 14 show no significant differences between the control power requirements between the orientations.
- Hot Case Tests 12 and 13 and comparably 17 and 18 respectively.
- Control power differences can entirely be explained by the warmer liquid return temperatures (probably a warmer sink) as seen in TC32.
- No significant differences in heater power are observed when comparing two orientations in the hot and cold sinks tested.
- Note: TC31 is at the exit of the condenser, TC32 is after the liq/vapor coupling blocks.
Heater Power: Effect of Sink and Heater Setpoint

DM LHP Thermal Vacuum Testing
Overall Control Heater Power for all 120 W Tests Only

- CC setpoint were varied between 6.5 and 14.5 °C
- The greater the difference between the CC setpoint and the condenser exit temperature, the greater the control heater power requirement
Heater Power: Comparison With Subcooling

DM LHP Thermal Vacuum Testing
Overall Control Heater Power for all 120 W Tests Only

Control Heater Power (W)

Temperature Difference CC - Liquid Line after blocks (TC32) (°C)

Test Data  ● Subcooling  Linear (Test Data)  Linear (Subcooling)
Heater Power: Effect of # coupling blocks

- Coupling blocks had a fairly uniform coupling under a wide variety of input powers, sink conditions and orientations (Test 1 had 8 blocks, Test 3 to 20 had 10 blocks)
- Coupling blocks may be modelled as a fixed-conductance using a log mean temperature difference
- Variations in results cannot be explained with variations in test conditions
- Coupling was dominated by laminar film coefficient on liquid line
- Even with the enhanced coupling vs. laminar, the heater power requirement was \( \sim 1/3 \) of model predictions

<table>
<thead>
<tr>
<th>Test #</th>
<th>C per block (W/K)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.079</td>
</tr>
<tr>
<td>3</td>
<td>0.081</td>
</tr>
<tr>
<td>9</td>
<td>0.092</td>
</tr>
<tr>
<td>10</td>
<td>0.097</td>
</tr>
<tr>
<td>11</td>
<td>0.088</td>
</tr>
<tr>
<td>12</td>
<td>0.070</td>
</tr>
<tr>
<td>13</td>
<td>0.090</td>
</tr>
<tr>
<td>14</td>
<td>0.084</td>
</tr>
<tr>
<td>15</td>
<td>0.077</td>
</tr>
<tr>
<td>16</td>
<td>0.088</td>
</tr>
<tr>
<td>17</td>
<td>0.081</td>
</tr>
<tr>
<td>18</td>
<td>0.099</td>
</tr>
<tr>
<td>19</td>
<td>0.101</td>
</tr>
<tr>
<td>20</td>
<td>0.072</td>
</tr>
<tr>
<td>avg</td>
<td>0.086</td>
</tr>
<tr>
<td>std dev</td>
<td>0.010</td>
</tr>
<tr>
<td>std dev/avg</td>
<td>0.113</td>
</tr>
</tbody>
</table>
Heater Power: Effect of Evap Power

- Control Heater Power was compared for a wide variety of applied evaporator powers: 100 W, 120 W, 201 W; the control heater power was independent of evaporator power in this range.
- This can only be explained through assuming that the CC is isolated from the liquid core and partly coupled to liquid return line.
  - The CC is coupled to the liquid return through a fixed conductance (0.19 W/K-6” of coupling) as measured in heater power.
  - Liquid return line had steady state Reynolds numbers below 2000.
  - The heat leak through the wick is based primarily on the liquid return line temperature, not pressure losses in system.
- Mass flow rate must be adjusted for difference between sensible heat of liquid returned and actual control heater power based on fixed coupling.
Heater Power: Changing Control Setpoint

- Raising the control setpoint results in diverting heat dissipation to sensibly heating the mass simulators.
  - The fastest setpoint rise possible was 0.6°C/5 minutes without shutting down the LHP.
  - If the starter heater is activated, the setpoint may be raised faster.
- No limitations were seen in the rate at which the setpoint is decreased 14°C at a step was attempted (LHP Un-controlled dropped 14°C in 30 minutes).
- Stabilization times are on the order of hours.
Control Temperature Stability

DM LP Thermal Vacuum Testing 9/11/99
Setpoint change from 14.5 to 6.5°C at 120 W
Conclusions

• A starter heater is required for startup of large thermal mass propylene LHP systems (also verified by independent testing at JPL and Dynatherm).
• Startup occurs after hours of time pass and the evaporator temperature rises to or above a “turn-over temperature” (which results in the Delta-T or “superheat” required between Evaporator and CC).
• Propylene LHP control heater power is solely a function of the difference between the liquid return line temperature and the CC setpoint times a constant conductance coupling.
• Utilizing liquid-vapor coupling blocks is a highly effective way to decrease control power without compromising control in the hot case.
  • Test measured 1/3 of predicted control power requirement.
• Temperature control of a mass simulator is possible to +/-0.1°C.