Thermal Vacuum Tests of GLAS
Propylene Loop Heat Pipe Development Model
Charles Baker/Orbital
Dan Butler/GSFC
Jentung Ku/GSFC
Tarik Kaya/ISU
Michael Nikitkin/DCI
March 1, 2000
Spacecraft Thermal Control Technology Workshop
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
• 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
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
Typical Cold Startup

DM LHP Thermal Vacuum Testing 9/28/99

Time (hours)

Temperature (°C)

Power (W)

TC1
Avg Evap
TC31-LL
TC7-VL
TC32-LL
TC36-CC
Avg Cond
Avg HP vapor
SINGLE MASS POWER
STARTER HTR POWER
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

- 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># of Tests</th>
<th>Avg of All Tests (°C)</th>
<th>Std Dev of All Tests (°C)</th>
<th>Avg of Max TC I Temps (°C)</th>
<th>Std Dev of Max TC I Temps (°C)</th>
<th>Avg of Max Overall Evap Temps (°C)</th>
<th>Std Dev of Time for Startup (hours)</th>
<th>Std Dev of Time for Superheating (°C)</th>
<th>Std Dev of Avg Superheat Temp (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>All with Starter Heater</td>
<td>17</td>
<td>18.1°C</td>
<td>3.6°C</td>
<td>3.7°C</td>
<td>15.7°C</td>
<td>12:20</td>
<td>4.0°C</td>
<td>7.07</td>
</tr>
<tr>
<td>(T&lt;20°C)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>20 W Starter Heater Only</td>
<td>12</td>
<td>17.7°C</td>
<td>4.3°C</td>
<td>4.2°C</td>
<td>15.1°C</td>
<td>8:30</td>
<td>4.2°C</td>
<td>5.06</td>
</tr>
<tr>
<td>15 W Starter Heater Only</td>
<td>5</td>
<td>18.9°C</td>
<td>2.5°C</td>
<td>2.5°C</td>
<td>16.6°C</td>
<td>18:28</td>
<td>3.5°C</td>
<td>5.31</td>
</tr>
</tbody>
</table>

- All with Starter Heater (T<20°C)
- 20 W Starter Heater Only
- 15 W Starter Heater Only

- Note: All calculations and measurements are rounded to the nearest degree Celsius.
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>Reflux Orientation</th>
<th>Adverse Orientation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Power Required (W)</td>
<td>TC31</td>
</tr>
<tr>
<td>9</td>
<td>2.6</td>
<td>-66.</td>
</tr>
<tr>
<td>12</td>
<td>1.9</td>
<td>-20.</td>
</tr>
<tr>
<td>13</td>
<td>2.4</td>
<td>-27.</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

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 ~1/3 of model predictions
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 LHP Thermal Vacuum Testing 9/11/99
Setpoint change from 14.5 to 6.0°C at 120 W

Temperature (°C)

Time (hours)

TC1 ✭ TC6 ✭ Avg Evap ✭ TC7-VL ✭ TC36-CC ✭ Avg HP vapor
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