Thermal Hardware for the Thermal Analyst

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Reason for This Course

• There are 3 parts to Thermal Engineering:
  1. Thermal Analysis
  2. Thermal hardware installation
  3. Thermal Vacuum Testing

• But many times Analysts are not involved in #2.
Course Outline

• MLI Blanketing Theory 101
• MLI blanketing installation
• Temperature Measurements
• Heaters and Thermostats
• Optical coatings (Paints and tapes)
• Propulsion Systems (tanks, lines, and thrusters)
MLI blanketing 101

Analyst:  
“The actual MLI doesn’t look like what’s in my Thermal Model”

Blanket Tech:  
“David, can you help me out? The Thermal Analyst can’t tell me what he wants”
Theoretical Blanket Effective Emissivity

![Graph showing the relationship between E-Star and the number of layers for Kapton and VDA layers.]

- **Kapton layers**
- **VDA layers**
Actual MLI Blanket

VDA Effective Emissivity

- Actual Blanket
- Theoretical Blanket

Number of Layers

E-Star

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What affects MLI blanket $\varepsilon^*$?

- Penetrations
- Ground Straps
- Crinkling
- Stitching
- Vents
- Separator layers
- Tightness
- Cryogenic Temperatures
- Atmospheric pressure
What affects Optical Properties?

• Emissivity usually not affected. Solar Absorptance will be with age.

• Atomic oxygen effects outer layer
  – Silver Teflon needs to be 10 mil instead of 5 mil thick in LEO

• Alpha increases with age (BOL vs. EOL)
Touching Layers = Bad

- 1 ft² blanket covering 30°C surface:
  - Good MLI blanket design = 1.2 watts lost
  - Smashed blanket = 38 watts lost
Blankets Vent or Blow Up

• Air Pressure on ground
  – 14.7 psi
  – 2117 lbs per square foot.
  – But pressure in Space = 0 psi.

• Blankets usually go from Ground to Space (or inside T/V chamber)
  – Air around MLI goes from 14.7 psi -> 0.

• MLI Blankets can only handle 0.1 psi (14.4 lbs per square foot).

• Venting needed:
  – Between MLI layers (or risk blowing up)
  – Between MLI and underlying metal (or risk blowing off surface)
  – Eliminate Gas conduction
Generic Launch Pressure
Inside Fairing

![Graph showing the pressure inside the fairing over time. The pressure decreases rapidly in the initial stages and then gradually levels off.]
Cryogenic Temperatures

Cold Temperatures effect MLI blanket efficiency

Temperature (C)

Effective Emissivity

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Things Grow and Shrink

• Coefficient of Thermal Expansion
  – Things grow bigger when hot
  – Things shrink when cold
  – Aluminum shrinks/grows a lot compared to Kapton
    • CTE = 0.000026 in/in °C
    • 72 inch piece, from -20 °C to +40 °C grows 1/8”
Blanket Buttons, Etc...

Top hat  Blanket buttons  Velcro
ClickBonds
(For heavier or thicker blankets)
Bonding techniques

• Buttons, Thermistors, Thermostats typically bonded with Stycast 2850FT Cat 9
  – Small bondline, so thermal resistance is low.

• Polymerics license required for bonding Flight hardware.

• Surface preparation is key to a good bond:
  – Clean surfaces
  – Abrade surfaces with sandpaper
  – Vacuum, then clean surface again
  – Hold down with Kapton until epoxy dries overnight.
    • Think about how to handle vertical surfaces!
Thermostats

- Typically bought from Honeywell.
- Type 700 is typical thermostat style

Style 701 (standard)  Style 717 (Prop lines)
Heaters

- Kapton Thermofoil Heaters
- Applied with 3M Y966 Acrylic Adhesive
  - Low outgassing
  - Y966 adhesive good to about +100°C
    - Bond with Stycast Epoxy if hotter than +100°C, or watt density higher than 3.5 W/in²
  - Overtaped with 3M 425 aluminum tape to help spread out heat.
Temperature Measuring

• Thermocouple
  – Cheap and easy. Voltage vs. Temperature
    • Remove after T/V testing or flyaway (snip and ground).
    • Type T or Type K. Make sure which one you are using!
    • Attach with 3M 425 Aluminum Tape

• Thermistor
  – Non linear $\Omega$ vs. Temperature (negative slope)
  – Resistances 2252 $\Omega$, 5K, 10K, etc...

• PRT
  – Very linear $\Omega$ vs. Temperature (positive slope)
  – Usually used for high or low (cryogenic) temperature.
  – 4 wire variety enhances accuracy if needed (usually cryogenic). Removes resistance of leads.
  – Resistances usually 100 $\Omega$
Thermal Enhancement

• Nusil CV-2946
  – 2-part material which needs to be mixed beforehand and degassed.
  – Stored in a freezer or hardens in an hour
  – Use Miller-Stephenson MS-143H as a release agent if needed. Teflon particles. Apply 3 layers.

• Arathane
  – mixed with 30-40% Boron Nitride also good.
  – Cabasil makes it thick.
Propulsion Systems
Analyst vs. Hardware

**Analyst:**
1. SINDA model has heaters on all nodes of a prop line.
2. Use CALL HEATER subroutine for thermostat cycling.
3. Use e* of 0.05 for MLI

**Hardware:**
1. Install Thermostats on Saddle Blocks. Pot terminals if necessary  
   Or buy 717 style Honeywell Thermostats.
2. Install thermostats/Saddle blocks on Prop Lines with Nusil and zip ties.
3. Wrap spiral Kapton heater around line
4. Hold down with 1 layer of 3M 425 Aluminum tape.
5. Apply 2\textsuperscript{nd} layer of Aluminun tape
6. Add Thermocouple for T/V testing.
7. Wire everything up
8. Wrap MLI around pipe
9. Ground the MLI with its Ground Strap to structure
Spiral Kapton Heaters for Prop Lines
Prop Line Tstats on Saddle Blocks

Honeywell Model Style 717

1/4" diameter tube mount shown For other options, consult factory.

Zip-tie
Nusil
Prop Line
Saddle Blocks w/ integral thermostats
Propellant Liquids

• Monoprop: Hydrazine

• Bi-Prop (Fuel + Oxidizer)
  – Monomethyl Hydrazine (MMH) is the fuel
  – Nitrogen Tetroxide (NTO) is the oxidizer
    • The freezing point can be lowered if you add nitric oxide.
    • The resulting oxidizer Mixed Oxides of Nitrogen (MON).
    • NTO has a freezing point of about -9°C
    • MON-3 (3% nitric oxide) freezes at -15°C
    • MON-25 (25% nitric oxide) freezes at -55°C
Propulsion Module Plumbing

Fuel Tank

Fuel Pressurant Line

Oxidizer Pressurant Line

Fuel Tank Liquid Line

Pressurant Supply

High Pressure Control Module

Fuel and Oxidizer Control Module

Low Pressure Control Module

Fill and Drain Valve Bracket

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Propulsion Tanks

- Aluminum Tape
- Thermostats
- Thermistors
- Heaters
- MLI blanketing
Propulsion Line Supports

- Plumbing lines are supported by thermally isolating brackets and standoffs
  - Machined Ultem 1000 Or Ultem 1200UC
  - Brackets are bonded or bolted to the primary structure

- Lines can be held with compliant clamps
  - Tefzel Cable ties may be used for off module plumbing runs – common for commercial satellites

“Racetrack” tube spacer and Tefzel Cable Tie

Saddle Clamp

Triana Propulsion Module

Line Clamp

¼” Propellant Line

Ultem isolator/bracket

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Propulsion Heaters

- **Liquid Lines:**
  - Entire length MLI blanketed
  - Heated with standard thermal practices
    - Dual element spiral Kapton heaters adhered with aluminum tape.
    - Two mechanical thermostats in series. Mounted in pairs on saddle blocks.

- **Propellant Tanks:**
  - Dual element Kapton Heaters

- **Control Modules**
  - Dual element Kapton patch heaters on baseplate

- **Thruster Valves**
  - Dual element Kapton patch heaters, mechanical thermostats.
  - Cat bed heater or chamber heater used pre-firing
Fill and Drain Valve and Thruster Plumbing

- Oxidizer F&D Valve (FD-O2)
- Fuel F&D Valve (FD-F2)
- Pressurant Supply F&D Valve (FD-H1)
- Pressurant F&D downstream of PVs (FD-H2)
- Oxidizer Tank Inlet (FD-O1)
- Fuel Tank Inlet (FD-F1)
- ACS Thruster “B”
- ACS Thruster “A”
- ACS Thruster “B” Oxidizer Line
- ACS Thruster “B” Fuel Line
- ACS Thruster “A” Oxidizer Line
- ACS Thruster “A” Fuel Line
Course Summary

• Learned about “real” vs. theoretical MLI

• Learned about “Actual” thermal hardware instead of “Thermal Model” Hardware.
  – Their bonding techniques and materials.

• Learned about the special case of Propulsion Thermal.