Thermal Hardware for Thermal Analysts

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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

Thermal 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”
Analyst vs. Hardware

STEREO/PLASTIC as an example

TSS Model of PLASTIC

Actual MLI on PLASTIC
Theoretical Blanket Effective Emissivity

![Graph showing the relationship between E-Star and the number of layers for Kapton and VDA materials. The graph indicates a decrease in E-Star as the number of layers increases.]
Actual MLI Blanket

VDA Effective Emissivity

E-Star

Number of Layers

Actual Blanket

Theoretical Blanket

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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 effected. 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 ft$^2$ blanket covering 30°C surface:
  – Good MLI blanket design = 1.2 watts lost
  – Smashed blanket = 38 watts lost
Stitching Effects

1 ft wide blanket

Distance (in)

E-Star

SEAM

SEAM

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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
Cryogenic Temperatures Affect MLI Blankets

Cold Temperatures effect MLI blanket efficiency

Emissivity shifts to the far infrared at very cold temperatures.
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.

• Polymericics 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.
Heater-Thermostat Redundancy

- Two thermostats wired in series
  - To prevent failed “on” condition

- Two heaters wired in parallel
  - To prevent failed “off” condition

- Heaters can be ordered with dual-elements
  - Cost is about the same as single element
  - Remember to order heaters with two color coded wires (to tell circuits apart)
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.
Optical Coatings

• Word of Advice: Never call an optical coating “Paint”!

• Things that effect Optical coatings:
  1. Atomic Oxygen*
  2. UV Radiation*
  3. Proton-Electron particle Radiation
  4. Contamination on the surface
  
  Note: * LEO orbits

• Example: Silver Telfon in LEO usually needs 10mil Teflon instead of 5 mil (AO erodes the Teflon)
Optical Coatings, Page 2

• Thickness of the coating is key:
  – Too thick makes the coating crack
  – Too thin effects the emissivity and solar absorptance

• Coating Selection
  – The Substrate: metal or composite?
  – Temperature range:
    • Polyurethanes do not do well at hot temperatures. They turn brown.
    • Silicates work better when hot but have their own problems.

• Coat on flat side of the radiator, not on pocketed side if possible.

• Fillets and bolt patterns create 5-10X more time to coat. $$$$ 

• Talk to your Coatings Engineer before you get too far down the path.
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$^{nd}$ 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
Honeywell Model Style 717

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

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“Racetrack” tube spacer and Tefzel Cable Tie

Line Clamp

1/4” Propellant Line

Ultem isolator/ bracket

Triana Propulsion Module

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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 “A”
- ACS Thruster “B”
- 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.