X-38 De-orbit Propulsion Stage MLI Performance Test

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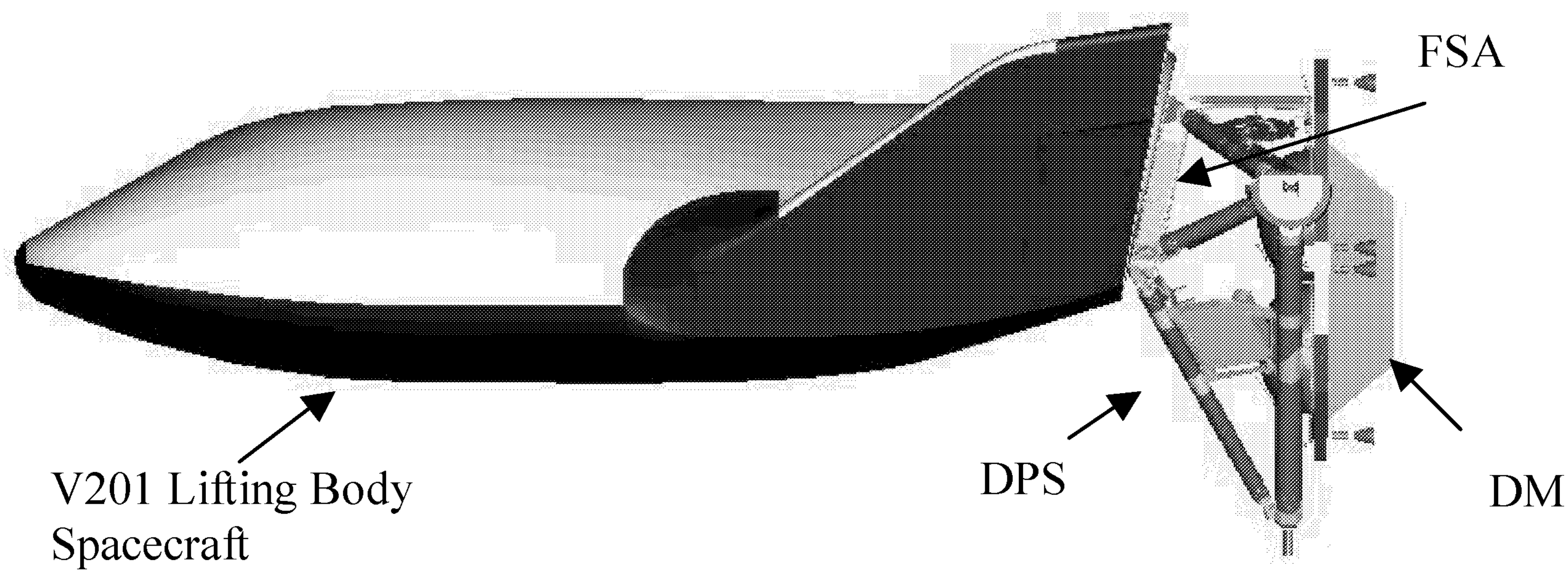
Background

- X-38 is Pathfinder for Space Station Crew Return Vehicle
- X-38 Launched in Space Shuttle
- De-Orbit Propulsion System (DPS) Maneuvers X-38 in Descent Trajectory and is Jettisoned Prior to Re-entry
- X-38 DPS design hot biased to reduce power and energy requirements
- Black Beta Cloth selected as outer layer on MLI
- Analytical Margin is Small and no DPS Thermal Testing Planned.

X-38



Objective

- Test DPS MLI
  - Sample Available
  - Test Facilities Available
    - Performed in MSFC Thermal Development Facility
- Determine if MLI Performance Meets or Exceeds that Assumed in Thermal Analyses
- Determine Performance Degradation due to Seams

Prep Work

- Literature Search of Potential Test Methods
- Test Fixture Conceptual Design
- Thermal Modeling and Analysis
- Design Modification
- Procurement/Manufacturing and Assembly
- Optical Property Measurement
- Instrumentation Acquisition
- Data Acquisition System Setup

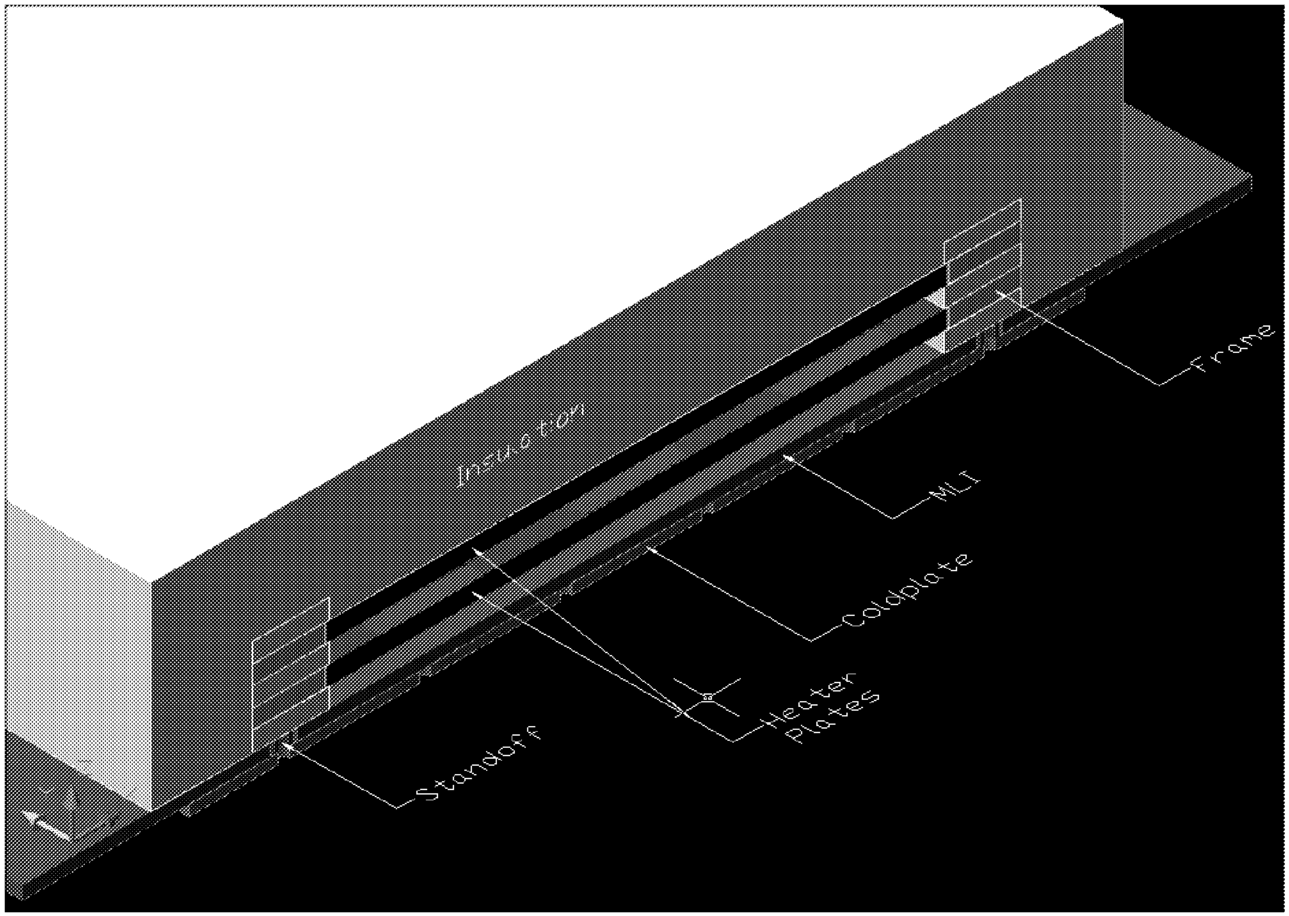
Initial Test Methodology

- Guarded Heat Flow Technique Loosely Based on ASTM-177-97
- Use Temperature Difference Between Primary Heater Plate and Coldplate, Measured Emissivity for the Primary Heater and MLI, and the Primary Heater Power Draw to Calculate Effective Emittance (ε*)
- Black Anodized Aluminum Heater Plate, $\varepsilon = 0.83$
- MLI Black Beta Cloth Outer Surface, $\varepsilon = 0.87$, $\alpha = 0.96$

Test Fixture

- Test Fixture Composed of Polysulfone Plastic Frame and two Black Anodized Aluminum Heater Plates
- Mounted to Space Station –1 Coldplate with Teflon Isolators
- Insulated with four inches of Cryolite Fiberglass Matte
- MLI Sandwiched in Interface Between Heater Plates and Coldplate
- One Square Foot Test Area

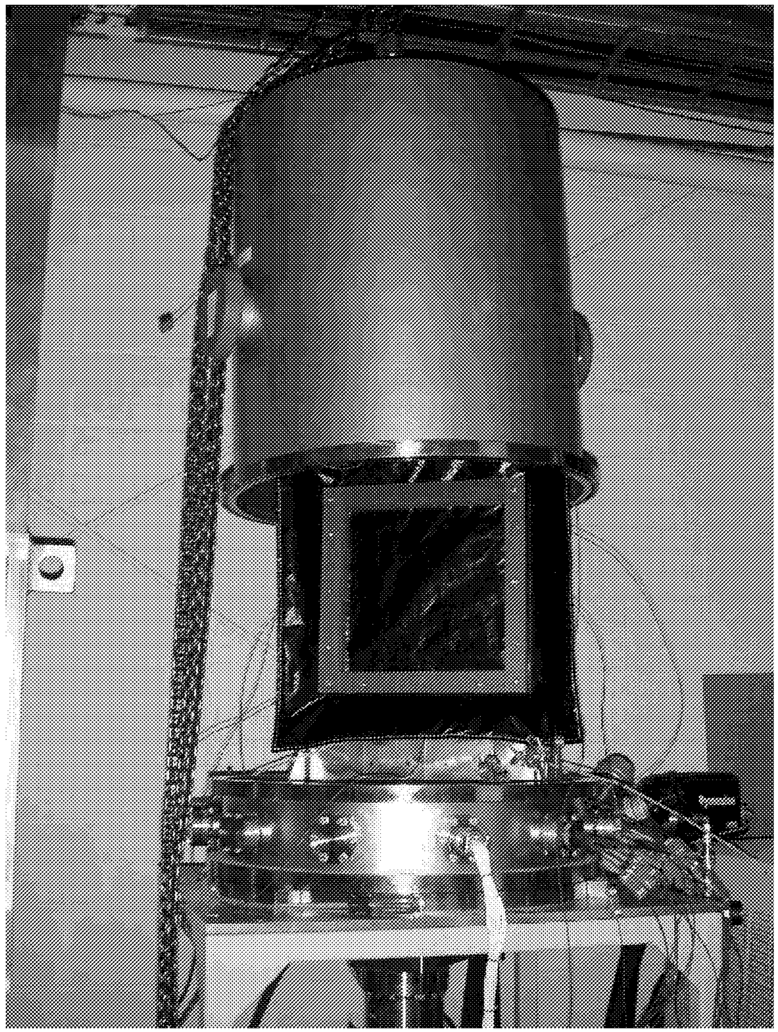
Test Fixture Cross-Section



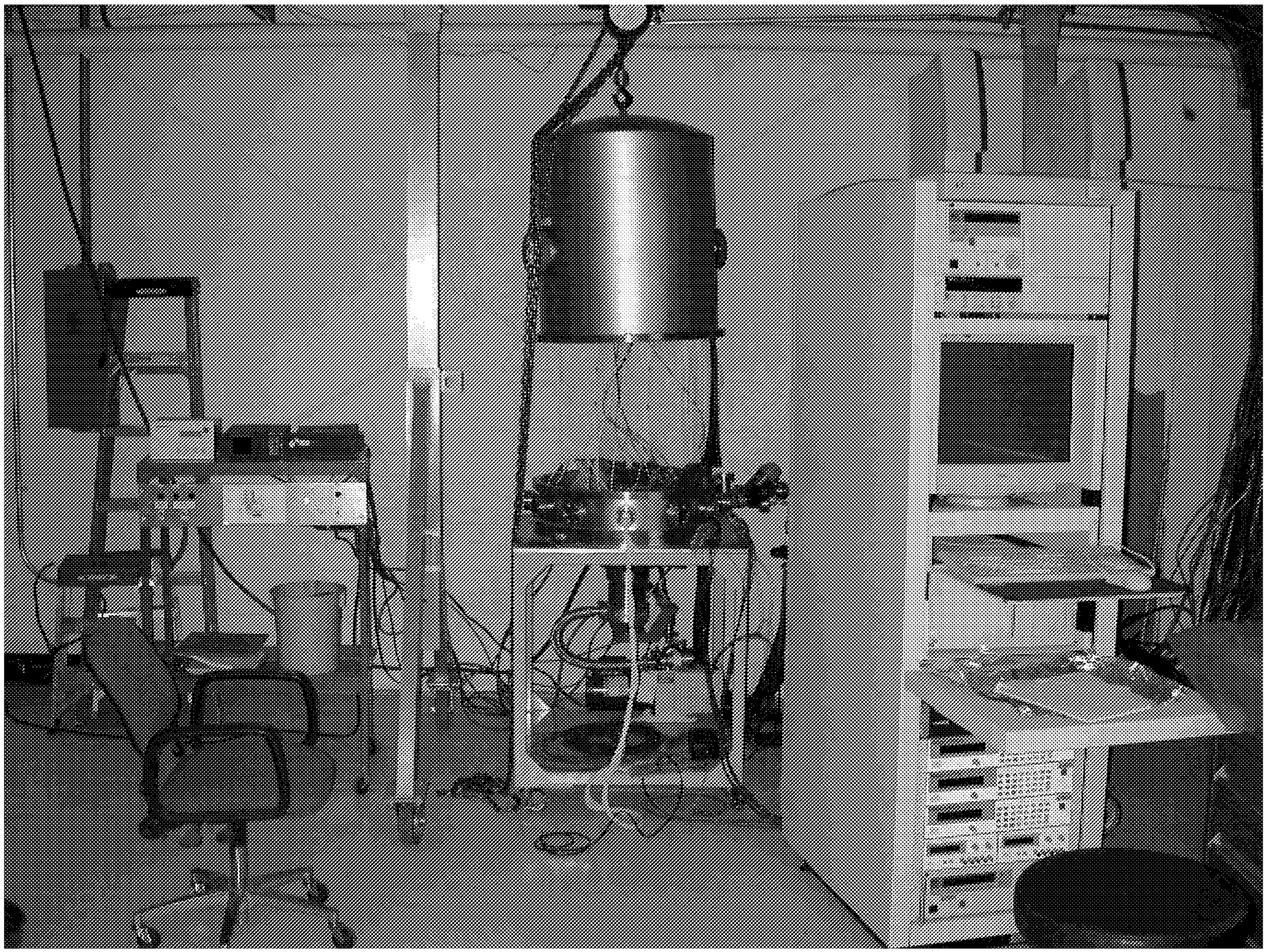
Test Setup

- 9 Minco Thermofoil Heaters per Heater Plate
- Temperature Sensors Mounted on Heater Plates, Coldplate, Frame, and Chamber Shell
- Fixture Isolated from Coldplate with Teflon Standoffs
- MLI Between Test Fixture and Coldplate
- Vacuum Chamber
- Johns Manville Cryo-lite Fiberglass Insulation
- ISS –1 Coldplate and Neslab Low Temperature Chiller
- Residual Gas Analyzer
- DAQ System and Power Supplies

Test Setup



Test Setup



Test Procedure

- Assemble MLI, Test Fixture, Insulation, and Coldplate in Vacuum Chamber
- Evacuate Chamber – Control Heaters to 300ºF, Chiller set to 5ºF.
- Adjust Heater Power so that Heater Plates are at the Same Temperature
- Record Primary Heater Plate Temperatures and Voltage and Current and Coldplate Temperature

Modifications

- Heater Plate Thermocouples Replaced with RTD’s wired to HP DAQ System
- RTD’s Bonded to the Heater Plates using Conductive Epoxy
- Fixture Re-oriented on Coldplate so the Open End was to the Left Rather than Top
- Aluminized Kapton Tape Applied to Fixture Exterior

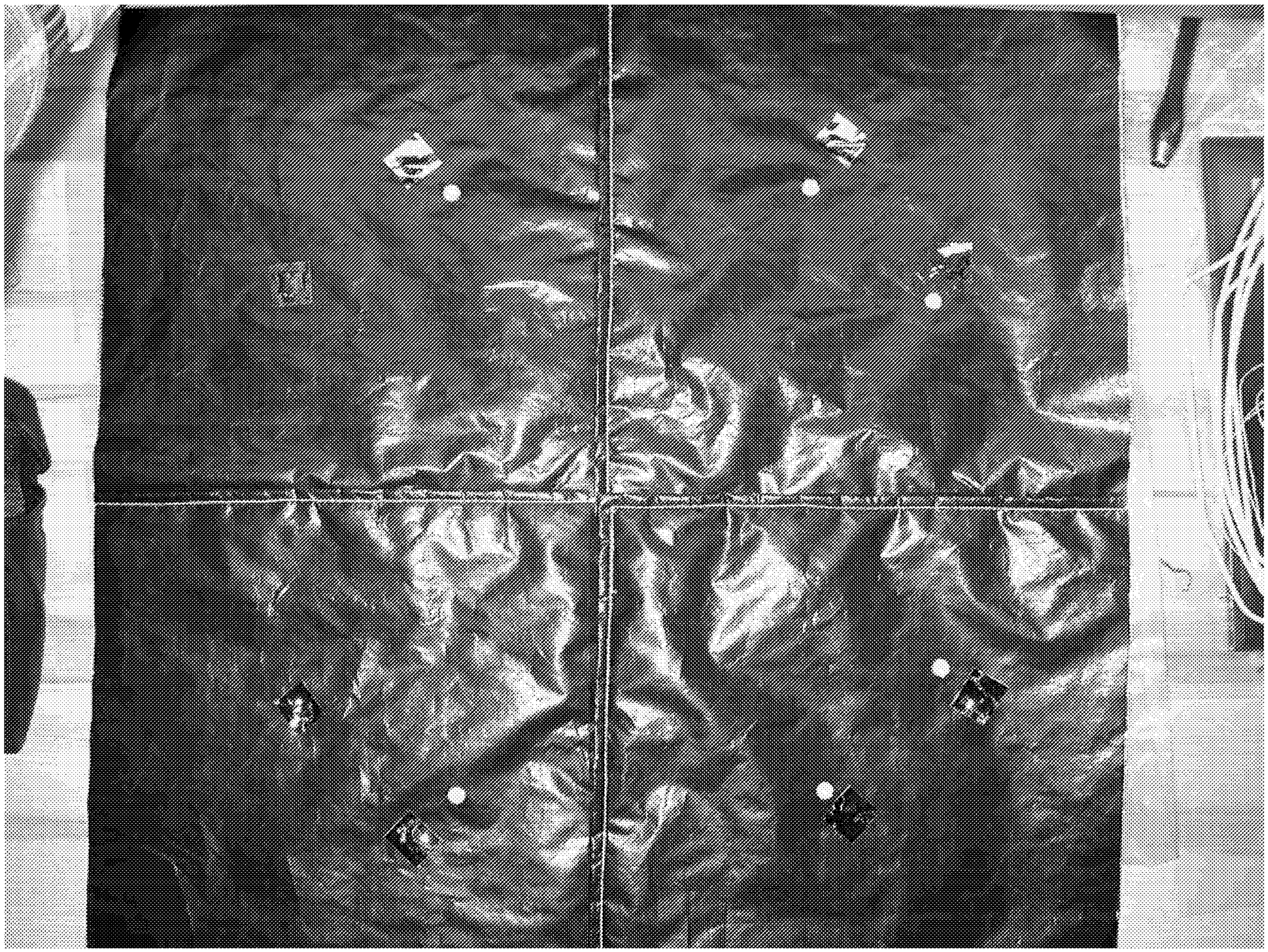
Retest

- Reconfigured Test Yielded more Uniform Temperatures
- Primary Heater Temperature of 297ºF and Coldplate Temperature of 12ºF yielded ε^* of 0.028 based on full heat load of 13.0 btu/hr across MLI
- ε^* of 0.016 – 0.019 used in DPS Thermal Analyses.
- Assessment of Test Results Indicates much more Heat Leak from Test Fixture than Expected Causing Over-Estimation of ε^*

Reconfiguration for Seam Test

- Removed MLI from Test Fixture and Quartered it.
- Each Piece was then Reversed and laid out so the Seams of Adjacent Pieces Overlap then Taped in Place
- 8 RTD's added to MLI side of Test Fixture Frame.
- Configuration then Reassembled.

MLI Configuration for Seam Test



Seam Test

- Primary Heater Temperature of 295ºF and Coldplate Temperature of 22.1ºF yielded ε^* of 0.044 based on full Heat Load of 19.1 btu/hr across MLI
- Assessment of Test Results Indicates much more Heat Leak from Test Fixture than Expected Causing Over-Estimation of ε^*
- Frame Temperatures of 235ºF Appreciable Higher than Expected

Post-Test Analysis

- Updated Thermal Model to as-Tested Configuration
- Identified Modeling Assumptions that Might Affect Results
  - Insulation k and Thickness
  - Heater Plate to Frame Heat Transfer
  - Frame (Polysulfone) k
  - Contact Conductance, Heater Plates to Frame and Frame to Frame
- Varied each Parameter to Determine Sensitivity
  - Results Insensitive to Frame k, Contact Conductance
- Looked for Combination that Matched Test Results
  - Apparently only 1
  - Insulation G * 3.8   Plate to Frame G * 0.49
- Seam Test $\varepsilon^* = 0.026$ MLI Test $\varepsilon^* = 0.011$

Error Analysis

- Look at Analysis Uncertainty due to Potential Instrumentation Errors
  - Assess Potential Errors due to RTD's, Thermocouples, Voltage & Current Measurements and DAQ System
- Rerun Model Correlation with each Error Applied in Both + and – Directions and Determine Effect on ε^* Prediction
  - Primary Heater Plate Temperature, +/- 0.828ºF
  - Guard Heater Plate Temperature, +/- 0.828ºF
  - Frame Temperatures, +/- 0.828ºF
  - Coldplate Temperature, +/- 2.7ºF
  - Chamber Temperature, +/- 2.7ºF
  - Heater Voltage, +/-(0.0003V+0.012) volts
  - Heater Current, +/-(0.002I+0.00025) amps

Results

- The Expected ε^* Range was Computed by Taking the Square Root of the Sum of the Squares of the Variances Induced by the Potential Error Cases and Applying those to the Nominal Values
  - Seam Test $\varepsilon^* = 0.017 – 0.035$
  - MLI Test $\varepsilon^* = 0.003 – 0.019$
- Assuming the Overlapped Seams Affect an Area 0.5” Wide and the Remainder of the Area in the Seam Test has the same ε^* as Computed for the MLI Test, an ε^* for just the Seam Area was Computed
  - $\varepsilon^* = 0.175 – 0.215$
  - This Value can be Combined with the ε^* from the MLI Test in an Area Weighted Manner to Estimate the Overall Performance of the X-38 MLI Blanket System.

Lessons Learned/Conclusions

- It's Difficult to Effectively Insulate an Effective Insulator
- Polysulfone is Easily Machinable, Vacuum Stable, and has a Good Temperature Range (-150ºF to +350ºF)
- Cryolite is a Fiberglass Matte Insulation with a Vacuum Stable Melamine Resin, Rated for –450ºF to +450ºF
  - It does have Quite an Affinity for Water Vapor.
  - The Thermal Conductivity is Apparently Higher than the Manufacturer's Value.
- A Horizontal Test Setup is much Preferable to Vertical
- A Guard Heater Complicates Model Correlation
- Testing a Larger Sample Area would have Improved Results