Transient and Steady-State Performance Testing of Active Thermal Surfaces

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Outline

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- Motivation and Objectives
- Theory of Operation
- Experimental Verification of Concept
- Development of Flight Hardware
- Ground Based Testing
- Conclusion Remarks

Motivations and Objectives

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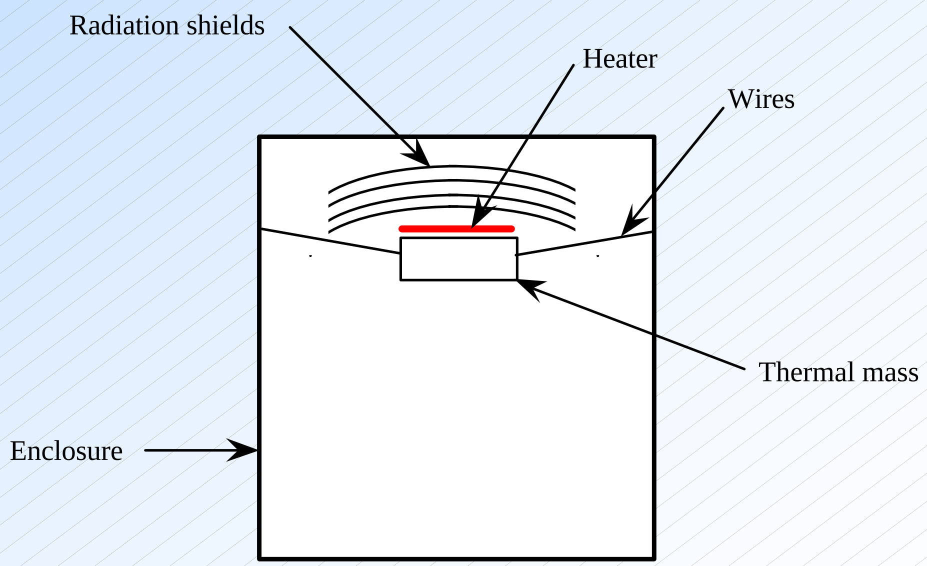
- **To improve thermal control of spacecraft, active materials and structures are being developed that allow the emissivity of a surface to change**
  - **Electrochromic coatings**
    - Polymeric and inorganic materials
  - **Electrostatic devices**
    - Gap between layers controlled by application of DC voltage
  - **MEMS Louvers**
    - Micromachined analogs of louvers
- **Objectives of work:**
  - **Develop lightweight, accurate, fast, robust, emissivity measurement technique that is capable of evaluating many coatings simultaneously**
  - **Assess this technique on ground**
  - **Develop apparatus for space flight experiment**
  - **Fly apparatus to determine long-term behavior of various passive and active emissivity coatings**

Methods of Measuring Emissivity

- **Calorimatry based**
  - **Heat in=Heat radiated away**
  - **Needed to isolate thermal mass from container to minimize heat leaks, account for heat transfer from wires, etc.**
  - **Can only test one surface at a time**
  - **Slow response**



Methods of Measuring Emissivity

- **Spectral methods**
  - **Measures the reflectivity of a surface at various wavelengths.**

$$a_l + t_l + r_l = 1$$

If surface is opaque (t_l=0),

$$a_l = 1 - r_l$$

Since $a_l = e_l$, $e_l = 1 - r_l$

  - **Non-contact measurement that can be performed remotely**
  - **Provides spectrally resolved information**
  - **Does NOT work for electrostatic emissivity control schemes (ESR developed by Sensortex)**

Theory of Operation

- **Employ RDF heat flux sensors**
  - **Differential thermopile: Heat passing through polyimide film produces a small temperature differential**
  - **Output voltage is proportional to heat flux**

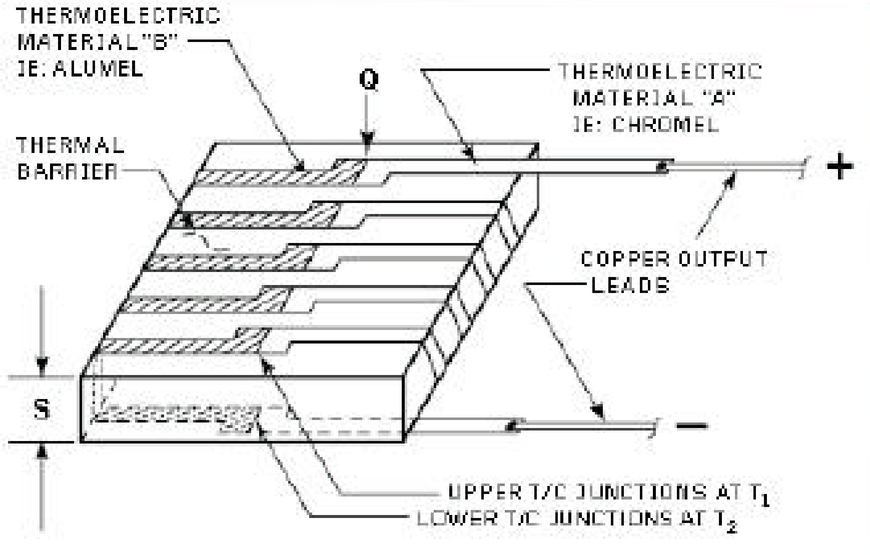
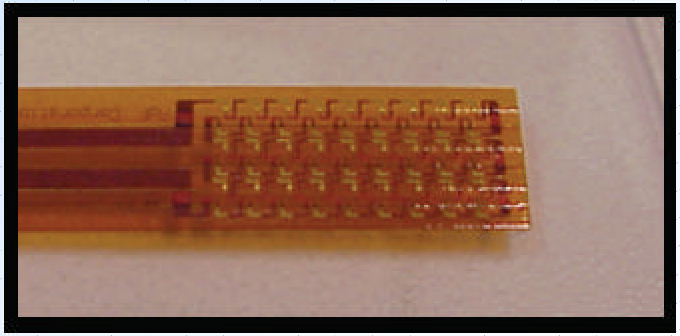


Figure 1. Micro-Foil® In-Depth Thermopile

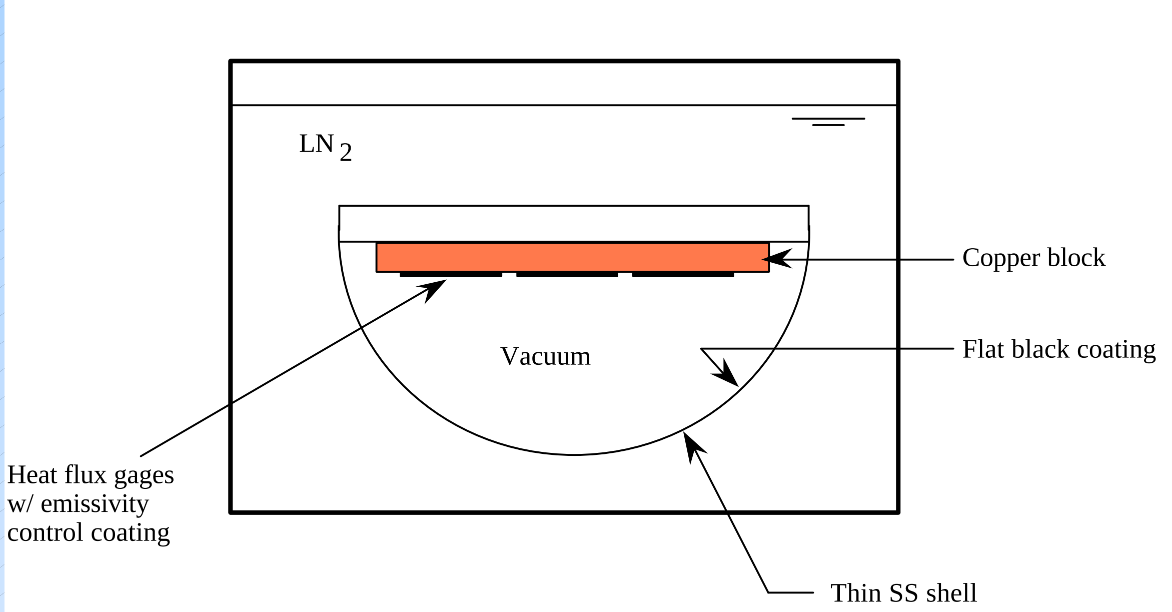


Photograph of a RDF Heat Flux Sensor (Model 27160)

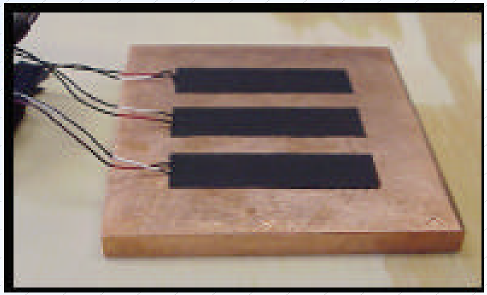
Theory of Operation

➢ Test Chamber Schematic

- **Heat flux gauges with coatings are mounted on a copper block and place in a vacuum chamber.**
- **Chamber is immersed in a bath of liquid nitrogen to simulate radiation to deep space.**



$$e = \frac{q''}{s\left(T_{Cu}^{4} - T_{W}^{4}\right)}$$



Three black painted sensors on copper substrate

Advantages of Current Concept

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- Measures DIRECTLY the total radiation heat transfer from the wall (the quantity of interest in thermal management of satellites).
- Self powered: Sensors require zero power. Only power to the data acquisition system is required for passive operation.
- Robust: No moving parts, very simple operation, easy to implement using space-qualified hardware, should easily pass vibration testing.
- Do not need to know temperature history like calorimetry.
- Can measure changes in emissivity of Sensortex device, electrochromics, MEMS louvers, etc.
- Fast transient response (~10^0 seconds).
- Compact: Can accommodate numerous active/passive sensors on the same substrate.
- Self calibration: One surface can be that of a known emissivity so in-situ calibration can be performed.

Ground Based Test Apparatus

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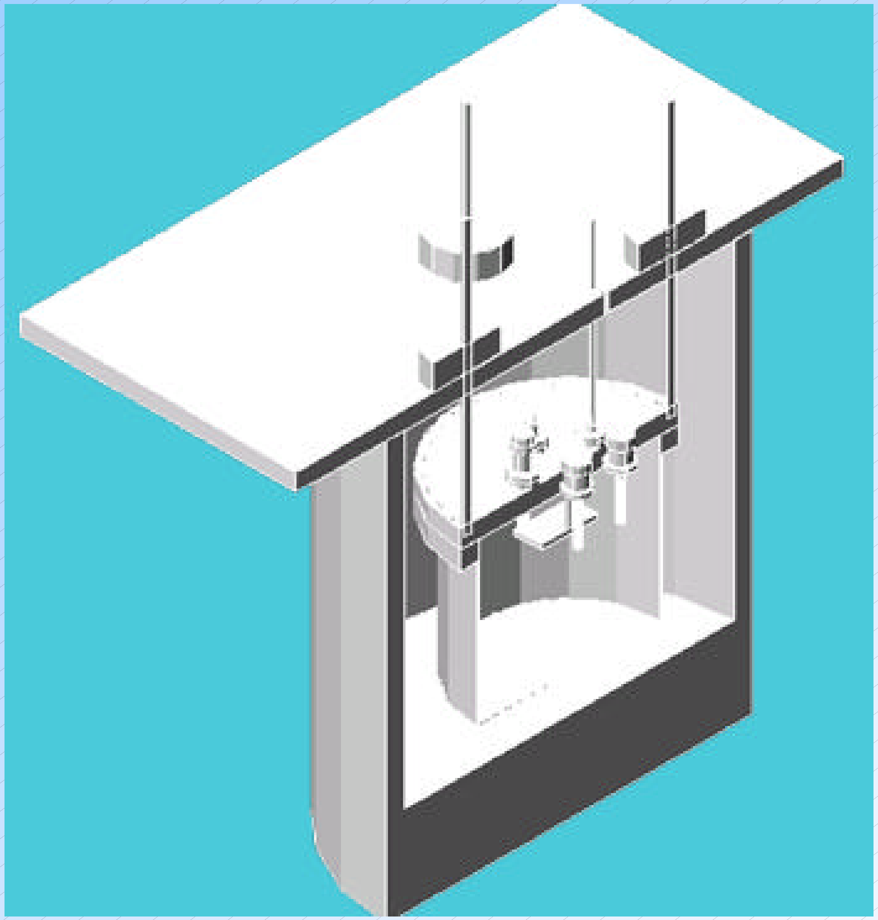
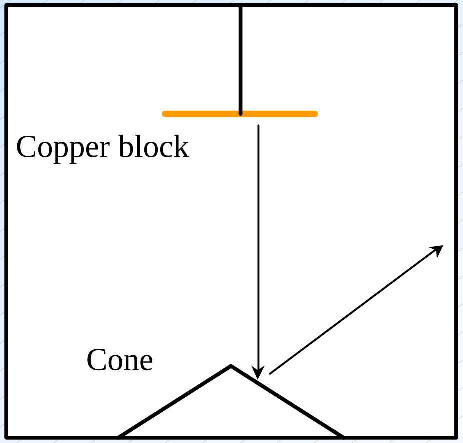


3D Schematic of Complete Assembly



Bottom cone to directs second reflection to chamber wall

Ground Based Test Apparatus

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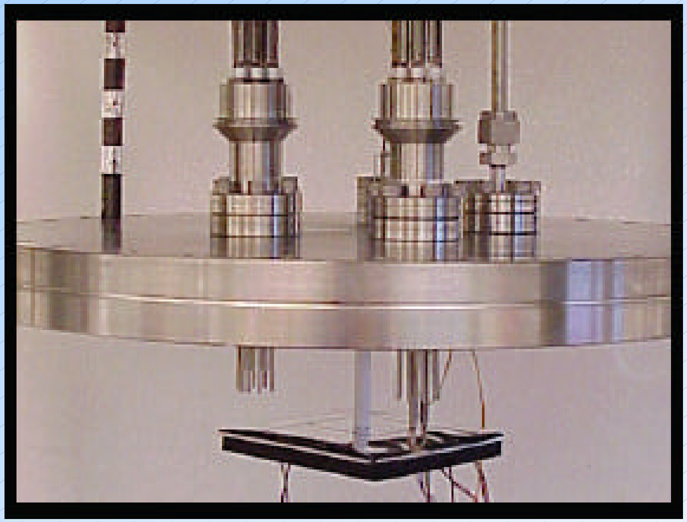
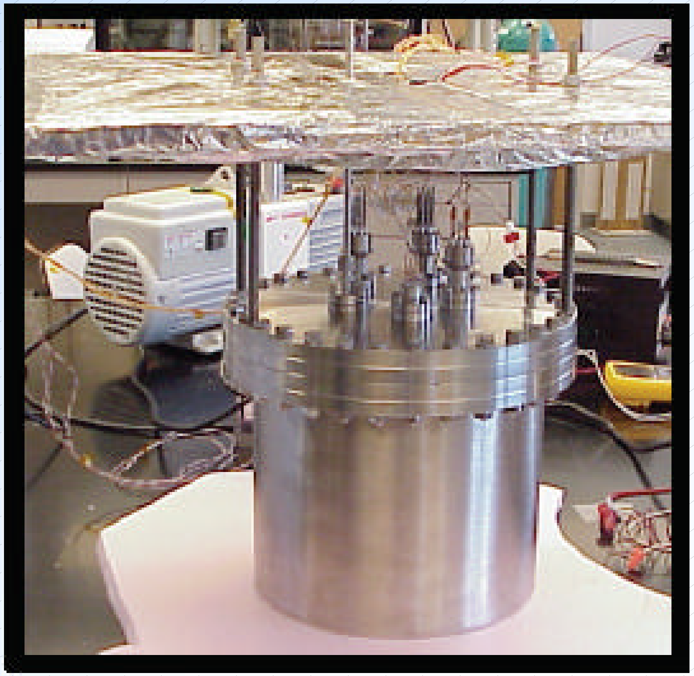
- **Thermocouples**
  - **3 on chamber walls, 1 on cone, 3 on lid, 4 on Cu block**
- **A pair of feedthroughs for each gauge and heater**



Vacuum chamber lid and test module assembly

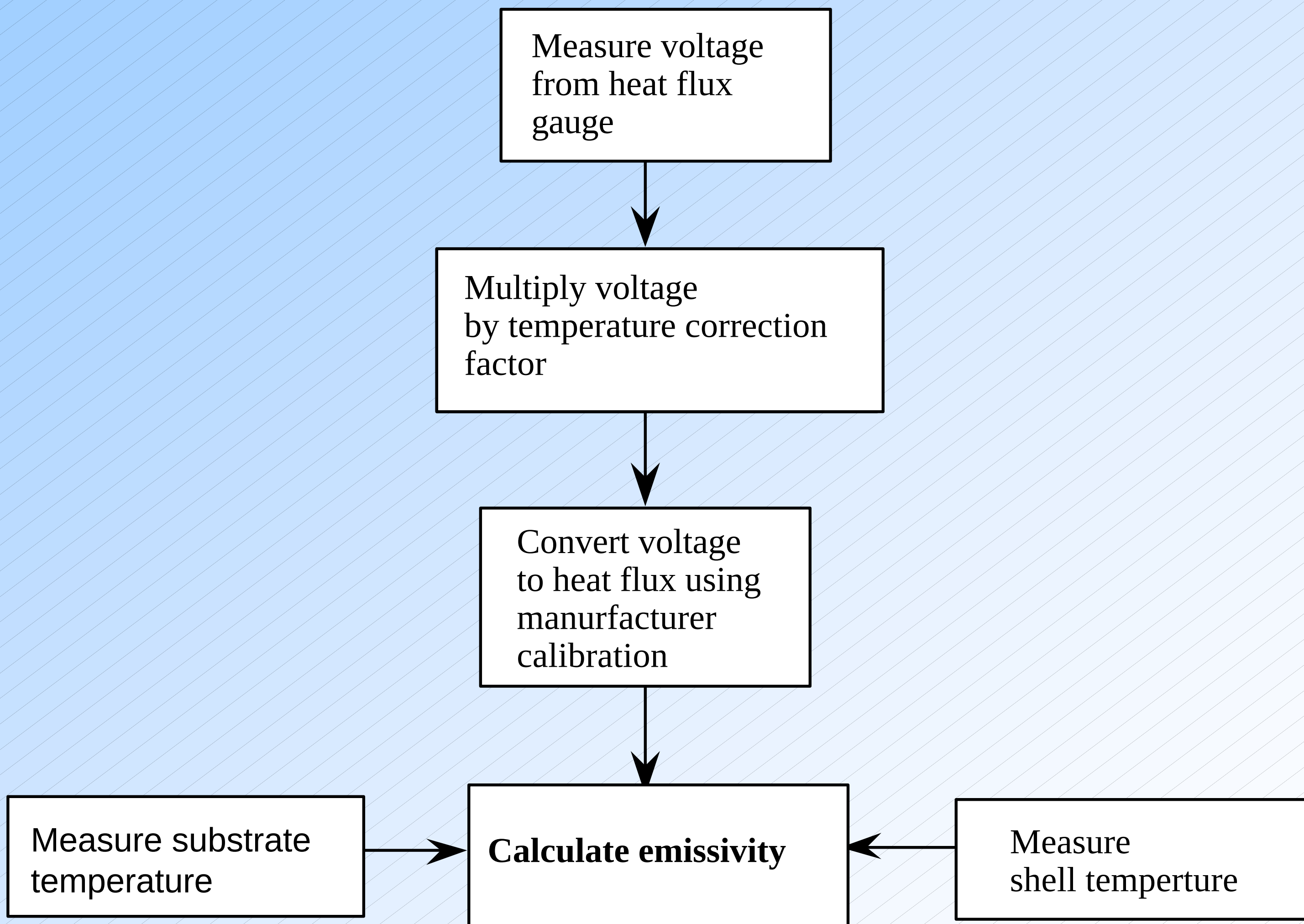


Vacuum chamber

Ground Based Test Apparatus

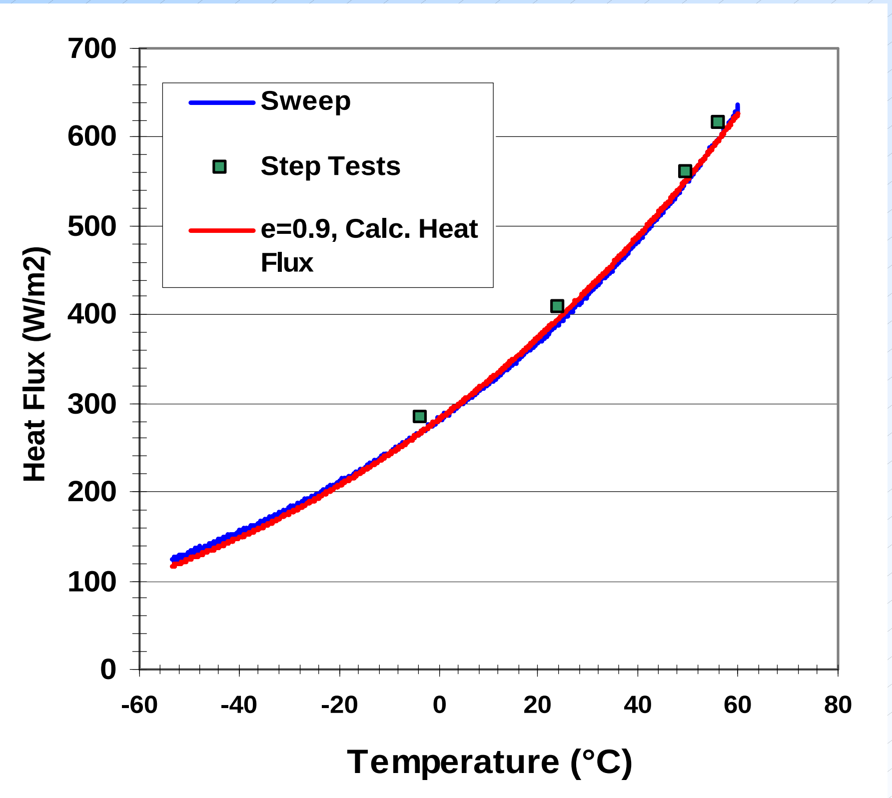
Test Apparatus

Data Reduction Procedure



Test Results

- **Heat flux results are in agreement with theory**



Comparison of the results of sweep and step tests with theory

Test Results

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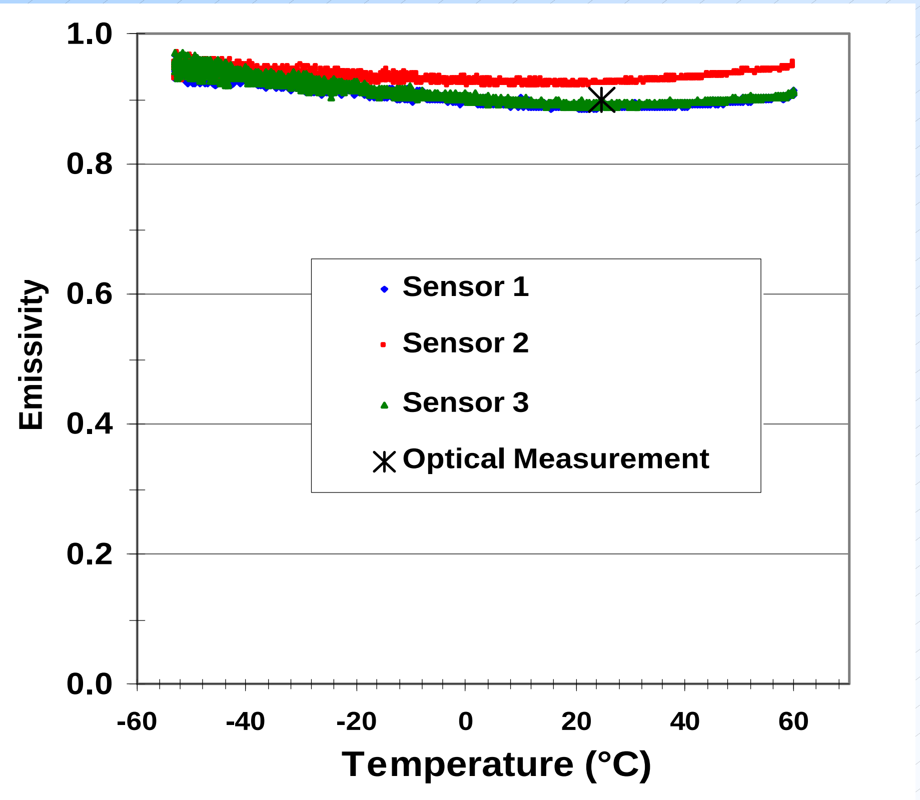
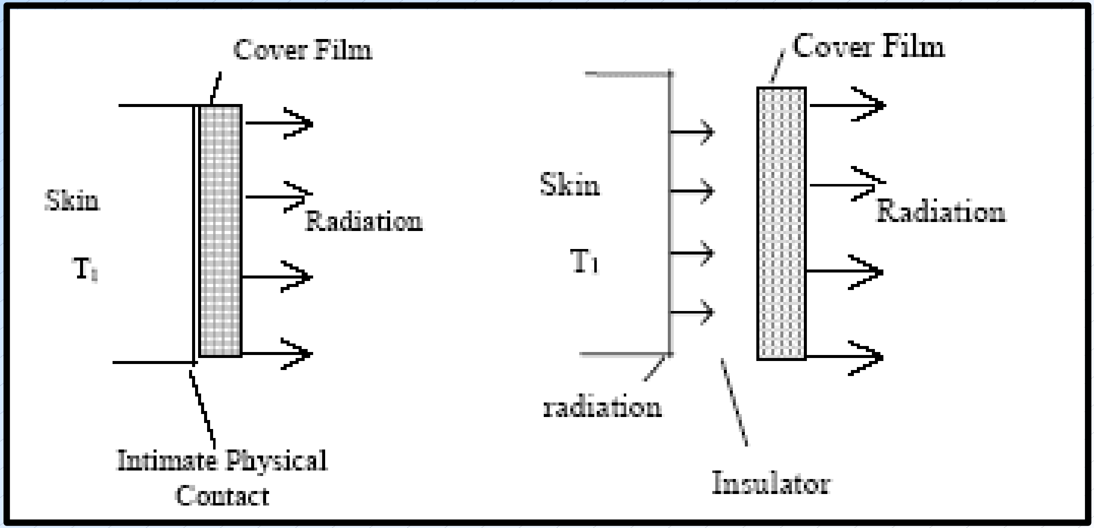
- Emissivity of the three back painted surfaces



Integration of the Heat Flux-Based Emissivity Measurement Technique with Sensortex Electrostatic Radiator (ESR)

Operational Principle of ESR

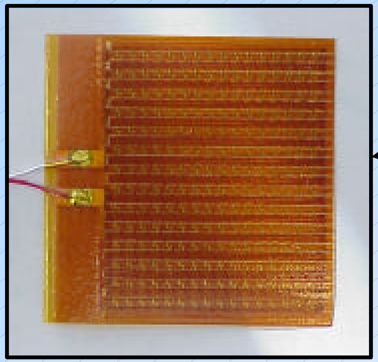
- **Application of a voltage potential between the cover film and skin pulls down the film**
  - **Backside of the film and skin have low emissivity**
    - Low heat transfer in separation mode
    - High heat transfer in contact mode

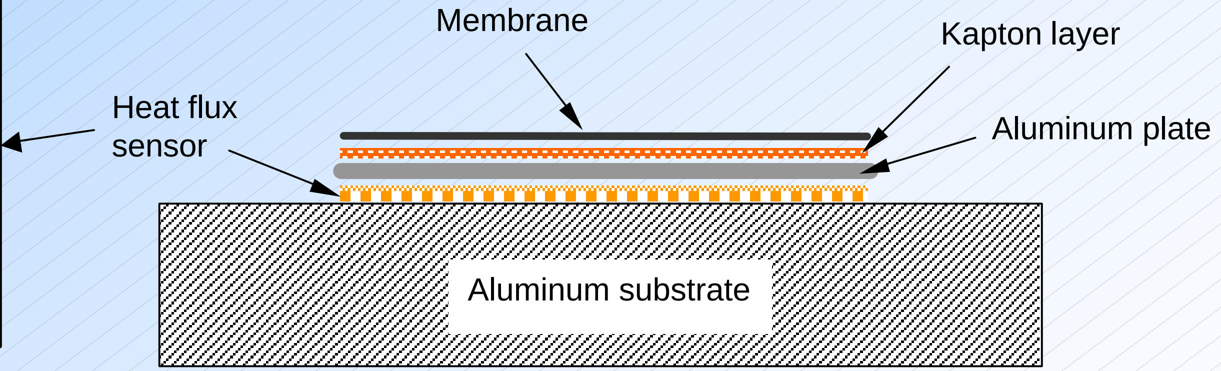


Schematic of the ESR operation principle

Heat Flux Sensor and Sensortex ESR Assembly

- **A custom made (manufactured by RDF, Inc.) heat flux sensor was installed between ESR and its substrate (i.e. skin)**





Schematic of heat flux sensor and ESR assembly

MISSE-6 Mission

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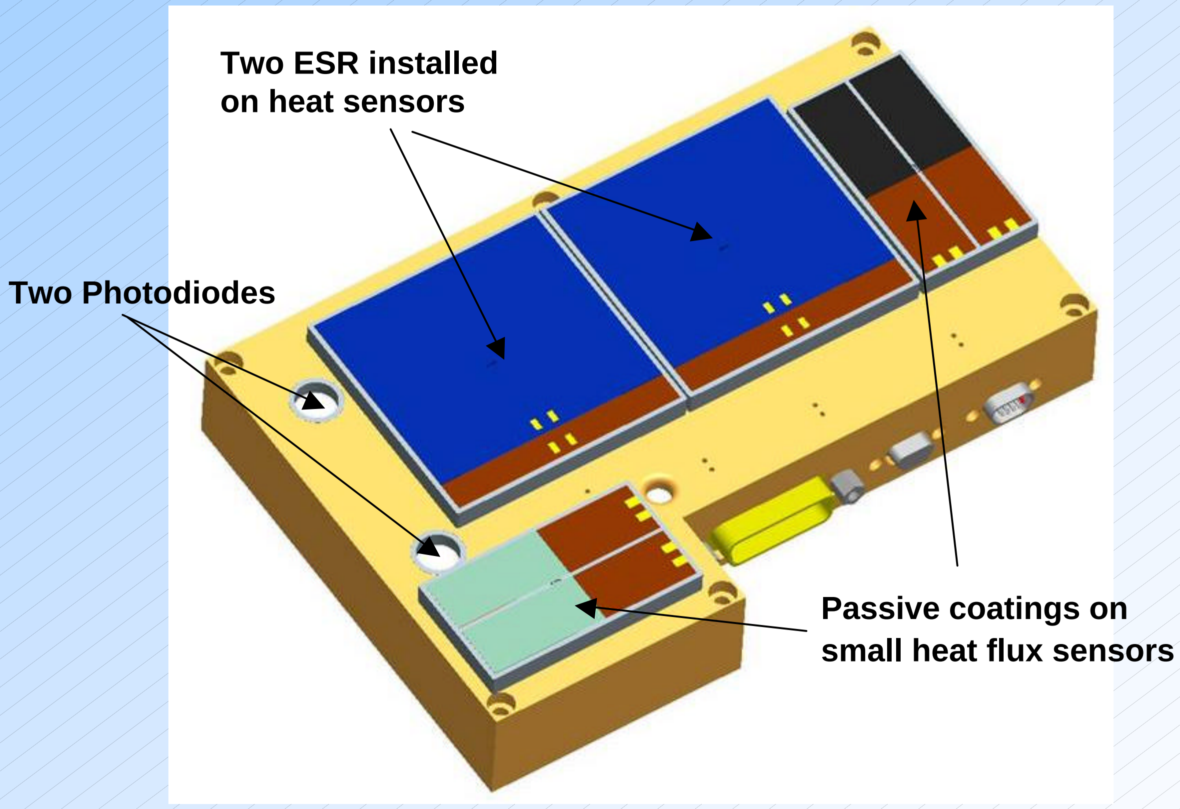
- Air Force – Boeing – NASA program
- Study effect of space exposure on new materials
- Deploy on exterior of International Space Station
- Nominal six month mission
- Self-contained
  - Power from ISS
  - No data telemetry
  - Limited volume, many experimental samples
- Reduced testing requirements
  - Fits with limited budget for electronics & testing

MISSE-6 Flight Module



Schematic diagram of MISSE module with six HFB emissivity sensors.
Two large sensors are for testing active thermal surfaces

Ground Based Testing

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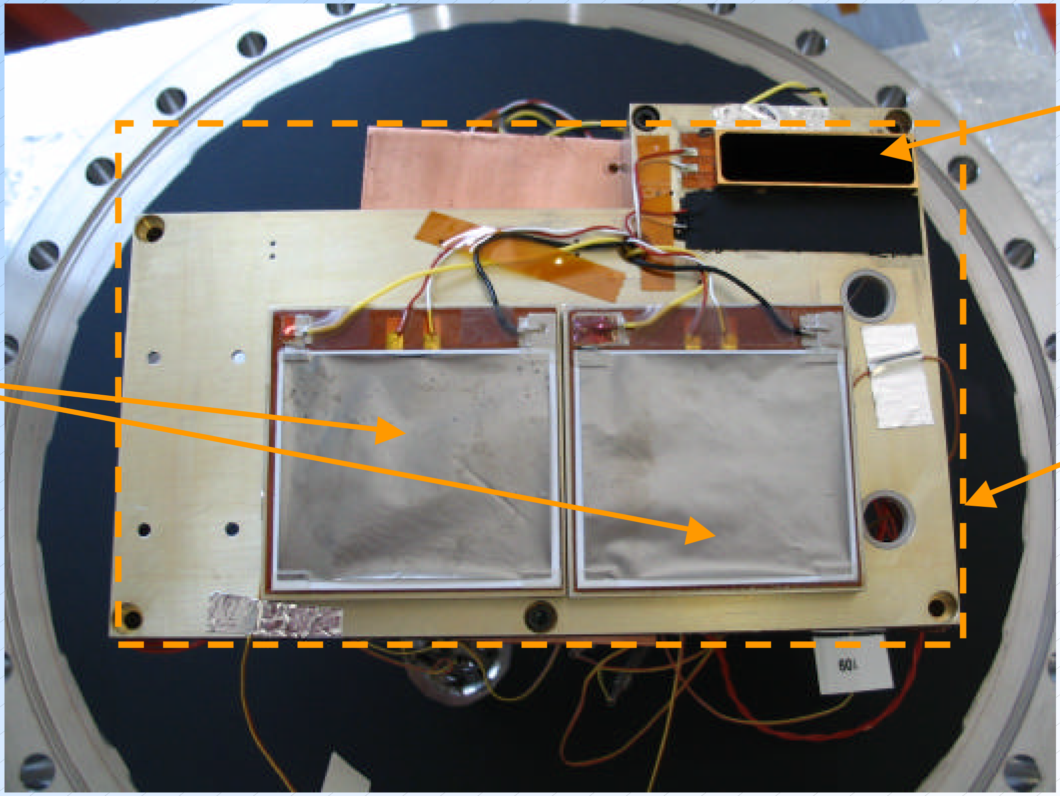
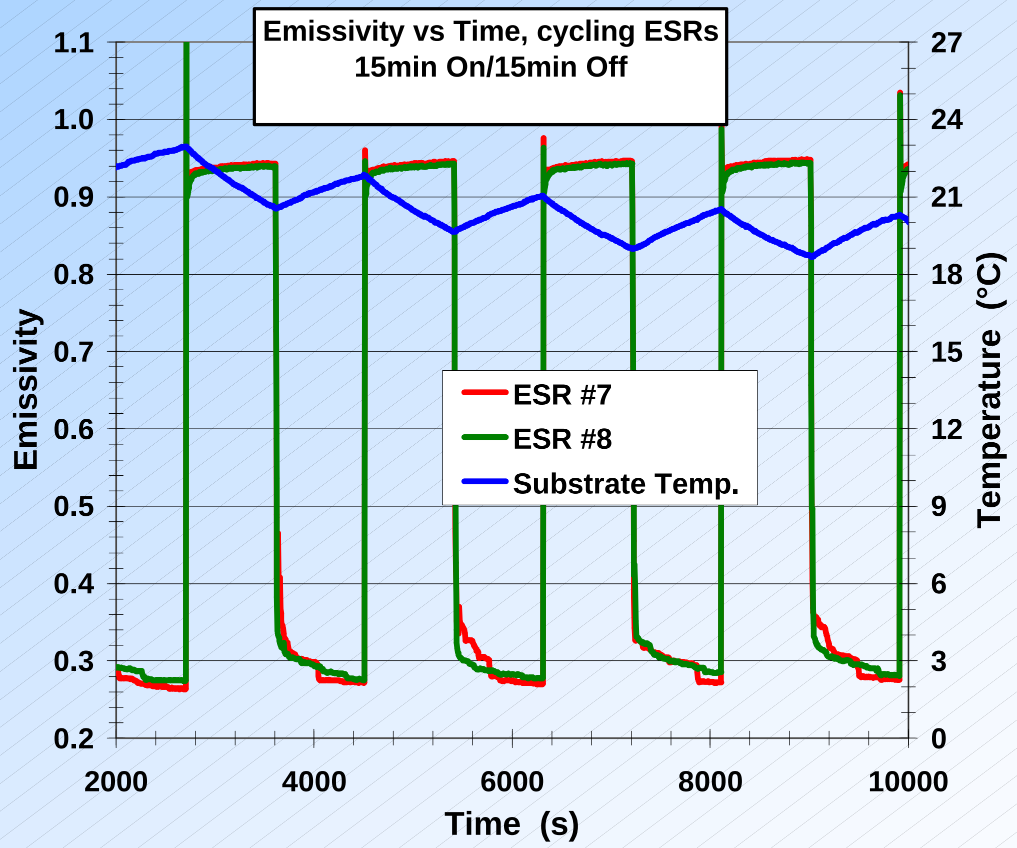
- ESR devices under test on MISSE-6 platform



Ground based testing of MISSE-6 flight module

Ground Based Test Results

- ESR test results at 300 V applied voltage



Conclusion Remarks

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- New heat-flux based method for measuring emissivity was developed:
  - Measures DIRECTLY the total radiation heat transfer from the wall (the quantity of interest in thermal management of satellites).
  - Self powered: Sensors require zero power. Only power to operate the data acquisition system is required.
  - Robust: No moving parts, very simple operation, and easy to implement using space-qualified hardware.
  - No need to know thermal properties and temperature history, unlike calorimetry.
  - Fast transient response (~10^0 seconds).
  - Compact: Can accommodate numerous active/passive sensors on the same substrate.
- Capability of the technique in measurement of ESR performance was demonstrated

Acknowledgements

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Thank You!