LESSONS LEARNED FROM TVAC TESTING OF CUBESAT SMART RADIATOR

An Experimental Study of a Smart Radiator Device for Enhanced Passive Thermal Control of Small Spacecraft (SSC19-WKII-06)

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CUBESAT THERMAL CONTROL:
THE PROBLEM

- Limited power available to thermal components
- Reduced mass of spacecraft

Small size

Low thermal mass

- High sensitivity to environment
- Rapid temp. swings
- Thermal control difficulties

CUBESAT THERMAL CONTROL:
COOLING METHODS

Traditional Radiator

PROS
- Proven in space
- Simple
- Light

CONS
- Unregulated heat transfer rate

Louver

PROS
- Regulated heat transfer
- Proven in space

CONS
- Heavy
- Moving parts (complicated)

Smart Radiator Device (SRD)

PROS
- Simple
- Regulated heat transfer
- Light

CONS
- Not space proven (low TRL)

CUBESAT THERMAL CONTROL:
MPB SRDS

- Thin film of VO_2 doped with Tungsten applied to tile substrate
- Coating material structure changes with temperature, which changes the emissivity
  - Low emissivity: 0.34-0.36 at -10°C
  - High emissivity: 0.75-0.76 at +100°C
- Results in variable heat rejection as satellite temperature changes

$$Q_{rad} = AF\sigma\varepsilon(T_{surface}^4 - T_{ambient}^4)$$

A = Area of surface
F = View factor
σ = Boltzmann constant
ε = Emissivity of surface
$T_{surface}$ = Temperature of surface
$T_{ambient}$ = Temperature of ambient

CUBESAT THERMAL CONTROL:
THE TEST CASE

Magellan and MPB
- Developing SRD manufacturing process

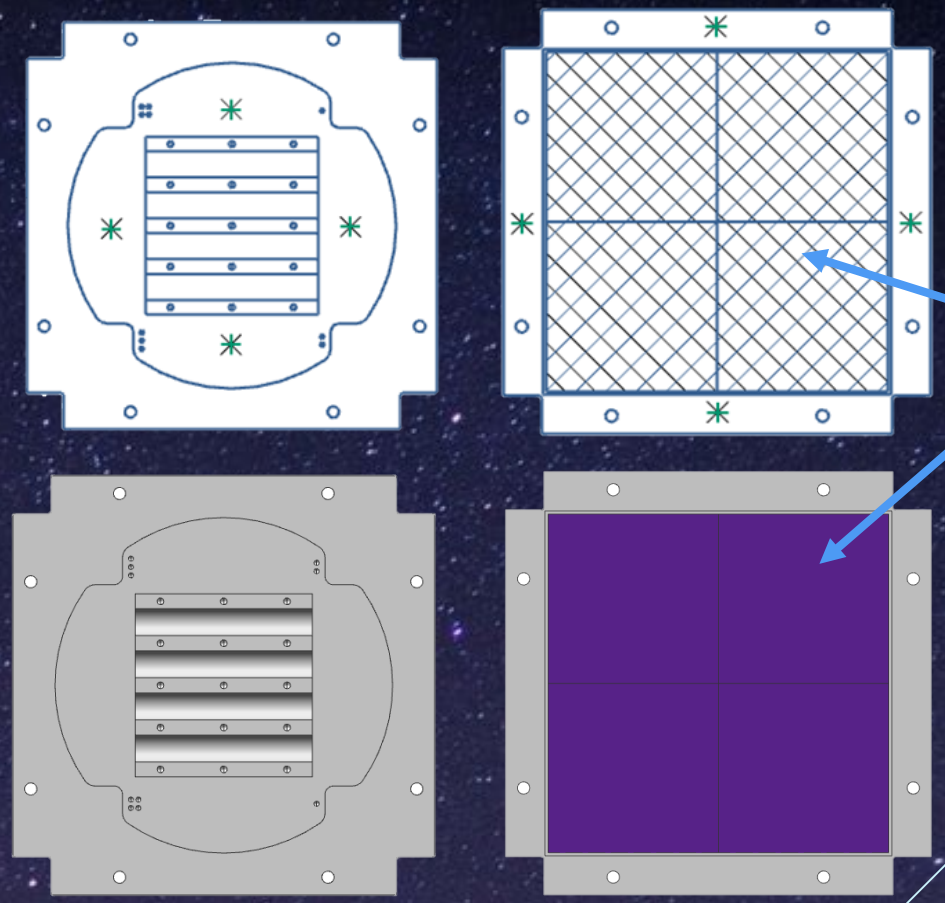
Magellan and Kepler
- Identify Kepler test mission
- Providing systems engineering to integrate SRDs in mission

Magellan and U of M
- Providing opportunity to test flight SRDs installed on flight article
- Engineering support and facilities for testing

Increase SRD TRL

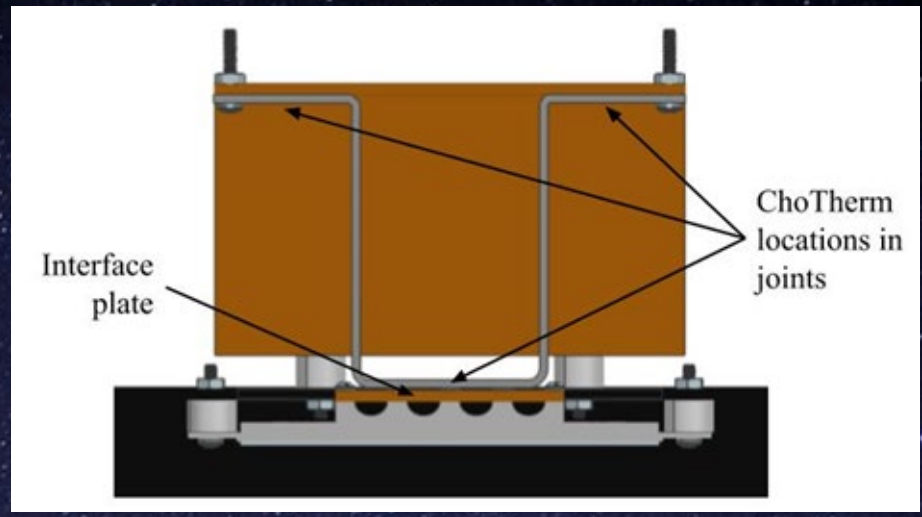
TVAC TESTING:
THE TEST ARTICLE

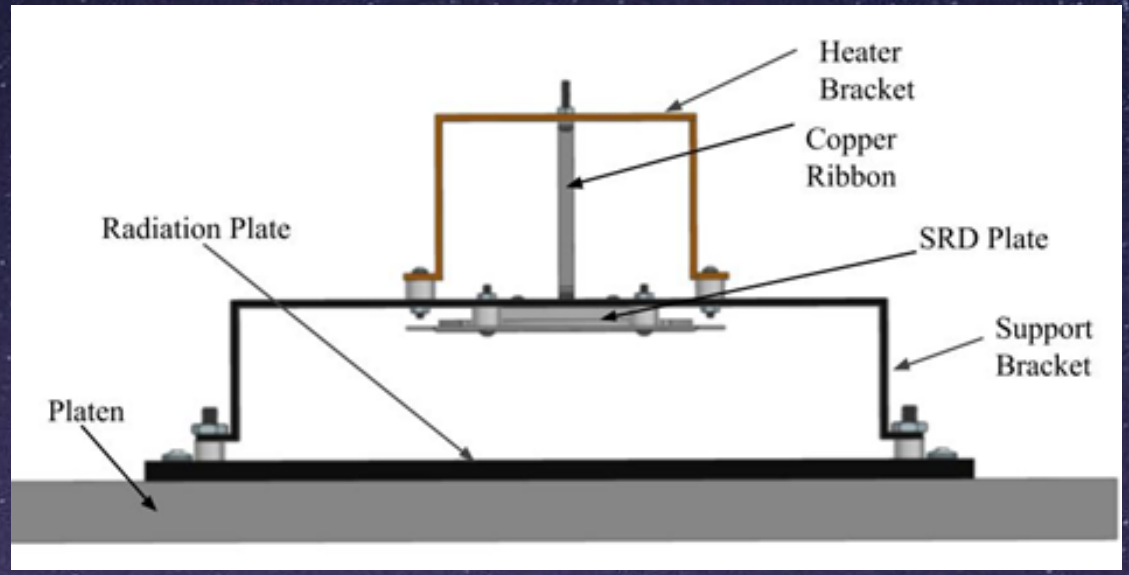
- Machined aluminum plate 10cm x 10cm is one CubeSat side panel
- Four SRD tiles epoxied to the external side of the panel
- Channels on reverse side of plate interface to heat pipe on satellite



TVAC TESTING:
THE TEST APPARATUS

- Apparatus outfitted with thermistors and surrounded with an MLI blanket





- Heat input through electric heaters
- Thermal gasket used to maximize heat transfer from heaters to SRDs

TVAC TESTING:
LESSONS LEARNED

Inconsistent contact between thermistor beads and apparatus

Bond thermistors with thermal epoxy

Thermistor wires create thermal bridges between components

Avoid contact between wires and apparatus

Inconsistent/low bolt torques cause gradients and slow stabilization

Use a torque wrench to secure fasteners

TVAC TESTING:
THE RESULTS

- Testing started with a cold soak
  - Platen set at -75°C
- Heaters set to known power inputs and temperatures monitored until reaching steady state
  - Criteria: $\Delta T < 1°C/hr$
- Temperature data at 12 steady state points was collected

Heater Power Input [W] (+/- 0.05)	Platen Temp. [°C] (+/- 0.2)	Chamber Pressure [µtorr] (+/- 0.5)	SRD Temp. [°C] (+/- 0.2)
0.00	-73.6	Not recorded	-62.7
1.03	-72.6	15.0	-54.0
2.54	-72.6	12.0	-40.5
6.43	-71.4	9.1	-9.9
9.69	-67.1	9.7	9.2
12.46	-64.8	10.0	20.3
14.90	-63.2	10.0	30.2
17.38	-61.9	9.9	39.8
19.84	-60.6	9.5	48.5
22.30	-59.1	9.6	56.6
24.74	-58.0	10.0	63.8
25.87	-56.7	7.6	67.0

DATA ANALYSIS:
ISSUES WITH CALCULATIONS

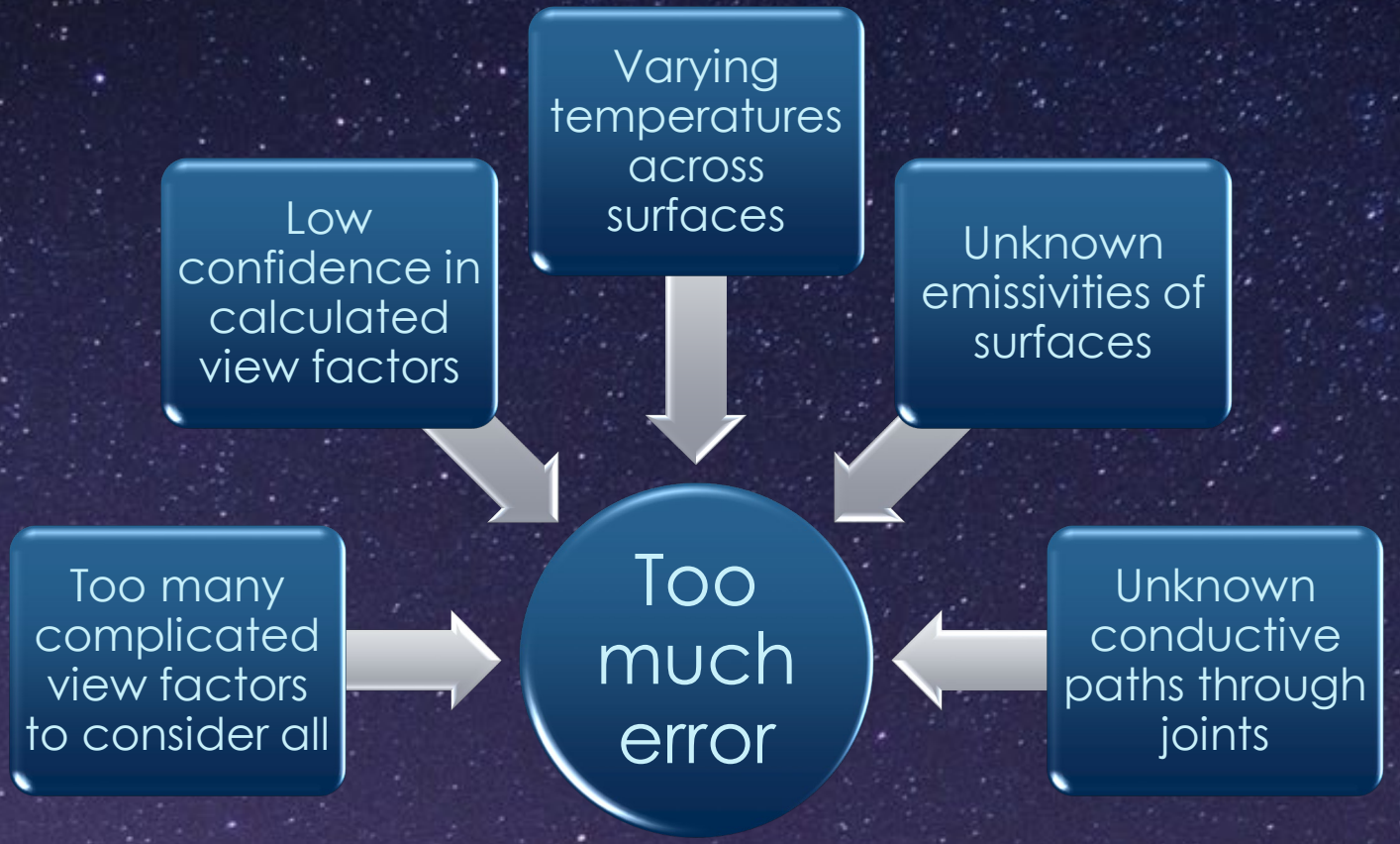
Control volume analysis to determine the emissivity of the SRDs at each steady state temperature

Considered in Analysis	Not Considered in Analysis
• Radiation from largest surfaces • Conductive paths through joints • Approximate view factors	• Radiation from smaller surfaces • Temperature variations across surfaces

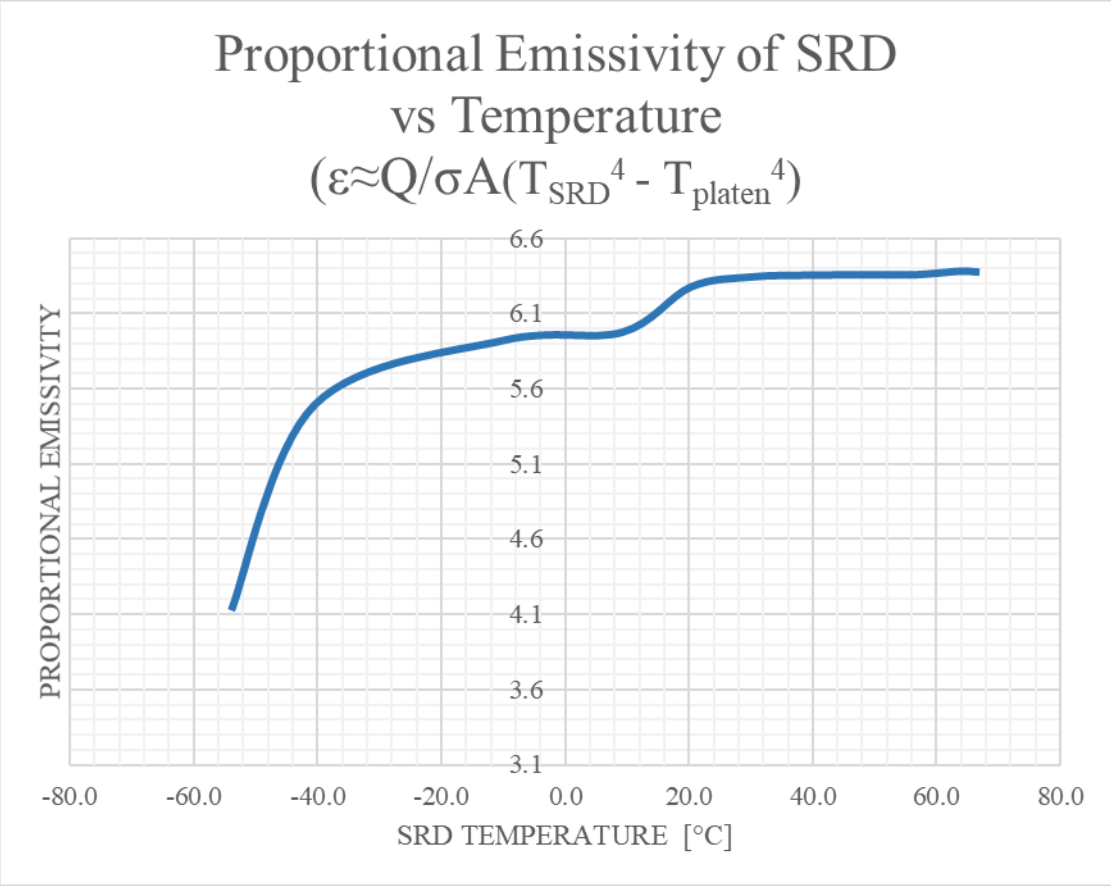
Quickly realized sources of error in these calculations were too high

- **Emissivity values were outside of the allowable range from 0-1**

DATA ANALYSIS:
ISSUES WITH CALCULATIONS



DATA ANALYSIS:
GENERAL TREND



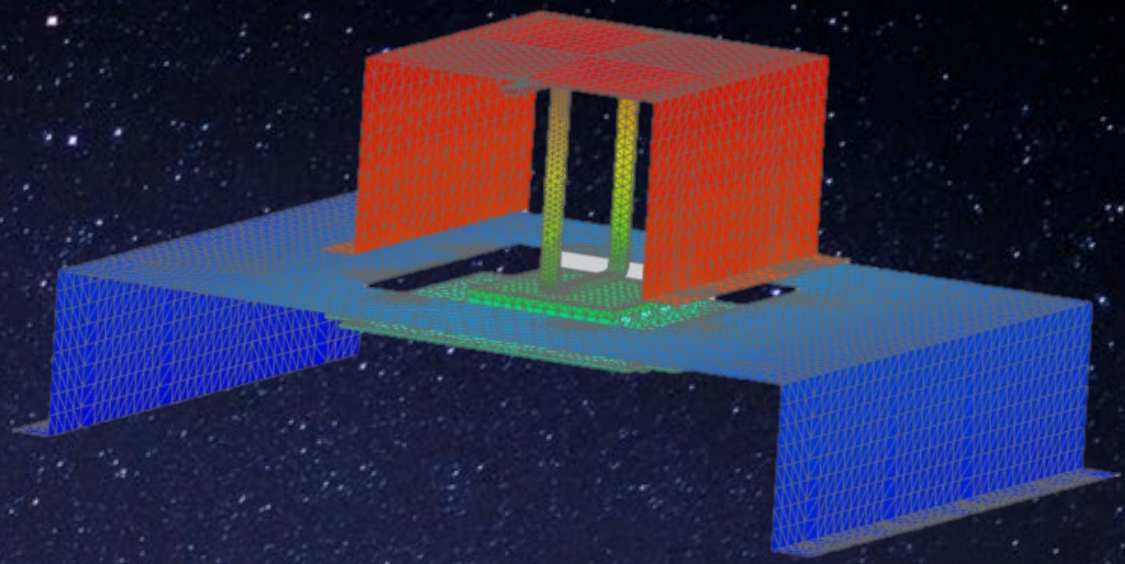
- Able to solve for the general trend in SRD emissivity
  - Rearranging the radiation equation to solve for emissivity
  - Assuming the trend in heater power is proportional to heat radiated from the SRD plate
- Shows an increase in ε with temperature

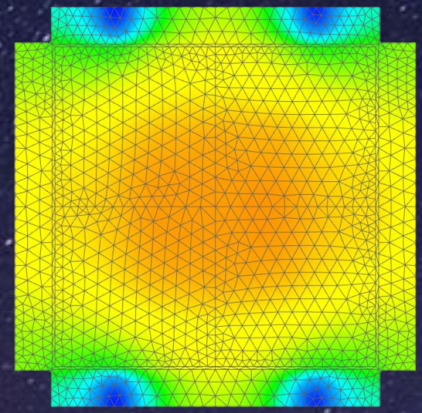
CONCLUSIONS

- **Data shows SRDs are functioning as expected**
- Simplified control volume analysis of TVAC testing is extremely error prone
  - Especially true for a small and complicated test article
  - Small size of SRD plate means a smaller signal to noise ratio compared to large spacecraft
  - Simplifications in calculations that are appropriate for large satellites may not be appropriate for smaller satellites

STEPS FORWARD

- Finite element simulations in NX Space Systems Thermal to determine the SRD emissivity profile
  - Software calculates view factors and radiative couplings
  - Can correlate test data to simulation results at each plateau to determine emissivity
- Use calculated SRD emissivity profile to perform simulations of SRDs on spacecraft





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