LUSEE-NIGHT PARABOLIC REFLECTOR RADIATOR THERMAL ANALYSIS

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ENGINEERING FORWARD

LuSEE-NIGHT Mission Overview

- The Lunar Surface Electromagnetics Experiment (LuSEE-Night) is a planned robotic radio telescope observatory designed to land and function on the far side of Earth's Moon
- The instrument will utilize deployable antennas and radio receivers to potentially observe these sensitive radio waves from the Dark Ages for the first time
- The main science instrument requires cooling
  - 80 W is estimated load to reject to space
- A passive side-facing radiator design was selected for cooling, but the lunar environment presents some challenges for a radiator

LuSEE-NIGHT
https://www.cosmo.bnl.gov/node/5

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LuSEE-Night Environment

- A significant challenge will be for the instrument to survive the harsh, cold, and dark environment of the lunar night on the far side of the Moon long enough to collect and return data to Earth
- The moon experiences 14 days of full sun and 14 days of full shadow
- The LuSEE-Night instrument needs to be able to operate in both extremes
- The radiator needs to be able to operate in sun and shadow conditions
  - The sun will always be 20 degrees to the back of the radiator

https://en.wikipedia.org/wiki/Moon#/media/File:Far_side_of_the_Moon.png

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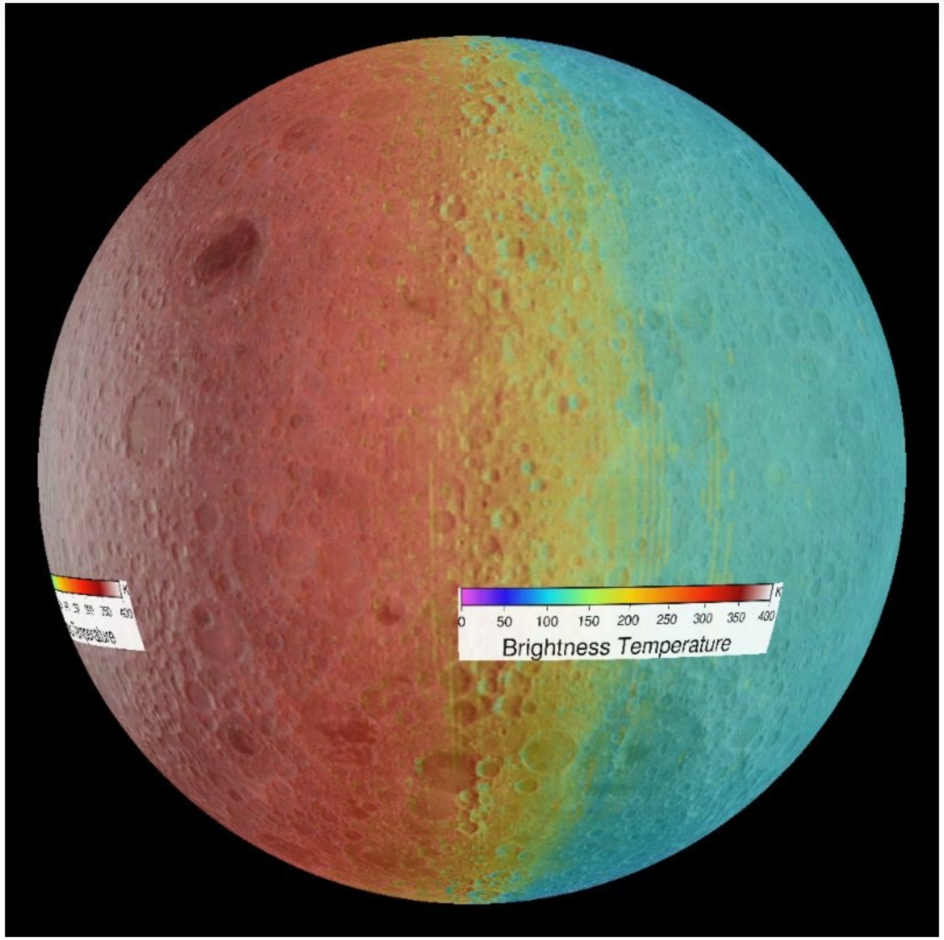
Lunar Environment

- From the NASA LRO mission, mapped IR temperature data of the lunar surfaces is available
  - The lunar surface temperature in full sun is 400 K
    - 400 K is conservative, as the actual temperature prediction is closer to 385 K
  - The lunar surface temperature in full shadow is 100 K
- Direct solar varies little from standard Earth values: 1421 W/m^2 to 1315 W/m^2 [1]
  - Earth is 1414 W/m^2 to 1322 W/m^2 [3]
- Lunar emissivity assumption is 1, which is conservatively high [3]
  - Lunar regolith emissivity is 0.95



https://sos.noaa.gov/catalog/datasets/moon-surface-temperature/

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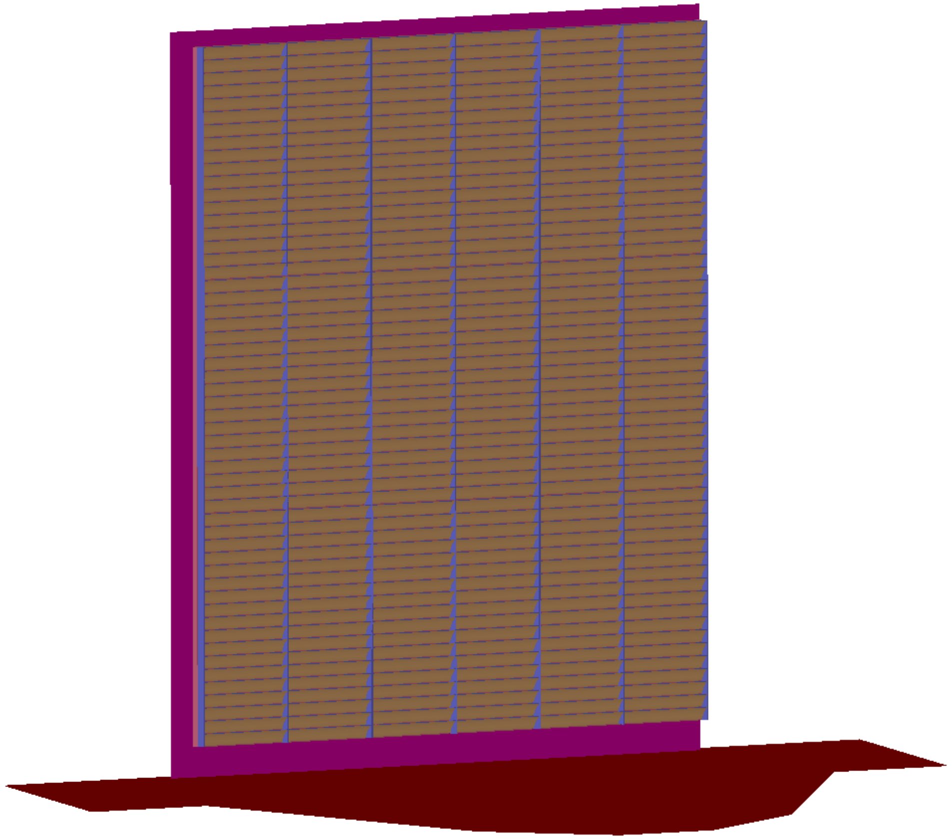
LuSEE-NIGHT PRR Thermal Model

- The project decided to add a parabolic reflector to the radiator to reflect the lunar surface heat to space before it hits the radiator
- The assembly is called the Parabolic Reflector Radiator (PRR)
- We created a highly detailed model to accurately capture the gradients and radiation exchange
  - Parabolic trough surfaces used for reflector
  - Multiple nodes through the length of the fin
  - Multiple nodes through the thickness of the radiator
  - Parabolic reflector edges modeled with 3D bricks
  - Total node count: 52,414



PRR Thermal Model

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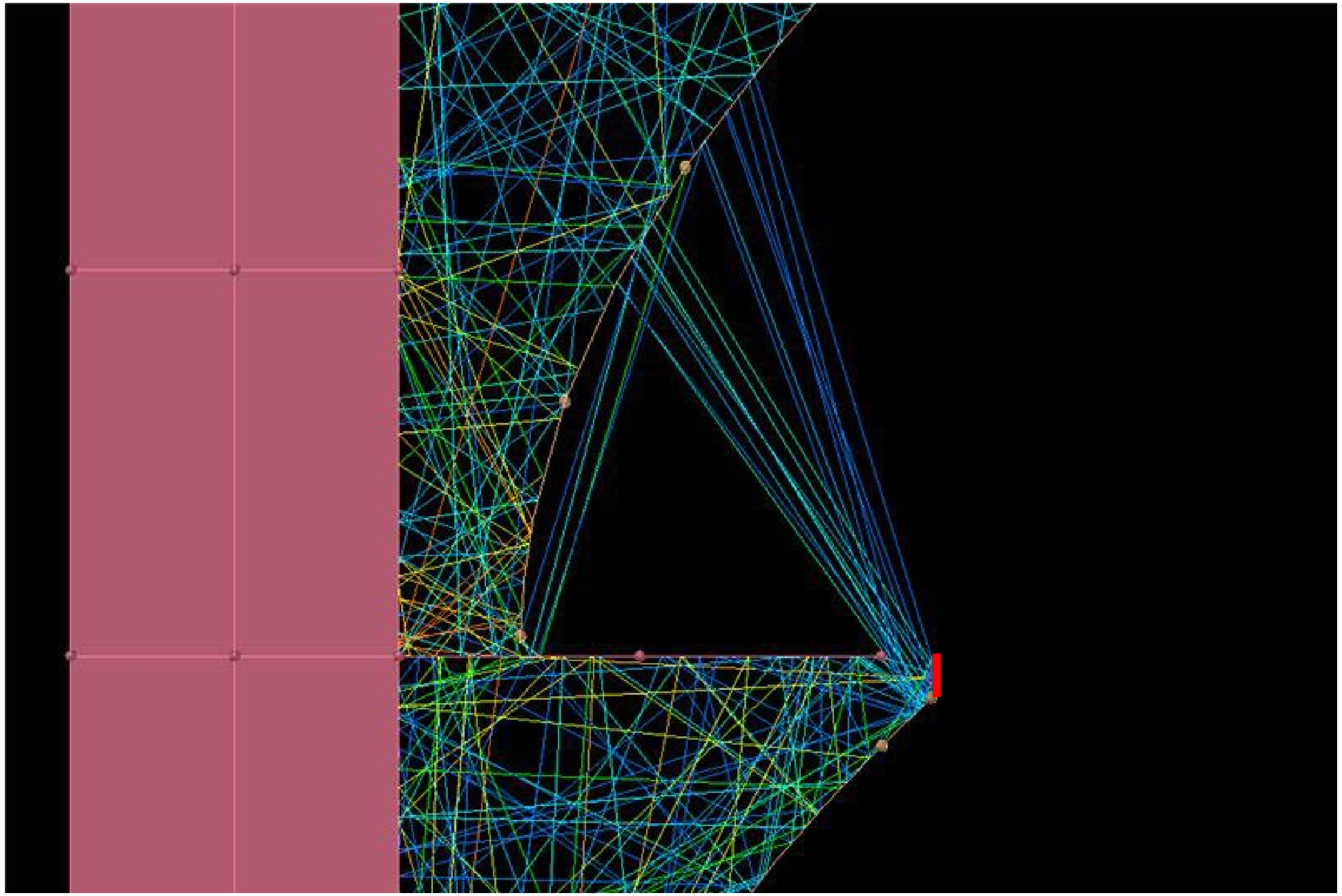
Detailed PRR RADK Checks

- It became important to verify that the radiation model was accurately capturing the effect of the parabolic reflector and focusing the rays in the correct place
  - The specularity of the parabolic reflector is critical to ensuring the rays are going to the right place
- We utilized the Thermal Desktop model to verify this
- These radiation checks identified another important aspect of the radiation heat exchange – that some of the rays are also hitting the back of the reflector lip
  - Shown with red line
  - This surface was added to capture the thickness of the reflector, since the parabolic trough is 2D



PRR Analysis Results

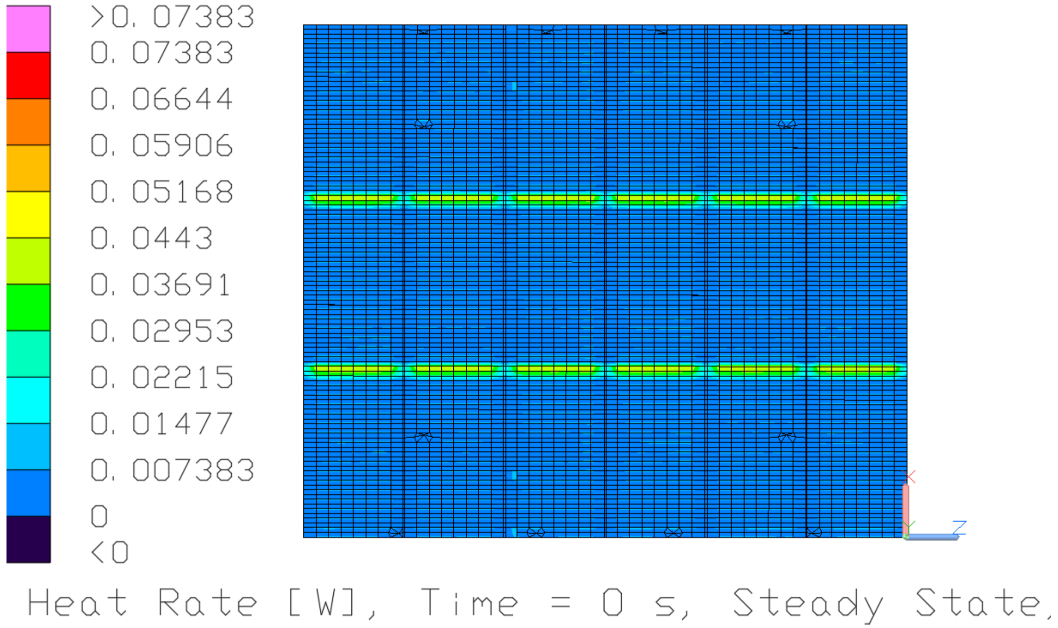
- The driving thermal requirements is to keep the radiator below 231 K (-42 °C)
- Two hot operational cases were analyzed:
  - One with max radiator loading of 80 W
    - Maximum possible loading
  - One with a max radiator loading of 15.8 W
    - Simulates just instrument leak
    - This represents the sink temperature case
- One cold operational case was analyzed
- Results verified that PRR design will meet driving thermal requirement

PRR Thermal Analysis Results

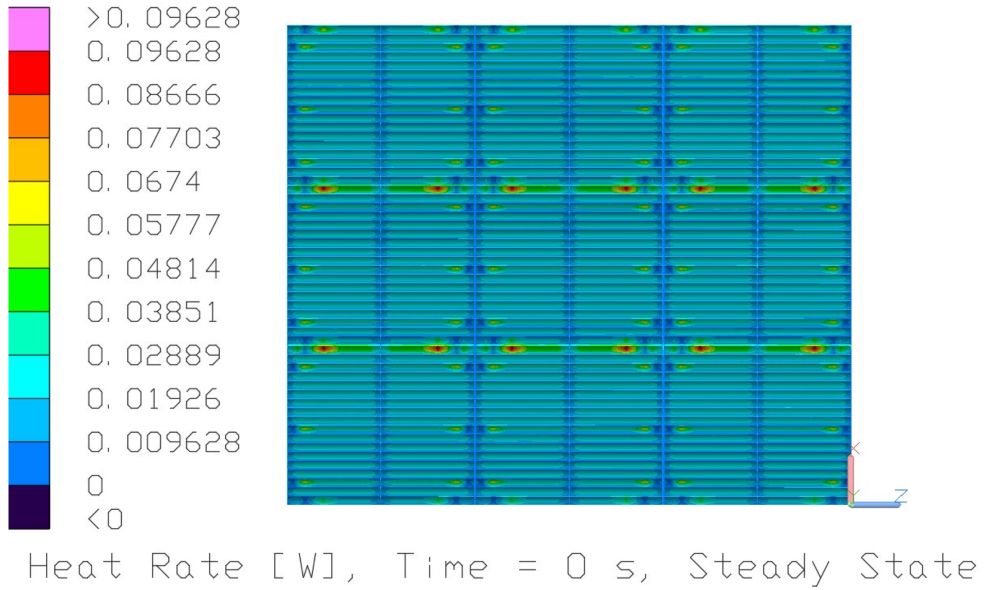
	Hot Op	Hot Op 2	Cold Op
INPUTS			
Lunar Surface (°C)	400	400	100
Deck (°C)	323	323	100
Mounting Plate Temp	323	323	253
Radiator Load (W)	80	15.8	12
ANALYSIS RESULTS			
Radiator Min Temp (°C)	-7.2	-57.0	-102.5
Radiator Max Temp (°C)	-6.2	-56.0	-101.8
Reflector Min (°C)	-6.9	-50.5	-137.9
Reflector Max (°C)	16.4	6.2	-104.3

LuSEE-Night Transit

- During transit out to the moon, the spacecraft will experience direct solar loading on the PRR
- Initially, we began with steady state analyses and full direct solar loading
- Analysis results showed temperatures were way too hot
  - The absorptivity was modestly low, but adds up over such a large area
  - The reflector's high reflectivity means low emissivity, which makes the reflector get hot
  - There is also a very large direct solar heat load hitting the radiator from reflector reflections



Radiator Solar Load = 217.0 W



Reflector Solar Load = 311.3 W

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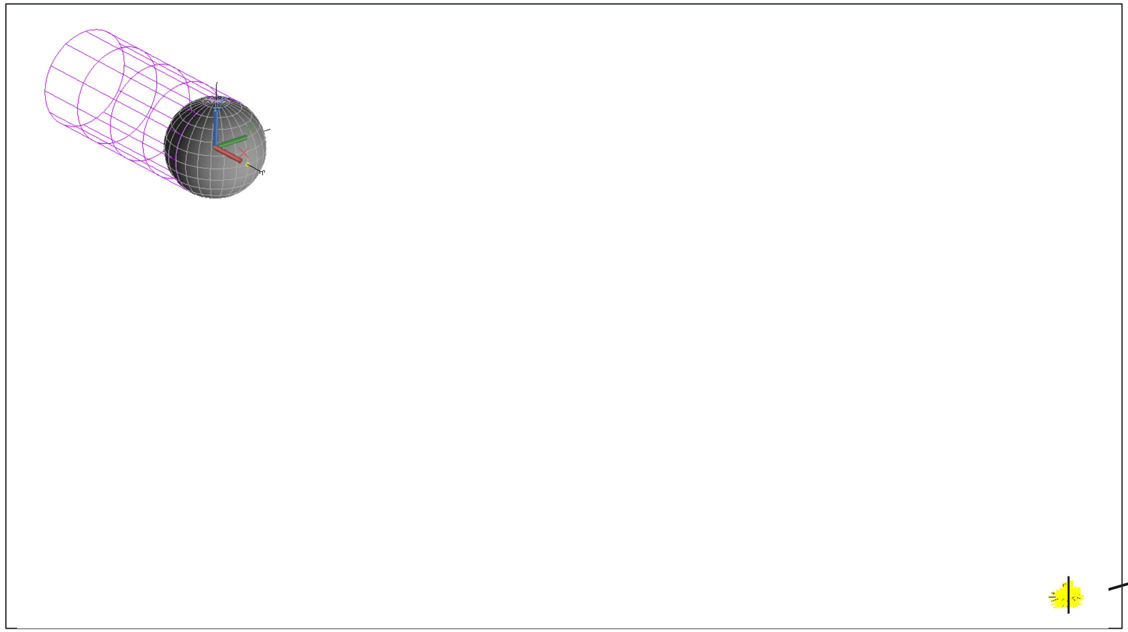
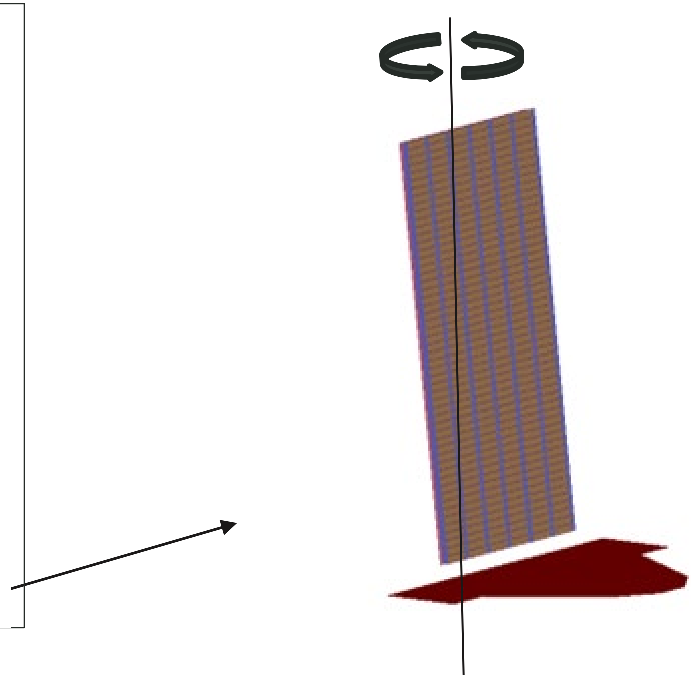
LUSEE-NIGHT TRANSIT

- Changed to a transient analysis with a rotation of 1 rev/hr to reduce loading
  - More realistic than constant full sun
- This was modeled with a planetary orbit with a constant latitude, longitude, and altitude
- Peak temperature dropped dramatically without the constant solar load



Lunar Orbit

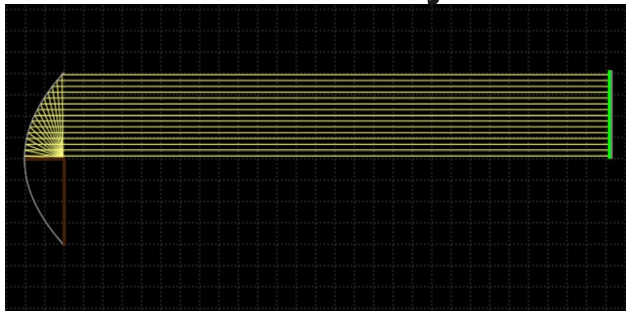


Zoom-in on PRR rotation

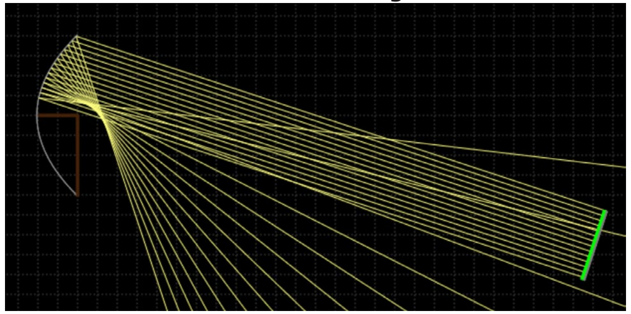
PRR Tilt

- The project agreed to consider a 12° PRR tilt to reduce direct solar loading during transit
- The impact of a 12° tilt on the maximum PRR temperature was significant
  - Maximum reflector temperature was reduced from 185°C to 92°C
- The temperature reduction was significant in order to ensure the Ultem 1010 would not melt

Collimated UV Rays Normal



Collimated UV Rays from Below



	Case A	Case B
INPUTS		
Tilt	0	12
UV Specularity	1	1
PRR Alpha	0.05	0.05
ANALYSIS RESULTS		
Radiator Min Temp (°C)	70.3	-55.2
Radiator Max Temp (°C)	72.8	-54.7
Reflector Min (°C)	78.4	-35.3
Reflector Max (°C)	185.0	92.2

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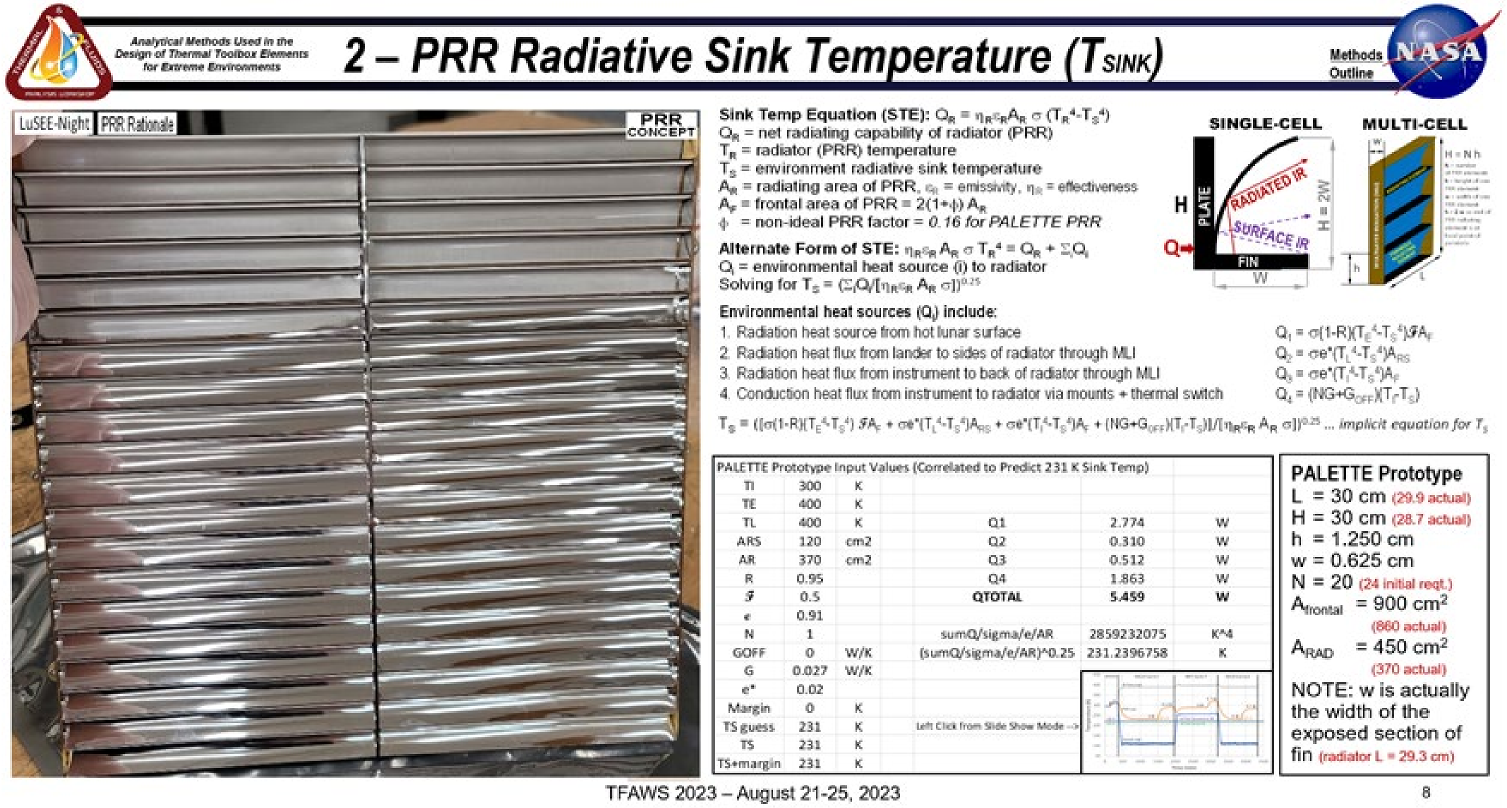
Detailed Model Compared to Excel

- Initial thermal analysis was completed using an excel spreadsheet
- After completion of the detailed Thermal Desktop model, we investigated why results did not match
  - The spreadsheet model was underpredicting



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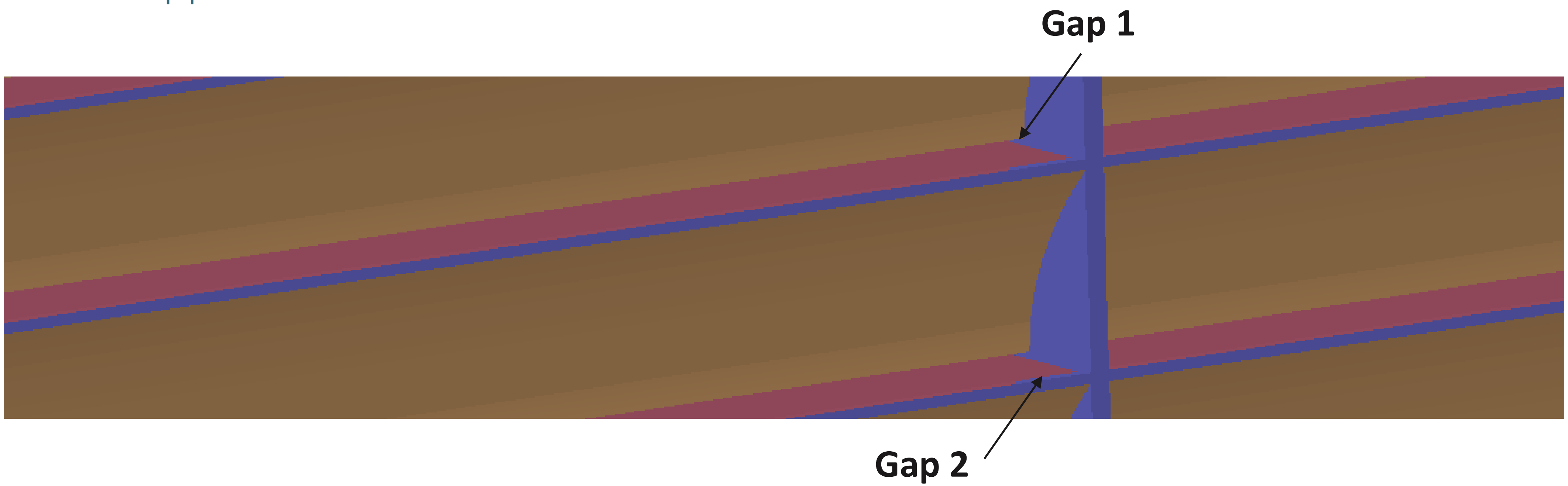
Detailed Model Compared to Excel

- Investigation revealed main discrepancy was the view factor of the radiator to space
- Excel spreadsheet used the area of the fin that is directly seeing space past the intersecting surface of the reflector
- Thermal Desktop was calculating a larger view factor
  - There is a portion of the fin surface that is below the intersecting plane that has a partial view to space (Gap 1)
  - There is another gap of exposed radiator between the fin lip and the reflector top (Gap 2)
- These gaps were confirmed with CAD to be real, and therefore the source of disagreement between the Excel model and Thermal Desktop predictions was identified



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Material Trades

- Structural concerns over the Ultem 1010 led to the consideration of different materials for the reflector and different reflector rib thicknesses
- Analysis results showed little sensitivity to rib thickness or material
  - Confirms that the design is primarily radiatively driven
- All configurations met thermal requirements

	Hot Op	Hot Op	Hot Op	Hot Op	Hot Op
INPUTS					
Lunar Surface (°C)	400	400	400	400	400
Deck (°C)	323	323	323	323	323
Mounting Plate Temp	323	323	323	323	323
Radiator Load (W)	80	80	80	80	80
PRR Rib Thickness (mm)	0.8	0.5	0.8	0.5	1.95
PRR Material	Ti	Ti	Al	Al	Ultem
ANALYSIS RESULTS					
Radiator Min Temp (°C)	-9.1	-9.4	-7.7	-7.7	-10.7
Radiator Max Temp (°C)	-8.0	-8.3	-6.5	-6.6	-9.5
Reflector Min (°C)	-8.4	-8.7	-7.0	-7.1	-9.2
Reflector Max (°C)	8.7	10.8	-4.2	-3.6	17.9

- Ultimately, aluminum was selected as the PRR material, which met both thermal and structural requirements

CONCLUSIONS

- The LuSEE-NIGHT PRR thermal analysis is complete
- Analysis showed thermal requirements are met under operational and transit environments
- Difficult environment drove complex radiator geometry
  - Thermal Desktop was able to capture small but significant features that initial spreadsheets didn't
- This was a really interesting project to work on

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References

[1] Human Landing System Lunar Thermal Analysis Guidebook, NASA, Jan 2021. [Online]. Available: https://ntrs.nasa.gov/citations/20210010030

[2] Cross-Program Design Specification for Natural Environments, NASA, Dec 2019. [Online]. Available: https://ntrs.nasa.gov/citations/20200000867

[3] D. Gilmore, Spacecraft Thermal Control Handbook, Vol 1. El Segundo, CA, USA: The Aerospace Press, 2002.

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