Mapping and Modeling the Effects of Lunar Dust on Thermally Sensitive Surfaces for Heat Rejection Analysis

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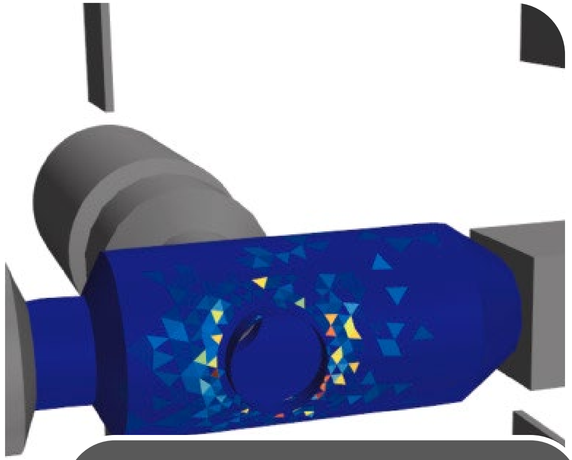
Introduction

- Lunar dust acts as a significant obstacle to effective heat rejection when it lands on thermally sensitive surfaces like radiators
- During Gateway's nominal operation, lunar dust may land on several thermally sensitive surfaces when visiting vehicles dock after landing on the lunar surface
- Previous analysis strategy has been to assume a flat dust degradation for entire radiator panels, either based on a percent area coverage or dust density for entire sections
- The following method generates a discretized look at lunar dust degradation. This discretization allows consideration of an uneven distribution of dust, which aligns with current model predictions

Gateway (NASA)

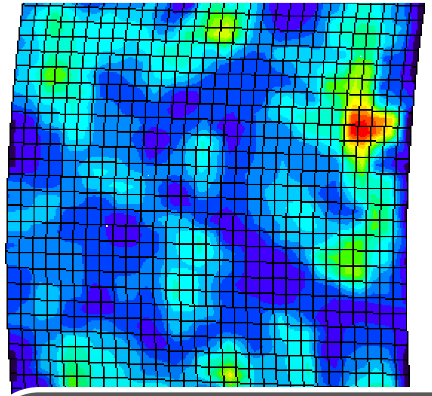
Methodology

Method: Run a multiple step analysis from dust distribution to heat rejection capability output.



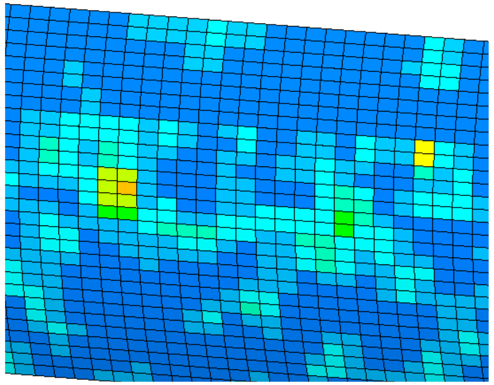
GOLDMAP dust map [1]

- Gateway On-orbit Lunar Dust Modeling and Analysis Program
- 3D dust density distribution map on radiators
- Data per one docking event



Thermal Desktop (TD)

- Data processed to TD format
- Import to describe dust distribution
- Convert to optical degradation impact based on test data relationship

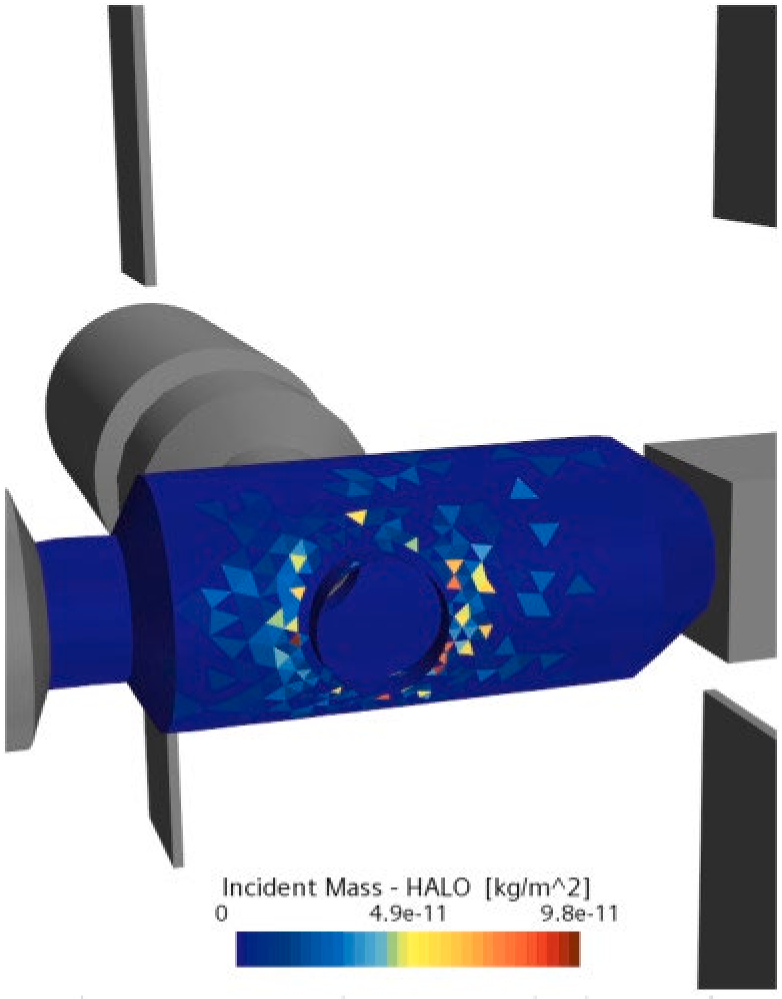


ATCS Fluids Model (AFM) in TD

- Modified HALO AFM to map distribution
- Simulate heat rejection capability (HRC) for worst case config with dust
- Compare to baseline

GOLDMAP Dust Distribution

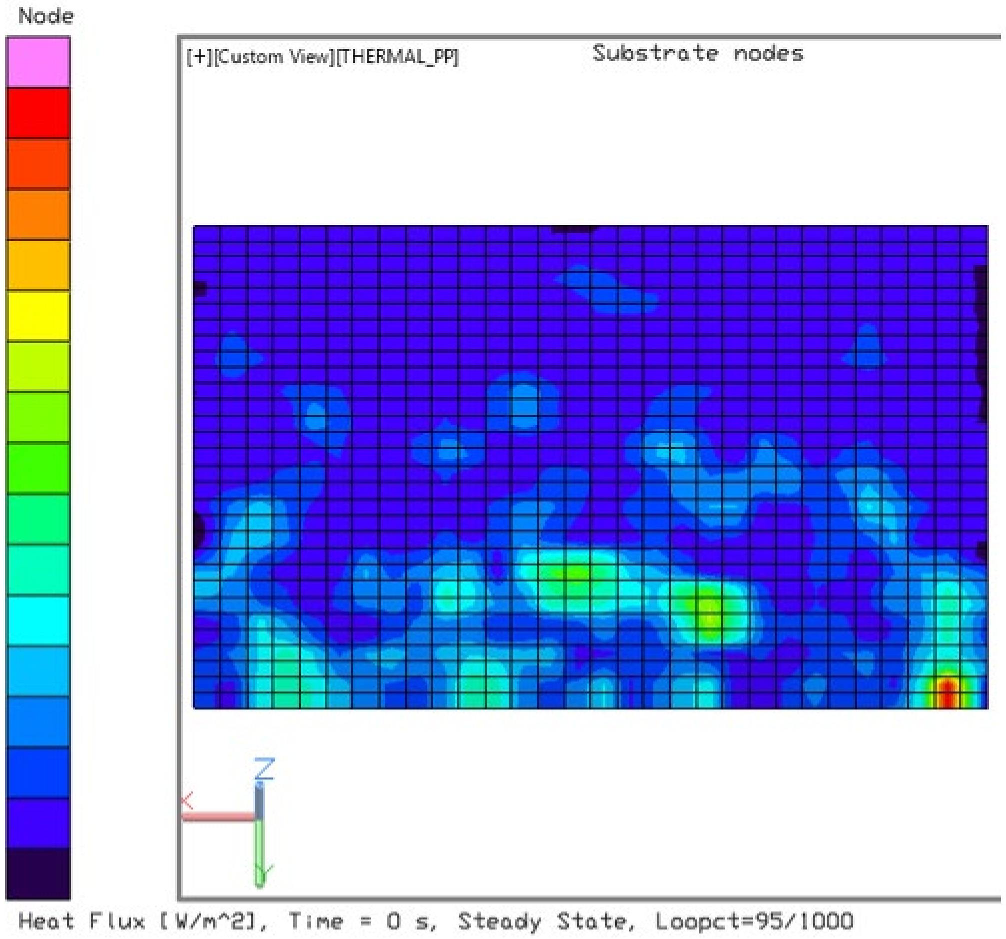
- To model how dust detaches from docking vehicles and lands on Gateway, the Gateway On-orbit Lunar Dust Modeling and Analysis Program (GOLDMAP) was developed [1]
- This analysis uses a Monte Carlo simulation to distribute dust in 1000 cases, varying dust diameter, initial dust load, and dust injection location.
- The results of this analysis creates a ‘map’ of where dust lands on the vehicle, with each dust density associated with a coordinate.



GOLDMAP Dust distribution on HALO [1]

Applying Dust Distribution in Thermal Desktop

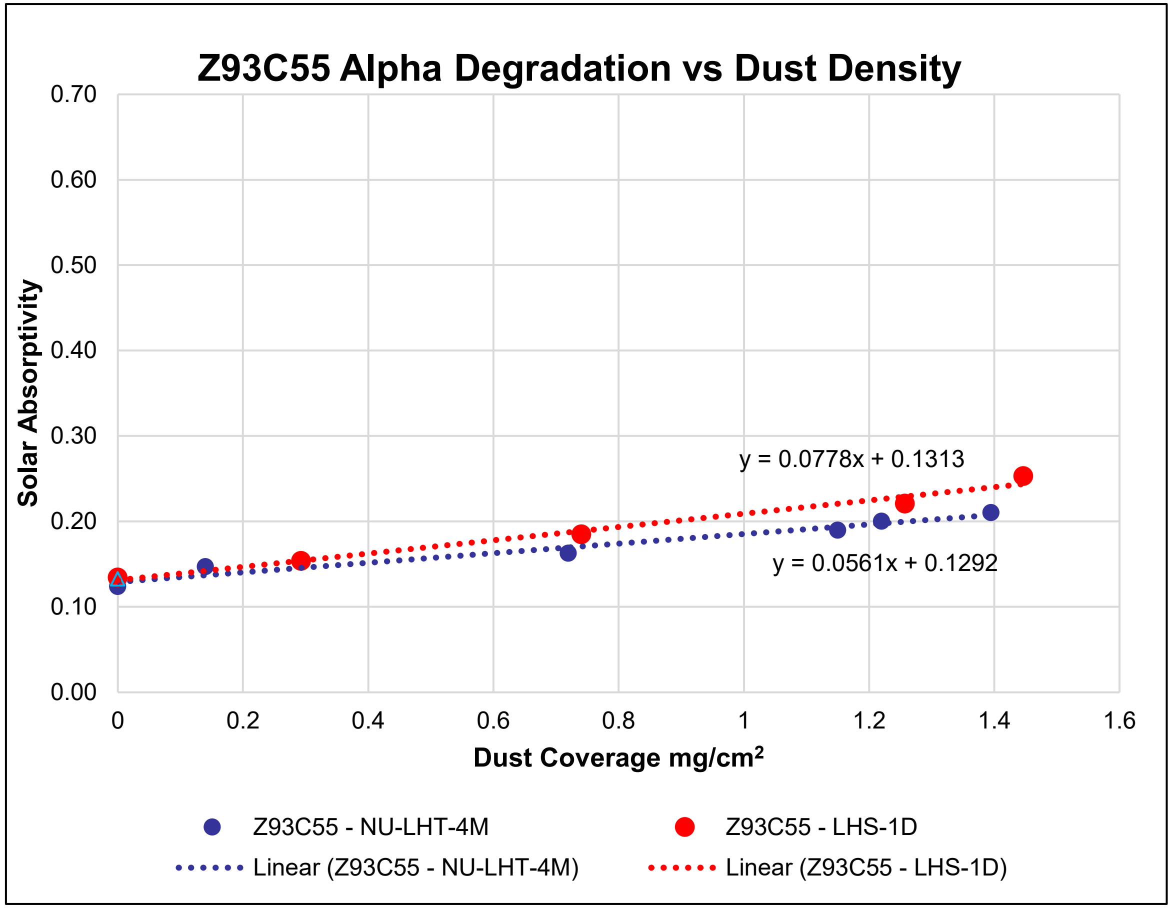
- To map lunar dust in Thermal Desktop (TD), a random GOLDMAP case was imported using the boundary condition mapper. This uses the dust density coordinates to map the dust onto the radiators. To get TD to read the input file, we represented the dust density as heat flux
- To ensure the dust location was accurately mapped, each radiators' nodalization was increased to 30x30
- Using MATLAB, the dust data from this case was trimmed to remove non radiator surfaces to increase accuracy
- The modified file was reimported into the model and run
- The result was a distribution of heat flux (dust density) for each node



Dust distribution on Radiator, shows as Heat Flux in TD

Optics Degradation Calculation

- With the dust densities pulled per node, the absorptivity and effective emissivity of each node can be calculated.
- Absorptivity
  - A fit curve generated from previous test data that examined absorptivity vs dust density was used, similar to the figure shown
  - The dust density of each node was pulled and plugged into the fit curve to get dust alpha degradation values for each node
- Emissivity
  - An initial emissivity of 0.90
  - Emissivity is assumed to be the effective emissivity based on previous test data in seen Ref [2]. This includes the dust insulative properties.
  - From this test data, a degradation curve was generated. Emissivity for each node was then calculated using liner interpolation along this curve



Plot of dust density vs alpha degradation for Z93C55

Implementing Calculated Dust Values

- Using Thermal Desktop's optical override feature, a list of every node and its corresponding absorptivity and emissivity values was input
- The example radiator to the right is using generic white paint beginning of life values with a random dust distribution for example
- With the newly applied dust optics, a heat rejection analysis was run to compare results

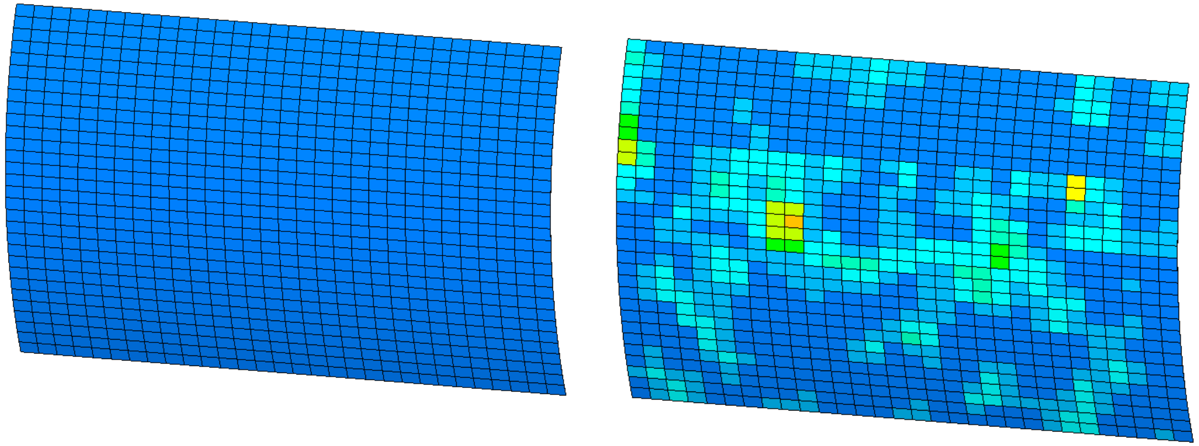


Figure: Before and after of absorptivity for a clean BOL radiator on the left vs dust applied radiator on the right

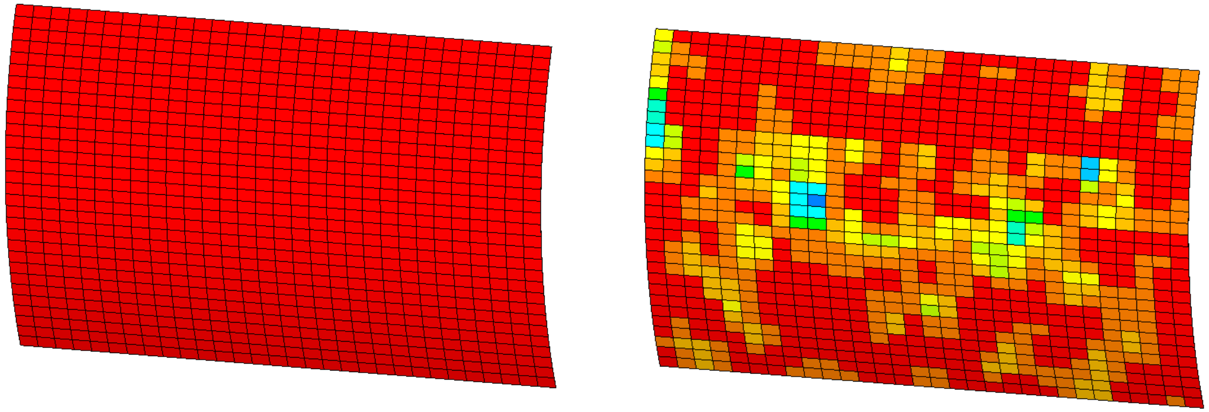


Figure: Before and after of emissivity for a clean BOL radiator on the left vs dust applied radiator on the right

Results

- Example Case
  - Assumed generic white paint optics
    - BOL alpha of 0.16
    - BOL emissivity of 0.9
  - Used LHS1D simulant for dust degradation
  - Assumed a low dust density case
- The table compares the percentage heat rejection decrease from undusted radiators for two different dust degradation calculation methods
- Average dust values method assumes an average dust degradation for entire radiator panels
- Discretized dust values uses the method discussed above, with each individual node having its own dust degraded optics based on a dust distribution map

Case	Average Dust Values [%]	Discretized Dust Values [%]	Difference
1	25.4	24.7	0.7
2	27.3	26.1	1.2
3	29.1	27.4	1.7

Table: Heat rejection percent decrease vs undusted radiators for two dust degradation methods

Conclusion and Pros and Cons

- Conclusion
  - Using a combination of a dust distribution map, Thermal Desktop's boundary condition mapper, dust degradation curves, and optics override, it was possible to create a discredited distribution of dust and models its effects on radiator heat rejection
  - Even in a low dust case and pristine BOL optics, there was a difference in heat rejection between the two methods
- Pros and Cons
  - Pros
    - Provides a more accurate overall heat rejection value and optics table for surfaces
    - Prevents heavily dusted areas from skewing the overall dust density values
    - Allows non-dusted areas of radiators to have their full effectiveness, instead of being considered 'degraded' due to using dust density averages for the entire panel
  - Cons
    - More complicated to calculate optic values. Script required to calculate all absorptivity/emissivity values due to sheer number of values
    - Reuqires highly nodalized model due, increasing model complexity and run time

References

1. Lee, R. G., Worthy, E. S., Willis, E. M., Brown, G. L., Cipriani, F., & Barker, D. C. (2023). Development of a comprehensive physics-based model for study of NASA gateway lunar dust contamination. *Acta Astronautica*, *210*, 616–626. https://doi.org/10.1016/j.actaastro.2023.05.025
2. Hurlbert, K., et al. (2024). "Determination of Percent Area Coverage of Lunar Simulant on a Surface and Observations of Fairy Castle Structures," NASA Technical Reports Server, URL: https://ntrs.nasa.gov/api/citations/20240007706/downloads/THE%202024%20ASCEND%20manuscript.pdf

Questions?