Using Thermal Desktop to Model the Effects of Plume Heating on MLI

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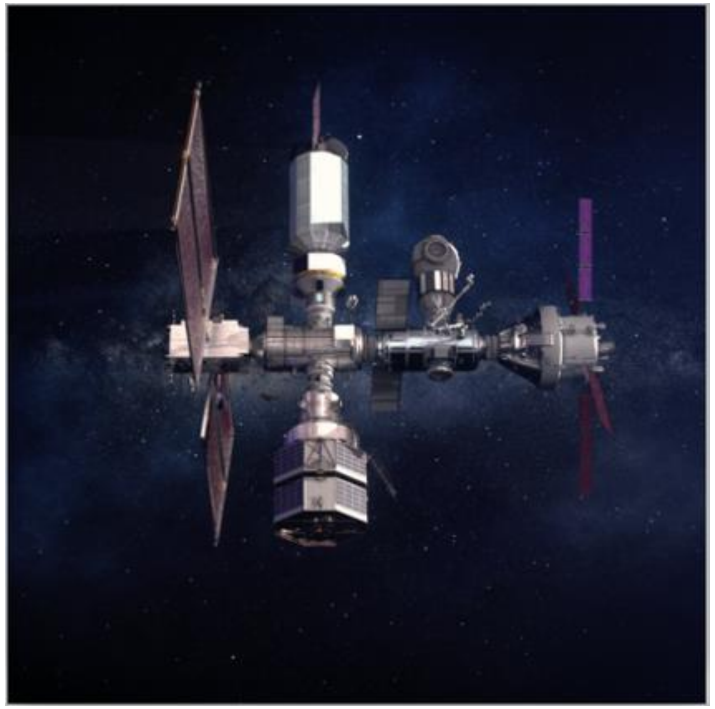
Introduction

- Most MLI on Gateway was chosen based on GEO heritage because the charged particle environment means electrically dissipative materials are needed
- Gateway also has high plume heating requirements for external surfaces due to docking and proximity operations around the vehicle (similar to ISS, though higher because of Gateway's compact configuration)
- Analysis was needed to verify Gateway MLI can withstand plume heating
- Typical modeling of MLI in Thermal Desktop utilizes a simple surface representative of all layers, but this method is not sufficient for characterizing each layer to determine if they will all meet their individual temperature limits
- This presentation goes over how MLI was modeled to better evaluate the effects of plume heating with one example
- MLI was modeled in 3D to provide insight into layer temperatures under plume loads
- To improve confidence in the model, sensitivity studies were done including varying distance between layers, layer conduction/effective emissivity, and plume duration and load



Gateway (NASA)

MLI Stack-up

- To assess our methodology, we chose a stack up with 21 layers of Kapton and mylar without scrim and with beta cloth as the external layer
  - (1) Beta Cloth
  - (2) Single Aluminized Kapton
  - (3) Double Aluminized Mylar
  - (4) Double Aluminized Kapton
- Maximum Material Temperature Limits
  - Sourced from Sheldahl, Dunmore, and JPS
  - Intermittent- no definition of acceptable time limit, used for transient case comparisons
  - Continuous- used for steady state case comparisons

Material	Intermittent (°C)	Continuous (°C)
Beta cloth	315	260
Aluminized Kapton	400	290
Aluminized Mylar	150	121

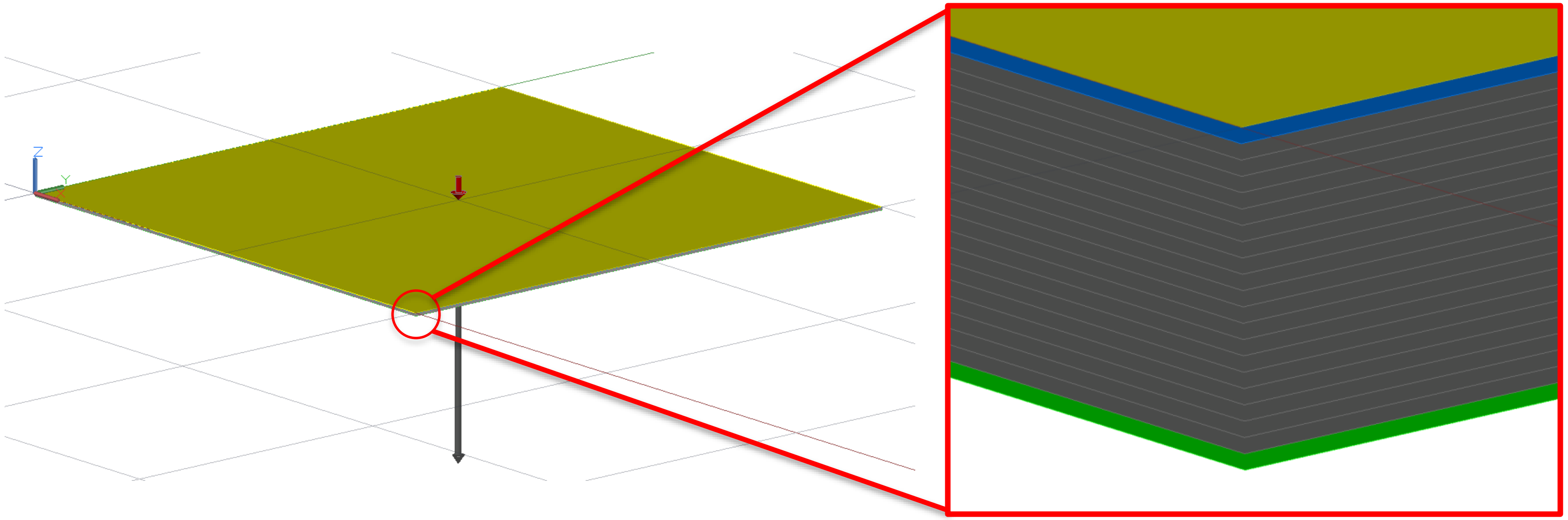
Thermal Desktop Model

- Area of $1m^2$
- Distance between layers set to 0.01 in – sensitivity analysis was run on this parameter
- ε^* set to 0.03 – sensitivity analysis was run on this parameter
- Internal temp set to 20 C (pressure shell temp)
- Edges include a closeout to prevent radks from escaping
- Solar source node to generate solar radks ($1400 W/m^2$)
- Plume heating is input as a heat load of 64 kW/m^2 for 0.5 sec applied uniformly across the external beta cloth surface
- Ran SS with solar source radks without plume to establish initial temperature
- Conduction between layers is then added as a contactor between each surface, the computation of which will be discussed shortly

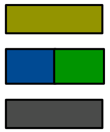
Material	ρ (kg/m^3)	Cp (J/kg/C)	k (W/m/C)
Beta cloth	1270	750	1.38
Kapton	1400	1090	0.12
Mylar	1390	1170	0.14

Material	α	ε	τ
Beta cloth	0.15	0.88	0.28
Aluminized Kapton	0.14	0.05	0
Non-Aluminized Kapton	0.44	0.71	0
Aluminized Mylar	0.14	0.04	0

Model Diagram



Notes:
Distance between layers is small



- The model was run in a steady state case with the solar source node generating radks and no plume heat load applied to determine the initial temperatures
- The model was then run in a 5 min transient case with a 64 kW/m^2 plume load applied uniformly across the 1 sqm surface for 0.5s

- Conduction between layers can be calculated as follows
  - Run the model without a heat load to calculate steady state layer temperatures
  - Use the top layer temperature from steady state case as T_{surf}
  - Use 20 C as T_{sink}

	ε*	$G_{interface}$ (W/m²K)
Assumed ε* values	0.05	5.89
	0.03	3.47
	0.011	2.16
	0.019	1.2

- **Given:**

$$\sigma = 5.67\text{x}10^{-8}\frac{W}{m^2K^4} \qquad \varepsilon^* = 0.03, \varepsilon_{layer} = 0.04, \text{N} = 20$$

$$\varepsilon_{theoretical} = \frac{1}{\frac{1}{\varepsilon_{layer}} + \frac{1}{\varepsilon_{layer}} - 1}\left(\frac{1}{N+1}\right) = 0.00097$$

- **Solve:**

$$\dot{q}_{blanket} = \dot{q}_{radiation} + \dot{q}_{conduction}$$

$$\dot{q}_{blanket} = \sigma\varepsilon^* A\left(T_{surf}^4 - T_{sink}^4\right) = 1.64\ \text{W}/m^2$$

$$\dot{q}_{radiation} = \sigma\varepsilon_{theoretical}A\left(T_{surf}^4 - T_{sink}^4\right) = .05\ \text{W}/m^2$$

$$\dot{q}_{conduction} = \dot{q}_{blanket} - \dot{q}_{radiation} = 1.64 - 0.05 = 1.58\ \text{W}/m^2$$

$$\dot{q}_{conduction} = AG\Delta T \rightarrow G = \frac{\dot{q}_{conduction}}{A\left(T_{surf} - T_{sink}\right)} = 0.174\ \text{W}/K$$

$$G_{interface} = NG = 3.47\ \text{W}/K$$

Results – Varying distance between layers

- From the transient run, the maximum temperature at the center of each layer was recorded
- The below table details the maximum temperature results of varying the distance between layers
- Layer conduction: ε*= 0.03 ($G_{interface} = 3.47\ \mathrm{W}/K$)
- Not all mylar layers are included here to improve readability
- Takeaways:
  - Varying distance between layers has a negligible effect on the temperatures
  - **Model results indicate that temperatures do not exceed the intermittent temperature limits in any of the tested cases while varying distance between layers**

Layer	Material	Max Continuous Temp Limit (°C)	0.01 in (°C)	0.05 in (°C)	0.1 in (°C)	0.5 in (°C)
Outer	Beta Cloth	315	190.7	190.8	190.8	190.9
1	Kapton	400	101.4	101.3	101.4	101.4
2	Mylar	150	89.4	89.2	89.3	89.3
3	Mylar	150	79.9	79.8	79.9	79.9
…						
Inner	Kapton	400	20.8	20.8	20.8	20.8

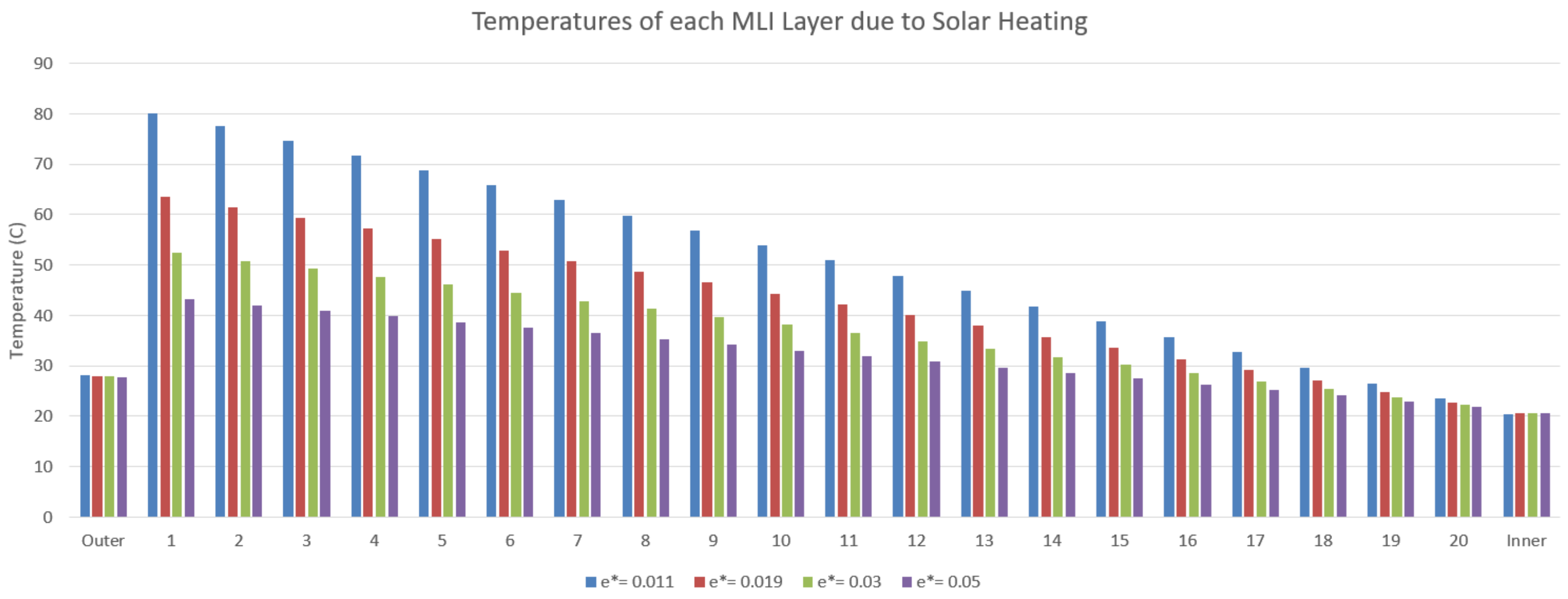
Analysis – Steady state varying emissivity

- Four different interface conduction values ($G_{interface}$) calculated based on varying emissivities
- Distance between layers (d) was assumed to be 0.01 in all four cases
- The steady state layer temperatures for each case are presented below:
  - Steady-State temperature of outer layer is lower than all other layers because it is transmissive and can more easily reject heat to the environment
- **No layers exceed temperature limits**

Layer	Material	Max Continuous Temp Limit (°C)	ε^* = 0.011 (1.2 W/K) (°C)	ε^* = 0.019 (2.16 W/K) (°C)	ε^* = 0.03 (3.47 W/K) (°C)	ε^* = 0.05 (5.86 W/K) (°C)
Outer	Beta Cloth	260	28.5	28.3	28.07	28
1	Kapton	290	80.5	63.9	52.5	43.5
2	Mylar	121	77.9	61.9	51.0	42.4
3	Mylar	121	74.9	59.7	49.4	41.2
…						
Inner	Kapton	290	20.4	20.5	20.6	20.7

Analysis – Steady state varying emissivity

- Steady-State temperature of outer layer is lower than all other layers because it is partially transmissive, conducts heat to lower layers, and can more easily reject heat to the environment
- The lower the ε^* and lower conduction between layers, the higher the temperature of layers near the top of the blanket due to solar heating



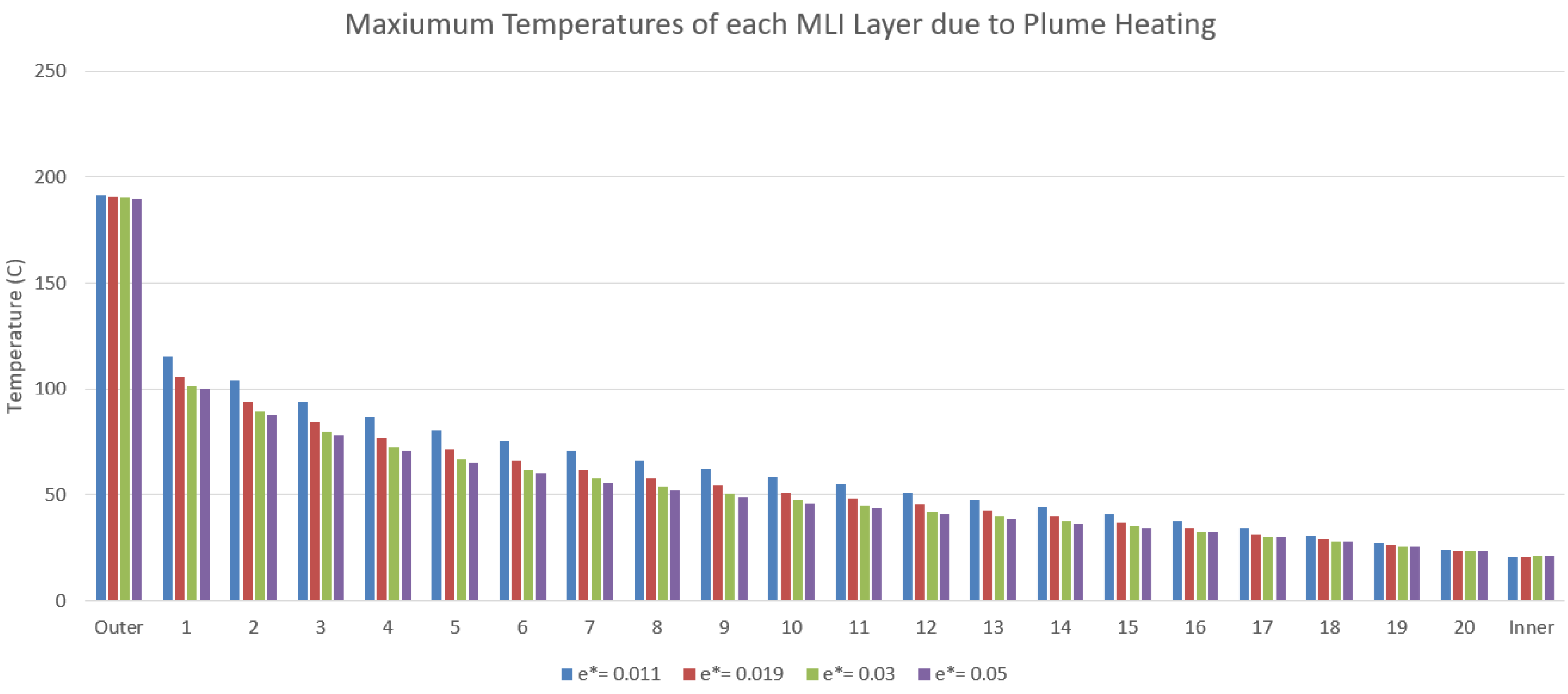
Results – Transient varying emissivity

- The below table details the maximum temperature results of varying emissivity when a 64 kW/m^2 plume flux applied for 0.5 sec
- Distance between layers: d = 0.01 in
- Not all mylar layers are included here to improve readability
- Takeaways:
  - Varying emissivity has a significant effect on layer temperatures
  - **No layers exceed temperature limits**

Layer	Material	Max Intermittent Temp Limit (C)	ε^* = 0.011 (1.2 W/K) (°C)	ε^* = 0.019 (2.16 W/K) (°C)	ε^* = 0.03 (3.47 W/K) (°C)	ε^* = 0.05 (5.86 W/K) (°C)
Outer	Beta Cloth	315	191.6	191.2	190.7	190.2
1	Kapton	400	115.6	106.1	101.3	100.1
2	Mylar	150	104.0	94.2	89.2	87.9
3	Mylar	150	94.3	84.6	79.7	78.4
…						
Inner	Kapton	400	20.5	20.6	20.8	21.3

Analysis – Transient varying emissivity

- Max temperature of each layer due to plume heating is not highly variable when evaluating different ε^* values and conduction between layers



Results- Varying heat flux and duration

- The below table details the maximum temperature results of varying heat flux and duration
- Distance between layers: d = 0.01 in
- $G_{interface} = 3.47\ W/K$ and $\varepsilon^* = 0.03$
- Not all mylar layers are included here to improve readability
- Takeaways:
  - A 64 kW/m^2 plume flux applied for 0.5s causes the highest layer temperatures in this MLI layup
  - The 0.5 kW/m^2 plume flux applied for 64s causes middle layers of the MLI to reach maximum temperatures hotter than the exterior beta cloth. However, the middle layers do not approach the maximum intermittent or continuous temperature for any of the materials in that case.

Layer	Material	Max Intermittent Temp Limit (C)	64 kW/m^2 for 0.5 sec (C)	48 kW/m2 for 0.66 sec (C)	32 kW/m^2 for 1 sec (C)	16 kW/m^2 for 2 sec (C)	0.5 kW/m^2 for 64 sec (C)
Outer	Beta Cloth	315	190.7	181.4	187.9	182.6	83.6
1	Kapton	400	101.3	100.3	101.4	101.6	93.5
2	Mylar	150	89.2	88.5	89.3	89.5	85.6
3	Mylar	150	79.7	79.2	79.8	80.0	78.4
…							
Inner	Kapton	400	20.8	20.8	20.8	20.8	20.9

Conclusions and Recommendations

- Conclusions for this blanket example:
  - All layers remained below their individual intermittent temperature limits under the tested plume load for all ε^*'s assessed. For extremely low ε^*, layers near the top may not meet temperature requirements.
  - The worst-case temperature for outer layers occurs with the highest load and shortest duration plume load analyzed.
  - The inner layer's worst case occurs during the longest duration plume heating but is likely not a cause for concern because it is less likely to overheat compared to more external layers.
- Conclusions and Recommendations
  - This method can be utilized for other blankets for which there are concerns about surviving plume heating
  - This model may be useful to analyze cases for plume heating testing in blankets
  - Transmissivity of layers is very important to results, especially if on the outermost layer, but this would apply to scrim as well
  - Reasonable estimates of distance between layers in the model does not significantly impact temperature results (when a typical ε^* is assumed) so this sensitivity does not need to be run again with future models
  - For other MLI layups the worst-case temperatures will be likely be seen with the highest plume flux and shortest duration, but due to some variability as flux and duration change, it is still recommended that this check be repeated for different MLI layups