THERMAL CONTROL

T3 ORBITAL FLOWSAT — CAL POLY Aerospace Engineering

Astronautics Senior Design 2023-2024
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Orbital Mechanics Model

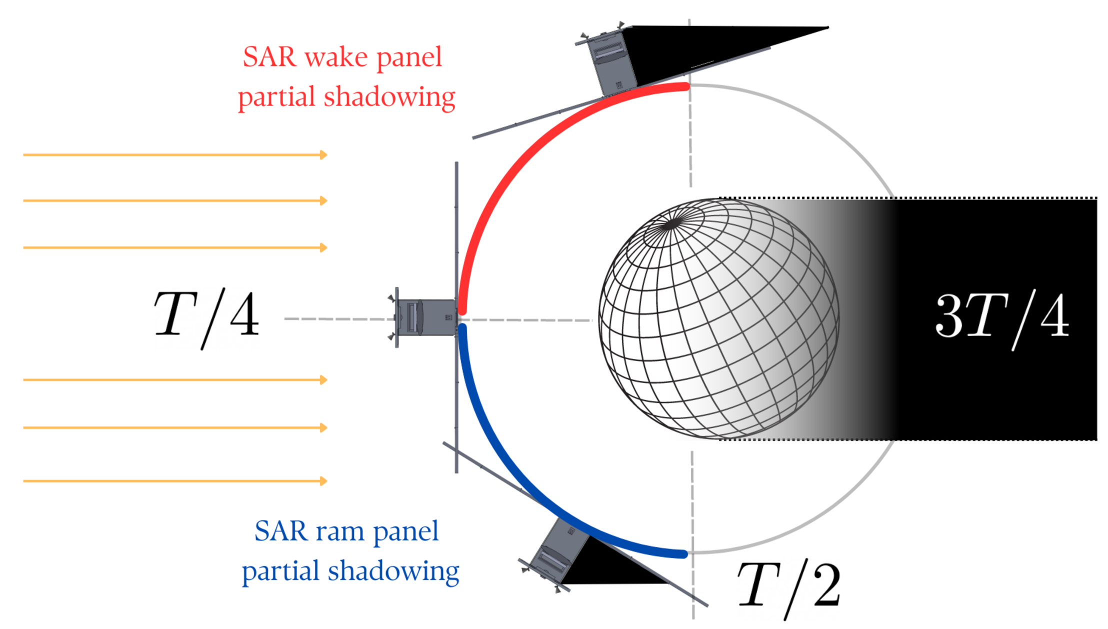


Figure 1. Two-dimensional model for SAR shadowing

Time in Daylight / Eclipse

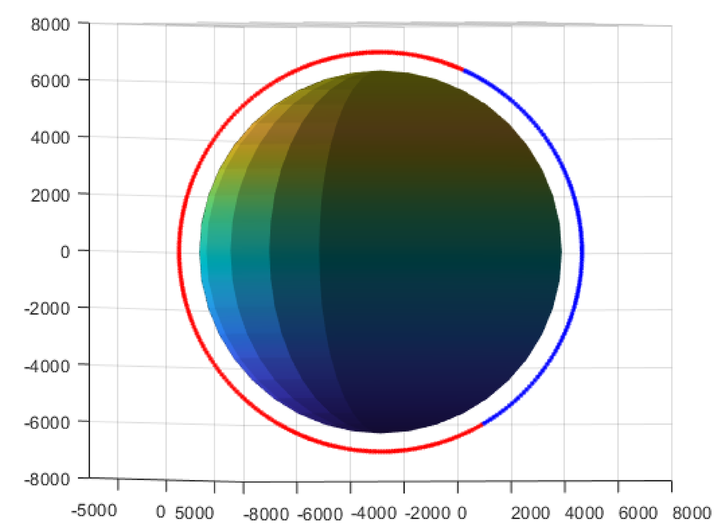


Figure 2. Day (red): 64 min; Eclipse (blue): 35 min

Model Assumptions

1. Circular orbit
2. Sun vector always normal to equator
3. 2D analysis for shading, sun angles, etc. (see **Fig. 1**)
4. Solar array only sees earth, sun (no partial blocking by bus structure or SAR)
5. SAR boom only sees earth, sun (no partial blocking by bus structure or solar array)
6. Bus fully covered in MLI (except for radiators)
7. Design for worst-case internal and external head loads
8. Spacecraft internals kept at constant 9.39 °C
9. Isothermal surfaces [6]
10. Conduction is primary heat transfer mode within s/c

Model Inputs

- Incident solar flux: 1366 W/m^2
- Earth IR flux: 239 W/m^2 [4]
- Earth bond albedo: 0.31 [4]
- Earth average temperature: 255 K [4]
- SAR top: Z93 white paint ($\epsilon = 0.85, \alpha = 0.15$)
- SAR bottom: polished aluminum ($\epsilon =, 0.05\ \alpha = 0.10$)
- Solar array sun side: $\epsilon_{EOL} = 0.85, \alpha_{EOL} = 0.66$
- Solar array anti-sun: Z93 paint ($\epsilon = 0.9, \alpha = 0.15$)
- View factor: differential disk to sphere [5]:

$$F_{1-2} = \left(\frac{r}{h}\right)^2 cos\theta$$

Where θ is the angle between the spacecraft (disk) normal and the center of the earth

Table 1. Thermal Qualifications °C [7]

Mode	S/C internal	MSI	PMWR	SAR (int)	EPS
Qualification	-10, 50	-20, 50	-15, 50	-20, 80	-10, 50
Acceptance	-5, 45	-15, 45	-10, 45	-15, 75	-5, 45
Operations	0, 40	-10, 40	-5, 40	-10, 70	0, 40

Thermal Environment

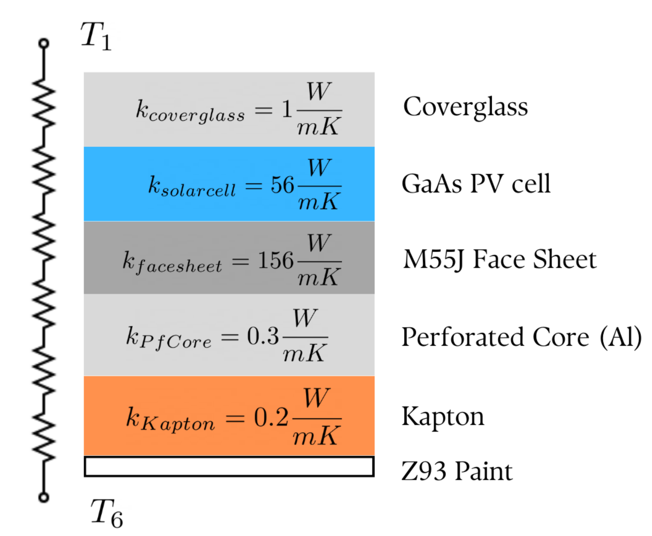


Figure 3. Solar Array Thermal Circuit

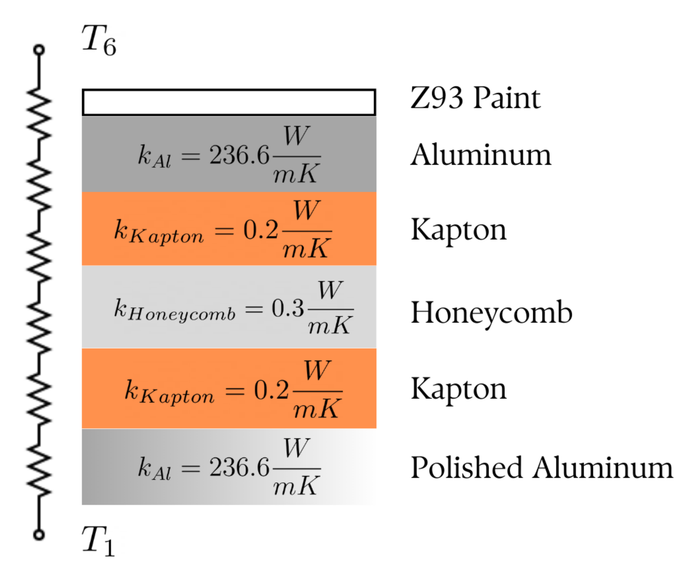


Figure 4. SAR Thermal Circuit

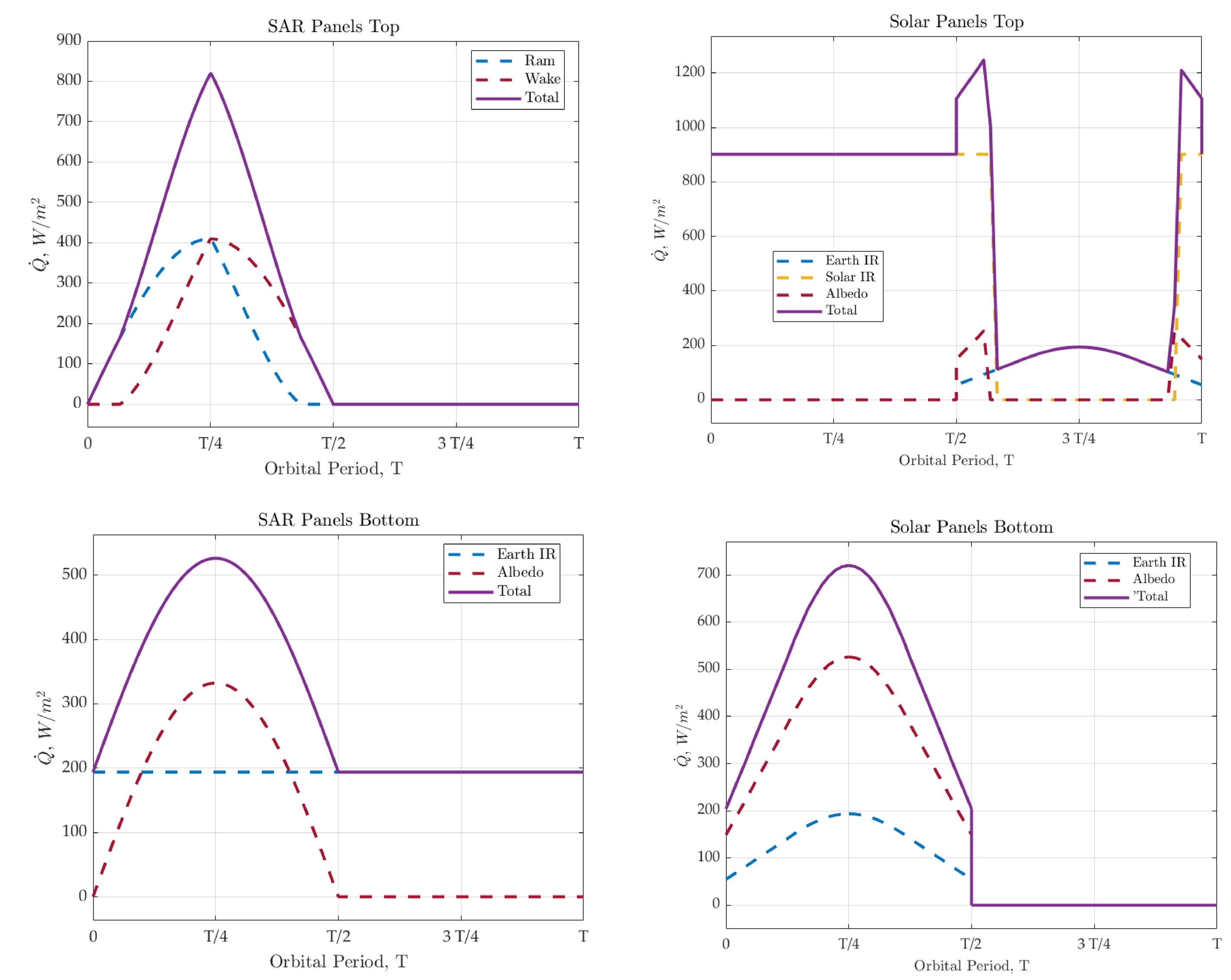


Figure 5. $\dot{Q}_{in}$ on Solar Arrays and SAR by sun and anti-sun faces

Transient Thermal Simulations

Thermal Circuit Analysis

$$R_K = \frac{l}{kA}$$

Where l = thickness, k = thermal conductivity, A = area

Surface Temperatures

$$q_k = \frac{T_1 - T_n}{\sum_{i=1}^{n} R_{k,i}}$$

Where T_n = node temperature, q_k = heat flux

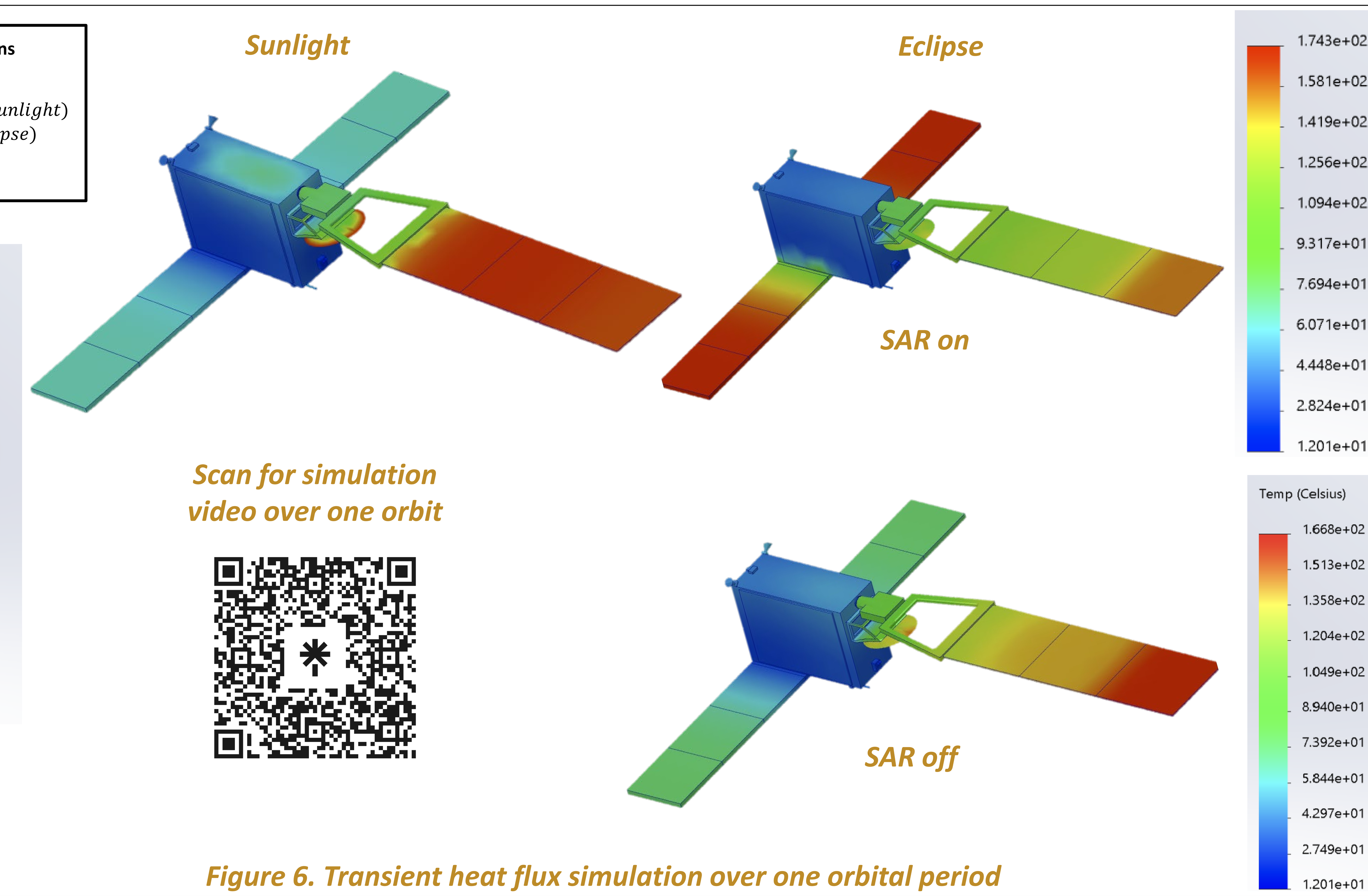
Radiative Heat Transfer

$$\dot{Q} = \sigma A\epsilon\left(T_H^4 - T_C^4\right)$$

Where $\dot{Q}$ = heat flux, σ = Stefan-Boltzmann constant, A = area, ϵ = material emissivity, T_H = hot side temperature, T_C = cold side temperature

Boundary Conditions

$T_{internal} = 291K$
$T_{\infty,hot} = 388\ K$ (sunlight)
$T_{\infty,cold} = 2\ K$ (eclipse)
$q_{k_{internal}} = 464\ W$
$n_{layers,MLI} = 20$



Scan for simulation video over one orbit

Figure 6. Transient heat flux simulation over one orbital period

Multi-Layer Insulation (MLI)

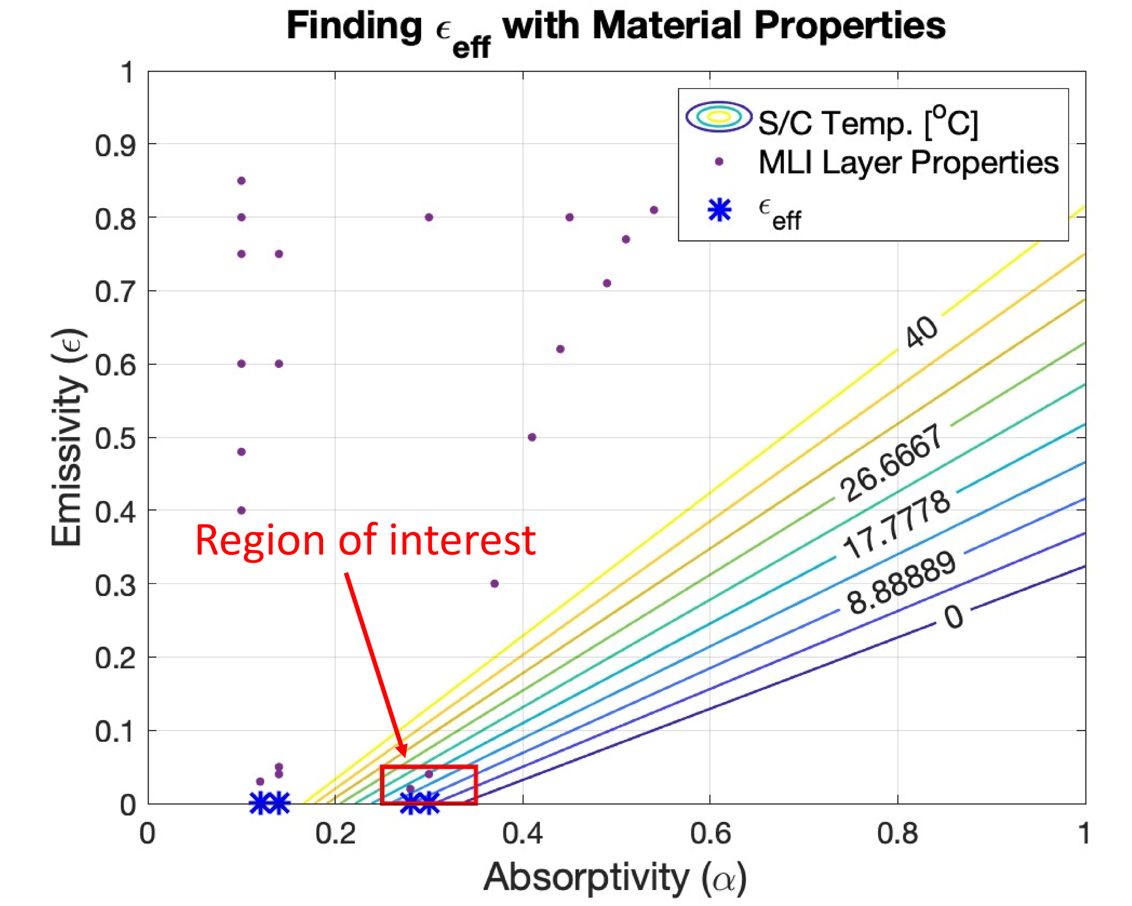


Figure 7. Effective Emissivity in Blue Compared to S/C Temp

$$\epsilon_{eff} = \left(\frac{1}{\epsilon_{inner}} + \frac{1}{\epsilon_{outer}} - 1 + \frac{2n}{\epsilon_{middle}} - n\right)^{-1}\ [1]$$

Assuming a constant internal heat flux of 425 W, the absorptivity and emissivity of space materials can be compared and compiled to calculate MLI effective emissivity. The absorptivity is assumed to be that of the outer layer. Realistically, the stitching of the MLI dominates and typically results in an emissivity of 0.025.

$$\epsilon_{calculated} = 7.39e-04$$
$$\epsilon_{realistic} = 0.025$$
$$\alpha = 0.3$$
$$thickness = 8.2\ mm$$
$$m_{total} = 2.4\ kg$$

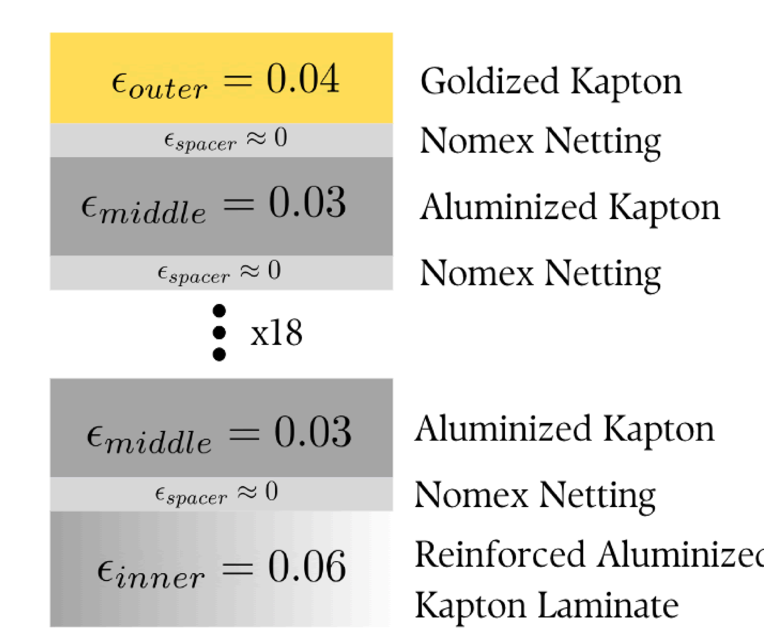
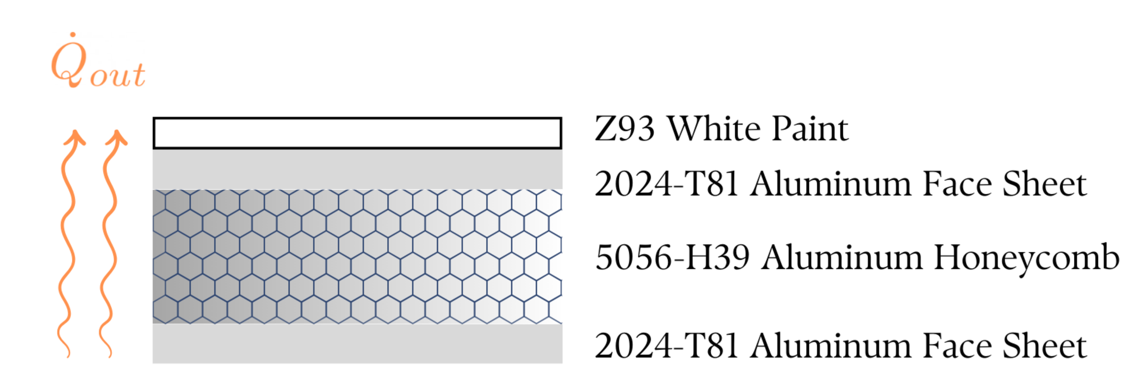


Figure 8. Layers of MLI Colored Based On Material [2, 3]

Radiator



Simplest Solution: Passive Radiator

$$\sum\dot{Q}_{solar} + \sum\dot{Q}_{albedo} + \sum\dot{Q}_{IR} + \dot{Q}_{elect} = \dot{Q}_{out,rad}$$

Assuming isothermal behavior for solar array and SAR panels, $\sum\dot{Q}_{in} = 795W$; and $\dot{Q}_{elect} = 464W$,

$$\dot{Q}_{rad} = 1260W \rightarrow T_{rad} = 430K, A_{rad} = 2.3m^2$$