Modelling of Radiative Heat Transfer of a Square Trihedral Design Radiator Panel on the Lunar Surface

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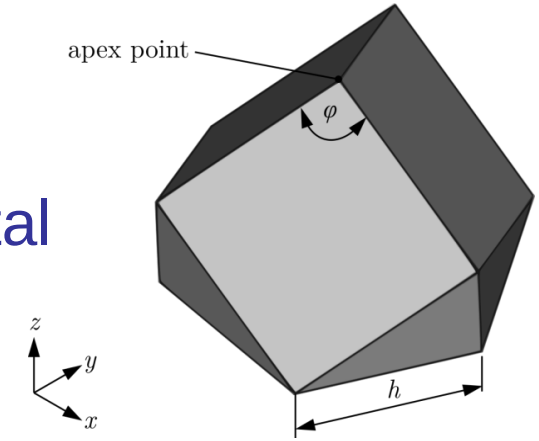
Contents

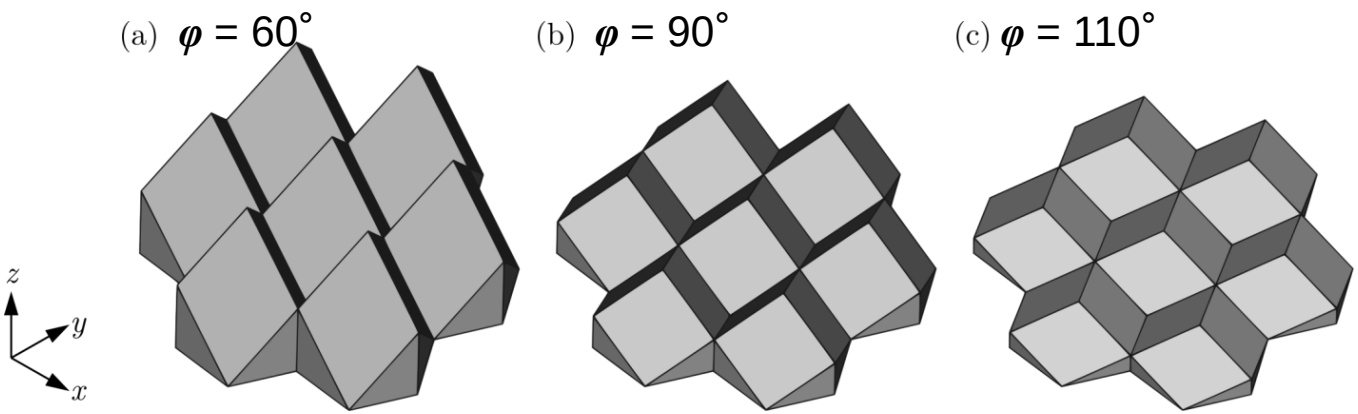
Introduction

- Power requirements for telecommunication satellites has increased from 2-5 kW to 20-30 kW since the 2000's.
- Increased miniaturisation of electronics and rapid growth of smallsat industry.
- This has led to greater heat dissipation requirements for spacecraft radiators.
- New concepts have been developed in recent years in order to enhance radiator performance.

Trihedral Design Radiator

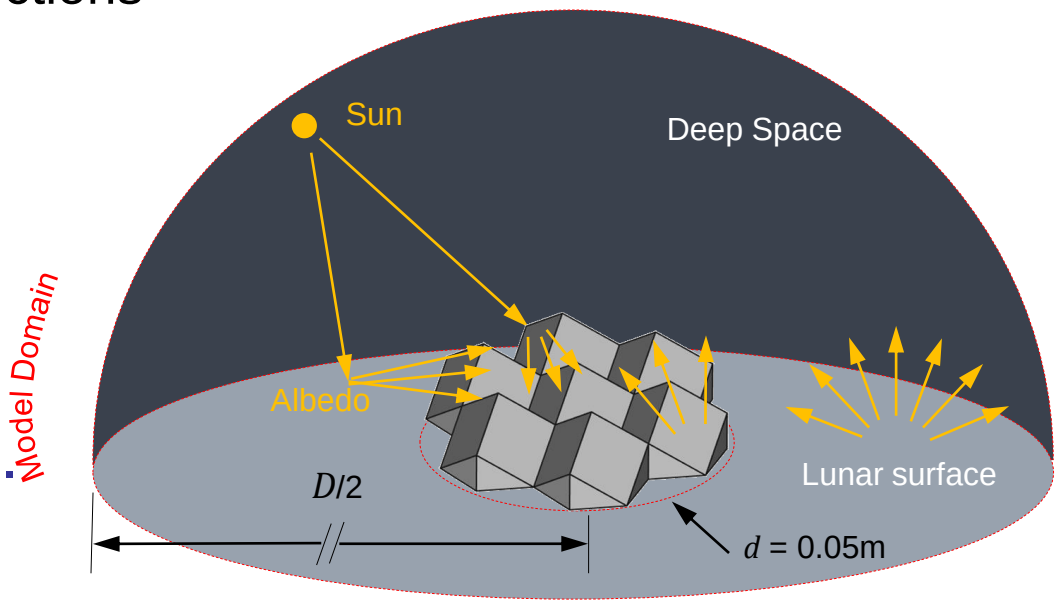


- Definition: "*Three plane faces which meet at a common apex point*".
- Aims to minimise effects of environmental radiation sources and increase the surface area visible to deep space.
- Single trihedral element can be tiled into an array.
- Similar geometry to corner cube retro-reflectors used in radar and optical industries.



Model Description

- Geometry on lunar surface with coordinates at Apollo 17 landing site (20˚N, 31˚E).
- Develop **radiative** model which takes into account all environmental sources of heat:
  - Direct solar flux
  - Indirect solar flux reflections
  - Albedo flux
  - Lunar infra-red flux
  - Internal heating
- Determine radiative heat transfer from each radiator surface.



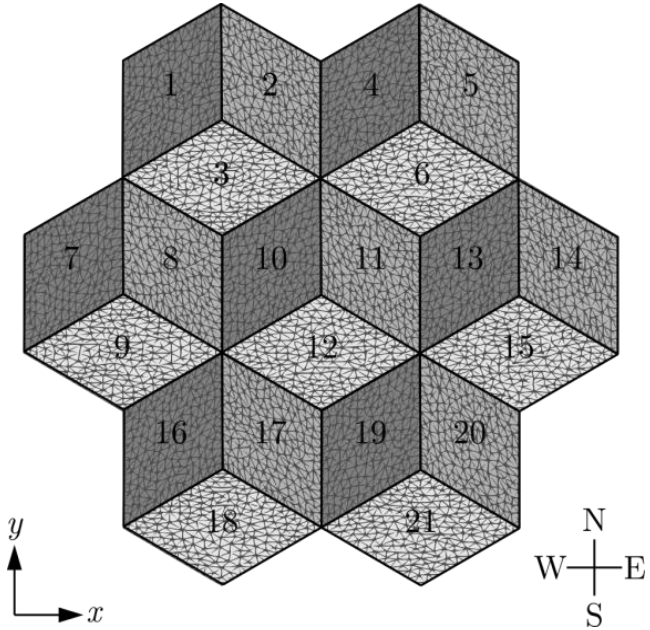
Model Description

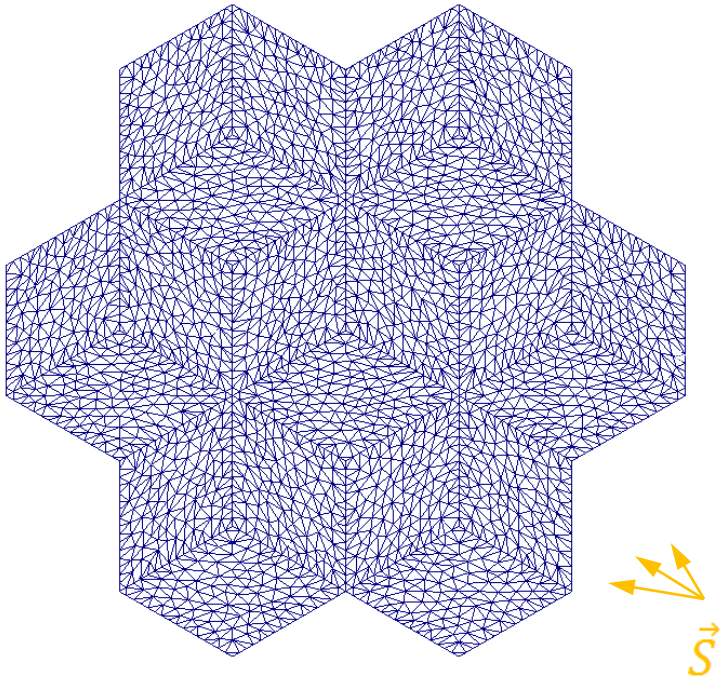
- Solar UV flux
  - Direct incident irradiation:

$$q''_{solar_{direct}} = G_{SC} \cos\theta$$

  - Direct incident irradiation per surface:

$$q''_{solar_{direct},i} = \frac{1}{A_i} \sum^{k} q''_{solar_{direct},k} a_k$$

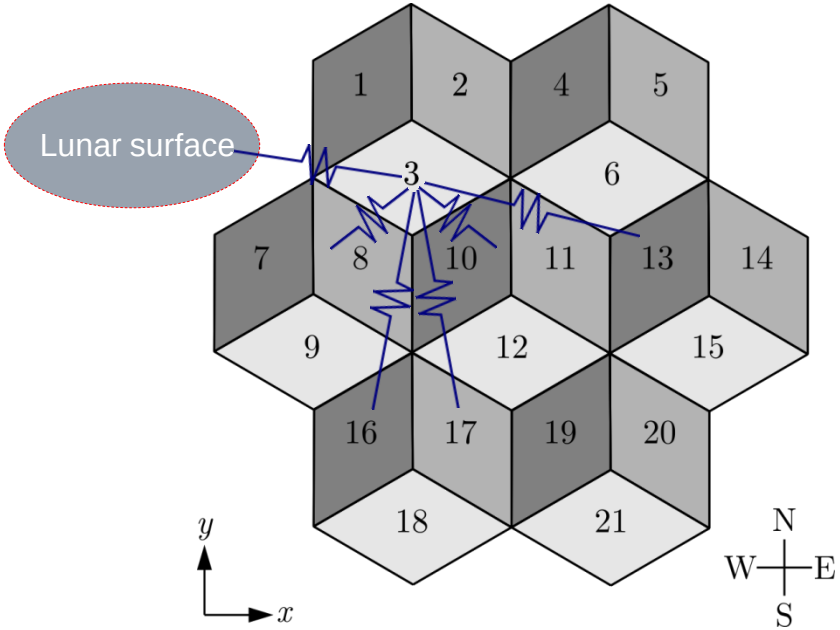




Model Description

- Solar UV flux
  - Indirect (diffuse) reflections and lunar Albedo by Radiation Network Methodology.
  - For each surface:

$$J_i(1-F_{ii}) - \sum_{i \neq j} F_{ij} J_j = (1-\alpha_i) q''_{solar_{direct},i}$$

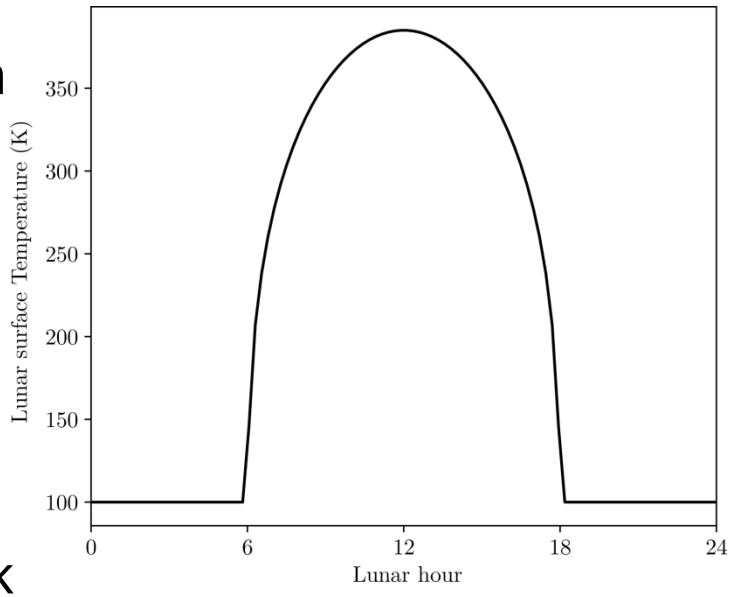


	α_{UV}	ε_{IR}
OSR[1]	0.12	0.8
Moon[2]	1-0.12	0.97

[1] Vlassov, V. *et al.*, 2010. J. Braz. Soc. Mech. Sci. 32, 400-408.
[2] Racca, G., 1995. Planet. Space Sci. 43, 835-842.

Model Description

- Lunar IR flux
  - Diffuse Infra-red heat radiated from lunar surface.
  - Lunar surface temperature varies as a function of location, time and surface properties[2].



T_{lunar} at Apollo 17 landing site

  - As before, apply Radiation Network Methodology to IR sources:

$$J_i[1 - F_{ii}(1 - \varepsilon_i)] - (1 - \varepsilon_i)\sum_{i \neq j} F_{ij} J_j = \varepsilon_i \sigma T_i^4$$

  - Setting T here for all radiator surfaces to a maximum allowable temperature of 40℃.

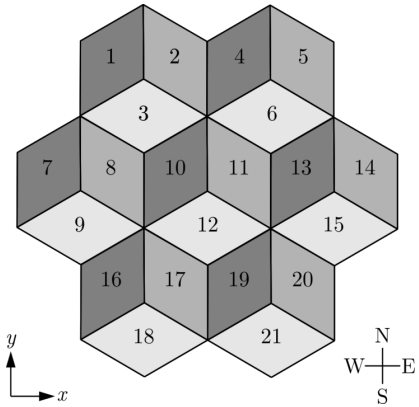
Model Description

- Net radiative heat transfer per surface
  - Difference of outgoing less incoming sources of heat:

$$q_{net,i} = \left(q_{solar_{out},i} + q_{IR_{out},i}\right) - \left(q_{solar_{in},i} + q_{IR_{in},i}\right)$$
$$= \left[\frac{\varepsilon_i A_i}{1-\varepsilon_i}\left(\sigma T_i^4 - J_i\right)\right] - \alpha_i\left(q_{solar_{direct},i} + q_{solar_{indirect},i}\right)$$

- Total radiator heat transfer rate:

$$q_{rad} = \sum_{i=1}^{21} q_{net,i}$$



Model Description

- View Factor Determination
  - Monte Carlo based Ray Tracing.
  - Shoots N rays originating from face centroid with a distribution defined by Lambert's cosine Law:

$$\gamma_{\mathbf{n}} = \sin^{-1}\sqrt{R_{\gamma_{\mathbf{n}}}}$$

$$\phi_{\mathbf{n}} = 2\pi R_{\phi_{\mathbf{n}}}$$

  - where:

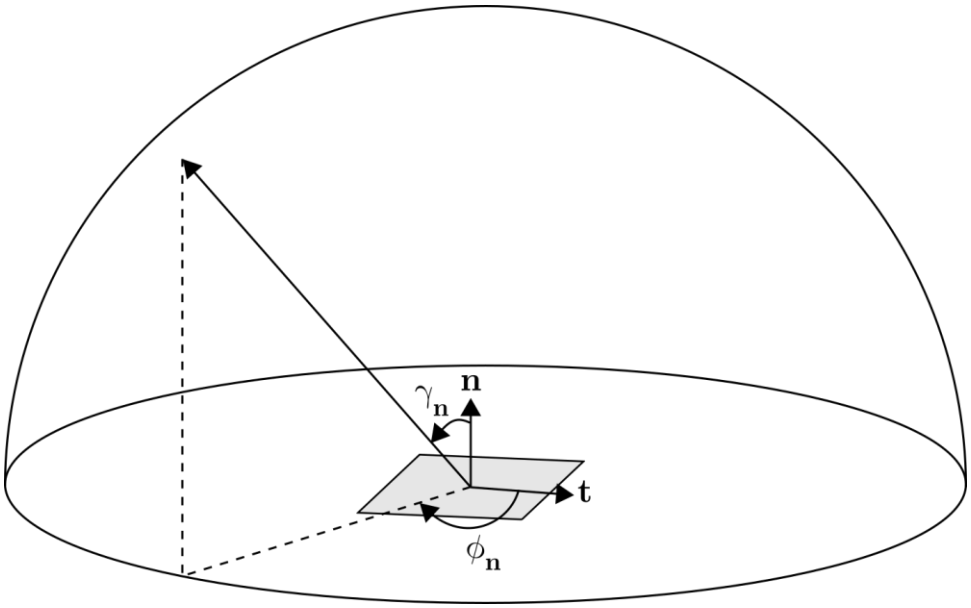
$$0 \le \gamma_{\mathbf{n}} \le \frac{\pi}{2}$$

$$0 \le \phi_{\mathbf{n}} \le 2\pi$$

$$0 \le R \le 1$$

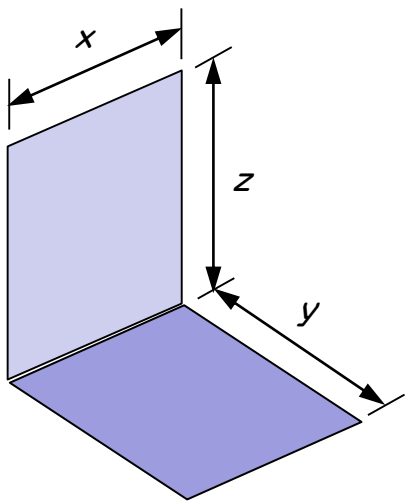
  - Then:

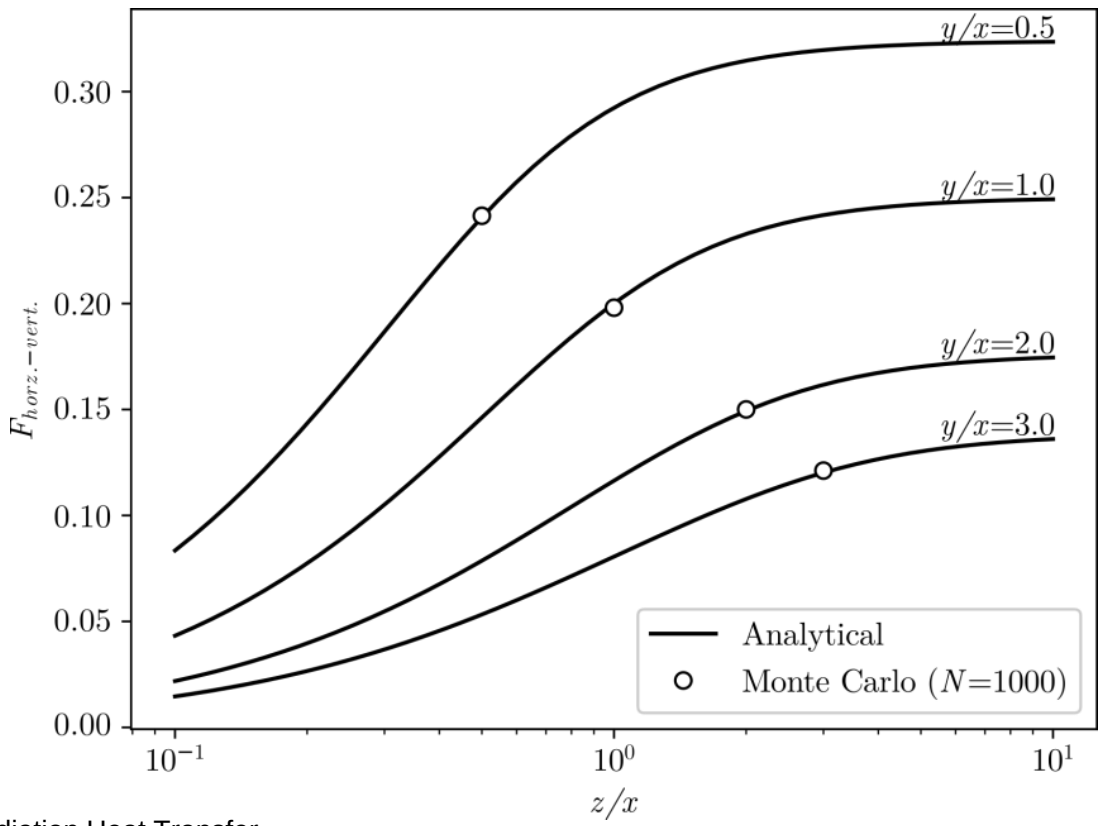
$$F_{ij} = \frac{n_{ij}}{N_i}$$



Model Description

- View Factor Determination (Validation)
  1. Comparison with analytical solution[3] for "*Perpendicular rectangles with a common edge*".

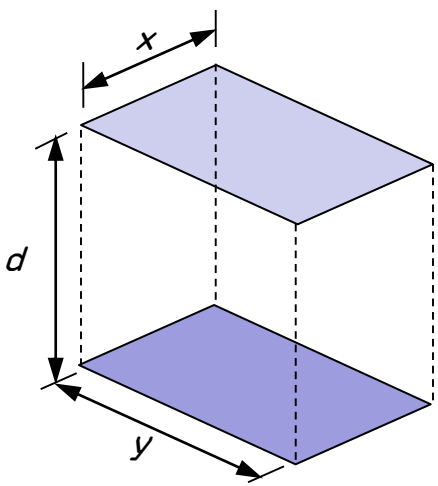


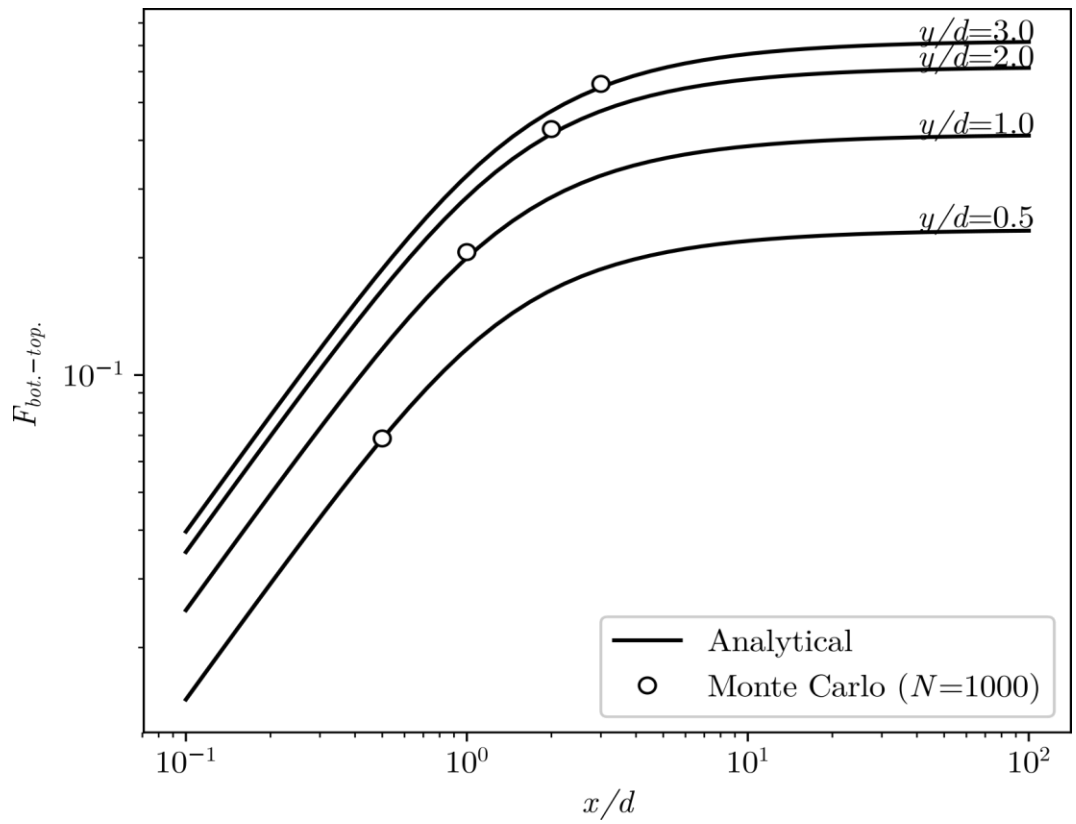


[3] Siegel, R., Howell, J., 1992. Thermal Radiation Heat Transfer.

Model Description

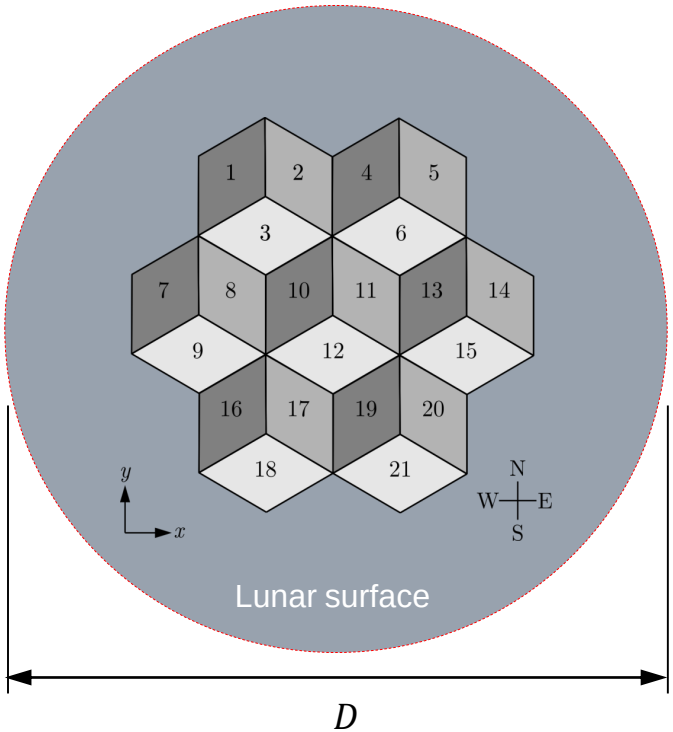
- View Factor Determination (Validation)
  2. Comparison with analytical solution[3] for "*Parallel, equal, directly opposed rectangles*".

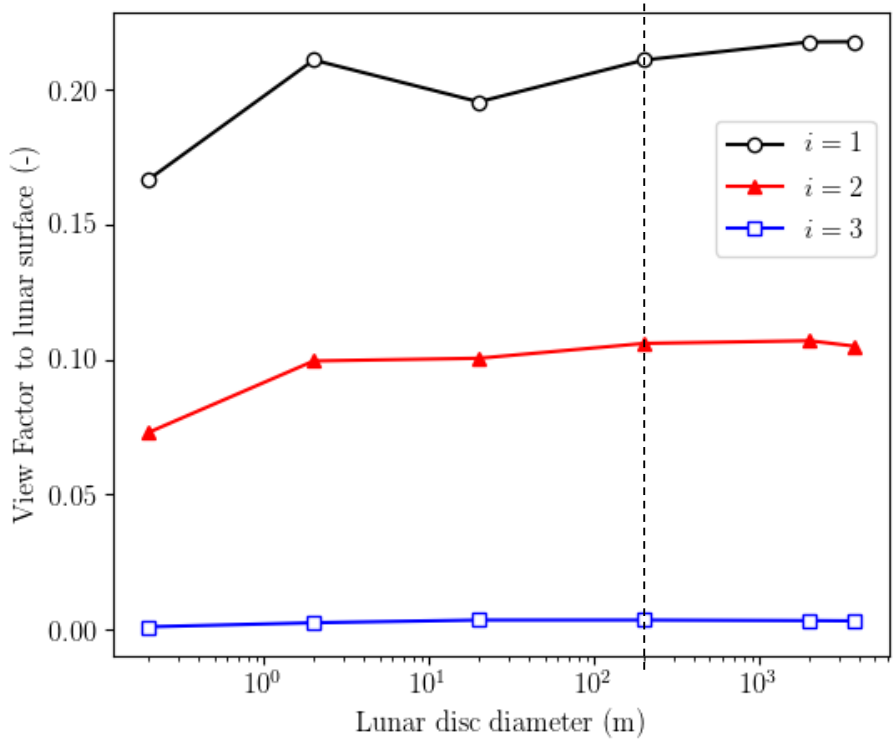




Model Description

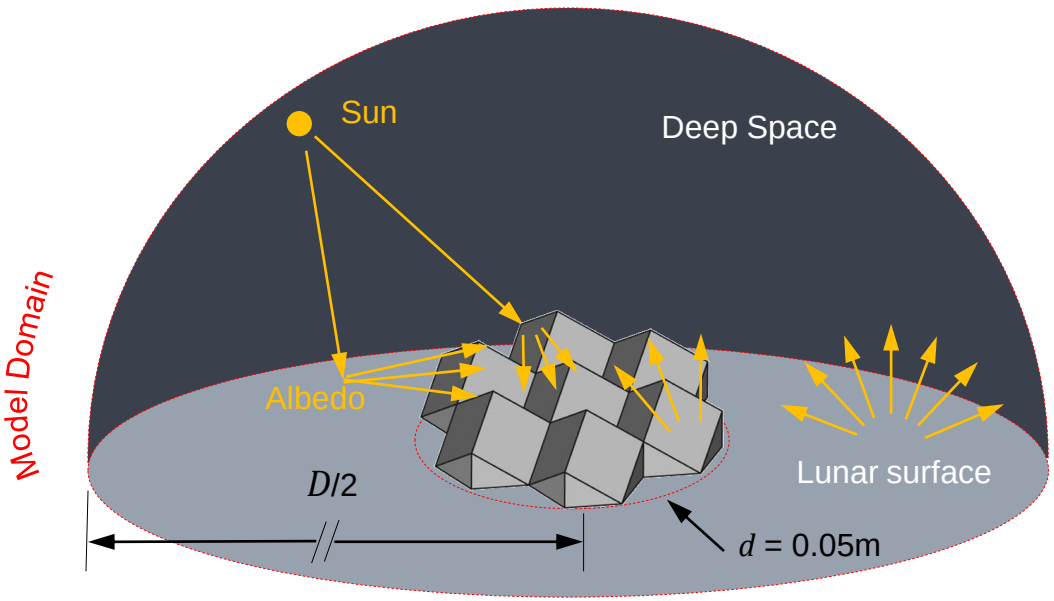
- View Factor Determination
  - Effect of Lunar disc diameter (D) on $F_{i,lunar}$





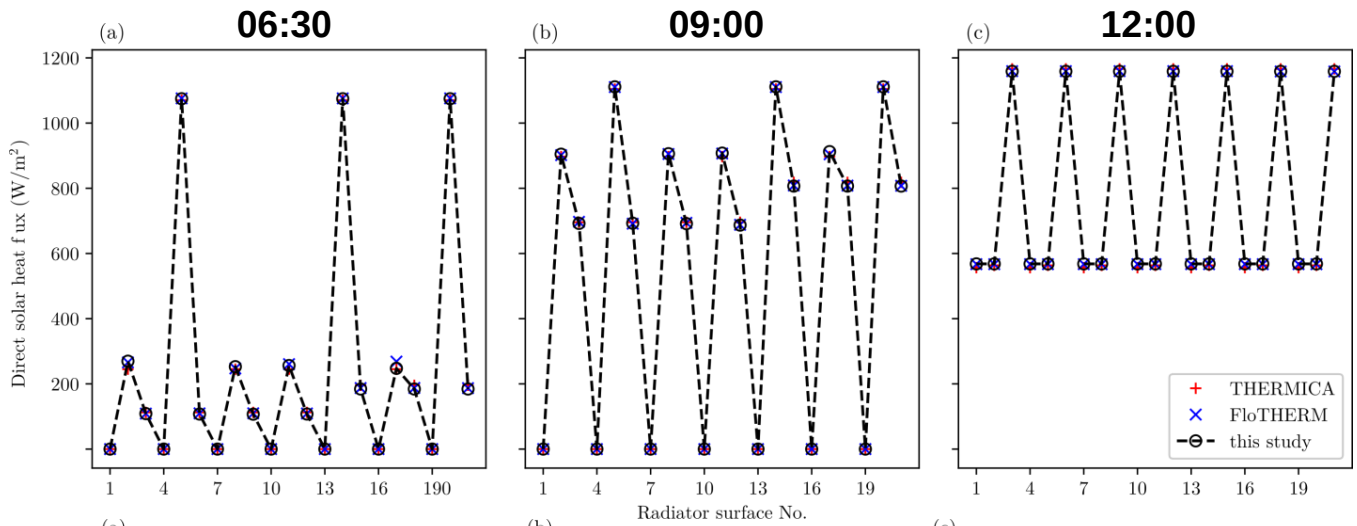
Results

- Comparison with commercial software
  - **SYSTEMA/THERMICA** v4 by Airbus.
  - **FloTHERM XT** v3.3 by Mentor.
- Test case at Apollo 17 landing site for $\varphi = 90^\circ$

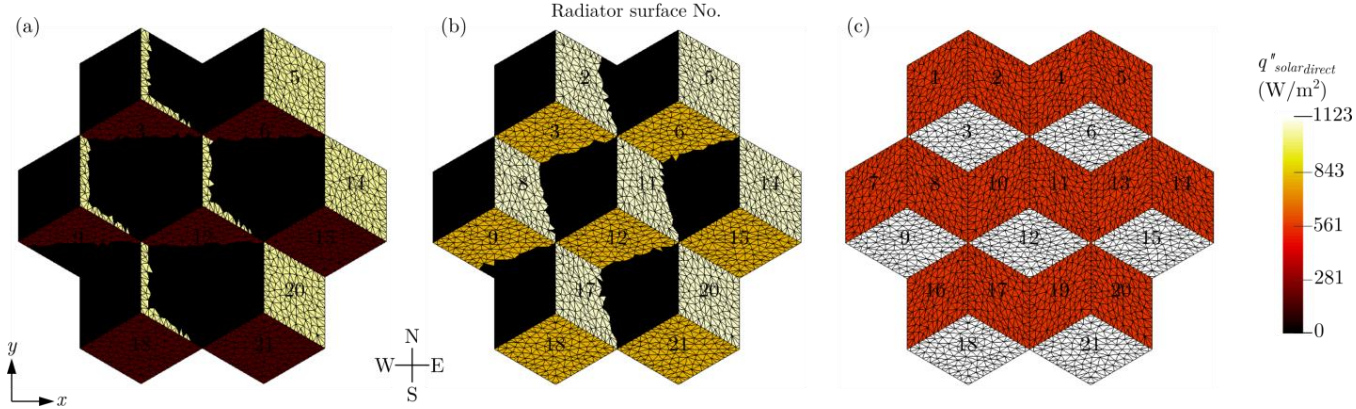


Results

- Comparison with commercial software
  - Direct solar heat flux:

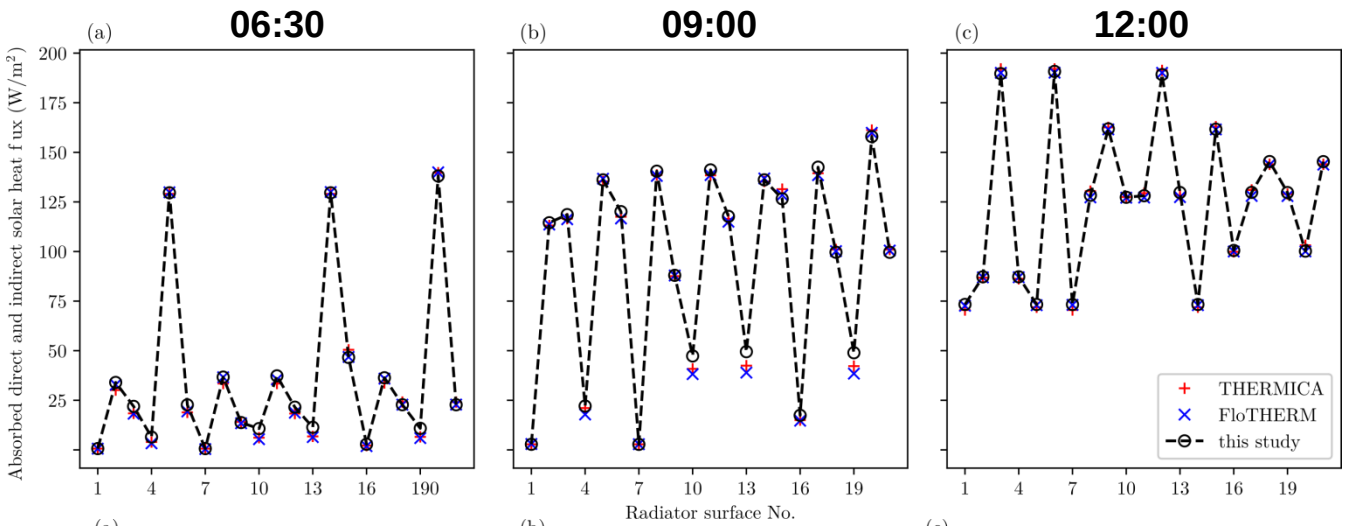


	RMSE w. THERMICA (W/m²)
06:30	7.96
09:00	7.27
12:00	8.44

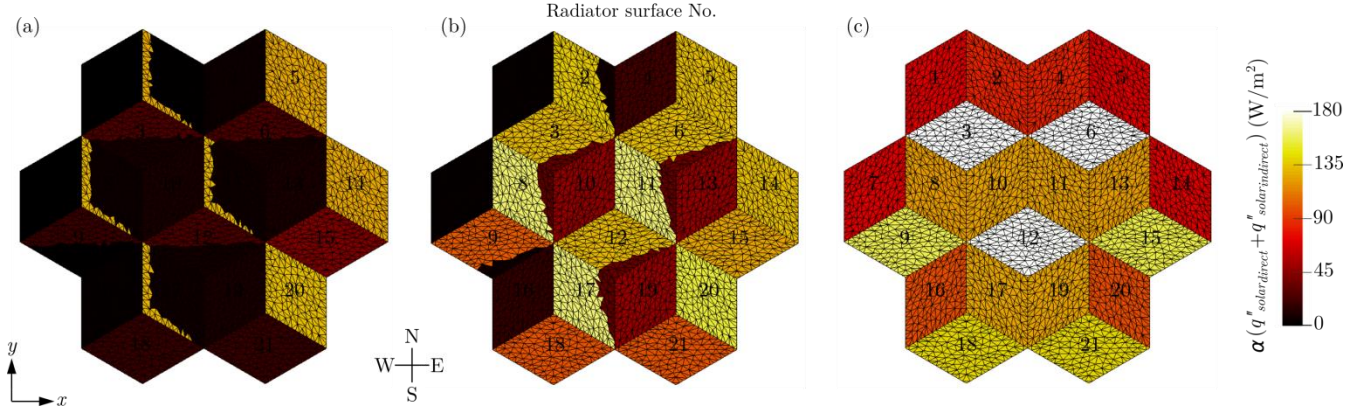


Results

- Comparison with commercial software
  - Direct and indirect absorbed solar heat flux:

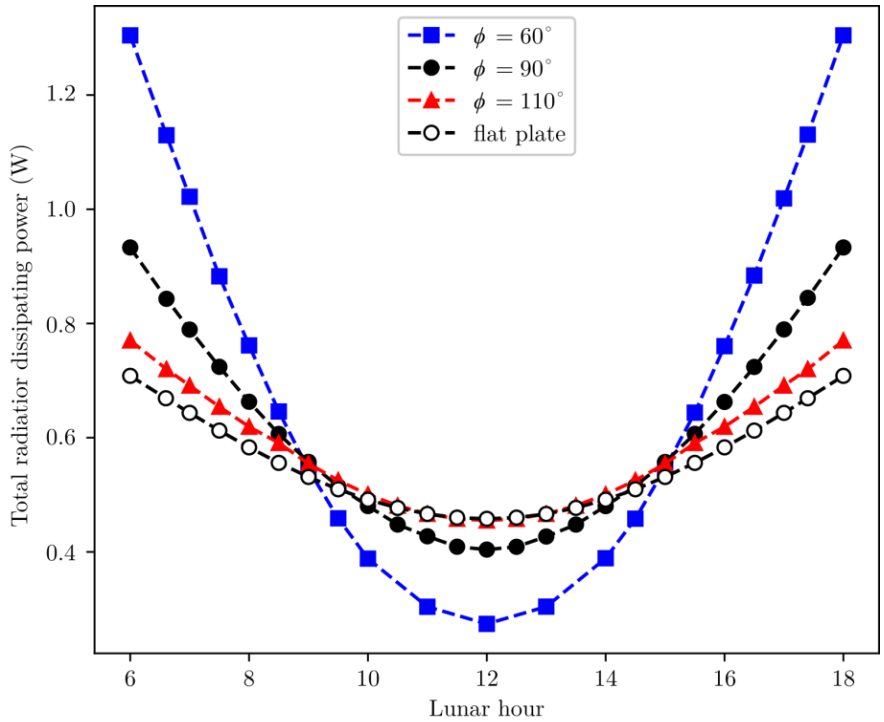


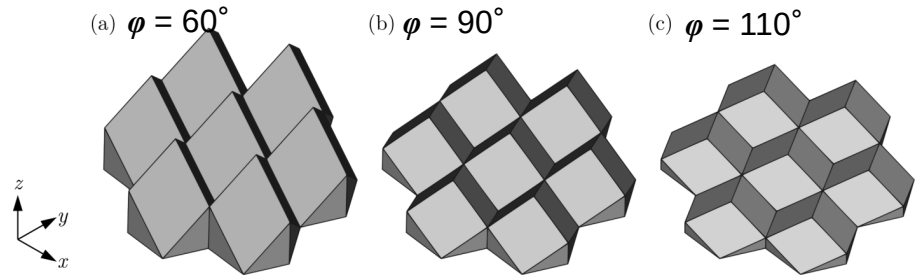
	RMSE w. THERMICA (W/m²)
06:30	2.87
09:00	3.22
12:00	1.65



Results

- Radiative Heat Transfer of Trihedral Radiator
  - Effect of Apex Angle (φ)



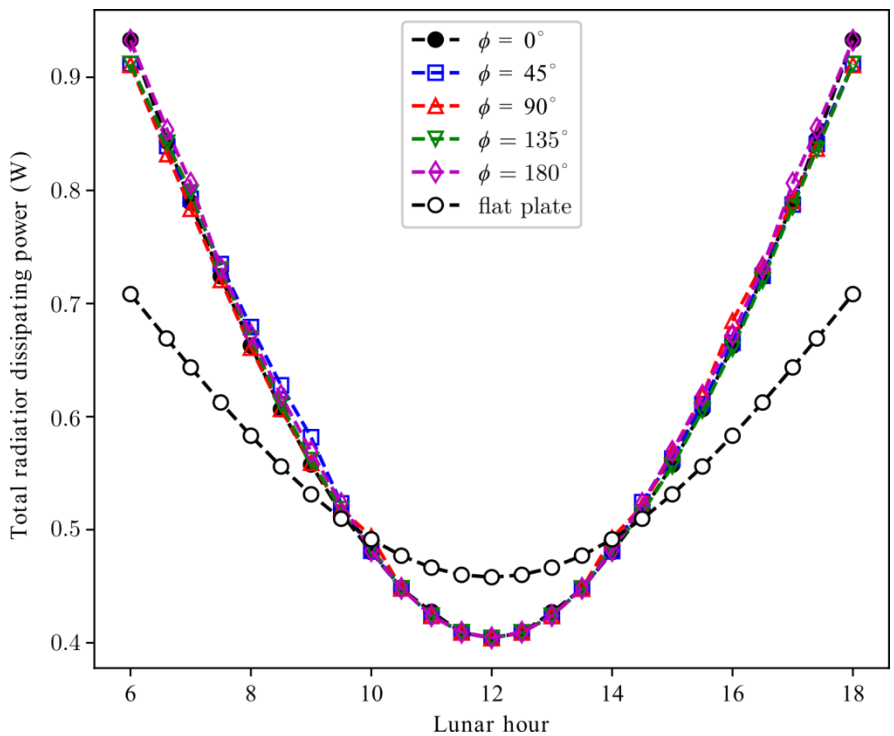


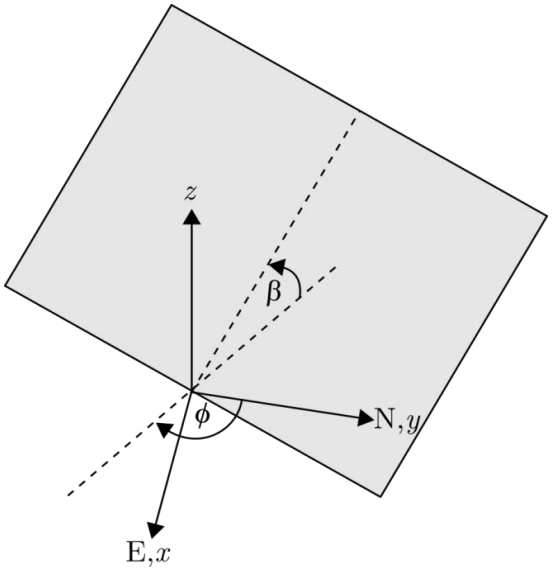
Compared to flat plate ($\varphi \equiv 120°$):

φ	Best case (sunrise/sunset)	Worst case (noon)	Full day
60°	+84.2%	-40.2%	+15.0%
90°	+31.7%	-11.8%	+8.4%
110°	+8.8%	-0.6%	+4.4%

Results

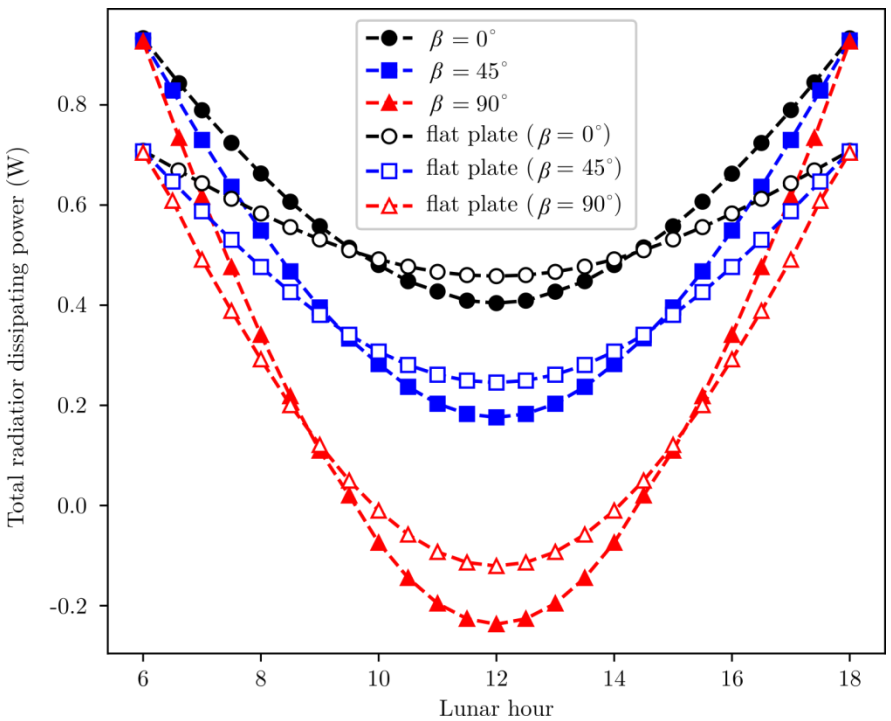
- Radiative Heat Transfer of Trihedral Radiator
  - Effect of Azimuth Angle (ϕ)

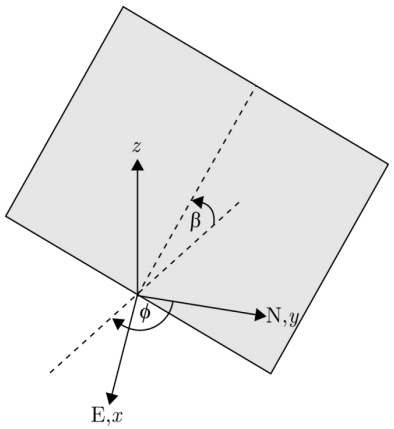




Results

- Radiative Heat Transfer of Trihedral Radiator
  - Effect of Inclination Angle (β)



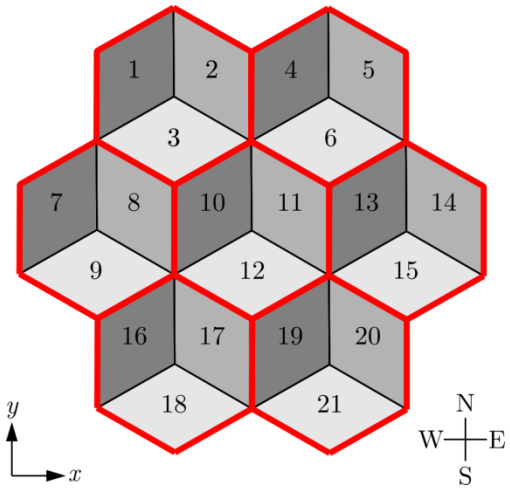


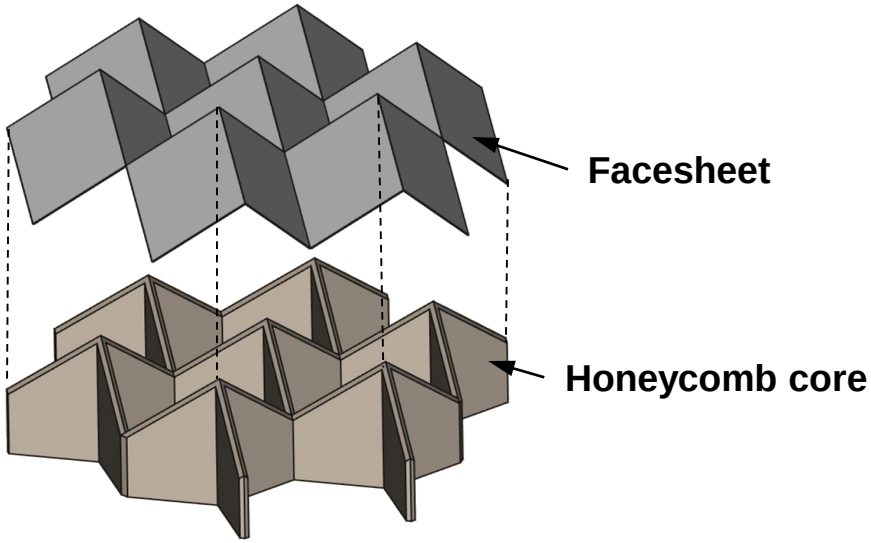
Compared to flat plate ($\varphi \equiv 120°$):

β	Best case (sunrise/sunset)	Worst case (noon)	Full day
0°	+31.5%	-11.8%	+8.4%
45°		-28.3%	+8.8%
90°		-96.2%	+2.7%

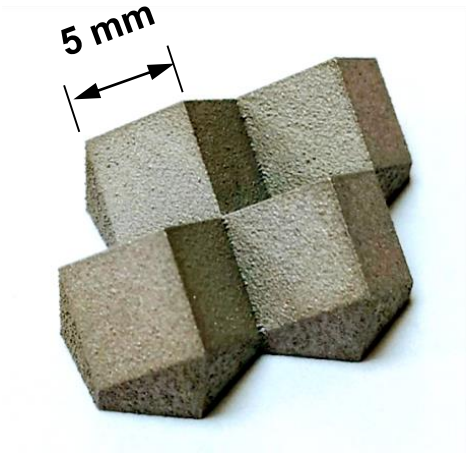
Manufacturability

- Honeycomb Panel





- Metal 3D printing
  - Sample array of 4 Trihedral elements additively manufactured with AlSi10Mg.

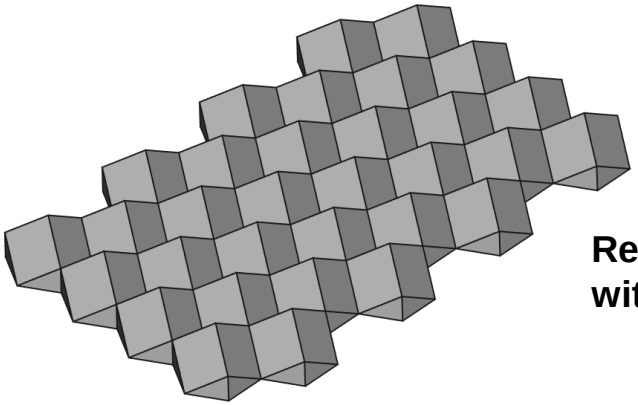


Conclusions

- Developed model with can predict radiative heat transfer of a radiator panel on lunar surface.
- Shows excellent agreement with commercial software.
- Initial results show that trihedral geometry offers good potential for most conditions studied here.
- Smaller apex angles dissipate more heat in morning compared to a flat plate, whereas larger apex angles reduce difference around noon.
- Azimuth angle has little impact on heat transfer, whereas as Inclination angle rotates towards vertical, net heat transfer is reduced significantly.

Future Work

- Expand the array to include greater number of elements.
  - Reduce impact of lunar IR heat flux on central surfaces



Rectangular array with 32 trihedral elements

- Add thermal conduction to model
  - Improve prediction to real-world behaviour and smooth discontinuities between connecting faces.

Acknowledgements

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Thank You

Questions...?