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Spacecraft Radiator Protection from Ionizing Radiation, Dust, and Excessive Heat Loss

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Outline

1. Introduction
2. Technology Description
3. Laboratory Evaluation of Performance
   A. UV attenuation
   B. X-ray attenuation
   C. Excessive heat loss mitigation
   D. Dust mitigation
4. Plan for Evaluation Under Simulated Lunar Surface Conditions
5. Conclusions & Potential Applications

Bottom Line Up Front (BLUF)

- Radiators provide thermal management by rejecting excess heat from spacecraft into the environment
- Key issues of current radiators
  - Radiator coating degrades when subjected to ionizing radiation and dust: lowers the heat rejection capability
  - Radiator fluids freeze when exposed to the extremely cold lunar night conditions near the poles compromising the structural integrity. Active heating is extremely energy inefficient
- State of the art in Radiator Protection: Passive louvers with thick Al vanes that open/close in response to heat
  - Too heavy to be scaled to larger spacecraft
  - Activation is too slow (hours) to protect against intense short duration events
- Solution: Actively controlled louver with exceptional ionizing radiation, dust, & excessive heat loss mitigation capability
  - Modular design enables scale up to any radiator size
  - Lightweight: <50% the mass of passive louvers
  - Fast actuation in seconds vs. hours for passive louvers
  - Reduced UV transmission by 100% and X-ray transmission by 57 – 69%
  - Reduces heat loss by 97% during cold lunar night
  - Reduces dust transmission by >93%

Measured at ~20° C and ~1 atm

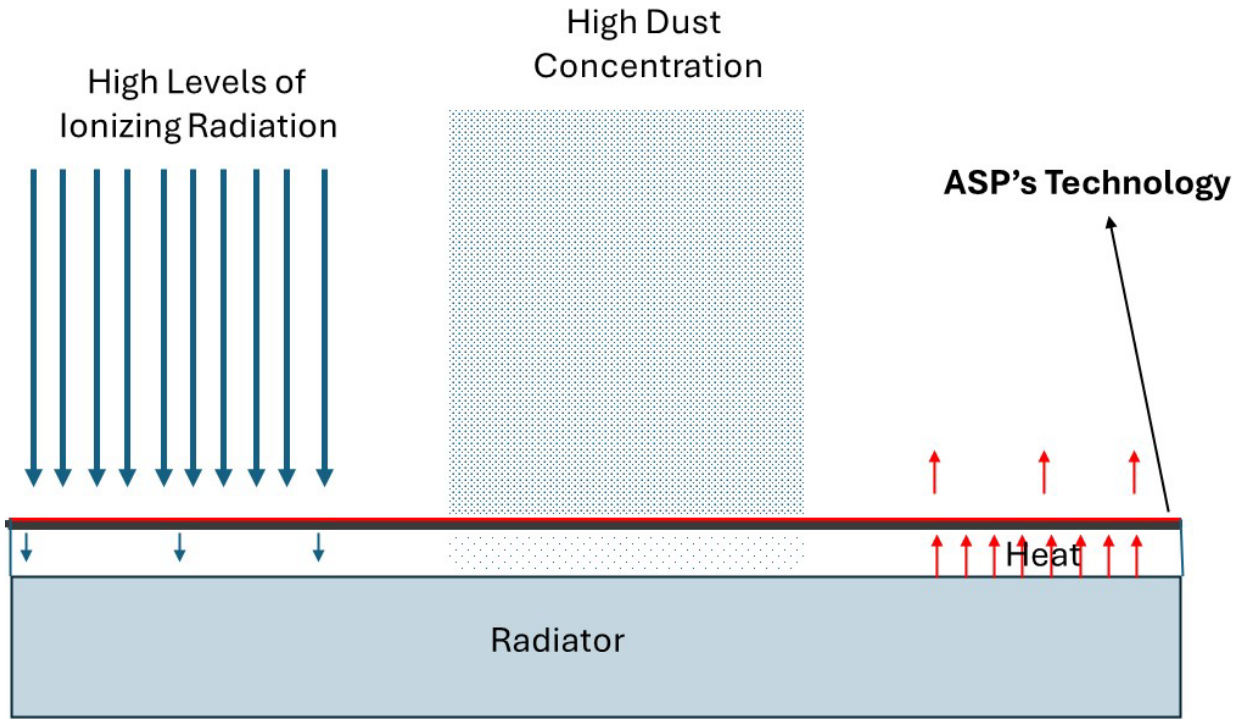
- Status of our technology development
  - 7/7/2025 – 3/6/2026: Designed, constructed, and tested a module under lab temperature and pressure
  - 3/7/2026 – 10/6/2026: Module customization for dust and excessive heat loss mitigation testing under simulated lunar T & P
  - 10/7/2026 – 7/6/2027: Cryogenic vacuum testing, prototype construction and delivery to NASA

1. Introduction: Problem

- Spacecraft radiators are equipped with an optical coating with custom properties
  - Low infrared absorptivity – helps minimize the absorption of solar radiation
  - High emissivity – helps maximize heat rejection from the spacecraft
- The optical properties of the radiator may degrade leading to possible increases in IR absorptivity and reduction in emissivity due to
  - Exposure to high energy ionizing radiation during transit through the Van Allen belts
  - Dust accumulation during lunar landing and surface operations
- Heat transfer fluids used in current radiators have melting points that are higher than the nighttime temperatures near the lunar south pole. Exposure to such conditions can freeze the coolant and compromise the integrity of radiator
- Exposure to high solar flux especially near the equator can heat the radiator excessively interfering with its ability to reject excess heat from the spacecraft
- Passive louvers are used currently to protect the spacecraft radiators. They offer limited protection, and are too heavy and too slow to be scaled to the future manned spacecraft systems

2. ASP's Radiator Protection Technology

- Protects spacecraft radiators from performance degradation due to ionizing radiation, dust, excessive heat loss, and solar entrapment
- Actively controlled louvers made from thin custom alloys
  - Lightweight (<50% the mass of passive louvers)
  - Rapid activation: seconds to open/close (vs. hours for SOA passive louvers)
  - Attenuates ionizing radiation more effectively than aluminum used in passive louvers
  - Extent of opening can be controlled to protect from solar entrapment
  - Low emissivity/absorptivity provide protection from excessive heat loss during the lunar night
- Treatment with Lotus coating
  - Licensed from GSFC
  - Lightweight and thin
  - Provides passive dust mitigation for louver vanes



ASP's Actively Controlled Louver

We have constructed two louver modules so far

- *Module 1 (31" × 31"): 6 vanes and Transmotec motor (shown below): not space certified, used for the tests presented here*
- Module 2 (26" × 26"): 5 vanes and off-the-shelf Maxon motor: not space certified. We plan to replace the off-the-shelf motor with space certified Maxon motor in 4 months



Louver with Closed Vanes



Louver with Open Vanes

Functionality Testing with Module 1

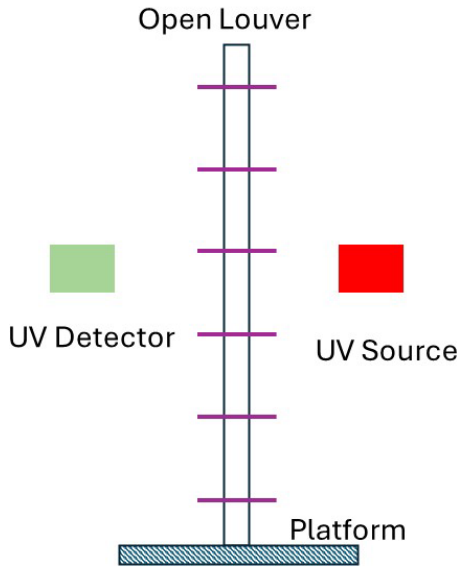
We applied different voltages to the Transmotec motor and measured the time, power and energy needed to open and close the louver vanes

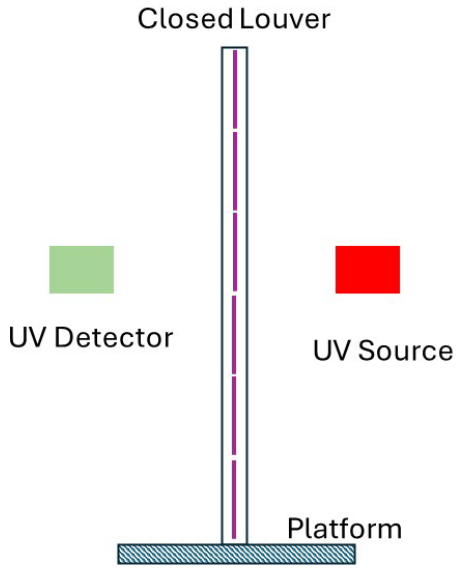
Voltage (V)	Time (s)	Current (A)	Power (W)	Energy (J)
4	1.73	0.43	1.7	2.9
6	1.09	0.40	2.4	2.6
8	0.93	0.34	2.7	2.5
10	0.62	0.30	3.0	1.9
12	0.58	0.42	5.0	2.9

- Orders of magnitude faster activation (seconds) than passive louvers (hours)
- The motor operation needs very low intermittent power and energy: slightly more than passive louvers

3A. UV Attenuation

Test	Distance from Louver (inches)	Power (mW)		UV Attenuation
		Open Louver	Closed Louver	%
UVL-1, 2	<0.2	1.9	0	100
UVL-3, 4	0.5	1.6	0	100
UVL-5, 6	1	1.2	0	100
UVL-7, 8	1.5	1	0	100
UVL-9, 10	2	0.5	0	100
UV-11, 12	3	0.1	0	100

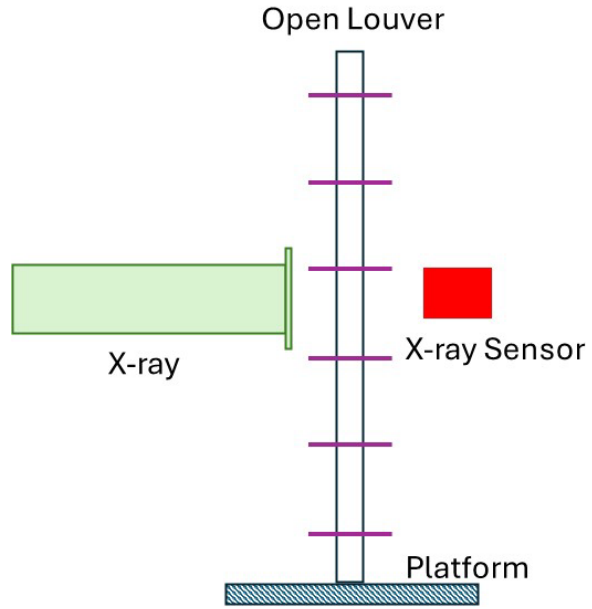


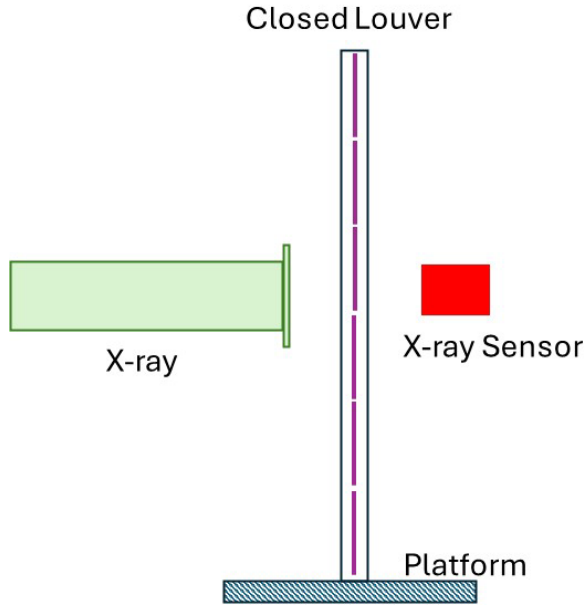


ASP's louver provides 100% attenuation of UV radiation when the vanes are in closed position

3B. X-ray Attenuation

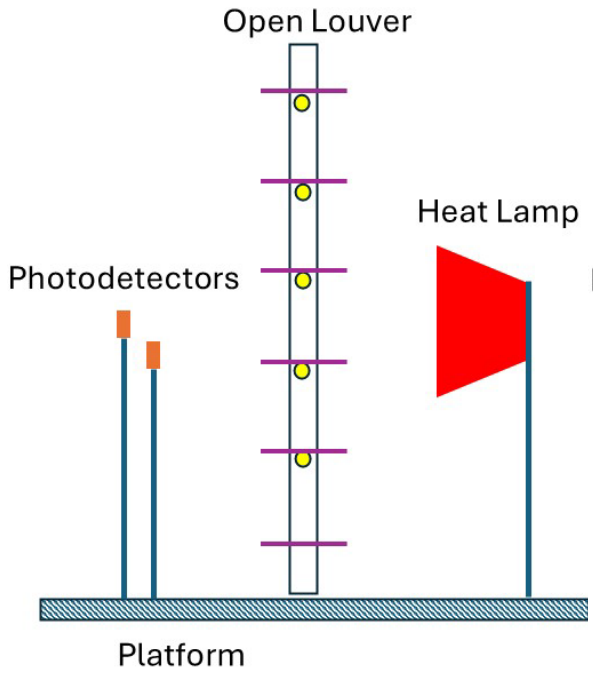
Test	Transmission (μSieverts/hr)	
	vanes open	vanes closed
70 keV X-ray		
1	85.63	33.82
2	75.93	33.82
3	76.67	31.77
4	76.67	31.77
5	77.45	38.65
Average	78.47	33.97
60 keV X-ray		
6	71.5	22.24
7	69.3	27.68
8	70.03	17.27
9	78.15	17.27
10	72.24	27.68
Average	72.24	22.43



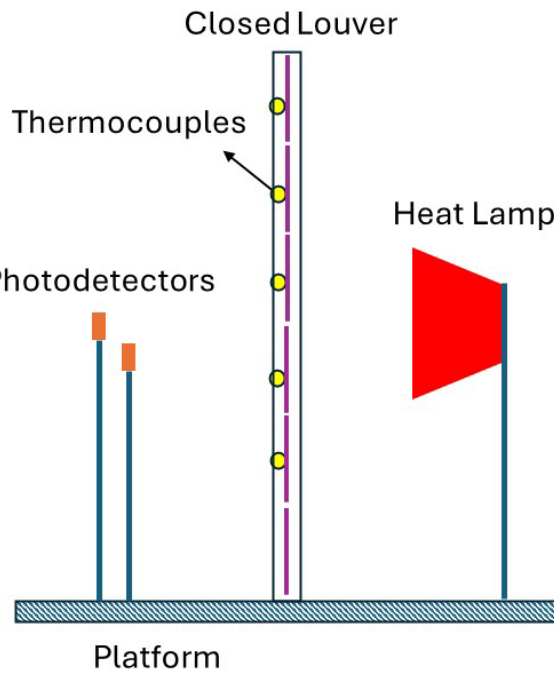


- **70 kV X-ray:** 57% radiation attenuation, attenuation coefficient ~42 cm^{-1}
- **60 kV X-ray:** 69% radiation attenuation, attenuation coefficient ~74.7 cm^{-1}
- For comparison, SOA passive louvers use aluminum that has an attenuation coefficient of 0.65 cm^{-1} at 70 keV and 0.75 cm^{-1} at 60 keV

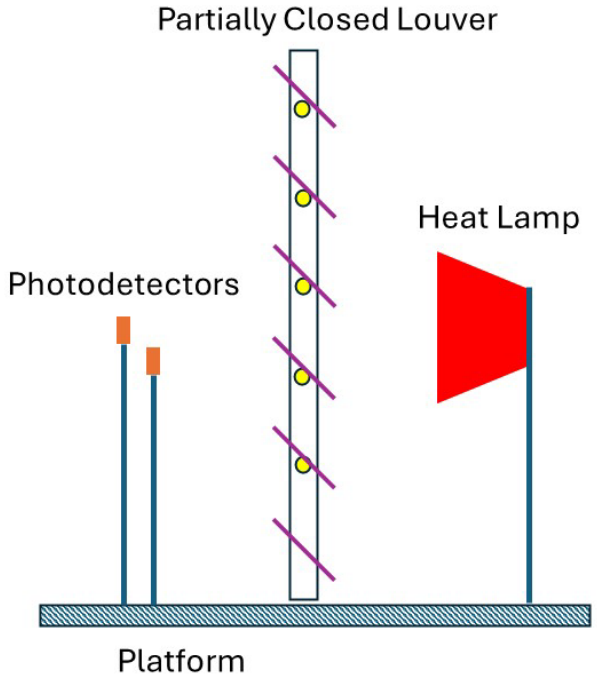
3C. Heat Loss Mitigation



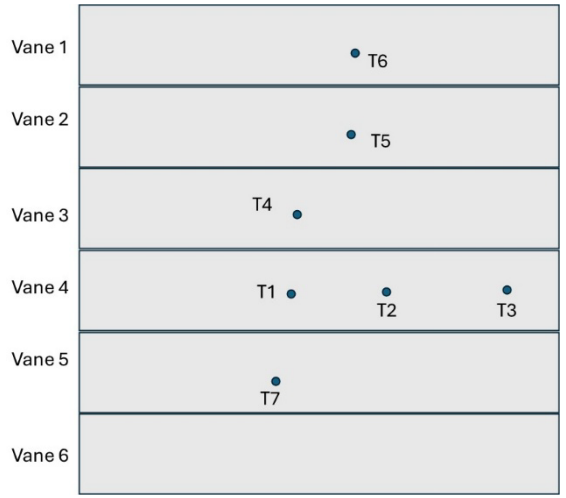
Open Vanes



Closed Vanes

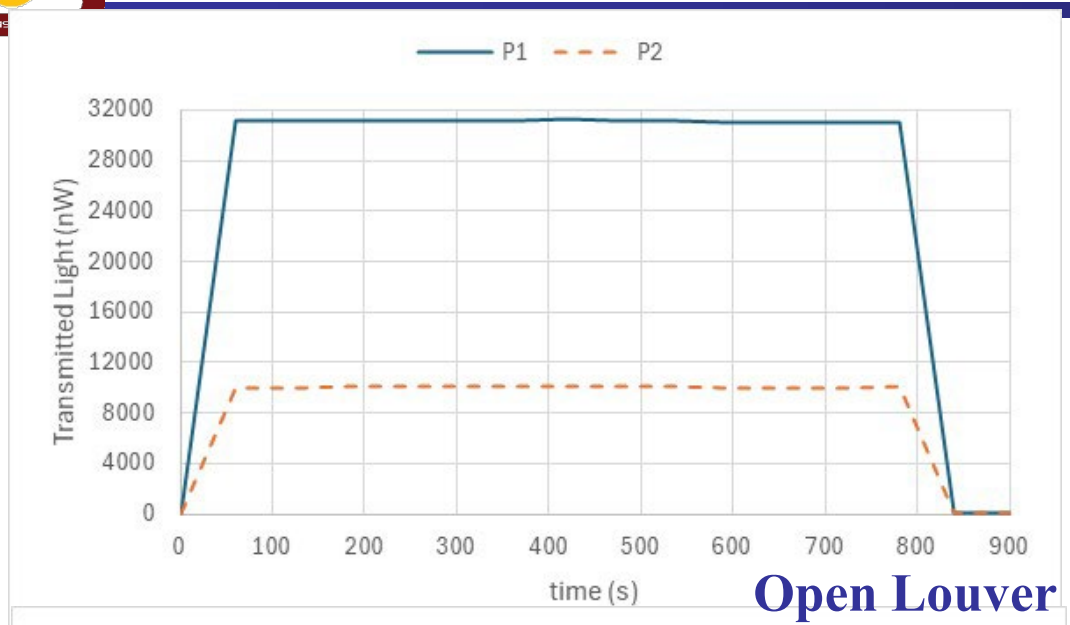


Partially Closed Vanes

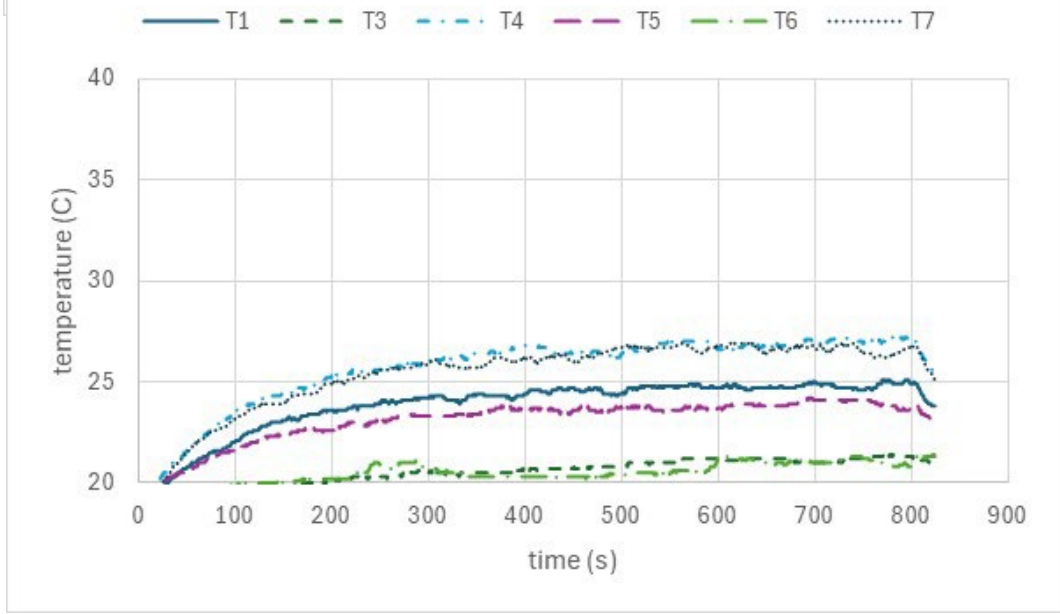


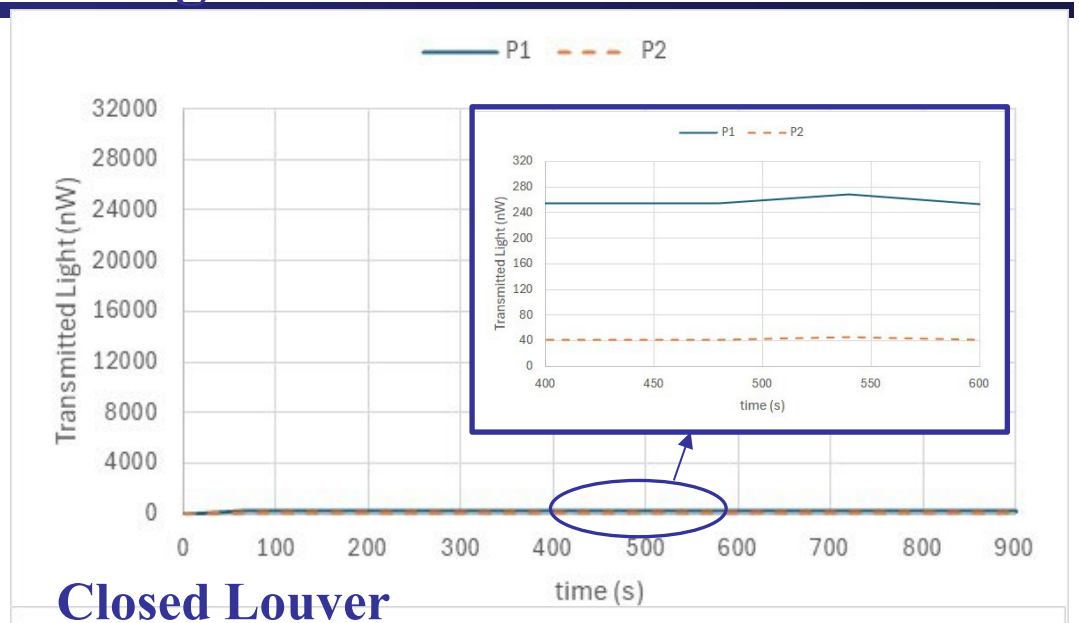
Thermocouple Locations

3C. Heat Loss Mitigation

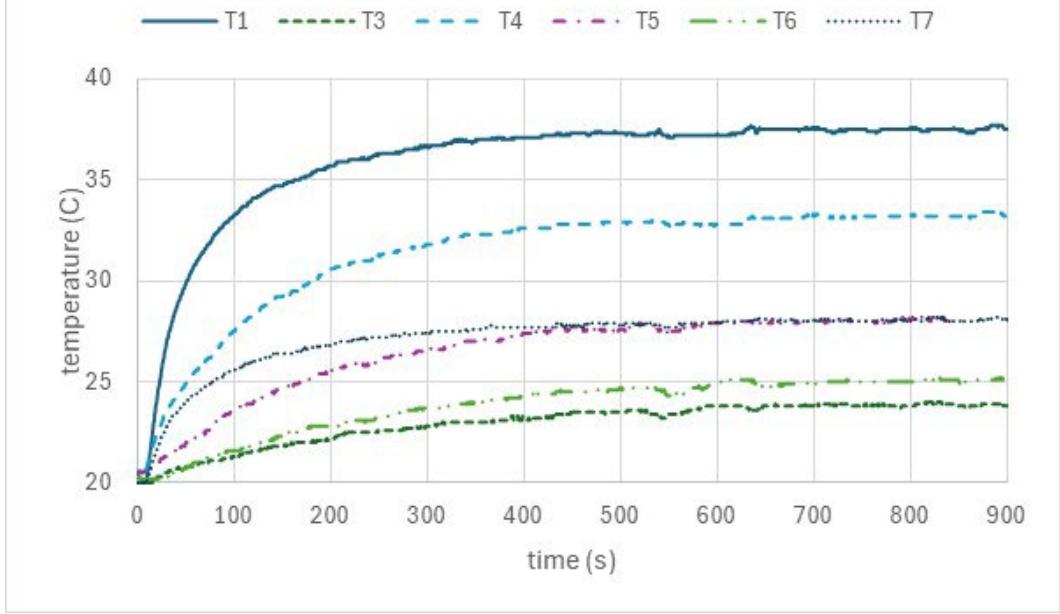


Open Louver



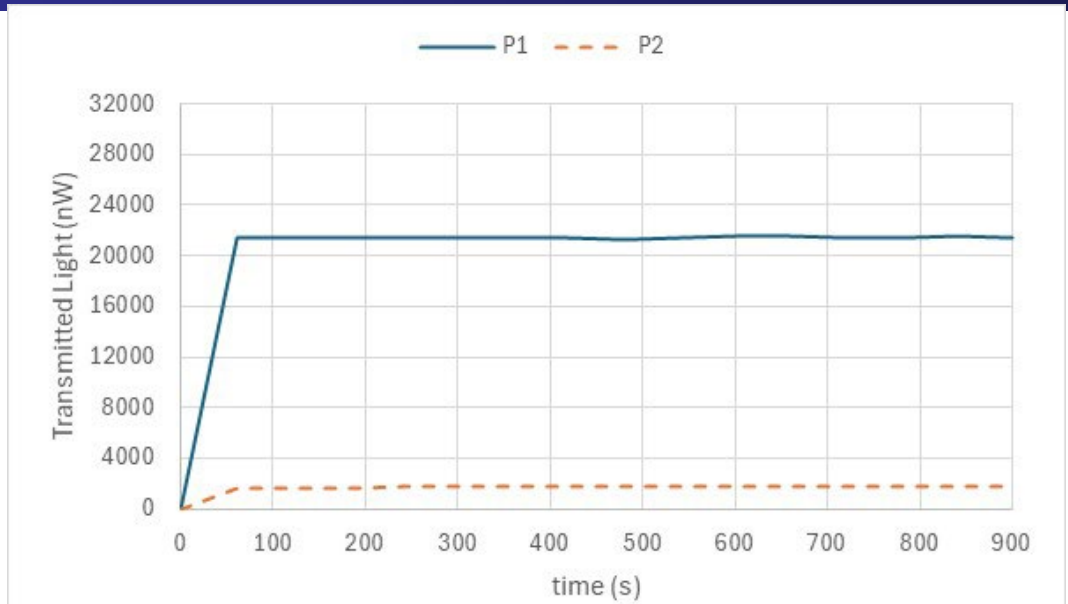


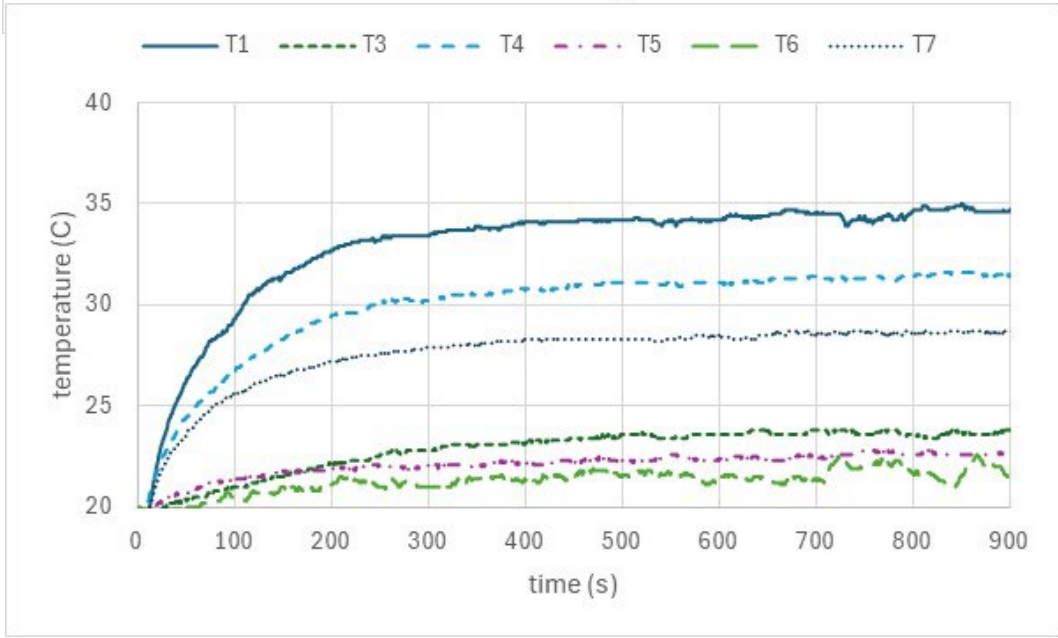
Closed Louver



3C. Heat Loss Mitigation

Partially Closed Louver: Vanes at 45°





3C. Compilation of Key Results

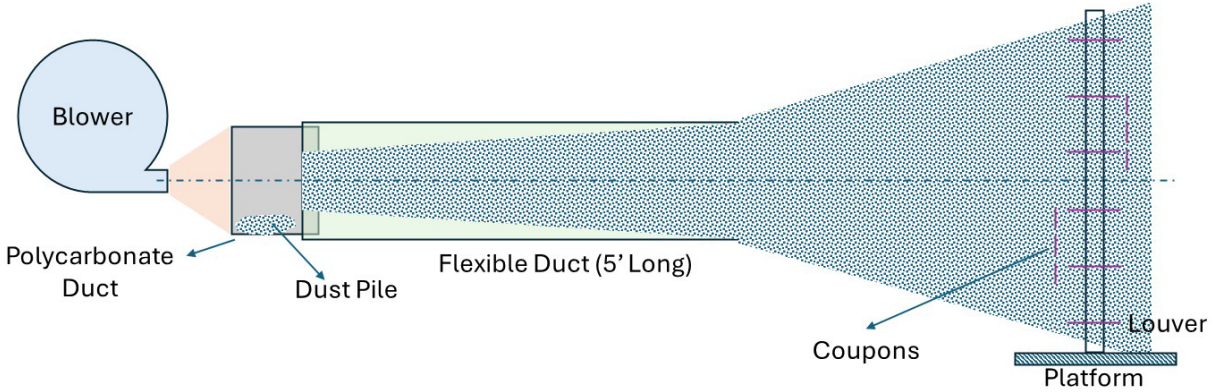
Vane Orientation	Test	Thermal Radiation Transmission				Thermal Radiation Absorption		
		P1 (nW)	P2 (nW)	% Transmission		ΔT_{ave} (°C)	Absorption (J)	Absorption (%)
Open	RAD1	31,131	10,058	100	100	4.3	1758	1.3
Closed	RAD2*	258	42	0.83	0.42	8.10	2826	2.09
Closed	RAD3	117	43	0.39	0.43	9.10	3249	2.41
Open	RAD4	30,053	9,899	100	100	4.20	1753	1.3
Open at 45°	RAD5	21,402	1,693	71.2	17.1	6.40	2379	1.76

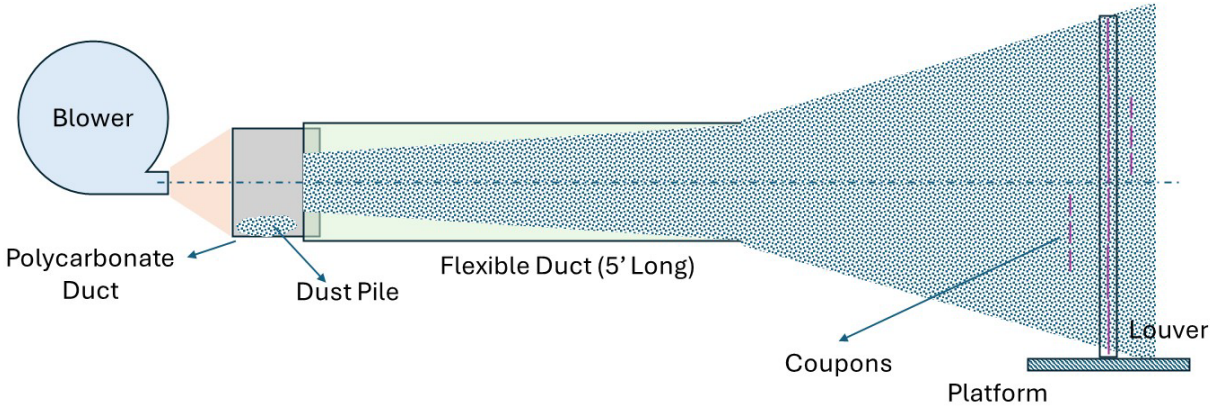
* Vanes did not close completely leaving a small gap between the vanes that caused some radiative leakage

- Closing the vanes reduces heat loss from the radiator by >97% (rest is either absorbed or transmitted)
- Extrapolation to lunar night suggests that closing the vanes reduces heat loss from the radiator significantly
- Opening the vanes at 45° can help the radiator function effectively (i.e., reject heat) even during nearby dust generating surface operations

3D. Dust Mitigation

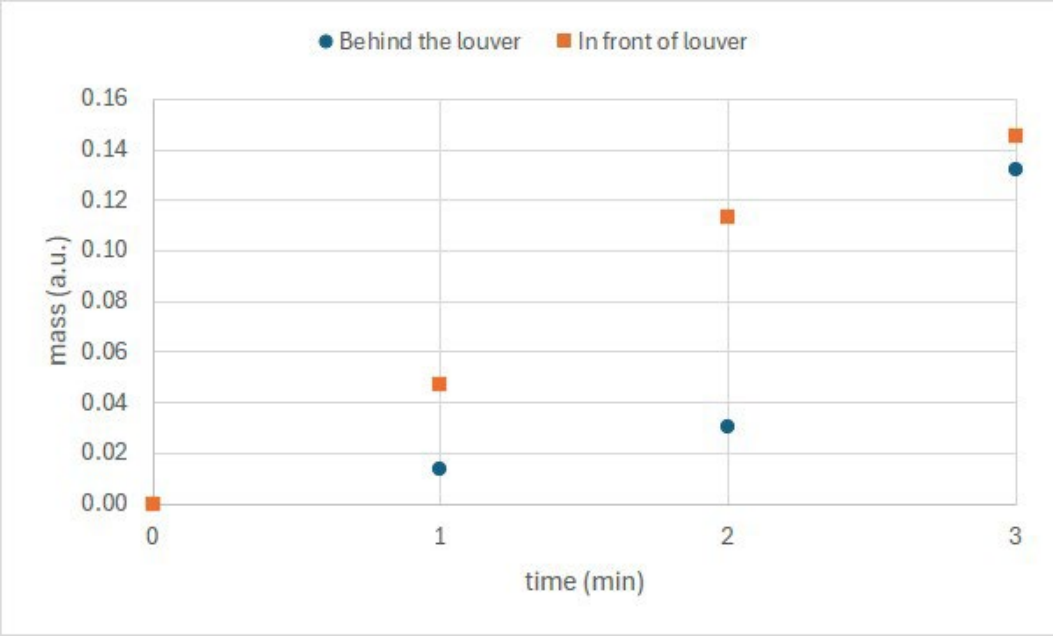
- Our louver shields the dust particles from reaching the radiator: dust can collect on the vanes
- Maturation of Lotus coating technology to protect louver vanes from dust deposition
  - We had some problems in getting the Lotus coating to work
  - We have been working on this technology in parallel
  - Currently our louver does not have Lotus coating
- Dust simulant
  - We used fine particulate talc as the dust simulant in our tests so far
  - We plan to use lunar dust simulant in the upcoming vacuum tests



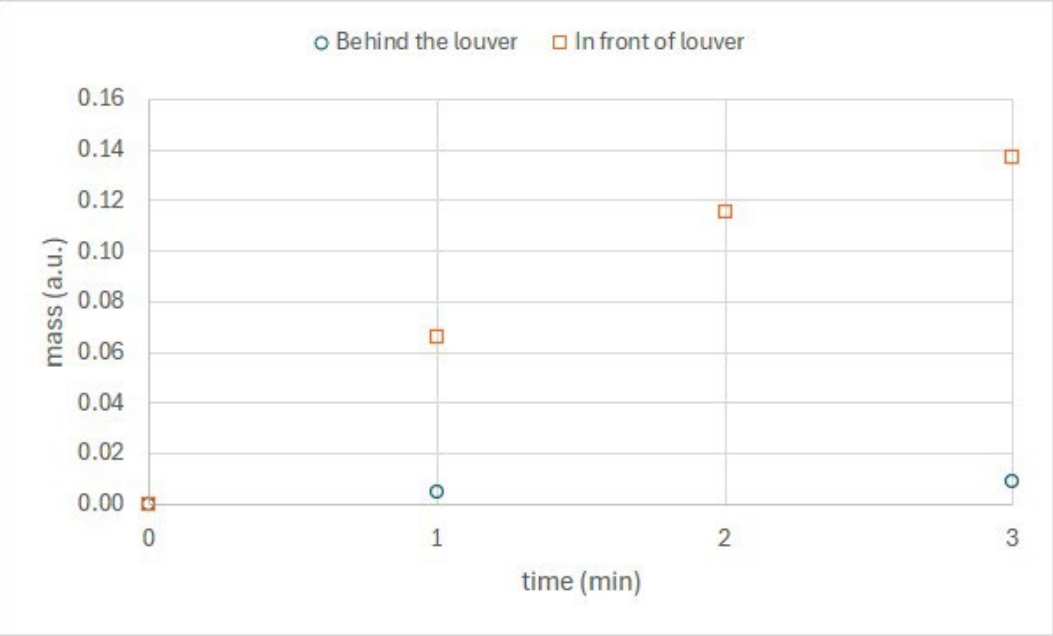


3D. Dust Mitigation

Louver with Open Vanes



Louver with Closed Vanes



- Closing the louver reduced the dust transmission by ~93.6%.
- We suspect that the carrier air helped some of the dust penetrate the gaps between closed louver vanes
- Some dust collected on louver vanes. Integrating the Lotus coating is expected to reduce this in the future
- Better performance is expected on the moon where ballistic particles can be intercepted easily by the vanes

3. Module Evaluation Under Lab Conditions

	Parameter	Vanes Open	Vanes Closed	Attenuation
A	UV Transmission (3.5 eV)	~1 – 2 mW	~0 mW	100%
B	X-ray transmission (60 – 70 kV)	78.5 µSieverts/hr	34 µSieverts/hr	57%
		72.2 µSieverts/hr	22.4 µSieverts/hr	69%
C	Thermal Radiation Transmission	31,130 nW	117 nW	~99.6%
		10,058 nW	43 nW	~99.6%
	Thermal Radiation Absorption	1760 J	3250 J	NA
D	Dust Mitigation	0.13 a.u.	0.01 a.u.	~93%

Next Step: Evaluation Under Lunar Surface Conditions

A. Ability of our louver module to function under low pressure and low temperature conditions
   - We built most of the components from materials that have been space tested in the past (alloy of tin and lead, aluminum, steel, etc.)
   - Our materials should survive the low temperatures of interest
   - We selected a space and vacuum rated motor from Maxon. It can survive non-operating (storage) temperatures down to ~-150° C: we may need a heater to maintain it above -150° C

B. Potential for outgassing from the components and materials used in our fabrication and their effect on system integrity

C. Excessive heat loss mitigation under vacuum and cryogenic conditions

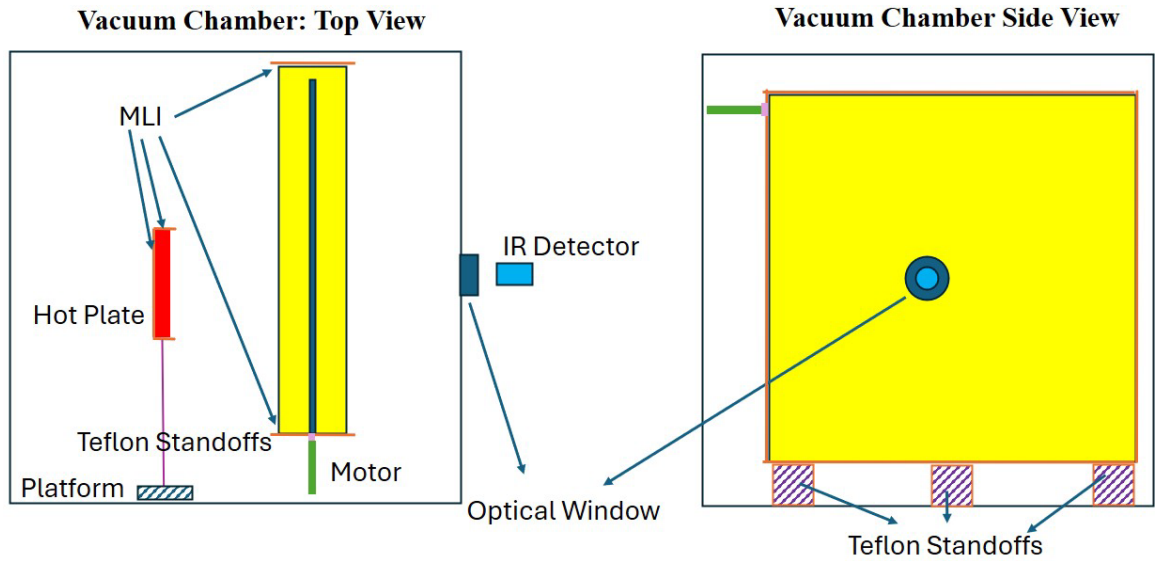
D. Dust mitigation under vacuum conditions



Evaluation Under Lunar Surface Conditions

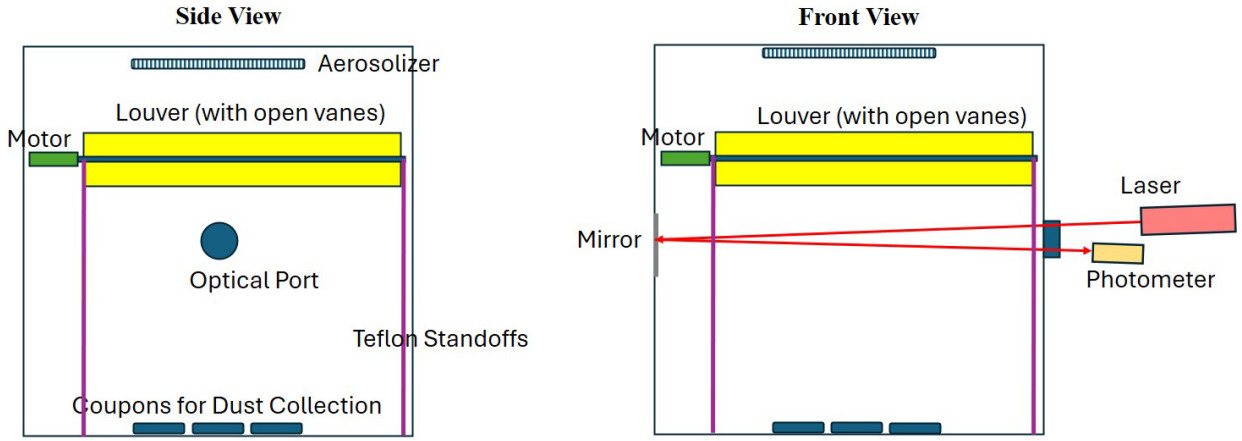
C. Excessive heat loss mitigation

- The chamber temperature and pressure lowered to lunar south pole conditions during the night
- A vertical hot plate maintained near 25° C simulates the radiator
- The hot plate and the louver are thermally insulated from the chamber walls
- Heat transfer to and across the louver measured using an IR sensor and thermocouples



D. Dust mitigation

- Aerosolizer located near the top of the chamber generates lunar dust simulant cloud that rains down vertically
- Dust collection coupons located at the bottom of the chamber simulate radiator surface
- Optical transmission measurements across the vacuum chamber measure dust aerosol concentration
- Dust transport across the louver with open and closed vanes measured



Comparison with Passive Louver

	ASP Louver	Passive Louver*	No Louver*
Control/Response	Active	Passive	None
Ionizing radiation attenuation (70 keV)	69%	17%	0%
UV attenuation (0.0035 keV)	100%	100%	0%
Dust mitigation	94%	94% (?)	0%
Heat loss (to mitigate radiator coolant freezeout)	<3%	14%	100%
Wall thickness of protective surface (mm)	0.2	2.5 (est.)	0
Mass of 7 m^2 system (kg)	27#	47 (est)	0
Activation time (s)	<3	3600 – 7200	0
Power Consumption (W)	<5 (intermittent)	0	4000 (continuous)

The louver vanes and the motor weigh <12 kg. The remaining 15 kg is due to the vane supports and frame. We expect to lower the mass to <20 kg through optimization in future phases of this project

* Cowan, D., "Actively Controlled Louver for Human Spacecraft Radiator Ultraviolet (UV), Dust, and Freeze Protection," 52nd International Conference on Environmental Systems, 16-20 July 2023, Calgary, Canada.

Conclusions & Potential Applications

- Conclusions
  - Radiator performance is likely to degrade due to ionizing radiation, dust and cold environmental conditions
  - SOA passive louvers are too heavy, too slow, and do not offer adequate protection
  - ASP's actively controlled louvers weigh less than 50% of the SOA passive louvers and provide activation in seconds
  - Tests conducted under standard laboratory conditions have shown that closing the vanes in ASP's louver can
    - Attenuate 100% of UV rays
    - Attenuate 57% to 69% of higher energy x-rays
    - Reduce heat loss from the radiator by more than 97% when exposed to cold environmental conditions
    - Reduce dust transmission by more than 93%
  - We propose to conduct some of the above measurements inside the cryogenic vacuum chamber at NASA JSC to examine the louver performance under simulated lunar surface conditions
- Potential Applications
  - The primary application is to protect the spacecraft radiators from ionizing radiation, dust and excessive cooling
  - Lotus coating (one of the components of our technology) can be used to protect optical/electrical components and solar panels on the moon and Mars
  - The protections (especially from ionizing radiation and lunar night conditions) can also be extended to other key assets that are susceptible to degradation and irreversible failure such as batteries

Acknowledgements & Contact Information

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  - Prof. Masud Rana: Lotus coating

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