Passive, Radially Deployed Radiator Panels for CubeSat Thermal Control

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Motivation

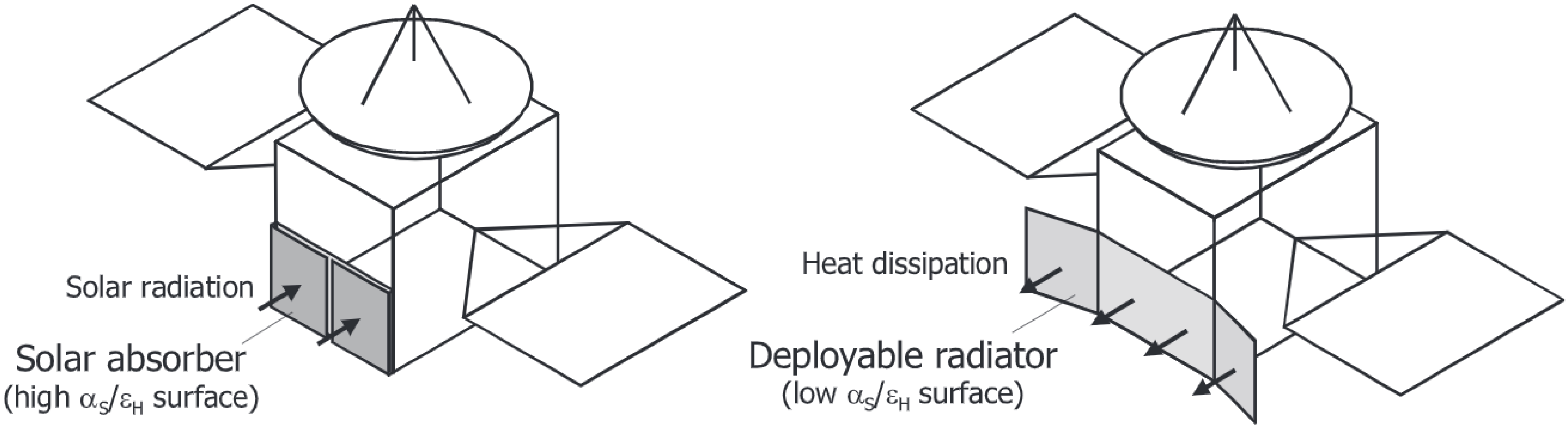
- CubeSat Thermal Control
  - Large fluctuations in external and internal thermal loads
  - Small form factor
  - High power to surface area ratio
  - Strict temperature limits on control electronics and instruments

		POWERED	
		Active	**Passive**
RESPONSIVE	**Static**	• Cold-biased satellite with survival heaters	• CubeSat without a thermal control system
	Dynamic	• Electrochromics • Motor controlled tracking radiator • Pumped fluid loop • Mechanically actuated variable geometry radiator	• Thermochromics • Thermal louvers actuated with bimetallic coils [1] • SMA actuated deployable radiator [2] • Current work

[1] Proceedings of AIAA, Evans 2019 [2] JSR, Nagano 2009

Deployable Radiators

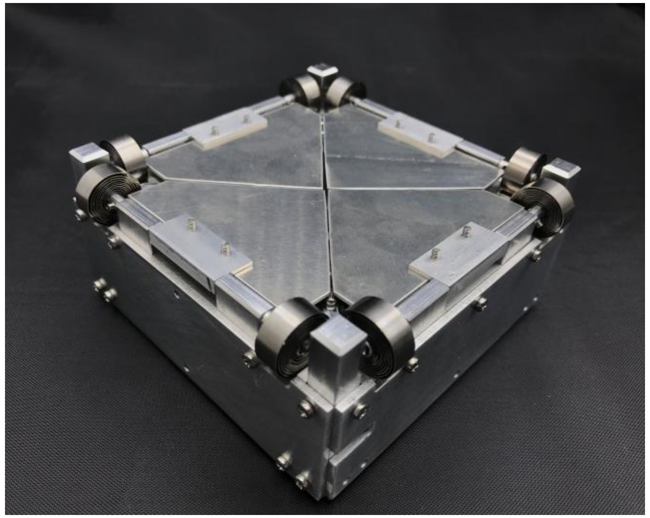
- Increase radiative surface area and effective emissivity
- 200% more radiative heat loss than body mounted radiators
- NASA Technology Roadmap target turndown ratio: 6
  - Turndown ratio: maximum / minimum radiative heat loss

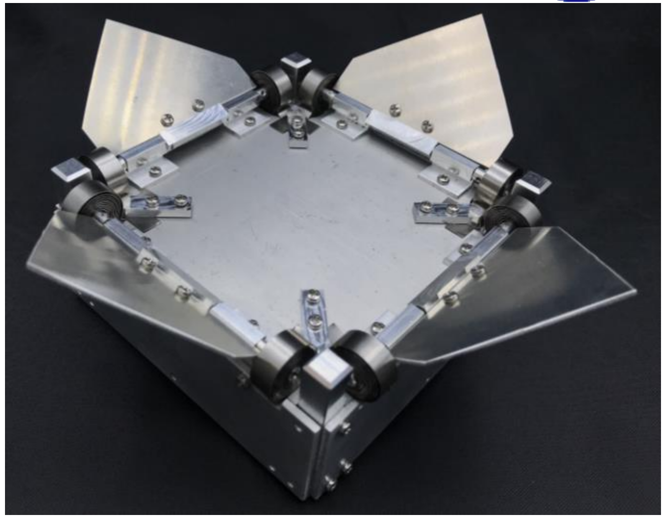


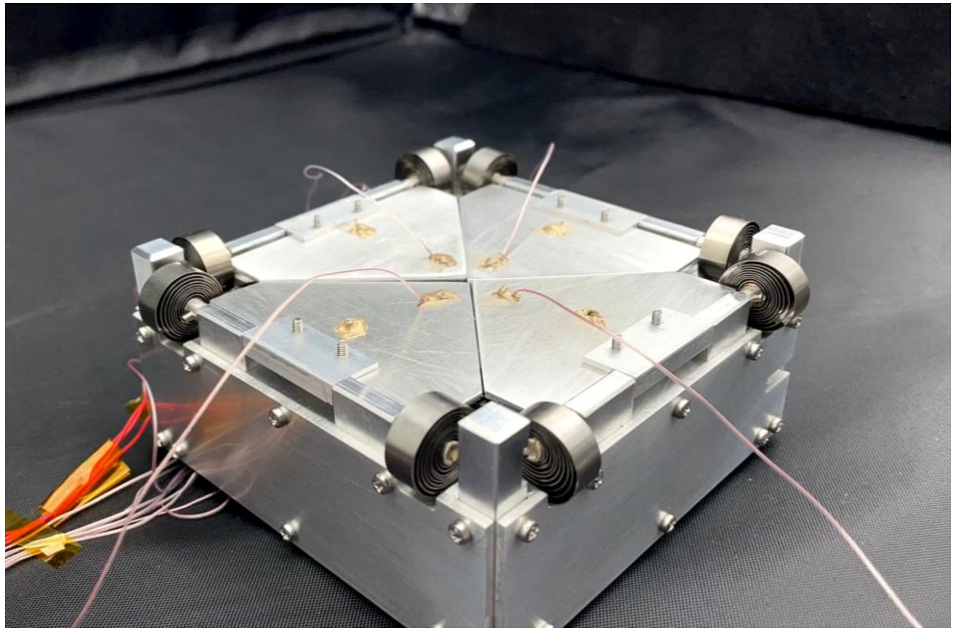
[2] JSR, Nagano 2009

Previous work

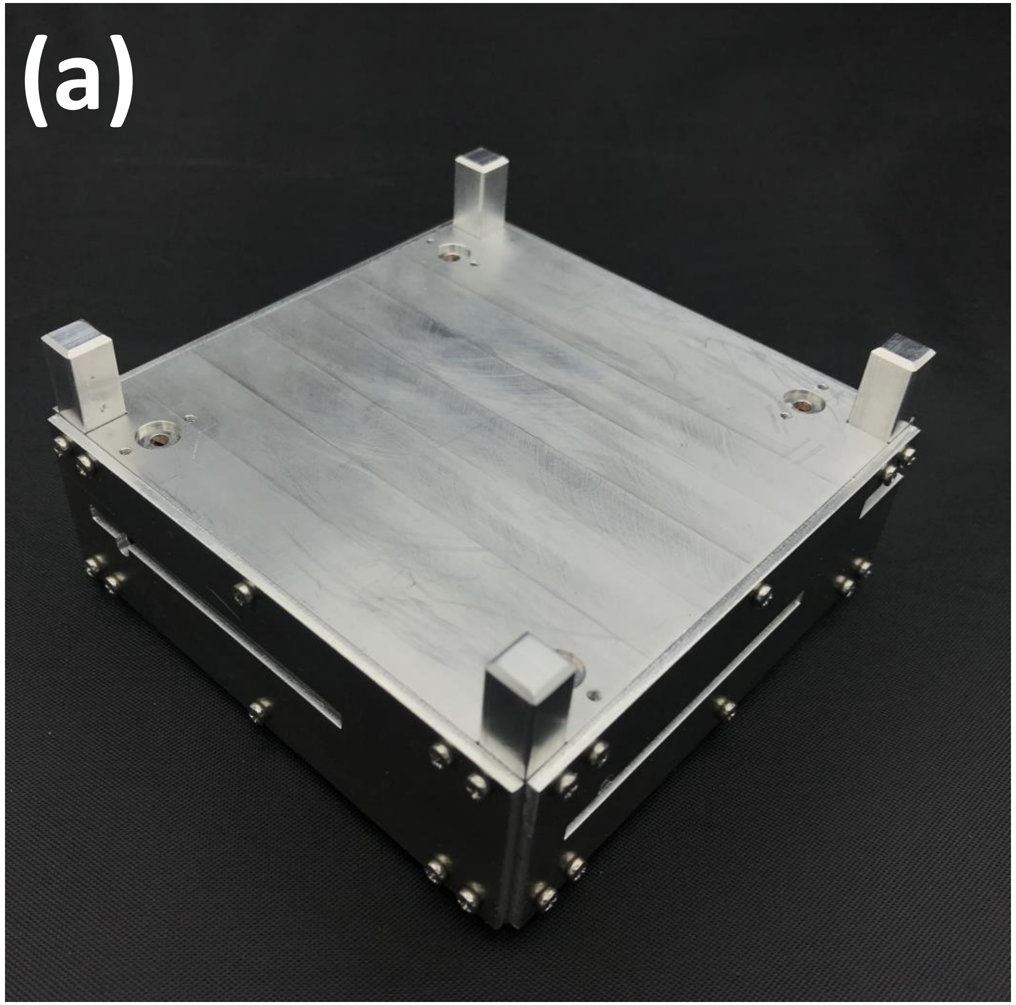
- This work is currently in review for publication
  - Presented at TFAWS 2022
- Triangular radiator fin array
  - Passively actuated by bimetallic coils
  - In deployed position, high emissivity surfaces are revealed
- Turndown ratio of 5.4
- Limited by difficult heat transfer to the radiator fins

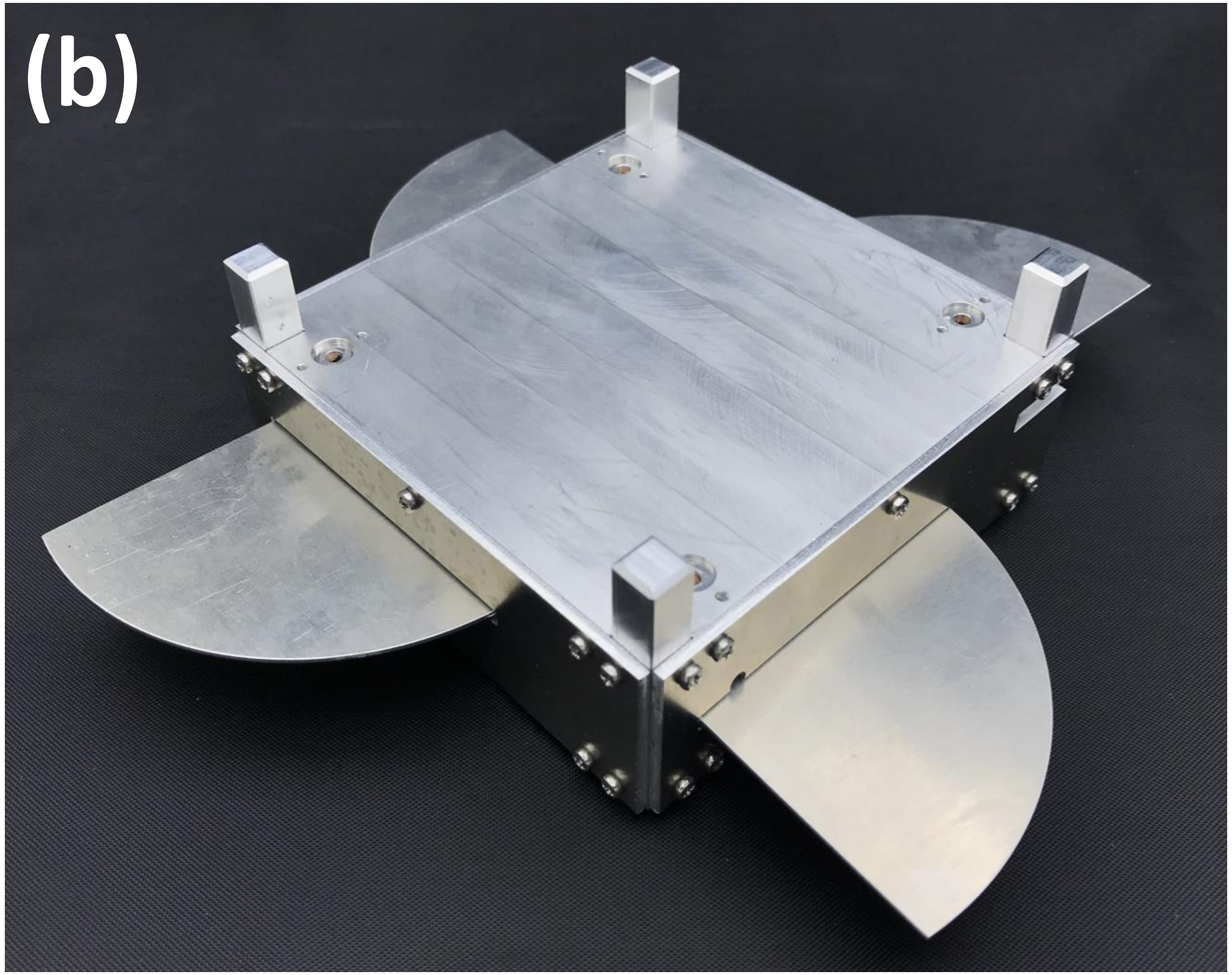






Proposed Design





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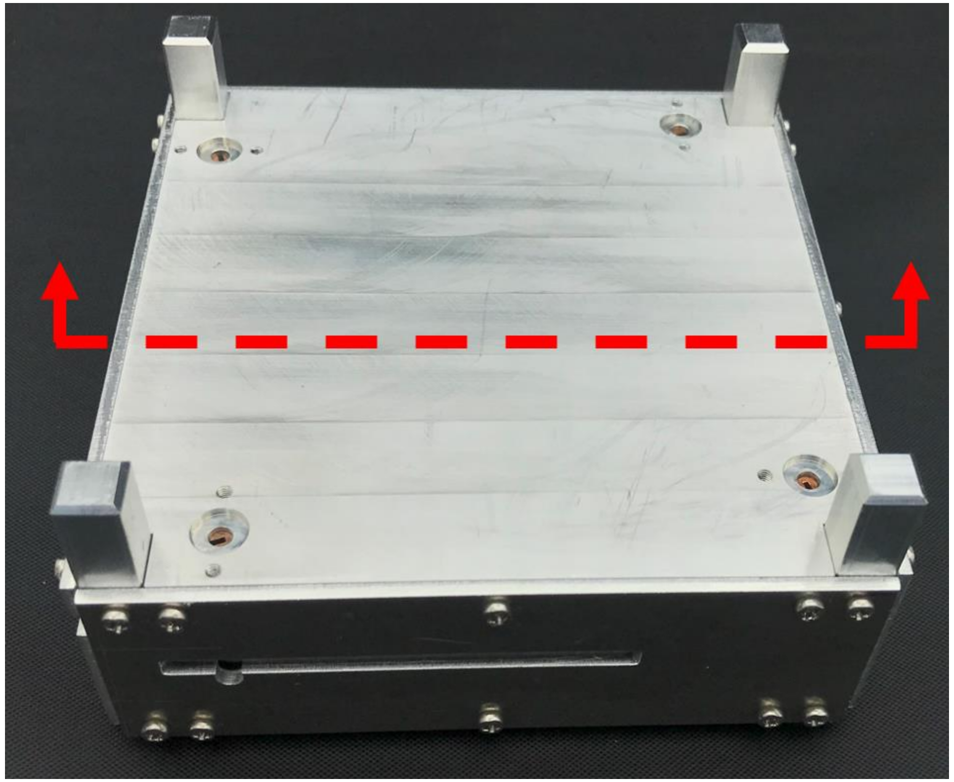

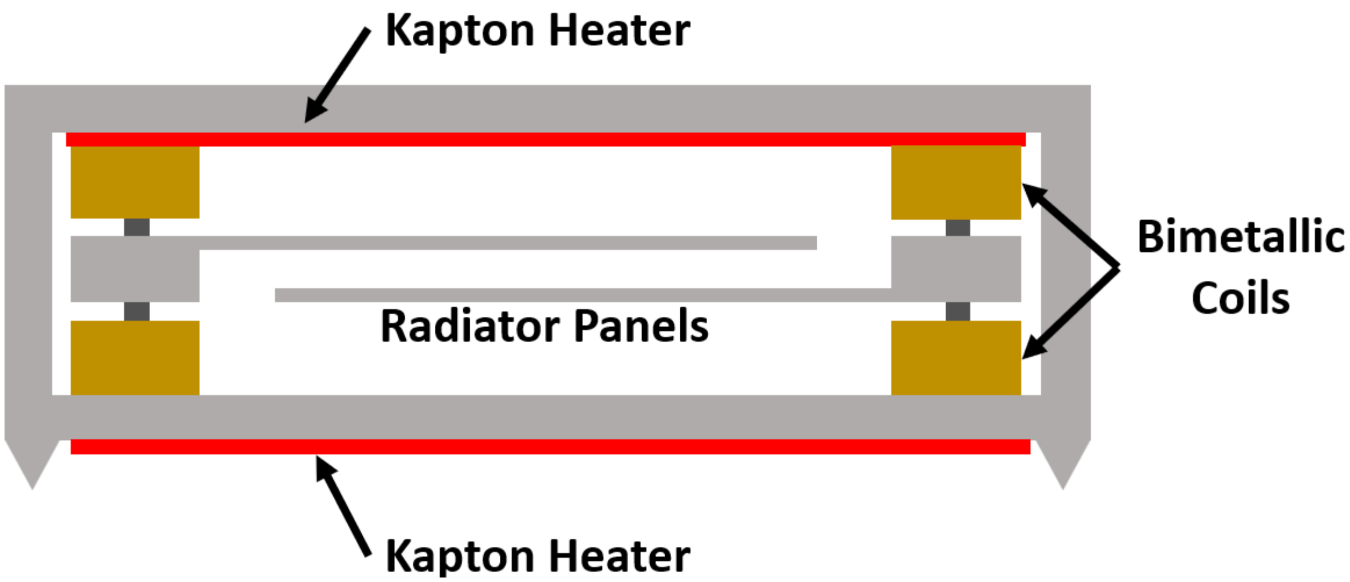

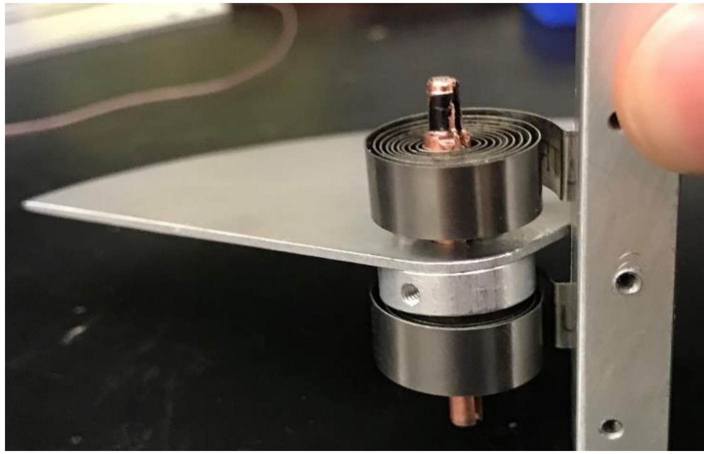

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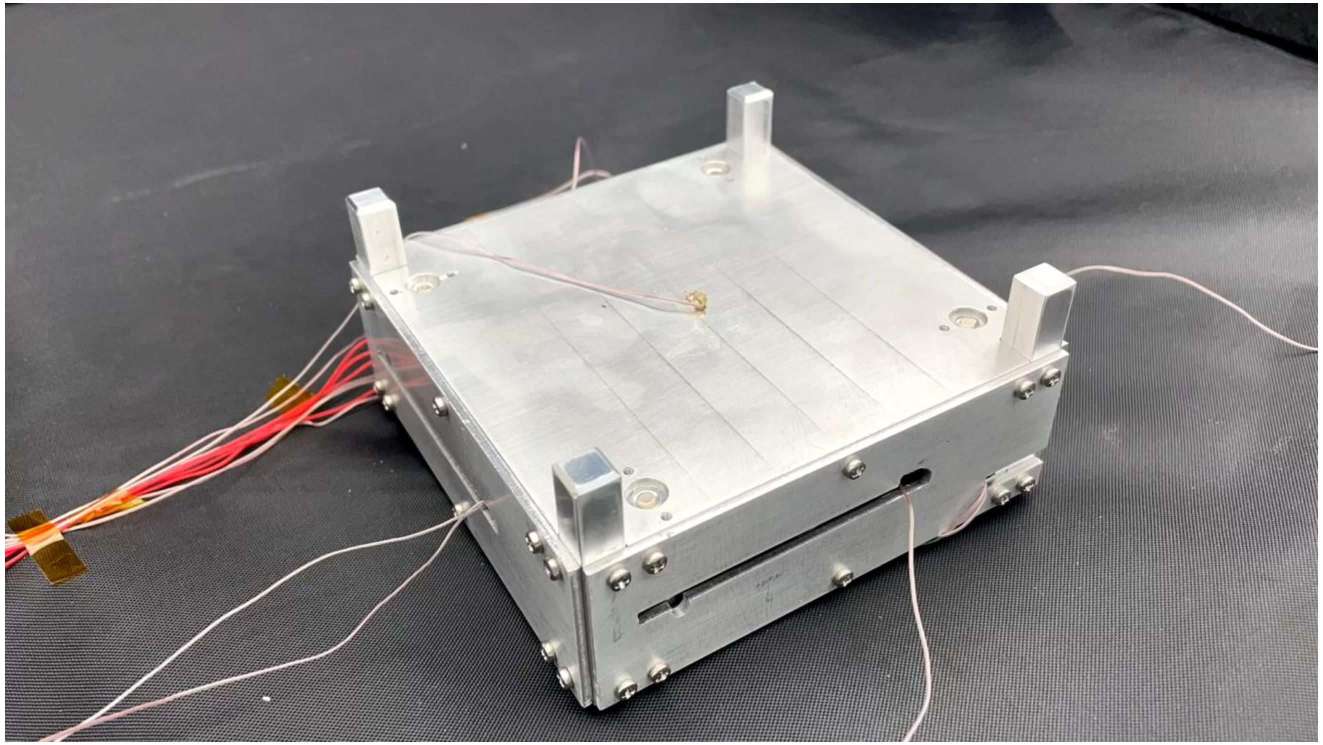
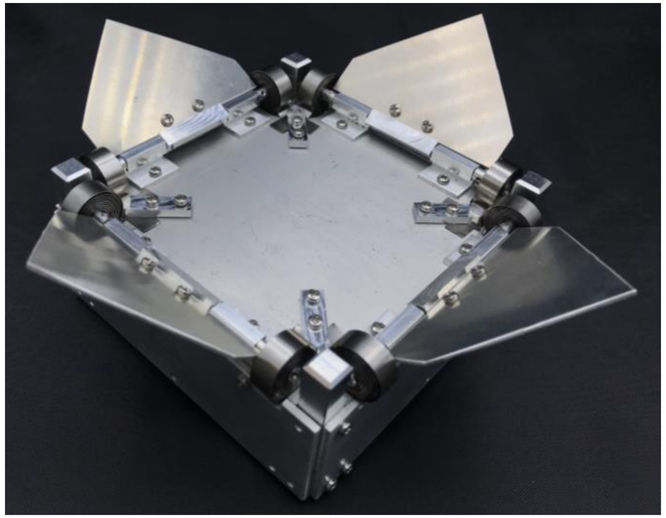


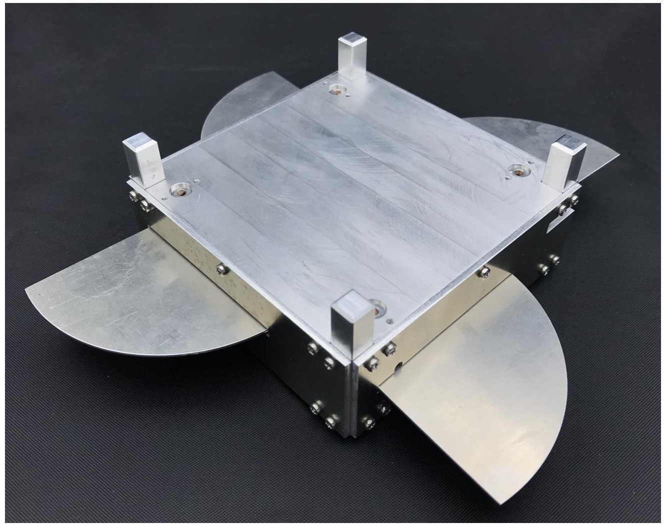
Atmospheric, 60 min test

Advantages of Proposed Design

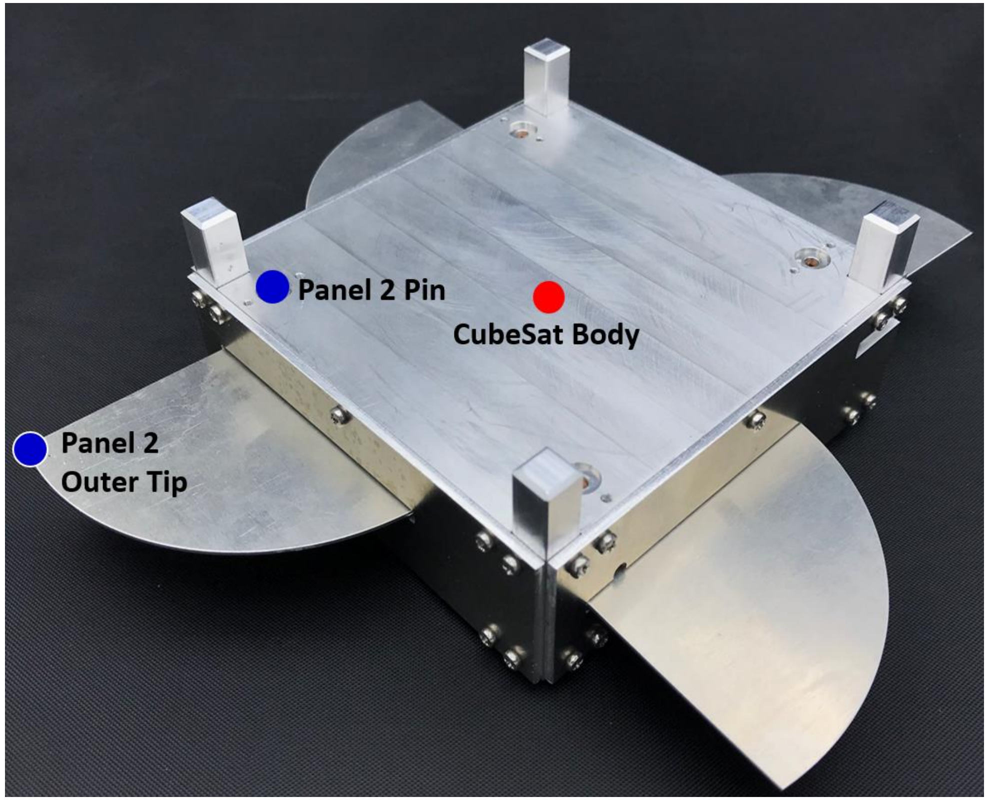
- Vs alternative passive thermal control systems
  - Improved reliability and redundancy (4 panels rather than 1)
  - Minimal hysteresis
  - Intermediate steady state positions achievable



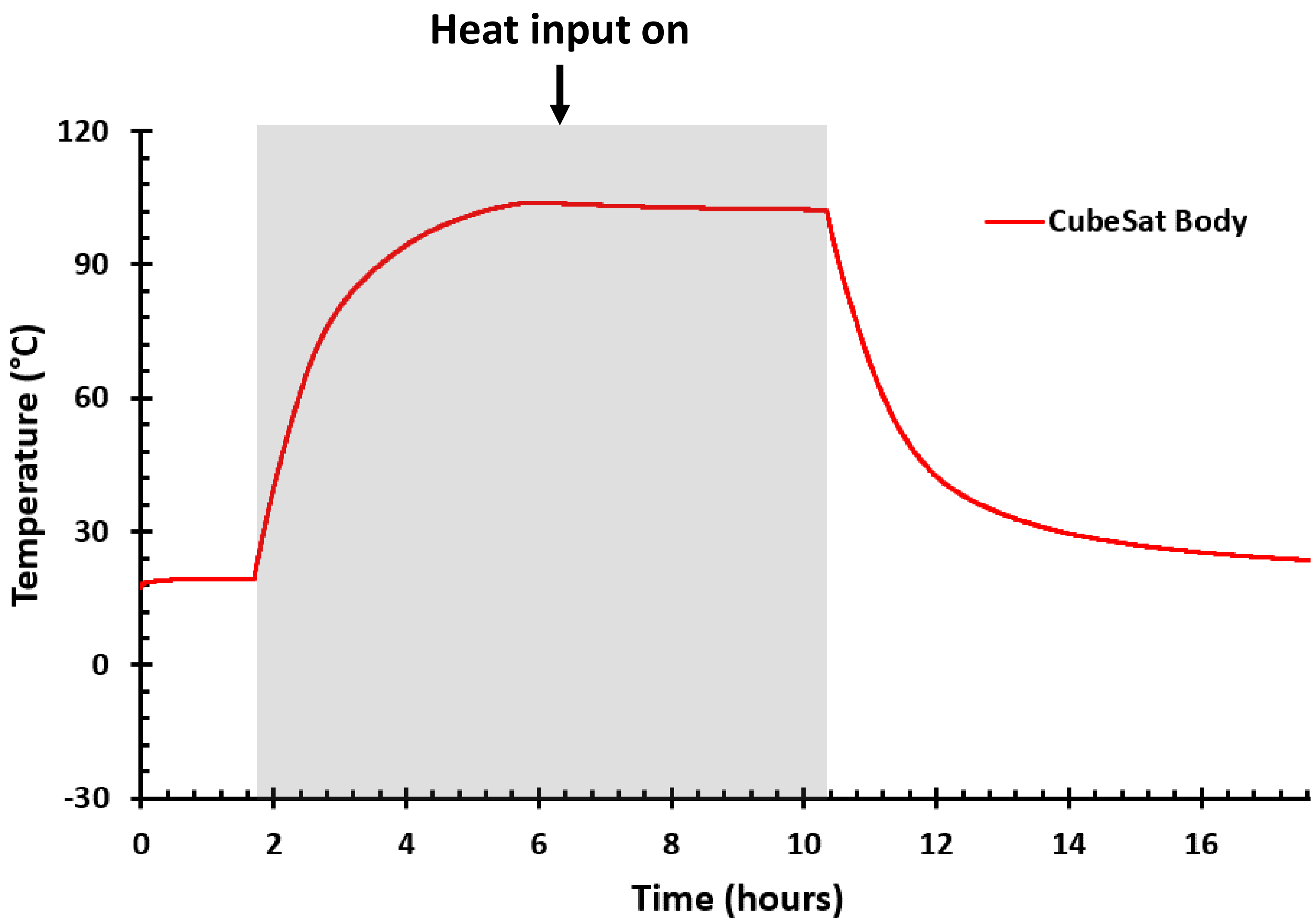
- Vs triangular fin design
  - Increased radial heat transfer to the coils and stowed panels
  - Improved responsiveness
  - Totally concealable fins leads to better cold case performance
  - Reduced change in temperature required to achieve full actuation



JPL Vacuum Chamber Test Setup



Steady State Testing Results



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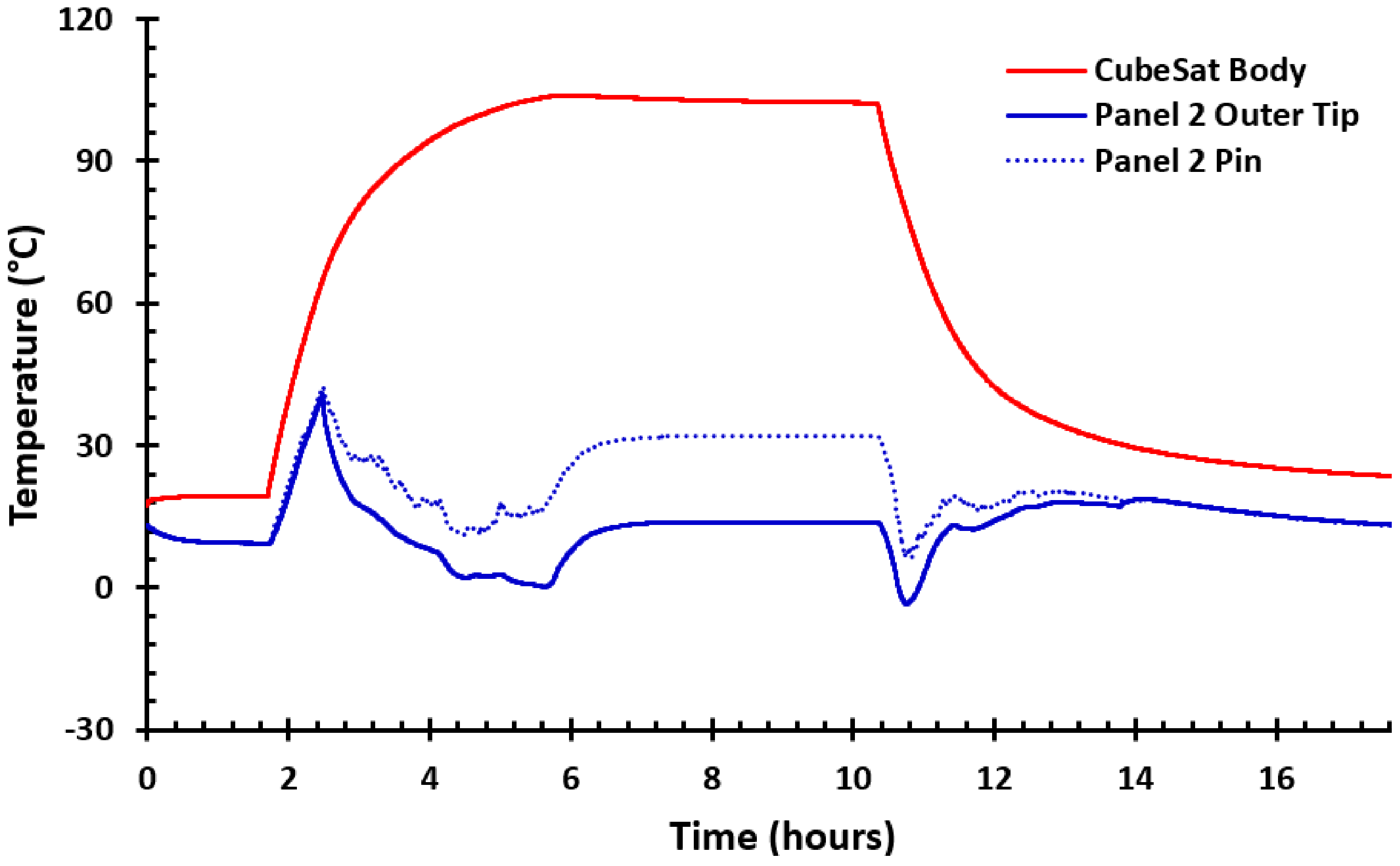

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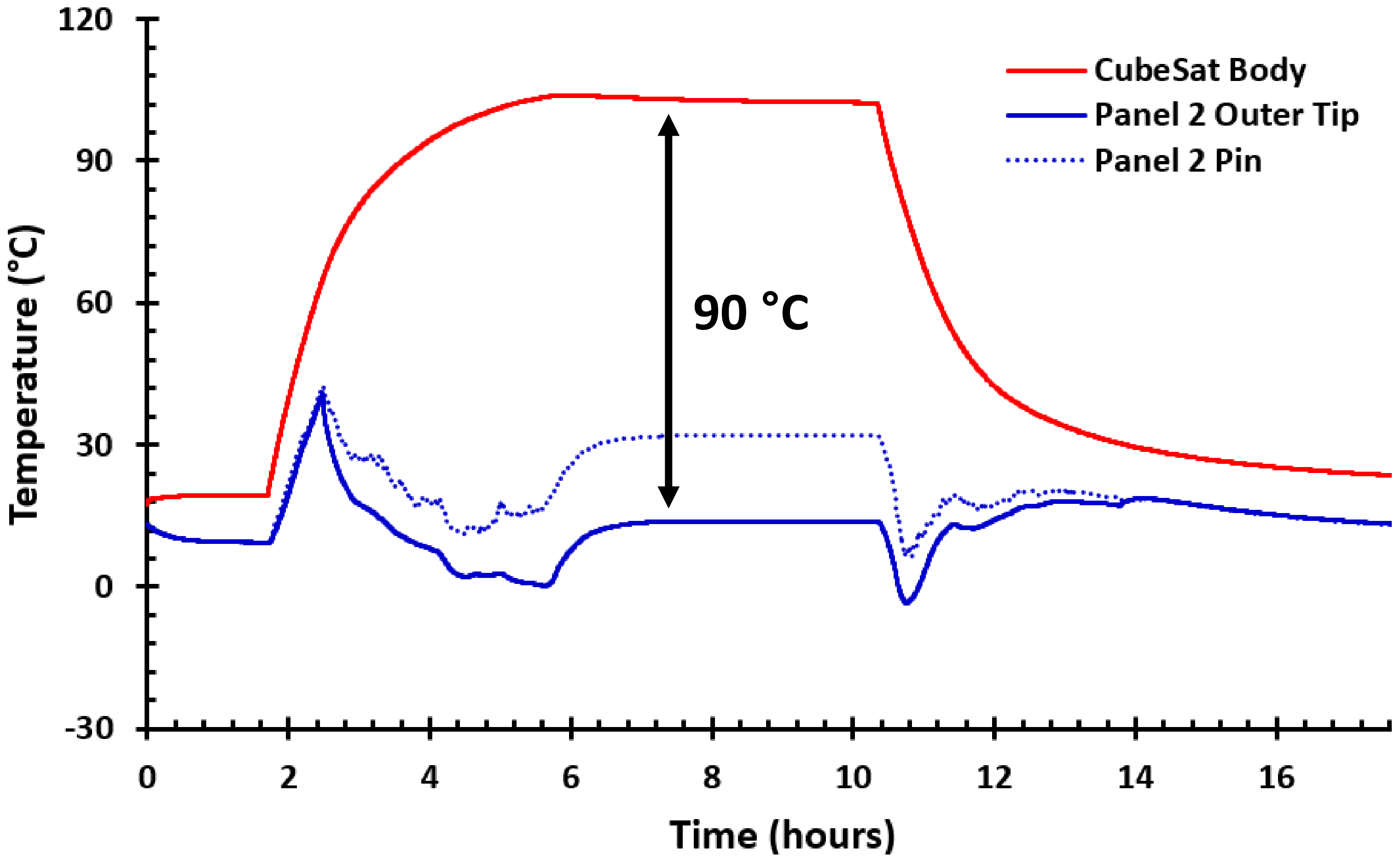

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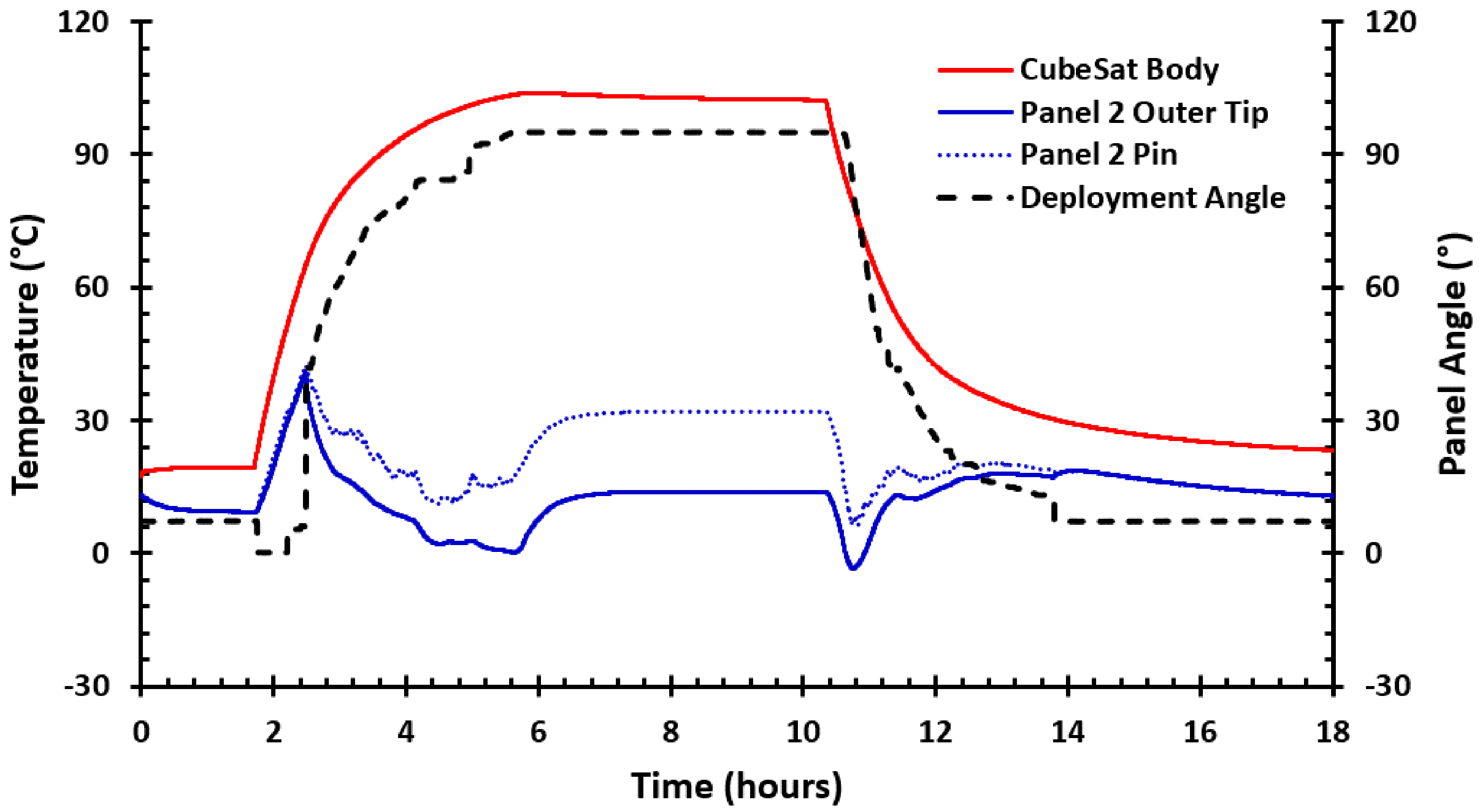

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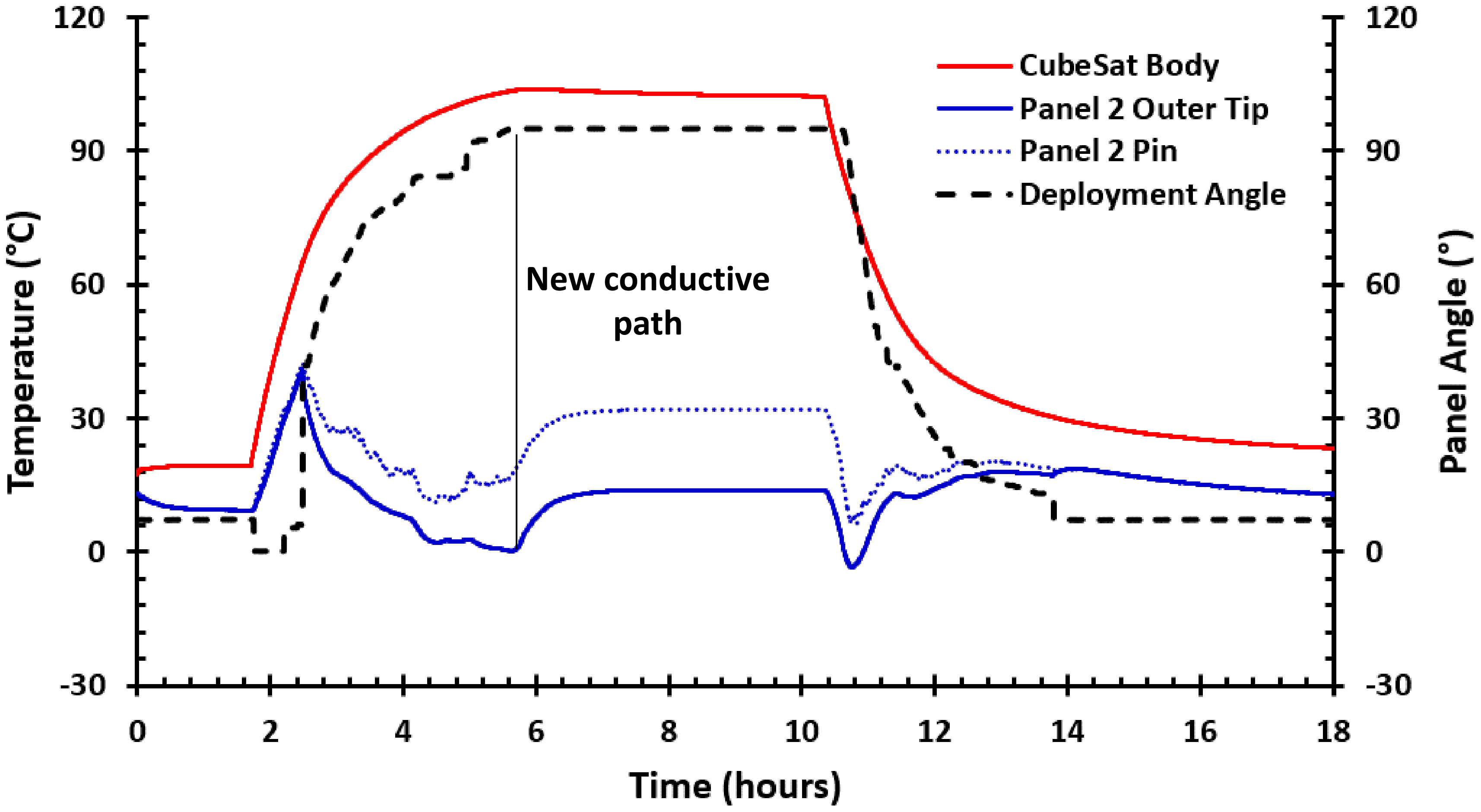
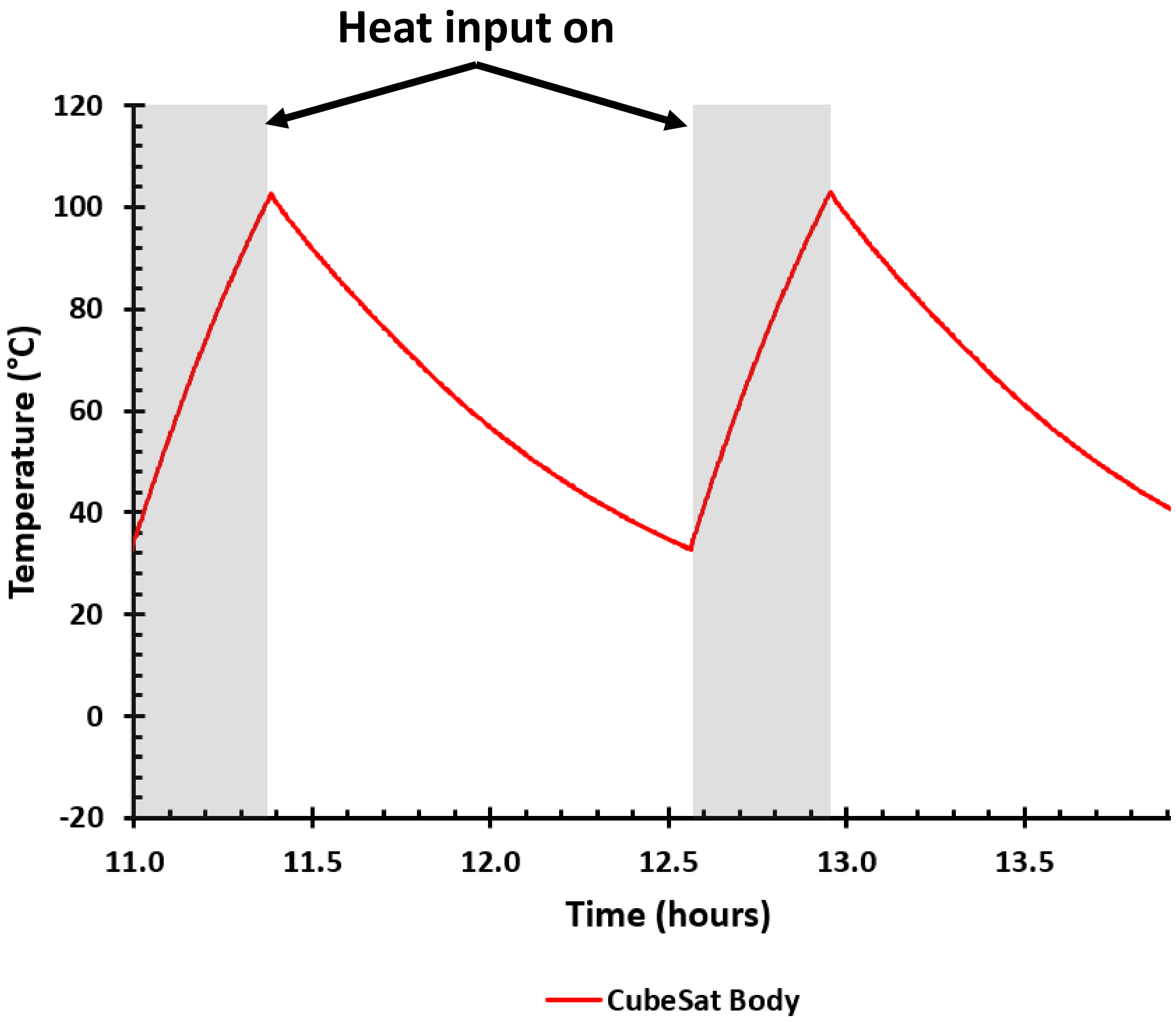
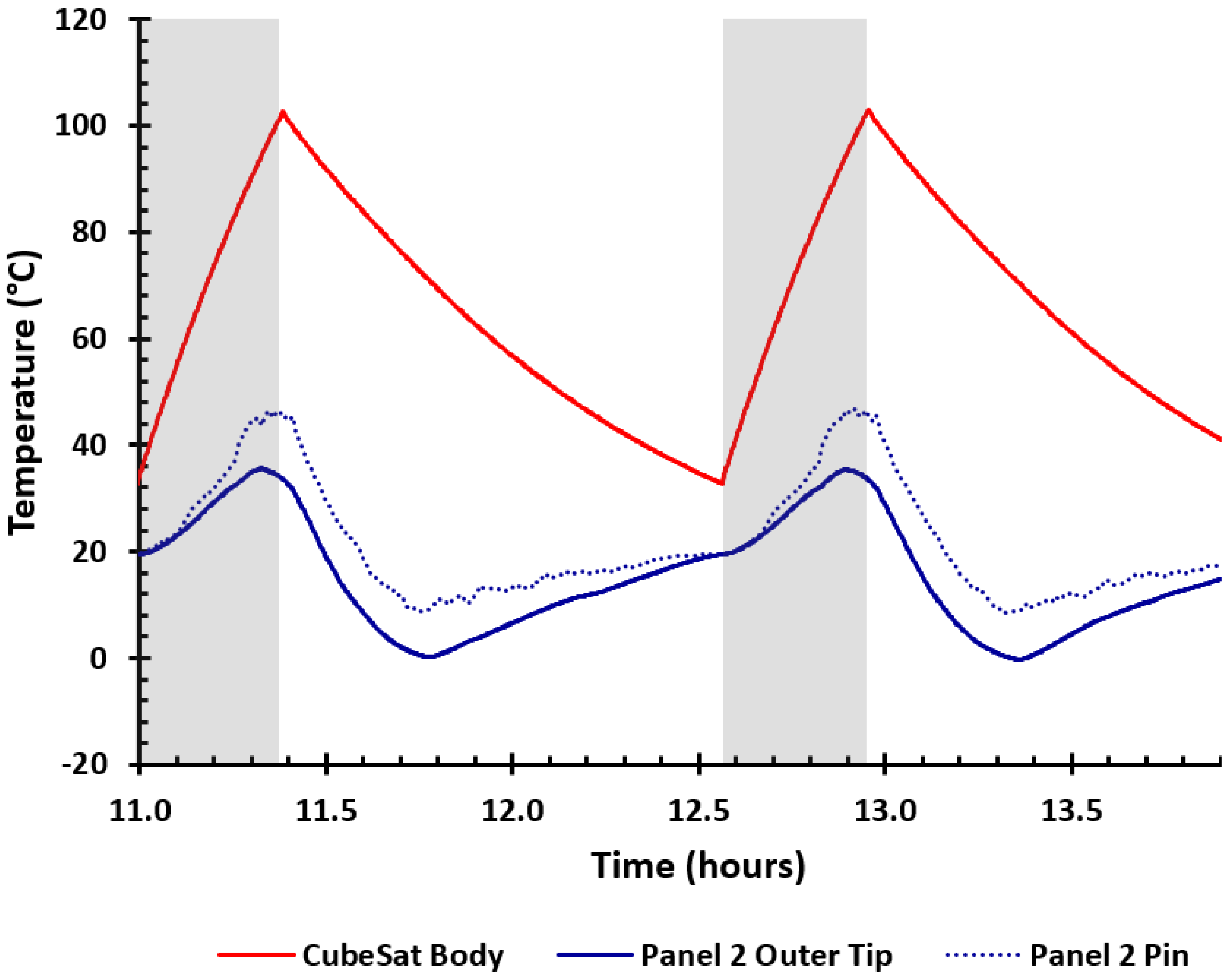


Transient Testing Results



Transient Testing Results



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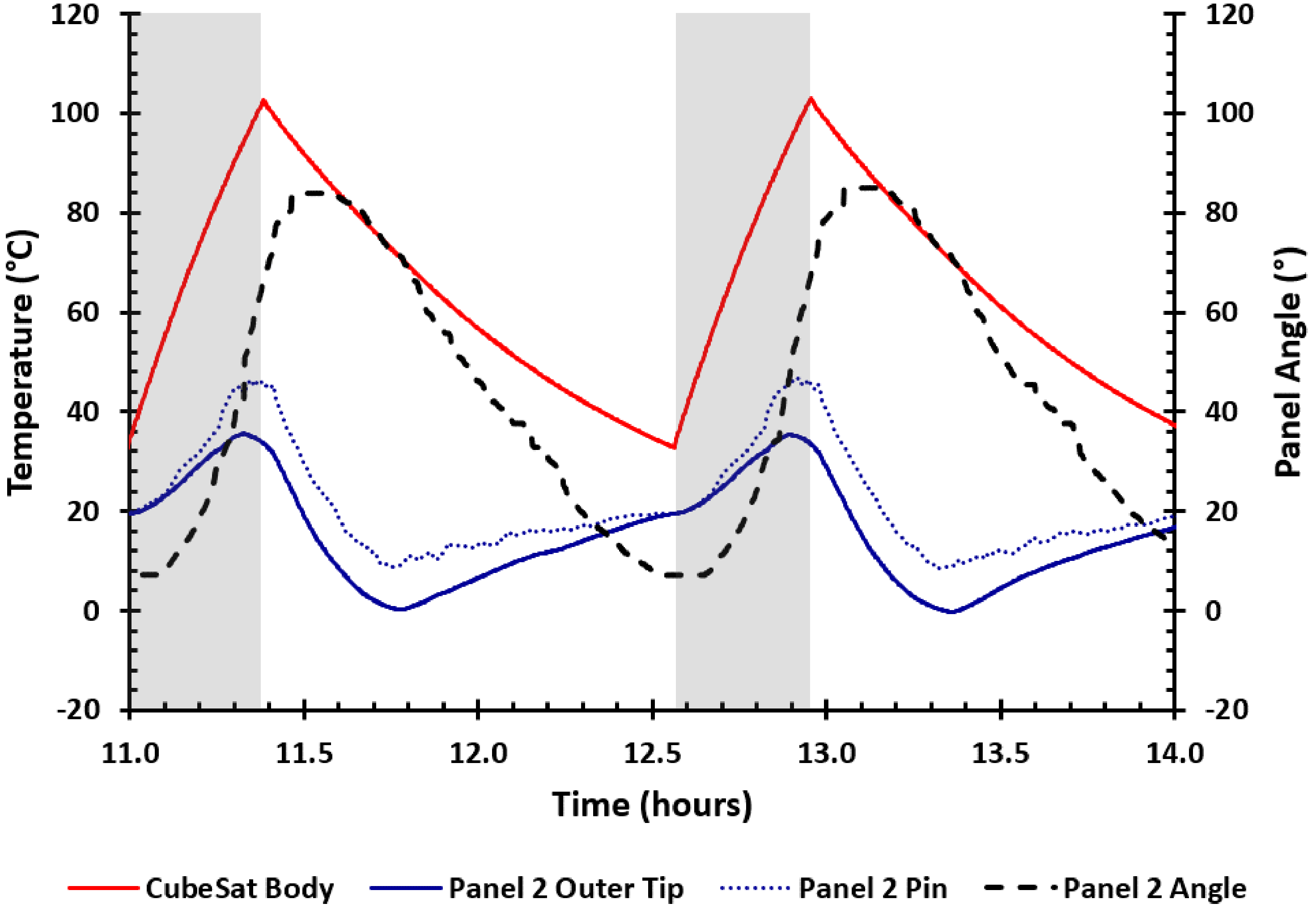
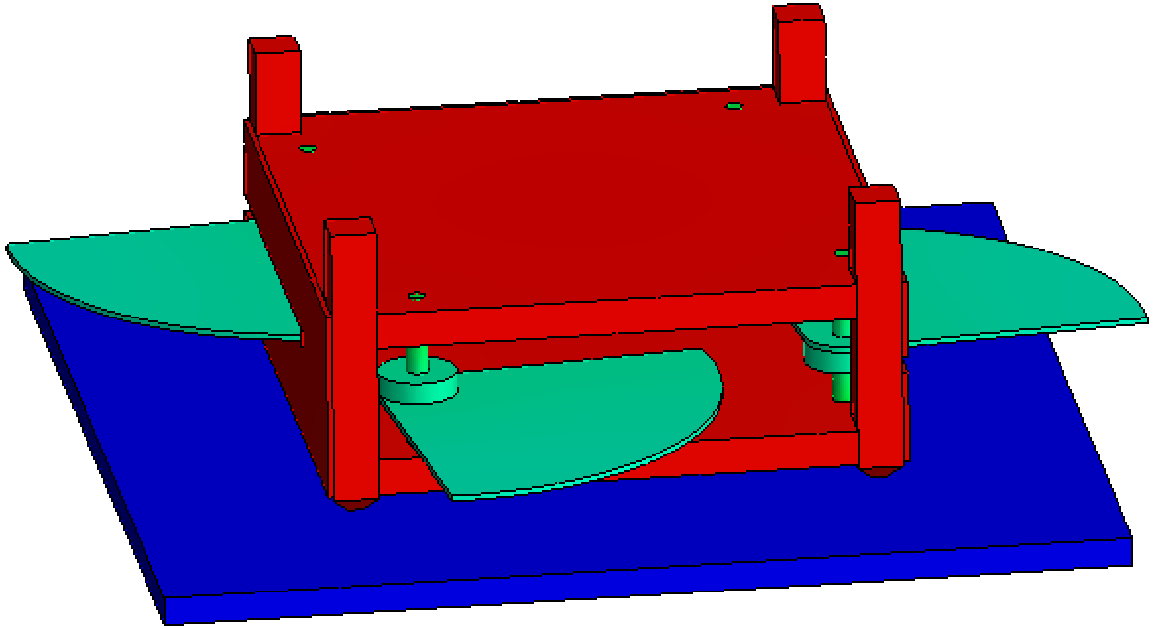


Thermal Desktop Simulation

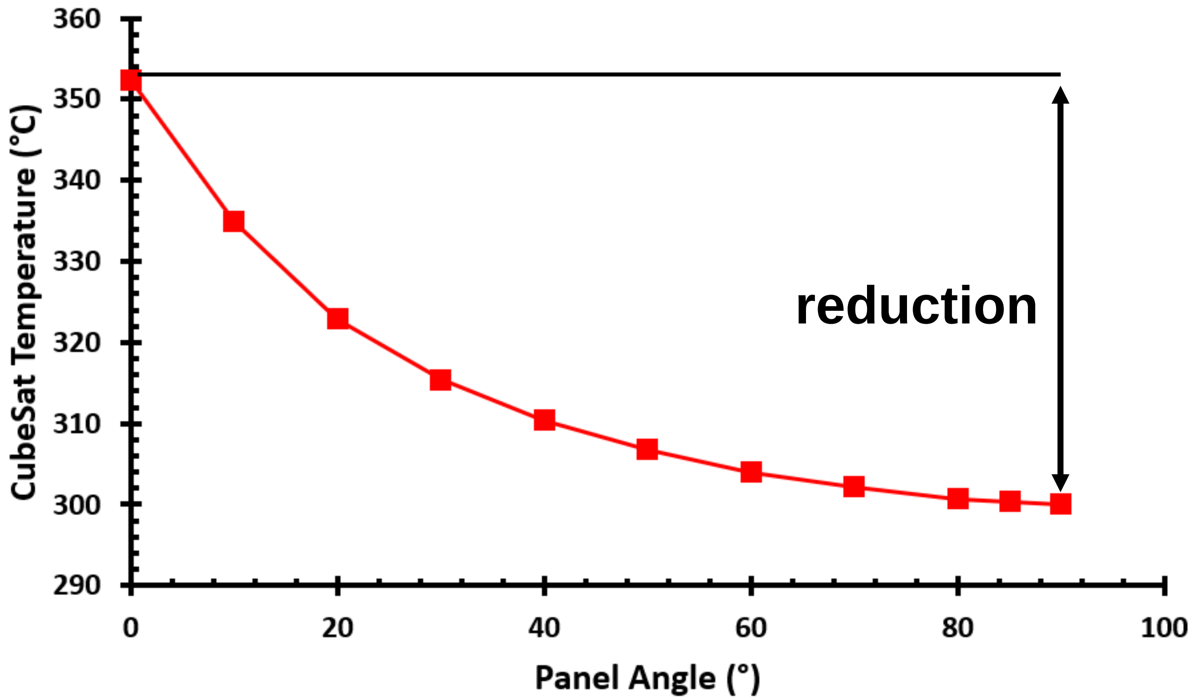
- Thermal model built in Thermal Desktop using known emissivities and conductivities
- 2 contact resistances were tuned
  - Calibration data obtained from steady state vacuum chamber testing
- Resulting agreement within 2.5 °C



Simulation Results

- Turndown ratio = 1.9
  - Max heat loss 2.75 W at 90˚
  - Min heat loss 1.44 W at 0˚

- Temperature decrease
  - Heat rate: 2.75 W
  - Evaluated over all deployment angles
  - 52 °C temperature reduction
    - 95% benefit by 67˚
    - 90% benefit by 55˚



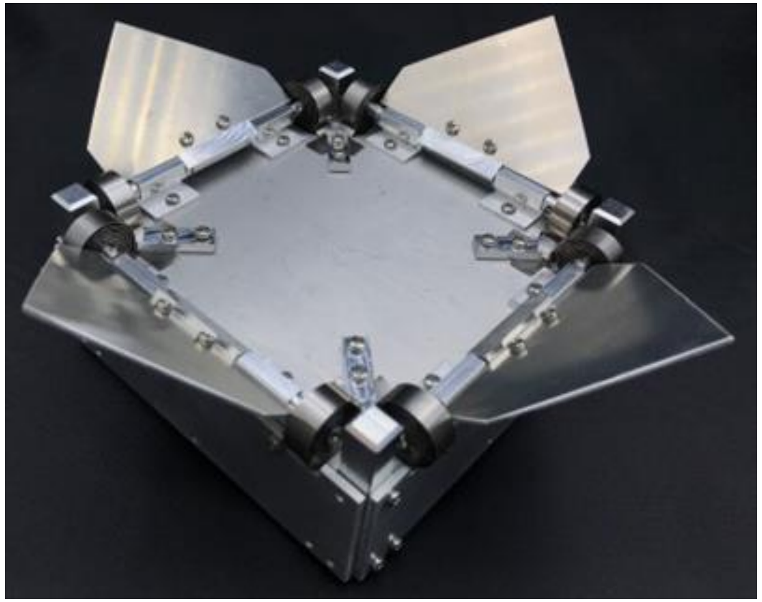
Comparison: Triangular Fin Design

Pros

- Greater maximum heat rejection, primarily due to upper body face as a radiating surface
- Easier to direct the radiative surfaces towards deep space; coating is only applied to one side

Cons

- Requires one exterior CubeSat face to be a radiator (no solar panels)
- Requires 135° rotation to achieve “full” deployment (90° for radial fin)



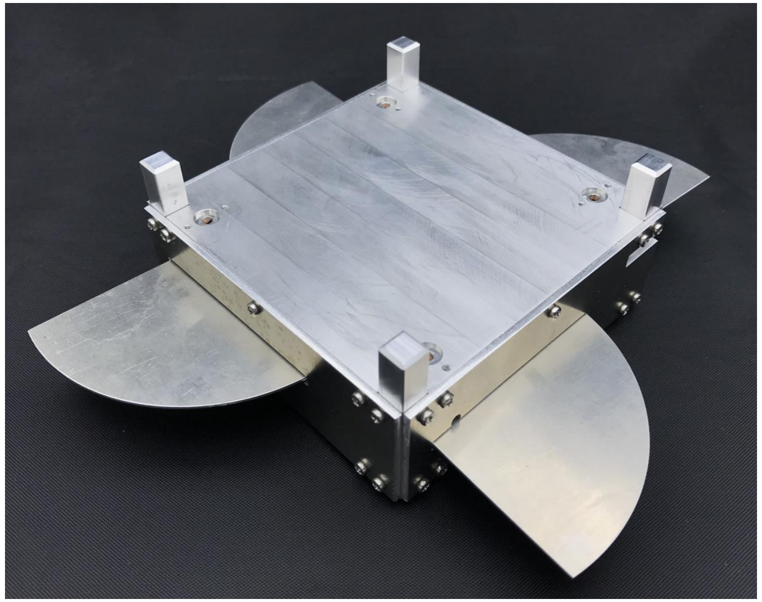
Comparison: Radial Fin Design

Pros

- Secondary conduction path to fin at full deployment
- Completely concealed during cold case operations
- Reduced phase lag from internally located bimetallic coils
- Possibility for better heat transfer to the fins due to radiative transfer from the interior on both sides

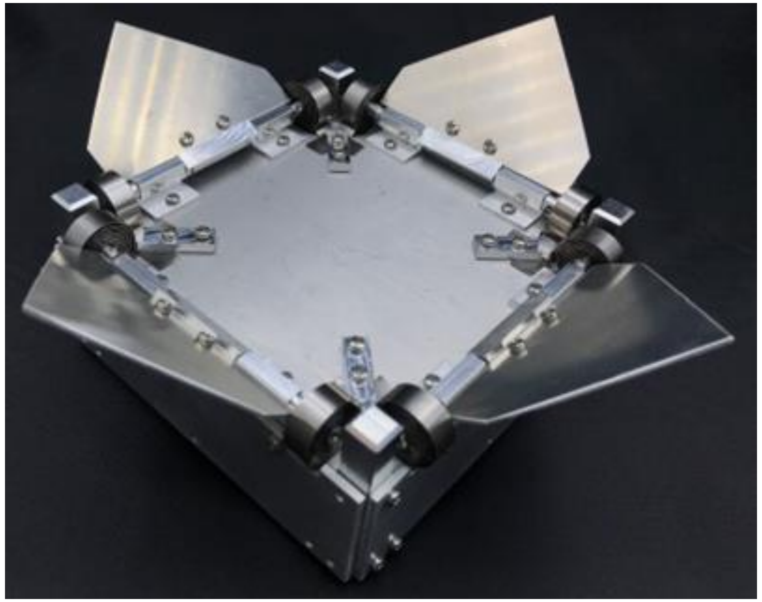
Cons

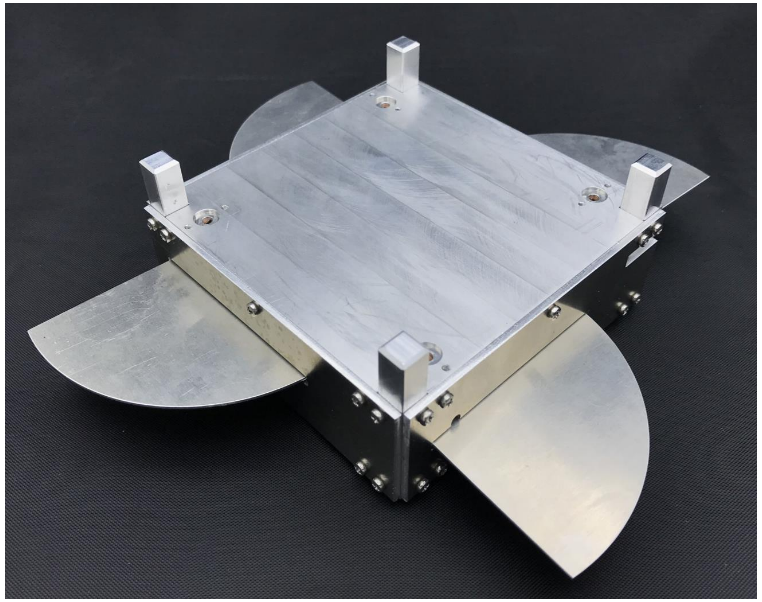
- Internally stored fins could interfere with some CubeSat designs, requires CubeSat volume



Conclusions

- Dynamic thermal control achievable via deployable radiator array
  - Passive deployment by bimetallic coils, allows for continuous states, minimal hysteresis
  - Array of 4 panels provides redundancy
- Conduction path is a key component of the system
  - effects phase lag, TD ratio, responsiveness of panels



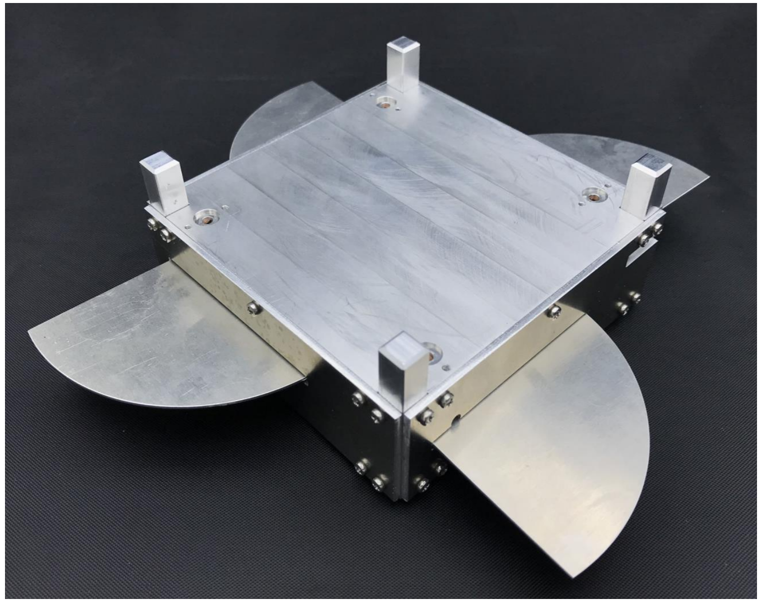


Future Work

- Heat transfer to the panels is still a challenge
  - Thermal hinges is an area of interest
  - Improve secondary conduction path at full deployment
  - Phase change materials in the fin could allow them to store more heat prior to full deployment

- Higher fidelity thermal vacuum chamber testing of a complete thermal control system
  - Simulated light/dark cycles to better asses transient behavior

- Thermal Desktop transient simulation
  - Suitable for lunar orbit?



Acknowledgements

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References

1. Evans, A. (2019). Design and Testing of the CubeSat Form Factor Thermal Control Louvers. *Proceedings of the AIAA/USU Conference on Small Satellites, Technical Poster Session IV, SSC19-P4-23*. https://ntrs.nasa.gov/search.jsp?R=20190028943

2. Nagano, H., Ohnishi, A., Higuchi, K., & Nagasaka, Y. (2009). Experimental Investigation of a Passive Deployable/Stowable Radiator. *Journal of Spacecraft and Rockets - J SPACECRAFT ROCKET*, *46*, 185–190. https://doi.org/10.2514/1.30170