Development of a lightweight thermal capacitor panel for thermal control of CubeSat applications

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Our Space Related Capabilities

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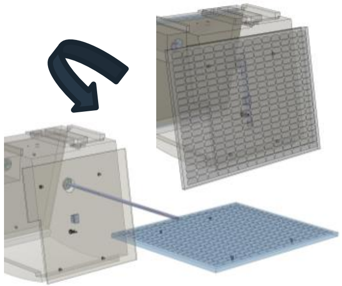
Deployable Systems

Solar Array Deployment Systems, Deployable Antenna, Magnetometers, Specialist ProxOps deployable products

Custom high performance co-engineered deployable devices



Thermal Management

Flat heat pipes, pumped two-phase cooling and thermal capacitors

Two-Phase Electronic Cooling Product Technologies

Roccor Space-Flight Heritage

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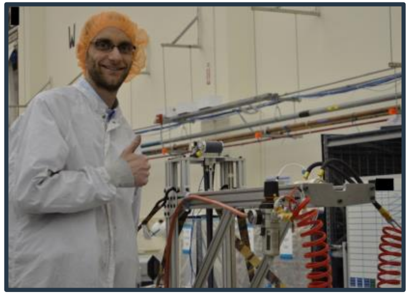
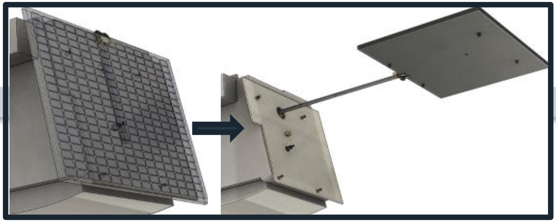
2017 Q3 | 2017 Q4 | 2018 Q1 | 2017 Q2

Deployable Boom (1)

Deployable Antenna Booms (2)



Furled CubeSat Antenna (2)



Solar Array Deployment Demo (10)

Solar Array Deployment Commercial Fleet (100’s)

Sample Projects

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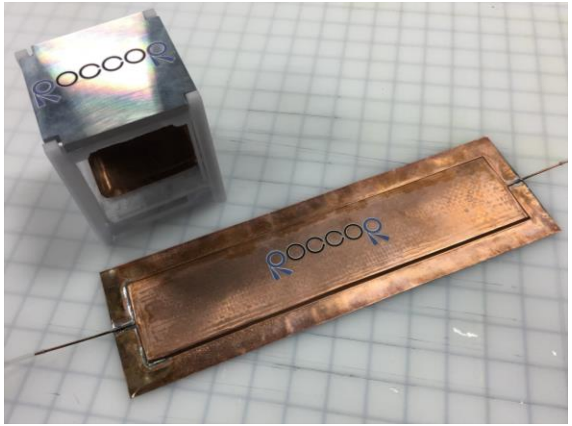

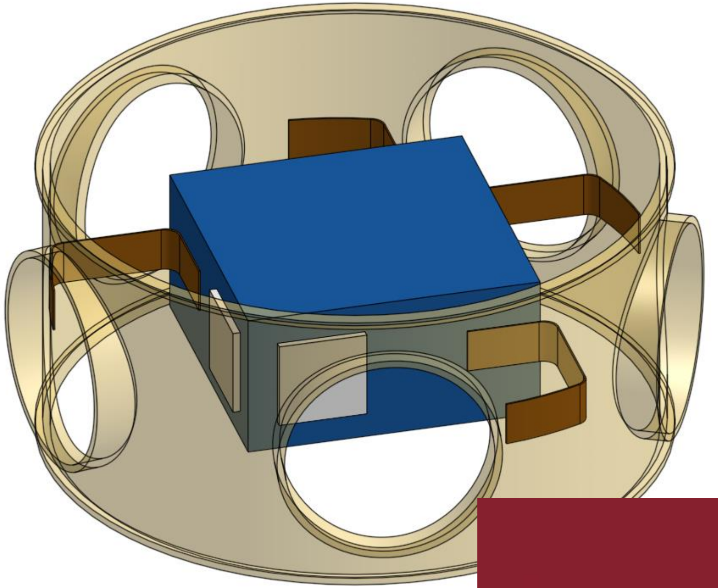

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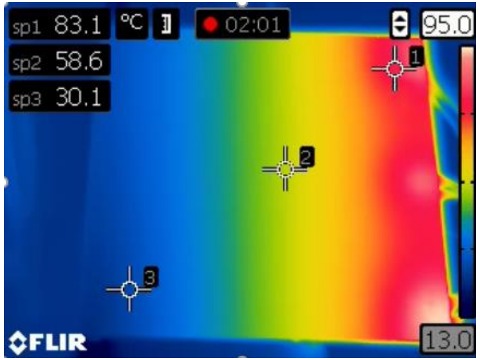
SPACE AND DEFENSE GROUP

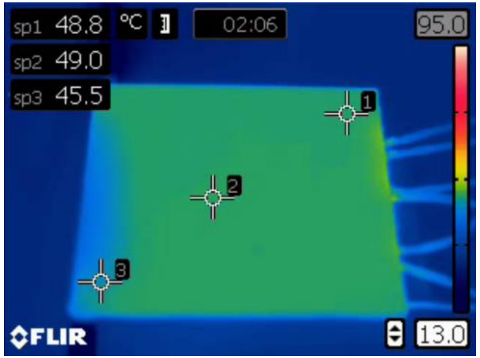
Thermal solutions for spacecraft in the cubesat to 1,000kg class and beyond

Why Two-Phase?

- **Benefits of two-phase flow:**
  - »Volume and mass savings → SWaP improvement
  - »Reduced mass flow rate
  - »Lower pressure drops
  - »Temperature uniformity among multiple heat sources
  - »Able to cool several components in series
- **Additional benefits of Roccor's approach:**
  - »Scalable manufacturing
  - »Commercial-off-the-shelf materials
  - »Design flexibility



10 cm x 10 cm Plain Copper at 120 W



10 cm x 10 cm FlatCool at 120 W

Need for a thermal solution to dampen large temperature fluctuations

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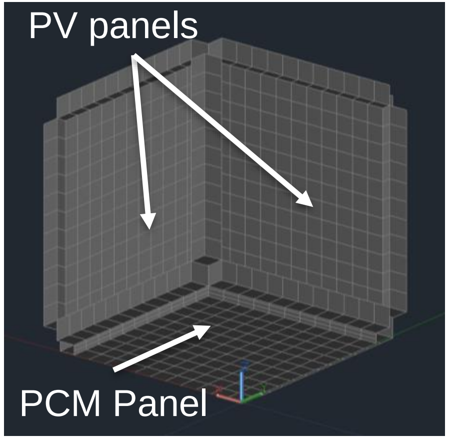
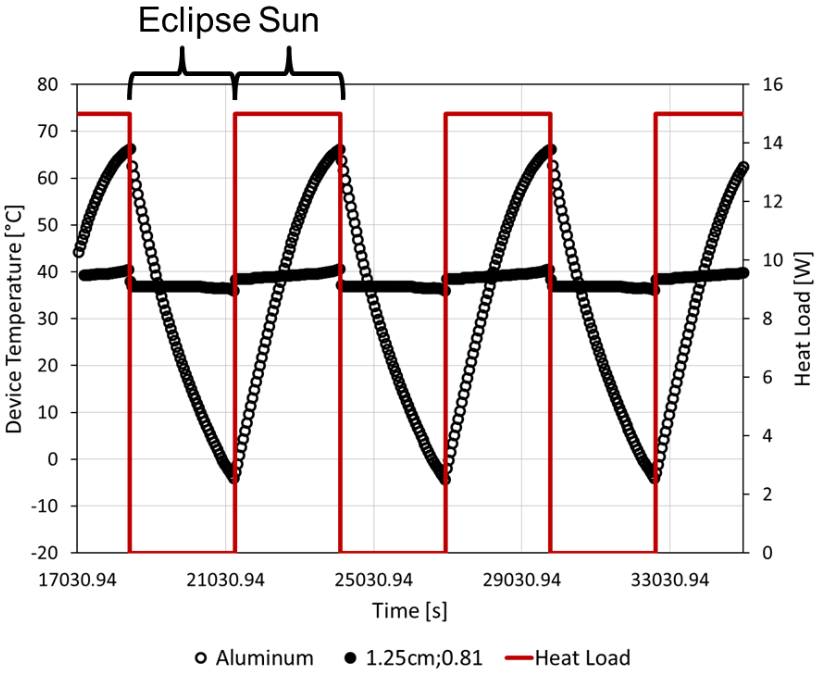
- **A Thermal Capacitor using Phase Change material:**
  - » Can dampen temperature fluctuations to maintain components within a tolerable range
  - » Can reduce large temperature swings that could lead to undesirable thermal stresses





Thermal Capacitor built using 3D Printed Aluminum

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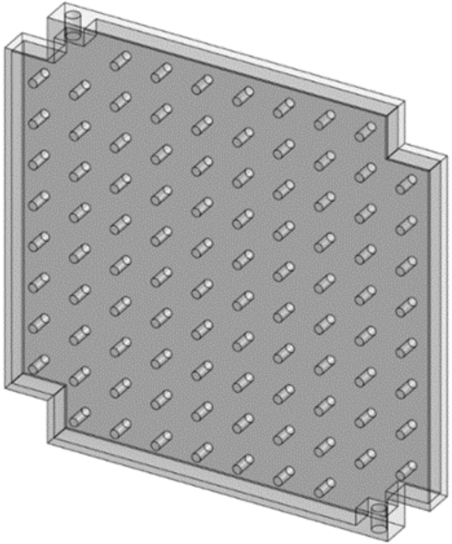
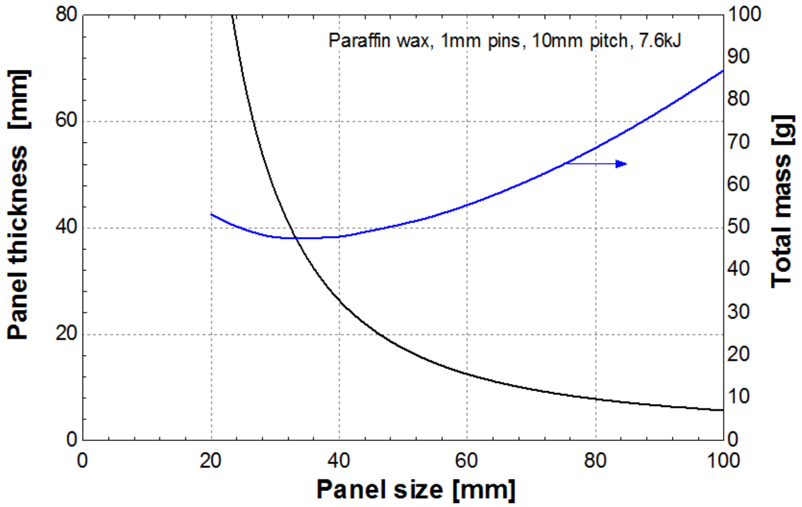
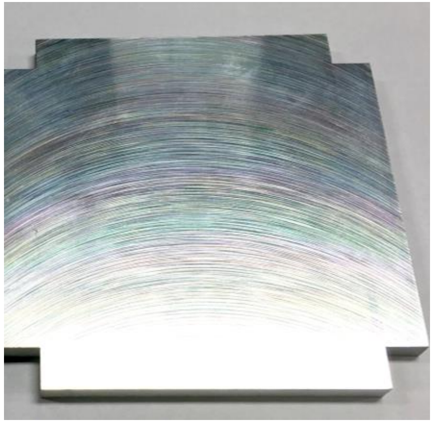
- **Direct Laser Metal Sintering (DMLS)**
- **Internal structure:**
  - »Load bearing
  - »Thermal conductivity enhancement
- **Monolithic construction**
- **Filling ports**



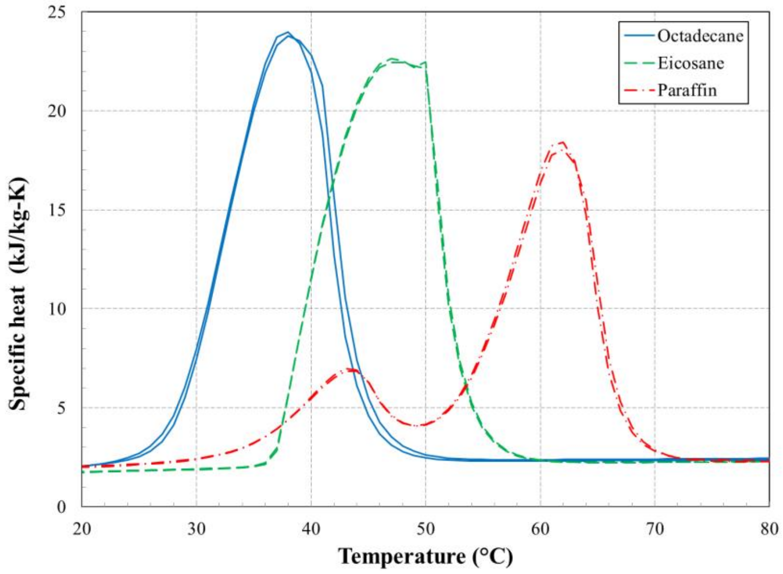
Design Optimization and Manufacturing





- Worked with DMLS manufacturers to identify minimum feature sizes, wall thickness, internal support structures, and filling ports
- Prototypes were within flatness specifications
- Prototypes can be post-processed for optical characteristics

PCM Thermophysical Properties

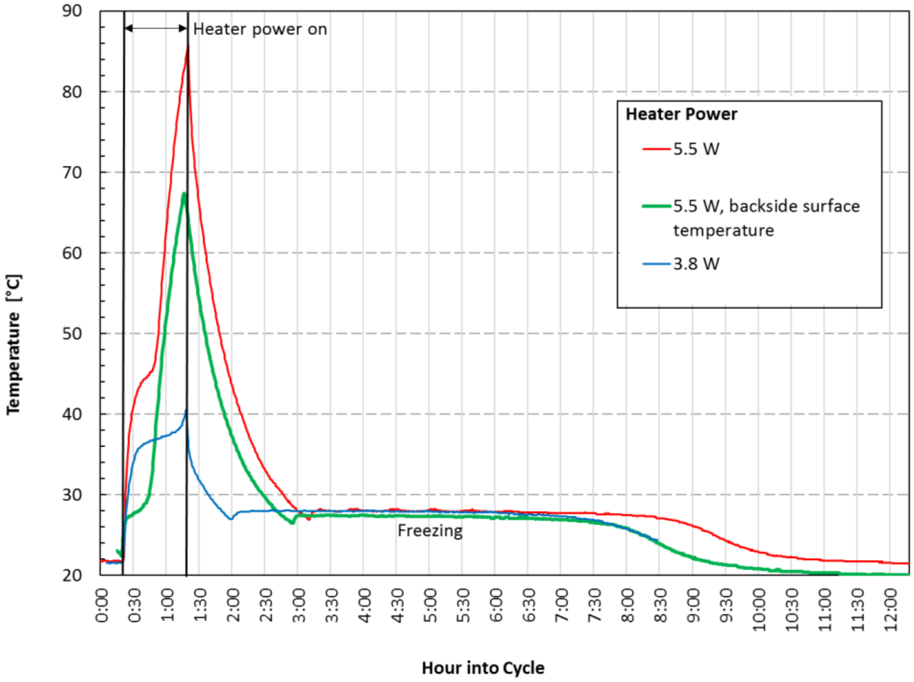


PCM	Latent Heat (kJ/kg)		Variance
	Literature	Experimental	
Octadecane	244.0	234.5	3.9%
Eicosane	247.3	237.2	4.1%

PCM	Thermal Conductivity (W/m-K)		Variance
	Literature	Experimental	
Octadecane (solid)	0.358	0.418	14%
Octadecane (liquid)	0.152	0.147	3%
Eicosane (liquid)	0.150	0.118	28%

- **Measured specific heat (and latent heat) and thermal conductivity, to verify literature values:**
  - »Differential scanning calorimeter testing for specific heat (at Netzsch)
  - »Flash method test for thermal conductivity (at Netzsch)
- **Specific heat is within 5% of literature (measurement error)**
- **Conductivity can be 28% from literature**
- **Specific heat curve can be used in Thermal Desktop model**

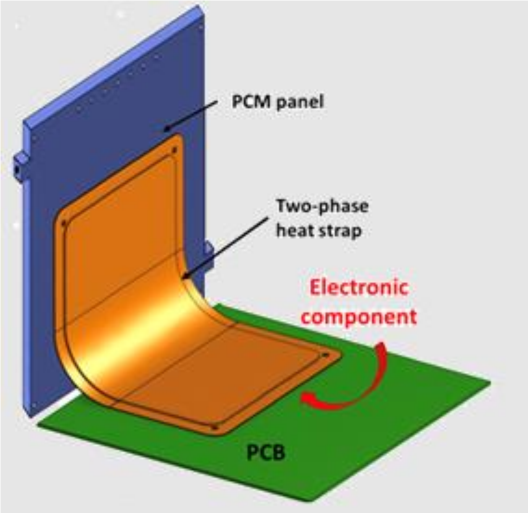
Thermal Testing

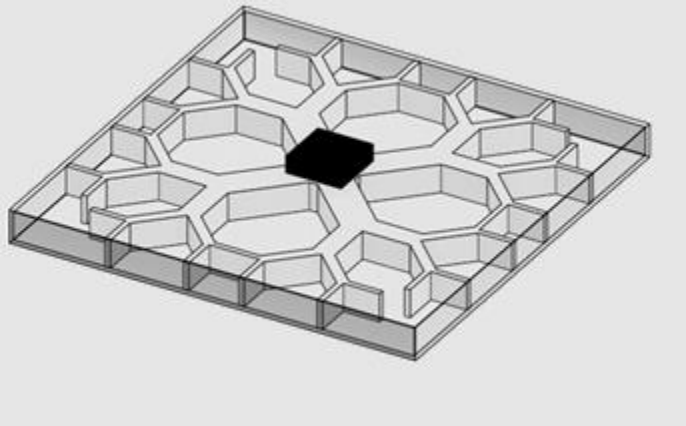


- Panel was filled with PCM and sealed
- Performed thermal testing under vacuum
- Completed 25 freeze/thaw tests
- No degradation was observed (no panel deformation, melt temperature or mass change)

Summary of Work and Future Work

- Testing and analysis performed demonstrated the proof of concept
- Future designs will be tailored for a given set of requirements
- Future testing will incorporate FlexCool™ heat strap





Thank you and questions

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- »Dr. Boris Yendler (Insat Consulting)

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Other PCM Panel Solutions

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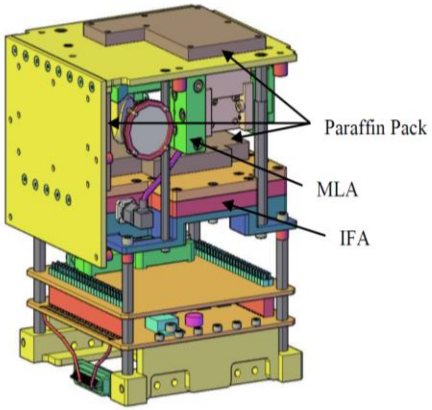
Requirements	Value
Operating temperature	20°C
Thermal stability	$\pm$1°C
MLA power dissipation	3 W
Eclipse time	30 min
Thermal Energy	7.35 kJ
PCM Solution	
Material	n-Hexadecane
Melt temperature	18.2°C
PCM mass	31 g
Total mass	~46 g
Panel structure: Fine aluminum honeycomb core K1100 carbon fibers Aluminum frame	



PCM panel for NASA Vegetation Canopy Lidar (VCL) project

[Choi, M., 2015, "Paraffin Phase Change Material for Maintaining Temperature Stability of IceCube Type of CubeSats in LEO", presented at AIAA Propulsion and Energy Forum and Exposition]

Other PCM Panel Solutions

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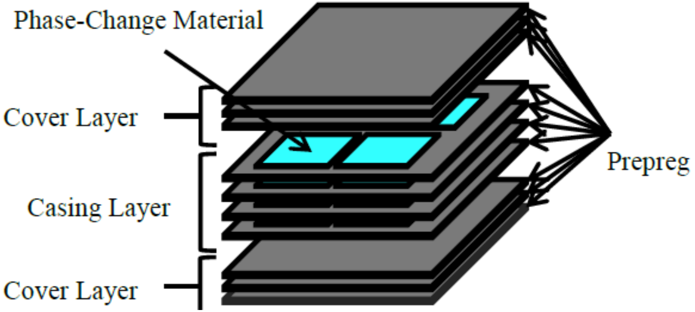
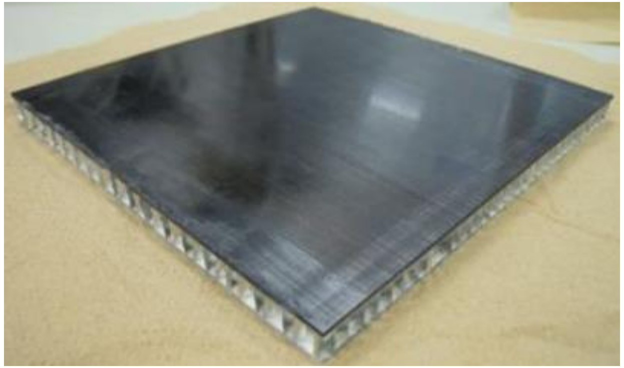
Requirements	Value
Thermal Energy	2.1 kJ
PCM Solution	
Material	Eicosane
Melt temperature	36.4°C
PCM mass	~10 g
Total mass	~100 g
Panel structure: Carbon fiber reinforced polymer	

Casing layers sized based on amount of PCM material and to reduce bending





[Yamada, K., and Nagano, H., 2014, "Heat Storage Panel Using a Phase-Change Material Encapsulated in a High-Thermal Conductivity CFRP for Micro Satellites", 44th International Conference on Environmental Systems.]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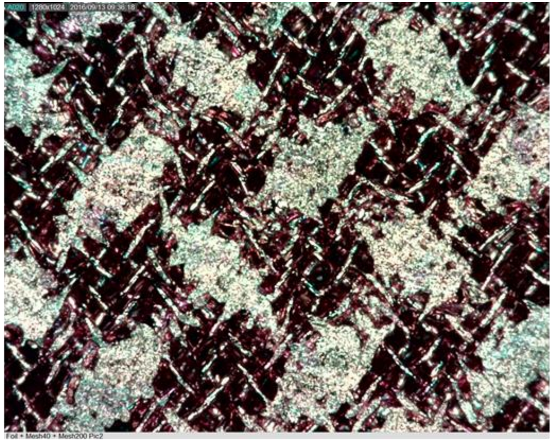
FlatCool™ Technology

Roccor's Enabling Technologies

- **Computational tools for design and analysis:**
  - »One-dimensional design models for flat heat pipes
  - »CFD and FEA models for detailed analysis
  - »Thermal Desktop analyses for space applications

- **Scalable manufacturing methods:**
  - »Commercial off-the-shelf materials (metal woven meshes)
  - »Diffusion bonding
  - »3D printing (direct metal laser sintering, stereolithography)

- **Ultra-omniphilic surface treatments:**
  - »Based on collaboration with New Mexico State University
  - »Increases capillary action and boiling of water on metal wicks



Diffusion Bonded Metal Woven Meshes