Hot & Cold: The FINCH Thermal Simulator

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I. Overview

Thermal modelling is an integral part of the satellite design process. However, detailed simulations require high-fidelity models and resources that are not readily available in the preliminary design stage. To gain insight into the on-orbit temperature ranges and heat loads that FINCH, a 3U hyperspectral imaging CubeSat, will experience, a six-node numerical model was developed in MATLAB.

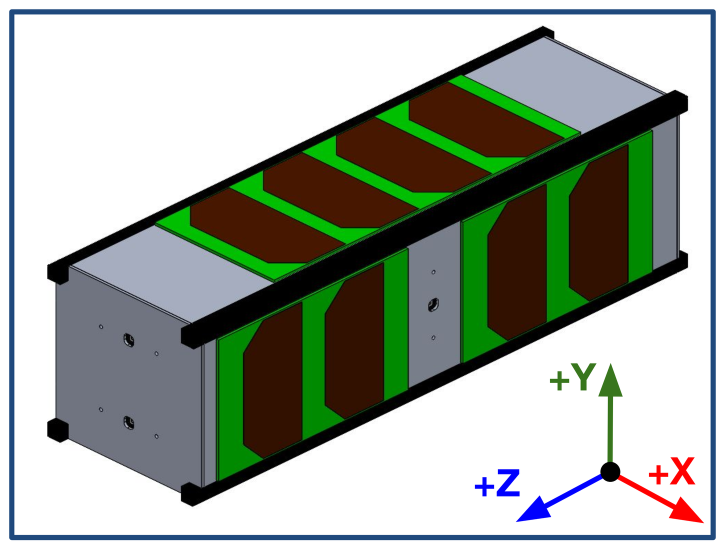

Figure 1: CAD Model of the FINCH 3U CubeSat

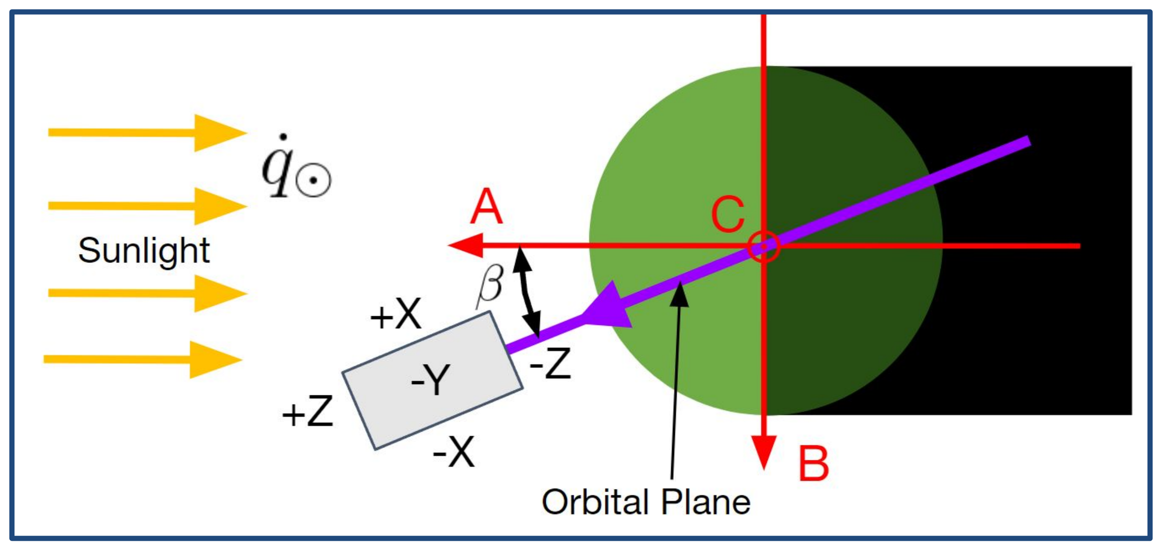

Figure 2: Orbital Geometry

This model was developed as an **alternative** to industry modelling software during preliminary design stages. The model:

- Allows teams to conduct **rapid iteration** of thermal design with reduced barrier to entry.
- Provides a platform to make **informed decisions** early in the design cycle.
- Encourages a first principles understanding of heat transfer and thermal modelling.

II. Modelling

Key modelling assumptions:

- **Lumped mass:** All points within each node are at the same temperature at each time step.
- **Constant material properties:** Each node's specific heat capacity is of aluminum 6061-T6.
- **Constant internal power generation**
- **Constant orbital parameters**

Thermo-optical properties were calculated based on material composition (Table 1). Absorptivity and emissivity values were determined using a weighted calculation:

$$\alpha_{Al-SC} = N_{SC}\alpha_{SC} + N_{Al}\alpha_{Al}$$

$$\varepsilon_{Al-SC} = N_{SC}\varepsilon_{SC} + N_{Al}\varepsilon_{Al}$$

Inputs: Thermal Optical Properties; Environmental and Orbital Parameters; Material Properties; Nodal Model → **CubeSat Thermal Simulator** → **Outputs:** Solar Loads over Orbit; Earth IR Loads over Orbit; Albedo Loads over Orbit; Temperature over Time

Figure 3: Thermal Simulator Inputs and Outputs

Node	Area (cm²)	Internal Power (W)	Panel Composition	Thermal Optical Properties	
				α	ε
+X,+Y,-Y	328	1.27	70% Al, 30% Solar Cell	0.75	0.62
-X	328	1.27	100% Al	0.38	0.08
+Z,-Z	100	1.27	100% Al	0.38	0.08

Table 1: Panel Physical and Thermal Optical Properties

Governing equations for each panel based on the heat transfer it experienced were implemented [1]. For example, the +X panel experiences all types of heat transfer, hence:

$$\dot{Q}_{net,+X} = \overbrace{F_{+X}\dot{q}_{\odot}A_{+X}\alpha}^{\text{Direct Solar Radiation}} + \overbrace{(VF_{walls})a\dot{q}_{\odot}\alpha A_{+X}\cos(\beta)\cos\left(\frac{2\pi t}{\tau}\right)}^{\text{Reflected Solar Radiation}} + \underbrace{(VF_{walls})\dot{q}_{\oplus IR}A_{+X}}_{\text{Earth IR Radiation}} + \underbrace{C\sum_{i=1}^{4}(T_i - T_{+X})}_{\text{Bolt Conduction}} - \underbrace{\varepsilon\sigma A_{+X}(T_{+X}^4 - T_{space}^4)}_{\text{Emitted Radiation}}$$

Due to the asymmetry of the six-node model, view factors were calculated to determine which panels would receive radiation and when [2].

III. Results and Comparison

Key findings and design decisions:

- The -X Panel was the coldest panel. Hence, a design decision was made to designate it as the radiator panel.
- The +Y Panel experienced the smallest temperature range. Hence, it was considered a candidate for battery pack placement.

Comparison of these results to results from Siemens NX Space Systems Thermal:

- The steady-state temperatures of the nodal model had a maximum error of 5°C on the hot peak and 9°C on the cold peak.
- Qualitative features of the temperature profile were identical.

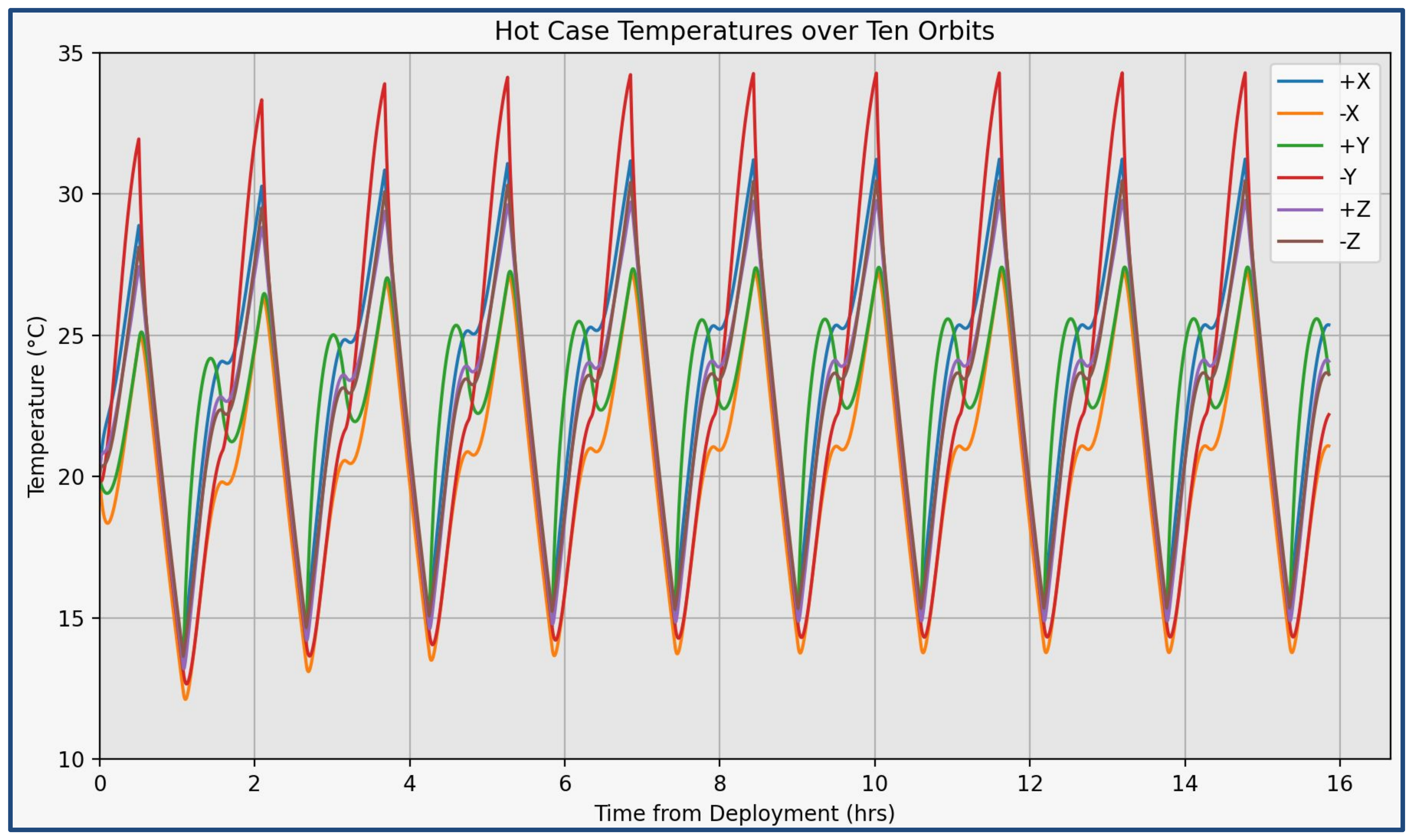

Figure 4: Nodal Model Temperatures Over 10 Orbits

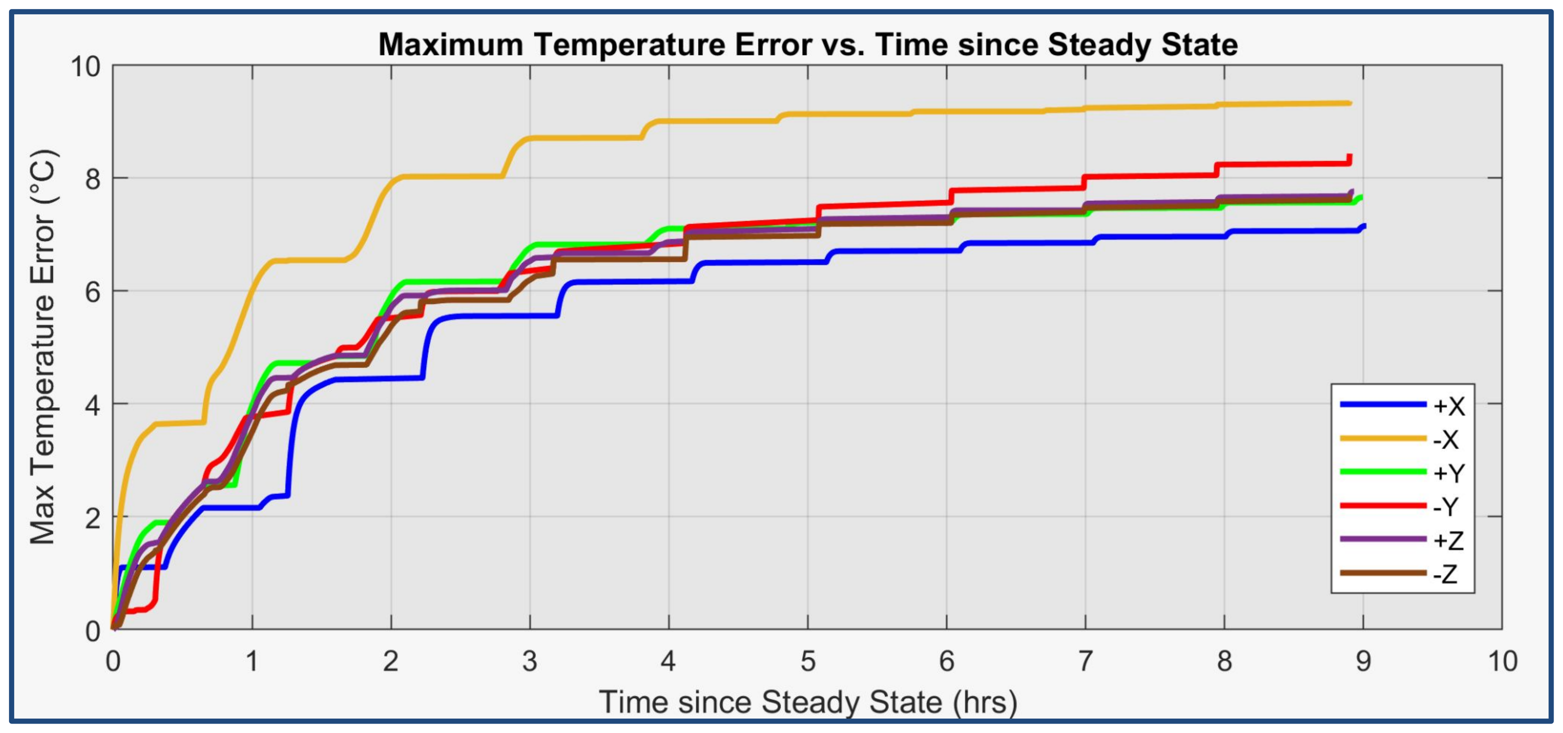

Figure 5: Siemens NX Model Temperatures Over 10 Orbits

Notable **discrepancies** in the model exist:

- The nodal model is consistently colder than the NX model, likely due to differences in view factor calculations and assumptions made.
- The nodal model is unable to model temperature gradients.

The model can be refined to be more accurate. However, general design considerations, such as making the +Y Panel support the battery pack, are still valid.

IV. Team Growth

The process of creating this simulation has deepened the team's understanding of engineering design in multiple ways:

- **Technical Synthesis:** Exposure to literature reviews and improved ability to synthesize relevant technical information.
- **Modelling and Knowledge:** Gained a first principles understanding of heat transfer; making rational simplifications and assumptions when facing uncertainty.
- **Design Aptitude:** Gained the ability to make deliberate, informed decisions based on available information.
- **Teamwork and Tooling:** A greater understanding of turning concepts into reality using modern programming languages and collaborative tools; exposure to optimizing current codebase and knowledge transfer through documentation.

V. Next Steps

To increase the accuracy of the model:

- Include internal satellite components as internal nodes.
- Include additional nodes to measure temperature gradients.

Modifications can extend the applications of this model, possibly allowing it to perform on par with industry software:

- **Additional Nodes:** Accommodate any number of nodes.
- **Non-Circular Orbits:** Include other orbital parameters (e.g., eccentricity) to accommodate non-elliptical orbits.

Developing this model inspired us to establish a culture of **learning through creating** within our team: researching information, developing the model, interpreting results, and reflecting on the process.

References:
[1] D. L. Cotten, C. Versteeg. "Preliminary Thermal Analysis of Small Satellites", *University of Georgia*, 2018.
[2] S. L. Rickman. "A Simplified, Closed-Form Method for Screening Spacecraft Orbital Heating Variations", *NASA*, 2002.