Leveraging Standardized Satellite Architecture For Thermal Analysis

European Space Thermal Engineering Workshop 2024

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Summary

Introduction

What are we doing at Loft Orbital ?

Simplicity

Our hardware and software abstraction layers, the Hub and Cockpit, remove the complexity of space missions.

Speed to orbit

We have an inventory of pre-assembled satellite platforms and pre-booked launches, so that we're ready when you are.

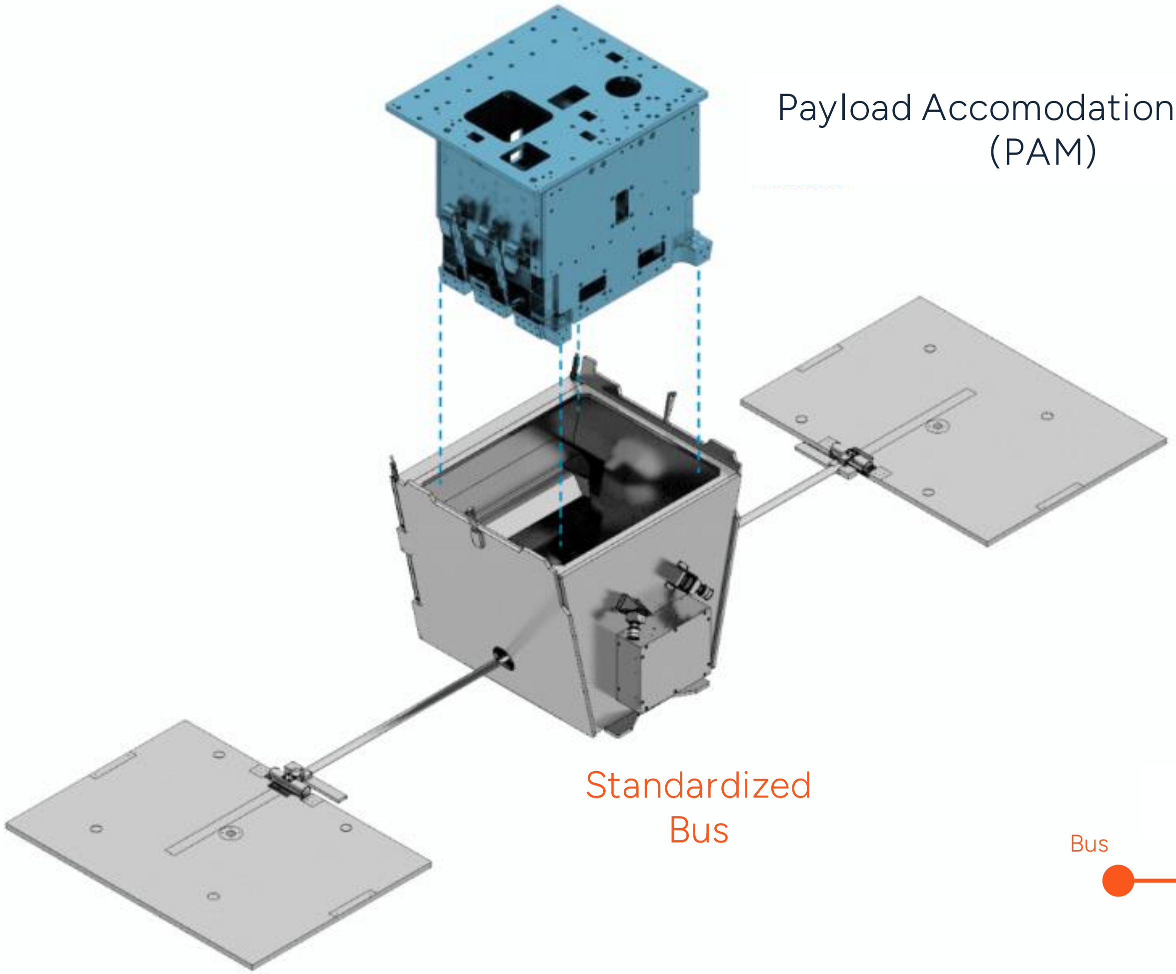
Reliability

We leverage commodity satellite buses with the proven heritage of over 600 copies on-orbit.

** The PAM is part of the Hub*

Introduction

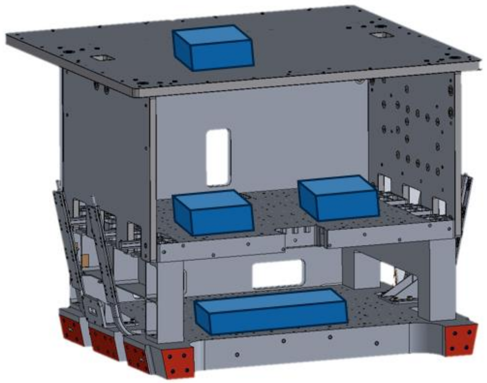
How do we achieve this hardware-wise?

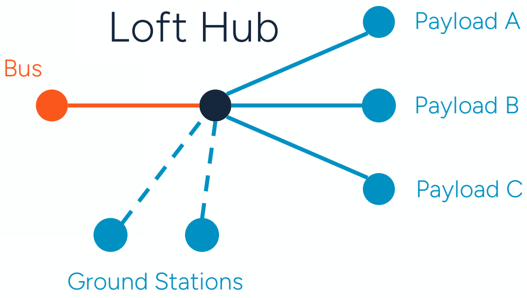


Payload Accomodation Module (PAM)

Standardized Bus

Customer Payloads





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Introduction

Our physical missions business cases

Rideshare

Fly hardware on an upcoming satellite.

Dedicated

Fly a full satellite for your mission.

Constellation

Fly a constellation with constant coverage and high revisit rates.

Introduction

Objectives

Surrogate Model: Leverage our Standardized Satellite Architecture For Thermal Analysis

- Leveraging our standardized thermal architecture
- Push thermal analysis upfront
- Better early phase thermal assessments
- Enhance accessibility of thermal analysis
- Reduce risks
- Empower everyone within the company to perform thermal analysis: Mechanical, Electrical, Systems, Operation, Sales Engineers etc..

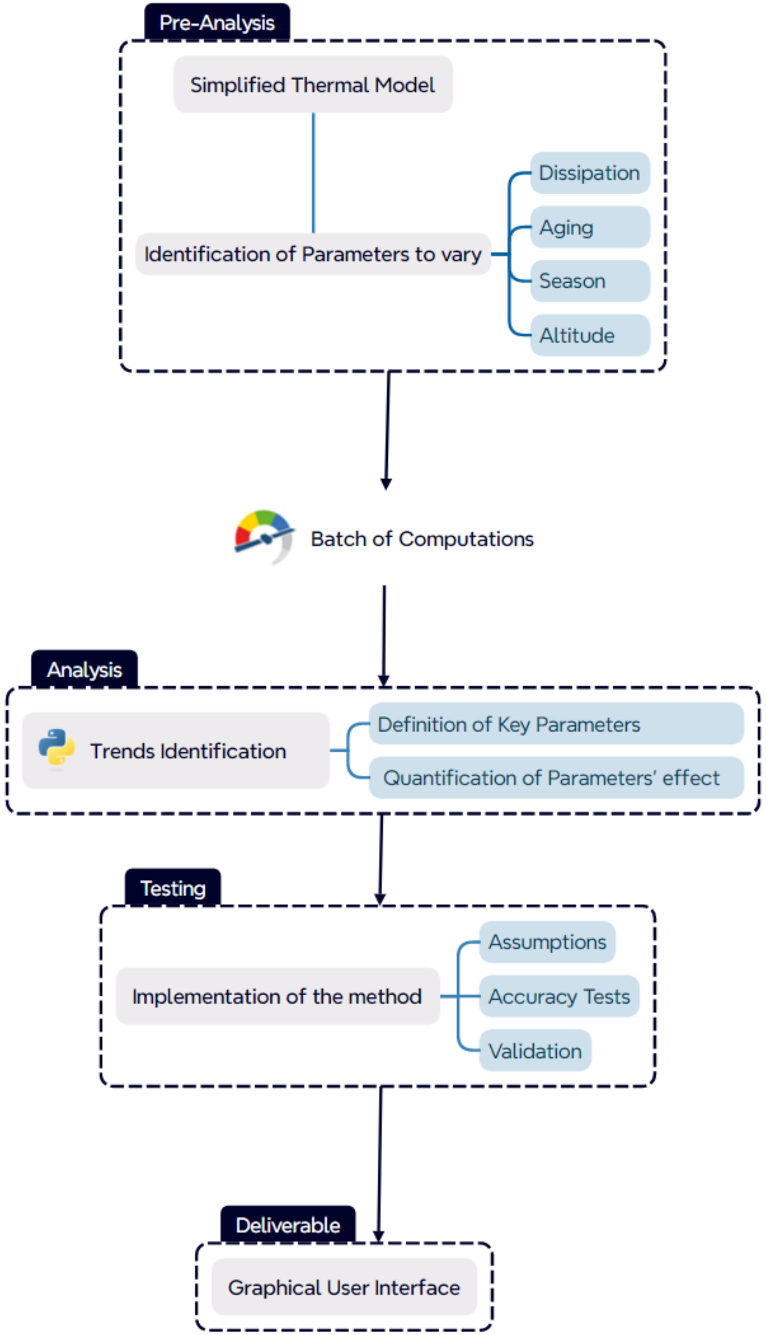
Make thermal analysis simple, fast and reliable for everyone at Loft

Method

Workflow diagram of the process

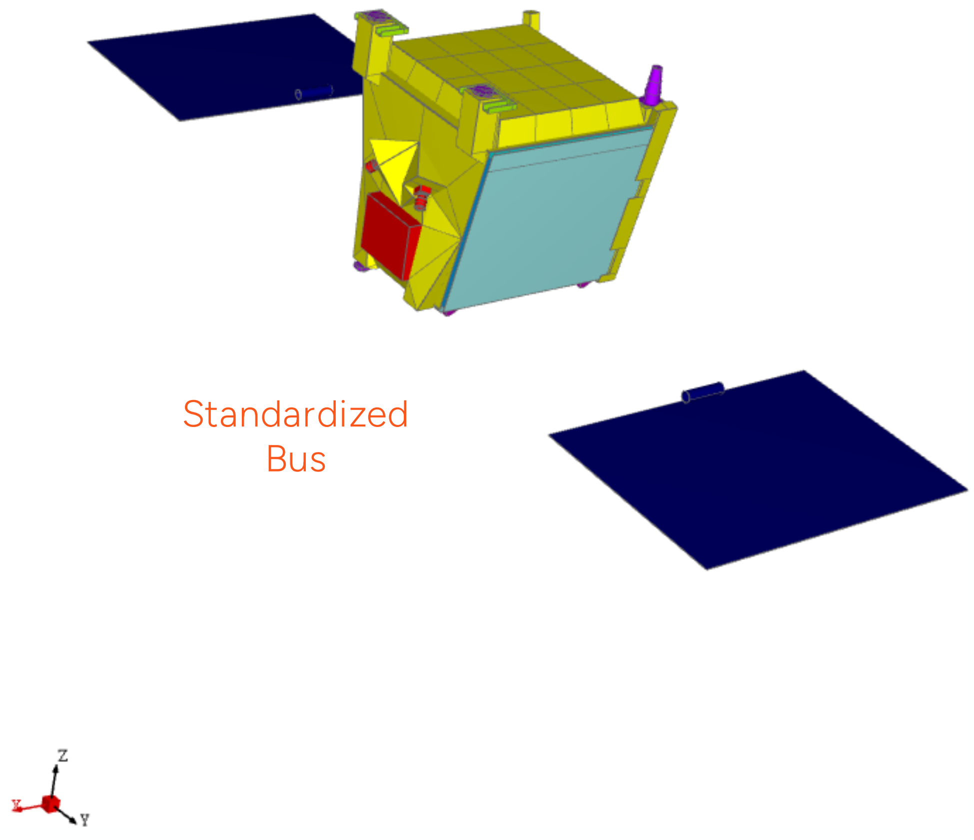
How can we achieve our goal?

Build a surrogate model of the generic platform

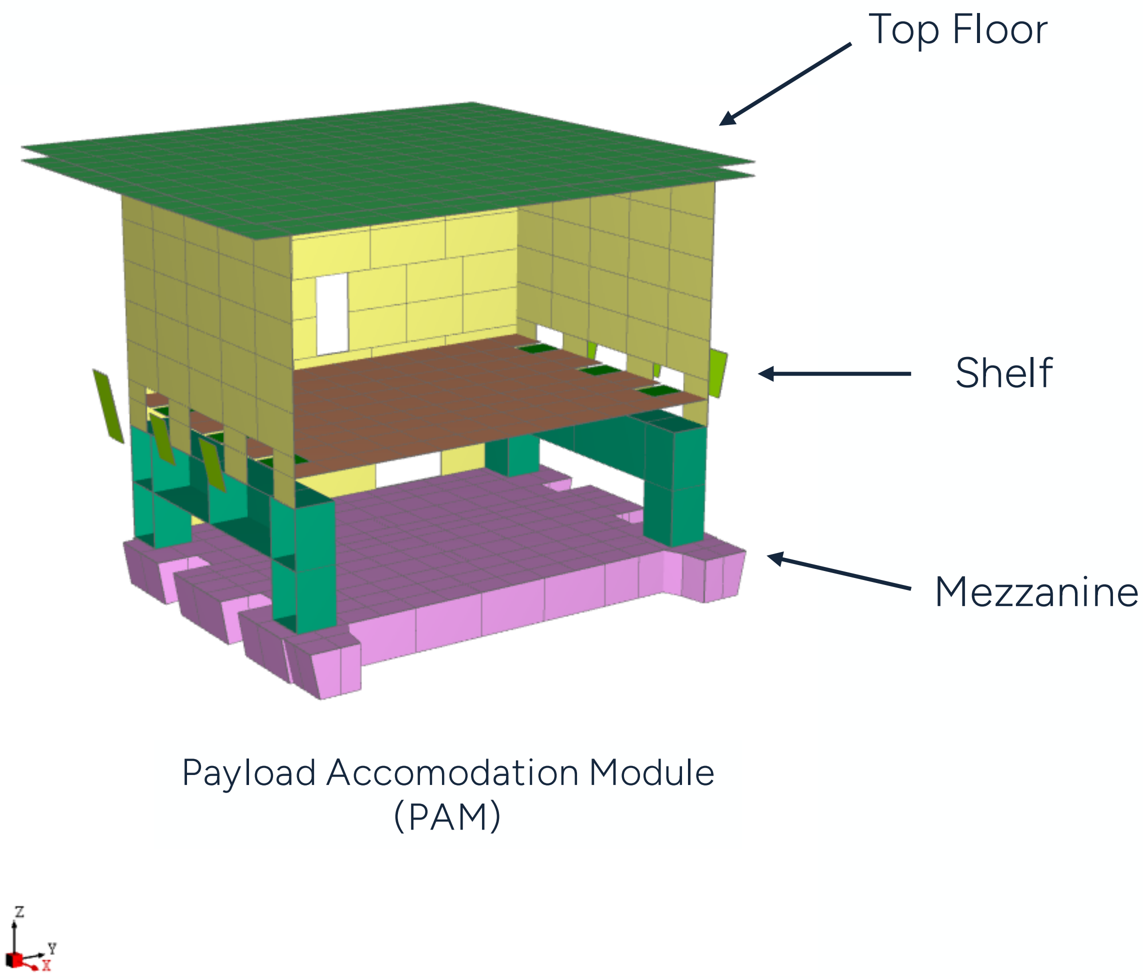


Method

Detailed thermal model of the spacecraft bus and PAM



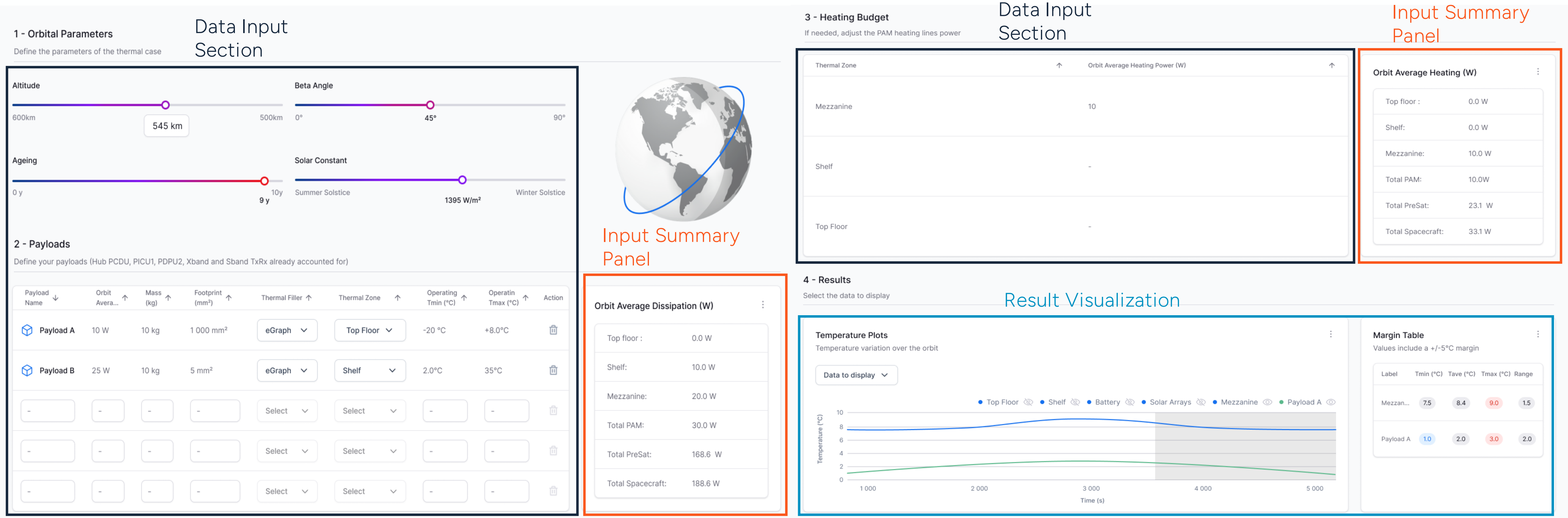
Standardized Bus



Payload Accomodation Module (PAM)

Method

User Interface of the final tool (fancy mockup..)



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Method

Step 1: Computations* & Parameters Variation

Batch A: 108 cases

Parameters studied:

- Floor, Shelf and Mezzanine thermal zones orbit average dissipations
- Aging
- Season

Batch B: 216 cases

Parameters studied:

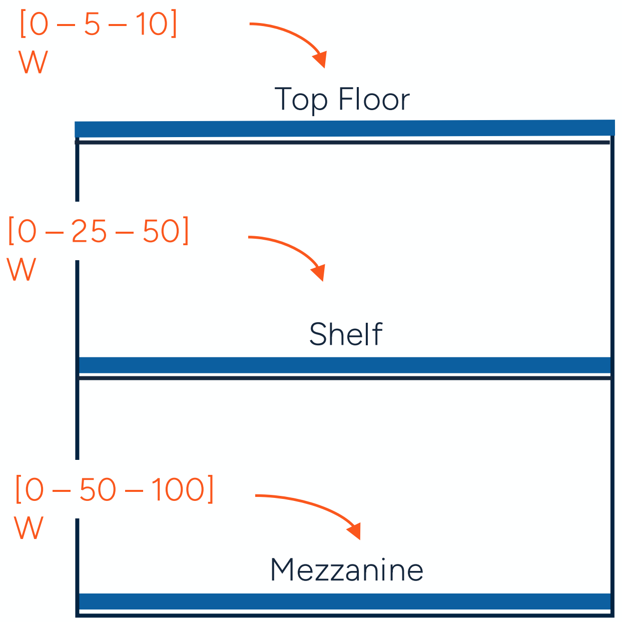
- Altitude

**The computations were performed using the Systema-Thermica software*

Method

Step 1: Computations* & Parameters Variation

- Modeled by single node on each thermal zone



The computations were performed using the Systema-Thermica software

Computations Parameters				
Spacecraft Mode		On Station		
Altitude		500km	550km	600km
Spacecraft Attitude		+Z NADIR		
Orbital Parameters				
LTAN		22h30		
Orbit Type		Sun Synchronous		
Inclination		97.5°		
Excentricity		0		
Environmental Fluxes				
Thermo-Optical Properties		BOL	EOL	
Season		Winter Solstice	Summer Solstice	
Total Orbit Average Bus Dissipation (W)		165		
PAM Dissipations (W)				
Duty cycle = 100%	Mezzanine	0	50	100
	Shelf	0	25	50
	Top Floor	0	5	10

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Method

Step 2: Data Analysis & Trends Identification

Our analysis is conducted by evaluating the effect of multiple parameters on the average temperature of a set of thermal zones and the total spacecraft heating budget over a complete orbit.

- Mezzanine
- Shelf
- Top Floor
- Radiators
- Battery
- Solar Arrays

Dissipation Effect

Aging Effect

Season Effect

Altitude Effect

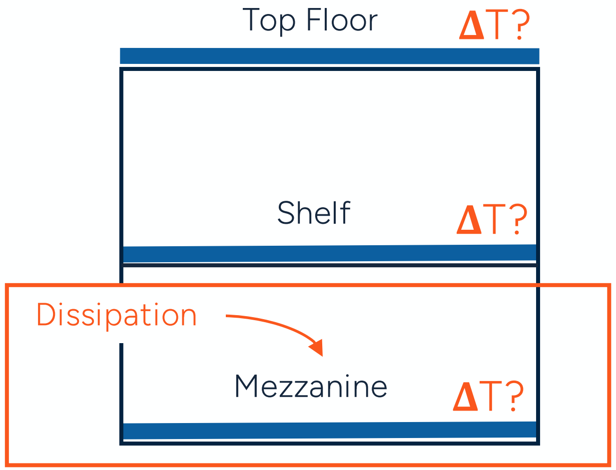
Method

Step 2: Data Analysis & Trends Identification

Dissipation Effect

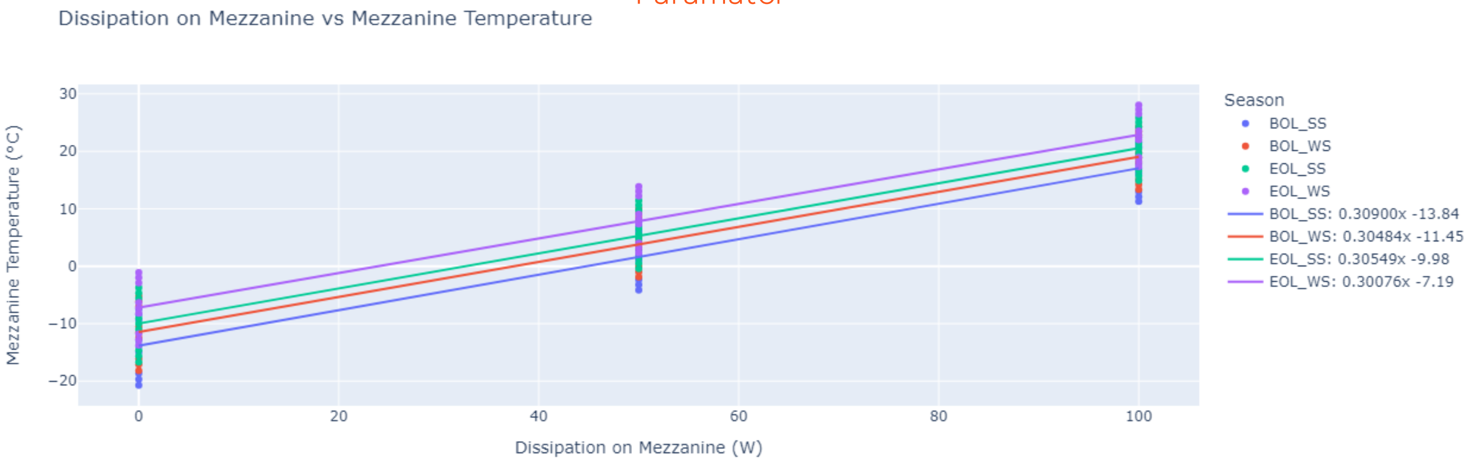
How does power dissipation on each thermal zone influence the temperature of other zones and the efficiency of radiators ?

Example:



ΔT Radiators?
ΔT Battery?
ΔT Solar Arrays?

Independant Paramater



Method

Step 2: Data Analysis & Trends Identification

Dissipation Effect

How does power dissipation on each thermal zone influence the temperature of other zones and the efficiency of radiators ?

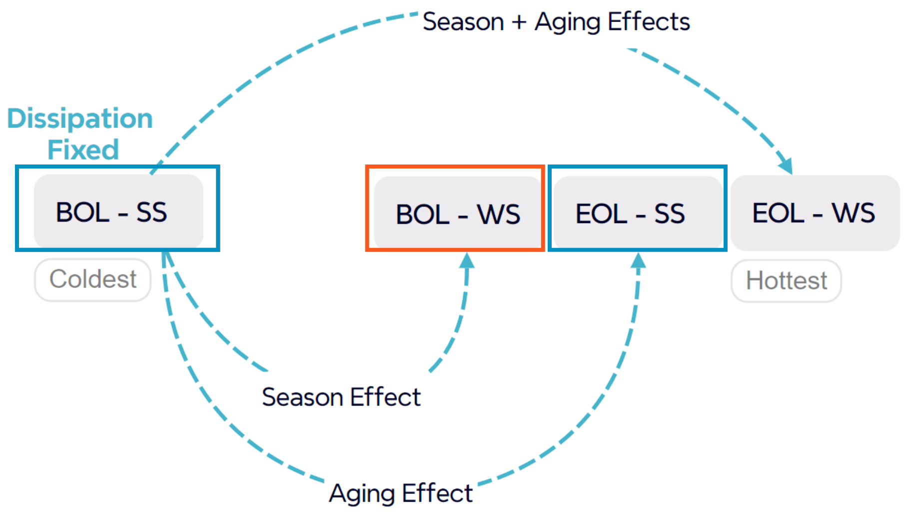
	Temperature Variations (°C)					
	Radiators	Mezzanine	Shelf	Top Floor	Battery	Solar Arrays
1W on Mezzanine	ΔT = +0.176°C	ΔT = +0.305°C	ΔT = +0.201°C	ΔT = +0.172°C	ΔT = +0.010°C	ΔT = +0.000°C
1W on Shelf	ΔT = +0.170°C	ΔT = +0.203°C	ΔT = +0.421°C	ΔT = +0.271°C	ΔT = +0.010°C	ΔT = +0.000°C
1W on Top Floor	ΔT = +0.151°C	ΔT= +0.176°C	ΔT = +0.274°C	ΔT = +1.234°C	ΔT = +0.010°C	ΔT = +0.000°C

Method

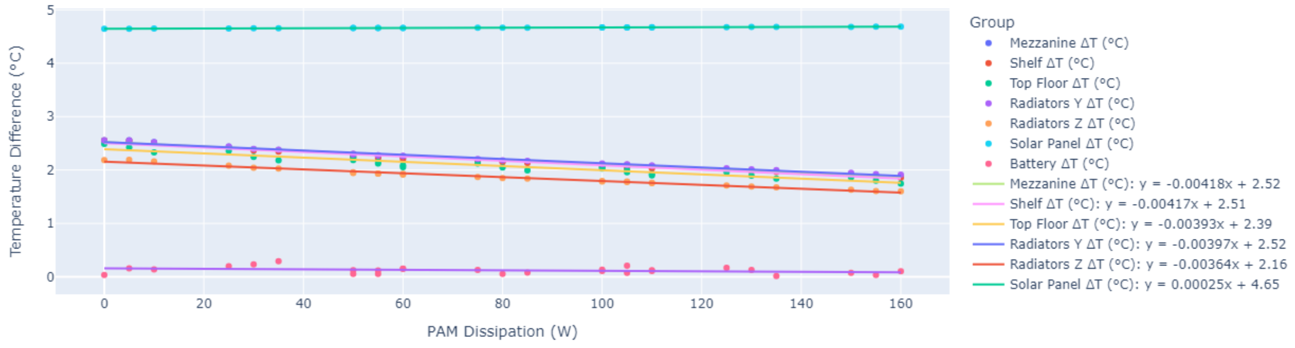
Step 2: Data Analysis & Trends Identification

Season & Aging Effects

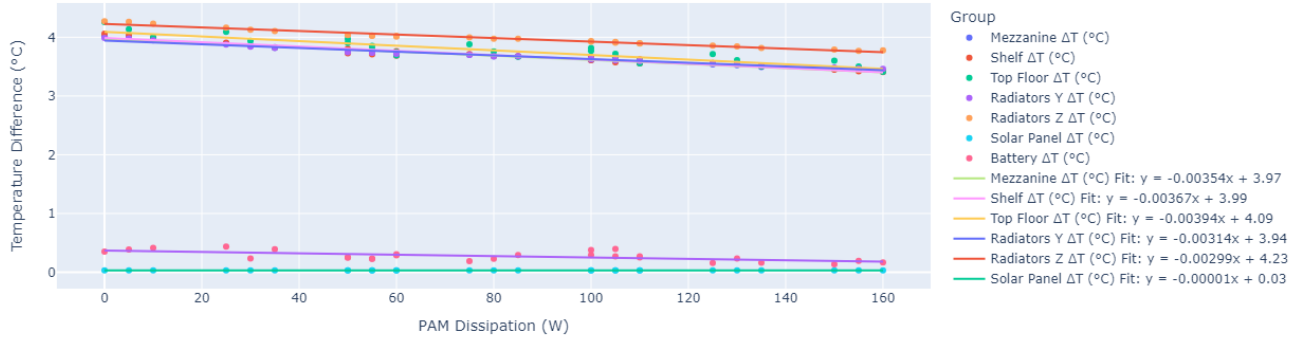
How do seasonal variations of the solar constant and the aging process of thermo-optical properties affect the temperature of the spacecraft?



Seasonal Effect on Temperature in BOL



Aging Effect on Temperature in SS

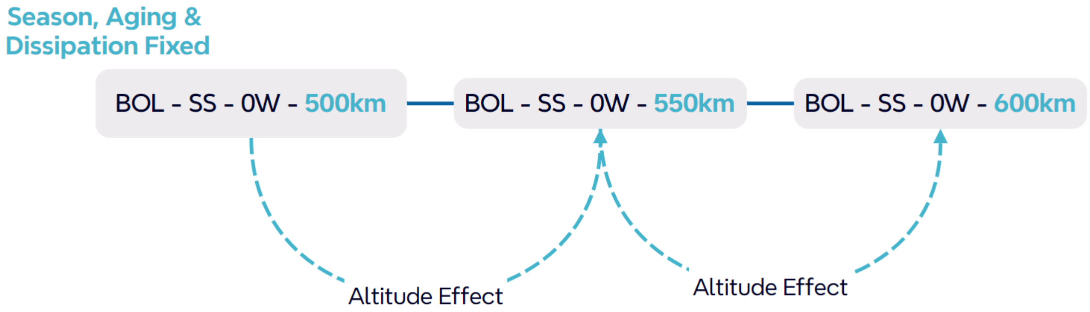


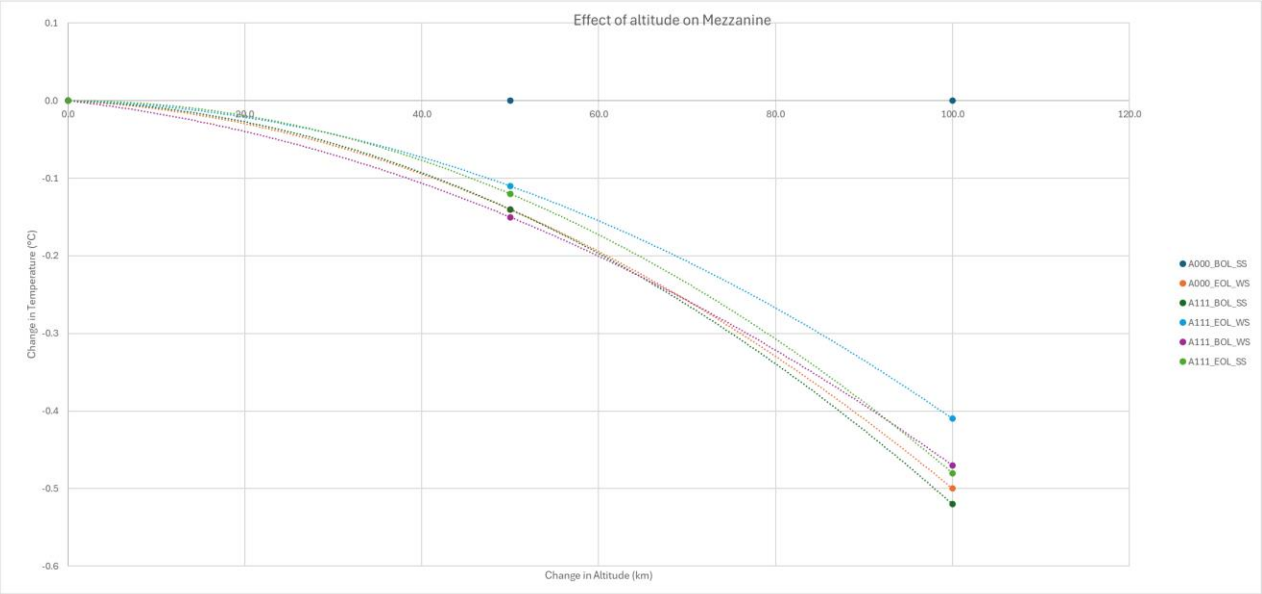
Method

Step 2: Data Analysis & Trends Identification

Altitude Effect

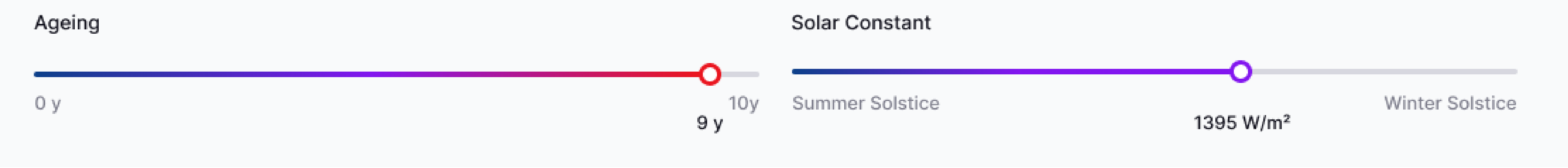
How does a change in altitude affect the temperature of the spacecraft?





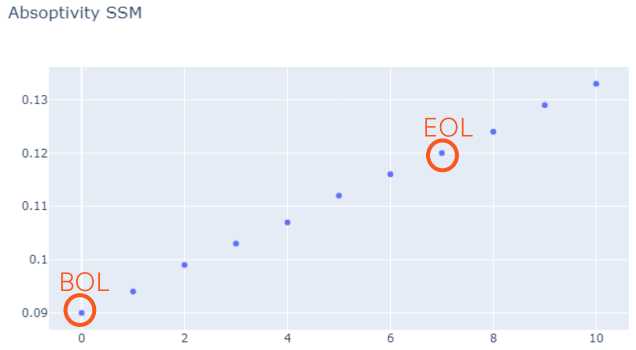
Method

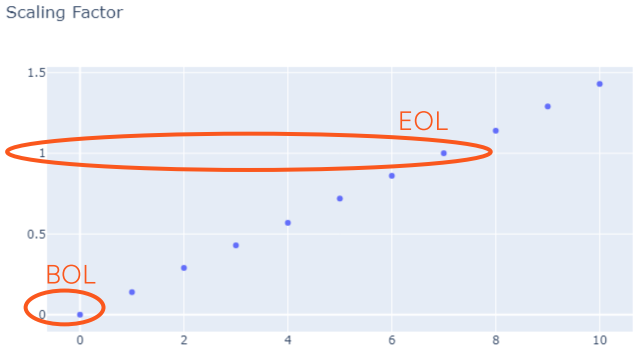
Scaling of aging & season



Known absorptivity values in BOL and EOL.

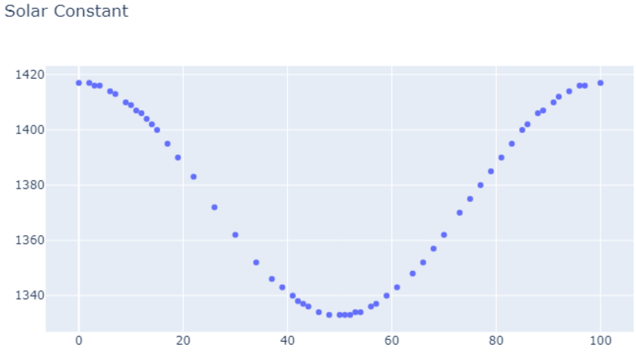
Variation approximated by a linear aging model.

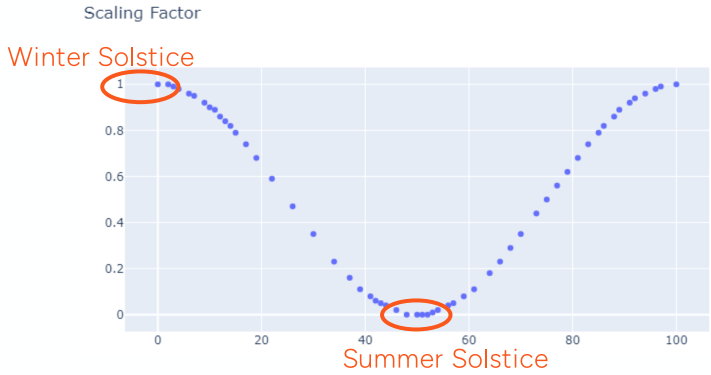




Known solar constant values.

Variation approximated by a cosine.





Method

Step 3: Thermal Zones Temperatures

		Base Case	Study Case
Dissipation	Mezzanine	0W	35W
	Shelf	0W	16W
	Top Floor	0W	0W
Aging		Begining Of Life - 0years	4years
Season		Summer Solstice	Winter Solstice
Altitude		500km	600km

Example: How do we predict the temperatures from the base case?

Dissipation Effect

ΔT (zone, radiators)
+ ΔT (zone, shelf)
+ ΔT (zone, shelf)
+ ΔT (zone, top floor)
+ ….

+

Aging Effect

Aging scaling factor * ΔT (zone, aging EOL-BOL)

+

Season Effect

Season scaling factor * ΔT (zone, season WS-SS)

+

Altitude Effect

ΔT (zone, altitude)

$$T_{zone} = T_{base\ case,\ zone} + \Delta T_{total,\ zone}$$

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Method

Step 3: Thermal Zones Temperatures

		Base Case	Study Case
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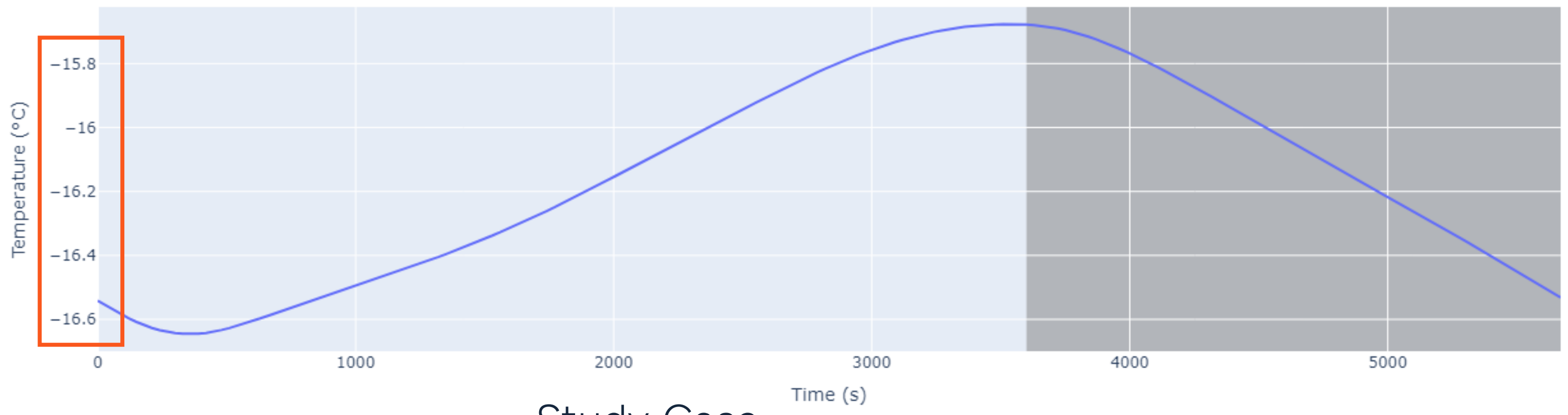
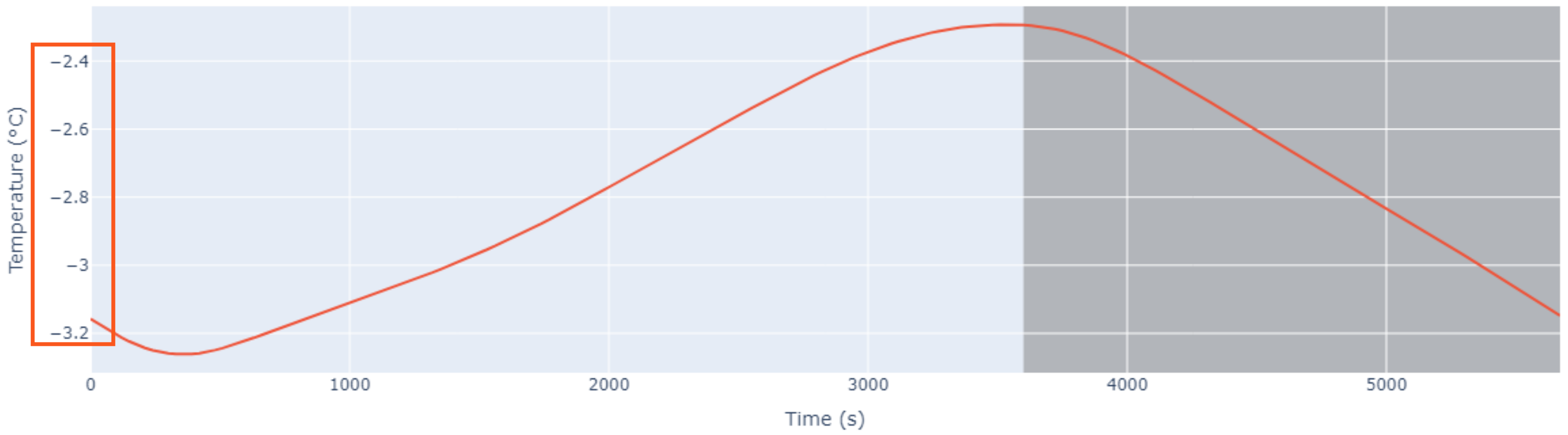
Base Case



+ $\Delta t_{total, zone}$

=

Study Case



Same thermal behavior

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Method

Step 4: Heating Budget

How can we predict the spacecraft heating power budget ?

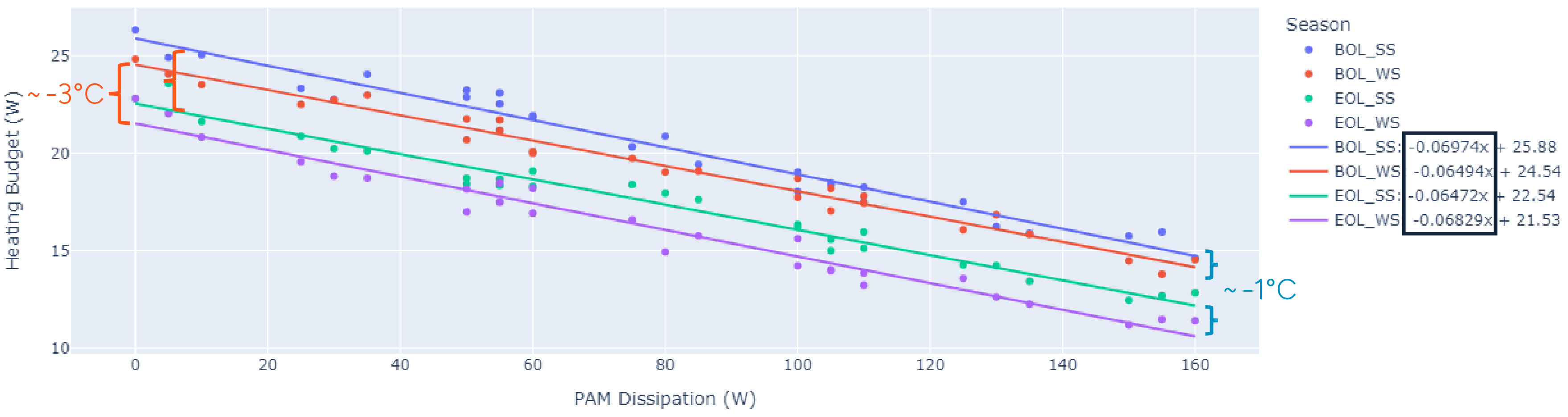
How can we model the addition of heating power ?

Thermal Zone	Orbit Average Heating Power (W)
Mezzanine	10
Shelf	-
Top Floor	-

Orbit Average Heating (W)

Top floor :	0.0 W
Shelf:	0.0 W
Mezzanine:	10.0 W
Total PAM:	20.0 W
Total PreSat:	23.1 W
Total Spacecraft:	23.1 W

PAM Dissipation vs Heating Budget



Heating Budget = Added Heating Power -0.0669 × PAM Dissipation + heating budget of Base case – 3 × aging scaling factor – 1 × season scaling factor

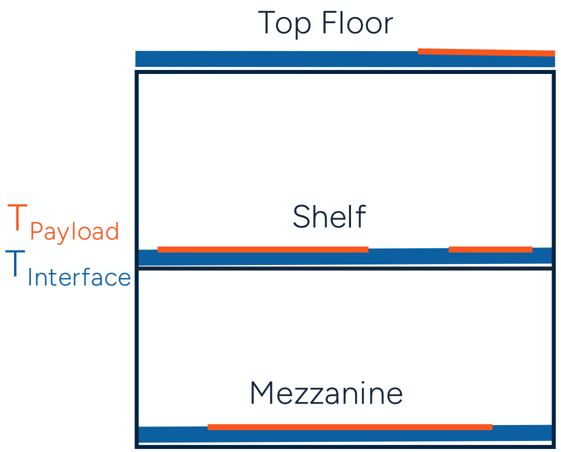
Method

Step 5: Payloads Temperature

$$\Delta T = \frac{Q}{hk \times S}$$

$$\tau = \frac{m \times Cp}{hk \times S}$$

1st order system simplification to consider transient effects



Q | S | hk | $Interface$

Payload Name	Orbit Avera...	Mass (kg)	Footprint (mm²)	Thermal Filler	Thermal Zone	Operating Tmin (°C)	Operatin Tmax (°C)	Action
Payload A	10 W	10 kg	1 000 mm²	eGraph	Top Floor	-20 °C	+8.0°C	
Payload B	25 W	10 kg	5 mm²	eGraph	Shelf	2.0°C	35°C	
-	-	-	-	Select	Select	-	-	
-	-	-	-	Select	Select	-	-	
-	-	-	-	Select	Select	-	-	

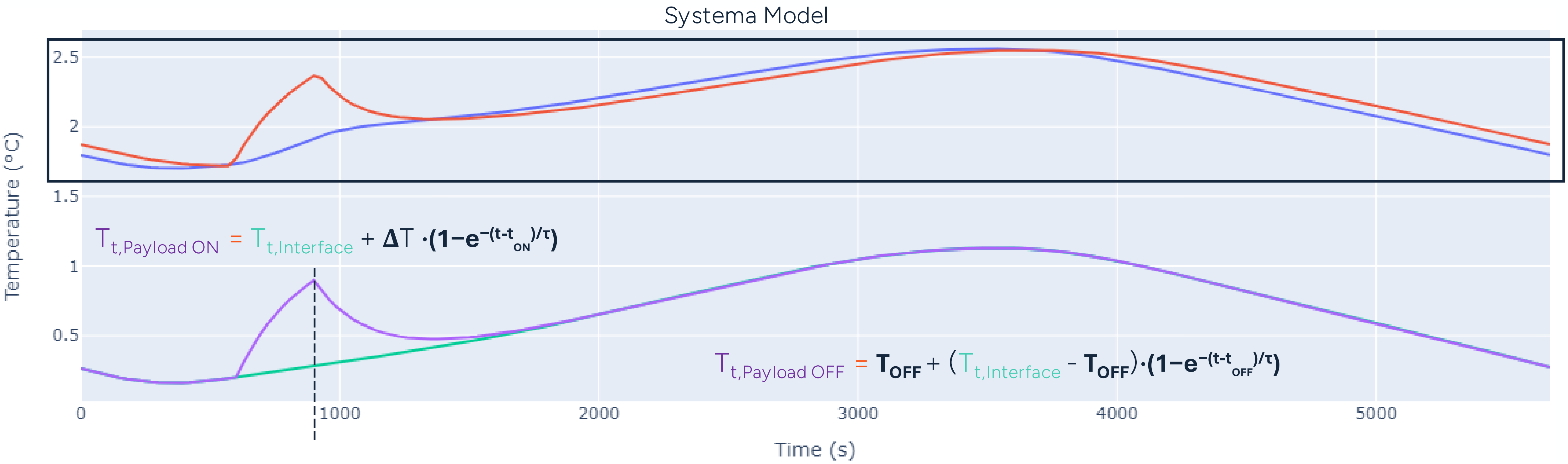
$$T_{t,Payload\ ON} = T_{t,Interface} + \Delta T \cdot (1 - e^{-(t-t_{ON})/\tau})$$

$$T_{t,Payload\ OFF} = T_{OFF} + (T_{t,Interface} - T_{OFF}) \cdot (1 - e^{-(t-t_{OFF})/\tau})$$

Method

Step 5: Payloads Temperature

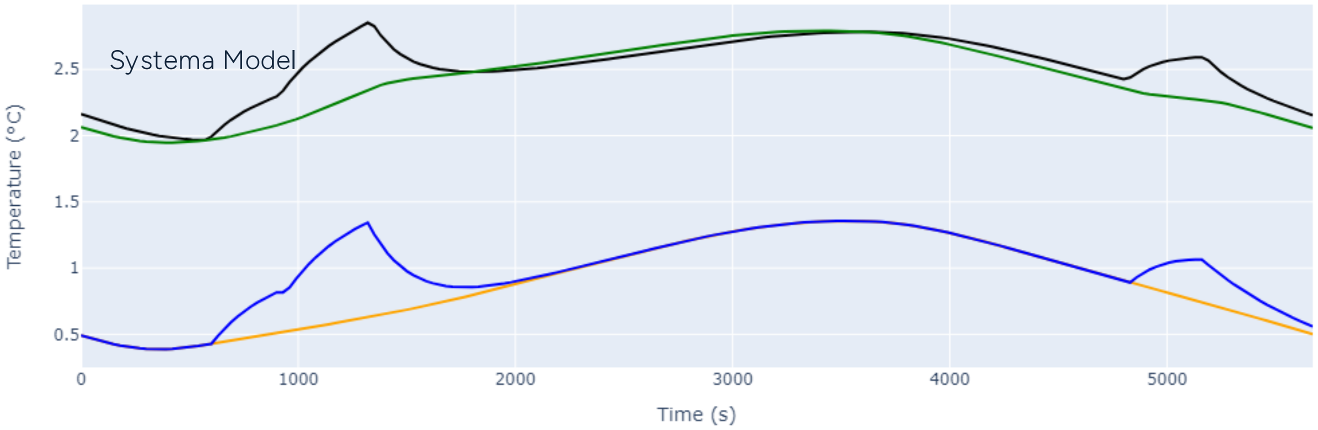
Ex: Payload ON for 5 minutes.



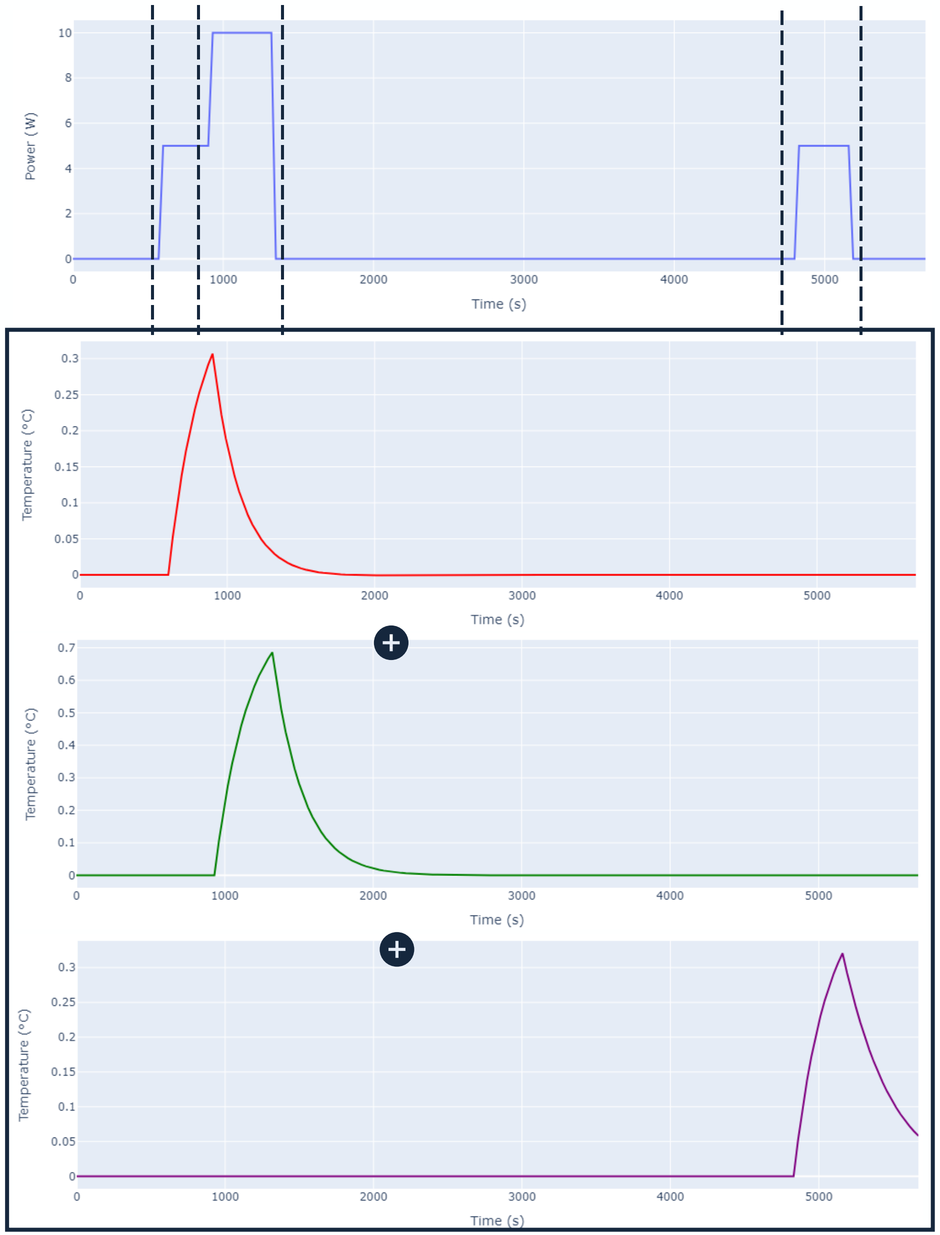
Method

Step 5: Payloads Temperature

Ex: Power Budget during an orbit.



$= T_{t,Interface}$ +



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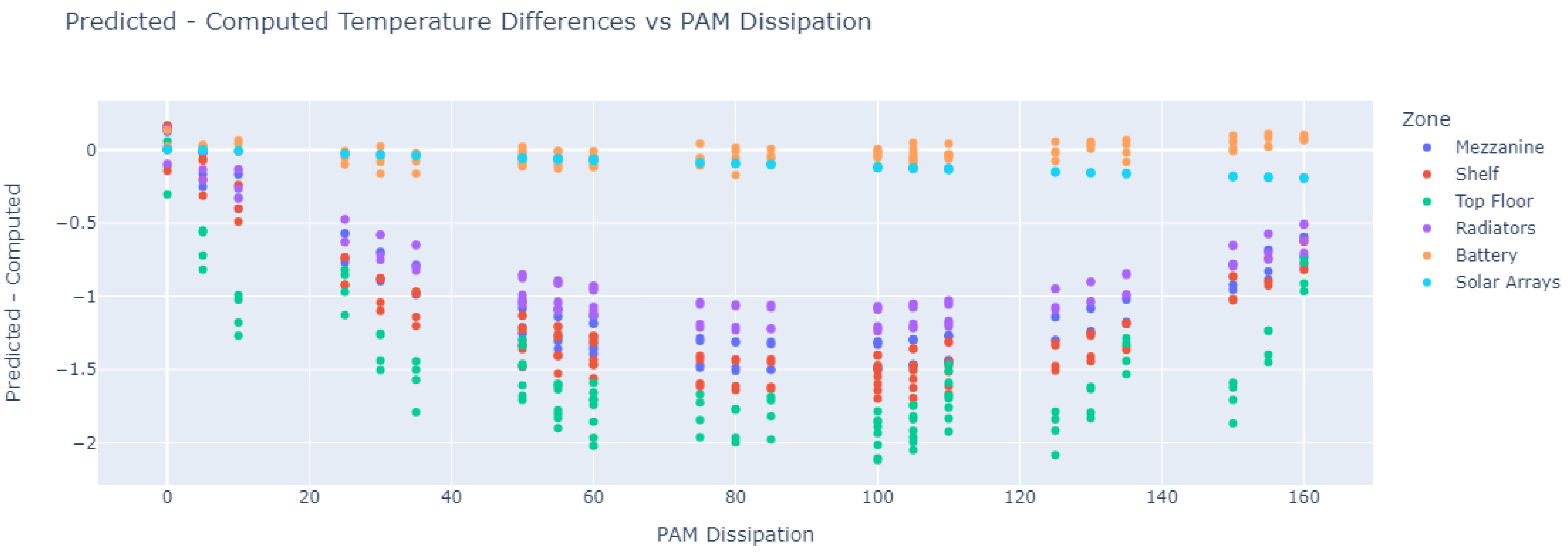
Modeling Accuracy

Average Orbital Temperatures

Margin of error target: +/-5°C



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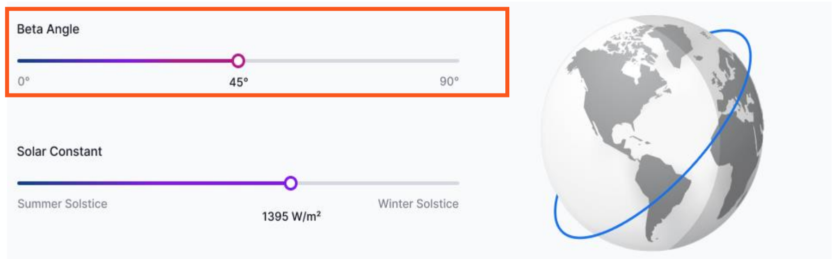
What’s next ?

Improvements of the tool and deployment to a wider audience within the company

Short term to do

- Benchmarking method across various SSO orbits
  Implement a scaling for the effect of the Beta Angle



- Connect this tool to the power budget analysis tools we have
- Release the final web app GUI

Long-term vision 🔭

- Comparison of our “hand made modelling” method with a machine learning approach
- Integrate the tool into Loft’s automated operations
- Ability to load a spacecraft configuration

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