Thermal simulation TCS

In this document, we describe the technical specifications of the system and we present the simulation results to validate theses specifications.

Thermal constraints

Since the satellite will be in orbit around Earth, it will be subjected to different sources of heat. The temperature must not be too high: It must not exceed the maximum given value by the operating range of the various components in order to prevent them from burn out, to avoid structure deforming and components dilatation that can damage the satellite.

We can identify four sources of heat:

- **Equipment**: The components within the satellite produce heat with the energy they consume.
- **Solar radiation**: This is the most important source of heat. The solar flux accounts between 1353 and 1375 Watts / m².
- **Albedo**: This refers to the solar radiation reflected by the Earth. This energy represents an average radiance of 196 W / m² in the sunny hemisphere of the Earth.
- **Earth radiation**: This accounts an energy of 190W / m² up to 240W / m².

The devices that are within the TCS module have their own interval of temperature for nominal operation.

The following table summarizes the averages, depending on the equipment:

Equipment	**Interval (°C)**	**Survival interval (°C)**
Electronic (Compute)	-25 to +70	-30 to +85
PCB (FR4)	-40 to 85	-40 to 130
Antenna	-30 to 70	-40 to 80

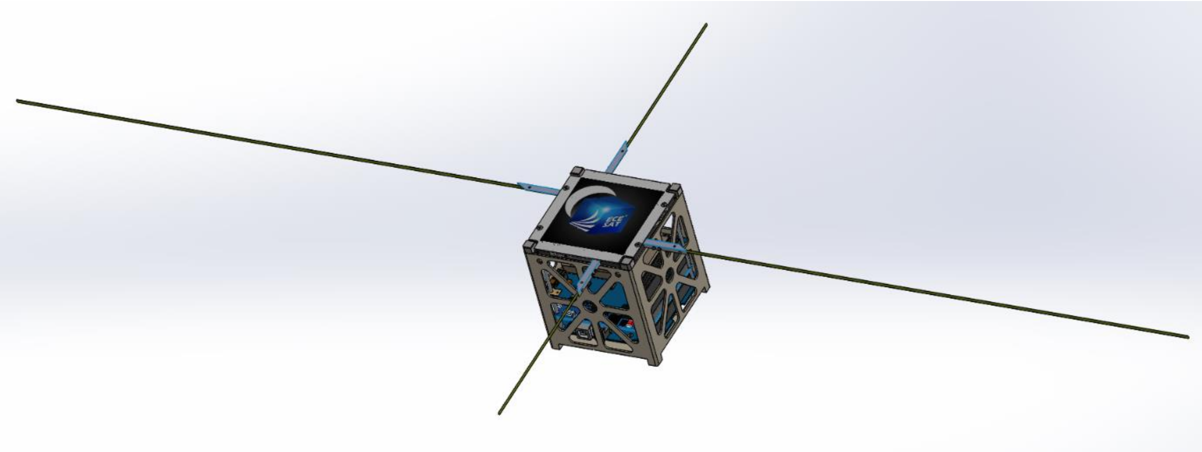
These values are given for information only.

In addition, the satellite operates in an environment ranging from -30 ° C to 85 ° C. We chose these temperature limits as a function of the telemetry data of a cubesat in low orbit in operation: the

FUNcube-1. It is noted that the temperatures inside (board) and outside (solar panel, antenna) of the satellite do not exceed these limits in all cases.

Simulations

To carry out our study we started by modeling a CubeSat type with a chassis, our TCS card and an antenna (here ISIS card):



The purpose of the thermal simulations is to validate the specifications in terms of permissible temperatures. Firstly, we have modeled the system in a simplified way to validate our order of magnitude and our simulation protocol. Secondly, we refine the model so that it gets closer to reality in terms of geometry and arrangement of components.

We will study in particular the temperature of the card for each of the different radiations

Modeling the thermal environment of the TCS

At first we want to know the scale of values in which our module will be immersed. To do this, we model a typical chassis that includes the support rods of the board and a square card PCB as simple as possible 1.6mm thick with the following thermal circuit board properties:

Coefficient of emissivity: 0.9

Material: FR4 - Fiberglass reinforced epoxy resin composite:

Properties	
Dielectric constant (Permittivity)	4,70 max / 4,35 at 500MHz / 4.34 at 1 GHz
Loss factor	0,02 at 1Mhz / 0,01 at 1 GHz
Dielectric strength	20 kV/mm
Surface Resistivity (min)	$2 * 10^5$ MΩ
Volumetric Resistivity (min)	$8 * 10^7$ MΩ*cm

Typical thickness	1,25 to 2,54 mm
Rigidity (Young's modulus)	17 Gpa
Coefficient of thermal expansion	11 ppm/K (in the fiber direction)
Coefficient of thermal expansion	15 ppm/K (in the fiber perpendicular direction)
Thermal conductivity	0,3 W/(m*K) (in the fiber direction)
Heat capacity	800 J/(kg*K)
Density	1,80 – 1,90 $kg*L^{-1}$

The properties of the chassis are as follows:

Aluminum alloy 3003 with an emissivity of 0.3 and the following properties:

Properties	Value	Units
Elasticity modulus	6.9e+010	N/m^2
Poisson coefficient	0.33	S.O.
Shear modulus	2.7e+010	N/m^2
Density	2700	Kg/m^3
Traction limit	110297000	N/m^2
Compression limit		N/m^2
Elasticity limit	41361300	N/m^2
Coefficient of thermal expansion	2.3e-005	/K
Thermal conductivity	170	W/ (m.K)

To simulate the energy exchange between the satellite and its environment, we added side panels in the same material as an electronic board because the solar panels are usually mounted on this type of board (FR4).

We will do several simulations at the extremes of the temperature scale and from one to three faces exposed to thermal energy sources

High temperature results

For these simulations, the CubeSat is considered to be at the highest temperature point of its orbit.

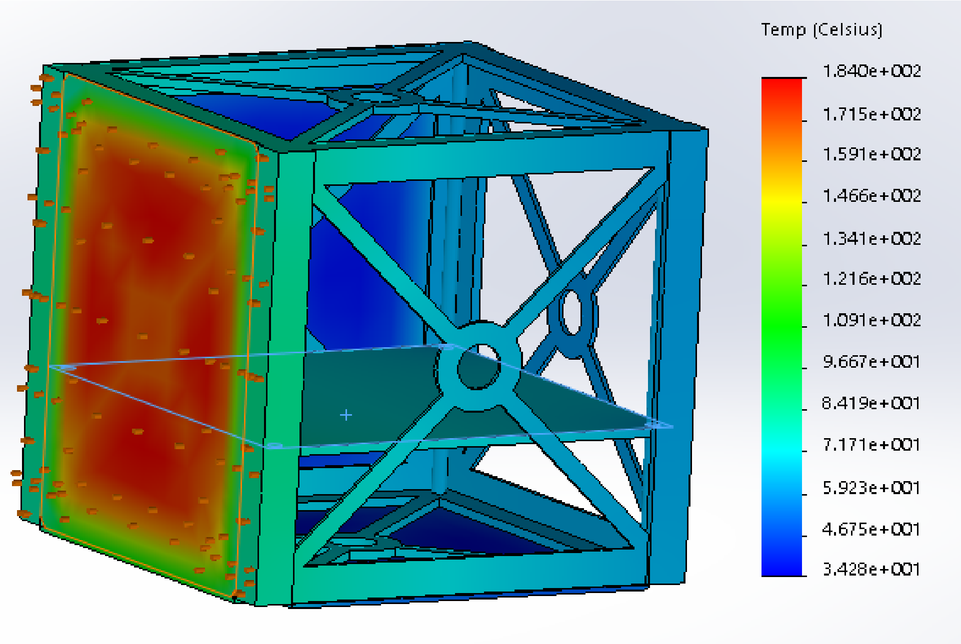
No equipment forming part of the CubeSat is considered to produce heat.

The temperature in the vacuum used for the study (critical case) is 85 ° C and the energy contribution from the environment to the surfaces is: 1375 + 196 + 240 = 1811 W / m² (radiation from the sun + reflection on the Earth + radiation of the Earth).

- Simulation with one face exposed:

Measured temperature values in the card:

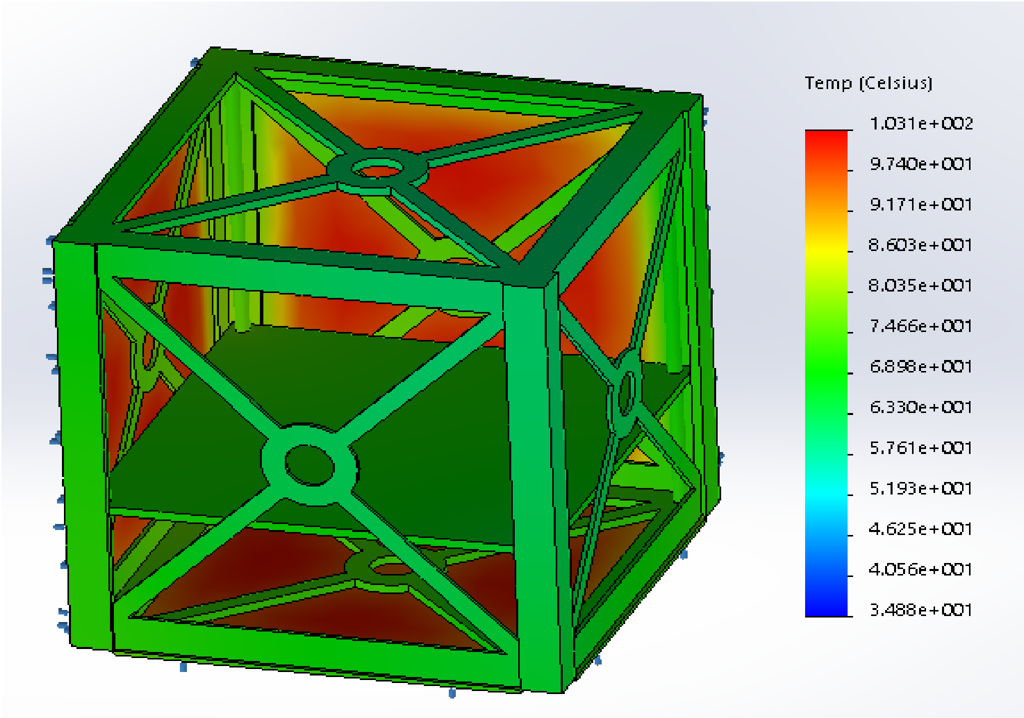
	Value	
Mean	71.221	Celsius
Max	80.254	Celsius
Min	62.351	Celsius



- Simulation with three faces exposed

Measured temperature values in the card:

Values		
Mean	70.534	Celsius
Max	76.913	Celsius
Min	64.062	Celsius



Low temperature results

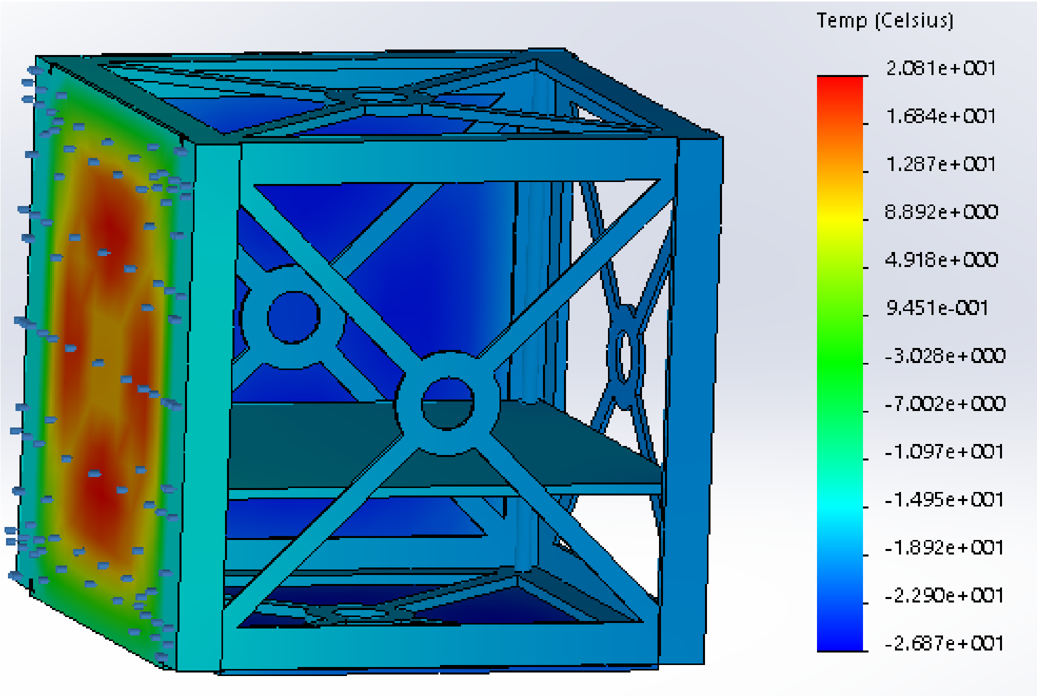
The temperature in the vacuum used for the study (critical case) is considered to be -30 ° C.

The temperature flux received from the ground on the exposed surfaces: 240 W / m²

- Simulation with one face exposed:

Measured temperature values in the card:

Values		
Mean	-17.269	Celsius
Max	-15.43	Celsius
Min	-19.069	Celsius

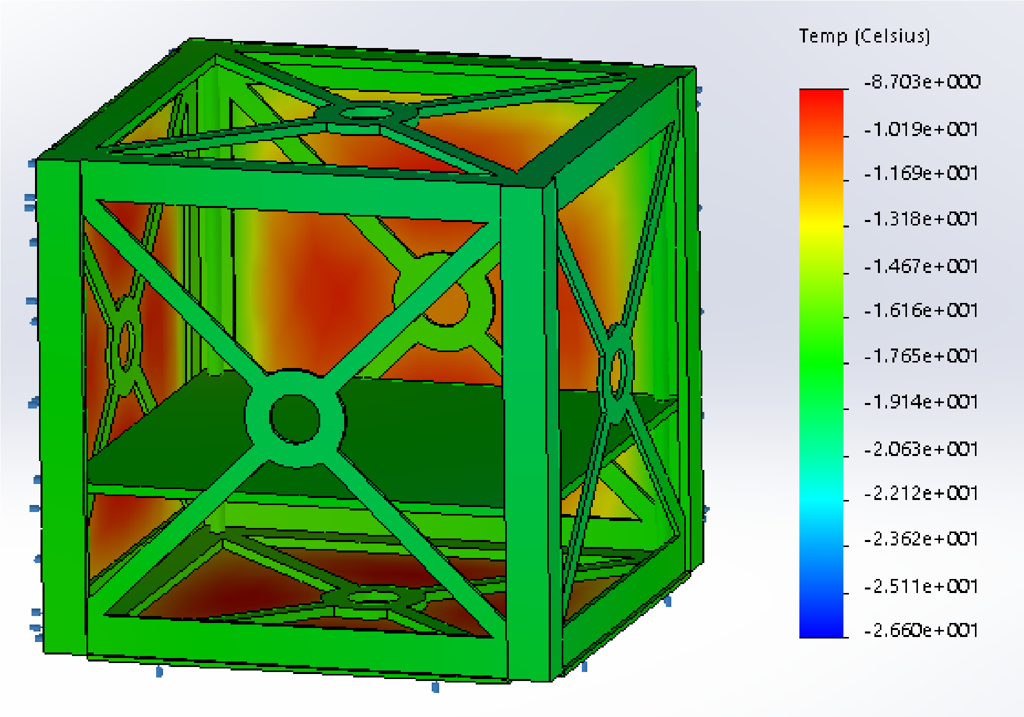


- Simulation with 3 faces exposed:

  - Measured temperature values in the card:

Values		
Mean	-17.622	Celsius
Max	-16.39	Celsius
Min	-18.869	Celsius

Summary table

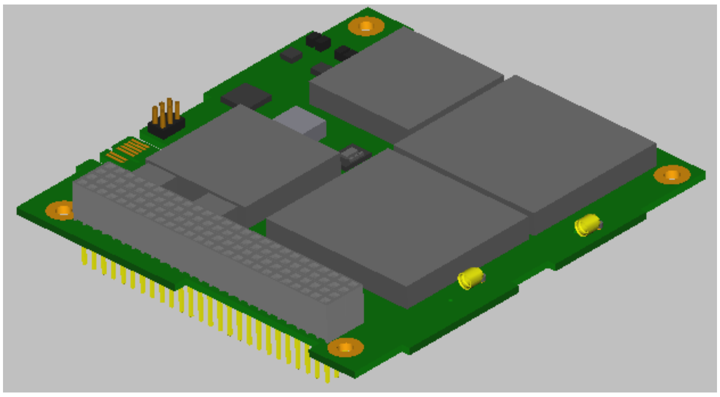


The table below lists the temperature scales in the board without components when it is subjected to the critical temperatures of its operating environment:

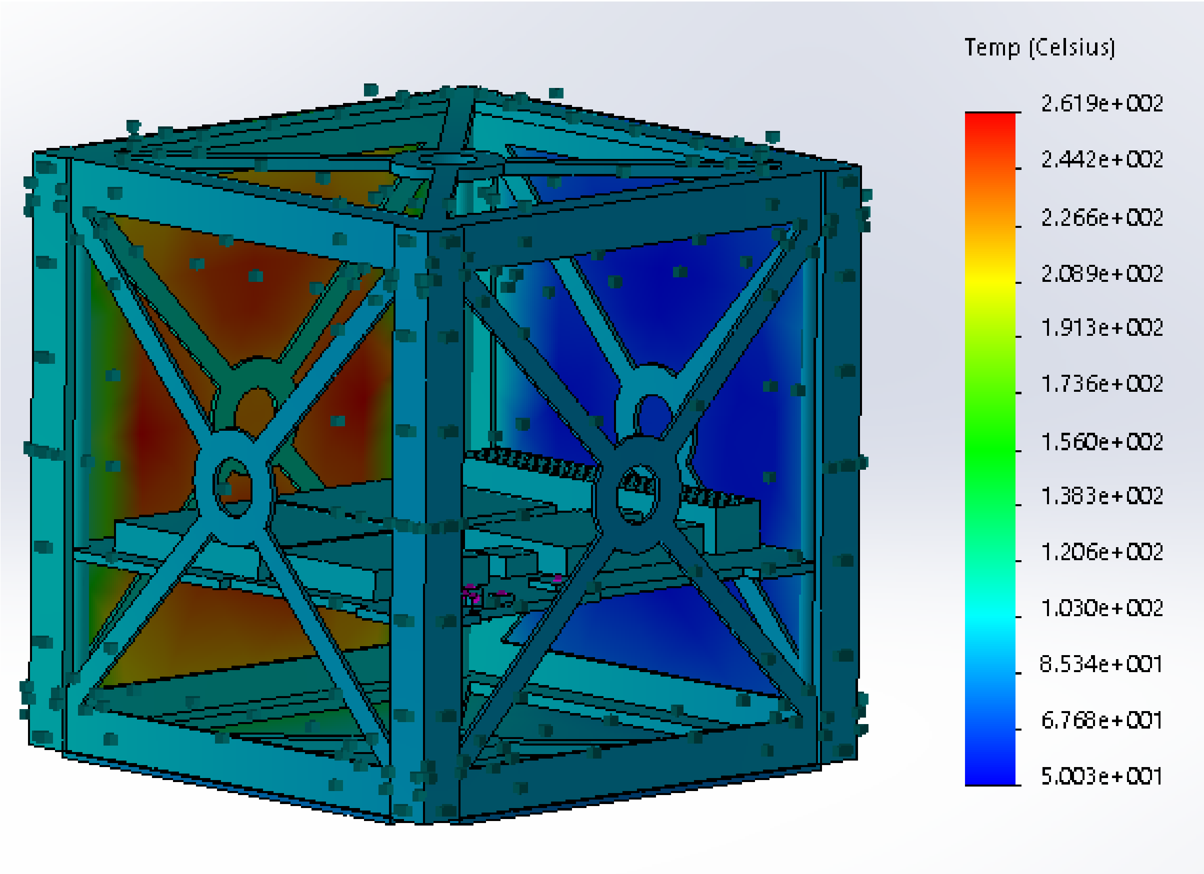
Temperature hypothesis/ Number of faces exposed	Low temperatures (°C)	High temperatures (°C)
1 Face	Min: -19.1 Max: -15.43 Mean: -17.27	Min: 62.35 Max: 80.25 Mean: 71.22
3 Faces	Min: -18.87 Max: -16.39 Mean: -17.62	Min: 64.1 Max: 76.9 Mean: 70.53

Refinement of the model

To have a more realistic model, we made a real model of the card of our telecommunication module. For this, we used as model the ISIS card to carry out these same simulations and to observe the temperature scale of a card with these components:



We started the simulation by using the Isis board instead of the PCB board



Measured temperature values in the card:

Value		
Mean	97.689	Celsius
Max	101.83	Celsius
Min	92.38	Celsius