THERMAL CONTROL PROPOSAL FOR SMALL SATELLITES

Carmen Alañón Cárdenas
Aerospace engineer
Universidad Alfonso X El Sabio
carmen171100@gmail.com

ABSTRACT

This article presents the design of a suitable Thermal Control solution for nanosatellites' and microsatellites' external surfaces and onboard equipment. Each of the designed components and the analysis that have been made is shown throughout the report. In addition, orbital Mechanics concepts are introduced. Finally, the author's proposal is explained to be implemented in a CubeSat satellite, characterized by its low manufacturing cost, simple construction and reduced development time.

Keywords: *Thermal Control, stratosphere, radiation, thermal analysis, Sun stage, Shadow stage.*

INTRODUCTION

The purpose of this article is to offer an overall idea of the process to follow in order to develop a small satellite subsystem, more specifically, the Thermal Control Subsystem, as well as to encourage college students to become a part of the aerospace industry at a young age.

Small satellites are born due to the need to carry out specific space missions taking the shortest possible time, leading to reduced costs compared to standard satellites. As these projects are designed for students, they must be able to be developed using accessible computer tools. [2]
The design process of any small-sized satellite subsystem is a complex one. There are many limits to consider, such as weight, space, economic, and temporary limits. Moreover, it is cooperative work between different teams involved in the project, so each idea must be accepted by the other subsystem team to avoid opposing proposals.

To make a Thermal Control proposal, the kind of mission to discharge must be known, such as the most relevant orbit parameters. In addition, the structure model must have been designed before making the appropriate analysis to show the essential geometrical parameters.

METHODOLOGY

1: Establish the mission's main objectives and targets that must be achieved once the satellite has reached the final orbit. For this article, the mission to develop is about Earth surface observation.

2: Mission analysis. At this stage, all of the Orbit parameters are settled, as the following ones:

A. Orbit definition: Just as photographs are meant to be taken during the mission, it should be in a Low Earth Orbit, with a maximum above sea level. In this way, high-quality images are guaranteed.
B. Eccentricity: The satellite moves between different atmosphere layers to describe a circular path. The eccentricity is zero.
C. Satellite velocity: It will be constant as the orbit is circular.
D. Period: The time required for the satellite to travel through an orbit.
E. Specific Energy increase. It is the total height of energy measured according to a reference point. [5]

3: Preliminary design. The structure team is the one that must firstly design the preliminary model and, after that, the detailed one. Once they have both been finished, thermal analysis processes can be applied. The following images 1 and 2 show the 1U CubeSat CATIA model, whose thermal behaviour will be studied later.

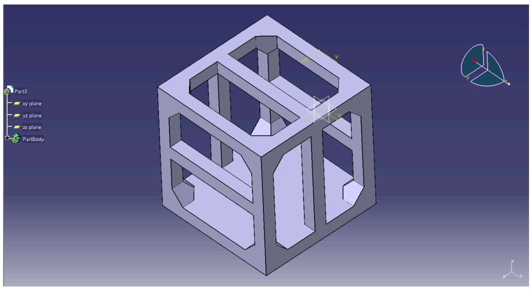

Image I. 1U CubeSat design

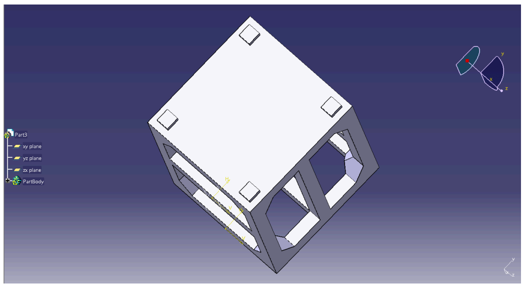

Image II. 1U CubeSat design

4: According to the mission needs, establish different Teams and their thermal requirements. They will be the structure team, the avionics team, the payload team and the thermal control team. It is helpful to remember which components belong to every team so that the weight of each one is always taken into consideration.

5: Study every material and method that turns out to be an excellent option to become a thermal solution to protect those parts that are the most sensitive to temperature changes (inside and outside walls, batteries, cameras). The complexity of this stage lies in the number of materials commonly used in the Aerospace industry, from the most common ones, such as copper and aluminium alloys, to polymers and composite materials.

Thermal analysis. The process involves studying the structure behaviour under the most extreme temperature conditions, both at the Sun and Shadow stages, as a time function. Through this proceeding, the viability of using Materials (described in Point V) in the final structure. Additionally, more information will be obtained if first the analysis is executed by simulating the structure with no protection and then including

the thermal protection. This way, once the results of both situations are compared, benefits from the chosen Materials are easily checked.
The following thermal approaches have been used during the development of this proposal.

A. Stationary Analysis. The speed of the external surfaces' temperature changes is so slow that it can be considered constant.

B. Transitory Analysis. Unlike the previous one, the transitory case considers the temperature changes at any point of the orbit.

6: Final Thermal Control proposal. Evaluating the results from different tests, the most effective methods are settled, and weight limitation is verified not to be exceeded.

ORBIT DESIGN

As it has been previously explained, the CubeSat orbit will be a LEO that reaches the stratosphere. The following parameters have been obtained:

Objective	Earth surface observation
Type of orbit	Heliosynchronous Low Earth Orbit
Orbit height, h (km)	30
Excentricity, e	0
Velocity, v (km/s)	7,89
Period, T (s)	5096,6
Specific entry increase, ξ (km^2/s^2)	-31,1
Temperature range (ºC)	25 to -30

The parameters mentioned above have been calculated through orbital mechanics expressions.

THERMAL CONTROL DESIGN

Structure

Three suitable materials for becoming the structure, as students can quickly obtain them, are [4]:

I) Aluminium. Even though it has a higher density than other options, it offers excellent thermomechanical properties and protection against radiation.
II) Wood. It is cheap and light, but its thermal and mechanical properties tend to change due to temperature gradients because of its biological origin.
III) Polylactic Acid. It is also light and affordable, although it offers meagre resistance against radiation.

Material	**Thermal conductivity** $\left(\frac{W}{mK}\right)$	**Heat capacity** $\left(\frac{J}{kgK}\right)$	**Density** $\left(\frac{kg}{m^3}\right)$
Aluminium	235	1050	2710
Wood	0,2	1700	447
PLA	0,197	1200	1240

The following graphics in MatLab show the changes in the different external surface temperatures during three orbits.

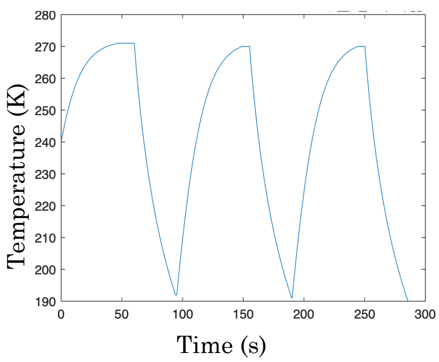

Image III. Temperature changes in the Aluminium structure during three orbits.

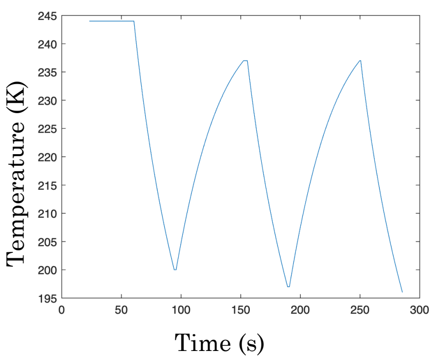

Image IV. Temperature changes in the Wood structure during three orbits.

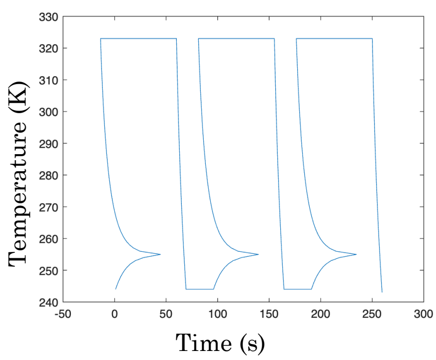

Image V. Temperature changes in the PLA structure during three orbits.

Even though the PLA solution is the one that works best against temperature extremes reducing them remarkably, its properties tend to change against temperature gradients, as the ones that the CubeSat will face. Also, aluminium structure behaves better than the wood one attending to the values reached. For these reasons, the aluminium structure is the chosen one to go one with the analysis.

The possible thermal solutions designed for the aluminium structure are the following:
I) Fibreglass. For the analysis, a 2g fibreglass sheet is simulated for each surface.
II) Black paint that prevents from radiation issues. It would be a layer of 0,1mm thickness for each body part.
III) Kapton (commercial polyimide). A 5-ply insulation board of 0,08 mm thickness each covers the whole external surface.

Material	**Thermal conductivity** $\left(\frac{W}{mK}\right)$	**Heat capacity** $\left(\frac{J}{kgK}\right)$	**Density** $\left(\frac{kg}{m^3}\right)$
Fibreglass	0,05	2250	150
Kapton	1,9	$1{,}15 \cdot 10^{-3}$	1330
Black paint	0,152	2700	1200

The results obtained from the thermal analysis with coatings are the followings.

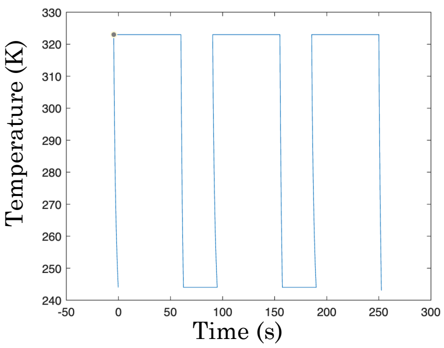

Image VII. Temperature changes in the fiberglass reinforced structure during three orbits.

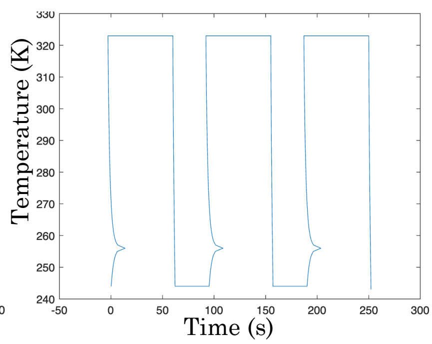

Image VI. Temperature changes in the Kapton reinforced structure during three orbits.

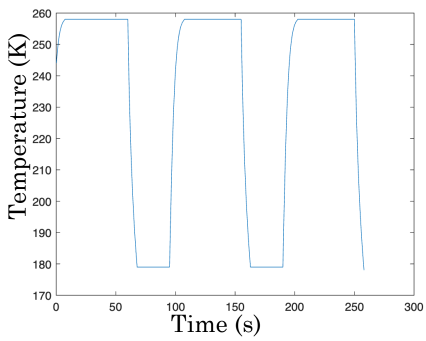

Image VIII. Temperature changes in the Black coating reinforced structure during three orbits.

Fibreglass layer, as Kapton MLI, help to keep heat inside the CubeSat as needed, they also unify the temperature peak. So both are good options to use. But the best option is to cover the CubeSat with a fibreglass layer, as a multilayer insulator board has to be pre-fabricated.

Internal equipment

A water Heat Pipe has been designed to ensure an efficient heat transfer inside the CubeSat. The size was around 9cmx9cmx9cm. Image IX shows the mentioned design in different orientations to describe it adequately.

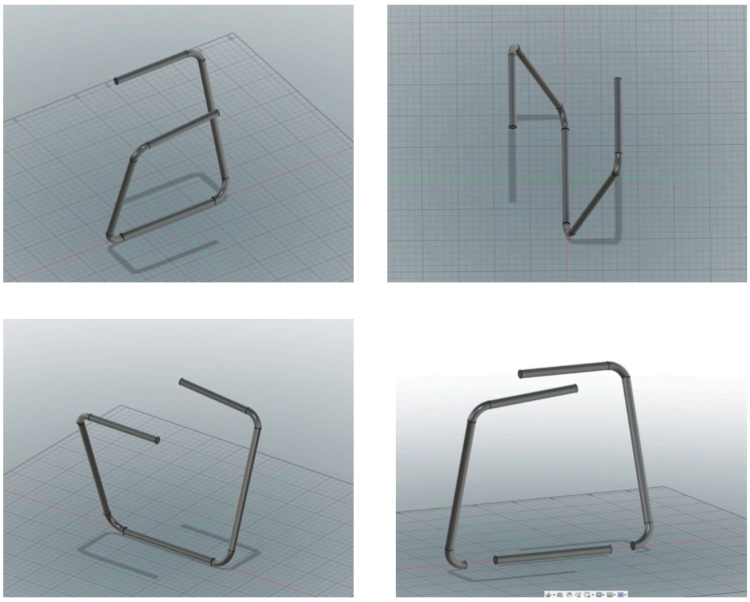

Image IX. Heat pipe design

RESULTS AND DISCUSSIONS

The results of the aluminium structure reinforced with a Kapton MLI are incredibly close to those of the same structure reinforced with fibreglass. As the first one requires a longer fabrication time, the second option seems more suitable. If necessary, the CubeSat may additionally be covered by a thermal blanket. Batteries, such as the camera, must be protected at all costs. If any of these two elements turned out to be switched off, the mission could be considered lost. They must be covered in white paint to reflect solar heat, along with thermal filler that will contribute to collected heat dissipation, just as the water Heat Pipe will do.
Solar Cells are exposed to several thermal fluctuations, so placing them above a fibreglass sheet can be helpful.

CONCLUSIONS

Avionics equipment would be unable to resist the stratosphere temperatures without thermal protection methods. They would reach, at the coldest stage, temperatures of about -80ºC; meanwhile, the lowest they can survive at is about -20ºC.

That is why the fibreglass sheet, different coatings and passive thermal components, as much as the Heat Pipe system, are needed.

For future CubeSat applications, it can be studied to attach a Louver system to the internal walls of the nanosatellite. This automatic element will collaborate to maintain heat received in the Sun stage once the satellite goes through Shadow stage.

BIBLIOGRAPHY

1. S. Piedra, M. Torres, S. Ledesma, *Thermal Numerical Analysis of the Primary Composite Structure of a Cubesat*. Colón, México. 2019. Available at: https://www.mdpi.com/2226-4310/6/9/97
2. L. R. Carrizo, *Introducción a los pequeños satélites*. La Paz, Bolivia. 2020.Available at: http://dicyt.uajms.edu.bo/revistas/index.php/universidad-y-cambio/article/view/237/202
3. R. Wilder, *Análisis térmico de un satélite del tipo CubeSat*. Lima, Perú, 2015.Available at: https://repositorioslatinoamericanos.uchile.cl/handle/2250/2344229
4. M. Susa, X. Maldague, S. Svaic, I. Boras, A. Bendada, *The influence of surface coatings on the differences between numerical and experimental results for samples subject to a pulse thermography examination*. Krakow, Polonia. 2008. Available at: https://www.ndt.net/article/qirt2008/12_11_16.pdf
5. S. A. Botta, *Diseño de Órbitas Terrestres: Aplicaciones, Desafíos y Herramientas*. Argentina. 2021. Available at: https://www.youtube.com/watch?v=IGoKnxr2hyY