LATIN AMERICAN CUBESAT WORKSHOP
SALVADOR, BR
OCTOBER 2024

Alcântara in Orbit Mission: Environmental Data Analysis to Contribute to the Sustainable Development of the Aerospace Sector in the Alcântara Region

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Abstract

This project presents the mission Alcântara in Orbit, which consists in the development of a nanosatellite CubeSat 1U, designed by students from the Military School Tiradentes I, with the purpose of monitoring the environment of the north region of Maranhão, in the context of the 2nd Brazilian Satellite Olympiad (OBSAT) in 2023. In the course of the competition, the nanosatellite was subjected to thermal, magnetic and vibrational testing, subsequently being released through a stratospheric balloon in the Barreira do Inferno Launch Center (CLBI). After the educational event, the project evolved into academic research, in collaboration with the Federal University of Maranhão (UFMA), aiming at the construction of a model 1U with advanced technical parameters for environmental data gathering through remote sensing in the city of Alcântara. The initiative aims to contribute to local sustainable development, benefiting the

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community and the Alcântara Space Center (CEA).

Keywords—Nanosatellite, Alcântara, Remote Monitoring, Sustainable Development, CubeSat

1 Introduction

Environmental monitoring through remote sensing is a significant practice for ecosystem preservation [1]. In this regard, the development of technologies that encompass this technique, such as CubeSats, is of paramount importance for sustainable development [1]. Regarding environmental conservation amidst the emission of polluting gases, the use of remote sensors to measure air quality is relevant, as the measurement of atmospheric pollutant concentrations generates data on the current air quality conditions and builds a historical record, in addition to enabling policymakers to plan actions and public policies [2]. However, obtaining information to combat these changes through large satellites is a process that requires high costs and long development time [3]. Thus, the need for a faster and more efficient alternative is evident, considering that the emission of greenhouse gases (GHGs) has increased at an accelerated rate in recent decades, resulting in increasingly frequent and severe impacts [4]. In this context, the standard CubeSat nanosatellite (10 centimeters x 10 centimeters x 10 centimeters format) emerges as a more viable and accessible alternative due to its flexibility and success rate, with room for potential failures, within a low and flexible budget [5]. An example of this is the Aldebaran-1 mission, produced at the Laboratory of Electronics and Embedded Space Systems (LABESEE) at the Federal University of Maranhão (UFMA) [6].

In this context, the Alcântara in Orbit mission and Jussara-0 (the first version of the satellite) were born from the work of high school students at Military School Tiradentes I with the initial goal of analyzing the socio-environmental impacts in the northern region of Maranhão, to participate in the 2nd Brazilian Satellite Olympiad MCTI (OBSAT) in 2023. The students designed, integrated all the components, programmed, and assembled everything into a standard 1U CubeSat nanosatellite model with a structure based on 3D printing, to meet and execute all subsystems. Consequently, the mission was incorporated into UFMA's Aerospace Engineering Coordination, through LABESEE, which proposed that UFMA offer the construction and launch of a standard 1U CubeSat into low orbit, in partnership with the startup Epic of Sun, responsible for the satellite's payload, in order to receive and transmit data provided by Data Collection Platforms (DCPs) to contribute to sustainable development.

Therefore, this article aims to present an overview of the development of the Alcântara in Orbit Mission and the Jussara-0 and Jussara-K satellites (the current version of the satellite), as well as their subsystems and results, in order to socio-environmentally contribute to the Alcântara community.

2 Related Works

2.1 Ground Station

The satellite communication, control operations and data transmission will be carried out by a station of radio communication that belongs to the junior enterprise Guará Space, located in the Advanced Entrepreneurship Center from UFMA (NAVE).

2.2 Aldebaran-1

The main reference for the construction and programming project of the Jussara-K satellite is the Aldebaran mission. Both are being developed in the Electronic Laboratory of Space Embedded Systems (LABESSE). The Aldebaran was the first satellite construction project of the laboratory. The knowledge acquired by that mission was substantial on the stage development of the project Jussara-K [6].

2.3 FloripaSAT

Besides the Aldebaran mission, the project also uses public data made available by others satellite missions, such as the FloripaSAT. This mission, through its development laboratory, the SpaceLab, released part of the data in its website, allowing technological knowledge gaps to be fulfilled with said data [7].

3 Objectives

3.1 Main Objective

The mission "Alcântara in Orbit" has as a main purpose the production of a satellite of the model CubeSat 1U in Low Earth Orbit (LEO). Said nanosatellite will be responsible for periodically receiving and relaying the information supplied by terrestrial Data Collection Platforms (DCPs), installed around the city of Alcântara. The main focus is to monitor regional environmental parameters, contributing to sustainable development of the Alcântara Space Center (CEA).

The predicted altitude for the Jussara-K satellite is 400 kilometers above earth surface. Once in position, the satellite must, through its subsystems, receive, process and transmit environmental data collected by the DCPs, as well as the data of the subsystem itself. Fig. 1 illustrates the mission architecture of the project and the stages of the launching process.

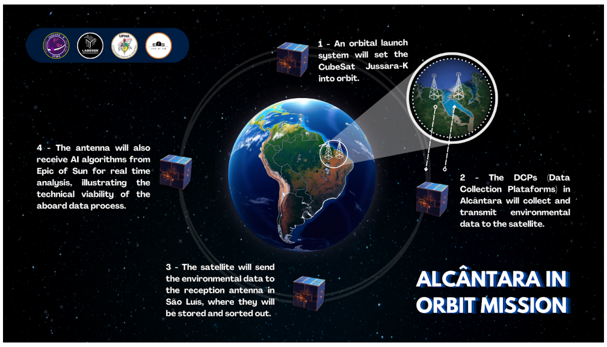

Figure 1: Mission architecture of the Alcântara in Orbit mission.

3.2 Specific Objectives

- Integrate the payload so that it does not interfere with its operation;
- Manage CubeSat during the mission;
- Integrate DCPs to send information;
- Integrate ground station for information collection;
- Ensure the collection of data necessary for the success of the mission.

Furthermore, the mission also has as specific objectives to investigate the socio-environmental damages, allowing an in-depth study of the impacts on local fauna and flora, as well as on human health and quality of life in the region; promote the development of viable and sustainable metrics dedicated to aerospace launches that are economically and ecologically beneficial for the sector; provide references and an informational basis to mitigate gaps in the global research on the aerospace sector and its sustainable development, thereby contributing to the refinement and definition of the necessary merits for the viability and implementation of specific measures; encourage the Alcântara community involvement with environmental causes and their implications, thus supporting traditional manifestations of life.

4 Materials and Methods

4.1 Jussara-0

For the first version of the satellite, the eBook [8] from the Brazilian Satellite Olympiad was used as a reference, which has construction recommendations for the prototype. The developing process of Jussara-0 was divided as follows:

4.1.1 OBDH (On-Board Data Handling)

To successfully carry out the mission, a subsystem that manages and stores the generated data is essential. The OBDH is, therefore, the brain of the satellite platform, as it is responsible for controlling and interfacing communication and data exchange between the other subsystems. Through this subsystem, it is possible to receive data generated by the sensors and execute commands from the ground station. In this context, the ESP-WROOM module, which includes the ESP-32 microcontroller, was chosen, because it not only has integrated Wi-Fi but also offers a good number of analog and digital input/output and measures compatible with the project's size and mass restrictions.

4.1.2 TT&C (Telemetry, Tracking and Command)

During the mission, interaction between a ground station and the satellite is necessary to enable data traffic between the two systems. To achieve this, the TT&C subsystem sent data related to temperature, pressure, battery level, and data collected from other sensors via Wi-Fi, using it solely as a communication method, without use of internet, to the competition's launch structure, which retransmitted the information via radio to the ground station, as well as store a MicroSD card for later reading.

For capturing data from the components, the code was divided into two files based on object-oriented principles and functional programming. A class was created on another file containing all the variables and functions for each component, and in the main file it is used for reading and manipulating telemetry and payload data, allowing for easier individual and overall testing.

4.1.3 EPS (Electrical Power Subsystem)

The power supply is an essential element for the development of the satellite, as it is responsible for generating, storing, and distributing the electrical energy required for the functioning of all electronic components in the other subsystems. Thus, to concoct the EPS and supply durability and efficiency in the operation of the components during the mission, Lithium Polymer batteries, voltage regulators, and a Battery Management System (BMS) module were used.

The overall power supply is provided by two rechargeable Lithium Polymer battery cells rated at 3.7 volts, connected in series, resulting in an approximate capacity of 7.4 volts and 800 mAh (milliampere-hour), accompanied by a Battery Management System (BMS) to optimize performance and protect against potential short circuits. Thereby, the voltage passes through the Adjustable Voltage Regulator LM2596 and is transformed to the appropriate level (+5 volts) to power the on-board computer and the microSD card module and the +3.3 volts output from the ESP-32 powers the other sensors. The connections were made aiming to ensure long-lasting power for the satellite during the mission, as well as facilitate future adoption, if necessary, of sensors and actuators with higher operating voltages. Fig. 2 represents the schematic of this subsystem.

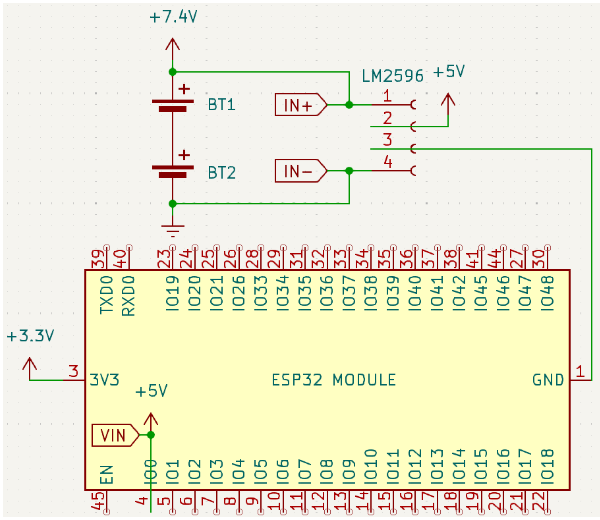

Figure 2: EPS circuit diagram.

4.1.4 TCS (Thermal Control Subsystem)

To maintain an adequate temperature for the satellite and its subsystems, it is necessary to elaborate a thermal control system with insulating materials, since the performance and effectiveness of the components depends on maintaining an appropriate temperature. As a result, in the Thermal Control Subsystem (TCS) was used EPE foam and Depron type materials - that guarantee protection and thermal insulation - to avoid heating of the components and promote an operating scenario with stable temperature.

4.1.5 Structure

Considering the necessity of developing a compact and functional structure, the chassis of the satellite, as presented in Fig. 3, was projected using the programs Tinkercad and Fusion 360, since they are accessible and allow simple and clear visualization of the technical and physical details of the project.

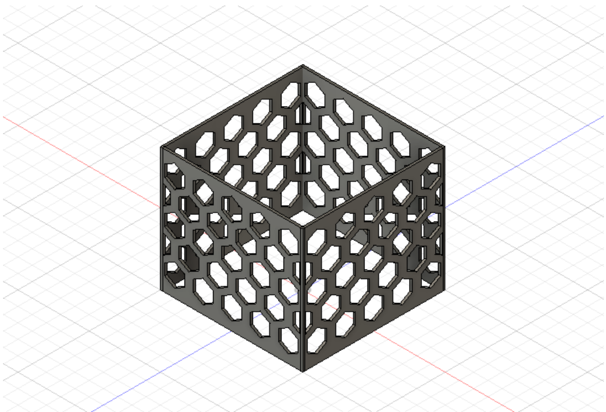

Figure 3: External structure in the 3D modeling program 3D Fusion 360.

Furthermore, the mechanical project involved the development of different systems for securing and integrating the sensors and actuators, as well as research and selection of suitable materials for greater resistance to extreme scenarios. Thus, for structuring and securing the satellite components, we used M3 screws and nuts, whose fittings were predetermined in a three-dimensional design in the CubeSat foundations, with 3D printing, using PLA thermoplastic filament as a main structuring method, since it provides adequate rigidity for protecting the components. We also designed pieces analogous to industrial ones produced by LEGO - a company renowned in the field of educational robotics - to improve practicality in joining the different layers of the satellite, innovate the securing and integration of components, and accelerate the assembly and disassembly process, which enables adjustments, repairs, and maintenance, as referenced in Fig. 4.

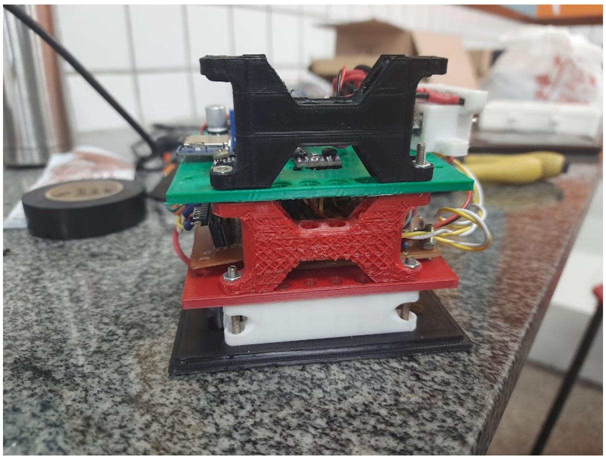

Figure 4: 3D printed internal structure.

To interface the components and the microcontroller, increase the satellite usable space, reduce the number of wires and increase the number of power and communication pins, the development of a printed circuit board (PCB) was necessary. Fig. 5 presents the design and electronic layout of the board, which were created using the open-source software KiCad.

Figure 5: PCB 3D preview.

For the manufacturing, an artisanal method was used to optimize time and financial resources. First, the design was printed on photographic paper. Then, using an iron, the design was pressed against a virgin phenolic board, properly cut to the dimensions of the design, to transfer the ink from the paper to its copper surface, forming the circuit traces. After that, the board is immersed in a ferric chloride solution, which will corrode the entire board, rendering it incapable of conducting electric current except for the areas covered by the ink. Thus, by washing with water and removing the ink, all traces remain intact and conductive. Finally, the board is drilled and the components are soldered so the circuit can function properly.

The components mostly use the I²C (Inter-Integrated Circuit) communication protocol, which allows better interfacing with the on-board computer by using only two pins for operation, SDA (Serial Data) and SCL (Serial Clock), which enables a significant reduction in the number of digital ports required.

4.2 Jussara-K

After the incorporation of the mission into UFMA/LABESEE, the development methodology for the artifact was defined according to ECSS (European Cooperation for Space Standardization) standards [9]. In this regard, the following subsystems were defined for the construction of the Jussara-K satellite.

4.2.1 On-Board Data Handling (OBDH) e Telemetry, Tracking and Command (TT&C)

Unlike what is usually used in projects of this type, the Jussara-K will feature a single board integrating both subsystems, as shown in Fig. 6. One of the motivations for this integration was the pursuit of energy saving, given that a significant portion of the energy will be directed to this subsystem, as it includes an embedded AI (artificial intelligence) in its payload. The board will use the MSP430F6659 microcontroller, which will function as the satellite's on-board control as well as the radio manager for the beacon and the SX1278F30 radio chip, which communicates with the microcontroller using the SPI (Serial Peripheral Interface) protocol. Regarding the radio, the satellite will use the same LoRa system model used previously in Aldebaran-1, which conveniently has a flight history.

Figure 6: TT&C and OBDH board.

The antennas will be made from a steel tape sourced from a common and accessible measuring tool: the measuring tape. The use of steel tape for the antenna is due to its flexibility, durability, and lightweight nature, which facilitates the accommodation and liberation of the antennas. The release system used will be inspired by the system from Isispace [10], a company specialized in the production and sale of satellites, which features a set of resistors connected to a wire that holds the antennas. At the moment of release, the resistors are activated and, through the Joule effect, generate heat that breaks the wire, releasing the antenna. Fig. 7 shows one of the tests conducted to determine the most suitable resistance value for the release of the antennas.

4.3 Electrical Power System (EPS)

The EPS is still being planned and developed and will feature an MSP430G2553 microcontroller for reading sensors and managing battery-related information, such as temperature, voltage, and current intensity. It will also include four photovoltaic panels and a real-time MPPT (Maximum Power Point Tracking) management system to maximize the solar energy generated by the panels.

For the base power supply, two 3.7 V nominal Li-Ion 18650 batteries will be used, connected in parallel to achieve an approximate capacity of 5000 mAh.

Thus, Buck-Boost converters will be used to supply 5V and 3.3V tensions for the other subsystems. Fig. 8 shows a block diagram of the EPS circuit.

4.4 Structure

The structure that will house the subsystem panels will be made of aerospace grade aluminum, as it is a lightweight material and resistant to corrosion, fatigue, and extreme temperature conditions [11].

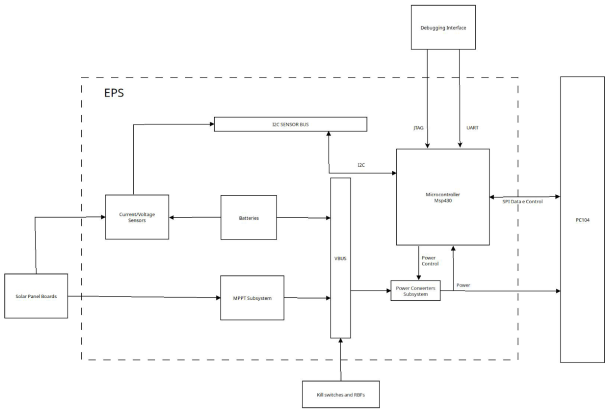

Figure 7: EPS circuit diagram.

4.5 Payload Epic of Sun

The project of the startup Epic of Sun, called KaraLAB, consists of an on-board computer for 1U cubesats capable of running embedded artificial intelligence (AI) algorithms for real-time data analysis optimized for operations in a space environment.

Its integration into the satellite of the mission "Alcântara in Orbit" aims to test the capability of executing complex algorithms with minimal resource consumption.

5 Results and Discussion

Throughout the Northeast Regional Event at the Barreira do Inferno Launch Center (CLBI), the OBSAT organization required robustness in all subsystems to validate the flight model, conducting thermal, magnetic, and vibration tests. As a result, the prototype was accepted for flight via a stratospheric balloon, as shown in Fig. 9, operating at an altitude of approximately 27 kilometers, illustrated in Fig. 10, for about 4 hours until its descent.

During the mission, the satellite successfully collected payload and telemetry data, storing

Figure 8: Stratospheric balloon.

Figure 9: Jussara-0 operating at an altitude of 27 kilometers.

it on a microSD card, while the data transmission via radio was handled by the event organization. After the recovery, the collected data was processed and organized to facilitate understanding of the mission results, with the code made public for the entire scientific community, as shown in Fig. 11, Fig. 12 and Fig. 13.

However, during the launch of Jussara-0, it was observed, as seen in Fig. 14, that the carbon dioxide (CO2) sensor did not capture data for a certain period of time. The hypothesis is that this electronic component did not withstand the low temperatures of the stratosphere. Thus, the need for more temperature-resistant materials is evident, a requirement addressed

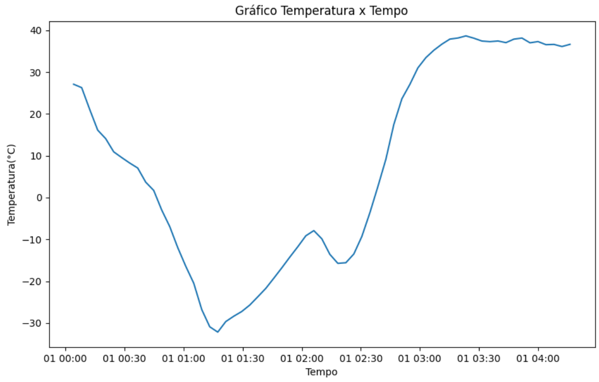

Figure 10: Graphic of the temperature data obtained in Celsius as a function of time in hours and minutes.

in the current version of the satellite, Jussara-K.

The Jussara-K satellite, in turn, is still under development. In this regard, simulations were conducted to define feasibility parameters for the "Alcântara in Orbit" mission. An orbital analysis of six satellites was carried out, with the purpose of organizing the timings for passes, data reception and transmission, as well as the duration of each window, which is a substantial factor for planning the telemetry and communication structure of the mission. To execute the simulations, the system provided by the National Aeronautics and Space Administration (NASA), the General Mission Analysis Tool (GMAT), was used. Additionally, Excel was used for data processing and calculations of the results obtained from the simulation, while Google Sheets was used to generate the graphs. Six already-launched CubeSats were selected, with two representatives for each type of orbit to be analyzed (POEM and POEM 2 for equatorial orbit, THYBOLT-1 and THYBOLT-2 for polar orbit, and AAUSAT 2 and COMPASS 1 for sun-synchronous orbit),

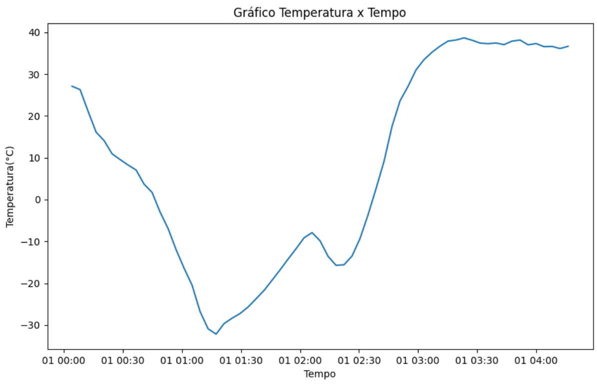

Figure 11: Graphic of the pressure data obtained in Pascal as a function of time in minutes and hours.

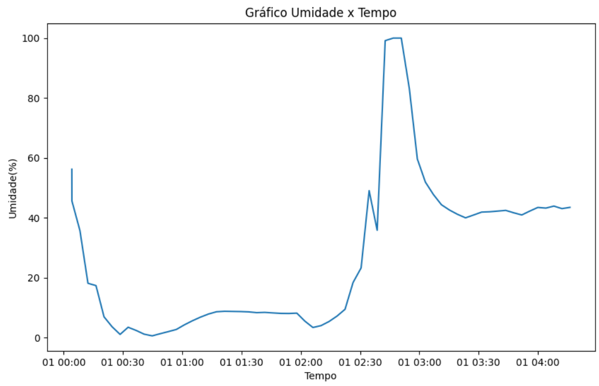

Figure 12: Graphic of the humidity data obtained in percentage as a function of time in minutes and hours.

with altitudes close to 500 kilometers above the equatorial surface and about 6878 kilometers from the Earth's core, in a 1U format. The simulations utilized the five orbital elements necessary to initiate simulations: Right Ascension of the Ascending Node (RAAN), Argument of Perigee (AOP), Inclination (INC), Eccentricity (ECC), and True Anomaly (TA), obtained from the Two Line Elements (TLEs) of the selected satellites, available on the real-time satellite tracking website "n2yo.com"[1].

After the simulation procedure, contact graphs of the satellites were generated using Google Sheets, resulting in graphs showing the duration in seconds of the passes per day, as shown in Fig.15, Fig. 16, Fig. 17, Fig. 18, Fig. 19, and Fig. 20.

The results included the average contact time, the standard deviation of this time, the maximum and minimum values, and the timing and dates of each pass, as shown in Table 1. From the analysis of the pass timing of all the satellites, it was not possible to establish a pattern for satellites operating in polar and equatorial orbits. However, satellites in Sun-Synchronous Orbits (SSO) exhibited well-defined pass patterns over short time intervals.

6 Conclusion

The present work showed a general understanding about the mission "Alcântara in Orbit", its development and history.

Through this project, the qualification of the involved students is being promoted, as well as the fomentation of projects in the aerospace sector and the establishment of a flight history for the Jussara-K satellite. The expected completion date for the satellite's development and its launch is 2025, with the anticipation that by this date all subsystems will be effectively validated and tested.

It is expected that once launched into orbit, the satellite will successfully collect environmental data from the Alcântara region through the successful integration of all subsystems. The information obtained through telemetry will later be processed and made publicly available via a website, in order to make the results

[1] https://www.n2yo.com/

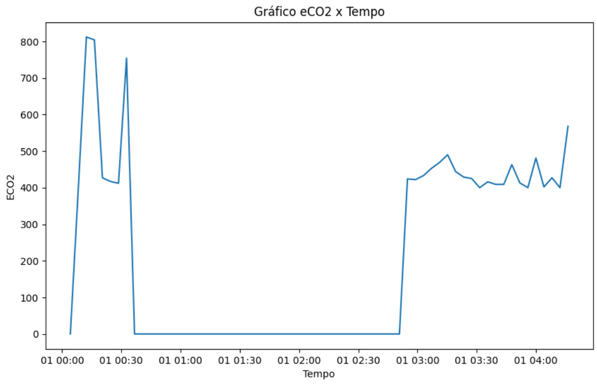

Figure 13: Graphic of the carbon dioxide (CO2) obtained in part per million as a function of time in minutes and hours.

Satellite	Average Contact Time	Standard Deviation	Maximum	Minimum	Daily Passing
THYBOLT-1	385.339.931	1.165.611.421	5.025.233.015	4.148.666.267	2 to 3
THYBOLT-2	3.907.140.467	1.095.806.857	5.042.664.882	5.914.864.757	2 to 3
POEM 2	4.653.431.456	6.394.580.182	5.483.745.707	3.041.100.207	14 to 15
POEM	4.661.987.761	653.661.184	5.492.862.133	3.125.705.216	14 to 15
AAUSAT 2	3.924.228.127	1.069.795.049	5.015.276.832	5.443.356.866	2 to 3
COMPASS 1	3.944.896.468	1.068.826.344	5.045.567.712	3.483.794.566	2 to 3

Figure 14: Orbital analysis value.

more accessible to the people of Alcântara. It is also expected that this data will be used to mitigate potential environmental imbalances and support the development of the scientific community.

Furthermore, there is an objective for the future that the Jussara-K CubeSat will serve as a reference for other projects and missions. This way, the project will not only contribute to the development of the mission, but also to the advancement of the Brazilian aerospace sector.

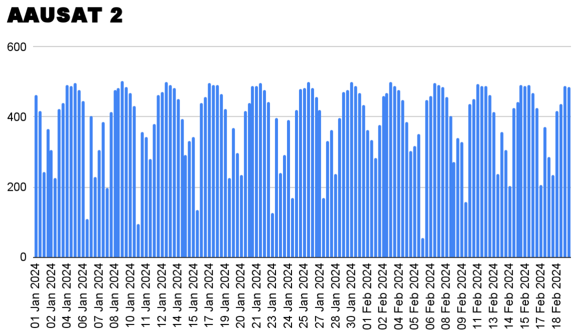

Figure 15: Contact timing of AAUSAT 2 in seconds.

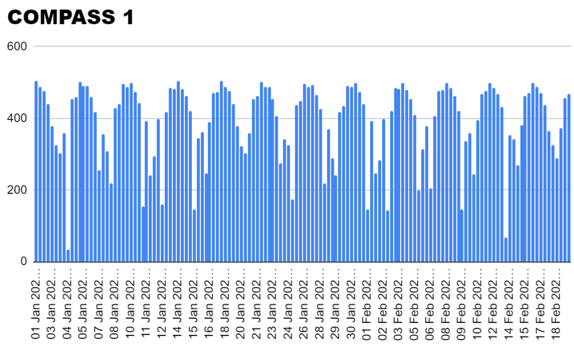

Figure 16: Contact timing of COMPASS 1 in seconds.

7 Acknowledgment

We would like to express our deep gratitude to God, whose guidance has been fundamental in our journey. We thank the Military School Tiradentes I for the learning environment and professors Uanser Mendonça and José Sóstenes for their support and motivation during OBSAT, making this project possible. We are grateful to UFMA, LABESEE, and the Aerospace Engineering students, whose support has been essential for the advancement of the mission. We also thank professors Carlos Brito, Luís Cláudio, and Braga Júnior for their trust in our work. Finally, we cannot forget João Gabriel and Álida Serra, as their efforts made it possible to bring the project to life. To everyone who contributed, our sincere thanks.

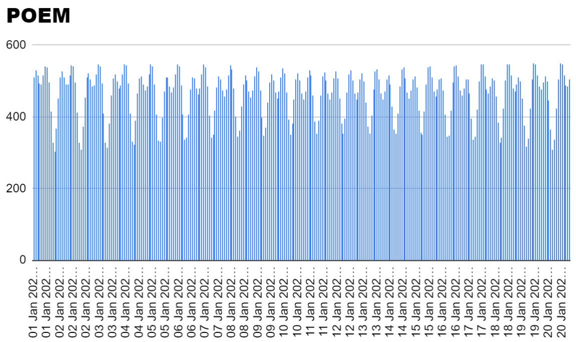

Figure 17: Contact timing of POEM in seconds.

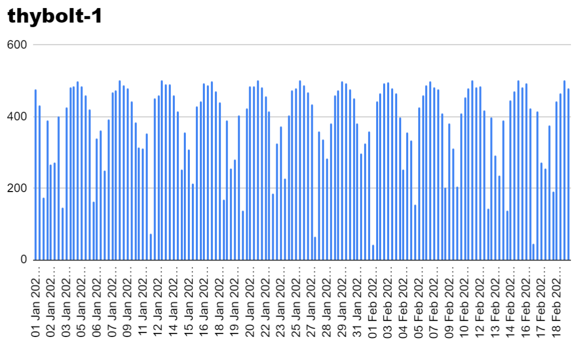

Figure 19: Contact timing of Thybolt-1 in seconds.

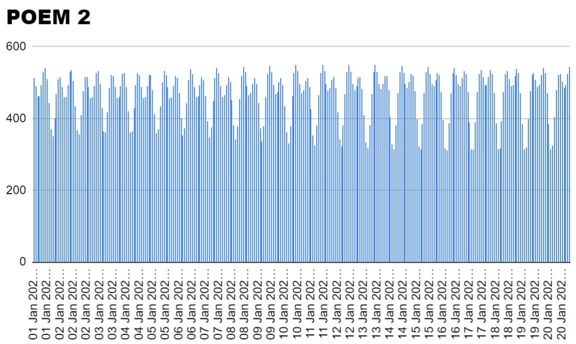

Figure 18: Contact timing of POEM 2 in seconds.

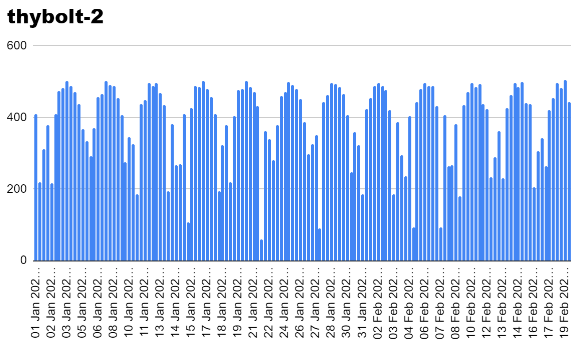

Figure 20: Contact timing of Thybolt-2 in seconds.

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