Design of a Low-Cost Nanosatellite for Atmospheric Monitoring

Juliana Silva Marquione
Federal University of Juiz de Fora
Juiz de Fora, Brazil
marquione.juliana@engenharia.ufjf.br

Igor Daher Cabral
Federal University of Juiz de Fora
Juiz de Fora, Brazil
igor.daher@engenharia.ufjf.br

Rafael Bonioli Kneip
Federal University of Juiz de Fora
Juiz de Fora, Brazil
rafael.kneip@engenharia.ufjf.br

Estêvão Coelho Teixeira
Electrical Circuits Departament
Federal University of Juiz de Fora
Juiz de Fora, Brazil
estevao@engenharia.ufjf.br

Washington Orlando Irrazabal Bohorquez
Production and Mechanical Engeneering Departament
Federal University of Juiz de Fora
Juiz de Fora, Brazil
wirraz@engenharia.ufjf.br

,

***Abstract*—It is an etablished discussion in the specific literature that the Antartic Ozone Hole has secundary impacts in low longitudes regions beyond the South Pole. Once the thinning of the ozone layer is a concerning result of this phenomenon, efforts should be made to extend its study to other regions, where the are not yet enough discussions of those effects. This work presents, then, the design of a simple nanosatellite that aims to monitoring the ozone layer in atmospheric, specifically in the Southeast region of Brazil. The satellite proposed has an autonomy of 6 hours and was design to reach altitudes up to 30 kilometers. The on-board data handling, sensors, telemetry, electronic power system and structure systems CanSat proposed were discussed. That way, the authors expected that this project represents a contribution in such an important field.**

***Index Terms*—CanSat; Oxygen Levels; Sensors;**

I. Introduction

Due to the Brewer-Dobson circulation, the ozone level in the terrestrial atmosphere is higher in the polar regions when compared to other global regions [1]. In the Antarctic region, the Antarctic Ozone Hole is a cyclical and seasonal phenomenon that causes thinning in the ozone layer. However, it was discovered that the so-called secondary effects of the arctic ozone layer are responsible for lowering the Total Ozone Column (TOC) values outside of polos, in low-longitude regions [2].

In South America, the phenomenon has been widely studied by Brazilian researchers over the last few years. The decrease in TOC in the region has been reported multiple times, resulting from analysis carried out with data from 1987 to 2007 [3], 2005 to 2014 [4], 2010 to 2011 [5] and 2016 [6].

Even though the increase of UV radiation on Earth is also related to other atmospheric aspects other than ozone layer holes, it is known that there is, in fact, such correlation. Once the increase of UV radiation due to ozone layer thinning can have dangerous impact on humans [7] [8] and other living organisms' health [9], monitoring it becomes important.

With the existence of commercially available components capable of measuring the concentration of ozone in the atmosphere, it becomes possible to build satellites on a small scale for this mission. Mini-satellites have been gaining prominence in recent years, either with the creation of academic competitions [10] and academic teams at universities aimed at their construction [11] or real missions in different areas of activity [12] [13].

Among these types of satellites, CanSats can be cited. "The CanSat project was proposed by Prof. Twiggs (Stanford University) in 1988" [14], with an educational aim of designing and building small satellites that have the same size as a soft drink can (350 ml). Since then, CanSats have been popularized and, in fact, used as an important educational tool [15] [16], with satellites being effectively constructed and launched by students to explore the space [17].

As mentioned before, once the secondary impact of the ozone layer hole is traditionally discussed for polar and lower longitude regions, but the harm caused by UV radiation is a global concern, it is important to not only maintain the investigation for such regions but extend it to other ones. More autonomous satellites and less expensive options should be considered for this task.

In this sense, this work aims to present a CanSat design to monitor the atmospheric ozone layer. The CanSat was idealized using out-of-shell electronics components, and it is designed to be easily constructed and applicable to a wide range of conditions.

The paper is divided as follows: in Section II, the mission requirements are described. Section III shows the system architecture in detail. In Section IV, partial results are discussed. Finally, Section V presents the conclusions.

II. Mission Requirements

The mission requirements are a set of rules that the project must follow to achieve the established objective. The requirements discussed in this topic are about on-board data handling, telemetry, tracking and command, electronic power system, attitude determination and control system.

This CanSat was planned to be launched on a stratospheric platform of helium-filled balloons, and was named Embaúba Sat to honor the Embaúba tree, native to Brazil, found in the Atlantic Forest and very common in the Zona da Mata region of Minas Gerais. This launching scenario requires some care with the electronic systems and structures. The system's design was based on these requirements, which will be highlighted throughout this work, according to the subsystem it concerns.

Structurally, there is the dimensional requirement that the CanSat must have a 66 mm diameter and 100 mm height, with a mass limited to 350 grams.

The CanSat was designed to be launched in a stratospheric balloon that operates at up to 30 kilometers altitude under extreme conditions of temperature and pressure variation. The satellite should remain attached to the balloon throughout the mission and should not be ejected either.

III. System Architecture

To meet the mission requirements, the system was structured in a simple way, with a microcontroller performing the on-board computer, a battery to power the circuit, and the sensors to capture the data. The Fig. 1 shows the system block diagram. Each part will be detailed in this section.

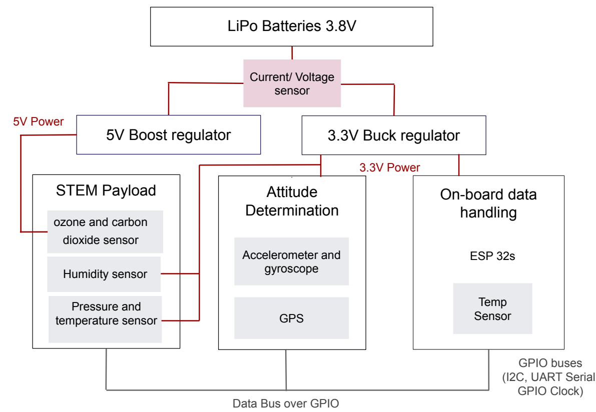


Fig. 1: Embaúba SAT Block Diagram.

A. On-board data handling

The component chosen to manage tasks was the ESP-32S, a product by Espressif. The motivation for choosing the component was the team's familiarity with the microcontroller, which meets the requirements for processing power, number of GPIOs, and WiFi communication.

ESP-32S is a powerful and versatile low-cost system-on-chip (SoC) with a dual-core processor and a host of other features [18]. Its dual-core Tensilica LX6 processor can operate at frequencies up to 240 MHz. This makes it capable of running complex parallel applications while still consuming very little power. Additionally, the ESP32S has 520 KB of SRAM and 4 MB of flash memory, providing plenty of space for code and data storage. The ESP-32S also presents many peripheral interfaces. In this project, the I2C connection was chosen to integrate the sensors with the main processing unit.

Moreover, the ESP-32S is compatible with a wide range of development environments, including the Arduino IDE, MicroPython, and the ESP-IDF. In this project, the PlatformIO extension for VSCode was used, which is equivalent to the Arduino IDE, for its versatility.

B. Sensors

The sensors can be divided into two groups, as shown in block diagram. In the first group are the sensors for acquiring data related to the on-board experiment. The second group consists of sensors for attitude determination and the control system of the CanSat.

The payload sensors are the BMP280, AHT10, MQ-131 and MQ-135. These sensors acquire the environmental data that is used in the study of the ozone layer. The attitude determination and control system consists of a MPU6050 and a GPS module. These sensors measure the satellite's acceleration, orientation in space, and geolocation. An explanation of the sensors used in the project is detailed as follows:

- BMP 280 is designed to measure atmospheric pressure with high precision and calculate temperature, altitude, and relative humidity [19]. In this project, it will be used to measure temperature and atmospheric pressure.
- AHT10 is a high-precision digital temperature and humidity sensor [20]. The motivation for using a sensor only to measure relative humidity is that the BMP 280 when used to measure humidity, pressure and temperature loses speed and accuracy of measurements. Therefore, to ensure the best system performance it was decided to use the AHT 10 to measure relative humidity.
- MQ-135 and MQ-131 are sensors used to detect different types of gases in ambient air. The MQ-135 used for carbon dioxide detection and MQ-131 for ozone detection [21] [22]. Both are dependent on ambient temperature and humidity, so we must evaluate all these data during the study of the experiment.
- MPU 6050 is an accelerometer and gyroscope, thus being able to measure the speed and attitude of the component and, consequently, of the system where it is being used [23]. The variables are separated in three dimensions, so the readout returns six outputs per measurement, of which three refer to speed and three to orientation in space.
- GPS NEO-6M is a Global Position System sensor that measures latitude, longitude, date, time and speed of displacement the module [24]. The sensor communicates with Global Satellite Navigation (GNSS).

C. Telemetry

Telemetry will be done by Wi-Fi communication from the satellite to the weather balloon, which is responsible for capturing and storing the data. First, the data will be damp with JSON, each data packet having a size of 90 bytes. After compression, the data will be transmitted over the WiFi network of the ESP 32s, which is connected to the balloon.

D. Electronic Power System

The power system requires care with extreme conditions, i.g. abrupt temperature variations and radiation exposure. Lithium-polymer (LiPo) batteries with 850 mAh and 3.8V were selected in order to provide an autonomy of about 6 hours to the system. To monitor the system energy consuming, a voltage and current meter will be used at the battery output. By analyzing the voltage drop over time, it is possible to estimate the battery life, which is important to validate the calculations made in the project and to control the mission life.

The batteries will be wrapped with a Teflon blanket, which is resistant to high and low temperatures. It has also high chemical resistance and a low expansion coefficient in the presence of heat and pressure. The Teflon blanket will, the, be used as an insulator to ensure the functioning of the batteries.

Finally, to provide the correct power supply for each component, two regulators will be used. The Buck regulator is used to convert a higher input voltage to a lower output voltage. In this project the Buck will convert from 3.8 V to 3.3 V. The Boost regulator has the opposite function to the Buck, i.e., it increases the input voltage to a higher output voltage. In this design, the boost will convert from 3.8 V to 5 V.

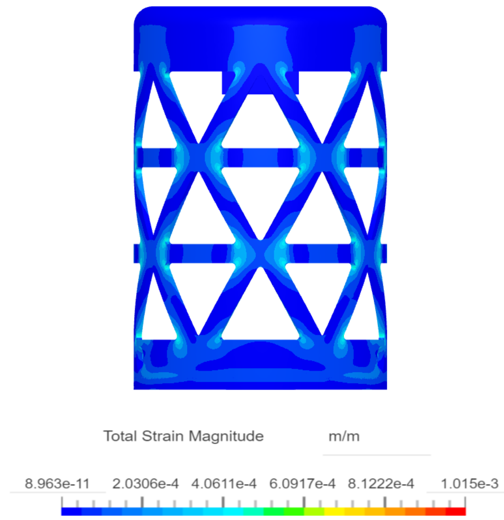
E. Structure

The CanSat structure will be composed of two substructures fabricated in Acrylonitrile butadiene styren (ABS). The first one is a hollow cylinder with a 1.5 mm wall thickness in which triangular-shaped holes were allocated to reduce mass. The second one will be attached to the first one through screws and it will be the base for the electronic systems.

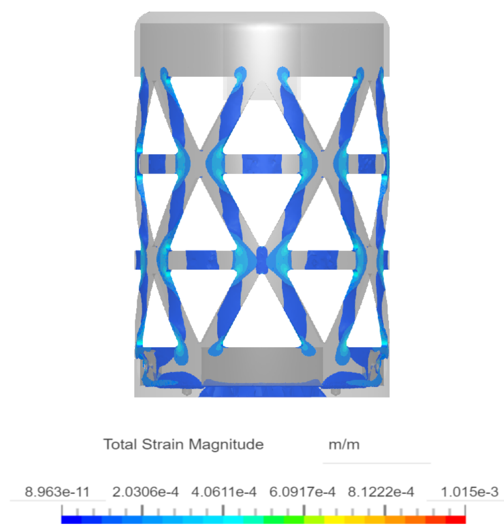
To validate the designed structure, a Finite Element Analysis (FEA) was carried out using the cloud-based simulation software SimScale. A critical case in which the CanSat is held by its top part was considered. In this scenario, the lower part of the satellite has to be able to endure the stress caused by the electronics weight. For the boundary conditions, the top curved face was defined as a fixed support, whereas on the inner face of the structure a 10 N force was applied, considering a factor of security. The contact between the two substructures was defined as Bonded, which was the closest option to a screw connection available on the software.

An initial simulation was carried out with a coarser mesh. This simulation showed that the regions with higher values of strain were located at the lowest part of the first substructure. Once theses values were located at stress concentration spots, the computer-aided design (CAD) was modified in order to create a curved face in the border, as recommended by the software documentation in such cases [26].

With the CAD modified, a new mesh was generated and used to carry out the simulation. This mesh, refined in the round face created, has 521879 tetrahedral elements and 852385 nodes. The strain contours are shown in the Figure 2a. The maximum strain obtained was $1.015 \cdot 10^{-3}$ m/m. The values of strain on the range between $1.015 \cdot 10^{-4}$ m/m and $1.015 \cdot 10^{-3}$ m/m are shown on Figure 2b.



(a) Values for the whole model.



(b) Values in the range between $1.015 \cdot 10^{-4}$ and $1.015 \cdot 10^{-3}$ m/m.

Fig. 2: Strain contours.

With this amount of strain, the ABS material should behave as an elastic linear material [27]. That means that the structure would not have permanent deformations, and then it is validated. A more refined mesh was generated and used in a new simulation. With 606845 elements and 976965 nodes, the strain value was $1.042 \cdot 10^{-3}$ m/m, only 3% above the previous one, showing good mesh convergence and reliability of the results presented.

For the valitaded structure, the fabrication process will be material extrusion, an additive manufacturing process ”in which material is selectively dispensed through a nozzle or orifice” [25]. This can be simply achieved with a 3D printer, which emphasizes the project goal of creating an easily reproducible nanosatellite.

IV. Results

The project is in progress, and the studies of the ozone layer have not yet been carried out. The team conducts tests to validate the schematics and Project Board Circuits. In these tests, the communication of the sensors with the microcontroller, system power consumption, and data acquisition rate analysis are evaluated in order to save energy.

The satellite programming is done using Real-Time Operating Systems, with task definitions that are distributed between the two processing cores of the ESP 32s. Since the project is multitasking, the use of a Real-Time Operating System makes the programming easier, since it is not necessary to perform synchronization so that one task does not crash another.

Before the stratospheric launch, the project will undergo an onboard launch on a 3 kilometer apogee rocket during the Latin American Space Challenge, in São Paulo, Tatuí city. In this launch, the functioning of the sensor system, telemetry, and power system will be analyzed.

The budget for the development of this project is one thousand and two hundred reais, including prototypes and tests to validate the systems. The launch for testing on the rocket is not included in the price as it will be done in collaboration with the team's rocket area.

V. Conclusion

The display of the components used in the Embaúba Sat makes it clear that the project is low cost and does not require very specific knowledge of electronics, which indicates that this nanosatellite can easily be constructed and applied for the important task it was designed to: atmospheric monitoring. Also, for that same reason, this project is a good start for university groups that are beginning to study satellite projects.

References

[1] Butchart, N. The Brewer-Dobson circulation. *Reviews Of Geophysics*. **52**, 157-184 (2014)

[2] Kirchhoff, V., Schuch, N., Pinheiro, D. & Harris, J. Evidence for an ozone hole perturbation at 30 south. *Atmospheric Environment*. **30**, 1481-1488 (1996)

[3] Silva, C. Efeitos secundários do buraco de ozônio antártico sobre a região sul do Brasil. Universidade Federal de Santa Maria, 2008.

[4] Pinheiro, D., Peres, L., Crespo, N., Schuch, N. & Leme, N. Influence of the Antarctic ozone hole over South of Brazil in 2010 and 2011. Annual Active Report, pp. 34-38, 2011.

[5] Nunes, M., Mariano, G. Alonso, M. Variabilidade espaço-temporal da coluna total de ozônio e sua relação com a radiação ultravioleta na América do Sul. Revista Brasileira De Geografia Fısica, 13, 2053-2073, 2020.

[6] Reis, M., Peres, L., Bittencourt, G., Pinheiro, D., Steffenel, L., Bencherif, H., Silva, R., Nunes, M., Bageston, J. Reis, G. Eventos de Influência do Buraco de Ozônio Antártico Ocorridos em 2016 Sobre o Sul do Brasil. Anuário Do Instituto De Geociências, 44, 36142, 2021.

[7] Neale, R., Lucas, R., Byrne, S., Hollestein, L., Rhodes, L., Yazar, S., Young, A., Berwick, M., Ireland, R. & Olsen, C. The effects of exposure to solar radiation on human health. *Photochemical Photobiological Sciences*. pp. 1-37 (2023)

[8] Agada, L. & Satendra, S. IMPACTS OF STRATOSPHERIC OZONE DEPLETION AND GLOBAL WARMINNG IN NORTHERN NIGERIA. *UNIZIK Journal Of Educational Research And Policy Studies*. **15**, 1-12 (2023)

[9] Correa, M., Saavedra, M., Parra, E., Ontiveros, E., Flores, J., Montiel, J., Contreras, J., Urrutia, E., Acevedo, J., Nopala, G. & Others Ultraviolet Radiation and Its Effects on Plants. (IntechOpen,2023)

[10] Ministério da Ciência, Tecnologia e Inovação. "OLIMPÍADA BRASILEIRA DE SATÉLITES MCTI". Brasil, 2023. Available: https://www.obsat.org.br/

[11] Kneip, R., Bohorquez, W., Oliveira Timotheo, G., Lara, M. & Tristão, L. ESTRUTURAÇÃO DE UMA EQUIPE UNIVERSITÁRIA PARA O DESENVOLVIMENTO DE NANOSSATÉLITES COMO PAYLOADS DE UM FOGUETE ACADÊMICO DE TRÊS QUILÔMETROS DE APOGEU.

[12] Veja. "Minissatélite vai procurar por planetas parecidos com a Terra" (May 6, 2016). Accessed: Jun. 15, 2023. Available: https://veja.abril.com.br/ciencia/minissatelite-vai-procurar-por-planetas-parecidos-com-a-terra

[13] Folha de Pernambuco. "Minissatélite vai procurar por planetas parecidos com a Terra" (Jun 28, 2022). Accessed: Jun. 15, 2023. Available: https://www.folhape.com.br/noticias/nasa-lanca-minissatelite-para-tentar-voltar-a-lua/231892/

[14] M. Rycroft and N. Crosby. Smaller Satellites: Bigger Business?: Concepts, Applications and Markets for Micro/Nanosatellites in a New Information World. Springer Science Business Media, 2013.

[15] Contente, J. and Galvão, C. STEM education and problem-solving in space science: A case study with CanSat. Education Sciences, 2, 251, 2022.

[16] Johnson, M. and Oliveri, V. A Case Study in Using the Can-Sized Satellite Platforms for Interdisciplinary Problem-Based Learning in Aeronautical and Electronic Engineering.International Journal Of Educational And Pedagogical Sciences, 17, 20-26, 2023.

[17] Cagua Colmenares, K., Vinche Hernández, A. and other. Construcción de un CanSat para la medición de temperatura, presión atmosférica y altitud. Fundación Universitaria Los Libertadores. Sede Bogotá,2023.

[18] BOSCH, "ESP32-S2 Hardware Design Guidelines", ESP32-S2, 2020.

[19] BOSCH, "BMP 280 Digital Pressure Sensor", BMP 280, 2018.

[20] Handson Techonology, "AHT10 High-Precision Digital Temperature Humidity Sensor Module", AHT10.

[21] Winsen, "Air Quality Gas Sensor", MQ135, 2015.

[22] Hwsensor, "MQ131 Semiconductor Sensor for Ozone", MQ131.

[23] InvenSense Icnc., "MPU-6000 and MPU-6050 Register Map and Description Revision 4.2", MPU 6050, 2013.

[24] u-blox, "NEO-6", NEO-6M, 2011.

[25] Standard Guidelines for Design for Additive Manufacturing, ISO/ASTM 52910:2017, ISO/ASTM International, 2017.

[26] Ajay Harish. "What is Convergence in Finite Element Analysis?" (Jun 5, 2023). Accessed: Jun. 16, 2023. Available: https://www.simscale.com/blog/convergence-finite-element-analysis/

[27] Banjanin, B., Vladic, G., Pál, M., Balos, S., Dramicanin, M., Rackov, M. & Knezevic, I. Consistency analysis of mechanical properties of elements produced by FDM additive manufacturing technology. Matéria (Rio De Janeiro)23 (2018)