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NANOSATC-BR2, 2 UNIT CUBESAT, POWER ANALYSIS, SOLAR FLUX PREDICTION, DESIGN AND 3D PRINTING OF THE FLIGHT MODEL FROM THE UFSM & INPE'S NANOSATC-BR, CUBESAT DEVELOPMENT PROGRAM

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In order to space missions work properly, it is necessary to previously simulate its behavior in space. The main purpose of this work is to predict the orbit behavior of a 2 Unit CubeSat by simulating its flight using a MATLAB code. With this starting point, it is possible to perform a Power Analysis for the satellite and analyze the incident thermal radiation on it for a future Thermal Analysis. In order to help students better understand the CubeSat model and its components, the flight model was designed and 3D printed. The NANOSATC-BR2 is the second nanosatellite from the program NANOSATC-BR, Development of CubeSats Program.

INTRODUCTION

The NANOSATC-BR, CubeSats Development Program has two nanosatellites at the moment, both of them being CubeSats. The first nanosatellite of the Program is the NANOSATC-BR1 (abbreviated as NCBR1), an 1U CubeSat that fulfills all the requirements to fit in the CubeSat category. This is a scientific, technologic and academic mission, whose objective is to acquire data via a magnetometer from the Earth`s magnetic field – specially from South American Mag-

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netic Anomaly (SAMA) region, and verify the survivability in space environment of two integrated circuits developed in Brazil[1]. One of the circuits was designed by the Santa Maria Design House (SMDH) and the other by the Federal University of Rio Grande do Sul (UFRGS). NCBR1 is in space orbit and it is transmitting data from its payloads for more than three years, since June-2014.

The second satellite of the Program is the NANOSATC-BR2 (abbreviated as NCBR2), which is a 2U CubeSat, and one of its most important scientific objective is to analyze the dynamics of the Ionosphere plasma using a Langmuir Probe. Regarding the technologic missions, one of them consists in validating an attitude determination system – the very first Brazilian one – with triple redundancy.

In order to make the whole Project of the NANOSATC-BR2 work correctly, it is necessary to make a competent Power Analysis that allows scientists and engineers to determine operation time for each component in the satellite, and therefore enable its operational capability. To achieve this, it is necessary to obtain data from both Power Generation and Power Consumption. For this purpose, a program was developed to obtain solar power generation. This program was also applied to determine the thermal radiation on each side of the satellite, which was found with the objective of facilitating a future Thermal Analysis considering Thermal Load.

The Mechanical Modeling performed using the CAD software Solidworks had the objective of organizing key components for the good 3D Printing of the CubeSat, such as the solar cells, the Langmuir Probe and the antennas. The 3D printed model helps the students understand components positioning and the relation between them, facilitating further simulations.

3D MODEL

Designing with CAD

The nanosatellites are considered a secondary payload in the launch vehicle, therefore, they shall be located in such a way that do not harm the primary payload. Because of that, scientists and engineers of California Polytechnic State University developed the P-POD (Poly Picosatellite Orbit Deployer), that is a structure to engage all the nanosatellites on the mission, creating a reliable connection between the launch vehicle and the nanosatellites. The connection between the CubeSat and the P-POD is provided through rail that fits in the structure, Figure 1.

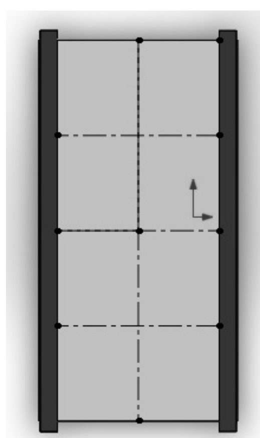

Figure 1. Initial Assembly for the Structure of a 2U CubeSat, showing 2 rails in the corners of the CubeSat Structure.

The height of a 2 Unit CubeSat is 200 mm and, since the rails are always designed longer than the structure itself in reality, normally they have a length of 227 mm, as specified by the Cal Poly - CubeSat Design Specification [2].

The next step for the Mechanical Modeling was attach to the solar cells to the structure, which were designed following the Innovative Solutions In Space (ISIS - Delft) standard design, as the Figure 2 shows.

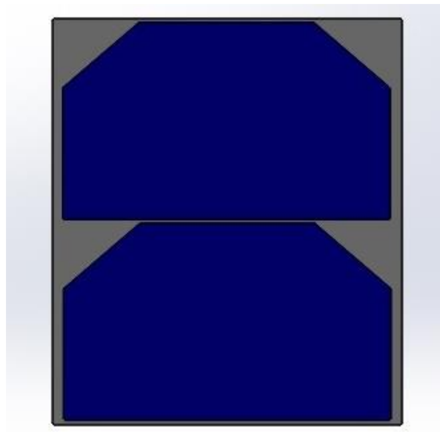

Figure 2: NANOSATC-BR2 Solar Cell Design

To conclude the design of NCBR2, it was necessary to add the antennas and the external payloads (both of them already deployed - as if they were operational in space). The Langmuir Probe, which is a key instrument for the success of the Technological Mission, was designed according to Figure 3.

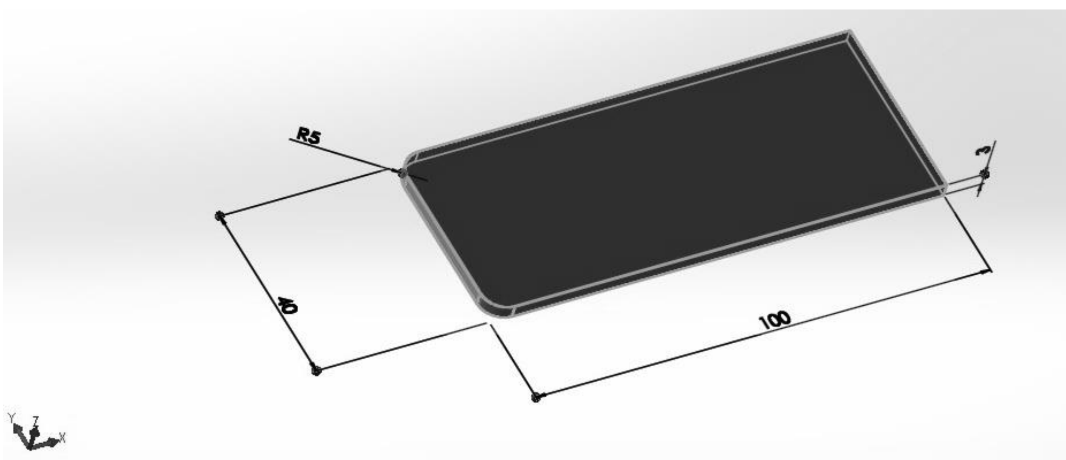

Figure. 3: Dimensions used for the Design of the NCBR2's Langmuir Probe

Several possibilities to position the Langmuir Probe were discussed with Engineers from the INPE/MCTIC, and the chosen conception included the Langmuir Probe on the sides of NCBR2. Besides that, instead of a rectangular design, the real Langmuir Probe will have two fillets, with a radius of 5 mm each on the corners. The Final Assembly of the NCBR2 CAD Model is represented by Figure 4, with the antennas (in yellow) already deployed.

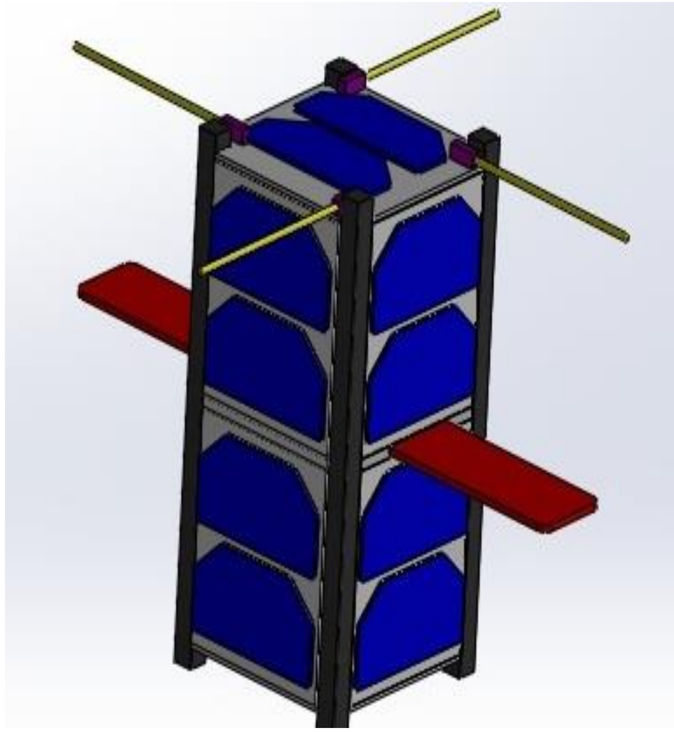

Figure. 4: NCBR2 CAD Model in Solid-works environment

3D Printing

The 3D Printer used for this work is a Hyrel Hydra Model, which is able to complete its task by using a G Code that can guide the extruder through its path during the 3D Printing. It is showed in Figure 5.

Figure 5: The LACESM/CT-UFSM's 3D Printer "Hyrel Hydra" used

An open source code, adapted by Hyrel 3D Corporation, is used to give commands and define the printing process. The Figure 6 shows the NANOSATC-BR2's Flight Model completed in exposition.

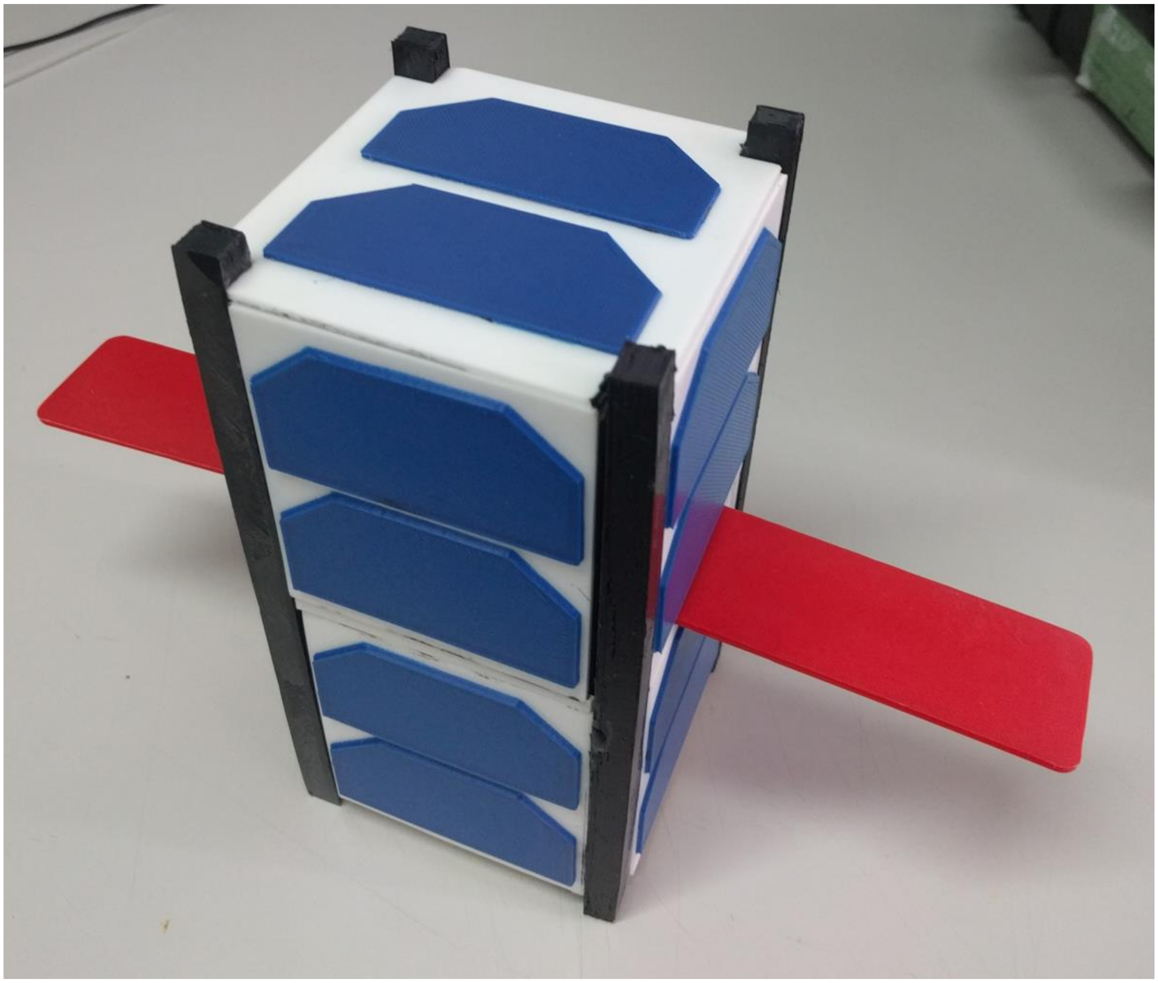

Figure 6: NANOSATC-BR2'S Flight Model Exposed

POWER ANALYSIS AND THERMAL LOAD

Simulation

Accomplishment of the Power Balance was necessary to determine the best operation range for the NCBR2. So, the power consumption for each component in the satellite and power generation by the solar cells were obtained. This data allows the regulation of the operational cycle for each payload that results in a positive energy balance.

The NCBR2 has 6 faces, two of them (bottom and top) containing two solar cells attached to each solar panel, while the other four (on the sides) contain 4 solar cells attached to the solar panels. For the correct analysis of the generation in each face, it is necessary to consider the relation between each area vector and the solar vector as a function of time, due to the solar flux energy per unit of area, and the cosine law (efficiency due the angle of solar incidence)[3], Figure 7.

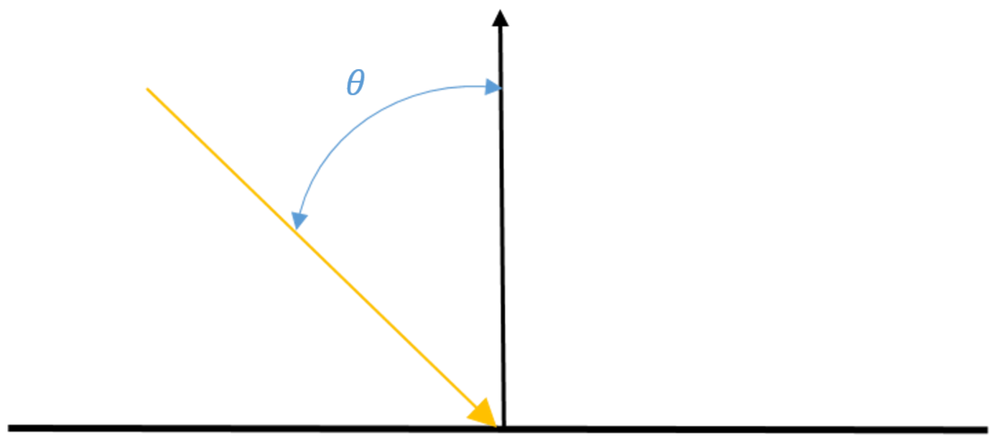

Figure 7. Incidence Angle (θ) between Area Vector (black) and Sun Vector (yellow)

In order to simulate the flight dynamics of the spacecraft, it was considered both translational motion and rotational motion as a function of time. The satellite has not been launched yet and to make a plausible orbit assumption, the NCBR1 orbits parameters were used. This can be used since the desirable orbit for NCBR2 is similar to the one used by NCBR1 due to its characteristics such as long reentry time, solar time exposure and ground station cover time, Figure 8.

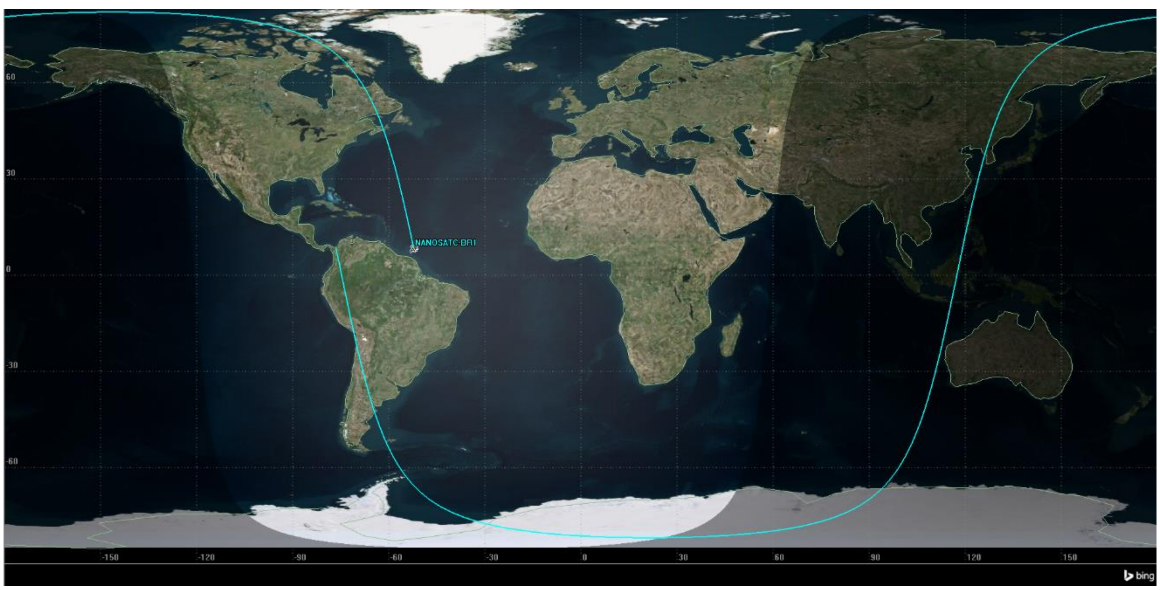

Figura 8. NANOSATCBR-1 orbit generated in software STK

The input Keplerian parameters to propagate the satellite - translational motion - were obtained from the Two Line Elements (TLE), provided by the North American Aerospace Defense Command (NORAD) for the NCBR1. With the initial conditions, it is possible to describe the satellite position in orbit in many reference systems, such as Earth Centered Inertial (ECI), Latitude Longitude Altitude (LLA), Spherical Celestial Coordinates and many others[4], although the desired variable is the true anomaly, used to analyze periods of eclipse. Perturbative forces such as atmospheric drag, solar pressure and third bodies were not considered.

Periods of eclipse, Figure 9, were found implementing a method based on orbit elements and sun position[5], returning the angle from the argument of perigee where eclipses starts and ends (true anomaly). Only the umbra cases were simulated, since penumbra can be ignored (occurs only during a few seconds) and antumbra does not occur.

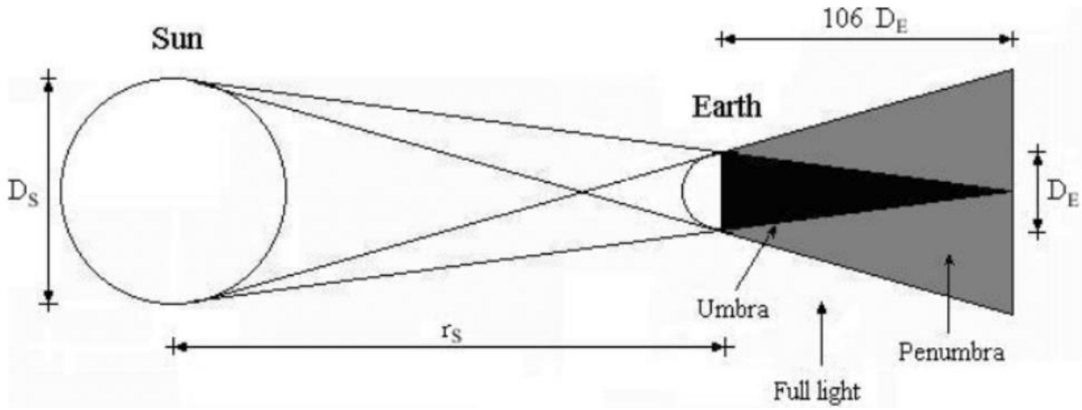

Figure 9. Umbra, Penumbra and Solar Incidence[5]

With the objective of simulating the satellite rotational motion, arbitrary initial conditions were used (angular velocity and attitude) since this parameters for NCBR1 are unknown. In order to use the data acquired from the sun vector properly (obtained knowing the position of the Sun relative to Earth), it is necessary to use all data in the same reference system. Because of that, the Earth Centered Inertial (ECI) was established as the main coordinate reference frame. For obtaining the vectors in the main ECI, a rotation matrix was used.

With the whole data in the ECI frame, solar flux in each face of the satellite could be found. Furthermore, Albedo and infrared radiation from de Earth were estimated in each face of the satellite, in order to analyze thermal load and its influence. Cold and Hot cases were generated separately so each can be studied individually. Hot Case occurs when radiation emission (Solar, infrared and albedo emission) is at maximum value, while Cold Case occurs when radiations emission it at minimum.

With eclipse and Sun position data, it is possible to estimate energy generation within the NANOSATC-BR2. Due to the fact that the angular velocities are unknown for the satellite, it is necessary to simulate some cases with different conditions. The best case for power generation happens when the same face points toward the sun position during the whole orbit period[6]. Unless the satellite has an attitude control system that makes this possible, this is not a likely condition. In this way, the framework proposed was used to simulate the satellite in more realistic scenarios. Thus, small angular velocity was assumed for attitude simulation. High angular velocities were neglected, since the satellite has a detumbling system to mitigate it (this system is originally designed to avoid problems with the communication system).

The solar cells efficiency was considered as 27.7% (Beginning of Life), and the conversions efficiency as 93%[7].

Power Consumption

The Power Consumption can be analyzed based on the energy used by each component and the period that these components will be active in orbit. For the NANOSATC-BR2 components, energy consumption is listed in Table 1.

Table 1. Power Consumption for NANOSATC-BR2

Components	Maximum Consumption	Duty Cycle	Consumption with duty cycle
Electric Power Subsystem	0,249 W	100 %	0,249 W
Board Computer	0,380 W	100 %	0,380 W
Receiver (*TRXUV RX)*	0,237 W	100 %	0,237 W
Transmitter (*TRXUV TX)*	0,787 W	4,2 %	0,033 W
Antenna system	0,040 W	100 %	0,040 W
2 Magnetometers (XEN 1210)	0,031 W	100 %	0,031 W
FPGA	0,049 W	100 %	0,049 W
2 SMDH ICs	0,030 W	100 %	0,030 W
Langmuir Probe	0,930 W	100 %	0,930 W
Attitude Determination System SDATF	0,271 W	100 %	0,271 W
TOTAL			**2,25 W**

Electric Power Subsystem interconnects solar cells with power supply buses, also conditioning – through converters - and storing energy in Li-Ion batteries[8]. Board Computer manages information and Ground Station requirements. Receiver, Transmitter and Antenna System are used to establish space to ground link communication. These components are the vital systems in the satellite.

The other components are the Payload contributing for the scientific and technological missions. They operate acquiring data, testing and validating circuits developed in partnership with the Program.

Maximum Consumption represents how much energy is necessary to operate all the payload and components 100% of the time. Duty Cycle represents the percent of time it will be active. Duty Cycle for NCBR2 Transmitter is just 4.2% since it is just operational during communication initiated by the Ground Station - during 15 orbits, just 2 covers the ground station.

Power Balance and Thermal Radiation

Considering different orbits and angular velocities, the power generation was estimated resulting in some values presented in Table 2.

Table 2. Power Generation

Angular velocity X axis (rad/s)	Angular velocity Y axis (rad/s)	Angular velocity Z axis (rad/s)	Mean Power Generated (W)
0	0	0	2.750
0.087	0.087	0.087	2.296
0.1221	0.035	0.070	2.233
0.2618	0.2618	0.2618	2.294
1.047	1.047	1.047	2.294
1.57	1.57	1.57	2.294

These values represent the average value for the whole orbit period, considering the total energy generated by the six faces. The first case is in line 1, where angular velocity is zero, and has one face pointed towards the sun with incidence angle almost zero. This is one of the best configurations for energy generation, however is heavily unlikely to happen.

The generation in each face was found. Figure 10 represents the values found for the low angular velocity (for better visualization).

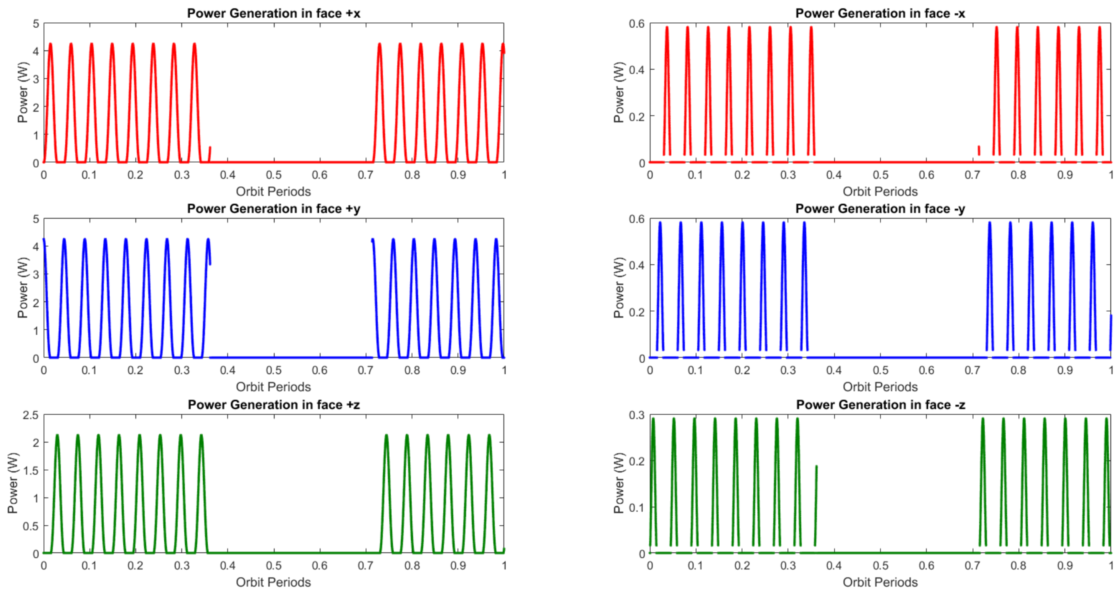

Figure 10. Power Generation in each face

However, the value of interest is the power generated by all solar cells combined. The graph representing this is found in Figure 11 (sum of energy generated in each face), where the notable generation gap occurs during eclipse.

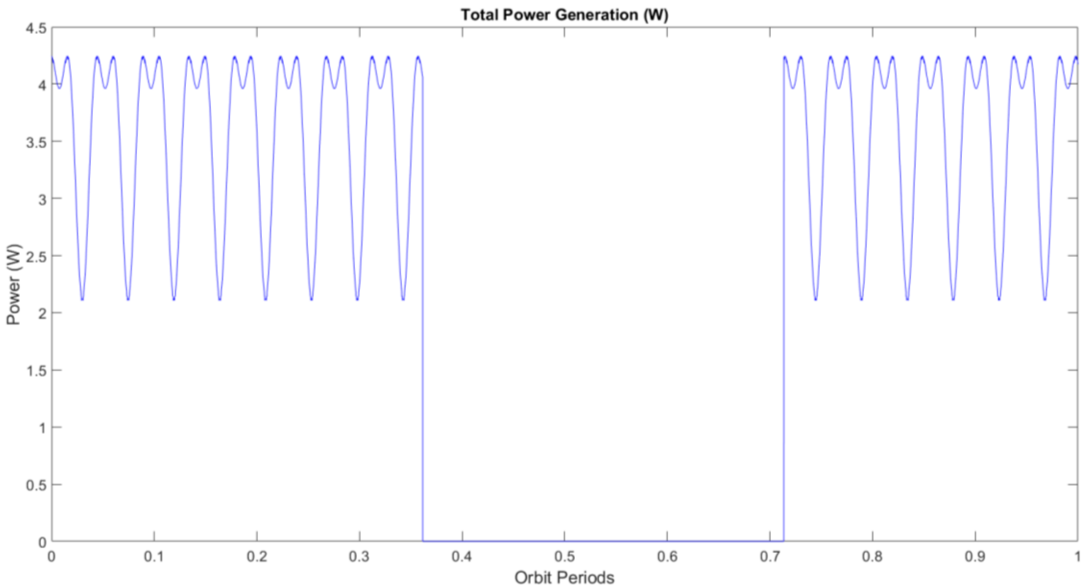

Figure 11. Total Power Generation as a function of time

Considering the average value for Power Generation and the Power Consumption, it is possible to generate a Power Balance. In order to achieve a positive Power Balance, operational cycle for the payload are determined, Table 3.

Table 3. Power Balance

Components	Maximum Consumption	Duty Cycle	Consumption with duty cycle
Electric Power Subsystem	0,249 W	100 %	0,249 W
Board Computer	0,380 W	100 %	0,380 W
Receptor (*TRXUV RX)*	0,237 W	100 %	0,237 W
Transmitter (*TRXUV TX)*	0,787 W	4,2 %	0,033 W
Antenna System	0,040 W	100 %	0,040 W
2 Magnetometers (XEN 1210)	0,031 W	100 %	0,031 W
FPGA	0,049 W	100 %	0,049 W
2 SMDH ICs	0,030 W	100 %	0,030 W
Langmuir Probe	0,800 W	73,4 %	0,683 W
Attitude Determination System SDATF	0,271 W	100 %	0,271 W
TOTAL			**2,003 W**

Although the generation is around 2.29 W, it is important to consider around 12.5%[3] of generation value to supply the batteries systems and assure the secure voltage levels.

Thermal radiation were calculated resulting in some mean values for each case: Hot case during insolation, Hot case during eclipse, Cold case during insolation, Cold case during eclipse.

Although these values are found in each face as a function of time, for the simplified Thermal Analysis it is used a mean value considering homogenous incidence (the total radiation the satellite faces distributed equally in all the faces). Table 4 shows the results for Hot Case and Table 5 for the Cold Case.

Table 4. Thermal Radiation Hot Case

Angular velocity X axis (rad/s)	Angular velocity Y axis (rad/s)	Angular velocity Z axis (rad/s)	Mean Heat Flux Solar Incidence (W/m^2)	Mean Heat Flux Eclipse (W/m^2)
0	0	0	454.03	54.24
0.087	0.087	0.087	518.52	55.91
0.1221	0.035	0.070	523.3	55.91
0.2618	0.2618	0.2618	518.31	55.92
0.5235	0.5235	0.5235	518.36	55.92
1.047	1.047	1.047	518.35	55.91
1.57	1.57	1.57	518.33	55.92

Table 5. Thermal Radiation Cold Case

Angular velocity X axis (rad/s)	Angular velocity Y axis (rad/s)	Angular velocity Z axis (rad/s)	Mean Heat Flux Solar Incidence (W/m^2)	Mean Heat Flux Eclipse (W/m^2)
0	0	0	395.41	26.32
0.087	0.087	0.087	452.24	27.13
0.1221	0.035	0.070	457.21	27.13
0.2618	0.2618	0.2618	452.02	27.13
0.5235	0.5235	0.5235	452.09	27.13
1.047	1.047	1.047	452.09	27.13
1.57	1.57	1.57	452.07	27.13

Values for instantaneous thermal radiation in each face, as a function of time, can be generated, in case of need for further Simulations.

CONCLUSION

Through the model simulated in MATLAB, it was possible to predict a more precise energy generation and, thus, evaluate the best duty cycle for the components and payload in the satellite. The results show that it is possible to the general components operate at full time, while the

Langmuir Probe must operate around 73% of the time. It represents operation both during solar exposure and eclipse periods.

Thermal Radiation results enable more precise studies in Thermal Simulations and to understand Thermal Load, since data for each condition is generated. Furthermore, each face can be analyzed individually, as a function of time, for a more complete thermal gradient analysis.

The NANOSATC-BR2 Flight Model is currently 3D Printed, helping students from Brazil better understand the satellite, it will be exposed in scientific events worldwide. It will be in permanent exposition at the Southern Regional Space Research Center of the National Institute for Space Research (INPE-CRS/COCRE/MCTIC), promoting the NANOSATC-BR, CubeSats Development Program during visits and scientific expositions.

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