International Academy of Astronautics
2nd IAA Latin American Symposium on Small Satellites:
Advanced Technologies and Distributed Systems Conference
Buenos Aires, Argentina, 11-15 November, 2019

IAA-XX-14/15-XX-XX

The launch of NANOSATC-BR2 and the making up of the first Brazilian INPE-UFSM CubeSats constellation

Nelson Jorge Schuch[(1)], Rodrigo Passos Marques[(1)], Fernando Sobroza Pedroso[(1)], Thales Ramos Mânica[(1)], Leonardo Zavareze da Costa[(1)], Jose Valentin Bageston[(1)], Juliano Moro[(1,2)], Otávio Santos Cupertino Durão[(3)], Marlos Rockenbach da Silva[(3)], Odim Mendes[(3)], Fátima Mattiello-Francisco[(3)], Danilo Almeida Pallamin[(3)], Andrei Piccinini Legg[(4)], André Luís da Silva[(4)], João Baptista dos Santos Martins[(4)] and Eduardo Escobar Bürger[(4)]

[(1)]*Southern Regional Space Research Center – CRCRS/COCRE/INPE-MCTIC, in collaboration with the Santa Maria Space Science Laboratory - LACESM/CT-UFSM, Santa Maria, RS, Brazil, njschuch@gmail.com, rodrigo_marques198@hotmail.com, fespedroso.rs@gmail.com, thalesrmanica@gmail.com, leonardozavareze@gmail.com, bageston@gmail.com, juliano.moro@inpe.br*
[(2)]*State Key Laboratory of Space Weather, Beijing, China*
[(3)]*National Institute for Space Research (INPE/MCTIC), São José dos Campos - SP, Brazil. otavio.durao@inpe.br, marlos.silva@inpe.br, odim.mendes@inpe.br, fatima.mattiello@inpe.br, danilopallamin@gmail.com*
[(4)]*Federal University of Santa Maria - UFSM, Technology Center, Professors, Santa Maria - RS, Brazil. andrei.legg@gmail.com, andre.silva@ufsm.br, batista@inf.ufsm.br, eduardoebrg@gmail.com*

Keywords: *cubesats, capacity building, nanosatellites constellation*

Abstract

The work discusses both the launch of NANOSATC-BR2 and the making up of the first Brazilian INPE-UFSM CubeSats constellation. Besides that, the work also brings information regarding the NANOSATC-BR, CubeSats Development Program, its Capacity Building Program (CBP), and the Program's present and future. Currently, the NANOSATC-BR Program consists of two CubeSats: NANOSATC-BR1 or NCBR1, (1U) & NANOSATC-BR2 or NCBR2, (2U). The NANOSATC-BR1 was launched as a tertiary payload by ISIS in the event ISILAUNCH-07, by a DNEPR launcher, at the Yasny Launching Base, in the Donbarovsky Region, Russia, on June 19th, 2014. The launch of NANOSATC-BR2 is already contracted, and it will be launched in the first quarter of 2020, from a Russian launching base yet to be determined. The INPE-UFSM's CBP with activities in space science, engineering and computer sciences, has the involvement of UFSM's undergraduate students, graduate students from other institutions, and the participation of INPE/MCTIC's graduate students, which develop activities in the Onboard Data Handling (OBDH) subsystem, Verification, Validation and Integration Testing for the NANOSATC-BR2, and the development of space technologies as well. The two NANOSATC-BR 1 & 2 Projects Ground Stations (GS) can operate with VHF/UHF and S bands antennas and are entirely operated by students. This paper also focuses on making up of the first Brazilian INPE-UFSM CubeSats constellation, with the development of NANOSATC-BR 3 & 4, in a partnership with the UFSM's Aerospace Engineering Course. The development concepts that guided the Program were to: i) monitor and determine the effects, in real-time, of the Earth's Magnetic field, the Geospace, and the Ionosphere; ii) study the disturbances at the Earth's Magnetosphere over the South America Territory and the energetic particle precipitation in the South American Magnetic Anomaly (SAMA). As payloads NCBR2: i) an attitude determination subsystem, fully developed in Brazil, under testing and integration with the NANOSATC-BR2 Engineering Model (EM) platform and the on-board data handling software - OBDH; ii) a Langmuir Probe also under integration and testing; iii) one board with three experiments - Field Programmable Gate Array (FPGA), Magnetometer - XEN-1210 - three-axis magnetometer with a resolution of 15nT from the Dutch company XI – Xensor Integration (www.xensor.nl) and an Integrated Circuit (IC), already manufactured and going through initial testing before integration, and iv) an amateur radio communication experiment, from the Radio Amateur Satellite Corporation - Brazil (AMSAT-Br) and the Brazilian League of Amateur Radio Emission (LABRE). With the success of the NANOSATC-BR CubeSats constellation, it is expected an increase in the Brazilian Government Agencies support, with more investments for the development of Space Technology and new Universities & Institutes initiatives. The Program has received financial support from the Brazilian Space Agency (AEB) and the Ministry of Science, Technology, Innovation, and Communications - MCTIC.

1. Introduction

The Brazilian INPE-UFSM NANOSATC-BR CubeSat Program consists of a Capacity Building Integrated Program on space science, engineering and computer sciences for the development of space technologies using CubeSat satellites. It started with the first Brazilian Scientific Nanosatellite, the NANOSATC-BR1. The INPE-UFSM's cooperation is basically between the Southern Regional Space Research Center (CRCRS/COCRE/INPE - MCTIC), from the Brazilian National Institute for Space Research - INPE/MCTIC, with the Santa Maria Space Science Laboratory - LACESM/CT-UFSM. Other relevant institutions are: the Santa Maria Design House (SMDH), a startup focused on developing electronic circuits for aerospace applications, and the Graduate Program in Microelectronics from the Federal University of Rio Grande do Sul - UFRGS. The Capacity Building Program was conceived at the Southern Regional Center of INPE, where acts the Program's General Coordinator and Manager. It has the technical support from the Mission's General Coordinator for Engineering and Space Technology at INPE's Headquarter (HQ), in São José dos Campos, São Paulo, with the involvement of undergraduate students from the Federal University of Santa Maria – UFSM and graduate students from INPE/MCTIC and UFRGS.

This paper is a follow-up paper from previous ones that have already been presented at IAA's International Workshops. It explains the Program's institutional arrangement and the technical characteristics of the satellites and their missions, as well as the Program's goals for the future in terms of payload development for the very first Brazilian CubeSat constellation.

The Brazilian INPE-UFSM NANOSATC-BR CubeSat Program has support from The Brazilian Space Agency (AEB).

2. NANOSATC-BR – Capacity Building

According to information obtained in Costa et al. (2010), the NANOSATC-BR, CubeSats Development Program, was implemented in 2006 as a highly specialized research initiative focused on aerospace technology, initially with the participation of a student from the Mechanical Engineering undergraduate course at UFSM. Throughout the development of the Program, new students from several Engineering and Physics courses at UFSM became involved in aerospace research since new perspectives and research opportunities emerged in the areas of Physics, Mechanical, Electrical, and Production (Schuch, et al., 2014).

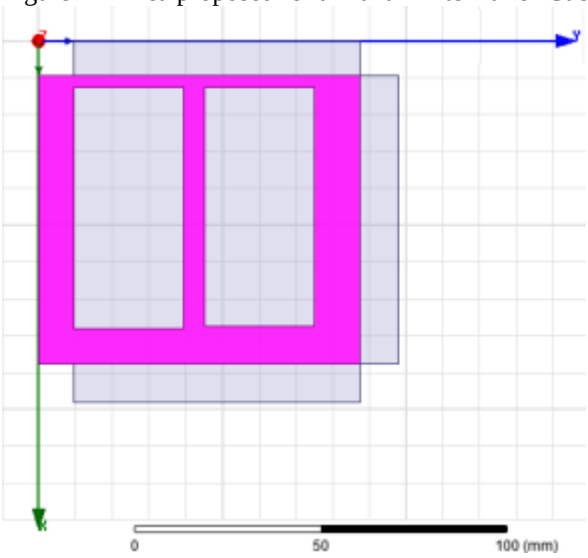
2.1 NANOSATC-BR – Engineering Aspects

With the beginning of the Aerospace Engineering undergraduate course at the Federal University of Santa Maria in 2015, several students had the chance to learn more about satellite technology and get involved directly in the NANOSATC-BR Project.

Currently, researches involving the following areas: structural and thermal analysis, attitude and control, power balance, CAD Design, Ground Station validation for operation in LEOP – Launch and Early Orbit Phase and Antenna development for small satellites. The later was the main theme of a final undergraduate thesis for the Electrical Engineering course, where the main objective was to propose and to simulate the behavior of a planar antenna for CubeSat Missions. In order to perform this task, the software Ansoft HFSS v13.0 was used.

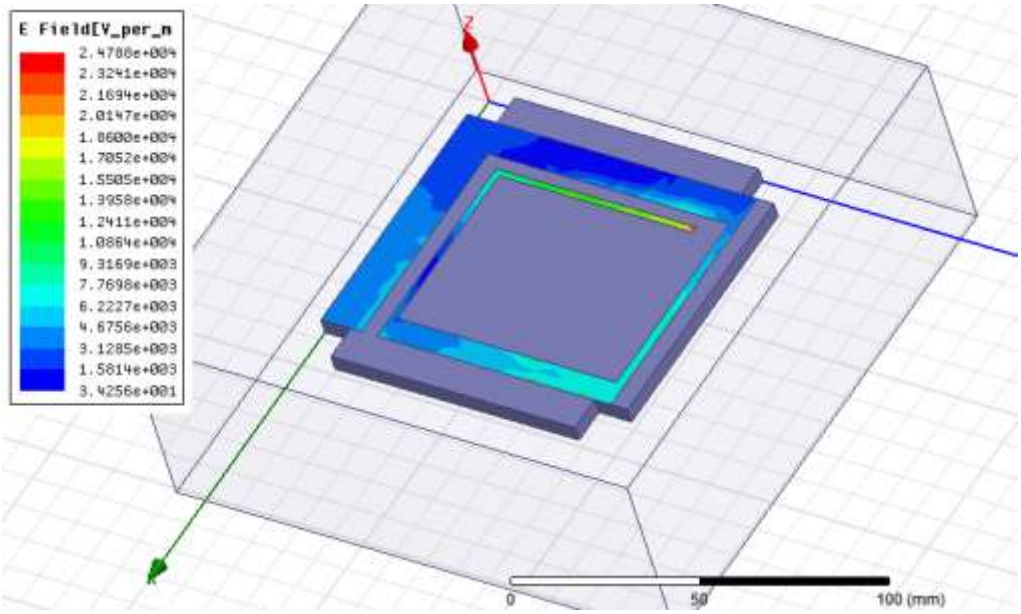
The start point for the analysis performed is shown in Figure 1. In pink, it is possible to observe the total area proposed for the planar antenna concept (40 x 80 mm):

Figure 1 – Area proposed for a Planar Antenna for CubeSats.



Small satellite missions may use the planar antenna model mainly because of three reasons: lower cost, lighter structure, and reliability. Since the planar antenna consists of a solid plate that emits electric field, its usage avoids the existence of deployment mechanisms, which are currently a common source of failures in CubeSat missions. In the future, experiments involving this kind of antenna may be used in the NANOSATC-BR CubeSats. The best results obtained so far for the planar antenna concept is illustrated in Figure 2. In blue, it is possible to observe the intensity of the electric field:

Figure 2 – Best results obtained up to now for the Planar Antenna concept.



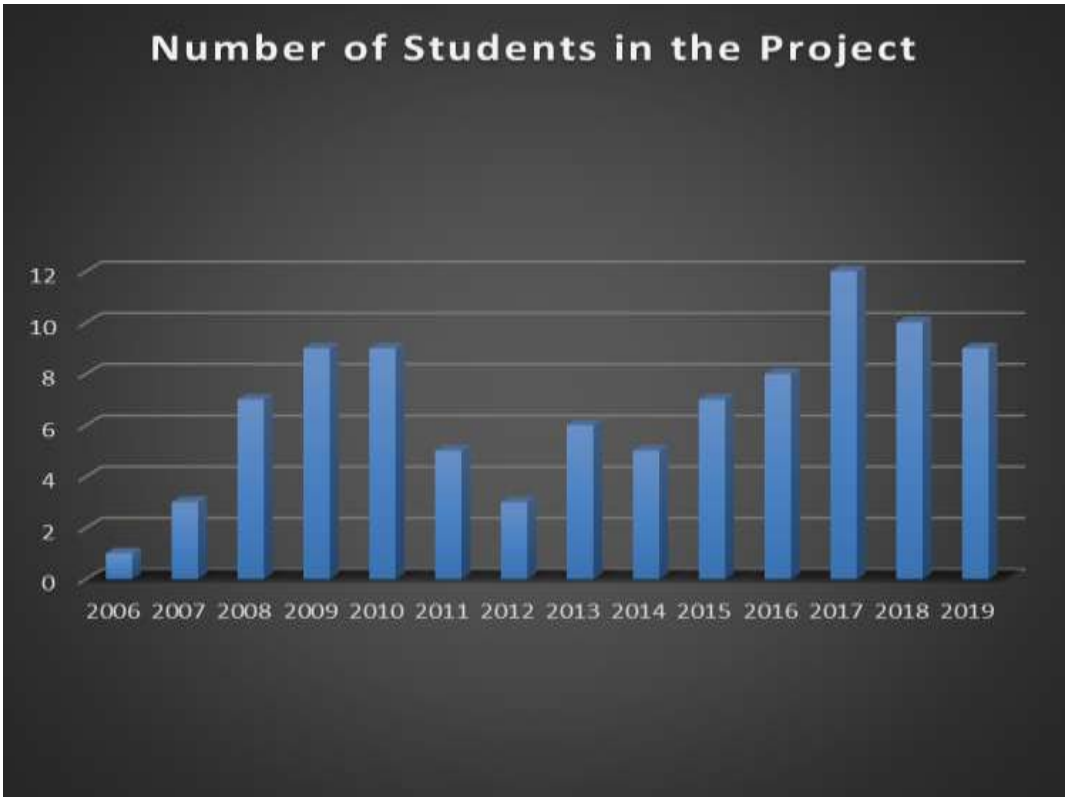
2.2 Number of Students in the Program

The higher number of scholarships, funded by the Brazilian Government, and the greater dissemination of the Program and its Projects, since its creation, in 2006, link to the increasing student number. Currently, the main objective of the NANOSATC-BR Program is the Capacity Building, which happens through the training of undergraduate students in their respective areas in UFSM Aerospace, Electrical, and Mechanical Engineering. The number of students directly involved with the Program is shown in Figure 3. An essential quality of this Program is the close participation of students, teachers, and researchers for the development of activities focused on excellence and results.

During the analyzed period, 34 (thirty-four) students with a technical background and from various undergraduate courses participated directly in researches related to satellite technology in the Program. The analysis took into consideration the following documents: technical reports, final undergraduate theses, and internship reports, with the study and knowledge, acquired directly through the NANOSATC-BR Program. With the recent conclusion of two final undergraduate theses from the Electrical Engineering and Aerospace Engineering courses in August 2019,developments related to antenna for CubeSats and attitude and control for flexible appendages of satellites were finished.

Throughout the development of the Program, more than 70 (seventy) people contributed directly to the NANOSATC-BR Projects, including researchers and teachers from various institutions in Brazil. It is possible to observe an increase in the number of students participating in the Projects since the creation of the Aerospace Engineering Course, in 2015, according to Figure 3:

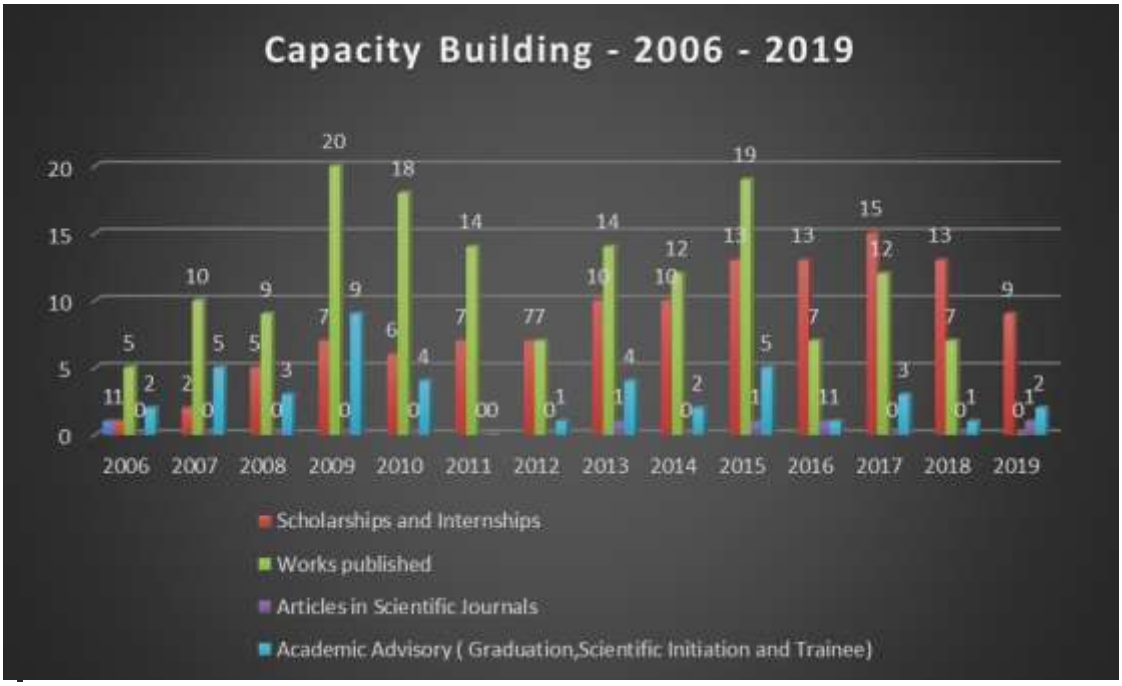
Figure 3 - Number of students in the Program NANOSATC-BR: 2006 - 2019.



2.3 Works published and participation in Congresses

The academic work produced by the students includes good engineering practices and techniques, with several publications in national and international congresses as well as participation in workshops, all directly related to the Program's activities. Soon, it is likely to observe an increase in the number of scientific articles and publications in events related to space technology since the NANOSATC-BR2 launch will occur in the first quarter of 2020. Right after the launch of the satellite, it is expected a more significant amount of scientific data and essential details from the spacecraft's operation in space obtained through telemetry. This availability of more information creates the perfect conditions for more publications and an increase in the number of works related to the NANOSATC-BR Program. In 2015, a similar situation occurred, with an increase in activities that happened, after the launch of the NANOSATC-BR1 in 2014. Figure 4 presents the current statistics.

Figure 4 - Technical, scientific production and human resources training in the period: 2006 to 2019.



* The number of scholarships was higher than the number of students in some periods due to the termination of the contract and the beginning of a new scholarship for the same student in that specific year.

The students' active participation in the Program and its multiple Projects has improved and qualified significantly the curriculum of these professionals, also motivating them for new initiatives. Some of these students were hired by aerospace companies such as AEL Systems and Embraer, while others had the chance to perform important technical activities as interns in companies and research centers around the world such as DLR (Germany), NASA – Goddard Space Flight Center (USA), SSAU – Samara State Aerospace University (Russia) and ISIS – Innovative Solutions In Space (Netherlands).

This way, the Program contributes to the development of the Brazilian industry by adding technology and scientific capacity to Brazilian institutions through qualified human resources, making them able to innovate and perform high-level research in new technological and scientific areas.

In addition, the Brazilian Government has recently exposed an increasing interest in investments related to nanosatellite projects due to their low cost and fast development. This may open a window of opportunity for CubeSat Projects, such as the NANOSATC-BR, CubeSats Development Program.

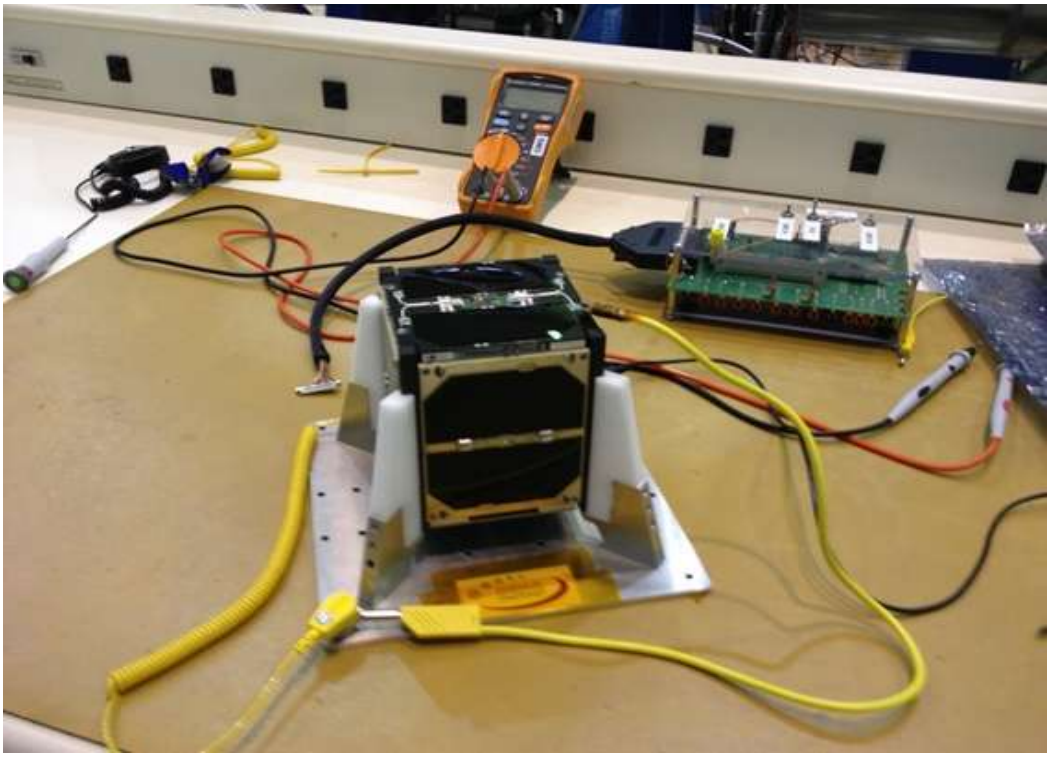
3. NANOSATC-BR Missions

The Program already consists of two CubeSats, the NANOSATC-BR1 and NANOSATC-BR2. It exists the possibility of launching two other CubeSats in the next ten years and operate them in space for at least six months each. These new missions aim to study and monitor the Geospace and Space Weather as well as its relationship with the solar cycle and the Earth's atmosphere.

3.1 NANOSATC-BR1

The first Brazilian CubeSat scientific satellite, the NANOSATC-BR1, is a 10x10x11.3 cm cube, weighing 0,965 kg, as shown in Figure 5:

Figure 5 – NANOSATC-BR1 Flight Model.



Its' name and up and down frequencies link were determined by the International Amateur Radio Union – IARU, in 2011. The NANOSATC-BR1's Engineering Model Platform (EM), the Flight Model Platform (FM), the Ground Support Equipment and the Ground Station for the INPE-UFSM's NANOSATC-BR1 mission and equipment were provided, integrated and tested by ISIS from Delft, The Netherlands.

The NANOSATC-BR1's Engineering Model (EM) and Flight Model (FM) platforms were delivered by ISIS at LIT/INPE-MCTIC, in São José dos Campos, SP, in 2012.

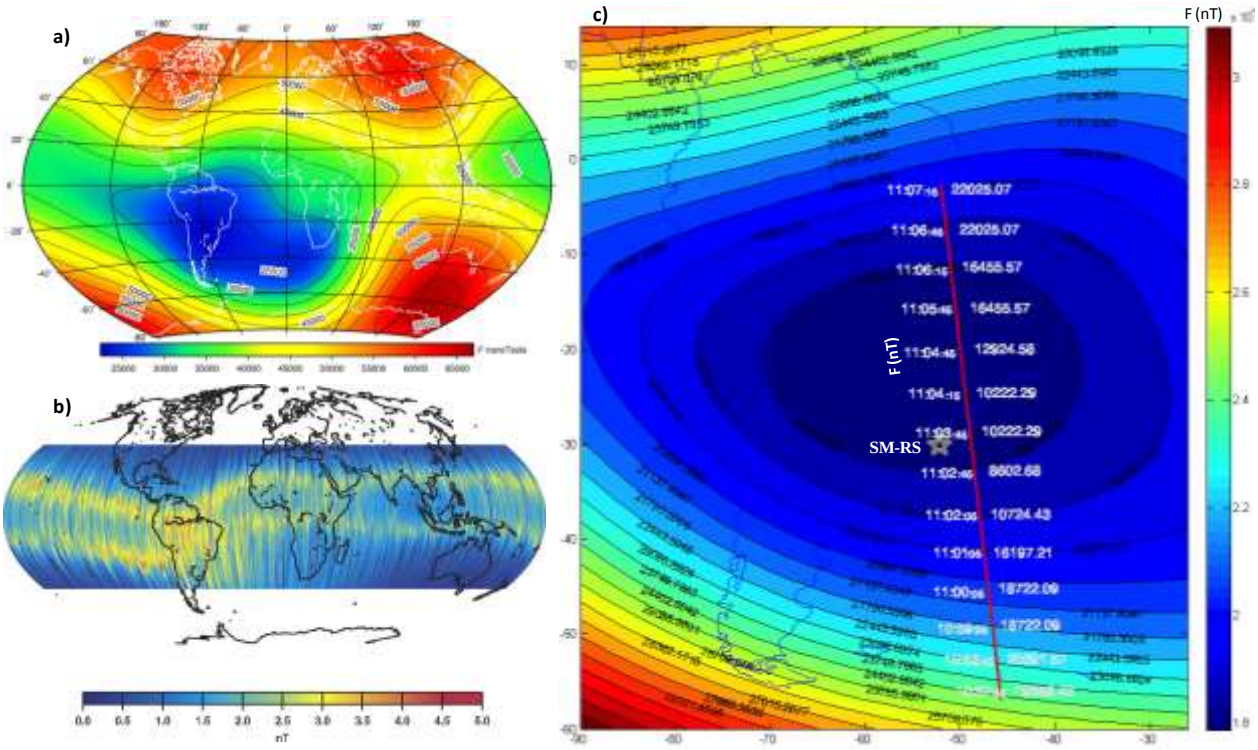
The accommodation of the payloads in the circuit board: Magnetometer, ICs, and FPGA, has been solved in cooperation between INPE, ISIS, UFRGS, and the company SMDH-UFSM.

The development concept of the NANOSATC-BR1 was to: i) monitor, in real-time, the Geospace, the disturbances at the Earth's Magnetosphere over the Brazilian Territory, and ii) the determination of their effects on regions such as the SAMA and the Equatorial Electrojet (EEJ). Its scientific mission consisted of:

- Earth Magnetic Field intensity measurements;
- SAMA and EEJ;
- XEN-1210 is a three-axis magnetometer with a resolution of 15nT from the Dutch company XI - Xensor Integration (www.xensor.nl);
- Only one payload circuit board with scientific and technological payloads.

The general results regarding the total Geomagnetic Field as estimated by models (including implication for the EEJ), and from the NANOSATC-BR1 magnetic measurements in the SAMA region are presented in Figure 6. Figure 6 (a) presents the IGRF (12th generation) model prediction for the Earth's total magnetic field for 2015, while in Figure 6 (b) is presented the distribution and amplitude variation (in nano Tesla - nT) of the high plasma density regions of the Appleton Anomaly, resulted from the correction for the magnetic field strength, where it was used magnetometer and CHAMP satellite data, and omitting this correction it will cause systematic errors in the EEJ determination (Lühr et al., 2014). Lastly, and most importantly, Figure 6 (c) presents the scientific results from the NANOSATC-BR1, as show the values near the red line (representing the path of the satellite) crossing the SAMA region at an altitude of around 600 km from South to North. This result was obtained on August 17, 2014, from 10:57 to 11:07 UT, and the magnetic Earth's field (in nT, the same unit of the IGRF model prediction) measurements are presented on the right side of the straight red line. It is important to note that near the border of SAMA region the Geomagnetic Field is around 20.000 nT in the southern part and 22.000 nT in the upper region, but these values fall rapidly near the center of the Geomagnetic Anomaly to values less than 10.000 nT which is the half of the predicted values from the IGRF model for the central portion of the SAMA.

Figure 6 - a) SAMA Geomagnetic Field Total Intensity from the International Geomagnetic Reference Field (IGRF-12) model, 12th generation, for 2015 (https://geomag.bgs.ac.uk/research/modelling/IGRF.html). b) Magnetic field amplitude (in nT) and distribution of the correction for the diamagnetic effect applied to the noon-time EEJ (Lühr et al. (2004). c) Results from NANOSATC-BR1 Scientific Mission Payload measurements of the SAMA region (straight red line, with the sounding time - UT - on the left and total magnetic field - nT - on the right) plotted over the IGRF-10 model (color scale - nT - on the right side of this Figure).



The NANOSATC-BR1 Technological Mission was to carry an FPGA and two integrated circuits (IC´s) designed by the company Santa Maria Design House (SMDH) and the Graduate Program in Microelectronics from the Federal University of Rio Grande do Sul - UFRGS, that were developed for space use due to their radiation resistance using different techniques: design (hardware) and fault tolerance (software). Those are the first circuits designed in Brazil for space applications that are currently flying in a Brazilian satellite.

The NANOSATC-BR1's Ground Station Network (GS) is already installed and fully operational at the Southern Regional Space Center from the National Institute for Space Research (CRCRS/COCRE/INPE-MCTIC), in Santa Maria, RS. The antenna is illustrated in Figure 7.

Figure 7 – Antenna installed at the roof of the Southern Regional Space Center from the National Institute for Space Research, in Santa Maria, RS, Brazil.

The antenna is capable of obtaining telemetry from CubeSats worldwide, and is currently controlled by the Ground Station of the NANOSATC-BR Program at the Southern Regional Space Center from the National Institute for Space Research, in Santa Maria, RS, Brazil, Figure 8,

Figure 8 – Ground Station of the NANOSATC-BR Program, installed jointly with the LITN – Laboratory of Integration and Tests for Nanosatellites at the Southern Regional Space Center from the National Institute for Space Research, in Santa Maria, RS, Brazil.

3.2 NANOSATC-BR2

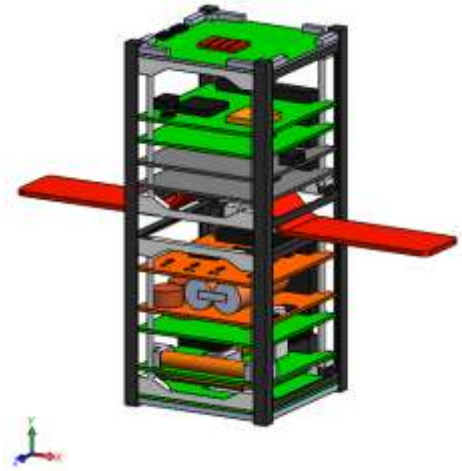
The Partnership INPE-UFSM is already developing the NANOSATC-BR2, second CubeSat of the NANOSATC-BR Program. Since it is a 2U CubeSat, (10x10x22.6 cm), it permits a more ambitious mission than the NANOSATC-BR1, with three primary objectives: scientific, academic/capacity building and technological. Figure 10 shows the satellite's EM under test at INPE in São José dos Campos - SP:

Figure 9 – NANOSATC-BR2's Engineering Model.

Its scientific mission is to monitor the Earth's Ionosphere and Magnetic Field. The current Ionosphere's composition disturbance in the SAMA region over Brazil has severe effects on satellite telecommunications and in services such as the GPS. The payloads for the scientific mission will be a miniaturized Langmuir probe and a fluxgate magnetometer (XEN-1210).

The NANOSATC-BR2 Project's Engineering Model (EM) and Flight Model (FM) platforms were delivered by ISIS, in January 2013, and are currently at LIT/INPE-MCTIC, in São José dos Campos, SP, Brazil. The CAD Model of the NANOSATC-BR2's internal components after the final integration, with the Langmuir Probe being the only external payload, in red, is shown in Figure 10:

Figure 10 – CAD Model of the NANOSATC-BR2 – Isometric view.



The NANOSATC-BR2's payloads are:

- SDATF: Fault-Tolerant Attitude Determination System - first triple redundancy attitude determination system in Brazilian satellites, manufactured in CubeSat standards and with its own algorithm, using the solar sensor platform and a magnetometer, made in cooperation by INPE/MCTIC with UFMG – Federal University of Minas Gerais (Electronic Engineering) and UFABC – Federal University of ABC (Aerospace Engineering). This payload is currently in integration and testing with the NANOSATC-BR2 platform;
- Langmuir probe: Delivered for testing and integration with NANOSATC-BR2's platform and onboard software - OBDH;
- Store Forward Communication Package – software experiment, developed by amateur radio communication from the Radio Amateur Satellite Corporation - Brazil (AMSAT-BR) and SP-LABRE.
- PCB with three experiments: FPGA-UFRGS; Magnetometer; Radiation Tolerant Circuits - SMDH/FATEC-UFSM.

All experiments will be integrated into the satellite structure and tested by the end of 2019 at the Laboratory of Integration and Tests – LIT/INPE–MCTIC, in São José dos Campos – SP, Brazil. The CubeSat's Flight Model will pass through several environmental tests in order to verify if the spacecraft will withstand the conditions imposed by the space environment, such as the structural and thermal vacuum tests.

The entire platform's flight software was developed in Brazil by INPE/MCTIC researchers and engineers, based on the experience gained from the NANOSATC-BR1 Project. The control software was also developed nationally.

The Program received funding from the Brazilian Space Agency (AEB) through UFSM-FATEC in May 2018 and managed to hire the launch of NANOSATC-BR2 in July 2019 along with ISIS. The satellite's future operation in orbit and tracking is under the responsibility of the Control and Tracking Team of the NANOSATC-BR Program.

Like NANOSATC-BR1 and other CubeSats projects, NANOSATC-BR2 will be launched in a piggyback release as a tertiary cargo by the beginning of 2020 by a Soyuz launch vehicle, operated by Roscosmos, of Russia.

3.3 NANOSATC-BR3 & NANOSATC-BR4: Current Situation

The engineering models of both CubeSats NANOSATC-BR1 & NANOSATC-BR2 are set to become the next Program satellites: NANOSATC-BR3, (NCBR3) & NANOSATC-BR4, (NCBR4). Therefore, it will be possible to plan upcoming scientific experiments and build new payloads based on experience gained from previous missions.

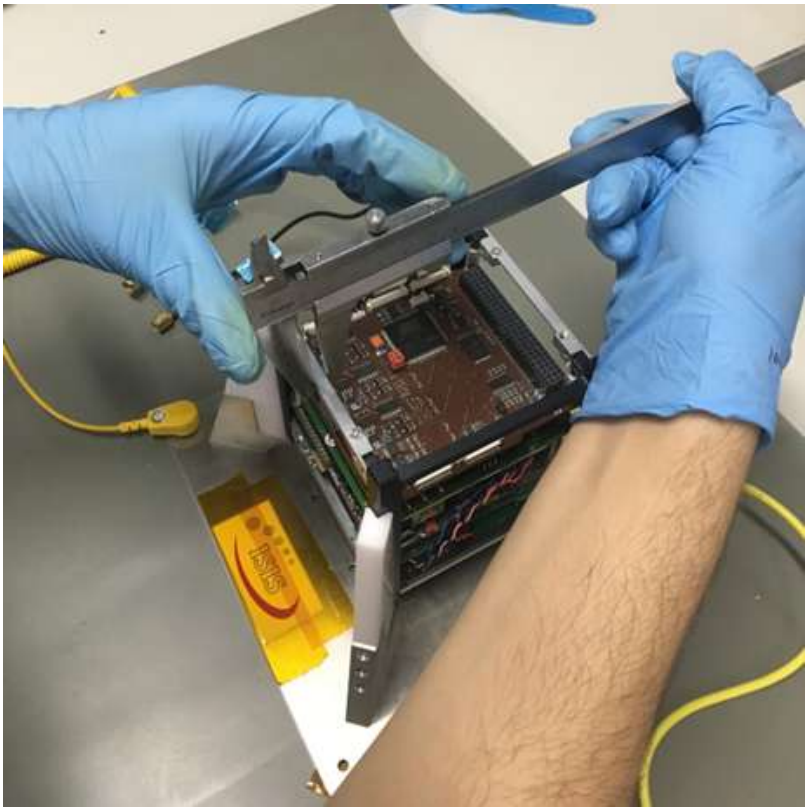
The NANOSATC-BR1 Engineering Model is currently available at the LITN – Laboratory of Integration and Tests for Nanosatellites at CRCRS/COCRE/INPE-MCTIC, as illustrated in Figure 11.

The presence of the Engineering Model at the Laboratory encourages students from the newly created Aerospace Engineering course and other related UFSM courses to learn assembly, integration, and testing (AI & T) techniques for CubeSats, and gain hands-on experience with the tools necessary for a professional's daily life. In order to effectively turn the Engineering Model platform into a Flight Model, some adjustments are required, such as building the solar panels and on-board antennas, as well as developing payload plates and components for future missions. This whole process will begin shortly after the release of NANOSATC-BR2.

In addition to the NANOSATC-BR1 Engineering Model, the NANOSATC-BR2 Engineering Model will be used to become one of the future CubeSats of the Program, the NANOSATC-BR4. It is currently being tested and used by INPE/MCTIC system and software engineers graduate students in São José dos Campos - SP.

Both future payloads and upcoming scientific missions will be discussed with researchers and engineers from the INPE/MCTIC, UFSM, and other Brazilian universities. Future missions of the NANOSATC-BR Program represent the continuity of the Projects and the beginning of other Aerospace Programs in Southern Brazil for the next decade.

Figure 11. NANOSATC-BR1 Engineering Model at LITN - CRCRS/COCRE/INPE-MCTIC in Santa Maria, RS.



4. Making up of the First Brazilian INPE-UFSM NANOSATS - CubeSats Constellation

The combination of the NANOSATC-BR 1 & 2 with the development of NANOSATC-BR 3 & 4 will conceive the very first Brazilian constellation of INPE-UFSM's small satellites, in a partnership with the UFSM's Aerospace Engineering Course. Several experiments are planned to be tested on these CubeSats in the future, including, but not limited to low-cost smart materials, communication algorithms between two satellites of the constellation and improvement of the current circuits tolerant to space radiation. All those experiments can be tested in the future NANOSATC-BR family.

The future projects aim to develop and manufacture innovative payloads for the space sector, in partnership with private companies and public higher education institutions, capable of enhancing mission performance for small satellites. One of the projects consists of an impact attenuator system that can reduce the effects of space radiation, with better performance and lower specific mass than the 6061 aluminum alloy, commonly used in space missions for electronic and structural components of satellites. The goal is to build a circuit board shield that can provide more effective protection against hazardous effects throughout the mission (such as Bit flap and LET - Linear Energy Transfer) while maintaining the structure's ability to provide grounding for onboard electronic subsystems. Another possible experiment is a testbed to qualify processing algorithms for applications of National interest, which will have hardware composed of several processors and programmable circuits capable of implementing various algorithms with various radiation error mitigation mechanisms.

The project also aims to manufacture printed circuit boards to test the experiments, performing electrical and functional tests, integrating and assembling the payloads in the structure of an engineering model of a 1U CubeSat nanosatellite, along with the development of the software to get the data needed. Thus, the present project proposes the creation of innovative space application prototypes for future commercialization and use in space missions of interest to Brazil.

The main technical and scientific challenges of these projects are the interaction between different areas of knowledge that include engineering (mechanical, electrical, aerospace, materials), computing, and physics. In addition to developing critical technologies for Brazil, this interaction is the first step in research and development of aerospace payload technologies that can improve the performance of space missions and extend the life of experiments and electronic circuits in the space environment.

5. Conclusions

The Brazilian INPE-UFSM NANOSATC-BR Cubesat Program has already proved to be an excellent tool for developing a new generation of scientists, engineers, and researchers with Aerospace Technologies in Brazil. However, the requirement is to support in an adequate, consistent, and continuous way to young Brazilian people contact with low cost and fast development space technologies. The Project also allows students to do researches in different areas of engineering, such as structural and thermal analysis, payload development and Electronic Power System - EPS conception.

The NANOSATC-BR1 & NANOSATC-BR2 Projects are already contributing in order to aggregate human resources, technology, and scientific capability to the Brazilian institutions, such as UFSM, UFRGS, ITA, USP, SMDH, INPE, UFMG, UFABC involving them directly to the Brazilian Space Program - PNAE.

Additionally, the expectation with the success of the efforts is an increase in the Brazilian Space Agency support and more investments from the Brazilian Government for the development of Space Technology and new universities initiatives in Brazil, such as the Brazilian INPE-UFSM NANOSATC-BR Cubesat Program, with its CubeSats in the NANOSATC-BR1 & NANOSATC-BR2 Projects.

6. Acknowledgments

The authors thank the Brazilian Space Agency - AEB, SEXEC/MCTIC, COCRE/INPE-MCTIC, UFSM-FATEC and USP's LSITEC Association for the support, opportunity, and grants for the Brazilian INPE-UFSM NANOSATC-BR, Cubesats Development Program, with its CubeSats: the NANOSATC-BR1 & the NANOSATC-BR2 Projects.

The authors thank Santa Maria Design House - SMDH/FATEC-UFSM, to Professors Dr. Ricardo Reis and Dr. Fernanda G. L. Kastensmidt from the Graduate Program in Microelectronics, Informatics Institute from UFRGS, to UFABC (Eng. Aeroespacial - Dr. Luiz Siqueira Filho), UFMG (Eng. Eletrônica - Dr. Ricardo Duarte), the CITAR-FINEP Project, and to MCTIC-CNPq/INPE (PCI-PIBIC-PIBIT) and FAPERGS Programs for fellowships.

The authors thank and acknowledge to Eng. Abe Bonnema and the ISIS's Board of Directors for the grant, tutorial and logistics support at Delft, Yasny and Brazil for the Brazilian students and for the NANOSATC-BR, CubeSats Development Program.

The Program and NANOSATC-BR1 Project thank Mr. Reiner Rothe, radio amateur from Germany and to Mr. Paulo Leite (PV8DX), radio amateur from Boa Vista, RR, Brazil, for tracking, downloading and sending systematically these data to the Program's database, at INPE/MCTIC, in São José dos Campos, in Brazil.

Dr. Nelson Jorge Schuch thanks the National Council for Scientific and Technological Development (CNPq) for the fellowship under the number 300886/2016-0. Dr. Marlos Rockenbach thanks CNPq for the fellowship under the number 301495/2015-7. Dr. Juliano Moro acknowledges the China-Brazil Joint Laboratory for Space Weather (CBJLSW) for supporting his Postdoctoral fellowship and CNPq for the grant 429517/2018-01.

References

[1] Bürger, E.E et al, "The Launch of the Brazilian INPE/UFSM´s Cubesat – The NanosatC-Br Space Weather Mission", Small Satellites Programmes for Sustainable Development Symposium, UN/Austria/ESA, 2009.

[2] Costa, L. L. et al, "NanosatC-Br – The First Brazilian Cubesat", 59th. IAC, Intl. Astronautical Federation, 2008.

[3] Schuch, N. J. ; Rockembach da Silva, M.; Durao, O. S. C. NANOSATC-BR CUBESAT DEVELOPMENT & CAPACITY BUILDING PROGRAMS: NANOSATC-BR1 & NANOSATC-BR2, 1st Latin American IAA CubeSat Workshop - IAA-XX-14-0S-0P – December, 2014 – Brasília, Brazil.

[3] Guareschi, W. N. et al, "Analysis of Field Programmable Gate Array Alternatives for Use In Nanosatellites", 61th. IAC, Intl. Astronautical Federation, 2010.

[4] Heirtzler, J. R., "The Future of the South Atlantic Anomaly and implications for radiation damage in space". Journal of Atmospheric and Solar-Terrestrial Physics, pp.1701-1708. 2002.

[5] Lühr, H., S. Maus, & M. Rother, "Noon-time equatorial electrojet: Its spatial features as determined by the CHAMP satellite", J. Geophys. Res., 109, A01306, doi:10.1029/2002JA009656. 2004.

[6] Batista, C.L.G., Martins, E. Mattiello-Francisco, F., 2018. On the use of a failure emulator mechanism for the nanosatelite subsystems integration tests. In: 19th IEEE Latin American Testing Symposium, LATS2018, IEEE Conference Proceeding.

[7] Conceição, C.A.P.L., Batista, C.L.G., Mattiello-Francisco, F., 2016. Dependability verification of nanosatellite embedded software supported by a reusable test system, WDES - Workshop on Dependability in Evolving Systems, Cali, Colombia, 7th Latin-American Symposium on Dependable Computing, 19-21 October, LADC2016. IEEE Conference Proceeding.

[8] Guareschi, W.N., Schuch. N.J., Petry, A., Charão, A.S., Tambara, L.A., 2010. Analysis of field programmable gate array alternatives for use in nanosatellites, 61th. IAC, Intl. Astronautical Federation.

[9] Heirtzler, J.R., 2002. The future of the South Atlantic Anomaly and implications for radiation damage in space. Journal of Atmospheric and Solar-Terrestrial Physics, pp.1701-1708.

[10] Medeiros, L., Zaffari, C.A., Noval, J.J.S., Teixeira, L., Martins, J.B.S., 2014. Using the NANOSATC-BR1 to evaluate the effects of space radiation incidence on a radiation hardened ASIC. In: 1st IAA Latin Ameri-can CubeSat Workshop, 2014, Brasília. Conference Proceedings 1st IAA.

[11] Noval, J.J.S. Medeiros, L., Martins, J.B.S., Schuch, N.J., Durao, O.S.C., Machado, R., 2016. Design considerations for Radiation Hardened ASIC used as technological payload in NANOSATC-BR1. In: 2nd IAA Latin American CubeSat Workshop, 2016, Florianópolis. Conference Proceedings 2nd IAA.

[12] Pallamin, D.A., Mattiello-Francisco, F., 2017. Modeling the interoperability between on-board computer and payloads of the NANOSATC-BR2 with support of the UPPAAL tool. In: 1st IAA Latin American Symposium on Small Satellites, Colombia, Session 9/IAA-LA-09-01.

[13] Woellert, K., Ehrenfreund, P., Ricco, A.J., Hertzfeld, H., 2011. Cubesats: Cost-effective science and technology platforms for emerging and developing nations, Advances in Space Research 47, 663-684.