NANOSATC-BR STATUS - A JOINT CUBESAT-BASED PROGRAM DEVELOPED BY INPE AND UFSM

Nelson Jorge Schuch,[*] Otávio Santos Cupertino Durão, Marlos Rockenbach da Silva, Fátima Mattiello-Francisco [†], André Luís da Silva[‡], and The NANOSATC-BR Team[§]

The INPE-UFSM's NANOSATC-BR, CubeSats Development Program started in 2008. Currently, the Program counts with two CubeSats: the NANOSATC-BR1 (1U) launched in 2014 and still in operation & the NANOSATC-BR2 (2U) under development and expected to be launched in 2018. In this paper the finalization of NANOSATC-BR2 development and the scientific and technological results of the NANOSATC-BR1 are presented. Considering the Capacity Building, the major target of the Program, the paper emphasizes the involvement of UFSM undergraduate and graduate students in the conception, development and operation of NANOSATC-BR1 and the participation of INPE graduate students in the OBDH software subsystem development, verification and validation for the NANOSATC-BR2. In addition, the collaborations of other Space Science, Engineering and Computer Science institutions involved in Brazil and abroad are discussed. Concerning NANOSATC-BR1, the paper reports the Capacity Building, the technological and the scientific results of the mission. The Program has received financial support from the Brazilian Space Agency (AEB) and from the Ministry of Science, Technology, Innovation and Communications - MCTIC.

The Brazillian NANOSATC-BR Team

1 - Nelson Jorge Schuch, 2 - Otávio Santos Cupertino Durão, 3 - Alexandre Álvares Pimenta, 4 - Polinaya Muralikrishna, 5 - Adriano Petry, 6 - Marlos Rockenbach da Silva, 7 - José Valentin Bageston, 8 - Odim Mendes Jr, 8 - Nalin Babulau Trivedi, 9 - Severino Luiz Guimarães Dutra, 10 - Alisson Dal Lago, 11 - Clezio Marcos Denardini, 12 - Ezequiel Echer, 13 - Luis Eduardo Antunes Viera, 14 - Geilson Loureiro, 15 - Maria de Fátima Francisco Mattiello, 16 - Mario Celso de Almeida, 17 - Valdemir Carrara, 18 - José Sergio de Almeida, 19 - Helio Kuga, 20 - Rafael Lopes Costa, 21 - Lucas Lopes Costa, 22 - Natanael Rodrigues Gomes, 23 - Renato Machado, 24 - Andrei Piccinini Legg, 25 - João Baptista dos Santos Martins, 26 - Ri-

[*] *Southern Regional Space Center - CRS/COCRE/INPE-MCTIC, in collaboration with the Santa Maria Space Science Laboratory - LACESM/CT-UFSM, Santa Maria -RS, Brazil. njschuch@gmail.com*

[†] *National Institute for Space Research (INPE/MCTIC), São José dos Campos - SP, Brazil. otavio.durao@inpe.br , marlos.silva@inpe.br , fatima.mattiello@inpe.br*

[‡] *Federal University of Santa Maria - UFSM, Assistant Professor, Aerospace Engineering, Santa Maria - RS, Brazil. andre.silva@ufsm.br*

[§] *The NANOSATC-BR Team - Seventy persons from: INPE/MCTIC, UFSM, SMDH, UFRGS, UFABC, UFMG, EMSISTI, ITA/DCTA-MD*

cardo Reis, 27 - Fernanda Gusmão de Lima Kastensmidt, 28 - Rubens Zolar Gehlen Bohrer, 29 - Eduardo Escobar Bürger, 30 - Cassio Espindola Antunes, 31 - Tardelli Ronan Coelho Stekel, 32 - Carlos Roberto Braga, 33 - Juliano Moro, 34 - William do Nascimento Guareschi, 35 - Claudio Machado Paulo, 36 - Fernando Landerdahl Alves, 37 - Lucas Lourencena Caldas Franke, 38 - Mauricio Ricardo Balestrin, 39 - Guilherme Paul Jaenisch, 40 - Iago Camargo da Silveira, 41 - Rodrigo Passo Marques, 42 - Tális Piovesan, 43 - Jose Paulo Marchezi, 44 - Tiago Bremm, 45 - Vinicius Deggeroni, 46 - Leonardo Zavareze da Costa, 47 - Pietro Fernando Moro, 48 - Thales Ramos Mânica, 49 - Anderson Vestena Bilibio, 50 - Andreos Vestena Bilibio, 51 - Tiago Travi Farias, 52 - Marcos Antonio Laurindo Dal Piaz, 53 - Lauro Barbosa Alves, 54 - Pablo Ilha Vaz, 55 - Elói Fonseca, 56 - Lidia Hissae Shibuya Sato, 57 - Marcelo Henrique Essado de Morais, 58 - Cristiano Strieder, 59 - Fernando Sobroza Pedroso, 60 - Alex Müller, 61 - Artur Gustavo Slongo, 62 - Lorenzzo Quevedo Mantovani, 63 - Alan Pitthan Couto; 64 - Pedro Camargo Kemmerich; 65 - Mauricio Beux Dos Santos, 66 - Ricardo Duarte, 67 - Luiz Siqueira Filho, 68 - Gabriel Henrique da Rosa Vizcarra, 69 - André Luís da Silva, 70 - Deniel Desconzi Moraes.

It is the NANOSATC-BR CUBESAT DEVELOPMENT PROGRAM policy not to delete any name of persons who did collaborate, directly or indirectly, with its Projects and after that left the Program.

INTRODUCTION

The NANOSATC-BR CubeSat Development Program consists of a Brazilian INPE-UFSM Capacity Building Program on space science, engineering and computer sciences for the development of space technologies using CubeSat satellites, starting with a first Brazilian Scientific Nanosatellite, the NANOSATC-BR1. The Capacity Building Program was conceived at the Southern Regional Space Research Center (CRS), from the Brazilian National Institute for Space Research - INPE/MCTIC, where acts the Program's General Coordinator and Manager, having technical collaboration and management of 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, ITA/DCTA/CA-MD 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 institutional arrangement and the technical characteristics of the satellites and their missions. The Program has support from the Brazilian Space Agency (AEB) and from the Ministry of Science, Technology, Innovation and Communications - MCTIC.

NANOSATC-BR – CAPACITY BUILDING

The major objective of the INPE-UFSM's NANOSATC-BR – CubeSats Development Program, through the NANOSATC-BR1 & NANOSATC-BR2 CubeSats Projects, is to perform a Specialized Human Resource Capacity Building Program through the training of UFSM's undergraduate and former students in their respective areas, mainly: Engineering, Computer Sciences and Physics, through Science, Technological & Innovation Initiation at INPE/MCTIC.

Students have an important weight on the Project's technical and scientific branches, since their tasks provide results for each subsystem. The results are consequence of their hard work made in conjunction basically with the UFSM's and INPE's specialists: Engineers, Technologists and Researchers which are the main providers of information.

On the other hand, the Capacity Building Missions aims the Capacity of a new generation of scientists, engineers and researchers engineering and computing sciences through a CubeSat Program.

Through the NANOSATC-BR Program it was possible to approximate the Brazilian Space Program to Universities, such as: UFSM, UFRGS, UFRN, UFABC, UFMG and USP. Therefore, the Program provides hands-on training and learning with Aerospace Engineering & Technologies and Space Weather issues.

Training of the students at INPE and at the Brazilian space industries as well, as at universities and space industries abroad: (TU - Berlin, University of Wurzburg and DLR in Bremen in Germany; Innovative Solutions In Space - ISIS - Delft in The Netherlands, and at The La Sapienza – Università Degli Studi di Roma, TU- Roma, in Italy, University at Buffalo, University of Tennessee and NASA - Goddard Space Flight Center, in USA), with funding from the CubeSat Dutch company Innovative Solutions in Spacce - ISIS, the Van Allen Project-NASA, the Brazilian Space Agency – AEB and from the Brazilian Program Science without Borders – SwB.

NANOSATC-BR MISSIONS

The Program already consists of two CubeSats, the NANOSATC-BR1 and NANOSATC-BR2 (Figure 1) and has the possibility of launching three other CubeSats in the next five years, operating them in space for at least 6 months each. These new missions aim to study and monitor the Geospace and Space Weather.

The NANOSATC-BR1 concept was developed 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 South America Magnetic Anomaly (SAMA). Its payloads are:

- A XEN-1210 three-axis magnetometer with a resolution of 15nT from the Dutch company XI - Xensor Integration (www.xensor.nl);
- One board with the magnetometer and two technological payloads (a fault tolerant FPGA[1] and a driver IC designed to be radiation tolerant).

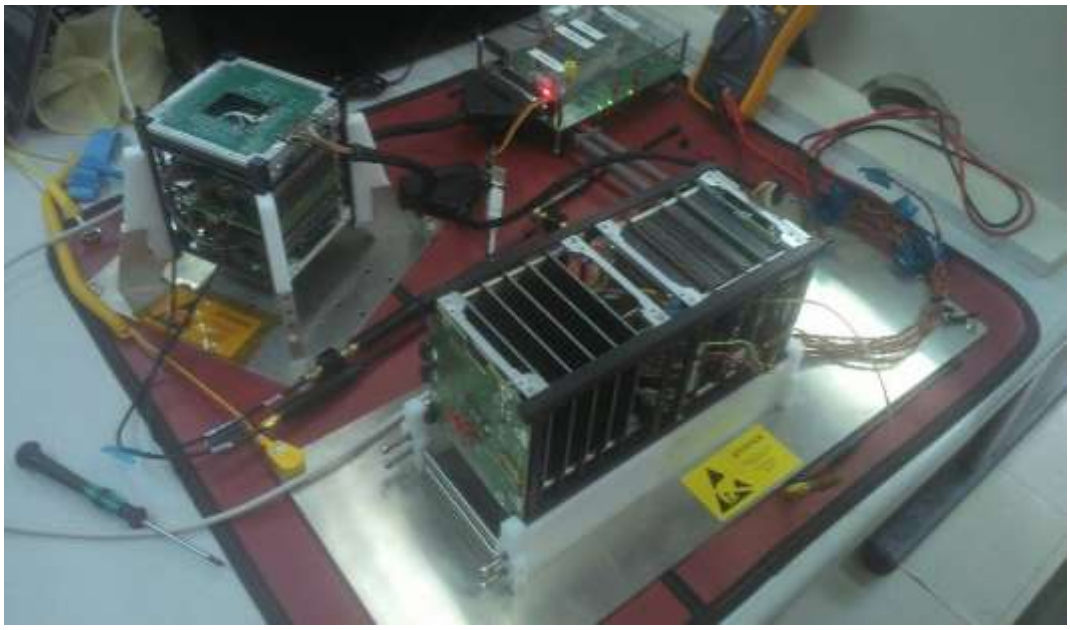

Figure 1: The NANOSATC-BR1 and NANOSATC-BR2 Engineering Model Platforms.

The NANOSATC-BR1 Technological Mission carries a FPGA[1] and one integrated circuit (IC) designed by the Santa Maria Design House (SMDH) and the Graduate Program in Microelectronics from UFRGS (Federal University of Rio Grande do Sul), that were developed for space use due to their radiation resistance. The two technological payloads then use two different techniques for fault tolerance due to radiation in space: design (IC) and embedded (software) FPGA. These were the first circuits designed in Brazil for space applications.

NANOSATC-BR1 - CURRENT SITUATION

The NANOSATC-BR1, is a 10x10x11.3 cm. cube, weighing 0,965 kg. It has its name and up and down frequencies link 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 pre-tested by ISIS from Delft, The Netherlands, except for the integration of the flight model done at the Integration and Testing Laboratory (LIT) of INPE/MCTIC. The full Assemble, Integration and Tests (AIT) of the complete CubeSat (platform and payload) was also done at LIT.

The NANOSATC-BR's Ground Station Network (GS) is already installed and in operations: GS(INPE-CRS), at CRS/INPE-MCTIC, Santa Maria, RS, and GS(INPE-ITA) at ITA/DCTA-MD, in São José dos Campos, SP, in Brazil, Figure 2.

The NANOSATC-BR1 was launched as a tertiary payload by ISIS in the event ISILAUNCH 07, by a DNEPR, at Yasny Launching Base, Donbarovsky Region, Russia, on June 19th, 2014 – Launch time (T): 19:11:11 UTC - Local time at Yasny: 01:11.

The NANOSATC-BR1 completed more than three years in orbit sending payloads and subsystems data. All payloads and subsystems, except the batteries in the power subsystem, continue to operate normally. The battery can no longer hold a charge because it was damage by magnetic solar storms in September-October 2014, therefore the NANOSATC-BR1 can transmit only when it is in sight by the sun. However, weekly Mr. Reiner Rothe, an amateur radio from Germany and Mr. Paulo Leite (PV8DX), amateur radio from Boa Vista, RR, Brazil, are making the NANOSATC-BR1 tracking, downloading and sending systematically these data to the Program's data base, at INPE in São José dos Campos, in Brazil.

Figure 2: The NANOSATC-BR's Ground Station Network (GS) is already installed and in operations: on left - GS(INPE-CRS) at CRS/INPE-MCTIC, in Santa Maria, RS, and *on right* - GS(INPE-ITA) at ITA/DCTA-MD, in São José dos Campos, SP, in Brazil.

The Technological Payload - The SMDH-IC Results

The Santa Maria Design House (SMDH), with design techniques and considerations, developed Integrated Circuits (IC) for space application regarding Total Ionization Dose (TID), instantaneous radiation dose effects denominated Single Event Effects (SEE) and Displacement Damage (DD) with Specific Integrated Circuit (ASIC) developed for one of the technological payloads of the NANOSATC-BR1. The radiation hardened digital cells designed by SMDH proved a tolerance to solar energetic particles with energies of up to 100MeV.

The SEE tolerance of two shift-registers with 256 stages and 8 inverters between each chain is shown in Figure 3. The blue bar corresponds to the shiftregisters designed using the conventional digital cells provided by the foundry. On the other hand, the red bars represent the radiation hardened digital cells designed by SMDH. It is remarkable to mention that radiation hardened cells designed by SMDH proved tolerance to SEE with X-rays events of severity R1 and R2[2]. In relation to the R3 event[2], the designed cells reported some errors by SEE. The amount of errors in the shift-registers designed using the standard cell library is comparatively larger than the shift registers using rad-hard cell library.

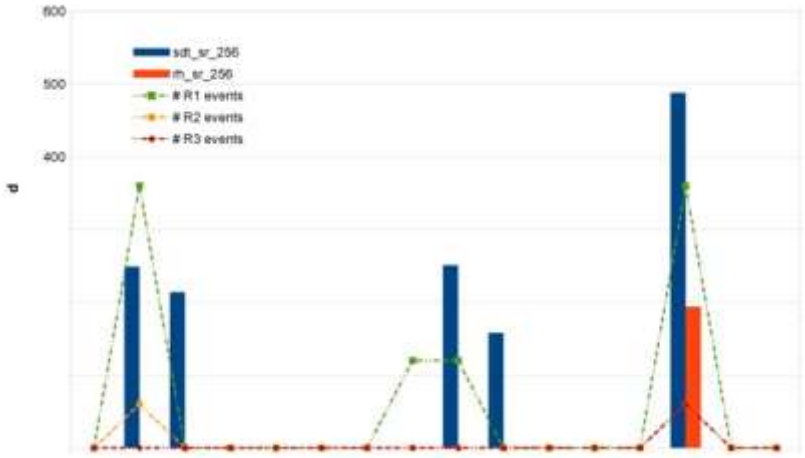

Figure 3: The NANOSATC-BR1 SEE tolerance comparison of two shift-registers (256 FF, 8 INV)[2].

The Solar energetic protons detected by GOES-15 satellite during September 2014 were used in order to analyze and quantify the energy levels measured during the R3 occurrence and thus estimate the tolerance of customized cells. The fluency of Solar Energetic Protons - SEPs[2] during September 2014 at different levels of energy is shown in Figure 4. During the first two weeks were reported SEPs with energies above 100MeV.

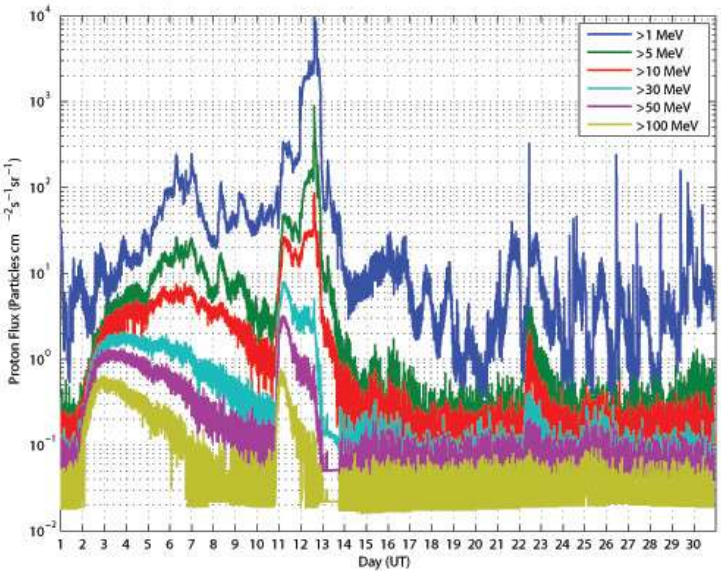

Figure 4: The Solar Energetic Protons - SEPs detected by GOES-15 satellite during September 2014[2].

The NANOSATC-BR1 Scientific Mission Payload Results

The observed data collected by the Scientific Mission Payload, which is a XEN-1210 magnetometer, shows an excellent correlation with theoretical figures for the intensity of Geomagnetic Field, for the same altitude with the theoretical modeling of IGRF-IAGA/IUGG. A map of the

total intensity of the Geomagnetic field at 614 km of altitude over South America, domain of the South America Magnetic Anomaly - AMAS[3], is shown in the right hand side of Figure 5. The spatial variation of the total intensity of the Geomagnetic field varies between 24.000nT the edge and 17,000 nT at the center of the AMAS, signalized by a black star in Figure 5. The Nanosatellites Earth Tracking and Control Station, GS(INPE-CRS), in Santa Maria - RS, is lying near the center of AMAS. The red line in Figure 5 indicates the approximate orbit of the NANOSATC-BR1 on August 17, 2014, from 10:57h to 11:07h. During this period, the scientific Nanosatellite moved from South Pole towards to the geographic North Pole.

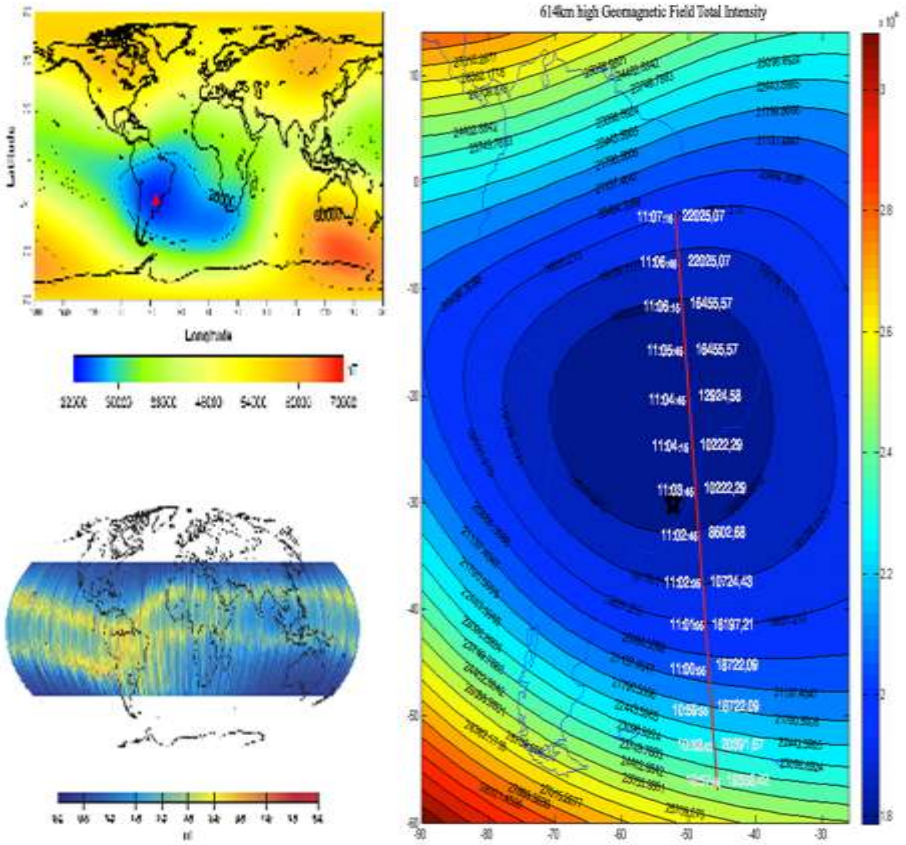

Figure 5: The South America Magnetic Anomaly - SAMA region Geomagnetic Field total Intensity (top left) and Equatorial Electron Jet - EEJ (bottom left) - Ref[3,4]. Results from NANOSATC-BR1 Scientific Mission Payload measurements of the SAMA region (right).

NANOSATC-BR2 - CURRENT SITUATION

The NANOSATC-BR2, is a 2U CubeSat, (10x10x22.6 cm), permits a more ambitious mission than the NANOSATC-BR1, with three major objectives: academic and capacity building, scientific mission and technological mission development. The scientific mission is to monitor the Earth's Ionosphere and Magnetic Field. The Ionosphere composition disturbances in the SAMA region over Brazil have severe effects on satellite telecommunications and in the precise location

with services such as GPS. The payload equipment for the scientific mission will be a Langmuir probe and a XEN-1210 magnetic field sensor based on the Hall effect. The Langmuir probe is available in a larger size and is being miniaturized for CubeSats.

In order to finalize the NANOSATC-BR2, which is now also known by the acronym NCBR2, its platform was developed to satisfy the payload equipment's requirements. The onboard data handling (OBDH) software is a key element for payload integration in NCBR2. It is a software-developed at INPE by graduate students in collaboration with emergent companies leaded also by INPE´s former students. The NANOSATC-BR2 also has the first attitude determination subsystem developed in Brazil as one of its experiments. It has triple redundancy using three microprocessors with one in hot standby. It's a joint project led by the UFMG with UFABC and INPE. The CubeSat will also carry two other technologic experiments as version two of those that are flying in NANOSAC-BR1. It also carries an amateur radio communication experiments from AMSAT-Br and LABRE.

All of these payloads are being integrated and tested with the on board software in the Engineering Model (EM), with the exception of the version two of the board flying in NANOSAC-BR1 whose first unity will be delivered for integration and tested in one month. The present status of the development is as follows:

- SDATF - Attitude Determination System tolerant to failure - First Brazilian System Attitude Determination, with triple redundancy, manufactured in CubeSat standards and with its own attitude determination algorithm, using the solar sensor platform and a magnetometer made in cooperation by INPE/MCTIC with UFMG (Dept. Electronics Engineering) and UFABC (Dept. Aerospace Engineering); presently in integration and testing with the NANOSATC-BR2 EM platform;

- Langmuir Probe - Delivered for testing and integration with the NANOSATC-BR2 EM platform and the onboard software - OBDH;

- Communication Experiment Packet (store forward) - AMSAT-BR and SP-LABRE.

- CubeSat board with three experiments: FPGA - UFRGS; Magnetometer; IC - SMDH/UFSM, first unit scheduled for delivery in Dec. 2017.

The entire platform flight software was developed in Brazil, by researchers and engineers from INPE/MCTIC, already working in this area (Determination & Attitude Control and Data Management), taking advantage of the experience of NANOSATC-BR1, students graduate at INPE/MCTIC on the course of the Space System Engineering (CSE), the undergraduate students, graduates and third parties startup company created by former INPE/MCTIC graduate students. The Control Law for the control software has also been developed in house.

The Project is now waiting the budget from the Brazilian Space Agency - AEB for hiring the launch and future operation of NANOSATC-BR2 in orbit. The NANOSATC-BR2 is planned to be launched in the second semester of 2018. Likewise NANOSATC-BR1 and other CubeSat projects, the NANOSATC-BR2 will be launched as a tertiary payload. The launch opportunities as well as the Launch Vehicle are under discussion.

CONCLUSIONS

Since it is provided to young Brazilian people contact with low cost and fast developments on Space Technology, the Brazilian: INPE-UFSM, NANOSATC-BR Cubesat Development Program, proved to be an excellent tool for developing a new generation of scientists, engineers and researches, in Aerospace Technologies in Brazil.

It is expected an increase in the Brazilian Government Agencies support and more investments for the development of Space Technology and for new universities initiatives, in Brazil, such as the Brazilian INPE-UFSM NANOSATC-BR Cubesat Development Program, with its CubeSats the NANOSATC-BR1 & NANOSATC-BR2 Projects.

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