The ITASAT – The Lessons Learned from the Mission Concept to the Operation

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ABSTRACT

The ITASAT Project was initiated as an effort of the Brazilian Space Agency (AEB), the Technological Institute of Aeronautics (ITA) and the National Institute of Space Research (INPE) to train human resources to the Aerospace sector due to the lack of experience of the students in practical projects in the aerospace segment in Brazil. In this effort students were challenged to design, build and operate a satellite in a hands-on project. Along the project years several changes happened on the satellite configuration, going through a 100 kg satellite to a 6U CubeSat and this last configuration was designed, assembled and tested. In December ITASAT was launched and since its launch has been tracked and operated by the ground operation team. In this paper we will discuss the lessons learned during the project, since the decision to change the satellite size and re-thinking the scope of the project objectives, focusing on system engineering, Assembly Integration and Testing (AIT), Verification and Validation (V&V) and ground operations. The paper will present the challenges of the group of students in this hands-on project, the mistakes and hits along the project phases.

INTRODUCTION

The ITASAT Project have had its origin in (2005) as a project to provide a space product in order to train and educate students. This type of space project has the endeavor to motivate students from many different backgrounds to integrate a team in a multidisciplinary field to develop capabilities not even in the universities, but also to provide competences to the Brazilian space industry sector. Hence, give the students the chance to participate in project to develop engineering skills and to solve a real space problem. Initially it was decided to design a project of a satellite up to 100 kg [1] to provide data collection in order to use the INPE´s satellite and ground segment legacy for remote sensing.

Although the first efforts to develop the 100kg category satellite purpose, a decision to reduce complexity and allow students for the human resource training changed the satellite category for a CubeSat approach [2]. This decision to change drastically the project´s approach category rather than a 100kg category brought a new paradigm and mindset challenge.

The project success drivers should continue besides of the challenges and ITASAT was completed in (2016) and waited to be launched until December 3rd in 2018 by the Falcon-9 rocket from Vandenberg Air Force Base.

The following section will describe the ITASAT platform and its subsystems, where also the operational results after its launch are presented.

THE ITASAT PLATFORM

Developed as a 6U CubeSat, ITASAT was designed to serve as a platform for future mission. In this design some aspects were considered, such as:

a) Focus on the system engineering and Assembly, Integration and Testing;

b) Use of commercial-off-the-shelf equipments (COTS);

c) Modularity (in hardware and in software);

d) Development of interface boards (for electrical and mechanical purposes);

e) Operation of the satellite.

The decision to focus on the System Engineering, AIT, software development and Verification and Validation (V&V) allowed the team to finalize the CubeSat in two years. To be able to achieve this timeframe, most of the subsystems were COTS, specified from different suppliers in order to fulfill the requirements of the payloads. This decision required for the team quite some efforts to keep the compatibility among all the COTS components.

The modularity of ITASAT is explained on [3] and [4] but it addresses the ability to change a part or an entire subsystem without minor (or any) changes in the design. The modularity was applied in the hardware, physical layout and in the software design. The CubeSat standardization aids this approach, once interfaces and mechanical dimensions are defined by [5]. But, although there is a standard, some electrical and mechanical interfaces had to be worked out, once there were specifics from suppliers, and specially with the payloads. The development of such kind of interfaces allowed the platform to be more flexible for different types of payloads. Figure 1 presents the ITASAT Protoflight Model after integration.

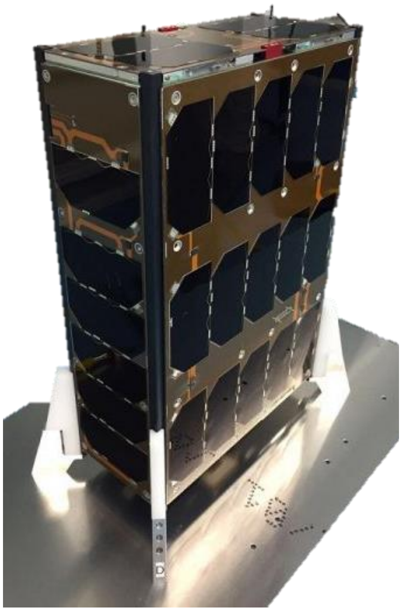


Figure 1: ITASAT Protoflight Model

In terms of operation, the ITASAT project aimed to train students in mission operation. To do so, a ground station in partnership with the National Institute of Space Research (INPE – *Instituto Nacional de Pesquisas Espaciais*) has being used and a satellite control software were specified and contracted a company to develop once there was no human resource available to develop this interface.

To explain the ITASAT CubeSat, the satellite can be divided into the ***platform*** (or bus) which is the part of the satellite responsible for providing sufficient conditions (i.e. power, data handling, housing, communication to ground and so on) for the ***payloads,*** i.e. the experiments to be tested on orbit.

The 6U platform

The 6U platform is composed by the subsystems divided according to the literature, but one of the differentials of ITASAT is the fact that there are two on board computers. One dedicated to on board data handling and one dedicated to the attitude control system.

Structure and Thermal Subsystem (STS): ITASAT uses a commercial 6U Structure. The ITASAT CubeSat internal disposition provided 2U's for the payloads and reserves 4U's for the platform, as shown in Figure 2. The thermal control of ITASAT is entirely passive.

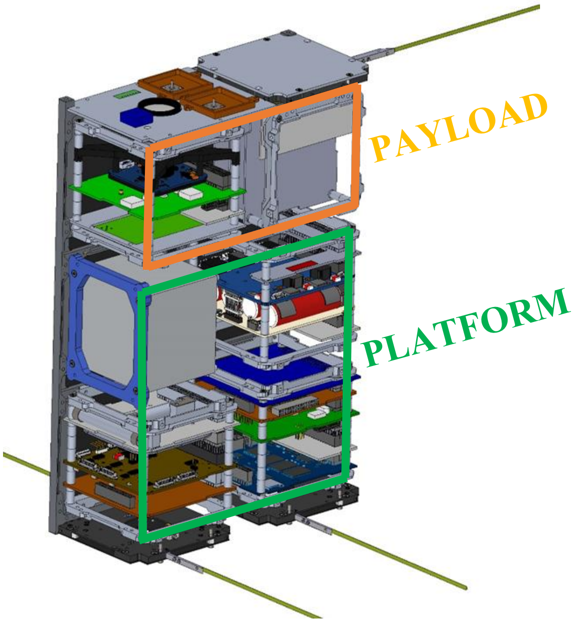


Figure 2: ITASAT Structure and internal disposition

Energy and Power Supply Subsystem (EPS): The EPS is based on a COTS solution that provides 40Wh/2600 mAh of autonomy in the Lithium-ion batteries and regulated (5V and 3V3) and unregulated (battery voltage – 16,8 V maximum) power lines. There are six controlled power lines used mainly for payload lines. Due to the requirements of some payloads and components selected to the project, an interface board providing additional controlled lines and a 12V power line was developed by the team.

To generate energy solar panels are fixed in 5 faces of the CubeSat, exception to the face where it is placed the camera. Tripe junction solar cells are applied in the project and have an efficiency of 28%. In this configuration the EPS system has a capacity to generate in average 6 to 7 W, considering ITASAT orbit. The conception of the EPS system is presented on Figure 3.

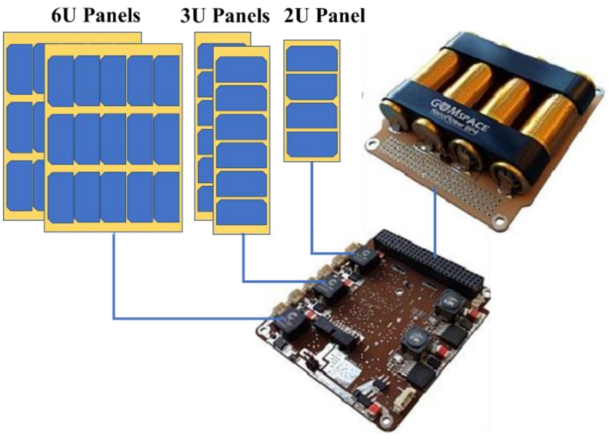


Figure 3: ITASAT EPS

On Board Data Handling Subsystem (OBDH): The OBDH system is composed by a commercial ARM-Cortex M3 based computer running FreeRTOS. The main features of the OBDH are:

a) High performance, low power 32-bit ARM Cortex-M3-based MCU
b) 4-48MHz @ 1.25 DMIPS/MHz
c) Internal & external watchdog for added reliability
d) 256 KB EEPROM
e) 4 MB flash for code Storage and 2 MB external SRAM for data storage
f) SEU protection by means of an FPGA-based EDAC and SEL protection by detecting and isolating latchup currents
g) MicroSD socket for storage up to 2 GB
h) GPIO, I2C, SPI, CAN, and UART interfaces;
i) Vibration & heated vacuum tests;
j) Radiation tests (TID @ 20 krad, SEE @ 60 MeV).

Figure 4 presents the OBDH computer chosen for ITASAT mission.

Source: https://cubespace.co.za/

Figure 4: ITASAT OBDH

All the embedded software was developed by the team following the architecture presented on Figure 5. The software development in layers allowed the team to divide the work and have more than one person working in the software. Also, project-based libraries could be shared between the developers. The development in layers also permitted changing the drivers without changing the application layers and aided the integration of software application developed by "third-parties".

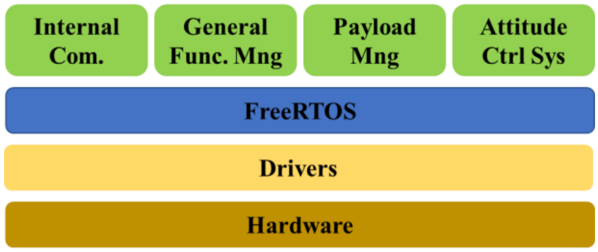


Figure 5: ITASAT Software Architecture and layers

Attitude Determination and Control System (ADCS): ITASAT has a dedicated computer for the ADCS System, based on an ARM 7 MCU that connects directly to the sensors (sun sensor, gyrometer and magnetometer) and acts on the actuators (magneto-torquers and reaction wheels) and was designed to implement three attitude control algorithms:

1) A B-dot attitude control system with the purpose to detumbling ITASAT, and count on the magneto torquers as actuators and the magnetometers as sensors.
2) A magnetic-based control system that aligns ITASAT with the Earth Magnetic Field, and
3) A three-axis control system based on reaction wheels and magnetorquers as actuators and gyrometer, magnetometer and photodiode as sensors

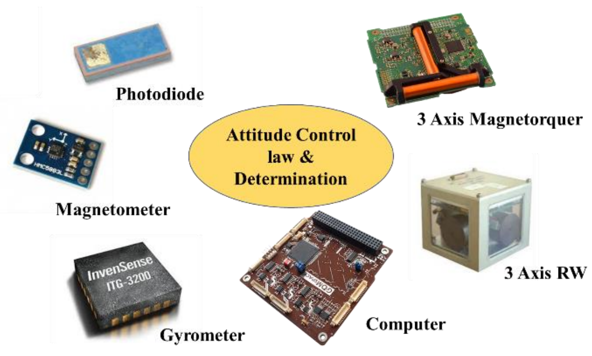


Figure 6: ITASAT ADCS Block Diagram

ITASAT has also implemented an attitude determination and estimation system. A more complete description of ITASAT attitude control system can be found in [6]. Figure 6 presents the main components of ITASAT ADCS.

Telemetry and Telecommand Subsystem (TMTC): The uplink channel of this project is based in a COTS UHF receiver in the satellite, amateur radio band coordinated with a data rate of 1200 bps and AFSK modulation scheme.

The CubeSat counts with two downlink channels using amateur radio band coordinated, one using a VHF COTS transmitter in the satellite, transmitting at 1200 to 9600 bps, BPSK modulation scheme and 22 dBm of RF output power, and a second COTS transmitter in S-Band transmitting up to 144 kbps, BPSK modulation scheme and adjustable RF output power from 27 to 33 dBm. The VHF and UHF radio are integrated in only one board and are for satellite command, control and status data reception. Payload data is also transmitted using VHF band. The S-Band radio is responsible for data streaming larger science data. Figure 7 presents the UHF/VHF Transceiver (on the left) and the S-Band radio (on the right).

Source: https://www.isispace.nl/

Figure 7: ITASAT TMTC

The payloads

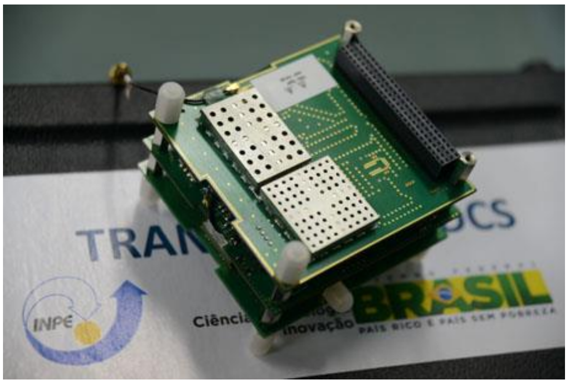
For this mission four experiments were allotted on ITASAT:

Data collection Transponder (DCS): The Data Collection Transponder (DCS Transponder) was developed by INPE CRN (Centro Regional Norte) in Natal to update the technology applied in the transponder and to miniaturize it to fit in a CubeSat (in size and power consumption). This transponder is compatible with the existing Brazilian Data Collection System.

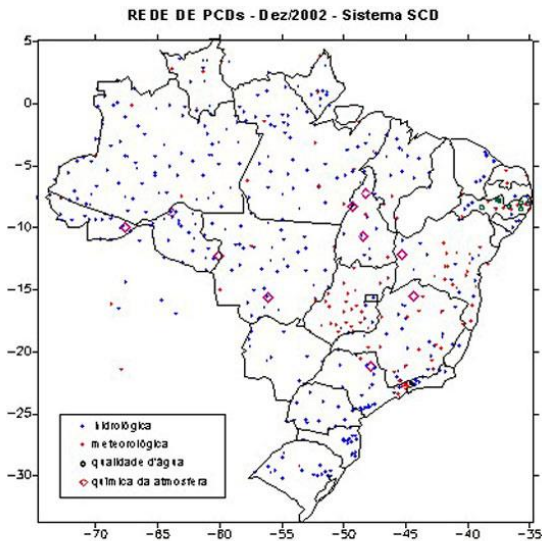
The DCS Transponders allows ITASAT, a 6U CubeSat with 5.2 kg, to perform the same function as SCD-1 and SCD-2, a 115 kg and 117 kg satellite respectively. (SCD - *Satélite de Coleta de Dados*).

This transponder may collect data from more than 900 Data Collection Platforms (DCP) spread over the Brazilian territory and over the coast area. These data are related to water quality, water levels, air quality, animals' migration and so on. More information about the Brazilian Data Collection System can be found in:

http://sinda.crn.inpe.br/PCD/SITE/novo/site/index.php



(a)



(b) Example of the data collection platforms distribution

Source: www.inpe.br

Figure 8: Data Collection Transponder and (b) data collection platforms over Brazil

GPS Receiver (GPS): The GPS receiver were developed by the Federal University of Rio Grande do Norte (UFRN – *Universidade Federal do Rio Grande do Norte*) and the Aeronautics and Space Institute (IAE - *Instituto de Aeronáutica e Espaço*) from the Air Force Department (DCTA – *Departamento de Ciência e Tecnologia Aeroespacial*) [7].

This GPS Receiver has already flown on a VSB-30 rocket [8]. To integrate the GPS receiver in the CubeSat Standard a Mechanical Interface had to be developed such as an electrical interface.

Figure 9: GPS Receiver

Camera (CAM): A commercial camera in the visible spectrum was chosen as a payload for ITASAT aiming to prove the attitude control system performance. The camera is a 3-megapixel color sensor with 35 mm lens performance of 60 m per pixel @ 650 km of altitude. In terms of image acquisition, the 1/2" (4:3) format color CMOS sensor provides an image of 2048 x 1536 pixels in 10-bit RGB Bayer pattern.

Source: https://gomspace.com/shop/payloads/earth-observation.aspx

Figure 10: COTS Camera

Communication Experiment (DCX-2): The DCX-2 Experiment was proposed by the Brazilian Amateur Community to carry on board of ITASAT an experiment of providing a communication channel with amateur radios over the globe. The experiment has three modes of operation:

1) ***Beacon:*** once in beacon mode the Cubesat transmits up to 10 messages stored on board in a regular interval between the messages and the CubeSat regular beacon.
2) ***Transponder:*** in transponder mode the CubeSat re-transmits in VHF a message received in UHF to all ground station in the same footprint (coverage area) than the satellite.
3) ***Store and Forward:*** in this mode the CubeSat is able to receive a message in UHF from an amateur radio and store on board this message until a second amateur radio request this message to the satellite that is then transmitted in VHF. This allows communication of two people in different countries (or different coverage areas).

ITASAT LAUNCH AND EARLY ORBIT OPERATION

In this section we will describe the Concept of Operation ConOps) of ITASAT, the launch event and the first orbits of the CubeSat.

Concept of Operations (ConOps)

Figure 11 presents the Concept of Operation for ITASAT.

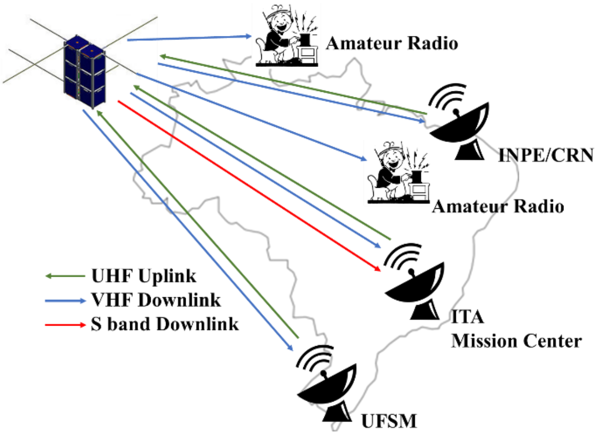
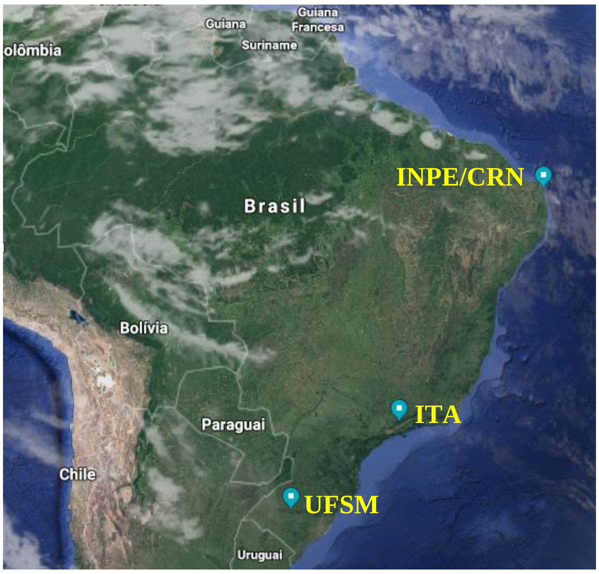


Figure 11: ITASAT ConOps

For ITASAT operation a ground station located at ITA, in São José dos Campos, was elected as the main station and the Mission Control Center. A ground Station located at *Universidade Federal de Santa Maria* (UFSM) was selected as a backup station. Afterwards a ground station located at INPE CRN in Natal was also include in the operation. All three stations are from INPE and work in a straight cooperation with ITA. These three stations can send commands and receive telemetries of ITASAT. ITA ground operation team is responsible for providing to the other stations regularly the operation plan. Figure 12 shows the real location of the three ground stations inside the Brazilian territory (a) and ITA Ground Station (b).

Once ITASAT makes use of amateur radio frequencies, every amateur radio in the World can receive ITASAT telemetries.



(a) Image created using Google Maps

(b)

Figure 12: (a) Ground Segment and (b) ITA Ground Station

Launch

ITASAT was launched on December 3rd, 2018 from the Vandenberg Air Force Base by a Falcon-9 launcher in the SSO-A flight. This launch was coordinated by Spaceflight, where 64 satellites were placed in orbit, being 15 microsatellites and 49 CubeSats. Thirty-five customers were granted, representing 17 countries. By the time of launch, ITASAT team received the launch parameters and a probable TLE from the launch provider (ISL).

OPM output (generated 2018-12-03-Mon-11-27-21 PST):

- UTC time at liftoff: 337:18:34:05.178
- Mission elapsed time (s): +2594.96
- ECEF (X,Y,Z) Position (m):
  - +298517.975,
  - +1606440.041,
  - -6765323.000
- ECEF (X,Y,Z) Velocity* (m/s):
  - +5498.193,
  - +5090.077,
  - +1448.050
- LVLH to BODY quaternion (S,X,Y,Z):
  - +0.0005875,
  - -0.9999968,
  - +0.0000773,
  - -0.0024395
- Inertial body rates (X,Y,Z) (deg/s):
  - -0.1570641,
  - +0.0477949,
  - +0.0014608
- Apogee Altitude** (km): +582.079
- Perigee Altitude** (km): +559.969
- Inclination (deg): +97.773
- Argument of Perigee (deg): +116.158
- Longitude of the Asc. Node*** (deg): +45.056
- True Anomaly (deg): +165.009

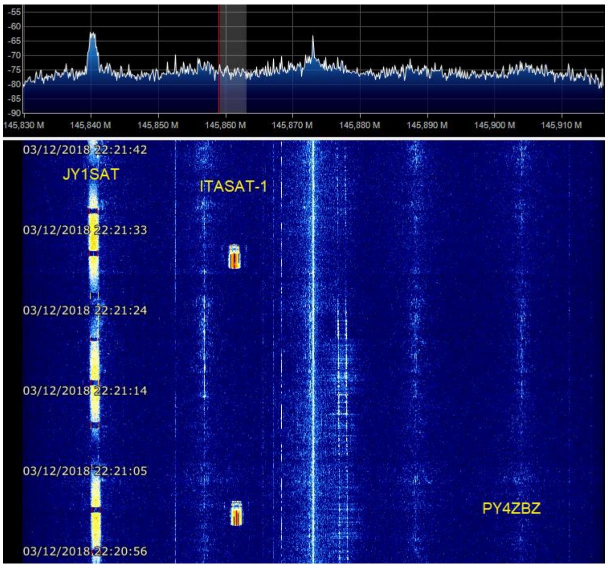
* ECEF velocity is Earth relative
** Apogee/Perigee altitude assumes a spherical Earth, 6378.137 km radius
*** LAN is defined as the angle between Greenwich Meridian (Earth longitude 0) and the ascending node

Results after launch

According to our orbit propagation, after jettison and the requirement to stay 30 minutes in silence, the first telemetry of ITASAT (beacon) should occur in about 3h and 30 minutes from the T_0 (launch event).

By the time, ITASAT should be flying over Europe. In this first pass over Europe, any European amateur radio had noticed the reception of the beacon. At around 10:20 pm (BRST), in the first pass over Brazil, the first ITASAT beacon was received by an amateur radio called Roland (PY4ZBZ). This amateur radio is in the city of Sete Lagoas, Minas Gerais, in the South-west region of Brazil. From this moment, more amateur radios and ground station were able to receive telemetries of our

CubeSat. ITASAT has been operated since then and the payloads commissioning has started.



Source: https://www.qsl.net/py4zbz/itasat.htm

Figure 13: First beacon reception by PY4ZBZ

LESSONS LEARNED

During the project life cycle many lessons were learned in the process to develop, integrate, test and operate ITASAT. Some of these lessons will be present in this section.

Developing approach

On ITASAT, during the development phase, an incremental approach was implemented and used. This approach aided the development process and allowed the verification after each increment, increasing the confidence of the project. This incremental approach was used in the SW development and platform assembly.

Other important aspect was the modular development approach implemented in the project, in addition to the incremental approach. This allowed to isolate functions independently, speeding the development and allowing teams to work in parallel. The modular approach also aided the exchange of parts and facilitate software in the loop development and testing, as well as hardware in the loop development and testing.

The incremental and modular approach was applied in the software architecture as well. The software architecture was defined in layers, since the beginning of the development. Because of this definition, the software development was divided in small parts and layers making it easier to handle the software. Different teams developed the application layer and supplier heritage codes could be adapted for the project necessity. As an example, the DCX-2 code was developed by an amateur radio and integrated in our software in few hours and it is working perfectly in the CubeSat. The key point on this approach was the clear definition of the software interfaces.

Electrical Interfaces for communication

On ITASAT, the main bus for communication among the onboard computer and all equipment and payload relies on I2C. This approach showed us that the I2C have electrical and logical limitations that causes bus overload and bus locking.

Even following all recommendation of cable lengths, pull up resistor location, for several times the team faced problems in the signal reception due to lines capacitance change and electrical changes had to be made. But the main issue was the bus overload and bus locking. Our ADCS system could not be fully tested because in the 3-axis controlled mode there is a bus overload that causes a halt in the I2C communication flux. Consequently, the onboard computer resets the system due to a failure on the I2C line. The function to reset the system was implemented as a Failure, Detection, Identification and Recovery (FDIR) Mechanism.

Late access on the CubeSat

ITASAT has only one connector that concentrates the functions of charging the battery, debug and Apply Before Flight (ABF). No late access for software upload were provisioned, what caused some restrictions to software upload after final integration.

Other issue on the late access connector was its location. On ITASAT the location of the connectors does not prioritized the disassembly, they were placed on the solar panel, so for each disassembly we needed to handle the solar panels, with the risk to cause a damage on it.

On the project, we had a few information regarding the CubeSat dispenser during the development phase and we had to make some assumptions that was not the best solution or best choice for the project. It is recommended that all possibilities be studied to reduce the risks.

Selection of the parts and Procurement

By the time of the development and specification of the parts of the satellite, not all requirements were well defined and not all the characteristics of the parts were well known, and it caused some restrictions afterwards during the development.

As an example, on ITASAT the "sun sensor" was a simple photodiode with a FOV of 60 degrees, that limits the use of the generated data in the ADCS system, causing blind zones where it cannot be determined the sun positioning, reducing the performance of the attitude determination and control algorithm.

On ITASAT project, major project delays occurred due to the delay on the supplier's chain and bureaucracy of the purchase process. Delays on this process (almost) always occur!

Other point included in the procurement is related to the acceptance of the parts. A well-defined and stablished process to accept the parts needs to be implemented in the project.

Communication

One of the biggest issues in any project is the communication, among the developers, with the suppliers, with the payload developers.

However, on ITASAT a close contact and frequent communication with the payload developers allowed us to implement and integrate the experiments with low re-work rate, but it had to be done.

A good channel of communication was also stablished with most of the suppliers, so creating a good network is fundamental to the success of the mission.

AIT process

During ITASAT assembling, integration and tests, specially to the dispenser, we realize that it would be a lot easier (and safer) if we had implemented secure mechanisms and devices for handling the satellite. The reflect of having few information of the dispenser on early phases led us to not consider some restrictions, and we failed in the first fit check.

At the project, the in-house development, due to the lack of time and resources, were not exhaustively tested and it caused minor non-conformities after acceptance tests. These non-conformities had to be managed by the team to be ready for flight.

Before the AIT of the Protoflight Model, we wrote a detailed procedure and this procedure was checked during the assembly stage. This procedure was tested in the Engineering Model.

The cables specifications and cables length were checked using the Engineering Model and 3D printed parts, aiding the team to see the cables routing inside the CubeSat. Each cable has a specification sheet and specific tags to avoid mismatch.

Use of two on board computers

One of the differentials of ITASAT CubeSat is the fact that we have two onboard computers on board. One computer por mission data management and other one dedicated to the attitude control system. This approach brought a lot of challenges to the team, once it was not easy to synchronize the operation of both computers, considering that each computer is the master of the communication in some sort of moment, but it gave to the platform more flexibility to adapt to changes and more flexibility during tests, once it was possible to perform tests separately.

The importance of the System Engineering

According to NASA Systems Engineering Handbook, *"the objective of systems engineering is to see to it that the system is designed, built, and operated so that it accomplishes its purpose in the most cost-effective way possible, considering performance, cost, schedule and risk."*

So, one of the purposes of System Engineering is to anticipate requirements and analyze the solution in all project phases. Even though efforts were applied on system engineering, the team had to learn how system engineering works during the execution of the project, and it led to a lack of efforts in some aspects and excess in other ones, as an example, many efforts were done on system requirements and modeling for developing purposes, but just few observations were done during operation and post integration.

Other example, already mentioned, we had no information about the dispenser internal envelope for the payload (CubeSat) at early stage, and consequently we did not pass in the FIT check at the first time.

Other point were the considerations in the mission analysis. The simulations of the power generation capacity and battery DoD performance where not confirmed during operation. As a result, we faced difficulties to charge the batteries to secure levels for operation, therefore we have resets more often than expected ***or*** designed. In this case it is recommended to include additional margins ***in the analysis***.

The good results of applying system engineering in the project were:

- After some reviews the configuration were baselined, and no changes were made after the project CDR.
- Use of SysML/UML to document the requirements and use cases, it reduced a bit the paperwork and aided the traceability.

- Stablished Document Tree and Configuration Management was implemented.
- Software was documented and configured using GitHub-like repository, aiding the configuration control and version control with no need of paper and manual control.
- AIT procedures were documented and realized by more than one person, doing a double check reducing the margin of error.

Schedule and Risks

From the beginning to the PFM model, the project was developed in two years, but some components were bought in very early stages of the project, increasing the risks of incompatibilities. This decision was made to reduce the impacts of delays on the project, and it showed quite important considering that we had delays on the procurement.

On ITASAT, a simplified risk analysis was performed, and one major risk were the absence of spare parts for all components of the satellite. The other major risk was the human resource, but this risk was successfully mitigated.

Other aspect to be addressed is the shelf life of the satellite. ITASAT shelf-life was longer than expected due to launch opportunities and delays. The battery charge procedures and impacts had to be carried out along the time, but it is clear now that these processes should be carried out in early phases of the project.

Mission Operation

On ITASAT, the main station is located at ITA in São José dos Campos. During the operation, we realize that for many times a coordination with other ground stations improved the operation, and in some cases it was mandatory. At the beginning of the ITASAT operation our station was OFF due some technical problems. We counted on the data provided by amateur radios and partner ground stations. It showed us the importance of having backup ground stations and spare parts to quickly fix problems.

One other point is that the beacon signal of ITASAT is configured by software on ground to be sent in a fixed time interval and there is no possibility to change this interval on flight. For many times we realize that the capability to change this time interval would give us more information when needed and less information in cases we would like to save power.

At the development time, we intended to implement historic log, but for many reasons, ITASAT do not have historic log with the behavior of the observatory over time. We have only beacon information, so we have some lacks in time with no information of the observatory behavior at all. The absence of this information makes a bit more difficulty the analysis of the CubeSat performance.

The team

The team is the heart of the any project, once projects and many other tasks are developed by people for people. The development team was one of the main strengths of this project.

The ITASAT team is located in two offices, close to each other and it improved the speed and quality of the development. This proximity allowed more discussion inside the team and a better understanding of the mutual work package, resulting in a team that knows well its role in the project and the impact of their work in each part, because they are close to the tasks for the whole team.

In the project there was a perceptive improvement after the project incorporates workers with experience on aerospace projects. The mix of expertise of students and professionals lead to a more robust team.

CONCLUSION

Besides all the challenges that the project experienced throughout the years, since its beginning in 2005 until the launch in 2018, including the main change to a CubeSat approach in 2013, the project was very successful in achieving its main objective, that was to train human resources for space projects and also to develop a platform for future missions. Many of the former ITASAT students are now working in the space business or related areas, where the acquired knowledge in the space area creates a competitive advantage. The project helped ITA to establish an aerospace engineering course and improved the competence in this field in Brazil. The project demonstrated also that a 6U satellite can accomplish missions that were before restricted to bigger satellites, like collecting data for several ground platforms around the country. The project showed also that CubeSats are not toys or plug-and-play devices: they can be so complex than bigger satellites, depending on the mission and the solutions that has been chosen. ITA made the choice to complexity, expressed by ITASAT two on-board computers and payed the ´price, expressed by the difficulties with the I2C bus. But exactly the overcome of these difficulties allowed the technical grow of the students involved in the project. The expertise developed by ITA in the design of this 6U platform allowed ITA to propose a joint mission between Brazil and United States, called SPORT to investigate the ionosphere. In this new mission, all lessons learned from ITASAT have been implemented and a more robust platform is under development. The lessons learned comprises things that we did well and things that we decided to change or improve, and tolls that we use and it went so well, that we intend to use in future mission as a baseline or a project standard for the laboratory projects, like the Systems Engineering Methodology.

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References

1. Shibuya Sato, L.H.; Saotome, O.; Timm, C.; Fernandes, D. and Yamaguti, W. "ITASAT-1: Brazilian university microsatellite for payload test and validation in Low Earth Orbit". 8th IAA Symposium on Small Satellite for Earth Observation, Berlin, Germany, April 2011.
2. Shibuya Sato, L.H.; Fonseca, E.; Santos, L.F.P.; Rosa, N.; Januzi, R.; Carnietto, C.; Schedler, E.; Alves, M.; Dagmar, S. "ITASAT-1 – UMA NOVA PROPOSTA DE PROJETO DE PEQUENOS SATÉLITES". XVI Simpósio de Aplicações Operacionais em Áreas de Defesa, São José dos Campos, Brasil. September 2014.
3. Shibuya Sato, L.H.; Fonseca, E.; Santos, L.F.P.; Januzi, R.; Rosa, N.; Schedler, E.; Alves, M.; Carnietto, C.; Ivo. F.; Euphrásio, P. S. "ITASAT Project – The new project philosophy and lessons learned". Proceedings of the 1st IAA Latin American CubeSat Workshop, Brasília, Brasil. December 2014.
4. Kingston, J. "Modular Architecture and Product Platform Concepts applied to multipurpose small spacecraft". 19th Annual AIAA/USU Conference on Small Satellites, August 2005.
5. Cal Poly SLO, "CubeSat Design Specification" r13. Available online and last access in 09/06/2019 <http://www.cubesat.org/index.php/documents/developers>
6. Carrara, V.; Januzi, R.; Makita, D.; Santos, L.F.P.; Shibuya Sato, L. H. "The ITASAT CubeSat Development and Design" Journal of Aerospace Technology and Management, Vol.9, No 2, pp.147-156, São José dos Campos, Brasil, April/June 2017
7. Albuquerque, G. "Construção e Validação de um receptor GPS para uso espacial". Master Thesis. Universidade Federal do Rio Grande do Norte, Rio Grande do Norte, Brasil, 2009.
8. Raposo, T. "Desenvolvimento e Testes de Software de um receptor de GPS para uso espacial" Master Thesis. Universidade Federal do Rio Grande do Norte, Rio Grande do Norte, Brasil, 2011.