VCUB1 Conception of Operation

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***Abstract*—VCUB1 is the first Earth observation and data collection satellite designed by the Brazilian private sector. It is a 6U nanosatellite, launched in April 2023, whose main payload is a 3U optical camera with a 4096 CCD with 16-stage TDI, which provides images in 4 bands (G, R, Red Edge and NIR). The VCUB1 mission successfully validated Visiona Technology developed software of three critical subsystems: Attitude and Orbit Control System (AOCS), On-Board Data Handling (OBDH) and Software Defined Radio (SDR). The OBDH was built over the NASA cFS framework, a modular software that allows different applications to be created according to the mission of each satellite and reused for new missions. In accordance with the activities described in the VCUB1 Concept of Operation (CONOPS), applications were created in the flight software to support and facilitate the performance of the operation. In these applications, automation was implemented to manage the satellite's behavior according to its current mode, using the MMG (Mode Management) application, and to manage the satellite's tasks according to its current position in relation to the Earth, using the WGS (World Geodetic System) application. In addition, using the tools provided by cFS and the satellite's equipment mechanisms, FDIRs (Fault Detection, Isolation and Recovery) were implemented to automatically deal with possible satellite faults. In the ground segment, procedures were created to make up the operation plan, which were improved throughout VCUB1's useful life. In addition, to optimize the operation, a script was developed to execute the procedures automatically. The operation and in-flight improvements made to VCUB1 provided Visiona's teams with a great deal of learning for new projects, and enabled VCUB1 to fulfill its mission until it was decommissioned.**

***Index Terms*—operation, automation, satellite, ground, software**

I. Introduction

VCUB1 is the first Earth observation and data collection CubeSat designed, developed and launched by a Brazilian private company [3]. VCUB1 is a 6U nanosatellite, launched in April 2023, whose main payload is a 3U optical camera with a 4096 CCD with 16-stage TDI, which provides images in 4 bands (G, R, Red Edge and NIR). A secondary payload is the Software Defined Radio (SDR) subsystem. VCUB1 platform is composed of: AOCS (Attitude and Orbit Control System), EPS (Electrical Power System), OBDH (On-Board Data Handling), TMTC (Telemetry and Telecommand), STC (Structures), and TCS (Thermal Control System).

The goal of the VCUB1 mission was to demonstrate in flight critical strategic technologies such as Attitude and Orbit Control System, On-Board Data Handling System and Software Defined Radio Payload. Additionally, to validate Visiona expertise in system engineering methods such as MBSE (Model-Based System Engineering). [1]

With the VCUB1 space system, as shown in 1, the Concepts of Operations (CONOPS) was established to specify the whole system operations, especially for the satellite operational modes and ground system operation capabilities, as well as all requirements for each life cycle phases, from Launch and Early Phase (LEOP) to Decommission phase.

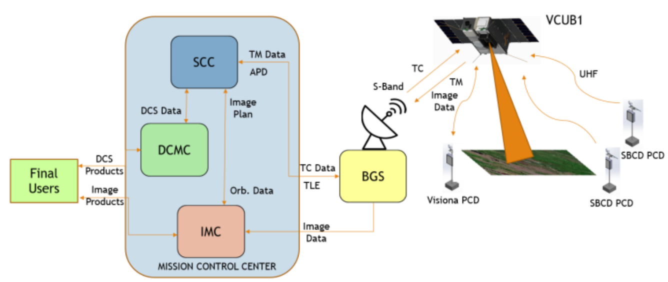

Fig. 1. VCUB1 System Overview.

VCUB1 CONOPS provides high-level requirements for satellite and ground operations, defining operational concepts. This concept of operation and automation considered the idea of not only creating useful data for stakeholders but also providing a user-friendly interface for operations. This paper aims to present these operational concepts and automations.

VCUB1 inside ION SCV010 Orbital Vehicle Transportation was launched successfully on April 15, 2023, by the SpaceX Falcon-9 Transporter-7 mission from Vandenberg. VCUB1 satellite separation from ION SCV010 was performed on April 22, 2023. Up to its reentry on January 26, 2025, VCUB1 provided an invaluable experience to Visiona, in validating the critical technologies in orbit and lessons learned in satellite development and especially in-flight operations.

II. On Board Data Handling Satellite Management

Most of the automatism implemented in the satellite is provided by the OBDH, which is responsible for managing the other satellite subsystems and their failures. The OBDH software was developed based on the cFS (core Flight System) NASA framework. [7]

The main components of the cFS architecture are:

- Platform Support Package (PSP): It provides the interface to the supporting hardware platform. [6]
- Operating System Abstraction Layer (OSAL): unties the software from specific operating systems, allowing the software to be portable. [6]
- Core Flight Executive (CFE): The main applications that facilitate the programming of other applications and communication between processes. [6]

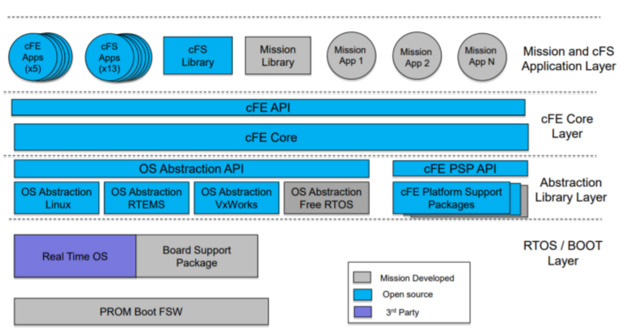

Fig. 2. cFS architecture. [7]

In addition to these components, cFS provides other applications, represented as cFS Apps in 2, to manage files, data storage, and errors, for example. And mission applications refer to the applications developed for each mission.

The mission applications developed by Visiona are divided into three groups, as shown in 3. The platform applications refer to the apps responsible for managing the behavior of the other subsystems that compose the satellite platform, such as AOCS and TMTC, and the behavior of the entire satellite, as defined in CONOPS, implementing automatism in the MMG and WGS applications that are presented in more detail in the next subsections.

The Hardware Abstraction Layer applications are composed of applications that interface the OBDH with others VCUB1 subsystem equipments. Finally, Payloads Apps are the applications that manage the satellite's payloads (Optical Camera and SDR). The modularity of the cFS architecture and the way the mission applications were implemented were the key to successfully updating and improving the software.

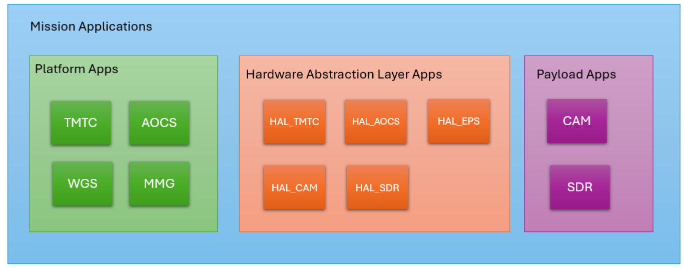

Fig. 3. VCUB1 Mission Applications.

A. *Mode Management Application (MMG)*

Mode Management is an application designed to manage the satellite's behavior in each phase defined in CONOPS. As specified, the following modes are implemented:

- ATB (Avionic Test Bench) is a mode used only to perform tests on the ground.
- MCM (Minimum Configuration Mode) is the initialization mode that VCUB1 enters after launch. Its function is to deploy solar panels. This operation is checked three times, if it works, it changes mode immediately and if not, after the last check, the satellite automatically enters in DTM (Detumbling Mode).
- DTM is a safe mode where is used to de-spin the satellite to acceptable residual angular speed and to stabilize it in 2 axes. One of the satellite axes (Y) will be aligned with the orbit normal axis, while the other 2 axes rotate roughly twice per orbit. And, in this mode, VCUB1 is constantly transmitting telemetry through a pulsed beacon to enable the ground segment to track the satellite.
- MPM (Magnetic Pointing Mode) is a power positive and safe mode, in which the satellite can remain for long periods of time, with the payloads turned off. The satellite is then stabilized in a nadir pointing configuration. To stabilize all 3 axes, it uses orbit knowledge, magnetic sensors, and magnetic actuators.
- FCM (Fast Charge Mode) is a safe mode that is used to stabilize the spacecraft in all 3 axes. The main difference from MPM is that the satellite solar panels are pointed orthogonally to the Sun's direction to generate the maximum amount of power. Orbit knowledge, magnetic sensors, and magnetic actuators are also required for attitude determination and control. While in eclipse, the satellite is nadir pointing to assure that the Camera and radiators are not pointed to deep space, preventing them to be too cold.
- SBM (Stand-By Mode) is a nominal mode in which the satellite waits to perform payload tasks. It is very similar to FCM in that, while illuminated by the Sun, the satellite's solar panels are also pointed orthogonally towards the Sun to generate maximum power. In the eclipse, the satellite is also pointing towards the nadir, but to ensure thermal stability. The satellite also points towards nadir when it passes a ground station to improve

the communication link. In addition, the camera remains in stand-by mode to maintain the camera temperature operational range.
- EEM (Earth Exploration Mode) is the mode in which the payloads are turned on. The satellite performs push-broom imaging with the camera payload and/or performs data collection mission with SDR payload. In this mode, the downlink of imagery data to the ground station also takes place, since the SDR is used for the downlink.

As mentioned above, the transition between MCM and DTM modes is automatic, as shown in 4. The transition from bottom to top between the other modes takes place by command. The top-down transitions to the safety modes are made automatically by the FDIR (Fault Detection, Isolation and Recovery) mechanism. And the transition from EEM to SBM mode is done automatically after the payload operation has finished.

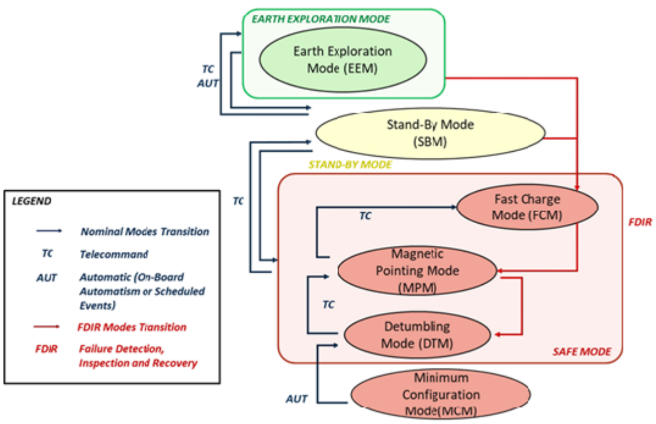

Fig. 4. VCUB1 Modes Transition.

Before performing any mode transition, the MMG checks if the satellite's status complies with the requirements for performing it.

B. Worldwide Geodetic System Application (WGS)

The WGS is an application responsible for managing the actions performed by other applications according to the satellite's position or Earth region. A polygon could be uploaded to describe the Earth region where the actions should be performed. Based on the coordinates provided by the AOCS, the WGS runs an algorithm that checks whether the satellite is inside or outside these predefined regions and, if the satellite is leaving or entering that region, it notifies the application associated with that region. This functionality allows other applications to act based on the satellite coordinates, making the WGS app an essential component of the satellite operation and automation.

The WGS was used mainly to notify the application responsible for image data transmission and Telemetry and Telecommand (TMTC), that the satellite is passing over a ground station. In this way, the transmission of telemetry was automatically enabled on all booked passes. Another use of WGS was to set up a Brazilian region where data collection service should be turned on by the SDR payload, as shown in 5. WGS app ability to determine the satellite's coordinates and communicate them to other apps was critical to the success of the VCUB1 mission.

Fig. 5. STK illustration of Brazil region for data collection operations.

III. Fault Detection, Isolation and Recovery (FDIR)

In any space project development, it is necessary to consider possible failure in parts or even in subsystems. These failures can compromise the system functions or even cause irreparable damage to the mission. Due to the criticality of this situation, fault handling functions are necessary to meet the autonomy, reliability and availability needs of a mission. The FDIR functions are to detect, isolate and recover from faults that could affect the nominal operation of the mission.

The philosophy adopted by VCUB1 for the FDIR mechanism is to categorize faults by subsystems and satellite modes. Accordingly, a group of FDIRs has been defined and classified as either Hardware (HW) or Software (SW) for each subsystem, where a hardware failure is directly associated with the equipment, and a software failure is indirectly associated with the equipment or the software itself. Additionally, FDIRs have been applied to each satellite mode. FDIR implementation considers the follows statements:

- FDIR disable checks when attempting to recover from it;
- The FDIRs cannot generate other failures;
- Different FDIR per mode;
- Some FDIRs are global, applicable to all modes. They are MM (Multi Mode);
- No FDIR should cause deadlocks, loops or damage the satellite in any way;
- Acknowledge of commands to HW will be described case by case. All hardware TM should be observable.
- A failure must be handled by only one FDIR;
- Some counters will be needed to check some AOCS Core flags. These counters should have tunable parameters and reset capabilities;
- All information should be checked for a time interval to ensure that no false positives are generated;
- The satellite must have at least one safe mode;
- The mode transitions performed by the FDIRs must be done gradually, as shown below:
  - MPM to DTM;
  - FCM to MPM;
  - SBM to FCM;
  - EEM to FCM.

In the VCUB1 mission, 93 FDIRs were implemented by software using two cFS applications, 78 by Limit Checker (LC) and 15 by Health and Safe (HS). The applications are described in more detail in the following subsections. Some FDIRs were also used and implemented in hardware, especially to preserve communication between the satellite and the ground station, which will be presented in the last subsection of this section.

A. Limit Checker Application (LC)

The LC application is responsible for monitoring the telemetry data points and comparing the value with the predefined limits. When a limit condition is found, the LC registers it as a fault. If the number of consecutive faults exceeds the predefined number of cycles, the LC sends a message and, optionally, starts a sequence of commands, an RTS (Relative Time tagged command Sequences) table. [2]

LC design is built around two fundamental structures: the watchpoints and the actionpoints, as shown in 6. [2]

A Watchpoint (WP) defines a comparison between the telemetry data and a predefined constant. Watchpoints are defined in the Watchpoint Definition Table (WDT). The statistics of the WP evaluations are stored in the Watchpoint Results Table (WRT). [2]

An Actionpoint (AP) defines the response that the LC will have based on the current state of one or more WPs, which are acquired by the WRT table. APs are defined in the Actionpoint Definition Table (ADT). To process the WP states, at least one logical operator is required. APs are evaluated whenever the LC receives a wake-up message from Scheduler Application (SCH). The evaluation statistics are stored in the Actionpoint

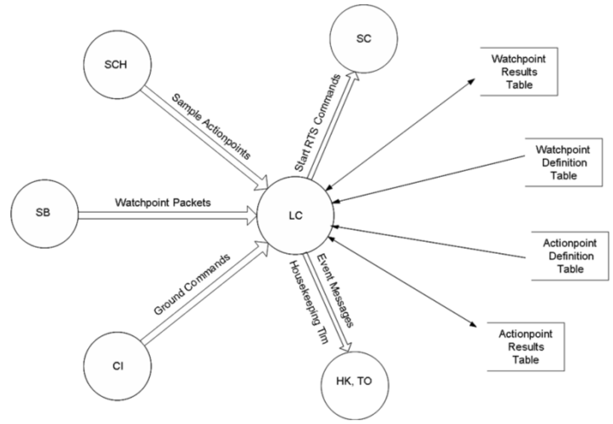

Fig. 6. LC architecture. [2]

Results Table (ART). The tables containing the definitions can be updated by the ground operators, and the tables containing the results can be downloaded for analysis. [2]

Figure 7 shows an example of the Watchpoint and Actionpoint mechanisms actuation within LC app used for FDIR implementation. In this example two conditions are violated that are defined in Watchpoint #3 and Watchpoint #7. In the Actionpoint #16, failcnt is increased by 1 as the polish expression is true, LC sends a stored command to trigger RTS #10. [2]

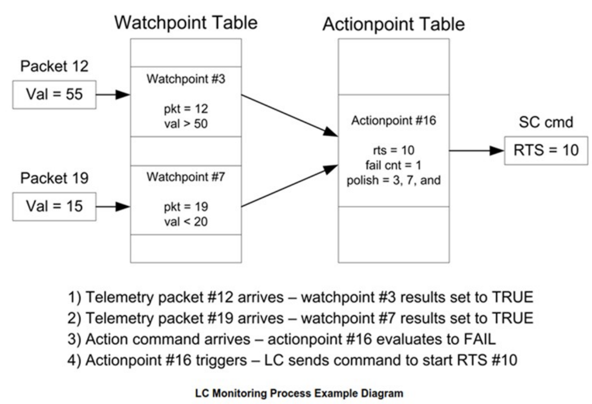

Fig. 7. LC example. [2]

Furthermore, an API to control the FDIRs has been implemented in the Satellite Control Center Real Time System (RTS), allowing for disabling or enabling of specific FDIRs with the FDIR ID as input. There is also a function to disable or enable all FDIRs.

B. Health and Safety Application (HS)

To ensure that the subsystem is working well, it is necessary to ensure that the applications that manage it are also working well. A cFS feature was used, the Health and Safe (HS) application. It provides an application monitor that checks whether the application is working and, if not, restarts the application. However, as it is not necessary for all applications to be running in some satellite modes, to reduce the OBDH processing consumption, the HS has been improved by adding a filter so that the monitor only acts in the modes in which each application should be running.

C. VCUB1 Hardware Failure recovery

The main functionality of the space system design to complete the mission successfully is the communication between the satellite and the ground stations. Low-orbit satellites, like VCUB1, must not transmit all the time, but whenever there is a pass over an available ground station it must be able to receive commands. If this functionality of the satellite is obstructed, two main possibilities were considered: the transmitter has been damaged, or the OBDH has crashed.

In the first case, a feature of the EPS battery was used, which has a watchdog, whereby if no telecommands are received within 24 hours, the satellite is rebooted.

This reboot functionality was also implemented by the eMCU, a very simple and reliable independent hardware capable of receiving some telecommand types. If after 72 hours, no Telecommand is received on board, the satellite is rebooted. Initially, we could consider that it would never be triggered due to the battery watchdog, but automation has been implemented to update the battery watchdog. So, if this automation was triggered on the satellite to update the battery watchdog, the eMCU watchdog would be the one to act.

In the second case, due to the independence of the eMCU from the OBDH, a special command received from the ground can restart the satellite at the time.

IV. VCUB1 Ground Segment

Ground Segment consists of all the ground infrastructure and communication equipment associated with the fixed and transportable stations. This segment enables commanding and tracking the satellite, receiving and processing telemetries, as well as distributing the information to controllers and end users. [4]

VCUB1 Ground Segment is composed of two main components:

- Mission Control Center (MCC);
- Ground Station (GS) network.

The VCUB1 Mission Control Center was fully structured and installed at the Visiona premises in São José dos Campos, SP, Brazil. MCC integrates the three main centers: Satellite Control Center (SCC), Image Mission Center (IMC), and Data Collection Mission Center (DCMC).

SCC is composed of the Real Time System (RTS), Flight Dynamic System (FDS) and a Dynamic Satellite Simulator (DSS). RTS is based on the Cosmos command and control provided by Ball Aerospace. Cosmos includes data visualization features for embedded systems, used during the satellite's assembly, integration, and testing phases, as well as during its operation in orbit [5]. To improve the Telemetry visualization on SCC, a Grafana dash boards are created using Cosmos received CCSDS Telemetry packets, as shown in 8.

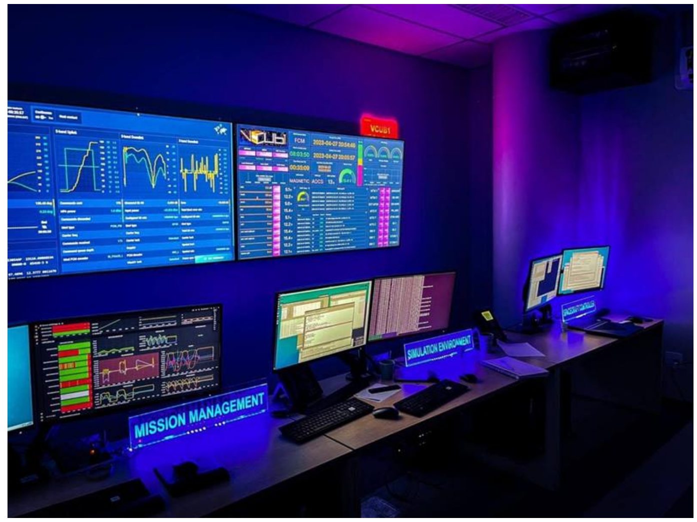

Fig. 8. VCUB1 Mission Control Center.

The Image Mission Center is composed of three subsystems: Image Mission Planning System (IMPS), RIFS (Raw Image Formatting System), and Raw Image Processing System (RIPS). This set of subsystems completes the full VCUB1 imaging processing chain, from planning to the final image processing, distribution to clients, and storage of both raw and processed images.

The Data Collection Mission Center aims to plan the data collection by the satellite, obtain the collected data by the Data Collection Platform (PCD) network installed on ground and transmitted to the satellite, process the raw files, and display them in a human-readable format.

For the VCUB1 mission, the ground stations were contracted as a service provided by KSAT, a total of 4276 passes were booked since LEOP until VCUB1 reentry, 764 to downlink data and image, and 3503 to TMTC operation. MCC connects to the ground stations though VPN and by using provided APIs to station base band connection enabling telemetry reception and telecommand transmission. The ground stations are in Svalbard (North Pole) and in Troll (South Pole), allowing satellite operations to occur both during the day and throughout the night.

For image downlink, the receiving process is automated, and the received images are stored in FTP (File Transfer Protocol) for later search.

The next subsection describes the activities carried out during the week in the nominal operation of VCUB1, according to the activities defined in CONOPS, and some of the tools that were used to facilitate and reduce errors in the operation. The last subsection describes the automation implemented on the ground to reduce the need for manual operation.

A. Operation Plan

The VCUB1 operation was basically divided into two periods. During the day, daily or weekly operations and tests were carried out, while at night, the downlink of images, data collected from the PCDs downlink, and telemetry downlink took place. The operation was divided in this way to optimize the human resources needed, for the daily and weekly activities and tests, it was necessary to have an operator to monitor the satellite's health via real time telemetries and send the required commands for each activity. For the downlink of images, data, and telemetries, however, there was no need for a person to be present at the MCC, as these activities were planned via uploaded tables or automatic operations, which are further detailed in the next section.

Due to this operation organization, daily planning was essential. During the first passes of the day, the mandatory daily or weekly activities were performed, such as uploading the TLE (daily) and resetting the OBDH (weekly). At the same time, an analysis of the telemetries downloaded during the night was carried out so that new tests could be planned. Additionally, the images downloaded overnight were processed to plan what would be downloaded the following night.

VCUB1 typical daily operations:

- Synchronization of the satellite's time with real-time (daily);
- TLE update (daily);
- Reset of the EPS WatchDog (every 24 hours);
- Reset of the EMCU WatchDog (every 72 hours);
- Reset of the OBC (weekly);
- Degauss (weekly).

Due to the number of processes carried out during the VCUB1 operations, scripts were created to minimize operational errors and facilitate the process. Around 160 scripts have been created, some of them for contingency, or for specific phases in the life of VCUB1, LEOP (Launch and Early Orbit) and IOT (In-Orbit Tests Phase), for example, and around 70 just for flight software updates.

These scripts contained all the necessary commands to perform a single activity or a set of activities. Each script included comments specifying the script version, the person responsible and reviewer of the script, constraints, contingencies, and the time required to run the script. The initial commands each procedure always involved checking the version being executed and synchronizing the command's counter of ground with the command's counter of satellite. Only after these checks were the commands for the main activity sent. Once completed, a message was displayed to the operator indicating that the script had finished successfully, along with the time it took for the script to execute completely. Before each pass, all the necessary scripts for that pass were opened and arranged in the order of execution.

The first mandatory actions in every pass were to connect with the contracted station base band, turn off the modulation, turn on the carrier, and then turn on the carrier sweep. Afterward, the modulation was turned on and it was checked if the lock was acquired on board, followed by verifying if valid telemetries were being received at the MCC, and finally, turning off the carrier sweep. All these commands were executed in a single script.

The Svalbard ground stations have less obstacles for signal reception compared with the Troll stations. As a result, the Svalbard stations were used for the image and data collection downlink. Another reason for using these stations for these activities was the time when these stations had a higher elevation angle to establish the communication link with VCUB1, which occurred during the night with automated receiving process without the need of operators.

The optical images were downloaded in lines, with a minimum size of 600 lines and a maximum of 30,000, which corresponds to an image length of 105 km. The images can be acquired in different lengths if the number of lines is a multiple of 600 with 14.5 km swath. In one pass, it was possible to download up to 30,000 lines; however, some lines might be lost due to interference or interruptions in the link between the satellite and the ground station. In such cases, those images lost lines are included in the operation plan to be uploaded in the next pass opportunity or next night.

The VCUB1 image transmission is performed by the SDR payload. To carry out the downlink, the following steps were necessary: turn on the SDR, set it to the downlink configuration, turn on the S-band antenna used for the image downlink, start the downlink, send the lines that needed to be downloaded, then stop the downlink and turn off all equipment that was used for the operation.

All these commands could be programmed to be executed according to either relative or absolute time within a table uploaded to the satellite during a telemetry and telecommand pass.

The RTS contained all the fixed commands, such as those for turning on and off the SDR and the S-band. The time interval between turning on and off the equipment was calculated based on the maximum possible time for downloading the image lines.

The ATS contained the command to start the RTS and the image lines to be downloaded during that pass. Thus, the ATS was set with the absolute time of the pass, starting the RTS with the commands sent relative to the first command. With this planning, it was possible to perform multiple downlinks within a single ATS, requiring only one ATS to be uploaded per day, since the RTS was already stored in the satellite's memory. The planning of imaging, image transfer, data collection, and the downlink of collected data were done in a manner like the image downlink, allowing different activities to be included in the same ATS.

Using these tools, it was possible to acquire 489 images, totaling approximately 500,000 km^2, over the entire lifetime of VCUB1, and download them in approximately 764 passes.

B. Operation Automation

Initial operations considered only Svalbard ground stations. Due to VCUB1 sun synchronous orbit and Svalbard station locations, the VCUB1 satellite passes with elevation over 15 degrees and occurs between 10 PM to 6 AM requiring the operators to work in night shifts. Furthermore, operations took place every day, including weekends.

To optimize the VCUB1 operations with operators working only during business hours, additional ground stations located in Troll were contracted and automation systems were implemented for night and weekend operations.

As mentioned in the previous section, the image and data downlink, data collection, imaging, and transfer were already automated, requiring no operator intervention, simply using the ATS and RTS tables, along with assistance from the regions created in WGS.

Thus, automation focused on operations that still required an operator, such as telemetry downloads, resetting the watchDogs, and uploading the TLE.

A script was created in which the pass times and the scripts that needed to be executed for each pass could be specified. When the automatic script is started, it checks the time of the next pass and starts a countdown. Once the countdown reached zero, the automatic script ran all the scripts set for that pass in order. Each script could be executed up to three times in case of a loss of communication with the ground station. If the issue persisted after three attempts, the next script would begin. Once all planned scripts were completed, the automatic script would check the time of the next pass and restart the countdown.

Another form of automation, used for weekends, was the resetting of the EPS WatchDog via an RTS table every 12 hours over a period of 3 days. This way, it was only necessary to start the RTS table on Friday, and throughout the weekend, the WatchDog would be reset every 12 hours, preventing the satellite from resetting during the weekend.

Conclusion

The success of the VCUB1 mission is not only the result of the work carried out before the launch, but also since its conception and throughout the satellite's operation. From the Day In the Life test to the decommissioning of VCUB1, improvements were made to the ground procedures, which facilitated the operation. During the flight, updates were made to the flight software: 53 critical software updates, 1020 AOCS configuration modifications, and 1596 application and RTS table updates. As a result of these updates, the automation was enhanced to the point where it was a success throughout the operation phase.

The operation of the VCUB1 satellite involved a series of complex and well-structured processes, focused on ensuring efficiency and continuity of activities both during the day and at night. From the start of operations, it was clear that automation would play a key role in optimizing human resources and reducing the need for manual intervention. The implementation of systems such as automated scripts, ATS and RTS tables, and the use of Troll ground stations allowed operations to be carried out during business hours with on-site controllers, and night shifts and weekends with no on-site controllers, without compromising the quality and performance of satellite operations. The use of automation was also crucial for managing critical activities, such as the image and data downlink, stored telemetry files downlink, and watchDog resets.

The detailed planning, combined with an effective task distribution strategy between Svalbard and Troll stations ensured continuous coverage and maximum utilization of available time for each pass, without overloading the operating team. With the integration of automated processes, the VCUB1 mission was able to meet daily and weekly operational requirements efficiently, ensuring uninterrupted data transmission and satellite monitoring.

Furthermore, the automation process helped minimize operational errors and increase operational reliability, highlighting the importance of a well-designed and integrated system for the success of complex space missions such as VCUB1.

VCUB1 in flight operation brought invaluable experience to Visiona teams in terms of lessons learned for future satellite development and its operations. All hardware reset mechanism and software FDIR automatism proved its value for satellite survival, enabling additionally software and firmware correction updates. It is worth mentioning the constant operation script evolution since LEOP meets operation restrictions such as operation cost reduction, business hour operation with increasing operation automation keeping reliable mission execution.

References

[1] FORTESCUE, Peter W.; STARK, John; SWINERD, Graham. Spacecraft systems engineering. 4th ed. Hoboken, N.J: Wiley, 2011.

[2] GARY, M. Smith. CFS LC Application's User Guide. Available at: https://github.com/nasa/LC/blob/main/docs/users_guide_historical/cFS Accessed on: 09 apr. 2025.

[3] AYALA, Paloma. Aqui tem selo Embrapii: nanossatélite 100% nacional tem resultados significativos. Embrapii. Available at: https://embrapii.org.br/nanossatelite-100-nacional-tem-resultados-significativos/. Accessed on: 28 mar. 2025.

[4] RODRIGUES, J. E. O. Processo de Referência para o desenvolvimento da arquitetura de uma estação terrena para pico e nanosatélites. Master's Thesis — Institute of Space Research (INPE), 2016.

[5] BALLAEROSPACE, Requirements and Design. Available at: https://ballaerospace.github.io/cosmos-website/docs/v4/requirements. Accessed on: Mar 30, 2025.

[6] NASA, core Fligth System (cFS) — Goddard Engineering and Technology Directorate. Available at: https://https://etd.gsfc.nasa.gov/capabilities/capabilities-listing/cfs/. Accessed on: Apr 03, 2025.

[7] MIRANDA, D.J.F., FERREIRA, M.G.V., KUCINSKIS, F. Proposta de processo de desenvolvimento de software embarcado para satélites utilizando o padrão opensource cFS/NASA. Workshop em Engenharia e Tecnologia Espaciais, 2018.