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YPSAT - ESA YOUNG PROFESSIONALS SATELLITE: FROM CONCEPT TO OPERATIONS

Marília de Almeida C. Matos [a] *, Riya Mody [a], Peter Stoeferle [a], Felix Abel [a], Tuur Strobbe [a], Antonin Boulnois [a], Philemon Jongen [a], Lasse Fredagsvik [a], Vincent Conings [a], Tobias Valero [a]

[a] *European Space Agency (ESA), marilia.matos@ext.esa.int*
* Corresponding Author

Abstract

On the 9th of July 2024, aboard the Ariane 6 inaugural launch, the ESA Young Professionals Satellite (YPSat) provided videos of the fairing separation, deployment of several CubeSats and in-orbit views of Earth. In addition, it measured Earth's magnetic field along the launch trajectory by integrating OSCAR-QUBE+, an innovative quantum-based sensor. YPSat is an educational initiative led by Young Professionals at The European Space Agency (ESA), aimed at gaining hands-on experience with space engineering and fostering cooperation with the space community.

A custom made 'Wake up System', fully designed by Young Professionals, activated the payload 40 seconds into the launch by detecting lift-off independently from the launcher. This initiated an on-board sequence to power-up the satellite. The recording of videos and images in flight was fully autonomous with a pre-defined timeline, with no telecommand capability from the ground. These videos and images, along with magnetometer data, were downlinked during a single pass which corresponded to the second orbit of the launcher upper stage over Europe. This pass was YPSat's only chance to downlink the mission data through a 2.44 GHz radio-amateur S-band link using the DVB-S2 standard.

YPSat's Concept of Operations involved several unique aspects and challenges. One of the most challenging aspects was the fact that the payload remained attached to the upper stage of the launcher throughout its lifetime. The single patch antenna was subject to a barbeque roll of the launcher upper stage resulting in YPSat pointing its antenna at Earth for only a fraction of the single pass, considerably narrowing the downlink window.

With a network of 11 supporting Ground Stations across Europe and South America, the YPSat Telecommunication team successfully recovered all the data necessary to achieve the mission's objectives. During the mission, several re-calculations were performed to fit two-line element sets to the trajectory of Ariane 6. This data was subsequently shared with the collaborating ground stations to adjust their pointing strategy and track YPSat during its flight onboard Ariane 6. Ground stations were requested to record raw data, which was subsequently decoded and used to reconstruct the captured images and videos.

YPSat is a first-of-its-kind mission from the Young ESA community, it achieved mission success after its relatively short project life cycle compromising two years of development. This was not only thanks to the commitment of the Young Professionals of the project, but also from the wide range of support received from a diverse set of ESA experts, including from ESA's Directorate of Operations.

Keywords: Young Professionals, ESA, Ariane 6, CubeSats, Ground Stations, Control Room, Launcher Tracking, Operations, Wake-Up System

Acronyms/Abbreviations

A6/A62	Ariane 6	**MLI**	Multi-Layer Insulation
AMSAT	Amateur Radio Satellite Organization	**MPEG**	Moving Picture Experts Group
AoS	Acquisition of Signal	**MPEG-TS**	MPEG Transport Stream
BBQ	BarBeQue	**OBC**	On-Board Computer
C&DH	Computer & Data Handling	**OBDH**	On-Board Data Handling
CRC	Cyclic Redundancy Check	**PC**	Personal Computer
DVB-S2	Digital Video Broadcasting Satellite 2nd Generation	**PCM**	Phase Change Material
EPS	Electrical Power System	**PoC**	Point Of Contact
ESA	European Space Agency	**QPSK**	Quadrature Phase-Shift Keying
ESEC	European Space Education Centre	**RHCP**	Right Hand Circular Polarization

ESOC	European Space Operations Centre	**SSTV**	Slow Scan TeleVision
ESTEC	European Space Research and Technology Centre	**SPP**	Space Packet Protocol
FTP	File Transfer Protocol Secure	**STS**	Space Transportation Systems
G/T	Gain-to-noise-Temperature	**TCS**	Thermal Control System
GS	Ground Station	**TEC**	Technology, Engineering and Quality
GSN	Ground Station Network	**TLE**	Two Line Element
HPBW	Half-Power BeamWidth	**TOV**	Time Offset Value
ITU	International Telecommunication Union	**TT&C**	Telemetry, Tracking and Command
ISM	Industrial, Scientific and Medical	**UDP**	User Data Protocol
KISS	Keep It Simple, Stupid	**VIRAC**	Ventspils International Radio Astronomy Centre
LHCP	Left Hand Circular Polarization	**WUS**	Wake-Up System
MA	Mission Analysis	**YPSat**	Young Professional Satellite

1. Introduction

The Young Professional Satellite (YPSat) represents a first-of-its-kind mission initiated in December 2021 at The European Space Agency (ESA), following a proposal by a group of Young Professionals at ESA to include a payload on the inaugural flight of Ariane 6 (A6). Faced with an ambitious development period of two years, the team adopted the "Keep It Simple, Stupid" (KISS) design principle to expedite development while ensuring reliability and mission success on July 9th, 2024, aboard A6. YPSat successfully captured and transmitted videos of the fairing separation, the deployment of several CubeSats, and in-orbit imagery of Earth. Additionally, it measured Earth's magnetic field along the launch trajectory using an innovative quantum-based sensor.

This paper aims to present YPSat’s Concept of Operations, design choices and actual operations during its short mission onboard A6, which involved several unique aspects and challenges.

2. YPSat Mission and Space Segment

2.1 Mission Objectives

YPSat is an educational project developed by ESA Young Professionals with the aim to gain hands-on experience in creating, planning, developing and operating a space mission [1] [2]. YPSat was launched on the inaugural flight of Ariane 6, with the primary technical objective of capturing critical phases of the launch, including fairing separation, CubeSat deployment, and in-orbit imagery.

2.2 Mission Profile

YPSat features a challenging mission profile and timeline, depicted in Figure 1, planned to last approximately three hours, as it stays attached to the upper stage of the Ariane 6 launcher during the full duration of its short mission. Furthermore, YPSat does not feature a Telecommand uplink, *i.e.*, all operations had to be pre-programmed and triggered autonomously during the flight.

34 days before the launch, the YPSat was integrated on the Ariane 6 upper stage, and the Wake-Up System (WUS) was activated to detect the launch. Typical payloads are dormant during launch and ascend and get switched-on by a signal from the launcher at or shortly after deployment. In case of YPSat, with one of the mission objectives being the recording of the fairing separation, the spacecraft needed to detect the launch to power on prior to the signal from the launcher. This was accomplished by means of a custom designed Wake-Up System (WUS) further described in [3], [4], and section 2.3.1 of this paper, that activates the OBC and allows the recording of fairing separation.. Should the launch detection by the WUS fail, YPSat would be waken-up by the launcher activation signal. The payload separation of several CubeSats carried aboard Ariane 6 would be the next event captured on video by YPSat, followed by several images of Earth being taken. During the early launch phase, the OSCAR-QUBE+ magnetometer was also activated to measure the earth’s magnetic fields throughout the atmosphere. YPSat imaging and measurements would be completed during the first orbit. In the second orbit YPSat would downlink its collected data during a single pass over Europe, before burning up over the Pacific Ocean during the last part of the second orbit. Additionally, GENESIS-A, a ham radio enabling amateur radio enthusiasts to directly connect with YPSat during flight was activated during the second pass.

Having only a single pass of some tens of minutes to downlink the data is challenging in itself. Given that the satellite is attached to the Ariane 6 upper stage, YPSat had no attitude control at the time of downlinking. During this time, the upper stage would perform a ‘BBQ-roll’ for thermal balancing with a rate of around 1 degree/second. However, the phase and exact rate of this roll were not known to YPSat. This BBQ roll meant that during the pass, the single S-band patch antenna would only face towards Earth and the Ground Station (GS) for a fraction of the time making the single shot communications window even smaller. Sections 3 and 4 of this paper describe how the design of Telecommunications sub-system and YPSat Ground Segment successfully responded to this uniquely challenging mission profile.

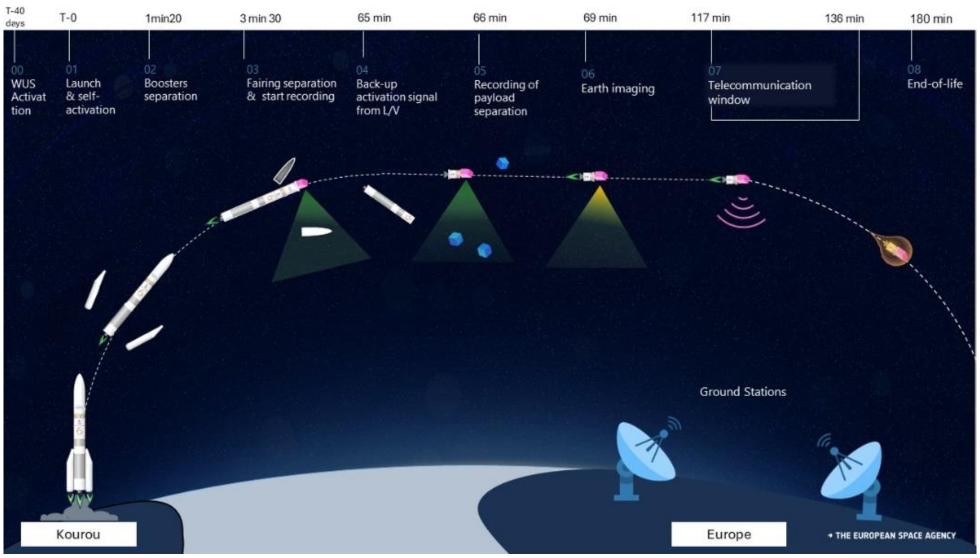

Figure 1: YPSat Concept of Operations, adapted from [5]

2.3 Spacecraft Design Overview

The YPSat architecture consists of three main segments as presented in Figure 2: the launch segment, space segment and ground segment.

- **Launch Segment:** It is provided by Ariane 6, developed by ArianeGroup and operated by its subsidiary Arianespace. YPSat remains attached to the upper stage of Ariane 6 throughout the mission.
- **Space Segment:** It comprises the YPSat spacecraft, which includes a Scanway Imaging System, an OSCAR-QUBE+ magnetometer, and a GENESIS-A ham radio to capture key events and scientific data.
- **Ground Segment:** It includes several ground stations across the YPSat’s visibility path that are responsible for receiving the downlinked data from YPSat during its single data transmission pass.

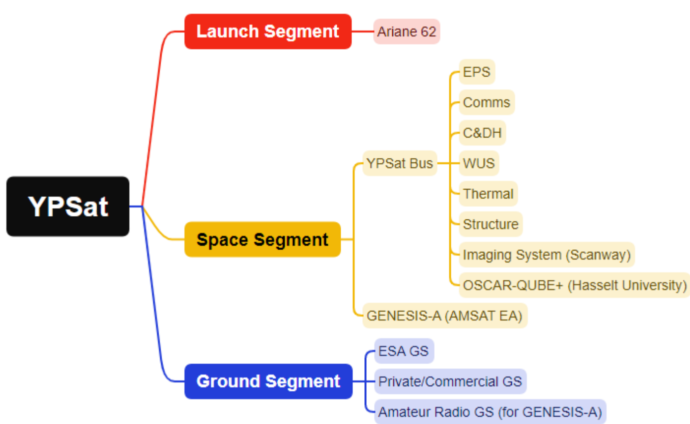

Figure 2 - YPSat Architecture

2.3.1 Space Segment & Payloads

The YPSat spacecraft is structured around six core sub-systems, each with specific responsibilities to ensure the mission's success:

- **Wake-Up System (WUS):** This custom-built sub-system detects the lift-off of Ariane 6 and initiates the satellite's start-up sequence. It uses accelerometers and barometric pressure sensors to confirm launch and activate the spacecraft. This custom system is required to power on the satellite before the usual power on succeeding payload separation.
- **Electrical Power System (EPS):** The EPS manages power supply from a Lithium-ion battery, ensuring that all sub-systems receive the necessary power throughout the mission.
- **On-Board Computer and Data Handling (C&DH or OBC):** The OBC controls YPSat's operations, records flight data, and manages the imaging system and the OSCAR-QUBE+ data handling [6]. It uses a real-time operating system to handle multiple tasks concurrently.
- **Thermal Control System (TCS):** The TCS maintains the operational temperature ranges of all components at a stable level using passive thermal control methods, including Multi-layer Insulation (MLI) and a Phase Change Material (PCM) to absorb thermal energy from the OBC.
- **Structural Sub-system:** The spacecraft's structure is designed to elevate the imaging system, providing a wide field of view over the Ariane 6 ballast, whilst withstanding the mechanical loads encountered during launch and providing a stable platform for the payloads.
- **Telecommunications Sub-system:** This sub-system is responsible for transmitting mission telemetry and scientific data back to Earth. To address the challenges of maintaining communication while remaining attached to the launcher, a dedicated downlink strategy was developed. Section 4.3 will provide further details on this strategy and the overall telecommunication system.

In addition to its sub-systems, YPSat hosts three primary payloads:

- **Scanway Imaging System**: This system includes two high-resolution cameras that capture images and videos of key mission events, such as fairing separation and CubeSat deployment. The cameras are controlled by a microcontroller board that processes and stores the captured data.
- **OSCAR-QUBE+ Magnetometer**: Developed by Hasselt University, this diamond-based quantum magnetometer measures Earth's magnetic field along the launch trajectory. The data collected will be used to test the concept of passive navigation using magnetic field measurements [7].
- **GENESIS-A Ham Radio**: Developed by AMSAT-EA, this amateur radio unit enables radio enthusiasts worldwide to establish communication with YPSat during operations. It transmits a low-energy radio signal and slow-scan television (SSTV) images.

2.3.2 System States

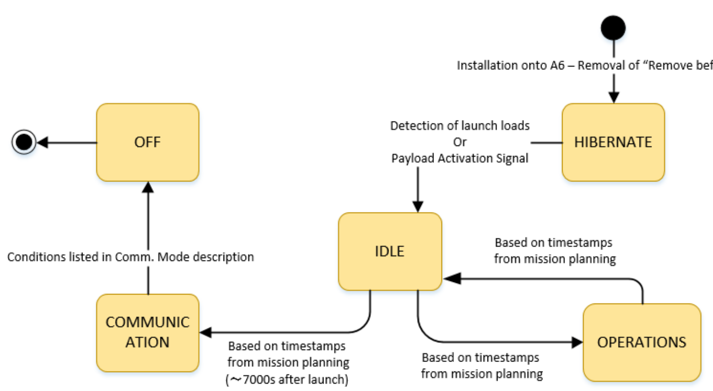

Figure 3 - High-level state machine diagram of the system states

The YPSat spacecraft switches between different operational modes during the short mission timeline described in Section 2.2 and as depicted in Figure 3. As the mission does not include any commanding capability during the flight, the switching between modes is executed after specific signals are received (*e.g.*, YPSat turns ON when the wake-up signal to battery is received), or after the internal timeline of the OBDH induces a mode switch. Before the fairing closure, YPSat is set to Hibernation Mode, waiting for the detection of lift-off by means of the accelerometers and pressure sensors. During the mission, the system switches to Operational Mode multiple times – for the fairing separation event, the payload deployment event as well as at specific times for the capturing of Earth images – and back to Idle Mode after the payload operations are completed.

During the second pass over Europe, the spacecraft switches to Communication Mode, during which the mission data is downlinked to the ground stations. After exiting the pass over Europe, YPSat continues downlinking data until its battery is depleted.

3. YPSat Telecommunication Sub-system

3.1 On-board Technical Specification & Interfaces

The telecommunication originates at the OBC which manages data collected from the different payloads. The OBC interfaces with a transmitter via an RS-485 connection, enabling data transfer and control. It encapsulates the payload data and stores it in the transmitter's internal memory and triggers transmission at scheduled times, during the downlink windows over Europe.

The transmitter, operating in the *Industrial, Scientific and Medical* (ISM) amateur S-band (2440 MHz), is responsible for modulating and amplifying the signal before it is sent to the antenna. It implements the DVB-S2 standard [8] with the following configuration:

- Occupied Bandwidth: 5.6 MHz (5 Msym/s)
- Modulation: Quadrature Phase Shift Keying (QPSK)
- Forward Error Correction Rate: 2/3
- Power Output: 33 dBm

The transmitter is powered through a PC-104 connector and complies with the frequency mask provided by A6.

After the amplification, the signal travels via a 50-ohm coaxial cable with a micro coaxial connector to the S-band patch antenna. The antenna operates within the 2400-2450 MHz range and is designed as a square patch with trimmed edges, enabling Left-Hand Circular Polarization (LHCP). The whole process is depicted in Figure 4. This design enhances communication reliability by reducing signal degradation due to polarization mismatches. The antenna's main specifications are [9]:

- Peak Gain: 8.3dBi
- Half-Power Beamwidth (HPBW): 70 degrees
- Dimensions: 98.0 x 98.0 x 11.9 mm
- Mass: 64 g
- Operational Temperature Range: -40°C to 125°C

The antenna radiates the transmitted signal with its peak gain characteristics and frequency response optimized around 2.425 GHz, ensuring effective data downlink.

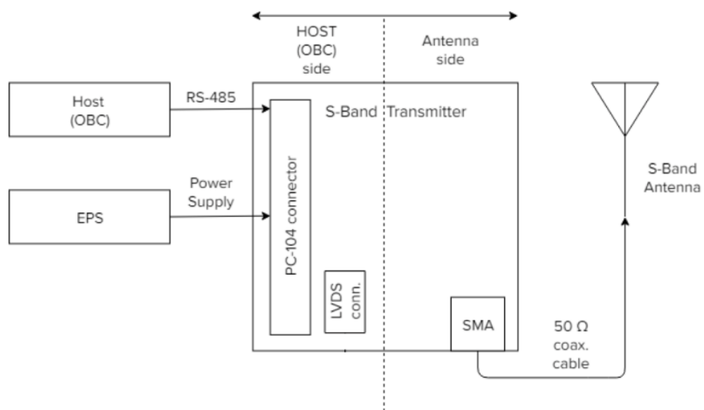

Figure 4 - Telecommunication Sub-System and Interfaces

3.2 Frequency selection

Due to the short time between project inception and initial launch date, a frequency in the amateur radio band was chosen for its simplified frequency filing process. The idea was to avoid any coordination requirements and station licensing that come with the commercial and widely used S-Band frequencies. Furthermore, the ITU filings for amateur radio satellite services are free of charge. Given the short mission duration, any interference criteria can be easily met by just comparing the battery lifetime to the amount of interference a mission has to accept according to ITU-R interference criteria [10]. With that choice came also a few important constraints. Any frequency usage of the amateur radio spectrum for space communication has to be coordinated with AMSAT and justified in light of its benefit for the Amateur Radio community. Because YPSat hosts the GENESIS-A payload, this step was straightforward. Furthermore, any transmission in the amateur radio spectrum must be unencrypted and open for anyone to receive. The challenge with this choice of amateur S-Band at 2.44GHz is to find Ground Stations that support this frequency range. Usually, ground stations have sharp band passes to block any short-range devices such as Wi-Fi or Bluetooth, that operate on this frequency, as well as the S-Band uplink signal that is operating just below of the usual receive frequency.

4. YPSat Ground Segment

The YPSat Ground Segment included multiple receiving stations in the visibility path of YPSat, with which YPSat signed a collaboration agreement.

4.1 Ground Stations Network Requirements and Architecture

The project had the following compatibility requirements for a cooperating Ground Station:

- Downlink capability at a frequency of 2.44 GHz
- Capability to receive signal transmitted in Left Hand Circular Polarisation
- Gain-to-noise-temperature (G/T) > 10 dB/K
- 10 MHz sampling bandwidth for open loop recordings
- Tracking capabilities
- Location in Central America, Europe or Central Asia

The requirements for the receiver protocol have been circumvented by introducing open loop recordings and a centrally located receiver.

4.2 Supporting Ground Stations

The Ground Segment baseline assumed the Ground Station Network (GSN) listed in Table 1, together with its characteristics.

Table 1 - YPSat Collaborating Ground Stations

Ground Station	Antenna Diameter [m]	Max Azimuth speed [deg/s]	Max Elevation speed [deg/s]	G/T [dB/K]	Polarisation Reception Capabilities	HPBW [degrees]
ESEC Redu	3.1	>0.3	>0.1	9.92	LHCP	2.27
Tartu Observatory	3.0	1.7	0.94	16.0	RHCP/LHCP	2.35
VIRAC	32.0	2.8	1.8	36.0	LHCP	0.22
University of Stuttgart	2.5	12	12	13.4	LHCP	2.82
AMSAT-DL	20.0	1.25	0.8	32.6	RHCP/LHCP	0.35
University of Nottingham	3.0	>0.4	> 0.1	12.9	LHCP	2.35

Astralintu	3.0	Value not provided	Value not provided	6.1	LHCP	2.35
Technical University of Denmark	1.2	6	3	Not provided	LHCP	5.86
University of Vasaa	1.8 (Effectively 1.45m due to suboptimal feed)	>2	>0.5	Not provided	LHCP	4.85
University of Bologna	3.0	Compliant with maximum speed	Compliant with maximum speed	16.0	LHCP	2.35
Turin IW1DTU	2.4	Compliant with maximum speed	Compliant with maximum speed	14.3	LHCP	2.93

Their location is depicted in Figure 5.

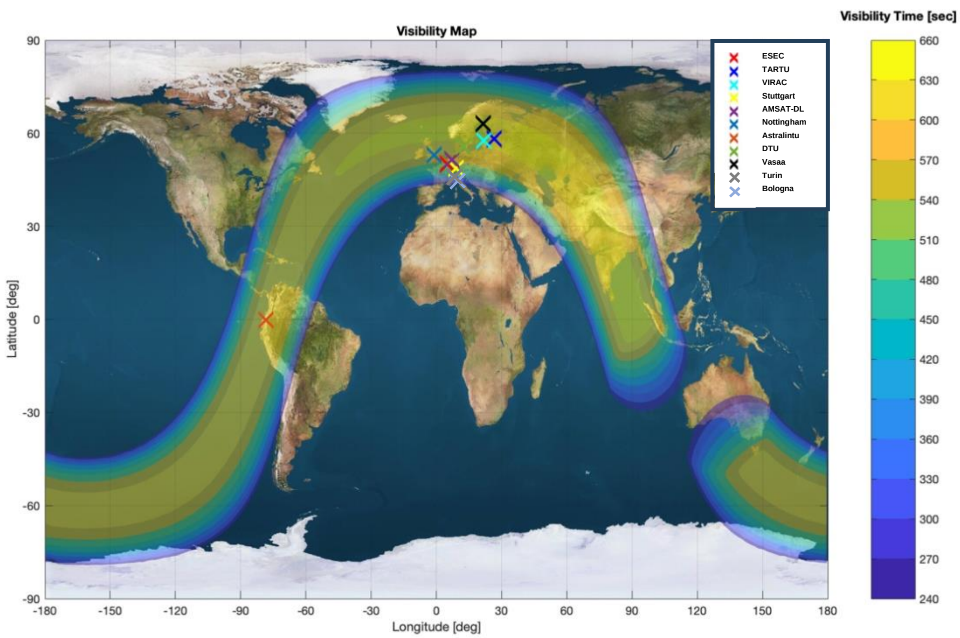

Figure 5 - Ground Visibility Track and Ground Stations Location

4.3 Downlink Strategy

The mission's success depended on the data downlinked while the A6 was in a barbeque roll at ~1deg/s. The roll itself reduced the effective downlink transmission. The main issue, however, was the uncertainty in the A6 mission profile, which was based on predictive Monte-Carlo simulations rather than real-time data. Any deviation – such as the barbecue roll not occurring with the expected phase or rate – could increase or decrease the link budget, making it difficult to fully rely on the expected downlink performance.

To maximize data retrieval, the design strategy relied on two key points:

1) Multiple ground stations to increase the transmission window and the probability of receiving data on specific areas.
2) High redundancy in transmission to compensate for intermittent visibility, *i.e.*, it was decided to transmit the same files continuously during the pass over Europe.

The strategy was developed assuming an effective data rate of 3.74 Mbps and a 251s transmission window, leading to a maximum data budget of 202.9MB under perfect conditions. However, due to potential inaccuracies of the mission profile, the actual data budget could have been significantly lower. After analysis of the worst-case scenarios, we opted for a redundancy factor of 11 resulting in a total downlinked data of approximately 15MB. This ensured at least one full reception of the mission data despite uncertainties. Ultimately, the redundancy factor was not arbitrarily fixed but chosen as a trade-off to best match the mission objectives, balancing data integrity with the constraints of the downlink window,

4.4 *Downlink Windows*

Figure 6 gives an overview of the predicted visibility and transmission times for the list of supporting ground stations. The transmission time was computed using a mission profile provided by Arianespace and the Ground Stations characteristics. The predicted accumulated visibility of YPSat collaborating Ground Stations shows overlap at several timestamps. After 7600 seconds of elapsed time there is a brief transmission window overlap of six ground stations, this overlap was planned to give redundancy to the downlink strategy.

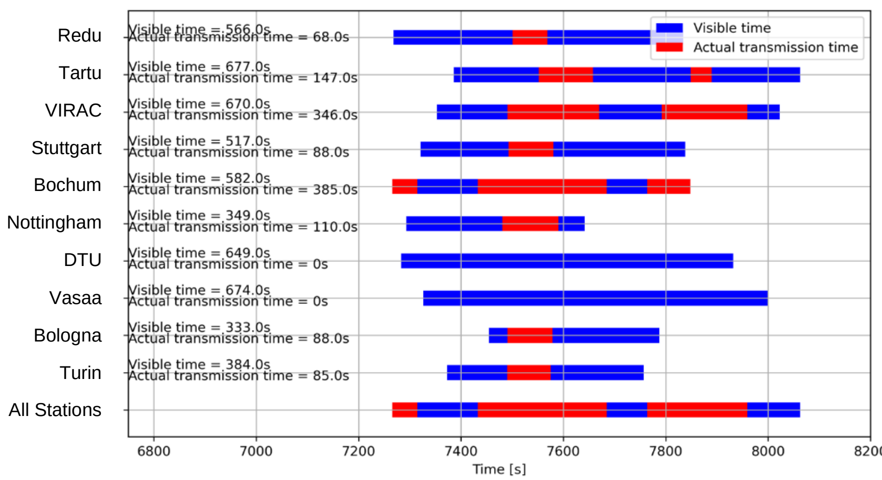

Figure 6 - Downlink Timeline for Ground Stations

5. YPSat Operations

YPSat Operations were conducted by the operational teams, which included a Mission Analysis team, a Telecommunications team, and a Ground Stations team at ESOC's Mission Control Room and at the Ground Stations sites.

5.1 Ground Segment Operations

5.1.1 Operational Roles and Responsibilities

The Ground Station Coordination Team, Mission Analysis team and YPSat project communications team were at ESOC during the launch and operations of YPSat with the following shared responsibilities:

- Ground Station Coordination Team: Manage the remote Ground Stations, in constant voice-loop with their representatives and with the Points of Contact (PoC) of the Ariane 6 Team.
- Mission Analysis and Flight Dynamics Team: Orbital Data Generation and Update for GS tracking.

- YPSat Project Communications Team: Documenting the on-going operations with pictures and videos and communicate the mission progress with the ESA Corporate Communications Office.

The Telecommunications Team was located at ESTEC with the responsibility of decoding the IQ samples received from the collaborating Ground Stations after the pass.

The engagements of supporting Ground Stations were described in cooperation agreements signed both by the Ground Station responsible and ESA.

5.1.2 Operational Interfaces

The YPSat ground segment consisted of the Operations Team (consisting of the Ground Stations Coordination team, Mission Analysis team, and Project Communications Team), the Ground Stations Network (GSN), and the Telecommunications team. The Ground Stations network in this context consists of both the supporting ground stations downlinking YPSat data, defined in Section 2.2, and the Ariane 6 launcher tracking stations, New Norcia – 2 in Australia and Galliot in French Guyana, providing launcher updates. Figure 7 depicts the interfaces between the ground segment components.

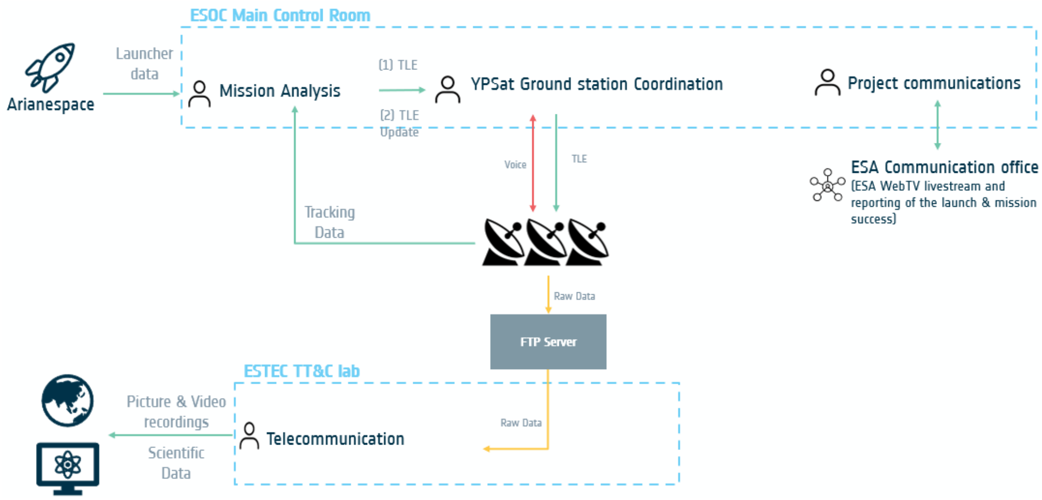

Figure 7 - Operations Interfaces

Four key interfaces were defined for the YPSat Ground Segment:

1. Bi-directional Voice-loop between the Ground Stations Coordination team and the Ground Stations Network.
2. Orbital data for GS tracking in the form of Two-Line Element (TLE) file transfer from the Mission Analysis team to the Ground Stations Coordination team, and from the Ground Stations Coordination team to supporting Ground Stations.
3. IQ Samples File Transfer Service from supporting Ground Stations to the Telecommunications team.
4. Ariane 6 Tracking data from launcher tracking Ground Stations to the Ground Stations Coordination team.

For all the supporting ground stations defined in Section 2.2, a voice loop was established to communicate key events such as the launch epoch, and Acquisition and Loss of signal at each ground station. For redundancy, backup channels with Zoom and phone contact details were also tested. For the launcher tracking stations, the voice loop infrastructure at ESOC was used to communicate the Time Offset Value (TOV). The TOV represents along track differences in a satellite's orbit in terms of a time-shift to align the predicted trajectory with real tracking data. Events occurring later than in the nominal timeline have a positive TOV offset applied. The TOV offset value does not communicate any cross-track errors.

The Two-line Element Set, TLE, consists of two 69-character lines of data encoding a list of orbital elements, which can be used together with NORAD's SGP4/SDP4 orbital model to determine the position and velocity of the associated satellite. The only valid characters in a two-line element set are the numbers 0-9, the capital letters A-Z, the period, the space, and the plus and minus signs—no other characters are valid. Nominal TLEs were prepared by the Mission Analysis team using trajectory information provided by Arianespace and the launch epoch. These TLEs, and any subsequent updates, were shared to the Ground Station Coordination team and subsequently the supporting Ground

Stations via e-mail. The supporting ground stations processed these TLEs by propagating the set of elements to obtain a set of azimuth and elevation angles needed to point the antenna towards the spacecraft.

Supporting ground stations recorded raw IQ samples with a specified sampling rate and data format and uploaded these to a shared server that was accessed by the Telecommunications Team. Supporting ground stations did not demodulate nor decode the received data. All decoding was performed offline by the YPSat Telecommunications team. The expected file transfer size for each supporting ground station was calculated before the launch using the visibility window predictions, and resources were allocated accordingly.

TOV information were received form the New Norcia-2 and Galliot launcher tracking stations. The Mission Analysis TLE generation tools were designed to forward-propagate the last state to correct for cross-track errors if necessary.

All the above interfaces were tested in dedicated compatibility tests and simulations, as detailed in Section 5.1.4.

5.1.3 Operational Procedures

The YPSat Operations team developed step-by-step procedures to be followed during the actual mission at different points in the operations timeline. An overview of the actual sequence is given in Figure 8.

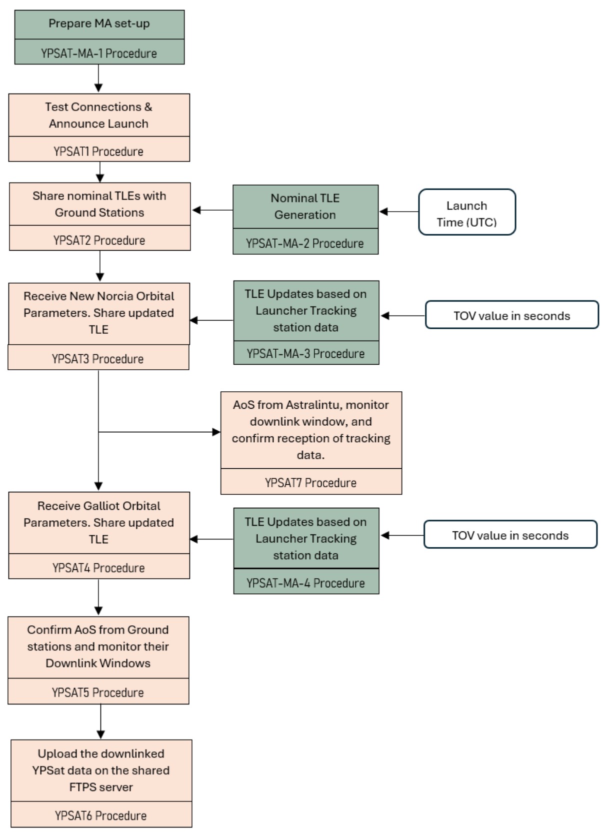

Figure 8 - Operations Procedures Overview

During the flight of YPSat, two different TLEs were generated for each ground station: a nominal TLE that is created right after launch, and an updated TLE that implements a correction based on the tracking data of, as a minimum, the New Norcia Ground Station. A process flow diagram of this TLE generation is provided in Figure 9.

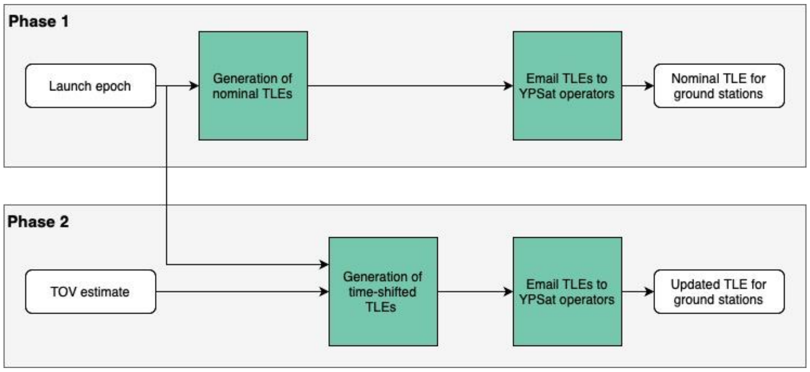

Figure 9 - TLE Generation Process

In the first phase, when calculating the nominal TLE for each ground station, it is required to have a confirmed epoch of launch, as the nominal trajectory information provided by Ariane is given as a function of elapsed time since launch. From this information, the nominal TLEs for the various ground stations can rapidly be generated and subsequently distributed to the different YPSat operators. As a result, a nominal TLE can be made available to all ground stations within minutes after launch.

Subsequently, during the second phase, tracking data of A6 was employed to improve the accuracy of the nominal TLEs. As input from the tracking stations, an estimate of the TOV was provided. As such, a recalculation of the TLEs can be performed using a time-shifted nominal A6 trajectory, shifting all epochs since launch by the estimated TOV value.

The data recovery procedure takes place at the Telemetry, Tracking and Command (TT&C) Lab at ESTEC, according to the process described in Figure 10.

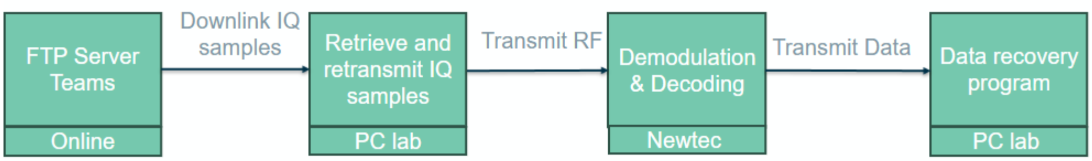

Figure 10 - Data Recovery Process

It was planned to process incoming signals from the Ground Stations immediately after their reception on the server to minimize the waiting time for media release of the video and images. For each of the received IQ samples, the signal was to be replayed using the telecommunication setup of the TT&C Lab.

Once retrieved, the samples were processed using a Newtec 6000, which demodulated the signal into MPEG-TS packets. These packets were then extracted into User Data Protocol (UDP) packets, captured using Wireshark, and reconstructed into Space Packet Protocol (SPP) of 1032 bytes. By decapsulating the UDP and MPEG-TS headers, the original data files were recovered.

To ensure data integrity and redundancy, a dedicated decoder was developed with key features, including:

- Cyclic Redundancy Checks (CRC) to prevent bit flips or data corruption on every SPP frame.
- Aggregation of data from different ground stations, allowing missing parts from one station to be supplemented by another one.
- Reconstruction of files despite signal loss using an internal counter.

If all frames' CRC during a file transmission are correct, the file is considered correct.

As nominally done for any other space mission, YPSat developed Flight rules as directives governing the procedures described above.

5.1.4 Ground Segment Simulations

The operational interfaces defined in Section 5.1.2 were exercised during a simulation scenario with the full ground segment. The objectives of the simulation were as listed below:

- Proper functioning and set up of the entire ground segment, including interfaces between systems and between entities.

- Correctness and adequacy of all mission operations data - Validation of the mission operations data demonstrates the correctness of the data and its compatibility with the ground segment
- Qualification of all operations and maintenance personnel.
- Ability of the operations teams to support the mission.

To achieve these objectives, the simulation exercised the generation of nominal and updated TLEs by the Mission Analysis team, the transfer of these TLEs via email to the Ground Stations Coordination team and subsequently the supporting ground stations with voice loop updates, the recording of raw IQ samples by ground stations, and the download and processing of the IQ samples by the Telecommunications team. Simulations were conducted with different groups of supporting ground stations, exercising nominal and redundant interfaces, and contingency scenarios, both technical and organisational. The representative updated TLEs were based on non-nominal launcher performance with example tracking data produced by taking the nominal trajectory and inserting errors within the expected three sigma value.

These simulations were key in ensuring that supporting ground stations could correctly process TLEs and prioritising the provision of TLEs for ground stations with more accurate pointing requirements and with longer processing times for the TLEs. Additionally, they ensured that the IQ samples could be correctly decoded with the correct sampling rate and format.

5.1.5 Actual Operations

During the inaugural flight of A6 on July 9th, nominal TLEs were generated and distributed to the collaborating ground stations within minutes after receiving the confirmed launch epoch. Subsequently, 84 minutes after launch, tracking data from the New Norcia-2 ground station was received, where a TOV value of a few seconds was reported. With these inputs, TOV-shifted TLEs were generated and redistributed to the ground station network. In the meantime, while waiting for new tracking data from the Galliot tracking station, the ground operators of Astralintu in Ecuador confirmed the reception of a beacon signal from one of the other passengers onboard the A6 upper stage, as YPSat's transmission was not yet active during this phase of the mission. Shortly after, at approximately 113 minutes after launch, tracking data from the Galliot ground station was received, from which it was apparent that the TOV value had slightly grown. Therefore, newly TOV-shifted TLEs were generated and redistributed to the collaborating ground stations. After this, it was now time to observe which of the collaborating ground stations could establish a link with YPSat during its flight over Europe, with the first visibility window opening six minutes later. A summary of the timeline that was followed during the actual operations is given in Table *2*.

Table 2 - Actual Timeline for TLE provision during the mission

EVENT	**TIME (T0 - Launch)**
Nominal TLE sent to Ground Stations	T0 + 2 min
TLE Update (with New Norcia tracking data)	T0 + 84 min
Astralintu - Beacon Reception	T0 + 96 min
TLE Update (with Galliot Tracking data)	T0 + 113 min (6 min before visibility window opened)

Nominally, the orbital parameters from New Norcia Ground Station were expected at time T0 + 70 minutes and from Galliot Station at T0 + 103 minutes.

6. Results and Discussion

6.1 Ground Station Data Recovery

The YPSat downlink strategy relied on multiple ground stations to maximize the likelihood of a full data reception. However, out of the 11 supporting ground station across multiple countries, only two (VIRAC and AMSAT-DL) received a usable signal. The remaining nine failed to detect any signal, likely due to factors such as pointing errors, high noise power, or insufficient antenna size.

VIRAC was the only Ground Station from which the whole data was obtained and successfully decoded by the Telecommunications team. The acquisition from VIRAC Ground Station resulted in a signal that lasted more than 120 seconds practically uninterrupted.

Due to the short mission duration and limited downlink window, the redundancy of the Ground Station Network played a crucial role in maximizing data retrieval. While AMSAT-DL received only ~1% of the total 15 MB file, making it unusable, VIRAC successfully received 399% of the expected data with redundancy, ensuring that the entire file was retrieved, verified, and reconstructed correctly. Considering these results, it remains unclear whether the decision of ISM Amateur S-band at 2.44GHz with lower ground station availability and reliability contributed to the reception issues, or, pointing and trajectory where the sole reasons for lack of reception at some ground stations. Either way, with the increase of responsive space and fast time-to-launch missions, emphasis on faster or simplified means to obtain frequency filing – especially for short duration missions like YPSat – could significantly ease the ground station and telecommunication design and operations of such missions.

6.2 Trajectory and Attitude Analysis

The pre-flight link budget analysis for the VIRAC Ground station indicated that there would be two communication opportunities between the ground station and YPSat, as indicated by the yellow rectangles in Figure 11. Nevertheless, the green rectangles show the periods of actual contact with YPSat, implying a discrepancy between the expected and realized downlink window.

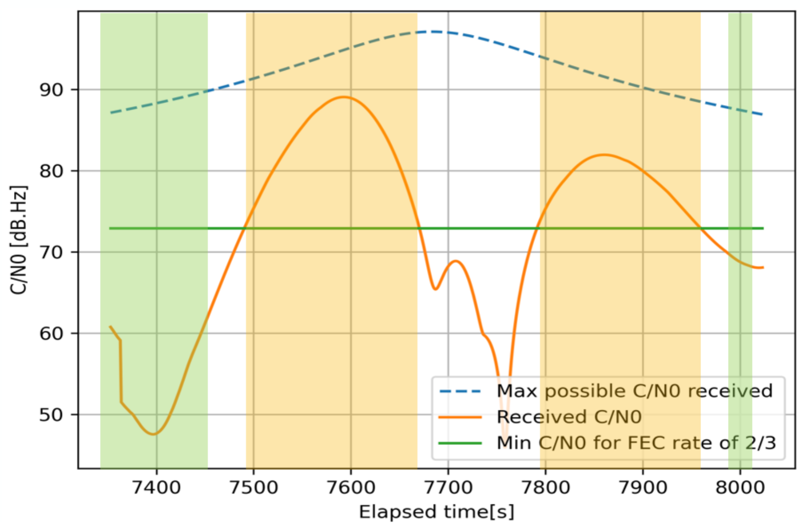

Figure 11 - VIRAC C/N0 (forecast trajectory and orientation)

To explain this behaviour, the orientation of the launcher must be considered. From the post-flight attitude data received from Ariane 6, it was concluded that the launcher was performing its barbeque roll out of phase when compared to the forecast attitude. With the real orientation of the launcher being different from the nominal one unexpected transmission windows at the beginning and end of the pass occurred, as illustrated in Figure 12. Note however that, when considering the actual attitude of the launcher, another transmission window in the middle of the pass should have been observed, as given by the yellow block, but it did not lead to any additional data downlink. This was due to the large pointing error of the ground station antenna with respect to YPSat flying overhead, where the applied trajectory's TOV did not accurately model the launcher's path at high angles of elevation with respect to the ground station. Nevertheless, this pointing error affected the pass to a lesser extent at the beginning and the end of the pass, as indicated by the green blocks, where the elevation angle with respect to the ground station remained low.

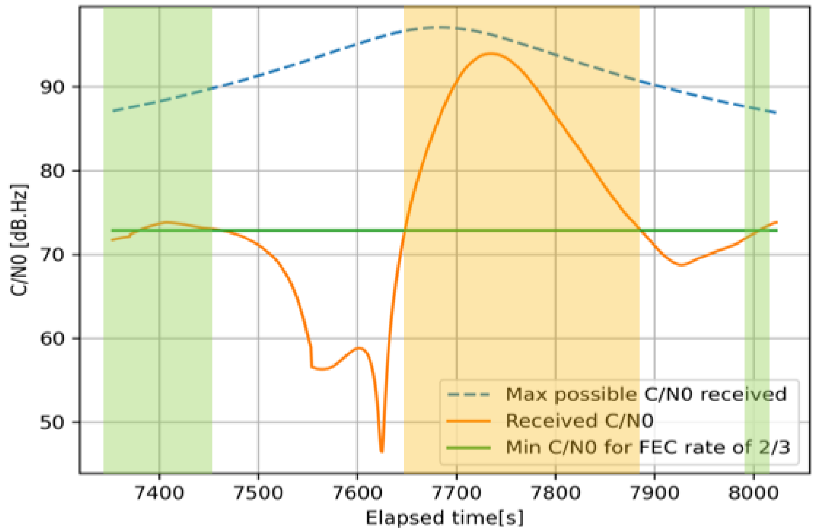

Figure 12 - VIRAC C/N0 (forecast trajectory and real orientation)

7. Conclusions

YPSat was launched successfully aboard the Ariane 6 from Kourou on the 9th of July 2024 and with the collaboration of 11 ground stations across Europe and South America, the YPSat team successfully recovered all the data necessary to achieve the mission's objectives. To accomplish this, the YPSat team members in the Main Control Room at ESOC performed frequent re-calculations to fit two-line element sets to the non-ballistic trajectory of Ariane 6, considering the TOV inputs from the launcher tracking stations. The TLE was subsequently shared with the collaborating ground stations to adjust their pointing strategy and track YPSat during its flight onboard Ariane 6. Ground stations were requested to record raw data that was then decoded and used to reconstruct images and videos. The open-loop recording allowed to simplify decoding and ground station validation.

The YPSat mission united young talents from across various ESA establishments, directorates, and disciplines, including Operations. The project has successfully designed, built, and operated the payload on the inaugural flight of Ariane 6, documenting through downlinked footage the key events of the launch, including recordings of the fairing separation and the deployment of CubeSats, as well as panoramic images of Earth and Space. The successful of the mission includes the downlink of the scientific data of YPSat’s two hosted payloads, which further expanded the mission’s outreach and engagement with the broader scientific community: OSCAR-QUBE+, an innovative quantum-based magnetometer which added a cutting-edge scientific dimension to the mission; and GENESIS-A, a ham radio enabling amateur radio enthusiasts to directly connect with YPSat during flight.

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