

AGILE DEPLOYMENT AND AUTOMATION OF ARGOTEC FLIGHT OPERATIONS SEGMENT FOR IRIDE CUBESAT CONSTELLATION

Teodoro Bonariol^{a*}, Edoardo Bruno^b, Biagio Cotugno^c, Francesco Soncini^d,

^a Argotec S.r.l., Via Luigi Burgo 8, 10099, San Mauro Torinese (TO), Italy, teodoro.bonariol@argotecgroup.com

^b Argotec S.r.l., Via Luigi Burgo 8, 10099, San Mauro Torinese (TO), Italy, edoardo.bruno@argotecgroup.com

^c Argotec S.r.l., Via Luigi Burgo 8, 10099, San Mauro Torinese (TO), Italy, biagio.cotugno@argotecgroup.com

^d Argotec S.r.l., Via Luigi Burgo 8, 10099, San Mauro Torinese (TO), Italy, francesco.soncini@argotecgroup.com

* Corresponding Author

Abstract

The proliferation of CubeSat constellations has revolutionized Earth Observation (EO) by providing cost-effective, rapidly deployable solutions with frequent revisit capabilities. This is the case of the Micro-Satellite constellation designed and developed by Argotec based on its HAWK Platform, under the IRIDE Program, from the EU-funded Recovery and Resilience Plan for Italy (PNRR) and managed by the European Space Agency (ESA). Argotec is responsible for the design, development, testing, and integration of the satellite platform (Space Segment), as well as for the design, development, testing, and operations of the corresponding Flight Operations Segment (FOS), ensuring the monitoring and control of the constellation.

This paper focuses on the design, development, and validation of the ground segment and on the operational concepts conceived for both ground and space operations. Based on the heritage of the LICIAcube and ArgoMoon missions, Argotec has designed and developed its Ground Segment for a Constellation of LEO microsattellites, with an agile method with the aim of achieving operational readiness in less than 2 years.

The adaptation and integration process of the key components of the Mission Control Centre is detailed, including the integration with the Ground Station (GS) Network provider and the external partners, such as the IRIDE Payload Data Ground System (PDGS) and the IRIDE Central Mission Planning & Management (CMP&M) nodes.

The implementation of automation is a critical focus, emphasizing its integration to enhance efficiency and reliability. The role of automation is showcased in the various processes, including the planning and scheduling of spacecrafts' activities, the collection of inputs from different sources, such as the GS Network or the external partners, the telecommand sending and telemetry monitoring according to the developed Flight Operations Procedures (FOPs) and the automated data ground processing and dissemination. The validation process encompasses a robust testing strategy with unit, integration, and system-level tests, supported by simulation environments and real-time hardware-in-the-loop testing.

The paper concludes by addressing the technical and operational challenges encountered, sharing valuable lessons learned, and highlighting the rapid development of the ground segment by a small company within a brief period. The paper emphasizes the Argotec all-in-house concept, where the Flight Control Team comprises operators who developed either the ground segment or the satellite, highlighting the benefits of seamless integration and enhanced control over the mission.

This presentation underscores Argotec innovative approach, demonstrating the potential for small companies to achieve significant milestones in space operations within constrained timelines.

Keywords: Earth Observation, Flight Operations Segment, Cubesat Constellation, Automation, IRIDE, Spacecraft Operations

Acronyms/Abbreviations

| | |
|--------|--|
| AOS | Acquisition of Signal |
| API | Application Programming Language |
| BOT | Begin of Track |
| CAM | Collision Avoidance Maneuvers |
| CMP | Central Mission Planning |
| CMP&M | Central Mission Planning & Management |
| CONOPS | Concept of Operations |
| DA | Data Archive |
| DIM | Data Interface Management |
| DP | Delivery Point |
| ECSS | European Cooperation for Space Standardization |
| EOT | End of Track |
| ESA | European Space Agency |

| | |
|--------|---|
| FCT | Flight Control Team |
| FDE | Flight Dynamics Engineer |
| FDS | Flight Dynamics and Collision Avoidance Service |
| FOP | Flight Operations Procedure |
| FOS | Flight Operations Segment |
| GC | Ground Controller |
| GNSS | Global Navigation Satellite System |
| GS | Ground Station |
| HEO | Hawk for Earth Observation |
| ICD | Interface Control Document |
| LEO | Low Earth Orbit |
| LOS | Loss of Signal |
| MARGOT | Multi-analysis and Real-time Ground Operations Tool |
| MCC | Mission Control Centre |
| MCS | Mission Control Software |
| MIB | Mission Information Base |
| MIBET | Mission Information Base Extraction Tool |
| MPO | Mission Planning Officer |
| MPT | Mission Planning Tool |
| OSW | On-Board Software |
| PDGS | Payload Data Ground System |
| PDPT | Payload Data Processing Tool |
| PNRR | Recovery and Resilience Plan for Italy |
| PUS | Packet Utilization Service |
| SCID | Spacecraft ID |
| SE | System Engineer |
| SFTP | Secure File Transfer Protocol |
| SK | Station Keeping |
| SOE | Sequence of Events |
| SOM | Spacecraft Operations Manager |
| SPACON | Spacecraft Controller |
| SSO | Sun-Synchronous Orbit |
| SVT | System Validation Test |
| TC | Telecommand |
| TM | Telemetry |
| XML | eXtensible Markup Language |
| XSD | XML Schema Definition |

1. Introduction

Argotec has designed and developed the Hawk for Earth Observation (HEO) constellation, under the IRIDE Program, from the EU-funded Recovery and Resilience Plan for Italy (PNRR) and managed by the European Space Agency (ESA). This constellation, designed for multispectral EO from a 590 km Low Earth Orbit (LEO), is undergoing phased deployment. A single satellite, the first of the IRIDE constellation, HEO Pathfinder (IRIDE-MS2-HEO-1, 2025-009CS, NORAD ID: 62697), has been successfully placed into a Sun-Synchronous Orbit (SSO) on January 16th, 2025 [1]. The remaining satellites, intended to complete the constellation of up to 40 units, will be deployed in subsequent launches. The primary objective is to acquire multispectral images of the Italian territory, with potential for broader coverage. Alongside the Space Segment, Argotec is responsible for the monitoring and control of the constellation, through the in-house developed Flight Operations Segment (FOS), which exploited the heritage of Argotec previous missions ArgoMoon and LICIACube [2].

The work carried out consists of:

- The design of the key component of the FOS, based on the heritage of previous missions.
- The successive development of the tools and their interfaces.
- The validation of the overall architecture through unit, integration, and system-level tests, supported by simulation environments and real-time hardware-in-the-loop testing.
- The operational readiness of the FOS and the operators, with the introduction of automation.

The implementation of the automation inside the FOS for its ground and in-orbit operations is critical for LEO satellites, but it is paramount for multi-spacecraft constellations, to significantly enhance mission reliability. This has been a key focus during the entire development phase, leading to various use of automated tasks, which will be highlighted in the paper.

All this work has been achieved in less than 2 years from contract assignment (December, 2022 [3]) to launch of the first satellite of the constellation (occurred on January 16th, 2025), thanks to the application of an agile methodology and the effort of all the Argotec Flight Control Team (FCT).

2. Flight Operations Segment Overview

The following chapter covers an overview of the HEO Constellation FOS whose high-level scheme is presented in Figure 1.

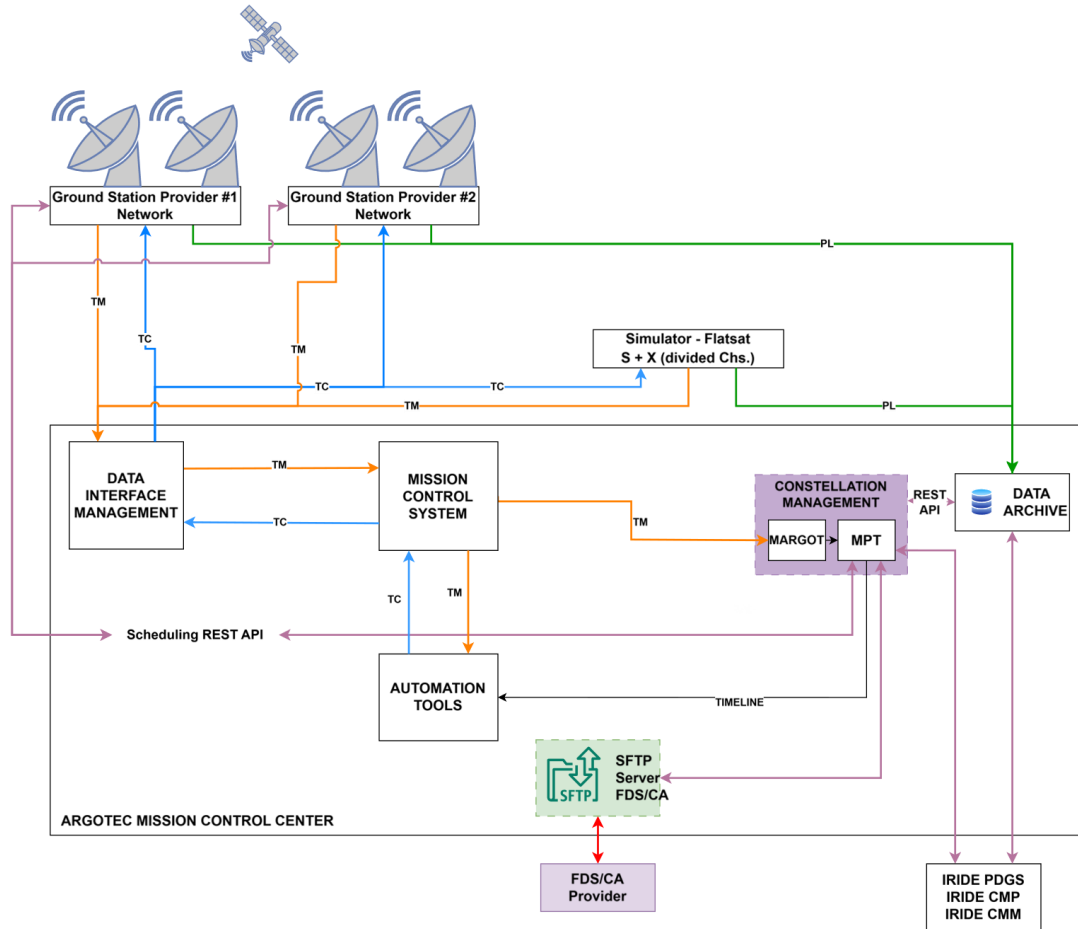


Figure 1. HEO Flight Operations Segment High-level Scheme.

The FOS interfaces with the GS Providers and/or the Simulator/Flatsat through the Data Interface Management (DIM) for the exchange of Telecommands (TC), Telemetries (TM) and Payload Data. It receives and sends data from/to the Flight Dynamics and Collision Avoidance Service (FDS) Provider and with the IRIDE Payload Data Ground System (PDGS) and the IRIDE Central Mission Planning & Management (CMP&M) nodes.

The Upstream flow can be summarized as follows, focusing on the main role of Mission Planning Tool (MPT). The requests for target acquisition over Italy or for payload calibration, arriving from the Central Mission Planning (CMP), which is the overall IRIDE constellation planning unit and therefore send the requests to schedule payload acquisitions to the FOS, are retrieved automatically and evaluated against planned activities and spacecraft resource constraints (e.g., battery level storage and consumption, on-board memory allocation). They can be accepted or rejected in accordance with the already planned activities.

The ephemeris data, scheduled Station Keeping (SK) and Collision Avoidance Maneuvers (CAM), and Sequence of Events (SOE) files from the FDS are autonomously retrieved daily. This data is then integrated into the operational timeline, ensuring synchronization with other scheduled activities.

The MPT retrieves the daily GS pass schedules via dedicated RESTful Application Programming Interfaces (APIs) provided by the GS operator.

Upon data collection, the tool automatically generates a mission timeline, including pre-planned activities and events such as GS passes, Sun-pointing, eclipses, and acquisitions. This timeline is automatically validated against onboard depletable resources (e.g., solar panel energy generation and power consumption), before being transferred to the automation tools. Moreover, right after the timeline generation, the MPT sends to the Data Archive (DA) the identifier of requests which have been planned to be downloaded during the daily downlink passage.

In the automation tools, the activities and events inside the timeline are imported and the associated Flight Operations Procedures (FOPs) are inserted accordingly. The automation tool is then capable of reading and executing the validated timeline and converting the programmed procedures into a series of TC (either real-time or time tagged), which are first forwarded to the Mission Control Software (MCS) and subsequently sent to the spacecraft through the DIM and the GS Network.

In terms of downstream data flow, the payload data and spacecraft TMs are received at the GS. The TMs are then forwarded to the DIM and subsequently received by the MCS. The TM data is displayed within the MCS, which also

sends this information to the Multi-analysis and Real-time Ground Operations Tool (MARGOT), which is the TM visualization tool used by the entire FCT, as well as to the automation tool.

Payload Data is streamed to the DA, where it is processed automatically and then forwarded to the IRIDE PDGS. The separation of distribution channels for TM data Payload data is necessary due to the high data rate transmission of the latter. This rate exceeds the capabilities of the DIM and MCS architecture, therefore a dedicated direct channel from the GS to the Mission Control Centre (MCC) has been designed and developed to accommodate this requirement.

3. Flight Operations Segment Elements

The development and integration process of the key components of the MCC is detailed in this chapter.

3.1 Data Interface Management

The primary purpose of the DIM is to provide an easily adaptable and configurable connection between the Argotec MCC and various external interfaces. These interfaces may include different GS providers or a satellite simulator, allowing for the reception of platform TM and the transmission of TC.

By establishing this interface between the MCC and external GS providers, the Argotec FOS maintains flexibility to accommodate different protocols used by multiple providers [4]. Although the DIM acts as a single point of contact for these external interfaces, it is equipped with an internal hot redundancy system and an automatic telemetry saving feature in case the connection with the MCC is lost.

Additionally, the DIM automatically establishes connections with the GS provider based on the schedule of satellite passes present in the MPT, which are retrieved through an internal API.

The system is composed of several components:

- A **Client**, responsible for establishing effective connections for both the downlink and uplink channels. It forwards telemetry data to the MCS and receives telecommands from the MCS.
- A **Broker**, tasked with managing the message traffic within the DIM. It operates on a publish/subscribe system, equipped with queuing and routing capabilities. This technology ensures that all data received from the node is preserved by being inserted into a specific queue. This mechanism enhances reliability and prevents data loss, even in the event of network connection issues.
- An **Interface**, responsible for connecting the MCS to the DIM itself. It acts as a connection driver, providing the MCS with an endpoint for sending TCs and receiving TMs.

To support the entire satellite constellation, the DIM is deployed in a multi-satellite configuration, enabling real-time communication with multiple satellites. This is accomplished through a single configuration file that includes specific information for each satellite, such as the Spacecraft ID (SCID). As a result, the DIM can simultaneously support TM reception and TC forwarding for multiple spacecraft, thanks to its queuing and routing system.

3.2 Mission Control System

The MCS, provided by an external company, features the following functionalities:

- Reception, distribution, processing, archiving and displaying of the spacecraft telemetry
- Definition and forwarding of commands, with monitoring of each verification stage
- SCOS-2000 based TM and TC Mission Information Base (MIB) database.

To enhance system automation, mission-specific sequences have been developed. One notable tool was developed to compare the uploaded stack of time-tagged telecommands with the TCs that are in the on-board schedule. In the context of EO missions, the reliability and synchronization of telecommunications are critical [5]. However, situations may arise where TCs are not received correctly by the on-board system. This can happen for various reasons, such as signal interference, temporary communication issues, or transmission errors. These events can lead to missing TCs within the scheduled sequence. In the event of any missing TC, a “repaired” stack is generated with the missing commands and it is automatically re-uplinked until the entire stack is correctly uplinked. Following this successful check, the on-board schedule is automatically enabled, through a specific FOP, by the automation tools. Moreover, the tool automatically saves the loaded stack and the downlinked on-board schedule in a dedicated folder, ensuring easy retrieval by the operator for the purpose of checking for any potential issues. Additionally, the tool performs a verification of the sequence of TCs associated with the acquisition procedure and provides a status report on its successful uploading to the MPT via an internal API. This process is designed to automatically forward the identifier of the planned downlinked acquisition to the DA, and to generate data dissemination reports for external providers.

```

Found TM[11,10] at byte:18044465
TT-TC Summary report size (bytes):7477
TT-TCs number:247
List of TCs not present in the on board schedule

For MPT: Check Acquisition Status after TT TC Schedule Loading
{
  "acquisitionID": "MARSnuqRM7aez3pRnG3tBzg6tkDVLt11",
  "status": 0
}
{
  "acquisitionID": "MARSnuqRM7aez3pRnG3tBzg6tkDVLt22",
  "status": 0
}
{
  "acquisitionID": "MARSnuqRM7aez3pRnG3tBzg6tkDVLt33",
  "status": 0
}
{
  "acquisitionID": "e1BqtX7o5rvTSkFPruadhPixX1Kwk0Ep",
  "status": 0
}
{
  "acquisitionID": "QWEqtX7o5rvTSkFPruadhPixX1Kwk0E1",
  "status": 0
}
{
  "acquisitionID": "17b93ab702cf4f98869a7149a6c57455",
  "status": 0
}
}
All TC of the stack are in the Schedule

```

Figure 2. Schedule Comparison Tool Output.

Furthermore, another script has been developed to automatically activate and deactivate the connection between the MCS and the DIM, respectively prior and after to the scheduled Begin of Track (BOT) and End of Track (EOT) for each communication window. This connection is monitored throughout the tracking pass, and in the event of a loss of a connection between the two systems, it is automatically reinstated.

The MIBET (Mission Information Base Extraction Tool) has been developed in Python to simplify the extraction and creation of a mission-specific database for TM and TC for the MCS and the automation tools. Starting with the files containing the TM and TC definitions, according to the European Cooperation for Space Standardization (ECSS) Packet Utilization Service (PUS), and a set of complementary environment files, this tool generates all the MIB tables, derived from the SCOS-2000 Database Import Interface Control Document (ICD) [6]. These tables are then uploaded to a dedicated mission server and, subsequently, converted into the corresponding files required by the tools. The MIBET can also retrieve input files based on the on-board software (OSW) version and upload them to the relevant database, thereby allowing versioning of the MIB. Consequently, the files can be converted from each database present in the mission server.

The MIBET compiles the tables following three main steps. First, all telemetry and telecommand input files are converted into JSON format to collect all pertinent data for MIB generation. The resulting JSON files are then used as a baseline to create and compile all MIB tables in a dataframe format. Some data is directly retrieved through the JSON, while other elements require post-processing to obtain the required information. Subsequently, the dataframe tables are loaded into a MySQL database, from which the tables are converted into files and uploaded to the MCS and the automation tools.

Concurrently, various data integrity checks are implemented to verify the accuracy and consistency of the original file structure and data, as well as each element of the MIB tables and the database feature. The execution of these processes yields a series of warnings that are reported to the user. It is important to note that critical warnings prevent the extraction of erroneous elements.

3.3 Automation Tools

The automation is provided by an external company, consisting of two tools. The first one is used to write, archive, test and validate the FOPs. The second is employed to generate and execute the timeline for real-time and non-real time activities.

The first tool is designed to facilitate the development of mission FOPs, drawing upon a range of features that have been meticulously used to enhance customization and the employment of automation. These features are:

- Receiving TM and performing automatic checks with branching scenarios based on pre-defined controls.

- Sending TCs and activating specific ground sequences in the MCS (e.g., procedures to automatically connect to the GS driver).
- Providing access to a common central database that is shared and accessible by all Flight Operations Engineers.

The scheduler tool facilitates the import of specific files that are essential for the importing the sequence of events and the FOPs. Non-real-time procedures are imported through specific files generated by the MPT, based on a validated timeline. For real-time operations, templates for procedure execution have been developed through multiple iterations of the activities to be performed, supported by extensive and robust testing and simulation campaigns. These templates account for a wide range of possible real-time scenarios, either allowing the possibility to use them as they are or the flexibility to customize the activities and procedures according to the specific needs of the communication window. During real-time tracking passes, operations are carried out automatically, thanks to the use of automatic TM check, TC sending and interlocks for procedure branching based on the spacecraft and activities execution status.

The automation tools support the multi-satellite requirements necessary for the HEO constellation, by offering several features, including:

- Separate MIB for each spacecraft.
- Tailoring of procedures for specific spacecraft(s).
- Distinct import of events and FOPs and subsequent extraction of the stack of time tagged TCs.
- Concurrent real-time execution of activities for multiple spacecrafts.

3.4 AGILE Procedure Writing and Testing

Following a thorough analysis of the HEO constellation Concept of Operations (ConOps) and of the ground ConOps, a comprehensive list of planned activities has been compiled, and dedicated FOPs have been formulated. The mission-independent FOPs have been adapted from previous deep-space missions to suit the HEO platform, while the mission-specific FOPs have been developed based on the current spacecraft capabilities.

The end-to-end workflow includes the creation of the flight procedure for each identified activity, which consists of a series of TC and real-time TM checks. This is followed by writing, debugging and testing the procedure using the automation tools and the Flatsat in-the-loop. Upon completion of this AGILE process, the procedure is deemed validated and ready for operational use. In the event of a procedure being modified or updated, it is tested and debugged again and, if the test process is successful, it is considered validated once more.

3.5 Mission Planning Tool

The MPT is the central system of the FOS [7]. It supports the in-orbit operations by generating and visualizing the timeline of each spacecraft in the constellation. These timelines include all activities that have been executed and completed by each satellite, as well as those scheduled for future execution. The MPT is built using Python and designed as a web-based application, structured to ensure scalability, flexibility, and efficient mission management.

As detailed in Chapter 2, the MPT autonomously acquires all the necessary inputs to generate the schedule. It retrieves requests for acquisition from external sources, such as the IRIDE CMP, and checks for any potential conflicts with other planned activities. The MPT then accepts or declines these requests, ensuring that only authorized activities are scheduled. From the GS provider, it retrieves the assigned communication windows through Scheduling REST APIs and incorporates them into the timeline.

Additionally, orbital sequences of events and any maneuvers are sourced from the FDS.

All activities, such as Sun-pointings, eclipses, communication windows, and acquisitions are automatically inserted into the schedule, with the system detecting conflicts. For example:

- If a maintenance activity is scheduled for the satellite, the requests for acquisition are automatically declined.
- If an acquisition is planned to occur during an assigned communication pass, resulting in the cancellation of the tracking pass.
- If a star tracker is blinded by the Sun during a specific operational mode, the MPT detects this issue and raises an error.
- If the sequence of planned activities exceeds the maximum battery state of charge, allowed within a specified timeframe, the operator is alerted during the timeline generation process.

The MPT also tracks the total amount of on-board memory allocated for acquisitions, notifying the operator if a planned acquisition exceeds the available memory.

Once the timeline has been generated, it must be approved by the Mission Planning Officer (MPO). Subsequently, the files required for the automation tools are generated. The MPT can assign predetermined sequences of FOPs to specific spacecraft activities, such as automatically inserting all necessary procedures for payload acquisition.

Furthermore, the MPT is designed to manage timelines for multiple spacecraft concurrently, with the capability to export one or more timelines to the automation tools, along with all the associated specific activities.

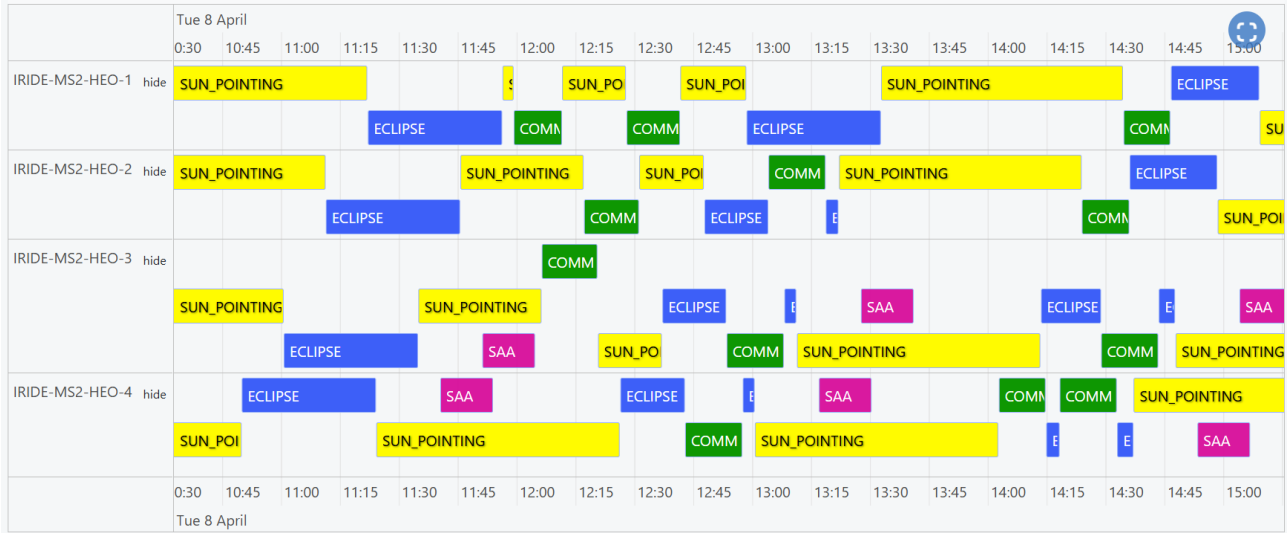


Figure 3. Multi-spacecraft timeline visualization.

3.6 MARGOT

MARGOT [8] is a telemetry visualization and management tool utilized by the FCT for both real-time operations and offline data processing. Developed by Argotec and based on Open-MCT, MARGOT enables the creation of customized telemetry screens with the capability to automatically highlight out-of-range values.

A key component of MARGOT is its backend database, which allows for the storage and retrieval of historical data. This database is essential for analyzing and processing large amounts of data offline. Users can display customized graphs, tables, or individual values by setting specific timeframes and scales for each item, providing greater flexibility for the various FCT operators. Additionally, the MARGOT backend generates synthetic telemetry data from real-time values, including osculating orbital elements derived from Global Navigation Satellite System (GNSS) data, thus enhancing the information accessible from the system.

MARGOT also plays a crucial role in external data exchange, facilitating the retrieval of data from its database to produce Flight Dynamics products without the need for external intervention, thanks to dedicated APIs.

Both the MPT and MARGOT are integrated within a central platform, which has been developed using modular architecture. This design allows for easy expansion with additional functionalities, such as an orbit and attitude visualization tool. Furthermore, the platform provides authentication for FCT members through the company identity service.

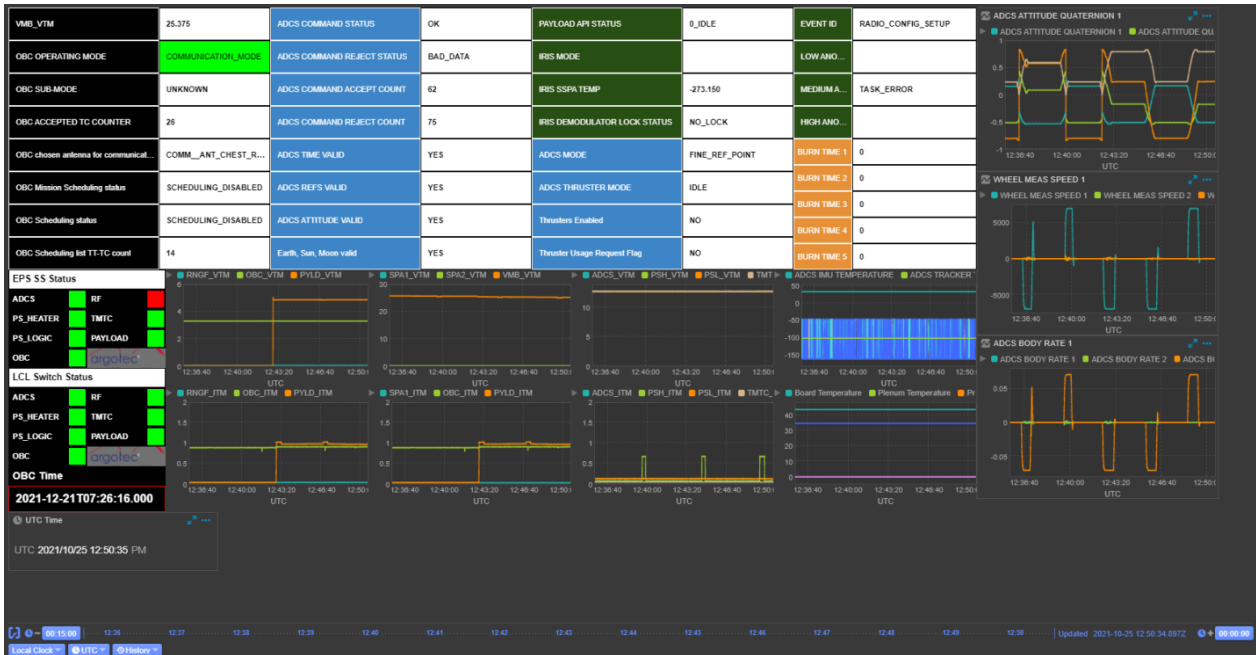


Figure 4. MARGOT Customized Screen Example.



Figure 5. 3D visualization of the satellite.

3.7 Flight Dynamics Service

The FDS is the result of a collaborative effort between the Argotec Flight Operations Team and an external provider. Data exchange between these two teams is automatically managed through a common Secure File Transfer Protocol (SFTP) server, known as the “Flight Dynamics Server.” This server was developed by Argotec and is hosted on its premises, incorporating several key features within its architecture:

- Data format checks based on the XML/XSD standards.
- Automatic upload and download of data products from other architectural nodes (i.e., MPT and MARGOT)
- Validation of maneuvers and generation of related TCs.

Orbital data – including GNSS, TM and GS Angular Data – are retrieved from the MARGOT database once they are downlinked from the spacecraft. The Flight Dynamics Server organizes them according to the common standards defined with the FDS provider before generating the final data product. After evaluation, a set of different data products (such as ephemerides, SOE, and maneuver files) are uploaded to the server by the provider. These products are automatically retrieved, parsed, and included in the MPT database.

The evaluation of orbital maneuvers follows this process: the FDS provider assesses the maneuvers, uploads them to the Flight Dynamics Server, and then validates them using a finely tuned script. This script evaluates the maneuver direction and pointing, the required ΔV , and the propellant mass needed.

These automatic checks rely on platform data collected in a dedicated database (the Flight Dynamics Database) to identify any discrepancies between the calculated maneuver and the actual capabilities of the platform. If no constraints are violated, the maneuver is converted into a set of TC parameters without any further human intervention.

3.8 Data Archive

The DA is designed to receive, process, and store payload data transmitted from spacecraft via X-band downlink. The DA consists of the following components:

- **Payload Listener Server:** This server is responsible for receiving data from the GS and forwarding it to the DA Server for processing.
- **Data Archive Server:** This server handles the automatic processing, decryption (if applicable), and storage of the received payload data. Once stored, the data is forwarded to the IRIDE PDGS through the Delivery Point (DP) interface. Additionally, the DA Server communicates with the MPT to receive planning information and inform the status of payload data downloads.

The DA has the capability to receive payload data from multiple satellites simultaneously. The Payload Listener Server also receives passage planning information from the Internal API, which includes the Acquisition of Signal (AOS) and Loss of Signal (LOS) timestamps, along with the satellite ID. A few minutes before the AOS (for example, 2 minutes prior), the Payload Listener Server initiates instances of receivers linked to the specific socket associated with the correct satellite for each passage. Each web socket closes a few minutes after the LOS.

The satellite ID is used to direct incoming data to the appropriate RabbitMQ queue through the Payload Data Processing Tool (PDPT) exchange and its corresponding routing key. For each satellite, an instance of the PDPT binds a queue to the relevant routing key, ensuring that data is correctly received and processed.

4. Flight Operations Segment Validation

The validation process has been performed using a robust testing strategy designed to ensure that each equipment, subsystem and the overall segment meet specific functional and performance requirements. This process has been executed incrementally at various levels of decomposition, including:

- **Segment Level:** The entire FOS architecture.
- **Subsystem Level:** The interfaces between tools within the MCC and the compatibility of the MCC with external ground entities.
- **Equipment Level:** Each single equipment, or tools, used during flight operations.

Verification with the GS Network Providers has been carried out through various tests, including:

- Network Compatibility Test.
- Radiofrequency Link Test.
- Data Exchange Format Test.
- Scheduler and Booking System Test.

At the Subsystem Level, the developed interfaces have been tested, specifically:

- DIM, MCS and Data Archive
- MCS and Automation Tools
- MCS, MPT and MARGOT
- Constellation Management Platform and FDS

At the System Level, both the upstream and downstream flows, as described in Chapter 2, have been tested using real-time hardware-in-the-loop systems, such as the Flatsat.

Following the comprehensive FOS validation, System Validation Tests (SVT) have been executed to confirm the compatibility of the Space and Ground Segment Systems for both ground and space operations, including the spacecraft flight model. The objectives of the SVT are as follows:

- Overall MIB validation
- TM validation
- TC validation
- Nominal FOPs validation

- Contingency FOPs validation

During each SVT session, specific sets of FOPs have been executed to achieve final operational validation. Should any modifications be necessary, whether at the MIB level or the FOP level (e.g., changes in the sequence of TCs or different TM value levels for branching), a dedicated AGILE process has been employed to ensure proper version control of the variations.

All tests have been successfully completed, confirming the validation and operational readiness of the FOS. The next phase involves achieving operational validation for the FCT operators through a specialized training and simulation campaign.

5. Flight Operational Readiness

The training of the HEO FCT consists of three sequential phases outlined below.

1. Individual Training

This initial phase involves self-study and on-the-job training. Key goals include becoming familiar with the spacecraft platform and ground segment by reviewing available documentation and participating in hands-on training. This may involve following test runs on the console and learning to use the necessary operational tools.

2. Team Simulations Training

The main objective of this phase is for the FCT to conduct a predefined series of simulations. These simulations cover both routine and critical mission operations, including scenarios with and without injected anomalies. Additionally, tasks that primarily involve automation, such as routine tracking passes, are simulated to ensure the smooth execution of the entire process chain without interruptions.

3. Knowledge Maintenance Training

This phase focuses on maintaining the FCT's operational competence prior to launch and throughout the mission's operational phase.

6. Flight Control Team

The Flight Operations Team is responsible for ensuring mission operational capabilities. This team plays a central role in the formation and training of the FCT, which is further supported by additional specialists, such as System Engineers, who bring critical technical knowledge to operational activities. The FCT ensures continuous operational readiness of both the space and ground segments. It actively monitors key system metrics and is prepared to address contingencies, escalating critical anomalies when needed. The team is structured into various operator roles, each with different levels of responsibility and expertise. Their involvement is driven by the nature of the mission activities, operational phases, and available communication windows with the spacecraft.

The development work conducted outside of real-time operations follows a Sprint-based approach, which aligns with AGILE principles. This methodology allows for better task distribution, constant updates to priorities based on requirements, and effective knowledge sharing regarding the status of ongoing activities.

The key members of the FCT include:

- Spacecraft Operations Manager (SOM)
- Spacecraft Controller and Automation Responsible (SPACON)
- Planning Operator (PLAN)
- Flight Dynamics Engineer (FDE)
- Ground Controller (GC)
- System Engineer (SE)

A flexible and interdisciplinary approach is utilized, with some personnel sharing responsibilities and roles; for instance, both the PLAN and SPACON contribute to the planning and implementation of FOPs.

Additionally, the team is supplemented by external experts who provide essential support during real-time operations, particularly with their knowledge of the spacecraft platform. This collaborative environment allows all team members to contribute their expertise and enhance their skills in satellite control, with the goal of incorporating and automating many real-time operations.

7. Conclusion

Some valuable lessons were learned during the development, testing, and validation of the Argotec Flight Operations Segment. As a small company, the members of the Flight Operations Team have taken on dual roles as both developers and operators of the Flight Operations Segment. While this setup can be less than ideal, it has allowed the team to follow the project through all phases, from the initial design to testing and operational stages. As a result, they have developed an impressive level of expertise not only in the individual tools but also in the overall architecture. This deep understanding enables the team to respond more quickly to non-nominal situations.

Additionally, having the ability to interface directly with the Space Segment of the mission—thanks to common in-house development—has provided a dual perspective in Flight Operations Segment development. This facilitates tailored and immediate modifications to the overall architecture, including both the spacecraft's on-board software and ground tools. The same adaptability applies to interactions with external partners and providers, where the capability to respond rapidly to changes has been crucial. This expedient response has been further enhanced by the implementation of AGILE methodology throughout the project, which ensures that team priorities are continuously and swiftly updated.

Furthermore, a young team may not always be the optimal choice for participating in and leading such an ambitious project. The initial phase was characterized by a continuous learning and development process. However, over the past two years, significant improvements have been made. The team has displayed resilience in the face of numerous challenges, consistently demonstrating the ability to persevere while enhancing its cohesion and unity.

The involvement of automation has played a critical role in various stages of FOS development, including design, testing, and in-orbit operations. Automation is essential for operating a Low Earth Orbit constellation, and its integration within operations is continually being improved. Currently, there is ongoing integration of Artificial Intelligence and Machine Learning processes into the automation workflow, with plans to utilize these technologies in the near future—for instance, in the analysis of telemetry trends.

The current state of the Flight Operations Segment is prepared to support the in-orbit operations of the HAWK for Earth Observation Constellation, and it serves as a foundation upon which Argotec and its Flight Operations Team can further develop capabilities for any prospective future missions.

Acknowledgements

The authors would like to acknowledge all the members of the Argotec Flight Operations Team, for sharing both the issues and the achievements experienced during the development of the FOS, which has led to the successful launch of the HEO Pathfinder spacecraft in January 2025.

References

- [1] European Space Agency, “*Lanciato il satellite precursore di IRIDE*”, 15 January 2025, https://www.esa.int/Space_in_Member_States/Italy/Lanciato_il_satellite_precursore_di_IRIDE (accessed 07.04.2025)
- [2] Pirrotta, S. et al, Italian First Deep Space Exploration Missions with ArgoMoon and LICIACube. In: Lee, Y.H., Schmidt, A., Trollope, E. (eds) Space Operations. (2025), SPACEOPS 2023. Springer Aerospace Technology. Springer, Cham.
- [3] European Space Agency, “*Firma Contratti IRIDE*”, 03 December 2022, https://www.esa.int/Space_in_Member_States/Italy/Firma_Contratti_IRIDE (accessed 07.04.2025)
- [4] ESA Requirements and Standards Division, ECSS-E-ST-50-04C – Space data links – Telecommand protocols, synchronization and channel coding, Noordwijk (NL), 2008
- [5] Martínez, Liz & Merlano Duncan, J.C. & Querol, Jorge & Kumar, Sumit & Krivochiza, Jevgenij & Sharma, Shree Krishna & Camps, Adriano & Ottersten, Björn. (2022). Architectures and Synchronization Techniques for Distributed Satellite Systems: A Survey. IEEE Access. 10. 1-1. 10.1109/ACCESS.2022.3169499.
- [6] SCOS-2000 Database Import ICD, EGOS-MCS-S2K-ICD-0001 Issue 7.2
- [7] Sala G., Cester, A. et al, Enhancing Space Mission Planning Efficiency: A Comprehensive Overview of the Argotec Mission Planning Tool and Its Core Component, EAGLE, IAC-24,B6,IP,49,x87703, 75th International Astronautical Congress (IAC), Milan, Italy, 2024, 14-18 October
- [8] Gallo, S., *Design and Development of a Ground Segment Software for Microsatellite Operations*, 17 December 2021