AstroTerra Control Ground Segment: Operations concept and implementation

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This paper describes the Control Ground Segment of the Spot 6 and Spot 7 satellites developed in the frame of the AstroTerra program. It provides the latest information about the organization of the Control Ground Segment operations and the set-up of the associated means. It recalls the overall software and hardware architecture, the main software products and the interfaces to the external world. The paper also highlights the automation decision taken to reduce the number of operators while managing up to 6 passes per day and per satellite over the command and control antenna for satellites commanding and programming. It explains how automation turns into reduced staffing or into optimized satellite usage. A special emphasis is put on the foreseen operations of Spot 6 and Spot 7 in their relationships to the Ground Segment requirements and design issues. The paper provides an inside view into the organizational aspects and the staffing requirements and how they have been integrated to meet the overall system goal.

I. AstroTerra program presentation

The Commercial Service of Spot 5 High Resolution (HR) at Astrium Services Geo-Information (embedding Spot Image) has exposed the strong expectation of the satellite imagery end-users for high resolution (2 m class) and wide swath width image data.

The AstroTerra program aims at providing a complete operational Earth Observation space system to take over the Spot 5 satellite High Resolution data services. The AstroTerra system is composed of Spot 6 and Spot 7, two identical satellites in sun synchronous low earth orbit. The satellites will provide imagery in the visible region of the electromagnetic Spectrum with a 60 km swath width and a 2.2 m ground sampling (possibly improved down to 1,5 m through post-processing) distance at NADIR.

Each satellite has a design life of ten years. Spot 6 will be launched into a low earth orbit by the Indian launcher PSLV (the Spot 7 launcher is not yet defined). The satellites are operated by a Control Ground Segment (CGS) in charge of commanding and controlling the satellite, maintaining the satellite capabilities and its orbit, and tasking the satellite according to the Mission Plan provided by the Exploitation Ground Segment (EGS).

The AstroTerra system is composed of:

- The Space Segment in charge of collecting the imagery data and including :
  - Spot 6 and Spot 7 observation satellites operating on a Low Earth Orbit
  - The AstroTerra Control Ground Segment, located in Astrium Satellite premises at Toulouse

- The customer Operator Segment also called Exploitation Ground Segment made of:
  - A network of AstroTerra Direct Receiving Stations (DRS)
  - An AstroTerra Polar Centre, located in Kiruna
  - The AstroTerra Operator Centre located in customer premises at Toulouse

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II. AstroTerra Control Ground Segment

The AstroTerra Ground Segment architecture is divided in two major parts:

- The Control Ground Segment controls, commands and monitors the Spot 6 and Spot 7 satellites on their orbit, and maintains the orbit. The Control Ground Segment provides all the requested means for managing the satellite configuration and for supporting the satellite maintenance.

- The Exploitation Ground Segment (EGS) programs the satellite mission plan and ingests the image data. It processes these data in order to produce, archive and deliver the Spot 6 and Spot 7 Image products.

The Control Ground Segment provides the following main functions:

- System Data Base management
- Satellite telemetry acquisition
- Satellite monitoring and control
- Control of feasibility and management of the satellite mission command plan
- Telecommand management and uploading
- Orbit monitoring and computation of the necessary orbit control maneuvers
- Operations automation

The Astrium Control Center product line benefits from many years of improvements and tailoring for the demanding export programs. It has started with THEOS (for Thailand) for which a sound and efficient design was conceived; then the solution has been adapted and enhanced for ALSAT-2 (for Algeria) and SSOT (for Chile).

The ground segments of Kazakhstan Remote Sensing (High Resolution satellite) and of Vietnamese VNREDSAT programs are being realized by Astrium. Their control ground segments inherit in a very recurring way of the in-house products line.
Instead of procuring one or two ground stations for commanding and controlling the satellites, the AstroTerra program has decided to rely on a S-band service, contracted to the Swedish Space Corporation. This service will provide access to one or several S-Band Stations in Kiruna and Inuvik for Telemetry and Telecommand data exchanges with the Spot 6 and Spot 7 satellites.

The main external interfaces of the Control Ground Segments are:

- The reception of satellite mission plan from the Exploitation Ground Segment and the emission of orbital information, satellite status and mission follow-up to the Exploitation Ground Segment
- The reception of external time reference to synchronize all subsystems
- The link to the S-band service
- The emission of operational alarms (SMS / email)
- The link to a Space debris collision risk evaluation service (provided by CNES, the French space agency)
- The link to the encryption device keys manager
- The link to the satellite simulator

### III. Software Architecture

The solution designed for AstroTerra Control Ground Segment relies on software products developed by Astrium.

MOSAIC, is a new software product developed in the frame of the AstroTerra project. MOSAIC has now become part of the Control Ground Segment product line.

AstroTerra has integrated the following products:

- Control Command: OPEN CENTER
- Flight Dynamics: QUARTZ++
- System Database : SIS (Satellite Information System)
- Centralized Logbook: C-LOG
- Interface adaptation and automation: MOSAIC
- Off-line Telemetry Trend Analysis : TELMA
A. OPEN CENTER: Command and Control (CCS)

OPEN CENTER is an Astrium product used both for Satellite Control Centers and for satellite Assembly Integration and Test (AIT). The Control Center therefore benefits from all the validation already performed during the AIT phase. It offers a complete system environment to manage all real time and off-line activities associated to satellite monitoring and control.

OPEN CENTER is composed of a configurable set of data-driven components. It includes a user-friendly environment allowing definition and execution of on-board operational procedures. It performs the following main functions:

- technical monitoring of the spacecraft, by processing the housekeeping telemetry and checking spacecraft status.
- control of the spacecraft, by preparing bus and payload telecommand plans and ensuring their proper uploading.
- automation of operations, through preparation and execution of activities.
- monitoring and control of the platform and images-band ground stations

OPEN CENTER is based on a component based-architecture, designed to cover in a generic way the following operational phases of a satellite Pass:

- preparation (synoptic, test sequences, configuration, etc.)
- real-time session
- replay session with standard archive
- analysis with standard archive (logbook, exploitation of parameter engineering values, exploitation of acquisition raw data, etc.)

As a standard ASTRIUM product, OPEN CENTER has been used on every test facilities for the last 10 years and on all export control centers. The product can be easily adapted to various external interfaces and data exchange protocols, as confirmed by more than 20 different programs. The product is also used on the AstroTerra Test Facility, which is a strong asset for optimizing tests, test data and environment, preparation and qualification of operational procedures.
B. QUARTZ++: Flight Dynamics

QUARTZ++ is an Astrium product for Flight Dynamics, used on both earth observation, science and telecommunication programs. The product benefits from more than 15 years of experience and continuous improvement. It has been used all over these years for the Launch and Early Operations Phase (LEOP) and for In Orbit operations. It is part of all Control Ground Segments delivered by Astrium.

QUARTZ++ relies on a user-friendly Graphical User Interface designed to minimize human errors. It automates to a great extend the computation and linking of different tasks among windows so as to minimize manual inputs.

The product is designed for openness, configurability and maintainability. It allows an easy integration of new flight dynamics functions as well as the addition of a new spacecraft. The Graphical User Interface lay-out, default values and database structures are easily customizable. The openness of the system is a key feature in order to install in a new system flight-proven flight dynamics algorithms.

The task sharing between modules provides the user with a lot of flexibility when operating the Flight Dynamics product. Several users may work in parallel on the software, each user performing activities on several satellites or clusters of satellites.

The architecture is designed in order to clearly separate the framework (windows, external interfaces, database management, etc.) and the flight dynamics science (algorithms), each part being under the responsibility of a different specialized team.

C. SIS – Satellite System Database

The SIS implements the Satellite Operational Data base. This solution has been the obvious choice for all systems developed by Astrium over the last 10 years.

It is a well proven solution, consistently used by the system teams of all Astrium observation and science satellites programs. It provides all necessary functions for the management of a system data base such as the one necessary for AstroTerra system.

It provides standard extraction tools for the input format required by the OPEN CENTER product, core of the AstroTerra Control Command Subsystem.

It also allows complete sharing of system data definition and management throughout the system development process, from satellite preliminary design to avionics and on board software validation, satellite integration (full compatibility with Astrium Test Facilities) and satellite operations.
D. C-LOG: Centralized Logbook

The Centralized Logbook (C-LOG) provides archival and distribution of all satellite and ground station events happening throughout the ground segment.

The C-LOG provides the following functions:

- Events injection interface allowing ground segment applications to log their events in the centralized Logbook database.
- Archival storage in a dedicated database of all system events along with their time stamp.
- Historical retrieval of logbook entries according to a given time span and user-defined criteria for displaying, printing or exporting in ASCII file.
- Real time distribution of logbook events for display purposes.
- Real time and historical visualization of logbook events including user-defined selection, printing and exporting in ASCII file of displayed data.
- Alarm management including access (visual / acoustic) to pending alarms, acknowledgement injection interface allowing external systems to acknowledge their related alarms and real time consolidation and distribution of alarms and acknowledgements.

The C-LOG product is based on 3-tier architecture:

- Data management through MySQL database.
- Data processing using dedicated tasks, acting as application servers.
- Data presentation and user interactions using distributed GUIs, acting as application clients.

E. MOSAIC: Interface Adaptation and Programming Automation (SPS)

MOSAIC is in charge of managing the Control Ground Segment system and satellite configuration, the flight reservation plan and the visibilities plan. It also provides a framework to implement and custom automatic activities dedicated to an earth observation mission. For example, activities can be dedicated to the analysis and check of the mission plans computed by the Mission Facilities (part of the Ground Segment in charge of the Mission Programming) and to the implementation of a mosaic of interfaces between the Exploitation Ground Segment and the Control Ground Segment.

The role of MOSAIC is to provide to the Control Ground Segment capabilities to:

- Display and edit satellites visibilities plan, including the reservation management with the S-Band ground stations.
- Display, edit and distribute the Flight Reservation Plan.
Display, edit and distribute in a centralized way the System & Satellite Configuration;
Perform interface adaption between all the Control Ground Segment subsystems and with the Exploitation
Ground Segment. This interface adaptation includes the distribution of data files from the data producer to
the data consumer with or without data format translation. For example, Mosaic can provide to the
Satellite Control Center the mission TC plan generated from the mission plan computed by the Exploitation
Ground Segment. Each interface adaptation is supported by a dedicated Activity that can be run
automatically by the Ground Segment Scheduler or on demand by the Operator from the Mosaic Graphical
User Interface.

Mosaic main features are:
- Centralized System & Satellite Configuration management
- Flight reservation plan management, including unusable mission slots
- Visibilities plan management.
- Activity management.
- An Executer dedicated to automatic Activity execution.
- Generic Activities implementation such as file transfer automation
- Framework to simplify implementation of new Activities (common services and tools).
- Mosaic instantiation for a dedicated Control Ground Segment managed by configuration file.

F. TELMA – Off-line Telemetry Trend Analyse

TELMA is a multi-satellites telemetry data (TM) post processing system. Its main purpose is to provide an offline
service of exploitation and analysis of TM, helping engineers during in-orbit support, monitoring and investigation phases.

TELMA handles telemetry dataflow from multi-platforms of earth observation or telecommunication
satellites, allowing fleet management with cross-satellite comparisons. It can exploit in parallel up to 50 satellites, and
guarantee the data results accessibility for up to 50 users.

TELMA manages a high number of automatic monitoring and processing treatments. It also provides telemetry:
- statistics (Min, Max, Mean, Standard deviation)
- daily plots
- status
- availability in percent (based on TM holes)

TELMA automatically generates reports (monthly, yearly satellite health report, insurers report), which can be specific
or generic for a satellites fleet. Telemetry and exploitation results are presented to user via an interactive, intuitive and
customizable graphical user interface.

TELMA provides different processes overviews, helping user to verify the daily processes status in one click and solve
problems faster. Users can define their own processing and monitoring, using an assisted GUI.

All TELMA features are available from a Web browser, as well as the processes and platform administration,
enabling a fully flexible access over the corporate network.
G. Long Term Maintenance

Each Spot 6 and Spot 7 satellite has been designed for at least a 10-year lifetime. Cumulating the two lifetimes and the validation phase prior to the first launch, the Control Ground Segment will have to be up and running for a minimum of twelve years.

The approach based on Astrium products has not only proven being very efficient to provide a cost effective solution but it is also to be considered in the view of long term maintenance. The in-house mastership of all components which are part of Astrium core activities ensures the long-term ability to have AstroTerra Control Ground Segment benefit from an evolutive maintenance following the new releases of the different products.

It is not planned however to install in AstroTerra neither each and every version of the products, nor of the operating systems or Commercial Off The Shelf. Apart from patches (if required), only some selected versions will be taken on-board after a System revalidation.

IV. Hardware Architecture

H. Description

The AstroTerra Control ground Segment hardware architecture has been designed to take into account some major requirements:
- On-line Telemetry access for the duration of the AstroTerra program (currently evaluated to 15 years for 2 satellites)
- No Single Point Of Failure (SPOF)
- A redundancy policy enabling all applications to switch from nominal to backup chain in case of failure

Two Control Ground Segments are installed at Astrium Toulouse premises, in two different buildings, to ensure proper redundancy: One Prime segment, with a complete redounded hardware configuration (nominal and backup chains) and a Secondary Ground Segment with a hardware configuration identical to the one of the Primary Segment.

The storage solution has benefited from a specific attention. It needed to keep online the complete spacecrafts archives and to support the intensive I/O operations resulting from compressed engineering telemetry processing. Two technical choices were taken into consideration:
- Network Attached Storage (NAS) solutions are specialized file-serving devices that provide support for heterogeneous files in a high-capacity package, but enforce NFS (Network File System) access, which

Figure 10. AstroTerra centers. One nominal Ground Control Center and one backup control center located at Astrium premises
is not compatible of the intensive I/O operations. In addition, some data will be stored in the database, and it is not recommended to have Oracle or MySQL daemon accessing the database via NFS.

- Storage Area Network (SAN). A SAN is a Fiber Channel networked infrastructure encompassing processing servers, network switches, disk controllers and disk enclosures that can be seen as a stand-alone processing and storage unit.

On the first programs Astrium HP Windows-based NAS was chosen for its simplicity and its cost-effectiveness; Difficulty in maintaining them on the long run and in managing them in a heterogeneous environment led Astrium to select SAN on the most recent programs. Although a SAN is more expensive than a NAS, the increased level of robustness and fault tolerance justifies the selection.

Figure 11. Hardware architecture. Sustainability and no Single Point Of Failure
In addition to offering extremely high storage flow (2 to 4 Gbit/s) and capacity (from tenth to hundredth Terabytes), SAN are also designed to cope with industry highest availability rates, avoiding any single point of failure: It is accessed by two servers managed as a cluster with Linux High Availability.

The servers are based on HP Proliant DL380 series.

The selected hardware was chosen among standard off-the-shelf computers amidst the best-sellers of the manufacturers. This guaranties an optimized spare policy and a better availability of the models over the years. Usually manufacturers as HP warranties this kind of hardware for 5 years after it has disappeared from the catalog. For best sellers, this duration can be extended. In addition, along the years, the selected servers and workstations have evolved but have been remarkably stable seen from applications point of view, requiring very few evolutions (apart from Operating System upgrade which often pulls other COTS upgrades).

The Operating Systems selected are Open Source (mainly Red Hat) to provide a longer sustainability of the solution.

V. Operations

Two years ago, at SpaceOps 2010, in Atlanta, USA, a presentation of the intended Spot6 and Spot7 operations strategy was given. Now that Spot6 launch is close, this chapter proposes an update of this strategy, refined along the years.

With Spot6 and Spot7, Astrium Satellites will for the first time operate commercial earth observation satellites. Astrium benefits from the perfect knowledge of the control ground segment and, naturally from intimate mastership of the operations requirement of its own satellites. However, setting up the operations of the ground control center has required defining and implementing infrastructure requirements, operations approach, staffing strategy, which are usually only specified by Astrium and implemented by its customers.

I. Presentation

Spot 6 and Spot 7 operations rely on an S-band service provided by the Swedish Space Corporation, through well defined interfaces. Telemetry analysis is performed off-line during office hours. This approach enables to maximize Spot 6 and Spot 7 visibility periods and, at the same time, keeps the cost down by sharing the required satellite resources with the needs of other systems.

The Exploitation Ground Segment prepares the payload mission during office hours in the Astrium Services GEO information (embedding Spot Image) offices, in Toulouse. When ready, the mission plan is transferred to the Control Ground Segment. In parallel the needs for controlling the satellite platform are assessed and a telecommand plan is produced, if required. Both the platform controlling plan and the mission plans will be uploaded to the satellite during the next pass over the reserved and available S-Band Service slots. The on-board recorded Telemetry will be downloaded during each real-time pass.

The AstroTerra system will nominally manage six mission plans per day in routine mode. This chronology has been designed to:

- Take into account the latest meteorological forecasts data in the tasking sequences
- Give the users an optimum reactivity for “last minute requests”

The nominal chronology is defined so to fulfill in an optimum way the customer requests pending on the related geographical areas of interest (e.g. Japan, China, Middle East, Western Europe, South America, North America) while respecting AstroTerra system constraints.

For being able to execute at the beginning of the geographical areas of interest any day of the orbital cycle, these plans will have to be ready for upload around the following GMT hours: Japan 00h00, China 02h00, Middle East 05h25, Western Europe 08h20, South America 12h00, North America 15h10.

J. Typical scenario
The orbit of Spot6 and Spot7 satellites are accurately controlled and therefore the S-Band visibilities that can be used for each day of the 26 days of the cycle will be defined once and for all. The whole system chronology and the horizon plans will then be fully defined over 26 days.

Each Mission Plan will be processed over a mission horizon covering a 24-hour period in order to be able to palliate a processing or uploading problem. In this case, each mission plan will contain a nominal part and five backup parts. If for any reason a new mission plan cannot be uploaded on board, the first backup part of the previous Mission Plan, already on board (which would have been superseded by the nominal part of the new mission plan), will be executed by the satellite.

**Figure 12.** AstroTerra chronology. Definition of the 6 programming periods in the system chronology.

Resulting from the mission plan availability defined by the system chronology, the “predefined” selection of ground station visibilities drives the daily schedule of the CGS activities related to mission plan management. A maximum time interval is defined covering each couple of successive passes of Spot 6 and Spot 7 over each selected station, for all possible orbits.

Associated to the passes, the chronology applies operational time constraints, in order to define the beginning of computation of each programming period in the Exploitation Segment in Spot Image (green arrow) and the latest time of reception of the mission plans file in the CGS (red arrow).

**Figure 13.** Time constraints. Definition of the time constraints of mission plan processing

The Exploitation Ground Segment is built to be fully automatic for processing routine daily tasks. As a consequence, the mission plan and the platform command plans uploading are designed to be carried out without human intervention.

**K. Staffing and organisation**

The organization of the routine operations of the Control Ground Segment relies on:

- 1 Ground Operations Manager, full time, working hours
- Equivalent of 1 person for sub-systems support, consisting in:
  - 1/3 person for CGS Support, working hours
  - 1/3 person for FDS Support, working hours
1/3 person for Quality Assurance and Configuration control, working hours

Controllers to operate the control center

The required “level” of controllers presence in the AstroTerra Control Ground Segment has been determined according to a global trade-off between the required system security level (and the actual impact of human presence on the security assessment) and the operation costs.

Several scenarios have been analyzed for the operations in routine mode:

- Three daily shifts providing a 24 hours a day enabling to staff all the passes in the control center
- Two daily 8-hour work shifts allowing to staff 4 passes out of the maximum of 6 passes
- One daily shift allowing to staff a maximum of 3 passes

After balancing the equation cost / risk / benefits and the legal aspects (maximum daily and weekly working duration, existing agreement with the trade unions, etc.), Astrium has selected the single daily shift organization. During the first months of routine operations the control center will operated seven days a week. A re-evaluation of the needs will then be performed and a decrease to operations with 5-days a week will be assessed.

In addition to the nominal staffing, on-call duties will be set-up enabling to cope with emergency situations, for example when a controller cannot be present in the center. When an anomaly occurs on the control center outside the controllers staffing time, an automatic notification will be sent to the on-call person; depending on the anomaly, the on-call person may come to the control center.

Considering the controllers origin, a trade-off was made between nominating Astrium own people or subcontracting this activity. Selection of Astrium people was quickly made, based on the strong arguments: Efficient feedback and improvement loops shall be put in place to strengthen the Astrium operations capabilities and to continue enhancing Control Ground Segment products and solution.

VI. Conclusion

The AstroTerra Control Ground Segment is based on existing products owned by Astrium. This permits to build up on the Ground Segments realized for the export markets as well as to take benefit of the use of some products in Assembly, Integration and Tests phase. The minimization of dependency towards third parties software providers will result in a lower Total Cost of Ownership.

AstroTerra has set up an efficient Control Ground Segment benefiting from a high level of automation; a new software product, MOSAIC, has been developed to take into account stringent requirements that will constitute a new cornerstone of the earth observation ground segments. As a result, the control segment will be operated with a low staffing profile, with a single shift during administrative hours, 7-days a week during the first months.
Based on a sound architecture and careful choice of hardware and a few Commercial Off The Shelf low-level products, AstroTerra Control Ground Segment is designed to cover the entire program lifetime, evaluated today to 12 years.