The Flight Operations Segment

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The Envisat Flight Operations Segment (FOS) provides the services needed to operate the Envisat platform and its instruments during the Launch and Early Orbit Phase (LEOP), the Commissioning Phase and the Routine Phase of the mission. In developing the FOS, extensive use has been made of existing components already developed and tested for the ERS missions. The resulting FOS is a distributed system, with a widely variable configuration depending on the different mission phases for which it will be used.

Introduction

The FOS is one element in the overall ground segment and it consists of the Flight Operations Control Centre (FOCC), the Kiruna (S) and Svalbard (N) ground stations, and the Launch and Early Orbit Phase (LEOP) network. Its main task is to monitor and control the Envisat satellite during the LEOP, Commissioning and Routine Phases, for which it interfaces with the following elements of the Envisat system:

– the satellite, for telemetry, telecommanding and ranging via the Kiruna, Svalbard, Villafranca (E) and LEOP stations
– the Payload Data Segment (PDS), for mission planning and reporting
– the Artemis Mission Control Centre, for the reservation of communication slots
– the Announcement of Opportunity Instrument (AOI) providers, for instrument operations
– the industrial partners (e.g. satellite Prime Contractor), for support during both the critical and routine mission phases.

Given the crucial role of the FOS in the overall success of the mission, stringent requirements for system availability, real-time performance, recovery, traceablity and validation have been systematically applied to all FOS elements. In addition, a validation of the operational procedures for all mission phases has been performed during System Validation Tests and during the FOS Simulation campaign.

FOS architecture

The FOS basically consists of the ground stations and the Flight Operations Control Centre (Fig. 1). ESA's Kiruna-Salmijarvi (S) facility serves as the prime station, complemented by the Svalbard (Spitzbergen) station to provide coverage during those orbits not visible from Kiruna. During the LEOP, the ground-station network will be temporarily extended to nine stations.

The Flight Operations Control Centre (FOCC), located at ESOC in Darmstadt, Germany, has the following components:

– The Flight Control System (FCS), which includes:
  - the spacecraft telemetry and telecommand database
  - the telemetry and telecommand systems, which are based on the corresponding, well-proven ERS systems
  - the Spacecraft Performance and Evaluation (Speval) archive, which is the long-term archive for telemetry and telecommand history data (with a web interface)
  - the on-board software maintenance system, which controls all patch and dump activities and guarantees configuration control for each change made to the on-board software
  - the mission planning system, which is used to plan and generate the daily command schedules.

– The Flight Dynamics System, which maintains the orbit and controls the on-board AOCS system.

– The Simulator, which realistically simulates the satellite's behaviour.

The ground stations

FOS GS - LEOP

During the LEOP, the requisite wide coverage of the flight path is provided by a network of nine ground stations, belonging to ESA or other organisations providing their services through

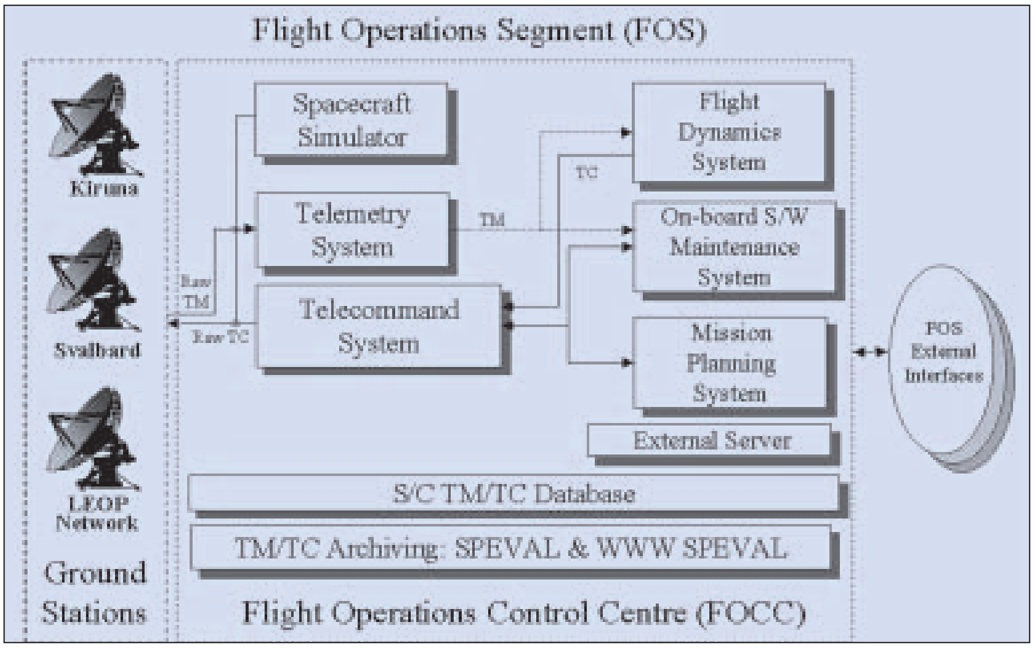

Figure 1. The structure of the Envisat Flight Operations Segment (FOS)

co-operation agreements. The LEOP ground-station network uses facilities at nine sites:
- Kourou
- Perth
- Villafranca
- Kiruna
- Santiago de Chile
- Wallops
- Poker Flat
- Kerguelen
- Svalbard.

The LEOP stations provide tracking, telemetry and command (TT&C) support in S-band. The ESA stations already being used for the Agency's missions did not require additional work in order to cope with Envisat. The non-ESA stations, although compatible at the radio-frequency level, have required some specific work at the base-band level (Santiago, Wallops and Poker Flat) or at the communications-link level (Kerguelen and Svalbard).

FOS GS - Routine
Monitoring and controlling the spacecraft during the Routine Phase of the mission relies on the ESA Kiruna-Salmijarvi (S) 15 m station as the prime station, complemented by the Svalbard station providing services during the Kiruna blind orbits. The ESA Villafranca (E) station will be used as the back-up during the Routine Phase.

The stations at Kiruna and Svalbard (Figs. 2 and 3) will provide full TT&C support in S-band when in direct visibility. The Kiruna-Salmijarvi station will also be used for the recovery of the housekeeping telemetry recorded by the on-board solid-state recorder over the whole orbit

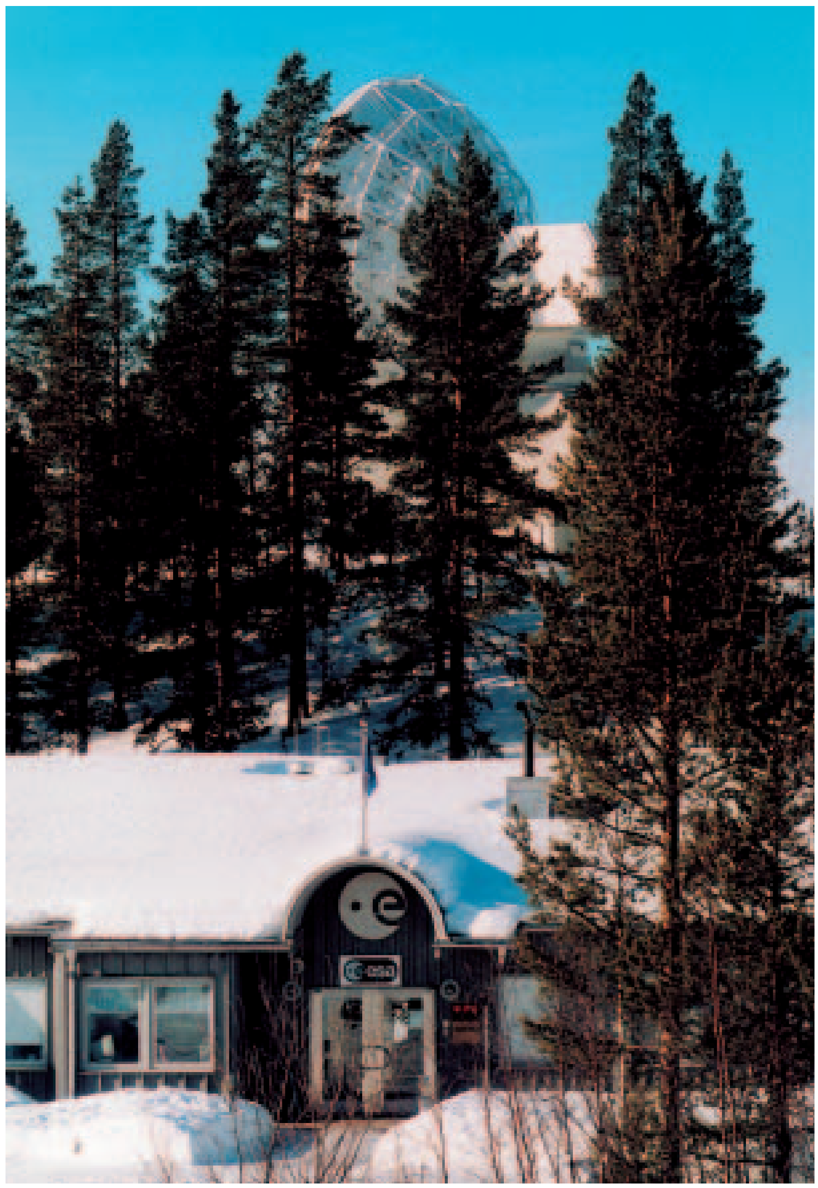

Figure 2. The Kiruna ground station, in Sweden

Figure 3. The Svalbard ground station, in Norway

and dumped at X-band when within ground-station visibility. In order to support both the ERS and Envisat missions, an off-the-shelf 13 m antenna has been procured by the Swedish Space Corporation, the site operator, to provide S- and X-band services. Following Envisat's launch, the 15 m antenna's front-end will be re-furbished to support the next five years of Envisat operations.

During the initial phase of the Envisat mission, the Svalbard service will be provided by the station owned by Kongsberg Lockheed Martin, and operated by TSS. TSS is currently procuring another station to provide services at S- and X-band, to be operational at the beginning of 2002.

The above ground stations and the other FOS elements are connected via the ESA OPSNET network, which includes leased and dial-up lines via X.25 nodes. During the LEOP and Routine Phases, the OPSNET element will be operated centrally from ESOC. A network-control system allows remote control of each node in the network and switching of lines if needed.

The Flight Control System

The Envisat FCS provides the operators with facilities to both monitor and control the spacecraft. It includes database management (DB), telemetry processing (TM), telecommanding (TC), mission planning (MPS), on-board software maintenance (OBSM), local and remote spacecraft data-evaluation facilities (Speval, and via the web WebSpeval), monitoring and control of the Kiruna facilities (TTCDAF) and interfaces with the other elements of the Envisat ground segment. The FCS application software consists of the mission-specific software developed by industry, and the generic SCOS-1 infrastructure software. The SCOS-2000 infrastructure OBSM kernel supports the Envisat-specific OBSM subsystem.

The FCS is installed at ESOC in Darmstadt. The operational environment has been provided in the Envisat Dedicated Control Room (DCR) since the first SVT. During the LEOP, the Envisat FOCC will be installed in the Main Control Room (MCR).

The system hardware platform is set of three VAX computer systems connected in a protected Local Area Network. The user interface consists of up to 22 work stations, each with three screens. The system architecture supports all of the user requirements in terms of system availability and system response times, which are most severe for the critical mission phases, e.g. the LEOP. During these critical mission phases, a 'warm standby' is required, because it is not possible to restart a VAX computer system within the required one-minute time limit for system unavailability, whereas a 'cold standby' is sufficient for the mission's Routine Phase.

The Flight Control System consists of the following components:

- The database management (DB) provides the functionality for creating and managing the system databases. The Satellite Reference Database (SRDB) provided by industry is imported into a static Oracle database. The operational database used for real-time processing is derived from this static database and incorporated into the operational environment.
- The telemetry (TM) subsystem receives and processes the satellite telemetry. It receives real-time telemetry via X-25 links from the ground stations, or on-board-stored telemetry via a file interface from the Payload Data Segment (PDS). The telemetry subsystem quality-checks and processes all telemetry formats.
- The telecommand (TC) subsystem provides all of the features necessary to prepare, uplink and verify the commands. A history of all commands sent to the satellite is also maintained. Full manual operation of the spacecraft is supported. In normal operation modes, however, this system will uplink parameters and commands received from internal or external sources.
- The Mission Planning System (MPS) is part of the Envisat end-to-end planning function responsible for the planning and scheduling of the satellite and ground facilities. Its main task is to plan the spacecraft operations, according to requests for operations as

defined in the Reference Operation Plan (ROP) and in the Preferred Exploitation Plan (PEP). This activity must be conducted within the framework of satellite and ground constraints and in co-ordination with the Artemis satellite ground-segment planning function. The MPS provides the satellite, the ground-station schedule and the Detailed Mission Operation Plan (DMOP) to the Payload Data Segment to enable the scheduling of the data-acquisition facilities. Finally, the MPS reports on the success of the operations with respect to the plan.

- The On-Board Software Maintenance (OBSM) subsystem provides the engineers with an environment in which the on-board processor flight software can be maintained. The key issue for this subsystem is configuration control and availability. The software updates are obtained from the Software Maintenance Facilities (SMF).
- The Spacecraft Data and Evaluation facilities (Speval, WebSpeval) will archive spacecraft and ground-station data gathered throughout the duration of the Envisat mission and will allow this data to be retrieved and analysed later. A security-controlled, web-based interface is provided to allow remote access.
- The Communications Management Function (CMF) controls the transfer of data files between different functions inside and outside the FOS. The CMF has a database-driven routing algorithm, which also guarantees delivery in the case of anomalies. External users are separated from the FOCC by a firewall.

The staggered Flight Control System deliveries were validated and accepted using the Envisat Simulator. Testing using satellite hardware was only conducted with fully released software versions.

The Flight Dynamics System

The Fight Dynamics System for Envisat is an ESA internal development, operated by flight-dynamics experts. The services provided include:

- orbit determination and control
- generation of AOCS-related telecommand parameters for the central flight software
- monitoring and performance evaluation of the AOCS hardware and software, and testing and validation of all of the flight-dynamics products.

The Flight Dynamics System runs on a server/client platform (Sun/Solaris), which is highly redundant in terms of its key hardware. Each of the four disciplines mentioned above constitutes a self-standing and mutually-interfaced subsystem.

For the early part of LEOP (Fig. 4), the Orbit Determination and Control Subsystem is a very critical component, as its task is to determine the actual orbit. Ariane-5 will inject Envisat directly into its operational orbit. Immediately after the spacecraft's separation from the launcher, a rapid procedure will be started that allows all nine supporting LEOP ground stations to quickly locate and acquire the satellite. On the basis of this, a series of orbit-correction manoeuvres will be prepared to compensate for the relatively minor Ariane orbit-injection errors, and to initiate a drift phase of 1-5 weeks that will allow the precise phasing of the orbital positions of Envisat and ERS-2. Already two days after lift-off, orbit determination, prediction and control activities will assume a routine mode of operation.

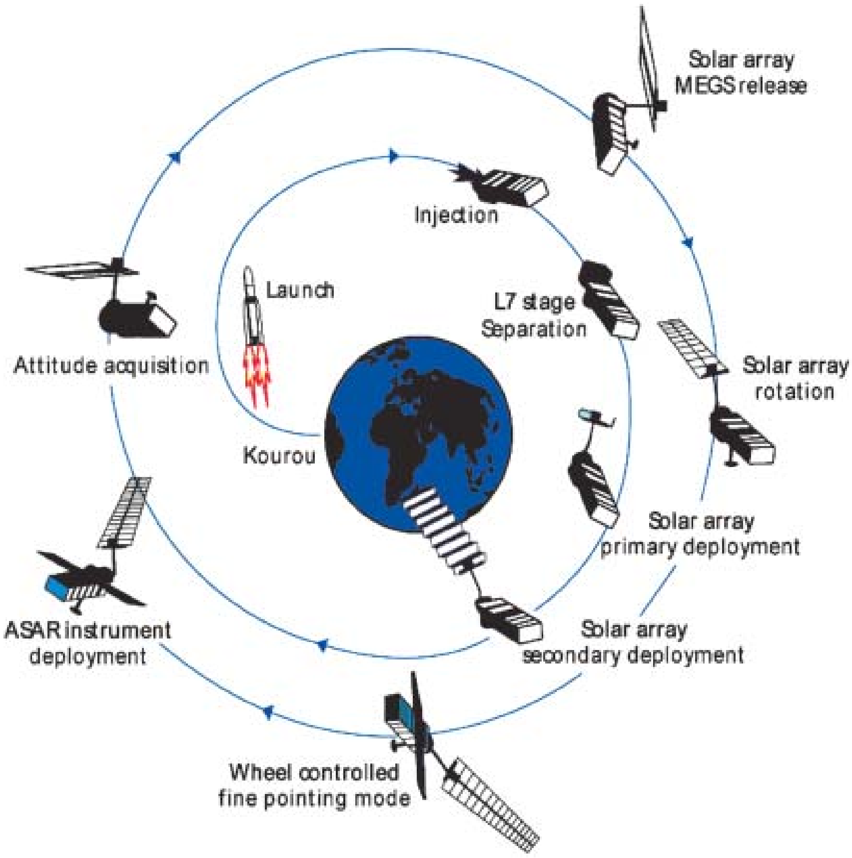

Figure 4. The Launch and Early Operations Phase (LEOP)

During the Routine Phase, the Orbit Determination and Control Subsystem will determine Envisat's orbit twice per day, predict its orbit for the next 8 days, provide this orbital information to the ground stations, and plan manoeuvres that will keep the orbit within the prescribed ground track, e.g. dead band.

During the LEOP, the AOCS Monitoring Subsystem will show how fast the satellite is rotating around its axes and will give an indication of how the automatic acquisition of the nominal attitude by the on-board control system is proceeding. It will also provide data shortly after spacecraft separation that will

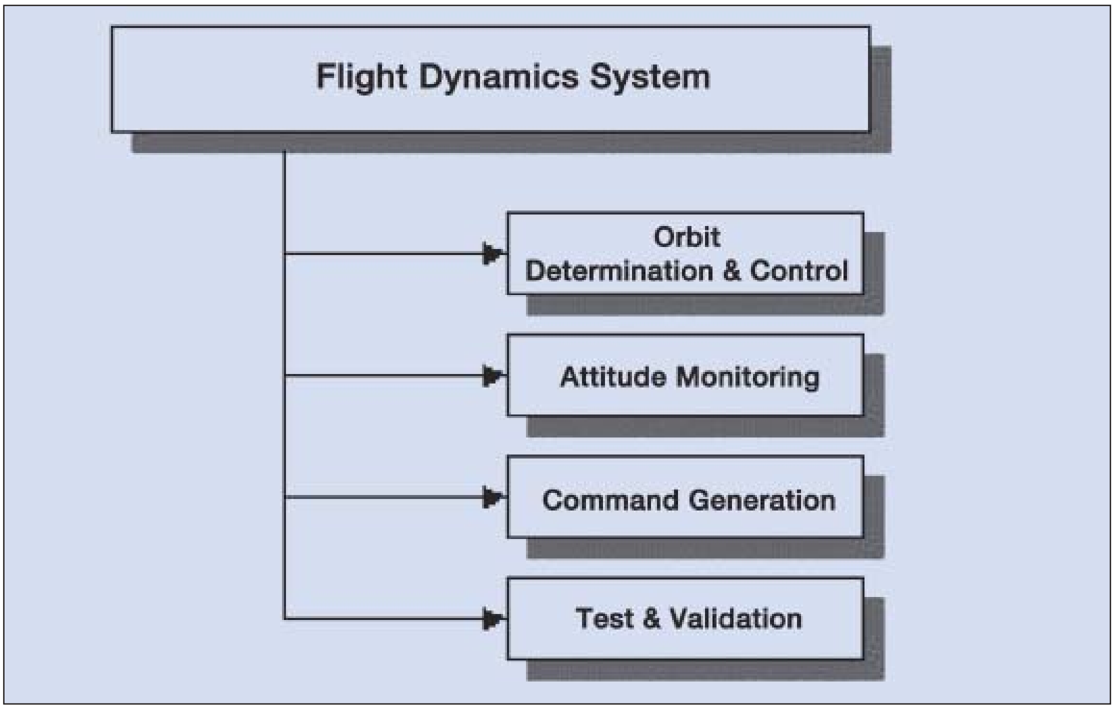

Figure 5. The Flight Dynamics facilities

indicate whether the solar array has been successfully deployed, which is essential for mission success. Further into the mission, the monitoring of spacecraft rates and other AOCS parameters such as reaction-wheel speeds and Earth-sensor measurements, will allow an assessment to be made of how well the on-board control algorithms and sensors are working, and how stable the satellite pointing is. This can then be compared to the estimates of spacecraft rates and attitude calculated by the on-board computer.

All the Flight Dynamics subsystems (Fig. 5) have been developed based on the similar ERS systems. For orbit determination, including high-precision orbit determination at the sub-decimetre level, this ERS experience has been used to develop the Navigation Package for Earth Orbiting Satellites (NAPEOS). This internal infrastructure product based on the flight-proven ERS orbit determination and control software can be reused for future Earth-orbiting missions.

An independent test and validation group has validated the mission-critical software developed as part of the flight-dynamics subsystem. The validation campaign included interface, single, subsystem and system tests and training. The key tools used in this campaign were a High-Precision Test Data Generator and a Tracking Data Generator, which generate realistic test data based on pre-defined attitude, orbit and ground-station parameters.

Once Envisat operations begin, the task of the test and validation group is to ensure the high quality of all products delivered to internal/ external parties.

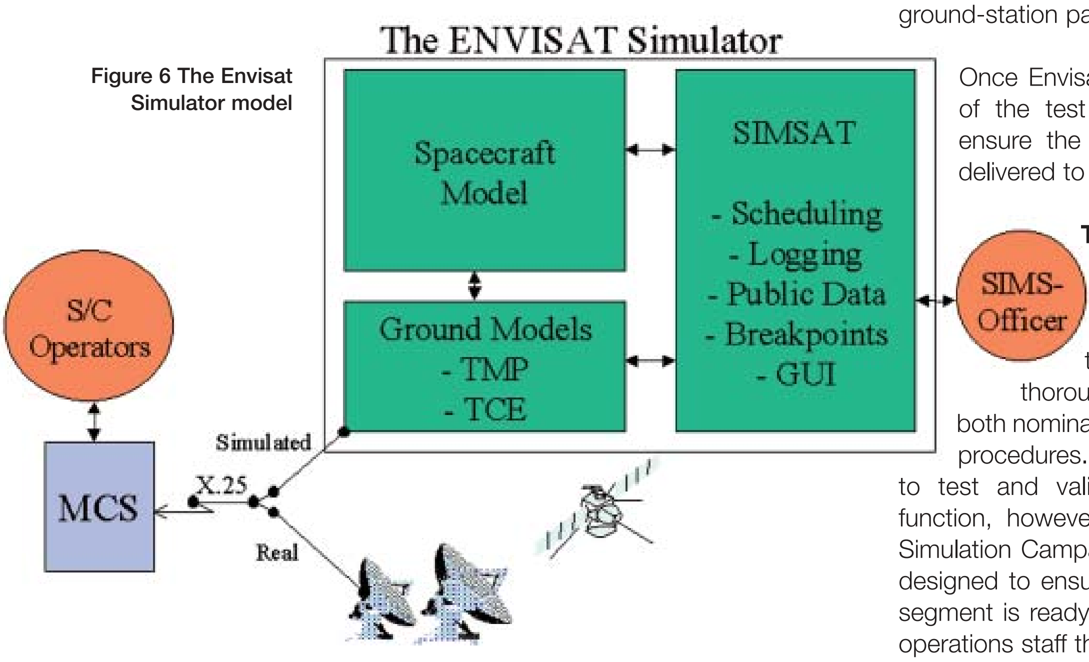

Figure 6 The Envisat Simulator model

The Simulator

The Envisat Simulator (Fig. 6) provides the spacecraft operations personnel with a training tool that allows the thorough testing and evaluation of both nominal and contingency operational procedures. In addition, it has been used to test and validate the FOS. Its primary function, however, is to support the Envisat Simulation Campaign prior to launch, which is designed to ensure that the complete ground segment is ready for the launch, including the operations staff themselves.

The Simulator runs on a DEC-Alpha work station and uses a generic 1750 emulator to model the satellite's on-board Central Communications Unit (CCU) and Payload Module Computer (PMC). This means that the actual flight software for both the CCU and the PMC can be executed in the Simulator, vastly adding to the realism and validity of the simulation.

The Simulator can be divided into three main parts: the infrastructure (SIMSAT), the spacecraft model itself, and the ground-equipment models. SIMSAT and the ground-equipment models are generic products that are used for a variety of the ESA spacecraft simulators. The spacecraft model is naturally unique and has been developed by industry using object-oriented analysis and design methods. It is therefore broken down in the same way as the spacecraft itself in terms of a Service Module, a Payload Equipment Bay, and the Payload Instruments. These components are then further broken down into the different components within these subsystems in a modular fashion.

Each delivery for the Envisat Simulator has gone through a series of tests before being accepted by the spacecraft operations team. Firstly, each module has been integration-tested by the developers, and then the whole system has been tested. The simulators were then formally delivered for 'provisional acceptance testing'. Once the Simulator had successfully passed such testing, it was released to the operations team for 'final acceptance testing'. These tests were based on the user requirements defined at the beginning of the Simulator's development lifecycle.

Operations

The operational concept is based on manual operations during critical phases and anomalies, conducted according to pre-defined flight operational procedures. All such procedures have been developed and validated at the FOCC (Fig. 7). During routine operations, schedules based on user inputs are generated automatically for operating the entire satellite.

Figure 7. The FOS Main Control Room

The mission operations can be divided into four distinct phases:
– the LEOP
– the Commissioning Phase, which can be further subdivided into a payload first switch-on (SODAP) and a Calibration and Validation (Cal/Val) Phase
– the Routine Phase, and
– the end-of-mission phase.

LEOP
During the initial LEOP, the prime objectives are to deploy the satellite appendages, to acquire the correct attitude, and to generate power from the solar array to re-charge the batteries. The FOS has to monitor the majority of the on-board auto-sequencing during the deployments. In the event of on-board contingencies, the flight control team has to react quickly to determine the cause of the anomaly and to execute the pre-defined recovery operations that have been practised many times during the simulations.

The satellite design allows only about four orbits without power from the solar array, which makes any contingency recovery extremely time-critical. This is why a dense network of nine ground stations with a fully redundant infrastructure has been built.

Two mission control teams operating in two shifts, 24 hours per day, will be available in the Control Centre. During the second part of the LEOP, acquisition of the operational orbit will be initiated and the Advanced Synthetic Aperture Radar (ASAR) antenna will be deployed. This phase will last approximately 1 week.

Commissioning
Once the LEOP has been completed, the initial commissioning of the Service Module, Payload Equipment Bay (PEB) and Instruments will commence. In this phase, the PEB and the instruments will be switched on incrementally and the in-flight performances of the various on-board subsystems and of the ground segment will be verified. Also as part of this phase, the Ka-band antenna will be deployed and some instrument covers will be released.

The instruments will then be calibrated and their Earth-observation products validated during dedicated campaigns. The overall duration of the Commissioning Phase will be approximately 6 months. With the exception of a few critical switch-on and deployment operations requiring extended coverage, a single Kiruna and/or Svalbard pass per orbit is sufficient to command and control the satellite during this phase.

The operational concept evolves around operations by procedure for the initial switch-on and deployment-and-release activities and automatic scheduling by the FOS Mission Planning System. Step-by-step, the latter will take over the planning and commanding of the Payload Module's Data Management System and then the instruments.

Routine Phase
The prime objective in the Routine Phase is to generate high-reliability Earth-observation products, as requested by the users. Most routine activities during this phase will be generated by dedicated software tools and procedural interaction will nominally be limited to routine monitoring, the up-linking of tele-command schedules, and maintenance activities (e.g. orbit maintenance). Routine AOCS commands will be generated automatically during this phase by the Flight Dynamics System, based on the latest orbit-prediction data.

For the Payload Equipment Bay and Instrument operations, the Mission Planning System will schedule the activities up to one year in advance, based on external requests for specific operations from the Payload Data Segment and Announcement of Opportunity centres, and a global observation plan. The resulting command schedule for the next 24 hours or more will then be up-linked to the time-tagged queue of the Payload Module Computer well in advance of the actual operation. The schedule is executed automatically on-board as long as the satellite performs nominally. The ground control system maintains an accurate model of this queue and verifies the correct execution automatically during the next ground-station pass when the on-board history telemetry formats are received.

The short duration of the individual ground-station passes (maximum of around 12 min of coverage) also calls for optimum uplinking at maximum rate. In the event of an on-board anomaly, the spacecraft will normally switch into a safe configuration. In this case, the FOS has to analyse the problem and recover the platform or instrument to a nominal mode of operation as safely and as quickly as possible.

Envisat has approximately 50 different on-board processors. The FOS is fully responsible for the maintenance of the instrument and Payload Module Computer software, and shares responsibility for Service Module software maintenance with industry during the Routine Phase. Dedicated software-maintenance facilities for the various processors and an On-

Board Software Maintenance System (OBSM) are available to generate and validate new on-board software images, to generate patch commands, to verify correct execution, and to perform configuration control for the various on-board software packages.

FOS validation

The FOS system definition has been driven by requirements defined by the operational team. The development effort has been conducted in close co-operation with the project team and industry. The FOS includes approximately 2700 user requirements.

Each subsystem has been developed in a staggered way and each staged delivery has been separately tested and accepted by ESA. These deliveries have each also been the target of one of the four System Verification Tests (SVTs). The SVTs are the tests in which the ground segment meets the satellite, and the four SVTs have therefore been the driving milestones for the entire project. For each SVT, a system has been integrated consisting of increasingly complex delta-deliveries. The process of building and integrating this hierarchy of deliveries was defined at requirement level by each requirement having an attribute identifying the particular SVT for which it was needed.

The Spacecraft Operations Manager and his team have conducted the SVTs using prototype Flight Operational Procedures. Although the main objective of the simulation programme is to train the operational teams, it also provides a final validation of the system and the associated Flight Operational Procedures.

The FOS System Operation Validation (SOV) tests validated the entire LEOP configuration to support both nominal and non-nominal LEOP scenarios and routine operations. An extensive simulation campaign will be performed before the launch, to validate all the nominal and contingency operational procedures, and to ensure coherence and smooth interaction between the FOS and the LEOP stations .

Once validated, the FOS configuration will be frozen and kept under strict (ISO-qualified) configuration control.

Conclusion

The development of the FOS started with an in-depth definition of requirements involving both the engineering and operations teams. The Envisat mission has also made systematic use of existing facilities previously developed and validated for the ERS mission, wherever possible. This approach, combined with strict enforcement of the requirements throughout all FOS development phases and for all FOS elements, has allowed the timely delivery of a Flight Operations Segment that is truly ready to be used. The close involvement of the FOS operations staff during the early phase of the development has helped to ensure a smooth and natural transition between the development and operations phases. esa

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