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ESOC

European Space Operations Centre

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ABSTRACT

ESA invests heavily in the development of highly complex satellites to meet the needs of its different Programme Directorates. For many outside observers, the moment of launch of the satellite is the high point and end of their involvement and interest.

However, the satellites are all designed to perform specific functions in space, either in the field of telecommunications, meteorology, observation of the Earth, microgravity, solar system science or space astronomy, and it is the responsibility of ESA's European Space Operations Centre (ESOC) in Darmstadt, Germany, to ensure that the objectives of each of the different missions are attained.

ESOC fulfils this resonsibility by undertaking the preparations necessary for establishing ground-segment facilities and services followed by the execution and conduct of the mission operations.

This brochure describes the process of preparation and execution of satellite mission operations as exercised at ESOC to provide insight into how such things are done.

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INTRODUCTION

The mandate of the European Space Operations Centre is to conduct mission operations for ESA Satellites and to establish, operate and maintain the necessary ground segment infrastructure.

Mission Operations

Mission operations is the process involving operations planning, satellite monitoring and control, in-orbit navigation, and data processing and distribution, by which the satellite mission objectives are achieved, be they the collection of meteorological or scientific data or the provision of a telecommunication service.

Lift-off of an Ariane-5 launcher

Monitoring and control starts as soon as the satellite is separated from the launch vehicle, its purpose being to activate the on-board systems for the tasks ahead in the challenging environment of space. Soon afterwards, the payload has to be configured to enable it to play its part in exploiting the mission according to plans based on the wishes of the users. It is a round-the-clock task performed throughout the duration of the mission.

Whenever the satellite is visible from the ground, health and status are monitored, a task involving the analysis of as many as five thousand telemetry parameters every minute. Operations are effected through instructions sent to the spacecraft in the form of telecommands to change on-board settings or to activate payload equipment. Continuous monitoring is necessary to verify correct execution of up to one hundred commands per minute.

Satellite nativation is the process by which a satellite is brought to and kept in the desired orbit and by which the required body orientation (attitude) is acquired. It involves determination, prediction and control of the satellite orbit hand in hand with determination and control of the satellite attitude. Changes in orbit and attitude are effected by the execution of often complex manoeuvres under ground control, using for example the on-board thrusters.

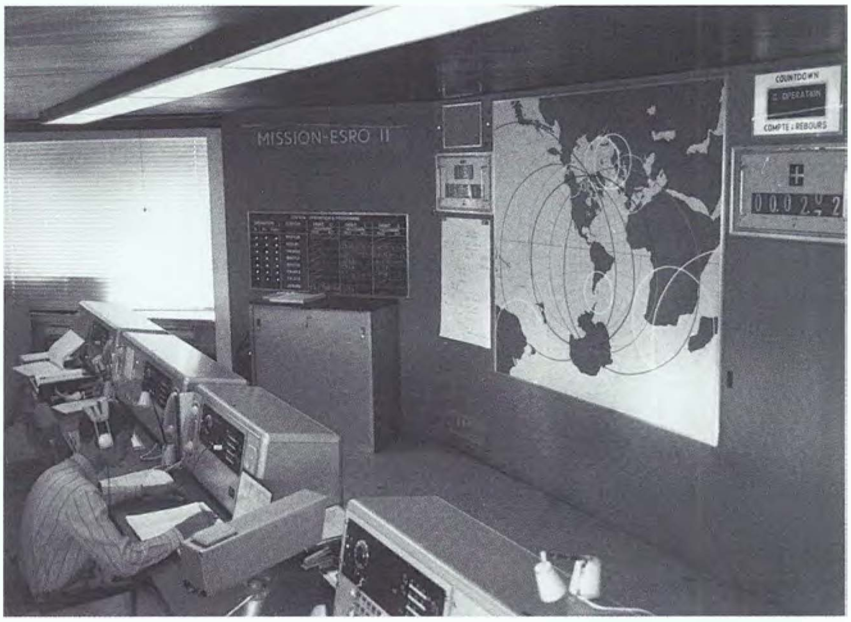
Ground Segment Infrastructure

ESOC has established a comprehensive ground segment infrastructure suitable and ready to support various types of missions, each having different demands, requirements and constraints. This infrastructure encompasses all facilities and services needed for mission operations and includes a network of ground stations around the world, a number of control centres, payload data-processing facilities, spacecraft control systems, simulation systems and communications systems. All ground facilities have to be highly reliable and maintainable: cost-effectiveness in operations is achieved by careful introduction of new technology.

The infrastructure is primarily intended for ESA missions, but can be made available to external Agencies and industry. Depending on the type of agreement, ESOC can provide all types of service, from full mission operations to consultancy.

Mission Success

The mission operations phase is generally the final and arguably the most critical phase in a space project, during which the return on investment is to be realised: the return in this case is the quantity, quality and availability of mission products or services, which in turn depend heavily on the effectiveness of mission operations. Mission success is then gauged by the return of mission products, and by the ability to recover from deficiencies or anomalies in the orbiting spacecraft.



One of the first Control Rooms for the ESRO-2 Mission

Since 1967 ESOC has successfully conducted more than 40 satellite missions (Appendix 1), each presenting a different challenge to the operations staff, including:

- Science missions in near-Earth, highly eccentric and interplanetary orbits,
- Microgravity missions in near-Earth orbit
- Earth observation missions in near-Earth orbit
- Meteorological missions in geostationary orbit
- Telecommunications missions in geostationary orbit

Of particular note are the following missions, for which ESOC had full responsibility:

- The navigation of the Giotto spacecraft to encounter Comet Halley in 1986 was a spectacular success. After surviving the encounter, a historical gravity-assist swing-by around the Earth in 1990 took Giotto into an orbit in which it was to encounter comet Grigg-Skjellerup two years later: the operations involved in the hibernation and blind reactivation of the spacecraft are of historical significance.
- The successful execution of the Eureca (European Retrievable Carrier) mission, including the deployment and retrieval of the spacecraft by the US Space Shuttle proved ESOC's ability to control from the ground complex rendezvous and docking manoeuvres in space, in close cooperation with another Agency (NASA).

Multi-mission control Area at ESOC

Image composition of MOP-2 and ADC

Meteosat MOP-1

- Between 1977 and 1995, ESOC conducted the six European Meteosat missions involving full spacecraft monitoring and control, navigation, payload control, payload data processing, image data extraction, data dissemination and archiving. The service provided to the meteorological community was exemplary in its quality and continuous availability.

In total, four otherwise doomed missions have been recovered by ESOC, namely TD-1A, Geos-1, Olympus and Hipparcos, the latter being of particular importance. In August 1989, Hipparcos, which was intended to undertake a 100 000-star survey from geostationary orbit, was left stranded in transfer orbit when its apogee boost motor failed to ignite. Within three months a revised mission had been defined and the necessary modifications to the ground segment and on-board software had been made, enabling the mission to be conducted in the unfavourable elliptical orbit. Outliving the planned mission duration, Hipparcos operations continued for three years to successfully achieve all intended scientific objectives.

The task of operations as conducted from ESOC is now a well-developed discipline involving highly skilled staff in intensive activities both in the preparations phase and in the operations execution phase. The philosophy for the control and operation of the various types of satellite intended to serve the needs of ESA's different spheres of interest is founded on the principles established during more than 30 years' experience. ESOC is recognised as a leading centre of excellence in Space Mission Operations that is unique in Europe. Conscious of the need to vigilantly maintain its high standards of quality, ESOC achieved ISO 9001 certification in 1999.

This extensive expertise allied with the comprehensive and technologically advanced ground segment infrastructure, ensures that ESOC maintains its position as mission-operations authority for ESA satellites and guarantees that, as such, it constitutes an invaluable resource for the Agency's future space projects.

Eureca returning to the Space Shuttle

PREPARING THE MISSION

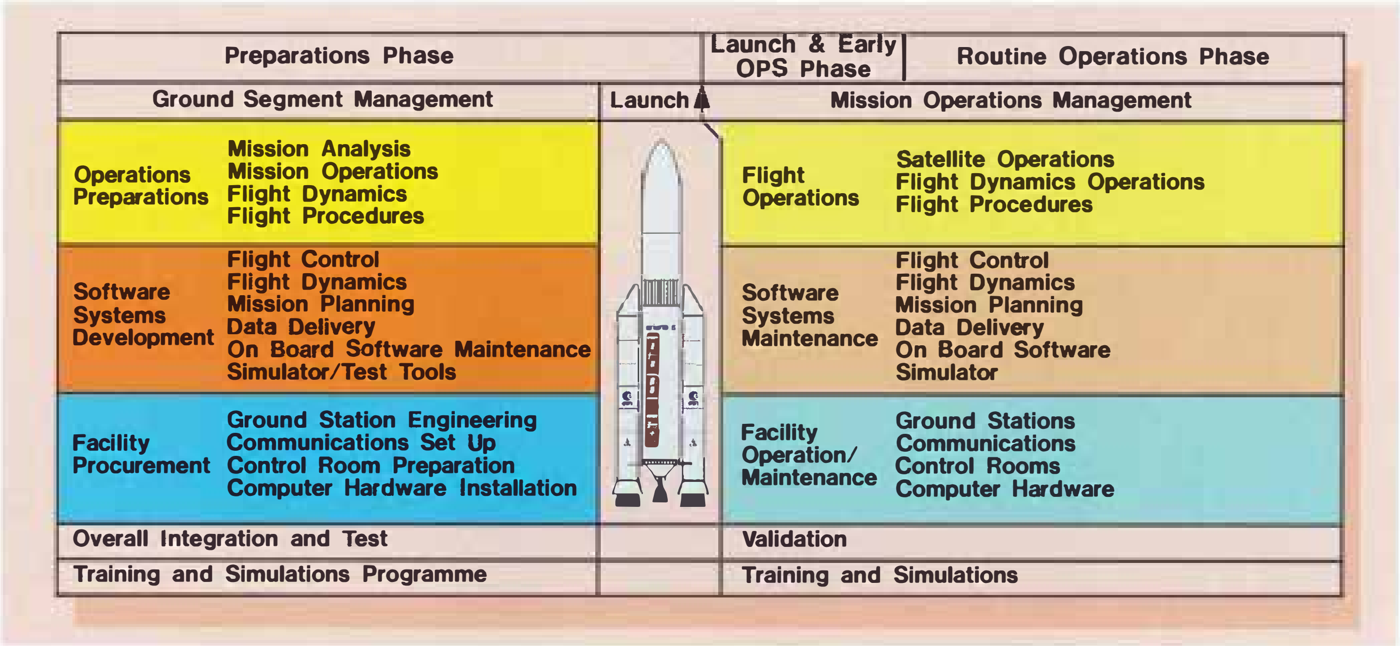
Introduction

In most cases, ESOC involvement starts when the mission and satellite concept is being developed, especially as regards analysis of the type of orbit required, the provisions that need to be included in the spacecraft design to facilitate the operational tasks and the ground-segment facilities required to support the mission. Such involvement continues throughout the assessment phase and the satellite Phase A studies.

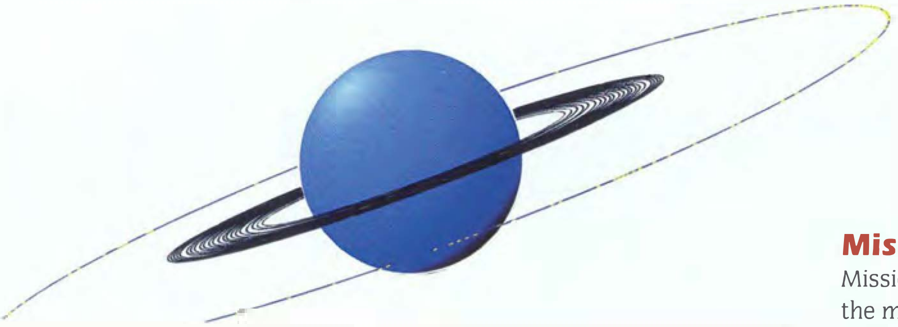
Once a mission has been selected, ESOC will be involved in providing operations requirements applicable to the spacecraft Phases B and C/D, in the formulation of a thorough specification of the ground segment services and facilities needed to support the mission and in establishing the necessary interfaces for exchange of data and information between the customer and ESOC.

The various units within ESOC then embark on the execution of the preparatory tasks that have to be completed during the period covering the satellite's development, integration and test programme (usually about five years). The culmination of the preparatory phase is the full readiness and availability of all facilities, services and personnel and the 'freezing' of all software systems, hardware and documentation prior to the start of mission operations.

The principal activities to be undertaken by ESOC in the mission preparations phase cover a wide range of disciplines, as illustrated in the Figure below and described in the following sections.



Preparations Phase		Launch & Early OPS Phase		Routine Operations Phase
Ground Segment Management		Launch	Mission Operations Management	
Operations Preparations	Mission Analysis Mission Operations Flight Dynamics Flight Procedures		Flight Operations	Satellite Operations Flight Dynamics Operations Flight Procedures
Software Systems Development	Flight Control Flight Dynamics Mission Planning Data Delivery On Board Software Maintenance Simulator/Test Tools		Software Systems Maintenance	Flight Control Flight Dynamics Mission Planning Data Delivery On Board Software Simulator
Facility Procurement	Ground Station Engineering Communications Set Up Control Room Preparation Computer Hardware Installation		Facility Operation/ Maintenance	Ground Stations Communications Control Rooms Computer Hardware
Overall Integration and Test			Validation	
Training and Simulations Programme			Training and Simulations	



Mission Analysis

Mission analysis is the term used to describe the mathematical analysis of satellite orbits, performed to determine how best to achieve the mission objectives in terms of achievable orbit, launch vehicle, ground station utilisation, operational complexity and lifetime.

These very important aspects are considered by ESOC early in the formative stage of the mission design in close cooperation with the Project. This is essential, since, later on, the results will be given to the satellite Prime Contractor as design driving information, for the selected orbit and the derived operations concept will have an influence on many aspects of the satellite design, as can be seen from Table 1.

Different categories of mission are best served by different types of orbit, as shown in Table 2.

Table 1: Influence of orbit on satellite design

Mission Type will drive:

- Launch energy vs. satellite mass
- Selection of launch vehicle and orbit injection strategy
- Satellite Dimensions

Orbit Injection and Control requirements will determine:

- Orbit Control concepts (mono/bi-propellant/solid fuel)
- Number and type of manoeuvres needed
- Fuel needed on board satellite

Actual Orbit will determine:

- Orbital lifetime and stability
- Ground station coverage afforded by available stations
- Types and positions of attitude sensors
- Range of solar input for power generation and thermal control
- Eclipse durations and battery requirements
- Downlink frequency and RF link margins

Table 2: Types of orbit for different missions

Type	Orbit	Mission type	Spacecraft/vehicle
1	Near-Earth Circular	Science	Spacelab
		Microgravity	Eureca, ISS
	Near-Earth Polar (also sun synchronous)	Earth Observation	ERS-1, ERS-2, Envisat
2	Highly Eccentric	Earth-Science	HEOS, Cluster
		Astronomical	Cos-B, Exosat, ISO, XMM, INTEGRAL, FIRST/PLANCK
3	Geostationary	Telecommunications	OTS, ECS, Marecs, Olympus, Artemis
		Meteorology	Meteosat
		Scientific	Geos, (Hipparcos)
4	Earth-Sun Libration Point	Solar Science	Soho
5	Interplanetary	Solar System Science	Giotto, Ulysses, Rosetta
6	Planetary	Planetary Science	Cassini/Huygens, Mars Express

The principal characteristics for each type are as follows:

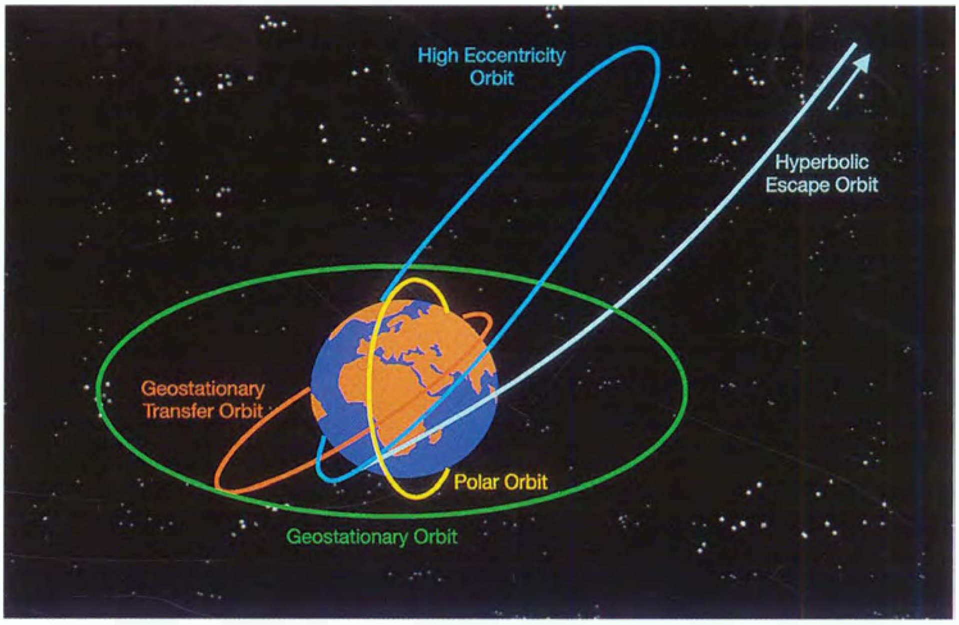
- Near-Earth orbits (Type 1) have low launch energy requirements and result in short communication distances: they can be reached directly by Space Shuttle, allowing potential for retrieval and repair. They are, however, subjected to air-drag perturbations and frequent eclipses and periods of direct ground contact are very short.
- Highly eccentric orbits (Type 2) have relatively low launch energy requirements and for most of the time keep the spacecraft away from the influence of the Earth. Orbit stability is a potential problem, as is the frequent passage through the Earth's radiation belts.
- Geostationary orbits (Type 3) are particularly suited for communications satellites and certain scientific and meteorological applications, but have high launch energy requirements.
- Orbits near the Earth/Sun libration point (Type 4) can be suited to solar or stellar observation: launch energy requirements are high and communication distances are large.
- Interplanetary orbits (Type 5) have high launch energy requirements (alleviated by gravity-assisted transfer orbits) and tend to result in long-duration missions. Commuications distances are very large, as can be the distance from the Sun (which leads to reduced energy from the Sun for power generation).
- Planetary orbits (Type 6) are similar to Type 5: ground-station visibility is interrupted by occulation and overall mission complexity is increased.

The illustration below shows a schematic of the different types of orbit.

By no means restricted to selection of the optimum orbit, mission analysis continues throughout the mission-preparation phase, addressing all orbit-related topics, including:

- calculation of seasonal and daily launch windows
- calculation of mission constraints, including ground-station visibility, eclipse periods, sky visibility and occulations
- definition of injection strategy and optimisation of orbit manoeuvres
- performance analysis of navigation system and estimation of propellant budget.

These mission anslysis tasks are performed with the aid of advanced methods of celestial mechanics, applied mathematics and control and estimation theory. Powerful workstations and a suite of sophisticated software tools and utilities allow in depth analysis of all aspects of orbits and trajectories. Animated graphical visualisations of particular regions of space, such as the magnetosphere or the radiation belts, or of 3-D relationships between the spacecraft, the Earth, the Sun and the planets, are also used to support the analysis and for public relations and educational purposes.



The Huygens Control Room

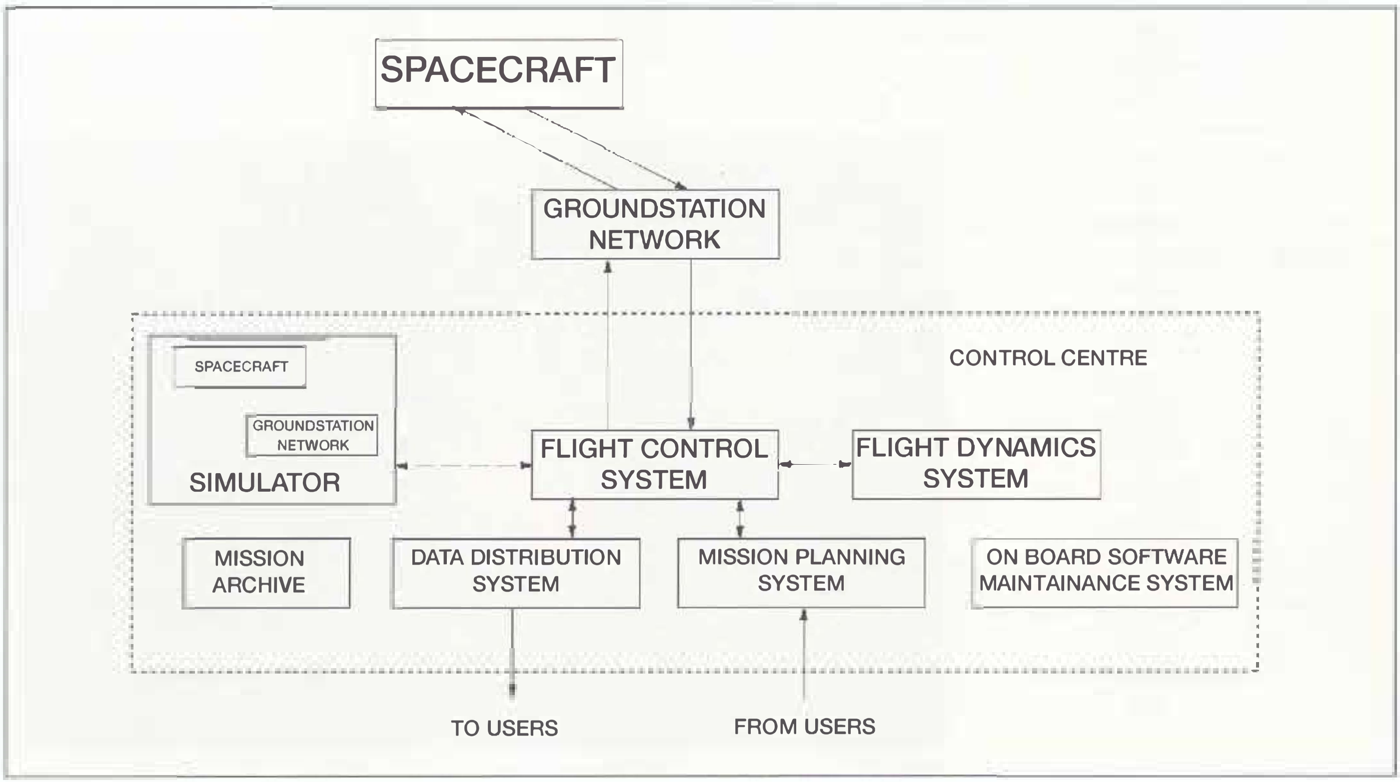
Preparing the Ground Segment

The term ground segment covers all elements, facilities and services needed in support of the mission operations activities on the ground and distinguishes them from the space segment, which comprises the launch vehicle and satellite.

The major elements of the ground segment to be established include:

- The ground station network to provide the telemetry, tracking and telecommand interface between the control centre and the satellite
- Software systems for satellite monitoring and control, flight dynamics, mission planning and data distribution
- Computer facilities to host the software systems and facilities for the maintenance and validation of satellite on-board software
- The satellite and ground segment simulator
- Control centre facilities, including control rooms from which mission operations are conducted
- Communications systems linking all the various elements together
- The trained Flight Control Team
- Operations plans and procedures and associated operations databases.

The various components of a typical ground segment are shown in the table below.



Operations Preparations

The process of defining the ground segment must go hand in hand with the design and development of the satellite: each mission requires different satellite design characteristics, each of which must have corresponding provisions in the ground segment.

The first step in the process is to formulate the Operations Concept. This defines the overall scenario for operation and control of the satellite, the payload and the different elements of the ground segment. The detailed specifications for the ground segment will later be based on this work. The different mission phases need to be assessed, as each will place different requirements on the ground segment.

Satellite and payload design information from which ground segment specifications are derived is acquired through the Project Team. The most important source of information in addition to the design specifications, is the Satellite User's Manual, delivered by the satellite Prime Contractor: it provides a thorough definition of the satellite and its subsystems, and defines what has to be done in each mission phase viewed from the operations perspective. It contains sufficient information to enable the operations staff to gain insight into all the internal functions of the satellite and is used to develop the plans and step-by-step procedures to be used by the satellite controllers in flight.

The Ground Station Network

The ground station provides the link between the satellite in orbit and the Operations Control Centre (OCC) on the ground. ESOC has established a network of ground stations (11 antennas) around the world to support ESA missions, referred to as ESTRACK, comprised of the following locations: Kourou (French Guiana), Malindi (Kenya), Maspalomas (Canary Islands, Spain), Villafranca (Spain, 3 terminals) Redu (Belgium), Kiruna (Sweden, 2 terminals), Perth (Australia) and New Norcia (Australia, 35 m under construction). Each mission has different ground station needs, and some special or collaborative missions call for the services of additional non-ESA stations, for example those belonging to other European agencies or to the NASA Deep Space Network.

Stations at various locations around the world are needed for the different phases of each type of mission; for all missions, it is necessary to have nearly continuous contact with the spacecraft in the first few days of its life (the Launch and Early Orbit Phase: LEOP), so that all the initial critical operations can be performed reliably and, in some cases, so that the spacecraft can be transferred from the injection orbit to operational orbit.

The ESA LEOP stations at Villafranca, Spain, Perth (Australia) and Kourou (French Guiana) are ideally placed to provide good coverage, particularly for satellites starting life in a geostationary transfer orbit.

ESA Maspalomas ground station

Ground station at Perth, Australia

Satellites inserted into polar orbits are best served by stations near the poles, as they see the spacecraft more often than stations near the equator: the ESA station at Salmijärvi (Kiruna, Sweden) is particularly suitable. To provide the maximum coverage in the LEOP for polar missions, several stations along the satellite track are needed and additional stations on loan from other agencies are enlisted to join forces with the other ESA stations at Perth, Kourou and Villafranca (Spain).

Table 3: Characteristics of a typical ESA ground station

Radio Frequency:	
Antenna Diameter	15 m
Transmit frequency	2025 - 2120 MHz
Receive frequency S-Band	2200 - 2300 MHz
Receive frequency X-Band	8400 - 8500 MHz
EIRP	74 dBW
G/T S-Band	29 dB/K
G/T X-Band	39 dB/K
Telemetry:	
Nominal Data Rate	up to 1 Mb/s
Maximum Data Rate	up to 105 Mb/s
Standards supported	PCM and CCSDS Packet Telemetry
Telecommand:	
Nominal Uplink Rate	2 kb/s
Standards supported	PCM and CCSDS Packet Telecommand
Tracking:	
Range measurement accuracy	1 m
Range rate measurement accuracy	0.1 mm/s

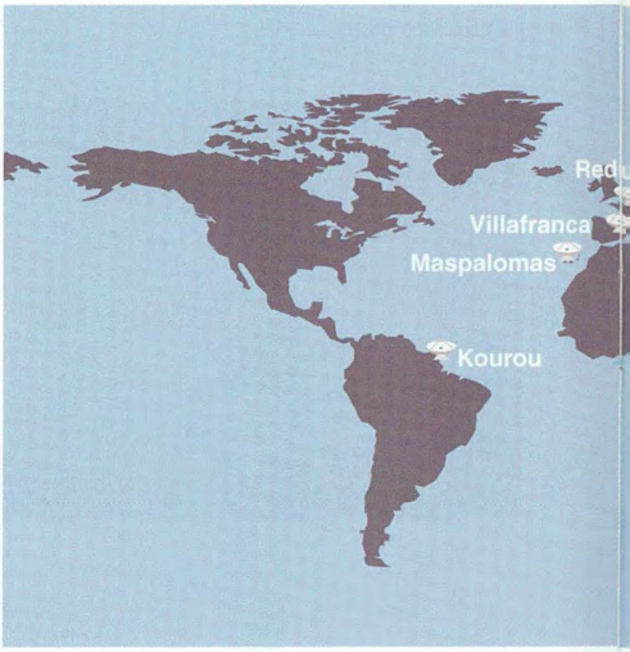
Ground stations for spacecraft in other orbits are selected with the aim of maximising the periods when the spacecraft is visible from the station: spacecraft in geostationary orbit, being visible 24 hours a day from points on a particular meridian, pose the least problem, as the station need only be located at or near the appropriate longitude. The ESA station at Redu (Belgium) has been used to serve a number of geostationary missions.

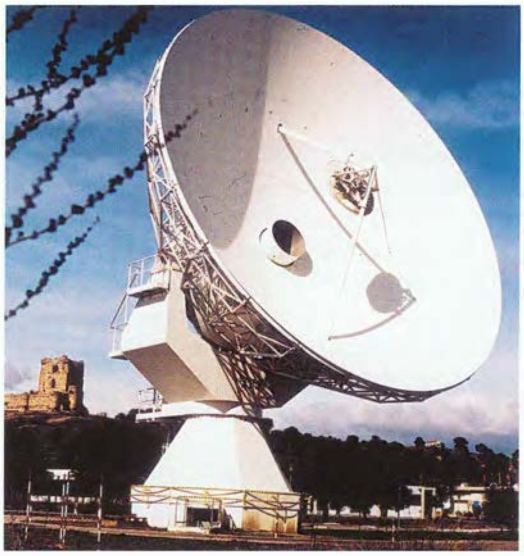
Any station selected to support mission operations will need to be tailored to suit the individual characteristics of the spacecraft in question, and various parts of the station equipment will be engineered to suit the up- and downlink frequencies, data types and other mission characteristics.

Table 3 shows the characteristics of a typical ESA S and X Band ground station. The illustration below shows the locations of the different ESA stations around the world.

Flight Control Systems

The facilities employed within the Control Centre for processing satellite telemetry and preparation of commands needed for the conduct of mission operations are broadly termed flight-control systems. They comprise the software and hardware systems set up to suit the needs of each mission. Many elements of these systems may be applicable to a range of missions: the process of defining how best to serve the needs of any new project includes consideration of the re-use of parts of existing



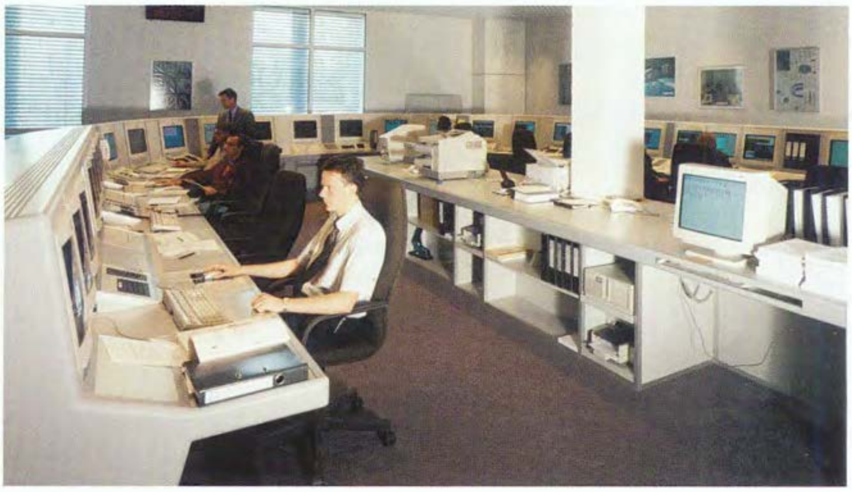


ESA ground station at Villafranca, Spain

flight-control systems and the extent to which new features are required. It is especially here that the application of standards in operational requirements for spacecraft design can result in savings in the cost of developing flight control systems.

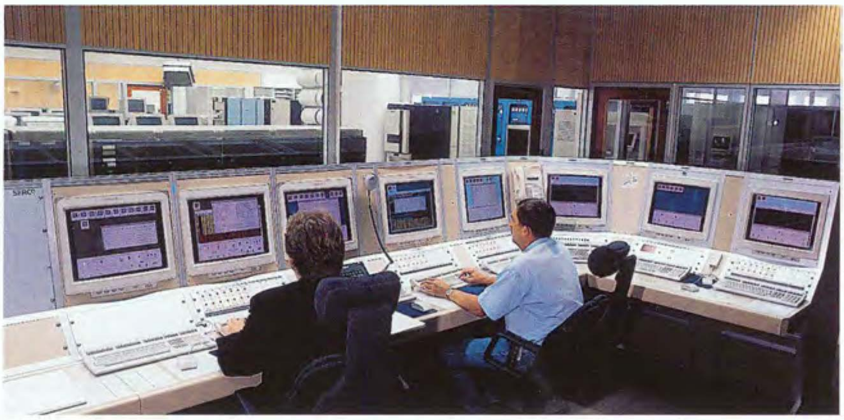
The systems used for the interpretation of telemetry and the generation of telecommand messages are database driven, and the information needed to establish the operations databases (ODB) is delivered by the satellite Prime Contractor to ESOC in electronic form. Error-free creation, validation and maintenance of this information are of paramount importance for reliable spacecraft operations.

The flight control systems are designed to perform a multitude of tasks, examples of which are shown in Table 4. Of particular importance is the need for high reliability in a real-time environment, quick system response, guaranteed availability of data and clarity of information. Special facilities are included to ensure all commands are correct before uplink and to watch for errors in the telemetry. The need to process large volumes of data and to manage complex autonomous on-board systems has placed heavy demands on the flight control systems. These are normally run on high availability Unix-based client/server configurations comprising prime and back-up elements.



Cluster Dedicated Control Room

Many satellite functions, particularly for Attitude and Orbit Control (AOCS) and On Board Data Handling (OBDH), are implemented in software resident in microprocessors on board the satellite. If any difficulties arise in the functioning of the satellite, it is often necessary to make modifications to the on-board software, for example to compensate for degradation or failure of on-board equipment (gyros or other hardware) later in the satellite life. Having responsibility for mission operations means that ESOC must make provision not only for maintenance of the on-board software, but also for operational validation of the modifications. Changes to the on-board software may necessitate changes to elements of the ground segment: these too must be correspondingly modified and operationally validated in an environment of the strictest configuration control to prevent later errors in operations.



Computer Room at ESOC

Table 4: Flight Control System Components and their Functions

Operations Preparation	Preparation and Maintenance of the – Flight Operations Plan (FOP) – Operations Database (ODB) – Mission Planning Database.
Mission Planning	Processing of external planning inputs. Generation and validation of satellite operations timelines.
Network Control	Link control between Operations Control Centre and the ground stations for – Telemetry data – Telecommands – Satellite tracking information.
Spacecraft Monitoring	Telemetry reception from ground station. Space to ground time correlation. Conversion of satellite telemetry to engineering values. Limit checking and status monitoring of satellite telemetry. Display of satellite data in graphical or numerical form in real time or fast forward / backward mode. On-line access to historical satellite data.
Spacecraft Commanding	Generation of command messages for all types of satellite commands. On-line or time-scheduled release of commands to the ground station for uplink to the satellite. Pre-transmission checking of command contents. Post-transmission verification of commanded actions. Logging and display of command history.
User Facilities	Control of user access using a system of privileges.
On Board S/W	Maintenance of on-board software for the satellite processors. Validation of the software changes before installation on board.
Data Distribution	Distribution of on-line and off-line data to external users (other Control Centres, Data Centres, Research Institutes).
Performance Analysis	Access and retrieval of all historical satellite data. Offline and periodic analysis and visualisation of user-defined algorithms. Generation of operations reports.

Flight Dynamics Systems

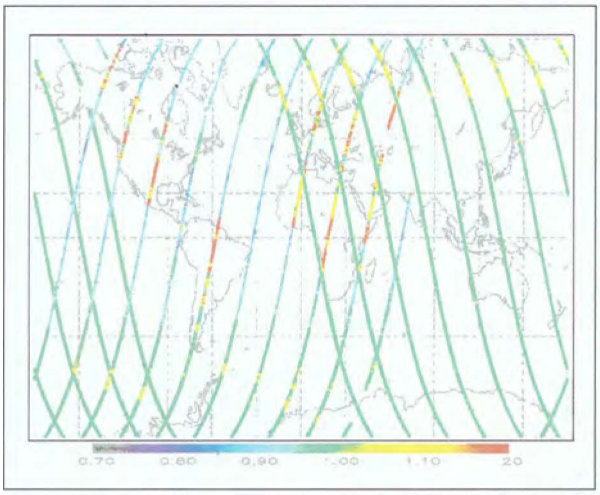
An important aspect of mission operations is satellite navigation, this being the determination, prediction and control of the satellite's orbit or trajectory in space and the determination and control of its orientation in space, i.e. its attitude. These activities are the domain of ESOC Flight Dynamics specialists and involve the use of dedicated Flight Dynamics systems.

In order to achieve the objectives of its mission, each satellite is intended to fly in a predefined orbit and it is the task of Flight Dynamics personnel to refine and put into practice the earlier mission analysis work. One of their first operational tasks in any mission is to determine the characteristics of the initial or injection orbit after the satellite has separated from the launch vehicle and to prepare the information needed to bring the satellite into its final orbit.

The first step is to process tracking data from the ground station and calculate the orbital elements of the initial orbit: detailed knowledge of both ground station systems and spacecraft systems is needed in this process. It is then necessary to identify how much the achieved orbit differs from the desired orbit and to make the necessary changes to the satellite velocity by performing orbit manoeuvres. The satellite will be equipped with the necessary boost motors and thrusters according to the injection strategy and mission needs. Interplanetary missions may require the implementation of suites of orbit manoeuvres over several years to take them on their journey through deep space to a particular region in space, perhaps swinging by other planets on the way, to give the extra boost needed. Missions involving in-orbit docking of one spacecraft to another, place high demands on the Flight Dynamics team and system.

Flight Dynamics Room at ESOC

Orbiting spacecraft are subject to minute perturbations, caused for example by solar-radiation pressure or resulting from gravitational effects of the Earth, the Moon and the planets. These orbital perturbations add up over time and must be counteracted by regular execution of small orbit-correction manoeuvres throughout the mission. For a geostationary spacecraft, this is known as 'station-keeping' and is necessary to keep the satellite within a specified latitude and longitude 'box' having dimensions of some small fraction of a degree.



The orbit of the European Remote Sensing satellite, ERS, is such as to take the spacecraft over the same locations on Earth at regular intervals. At its altitude of 800 km, the atmospheric drag slowly reduces the height of the orbit and upsets ground track repetition: as the extent of the drag depends on the density of the atmosphere, it is necessary to take forecasts of solar activity into account in the planning of orbit manoeuvres.

Control Centre Facilities

In addition to the software and hardware systems established for the performance of mission operations, it is necessary to provide a range of support facilities, including the control rooms in the Control Centre and communications networks linking the various computer systems, both within and outside the Control Centre. The various control room facilities at ESOC include:

- The Main Control Room, used for the conduct of operations in the early phases (LEOP) of a mission (as shown below)
- The Flight Dynamics Room
- The Project Support Room, in which staff from the Project and industry are accommodated while they provide on-site consultancy during LEOP
- The Dedicated Control Room, from which operations are conducted in the later routine phases of the mission
- The Ground Configuration Control Room, where operators oversee and configure the links and systems for data and command routing between the ground stations and the Control Centre.

ESOC has also established further specialised control centre facilities at the following ESA sites:

- The Science Operations Centre at the Villafranca ground station near Madrid
- The Telecommunications Operations Centre at the Redu ground station in Belgium.

One further important aspect is the establishment of facilities to allow reliable round-the-clock communication between each station in the ground network and the Control Centre for telemetry, telecommands and voice and data traffic. ESOC has set up and maintains a communications network to complement the ground station network and provides facilities for other communications needs, covering for example, links between the different ESA sites and their working partners in industry, at research institutes and at other Agency sites.

Main Control Room in the OCC at ESOC

Dedicated Control Room for Earth Observation

Ground Segment Integration and Validation

In order for the whole ground segment to work correctly, providing ready access to the satellite at all required times and fulfilling the intended mission requirements, a thorough and systematic series of tests must be carried out at all stages of ground-segment integration, moving from testing of units, to testing of subsystems to testing of large systems, to final operational testing of the whole ground segment.

This activity extends over a period of many months towards the end of the preparations phase and requires the services of a team of experts in ground segment integration and testing, who first define a comprehensive test plan and then execute the plan step by step.

Table 6 shows some of the more significant tests performed during this phase.

Satellite Simulators

The single most important tool for the validation of the ground segment systems, operational databases and flight control procedures is the so-called satellite simulator. The simulator is itself a sophisticated software system modelling the satellite in such a way that when connected to the flight-control systems, it enables operations staff to exercise all satellite operations in a highly realistic fashion.

The simulators are developed by the Simulator Group at ESOC: the sources of information for simulator developers are the satellite specifications, the detailed design documents and the requirements documents for on-board software. The simulator is built up around reusable modules, with additional modules to represent the specific features of the mission in question

Table 6: Integration and validation tests

Test Activity	Scope
Software System Acceptance	To validate all functions of delivered software systems
Database Validation	To confirm the correctness of all entries in the operations databases
Procedure Validation	To validate all operations procedures
Station Acceptance Tests	To validate all ground station functions
RF Compatability Test	To test the interface between the satellite and the ground station RF systems
System Validation Test (SVT)	To validate all flight control and flight dynamics systems against the Flight Model Satellite on-line tests
Operations Validation Tests (OVT)	To validate the ground segment operationally (end to end)
Mission Readiness Tests (MRT)	To validate readiness to commence mission operations

Table 7 summarises the features of a typical scientific satellite simulator.

The Simulations Programme

The simulations programme is conducted at the end of the preparations phase, its purpose being to enable all planned operations to be exercised in a realistic environment and the operations staff to be trained to work together as an efficient flight-control team well versed in both nominal and contingency operations.

Table 7: Major features of a scientific satellite simulator

Element	Modelling
Satellite Subsystems	Fully representative hardware, software, mechanisms, pyros, motors, appendages etc. Realistic telemetry in all modes Correct command responses
On-Board Software Systems	Hardware emulation Executable on-board software
Satellite Dynamics	Satellite mass properties Attitude manoeuvre execution Attitude sensor fields of view
Satellite Environment	Orbital motion and orbit manoeuvres Eclipse and thermal inputs Ground station contact periods Star catalogues (including planets)
Network Interfaces	Ground stations Communications
Simulator Control	Faster than real time Operator-injected anomalies Simulator monitoring Command/telemetry replay facility

The simulations programme is designed to transform a number of trained individuals into an integrated mission operations team. This is effected by undertaking a selected set of mission operations cases in a realistic operational manner, creating a training environment hardly distinguishable from real life in which the Flight Control team interact with the satellite simulator as if it were the real spacecraft.

Typical cases to be exercised include:

- Pre-launch phase interactions with CSG, Kourou, through to lift-off and spacecraft separation
- Spacecraft separation through to establishment of 3-axis spacecraft control
- Spacecraft attitude and orbit manoeuvres and related calibration
- Spacecraft subsystem check-out
- Instrument switch-on and check-out
- Routine operations, including perigee exit, start of observations, eclipse, perigee entry etc.

Strong emphasis is placed on the execution of both nominal and contingency operations. Anomalies defined by the Simulations Officer are not known to those taking part, but are injected into the simulation to create the desired realism and to train operations staff in anomaly identification and recovery procedures. Simulations are further a means of proving the mission documentation and operational procedures, and ensuring that the ground segment performs as required.

Such simulations have in the past brought to light satellite design problems that had not hitherto been identified in the satellite integration and test programme.

At the termination of the simulations programme and after several years of mission preparations, the Flight Control Team is ready and eager to take on its responsibilities in the execution and conduct of mission operations.

CONDUCTING MISSION OPERATIONS

Establishing Contact with the Spacecraft

Contact with the spacecraft is necessary for the day-to-day execution of the mission operations and is established when the spacecraft passes over a suitable ground station. A suitable station is one which has been tailored to interact with the spacecraft in question.

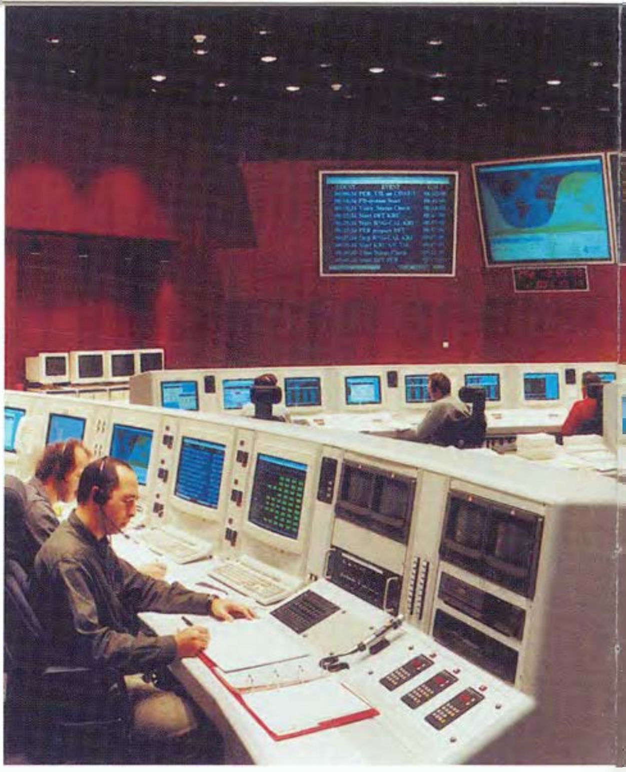
Unless it is in geostationary orbit, where it will appear to stay in a fixed position in the sky, the spacecraft will generally rise over the horizon and become visible from the station. In anticipation of the upward path, the station will have moved its antenna in azimuth and elevation towards a direction predicted on the basis of the determination of the orbit. As soon as the spacecraft appears, the station will lock on to its radio signal and start to track its movement in the sky automatically: should the signal be disturbed, the antenna will continue to track according to a predicted satellite path (also derived from the known orbit).
Soon after locking on to the radio signal, the ground station will be able to demodulate and decode the telemetry and route it directly to the Control Centre giving the operations staff the data they need to assess the health of the returning spacecraft. At this point, the ground station transmits a radio carrier signal to the spacecraft: in order to ensure that the on-board receiver locks on to the uplinked carrier and to compensate for the Doppler effect caused by the rapid motion of the spacecraft, the uplink frequency is made to sweep around the nominal value. After the end of this sweep and with confirmation in the telemetry data that the on-board receiver is in uplink lock, the ground station is ready to uplink any commands received from the Control Centre.

Conducting satellite operations at ESOC

All telecommand request messages received from the Control Centre are checked by the station telecommand equipment and transmitted to the satellite by modulating the RF carrier. While commanding and receiving telemetry, the station may make range and range-rate measurements, to be passed to the Control Centre for orbit determination.

Throughout the period of contact (the pass), the station will continue to track the spacecraft in the sky and provide the telemetry and command services to the Control Centre. For local safety reasons, the uplink service will be

Envisat



terminated when the elevation of the ground station antenna falls to 5 degrees above the horizon on the downward path: as the spacecraft finally approaches and falls below the horizon, telemetry contact will be lost, marking the end of the pass.

The Launch and Early Orbit Phase

The launch vehicle authority is responsible for the actual launch and management of the launch vehicle carrying the spacecraft into orbit. ESOC takes over responsibility for mission operations at the moment the satellite separates from the launch vehicle in the phase referred to as the Launch and Early Orbit Phase (LEOP), when the first ground contact with the satellite is established.

This phase is critical, as activities must be performed under strict time constraints for the purpose of setting up the spacecraft for full operations in orbit and include deploying mechanical parts such as solar panels and antennas, which are normally held in a folded position during the launch. It is also necessary to move the satellite from the launch vehicle injection orbit into the orbit selected for routine operations. Other time-critical operations involve setting up the on-board conditions needed to determine and control satellite attitude and to configure it for the tasks to come.

Ground configuration Control Room

The LEOP activities are conducted by an extended Flight Control Team headed by a designated Flight Operations Director, who is responsible for direction, coordination and conduct of the mission operations. The Flight Control Team is supported by teams from the Project responsible for satellite development and the specialists from industry: such measures ensure that all necessary expertise is on hand during execution of the LEOP operations.

The Flight Control Team is made up principally of specialists in satellite operations and in flight dynamics who perform their tasks with the aid of workstation facilities in the Main Control Room (MCR) of the Control Centre, providing round-the-clock support for the duration of the LEOP. The key players in the Flight Control Team include the Spacecraft Operations Manager, the Ground Operations Manager and the Flight Dynamics Coordinator.

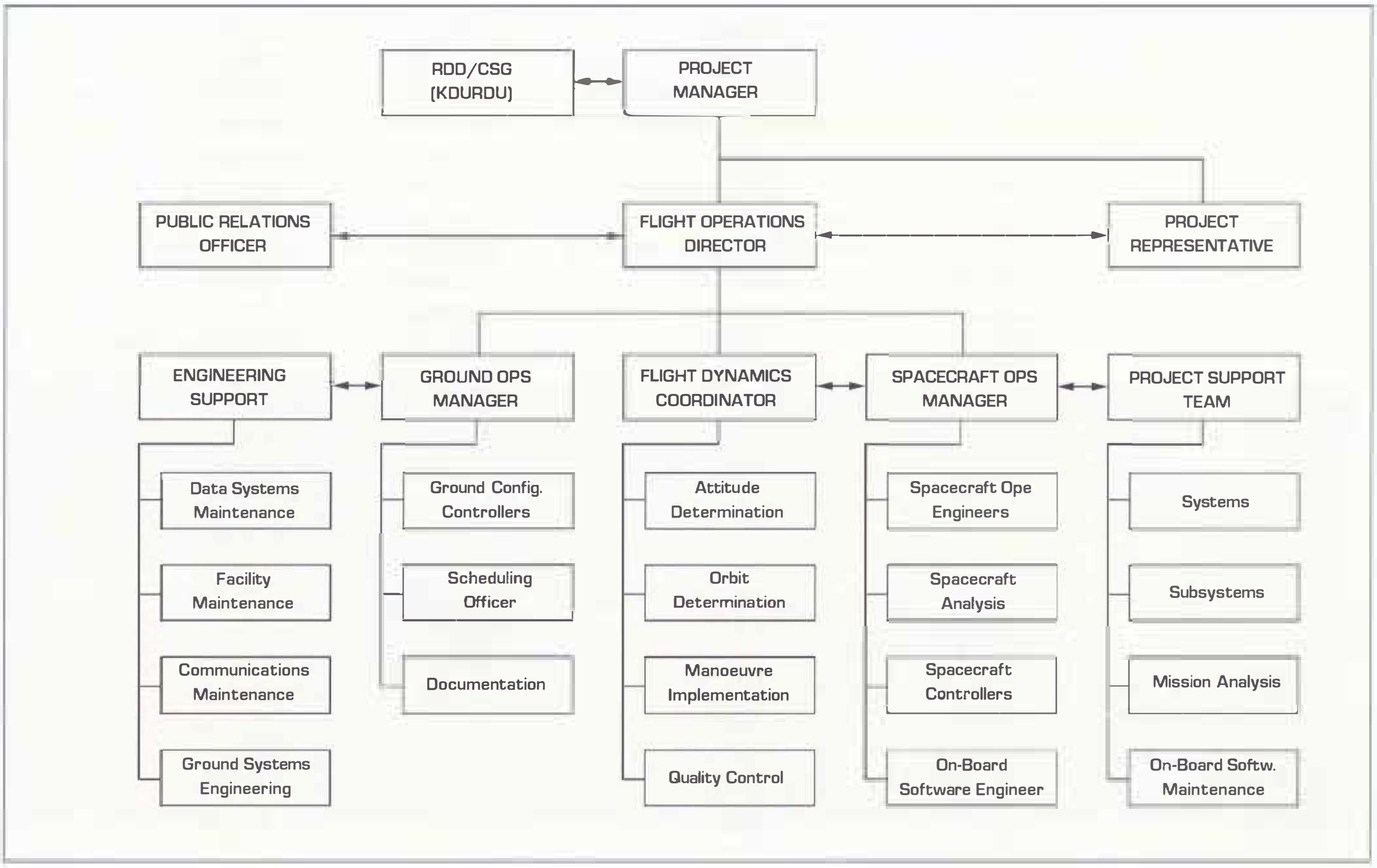
Each manages the activities of a specialised team of fully trained staff in such a way as to conduct all planned operations and to recover from any unforeseen situations arising with the newly operating spacecraft and the associated ground segment.

The Flight Control Team is augmented by a range of service support personnel responsible for computer hardware and software,

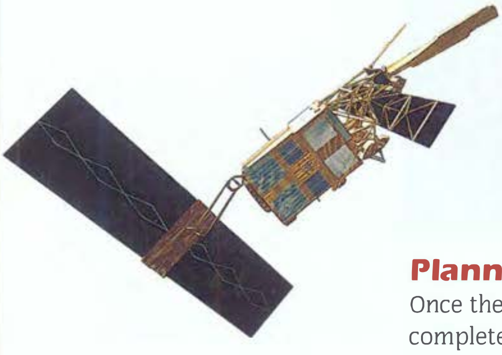
Main Control Room

communications and ground station equipment, Control Centre facilities, telex and telefax operators and general services staff all providing round-the-clock support in this phase.

The table below shows the breakdown of a typical Flight Control Team in the LEOP. Once the milestones of the LEOP have been passed (i.e. achievement of the required orbit, deployment of satellite appendages and initiation of payload operations), the LEOP is terminated and a reduced operations team moves to the Dedicated Control Room (DCR) for continuation of operations in the subsequent phases of the mission, in which satellite and payload commissioning or even deep space travel may be undertaken.



ERS Mission Planning Office



Planning Routine Operations

Once the early orbit phases have been completed and the satellite has been fully checked out in orbit, the routine operations phase commences, in which the satellite is operated in the way intended to provide the services or products required. This phase is one in which all activities have to be planned and executed in an orderly and dependable fashion.

The planning process needed depends on the type of mission and the way satellite control is to be performed, but will often involve the formulation of operations plans some weeks ahead of schedule and covering several days at a time. These operations plans must not only take account of the requests for execution of specific tasks, for example radar imaging of a particular region of the Earth's surface, they must also take account of the constraints associated with operation of the satellite. These constraints may take the form of limitations in available power under certain conditions, restrictions in available on-board storage of telemetry data or restrictions about the directions in which the satellite is permitted to point as it moves around the orbit. Any conflicts identified in the planning process must be resolved by rescheduling and regeneration of the plans.

The planning inputs are derived from requests made by members of the user community, by external bodies or by the operations staff themselves. In addition to the user-oriented activities, it is necessary to plan for conduct of all satellite operations that are needed for orbit and attitude control, satellite health and safety maintenance and any other related operations activities. These must all be incorporated into the overall plan for the whole satellite and for the period in question.

Once the operations plans are established, they must be converted into the appropriate telecommands for uplink to the spacecraft at the appropriate time in order to execute the planned satellite operations.

Routine Satellite Operations

Routine satellite operations are conducted by telemetry and telecommand interactions between the Control Centre and the satellite, according to the operations concept devised during the satellite and ground segment development phase. The extent of these interactions is dependent on the following:

- the type of mission (telecommunications, observatory, deep space etc.)
- the type of orbit (geostationary, highly elliptical etc.)
- the extent to which ground contact is available (number of stations and visibility afforded)
- the provisions made on board the spacecraft for command execution and telemetry delivery to the ground
- the complexity of the activities to be performed.

An Earth-resources satellite (such as ERS-2) in a low polar orbit is typically only visible for a ten-minute period in each of ten out of fourteen orbits (of 100 minutes each). When out of contact with the ground, such a satellite must be able to execute complex operations and to store the telemetry data on board. In such a case, the Control Centre must define all instructions for the upcoming orbits in advance, in the form of a schedule: the schedule is then loaded on board the satellite for later timed execution. Each time the satellite passes over a suitable ground station, the Control Centre loads more instructions into the schedule and commands the satellite to downlink the data it has stored since the last pass. The operations concept for such a mission can be characterised as requiring:

- a high degree of operations planning
- production, uplink and execution of an on-board schedule
- storage and dump of satellite telemetry, and
- a high degree of autonomous on-board safety monitoring and control.

A satellite in deep space, on the other hand, may be visible from the ground for up to ten hours per day on some days and perhaps not contactable for days or weeks in between. A further complication is the time taken for commands to reach the spacecraft and for the telemetry to return to Earth; potentially up to one or two hours, travelling at the speed of light. In such a case, the operations concept would be analogous so that for ERS, employing an on-board schedule and on-board data storage. Such a satellite would also be able to take care of its own safety during the months of deep space flight: this may entail the autonomous switching of heaters to maintain equipment temperatures, it may entail the detection of faulty equipment and switching over to spare units or it may even involve an autonomously controlled series of manoeuvres to re-establish contact with the ground after some on-board or ground failure. The Control Centre's role in this mission would be to prepare all necessary instructions for these and other on-board autonomous functions, involving often complex analysis and modelling. In comparison with the more exotic missions, a satellite in geostationary orbit offering twenty-four hour coverage, permits a much simpler operations concept.

Whatever the concept for satellite operations, the Control Centre's task will be to perform all necessary operations according to the mission's needs: typical routine operations for a scientific observatory mission (XMM) are shown in Table 8.

Table 8: Outline of Routine Operations for the XMM Spacecraft

Start of Pass Activities:

- Acquire satellite telemetry and confirm satellite health and status
- Start the uplink and commence ranging measurements
- Determine spacecraft attitude with the aid of star tracker data
- Adjust satellite temperatures and monitor telescope thermal situtation
- Monitor on-board power situation and charge batteries if necessary
- Set up instruments for start of observations (processor loads)
- Calibrate attitude sensors
- Load instructions for satellite and instrument safety monitoring and control

Science Observations:

- Start sequence of attitude manoeuvres for planned observations (new pointing direction every few hours)
- Change instrument settings for each new pointing
- Monitor satellite attitude and angular momentum
- Perform instrument calibrations
- Switch from one on-board antenna to another in order to keep contact (if necessary)
- Route science data to Science Centre

Before end of Pass:

- Switch instruments into safe mode (to avoid saturation in Earth radiation belts)
- Manoeuvre satellite to safe attitude for perigee passage (to avoid Earth)
- Set up power system for eclipse operation (battery discharge)


ERS Dedicated Control Room

Halley Multicolour Camera composite image of the nucleus of Comet Halley
© 1986 Max-Planck Institut für Aeronomie

Table 9: Examples of mission products

Mission Product	User or Processing Authority
Meteosat Images	ESOC (before 1996) EUMETSAT after 1996
ERS Synthetic Aperture Radar Images	Fast Delivery Products: Kiruna Ground Station Final Products: P.A.F.'s (National Centres)
ERS Ozone Monitoring Data (GOME)	ESTEC and Principal Investigator Institutes
GIOTTO Instrument Science Data	Principal Investigators at ESOC Principal Investigator Institutes, Europe/USA
Giotto Halley Multicolour Camera Images	Max Planck Institute, Germany
ISO Instrument Science Data	ISO Science Operations Centre, Villafranca, Spain
Cluster Instrument Science Data	Quick Look: Joint Science Operations Centre, UK Final: Principal Investigator Institutes, Europe/USA
Hipparcos Astrometric Data	HIPPARCOS Star Catalogue Consortia (FAST in France, NDAC in UK, TYCHO in Denmark)

Mission Services and Products

The services and products to be provided during a space mission are defined by the type of mission being flown. For a telecommunications mission, the goal is to provide the users with a continuous point-to-point telecommunications service.

The goals of any science or application mission are to make scientific observations or other measurements from space and to analyse and study the results. Final processing of the telemetry data may be the responsibility of ESOC, or an external data centre: it may alternatively be the responsibility of a small group of specialists, or of individual researchers within the science community. Whatever the final destination, it is ESOC's task to provide a maximum amount of good-quality data to users in the form of mission products.

In years gone by, data products were delivered on magnetic tapes by mail. Nowadays, users can receive their data on CD ROM or across local or international communications links: users today are able to access product stores via the internet in order to request and download products of their choice along with the tools needed for product anaysis.

Table 9 gives examples of mission products and the user responsible for final processing.

Quality Management

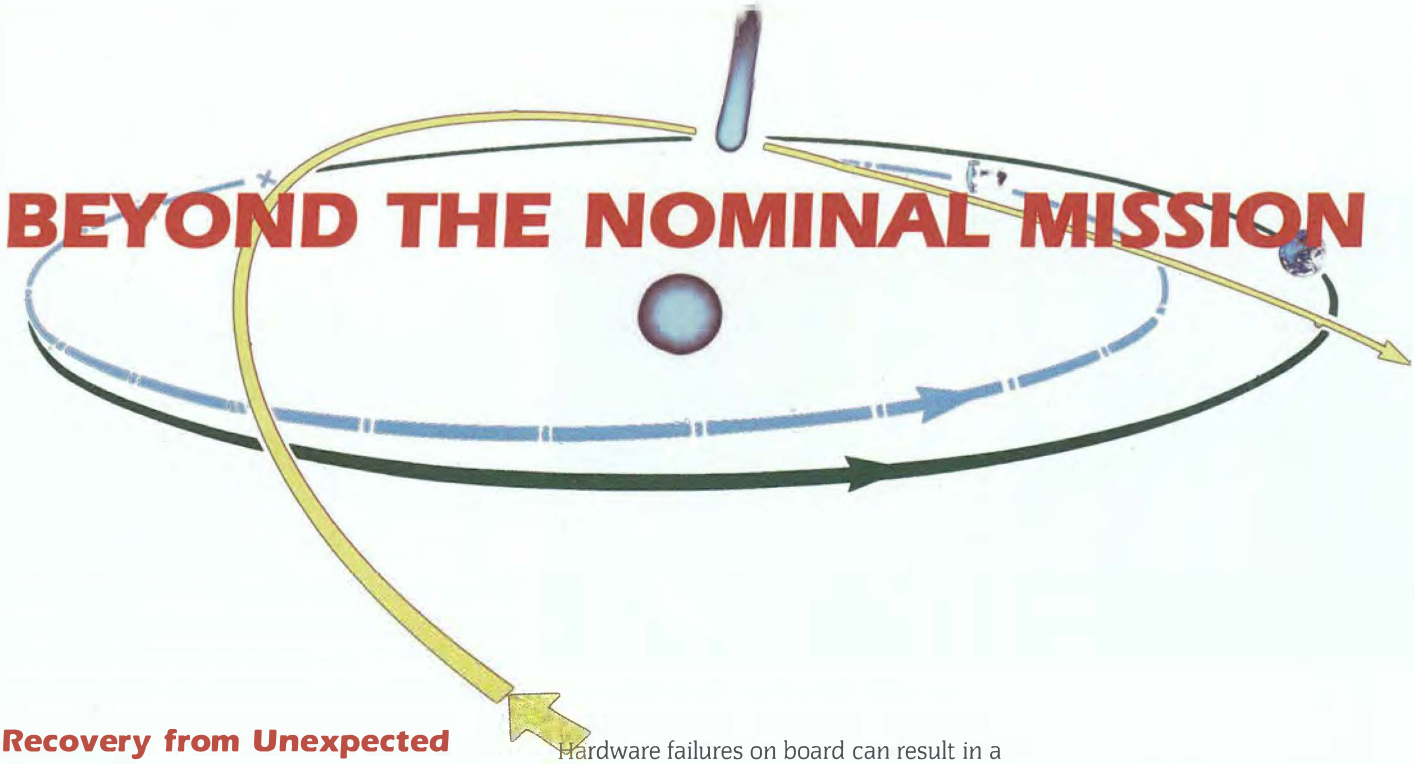
Ever conscious of the need to ensure customer satisfaction with the services it provides, ESOC has embarked upon a process of quality management and continuous quality improvement.

The ESOC Quality Management System encompasses all activities of the centre, ranging from early negotiation of possible operations services through the whole mission preparations phase, and during the mission operations execution phase, including mission termination.

The procedures within the quality management system address contractual activities, ground segment development cycle, anomaly identification and resolution and reporting.

ESOC achieved full ISO 9001 certification in November 1999 and is committed to a programme of self-evaluation and improvement in the future.

BEYOND THE NOMINAL MISSION



Recovery from Unexpected Events

It is the task of the Control Centre to maximise mission return and to ensure the safe and reliable conduct of all mission operations. Not all operations progress smoothly, however, and in the harsh environment of space, unexpected events sometimes occur. Considerable effort is invested in the preparations phases to minimise possible sources of failure, both on the satellite and in the ground segment, and to prepare procedures and plans for recovery if they occur during the mission.

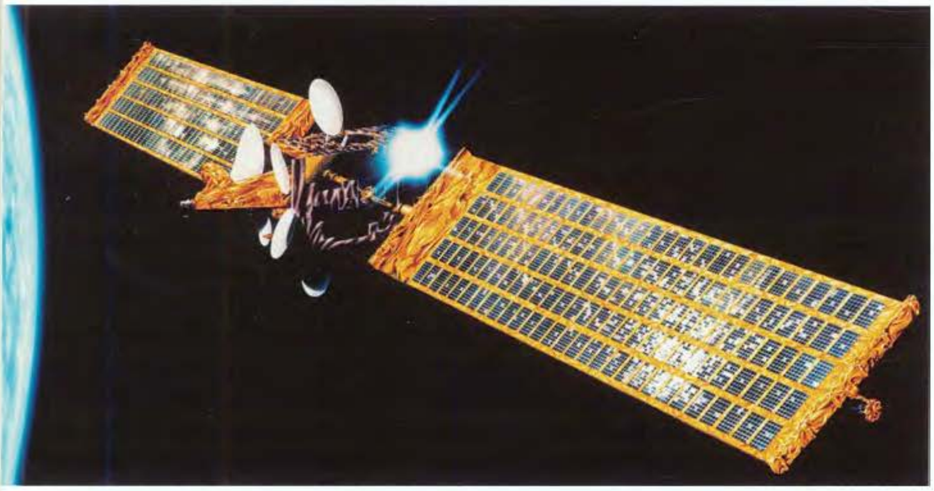
Using automated features of the Flight Control Systems, operations staff monitor for unexpected events in the satellite telemetry as it arrives at the Control Centre: the status or values of all important telemetry parameters will be checked against a set of predefined limits, and audible alarms will sound if any out-of-limit value is found. The out-oflimit value may simply indicate a slowly increasing temperature of little concern, but it may equally indicate a serious on-board equipment failure, such as an error in the execution of a command or the malfunctioning of a microprocessor.

For every alarm raised, the spacecraft controllers will identify the anomaly and take the necessary recovery actions, using procedures defined in advance: they will have been regularly trained in the recovery of anomalies (using the satellite simulator) so they will know how to spot them and what to do. If a new recovery procedure needs to be devised for a complex unforeseen anomaly, it will be developed and exercised on the simulator before the operation is attempted on the spacecraft itself.

Hardware failures on board can result in a need to change the way the spacecraft operates, for example, if a gyro fails to provide attitude rate information. In such instances, it may be possible to compensate for the failure by redefining some of the on-board control algorithms and defining new on-board software to do the job: all changes in the on-board software will be fully validated – again with the aid of the simulator – before being loaded on board.

Anomalies are not restricted to the satellite, the ground segment is also subject to occasional errors and failures. The operations staff must equally be well versed in recovery from failures in the ground equipment, such as the ground station antenna motor or data links to the ground station as well as damage caused by the weather (electric storm, wind, flood). The first concern in such circumstances is to ensure that the spacecraft is not in danger and to resume normal operations as soon as possible, by means of back-up equipment.

In rare cases, the unexpected event turns out to have a major impact on the ability to continue with the mission as originally foreseen, and it becomes necessary to embark upon a major recovery effort, identifying new ways of rescuing the satellite or defining a means of salvaging the mission. Time is of the essence here, as the spacecraft can degrade further while the rescue plan is being developed. ESOC has been faced with and met such challenges several times in the past.



Olympus

Satellite Rescue

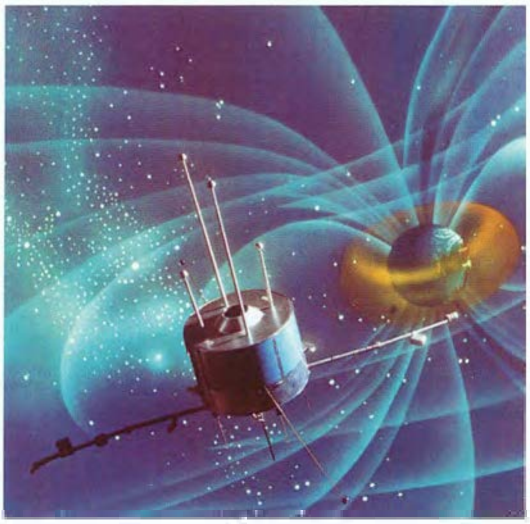
Olympus was a telecommunications spacecraft launched in 1989. ESOC was responsible for conduct of the LEOP but transferred responsibility for the routine phase to the Italian Space Agency's control centre in Fucino. As time went by, premature degradation of the spacecraft made its operation increasingly more complicated. By May 1991, only one solar panel was able to provide electrical power, and errors in the on-board Earth sensors made attitude control difficult. After detecting a new on-board anomaly, the spacecraft set itself into a back-up mode: returning to normal service was now no longer a straightforward task, however. During the complex operations that this required, the spacecraft unexpectedly began to tumble. The spacecraft tried to control its own motion, but the autonomous thruster firings caused the satellite to move from its nominal orbital position and to drift out of contact with the ground. Within one week both the thruster propellant and battery electrolyte were frozen, there was virtually no telemetry, no telecommand capability and only marginal, fluctuating power. The spacecraft was slowly rotating and drifting around the world at 5 degrees per day.

ESOC was called upon to establish a rescue plan: a team of some fifty operations and satellite specialists was assembled to devise and implement what was to be a very complex plan. The services of additional ground stations (including those of CNES and NASA) were drafted in and ESOC facilities were expanded to assume mission control: after weeks of intensive and extremely critical operations and after the uplinking of several thousand telecommands, basic control was regained at the end of July. The spacecraft was moved back to its nominal orbit two weeks later and resumed operations as before very soon afterwards: ESOC had been able to bring the crippled spacecraft back to life.

Mission Redefinition

GEOS was a scientific spacecraft launched in April 1977. It was due to be inserted into a geostationary transfer orbit by a Thor Delta launch vehicle and moved into a geostationary orbit by firing the on-board boost motor. Owing to a partial failure of the launcher, the spacecraft was placed into an orbit having a period of only 3.8 hours and not 10.5 as expected. The spin-rate was also unacceptably low at 1.5 instead of 90 rpm: the satellite was wobbling badly with a cone angle of 35 degrees.

First contact with the spacecraft showed that the spin rate was too low, and a spin-up manoeuvre was quickly executed. After some rough estimation, it became clear that both the spacecraft attitude and its orbit were well off target. An attitude correction manoeuvre was needed ot keep satellite temperatures within reasonable bounds but, more importantly, the low orbit meant that the solar cells were in danger of being rapidly degraded by the Earth's radiation belts: it was essential to move the spacecraft into a different orbit as quickly as possible. Insertion into the originally planned geostationary orbit



GEOS

was no longer feasible and through extensive analysis a search was started for the best possible orbit that could be reached with the aid of the boost motor. This was not easy, as the orbit had not only to satisfy the scientific needs of the payload, but had to take account of a number of stringent constraints, including the availability of ground-station visibility, the viewing angle of the spacecraft antenna, the orbit stability and eclipse durations.

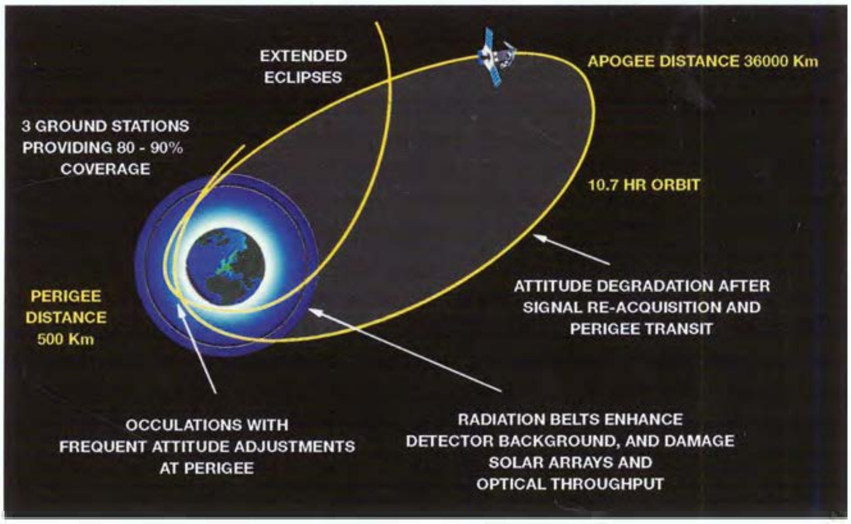
After five days, an acceptable solution had been found and the satellite was placed in an inclined, elliptic orbit with a period of twelve hours. In this orbit, GEOS went on to provide very useful scientific data: as a result of the injection failure, ESA decided to launch a second identical spacecraft, GEOS-2, which successfully entered geostationary orbit some fifteen months later. The speed with which ESOC was able to devise a solution for GEOS was, however, instrumental in salvaging the mission.

HIPPARCOS was a scientific satellite dedicated to extremely precise measurements of star positions, distances and space motions. It, too, was intended for geostationary orbit where it would have been in continuous contact with ESA's Odenwald ground station. Launched in August 1989, the transfer-orbit operations proceeded smoothly until the moment when the apogee boost motor was instructed to ignite: owing to a failure in both pyrotechnic chains, ignition failed to take place and the spacecraft was unable to move out of its transfer orbit.

Using the small amount of hydrazine fuel available, the orbit perigee was raised to reduce air drag and the harmful effects of atomic oxygen. In the elliptic orbit with its period of 10 hours 40 minutes, coverage from Odenwald was only about 32% of the time. Additional stations were needed and equipment had to be procured and installed at Perth and Kourou: NASA later provided the support of its Goldstone station in the Mojave desert.

Hipparcos

Contact was not continuous and long eclipses were experienced; there was frequent payload occultation; attitude knowledge was hard to obtain and attitude control was very difficult in the perigee region because it was there that the spacecraft passed through the Van Allen radiation belts. A significant proportion of the Hipparcos flight operations procedures had to be rewritten: early on, operations were extremely risky, since the pressure of time did not allow full assessment of all possible eventualities of preparation for potential contingencies.



Hipparcos orbits

The implementation of the revised mission allowed scientific data collection to start less than four months after launch. At first, the data recovery rate was about 50%, but this later increased to 65% after optimisation of operations procedures. Despite the successive failure of four of the five gyroscopes and numerous other anomalies, largely attributable to the severe radiation levels, the Hipparcos mission lasted four years – 18 months longer than had been foreseen for the original, nominal mission.

Although trapped in the wrong orbit and experiencing damaging levels of radiation, Hipparcos accomplished all its scientific goals. An ingenious zero-gyro attitude-control procedure had even been developed, but radiation damage to the on-board computer stopped the mission before that could be tried out.

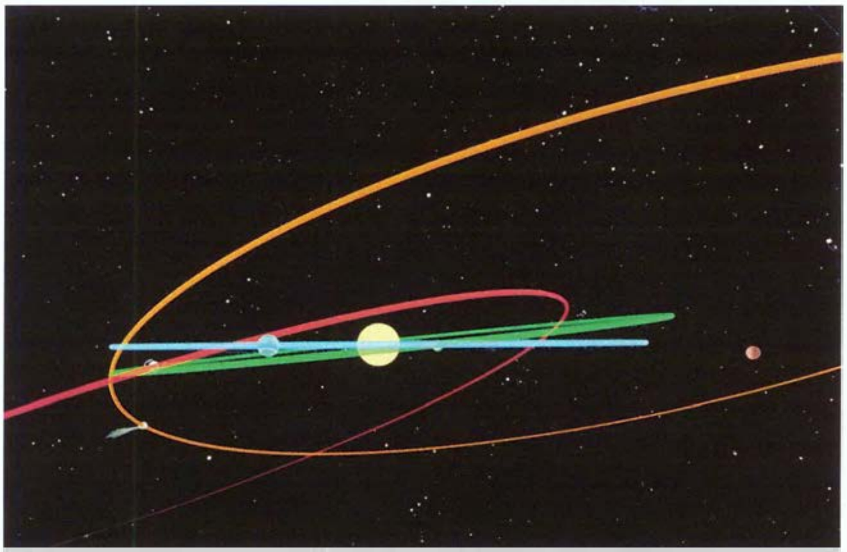
Scientists watching Giotto encounter with Comet Grigg-Skjellerup

The Giotto spacecraft

In the case of Giotto, ESOC was faced with the challenge of defining a second comet encounter mission for an already orbiting satellite. Launched in July 1985, the scientific spacecraft was designed for a nine-month interplanetary journey to a high-speed fly-by of comet Halley. This mission was very successful and, contrary to expectations, the satellite survived the hyper-velocity dust impacts around closest approach to the comet, although it took a severe battering. Moreover, 90% of the original fuel load was still being carried thanks to thrifty navigation and precise injection accuracies of both Ariane and the on-board boost motor.

Despite structural damage, radical changes in thermal behaviour, instability in the power-control system, a punctured star-mapper baffle and the loss of many autonomous functions, the spacecraft was still operable. No detailed extended mission plan had, at that time, been worked out and resources were not available to permit further continuous control. To keep most options open, Giotto was placed on an Earth-return trajectory (which cost more than half the remaining fuel), then configured into minimum-power mode; its attitude was changed to make it thermally optimal and the transmitter was switched off: it had been put to sleep.

Orbit of Giotto for the Extended Mission (GEM)



After four years in hibernation, Giotto was reactivated. Re-establishing communications, an operation never before attempted, had to be achieved blind, with no telemetry and with Giotto at a distance of 100 million km from Earth. The strategy which had required man-years of effort to devise, led to six days of complex operations, and resulted in successful reactivation of the spacecraft.

Check-out of the spacecraft revealed that about half the scientific payload was still working, but on-board redundancy had been further reduced by two failures of vital spacecraft units. Comet Grigg-Skjellerup was chosen as the next target, being the best compromise between scientific interest and operational feasibility. Even so, the damaged satellite still had to operate outside its intended design envelope in many respects.

ESOC took Giotto on to make the first-ever Earth gravity-assist swing by for a spacecraft returning from deep space. It was put into hibernation a second time, survived extremes of high temperature and was reactivated again two years later, in May 1992. At the second encounter, in July 1992, when Giotto approached to within 200 km of the cometary nucleus, the great distance from the sun caused the power margin to be so low that it is doubtful whether even one additional experiment could have been switched on. The Giotto extended mission added only a few percent to the cost of the original mission.

Mission Termination

A spacecraft is designed to fulfil the mission objectives for a defined period of time, ranging typically from two years to ten years or more. Aspects which must be taken into account when designing for lifetime are principally:

- the need to maintain the desired orbit (geostationary, polar., etc.) throughout the mission and the provision of sufficient fuel for all foreseen orbit manoeuvres;
- the need to ensure that the spacecraft attitude is controlled throughout the mission and provision of sufficient fuel for all foreseen attitude manoeuvres and momentum control;
- the need to provide sufficient electrical power throughout the mission, account being taken of the time- and orbit-dependent degradation that solar cells experience in orbit;
- the need to provide adequate equipment resilience to in-orbit degradation and adequate equipment redundancy to achieve the desired reliability goals over the mission.

Mission operations will continue while the spacecraft and its payload are fulfilling the mission objectives. If the resources needed on board (power, fuel) become depleted, or if failures of on-board equipment occur, making operations more and more difficult, then mission termination has to be considered.

In some cases, mission termination can be dramatic (sudden loss of the spacecraft), in other cases it can be extremely long and laborious (the final months of the successful Hipparcos mission), and in yet other cases quite straightforward (termination of the Giotto Extended Mission).

If termination can be planned, then it is often desirable to perform a series of end-oflife tests on spacecraft mechanisms, for example. If possible, it is worthwhile moving the spacecraft into a so-called graveyard orbit where it poses less of a risk to other orbiting satellites or to the space environment.
For the control centre, a mission is deemed to have terminated when ground contact with the spacecraft is finally and permanently terminated, whatever the fate of the spacecraft, whether it is slowly drawn towards Earth to finally burn up in the atmosphere, or whether it remains in orbit unattended for thousands of years.

Space Debris

Space debris is a term used to describe the ever-increasing amount of inactive space hardware in orbit around the Earth: it is the collection of burnt-out launch vehicle upper stages, dead or inactive spacecraft, ejected boost motors, fragments of satellite and rocket stage breakup, and innumerable other metallic shields, booms, covers and caps. They range from items the size of an automobile or bigger down to microscopic dust. Space debris is becoming a serious threat to current and future missions, as the steadily growing risk of collision with active spacecraft, especially in highly populated orbits like the geostationary 'ring' or the low-Earth orbit region (altitude less than 2000 km), is of concern to all space agencies.

Observable space debris population based on NASA/USSpaceCom data. Objects have been considerably enlarged in order to make them visible.

In order to alleviate the problem, it is now common practice, certainly for ESA, to apply mitigating measures. Launch-vehicle and satellite designers are becoming 'debris conscious' and are endeavouring to reduce to a minimum the debris produced once their vehicle or satellite enters space. ESA has adopted the policy of moving each geostationary spacecraft at the end of its useful life into a disposal orbit at least 300 km above the geostationary ring.

Another concern is the danger of re-entry into the Earth's atmosphere: most objects are burnt up on re-entry, but fragments of large massive objects have been known to strike the surface of the Earth, potentially threatening populated areas.

The following spacecraft have re-entered and have reached the surface of the Earth without complete disintegration:

- KOSMOS 954 in January 1978: a Russian spacecraft containing a nuclear reactor;
- SKYLAB in July 1979: the 75 ton US space laboratory;
- KOSMOS 1402, one part in January 1983 and another part in February 1983: a Russian spacecraft containing a nuclear reactor;
- Salyut-7/Kosmos 1686 in February 1991: the 40 ton Russian space station.

In such cases, ESOC has been involved in the analysis and prediction of the time and location of re-entry so that the authorities of ESA Member States can be advised in time. ESOC is also the co-ordinator of ESA's space debris research programme, which focuses on the following activities:

- assessment and modelling of the terrestrial particulate environment
- maintenance of the space debris database, DISCOS
- analysis and prediction of lifetime in orbit of ESA objects in space
- hypervelocity impact analysis and shielding measures
- debris control methods and orbital analysis.

DISCOS is unique in Europe and contains information such as orbit parameters, size and mass of the current population of about 7500 orbiting space objects larger than 10-20 cm. New additions are made to the catalogue several times a week as agencies start new or terminate current missions and as radar and optical sensors of the US Space Surveillance Network provide new information.

These measures make it possible to predict the evolution of the debris population and are aimed at achieving a future global understanding of the problem.

An important objective of these activities is to understand the evolution of the debris population and identify and apply mitigation measures in order to keep the space debris hazard within acceptable tolerances.

Aerial view of ESOC at Darmstadt, Germany

Appendix 1 : ESA missions supported from ESOC

Name	**Purpose**	**Launch date**	**Mission duration (years)**	**Orbit**	**Stations**	**Remarks**
ESRO-2	Science	17.05.1968	3	LEO	Redu/Falkland/FBA/Spitzbergen/Tromsø	
ESRO-1A	Science	03.10.1968	2	LEO	Redu/Falkland/FBA/Tromsø	
HEOS-A1	Science	05.12.1968	7	HEO	Redu/FBA/	
ESRO-1B	Science	01.10.1969	2 months	LEO	Redu/Falkland/FBA/Tromsø	Launch vehicle underperformance
HEOS-A2	Science	31.01.1972	2	HEO	Redu/FBA/Spitzbergen	
TD-1A	Science	12.03.1972	2	LEO	various	
ESRO-4	Science	20.11.1972	2	LEO	Redu/FBA/Spitzbergen/Tromsø	
COS-B	Science	09.08.1975	7	HEO	Redu	
GEOS-1	Science	20.04.1977	5	GTO	Redu/ODW/NASA	
ISEE-2	Science	22.10.1977	10	HEO	STDN	OCC at GSFC
Meteosat-1	Meteorology	23.11.1977	8	GEO	ODW	
IUE	Science	28.01.1978	18 years/8 months	HEO	Vilspa	OCC at Vilspa (joint NASA mission)
GEOS-2	Science	14.07.1978	6	GEO	Redu/ODW	
OTS-2	Telecom	11.05.1978	13	GEO	Fucino/Redu	
Meteosat-2	Meteorology	19.06.1981	10	GEO	ODW	
Marecs-A	Telecom	20.12.1981	14 years/9 months	GEO	Redu/Vilspa	
Exosat	Science	26.05.1983	3	HEO	Vilspa	
ECS-1	Telecom	16.08.1983	13 years/6 months	GEO	Redu	OCC in Redu
ECS-2	Telecom	04.08.1984	9	GEO	Redu	OCC in Redu
Marecs-B2	Telecom	10.11.1984	ongoing	GEO	Redu/Vilspa	
Giotto	Science	02.07.1985	hibernation	interplanetary	Carnarvon/Parkes/DSN/Perth	
ECS-4	Telecom	10.09.1987	ongoing	GEO	Redu	OCC in Redu
Meteosat-P2	Meteorology	15.06.1988	7	GEO	ODW	
ECS-5	Telecom	21.07.1988	12	GEO	Redu	OCC in Redu
MOP-1	Meteorology	06.03.1989	6	GEO	ODW	
Olympus	Telecom	12.07.1989	4	GEO	Fucino	Only LEOP
Hipparcos	Science	08.08.1989	4	GTO	ODW/Perth/Goldstone	
Ulysses	Science	06.10.1990	ongoing	interplanetary	DSN	OCC at JPL
MOP-2	Meteorology	02.03.1991	ongoing	GEO	ODW	OCC moved to EUMETSAT
ERS-1	Earth Observ.	17.07.1991	9	LEO	Kiruna	
Eureca	Microgravity	31.07.1992	1	LEO	MASPAL/KRU	Retrieved by Shuttle
MOP-3	Meteorology	20.11.1993	ongoing	GEO	ODW	OCC moved to EUMETSAT
ERS-2	Earth Observ.	21.04.1995	ongoing	LEO	Kiruna	
ISO	Science	17.11.1995	3	HEO	Vilspa/Goldstone	LEOP in ESOC Routine in Vilspa
Huygens	Science	15.10.1997	ongoing	interplanetary	via JPL, Pasadena	Joint NASA mission
Teamsat	Technology	30.10.1997	5 days	GTO	Kourou	joint with ESTEC
Pastel	Payload on Spot4	24.04.1998	ongoing	LEO		CNES mission
XMM	Science	10.12.1999	ongoing	HEO	Perth, KRU/Santiago (Chile)	
Cluster II	Science	16.07.2000 09.08.2000	ongoing	HEO	Vilspa	

Glossary of terms

AOCS	Attitude and Orbit Control Subsystem
CD ROM	Compact Disc Read Only Memory
CNES	Centre National d'Etudes Spatiales
CSG	Centre Spatial Guyana
DCR	Dedicated Control Room at ESOC
DISCOS	Database and Information System Characterising Objects in Space
D/OPS	ESA Directorate of Operations
EIRP	Effective Isotropical Radiated Power
ESA	European Space Agency
ESOC	European Space Operations Centre
FOP	Flight Operations Plan
G/T	Gain/Noise Temperature
LEOP	Launch and Early Orbit Phase
MCR	Main Control Room at ESOC
NASA	National Aeronautics and Space Administration (USA)
NASDA	National Aeronautics and Space Development Agency (Japan)
OBDH	On Board Data Handling Subsystem
OCC	Operations Control Centre at ESOC
ODB	Operations Database
ORATOS	Orbit and Attitude Operations System
PCM	Pulse Coded Modulation
RF	Radio Frequency

Published by	ESA Publications Division ESTEC, Noordwijk, The Netherlands
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Coordinator:	Jocelyne Landeau Constantin
Editor	Brigitte Schürmann
Layout:	Isabel Kenny
Price:	25 Dfl / 10 Euros
International Standard Book: Number:	ISBN 92-9092-380-6

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