

MISSION PLANNING FOR AN EARTH OBSERVATION
LOW EARTH ORBITER: ERS-1

N 9 4 - 2 3 8 6 8

Paul Lockyer

Cray Systems, Transom House, Victoria Street, Bristol, UK.

ABSTRACT

ERS-1, the first European Remote Sensing satellite, has a payload predominantly of microwave instruments and is in a polar sun-synchronous orbit.

All ground and on-board activities from user requests to delivery of data products are combined into one integrated system. In view of the high number of products which can be generated by ERS-1, the Mission Planning System (MPS), which plans the on-board activities of ERS-1, is an essential tool for operations since manual planning of the large number of daily operations is out of the question both on workload and safety grounds. In addition the MPS, in line with the integrated nature of the ERS-1 system, also plans activities at the prime ground station, including among others, the operation of the payload data processing systems there.

This paper outlines the operations concepts for ERS-1 mission planning, and describes the Mission Planning System used at the ERS-1 Control Centre. Novel functionalities, such as automatic resource clash resolution, are described. A critical discussion gives lessons learned for future mission planning systems.

Key Words: Mission Planning, Resource scheduling, Expert System, ERS-1.

1 INTRODUCTION

A mission of the range and diversity of ERS-1 requires careful operational planning in order to make efficient use of the opportunities for data acquisition during the limited mission lifetime. The Mission Planning System (MPS) is required to produce the command schedules for the spacecraft, acquisition schedules for the ground segment and processing schedules for the prime ground station, subject to a large number of operational mission constraints.

1.1 The ERS-1 Mission

The ERS-1 satellite is in a sun-synchronous polar orbit of the Earth of approximately 100 minutes duration ; 70 minutes of exposure to the sun and 30 minutes of darkness. The ERS-1 mission provides data which are used to address a wide range of environmental issues as well as adding a new dimension to our studies of the Earth.

1.2 The ERS-1 Spacecraft

The ERS-1 spacecraft is based on a SPOT platform with the scientific instruments and the on-board Instrument Data Handling and Transmission (IDHT) system controlled by MPS generated command schedules.

A brief summary of these instruments and their operating constraints shows some of the requirements of the MPS instrument resource conflict checking algorithms.

1.2.1 The Active Microwave Instrument

The AMI contains two separate radars and can be operated in one of four active modes - Synthetic Aperture Radar (SAR) image mode, wind, wave or wind/wave interleave mode. Each of these active modes has various different categorisations dependent upon calibration; on-board or on-ground range compression and whether the satellite is in roll/tilt mode or not.

Any switching between active modes can only be achieved by first switching to one of three inactive modes. Each mode has minimum and maximum durations for individual switchings. The image modes also have tolerances on the amount of time they can be operated in eclipse and daylight periods.

1.2.2 The Radar Altimeter

The RA is a nadir pointing pulse radar designed to make precise measurements of echoes from

ocean and ice surfaces. The RA can be commanded in one of six active modes with only one inactive mode. Operating constraints for the RA apply in a similar manner to those described for the AMI.

1.2.3 The Along-Track Scanning Radiometer and Microwave Sounder

The ATSR-M consists of two instruments, an Infrared Radiometer and a Microwave Radiometer, and is used to measure global sea-surface temperature for climate research purposes. The instrument is operated for long uninterrupted periods in a particular mode.

1.2.4 The Precise Range and Range-rate Equipment

The PRARE was to have been the simplest of all the instruments to command. Its internal computers gathering ranging data, storing it, and then dumping it independently of the main spacecraft IDHT system. Unfortunately, the PRARE has not yet been operational.

1.2.5 The Instrument Data Handling and Transmission System

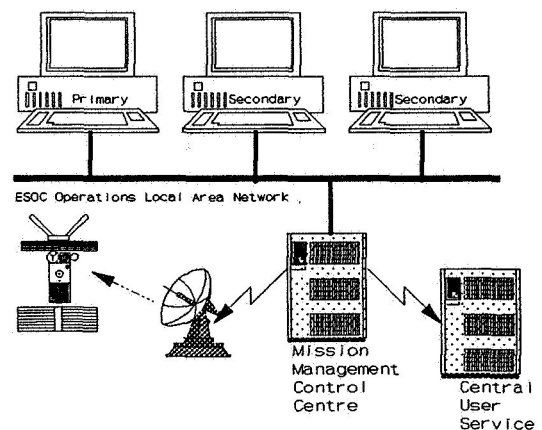
ERS-1 has two telemetry systems. There is the classical telemetry, tracking and control system operating at S-band. As this low rate (2Kbit/s) cannot be used for the science data the platform also includes a complex IDHT system. This system consists of two tape recorders, each having a 6.5Gbit capacity, which are operated redundantly and two X-band links. One X-band link is dedicated to the AMI SAR and transmits real time image data at High Bit Rate (HBR). The other link is used to dump recorded data, live instrument data and a copy of the S-band data at Low Bit Rate (LBR).

In addition to the timings of certain events which trigger record, playback and link switchings the system has constraints dictating that the independent units cannot be commanded simultaneously. When a recorder reaches beginning of tape it will automatically switch to a standby mode. The timings of these events must be predicted by MPS and the commanding of other IDHT units must not coincide with these times.

1.3 The ERS-1 Ground Segment

The primary ground station for ERS-1 is in Kiruna, Sweden. The station is remotely controlled by the Mission Management and Control Centre (MMCC) at the European Space Operations Centre (ESOC) in Darmstadt, Germany using MPS generated schedules. It contains the equipment to control and operate the satellite and the ERS PROduct DISsemination (PRODIS) system. PRODIS collects the science data and processes it into packaged data products. Many of these, the Fast Delivery Products (FDPs), are disseminated rapidly to users. Such products can be requested by users via the Central User Service (CUS).

2 SYSTEM ARCHITECTURE



System Architecture

The MPS resides in the Mission Management and Planning Office (MMPO) at ESOC. It consists of three VAX 3100 workstations. The VAXes are connected via DECnet on the ESOC operations Local Area Network to the MMCC from which it receives and transmits its input and output data. The system has been implemented primarily in Pascal with a DECwindows user interface.

3 PLANNING ENVIRONMENT

The MPS services user requests in the most efficient manner possible given numerous predefined constraints. These requests originate from Principal Investigators throughout the user community who interface directly with the CUS at the Earthnet ERS-1 Central Facility at ESRIN in Italy. Requests also come directly from the ERS-1 project at ESTEC in the Netherlands and from the

MMPO at ESOC.

4 SYSTEM INPUTS

4.1 Scenario Definition

In order to control the ERS-1 spacecraft the MPS requires the definition of all ground stations used during any orbit. This data is used by MPS to determine commanding windows and timings for down linking of HBR and LBR instrument data in addition to the normal spacecraft telemetry data. When performing a data dump to high-latitude ground stations such as the prime Kiruna station, the spacecraft solar array sometimes causes a brief occultation of the link. The occurrences and timings of these occultations are calculated within MPS and are used in the planning algorithms.

The ERS-1 project at ESTEC have defined zones covering all areas of interest on the Earth's surface. These zones cover areas of land, sea and ice. Each zone has a unique identifier and the MPS calculates timings of zone crossings by the spacecraft in a similar manner to the visibility of ground stations. The different instrument modes have different ground swaths which mean that the timings of zone crossings are different for each instrument and mode.

4.2 Instrument Requests

The ERS-1 MPS accepts requests for instrument switchings via four different mechanisms which are described below :

4.2.1 Instrument Zone Operation Requests (IZORs)

IZORs require individual instruments to be in particular modes whenever the relevant swath enters a particular zone. This is the simplest method for the project to ensure that land data is acquired when the spacecraft is over land and ocean when over ocean etc. IZORs have a priority and start and end validity date and time.

4.2.2 Sensor Operation Requests (SORs)

MPS also accept SORs which are explicit requests for individual instruments to be in particular modes at given times. These requests also have an associated priority.

4.2.3 Operations Requests (ORs)

It is possible for the MMPO to create ORs. These requests are typically for specific spacecraft command sequences, defined within the MMCC, but which require some, or all, of the instruments to be in a predefined state before and after the command is issued. The requests also have an associated priority as well as a user defined scheduling mechanism.

4.2.4 Emergency Requests (ERs)

In the event of a computer link failure between ESOC and the CUS at ESRIN in Italy, user requests can still be entered into the system manually by the MMPO staff using ERs. These requests have the same attributes as SORs though the source for these requests can come from fax, telex or normal telephone messages.

4.3 Fast Delivery Product Requests (FDPs)

Users can request processed product items from the Kiruna PRODIS system. These requests contain start and stop times as well as product type and other necessary attributes for each FDP.

4.4 Flight Dynamics Corrections

The MPS utilises a reference orbit model. It is inevitable that the orbit will drift slightly from this reference and indeed fine orbit control manoeuvres are made at regular intervals to correct these drifts. In order to accurately command the scientific instruments MPS uses data provided by the Flight Dynamics Services team at ESOC who are responsible for the attitude and orbit control of ERS-1. The actual UTC times for the start of each orbit are corrected by MPS daily according to this input data.

4.5 Unavailability Data

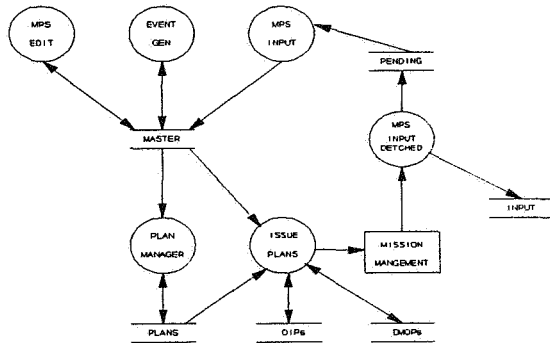
MPS also accepts input data detailing ground station and PRODIS equipment unavailability timings. It is necessary to schedule alternative ground stations or use alternative processing equipment to generate and disseminate ERS-1 data products if such data is received.

5 SYSTEM OUTPUTS

In a standard planning cycle the first system output is the Detailed Mission Operations Plan (DMOP). This plan, detailing spacecraft operations, orbital events, zone and station visibility data and fast delivery products, is returned to the CUS at ESRIN providing feedback as to which original requests will be satisfied. This data is usually presented to CUS three weeks before the planned events.

Once the DMOP has been agreed the Operations Implementation Plans (OIPs) are generated by MPS. These files, including the actual command schedules for the spacecraft and PRODIS, are generated the day before the scheduled execution time in order to have the latest, and most accurate, flight dynamics corrections.

6 DATA PROCESSING



Data Flow Diagram

The MPS system consists of five interactive processes and one detached process. Most of the processes are used to control the configuration of the many entities involved in the planning exercise. The heart of the MPS is the planning executive, the Plan Manager, which is used to bring all the configured input items together, schedule the applicable requests according to the operational constraints, generate secondary events such as tape recorder switchings, which are entirely dependent on instrument activities, and produce a data file from which DMOPs and OIPs can be produced.

The planning routines operate on Pascal data structures based time and event classification ordered linked lists. All MPS data flow is via binary files which are based on this data structure.

6.1 Mission Management

Mission Management is an external process, part of the ERS-1 MMCC, running only on the primary node. This process provides the input data for planning and accepts the output data files from the MPS for distribution to the relevant command and control centres.

6.2 MPS Input (Detached)

This process is the MPS interface with Mission Management. No operator interface is required as this automatic process receives all input data and converts it into an internal binary format for later processing. The original text files are also maintained on disk for operator reference.

6.3 MPS Input

An interactive process providing the operator with an interface through which to view, accept or reject any of the binary files created by the MPS Input (Detached) process. Any files which are accepted will be merged into existing master database files to be used within the MPS.

6.4 Event Generator

The Event Generator is used to create, modify or extend a Reference Orbit Template (ROT).

The ROT contains data pertaining to the quasi-static events occurring during each orbit. The events described include orbit start times, entries into and out of eclipse, times of ground station visibility and the times of entries and exits of the different instrument swaths over the predefined zones.

6.5 MPS Edit

The MPS Edit facility provides the user with an interface to the orbit definition, input data and the ROT master database files permitting manual edit facilities.

6.6 Plan Manager

The Plan Manager process contains the planning executive and is an interactive process giving the user some influence over the processing of all input data and the generation of binary database files consisting of the actual data which is used

to generate the DMOPs and the OIPs.

The planning executive starts by taking a snapshot of the ROT for a given time period, measured in orbits. The user must also enter the start planning status vector defining items such as the start modes for each instrument.

6.6.1 Request Scheduling

The quasi-static data from the ROT is supplemented by adding data from the request master database files. Every request and its attributes will be added and marked as 'enabled'.

6.6.2 Primary Conflict Checking

Once all requests have been scheduled the conflict detection algorithms are applied. At this point conflicting requests for a given instrument are resolved on a priority basis. Any conflicting requests which are concurrent with a given high priority request are marked as 'disabled'. It is possible to have a single low priority request split into two or more segments because of overlapping higher priority requests.

6.6.3 Request Merging

The MPS is expected to optimise instrument switchings in order to obtain optimum performance from the delicate scientific electronics. If an instrument has two contiguous requests for the same active modes they can be merged into a single request. In some circumstances it is permitted to join two consecutive requests for the same mode even if they are not contiguous.

6.6.4 IDHT Scheduling

Once the requests have been scheduled and instrument switchings have been optimised the schedules used to drive the IDHT can be generated.

The first data to be generated is the selection of ground stations to receive the LBR and HBR science data. Any station with a coverage time greater than an allowed minimum will be acceptable to receive HBR data generated by the AMI SAR. The LBR station selection is slightly more complicated as there must be only one per orbit. The station with the longest coverage and

the highest priority is selected as long as this does not contravene other specified rules. Some stations cannot be used for two consecutive passes because of local operating constraints.

Once the ground stations have been selected the recording time (time between passes) and the associated replay times (time over a LBR ground station) can be calculated. It is possible that initially there will be insufficient time to replay all the data which is recorded. If this happens the margins allowed for data acquisition at the ground station are relaxed permitting more replay time (the recorders replay over 13 times faster than they record). If there is still insufficient time then the recording will be descoped. This descoping is based on Earth zones at a given priority. The original user request priorities have no influence at this time.

The amount of data recorded and associated playback time may be affected by occultations. The tape recorder will automatically suspend replay and rewind the tape a little before starting again after any occultation. MPS does not need to explicitly command this but it does need to be aware of exactly how much data is being played back and when the recorders are switching modes.

Once the amount of data to be recorded has been calculated the IDHT switchings can be derived. The recorder is turned on when necessary and switched to playback for the ground station pass. The LBR link is turned on over the selected LBR ground stations. The HBR link is turned on if there is AMI SAR data and the satellite is over the HBR ground station.

6.6.5 Secondary Conflict Checking

The remainder of the instrument constraint checking is performed after all events have been processed. Rules checking for minimum and maximum durations for each instrument mode are checked. The operation of the AMI SAR in eclipse is also checked against predefined time constraints. Requests will be descoped if they contravene any rules.

At this point in the planning executive requests may be descoped to permit mode transitions. Most instruments require that standby modes are used between active modes, until now the Plan

Manager has only concerned itself with the scheduling of active modes.

6.6.6 Energy Management

As ERS-1 is powered in daylight by its solar panels and by battery in eclipse there are limitations on the power available at any given time. Once all instrument switchings have been derived for the whole planning period the MPS energy management routines ensure that a maximum 28% battery Depth Of Discharge (DOD) is achieved per orbit, a maximum average 24% battery DOD is achieved over the last five orbits and that the energy deficit from the battery is zero when entering eclipse.

Should any of these parameters be exceeded the routines calculate the equivalent amount of science data, taking into account any IDHT switchings which may change, which need to be descope. The relevant requests are descope and all IDHT switchings are removed. The planning executive is then repeated to re-apply the new IDHT switchings and confirm that the operational constraints are still being followed before the power figures are checked again. On the second pass the data should pass the checks. The descope is deliberately pessimistic and it may take more than two passes before the power constraints are satisfied.

6.6.7 Instrument and PRODIS Commanding

Once all the instruments requests have been scheduled a single pass is made adding the relevant spacecraft macrocommands. Some instrument modes have implicit switchings from active to inactive modes after a particular duration, others need to be explicitly commanded between each active and inactive mode.

The PRODIS equipment at the Kiruna data processing centre is scheduled dependent on the explicit FDP requests, as well as default products, using the predicted output of the instruments and the visibility of the spacecraft at the prime ground station.

6.7 Issue Plans

This interactive process enables the user to generate any of the MPS output files from the output of the Plan Manager process. This process

also adjusts the timings of events according to the flight dynamics corrections.

7 LESSONS LEARNED FOR FUTURE MISSION PLANNING SYSTEMS

ERS-1 is by far the most complex satellite operated by ESA. As a consequence the MPS is the most complicated operational satellite planning tool designed and used by ESA. Although the mission operating constraints were defined, and the MPS was delivered before the launch date, it was always anticipated that these would evolve post launch. For example, the system flexibility permits users to change defaults for instrument modes or operating margins for the IDHT following analysis of operational data by the ERS-1 project. Major changes in operations such as the IDHT recorder descope over zones (the original requirement being to descope according to request priority) have involved software design changes.

Future mission planning systems should aim to be even more flexible. They should allow for the evolution of mission operating requirements with minimal knock-on effects. It should be possible to switch individual rules in or out and customise the system still using the expertise of a system design engineer but without the need for relatively major software updates.

8 ACKNOWLEDGEMENTS

The author wishes to express his thanks to the staff of the Data Processing Division at ESOC who helped make this paper possible and to Mike Jones for preparing the abstract.