N94-23866

A REVIEW OF MISSION PLANNING SYSTEMS

M. Jones, E. M. Sørensen, T. Wolff

European Space Operations Centre,
Robert-Bosch-Str. 5, 6100 Darmstadt, Germany

C. R. Haddow
Logica Space and Communications Ltd., London, UK

ABSTRACT

A general definition of Mission Planning is first given, covering the full scope of an end-to-end mission planning system. Noting the mission-specific nature of most mission planning systems, a classification of autonomous spacecraft missions is made into Observatory, Survey, multi-instrument science and Telecommunications missions. The mission planning approach for one mission in each category is examined critically, the missions chosen being ISO (Infrared Space Observatory), ERS-1 (European Remote Sensing Satellite) and Eureca (European Retrievable Carrier). The paper gives a summary of lessons learned from these missions, suggesting improvements in areas such as requirements analysis, testing, user interfacing, rules and constraints handling.

The paper will also examine commonalities in functions, which could constitute a basis for identification of generic mission planning support tools.

I. DEFINITION AND SCOPE OF MISSION PLANNING

The term "mission planning" is used in this paper to refer to any system which plans the operations of a space system or any of its component parts. A Mission Planning system may plan platform operations, payload operations, on-board data handling (recorder or memory). It may also plan ground operations associated with the foregoing (ground station activities, payload data processing, product dissemination).

The inputs to a planning system from the payload users can be either of the following:

- requests for particular data, products or measurements

- specification of specific payload operations, which may vary from high-level specification of operations required to binary command data at the lowest level

The main outputs will be the *final operations plan*, which is passed to the commanding system at the control centre for translation into uplinkable form and execution. An appropriate set of mission rules and constraints governs the derivation of the operations plan from the user inputs.

II. CLASSIFICATION OF MISSIONS

Four mission types are identified: Survey, Observatory, Multi-Instrument PI Missions and Telecommunications.

Observatory Missions: the spacecraft has one main instrument (usually a telescope, although there may be several focal plane instruments). Users are allocated observing time during which they have dedicated usage of the instrument to study particular objects. Spacecraft and associated centralised ground facilities can be considered to be the "Observatory". Operationally, payload control is typically carried out by a centralised operating agency, but end users are given facilities to control the instrument during their allocated slots. Observers are normally at the ground observatory facilities during their operational periods.

PRECEDING PAGE BLANK NOT FILMED

Survey Missions: these carry out repetitive observations on a large scale. The spacecraft will typically have a single payload instrument, or a small number of closely related ones. The spacecraft and payload are normally operated by a centralised agency on behalf of a number of end users, who can request specific observations within the planned strategy.

Multi-Instrument: the spacecraft has a number of (in principle) independent experiments, each provided by a separate "Principal Investigator" (PI). A centralised agency will operate the platform, but PIs are responsible for operation of their experiments, using services provided by operating agency. PIs can be remote from the control centre, submitting requests and getting data from their experiments electronically.

Telecommunications Missions: the spacecraft has a transponder(or transponders) to provide communications between ground stations ("fixed" service) or between another spacecraft and ground(data relay service). The spacecraft and its payload is usually operated by a centralised agency on behalf of the end users. Allocation of transponder communication channels to users (or subscribers) is made as a function of service requests.

The above classification of missions shows the common characteristic that missions are usually operated by a central agency on behalf of the end users. This reflects the fact that there is normally only one uplink route for commands and that operation of the platform and the payload are often interlinked (e.g. through resource dependencies). In all cases some sort of mission planning is needed to process user requests.

III. MISSION PLANNING FOR SURVEY MISSIONS: ERS-1

The first European Remote Sensing Satellite (ERS-1) was launched in July 1991 by ARIANE-3. The main mission of ERS-1 is the monitoring of the state of the ocean and ice. It is in a near polar orbit at an altitude of c. 800 km. Its main payload is the AMI (Active Microwave Instrumentation) which comprises a synthetic aperture radar (SAR), a wind scatterometer and a radar altimeter. An on-board data handling system (IDHS) includes a tape recorder, which records data from all instruments except the SAR; the tape recorder operations have to be scheduled. The SAR can only be operated in ground station contact, so that the data acquired can be downlinked in real time.

The prime ground station both for TT&C and payload data acquisition is at Salmijaervi near Kiruna, Sweden and the control centre (the ERS Mission Management and Control Centre - MMCC) is at the European Space Operations Centre (ESOC), Darmstadt, Germany. Services for end users are provided by the ERS-1 Earthnet Central Facility (EECF) at ESRIN, Frascati, Italy.

The ERS Mission Planning System (MPS) is responsible for planning (1) spacecraft and payload operations and (2) ground station operations, in particular data acquisition and data processing

ERS-1 operates mainly autonomously based upon uplinked command schedules covering 24 hours. Mission Planning is therefore central to ERS-1 operations.

Mission Planning for ERS-1 is split into two parts

1. Preparation of the Preferred Payload Exploitation (PEP) from external user requests.

2. Preparation of the Detailed Mission Operations Plan (DMOP) from which the command schedule file uplinked to the spacecraft is generated.

Step 1 (the user-oriented part) takes place at the ERS-1 Earthnet Centre Facility, Step 2 takes place at ESOC, the DMOP being produced by the ERS-1 Mission Planning System (MPS). The DMOP is passed to the MMCC for execution. It is also transmitted back to EECF for information. A restituted DMOP, reflecting the actually executed operations, is also sent to EECF. Plans cover 3 days and are available at least 24 hours before execution.

CRITICAL DISCUSSION

The ERS-1 MPS is the most ambitious and expensive mission planning system developed at ESOC. The split of responsibility between ESRIN and ESOC is in principle sound, with ESRIN collecting and filtering user requests and then passing them to the MPS at ESOC in a high level form for conversion into the final schedule for uplink.

The following problems are noted

Rules and Constraints: the rules and constraints for mission planning are specified in a Budgets and Constraints Document. The rules have been hard coded into the MPS. As a consequence it is not easy to make changes in them. Ways of incorporating rules and constraints into an early modifiable database or knowledge base need to be examined.

Interface between control centre and user centre; Definition of this interface was not done under sufficiently rigorous control. This highlights the need for preparing a complete Interface Control Document under configuration control at a fairly early stage. Furthermore, the MMCC/EECF interface does not provide sufficient constraints information to allow the MPS to complete its work without discussion between EECF and ESOC Mission Planning staff.

Testing: testing of such a complex system is difficult and needs considerable user support (i.e. from operations personnel). Provision of user-defined test procedures for use by developers was found to be necessary, as was more formal acceptance tests by operational mission planners

IV. OBSERVATORY MISSIONS: ISO

The Infrared Solar Observatory (ISO) is planned for launch in 1995. It will carry a telescope with four focal plane instruments. It will fly in a near geosynchronous orbit, which gives, on average, 10 hour passes over the prime ground station situated at Villafranca, near Madrid, Spain. ISO operations are carried out in real-time according to a ground-executed schedule, i.e. not an on-board schedule like ERS-1 (sect. 3.1) or EURECA (sect. 3.3). Only one of the four focal plane instruments operates at any given time. Observations can vary in length from 2 minutes to 10 hours. There are no resource constraints.

Mission planning for ISO is split into a user-oriented part (MPP1) under the responsibility of ESA's Space Science Department and an operations oriented part (MPP2) under ESOC responsibility. The mission planning concept involves an iteration between these parts: Firstly, a Planning Skeleton file (PSF) is prepared by MPP2, in which slots are identified for payload operations and for platform operations. Secondly, MPP1 processes observation requests and produces an instrument command schedule to fit in the allocated slots. The instrument commands are expressed as mnemonics, referring to pre-prepared binary command sequences. MPP1 transmits this PSF to MPP2 as the Planned Observations file (POF). Thirdly, MPP2 inserts flight dynamics (e.g. attitude adjustment) commands necessary for the instrument observations and merges in command requests from ESOC operations staff. The result is a Central Command Schedule (CCS) for submission to the commanding system.

CRITICAL DISCUSSION

A number of very positive points about the ISO approach are:

- Use of the PSF technique, allowing platform and payload operations to be planned separately. This appears to be particularly applicable for missions like ISO.

- A very rigorous approach taken to preparation and control of interfaces (via formal Interface Control Documents) also resulted in early definition of the interfaces and functionality of the ISO Mission Planning System, so development of both parts could proceed independently.

Another interesting feature has been the application of a rigorous separation between platform and payload, the idea being separation of responsibilities for platform and payload control the former being that of the operations control centre (ESOC) and the latter that of the Observatory. This has led to what is in effect two control systems constrained by the necessity of having <u>one</u> uplinker. These two *de facto* control systems are distributed over a complex configuration of computers. This affects both mission planning and the on-line control systems. This has several consequences

- End to end testing of the whole mission planning and commanding process is made more complex, since instrument command execution verification occurs within instrument workstations rather than on the real-time control system.

- The split of operational responsibility has led to a large number of file transfers between systems. This is related to the large amount of hardware associated with the different groups. This may have performance and reliability impacts.

- Instrument commands sequences are prepared by MPP2 in uplink form. Input from MPP1 to MPP2 is in the form of mnemonics referencing these pre-prepared uplink blocks. A command translator converts the mnemonics to the uplink form. This is cumbersome and could be inflexible and error prone if instrument command sequences need to be changed.

3 MULTI-INSTRUMENT MISSIONS: EURECA

EURECA was launched by the Space Shuttle on 29th July 1992 and is planned to be retrieved by the Shuttle about April 1993. EURECA carries a complement of some 15 experiments, serviced in some cases by core (or common) facilities (furnaces etc.). The experiments are in the main independent, except where they make use of core facilities. A number of discipline areas are covered, including microgravity (protein crystallisation and materials science), solar science, in-orbit data relay and spacecraft technology (e.g. a new type of ion thruster). EURECA flies in a 28° inclination circular low-earth orbit at an altitude of c.500km. Two ground stations at Maspalomas (Canary Islands) and Kourou (French Guiana) are being used during the routine phase. Station passes are short (2-10min.) and occur in a consecutive set of 4-5 orbits. The contact ratio with the ground is thus very low and payload operations mostly occur autonomously when the spacecraft is out of contact with any ground station. This makes planning of payload and platform operations essential, especially as the resource constraints on EURECA (primarily power, cooling and data storage) are such that it is not possible to run all experiments in parallel. Thus EURECA mission planning is used to schedule operation of the experiments such that available resource limits are not exceeded. Passes are devoted mainly to uplinking of schedules and dumping of data from on-board memory.

EURECA mission planning can be split into two parts: pre-launch planning and operational planning.

Pre-launch planning; This produces a baseline plan for the entire mission based on certain assumptions, for example the amount of power generated by the solar panels, the efficiency of the on-board cooling loop and the expected orbit and launch time. The baseline plans served to do the following;

1. Determine that sufficient time could be allocated to each experiment to satisfy the requirements of the principle investigator.

2. Provide a basis for the daily planning during the actual mission, obviously this could not be exact since the real orbit and hence times of events differs from that predicated prelaunch. Also the radiators appear to be less efficient than predicted (this latter providing a benefit in power availably as less heating is required to keep the freon loop inside its nominal operating temperature range).

Operational planning; This is carried out daily with the aim of generating a list of telecommands for uplink to the on-board master schedule for time-tagged execution. It takes account of the following:

- the baseline plan
- requested changes (from the principle investigators)
- latest orbital event file
- known spacecraft status (i.e. resource availability)

The EURECA mission planning system provides tools which assist both phases. These consist of the following:

1. Operation Definition Editor; this defines the resource profiles (power, cooling, data rate etc.) of each schedulable operation as a function of time.

2. Operation Request Editor; this is used to define the time constraints which should be applied when scheduling the start of an operation. These constraints are expressed as windows relative to GMT, orbit number, orbital events (eclipse start/end, South Atlantic anomaly transits, ground station passes) or combinations of these.

3. Mission Planning Aid (MPA); this is an interactive tool, with an X-windows based user interface. The operation definitions and requests defined by the above editors, along with the orbital event file, are used as input to schedule operations. It can be run in three basic modes. The first mode is fully interactive, in which the user must intervene to resolve any clashes found, either by accepting the clash, rejecting the operation or moving the start of the operation such that there is no longer a resource conflict. The other two modes are "semi-interactive" where the user can either specify that all operations causing clashes be rejected or alternatively be accepted.

These last two modes are described as "semi-interactive" because certain conflicts (viz the execution of master schedule commands during downlink of the onboard memory unit) are considered too critical to be handled automatically and so user intervention is always required in these cases.

The above tasks run on VAX workstations in complete "stand alone" from the rest of the EURECA dedicated control system (EDCS). Once the daily planning has been completed a file of commands for the desired time period, typically extending 48 hours from the end of the next pass sequence, is generated and then sent via DECNET to the prime EDCS VAX, where it is inserted into the commanding chain and later uplinked.

CRITICAL DISCUSSION

A principle difference between the EURECA mission planning approach and those of ERS-1 and ISO is the absence of an explicitly identified user-oriented step, despite the quite large number of PIs. The whole process takes place at the control centre. Because mission planning is done under a single responsibility this user-oriented step was not explicitly identified.

The general principles upon which the EURECA Mission Planning Aid is based seem to be sound. Much of the planning of the mission is done in advance. The bulk of the changes in the schedule from day to day, will be due to the shift in the orbital event times. Inputs from PIs also influence the daily schedules, but have not been, so far, large in volume: The mission design, in which prefiltering and harmonisation of requests was done pre-launch has been borne out in practice. However, such an approach would not have been appropriate for a mission like ERS-1, in which the influence of user requests is much more dynamic and cannot be planned in advance to the same extent.

The MPA detects resource clashes. However, the following deficiencies should be noted:

- it does not give an analysis of the contributions to the resource clash; to find this out the user has to examine the operations requests, which is not straightforward especially since instruments switched on considerably earlier than the time of the clash may be resource consumers.

- it does not provide any means to automatically resolve resource clashes (as the ERS-1 MPS does). This reflects the fact that PIs have not been able to specify any algorithm for solving these clashes.

- it lacks flexibility in applying the scheduling constraints. The requirements for these were defined well before launch, but in practice it has been found that change requests can be difficult to formulate in terms of the scheduling rules.

- The command request interface with the PI's are received in a written form. They can be slightly "fuzzy", which involves the operations staff in considerable interpretation work.

V. LESSONS LEARNED

Examination of the critical discussions above, shows the following common themes:

1. Mission planning systems naturally split into two parts, the user interfacing part (Phase 1 or MPP1) and that producing the operations schedules and interfacing to the control system(Phase 2 or MPP2). A number of major problems resulted from difficulties in the set up and interaction of these two parts, particularly when they are under separate responsibilities. Problems can be avoided by clear formal agreements on separation of tasks, document and controlled interface descriptions/agreements.

2. Mission Planning systems carry out their scheduling using a set of rules and constraints. Problems result both from late knowledge of these rules and from the "hardwiring " of these rules into planning systems, making the inevitable changes and corrections difficult.

3. Mission planning systems normally run off-line; as a consequence they tend to be tested less thoroughly in operations than spacecraft control systems. However they are already important operational tools and will become more so as missions become more complex. Testing of mission planning systems will therefore have to be more thoroughly integrated into mission test programs.

4. The discipline of goal-oriented optimisation needs more thorough exploration, at least as far as ESA Mission Planning systems are concerned. Algorithms from the Operations Research disciplines exist to do this, but there has been little practical study of their application to Mission Planning.

5. Projects are being set up in which the division of responsibilities (a management matter) assumes that platform and payload control can be separated (a technical matter). The ISO example is a more or less successful attempt to do this, although it does illustrate some of the potential pitfalls of this approach.

6. While certain aspects of mission planning are of a specialised nature (perhaps mission specific) it is possible to identify areas (e.g. scheduling rules) where it may be possible to use existing commercially available products to reduce the amount of customised software.

VI. GENERIC MISSION PLANNING TOOLS

Having completed this rather high level review of some recent mission planning systems developed at ESOC, it is worth noting that all the systems were developed independently and use no common elements. While it is clear that there are a number of essential differences between the missions concerned, it is also clear that there are some commonalities. Is it possible to identify some common functions which could be implemented as reusable tools? An ongoing ESA study is examining this problem. To date the mission planning approaches discussed here have been analyzed in detail, together with a number of other approaches from both ESA and NASA. 31 distinct mission planning functionalities have been identified and a commonality matrix established for the various missions. Common functions include, among other planning request handling, orbit propagation, activity scheduling, conflict identification and resolution, time-line visualisation with zooming, command schedule generation. The plan is that a workable concept for generic mission planning facilities can be developed and that key elements of it can be prototyped and demonstrated in application to real missions. This should feed into both the ongoing programme of spacecraft control infrastructure development (SCOS-II, see Ref. 2) and the Advanced Technology Operations Systems (ATOS, see Ref. 3), which seeks to develop knowledge-based elements to be added to this infrastructure.

VII. REFERENCES

1. Mission Planning for an Earth Observation Low Earth Orbiter: ERS-1, K Hirst and E M Sørensen, 1992, Proceedings of SPACEOPS 1992, Pasadena, CA,

2. SCOS-II: ESA's New Generation of Mission Control System, 1992, J F Kaufeler et al, Proceedings of SPACEOPS 1992, Pasadena, CA,

3. The Advanced Technology Operations System ATOS, 1992, J F Kaufeler et al, Proceedings of SPACEOPS 1992, Pasadena, CA.