

EFFICIENT AND EFFECTIVE MULTI-ORGANISATION MISSION PREPARATION ACTIVITIES

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1 The harnessing of spacecraft operational knowledge

The achievement of successful and cost-efficient mission operations takes careful and effective management throughout the mission development lifecycle prior to launch as well as in the operational mission phases. Regardless of the organisational structures involved in the mission development and execution, a key factor for success and efficiency is the way in which spacecraft system operational knowledge is developed, validated and made ready for the operational phases of the mission.

This spacecraft knowledge accumulates from the time the first design specifications are written and involves different entities:

- AIT teams build the database to reflect the design of the spacecraft and validate the data using test procedures and sequences
- Manufacturer spacecraft system teams enhance this spacecraft operations knowledge by generating user / operations manuals and determining flight conditions for database parameters
- Spacecraft Operations Centre Teams utilise and refine the spacecraft knowledge through the building of the operational database and the generation of the flight operations procedures based upon the inputs from the manufacturer and the constraints of the ground segment.

The procedures and databases are therefore the key elements in the flow of the spacecraft operations knowledge.

Planning and managing this flow of spacecraft operations knowledge can make the difference between mission success or failure; between a mission on time to meet the planetary fly-by launch constraint or a mission saddled with schedule overrun costs; between having an economically viable mission preparation budget or having the mission scrapped before it gets off the drawing board.

A typical spacecraft mission involves numerous players, such as space agencies (cooperation on a single mission is becoming more frequent), large industrial prime contractors for spacecraft and ground segment and a vast hierarchy of sub-contractors. Getting the information flow right in this kind of environment is therefore of vital importance to the objectives of controlling the cost and ensuring the high quality of a mission operations preparation.

Within programmes of national and international agencies, achievement of these objectives has often been thwarted by the lack of common systems or standards between the various teams involved in this lifecycle. This has typically been the cause of significant effort expenditure in the production of interface control documentation, data export and import mechanisms, duplicated effort in procedure generation and re-validation activities.

2 The Rosetta Case-Study Example of the Problems and Solutions

The management of ESA's Rosetta deep space encounter mission preparation have put in place the tools to remove these interface and duplication problems and achieve a seamless integration of the database and procedures for the various mission preparation activities.

2.1 The Rosetta Mission

Unlike many other spacecraft programmes, the Rosetta mission preparation (Warhaut *et al.*, 2000) must be completed on time to meet the hard launch constraint (January 2003) caused by the need to perform a set of gravitational assist manoeuvres at Mars in 2005 and twice at Earth (2005 and 2007), as illustrated in Figure 1. This approach has been selected to give the spacecraft the correct acceleration such that it will be able to reach the nucleus of comet 46P-Wirtanen and match its heliocentric orbital parameters. Compared to a more straightforward flyby mission, the Rosetta spacecraft (Gardini *et al.*, 1999) will slowly approach the comet nucleus in 2012, and orbit it from distances varying from a few hundred down to just several from the surface for more than 1 year. In the initial period of its near-comet phase, while the nucleus is still close to its Aphelion, and therefore relatively inactive, a small Lander will be ballistically delivered to the surface of the comet, from where it will perform in-situ measurements and utilise the Rosetta spacecraft as data relay to and from Earth. Figure 2 shows the activity profile of this long mission, which is characterised by its main scientific phase starting as late as 9 years after launch.

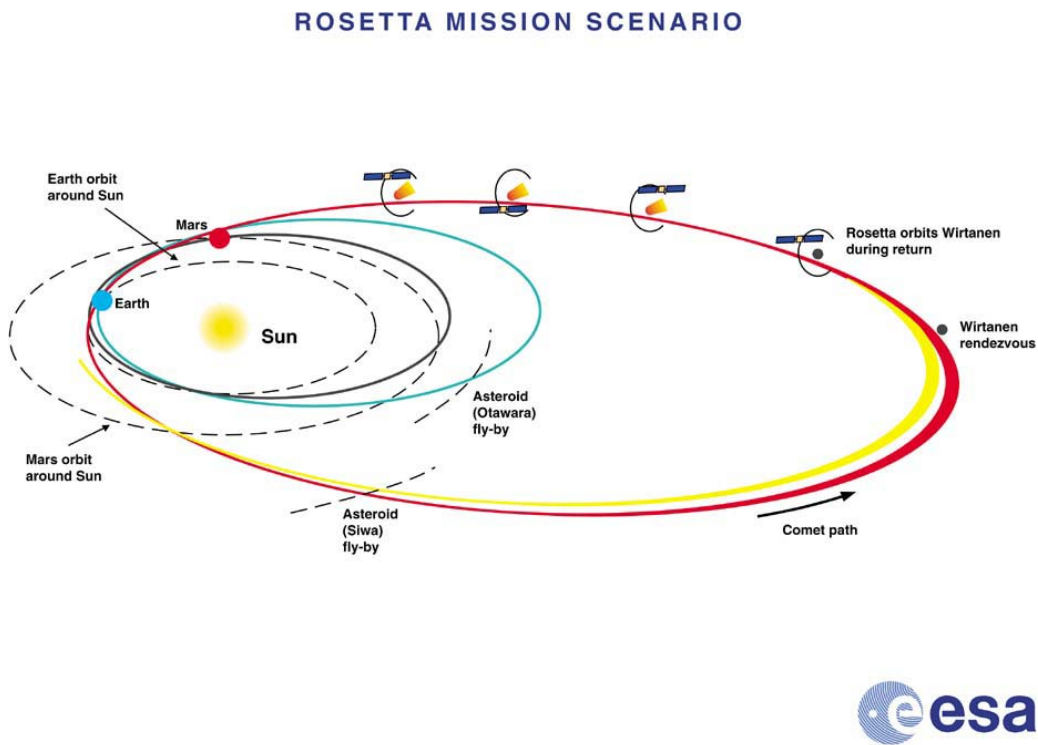


Figure 1

Failure to achieve the launch date, which is constrained to a window of 19 days opening on 13 January 2003 within which a total of 7 instantaneous daily opportunities exist, would result in a delay of several years (the next realistic mission opportunities occur between two and four years later). The readiness of validated database and procedures is therefore a critical issue.

Another significant factor for the procedures and database approach is the extensive lifetime foreseen – indeed too long to expect continuity of a single ground operations and engineering support team. Furthermore, it is clear from Figure 2 that there are the multiple extensive periods of inactivity during mission operations that will mean a re-learning of spacecraft knowledge even where the same team is involved. These factors imply extra attention to the configuration control of all satellite system operational knowledge (Ferri, 2001) must be made.

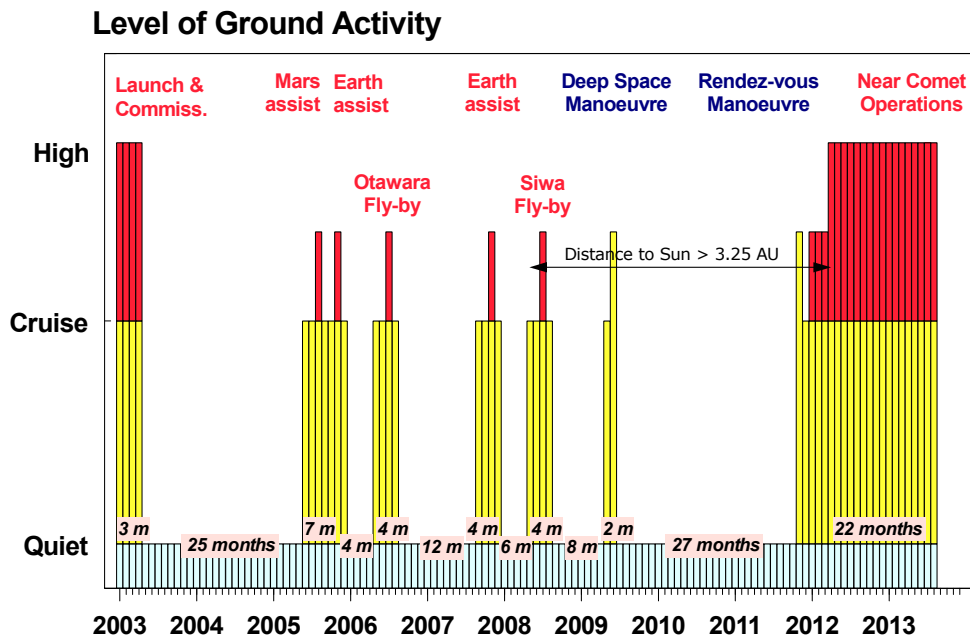


Figure 2: Level Of Ground Activity During Rosetta Mission

2.2 Commonality between AIV and Flight Operations

Given the special characteristics of the Rosetta mission, and in particular the long duration of the mission and the continuation of development and testing activities, both on ground and on board foreseen during the long interplanetary cruise phase, significant consideration was given by the Rosetta Project from the beginning to maximising commonality between the traditional pre-launch testing activities and the post-launch mission operations (*Montagnon et al., 2001*).

At conceptual level, and taking into account the constraints given by the organisational set-up, the heart of this commonality was identified in the tools to support the two different activities. In particular, it was decided that the Mission Database (called Rosetta System Database, or RSDB) and the Procedure Generation Tool would be common for both areas (*Ferri et al., 1998, 1999, Sørensen et al., , 2000*).

Unfortunately the unavailability of off-the-shelf tools at the beginning of the programme and the different schedules for the two areas of AIV and Flight Operations, resulted in the need to accept several compromises. This meant that the initial preparation was commenced without full commonality of approach.

2.3 Typical difficulties associated with spacecraft knowledge transfer

Typical previous mission experience concerning the generation, validation, transfer and execution of the spacecraft operational knowledge has been that there are significant inefficiencies. This mainly stems from the lack of standardisation between the different teams and organisations that are involved. At each entity, the operational knowledge must typically be restructured or be rewritten to suit the particular environment and standard that the company or test environment has implemented. This is further aggravated by the fact that in many cases each level uses different tools and format. For example, the System / AIV responsible engineers will write the test definition in a certain format

using e.g. MS Word or Excel. The actual test engineers will then convert this into the test language that can run with the EGSE (in a similar way to software code). This introduces extra manpower resources in terms of quantity, skills, and increases the schedule risk and risk to the integrity of the system through the possibility of deviations between the system procedures and the tested procedures.

Add into this the typical tiers of subcontractors who will normally also be involved in preparation of procedures at subsystem level and sometimes the AIV of their own subsystems, then further data formats are often introduced.

It should also be noted that a standard format does not necessarily imply compatibility at each level. The approach to filling in the data must also be standardised and controlled to ensure the interchangeability of data.

A similar problem has typically existed in transferring the operational knowledge from the satellite manufacturer to the mission operations teams. Information has typically been sent in formats unsuitable for the operations environment, often because the tools in use at the operations centre were not regarded as suitable for the AIV and FOM production team's usage.

In order to overcome these difficulties, the Rosetta Management have decided to integrate a toolset which they believe will prove decisive in raising the efficiency of the satellite operational knowledge lifecycle processes and result in cost savings in mission preparation coupled with a higher degree of confidence in the quality of the operations database and procedures.

3 The Mission Operations Information System (MOIS)

The toolset is the Mission Operations Information System (MOIS). This (as illustrated in Figure 3), is an integrated set of tools supporting spacecraft mission preparation processes such as:

- procedure top level design (Flowcharter)
- procedure development (Writer)
- activity timeline refinement (Timeliner)
- validation of procedures (Validator & Test Harness)
- configuration control of problems, updates, versions (Reporter)
- Database generation, import, export (DB)
- Procedure Execution (Executor)
- Parallel execution environment (supervisor)
- Operations language support and function/directive management

The tool puts great emphasis on configuration control and validation features which allow the managers of mission preparation activities in AIT, FOM production as well as Mission Operations teams to track the history and the validation status of the components of the procedures and the database, as well as be sure of the coherence of all the data through an integrated, powerful change control mechanism. In the area of flight operations the MOIS tool has been utilised at ESOC for years by major ESA missions. In fact the tool was originally developed under ESOC operations engineer supervision, building on a multi-year experience from home-made tools used for previous missions. It has been subsequently enhanced and expanded by Rhea System and turned into a commercially available product.

The Rosetta mission had already embarked upon its preparation activities by the time MOIS was integrated. In fact the mission preparation was suffering from many of the problems associated with the lack of commonality in approaches of the various entities and the deficiencies of the tools they had been using. Although an earlier integration of the tool would have enhanced the benefits, the MOIS features have helped in ensuring a seamless integration of validated information.

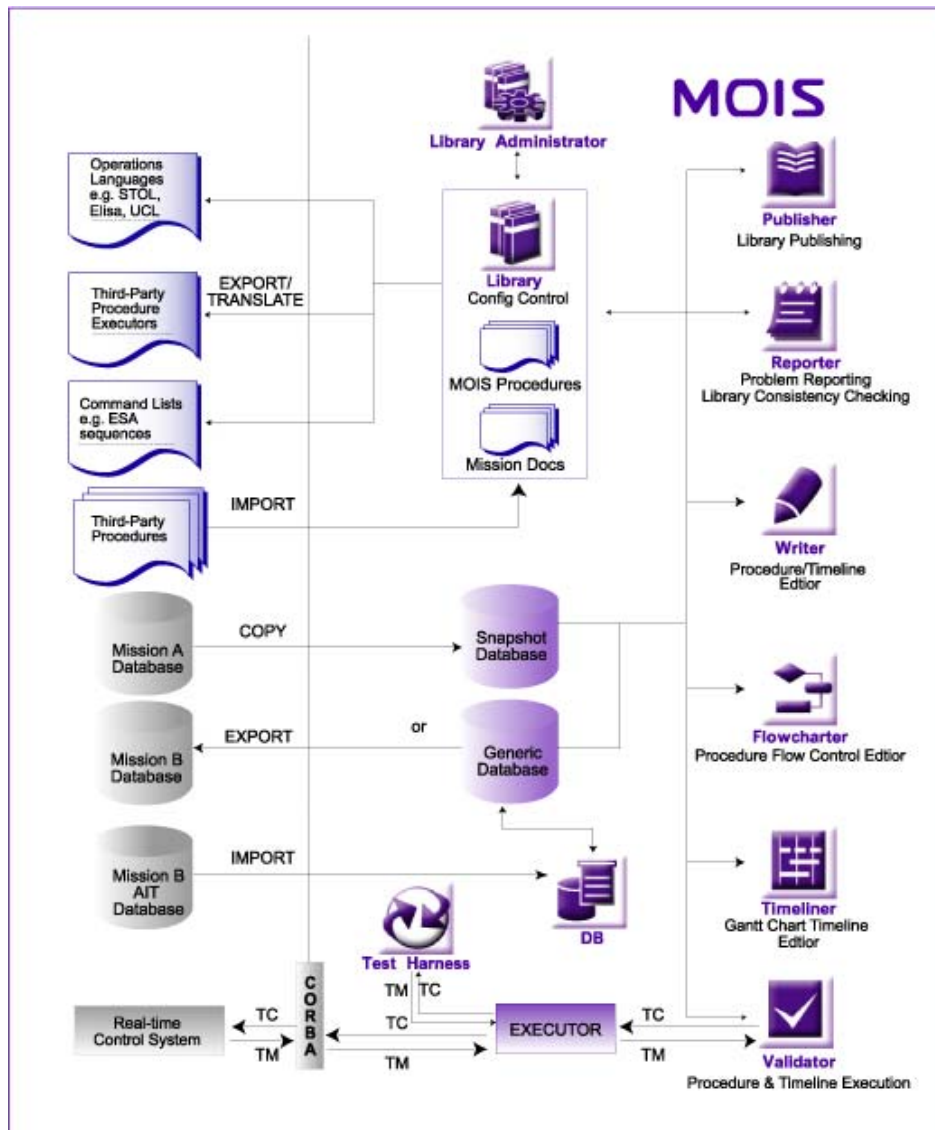


Figure 3: Mission Operations Information System Architecture

4 Experiences and Lessons Learned

An important aspect in the selection of the MOIS tool for Rosetta was its ability to interface to the various systems involved in the mission preparation, such as the Electrical Ground Support Equipment (EGSE), Mission Control System (MCS) and office documentation systems. Referring to Figure 4, it is seen that the integration of MOIS provides a standard and seamless view and control of procedures and databases without enforcing changes in the heritage infrastructure for EGSE and MCS in use in the different organisations.

In the area of flight operations the MOIS system has supported the generation and maintenance of about 400 Rosetta System Validation Test procedures. The flight operations engineers follow these procedures manually during the short and precious windows assigned to ESOC for testing of their

systems directly with the spacecraft. In addition, the first two issues of the Flight Operations Plan, with a total of about 800 nominal and contingency procedures, plus a few mission phase timelines, have been generated and are under MOIS configuration control.

In the AIT area, MOIS procedures are written taking full advantage of the user-friendly procedure design features, database consistency checks and configuration control features. Astrium were able to use their heritage EGSE system which supports its own test sequence coding language (Elisa) since MOIS is able to generate the code. Experience has shown that the outputted Elisa code always compiles without any problem and that the test can be run immediately taking advantage of the existing Elisa automatic verification, the control of the test progress and the on-line production of a test logbook, which can be used for Test Report writing. Clearly this has resulted in manpower saving, although occasionally skilled software and test language engineers may still be needed to refine the code.

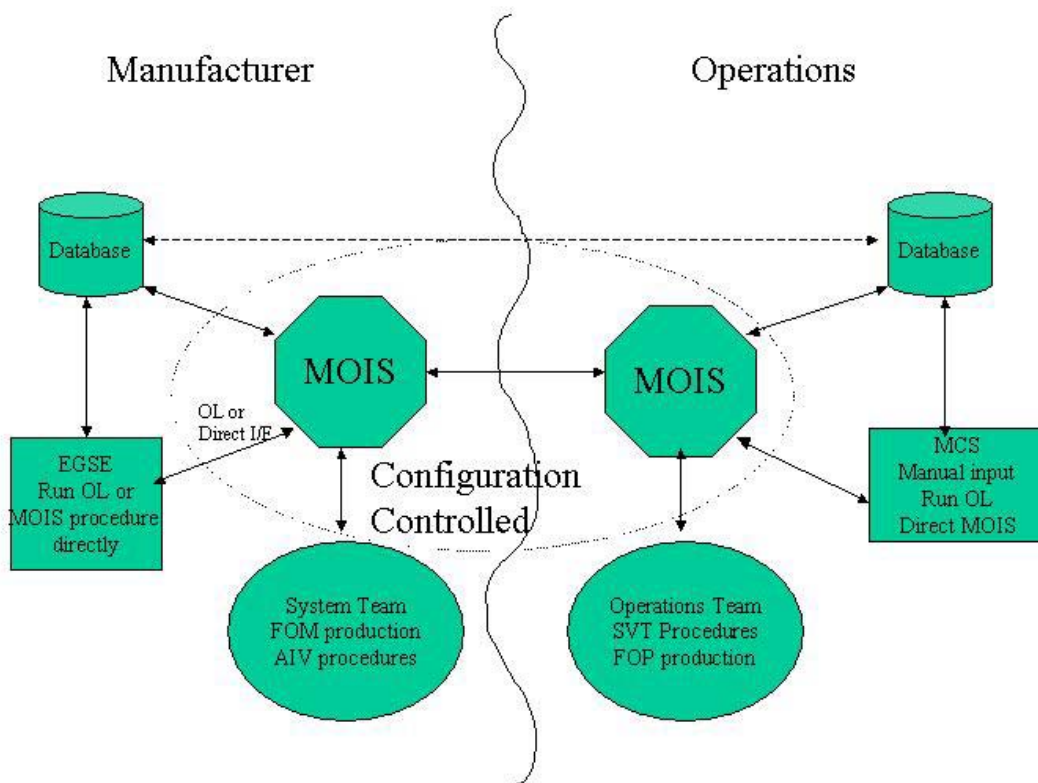


Figure 4: Configuration Control of AIT and Operations Database and Procedures using MOIS

As an example it has been possible to produce the test code for a large delta-V manoeuvre (approximately 3000 code lines) and run it without any manual changes. The time for conversion of the test code from the MOIS level is negligible as it is performed at the time you press an icon within the MOIS tool.

Since the start of MOIS utilisation in the areas of AIV by the Industrial team, exchange of MOIS procedures between the two teams has taken place: the system test procedures produced by Industry have been delivered to ESOC for review and comments. In the other direction, the Industrial AIV team has recently requested ESOC to send electronic copies of the flight procedures produced with MOIS at ESOC, for possible utilisation directly into future system test scenarios. Indeed, some of the

lower level MOIS procedures used in the large delta-V manoeuvre were written by ESOC as operational procedures and therefore ESOC can be sure that this procedure has been tested fully and independently against the spacecraft itself (without relying purely on the very limited access to spacecraft time in System Validation Tests).

In Rosetta, Test Readiness Reviews take place between the Prime Contractor test team and ESTEC/ESOC on the test to be performed next. It is clear that this review is tremendously simplified when both sides are using a common tool to generate test procedures on one side and Flight Operations Procedures on the other. Using the configuration management tools to report on the state of procedure validation and problems on both sides increases the level of feedback to the Programme Management and therefore the effectiveness of the control they can exercise in the management of overall costs and schedule, which is a particularly critical issue for the fixed-launch window Rosetta mission.

The potential advantages of such cross-fertilisation between the AIV and flight operations procedures have therefore been recognised by Astrium and ESOC. In particular the exchange of operational knowledge is facilitated, the duplication of efforts in generating and validating procedures is minimised and the level of confidence in Flight Operations procedures increases. The late introduction of MOIS in the case of Rosetta AIV has of course reduced the potential benefits which might have been achieved if the product had been available earlier, but the savings in time and cost and increases in product confidence already realised show the full potential of what could be achieved on future missions.

It is worth noting that had it been possible to deploy MOIS throughout the Programme at an earlier point in time, the mission preparation would have benefited from the common interface for operations knowledge transfer between the Prime and its Sub-contractors thus extending the common configuration control of this knowledge to all tiers of the Programme.

The Rosetta experience has also demonstrated that some essential pre-requisites have to be satisfied in order to maximise the benefits of the use of a common MOIS tool in AIV and operations:

- The system database driving the two control procedure definition and subsequently used by the check-out / control systems (for AIV and Mission Operations) must be identical;
- The two control systems shall also be compatible such that differences in database structure required are minimised.
- Database population activities have to be controlled by a centralised authority, which ensures consistency of inputs and minimises conflicts between different needs of different users;
- The MOIS tool should be selected and utilised from the beginning by both AIV and Flight Operations teams to get the maximum benefit in manpower and schedule savings.

5 Future usage of MOIS

Based on the experience gained in the application for Rosetta, Astrium GmbH plans to adopt MOIS as a standard tool for future projects. The focus will be on the preparation and validation of flight control procedures. It has been agreed with ESA, that for the CryoSat project, essential parts of the flight operations manual will be delivered as MOIS procedures. They will be developed, debugged and validated during the course of the AIT programme. Instead of the code generation as performed on Rosetta, Astrium are planning to make use of the MOIS Validator tool which includes an executor allowing direct communication with an external control system by issuing command execution requests and telemetry status requests. The procedure therefore runs in its user-friendly form “on-line” without any code version needing to exist. This therefore removes any possibility that inconsistencies could occur due to updates made at the level of the test code, rather than on the originating MOIS procedure.

Other applications are also being assessed such as the preparation and pre-validation of On Board Control Procedures (OBCP's) where MOIS would be used to design the on-board software algorithms prior to the generation of the on-board software by the subsystem responsible contractor.

Due to its versatility in generating executable procedures, along with the capabilities to directly interface with virtually any control system, MOIS has the potential to be a bridge for transport and exchange of test and operation procedures over various spacecraft development status and integration stages up to mission control.

In ESOC, MOIS is already being used as the standard procedure tool for new operational missions and an upgrade to the latest MOIS 5 software has been agreed. ESOC is looking closely at the procedure execution automation functionality, which is a central and strategic interest area for ESOC for the incoming years (*Ferri and Sorensen, 1998*).

6 Conclusions

The inherent inefficiencies in the transfer of spacecraft operational knowledge, which are particularly apparent in multi-organisational mission preparations, have been explained within this Paper.

The implementation of MOIS on Rosetta has shown a pragmatic way forward to achieve the benefits of commonality between the AIT and operations as well as between various teams within the spacecraft manufacturer organisation.

Despite late integration, this implementation has already resulted in large savings in manpower cost, relaxed the schedule for AIT / Operations and increased the quality of operations products and confidence in the mission operations success.

Even greater benefits have been identified for future missions able to bring in the MOIS toolset at the start of activities.

7 References

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