Towards a Common Check-out and Control System for Rosetta

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Definition of the Rosetta ground segment began in 1996 and it soon became clear that a common checkout and mission-control system would be very beneficial for the mission. The chosen approach for achieving this goal was to develop building blocks for the Central Checkout System that can be re-utilised later in the development of the Flight Control System. The Rosetta prime contractor and AIV contractor fully endorsed this approach and the complete system is currently under development. The first delivery of the database system should take place in November 1998, followed by that of the first Central Checkout System in 1999.

Introduction

The International Rosetta mission will be launched in 2003. After journeying through space for almost 10 years, the spacecraft will approach comet P-Wirtanen and orbit it for about one and a half years, performing scientific investigations of the cometary environment from just a few kilometres above the nucleus' surface. Rosetta will also release a probe that will land on the surface of the nucleus to make in-situ investigations.

During its long journey to the comet, the spacecraft will spend most of its time in semi-hibernation (low activity status), although periodic check-outs of the functioning of all subsystems and the payload will be carried out. The application software and the on-ground and on-board control procedures required for the scientific phase around the comet will not be fully developed and tested before launch, since the long duration of the mission would probably make them obsolete before they are first used. Consequently, Rosetta's on-board data-handling system must be developed as an open system to allow those procedures to be up-linked to the spacecraft at a later date, after their final testing and validation on the ground. This means that the check-out phase, which for a normal spacecraft is completed before launch, will continue well into the mission for Rosetta.

The computer systems and the software used for the check-out phase and for the mission operations phase are normally developed separately and used by different groups of engineers and technicians. On the other hand, many of the functions they are required to perform are identical and a common core system can in principle be defined that can be used in both environments. The less distinct border between check-out and flight operations for the Rosetta mission make it particularly suitable for a first attempt to integrate these two activities, starting with the development of common systems and support tools.

The ESOC Mission Operations Department, together with the Rosetta Project Office at ESTEC, has defined an approach that takes into account the development schedule for this mission and in particular the fixed launch date of January 2003. The concept chosen leads to the development of building blocks for the Central Checkout System that can be re-utilised later in the development of the Flight Control System. This common core, known as the Rosetta Common Checkout and Control System (RCCCS), will form the basis for this new approach, which will be followed by other ESA science missions in the future.

Spacecraft checkout and mission operations

The activities associated with the Assembly, Integration and Validation (AIV) programme for the space segment of a major ESA mission like Rosetta typically start about two to three years before launch. During this phase, the different parts of the spacecraft are put together to form first the subsystems and payload instruments, and then the spacecraft itself. The process is validated at all levels through a series of check-out and test activities, which permeate the assembly and integration work throughout, culminating with the system-level validation tests, which also involve the ground segment. Finally, the spacecraft is shipped to the launch site, where the last preparatory activities for the flight take place and confidence and final validation tests are carried out.

The equipment used to support this long and crucial phase in the mission's preparation can be described as a set of mechanical and electrical support equipment that is mostly spacecraft-specific. The Electrical Ground Support Equipment (EGSE) includes Special Check-Out Equipment (SCOE) to, for example, provide signals to the optical sensors of the spacecraft's attitude control subsystem so as to simulate the real conditions they will encounter in space. Other SCOE provides electrical power to the spacecraft, simulating the outputs of the solar arrays and batteries, or allows the measurement of electrical signals from selected power or data lines on the spacecraft.

The core of the EGSE is the Central Checkout System (CCS), a computer system that controls all of the activities of the other EGSE equipment. It enables one to construct and send telecommands to the spacecraft and receive and interpret telemetry data from it, via a special interface that utilises either a direct-video or a radio-frequency link. The CCS can be operated manually by an operator who can type an instruction via a command-line interface and visualise the status of the spacecraft or of the EGSE equipment on a display. Owing to the importance of repeatability of the test activities, however, the normal mode of operation for the CCS is via a pre-defined list of control instructions and telecommands, called the 'test script' or 'control file', which can be executed automatically by the CCS. The system also has facilities to identify potentially dangerous situations and signal them to the test operator via alarm messages or by automatically interrupting the test sequence and taking measures to put the spacecraft and the equipment into a safe configuration. The CCS archives all data collected during the entire AIV phase, and these data can be accessed on-line or retrieved later for investigation purposes by the AIV team, or even remotely by the subsystems and payload developers and by the scientific community.

The operations phase of a mission starts shortly after separation of the spacecraft from the launcher, typically 20 to 30 minutes after lift-off. The equipment necessary to support this phase is partially located in the ground stations around the World, with the task of maintaining the radio-frequency (RF) link with the spacecraft. Remaining parts are vested in the Operations Control Centre (OCC), in charge of the monitoring and control of all the spacecraft and ground-segment functions.

The core of the OCC is the Flight Control System (FCS), a computer system and its software that interfaces with the ground stations to receive telemetry and tracking data from the spacecraft, and to transmit telecommands to it. The FCS monitors the incoming telemetry and raises alarms to an operator, the spacecraft controller. It handles manual real-time and time-tagged commanding, as well as background commanding in the form of automatic command queues. Mission operations are normally scheduled by combining inputs from the users (for a science mission typically collected by a Science Operations Centre) and from the operations team into a schedule of telecommands, which is periodically sent to the spacecraft. The FCS can also generate schedules for the simultaneous operation of the relevant ground stations. All data received are archived for on-line and offline retrieval and analysis by the operations team, or remotely by the scientific community.

As can be seen from the above, many of the activities carried out in the AIV phase are identical to those of the mission-operations phase, but the objectives and context are different:

- The AIV objectives are to test the behaviour and performance of the spacecraft and its components and to prove that the required functionality and performance are according to specification. The mission-operations objectives are to maximise the mission's return in terms of quality and quantity of the products during the spacecraft's in-orbit lifetime.
- The AIV context is the ground testing of all spacecraft modes (both prime and backup), in some cases deliberately causing anomalies, with a quick access/recovery capability together with interruptible operation periods. Corrective maintenance is also possible without the need for operating other functions. The mission-operations context is a spacecraft in orbit with limited and less-reliable access. Operations and corrective maintenance are more complex.

Due to the above differences, there have traditionally been differences in the computer systems used in the two areas, particularly where system functionality is concerned. For a mission-control system, the emphasis is on safety, reliability, maximisation of productivity and minimisation of risk. For AIV, the emphasis is on test repeatability, and thus the automation of test sequences.

CCS and FCS commonality

Despite the different objectives and contexts for checkout and mission operations, they have major functions in common. As pointed out above, during most of its life cycle a space project requires facilities that allow monitoring and control of the spacecraft's functions. A single system could in principle be used for the following phases of that life cycle:

– integration and testing of the subsystems at system level
– integration and testing of the payload at system level
– testing of the fully integrated spacecraft as a complete mission system
– launch pad operations, and
– mission operations.

In all of these phases it is necessary to monitor and control the activities throughout the cycle of assembling, integrating, testing, and operating. When assembling, integrating, and testing a subsystem, for example, there is a user, the subsystem tester, controlling subsystem activities through signals and/or commands and monitoring subsystem activities by interpreting signals and/or telemetry. For subsystems with computing capabilities, the tester may be loading software, tables of parameters, procedures (sequences of commands) and commands to invoke software programs and procedures. The subsystem may report health status and performance summaries via telemetry. The subsystem may also perform some level of self-calibration and diagnostics and report the results to the tester.

Integration of the spacecraft and its payload onto a launch vehicle is conducted at the launch site. During this phase, both the launcher and the spacecraft/payload continue to be tested as systems, and the combined launcher and spacecraft/payload takes part in a countdown rehearsal. Spacecraft/payload test activities are monitored and controlled by testers at the launch site and the mission control and operations centre. The monitoring and control techniques used in this phase are similar to those used in the spacecraft integration and test phase.

Finally, mission operations begin after the spacecraft has separated from the launch vehicle. The mission operations centre monitors and controls both the spacecraft and the ground stations used to track and

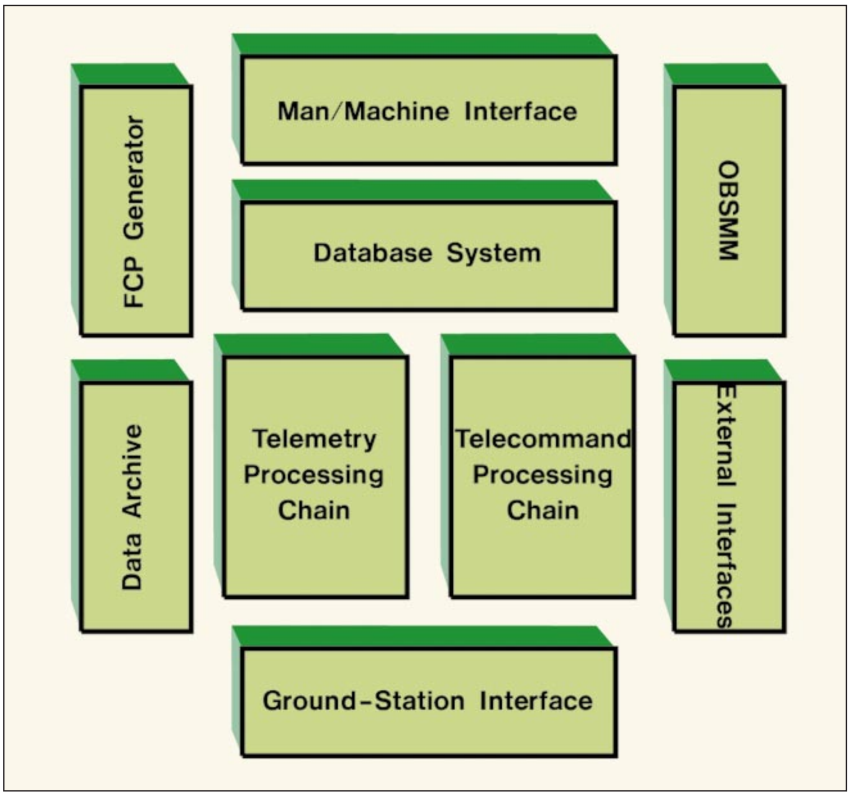
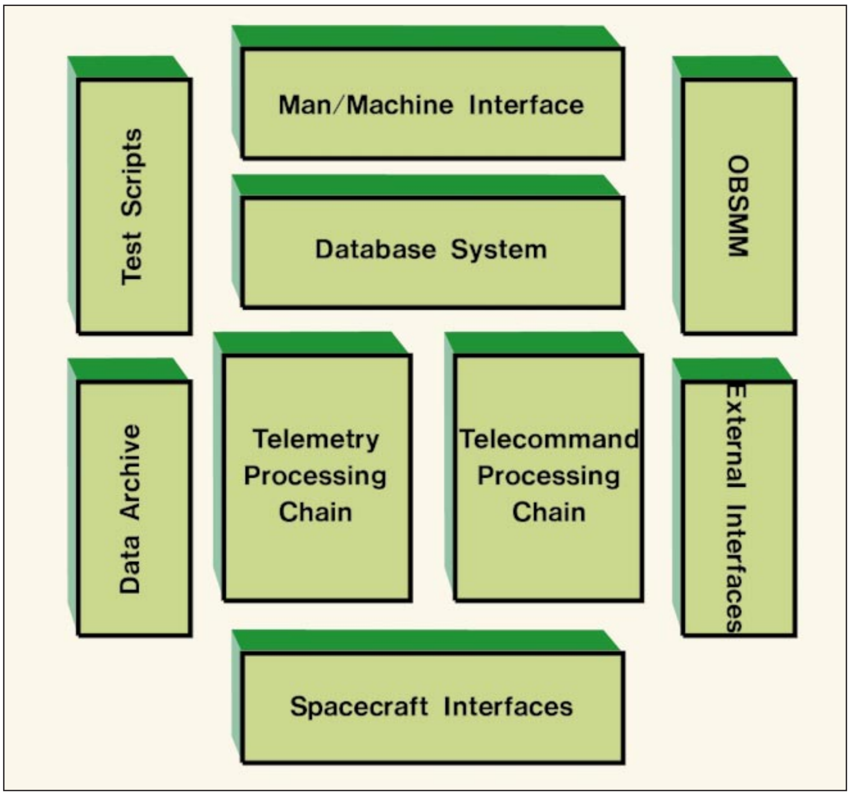


Figure 1. Functional building blocks for a generic Flight Control System (FCS)

Figure 2. Functional building blocks for a generic Central Check-out System (CCS)



communicate with it. The monitoring and control techniques used in this phase may include all of those used in the previous phases.

Identification of the FCS and CCS components can be defined as 'common' is based on the functional breakdowns of the two systems, shown in Figures 1 and 2, respectively. These building blocks are briefly described and compared in Table 1, which shows that there is indeed a large degree of commonality.

Figure 3 shows the functionality for a common checkout and mission control system that provides a central core of identical functional blocks for both the CCS and FCS. This type of exercise also highlights functional blocks

Table 1. Description of functional building blocks for an FCS and a CCS

Flight Control System (FCS)	**Central Checkout System (CCS)**
Man/Machine Interfaces Provides the operator with interfaces to the monitoring and control system, including the database system.	*Man/Machine Interfaces* Function identical to the one described for the FCS.
Database System Allows the definition and handling of all the mission parameters required to drive the control system.	*Database System* Identical to the one described for the FCS.
Telemetry Processing Chain Performs the processing of the data received from the spacecraft and the ground systems, including parameter extraction, interpretation.	*Telemetry Processing Chain* Identical to the one described for the FCS.
Telecommand Processing Chain Constructs and sends the telecommands to the spacecraft and the instructions to the ground equipment. It also interfaces with the telemetry function to verify correct execution.	*Telecommand Processing Chain* Identical to the one described for the FCS.
Ground Station Interfaces Handles the interfaces to the ground stations for transfer of telemetry, telecommand, tracking and station control data.	*Spacecraft Interfaces* Allows the CCE to interface directly with the spacecraft.
External Interfaces Handles the interfaces to mission-operations-specific functional blocks such as the Flight Dynamics System, the Mission Planning System, and the Science Operations Centres.	*External Interfaces* Handles the interfaces to the special checkout equipment and the payload checkout systems.
Flight Operations Procedures Generator Produces all the procedures and timelines necessary to carry out the flight operations.	*Test Scripts Generator* Produces the computerised procedures used to automatically drive the test sessions.
Data Archiving Supports the long-term archiving and the on-line and off-line (retrieval) data distribution to a variety of external users of the FCS, in particular to the scientific community, industry and project engineers.	*Data Archiving* Supports the long-term archiving and on-line and off-line (retrieval) data distribution to a variety of external users of the CCE, in particular to the payload instrument test equipment and to industry and project engineers.
On-Board Software Maintenance Management Used to maintain the on-board software via telecommands during flight.	*On-Board Software Maintenance Management* Used to maintain the on-board software during AIV via telecommands or direct access to the spacecraft.

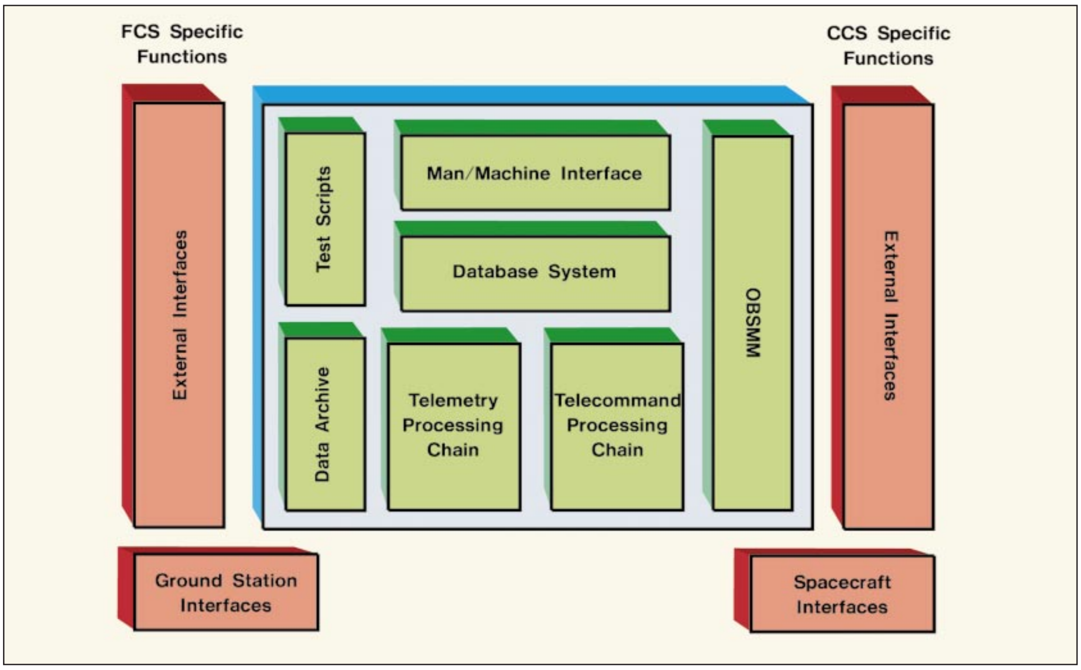


Figure 3. Implementation concept for a generic Central Check-out and Control System (CCCS)

specific to the CCS environment (e.g. direct interfaces to the spacecraft, SCOE functions) or the FCS environment (e.g. flight dynamics, mission planning, ground-station interfaces). Nevertheless, a Common Check-out and Control System can be defined reasonably easily if the interfaces to the environment-specific blocks are separately defined and linked to the central core in the same way.

The Rosetta approach

In general, then, all major elements of a CCS and FCS could be shared, but the implementation of a fully common system calls for a completely new development effort, due to the deeply-embedded differences in the systems currently available for checkout and mission operations. To avoid introducing unnecessary risk with respect to cost and schedule, the Rosetta project has elected to choose only a subset of the theoretically common functional blocks for system development. The selection was based on a trade-off of the need for new developments against the savings in effort on the users' side, the type and number of interfaces to other elements, and the schedule and cost impacts. Blocks that anyway needed mission-specific development have of course been included. The result is shown in Figure 4, where the

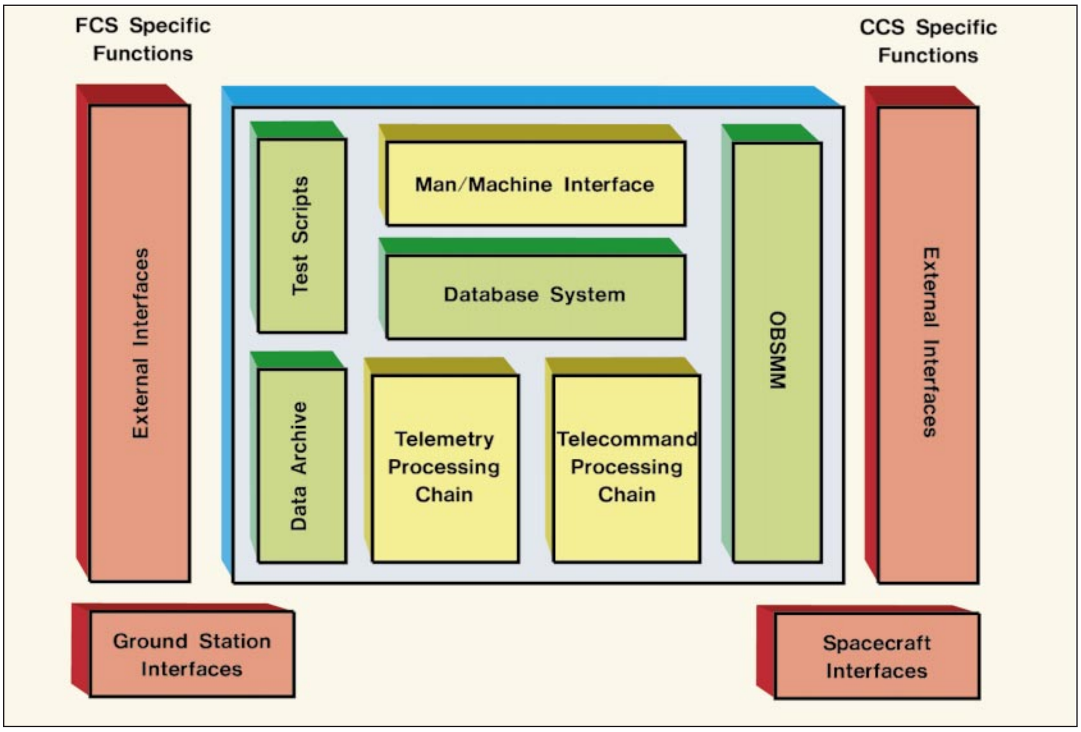


Figure 4. Implementation approach for the Rosetta Common Check-out and Control System (RCCCS)

colour coding indicates the amount of commonality achieved. Green means the block will be developed as fully common between the two systems ('plug and play' systems); yellow means that the FCS block will be developed separately, but will re-use software modules from the corresponding CCE block whenever practical ('pick and choose' systems); and orange indicates that different blocks will be developed for the two systems.

This low-risk approach is expected to require more effort when reviewing the design specifications, but cost savings are expected in the overall development of the common functional blocks. Additional benefits are also expected in other areas of the overall mission-preparation activities, such as preparation and validation of the mission database and flight operations procedures, which are normally extremely labour-intensive activities.

The first utilisation of the RCCCS will be for Rosetta integration and testing activities, followed by the preparation of the mission control scenario. Some of the FCS-specific functions, in particular those related to Rosetta's near-comet activities, will only be needed long after launch.

Major milestones have already been completed with the definition of the high-level functional requirements, the contract award for the development of the CCS part, and the definition of the detailed requirements for two of the common functional blocks, namely the Database System and the Data Archive. Table 2 indicates the remaining milestones until the end of the mission.

Table 2. Implementation schedule for the RCCCS

Year	Phase	Objective
1998/1999	CCS and common elements of the FCS developed	CCS and common FCS elements development phase monitored by ESTEC, ESOC and contractors. Identification of further common packages of code during the review cycles
Mid-1999	EQM AIV preparation starts with database contents definition	Database system available for population. ESTEC and ESOC review contents
3rd quarter 1999	EQM AIV preparation continues with OBCP definition and preparation	OBCP definition and preparation system available for system level AIV on EQM
Beginning 2000	EQM AIV starts	
Mid-2000	Mission operations preparation	Use of FCS starts with acceptance testing of first delivery, followed by spacecraft-related tests (Listen-In Tests, System Validation Tests) and mission simulations
3rd quarter 1999	Flight-model AIV starts	
Jan. 2003	Rosetta launch	
2005	Asteroid fly-by	FCS modules for optical navigation are required
2009	Near-comet operations preparation	FCS modules for mission planning are required
2012/2013	Near-comet operations	
Mid-2013	Comet perihelion passage	Rosetta end-of-mission

Future applications

The main drivers for the approach adopted to a common check-out and mission control system for Rosetta are the nature of the mission itself and development constraints in terms of schedule and the re-use of existing systems. The same approach has already been selected for another major ESA science mission, First/Planck. As this mission is due to be launched a few years after Rosetta, it can build on the Rosetta approach and take advantage of the experience gained therein. The possibilities for re-using tools and modules already developed for Rosetta will also be examined. It is also expected that First/Planck will have more fully common CCS and FCS blocks, cost and schedule constraints permitting. It can also take maximum advantage of new technologies, thereby providing a further substantial step towards a European infrastructure for common checkout and control systems.

Other possible candidates for the utilisation of this approach, and eventually of the tools being developed, will be the scientific missions in the 'Smart' and 'Flexi' series. The short development schedules and tight budgetary constraints for these missions make them ideal candidates for the exploitation of the CCS/FCS commonality concept, particularly if it has already been proven by other major scientific missions.