ENVISAT MISSION CONTROL: AN EFFECTIVE EVOLUTION FROM ERS

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ABSTRACT: ENVISAT is ESA's next step in the programme of Earth Observation Satellite Missions, following in the footsteps of the successful ERS-1 and ERS-2 satellites. ENVISAT was conceived as a significantly larger satellite than ERS and in its 4.5 years of routine operations will produce in the order of 700 TBytes of raw data. The paper shows how the experience from the ERS Programme has led to the mission design and operations control approach as it appears today. Factors considered include the scope of the mission, the onboard / on-ground split of control functions, the mission control team preparation level of validation, etc. It is demonstrated that the tradeoffs between cost and risk which dictate the optimal approach to a satellite mission control indicate a good efficiency for ENVISAT taking account of its extensive mission objectives. The paper concludes that the environmental monitoring objectives will be effectively and efficiently served by the ENVISAT system and its supporting mission control philosophy.

1. CONTINUATION OF EARTH OBSERVATION FROM ERS TO ENVISAT.

Earth observation by remote sensing is today regarded as one of the most important short and medium term disciplines for the space community, as evidence of the damaging effect of mankind's pollution of the eco-system becomes insurmountable and more and more extensive, cross border agreements regarding agriculture, resource usage etc. are made which can only effectively be monitored by the watchful eye of remote sensing satellites.

ERS-1 launched in 1991 was conceived as a pre-operational Earth Observation satellite with a demonstration role for the capabilities and applications of remote sensing from space for scientific and civil applications purposes. From the outset, the satellite's ability to reliably acquire high quantities of quality data resulted in the users perception of the satellite as fully operational and data demands were made with the corresponding expectations on availability. Operated by ESOC, the reliability of the mission control facilities and expertise of the supporting personnel were significant in this achievement. With ERS-1 still going strong beyond its foreseen operational lifetime, the near identical ERS-2 was launched in 1995 to help guarantee continuing product availability with improved reliability, supported by duplicated control facilities and the same, but enhanced personnel contingent responsible for ERS-1 success. This has enabled dual satellite operations up to June 1996 prior to hibernation of the routine ERS-1 mission.

Envisat, due for launch in 1999 and also to be operated by ESOC, was conceived as a significantly larger satellite than ERS, enabling not only the continuation and enhancement of measurement objectives already made by ERS, but allowing the embarkation of additional instruments with new and scientifically important objectives.

Though much larger, the effective evolution of the ERS control philosophy, both in the onboard design and in the ground operations concept has led to the Envisat mission control design being remarkable in its expected efficiency ratio between cost and product data return.

2. THE EFFICIENCY OF ENVISAT MISSION CONTROL

Table 1 provides a comparison of the major parameters indicating the relative size and data returns of Envisat over ERS-2. With parameters being around 2 or 3 times the magnitude of those on ERS, the impact on the mission control complexity and cost may be expected to be significant.

	ERS-2	**Envisat**
Measurement data	120 GB / day	420 GB / day
Mass	2.5 tonnes	8.0 tonnes
Power	2.5 KW	5.5 KW
Dimensions [1]	5.4m x 2.6m x 1.3m	9.0m x 2.8m x 2.1m
No. Processors [2]	10	51
No. C+C Processors [3]	8	16
TM parameters	6600	13700
Telecommands	2700	5200

Notes:

[1] Structural dimensions not including array / antennas

[2] Only prime processors are considered (i.e. redundancy not counted)

[3] Only prime, controllable processors are considered. Does not include additional patchable processors for on board measurement data processing.

Table 1: Comparison of ERS and Envisat Satellite Specifications

In Table 2, the relative costs between ERS and Envisat of preparation of the mission control centre and routine operations are shown. For ease of comparison, all figures are normalised to the actual ERS -1 costs. ERS-2 is costed both as a stand-alone mission and in full parallel operations with ERS-1. To illustrate the relative performance of a mission collecting similar amounts of data to Envisat, a hypothetical four satellite ERS system is costed, assuming the delta costs from ERS-1 to ERS-2 would be necessary for subsequent satellites. Since the objective of all these satellite missions is the return of measurement data, two figures of merit are provided. One covers the instantaneous data return in proportion to the operations control costs. The second includes all costs associated with the preparation and operation of the missions over the total data return. As can be seen, from the Figures of Merit, the multiple operation of identical satellites yields improvements in efficiency, but it can be seen that the operation of the single Envisat satellite is in fact more efficient than even the hypothetical four satellite ERS

All figures normalised to ERS-1	ERS-1	ERS-2 [5]	ERS-1 + ERS-2	4 x ERS [6]	Envisat
Data Return / time: A	1.00	1.00	2.00	4.00	3.50
Mission Data Return: B [1]	1.00	1.00	2.00	4.00	3.32
Operations Preparation Cost: C [2]	1.00	0.24	1.24	1.71	0.75
Control Cost / time: D [2]	1.00	1.00	1.53	2.60	1.33
Control Cost Figure of Merit: E [3]	1.00	1.00	1.31	1.54	2.63
Operations Cost Figure of Merit: F [4]	1.00	2.32	1.53	2.07	3.76

Notes:

1 ERS mission lifetimes are taken to be 4.75 yrs (equal to the extended routine operations lifetime of ERS-1 prior to hibernation) and 4.5 yrs for Envisat (design lifetime, no extension).

2 No measurement data processing costs are included in ERS or Envisat figures

3 This figure is derived from the mean amount of measurement data obtained from the satellites over the operations control cost over any given time period: E = A / D.

4 This figure is derived from the mission lifetime data return over the total preparation and routine operations costs: F = B / (C + D*lifetime). Absolute figures used in calculation prior to normalisation.

5 Costs assume stand-alone operation of ERS-2 and do not include preparation costs associated with the additional GOME instrument.

6 Hypothetical four satellite ERS system, assuming the delta preparation cost from ERS-1 to ERS-2 (see note 5) is the same for subsequent satellites.

Table 2: Relative Costs of ERS and Envisat

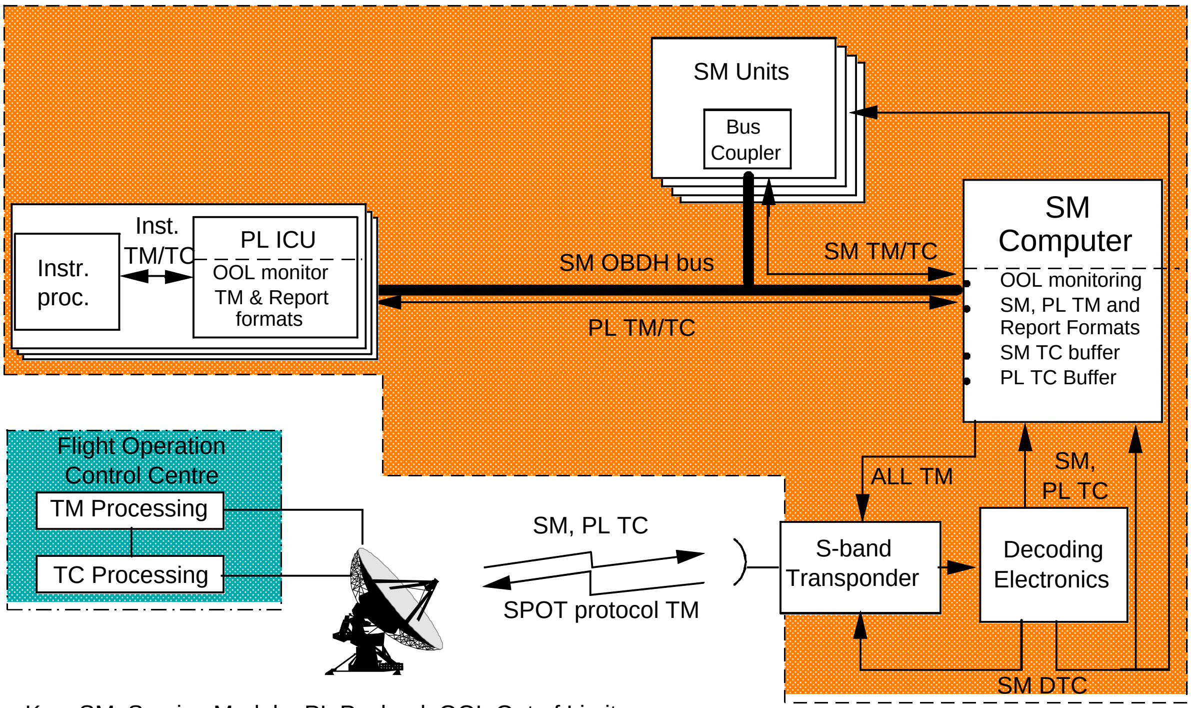
3. FACTORS CONTRIBUTING TO EFFICIENT MISSION CONTROL

An essential contributory factor to the reduction in relative operations costs from ERS-1 through to Envisat is that the satellites belong to the same family, based upon SPOT derived platforms and therefore share similar command and control philosophies and ground interfaces. This in turn allows the flight control ground system to be adapted rather than re-designed and the experience gained from the initial satellite operations to be effectively applied to the successor satellites. Clearly lessons can be learned from each satellite and applied to the successor missions in terms of functional improvements or in terms of the targeting of resources more effectively to reduce costs.

Both the onboard and ground control designs and concepts influence the reliability and costs of operations. In order to understand how a satellite the size of Envisat can be controlled in a similar manner to the much smaller ERS satellites, it is worth looking at the onboard control philosophy.

3.1 ON BOARD CONTROL PHILOSOPHIES OF ERS AND ENVISAT

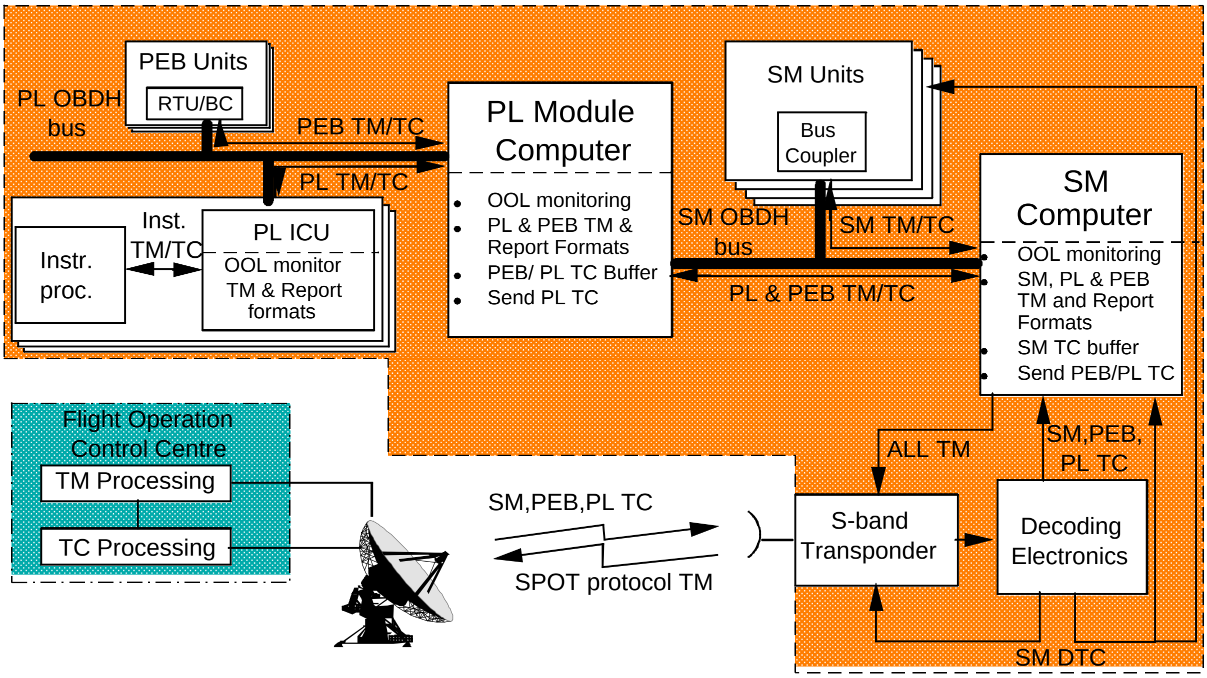
Figure 1 shows a schematic of the ERS on board command and control hierarchy. The SPOT derived Service Module (platform) computer executes commands destined for the platform subsystems but only transfers commands destined for the payload to dedicated Instrument Control Units (ICU's). This it may do either immediately or after storing the commands with time tags in a queue. The ICU will then execute the commands, in some cases passing lower level commands to an instrument secondary processor. The ICU's store histories of all executed commands and any detected anomalies, as well as other monitoring information which may be requested from the ground via the SM computer in a report format during any ground visibility. Similarly, the SM computer stores its own historical data for ground access. This allows the ground to quickly ascertain the success of scheduled operations which have occurred outside of ground visibility (90% of the orbit) and to gain quick access to information which pertains to an onboard anomaly. Also, the processors are capable of detecting anomalies in other processors lower in the onboard hierarchy and performing autonomous switch downs as appropriate.



Key: SM Service Module; PL Payload; OOL Out of Limits;
OBDH On Board Data Handling; DTC Direct Telecommand

Figure 1. ERS On Board Command and Control Elements

Figure 2 shows the equivalent schematic for Envisat. The SM computer now delegates its interface to the payload to an additional, dedicated processor due to the magnitude of data needed to be handled. The SM computer therefore performs platform housekeeping only and the Payload Module Computer (PMC) interfaces with the instruments and supporting payload units as well as holding a payload time-tagged queue which is eleven times larger than that used on ERS! The PMC interfaces with ICU's in the same manner as ERS, as well as controlling directly additional payload related subsystems. Despite the addition of the PMC, the larger number of instruments and the order of magnitude increase in the number of commands to be sent, the interface from ground to CCU is virtually the same as that for ERS. The on board processors still have the same commanding concept and provide the same level of reporting facilities and hierarchical anomaly protection as per ERS. The ground interface for housekeeping telemetry remains as a SPOT derived PCM protocol.



Key: SM Service Module; PEB Payload Equipment Bay; PL Payload; OOL Out of Limits;
OBDH On Board Data Handling; DTC Direct Telecommand; RTU Remote Terminal Unit

Figure 2. Envisat On Board Command and Control Elements

Due to the similarity of the on board command and control concept, the operations experience gained on ERS is largely applicable to the Envisat satellite and as been fed into the design, resulting in improvements in the level of reporting possible to aid in anomaly diagnosis and better on board localisation of anomalies prior to switch downs. Each of these improvements will aid the potential reliability of Envisat.

3.2 GROUND PREPARATIONS FOR FLIGHT OPERATIONS CONTROL

The key factors affecting the on ground control system design and the ground operations concept are the ground segment interface and the on board control philosophy respectively. As indicated above, Envisat is similar in both respects to the ERS missions. The major difference is one of scale. The various elements and activities involved within the preparations for flight operations control are discussed below to establish how the ERS experience has benefited Envisat and where efficiency and effectiveness are being improved, so as to lead to the relative cost figures presented in Table 2.

- The Flight Operations Control System

The flight operations control system is functionally an evolution from the ERS system. Performance is not expected to be problematic since the command uplink rate is identical to that of ERS (it is just necessary to uplink for longer), and the housekeeping telemetry downlink rate is just twice that of ERS. Such an increase is well within the capabilities of new generation ground processors. Since the on board control hierarchy manages the distribution of commands and monitoring from the additional number of instrument processors, the number of operators required on ground remains identical to ERS.

The satellite command and telemetry data base used by the control system is expected to be significantly larger than that used for ERS. Referring to Table 1, it can be seen that the increase in the number of telemetry and telecommand entries of Envisat over ERS is proportional to the increase in the number of control processors. This is because the control processors are based upon ERS derived designs, and hence the commanding requirements are similar, as is the amount of generated TM. Although command and telemetry data is similarly structured between ERS and Envisat, there is no commonality between actual data content and therefore the Envisat data base must be filled out from scratch. To achieve this manually in the normal timescales in the operations preparation environment would be barely feasible. This has been recognised at the outset of the Project and has resulted in the gradual compilation of all major data base entries through the industrial subsystem contractors integration testing activities. As illustrated in Figure 3, the data base for each subsystem is integrated into the next hierarchical layer until a complete Satellite Reference Data Base (SRDB) is held at the satellite integration site. The SRDB is first passed to the operations control centre early on in its life when it contains the data of a single subsystem only and is redelivered numerous times up to the launch growing in size and becoming more stable through the continued test activities. Therefore, despite the larger data base, the operations preparation costs associated with data base preparation will be lower than the equivalent ERS costs.

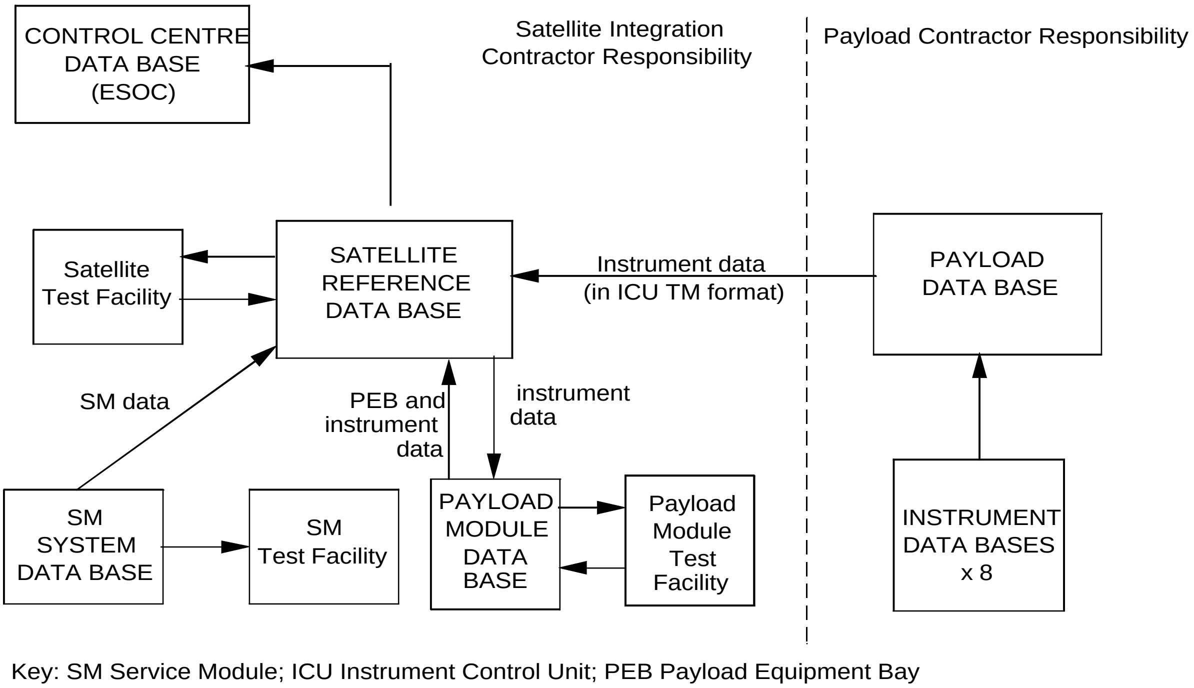


Figure 3. Transfer of the Industrial Data Base to the Operations Centre

The flight control team must still make important additions to the data base, the most significant of which are the command sequences compliant with the flight control procedures they generate. The number of procedures and command sequences to generate is clearly going to be significantly larger than for ERS. Attention has therefore been made to the provision of inputs available to formulate them. The prime input is the Flight Operations Manual (FOM) which is also known as the Spacecraft Users Manual on some missions.

- An Effective Flight Operations Manual

Supplied by the satellite industrial contractor to the operations centre, the FOM should be a structured compilation of all operational information which will or could be required in nominal and contingency flight operations. Unfortunately, this goal is rarely achieved and inputs are often late with respect to the flight operations preparation schedule needs. In the case of Envisat, given the diversity and scope of on board subsystems and the complex industrial contractor hierarchy, the potential for problems is enormous. Particular attention has therefore been made to avoiding this situation by establishing firm and detailed definitions of the contents structure, mechanisms for the provision of information and a realistic, but coherent schedule with which to achieve these goals.

It is therefore expected to be provided with procedural information in the FOM's which can be translated into the flight control procedures and command sequences in a more straightforward and efficient manner. There is still scope for significant improvement on future missions using transfer mechanisms for procedures from the industrial contractors' integration test facilities in a similar manner to the transfer of the SRDB described previously.

- Validation of the Mission Control Activities

In common with other ESA developed missions, the operations centre preparation activities on ERS were validated through a small number of tests with the satellite on line in its integration facility (the so called System Validation Tests, SVT's) and by connecting to an ESA developed satellite simulator for the remainder. This approach has proven to be successful and is therefore being followed for Envisat. However, this is not to say that lessons have not been learned from the ERS experience. Indeed, efficiency is being improved in a number of ways, including:

- the formulation of a clearer definition of exactly which features must be tested in the SVT's and which ones will be sufficiently tested at lower cost with the satellite simulator;

- assessment of which SVT tests can fulfil the needs of both the industrial AIT programme and the operations centre and thereby save time and money in the AIT schedule;

- analysis on which level of complexity the satellite simulator needs to go to in order to effectively validate the flight procedures, thereby enabling descoping of software requirements for the simulator;

- assessment of the level of required formulation and validation of contingency recovery procedures to strike the optimum balance between required validation effort (for testing and simulator modelling requirements) and the probable impact of the corresponding failure;

- tracking of the validation status of data base parameters and attributes in order to effectively aid personnel in directing the required tests accordingly.

- Effective On Board Software Maintenance

The ERS operations team has responsibility for performing the maintenance of on board software based upon images received from industry. As operations entered the routine phase it was found that the quality of the supplied industrial developed images did not meet the requirements to ensure nominal and secure operations of the satellite. Validation of the supplied images by operations personnel through inspection of code and use of the flight software emulator in the satellite simulator routinely identified problems in the delivered images with the potential to endanger the mission. The reason for this is clear: there is a tendency for a transfer of expertise to occur following the launch and commissioning of a satellite, from the industrial supplier (where development staff leave the mission for a new project) to the operations centre (where the operations personnel are working every day with intimate knowledge of the satellite subsystems and processes).

Recognising this, the majority of software maintenance facilities used for development of the on board images are to be transferred from their industrial sites to the Envisat operations centre at ESOC. Operations personnel will therefore be able to make authorised updates directly, saving the costs involved with large industrial maintenance contracts, but with relatively little extra manpower requirements at the operations centre. Due to the duplication of satellite expertise between the software developers and operations personnel, redundancy in the operations team is gained as a bonus.

4. CONCLUSION

In spite of the far larger scope of the Envisat mission over ERS, it has proven possible to plan the preparation and routine operations to be of similar cost in absolute terms. Taking into account the greater scale of the satellite and that well over three times as much science and application measurement data will be obtained for this cost, the effectiveness of the mission control concept and design is clear.

It can therefore be concluded that the environmental monitoring objectives requiring the acquisition of large quantities of diverse, high quality data at high reliability will be effectively and efficiently served by the ENVISAT system and its supporting mission control philosophy.