TEAMSAT’s Low-Cost EGSE and Mission Control Systems

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Introduction
Electrical Ground Support Equipment is used to check out spacecraft and payloads during their development prior to launch. A Mission Control System is used to monitor and control the spacecraft and its payload after launch. Traditionally the EGSE and MCS are separate systems, but in the case of TEAMSAT the baseline approach was to have a low-cost, portable EGSE/MCS system, suitable for both the TEAM and YES satellites. It would be used in Europe for satellite development and then moved to Kourou to support launch and mission operations. This philosophy was driven primarily by the lack of resources (people, budget and time), but also provided an opportunity to test the principle of commonality across the development and operational phases. This article describes what happened in practice.

For processing of the telemetry data, a software package offering packet telemetry parameter calibration, display, graphical representation and archiving was purchased from Micro Scitech. This left only one problem to solve: separation of the virtual telemetry channels, their archiving and their distribution to user PCs. For this no existing product was available and the decision was taken to develop this software in the EGSE laboratory at ESTEC. It was treated as an exercise in ‘object-oriented’ development using the software environment ‘Delphi’. The result was a set of basic software units which were used by students to build their experiment software in record time and with minimum training.
The overall EGSE integration and testing was done in the EGSE laboratory prior to its use with the spacecraft. The resulting architecture used both in spacecraft development at ESTEC and for launch-site operations in Kourou is shown in Figure 1.

As TEAMSAT comprised two satellites, TEAM and YES, it was in fact necessary to have two systems to perform testing if time was to be used efficiently. Unfortunately, it was not possible to acquire enough equipment to build two systems. At times when parallel testing was required, it proved possible to use the flight operations equipment (SCOS, NCTRS and NDIU described later in this article) as a second command and display facility. This proved invaluable in speeding up the testing process and certainly contributed to having the complete spacecraft integrated and delivered on time to Kourou. Using the flight operations equipment in this way was a good demonstration of the potential for commonality between the two domains.

Concerning cost, it was possible to build the test system for 20 kECU and one man-year of engineering effort. However, it must be remembered that without the generous offers of free use of equipment and the use of EGSE laboratory equipment this would not have been possible.

The Experiment Control Centre (ECC)
In the original baseline, the ECC was to be co-located with the Mission Control Centre in Kourou using the hardware and software of the EGSE. Once again, economic considerations dictated a change in policy which had significant technical impact. Due to the high cost of maintaining an operations team in Kourou comprised of experimenters, young graduates, ESA staff and contractor’s engineers, it was decided to re-locate the experiment operations activity to ESTEC. This eliminated the need for travel and subsistence expenditure.

Since all EGSE was located at the Guiana Space Centre (CSG), Kourou and was needed for the launch campaign, it became necessary to duplicate most of the EGSE, including the experiment EGSE. The software was not a problem, but twelve PCs were needed. This time the office automation programme came to the rescue with the loan of 12 new PCs which were installed and commissioned in only 2 days by ADM-IS staff. Reliable communications were also needed between ESTEC and ESOC for receipt of telemetry and transmission of telecommand packets. This facility was also designed, installed and tested by ESOC personnel in record time. The whole ECC was designed, built and tested in only 4 weeks, this being the time available from the taking of the decision until the planned launch date in late September.

The ECC consisted of two complete systems, one for TEAM and one for YES. Each had a virtual channel demultiplexer/archiver connected to ESOC via ISDN. Serial data links passed telemetry data to the PCs used for data processing for each experiment. Some PCs also had the capability to generate telecommand data packets, which were then forwarded to ESOC for transmission to the spacecraft. Each spacecraft also had a housekeeping display PC for monitoring of its health.
A complete mission simulation consisting of a graphical presentation of the Ariane-5 launch sequence followed by simulation of the TEAMSAT orbit was also provided in the ECC. This proved to be extremely useful during the mission operations, to visualise the spacecraft orientation and to plan operations which could only be carried out in specific parts of the orbit. The simulation was supplied free of charge by the company Silicon Worlds and ran on a workstation provided by the Simulation Section of ESTEC. The ECC is shown diagrammatically in Figure 2.

The Mission Control System (MCS)

Following the principle of commonality, the initial intention for the MCS was to re-use the EGSE, including the experiment test equipment which would be used for experiment monitoring and control. This decision proved to be overly simplistic when faced with the needs for interfacing to an existing ground-station network and providing additional services such as ranging, orbit determination and operational flight-procedure development. Closer examination revealed that deviation from the commonality principle in order to re-use the Agency's existing facilities managed by ESOC brought significant advantages – multiple ground stations, a proven infrastructure and most of all, support from teams with vast experience and fully familiar with configuring, operating and using them. This led to the decision to use the ESA ground-station network and the SCOS-II Mission Control System together with a core team from ESOC to support the mission operations. The work to prepare for operations is covered later in this article.

MCS requirements

In terms of overall flight control, TEAMSAT required:
- access to two ground stations to provide adequate orbital coverage
- spacecraft control facilities
- flight dynamics support, in particular to provide accurate orbit prediction for both spacecraft, essential to plan the signal acquisition by the ground stations; this support was particularly important as the two spacecraft were not provided with an on-board attitude and orbit control capability
- mission planning support, to schedule experiment operations, with emphasis on power conservation
- transmission of the experiment telemetry data to the ECC
- a mission control system providing the usual capabilities needed by operations staff:
  - spacecraft database setup
  - telemetry receiver/packetiser
  - raw data distribution, archiving and retrieval
  - telemetry processing, including at least parameter extraction, parameter validity checks and parameter engineering value calculations
can be added according to the size and demands of the mission being supported. For instance, a mission control system can be provided on a single workstation, the so-called ‘SCOS-in-a-box’ configuration. By contrast, the operationally demanding Meteosat-7 launch and early orbit operations (LEOP) used a configuration of 26 workstations. The approach for TEAM/YES was that of ‘SCOS-in-a-box’, with essentially one Sun workstation (namely a Sun/SPARC 10) dedicated to each spacecraft.

In addition, there was a late requirement to display images from one of the YES on-board cameras.

**Operations ground facilities approach**

The following ground facilities were provided:
- ground stations: ESA ground stations at Kourou (French Guiana) and Perth (Australia) were used together with the ESA ground station communications network (OPSNET)
- spacecraft control facilities
- flight dynamics support: based on ESOC facilities and expertise
- mission planning: no specific facilities were developed, but a mission-planning specialist (from the ERS-2 project) performed the task using commercial off-the-shelf (COTS) tools (spreadsheet and word processor).

**Selection of the operations control system**

The time available was very short. When it was decided to investigate an alternative to re-use of the EGSE for operations, there was no choice but to base the system on existing facilities. In addition, it was known that the hardware would have to be installed successively at three sites: initially at ESOC, then at ESTEC, and finally at Kourou. Thus, equipment compactness and portability were essential features. ESOC’s older infrastructure, SCOS-I, was considered unsuitable since it was cumbersome to modify and configure and in addition would have required a considerable amount of expensive, and not particularly portable, hardware.

In February 1997, ESOC’s newest configurable control system, SCOS-II, was in use for one mission – the SOHO monitoring and data retrieval system, installed at NASA Goddard Space Flight Centre (GSFC). It was also being prepared for two other missions, Meteosat-7 (launch and early orbit phase) and Huygens. SCOS-II subsequently supported both of these missions very successfully, in September and October 1997 respectively.

The SCOS-II hardware architecture comprises a network of Sun workstations, running the Solaris 2.5 operating system. A key feature of SCOS-II is that it is scaleable, i.e. workstations can be added according to the size and demands of the mission being supported. For instance, a mission control system can be provided on a single workstation, the so-called ‘SCOS-in-a-box’ configuration. By contrast, the operationally demanding Meteosat-7 launch and early orbit operations (LEOP) used a configuration of 26 workstations. The approach for TEAM/YES was that of ‘SCOS-in-a-box’, with essentially one Sun workstation (namely a Sun/SPARC 10) dedicated to each spacecraft.

Another recent development in ESOC’s control centre approach is the use of a standard ‘front-end’ to the ground-station network. This ‘front-end’, called the NCTRS (Network Control and Telemetry Routing System), takes care of the ground station network protocol (OSI, X.25) and the specific interfaces to the various types of equipment in the ground stations. The control system uses the widely supported TCP/IP protocol for its various interfaces, including those to the NCTRS for telemetry, telecommand and tracking data. The NCTRS also runs on a Sun Solaris workstation, one of which was used for each spacecraft. A simplified block diagram of the overall control and data-processing system for a single spacecraft is shown in Figure 3.

**Project-specific additions to SCOS-II**

As SCOS-II provided most of the required functions, it was necessary to make only small additions to the system. These were in the areas of:
- TM virtual channels and packetisation handling
- TC packet protocol handling
- real-time experiment image displays.

SCOS-II assumes it receives telemetry data in the form of SCOS-II packets, whereas the data received from the ground station was in the form of transfer frames containing virtual channels. These in turn contain source packets. A TM receiver/packetiser was therefore developed (based on an available example) to select virtual channels and convert the transfer frames into SCOS-II packets (essentially the source packets, with a special header added).

A problem for the MCS was that there was no ground-station equipment available that supported the TC packet protocol. The equipment did in fact exist, but at the time it had not been deployed at the stations, nor was the necessary NCTRS interfacing supported. The approach adopted was to write special software to convert the TC packets generated by SCOS-II data units of the TC packet protocol. The older generation (Mark II) of
telecommand equipment was then used in ‘transparent mode’ to up-link the command data.

A display of the data acquired by one of the YES on-board cameras was developed using the SCOS-II data processing and ‘mimics’ display capabilities. In SCOS-II, ‘mimics’ displays are normally used to present block diagrams of spacecraft subsystems. A mechanism was therefore devised to use them to display camera data, with decompression and display of the JPEG data triggered on receipt of the data packets. Subsequent images coming from the same camera refreshed the image on the mimic display in real time. This new approach could in fact become a standard facility in control systems in cases when on-board cameras are used for spacecraft health monitoring.

**MCS development**

Key events of the MCS development are shown in Table 1, highlighting the short lead times for the successive deliveries of the control system. For example, a usable basic version of the control system was available only six weeks after the start of the implementation.

Preparation was completed on 25 September, five days before the expected launch date. At this point, a significant launch delay was announced. To avoid the substantial costs of keeping the operations team in Kourou, it was decided to relocate the MCS at ESOC. This posed the risk that the system could not be re-integrated in time. Added to this was the need to reconfigure and revalidate the communications system which was, in the event, done within a remarkably short time of only eight days, taking advantage of the expertise and infrastructure available at ESOC. This resulted in the final operational configuration shown in Figure 4. By the end of the first week of October 1997, the sequence of testing, simulations and dress rehearsal could be repeated with the new set-up. The whole ground system and operations team was then fully prepared for the launch on 30 October and the subsequent five-day mission.

**Cost Aspects**

Both EGSE and MCS were developed at low cost. In the case of the MCS, just one-and-a-half man-years, including software support to operations, was expended. The equipment was drawn from a pool of existing workstations in ESOC.

Why was the low cost so low? The reasons include the following:

- The necessary control system infrastructure (SCOS-II and NCTRS) was available to satisfy the larger part of the requirements (some 95%). Furthermore, since little new development was required, little documentation was necessary. A key point was that the SCOS-II/NCTRS technology allowed rapid customisation, largely without programming effort.
- The use of a small, highly-motivated team with skills in the SCOS-II and NCTRS packages, working against a very demanding schedule.

### Table 1

<table>
<thead>
<tr>
<th>Event</th>
<th>Date (in 1997)</th>
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<tbody>
<tr>
<td>Analysis of requirements</td>
<td>End February</td>
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<tr>
<td>Kick-off of implementation work</td>
<td>Mid March</td>
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<tr>
<td>First version of basic control system</td>
<td>End April</td>
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<tr>
<td>Initial installation in Kourou (4 workstations)</td>
<td>Mid July</td>
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<tr>
<td>Completion of final installation in Kourou</td>
<td>Mid September</td>
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<tr>
<td>Announcement of launch delay</td>
<td>25 September</td>
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<td>Reintegration of Control Centre at ESOC, in Darmstadt, completed</td>
<td>10 October</td>
</tr>
<tr>
<td>Launch</td>
<td>30 October</td>
</tr>
<tr>
<td>End of mission</td>
<td>4 November</td>
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The availability of COTS hardware and software products was an essential contributor to the project's success. The indications are that significant cost reductions in the provision of ground control systems should be feasible by taking advantage of COTS products and reusable facilities like SCOS-II. This is expected to bring more choice and competitiveness to the supply of ground systems for space projects.

In the case of the EGSE, the explanation is similar. Use of existing products, some at no cost, contributed significantly to the low cost. Using experienced staff to guide students and young engineers had both cost-saving and educational benefits. It should also be remembered that testing was limited in duration, due to the lack of available time, and was manual in nature. As a consequence, no test software had to be developed. Testing relied upon written procedures and manual checks from data displayed on PC screens.

**Conclusions**

TEAMSAT was a practical and successful example of low-cost ground systems implementation and operation. The analysis shows that the low costs depended chiefly on the availability of facilities (hardware and software) which could do the job and the necessary human resources with the right expertise, organised in small, highly motivated teams. It is also important to note that without these resources, it would not have been possible to provide ground systems in the short time available.