Making European Industry More Competitive

The Example of ESOC's Operational Software

Michael Jones & Nestor Peccia
Ground Segment Engineering Department, ESA
Directorate of Operations and Infrastructure,
ESOC, Darmstadt, Germany

For Europe to remain competitive, the capabilities of its industry in ground operations software must continue to grow. Building on the expertise of ESOC, the ultimate goal is a suite of 'plug and play' software that users could call on by selecting the various components from European suppliers.

Introduction

ESA's mission is to shape the development of Europe's space capability and to ensure that investment in the space sector continues to deliver benefits to Europe's citizens. In practical terms, this means that ESA has to ensure that Europe's space industry develops and maintains these capabilities. They must cover a wide range, spanning the space segment, launchers and ground segments. Another challenge is to supply space systems at competitive prices. Ambitious space programmes with limited budgets make this essential everywhere. Another significant aspect is the globalisation of the space business and the growth and improvements of technical standards that enable global inter-operation. To be a player in the world space market, European industry must offer competitive solutions. This article describes an initiative to develop and strengthen industry capabilities in operations software for the ground segment. This involves promoting reusable software products originally developed for ESA purposes. The effort began around 5 years ago with the SCOS-2000 mission control kernel. This initial effort was very successful and is now being extended to the much wider palette of products forming the ESOC Ground Operations Software (EGOS). The article also draws together the various threads that make such an endeavour possible; these include standardisation and

Working in the ESOC backup Mission Control Room

ground segment technology harmonisation. The ultimate aim is to encourage the emergence of a European suite of ground operations software, from which users meet their needs in a 'plug and play' manner by selecting components from European suppliers.

Ground Segment Operations Software

For many years, ESOC has been developing high-quality software for its core business of spacecraft operations. This includes software for:

– mission control: command and control of the spacecraft;
– simulators: providing support for testing the system and training the operations personnel;
– flight dynamics: controlling the attitude and orbit of the spacecraft;
– mission analysis: designing the mission for manoeuvres and flybys to achieve mission aims.

Much of this software is used and rigorously tested for the demanding tasks of preparing and supporting spacecraft operations. Because of ESOC's need to apply it to many missions, much of it was designed for reuse, as one of the most effective ways to increase productivity. Risk reduction is another important advantage, since reused software has already been validated operationally.

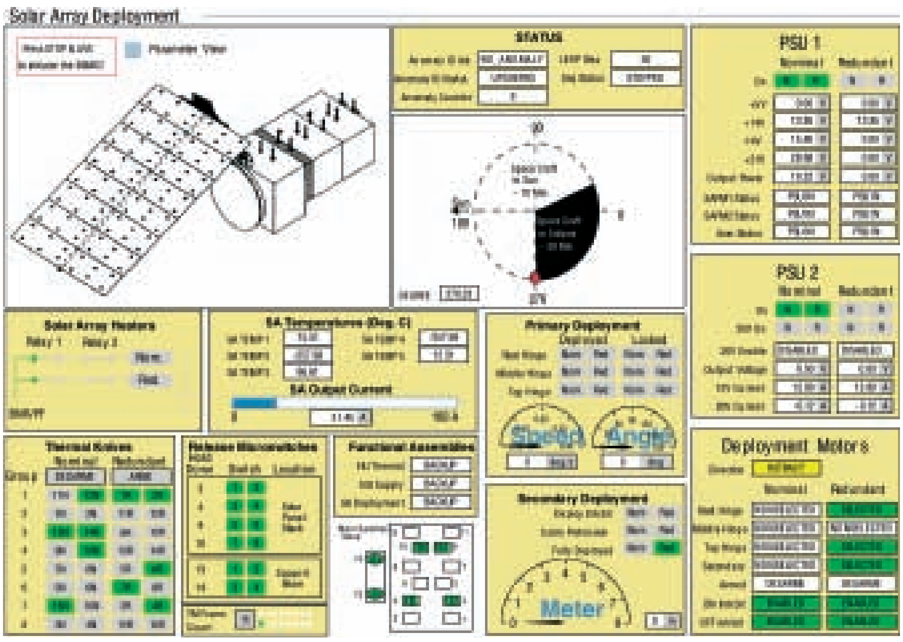
The idea then arises: why not encourage other spacecraft operators to use this software and take benefit of the investments already made? Linked to this is the consideration that suppliers of such software are also looking for business with other spacecraft operators, so this would open up new markets. Indeed, this could apply not only to ESOC's suppliers, but also to any European company able to exploit the software. It follows that such reuse could help to make European industry more competitive.

In fact, ESA has been doing this for many years via the licensing of a wide range of software developed for ESA purposes, although it was left to the initiative of the licensees to exploit the software, commercially or otherwise. Furthermore, in the last 5 years or so, ESOC has been promoting certain software as supported 'products'. The seed for this was ESOC's SCOS-2000 mission control kernel, but the idea has now been broadened. As described later, it will eventually include the full range of ground systems software.

Reusable Software

Reusable software has to be designed and developed for reuse from the outset. There is a rule of thumb that if more than about 20% of a software module has to be rewritten when reusing it, then it is more effective to design and rewrite the whole module from scratch. The challenge of developing reusable software is to stay well below this threshold. This can be achieved via various techniques, such as;

– allowing configurability via the setting of parameters or a via database;
– allowing extension of functionality using software engineering techniques



Mimic Display from the MetOp Mission Control System, based on SCOS-2000. ESOC will support the Launch and Early Orbit Phase of Eumetsat's MetOp weather satellites

A session in ESOC's Simulation Studio

such as inheritance in object-oriented methods. This allows the reused software to remain unchanged, the additional functions being provided via the use of 'derived classes'.

Standardisation
Another enabling factor for reusable ground systems software is standardisation. Space agencies and industry have invested in engineering standardisation as a means of decreasing project risks and reducing development and operations costs. Risks are reduced because standardisation offers proven and consolidated processes, methods and interfaces. Cost is reduced because standardisation permits reuse of processes, solutions and components.

For space engineering, there are two main bodies concerned with standardisation: the Consultative Committee for Space Data Systems (CCSDS), and the European Cooperation for Space Standardisation (ECSS)

The CCSDS is an international standardisation body primarily addressing communications and data-handling techniques for interoperability between different space agencies, and standardisation of space-related information technologies. Today, membership of CCSDS includes ten space agencies and several other participating organisations in the form of observers, associates and liaisons.

The ECSS was established in 1993 to develop a coherent, single set of standards for use in all design and development of space systems in Europe. It involves ESA and the national space agencies, and, importantly, it includes European industry under the umbrella of Eurospace. Eurospace is a non-profit organisation that fosters the development of space activities in Europe and promotes a better understanding of space industry-related issues. This means that, in ECSS, both the institutions and industry are stakeholders in the standards.

CCSDS and ECSS have between them produced a large body of engineering standards that are now in regular use, particularly in ESA. A number of these standards have allowed the development of standard components (or infrastructure) for ground systems software. Examples are:

- from the CCSDS, the Space Link Extension (SLE) services, which provide standard interfaces to ground stations, permitting one agency to use the ground station of another;
- from the ECSS, standards of particular relevance are ECSS-E-70A, which is the top-level standard defining the process lifecycle of developing and using operations systems, and the Telemetry & Telecommand Packet Utilisation Standard, ECSS-E-70-41, which identifies a set of services for using telecommand packets and telemetry source packets in the remote monitoring and control of payloads space systems.

These examples merely scratch the surface but the point is that software developed to support such standards is naturally reusable.

Early Days: MSSS and SCOS
At ESOC, it has been the practice for some 30 years to use a generic mission control system as the basis for the control system of each mission. This was first done in the mid-1970s with the Multi-Satellite Support System (MSSS). The basic concepts of this system were that:

- it could be configured to support several missions at the same time;
- it was table-driven. The data structures of the commands and telemetry data of the each spacecraft were defined in tables, so customisation to a new spacecraft could be done largely by updating tables.

These were novel concepts for the time. MSSS was highly successful and remained in use for well over 20 years. It was also used as the basis for some systems developed commercially for other spacecraft, in particular the Inmarsat Mission Control System (MCS).

The next MCS generation was the Spacecraft Operations Control System (SCOS). The first generation SCOS-I was developed in the mid-1980s and had a centralised architecture based on VAX minicomputers. Like MSSS, it was implemented mainly in FORTRAN. SCOS-I systems continue to support several major ESA missions: Envisat, ERS-2 and Cluster.

Growing Maturity: SCOS-2000
The successor to SCOS-I was SCOS-II, later renamed SCOS-2000. Early versions

were used for the control system of the Huygens Titan probe, the control system for the launch and early orbit phase of Meteosat-7, and a low-cost control system for the Teamsat young engineers' satellite. The launches of all of these were successfully supported in 1997. In the case of Huygens, the system remained in use until its successful landing on Titan in January 2005.

Despite the similar name, SCOS-2000 was completely new. It used client server technology in a distributed system of Sun Solaris workstations. Designed using object-oriented methods, it was written in C++, and developed with the following strategic aims:

– ease of configuration and/or customisation, therefore lowering associated costs;
– functional richness, reducing the need for mission-dedicated functions and lowering mission-specific costs;
– scalability, allowing the system to be adapted to missions of any size or for any phase of a mission;
– vendor independence, which reduces or avoids the need for periodic migration exercises as hardware platforms or Commercial Off The Shelf (COTS) software becomes obsolete.

All four aims have been achieved. Vendor independence was fully achieved in 2002 with the introduction of a SCOS-2000 version that could run on either Sun Solaris or Linux platforms.

Promoting SCOS-2000

As a consequence of using SCOS-2000, costs of ESOC control systems have come down by a factor of 2–3, and more in some cases. This reinforced the thoughts about the possible wider use in the space sector. SCOS-2000 had some clear advantages for this.

Firstly, it was classed by ESA as 'operational software', which meant that ESA owned the Intellectual Property Rights. According to the ESA Convention, this gives the ESA Member States and bodies under their jurisdiction the right to have a licence to it free of charge.

Secondly, continuity of support is guaranteed since SCOS-2000 is used by ESA on all missions supported by ESOC. In particular, the ESA Investment Plan funds basic maintenance and keeping of the product in step with evolution of the underlying technology and platforms. ESA is using SCOS-2000 on major programmes such as Rosetta (launched in 2004, due to arrive at its target comet in 2014), Mars Express, Venus Express and the Galileo constellation of navigation satellites. Thus the product necessarily has a long time horizon. The promotion of SCOS-2000 began in 2000 by:

– ensuring that experience with SCOS-2000 and its technology was well spread among ESOC's frame contractors. The contractors carry out all the development of mission control system infrastructure and of mission control systems at ESOC;
– encouraging these contractors to use SCOS-2000 in their bids to other customers within and beyond ESA;
– holding regular workshops to share experience on the use of SCOS-2000 between its users;
– providing training courses.

As a result of these and other measures, SCOS-2000 is now in use by many operators. The table shows that the overwhelming choice for the operating system is Linux, which resoundingly confirms the correctness of the decision to make Linux one of the SCOS-2000 operating systems. The list includes several examples of using the system for spacecraft checkout. There is also an example of reuse in a different but related field to that for which it was originally developed. This came as an initiative from the ESA Directorate of Science, which chose SCOS-2000 as a platform for the Central Control System supporting assembly, integration and test activities on the Herschel/Planck platform and its payloads.

Organisation	System/Project	Industrial supplier	Operating System
Eutelsat	NEO	GMV (E)	Linux
CSA	Radarsat	Terma (D)	Linux
ASI	Agile	Telespazio	Linux
DLR	CHAMP TerraSAR-X Central Check-Out System TerraSAR-X Mission Operations System	Siemens Austria	Linux
SES Astra 1 M	MCS	GMV	Linux
ESA	Herschel/Planck Central Checkout System	Terma	Linux
ESA	Vega launcher EGSE	Vitrociset	Linux
ASI	Cosmo-SkyMed	Dataspazio	Solaris

Projects using SCOS-2000 outside of ESOC

In the Eutelsat case, 'NEO' controls a fleet of satellites from European, US and Russian manufacturers. NEO replaced a 'park' of different control systems with a single solution based on the SCOS-2000 platform. The NEO project also resulted in a joint venture called 'hifly©' between two European companies, SciSys (UK) and GMV (E). According to the companies, hifly© product is an MCS solution for commercial satellite operations that is *"powered by SCOS-2000"*.

In the case of DLR's German Space Operations Centre at Oberpfaffenhofen, near Munich, SCOS-2000 was selected as a cost-effective solution to replace an ageing Compaq/VAX architecture.

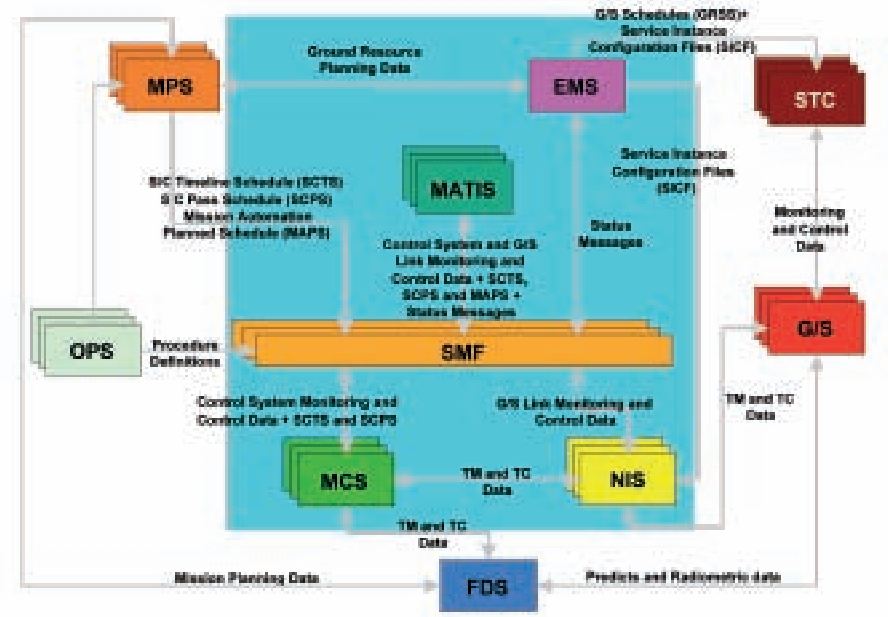
Expanding the Scope

It is clear that SCOS-2000 has become a 'best-selling' software product, with some 70 licenses granted over the last 6 years. In fact, it is now a world-leading MCS product.

By 2002, it became obvious that there were other candidate products, such as:

– ESOC's generic simulator infrastructure SIMSAT (Software Infrastructure for Modelling Satellites), which also has a pedigree stretching back over 20 years;
– the SLE Application Programmer Interface package, which provides a standard means of communicating with the ground station backend over the TCP/IP communications protocol, and also provides cross-support capability with other agencies.

It was also becoming clear that synergies could be achieved between the various products. For example, SIMSAT was



The envisaged future architecture of ESOC ground segments, including operations automation. EMS: ESTRACK Management System. FDS: Flight Dynamics System. G/S: ground station. MATIS: Mission Automation System. MCS: Mission Control System. MPS: Mission Planning System. NIS: Network Interface System. OPS: Operations Preparations System. STC: Station Computer. TC: telecommand. TM: telemetry

originally developed to run on MS Windows, which apart from limiting synergy with the UNIX/ Linux systems of SCOS-2000, also implied the support of a further information and communications technology infrastructure at ESOC.

Organisational Considerations

Differences in organisational responsibility led to the divergences mentioned above, including the use of different platforms, different COTS software, and different software solutions for common problems such as logging and error handling. The various responsible units had independently developed parts of the infrastructure without considering potential commonalities in technology, design and implementation.

In 2002, the management of ESOC's Ground Systems Engineering Department decided to add two new divisions:

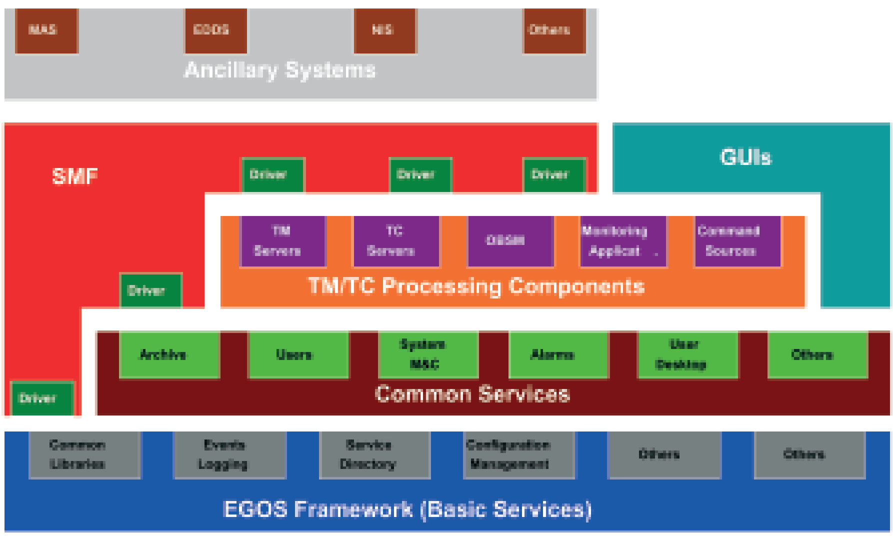
- the Data Systems Infrastructure Division, responsible for the implementation and maintenance of the generic mission data system infrastructure, including mission control systems, simulators and ground station backend software;
- the Mission Data Systems Division, responsible for implementation and maintenance of mission control systems and simulators for missions. This division is also the counterpart to the 'customer', which for an ESA mission is represented by the flight control team and its management.

This reorganisation had two main effects. First, it put mission control, simulator and ground station infrastructure software under the control of a single unit. This unit, the Data Systems Infrastructure Division, has the mandate to ensure consistency and synergy between infrastructure products. Secondly, it allows that unit to focus on reuse, be it of infrastructure or of software developed specifically for particular families of missions.

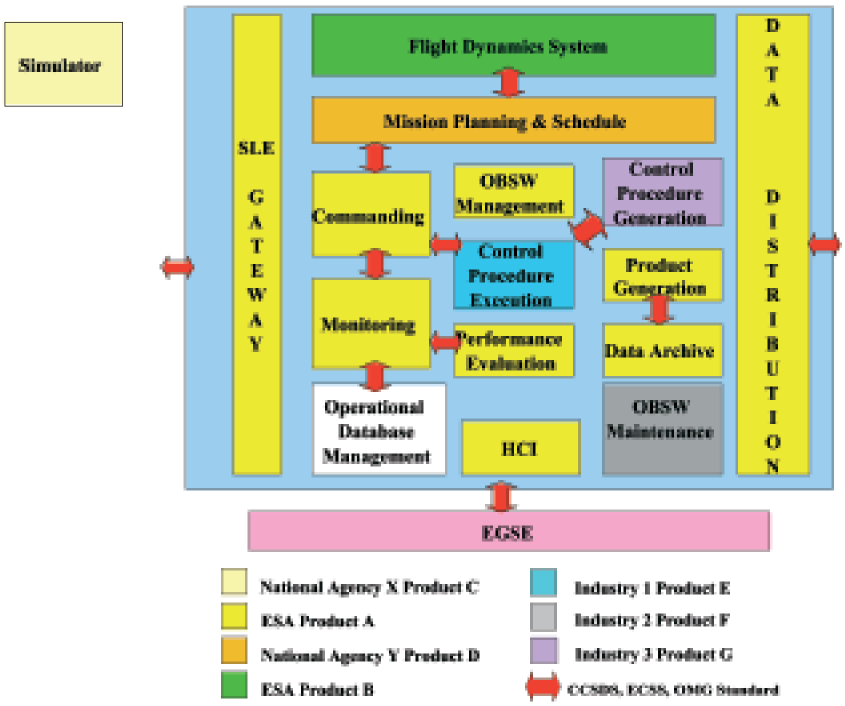
ESA/ESOC Ground Operations Software

In the 3 years since the new organisation was set up, the process of expanding the scope and coherence of the infrastructure has proceeded rapidly. Notable achievements have been:

- porting of the simulator infrastructure to Linux/PC platforms;
- the development of a new generation of telemetry and telecommand encoders, integrated in one package, TMTCS, and supporting the SLE services;
- extension of SCOS-2000 to support multiple spacecraft. This is essential for constellation missions such as Galileo and for future formation-flying missions.



EGOS components, with layering into low-, middle- and high-level components. EDSS: EGOS Data Distribution System. GUI: Graphical User Interface. MAS: Mission Automation System. NIS: Network Interface System. OBSM: On-Board Software Management (System). SMF: Services Management Framework.



How a system can be built up in alternative ways as 'plug and play'. EGSE: electrical ground support equipment. HCI: Human-Computer Interface. OBSW: On-Board SoftWare. OMG: Object Management Group. SLE: Space Link Extension

This also enables server consolidation – reducing the number of servers;

– reengineering of EGOS components, involving the identification and layering of common functions and services, with the aim of reducing the amount of 'middleware' and low-level software, and avoiding duplication.

Work has started on a Mission Automation System (MATIS) and the ESTRACK Management System (EMS; ESTRACK is the ESA ground station network).

Evolution not Revolution

The general philosophy followed for EGOS is 'evolution not revolution'. This emphasises reuse or, more broadly, reengineering of existing software. New products and product lines are developed to respond to new services or needs. However, even in this case, available products are taken as the basis for new product lines wherever feasible. Bearing in mind that reusable software is in effect a repository of knowledge, we try to avoid redevelopment from scratch, since this risks losing this embedded knowledge and may even create new problems if the redevelopment is based on wrong assumptions or requirements.

Technology Harmonisation

The process of devising an improved strategy for the evolution of European space technology began in 2000 in response to a resolution at the ESA Ministerial Council of May 1999 entitled *Shaping the Future of Europe in Space*. This resolution included the statement *"… the new and demanding challenges of the 21st Century call for a concerted European effort, so that Europe achieves its fullest potential for international cooperation and world competition"*. This resulted in a Technology Harmonisation initiative. Broadly speaking, its approach was to:

– identify the technology needs for European space programmes. These were set out in the *European Space Technology Requirements Document* also referred to as Dossier 0. This covers some 22 technology areas, one of which is ground systems software;

– make a consolidated plan of all relevant technology-development activities in Europe, including an overview of all planned institutional space technology programmes, with related strategic plans ('roadmaps'). This is the *European Space Technology Master Plan*.

The idea, therefore, is to ensure that the R&D contributions of the partners are complementary, avoiding wasteful overlaps or the spreading of resources too thinly. In the ground systems software area, the problem of lack of strategic control had been evident for many years: many suppliers were producing incompatible solutions, even though they addressed the same problem.

In the particular case of ground systems software, the harmonisation approach was done in three phases:

1. define, in agreement with the users, a common system standard architecture with common requirements for the identified blocks ('modules') in the architecture;
2. define standard interfaces between the models;
3. produce the needed solutions responding to the common requirements and using the standard interfaces, reusing or reengineering as far as possible existing products. This, of course, is in line with the 'evolution not revolution' philosophy.

The outputs of Phases 1 and 2 are intended to be inputs to the ECSS standardisation process.

The Steering Board of European Technology Harmonisation on Ground Systems Software was set up to oversee this plan. Contracts were let under ESA's Technology Research Programme to carry out the work. The Steering Board has representatives from ESA and national agencies (ASI, CNES, DLR, BNSC, CDTI, ASA) and the European software industry (Critical, Dataspazio, GMV, LogicaCMG, Terma, SciSys, Siemens, VCS, Vega).

Phase 1 has been completed, with a reviewed set of documents comprising the High-Level Requirements and the architecture. Phase 2 is under way to define (as proposed standards) by the end of 2006 the following four major interfaces:

- monitoring and control to flight dynamics;
- flight dynamics to mission planning;
- mission planning to monitoring and control;
- simulator to electrical ground support equipment (EGSE).

The vision is that technology harmonisation of ground systems software will enable EGOS to become a European Ground Operations System.

Conclusions

The benefits that reusable software can bring to an organisation like ESA have been shown. A consequence is that other spacecraft operators can use this software and European industry can use it to gain a competitive edge, as demonstrated by the number of successful projects based on ESA/ESOC products, in particular SCOS-2000. Success has depended on a strong strategic vision, exploiting the advantages that standardisation brings, and having an appropriate organisation to develop the products and apply them. The success has also depended on strong cooperation with industry, in particular from ESOC's in-house suppliers, who have been active in selling solutions based upon ESOC operations software products. The European Technology Harmonisation on Ground Systems Software is expected to expand this initiative further, both by resulting in further standardisation of services, architecture and interfaces and by bringing in the institutional and industry players at the European level.