PLENARY SPEECHES

COMMONALITY OF FLIGHT CONTROL SYSTEMS FOR SUPPORT OF EUROPEAN TELECOMMUNICATIONS MISSIONS

KURT DEBATIN

Head, Mission Operations Department

European Space Agency, European Space Operations Centre

This paper is concerned with the presentation of mission-independent software systems that provide a common software platform to ground data systems for mission operations. The objectives of such common software platforms are to reduce the cost of the development of mission-dedicated software systems and to increase the level of reliability of the ground data systems for mission operations.

In accordance with this objective, the Multi-Satellite Support System (MSSS) was developed at the European Space Operations Centre (ESOC). Between 1975 and 1992, the MSSS provided support to 16 European Space Agency (ESA) missions, among them very demanding science missions such as GEOS, EXOSAT, and Giotto. The successful support of these missions proved the validity of the MSSS concept with its extended mission-independent platform. This paper describes the MSSS concept and focuses on the wide use of MSSS as a flight control system for geosynchronous telecommunications satellites.

Reference is made to more than 15 telecommunications missions that are operated from Western Europe using flight control systems with an underlying MSSS concept, demonstrating the benefits of a commonly used software platform.

Finally, the paper outlines the design of the new generation of flight control systems, which is being developed at ESOC for this decade, following a period of more than 15 years of MSSS support.

BACKGROUND

At present, some 30 telecommunications satellites are being operated in Western Europe. These satellites provide TV and radio broadcasting services, telephone and data traffic, and other special services. The satellites are all positioned in a geosynchronous orbit. The different satellites, their missions, and the organisations providing the services are listed in Table 1. The list cannot claim completeness and does not include missions that provide military services.

At the functional and technical levels, the ground segment of a telecommunication mission can be divided between the ground infrastructure, which supports the services to the user community, and the ground control system, which supports the operation and control of the orbiting spacecraft.

The ground control system basically comprises the flight control system and the telemetry, tracking, and command (TT&C) ground station. The TT&C station links the flight control system with the orbiting spacecraft. It supports telemetry acquisition, command uplink, and range measurements (see Figure 1).

For reasons of mission safety, the ground control system may be provided with backup facilities, e.g., by means of a second TT&C station and a redundant flight control system. The function of flight control systems is to provide computerised support for the navigation of the spacecraft and for monitoring and control of the spacecraft systems. Spacecraft navigation includes orbit maintenance and repositioning of the spacecraft in the geosynchronous ring.

The 30 telecommunication satellites are supported by some 14 flight control systems. Most of these systems support several missions in parallel. In such cases, one flight control system may be linked with several TT&C stations at geographically strategic positions.

Given the large commonality of flight control system requirements of the different telecommunications missions, it would seem most cost effective to base the development of the various flight control systems on a common software and hardware

Table 1. West European Telecommunications Satellites.

| Satellite	Position	Mission	Service Provider	Operator, Location
MARECS-A	22.5° E	FSS	ESA/Inmarsat	ESA, Darmstadt (D)
MARECS-B2	15.0° W	FSS	ESA/Inmarsat	ESA, Darmstadt (D)
Inmarsat II-F1	64.0° E	FSS	Inmarsat	Inmarsat, London (UK)
Inmarsat II-F2	344.0° E	FSS	Inmarsat	Inmarsat, London (UK)
Inmarsat II-F3	178.0° E	FSS	Inmarsat	Inmarsat, London (UK)
Inmarsat II-F4	306.0° E	FSS	Inmarsat	Inmarsat, London (UK)
ECS-1	25.5° E	FSS	Eutelsat	ESA, Redu (B)
ECS-2	2.0° E	FSS	Eutelsat	ESA, Redu (B)
ECS-4	25.3° E	FSS	Eutelsat	ESA, Redu (B)
ECS-5	21.5° E	FSS	Eutelsat	ESA, Redu (B)
Eutelsat II-F1	13.0° E	FSS	Eutelsat	Eutelsat, Paris (F)
Eutelsat II-F2	10.0° E	FSS	Eutelsat	Eutelsat, Paris (F)
Eutelsat II-F3	16.0° E	FSS	Eutelsat	Eutelsat, Paris (F)
Eutelsat II-F4	7.0° E	FSS	Eutelsat	Eutelsat, Paris (F)
Olympus	19.0° W	DBS/FSS	ESA	ESA, Fucino (I)
Italsat	13.0° E	FSS	ASI	Telespazio, Fucino (I)
DFS Kopernikus I	23.5° E	FSS	German Telecom	German Telecom, Usingen (G)
DFS Kopernikus II	28.5° E	FSS	German Telecom	German Telecom, Usingen (G)
TV-SAT 2	19.2° W	DBS	German Telecom	German Telecom, Usingen (G)
Astra 1A	19.2° E	DBS	SES	SES, Betzdorf (L)
Astra 1B	19.2° E	DBS	SES	SES, Betzdorf (L)
Marco Polo 1	31.0° W	DBS	BSB	BSB, Southampton (UK)
Marco Polo 2	31.0° W	DBS	BSB	BSB, Southampton (UK)
Tele-X	5.0° E	DBS	Filmnet/SSC	SSC, Kiruna (S)
Telecom 2A	8.0° W	FSS	French Telecom	CNES, Toulouse (F)
Telecom 2B	5.0° W	FSS	French Telecom	CNES, Toulouse (F)
Telecom 1C	5.0° W	FSS	French Telecom	CNES, Toulouse (F)
TDF 1	19.0° W	DBS	TDF	CNES, Toulouse (F)
TDF 2	19.0° W	DBS	TDF	CNES, Toulouse (F)
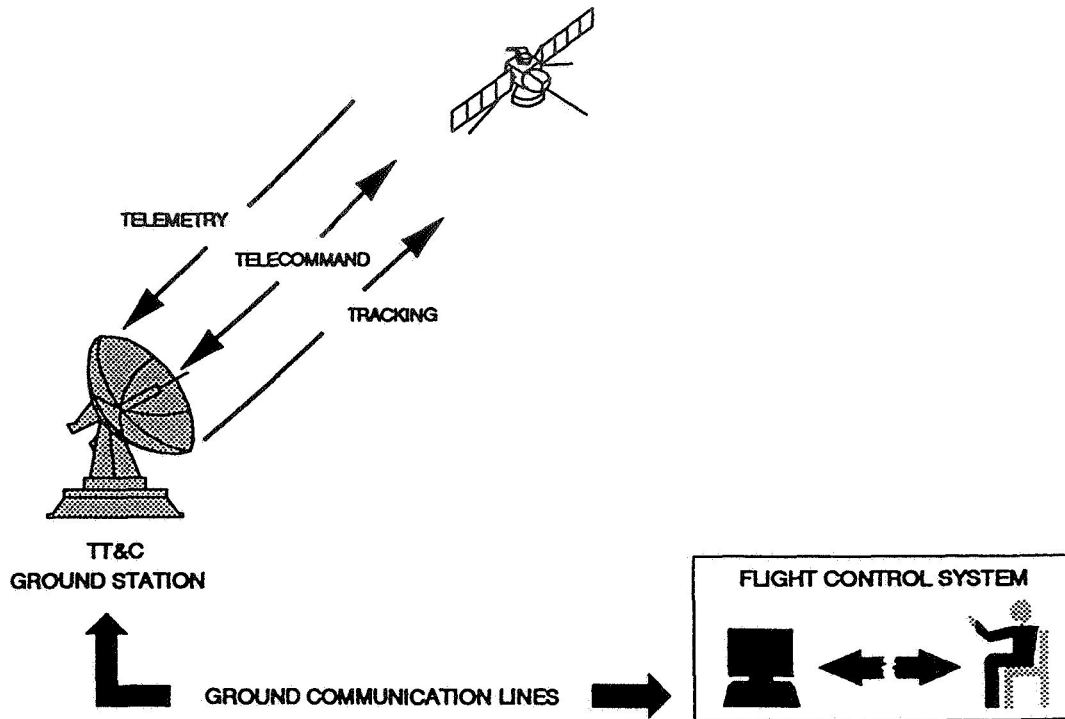
Figure 1. Ground Control System.

platform, bearing in mind that stand-alone software development of a flight control system may well exceed the equivalent effort of 50 man-years.

In reality, however, other factors very often dictate the development of a flight control system: procurement and industrial politics, in-house strategies, contractual constraints, and last, but not least, the "re-invent the wheel" syndrome.

This paper reports on a very fruitful cooperation between the European Space Agency (ESA), telecommunications space agencies, and the European software industry, materialising in a commonly used flight control system concept based on ESA's Multi-Satellite Support System (MSSS).

MSSS DESIGN

MSSS was conceived with two prime objectives in mind:

• Provide a flight control system with the capability of supporting several satellite missions simultaneously, the number of supported missions being limited by the capacity of the underlying computer hardware platform only.

• Supply the flight control system with a high degree of mission-independent functionality, so as to minimise the need for additional, mission-specific implementations.

The overall system structure that has evolved in response to these objectives is shown in Figure 2. It consists of the following major components:

• Spacecraft database

• Functional subsystems

• MSSS configuration control database

• Support subsystems

• Archive

The functional subsystems and the support subsystems comprise generic, i.e., largely mission-independent, processing tasks. The tasks of the functional subsystems include references to the tables in the spacecraft database that describe the spacecraft and mission-specific parameters. The tasks also have access to the tables of the MSSS configuration control database that define the mission-specific processing environment upon initialisation of a task. This means that the tasks of the functional subsystems can be regarded as engines which are driven by the tables of the databases.

This table-driven approach ensures a high degree of flexibility. Additional support of a new satellite mission does not necessitate cumbersome
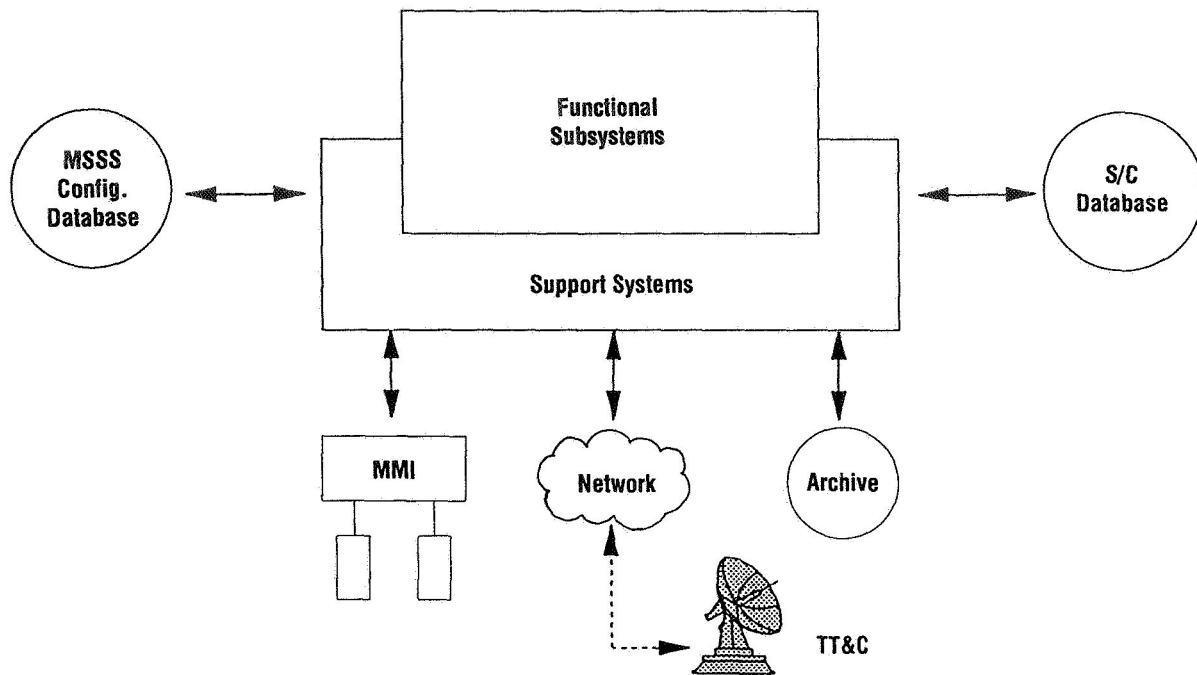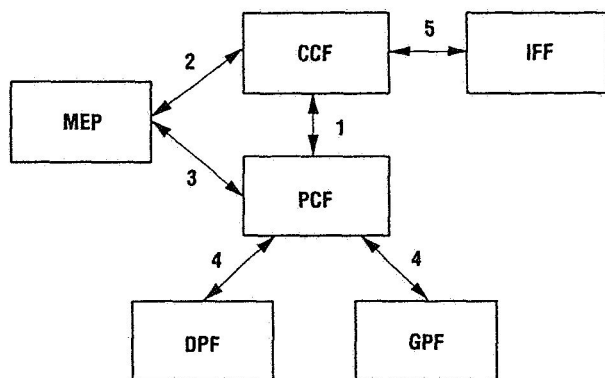
Figure 2. Functional Diagram of MSSS.

Figure 3. Files of the Spacecraft Database.

and risky software changes at the functional subsystem level but only requires the incorporation of the new mission-specific parameter tables in the databases. The different components of the MSSS are described below in more detail.

THE SPACECRAFT DATABASE

For each spacecraft to be supported, the spacecraft database contains a set of files that define the characteristics of the formats, available commands, and structure of telemetry in terms of subframes and frames (see Figure 3). The files of the spacecraft database can be directly edited by the user.

The parameter characteristic file (PCF) holds the parameter details associated with the telemetry data stream from a satellite. The file identifies each parameter and provides parameter-specific information such as calibration curve factors, number of occurrences per frame and subframe, status and limit checks, and the related mode equation number.

The mode equation file (MEF) defines all mode equations applicable to a satellite mission. The operands of the mode equations refer to parameters in the PCF.

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The command characteristic file (CCF) holds an entry for each spacecraft command and related information. The information describes the characteristics of the command, e.g., it specifies command validation and verification with reference to the applicable mode equation and to the telemetry parameters as defined in the MEF and PCF, respectively.

The individual function file (IFF) complements the CCF with more detailed information on specific command functions, e.g., in conjunction with memory load commands.

The display files DPF and GPF hold details of the alphanumeric and the graphics display pro formae covering also the included PCF parameters.

FUNCTIONAL SUBSYSTEMS

For each satellite mission, the functional subsystems perform the following major tasks:

- Telemetry processing, which covers the acquisition of the telemetry, processing (mode equations, derived parameters), validation (out of limits), and filing.

- Telecommanding, which includes the transmission of telecommands and their validation and verification; and the manual, scheduled, and automatic generation of commands or sequences of commands.

- Information display, which covers all types of displays of real-time data and retrieved data in accordance with the pro formae as described in the display files of the spacecraft database.

- Archiving of telemetry and command history data.

- Acquisition of ranging data and transmission of antenna steering information to ground stations.

- Remote station monitoring and control.

CONFIGURATION CONTROL DATABASE

The MSSS configuration control database contains a set of tables that define the processing environment for the tasks of the functional subsystems. For example, the environment may define the routing and the layout of a spacecraft data stream by format and size of subframes and frames, and by the included parameter identities. At initialisation, the tasks read the relevant tables.

In addition to this relatively static definition of task-oriented data processing environments, the database also includes a file that dynamically registers parameter processing and data routing options and associated changes so that they can take effect in near real time, i.e., during the execution of a task.

SUPPORT SUBSYSTEMS

The support subsystems comprise tasks that provide common services to the functional subsystems. These services include buffer management, record filing and access routines to databases, management of dynamic configuration tables in memory, error detection and recording, event scheduling, etc.

In a wider sense, the subsystems also provide middleware functions such as console drivers, display form filling, and direct access methods.

ARCHIVE

The archive holds the telemetry and command history files.

USE OF MSSS AS A FLIGHT CONTROL SYSTEM

The validity of the MSSS concept with its parameter table structure is in particular demonstrated by its wide use as a flight control system in support of telecommunications missions (see Figure 4). Here it has set a de facto European standard.

The first telecommunications mission supported by MSSS was OTS, ESA's first telecommunication test satellite. MSSS was then also used for operational support of two maritime missions, MARECS-A and MARECS-B2. The two missions are still operated on behalf of Inmarsat from ESA's European Space Operations Centre (ESOC) in Darmstadt, Germany.

Another series of telecommunications missions, ECS-1, ECS-2, ECS-4, and ECS-5, are also being supported by MSSS. The four missions are operated for Eutelsat from ESA's Control Centre at Redu, Belgium.

Initially, the MSSS hardware platform was based on two back-end computers from CII and front-end processors from Siemens. Between 1981 and 1986, the platform was gradually changed. The CII computers were replaced by more powerful computers of type Encore, and then the Siemens processors were removed and new Intel-based workstations were added. These changes have
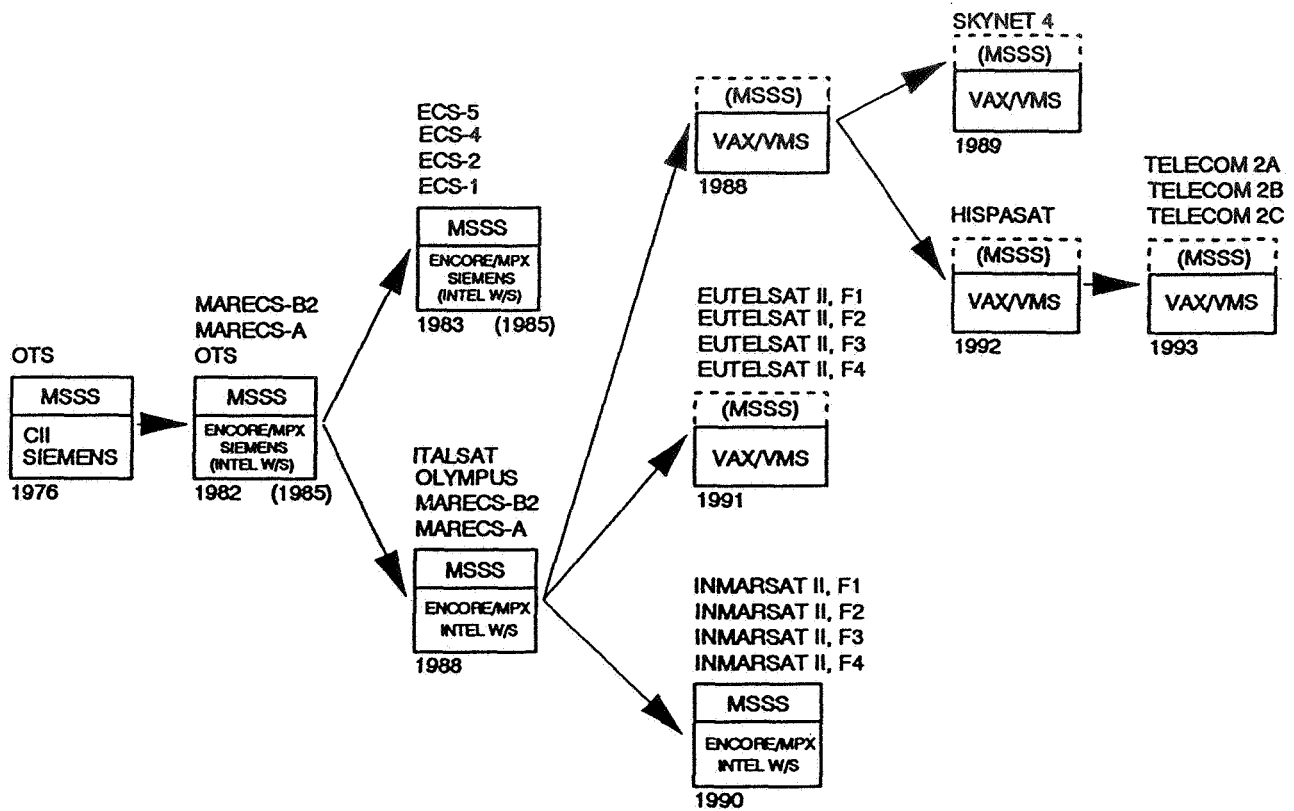
Figure 4. MSSS History.

resulted in a substantial increase of the MSSS performance, providing sufficient capacity to cope with the parallel support of at least six satellite missions of the ECS class.

The next telecommunications mission supported by MSSS was Olympus-F1, ESA's second telecommunications test satellite. To support this highly complex satellite weighing 1.4 tons, the functionality of MSSS had to be upgraded. The upgrades encompassed considerable extensions to the command and telemetry table structure in order to accommodate additional block commands and an extended set of telemetry parameter references. The system also had to be provided with a facility for onboard software maintenance and configuration control. Furthermore, the onboard generation of parameters in dwell mode called for the implementation of special telemetry data processing and display modules.

The Olympus upgrades required a software development effort equivalent to some 20 man-years, which, even though representing a significant expense, was considerably less than the cost of development from scratch. On the other hand, these investments broadened the functionality and the maturity of MSSS to such an extent that it was able to meet the requirements of other, more advanced telecommunications missions. As a consequence, only minor adaptations had to be made to MSSS for the support of the Italian space agency's Italsat. This satellite, which provides a capacity of approximately 12,000 telephone circuits, was operated during LEOP and during several months following LEOP from ESOC before control was transferred to the Italian Control Centre in Fucino.

In 1989, Inmarsat decided to use MSSS as the flight control system for their new series of satellite missions: Inmarsat II-F1, II-F2, II-F3, and II-F4. The installation and commissioning of MSSS at the London Inmarsat Control Centre was constrained by a rather tight time schedule. It included as major activities the procurement and installation of the computer hardware, the implementation of the MSSS software, and the parametric configuration

of the table structure in accordance with the specific mission requirements. In addition, a number of modifications and enhancements to the system had to be implemented. They were mainly concerned with specific spacecraft requirements, e.g., onboard, time-tagged command control and command confirmation; support of telecommand blocks; and dwell telemetry parameter displays. Also, station monitoring and control facilities were implemented with the same functionality as was provided for spacecraft monitoring and control. After one year, all tasks, including the enhancements, were completed and MSSS was ready for operation. The system is currently supporting the four Inmarsat missions and four TT&C stations.

European software companies have also adopted the MSSS concept for the further development of flight control systems. In this way, their significant involvement in the development of MSSS at ESOC has come to fruition.

Science Systems Ltd., which received an MSSS software licence from ESA, transformed MSSS to a new platform on VAX/VMS computers from DEC. The new system, known as the Kernel TT&C System, was used as the basis of a flight control system which Science Systems Ltd. developed for the British Ministry of Defence for the support of Skynet 4 and NATO IV. It was implemented as a distributed system on VAX machines and was provided with extensive redundancy and flexible reconfiguration capabilities at the basic system level to ensure the required high degree of system availability. The workstations were provided with advanced display facilities based on X-Windows and GKS graphics software. This system in support of Skynet has been in operation since 1990 and provides services to the military.

Another implementation of the Kernel system was specifically tailored to the needs of the Eurostar platform. This involved, in particular, considerable enhancements to the telecommand subsystem. This new version provides the basis of the flight control system that supports the Hispasat mission from the Arganda Control Centre near Madrid, Spain. It will also constitute the core of the flight control system which will be used for the support of the French Telecom 2A, 2B, and 2C missions.

In parallel to this, the British firm Logica, based on an MSSS licence from ESA and in response to an order from Eutelsat, has also per-

formed an MSSS-based implementation on a hardware platform from DEC consisting of a VAX range of computers and VAX workstations. The MSSS table structure was implemented on a relational database from Ingres. The major changes in the implementation by Logica are concerned with the provision of sophisticated display facilities on the workstations and with the processing and display of the spacecraft data stream at the level of frames rather than subframes. An only slightly modified version of this implementation will be used as a flight control system for the support of Turksat.

In conclusion, up to 20 telecommunications missions have been supported by flight control systems with an MSSS-based architecture. It has to be recognised, however, that the diverse systems show considerable variations. Incremental system changes of a more or less substantial nature have been introduced since 1976, when MSSS was used for the first time. This is not surprising, when one considers the different technical, contractual, and political frame conditions under which these systems have been implemented during a period of more than 15 years.

Different operations concepts have evolved, which have in particular brought about considerable extensions of the display facilities on the workstations. Major system changes arose from different spacecraft designs and mission requirements in combination with the changeover of the computer platform from Encore/MPS to VAX/VMS. Notwithstanding these differences, the various systems can be traced back to a common architecture, and this has reduced cost and technical risks far below the level that normally has to be assumed for new and independent developments.

Associated with MSSS, the Portable ESOC Package for Synchronous Orbit Control (PEPSOC) was developed at ESOC. It is used for orbital control of geosynchronous satellite missions, i.e., it determines the orbital position of the spacecraft by means of range measurements and specifies the orbit manoeuvres (velocity increment vectors) for repositioning the spacecraft.

PEPSOC is a software package that runs on a workstation or on a PC and can be easily interfaced with any flight control system. PEPSOC is

recognised as a standard tool by the European space community, not only in connection with MSSS-based systems, as proven by more than 17 PEPSOC licences that have been granted to industry and space agencies.

FUTURE OUTLOOK

The future evolution of flight control systems will be determined by the increasing complexity of spacecraft systems and by the introduction of innovative informatics technologies.

ESOC has given due consideration to this foreseeable evolution and has started with the development of the architecture for a new generation of flight control systems. Following the MSSS success story, the new generation, named Spacecraft Operations System (SCOS), is intended to cover the agency's requirements over the next decade for the support of different classes of missions, including telecommunications missions and highly complex science missions.

In essence, the new architecture features the following elements:

- Packetised telemetry and telecommanding according to the defined CCSDS standards.
- Object-oriented approach.
- UNIX-based platform.

The handling of telemetry and command packets in combination with the object-oriented processing approach will provide the user with more efficient and comprehensive access to the functionality of the individual subsystems and units of the orbiting spacecraft. The database will hold operational procedures and associated data that can be addressed as concise entities. In many respects, the changeover from MSSS to SCOS can be compared with the parallel technological move from a relational database to an object-oriented database approach.

Similar to MSSS, SCOS will provide a large, mission-independent system platform. This will be accomplished by taking advantage of the inheritance feature of object-oriented modules and by a possible later introduction of packet utilisation standards, which will define the data files in the TM/TC packets.

The choice of UNIX as the operating system is obvious because of its worldwide recognition as an international standard. Although UNIX is not conceived as a real-time operating system, there now exist UNIX versions that offer real-time capabilities. The UNIX platform will be structured around a network of UNIX-supported workstations. The integration of the workstations into a LAN-based structure with distributed client and server functions provides an environment that can be easily configured to the needs of different classes of missions and in the short term to different mission scenarios.

The workstations provide the capacity for the support of the required processing and database functions, and advanced human–machine interfaces based on the UNIX operating system. UNIX will ensure portability of SCOS between different hardware platforms and thus removes a traditional problem associated with MSSS.