

HIGHLIGHTS OF THE EUROPEAN GROUND SYSTEM – COMMON CORE INITIATIVE

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Abstract

The European Ground Systems – Common Core (EGS-CC) is a European initiative to develop a common infrastructure to support space systems monitoring and control in pre- and post-launch phases for all mission types. In addition to the modernisation of legacy systems, this is expected to bring significant benefits in the whole process of developing, deploying and using monitoring and control systems, such as the seamless transition from spacecraft Assembly, Integration and Testing (AIT) to mission operations, cost and risk reductions, promotion of cross-fertilisation across organizations. The initiative is being performed as a collaboration between ESA, European National Agencies and European Industry. In this paper we describe the main highlights of the initiative along with the current status and future planning of the EGS-CC programme.

INTRODUCTION

Background

Within Europe there are many different systems for monitoring and control currently used by companies/agencies for space system operations, Assembly Integration and Testing (AIT) and other pre-launch phases. The vast majority of these systems have been designed specifically for operations or AIT, although some of them have been used in both scenarios. Another common problem is that multiple heterogeneous systems are used by the different companies involved in the different phases, from subsystem level integration up to launch and subsequent mission operations. The compatibility/exchange of information is jeopardised by the lack of a common infrastructure which leads to little synergy across missions and project phases. Last but not least, many of these existing systems are going to face soon significant obsolescence problems. The systems are often using old software technologies that are difficult to modernise. The maintenance and evolution costs are therefore expected to become excessive with time.

Given the difficulties mentioned above, during 2009-2010, the European Space Agency (ESA) discussed with the main European Large System Integrators, including Astrium Satellites, Astrium Space Transportation (both have now become Airbus Defence and Space), Thales Alenia Space (France and Italy) and OHB System, the possibility of a collaboration to develop the so-called European Ground Systems Common Core (EGS-CC), which will be described in detail in the following sections. Several national space agencies, (in particular the German one, DLR) also indicated their desire to join the

initiative and a Collaboration Agreement was finalised in support of the EGS-CC initiative.

Objectives

The objective of the European Ground Systems – Common Core (EGS-CC) is to develop a common infrastructure to support space systems Monitoring and Control (M&C) in pre- and post-launch phases for all types of missions and target applications. This initiative is expected to bring significant benefits, including:

- Reduce development, sustaining and maintenance costs by sharing a single infrastructure across multiple organisations;
- Increase synergy across all pre- and post-launch mission phases, starting from the functional verification at subsystem level throughout spacecraft Assembly, Integration and Testing (AIT), launch and mission operations;
- Facilitate cost and risk reductions when implementing space projects through the provision of a stable common infrastructure which can be easily tailored for the needs of a specific mission and/or target application;
- Enable the modernization of legacy implementations of Electrical Ground Support Equipment (EGSE) and Mission Control Systems (MCS);
- Promote the cross-fertilisation and enable the exchange of ancillary implementations across organizations and across missions.

In order to meet these ambitious objectives, it is expected that the EGS-CC product provides features which go beyond the capabilities of the current implementations, namely:

- Support of all mission phases: the needs of pre- and post-launch utilisation scenarios as well as the transition between them are to be taken into account, without necessarily increasing the system complexity. Clearly the objectives of, and the approach adopted for space systems monitoring and control activities are largely different between pre- and post-launch phases;
- Support of all mission types: this feature is particularly relevant to post-launch scenarios as different types of missions (e.g. short visibility passes, continuous coverage, deep space, constellations) may imply significant variations in the functions to be supported by the monitoring and control system on ground in order to execute mission operations;

- Support of heterogeneous controlled systems: not only spacecraft and not only systems interacting with their control counterpart by means Telemetry and Telecommand (TM/TC) data. The system is expected to enable the development of target applications supporting also other categories of controlled systems, such as the ground equipment involved in the execution of pre-launch validation activities (e.g. Special Check-Out Equipment, SCOE) or post-launch mission operations (e.g. other control centre applications or ground stations);
- Open, component based, service oriented architecture: in order to enable the parallel development as well as the effective maintenance and re-use of a generic infrastructure it is essential to decompose it in a modular and hierarchical manner which reflects a proper separation of concerns of the various elements;
- Generic and extensible functionality: genericity applies to all functions whose implementation can be shared by all target applications, extensibility is instead the mechanism enabling the integration of application specific features without source code level modifications of the infrastructure implementation;
- Clear separation between the infrastructure and the application specific implementations: the EGS-CC shall offer a rich variety of interfaces and services which can be used without any knowledge and need of modification of the underlying implementation (binary compatibility);
- Strict control of dependencies: the modularity of the system and the capability to plug-in/plug-out different implementations would not be feasible in the absence of strict rules to control the cross-dependencies;
- Clear separation between generic M&C functions and specific features of the controlled system: all differences related to the specific characteristics of a given controlled system as well as to the way to communicate with it are to be encapsulated in an adaptation layer and should not impact the implementation of generic monitoring and control capabilities;
- Operations abstraction: current implementations heavily rely on the definition and execution of operations at a very low level (e.g. individual telecommands, individual telemetry parameters). Introducing a proper level of abstraction may simplify the interaction with other systems (e.g. test manager, mission planning, flight dynamics) and enable an efficient re-use of the same artefacts in heterogeneous environments (e.g. from sub-system to system level);
- Native support of automation: one of the objectives of the EGS-CC is to enable tangible cost reductions in the execution of pre-launch AIT and post-launch mission operations activities. Automation at all levels (from the artefacts deployment up to execution of planned operations) is considered essential in order to achieve this objective;
- High performance: the various utilisation scenarios to be served often introduce orthogonal performance drivers (e.g. processing, data storage and distribution rates, data volumes, number of parallel users). It is also important not to introduce dependencies on expensive hardware resources which may not be compatible with minimalistic target applications;
- Standardised interfaces: external interfaces support the capability to interact with external systems not belonging to the EGS-CC based target applications. Considering the large variety of environments that the EGS-CC is expected to be deployed into, it is essential that the relevant international standards are adopted in order to ensure interoperability as far as possible;
- Longevity and long term maintainability: space programs are characterised by a very long lifetime. The EGS-CC is an infrastructure which is expected to be adopted by future space programs from the early phases of the space segment development until the end of the in-orbit operations. This imposes the need of enabling the long term maintenance of EGS-CC based systems at a relatively low cost;
- Technology use: in order to enable its efficient development within a reasonable timeframe, it is anticipated that the EGS-CC implementation will heavily rely on re-use of off-the-shelf third party technologies. However, the impact onto the long term maintainability of the system shall be minimised. Software technologies are subject to continuous evolution and have a lifetime which is typically shorter than the one required by an infrastructure such as the EGS-CC. It is therefore essential that the implementation of the EGS-CC business logic is isolated as far as possible from the re-used technologies and products;
- Scalability: it must be possible to deploy EGS-CC as part of very small target applications, e.g. an instrument development system running on a single computer, or as part of very large systems, such as a constellation MCS running on multiple platforms and supporting a significant number of parallel users.

The target features listed above have to be (and have been) taken into account across the complete lifecycle, from the early conceptual definition until the final system validation of the EGS-CC. This is of fundamental importance considering that many of the desired features are in conflict with each other and thus it would be very difficult to support them if the relevant implications were not considered in their entirety from the very beginning.

MAIN SYSTEM CONCEPTS

In this section we briefly introduce some of the main concepts driving the specification and design of the EGS-CC product.

System Decomposition

The EGS-CC has been hierarchically decomposed in layers, subsystems and components, segregating the different responsibilities by means of clearly defined interfaces between them. The following Figure 1 shows the high-level decomposition of the EGS-CC.

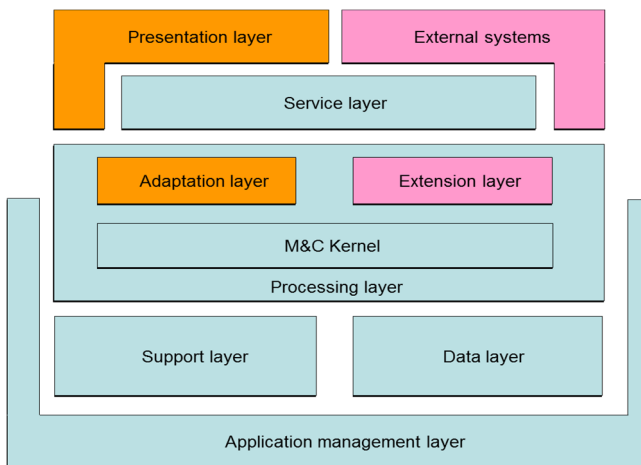


Figure 1. EGS-CC High-level Decomposition.

The EGS-CC mainly consists of two distinct parts, namely:

- Kernel (shown in blue in Figure 1 above) containing a general purpose support layer as well as generic monitoring and control functions. It is intended to be implemented such that it can be reused without modifications across all EGS-CC based systems for all applications, missions and purposes. The kernel can be extended with mission specific functions (shown in pink) through well-defined extension points;
- Reference implementations (shown in orange), representing the layer which adapts the EGS-CC kernel to a given application and mission. It includes components implementing standardised interfaces, the adaptation to the controlled system, the user interfaces and ancillary functions such as preparation and evaluation. The EGS-CC will provide specific reference implementations assuming a selected category of missions and applications (e.g. a spacecraft based on the Packet Utilisation Standard (PUS, [1]), a ground station providing Space Link Extension (SLE, [2]) services). The components belonging to the Reference implementations layer may be replaced or adapted for the specific needs of a mission or organisation.

In addition, a Reference Test Facility (RTF) will be provided, supporting the simulations of external functionality as well as system test activities management functions. The test facility is only needed during the validation phases of the EGS-CC based systems but plays an important role in the whole process of delivering and deploying EGS-CC based target applications. It includes functions supporting the definition, execution and evaluation

of software test sessions as well as the capability to simulate at various degrees of fidelity the main external systems interacting with the EGS-CC, including the controlled system itself.

The lowest architectural layers of the Kernel provide cross-cutting features used across all EGS-CC functions and include:

- Applications management, providing the framework in which the EGS-CC components are developed and executed. It represents the lowest level of the application, in which the support and processing components are integrated;
- Support libraries and services, providing general purpose functions (e.g. logging) to ease the development of processing or application components in a harmonised way;
- Data handling, responsible for the storage, distribution and management of data definitions as well as of processing input and output data.

The processing layer contains the business logic of the system. It contains the following important sub-layers, according to their functionality:

- M&C kernel layer, providing generic implementation of the common monitoring and control functionality for the different applications (e.g. controlled system modelling, state evaluation, control activities management);
- Adaptation layer, containing the components which implement application and mission specific functionality, to adapt the EGS-CC to different target applications and controlled systems. The adaptation layer includes specific interfaces with external systems, such as SLE transfer of TM/TC data for spacecraft missions, or applicable protocols to interact with ground support equipment such as SCOE;
- Extension layer, containing components with additional functionality specific for different applications or missions, which extends the functionality provided by the EGS-CC generic and adaptation layers.

The service layer encapsulates the system interfaces into well-defined services. It enables the provision of services to external consumers, giving access to system functions and data without any specific dependency on the implementation details. The presentation layer contains user interface components, which may interact with the processing layer directly, or through the service layer.

Data Modelling

The EGS-CC is a data centric system. A lot of emphasis has been put in the modelling of the data related to the complete lifecycle of monitoring and control activities supported by the EGS-CC. The relevant data have been modelled at conceptual level and designed at logical level. This has been considered as an essential step to enable the efficient hand-over of data (and in that engineering

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knowledge) throughout the project phases and to ease the collaboration between the different parties involved in the space system engineering, development, integration, testing, operation and evaluation of a space system. The EGS-CC data model identifies uniquely all data items in use along the process such that the relevant interfaces can be specified, in particular the ones enabling the exchange of data definitions. The actual technology for the data exchange (e.g. XML) is not imposed by the data model, which is therefore robust against future technology changes.

Monitoring and Control Model

The Monitoring and Control Model (MCM) provides the functional core of the EGS-CC kernel. It includes the capability to model the complete space system under control from a monitoring and control perspective. It encapsulates the main monitoring and control functions (e.g. parameter processor, activities handler, events processor) and provides access to all data of monitoring and control relevance, thus acting as an abstraction layer for M&C operations. It is based on the principles of the M&C view of the Space System Model (SSM) defined within the ECSS E-ST-70-31C Ground Systems and Operations – Monitoring and Control Data Definition [3] standard. Information related to the space system is organised in a structured way which reflects the functional decomposition of the space system, including the controlled system as well as the all other related systems, including the control system itself. The MCM covers both the Space Segment (e.g. a satellite) and Ground Segment (i.e. the overall infrastructure required during Development, Assembly, Integration and Testing and for Operations) for the AIT or operational contexts. The decomposition of a typical space system as depicted in the MCM is illustrated in the Figure 2 below.

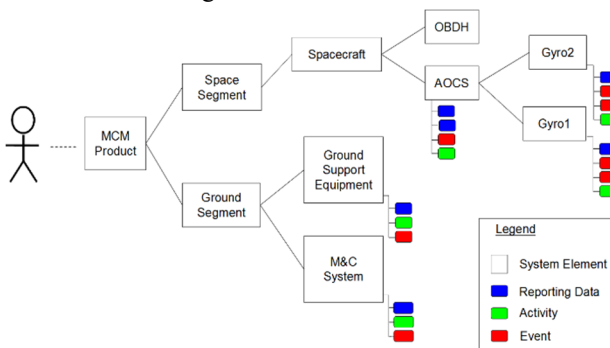


Figure 2. Monitoring and Control Model.

The Figure 2 shows the space system represented in the MCM as a hierarchy of Monitoring and Control Elements. The M&C element is a data structure whose properties provide the means to organise the space system knowledge in a hierarchical structure. From the highest level downwards, this is typically: system, subsystem, set, equipment or software product, assembly, part (hardware) or module (software), but it is not required to be a one-to-one mapping of the physical decomposition of the space

system. It is ultimately up to the users/developers defining the model to organise its hierarchy in the way which is most suited to their needs. The space system monitoring and control knowledge is categorised into ‘aspects’ such as activities, events and reporting data:

- Activity – An activity represents a space system monitoring and control function which can be invoked through the EGS-CC. An activity can be implemented by executing the corresponding control actions within the EGS-CC based system itself (e.g. a procedure, a script, a call to a system function) or by releasing a command to the space segment or to any other element of the system under control e.g. a command to a SCOE or a directive to the TM/TC data services provider in a ground station;
- Event – An event is an occurrence of a condition or group of conditions of operational significance. Events are widely used within the space system to enable awareness of state changes as well as to trigger the invocation of activities;
- Reporting Data – Reporting data is information relevant to its state that a monitoring and control element provides.

Although the MCM organises reporting data, activities and events into a more logical structure, the view presented to the end user can be customised as required. For example, it is still possible for the end user to view and interact with the system as a more traditional flat list of parameters and commands if so desired. Each MCM object is represented by a definition (metadata) and is associated to a ‘path name’ which is unique within a given MCM definition. However, each object is also associated to a unique ID which is preserved across its entire lifetime and never changes, even if the M&C element containing the object is ‘moved’ in the MCM hierarchy. This naming concept enables the progressive integration of M&C elements definitions preserving all artefacts (e.g. automation procedures, user defined displays, expression definitions) which make reference to any object belonging to them.

The MCM concept ensures a clean separation between the M&C abstract view and its associated generic processing and the specific processing related to the data units exchanged with the controlled system. This approach allows the application of the same M&C kernel to different types of controlled systems, such as spacecraft, ground support equipment, ground station equipment, etc. It means that the M&C system can control not only the target system (e.g. a spacecraft), but also all other contributing ground systems (e.g. EGSE supporting equipment, and the EGS-CC itself), with which the exchanged data are not necessarily based on TM/TC packets.

As stated above, the MCM is a model of the complete space system for the purpose of monitoring and control. The main inputs to the MCM therefore are monitoring

data received from the controlled system, referred to as raw monitoring data. Other MCM source and input data are generated by the EGS-CC components which can contribute to state changes in the MCM (e.g. requests to initiate activities, reporting data about EGS-CC components). Both the raw data and the internally generated input data are stored in a source data archive and fed into an MCM processing model which generates the dynamic state of the MCM, eventually stored in the processed data archive. There is one instance of the MCM per processing context e.g. live processing of real-time data, playback processing of deferred data, re-processing of historical source data e.g. using a new set of data definitions.

The MCM is associated to an access layer which acts as a mediator to manage any data related to the system under control, including all categories of data listed in the previous section. This encompasses:

- all monitoring and control data definitions produced during the development and the maintenance of the space system and used to tailor an EGS-CC based system for a given target application, as well as
- all monitoring and control data produced by the space system during testing and operations (e.g. the output of the ground processing of source data and control requests), providing a view of the state of the system under control as represented in the MCM. The processed data archive is populated with data output from the MCM processor fed by (real-time or deferred) source data received from the controlled system and other EGS-CC components. The processed data may be retrieved from the processed data archive at any stage and does not require the processing of data stored in the source data archive. It is thus possible to retrieve and use the archived processed data without the need of additional information and maintaining full configuration control of the data.

An overview of the data management concepts illustrated in this section is provided by the following Figure 3.

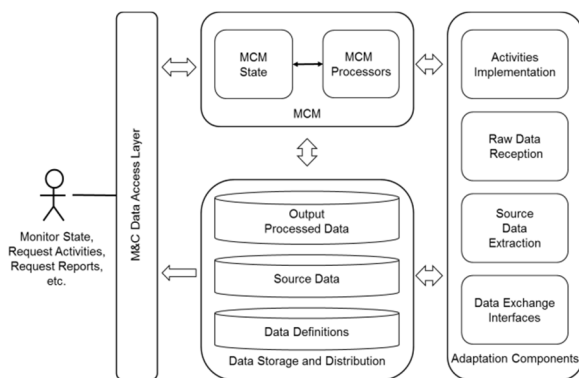


Figure 3. Data Management Overview.

Hierarchical Design

In order to fulfil its objectives, the EGS-CC design follows both a Component Based Architecture and Service Orientated Architecture. This is supported by underlying middleware platforms supporting the composition of implementation components into running applications as well as the integration of heterogeneous systems communicating via different protocols.

The EGS-CC design and its development governance rules are based on a clear separation of concerns between components such to avoid any dependency on their internal implementations. This is achieved by treating each component as a ‘black box’ and by supporting their hierarchical composition. Level-0 components represent the top level and provide the only interfaces which are visible to any other component not included in it.

In order to achieve effective modularity of the system (and not only a hierarchical design), each Level-0 component is managed as a stand-alone entity including all artefacts required by external components to interact with it. In particular, each Level-0 component is associated to a dedicated technical specification (defining its requirements, interfaces and design) and a dedicated set of validation artefacts supporting its validation in isolation. A complete separation of concerns between the developers and maintainers of a given Level-0 component and the developers/maintainers of other (EGS-CC or custom) components interfacing with it has been enforced. This has enabled the parallel development and maintenance of EGS-CC and custom components, which is of paramount importance both for the EGS-CC itself as well as for EGS-CC based systems.

THE EGS-CC CHALLENGES

In this section the main challenges to be faced in the development and adoption of the EGS-CC are presented.

A Complex Development

The EGS-CC development takes place in a complex scenario. This is mainly driven by organisational and schedule issues.

From the organisational point of view, the initiative is the result of a collaboration agreement among the stakeholders mentioned above and is directly monitored and guided by a Steering Board that includes representatives from each stakeholder. The technical aspects are monitored and driven, to a large extent, by two teams with complementary responsibilities which also consist of stakeholder representatives: the Systems Engineering Team and the System Integrators Team. The actual development and validation is being carried out by a large consortium of about twenty European companies, distributed over ten countries, under a contract with ESA, who manages it on behalf of the stakeholders. This setup requires careful management of a complex network of organisational interfaces.

From the schedule point of view, a fundamental driver for the development under way is the introduction of the EGS-CC in missions currently in development. Given the schedules of current and future space missions, with long lifecycles, waiting for the completion of the full development to introduce the EGS-CC would imply that it would not go into actual operation for many years, making its adoption eventually difficult. For this reason, there is a need to develop and validate the EGS-CC products in parallel with their first user missions to a large extent. This has been addressed through an innovative iterative development lifecycle where intermediate releases with two different levels of frequency, validation and quality are delivered to a number of stakeholders for progressive integration into their respective infrastructures. In addition to the careful definition of the governance principles and processes, this complex organisational set-up and lifecycle have required the development of a specific Software Development Environment (SDE) able to support such a distributed team of teams and to automate as far as possible the generation of development artefacts to support the frequent delivery of releases.

A Disruptive Change

The adoption of the EGS-CC as the basis for operational systems in the stakeholders' organisation represents an excellent opportunity for modernising the relevant ground data systems infrastructure but at the same time it is expected to introduce disruptive changes in many respects. The main ones are briefly addressed in the following paragraphs:

- **Terminology:** as part of the EGS-CC initiative a significant effort has been put in place in order to define and adopt a commonly agreed terminology. Due to the heterogeneous heritage of the various stakeholders involved, this was considered as an essential step to start the collaboration and share a product. Of course the consistent adoption of a newly defined set of terms implies a significant familiarisation and adaptation effort at all levels within the development and operational teams;
- **Engineering culture:** the EGS-CC product will constitute a powerful basis for developing monitoring and control target applications. It is considered essential that the engineering process leading to complete applications customised for a given controlled system relies on 'black box' re-use of the EGS-CC product artefacts ('EGS-CC as a third party product'). This implies a radical change compared to the current process which assumes the freedom of modifying the underlying infrastructure when designing and developing e.g. Mission Control Systems;
- **Engineering support tools and associated processes:** in order to enable the distributed and parallel development of its components as well as their progressive integration and verification, the engineering processes forming the basis for the EGS-CC components development and validation have been accu-

rately prescribed. Modern engineering paradigms have been adopted, such as model based engineering, component and interface based design, layered validation, end-to-end automation of Verification and Validation (V&V) processes. The EGS-CC product includes the development and integration environments (generically referred to as Software Development Environment, SDE), consisting of a rich collection of support tools collated together by means of well-defined artefacts and procedures. The intention is that all stakeholders adopt the same engineering processes and SDE for the required EGS-CC extensions;

- **Technology:** the current implementation of ground data systems in the various stakeholder organisations largely relies on technologies which are superseded by the more modern ones selected to form the development stack of EGS-CC components. This radical change in the technology stack will impact on the expertise profile required on the side of developers and technical managers;
- **Data model:** one of the key aspects of monitoring and control systems is their ability to be tailored for a given controlled system (e.g. a spacecraft). The definition of tailoring data is under the responsibility of the user teams and require very precise knowledge of the data semantics and their actual use within the run-time environment. Currently all involved teams are very familiar with the data models used by their systems. A significant effort shall be devoted to the task of acquiring an equivalent level of familiarity with the Conceptual Data Model (CDM) of the EGS-CC, which defines equivalent data types but on the basis of a largely different approach and data semantics. Also, the expected lifecycle of data definitions will be significantly impacted, in that a significant amount of them are expected to be defined in the early phases of the controlled system development and progressively integrated and validated throughout the mission preparation phase;
- **External interfaces:** the monitoring and control systems devoted to spacecraft as well as ground stations control require and provide many interfaces to other complex systems supporting complementary functions. Only a few of these interfaces are covered by international standards and thus can be assumed to be implemented in a similar fashion in the current and future generation systems. The EGS-CC will natively support many of the required and provided interfaces, however of course using an implementation which is different than the ones of the current legacy systems;
- **Approach to operations:** the EGS-CC architecture is based on a clear separation between core functions supporting monitoring and control operations for any type of controlled systems and an implementation layer providing the necessary adaptations to exchange data according to the specific protocols and interfaces supported by a given controlled system

(e.g. a spacecraft). As described in the previous section, the core M&C functions rely on the concept of ‘model based operations’, whereby the controlled system is represented by a hierarchy of elements and associated M&C aspects (e.g. state parameters, events and control activities). This abstraction layer enables the design of control operations focussing on the objectives, which are achieved through one of many possible implementations e.g. by executing an automation procedure, by invoking a dedicated service or simply by encoding and transmitting a command to be routed to the controlled system. Operating through a model will introduce a very significant change in the way that pre- and post-launch spacecraft operations will be executed.

PROGRAMMATICS

The development and maintenance of the EGS-CC is split into a number of phases, following the typical space project phasing, as summarised below:

- Phase A - User Requirements & System Concept
- Phase B - Software Requirements Engineering and Architectural Design
- Phase C/D – Development and Validation
- Phase E - Maintenance and Evolution

The phase A activities started in February 2011 and culminated with the successful completion of the System Requirements Review by the end of 2012. Phase A was performed by the Systems Engineering Team under the supervision of the EGS-CC Steering Board. Phase B started at the beginning of 2013 and was carried out by industry, under the supervision of the Systems Engineering Team, through two separate contracts: the Technology Proof of Concept, and the Software Requirements and Architectural Design definition. Phase B included a major formal review, the Software Requirements Review, which involved the stakeholder organisations as well as European space software industry in general. Phase B terminated in 2014 with the successful completion of the Preliminary Design Review.

A combined Phase C/D started in 2015 and is currently under way. This phase is funded through the ESA General Support Technology Programme. This is a voluntary Programme whereby each activity is funded through the subscription of interested ESA Member Countries. In the case of the EGS-CC there have been ten subscribing countries.

CONCLUSION

The Technical Specification and the definition of the software lifecycle and associated SDE were completed as outputs of Phase B. On the basis of that Technical Specification, the detailed design, implementation, integration and validation of the EGS-CC products is currently under way and is expected to be completed in 2019. The initiative is very ambitious and fundamental risks of such a

large, complex and fast development have been addressed. Some of them have, indeed, materialised and the development is suffering from some delay. However, the initiative is progressing firmly due, to a very large extent, to a very strong collaboration spirit among the stakeholders and the members of the Phase C/D industrial consortium, who have always strived for consensus.

ACKNOWLEDGEMENT

The authors of this paper would like to acknowledge the excellent contribution to the EGS-CC initiative given by the representatives of the stakeholder organisations and the industrial consortium.

ACRONYMS LIST

CNES	Le centre national d'études spatiales
DLR	Deutsches Zentrum für Luft- und Raumfahrt
EGS-CC	European Ground Systems Common Core
EGSE	Electrical Ground Support Equipment
ESA	European Space Agency
ESOC	European Space Operation Centre
ESTEC	European Space TEchnology Centre
M&C	Monitoring and Control
MCM	Monitoring and Control Model
MCS	Mission Control System
PUS	Packet Utilisation Standard
RTF	Reference Test Facility
SCOE	Special Check-Out Equipment
SDE	Software Development Environment
SLE	Space Link Extension
TM	Telemetry
TC	Telecommand
XML	eXtensible Mark-up Language

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