European Technology Harmonisation on Ground Software Systems: Reference Architecture and ICDs

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RHEA recently led a consortium of companies on a project for the European Technology Harmonisation Steering Board for Ground Software Systems (THSB). The project consolidated a number of related activities to construct a coherent Reference Architecture (RA) model representing a best practice design for a satellite operations ground segment. The RA also covers related aspects of the satellite manufacturing process.

The RA model was initially developed according to CCSDS RASDS / RM-ODP methods and is implemented in UML using the Enterprise Architect (EA) modelling tool. Its principal deliverable is a set of ground segment interface control documents (ICDs) representing the services offered between a Monitoring and Control System (M&C), a Mission Planning System (MPS) and a Flight Dynamics System (FDS). These ICDs will be submitted to ECSS for consideration as guidebooks for the specification of ground segment interfaces.

A key aspect of this work was to align the RA with relevant and emerging standards: the ECSS Space System Model (SSM) E31 [ref[1]] and the CCSDS Mission Operations (MO) standards [ref[5]] [ref[6]]. The RA ICDs are defined in terms of CCSDS services. At the top level are the CCSDS MO functional services [ref[7]]. These reference the CCSDS Common Object Model (COM) [ref[3]] which sits on top of the CCSDS Message Abstraction Layer (MAL) [ref[4]], which itself is independent of any chosen message transport implementation. The messages are instantiations of E31's Activities, Reporting Data and Events.

Reference architectures for the Operational Control System (OCS) and Electrical Ground Segment Equipment (EGSE) had evolved independently, even though a commonality in functionality is universally recognised. The updated RA has therefore converged on a 'common core' of services for both environments. It is hoped that this architecture will prove a useful reference for future activities such as the European Ground Segment Common Core initiative (EGS-CC).

An important aspect of the project is the automatic generation of written documents and data schemas directly from the RA model. These are now auto-generated via macros stored within the EA project file. XML schemas for the M&C, FDS and MPS service messages are generated in a single operation.

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I. Background

This project represents the culmination of a series of projects running since 2003 that have been performed for the European Technology Harmonisation Steering Board for Ground Software Systems (THSB). They were:

- Definition of a Reference Architecture (RA) (led by Critical Software);
- Establishing an initial set of standard interfaces (led by Critical Software);
- Validation of the initial set of standard interfaces by prototyping (led by Terma);
- Simulation - EGSE Interfaces (Rovsing, Dutch Space)
- Control Procedure Execution (CPE) (led by RHEA).
- Update of Reference Architecture – the subject of this paper

The overall objectives were presented to SpaceOps 2006 by Nestor Peccia [ref[8]], subtitled “As difficult as a T-Rex turning vegetarian”. The primary scope of the harmonisation activity has been the interfaces between the M&C, MPS and FDS systems as shown below.

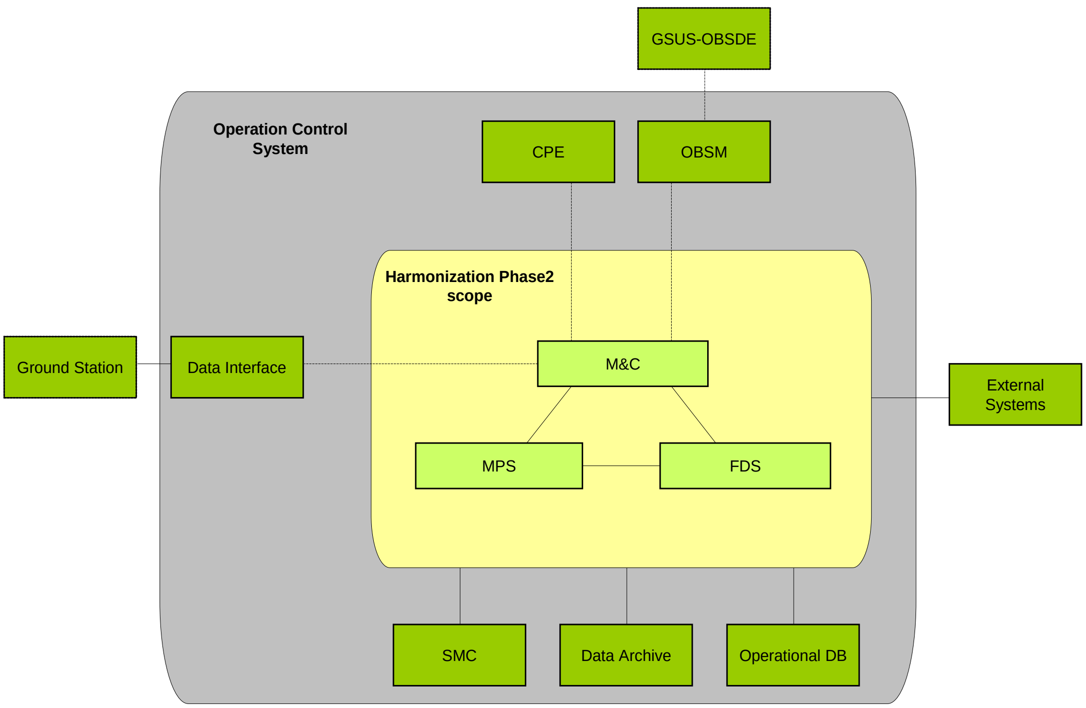

Figure 1 Scope of the Phase 2 Activities

- The Flight Dynamics System (FDS) provides all the computations needed to obtain and maintain the orbit, estimate the attitude and provide the products required by other systems related to these computations (sensor visibilities, ground stations coverage, ascending/descending nodes, AOCS values for telecommands, etc.). The FDS produces data about the spacecraft and its environment and in some cases performs guidance operation planning tasks in a specialised parallel planning system.
- The Monitoring and Control (M&C) system provides the monitoring and control interface to the spacecraft, effecting the transfer of control data to and reception of monitoring data from the spacecraft when in ground station contact.
- The Mission Planning System (MPS) provides out-of-contact spacecraft and support systems operations planning for the mission. It can accept requests for spacecraft operations from related planning entities such as an FDS or MES and reconcile them with the current spacecraft state and other planned operations, provide information about planned operations to other ground systems and schedule the spacecraft operations via the M&C system.

II. Project Objectives

The purpose of this project was to update the Reference Architecture (RA) according to the recommendations of previous activities, to harmonise the model with emerging standards from ECSS and CCSDS, to investigate a service oriented framework for future system modelling and to refresh and revise the modelling and document generation tools.

The project had many challenges. The required tasks were already complex, but had been specified in isolation from one another and were consequently inconsistent. Furthermore, the situation was dynamic; significant evolution of the corresponding CCSDS standards was taking place at the same time.

Reference architectures for the Operational Control System (OCS) and the Electrical Ground Segment Equipment (EGSE) had been established and had evolved independently, even though there is a clear commonality in functionality between them. A fundamental task was to establish a reference architecture which converges on a 'common core' of functions used in both environments. This design work had to establish the core 'building blocks' and their associated interfaces, so that the RA could act as a reference for future projects.

A detailed investigation into the compatibility between CCSDS and ECSS standards was performed, as both were required to be used within the same architecture.

Service-based ICDs replaced the 'point-to-point' documents that existed previously between the 3 main components. This was relevant to establishing service interfaces offered by the 'Common Core' of OCS and EGSE functions and removed a considerable amount of duplication. This step also played a key role in identifying the relationships between the RA and the ECSS and CCSDS standards. Whereas the current RA is somewhat retrospective (addressing the commonalities between existing solutions) the service view is more forward looking allowing new solutions to be developed with service oriented architectures.

The RA model was first established several years ago in UML using an earlier version of the Enterprise Architect (EA) tool. An upgrade to the latest version addressed some known problems. Finally an automatic mechanism to generate the ICDs (documentation and XML schemas) was implemented.

III. Updates to the Enterprise Architect Model

A. Merge of Phase 1 and Phase 2 Models.

When examining the content of models produced in previous phases, the team found significant fragmentation. In particular the Phase 1 model contained a wider scope 'architecture', whereas the phase 2 model contained the detailed data model necessary for the ICD specifications. The tasks were to:

- Merge the phase 1 and phase 2 models preserving the phase 2 data model integrity.
- Describe all phase 1 data objects in the model (*InformationView*)
- Rationalise the OCS Service View, making it consistent with the phase 2 data objects
- Remove clutter, e.g. repeated interfaces that add no value and unused data objects (e.g. SMF)

B. Common Core of Operational Control System (OCS) and EGSE Models

Previous versions of the model showed the OCS and EGSE with different architectures, even though they are functionally similar. The RA model now features "common core" components which are used in both systems. They are shown in green to distinguish them visually.

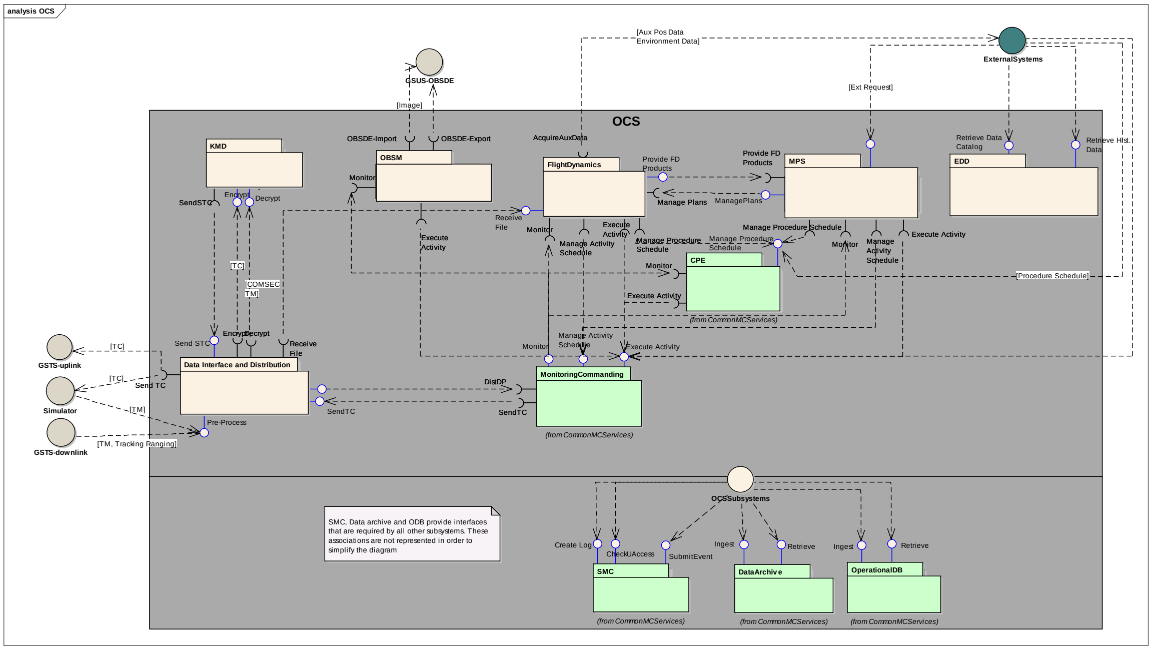

Figure 2 Operational Control System Architecture Featuring Common Components and Interfaces

C. Service Oriented View

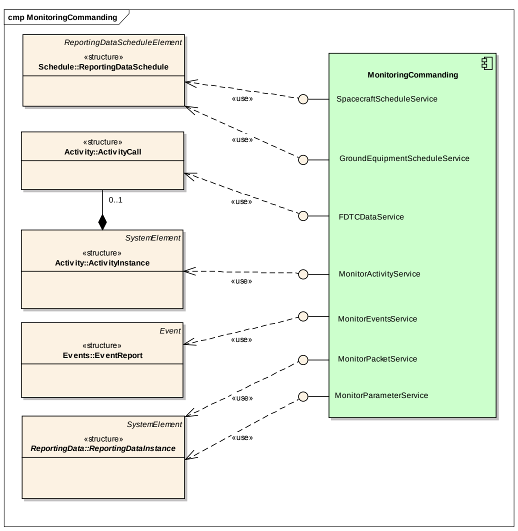

Figure 3 M&C Services

The UML model was reorganised to represent interfaces in a service oriented manner as opposed to being structured to support "point-to-point" interfaces.

Each ICD is now dedicated to one ground segment component (MPS, FDS, M&C) with each document defining the services provided by that component. Significant reorganisation of the model was needed to achieve this.

The ICDs are now easily extensible to include additional services in the future.

D. Changes Resulting from OCS ICDs validation

A previous harmonisation project had implemented earlier versions of the ICDs and had then formally validated them - a required step in the standardisation process. The validation phase uncovered a number of detailed issues and concluded with a number of specific recommendations to deal with them. These recommendations were implemented in the RA as follows:-

- Textual descriptions of each interface (service) were reviewed and further descriptions of the usage and purpose of the services were added
- The EA UML data model was aligned to the CCSDS MAL primitives and to CCSDS COM operations.

- The data model documentation was reviewed and updated to ensure that model descriptions contained in the auto-generated ICDs are consistent with any updates made to the model.
- The M&C *SpacecraftSchedule* service was adapted to ensure it supports the concept behind the current *FDTCData* interface (the service which allows controlled last minute updates to the spacecraft schedule).

IV. Alignment to ECSS E31 [ref[1]] and CCSDS MO [ref[7]] Standards

A. Conceptual Mapping between the standards.

The challenge of adopting both ECSS and CCSDS MO standards in the same architecture was resolved by establishing distinctive roles for each and performing the detailed mappings as necessary:

- The ECSS E31 Space System Model [ref[1]] is used for the Information (data) view. Messages are defined in E31 terms (*ServiceView*)
- Service mechanisms (external interfaces) are implemented as CCSDS COM services (*InterfaceOperationsView*)
- Services operate with the standard MAL [ref[4]] interaction patterns used by the CCSDS COM.

ECSS Concept	CCSDS Concept	Comment
System Element	COM Entity Represented by MAL Domain	Conceptually similar as both are hierarchically organised elements in a space system. Identification schemes are compatible
Activity	COM Activity (represented by MAL Operations)	Activities are prescribed as MAL operations which are monitored by COM Activity Service. (*) Note that the M&C *Action* Service would be applicable for user-specified Activities.
Reporting Data	COM Status Aspect	Reporting Data and Events are handled as different "aspects" of COM status.
Event	COM Status Event	(*) The term "event" is also used in the reference architecture interfaces where it is closer in nature to the CCSDS MC "Alert" service.
Packet Utilisation Standard (PUS) *Service*	Each PUS Service can map directly onto MO services, but not in a mechanistic way: MO offers equivalent services organised across MAL, COM and Functional Service layers	

Table 1 Mapping Between ECSS and CCSDS Concepts

In conclusion, a solution was found to allow ECSS and CCSDS standards to cohabit, by identifying specific roles, despite some overlap between concepts and terminology. In that sense the exercise is considered a success. However, the mappings are not trivial and there are some terminology differences, which suggest some added complexity in any system that implements both standards (as the RA now does).

B. Alignment to ECSS E31 [ref[1]] Space System Model

The ECSS-E31standard introduces the concept of a space system model (SSM) which captures the space system knowledge by reflecting the structure of the space system itself. The SSM is hierarchically broken down into system elements (SE) mirroring the functional breakdown of the space system. An SE is a data structure whose properties are the means to capture space system

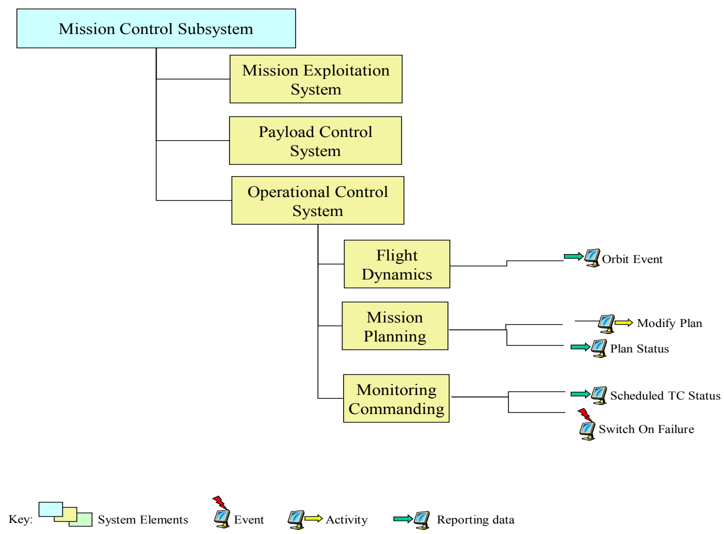

Figure 4 Space System Model

Figure 5 shows the *FlightScheduleService* as represented in UML in the EA Model. This service offers a number of operations for manipulating a schedule and monitoring the items in it. This service references standard operations as specified in the Common Object Model wherever possible. Each service operates according to one of the standard interaction patterns also used by CCSDS.

Service operations are published as CCSDS MO services according to Table 2 below. It can be seen that the majority of services can be supported by standard MO operations (in grey). A new operation is required only for the reschedule service.

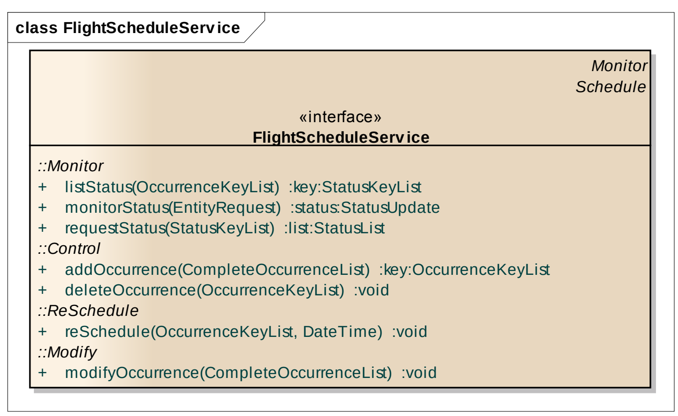

Figure 5 Service Example

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Area Identifier	Service Identifier	Area Number	Service Number	Service Version
MPH	FlightSchedule	10	4	1
Interaction Pattern	**Operation Name**	**Operation Number**	**Support in replay**	**Capability Set**
REQUEST	addOccurrence	10	No	6
SUBMIT	modifyOccurrence	11	No	
SUBMIT	deleteOccurrence	12	No	
REQUEST	listStatus	14	No	8
REQUEST	requestStatus	15	No	
SEND	reschedule	100	No	

Table 2 CCSDS MO Service Configuration

V. Modelling Methodology & Tools

An important result for the project was the creation of a consolidated Model Based System Engineering (MBSE) environment. This was done by capitalising on features offered by the latest version of Enterprise Architect (EA) and realigning the UML model to make best use of these features. Specifically:

- Consolidation of earlier models to create a single UML model that covers the
  - *Enterprise View*, containing the high level requirements
  - *Information View*, describing the object catalogue and detailed data structures
  - *Computation View*, including Views describing the service interfaces.
- XML schema generation directly from the model by implementation of a dedicated EA plug-in providing automatic generation of schemas compliant with specified rules and conventions.
- An in-built glossary of terms and acronyms, for common use within the model, documents and interfaces
- Document generation directly from the EA user interface, based on Word templates. The majority of information inside all documents is now generated directly from the model

VI. Delivered Items / Conclusions

The following items were completed and delivered:

- UML Model in Enterprise Architect, including a glossary.
- XML schema generation plug-in and exported schemas
- EUHA-GS-GLO-1001: Framework and Glossary of Terms
- EUHA-GS-RQ-1001: High Level Requirements.
- EUHA-GS-TN-1001: Model Information Viewpoint
- EUHA-GS-TN-1002: Model Computational Viewpoint
- EUHA-GS-TN-1003: Model Engineering Viewpoint
- EUHA-GS-TN-1004: Common ICD
- EUHA-MC-ICD-1002: M&C Services ICD
- EUHA-MP-ICD-1002: MPS Services ICD
- EUHA-FD-ICD-1002: FDS Services ICD

These deliverables can now be easily updated in future harmonisation projects, such as an expansion in scope of the interfaces, an upgrade of the infrastructure to support new interfaces or inputs from further evolutions of the ECSS and CCSDS standards.

VII. Appendix A
Acronym List

AOCS	Attitude and Orbit Control System (see FDS)
CCSDS	Consultative Committee for Space Data Systems
COM	Common Object Model (see CCSDS)
CPE	Control Procedure Execution (study)
E31	[ref[1]],
E32	[ref[2]],
EA	Enterprise Architect (modelling tool) http://www.sparxsystems.com.au/
ECSS	European Cooperation for Space Standardization
EGS-CC	European Ground Segment Common Core
EGSE	Electrical Ground Segment Equipment
FDS	Flight Dynamics System
ICD	Interface Control Document
M&C	Monitoring and Control (system)
MBSE	Model Based System Engineering
MES	Mission Exploitation System
MO	Mission Operations (services of the COM)
MPS	Mission Planning System
OCS	Operational Control System
RA	Reference Architecture
RASDS	Reference Architecture for Space Data Systems http://public.ccsds.org/publications/archive/311x0m1.pdf
RM-ODP	ISO Reference Model for Open Distributed Processing http://rm-odp.wikispaces.com/RM-ODP+Standards
SE	System Element – see E31
SMF	Service Management Framework
SSM	Space System Model – see E31
THSB	European Technology Harmonisation Steering Board for Ground Software Systems
UML	Universal Modelling Language
XML	eXtensible Markup Language

VIII. References

[1] Space engineering, Ground systems & operations – Monitoring and control data definition E31: ECSS-E-ST-70-31C, 31 July 2008

[2] Space engineering Test and Operations Procedure Language E32: ECSS-E-ST-70-32C, 31 July 2008

[3] CCSDS Draft Recommendation for Mission Operations Common Object Model, CCSDS 521.1-R-3, Proposed Red Book June 2011

[4] CCSDS Mission Operations – Message Abstraction Layer, CCSDS 521.0-B-1 Blue Book September 2010

[5] CCSDS Mission Operations Service Concept , CCSDS 520.0-G-2, Green Book, December 2010

[6] CCSDS Mission Operations Reference Model, Recommended Practice, CCSDS 520.1-M-1, Magenta Book, July 2010

[7] CCSDS Mission Operations Monitoring and Control Service, Draft Recommended Standard, CCSDS 522.0-R-3, Red Book, May 2011

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[9] A.Schwab, W.zur Borg, "OBCPs - an integrated part of BepiColombo Autonomy and Operations Flexibility", SpaceOps 2012