Implementation of MBSE solution for Advanced Digital Ground Segment Engineering: Abstract

Author(s): Kaarel Lumi (kaarel.lumi@cgi.com), Russell Gibson (Russell.gibson@cgi.com), Todor Stoitsev (t.stoitsev@space-cube.de), Joep Neijt (Joep.neijt@solenix.ch), Marcus Wallum (marcus.wallum@esa.int)

Background

Space system engineering is a complex activity, encompassing several phases and associated processes that are performed across different engineering domains and involve various stakeholders. Space systems engineering in Europe is governed through a comprehensive set of standards, developed by the European Cooperation for Space Standardization (ECSS). The standards define a number of formal requirements and documents for the engineering activities, serving as the main artefacts for capturing and exchanging engineering information across engineering disciplines and customer-supplier boundaries. Using documents to capture and exchange engineering information brings a number of disadvantages. As documents capture information in a rather static, disjointed manner (as written text), there is a high risk of producing overlapping or redundant information. Moreover, as no formal semantics are enforced in free text, the risk of inconsistencies and misinterpretation of the engineering information increases, not only across engineering disciplines but also at customer-supplier boundaries. Further, textual representations are not formalized and the captured engineering information cannot be subjected to automated analysis and consistency checking. Any lack of context or semantic gaps are filled through implicit knowledge of system engineers, which is not externalized and cannot be easily reused. As a result, from the described issues, the document-based approach comes also with very time-consuming and risky change management, because changes bring risks of breaking formally reviewed and agreed baselines. In many cases this can lead to introducing risks due to lack of formal completeness or change impact analysis or even avoiding changes overall, thereby missing opportunities for optimizations and innovation throughout a system lifecycle.

The digitalisation of ground segment engineering processes, as one of the main engineering domains, via deployment of Model-Based Systems Engineering (MBSE) practices and facilities is seen as a key strategic goal. The aim is to circumvent the problems described above and enable greater efficiency for the management and operation of complex ground segment system engineering activities, in particular, but not only for, those missions operated by the European Space Operations Centre (ESOC) and associated Mission Operations Infrastructure (MOI).

The Paperless End-to-End Ground Segment Engineering (PLGSE) study was conducted as part of the ESA Technology Development Element programme and was the first major effort to develop and adopt an MBSE framework for ground segment engineering, with focus on ESOC MOI and in support of mission engineering phases B2-D. PLGSE delivered the first version of a Ground Segment Engineering Framework (GSEF) supporting MBSE in the target context in line with specific requirements from relevant stakeholders, in particular for the Euclid mission and the System Engineering and Integration and Test Manager actors. The prototype has already successfully supported the Multi-Mission Infrastructure EGOS-MG functional modelling and for the first time, a model-based review with around 50 reviewers for the project’s SRR milestone. The Advanced Digital Ground Segment Engineering (ADGE) project is a follow-on activity to PLGSE, conducted under the General Studies and Technology Programme (GSTP). ADGE aims to improve the TRL of the prototype GSEF and extend support, through the analysis of engineering processes, requirements and stakeholder needs, to integration with the space segment, subsystem domains (including mission data systems, ground stations etc.), and science ground segment engineering.

The following sections of this abstract summarise the objectives of the ADGE project, progress made to date and the next stages for its development.

Objectives

Considering the above, the core objective of the ADGE project is to build a mature, modern, fully web-based platform that enables a model-based approach for ground segment engineering, to be used by mission and subsystem engineers to design, develop, validate and support operations of multi-mission and mission-specific ground segments. The ADGE platform will implement ECSS and Quality Management System processes and aims to enable a transition, for all ESA missions, of the ground segment systems engineering domain to a fully model-centric approach. As for any MBSE effort, the application aims to improve and provide benefit for the following domain concepts:

- Traceability - Covering for example common aspects such as links between requirements and design elements (components, interfaces)
- Trade-offs – Enabling users to compare model design and architecture baseline options
- Change-impact analysis –enabling visibility of consequences of changes to any engineering artefact on the system as a whole
- Configuration control – Including retrieval of associated version control information at any point in time and branch, merge and compare capabilities for engineering data artefacts such as requirements, design elements or associated tests
- Communication and collaboration – Facilitating effective exchanges within and across subdomain teams and supporting both frequent/agile change review processes for model artefacts and formal project reviews for system model baselines overall
- Re-use – in support of future multi-mission infrastructure concepts, promoting re-use of infrastructure baselines and reference architectures and enabling formal traceability to mission-specific implementations and extensions
- Authoritative source of truth – through integration with other engineering domain tools
- Digitalisation - Overall digitalisation and formalism of the ground segment system engineering artefacts, enabling future opportunities and capabilities in the domains of big data analysis, AI-based reasoning and Digital Twin initiatives

Progress

To date an analysis phase has been completed, including an in-depth review of existing MBSE tools, a review of existing business and ground segment engineering processes at ESOC and the conduct of extensive interviews with representative ESOC stakeholders in order to capture user needs and expectations of the ADGE framework. The results from the analysis phase clearly showed the need to progress with the development of the precursor GSEF framework, implemented by the PLGSE project. Other modelling solutions were compared and traded-off against GSEF (e.g. Cameo Systems Modeller, Enterprise Architect, Capella). The decision to progress with a custom development was driven by several reasons but primarily because no other solution provides a fully web-based platform that enables all the required functionality. A bespoke platform also allows more flexibility to control the user experience which in turn will enable a lower barrier to entry for users without formal modelling skills. The custom development will be an open-source community licensed software platform that capitalises on cutting edge developments in the modelling framework tool and overall systems engineering domains.

One such development is the evolution of the Object Management Group's (OMG) language SysML to SysML v2. Migration of the GSEF data model (pertaining to requirements, components, interfaces, tests etc.) to a SysML v2 domain model library representation was evaluated as part of the ADGE design phase and the decision to progress with a SysML v2 domain model library has been made. Such a migration will largely facilitate data model tailoring for a given application context as well as reuse of model elements and access to the SysML v2 API. This is a key objective also to position the framework with adequate flexibility to future data model changes, for example to cleanly map to an overall Space Systems Ontology. Further, the migration will introduce key concepts not currently present in GSEF such as, for example, variability modelling, viewpoints and behaviours. From stakeholder interviews, reuse capabilities are seen as key to increasing efficiency as infrastructure systems and associated models can be reused and thus only delta system/model changes would require validation and testing. There would be no need to revalidate the reused design and architecture for the majority of required functionality for a mission, as it has already been previously validated. The SysML v2 domain model library infrastructure is currently under prototyping at the time of writing.

An Eclipse CDO (Connected Data Objects) based model repository is also currently being prototyped. CDO provides support for concurrent editing, allowing users to work in parallel on the same branch of the model, as used also by the Capella Teams plugin. This is achieved through opportunistic locking for web clients: as soon as a user starts editing an element in the model, it is locked for editing for other users on the same branch. When a collection of modifications to the model are "saved" by the user (as a CDO transaction is committed), they will automatically become available to others. The use of CDO will also enable the support of multiple branches and merging.

A diagramming solution to be used as the primary model-based user interaction is currently being prototyped around the Sirius Web platform. Sirius Web leverages Spring Boot technology for back-end components and a React-based front-end leveraging Eclipse Sprotty.

A simple yet effective User Experience (UX) and User Interface (UI) is critical to the success of the ADGE platform. Some MBSE concepts, languages and tools can be highly complex with steep learning curves that contribute to user rejection. This means that ensuring an 'as simple as possible, as complex as necessary' definition of the exposed data model and involving end users throughout the development is very important to the uptake and usage of the platform. At this stage in the project, at the time of writing, several UX/UI related concepts are being prototyped with the intention to share with end users to obtain feedback.

Next steps

After prototyping is completed, a minimum viable product will be produced and demonstrated to stakeholders to obtain feedback. A shadow-engineering exercise is foreseen to be undertaken with a real mission ground segment development to validate the platform in a working environment. Development and testing of the framework will continue based on user feedback and the project is expected to complete in 2022.

Conclusion

ADGE is an ambitious project that aims to develop a state-of-the-art web-based MBSE framework specifically validated to support ground segment system engineering at ESOC in order to address inefficiencies associated with paper-based system engineering approaches. An in-depth analysis phase has been completed and the current focus at time of writing is architectural design and prototyping key platform features. Next steps include development of an MVP to gain further feedback from stakeholders and to continue the development of the platform in advance of a shadow engineering exercise in a real working environment. This presentation will provide an insight to the motivations, challenges, target capabilities and outlook of the ongoing development.