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Model based systems engineering and concurrent engineering for space systems

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Abstract. The objective of this paper is to present the rationale and application of Model Based System Engineering and Concurrent Engineering for space systems. In the context of the New Space Economy, characterized by disruptive technologies, standardization, and the entry of private investments into the industry, it is critical to manage space systems effectively among the different involved stakeholders. In order to address all related challenges, systems modelling approaches are used at different levels, from subsystems to satellites to complex mission architectures, like fractionated and federated systems.

Introduction

The New Space Economy refers to the growing commercialization of space services and exploration driven by disruptive technologies and increased accessibility. Private investment is surging, and Morgan Stanley predicts the global space industry could reach $1 trillion by 2040 (Fig. 1), impacting various sectors. Satellite broadband Internet access is expected to contribute significantly to this growth [1].

In this dynamic landscape, the juxtaposition of standardization and disruptive technologies presents a central challenge. Standardization, as demonstrated by the success of CubeSat technology, offers cost-effective development, while disruptive technologies, exemplified by Inter Satellite links, continuously reshape the market. Harmonizing these aspects becomes crucial to swiftly deliver new services, demanding adaptability across various systems while minimizing redesign costs. Effective trade-offs and design change impact analyses play a pivotal role in navigating this intricate balance and arriving at optimal solutions.

The complexity of space programs has led to the study of Model-Based Systems Engineering (MBSE) and Concurrent Engineering (CE) approaches for efficient data management and collaboration across disciplines. MBSE has demonstrated effectiveness in small-sat lifecycle management [2], while CE is a well-proven approach for designing complex space systems in the pre-phase 0/A [3].

The current elaborate will present these methodologies, the scenario of a complex space mission and the implementation steps to arrive at a modelling tool for distributed systems design management.

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Methodologies

MBSE approaches have been applied in different engineering domains. They enhance the ability to capture, analyse, share and manage the information associated with a system [4]. Among the various solutions in terms of tool and methodology, the Capella tool (Fig. 1), based on the Arcadia [5] methodology has been selected in the frame of the doctoral project. Capella supports system engineering activities at different levels: operational analysis, system analysis, logical architecture, physical architecture and EPBS (End Product Breakdown Structure).

Concurrent engineering is a method of designing and developing products, which overcomes

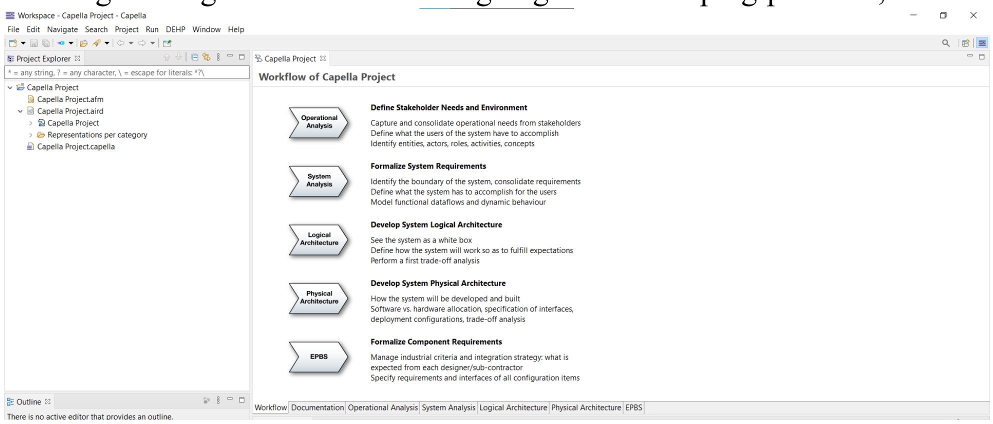

Fig. 1 Capella Workspace

the more classic sequential and centralized design approaches. Different expertise teams work simultaneously communicating with each other. Benefits can be seen in performance, with reduced study duration, reduced costs, and quality improvement. A typical concurrent engineering study process is characterized by a team of specialists working in a dedicated facility for different sessions using a centralized system data model to share information. Regarding the latter, the COncurrent Model-based dEsign Tool (COMET) (Fig. 2) [6] is the chosen software which enables the different members of a team to co-work on the same system and exchange design information through different iterations.

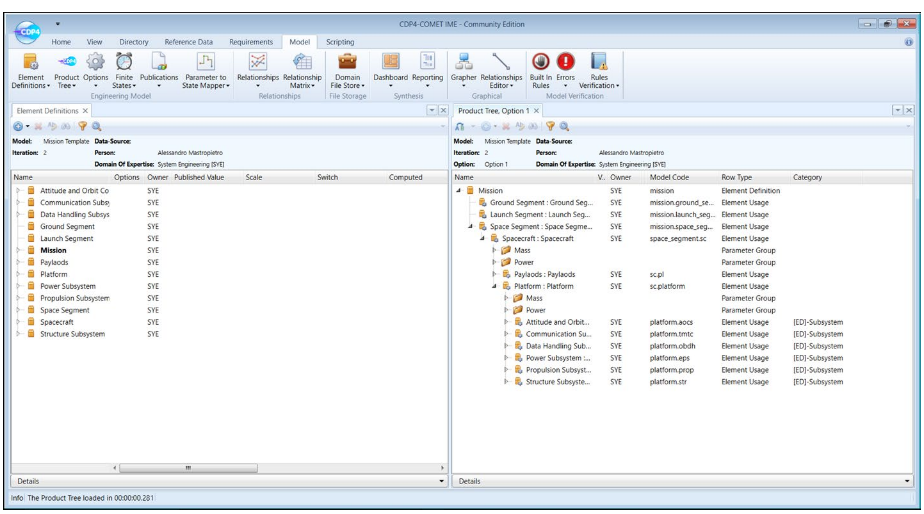

Fig. 2 COMET Workspace – Mission Template

MBSE and CE support the centralization of design information, acting as a source of truth. This empowers decision-makers with a comprehensive understanding, potentially accelerating Time to Market (TTM) [7]. The methodologies establish traceability for requirements and functionalities across system architecture levels, ensuring alignment with stakeholder expectations and

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facilitating adaptive responses to evolving needs. The capacity to analyse the impact of design changes on system architecture, along with RAMS analysis, enhances resilience and fosters operational confidence. Furthermore, this modelling approach contributes to the realization of a digital twin and, consequently, to the improvement of a model, development after development. This dynamic approach proves vital in accurately assessing and analysing the ever-evolving landscape of New Space, where the entry of new players intensifies the importance of safety, reliability, and adaptability considerations in both hardware and software domains.

Fractionated and Federated Systems

Over the past decade, increasing global demand for connectivity, navigation services and climate monitoring has caused a profound transformation of the space market [8]. This change has been facilitated by recent technological advances, which have introduced higher levels of digitization, miniaturization and reusability. [9].

The physical and service limitations of the classic space infrastructures, characterized by single big platforms, highlight the potential of a multi-mission scenario ecosystem of fractionated and federated space systems for future space missions [10]. Fractionation, involving the distribution of functions among interconnected modules, and federation, clustering satellites to dynamically share resources, are collaborative approaches to enhance overall satellite network performance.

The design complexities encompass various aspects, from architecture definition and payload design to co-design of space and ground segments, demanding efficient decision-making and facilitating easier maintainability for future development. Emphasizing the critical role of effective stakeholder communication, safety, and reliability considerations, it’s necessary to meticulously track design decisions for continuous improvement in future space mission development, ultimately optimizing resource utilization.

Implementation

Contributing to the realization of a proof-of-concept digital tool able to support federated and fractionated space systems design, like a multi-layer constellation for telecommunication purposes, requires a solid and robust foundation. The starting point for this work is the assessment of already existing tools with a forward-looking vision. Modelling spacecraft subsystems allows training on the modelling tools and methodology showing its strengths, to be exploited, and weaknesses, to be improved. Subsequently, a spacecraft can be considered to experience the concept of a System of Systems (SoS) with respect to its subsystems. The design of a payload and its integration into the spacecraft presents here the perfect opportunity to develop co-design models and study their maintainability. At this level, it is already possible to make important considerations about the best strategies for co-engineering from a modelling point of view and try to understand which level of abstraction is needed depending on the mission ecosystem and stakeholders. Finally, the modelling of a complex space mission scenario can be faced. Many challenges shall be addressed from the design of a distributed space segment to its co-design with the ground segment. The experience gained at the different levels of research will make it possible to make the best use of modelling capabilities and, if necessary, to propose new modelling solutions.

Conclusion

Integrating Model-Based Systems Engineering (MBSE) and Concurrent Engineering (CE) has proven to be promising in space applications, offering potential benefits for managing space systems architectures, improving decision-making, and fostering collaboration. However, implementing these methodologies coherently within the New Space sector poses challenges in aligning diverse stakeholders, standardization and disruptive technologies. In the context of the MSCA doctoral program Harmony [10], the objective of the current research is to develop a digital tool, based on MBSE and CE, to aid decision-makers in designing space systems, emphasizing understanding parameter impacts and interface changes for robustness and adaptability. Moreover, the consortium's multidisciplinary nature facilitates training on model-based and concurrent engineering approaches for distributed space systems and their implementation.

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References

[1] Information on https://www.morganstanley.com/ideas/investing-in-space

[2] P. Minacapilli, M. Lavagna, Small sats lifecycle management through MBSE aided decision making tailored tool, 72nd International Astronautical Congress (IAC 2021), (2021).

[3] J. Hoffmann, M. Deutsch, R. Bertrand, Development of a Concurrent Engineering Tutorial as part of the "ESA_Lab@" initiative, 4th Symposium on Space Educational Activities, Barcelona, (2022). https://doi.org/10.5821/conference-9788419184405.029

[4] L. Bitetti, R. De Ferluc, D. Mailland, G. Gregoris, F.Capogna: Model-Based Approach for RAMS Analyses in the Space Domain with Capella Open-Source Tool, International Symposium on Model-Based Safety and Assessment, (2019). https://doi.org/10.1007/978-3-030-32872-6_2

[5] P. Roques, Systems Architecture Modeling with the Arcadia Method, first ed., ISTE Press Ltd and Elsevier Ltd, UK, 2018. ISBN 9781785481680. https://doi.org/10.1016/B978-1-78548-168-0.50001-3

[6] RHEA GROUP, CDP4-COMET A platform for Collaborative Model Based System Engineering User Manual, (2024)

[7] Information on https://www.tcgen.com/time-to-market/

[8] Information on https://www.unoosa.org/oosa/osoindex/index.jspx?lf_id=

[9] O. Kodheli, E. Lagunas, N. Maturo, S.K. Sharma, B. Shankar, D. Spano, S. Chatzinotas, S. Kisseleff, J. Querol, L. Lei, T.X. Vu, G. Goussetis, Satellite Communications in the New Space Era: A Survey and Future Challenges, IEEE Comms Surveys & Tutorials, Vol. 23, No. 1, pp. 70-109, (2021). https://doi.org/10.1109/COMST.2020.3028247

[10] Information on https://www.harmony-horizoneurope.eu/