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Applying the 'Spacecraft Early Analysis Model' to the Biomass Mission

Model-Based Systems Engineering (MBSE) represents a move away from the traditional approach of Document-Based Systems Engineering (DBSE), and is used to promote consistency, communication, clarity and maintainability within systems engineering projects. In previous work, industry focus groups have indicated that one way this can be achieved is by performing early functional validation of elements of the spacecraft avionics.

This paper presents an extended approach and model template, introduced in a paper previously published by the authors, to enable early functional definition and analysis of a spacecraft. The approach uses the 'Spacecraft Early Analysis Model' (SEAM), a SysML-based model framework for the definition, development and analysis of a space-based mission and corresponding space system. In using this model, the traditional Mission Operations Concept Document is replaced with a model-based representation of the design that can be executed, interrogated and quantified. The objective of this model template is to improve the clarity, consistency and quality of the design information, and to structure this information in such a way as to enable the high-level simulation of the design much earlier in the system life cycle. This approach focusses on the definition of the concept of operations during Phase B of the spacecraft system lifecycle.

The SEAM pulls together different, traditionally disparate, analysis tools and enables them to work together, producing an integrated system model spanning multiple tools. It facilitates the definition and simulation of the mission using dedicated orbit modelling software System Tool Kit (STK), complex mathematical analysis using MATLAB, spreadsheet-based data manipulation using Microsoft Excel, and can be extended to incorporate IBM DOORS for the handling of requirements. At its core, the SEAM utilises Cameo Systems Modeler (by No Magic).

The structure of the core SysML-based model builds on the principle described by Stephane Estable in the 'Federated and Executable Models' approach – the preservation of separation between the mission definition and the system definition. The SEAM builds on this by introducing a third distinct layer: the operational definition. Maintaining separation between these three aspects of the model allows for greater flexibility of modelling and clarity when looking to analyse, modify or validate the mission, operations, and system definitions. The SEAM uses a complementary systems engineering methodology to derive appropriate functional and logical architectures.

The SEAM has been developed iteratively by applying it to case studies taken from real spacecraft under development by Airbus, refining the capabilities of the template accordingly, and subsequently generalising the model. The resulting version of the SEAM contains multiple reusable and customisable MBSE patterns that will ultimately provide users with a comprehensive, consistent and intuitive SysML-based structure to follow when applying the SEAM to a specific mission.

The case study presented herein focusses on the Biomass mission – an ESA-led, low-Earth orbit, Earth-observation mission due to be launched in 2022. The primary mission objectives are to determine the distribution of above-ground biomass in the world forests and to measure annual changes in this stock over the period of the mission. To achieve these objectives, a P-band (435 MHz) Synthetic Aperture Radar (SAR) has been selected as the payload. The Biomass space segment consists of a single low-Earth orbit spacecraft (Biomass) carrying the SAR instrument. The spacecraft will utilise a large deployable reflector, and this must be deployed during the early phases of the mission. This deployment process is an example of a critical sequence, characterised by an intricate decision-making process and subject to a complex relationship between the ground and space segments where communication can be limited. The MBSE approach adopted enables the definition and analysis of this critical sequence, pulling together multiple analysis tools to analyse the design of the system and the concept of operations, generate a deployment sequence timeline, and assess this against the mission needs.

The preliminary results of this work demonstrate that the deployment timeline is heavily influenced by the orbit chosen (which affects the availability of communication windows). In fact, the spacecraft is functionally active for only ~20% of the total time required to complete deployment. A significant amount of time is spent establishing communications windows and making continuation decisions on the ground. The case study has successfully demonstrated the SEAM's ability to model critical sequences and validate this spacecraft functionality and the concept of operations against the mission needs.

Next steps in the development of the SEAM include its application to a wider variety of case studies and missions to develop and demonstrate its versatility, and the development of metrics to measure its perceived value among practitioners. For example, the SEAM has also been applied to ExoMars, a Mars rover mission due to launch in 2022. Future applications may include constellations and crewed missions.

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