

Model-Supported Verification of Space Systems

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Abstract: - Verification of space systems is a complex process that involves large amounts of resources, engineering work and documentation. Several criticalities exist which can reduce the effectiveness of the process, as the need to track requirements and verification activities along the product life cycle, the consistency of data and the generation of documentation containing punctual pieces of information. The current verification approach is effective from a technical point of view, which means that few non conformances able to impact the mission escape the verification campaign prior of launch. Nevertheless, the process can have margin of improvement. The introduction of a model-based methodology has been theorized and is described in this paper, evidencing how the documents and products currently involved in the verification process can be represented as models to obtain a number of advantages. The approach is differentiated per verification method, with a particular focus on test and analysis, which involve a major part of the system requirements and the most costly verification activities.

Key-Words: - verification of space systems, model-based methodology, test and analysis, system requirements

1 Introduction

A solid approach has been developed in years by space industry for the management of large programs; large project teams are coordinated along the entire product life, starting from the conceptual design through the assembly and integration up to operation and disposal, coping with product complexity (that can be defined through technical, industrial and operational complexity [1]).

It must be noted that, in order to guarantee mission success, requirements have to be defined and verified; requirements therefore guide the whole process both from a technical and a contractual point of view, and verification plays the key role of managing these aspects of the process.

According to the success of most of the recent European missions, the current approach proves to be very effective [2]: this means that it is able to anticipate on-ground problems that could have caused severe consequences if occurred in orbit. The related processes are well established by the European Cooperation for Space Standardization (ECSS) [3] and optimized. The main products of verification are documents and reports. The purpose of the activities described here has been to investigate the possibility to move the verification process from document-based approach to a model-based approach.

2 Verification of Space Systems

Verification is defined as the process which demonstrates through the provision of objective evidence that the product is designed and produced according to its specifications and the agreed deviations and waivers, and is free of defects [4].

The planning of a space project, as reported in [5], is structured into seven sequential phases:

- Phase 0: mission analysis / needs identification
- Phase A: feasibility
- Phase B: preliminary definition (Project)
- Phase C: detailed definition (Product)
- Phase D: production/ground qualification testing
- Phase E1: overall test commissioning
- Phase E2: utilization
- Phase F: disposal

The ensemble of verification stage (development, qualification, acceptance, pre-launch, on orbit or post-landing), method (test, analysis, review of design or inspection) and level (System, Segment, Element, Subsystem or Equipment) define the so-called verification matrix [3]. Along the product life cycle, several verification activities occur; these can be grouped in two macro-phases:

- design and development, with top down definition from system to unit level;
- integration and verification, with a bottom up approach.

3 System Models for Verification

A model is defined as a representation of one or more concepts that can be realized in the physical world, usually as an abstraction with respect to a specific objective [6]. It should be noted that, on the basis of the Model Taxonomy introduced by [7], it is possible to identify six types of model:

- **Product Instance Models:** real physical items used to verify all or part of the requirements through direct tests and measurements.
- **Product Static Models:** structured data sets representing relevant information about the represented item, including topology, finite states, functionalities, requirements, etc.
- **Product Dynamic Models:** executable models of a software tool that simulates the reality (e.g. the conditions and the operations expected during the mission) with a certain degree of fidelity and approximation.
- **Data Meta-Models:** models that describe the structure of data.
- **Modeling Infrastructure Models:** models that define a super-structure in which integrating each used modeling tool, targeted at harmonization among those tools.
- **Process Models:** models that provide the top methodology which links all the other particular methodologies.

Space industry typically refers to the product instance models simply as models. The product instance models most commonly used for the verification of space systems are:

- **Flight Model (FM):** it is the model that is going to be launched and to achieve the mission objectives; acceptance is done on this model;
- **Qualification Model (QM):** it is the faithful reproduction of the flight model for complete qualification;
- **ProtoFlight Model (PFM):** it is a flight model that is used not only for acceptance, but also for the qualification of one or more or all requirements (note that one only requirement qualified on a FM is enough to make it a PFM);
- **Structural (Thermal) Model (SM/STM):** it is a model used to qualify only the structural (and thermal) requirements of the specification.

According to the INCOSE vision [8], a common MBSE reference model (called System Model) is the basis for ensuring consistency, and allows each type of model to be in line with a common architecture. Such system model should be out of the verification perimeter, being a necessary constraint to all activities in the engineering domain which apply a common MBSE methodology to their processes.

However, applying *ex novo* a MBSE infrastructure to a well-established very complex engineering process would be unpractical. At an initial stage of the introduction of MBSE methodologies to the verification of space system, a dedicated system model could be built. Such model is a Product Static Model, or descriptive model. The system model must rely on a precise definition, or Data Meta-Model, able to describe which attributes and relations characterize the model itself and its components. Also, the system model has to include the definition of the related processes (Process Model). Such system model can be the core of a MBSE infrastructure able to cope with the typical verification tasks [9-10], as shown in Fig. 1. The process relies on the possibility to model all the involved elements.

4 Model-supported verification

Verification by analysis usually involves a simulation, which needs a calculation model built from a representative continuous and/or discrete model or set of models.

Three main concepts have to be considered:

- each discipline (e.g. thermal control, structure, electromagnetic compatibility) needs to consider a model of reality (including product and environment) simplified to be able to fulfill some specific objectives;
- each discipline model is therefore representative of some aspects of the same product; this means that they describe the same product, therefore they must be reciprocally consistent;
- each discipline model must be also consistent with the definition of the product itself (in a MBSE verification approach, this corresponds to the system description model).

Beyond classical modelling inside the perimeter of each discipline, a new need emerge, that is the model to model transformation, to guarantee consistency. In the software industry, model to model transformation is already a thing, and generally there is growing interest in this topic also for physical models [11-14]. Moreover, within the same discipline it is necessary, in some cases, to simulate the behavior of the system or of a component at different level of complexity [15-16], depending on the progress of the design (e.g. preliminary design vs. advanced design definition) or the objective of the simulation [17-18].

In engineering, there is growing interest in multidisciplinary multiphysics simulations, to assess interactions among the different domains and to dedicate proper granularity of simulations [19-22].

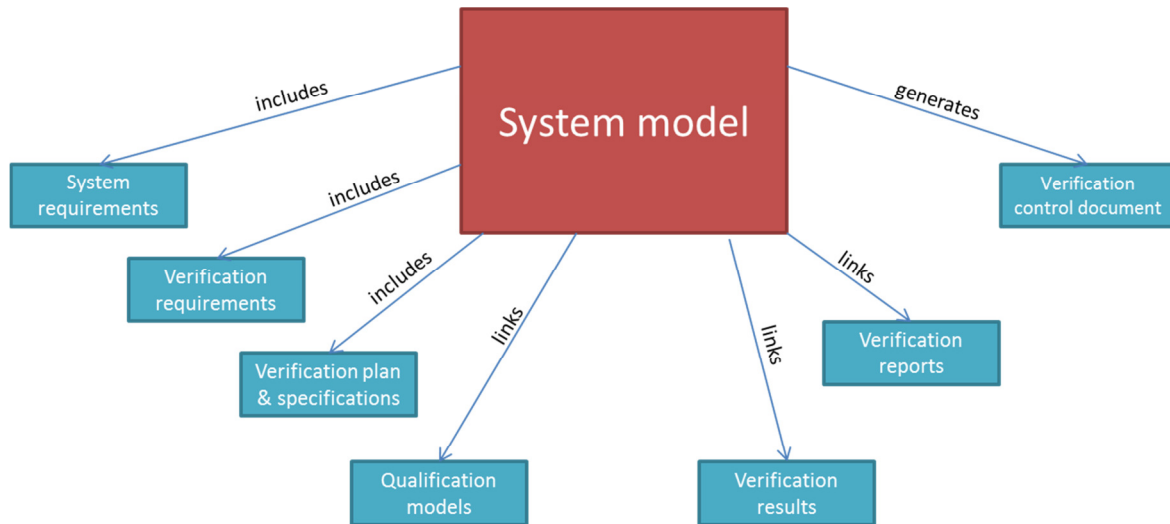


Fig. 1: Model-based verification process

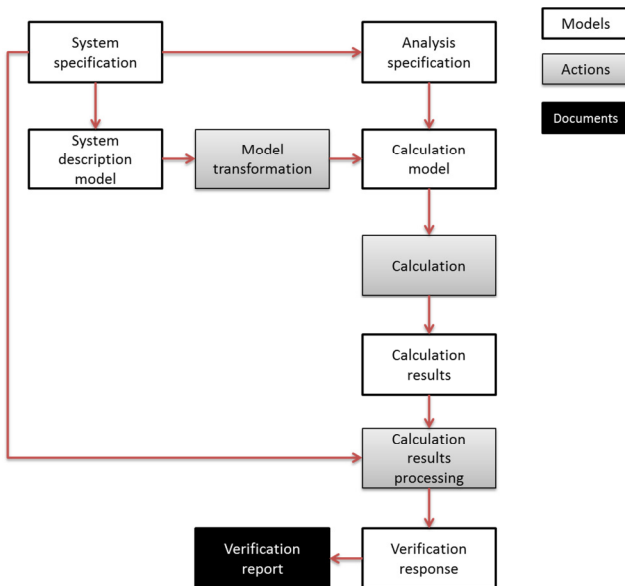


Fig. 2: Verification by analysis supported by MBSE

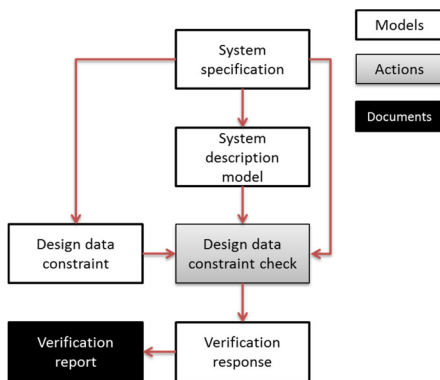


Fig. 3: Verification by review of design supported by MBSE

Discrete models use calculation grids and meshes to perform simulation on the volume of the product. Different models usually rely on different meshes; this means that different simulations calculate discrete distributions at nodes that differ in spatial coordinates. The charts in Figs. 2, 3 and 4 present a model-based approach to verification, diversified per verification method.

5 Conclusions

The application of model-based methodologies to the verification of space systems is possible with a gradual transition of documents and other involved actors to corresponding models. Such transition can minimize its impact because it is not necessary to apply a whole MBSE infrastructure ex novo; rather a progressive partial application is possible. Verification by analysis is more prone to an initial application of the new methodology. To validate the approach, the methodologies described in this paper have been applied to the specification of a piece of equipment of the International Space Station; such case study permitted to prove the applicability of the proposed approach; however, the impossibility to make a large scale comparison between the document-based and the model-based approach makes at the moment any assertion on the higher effectiveness of the proposed method purely hypothetical. Such large investigation would be fundamental for the evaluation of Key Performance Indicators (KPI, e.g. the reduction of Review Item Discrepancies – RID – received from the customer at each milestone), to assess the real benefit of model-based verification.

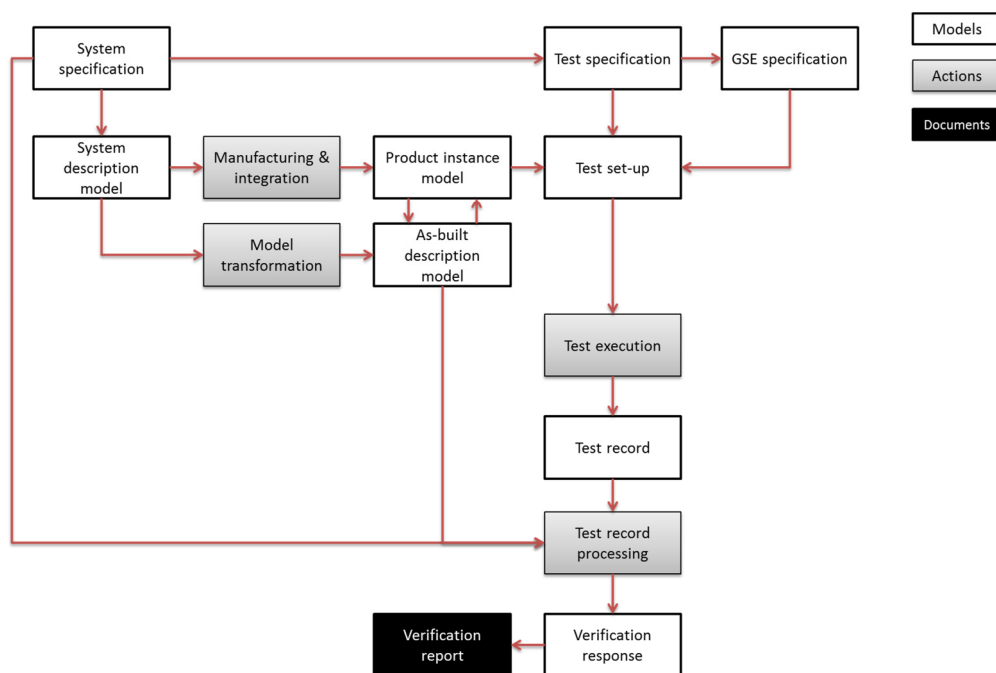


Fig. 4: Verification by test supported by MBSE

6 Acknowledgements

The authors thank the Verification Team and the COSE Center of Thales Alenia Space Italy in Turin for support received and for the possibility to use a real system specification as a case study, inside the perimeter of a non-disclosure agreement for what concern sensitive project data.

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