Digital Twin for (AOCS) Hardware Unit Modelling: Definition of TRL Scale

Executive Summary Report (ESR)

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Digital Twin for (AOCS) Hardware Unit Modelling: Definition of TRL Scale

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Activity summary:

The activity is to clearly identify the need of harware in the validation process of an AOCS system attending to ESA's development standards then to demonstrate when and how the physicals units could be replaced by a representative Digital Twin along the developpement and the validation cycle of AOCS system. A maturity scale for digital twins is proposed as well as "guidelines" to accompany the transition from the current V&V AOCS process to the alternative solution with Digital Twin.

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1 Introduction

A digital twin, like a virtual prototype, is a dynamic digital representation of a physical system. However, unlike a virtual prototype, a digital twin is a virtual instance of a physical system that is continually updated with the latter's performance, maintenance, and health status data throughout the physical system's life cycle.

Digital twin of AOCS equipment can be integrated in the AOCS development cycle, combined with model based subsystem engineering, to simulate the physical AOCS hardware at the right level of abstraction, in consistency with the AOCS test bench used and corresponding Verification and Validation objectives along the AOCS lifecycle.

The objective of the study "Digital Twin for AOCS Hardware Unit Modelling: Definition of TRL Scale" is to define the maturity (TRL) scale, and the corresponding products and milestones in the lifecycle of the AOCS hardware Digital Twins used in AOCS model based development, inspiring from the TRL definition for the equivalent physical hardware models.

Provide a readiness scale for interchangeability between physical hardware and simulator/virtual models in the AOCS subsystem engineering V&V cycle.

2 Project Background

Although the development process of a Hardware Unit could be different depending on the scope of the program, the conventional process is organized around four main milestones:

- System Requirement Review (SRR): the system specification is reviewed and a preliminary architecture meeting the design objectives is proposed. The main design trade-offs are identified.
- Preliminary Design Review (PDR): by the end of this phase the main design trade-offs are closed; the system architecture and operational concepts have been consolidated and justification about how the proposed design meets the system specification is provided. This justification may include analysis and simulation results.
- Critical Design Review (CDR): in this review a finalized architecture of the system is presented, and the compliance with the requirements is demonstrated with simulations using a high fidelity simulator.
- Qualification Review (QR): the hardware units are integrated and the whole system is validated with dedicated tests involving software and hardware elements.
- An additional step could be considered attending to in flight commissioning of AOCS equipment and calibration. This step could have a twofold objective: first, asses the correct functioning of the equipment and update the adjustable parameters (tunings) of AOCS algorithms. Secondly, acquire more knowledge about the equipment and its behaviour in flight to provide feedback to engineering teams for future projects. This activity could be extended all over the operating lifetime of the equipment.

The activity propose to introduce in this conventional process the technical solution of a digital twin to replace the usual virtual models (MIL/SIL tests) and H/W models (HIL tests) that are used in the verification and validation process of the AOCS system.

3 Methodology

The activity was divided into 4 tasks:

1/ The first task of the study is consecrated to a literature review of ECSS standards and handbooks, identifying the need of AOCS physical units for validation and verification aspects. Thales Alenia Space heritage and expertise in the development and implementation of AOCS systems for commercial and institutional programs being an important asset for this phase. By the end of this task, a clear summary of the use of physical units in a conventional development program and a proposition of substitution of the physical unit by a virtual model is outlined.

2/ The second task deals with the problematic of defining modelling and implementation guidelines about the use of Digital Twins attending to 4 key aspects:

- Different perimeters of Digital Twins attending to performance/functional/interface and other aspects.
- The ongoing development of Digital Twins in parallel with the evolving knowledge of hardware equipment.
- Usage of Digital Twins along the development cycle of AOCS systems.
- Improvement of Digital Twins considering feedback from in-flight operations.

By the end of task, the contents of a Digital Twin attending to the expected usage is clearly identified, considering the scope of the model (performance/functional etc.) and the implementation perimeter Guidelines for maintenance and improvement of Digital Twins are proposed.

3/ The third task identifies a set of recommendations to develop Digital Twins and the applicability of these models to the different milestones of the AOCS design process.

The proposed workflow is slightly different when considering a unit under development or a recurring unit with higher maturity.

Attending to this, the Digital Twins have different levels of fidelity depending on the Technical Readiness Level of the considered unit.

The study takes into account that the test plan used in conventional developments depend on the maturity of the equipment, the risk assessment associated to the equipment or the technology used and the criticality to the mission. This means that in some projects, thorough testing and validation using physical equipment are necessary, while in others, certain tests may be omitted or replaced with alternative methods of verification. A similar logic is applied to the use of Digital Twins, evaluating in detail the applicability or suitability of the model to a specific validation step considering the particular features of the equipment and the mission that is considered.

In particular, it is likely that a similar equipment will not pass through the same tests for a highly recurrent project, for a constellation or for a new development. In this task, a link between the type of missions and the validation philosophy will be established, detailing for each particular scenario the possibilities of using Digital Twins along the development and validation steps.

4/ By the end of the first three tasks a clear vision of when and how to implement a Digital Twin is presented. The last focuses in the analysis of the main gaps between the conventional process and the proposed approach with the introduction of digital models.

In this task, the potential risks introduced by the novel approach is identified and a way forward to make the process acceptable attending to the typical quality standards required by Thales Alenia Space and ESA is exposed.

Finally, a roadmap for the continuation of this work is proposed, identifying a promising use case to test the proposed methodology in a program under development.

4 Key Findings

Although it is difficult to list everything here, the most interesting concepts highlighted during this study are probably the following:

The activity leads to give a clear description of the lifecycle of a hardware model in the frame of the development of an equipment at supplier level followed by the lifecycle of the hardware models in the frame of the development of a satellite or satellites constellation.

The same approach and description are given about the conventional AOCS Equipment Virtual models lifecycle, followed by the link between Virtual models and test perimeter during the AOCS lifecycle.

One of the most important key finding is to give a complete description of the key features parameters of a Digital Twin and to propose a relevant scale of maturity for the Digital Twin and to identify their scope of application in the AOCS Vérification & Validation process. This step was made possible by a fine and detailed analysis of the equivalences between conventional virtual model/Hardware model and digital twins.

To allow these equivalences a list of key characteristics has been established, it contains in particular the functional aspects, performances, representativeness of interfaces, links with other subsystems for multiphysics aspects, the representativeness of internal redundancies, the ability to perform FDIR tests, real time representativeness etc...

Additionally, an evolutionary process for creating a Digital Twin has been proposed. This process emphasizes the necessity of favoring the transfer of a virtual model from one environment to another (for example, from MATLAB to C++ for the AOCS robustness simulator and the operations simulator, respectively) rather than a complete recoding of the model. This approach aims to improve the feedback loop speed during the operational life of the equipment, whether in-flight or in AIT, across all simulators.

Furthermore, this process identifies the moments during which the modifications that transform a model into a Digital Twin—rather than merely a simple virtual test model for AOCS (such as the connection with the satellite database, physical or thermal modeling of the equipment, etc.)—should be implemented, and at which point the feedback loop (i.e. when the knowledge of the new telemetries on the equipment) shall be reinserted.

A list of "guideline" is proposed to accompany the transition from the current V&V AOCS process to the alternative solution using Digital Twin.

A "roadmap" is made on the next steps of development and validation of the digital twin to be implemented in the framework of future work .

5 Conclusion

The activity has allowed to clearly identify the need of harware in the validation process of an AOCS system attending to ESA's development standards and to demonstrate when and how the physicals units could be replaced by a representative Digital Twin along the developpement and the validation cycle of AOCS system.

By analogy with the concept of TRL for H/W equipment, a specific maturity scale for digital twins has been proposed and their scope of application in the AOCS Verification & Validation process.

A set of "guidelines" to accompany the transition from the current V&V AOCS process to the alternative solution with Digital Twin is proposed.

6 Future Work

In order to build on the work already undertaken, it is proposed that industrial partners develop numerical twins of a typical sensor and actuator used in the LEO mission AOCS. In practice, the development of a Star Traker digital twin and a magneto torquer digital twin are already initiated. They will be tested in TAS on a test bench using usually actual H/W equipment.

This future step should allow us to better apprehend the steps associated with the development of a digital twin, in particular the multiphysical aspects (integration of thermal, mechanical, electrical aspects…) that do not exist on conventional virtual models.

The verification of the integration of digital twins on the test bench is also an important step in the realization of the process. This future study should make it possible to check some of the "guidelines" proposed in our study, to amend or supplement the list if necessary.