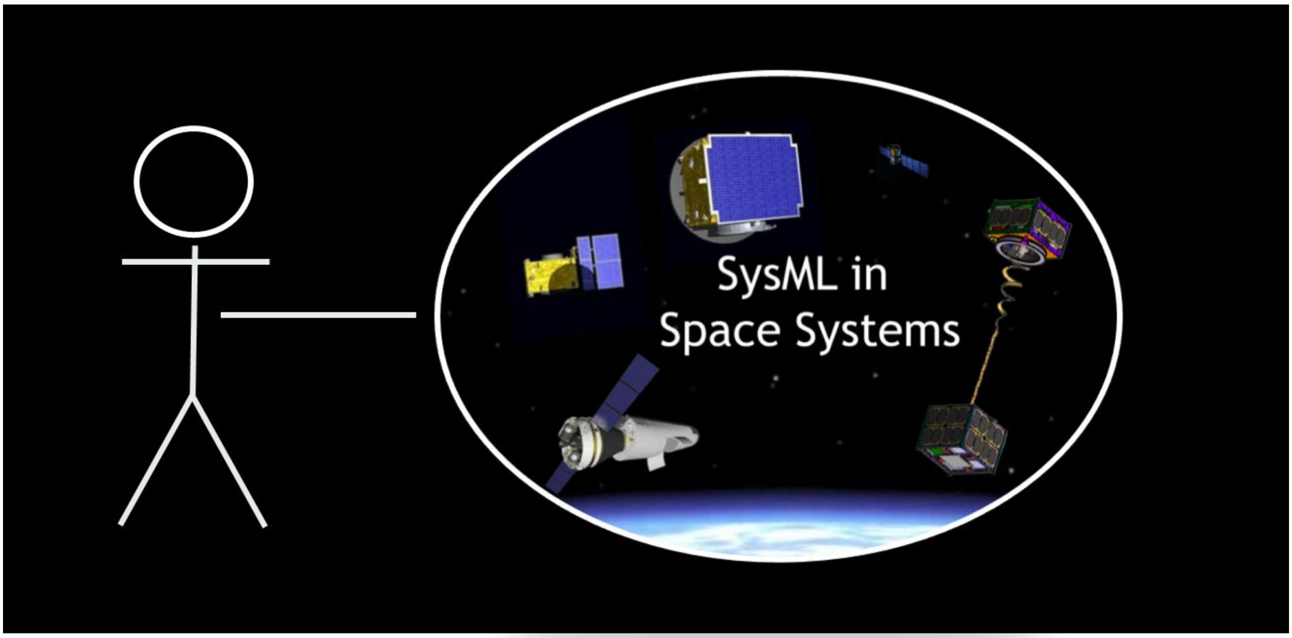
## AOCS/GNC Design with SysML




# D4.3 Executive Summary

Prepared by SENER for OSIP Project SysAOCS

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## Introduction

This executive summary describes the SysAOCS study performed by SENER Aeroespacial in the frame of the Open Space Innovation Platform (OSIP) campaign *"Model-Based System Engineering: from Documents to Models"*. It presents the aims of the study, the planning, the work performed and the outputs obtained. At the end of the document, the main outcomes are described.

## The SysAOCS Project

The objective of the SysAOCS project was to investigate the use of SysML to digitalize the AOCS/GNC description. The project started in February 2022 and was organized into 4 tasks running for a total duration of 1 year. The first task was devoted to the investigation of previous related activities and the selection of two study cases. Among the different SysML methodologies, the SysML ESA Solution was selected and used to build a dedicated AOCS/GNC profile. Space Rider GNC and Euclid AOCS/GNC were picked as reference study case due to documentation available for SENER, the maturity level of the AOCS/GNC as of functional, operational and physical architectures, and diversity of the missions, the former being a re-entry mission and the latter a science one. Task 2 was focused on the AOCS implementation in SysML using data from the selected use cases for the validation of the profile. This validation exercise was very useful to discover gaps and to adapt the SysML profile to cover them. SENER team put special care on the model descriptiveness and, in particular, on the readability of the diagrams from the perspective of AOCS GNC engineers. Feedback from SENER and ESA experts was gathered in dedicated workshop and used to improve the models. Task 3 was dedicated to model the AOCS/GNC design decisions including tarde-off and analysis and to establish data continuity between SyML and Mathworks tools. Finally, during the last task 4 the team compiled the guidelines for the AOCS implementation in SysML in a standardisation document and prepared a roadmap of future activities. The programmatic of the SysAOCS activity and the corresponding tasks are shown in Figure 1.

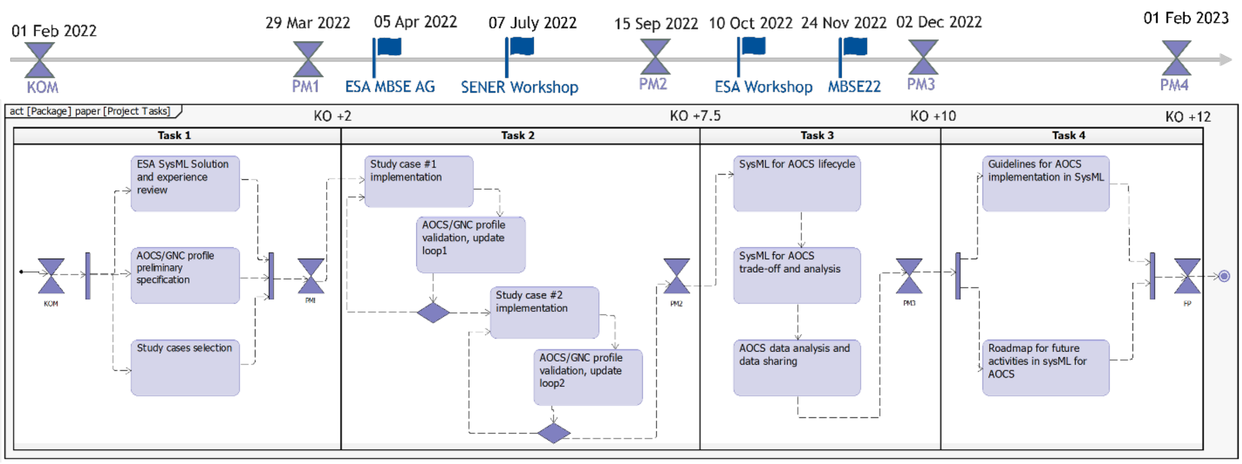


*Figure 1: SysAOCS Study Tasks and Main Events*

## AOCS/GNC Implementation in Rhapsody using the ESA SysML Solution

The ESA SysML Solution is the modelling method adopted to implement the AOCS/GNC study cases and generate the SysML templates. This method proposes to organize models into viewpoints or "layers", that address different aspects of the system and will represent it from 2 perpectives: *black-box or problem space* and *white-box or solution space*. The former provides context with no interest in the internal workings whereas the latter emphasises the internal structure and interaction of the system.

Using real GNC data, available from the DDF documents, it is possible to address the problematics of a complex subsystem that combines hardware and software and adapt the diagrams and the method. In this activity, SENER performed a tailoring of the *Solution* including an International System value type library, failure analysis for FDIR description, budget tables and two new concepts named "system" and "information product" (Figure 2).

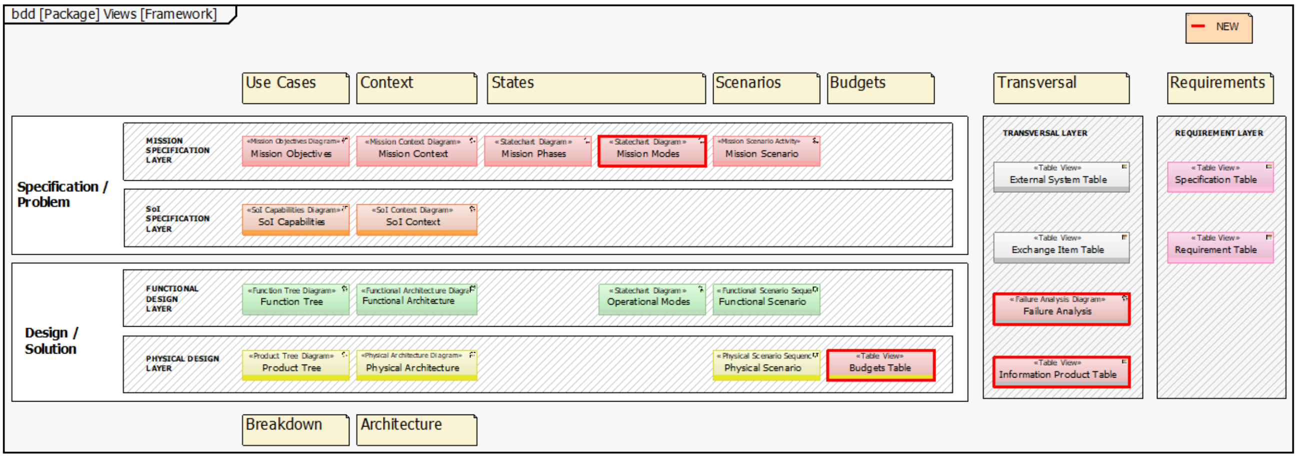


*Figure 2: Tailored ESA SysML Solution*

The model organization resulted to be of paramount importance in order to support navigability, reuse and maintainability. The proposed AOCS SysML model includes enhanced navigability with deeply nested diagrams to easily access system information at lower levels. Moreover, to foster the reuse of data, SENER proposes to create two main packages, one for the DDF (or any other AOCS document) and the other as a common database. The first package will contain hyperlinks to diagrams, tables and matrix views needed to justify the information required from the ECSS standard, whereas the common database will contain all the mission information. Additional packages such as a methodology package containing information regarding the ESA SysML Solution and a modelling resources packages for auxiliary elements are included at project level. This model organization limits the duplication and enables the reuse of elements in different AOCS documents.

## Space Rider GNC Study Case

Space Rider (SR) is a reusable European space transportation system enabling routine “access to” and “return from” space that includes a Ground and Operation Segment, Space Segment and Launch Segment. The **Mission Specification** and **SoI Specification** layers are used as context to describe the Space Rider mission and to introduce the External Systems and the SoI (GNC). The Space System hierarchy up to System of Interest and the high-level interactions between those entities are depicted using Mission Context or SoI Context diagrams, as the one depicted in Figure 3. Detailed interfaces will be represented in the **Functional and Physical Design** layers. These layers not only contain the functional and physical architectures of the SoI (where interfaces are represented) but also the functional and physical breakdown trees and scenarios. Operational modes are modelled as part of the Functional Design layer as well.

The **Transversal layer** compiles all elements used throughout the other layers, in particular failure analysis for Fault Detection, Isolation and Recovery (FDIR) design. This FDIR description includes the failures that could make functions not available, classified by severity level, have been identified and linked to the corresponding function. Along the failure, new elements are employed: recovery actions taken depending on the FDIR level, the effect of their occurrence, mitigations to prevent the failure from happening and detection means.

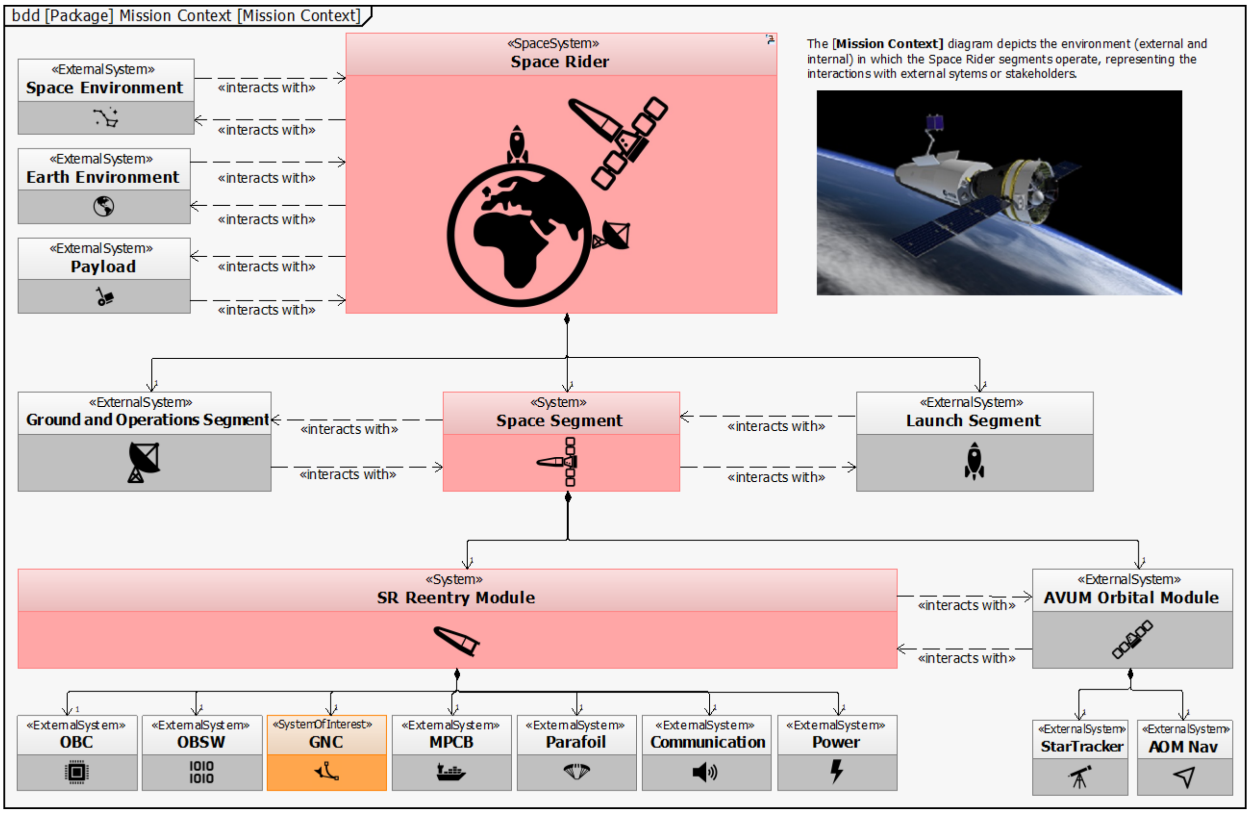


*Figure 3: Space Rider Context diagram*

**Euclid AOCS Study Case**

Upon implementation of the SR study case, the SysAOCS Team deemed necessary to include the mission modes at spacecraft level for a feasible AOCS description. The *Solution* offers operational modes modelling for elements from SoI onwards, therefore spacecraft modes are exclusively contemplated when the SoI is the Space System. SENER defined a new element named “mission mode” based on the existing operational mode. Euclid is an ESA second class mission dedicated to investigating the dark matter and dark universe. The Space Segment is composed of the Payload Module, which integrates the telescope and required instruments, and the Service Module, comprising all the subsystems necessary for the mission. The SoI in the Euclid study case is the AOCS (depicted in orange in **¡Error! No se encuentra el origen de la referencia.**). Implementing this study case arose the problematic of having a scattered System of Interest, not supported by the *Solution*, since the Fine Guidance Sensor necessary for the control of the spacecraft and therefore part of the AOCS, is mounted into the Payload Module, as seen in **¡Error! No se encuentra el origen de la referencia.**. SENER employed external system to represent the structural belonginess and product for the real description of the sensor. The main difference with respect to the SR study case is the modelling of the AOCS/GNC decomposition into products. The product tree in SR GNC is organized by navigation, guidance and control functions and subfunctions, whilst the Euclid AOCS is structured by a mode architecture. This organization influences the implementation of mode cycle diagrams and interface diagrams. Therefore, dividing the AOCS/GNC profile into two profiles was deemed necessary to better fit the differences in structure between an AOCS and a GNC.

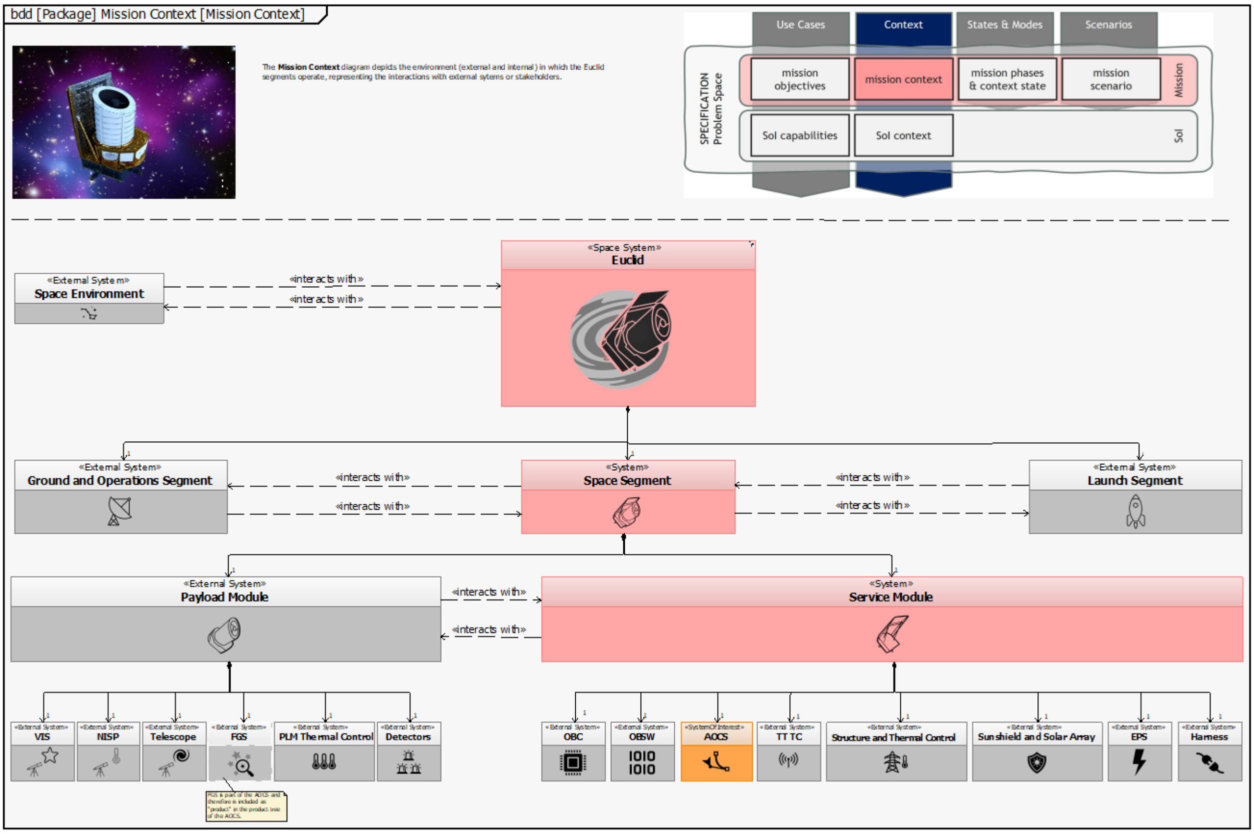


*Figure 4: Euclid AOCS Context diagram*

**Trade-off and Analysis Implementation**

Task 3 activity was aimed at capturing the design process describing the trade-off and the analysis activities performed in the DJF document. At the same time, the database organization robustness was tested including a second "digital document". The *Solution* required another tailoring to include the required elements for the trade-off modelling. Those changes mainly consisting of the definition of the element "criteria", for the different notions that are considered for the product alternative selection, and the stereotype "baseline" to describe the selected product out of the possible ones.

AOCS lifecycle was only implemented in the Space Rider study case, due to time constraints in the project. The DJF document contains all the analysis and trade-off performed in the frame of the design activity and required to justify all the design choices. The trade-off process has been structured in 6 steps (Figure 4) and validated using real data from the case study. This process is completely reusable and allows for automatization of the preferred solution selection. All the information of the elements not selected, remains in the common database available for future projects.

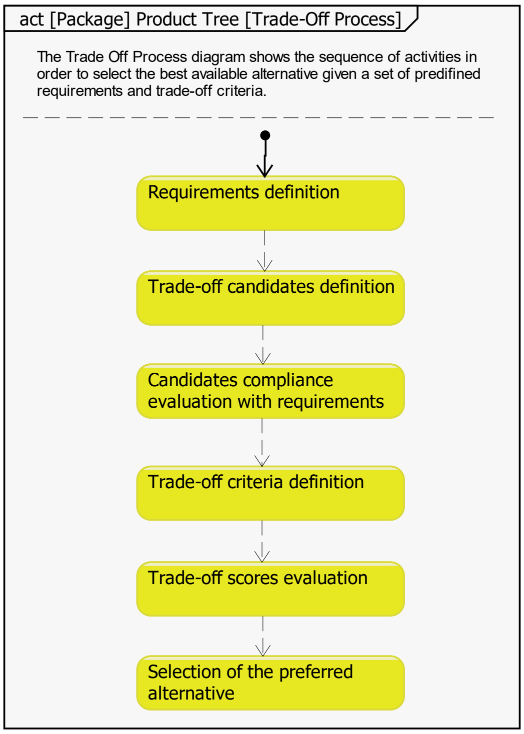


*Figure 5: Space Rider Trade-off Process*

The Space Rider and Euclid SysML implementation examples, AOOCS/GNC templates and the ESA SysML Solution were updated at the end of this task.

**Guidelines for AOCS/GNC Design using SysML**

One of the main outputs of this study is the generation of guidelines for AOCS/GNC modelling using SysML. These guidelines include generic SysML recommendations based on lessons learned for efficient modelling and dedicated indications for AOCS/GNC design using the Tailored ESA SysML Solution method as modelling approach.

The generic guidelines cover the model organization, diagram layout and naming convention, recommendations on how to generate clear diagrams, providing additional descriptive information and decomposing the information into several ones. As for the AOCS/GNC related recommendations, the Team has provided instructions on how to use the Solution method and how to properly model the common database and design documents to enhance the reuse of data.

**AOCS Implementation Roadmap**

The proposed roadmap is organized in 4 steps: migration of the SysAOCS output to Cameo Systems Modeler, complete the AOCS/GNC document digitalisation (specification, plan, test documents, …), enforce data exchange between tools used by AOCS/GNC engineers and lastly implement the AOCS/GNC SysML Profile in a pilot project.

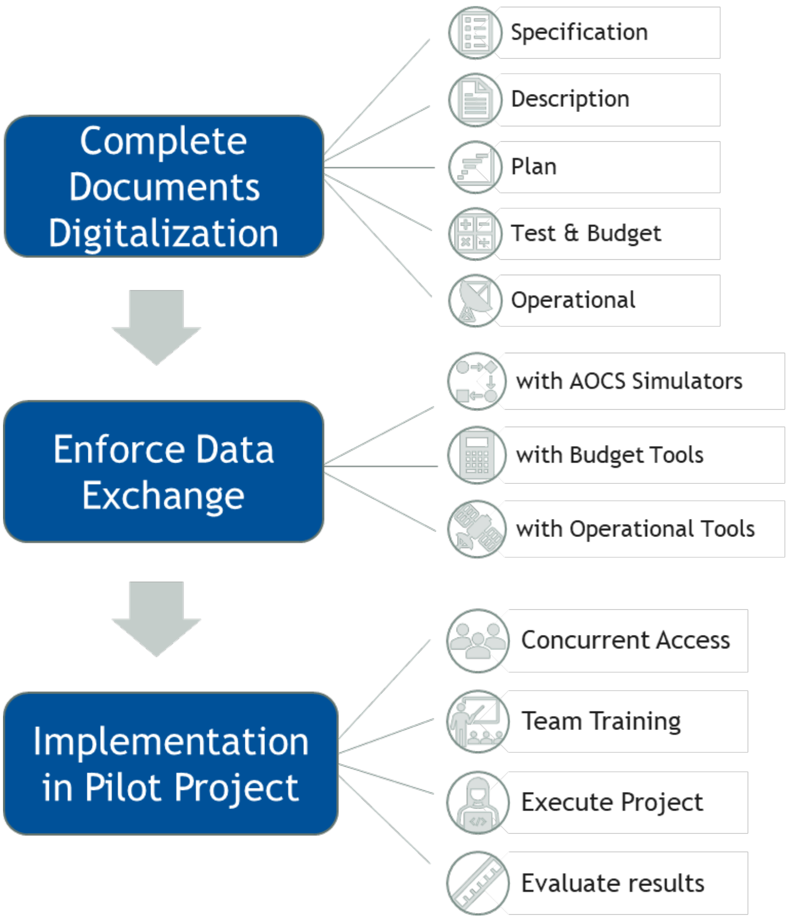


*Figure 6: SysAOCS roadmap*

Different activities of interest have been identified by ESA and SENER Aeroespacial. The Agency is more interested in activities related to the Space System Ontology (AOCS/GNC Universe of Disclosure, modelling in Norma-Pro) and the model exchange between companies. On the other hand, SENER has identified the following activities:

- Development of a tool to connect the SENER MATLAB based Design Simulation Facility (DSF) with the SysML database.
- Use of a tailored ESA SysML Solution to describe the EC E.T.PACK-F project.
- Generalization of the ESA SysML solution to include the UAF tailoring currently in use in SENER military projects.
- Implementation of the tailored ESA SysML Solution templates and method in the EC Horizon Europe SAFEST project.

**Conclusions And Outcomes**

For 12 months SENER worked with the *Solution* to describe the Space Rider and Euclid DDF and DJF. The AOCS/GNC documents digitalization with SysML replaces static documents with highly interconnected diagrams. The proposed SysML model was reviewed by SENER and ESA AOCS/GNC engineers and improved in several iteration cycles. The team can now clearly state that the main benefits of the digitalization are:

- Clear understanding of the system at the proper level of complexity.
- Efficient generation, maintenance and reuse of the design information following a structured design methodology.
- Centralization of all engineering data in a common database with possible link to other specific design and exploitation tools.

and the only drawback is the learning curve to master SysML.

Thanks to the excellent results of the activity SENER is planning to change its internal standard to adopt a digital Model Based AOCS/GNC design approach. The European Commission ETPACK project is the first SENER project to adopt SysML as main design database (Figure 7).

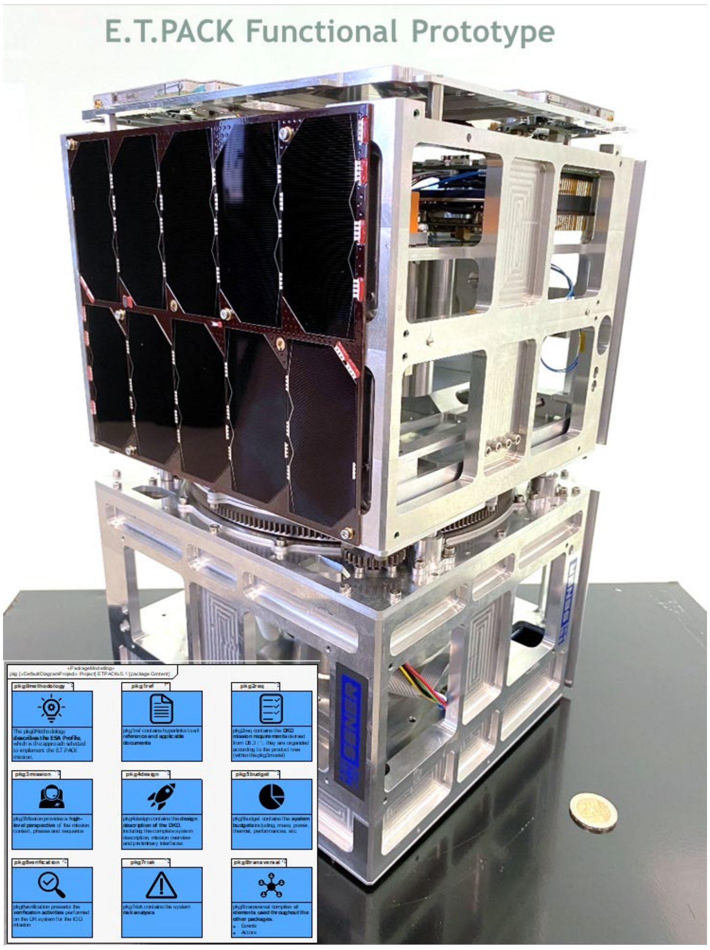


*Figure 7: E.T.PACK Deorbit Demonstrator and its SysML database*