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SysML in
Space Systems

Sofía Orte Arribas[1]
Lorenzo Tarabini-Castellani[1]
Álvaro Martinez[1]
Sergio García[1]
Quirien Wijnands[2]

(1) SENER Aeroespacial   (2) ESA/ESTEC

SysAOCS, how to digitalize the AOCS/GNC description using SysML

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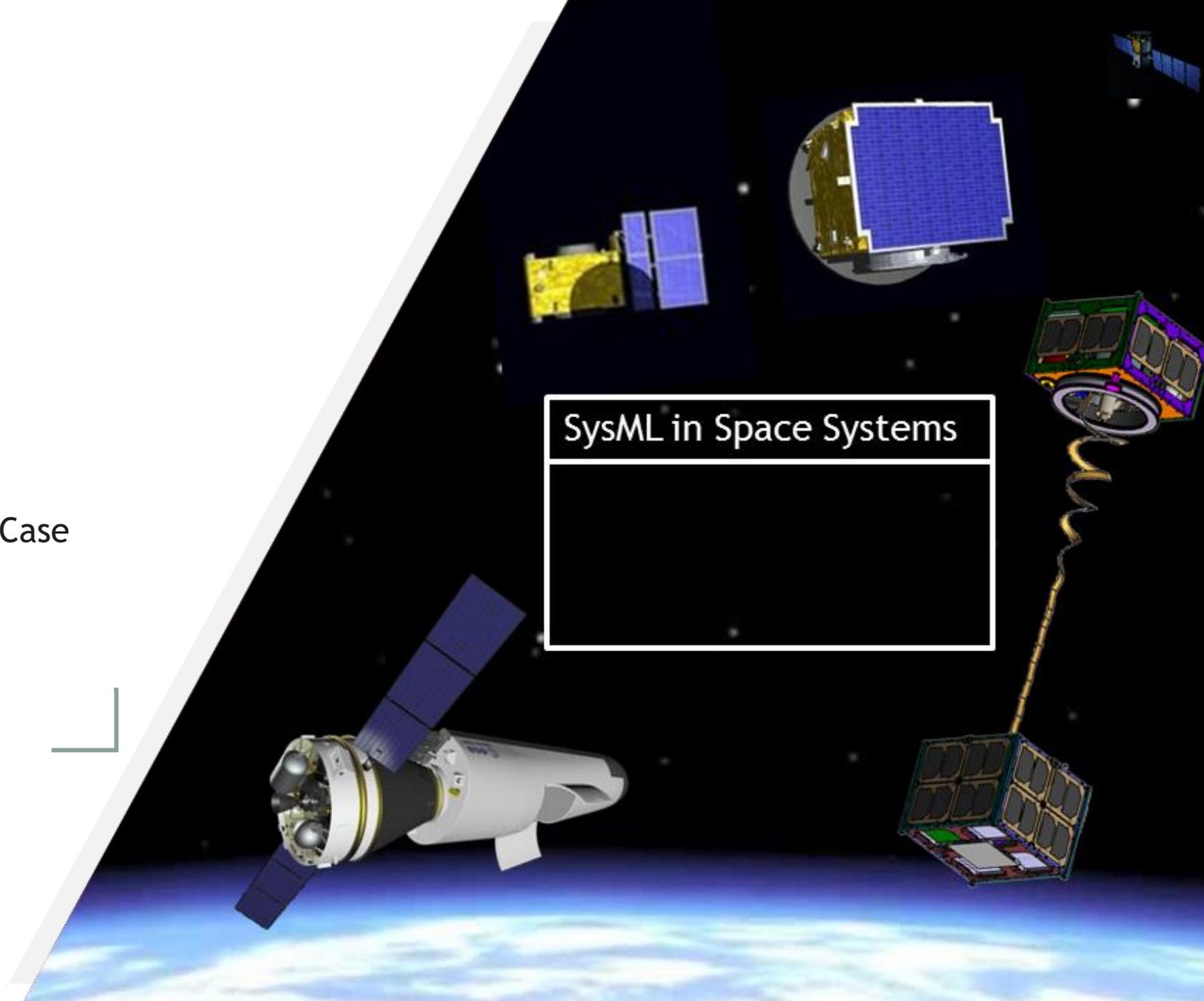
SysML in Space Systems

1. Introduction

SysML in Space Systems

1. Introduction
The SysAOCS Project

OBJECTIVES

- Investigate the use of SysML to digitalize the AOCS/GNC description

EXPECTED BENEFITS

- Information accessibility
- Flexibility for modification
- Integration with models at system level
- Reusability across projects
- Digital continuity of the AOCS/GNC subsystem evolution

OUTPUTS

- SysML guidelines
- Relations amongst model elements and diagrams
- SysML templates
- Two real AOCS/GNC implementation examples
- Roadmap for reuse of data

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1. Introduction
Project Tasks

The project started in February 2022 and is organized into 4 tasks running for a total duration of 1 year

The first task was completed at the end of March 2022 and task 2 was under execution at the time of writing and therefore is the focus of this presentation

act [Package] paper [Project Tasks]

| Task 1 | Task 2 | Task 3 | Task 4 |

- ESA SysML Solution and experience review
- AOCS/GNC profile preliminary specification
- Study cases selection
- KOM / PM!
- Study case #1 implementation
- AOCS/GNC profile validation, update loop1
- Study case #2 implementation
- AOCS/GNC profile validation, update loop2
- PM2
- SysML for AOCS lifecycle
- SysML for AOCS trade-off and analysis
- AOCS data analysis and data sharing
- PM3
- Guidelines for AOCS implementation in SysML
- Roadmap for future activities in sysML for AOCS
- FP

1. Introduction
Modelling Tool and Methodology

During the KOM it was decided to use IBM Rhapsody as modelling tool due to modelling skills in SENER and license availability

A trade-off among methodologies was performed as part of the OSIP proposition and the ESA SysML Solution was selected

TOOL

IBM Rhapsody

LANGUAGE

SysML based

METHODOLOGY

ESA SysML Solution

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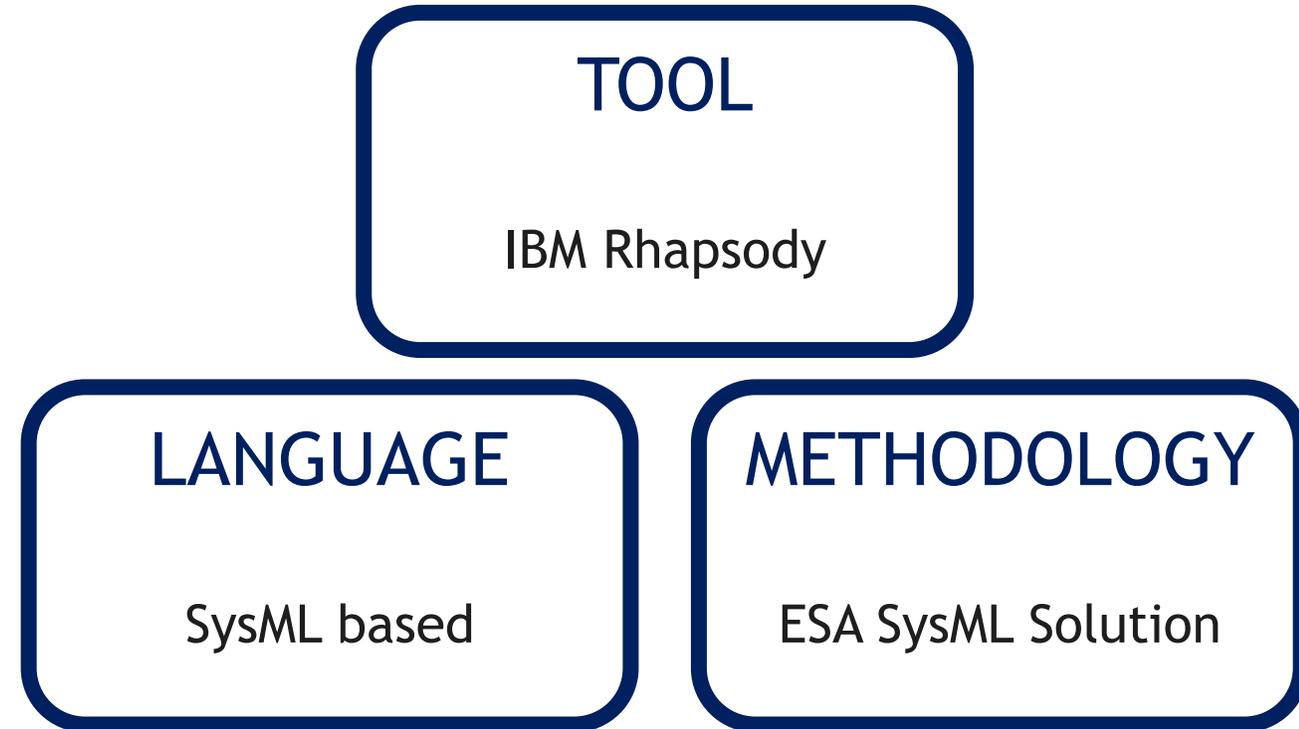
2. ESA SysML Solution

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2. ESA SysML Solution
Viewpoints or Layers

The ESA SysML Solution makes a clear distinction between the mission and the "System of Interest" (SoI), describing them from two perspectives:

- Black-box perspective: Provide the description of the complete mission and SoI with no interest in its internal workings

- White-box perspective: Functional and physical design of the SoI with emphasis on its internal structure and interfaces

The ESA SysML Solution organizes models in viewpoints or "layers" that can capture both the software and hardware aspects of an AOCS/GNC subsystem.

PROBLEM SPACE
(black-box perspective)

- MISSION SPECIFICATION
- SYSTEM OF INTEREST SPECIFICATION

SOLUTION SPACE
(white-box perspective)

- FUNCTIONAL DESIGN
- PHYSICAL DESIGN

- REQUIREMENT
- TRANSVERSAL
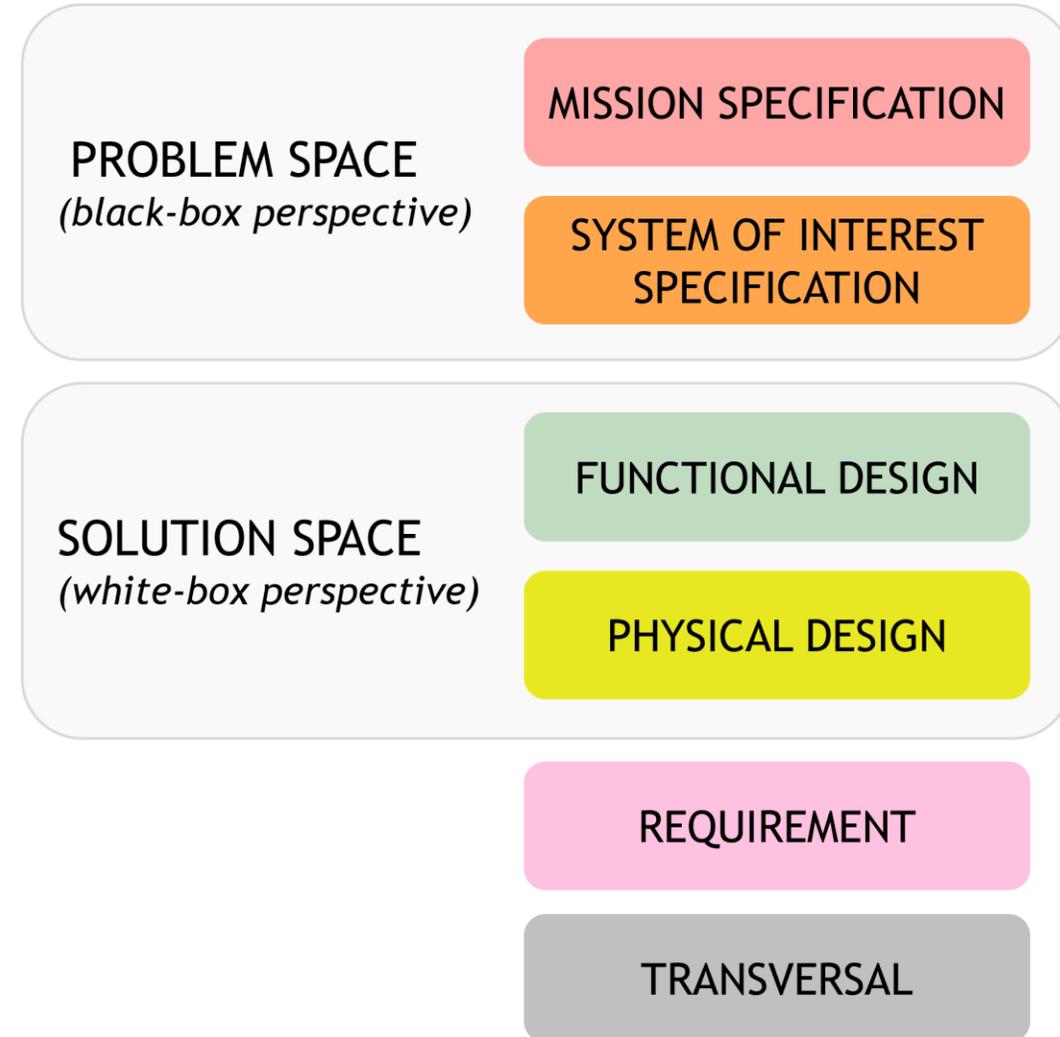
2. ESA SysML Solution
Basic elements

Replacing the SysML basic "block" element, the *Solution* defines new elements:

- Space System

- System of Interest (SoI)

- Function (and L0 Function)

- Product (and L0 Product)

The SoI is clearly separated from any other system involved in the mission. These "external systems" replace the SysML "actors"

bdd [«DefaultDiagram» Project] SysAOCS_SR [Basic Elements]
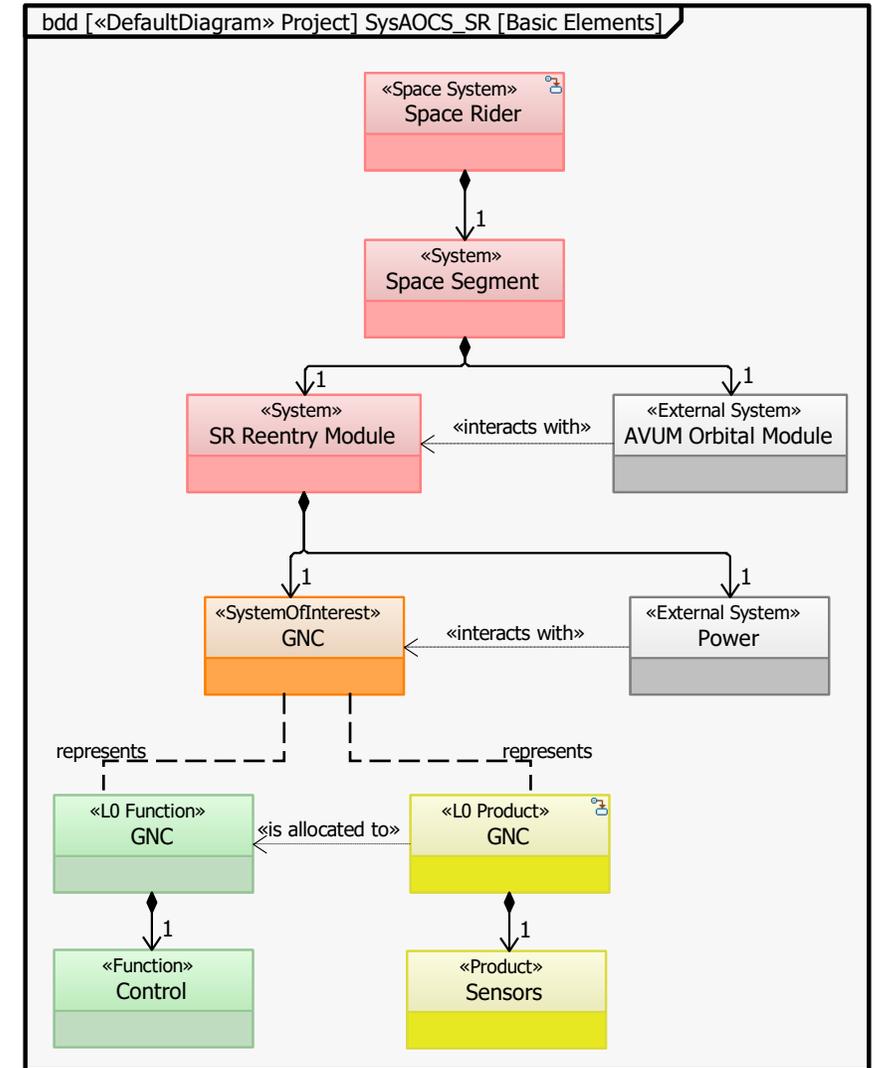
2. ESA SysML Solution
Modelling Process

The main goal of the layers belonging to the problem (specification) space is to translate the "requirements" imposed by the client into "mission objectives", defining the space system, and "capabilities" provided by the SoI

Once capabilities are specified, the solution (design) space aims to provide the set of functions (tasks) necessary during the mission in order to meet the capabilities and the products implementing those tasks (i.e., an IMU or a control algorithm)

This process is **iterative and recursive**

Client — imposes → REQUIREMENT

Space System — is defined by → MISSION OBJECTIVE — What the problem is

System of Interest — provides → CAPABILITY — What the SoI does to realize the mission objectives

PROBLEM/SPECIFICATION

FUNCTION — How the SoI works

SOLUTION/DESIGN

PRODUCT — How the SoI is implemented

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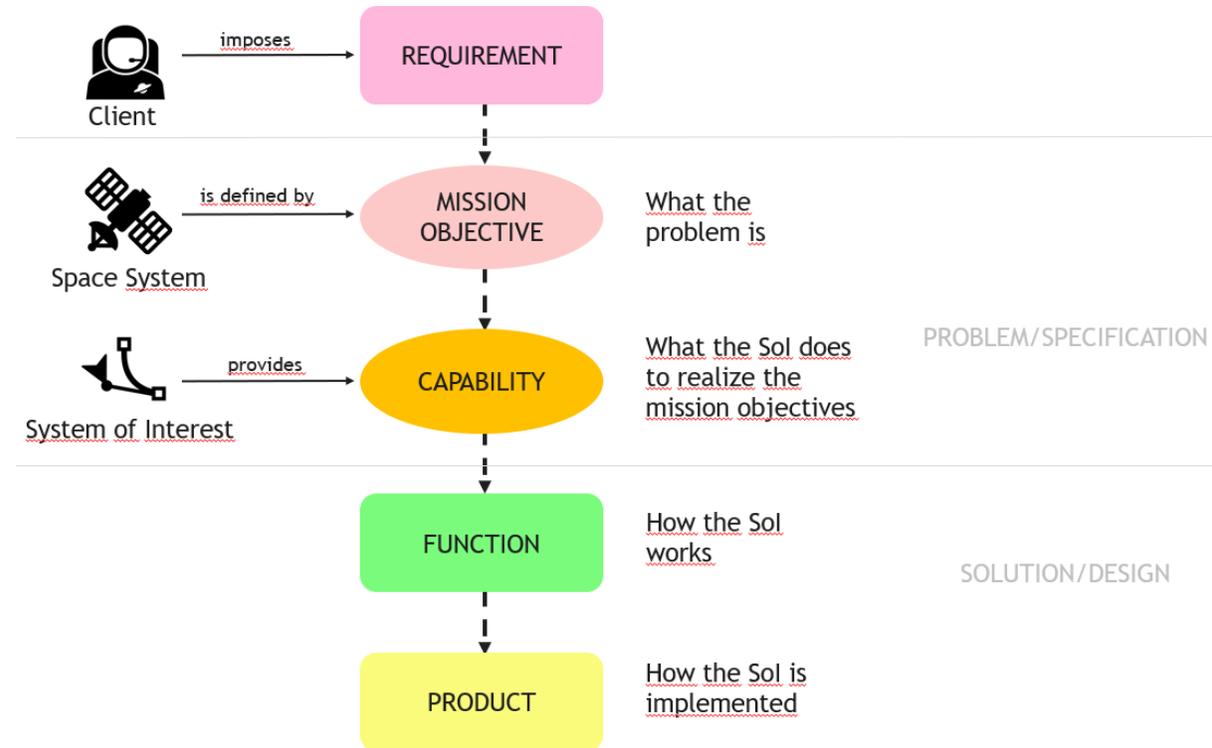
3. Space Rider GNC Study Case

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3. Space Rider Study Case
Tailoring Needs

- New modelling elements:
  - "System": any element or system of the space system segments containing the SoI at lower-levels (ECSS-S-ST-00-01C)
  - Elements addressing FDIR description
- New diagrams and table views to employ:
  - Failure Analysis diagram
  - Budgets table
- International System value type library
- Tags to extend proposed element attributes

bdd [Package] Transversal Layer [Failure Analysis]

The Failure Analysis diagram is based on a SysML Block Definition Diagram and it represents the Failure analysis and design.

It shall include the following elements:
- Failure
- Mitigation
- Detect
- Effect
- Recovery Action
- Model Element from which the Failure is derived

and relations:
- Derive Risk
- Prevent
- Identify
- Cause
- Trigger
- Act On

«Stereotype»
Mitigation

«Stereotype»
Detection

«Stereotype»
Failure
Situation or event in which a system may malfunction and trigger potential hazards or affect the outcome objectives. A risk is represented with two attributes: the probability of occurrence (how often the situation occurs, type real) and criticality (extent of potential harm) of the event
Tags
Severity=

«Stereotype»
Effect
Result or consequence that appears in the system if the risk event occurs

«Stereotype»
Recovery Action
Tags
FDIR Level=

«prevents» «causes» «identifies» «acts on» «triggers»

3. Space Rider Study Case
Mission Specification Layer

The Mission Specification layer is used as context to describe the Space Rider mission and to introduce the AOCS/GNC System of Interest. It also identifies external systems interacting with the space system or SoI

Space Rider is a reusable European space transportation system enabling routine "access to" and "return from" space

The mission objectives, mission phases and activities performed during the each of the phases are also modeled in this layer

bdd [Package] Mission Context [Mission Context]

The [**Mission Context**] diagram depicts the environment (external and internal) in which the Space Rider segments operate, representing the interactions with external sytems or stakeholders.
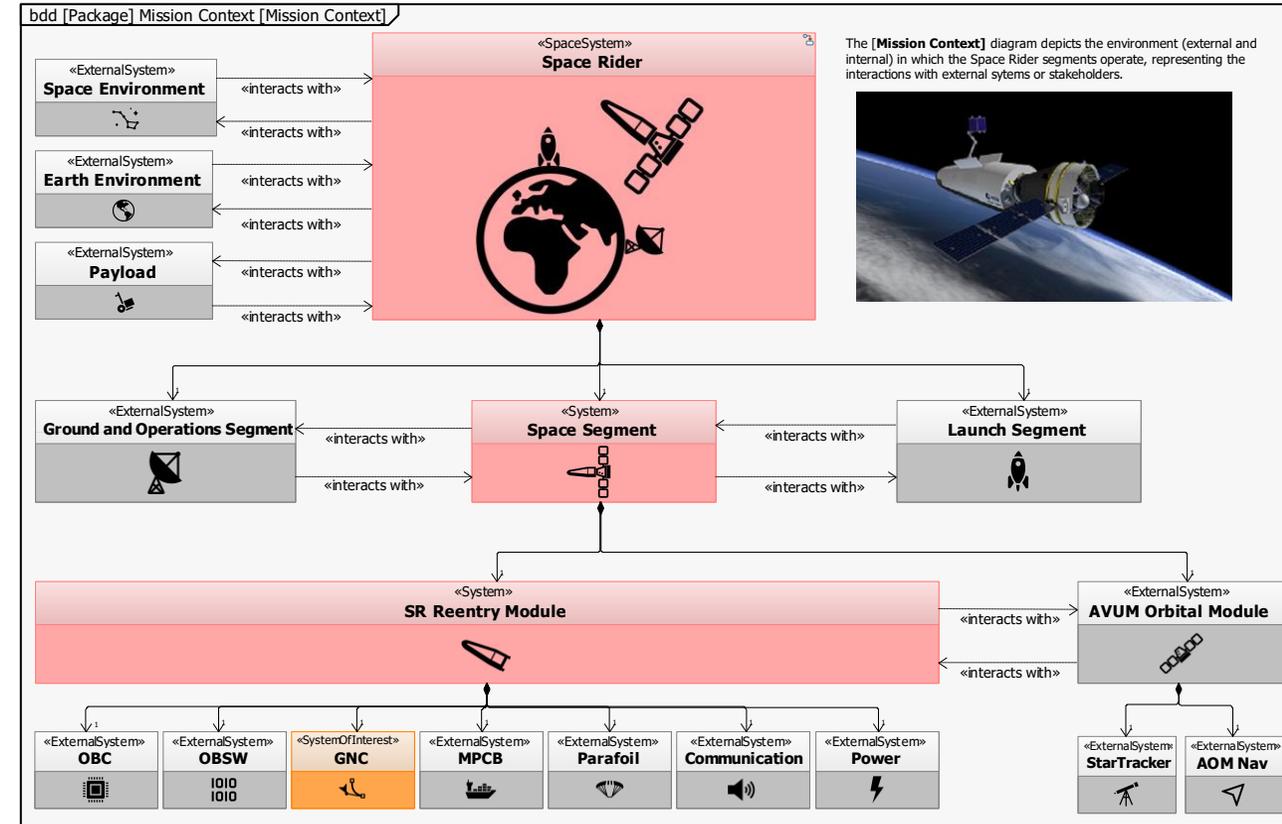
3. Space Rider Study Case

Functional Design Layer

The Functional Design layer describes the behavior of the SoI by defining a top-level function that represents it from a functional point of view (named "L0 function") and its decomposition into lower-level functions

Functional Architecture diagrams depict GNC functions internal and external interfaces. The interfaces are represented by the "exchange items" flowing to or from the functions, depicted as arrows on the connectors.

The sequence of functions including all the event occurrences are addressed using a Functional Scenario sequence or activity diagram.

The SR GNC Operational Modes are defined and represented in statecharts. All GNC **functions are "active in" on one or more operational modes** identified for the AOCS/GNC, which **will be "valid in" the mission phases** regarding the re-entry.
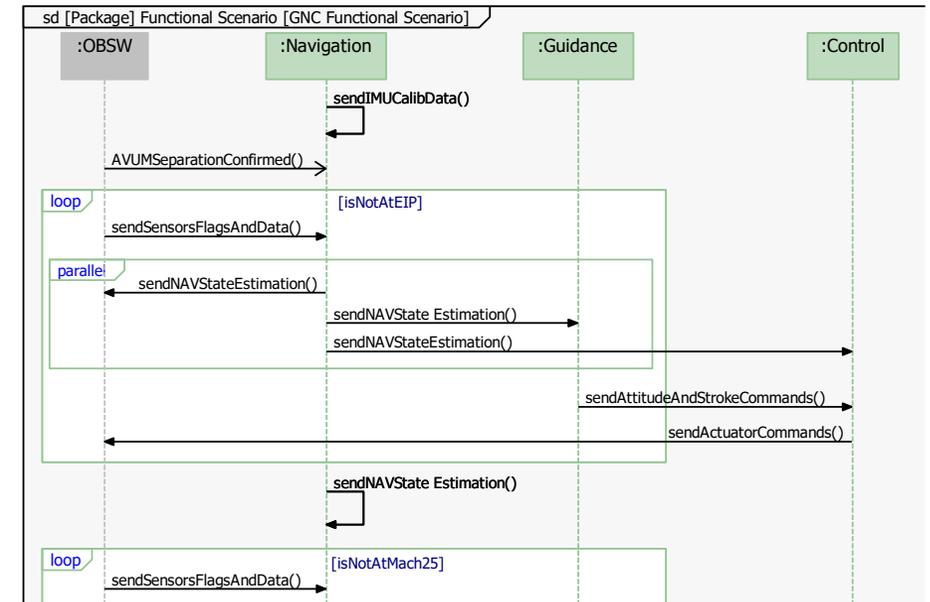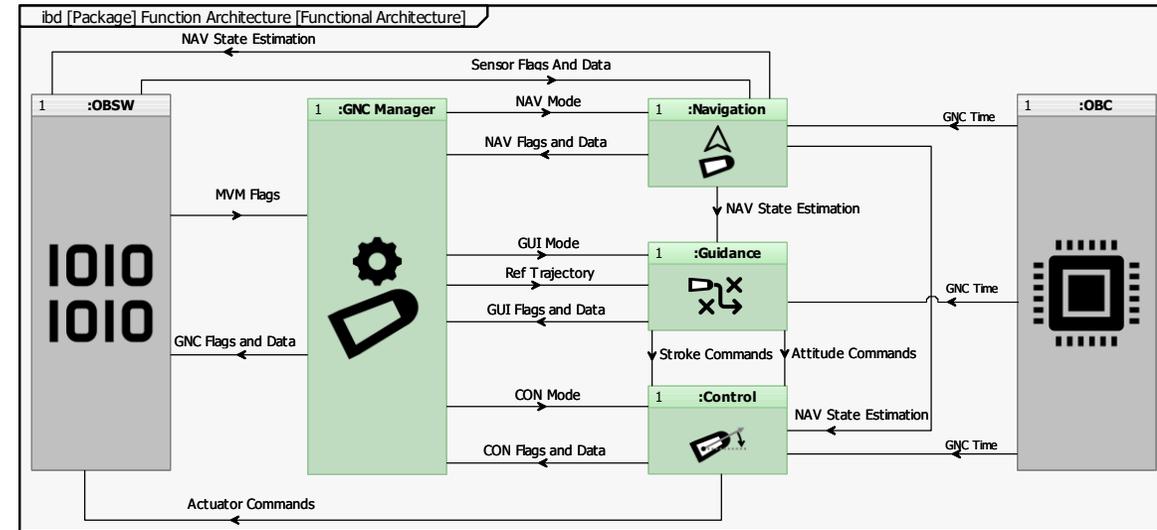
3. Space Rider Study Case
Physical Design Layer

The Physical Design layer represents the GNC from a physical point of view starting from an "L0 product", which is decomposed into the sub-products.

Other methodologies use "component" rather than "product" for the Physical Design, however, SENER considers that the product concept defined by ECSS-S-ST-00-01C is better suited for the hardware and software elements of the AOCS/GNC subsystem.

This physical decomposition is represented in a Product Tree diagram and interfaces between the main GNC products and the OBSW external system are shown in Physical Architecture diagrams
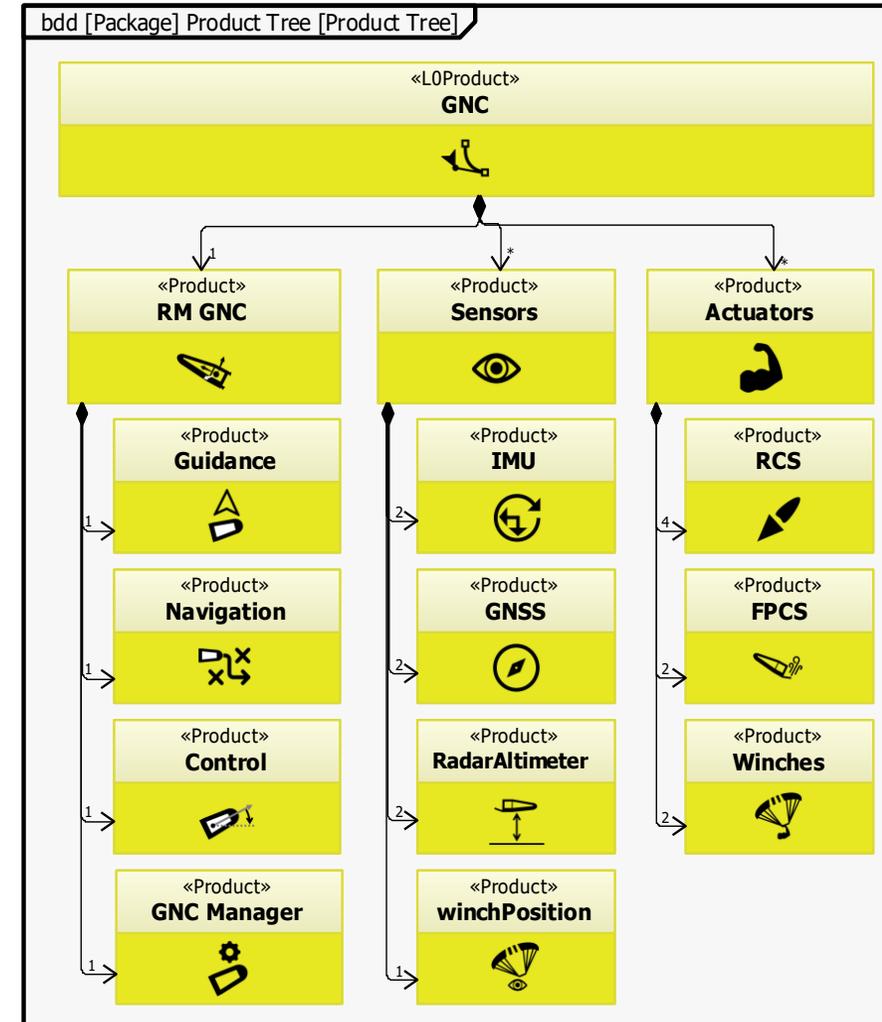
3. Space Rider Study Case

Transversal Layer

The Transversal layer compiles all elements used throughout the other layers:

- External systems interacting with the space system or SoI

- Exchange items flowing to or from functions and products

- Failure analysis elements for FDIR design

For FDIR description, "failures" that could make functions not available, "recovery actions", "effect" of their occurrence, "mitigations" to prevent the failure from happening and "detection" means

bdd [Failure] Landing phase initial conditions [Landing phase initial conditions FDIR]

«Function»
Guidance

«derives from»

«Detection»
Check if landing point can be reached

The guidance will check if the landing point can be reached and provide a flag to FDI such a caseInternal detection. Safety flag shall be issued by the function.

Observable
Guidance flag mode are/should be

«identifies»

«Failure»
Landing phase initial conditions

Landing phase initial conditions and wind conditions are such that it is not possible to reach the landing area

Tags
🗁Severity=1

«causes»

«Effect»
No pinpoint landing

Local: Guidance function detects that the expected wind conditions and initial height do not allow to reach the landing point
End: No pinpoint landing

«acts on»

«Recovery Action»
Communicate the state to safety Spike filter

FDIR shall communicate the state to safety Spike filter (3 times TBC) to be implemented

Tags
🗁FDIR Level=2

«triggers»

3. Space Rider Study Case
Model Organization

SENER proposes to create two main packages:

- DDF (or any other AOCS document): Hyperlinks to diagrams, tables and matrix views needed to justify the information required from the ECSS standard
- Common database: All the mission information

This model organization limits the duplication and simplifies the reuse of elements in different AOCS documents. It supports navigability with deeply nested diagrams to easily access system information at lower levels
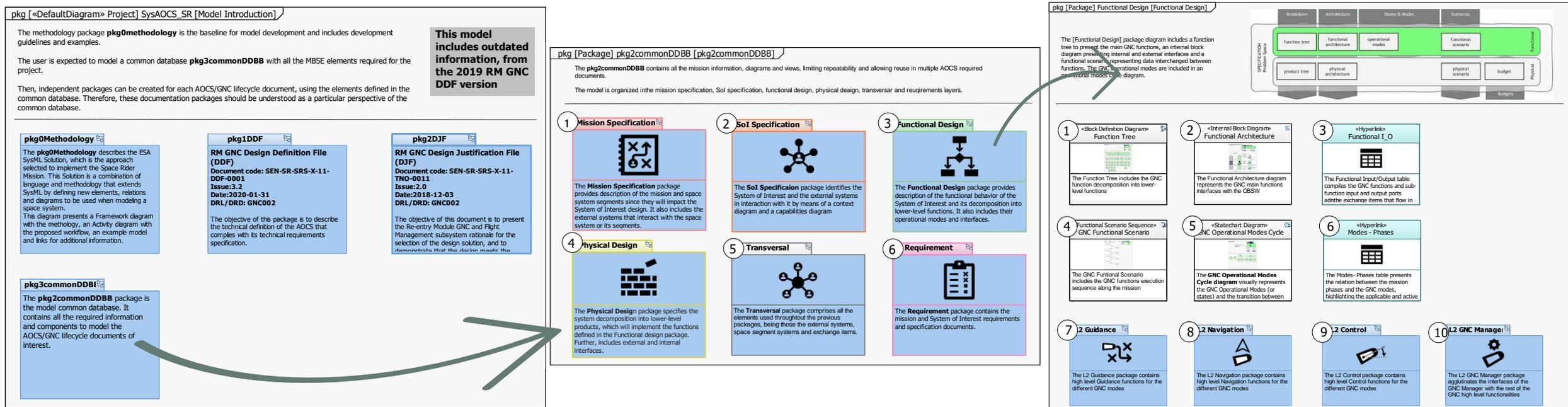
4. Euclid AOCS Study Case

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4. Euclid AOCS Study Case
Tailoring needs

- Model **spacecraft modes**: New element "mission mode" and new diagram

- Image **mapping to ESA SysML Solution**: Help locate the diagram in the model

- Implementation of **Custom Views** to allow filtering diagrams: FDIR and nominal mode transitions
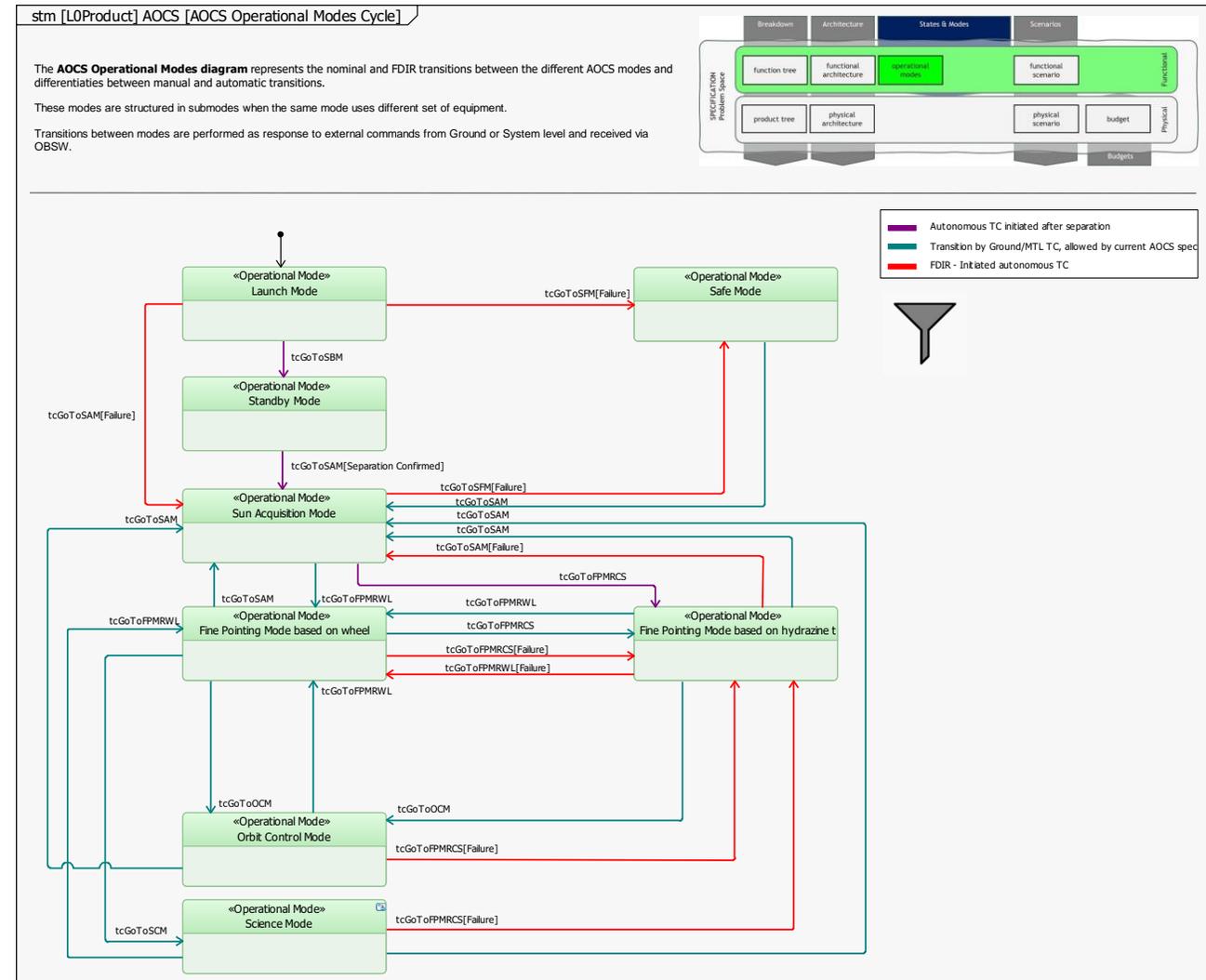
4. Euclid AOCS Study Case

Mission Specification layer

Euclid is an ESA second class mission dedicated to investigating the dark matter and dark universe.

The Space Segment is composed of:

- Payload Module: telescope and required instruments
- Service Module: subsystems necessary for the mission, including the SoI, the AOCS

Implementation of this study case arose the problematic of having a scattered System of Interest, not supported by the *Solution*.

→ external system to represent the structural belonginess and product for the real description of the sensor.
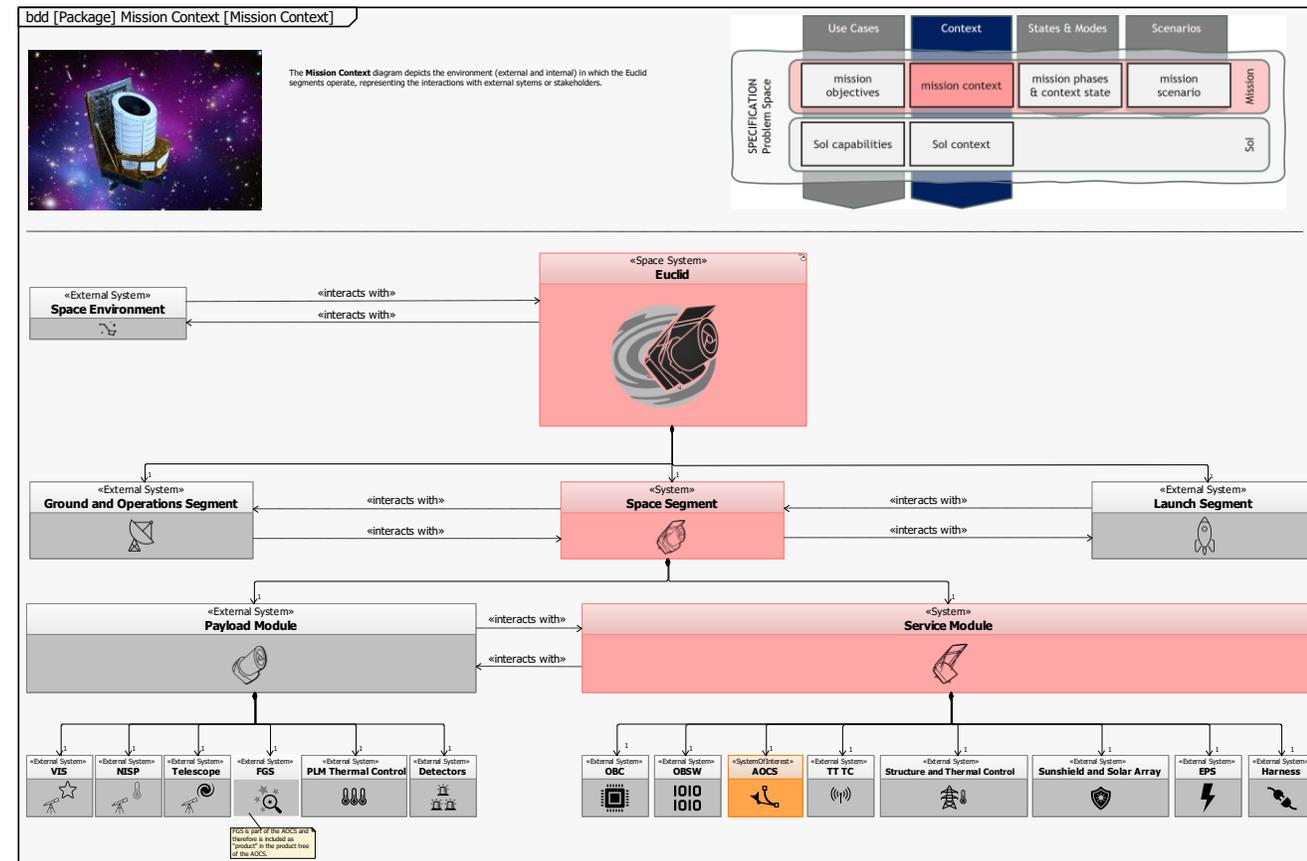
4. Euclid AOCS Study Case
Physical Design layer

The main difference with respect to the SR mission is the modelling of the AOCS decomposition into products.

- SR GNC is organized by navigation, guidance and control functions and subfunctions,

- Euclid AOCS is structured by a mode architecture

This organization influences the implementation of mode cycle diagrams and interface diagrams

Diverging the AOCS/GNC profile into two profiles was deemed necessary to better fit the differences in structure between an AOCS and a GNC
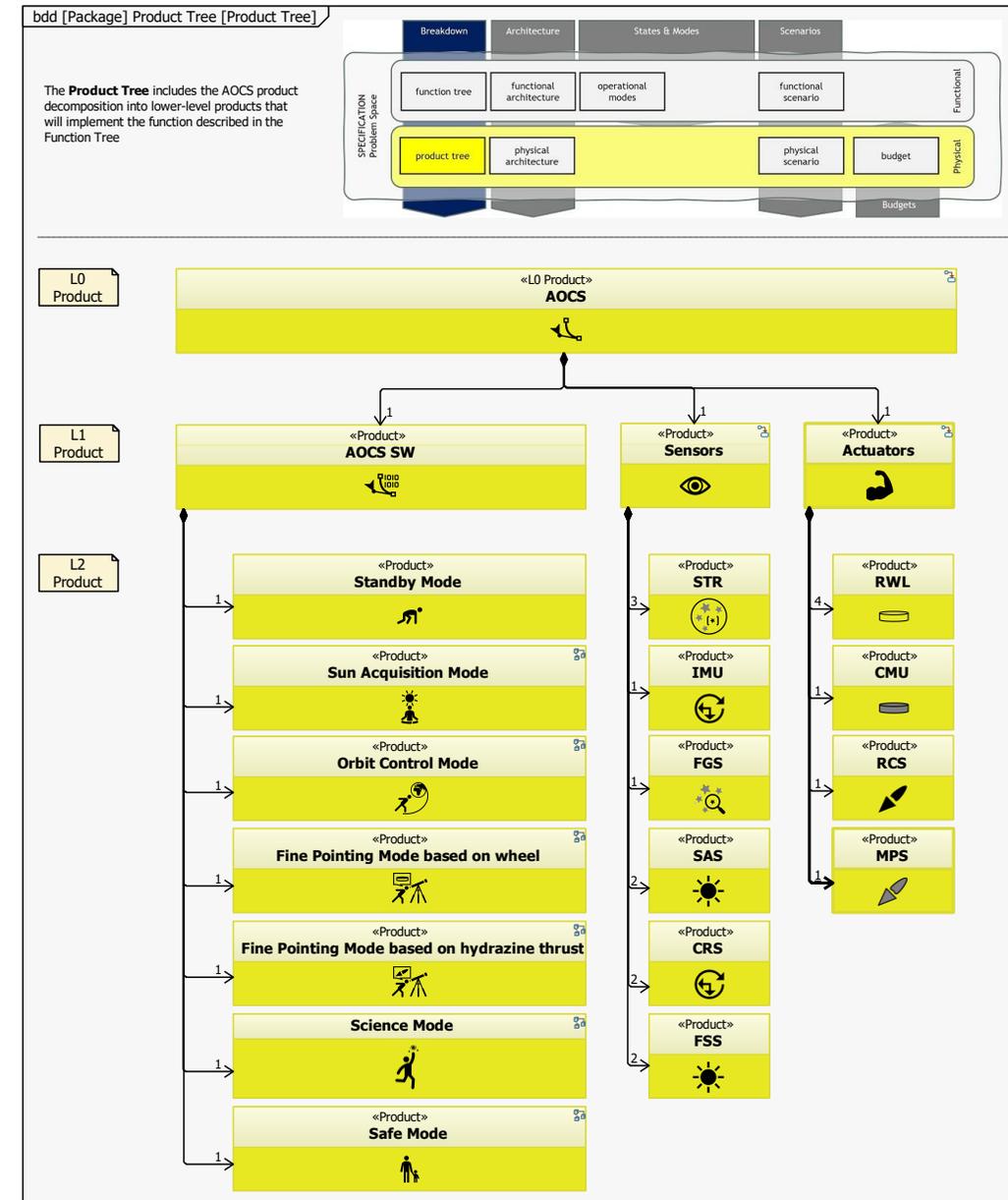
5. Conclusions

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5. Conclusions

- Along the SysAOCS project, two study cases were employed based on real AOCS/GNC architectures, Space Rider and Euclid, to implement the ESA SysML Solution and generate an AOCS/GNC profile. Little rework was needed to adapt the *Solution* to an AOCS/GNC subsystem

- The AOCS/GNC models have been reviewed by system engineers and AOCS/GNC engineers in SENER and ESA, who gave very good feedback in terms of clarity, readability and completeness

- The main outcome of the activity is the discovery of the very good maturity level of the ESA SysML Solution and its full suitability to describe the AOCS/GNC subsystem

- A key takeaway is the proposed model organization, which enables a quick, flexible and traceable modelling of any required AOCS/GNC lifecycle document from the information contained in the common database

6. References

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6. References

[1] **ARCADIA method**: https://www.eclipse.org/capella/arcadia.html

[2] J.B. Bernaudin, F. Payot. **MBSE for MSR-ERO: a use case**. MBSE 2021 29/09/2021

[3] OMG. **United Architecture Framework (UAF) Domain Metamodel v1.2.** 03/2022

[4] IBM. **Harmony aMBSE Deskbook Version 1.02.** 09/2017

[5] A. Gonzalez Fernandez. **ESA MBSE Evolution: From ESA SysML Toolbox to ESA MBSE Solution**. MBSE 2021 29/09/2021.

[6] L. Tarabini Castellani, R. Haya, A. Ayuso, **Space Rider Thruster Configuration and Control Strategy Optimisation.** 10th International ESA Conference on Guidance, Navigation & Control Systems, Salzburg (Austria). 05/2017

[7] J. Salvador Llorente, A. Asenjo, R. Sánchez, C. Ardura, F. Cacciatore, L. Meijer, M. Saponara, C. Rosso, G. Saavedra. **Euclid AOCS – Hihest pointing stability for Dark Universe Investigation.** EUCASS 2019

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