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Scalable Attitude and Orbit Control System for CubeSats

ASI Workshop “L’impegno italiano nel settore dei CubeSat: tecnologie e missioni future” – 2° edizione

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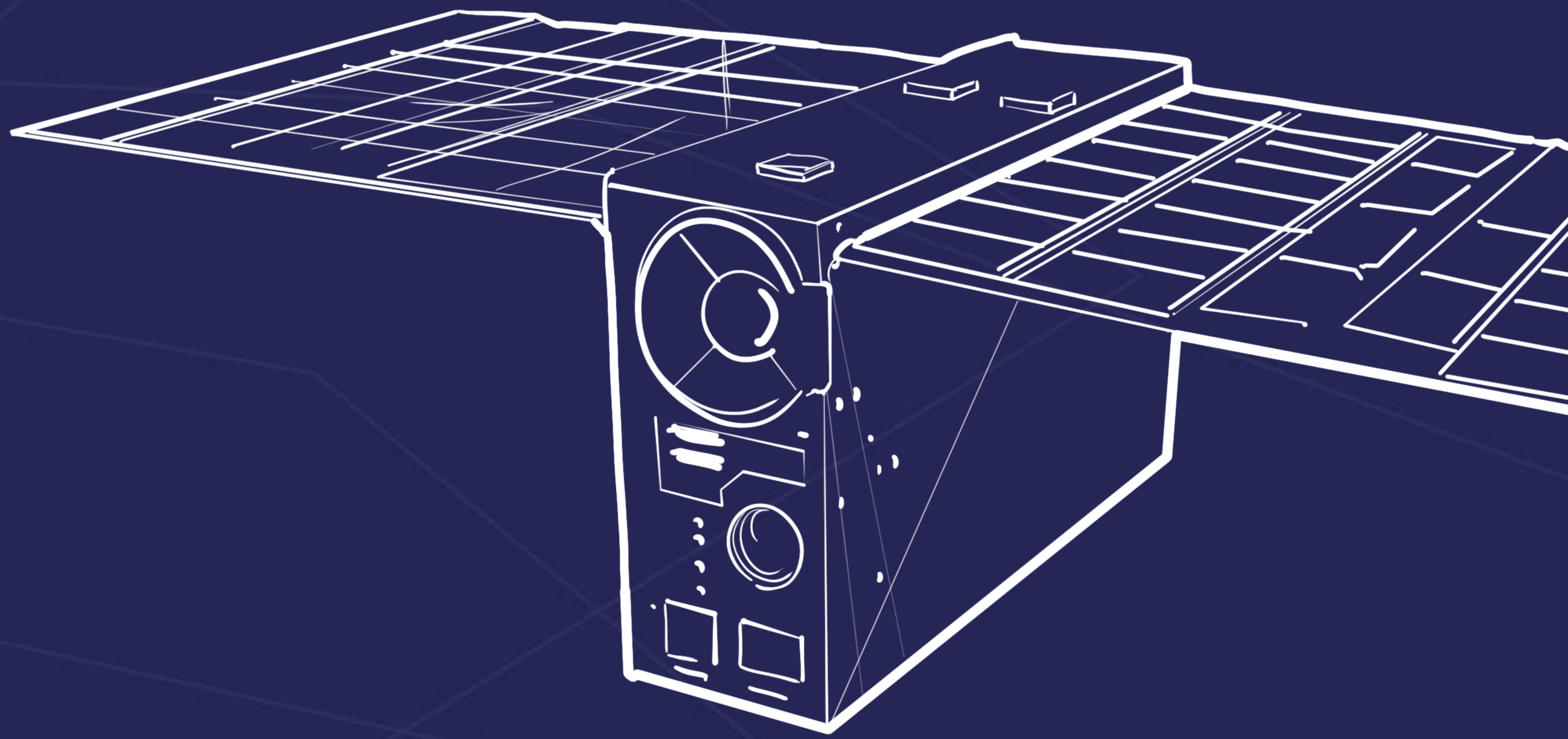
Town, State: Rome, Italy

Date: 02/07/2024

Agenda

1. Argotec Portfolio
2. PYXIS – a Versatile AOCS Subsystem
3. Next Steps in the Development



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Argotec Portfolio

Small Satellite Platforms

Argotec designs and manufactures high-reliable rad-hard small satellite platforms able to **operate in different environments, from deep space to LEO.**

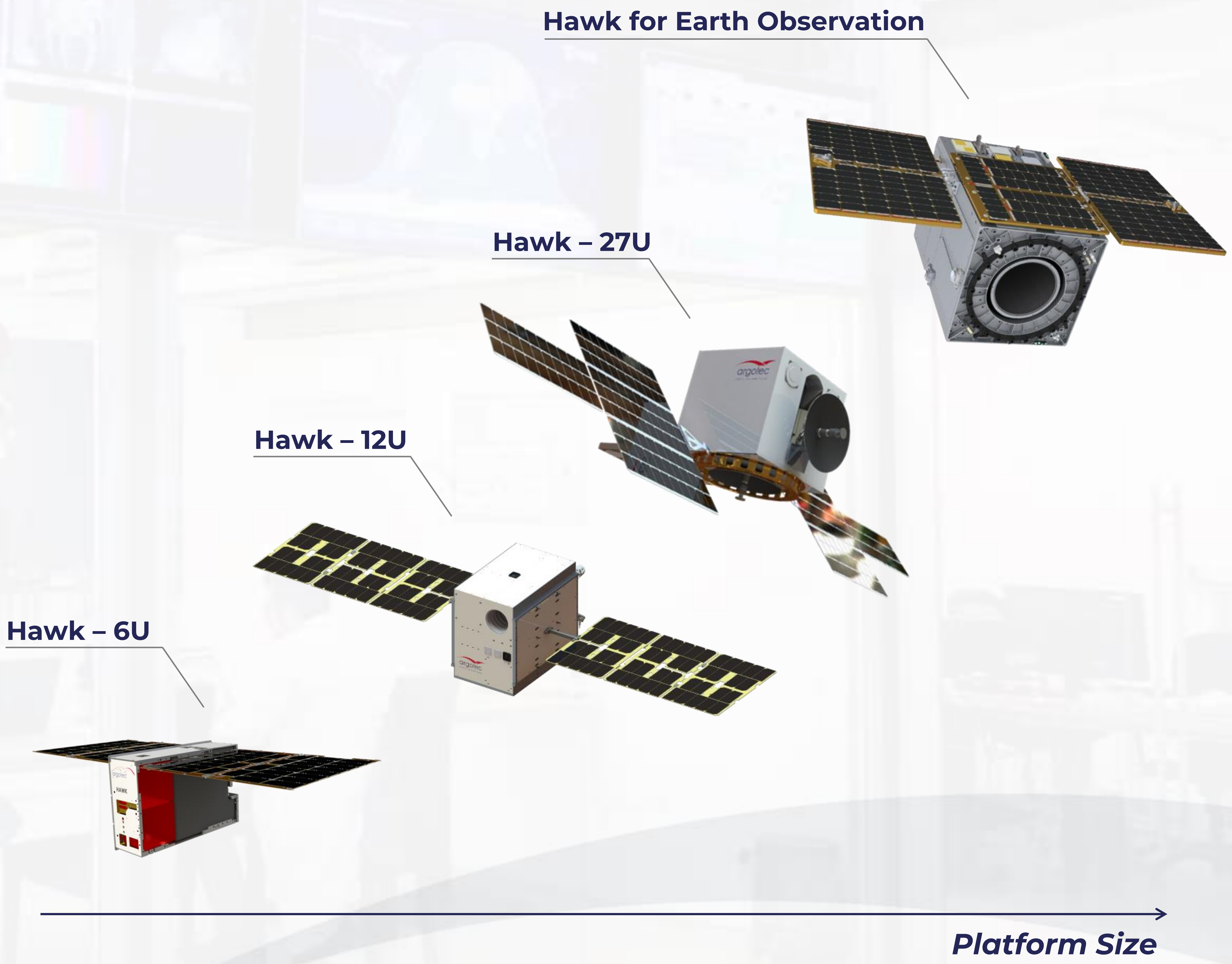
The company developed a proprietary scalable satellite platform **from 6U up to 27U** (and more, up to 200 kg).

In 2023, Argotec is the only company in the world to have built **two small satellites that have operated in deep space.**

ArgoMoon
(Artemis I)

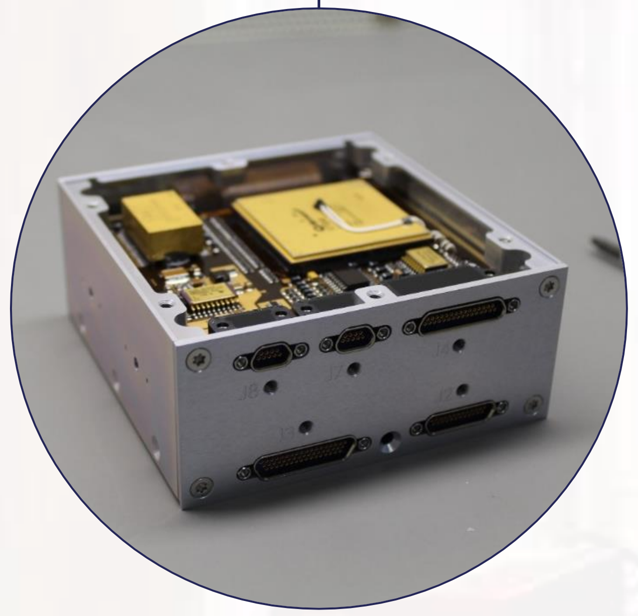
LICIACube
(DART)

Argotec was the first company to sign the IRIDE agreements. The goal is to provide a constellation of 40 satellites to integrate one of the biggest Earth Observation constellation in Europe.



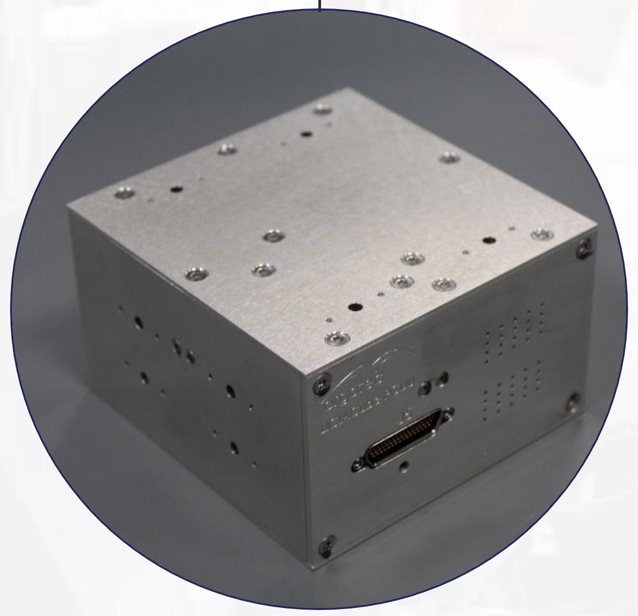
Argotec Portfolio

All-in-House Concept



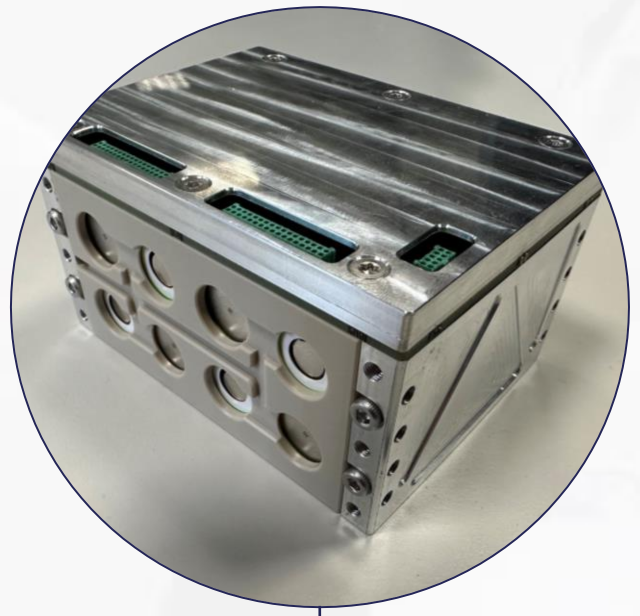
FERMI - OBC

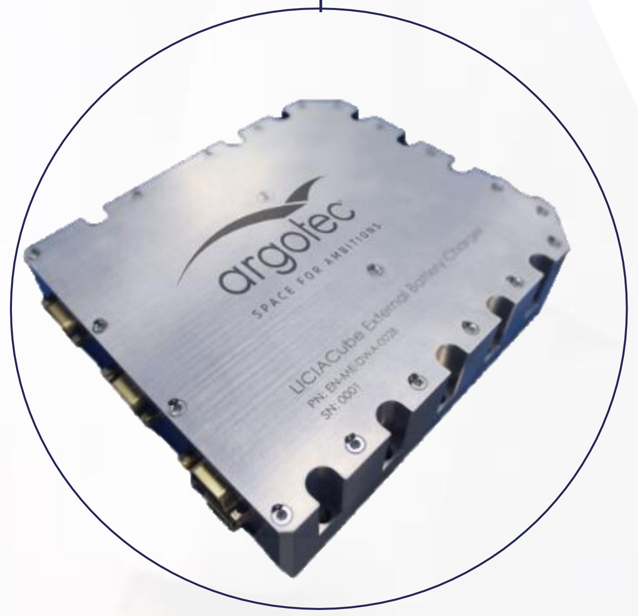
HACK - OBC



VOLTA - PCDU

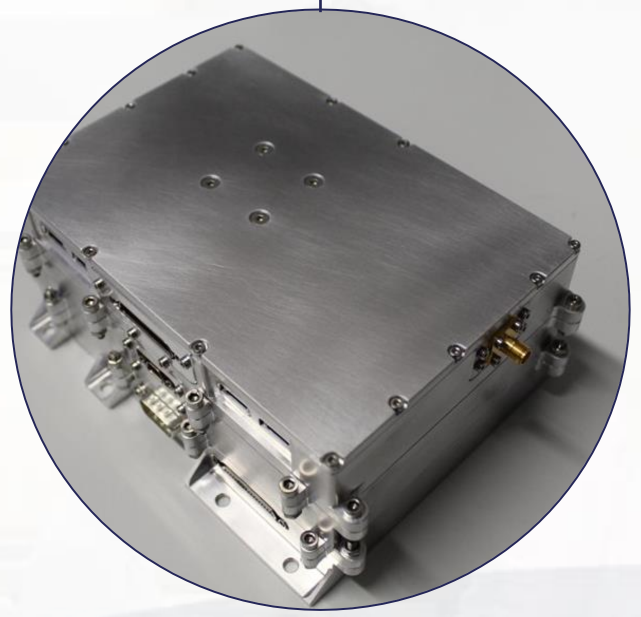
ELEKTRA – Battery System





External Battery Charger

ZEUS - PCDU



ERMES – Deep Space Transreceiver

Argotec Portfolio

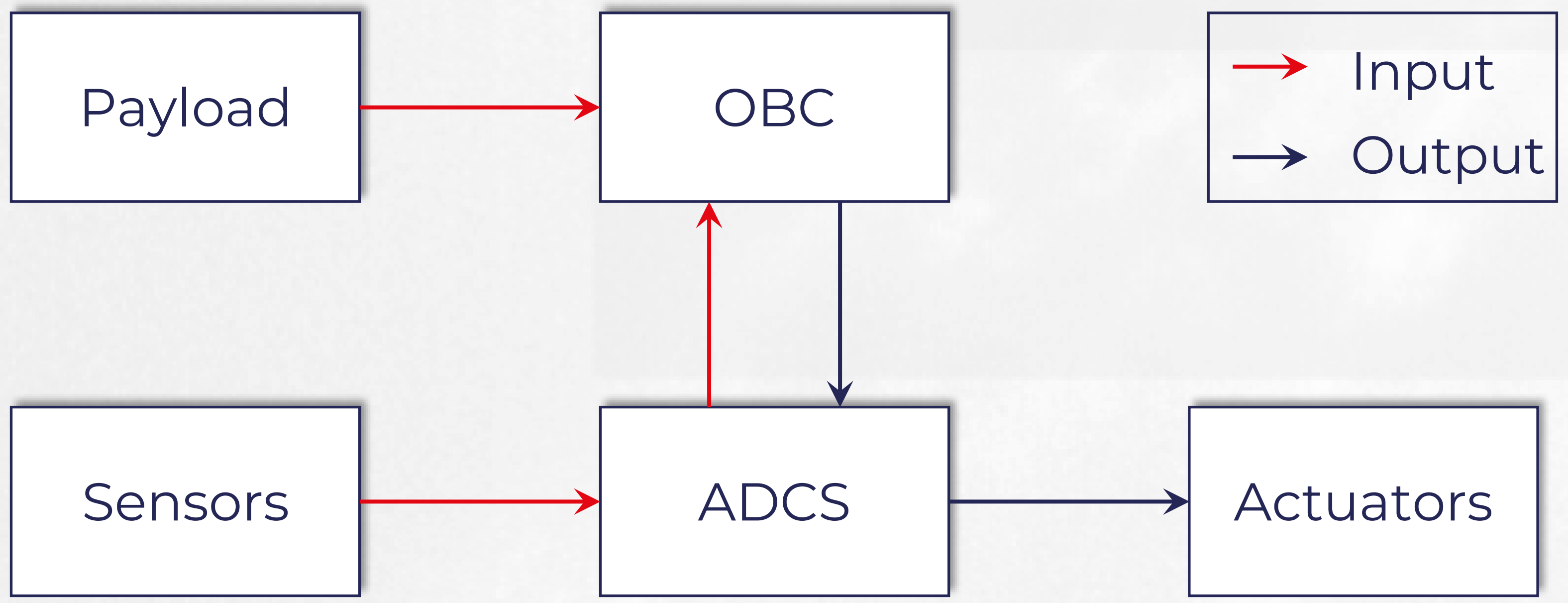
LICIACube Mission and GNC Application

For the **LICIACube** mission, an **autonomous navigation system** was developed for its Science phase:

Its objective was to capture the **impact** between **DART** and **Dimorphos** while performing a fly-by of approximately 55 km.

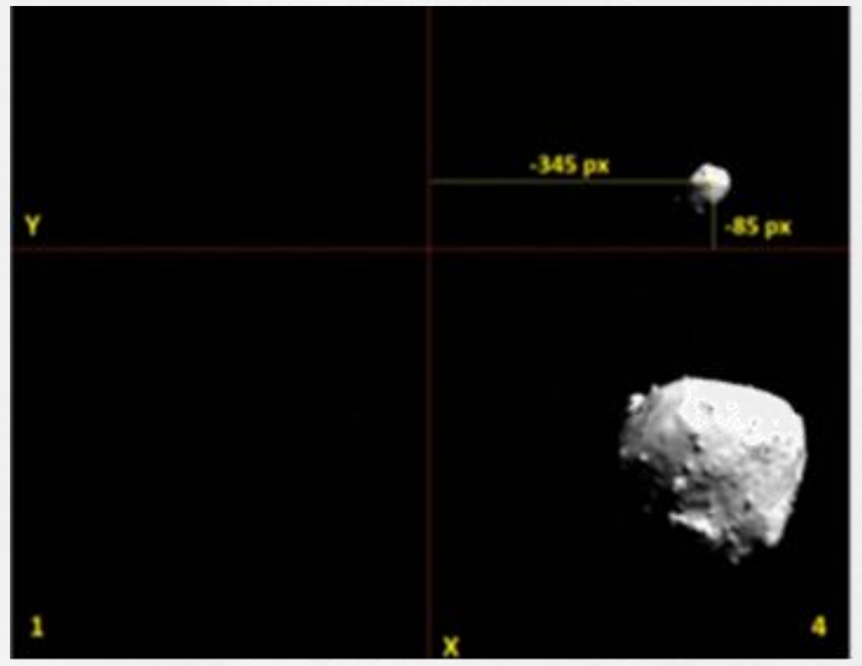
For this system, we used the ADCS by commanding it with **our own attitude controller**, which used the data from the ADCS sensors and actuators as well as from the payload thanks to an **AI** trained in image recognition.

The **systems parameter** would **change** in **different phases** of the science phase, to be able to keep track of the asteroids.



The system was validated thanks to SIL and HIL testing:

HIL



Reality

(Credits: ASI – NASA)

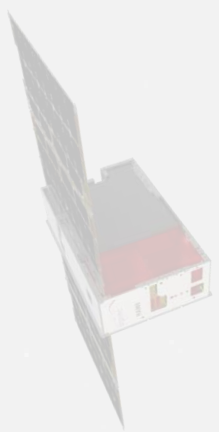
PYXIS – a Versatile AOCS Subsystem

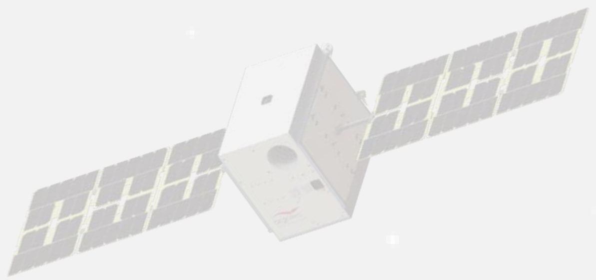
Argotec's Rationale and Goal

In the field of AOCS technologies, there are few available options in terms of avionics, particularly for missions with stringent requirements and deep space applications.

PYXIS aims to fill this gap. Argotec's goal is:

- to realize an **integrated**, **modular** and **scalable** AOCS that can be adapted to a wide variety of smallsats.
- offering **state-of-the-art performance** and **short lead time**.
- and most importantly that **can be applied** in both LEO and **Deep Space** missions, with a special focus on the latter.





The AOCS may therefore be employed in missions including:

- Earth observation
- Communication
- Science
- Etc.

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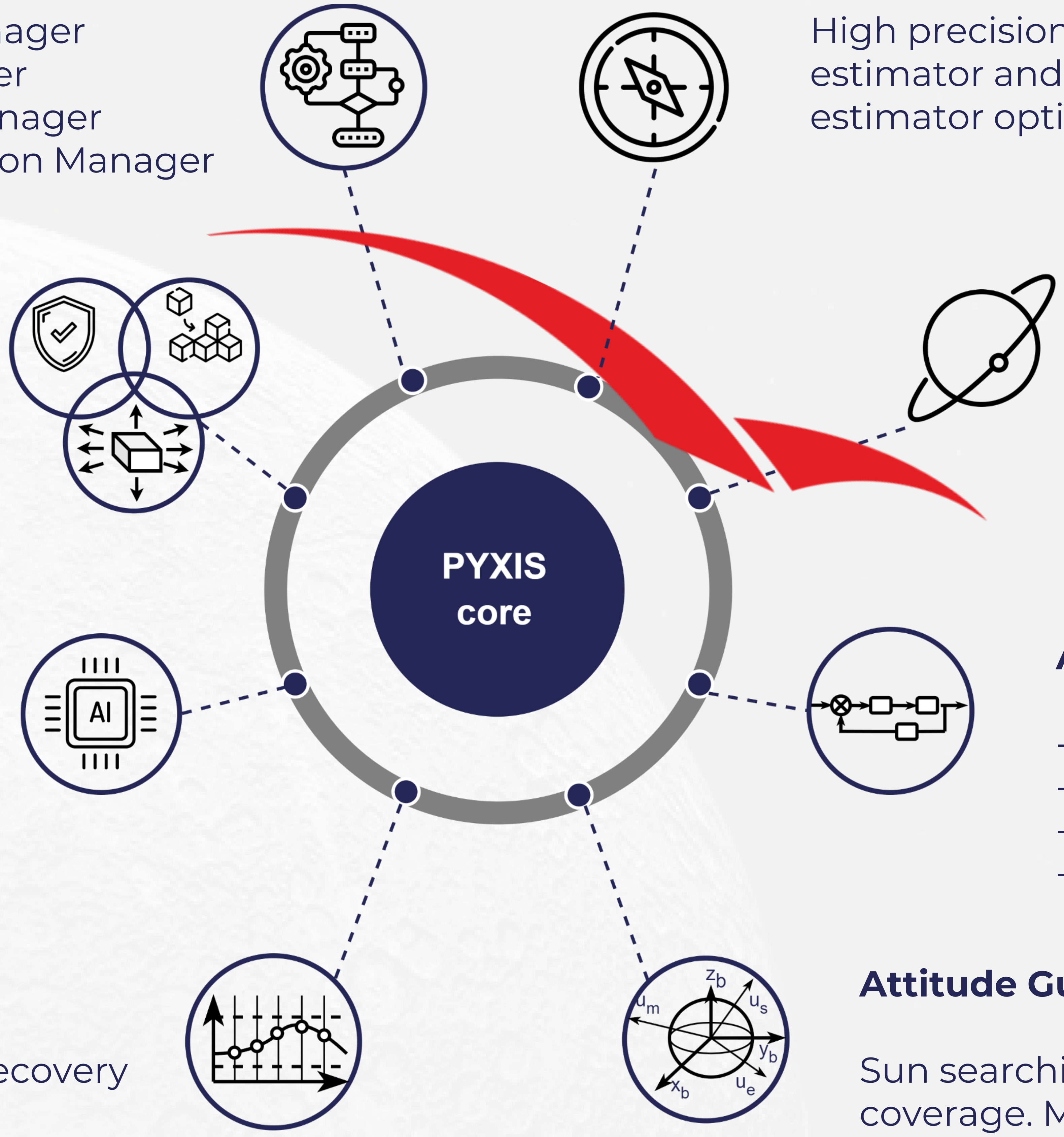
PYXIS – a Versatile AOCS Subsystem

AOCS Subsystem Functionalities



Multiple Manager Modules

- Control Modes Manager
- Equipment Manager
- Telecommands Manager
- System Configuration Manager

Attitude Determination

High precision gyro-stellar estimator and other coarse estimator options available

Reliability, Modularity, Scalability

Both hardware and software highly modular and reliable. Easy customization of SW algorithms. Scalable in terms of sensor and actuator suites.

Orbit Propagators

Multiple orbit propagators available for both earth orbit and deep space missions

AI On-Board

AI-based controller for under actuated spacecraft. AI-based system momentum management

Attitude Control

- High accuracy fine pointing controller
- High agility acquisition controller
- High robustness
- Spacecraft momentum control

FDIR Functions

Fault detection, isolation and recovery functions available on-board.

Attitude Guidance

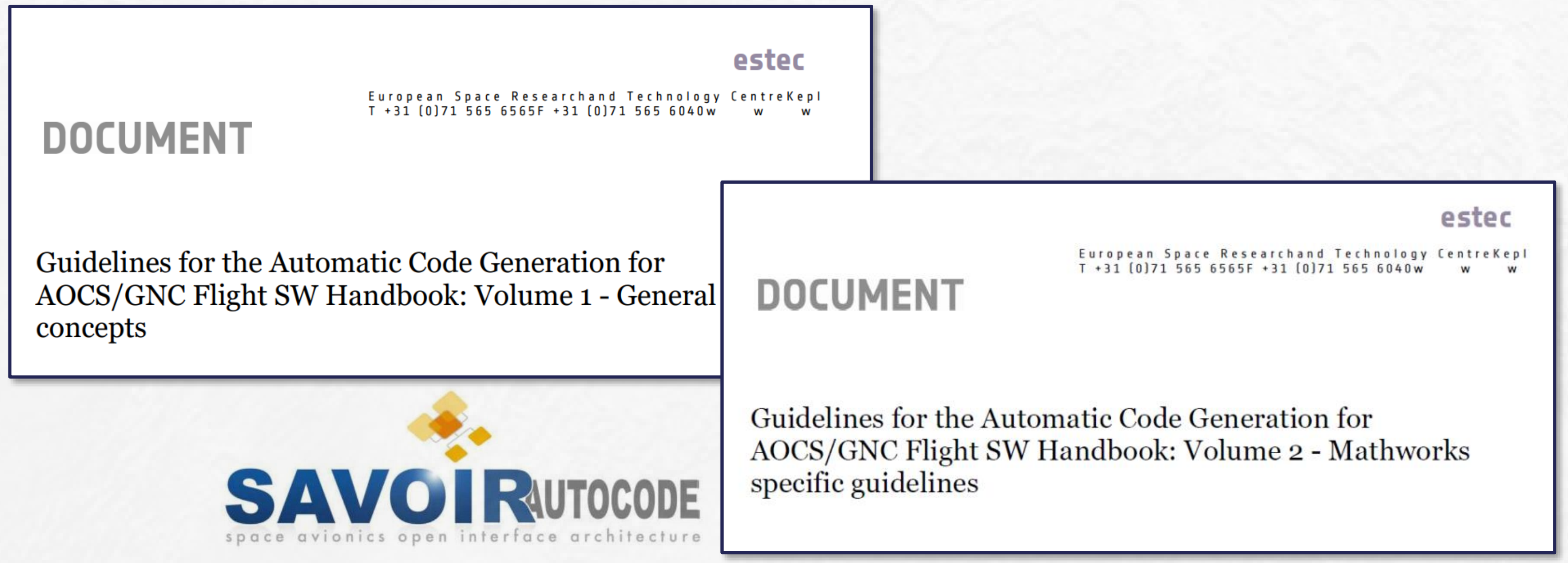
Sun searching maneuvers with full celestial sphere coverage. Multiple pointing options: target tracking control, sun/moon/earth pointing, etc. Desired pointing vectors based on high accuracy on-board models.

PYXIS – a Versatile AOCS Subsystem

On-Board Software Architecture Features

PYXIS On-Board software is divided in two main parts: the central core, which is hardware-independent, and the low-level code to interface with the hardware.

- Over 90% of the flight software is auto-coded using MATLAB/Simulink and Model Based Design technique.
- Near 100% software re-use across all spacecraft.
- The MATLAB/Simulink models for the flight software were created in strict compliance with the guidelines in the Handbook compiled by SAVOIR.


estec

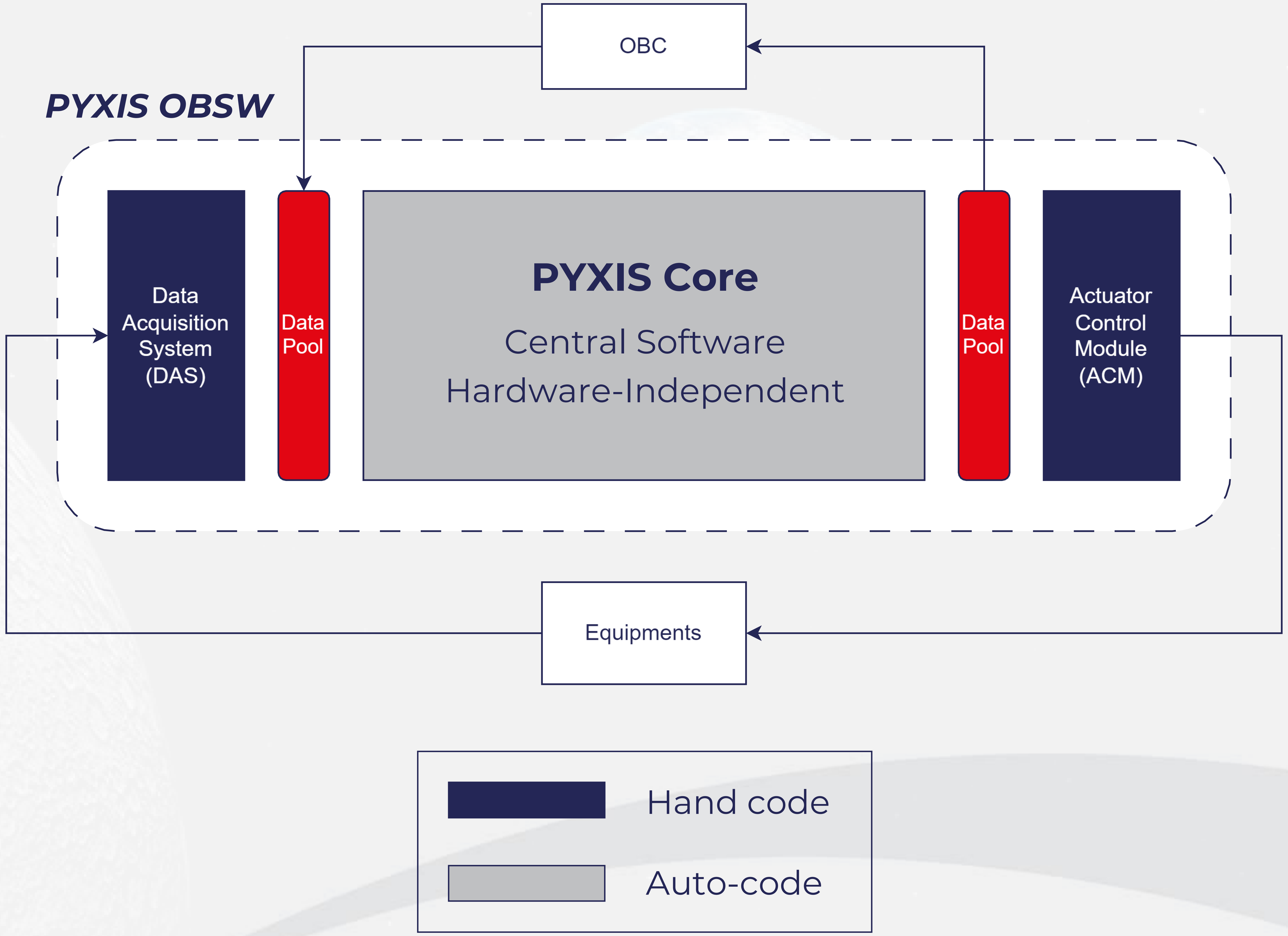
DOCUMENT

Guidelines for the Automatic Code Generation for AOCS/GNC Flight SW Handbook: Volume 1 - General concepts

estec

DOCUMENT

Guidelines for the Automatic Code Generation for AOCS/GNC Flight SW Handbook: Volume 2 - Mathworks specific guidelines



PYXIS – a Versatile AOCS Subsystem

On-Board Software Architecture Features

1. Portability

Easy transfer across platforms: Since the core is hardware-independent, it can be easily ported to different hardware platforms without significant modifications.

2. Maintainability

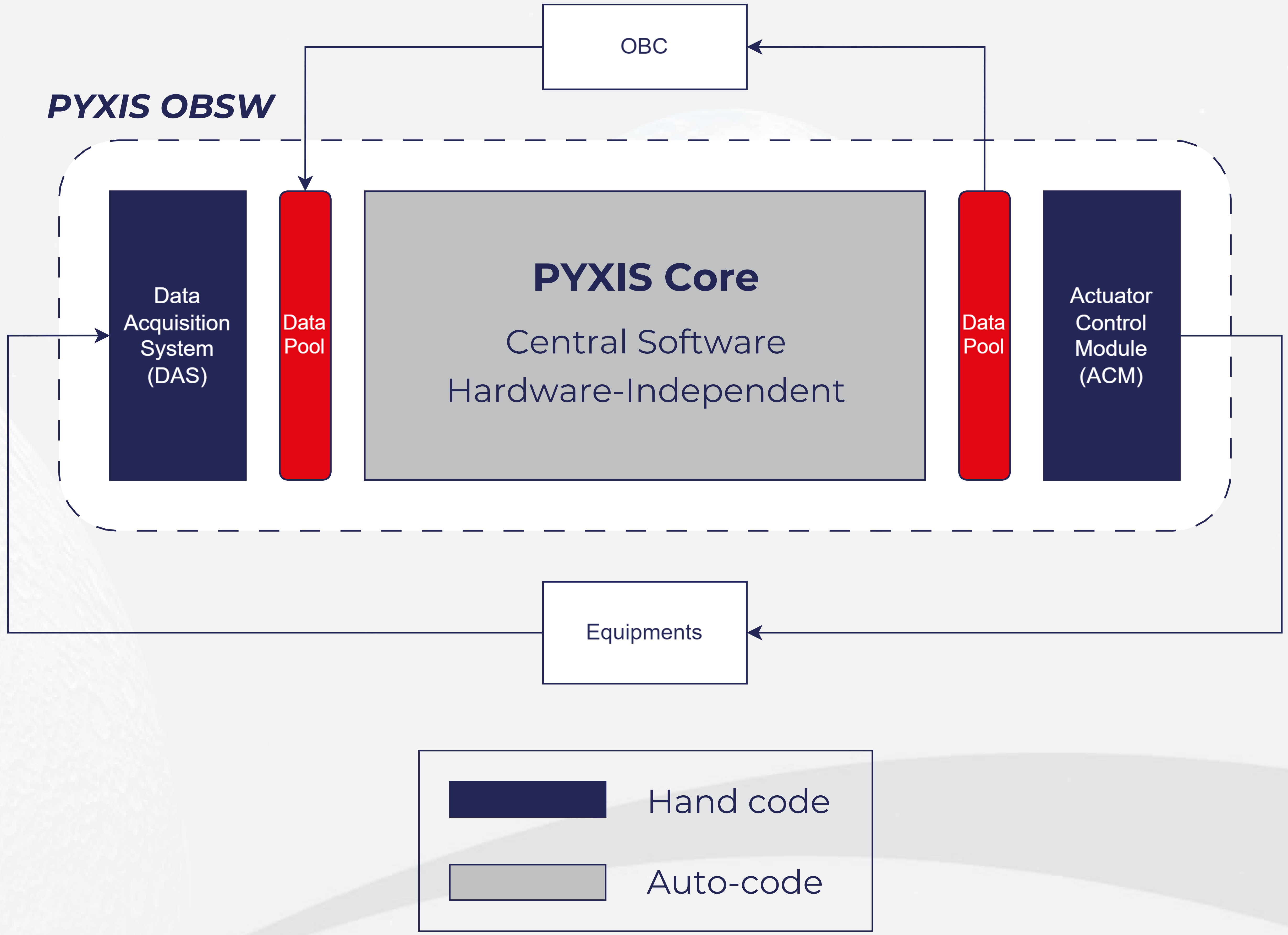
Separation of responsibilities: This architecture isolates changes, so modifications in the hardware interface software do not affect the central core, and vice versa.

3. Scalability

Simplified hardware/software updates: Updating hardware or adding new devices can be handled by modifying only the interface software, without altering the core, and vice versa.

4. Reliability

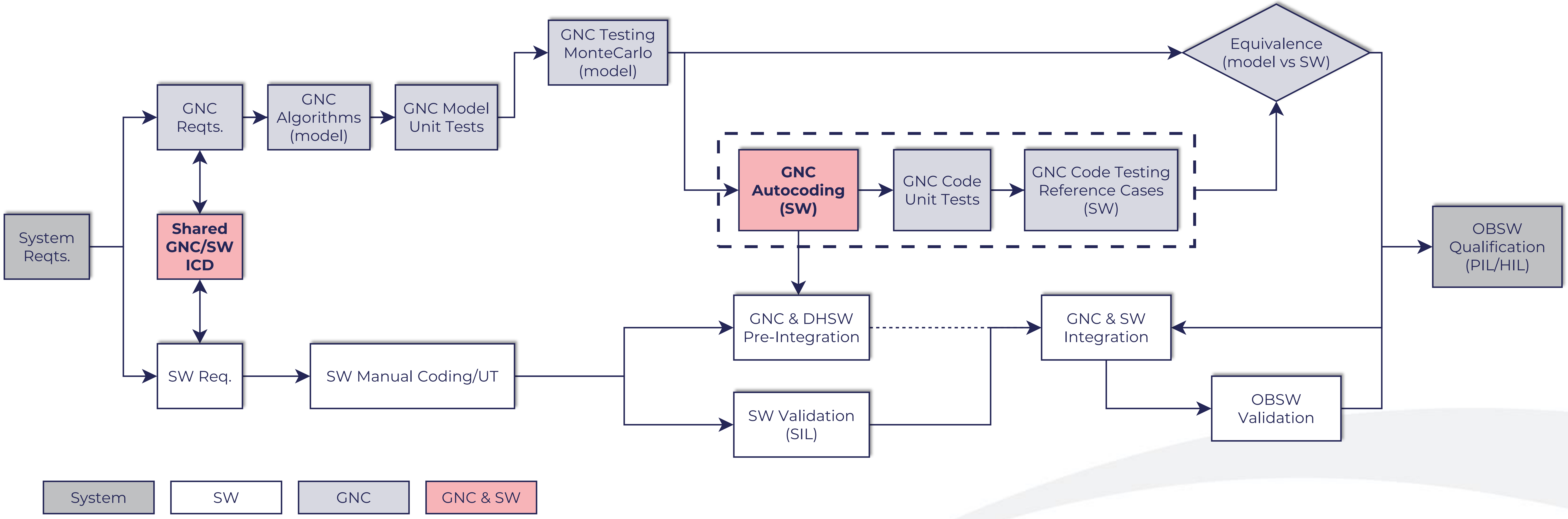
Independent core testing: The core can be tested independently of the hardware, making it easier to identify and fix errors effectively.



PYXIS – a Versatile AOCS Subsystem

Development of New Algorithms

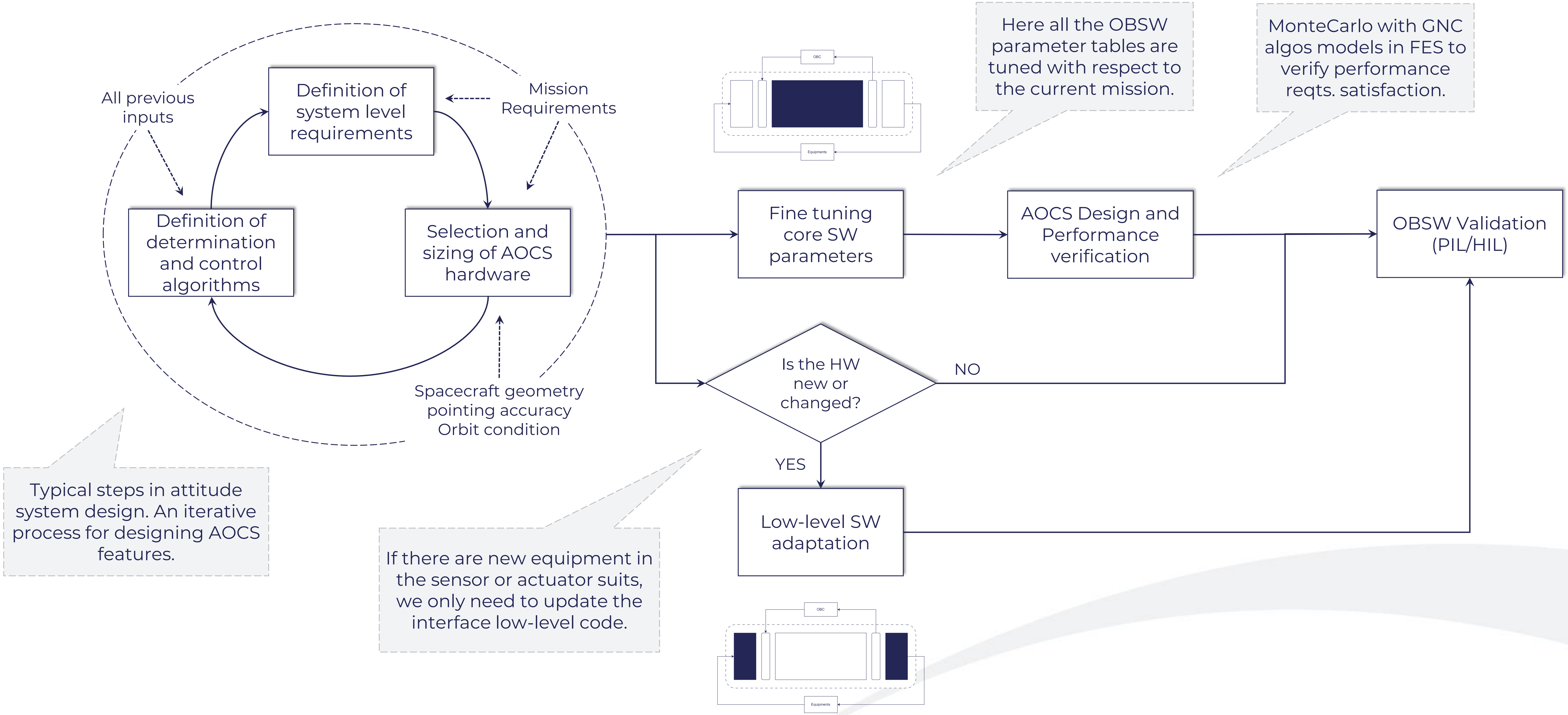
With this OBSW architecture and the autocoding approach, adding new GNC algorithms (e.g., personalized GNC algo to satisfy specific mission needs) becomes easier and faster. The following drawing summarizes an example of the GNC SW development process with autocoding:



Adapted from: SAVOIR-HB-005_i1 Guidelines for the Automatic Code Generation for AOCS/GNC Flight SW Handbook: Volume 1 – General concepts

PYXIS – a Versatile AOCS Subsystem

Fine Tuning and Tailoring for Missions



PYXIS – a Versatile AOCS Subsystem

Hardware Features

Mission Types:

- Earth Orbit Missions:
  - Utilize reaction wheels with magnetic torquers for angular momentum management.

- Deep Space Missions:
  - Magnetic torquers are not viable due to the absence of a magnetic field.
  - Employ Reaction Control Systems (RCS) with thrusters for both high agility attitude maneuvers and angular momentum management.
  - RCS also supports orbit control, necessitating a propulsion system.

Actuator Considerations:

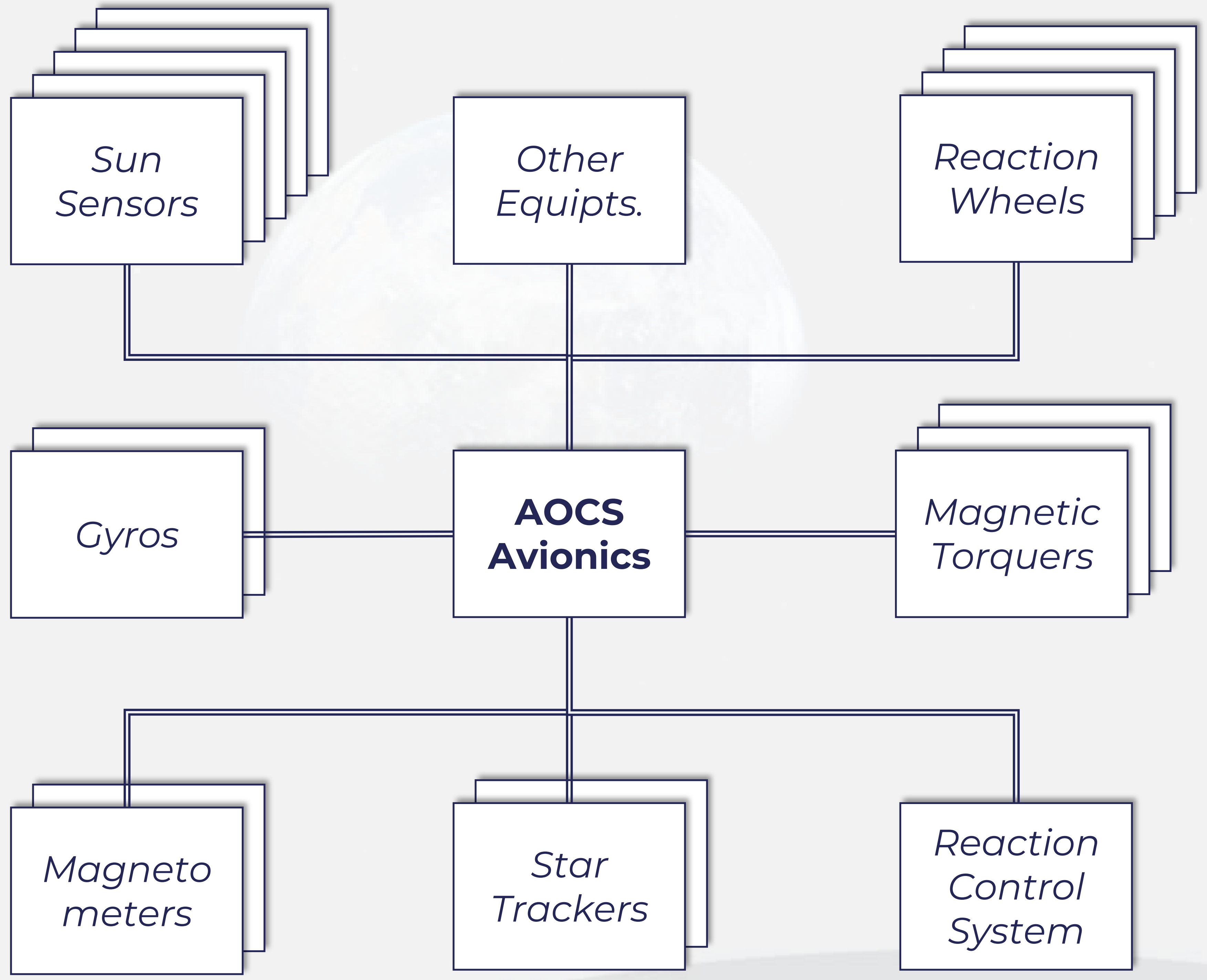
- Design must include functionalities and interfaces for various actuator types to ensure adaptability across missions.

Sensor Integration:

- Star Trackers: Ensure high accuracy in pointing.
- Gyroscopes: Measure angular velocity and propagate attitude during star tracker data gaps.
- Sun Sensors: Acquire sun direction for initial spacecraft release and safe mode operations.
- Magnetometers: Measure local magnetic fields, aiding attitude determination and magnetic torquer control.

Sensors/Actuators Setup:

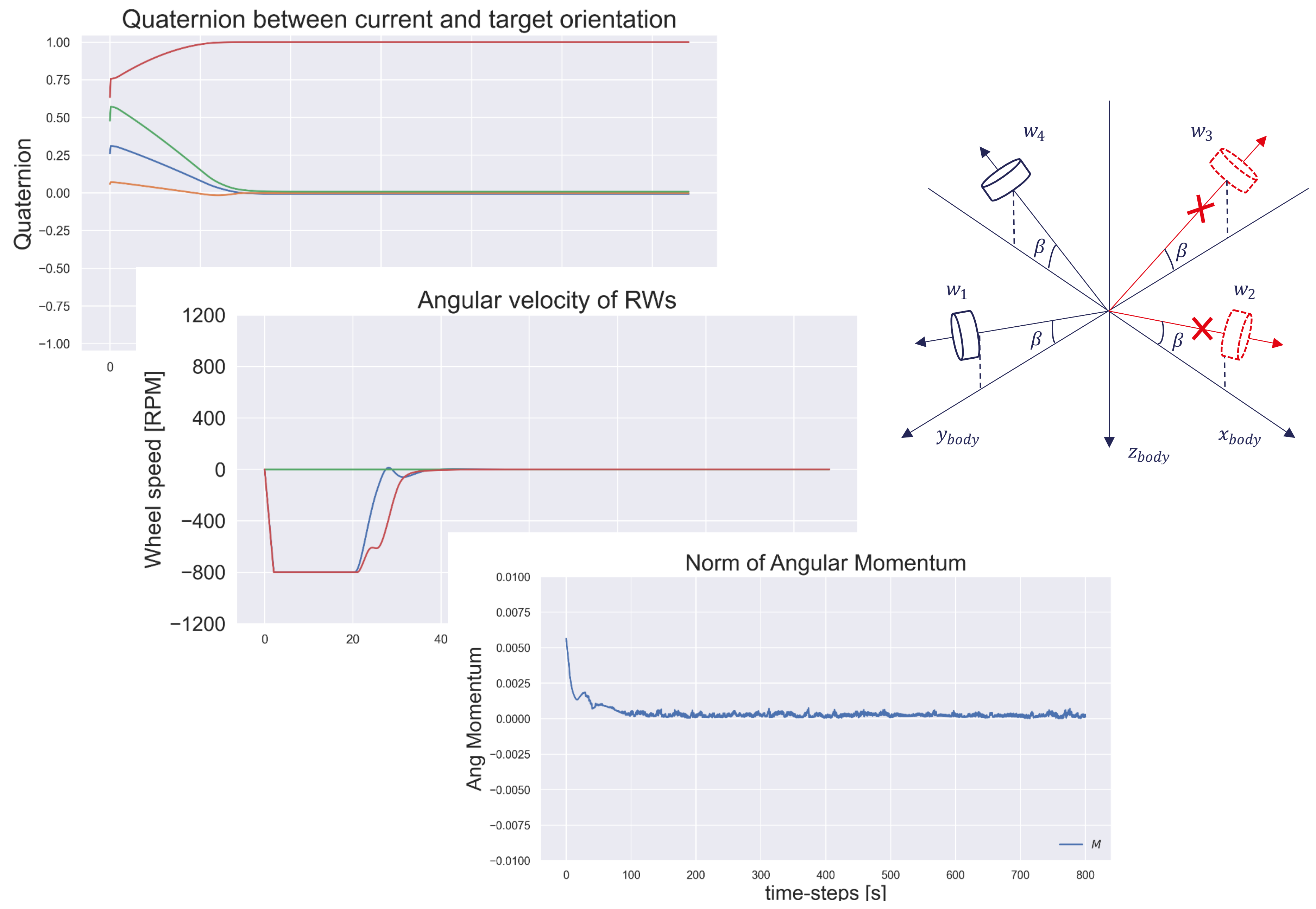
- Determine the quantity and necessity of each sensor/actuator type through context study.
- High-fidelity models can simulate sensors/actuators in test setups.

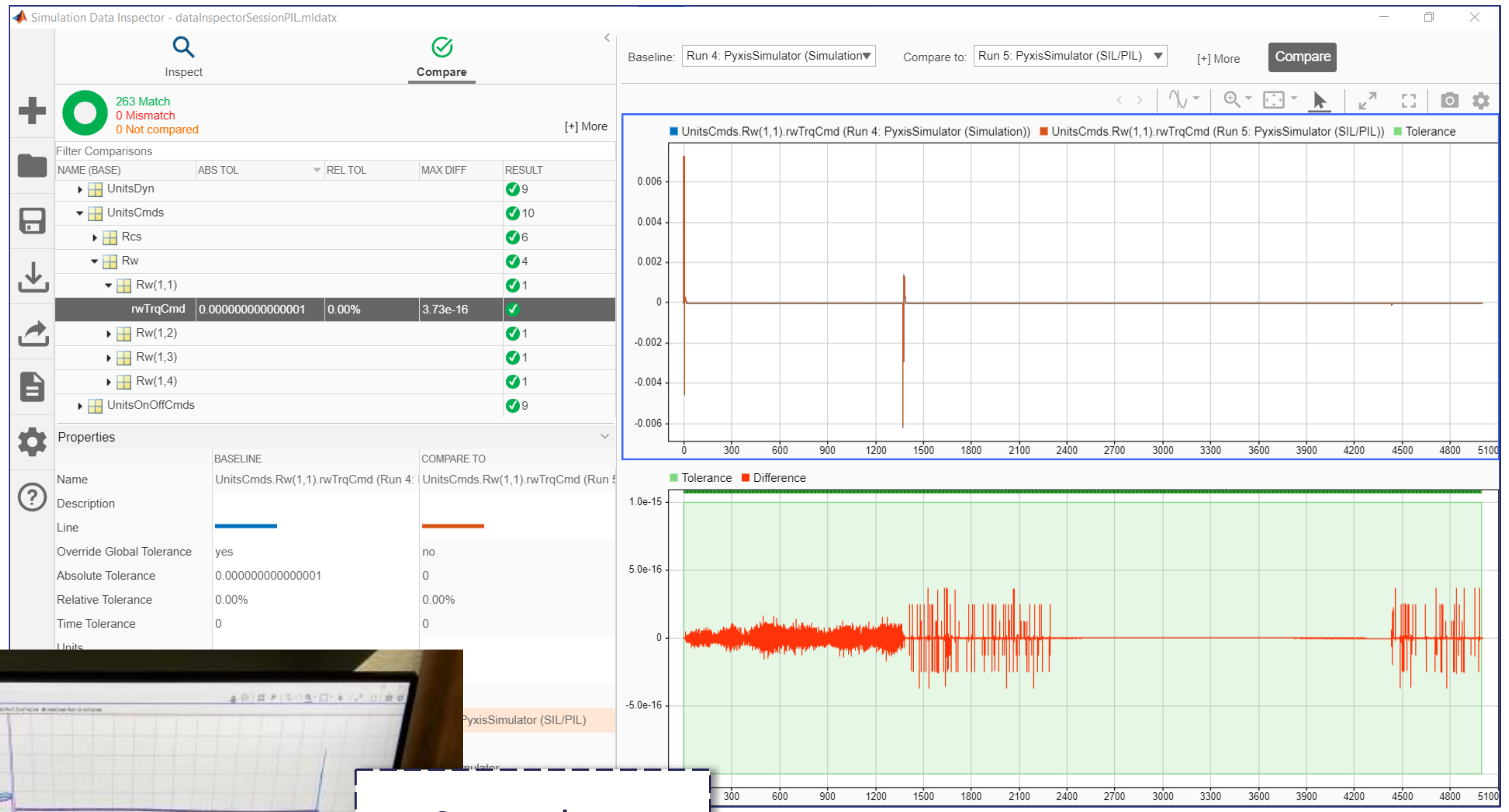


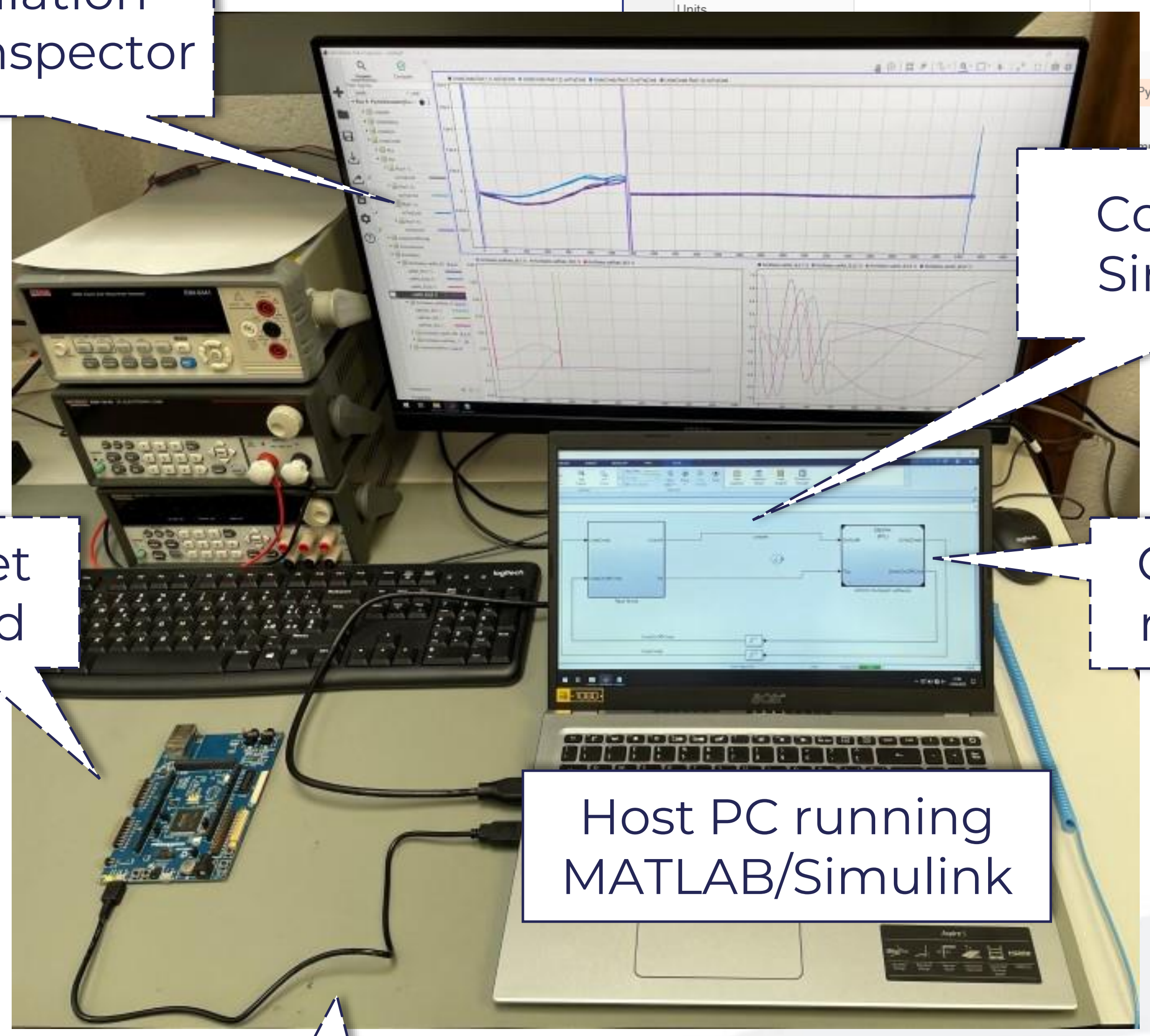
Next Steps in the Development

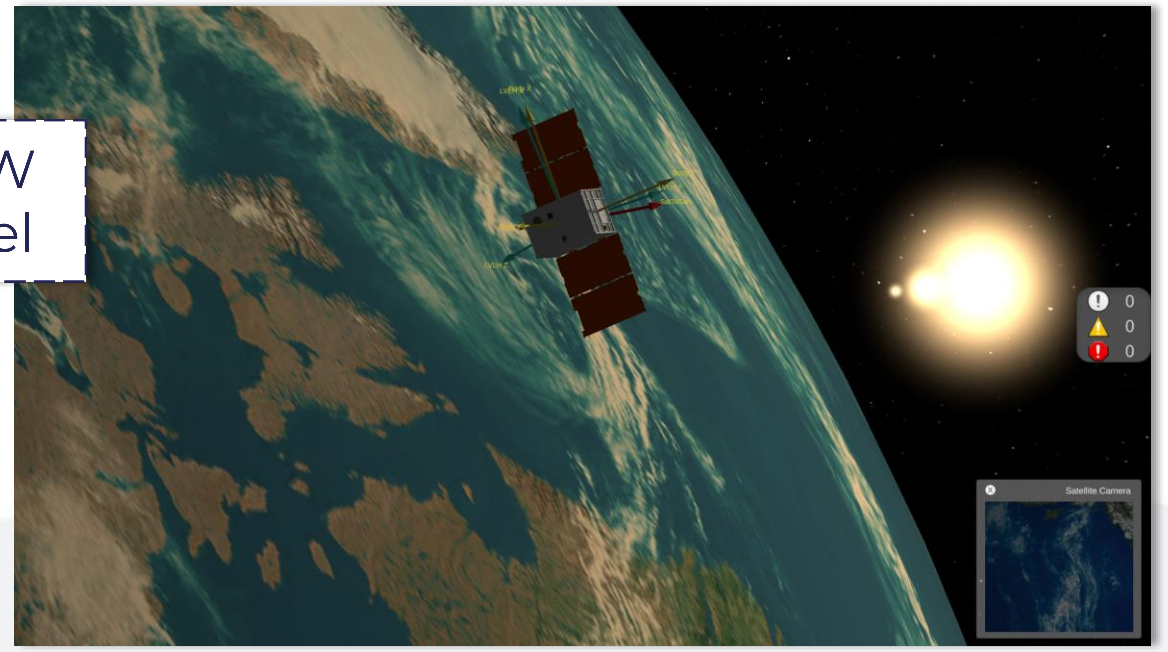
Achieved Results

- To date, most of the GNC algorithms have been tested with Processor-in-the-Loop tests.
- Along with the implementation of classical GNC algorithms, algorithms based on Artificial Intelligence (AI) have been developed and PIL tested in Argotec.







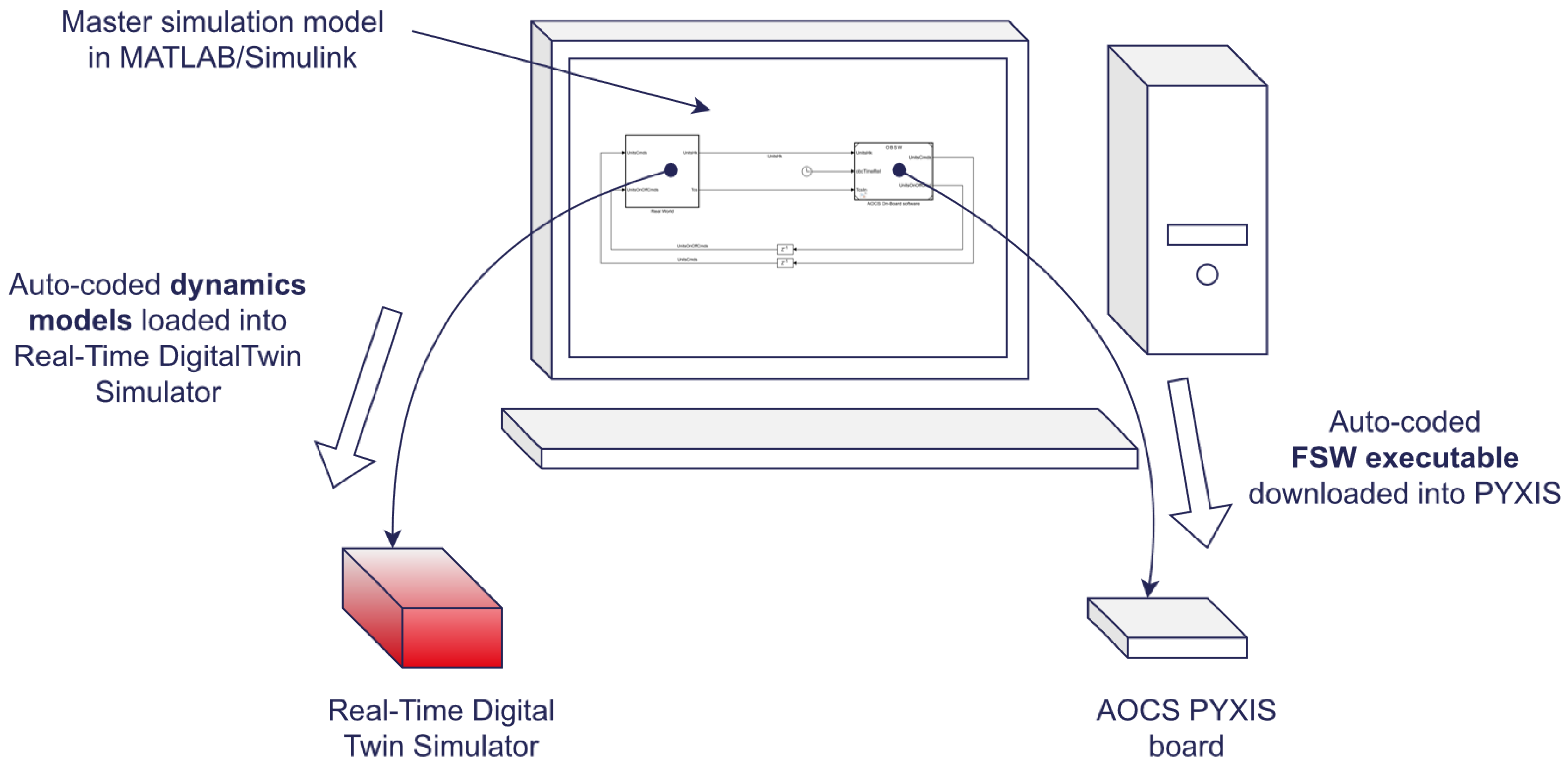


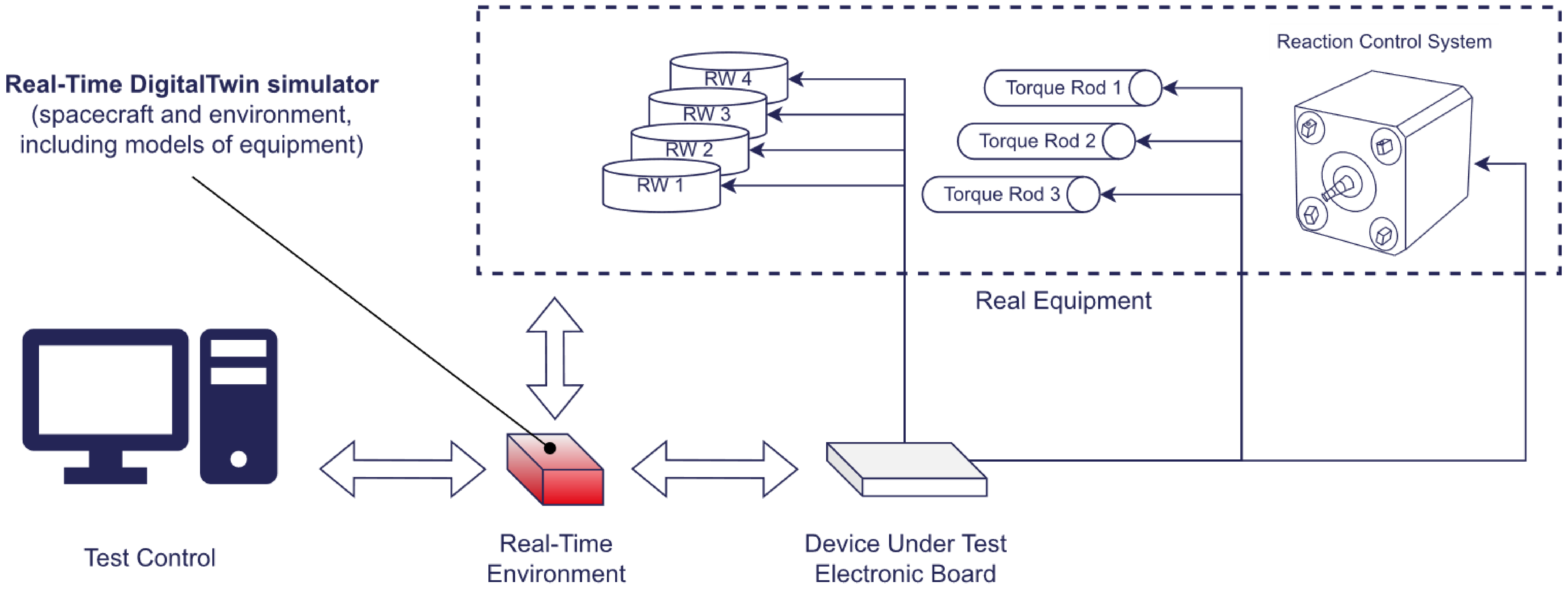
PYXIS 3D Visualizer

Next Steps in the Development

Next Steps

- To support HIL closed-loop testing a Real-Time Digital Twin Simulator (RDTS) will be developed.
- It can be configured for any initial orbit and attitude conditions and can simulates any equipment with high-fidelity models.
- The HIL setup will provide true "test-as-you-fly" capability.
- The RDTS's software is auto-coded from same master simulation as flight software.





Avionics Test Bench (ATB) where unit models are fully or partially replaced by HW.

Actuators will be introduced first followed by incremental introduction of sensors. Equipment that is not physically present will be simulated by the RDTS with high-fidelity models.

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Thank you

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