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Enabling Seamless Collaboration in AOCS/GNC Engineering: COOPERANTS Project's Approach to Continuous Integration and Verification of Component Models

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Abstract

This publication introduces the groundbreaking COOPERANTS project, a collaborative initiative uniting industry, SMEs, and research institutions in the aerospace sector.
Addressing critical challenges in digital collaboration, COOPERANTS establishes a shared data space based on Gaia-X standards. Focused on the Advanced Smart Services domain, the specific task, "Component Models for Continuous Integration and Verification," aims to revolutionize the digital exchange between component manufacturers and system integrators in the AOCS/GNC domain of the space industry.
The current lack of developments facilitating a continuous digital exchange for the development and integration of space systems has prompted COOPERANTS to take the lead. While the European Space Agency (ESA) is exploring initial steps with Electronic Data Sheets (EDS) for components, an accepted and final standard is yet to be defined. COOPERANTS seeks to bridge this gap by developing data structures and models, forming "Digital Twins," enabling the seamless exchange and integration of components throughout the development cycle.
The primary objective of this project is to establish a systematic foundation for creating and exchanging functional "Digital Twins". These facilitate the generation and configuration of equipment models for the development and validation of on-board software. These software models, crucial for numerical simulations across various stages of development (MiL, SiL, HiL), contribute to the continuous integration of the overall system.
The publication outlines the goals of the project, emphasizing the creation of a systematic basis for the generation and exchange of functional "Digital Twins." These models provide crucial insights into component behavior, accuracy, and potential error scenarios throughout the development cycle, significantly enhancing efficiency and reducing project costs and risks. A pilot project with a component manufacturer showcases the successful integration of component models into the development cycle, demonstrating the project's viability.
The proposed solution involves defining requirements, establishing interfaces and data structures for model and model-data exchange, and implementing a generic interface for exchanging individual model components. The process culminates in the execution of a pilot project. This publication provides an insightful overview of COOPERANTS' innovative approach and initial outcomes, paving the way for a new era of collaborative and digitally integrated space development.

1. Introduction

1.1 Motivation

The traditional approach to designing and developing an Attitude and Orbit Control System (AOCS) was characterized by manual, paper-based, and linear processes, which were both time-consuming and prone to errors. The lack of digital tools necessitated reliance on physical and electronic documents, face-to-face meetings, and conventional communication methods (e.g., phone calls, emails). Below, the primary gaps in this approach are detailed.

Focusing on Phase A of the AOCS design and development process, which includes preliminary simulations used for component selection and feasibility studies, several drawbacks arise due to the absence of standardized electronic data sheets for sensors and actuators. These drawbacks are mainly related to challenges in accessing, sharing, and interpreting component specifications crucial for accurate simulations and decision-making:

1. **Inconsistent Data Formats**: Without standardized electronic data sheets, component specifications for sensors and actuators may be presented in various formats, leading to inconsistencies in data interpretation and utilization in simulations. Engineers often need to convert or manually enter data into a usable format, increasing the risk of errors.

2. **Limited Accessibility**: If sensor and actuator data are not centrally stored and easily accessible, engineers may face delays in obtaining necessary specifications for preliminary simulations. This can slow down feasibility studies and the component selection process, as acquiring up-to-date and complete data from manufacturers without a standardized digital repository can be time-consuming.

3. **Data Integrity and Version Control**: Sharing data sheets and specifications via email or physical documents poses the risk of using outdated or incorrect information in simulations. The lack of a centralized, version-controlled database makes it difficult to ensure that all team members are using the most current data, leading to potential discrepancies in simulation results.

4. **Efficiency in Simulation Iterations**: Preliminary simulations often require multiple iterations with varied component specifications to explore different design scenarios. Manual handling of sensor and actuator data can make these iterations cumbersome and time-intensive, limiting the ability to quickly evaluate different design options and make informed decisions.

These challenges highlight the importance of digitalization and standardization in modern spacecraft design and development. Addressing these issues through more unified data management and sharing practices can significantly enhance the efficiency, accuracy, and collaborative potential of the AOCS development process.

In later phases of AOCS development, where detailed models of sensors and actuators are crucial for validating performance and verifying system functionality, the absence of standardized models and data sets introduces several additional challenges:

1. **Incompatibility Across Simulation Platforms**: Current practices often lead to compatibility issues between sensor and actuator models and the various simulation platforms used across different phases of development. Adapting models to work across different environments can be resource-intensive and prone to errors.

2. **Increased Development Burden**: The need to individually develop or adapt models for each sensor and actuator, based on disparate data sheets and specifications, places a significant burden on development teams. This process is inefficient and increases the likelihood of introducing errors into the system.

3. **Difficulty in Model Validation**: Validating the accuracy of sensor and actuator models is a complex and uncertain process. Engineers must rely on limited data or perform extensive testing to ensure models reflect real-world performance, which may still leave substantial uncertainties.

4. **Challenges in System-Level Integration and Testing**: The integration of sensor and actuator models at the system level requires defining and maintaining interfaces. Differences in model interfaces and performance metrics can lead to integration challenges, making it difficult to assess and optimize overall system performance.

In the current framework, without digitalization and standardized models and data sets, the AOCS development process is marked by inefficiencies and challenges that impact the timely, cost-effective, and successful completion of space missions. The reliance on custom, project-specific solutions for each sensor and actuator model exacerbates these issues, highlighting the need for a more digital and standardized approach to AOCS development.

Recognizing these issues, several initiatives have been undertaken to address them. The following digitalization approaches can enhance the AOCS development process by leveraging modern technologies and methodologies to streamline design, testing, integration, and operation:

- **Model-Based Systems Engineering (MBSE)**: MBSE uses digital models as the primary means of information exchange throughout the engineering process. For AOCS development, MBSE facilitates the integration of different subsystem models, enabling a more cohesive design process and easier iteration between design phases.

- **Digital Twin Technology**: Creating a digital twin of the AOCS allows for real-time monitoring and simulation of the system throughout its life cycle. This approach can predict performance under various conditions, identify potential issues before they arise in the physical system, and support decision-making during mission operations. Although this approach is not new and has been applied in many missions, it lacks continuity from the very early mission design to mission operations.

- **Cloud-Based Collaboration Platforms**: Cloud-based platforms can centralize data and models, enabling remote teams to collaborate more effectively. These platforms support version control, real-time updates, and access control, ensuring that team members always work with the latest information.

- **Continuous Integration and Deployment (CI/CD) for Software Development**: Implementing CI/CD pipelines for the software components of AOCS allows for the continuous integration of code changes into a shared repository. This facilitates automated testing and deployment, leading to more efficient development cycles and higher software quality. While this is a common approach today, it lacks interoperability and compatibility between Lead System Integrators (LSIs).

By leveraging these digitalization strategies, AOCS development can become more efficient, flexible, and robust, leading to better-performing systems that can be developed and iterated upon more quickly and at a lower cost. The COOPERANTS (Collaborative Processes and Services for Aeronautics and Space) project aims to develop the infrastructure and services to enable these strategies.

1.2 What is COOPERANTS?

COOPERANTS (Collaborative Processes and Services for Aeronautics and Space) [1] is a lighthouse project designed to accelerate the digitization of the aerospace industry by developing efficient, decentralized working methods and processes throughout the life cycle of space and air vehicles. It aims to enhance the competitiveness of the industry within Germany and the European Union by fostering collaboration across national consortia, integrating innovative technologies, and creating a secure digital ecosystem in alignment with the Gaia-X initiative. This project facilitates a collaborative environment where data is shared securely and efficiently, ensuring control and sovereignty over data while driving forward the European data economy and digital sovereignty.

1.3 What is Gaia-X?

Gaia-X [2, 3] is a European initiative aimed at creating a federated, open, and secure data infrastructure that upholds European values of data sovereignty, transparency, and interoperability. It seeks to establish a trustworthy and efficient digital ecosystem where businesses, governments, and individuals can store, share, and manage data across various cloud services and platforms while retaining full control over their data. Gaia-X envisions enabling a digital single market within Europe, fostering innovation, data sharing, and the development of new services across industries by setting standards and frameworks for data usage and cloud interoperability. This initiative brings together stakeholders from the public and private sectors to collaborate on building a decentralized infrastructure that supports the digital economy's needs while ensuring compliance with EU regulations and standards.

1.4 AOCS Component Models for Continuous Development, Integration, and Verification

In the context of AOCS development, a specific answer to the digitalization of the development process is provided in the work package "Component Models for Continuous Integration and Verification." The goal of this work package is to develop and establish a framework for the development, integration, and verification of sensor and actuator models within the AOCS design and development process, thereby addressing the current inefficiencies and risks associated with past and current practices. It aims to contribute to the following key aspects:

- **Enhance Model Compatibility**: Develop and adopt standardized model formats and interfaces for sensors and actuators that ensure seamless compatibility across various simulation platforms and tools. This will facilitate smoother integration processes and reduce the burden of model adaptation.

- **Streamline Development Processes**: Implement a centralized marketplace of standardized, validated models and data sets for sensors and actuators. This repository will serve as a shared resource, significantly reducing the time and effort required to develop or adapt individual models for each component.

- **Simplify Model Validation**: Establish benchmark data sets and validation protocols based on standardized models. This will enable more straightforward and reliable validation of sensor and actuator models, ensuring their accuracy and real-world performance alignment.

- **Foster Effective Collaboration**: Create a shared platform or framework that allows for the easy exchange and collaborative refinement of standardized models among teams and organizations. This platform will support collective efforts in optimizing design and troubleshooting, enhancing the collaborative potential within and across projects.

- **Enable Efficient Design Exploration**: Utilize the standardized models and data sets to facilitate rapid and comprehensive exploration of design alternatives. This will allow teams to efficiently evaluate different sensor and actuator configurations, leading to optimal design decisions based on robust simulations.

- **Ensure Systematic Verification and Compliance**: Leverage standardized models to streamline the verification process, ensuring that all AOCS components and the system as a whole meet regulatory and mission-specific requirements with a higher degree of confidence and efficiency.

- **Promote Knowledge Sharing and Re-usability**: Encourage the development of a knowledge base around standardized models and data sets that can be reused and built upon in future projects, minimizing redundant efforts and fostering innovation.

COOPERANTS aims to serve as a pathfinder to overcome fragmentation and inefficiencies in the current AOCS development landscape by implementing a new approach to sensor and actuator modeling. This will not only improve the design, integration, and verification phases but also enhance collaboration, compliance, and innovation within the aerospace industry.

To achieve these goals, the work package will contribute to the following areas:

- Define the marketplace for equipment, models, and data sets.

- Develop procedures and tools to convert and share models between platforms.

- Integrate models into system simulations for verification.

- Provide simulation models and simulations as a service.

2. Embedding the AOCS Development Work Flow in a Digital Environment

To facilitate the creation and ongoing exchange of digital data throughout the development and verification phases of space missions, it is essential to understand the AOCS development work flow, which helps derive the requirements for information, models, and functions. This digital data, comprising both raw data and models, is crucial for the systematic development and validation of the AOCS on-board software. The models simulate the performance, accuracy, and potential error scenarios of components, serving as essential tools throughout the entire development cycle for both development and verification by the system integrator (MiL, SiL, HiL). The goal is for these models to consistently inform the system integrator of component properties from design through to delivery, integrating the component development life cycle into the system's continuous integration process.

Figure 1 illustrates the interaction between four key roles in the AOCS development process within the Gaia-X ecosystem. These roles exchange information, data, and models via the Gaia-X cloud:

- The **Equipment Supplier** provides AOCS equipment, along with associated data and documentation, to other stakeholders through the cloud.

- The **Simulation Company** develops and maintains simulation models based on the provided data, making these models available for integration and testing.

- The **Lead System Integrator (LSI)** configures and integrates these models into its simulation environment for system verification.

- The **Customer**, such as a space agency, oversees the simulations, validates results, and ensures compliance with required standards.

The digital framework allows for expanded access, enabling external users to utilize simulators, models, and data, including for machine learning purposes.

An analysis of key interactions among suppliers, the Lead System Integrator (LSI), and mission customers throughout the project life cycle has highlighted a need for two distinct data exchange zones: a marketplace for equipment and their models, and a protected project area for sharing data during the development, implementation, integration, and verification phases.

The marketplace is mainly used at project inception when the LSI Systems Engineer must conduct a thorough

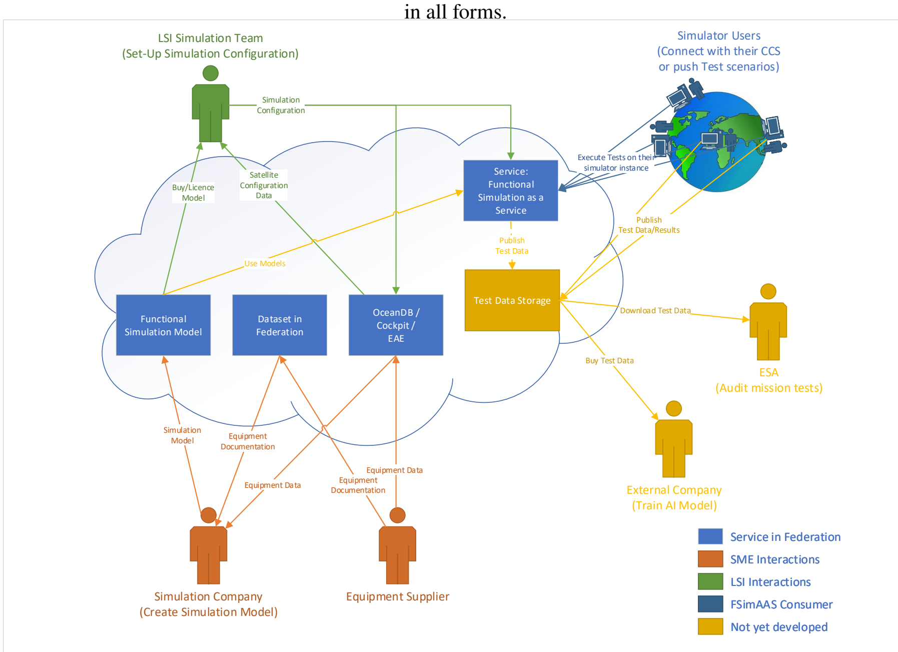

Fig. 1: Concept of utilizing a digital environment (e.g., Gaia-X) for the AOCS development work flow.

market analysis to identify available equipment. This process enables the selection of components, the determination of budget allocations, and the potential configuration of a spacecraft. Typically, this analysis involves extensive research, engagement with multiple suppliers, and a review of their product catalogues. Additionally, customers frequently conduct reviews and audits of project progress.

Following the signing of contracts, suppliers can transmit sensitive data to the LSI in a protected project area, maintaining data sovereignty. In the context of numerical simulations, the simulation team can employ the equipment data to develop or adjust simulation models. These models are then disseminated across various areas, enabling participants to execute the numerical simulations. Concurrently, the LSI can utilize this sensitive data and share outcomes with customers such as ESA.

In this setup, GAIA-X connects various participants through dedicated work spaces: the marketplace and the protected project area.

Figure 2 provides a graphical overview of the architecture reflecting these needs and embedded into Gaia-X.

2.1 *Marketplace*

The marketplace is to be established as a public platform specifically designed for the initial phases of a project. It is aimed at facilitating the exploration and selection of equipment and suppliers, crucial for the foundational stages of project development.

2.1.1 *Purpose of the Marketplace*

The marketplace primarily functions to enable the Lead System Integrator (LSI) to effectively survey available equipment and suppliers. It serves as a central repository where suppliers can list their products, complete with comprehensive details such as interfaces, Technology Readiness Levels (TRL), costs, and design descriptions. This setup allows the LSI to access a wide array of potential resources necessary for the project. In this dynamic environment, the LSI leverages the marketplace to filter and select equipment that meets specific project requirements. This process often involves evaluating equipment based on particular attributes like TRL or compatibility with existing systems, ensuring that selections align precisely with project needs.

2.1.2 *Features and Functionalities*

The marketplace offers high-level data from suppliers in a machine-readable format, significantly simplifying the task of filtering and comparing different equipment options. This capability is instrumental in supporting the LSI to make informed, efficient decisions. Suppliers in the marketplace provide detailed profiles that encapsulate general information about their capabilities, historical performance, and reliability. These profiles are crucial for the

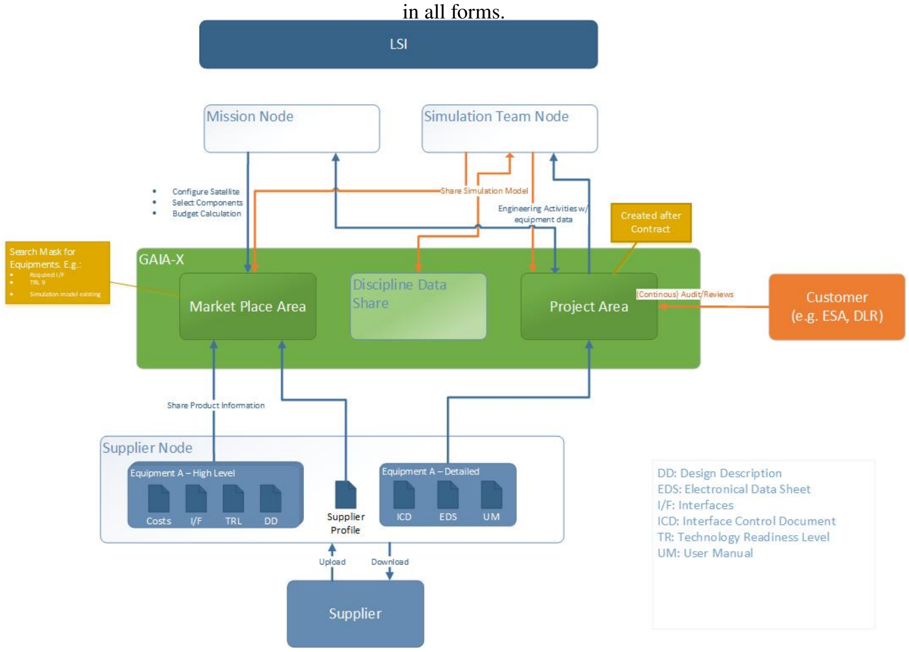

Fig. 2: Architecture of the AOCS development environment in Gaia-X.

LSI in assessing the suitability of potential partners for the project.

2.1.3 *Implementation and Use*

During the early project phases, the LSI Systems Engineer utilizes the marketplace to conduct a thorough market analysis. This analysis is pivotal in identifying the best components that meet the project's requirements, including considerations for budget impacts and potential satellite configurations. The marketplace enhances decision-making processes by providing a comprehensive view of the available technological landscape. It equips the LSI with the knowledge of what technologies are available and identifies which suppliers can meet the stringent requirements of the project.

2.1.4 *Strategic Importance*

By centralizing supplier information and equipment data, the marketplace significantly streamlines the procurement process. This centralization reduces the time and effort required to identify and engage with potential suppliers, making the procurement process more efficient. Having access to a broad range of equipment and supplier data early in the project life cycle greatly enhances project planning. This access allows for more accurate forecasting and budgeting, which are critical for the successful planning and execution of complex projects such as space missions.

2.2 *Protected Project Area*

The protected project area serves as a secure environment within the project infrastructure, specifically designed for handling sensitive data exchanges between the project's key stakeholders, including suppliers, the Lead System Integrator (LSI), and customers. This area is pivotal for managing proprietary and confidential information throughout the life cycle of space mission projects.

2.2.1 *Purpose and Functionality*

The primary purpose of the protected project area is to ensure data security and confidentiality. It acts as a safeguarded space where sensitive information related to the project can be exchanged and stored without the risk of unauthorized access or data breaches. This secure environment is crucial for maintaining the integrity and sovereignty of data, which is particularly important in industries where data sensitivity is high, such as aerospace and defense. Access to the protected project area is strictly regulated through robust access controls and authentication mechanisms. Only authorized personnel are granted access based on their role and involvement in the project, ensuring that each stakeholder can only access data relevant to their specific tasks. This controlled access facilitates secure collaboration between different parties, allowing them to share, discuss, and work on sensitive project details within a protected framework.

2.2.2 Implementation and Use

Within the protected project area, stakeholders can securely communicate and collaborate on various aspects of the project. This includes the sharing of design documents, simulation data, simulation models, simulators, test results, and other critical information that requires a high level of protection. The area is equipped with tools that support secure file sharing, real-time communication, and collaborative problem-solving, all within a secure digital environment. The protected project area is designed to comply with strict data protection regulations and standards, ensuring that all data handling processes meet legal and ethical requirements. This is essential for projects that involve multiple international stakeholders, where compliance with diverse regulatory frameworks is necessary. The area helps in managing data in a way that respects data sovereignty, with mechanisms in place to control where and how data is stored and accessed.

2.2.3 Strategic Importance

The establishment of a protected project area enhances the overall security and trustworthiness of the project. By demonstrating a commitment to data security and regulatory compliance, project leaders can strengthen relationships with stakeholders and build a reputation for reliability and integrity. This is crucial for attracting and retaining partners and customers in sectors where security is a paramount concern. In the scenario of high-stakes development, such as that in aerospace, the protected project area enables the detailed and secure analysis of data and development models. Engineers and scientists can work with sensitive data to refine designs, improve systems, and validate technologies without the risk of compromising intellectual property or strategic information.

3. Analysis and Requirements Breakdown on Services and Tools

Since this work is embedded within the COOPERANTS project, underlying and general services and tools are the subject of other work packages. Therefore, the focus of this analysis is to identify the specifically needed services and tools for the AOCS development and verification process. This section outlines the process of translating the high-level requirements into practical, achievable tasks. The purpose is to ensure clarity and prevent any overlap with other ongoing work packages.

3.1 Analysis of Requirements and Their Implementation

The concept of work spaces overlaps within COOPERANTS with work packages addressing generic needs of digital collaboration, such as the work package ”Data Spaces.” In terms of data handling, the foundational element is the management of data formats and their integration with existing databases, which is covered in the work package ”Collaborative Engineering.” The marketplace is envisioned to add significant value during early project phases of AOCS development. This is similar to other engineering disciplines and development processes. Therefore, the development of the marketplace is handled in the generic work package ”Collaborative Engineering,” which involves creating a platform for sharing this information. Similarly, the establishment of a dedicated project area offers substantial benefits for collaborative work within a cloud-based infrastructure; however, its implementation may extend beyond the scope of this work package.

3.2 Conclusion and Future Directions

Given the current constraints, the concept of work spaces will be adopted. Instead, the focus will shift towards General Data Requirements and the utilization of readily available information. Key tasks of this work are centered around the digital exchange of equipment information to support model-based development of simulation models and the sharing of these models via GAIA-X. This approach emphasizes the marketplace's role in facilitating access to simulation models for external customers. To successfully implement this, a standardized data format and tools for verifying and uploading usable simulation models are necessary. Additionally, simulations representing digital versions of real equipment should link directly to their corresponding hardware units. Executing simulations in the cloud involves accessing and loading models from various cloud nodes into a unified simulation environment and running these environments on a cloud node while allowing peripheral access from edge devices.

In conclusion, this work focuses on the following three main aspects:

1. **Exchange of Equipment Information**: Addressing the technical and logistical aspects of sharing equipment data across platforms.
2. **Exchange of Equipment Model/Artifact Library**: Establishing a comprehensive library of equipment models that can be accessed and utilized across different stages of the project.
3. **Remote Execution of Simulation Environment**:

Facilitating the execution of simulations remotely, which encompasses loading and running simulation models effectively in a cloud-based framework.

In the following section, the design and implementation of the three elements are provided in more detail.

4. Design & Implementation

In COOPERANTS, functions, processes, and databases are integrated as "Smart Services." These services refer to advanced, digital solutions that facilitate collaborative and decentralized working methods across the aerospace industry's entire life cycle. They are designed to enhance efficiency and security, with a particular focus on the following areas:

- Collaborative Program Management and Engineering
- Intelligent Assistants and Dashboard Systems
- Simulation and Verification
- Data Management and Integration

Figure 3 depicts how the three main aspects (cf. Sect. 3.2) will be integrated into Gaia-X and how they will interact as part of the AOCS development and verification process. The following subsections describe these elements in more detail.

4.1 Exchange of Equipment Information

4.1.1 Design

For establishing and operating a marketplace for equipment information and models, Tab. 1 outlines the specific requirements. This marketplace is designed to facilitate the digital exchange of critical equipment data among stakeholders within the aerospace and defense industries. The aim is to enhance interoperability, streamline design and manufacturing processes, and ensure compliance with industry standards through a centralized platform. Each requirement listed below addresses essential aspects of data standardization, governance, and accessibility. The infrastructure and tooling provided through cloud technologies support the efficient management and dissemination of this information, thereby fostering a more connected and transparent supply chain environment.

4.1.2 Implementation and Results

The marketplace development is managed by a dedicated team within COOPERANTS, enabling not only the sharing of data but also providing access to algorithms and software as a service (SaaS) concepts. The current focus of this activity is on providing and locating these data sets and services. Consequently, at present, the data cannot be clustered for specific equipment, nor is version control available. Nevertheless, the foundation has been established so that, in the future, missing functionalities can be added to enable a fully functional equipment warehouse.

4.2 Exchange of Equipment Model/Artifact Library

4.2.1 Design

The purpose of the equipment model library is to facilitate a standardized, accessible, and efficient method for managing and exchanging equipment models, significantly enhancing collaborative efforts and streamlining processes from design through verification and beyond. The requirements in Tab. 2 aim to support not only the creation and maintenance of this model library but also ensure its integration with existing project management and development tools. By doing so, it provides an infrastructure that enhances the re-usability of models, ensures adherence to industry standards, and supports the diverse needs of project stakeholders. The table organizes these requirements in terms of the data or items to be exchanged, the supporting cloud infrastructure and tooling, and exchanged information.

4.2.2 Implementation and Results

The primary objective is to enable the digital exchange and integration of simulation models for Attitude and Orbit Control System (AOCS) components of satellites, focusing on using standards for the exchange of models and libraries. In this context, existing formats and standards were analyzed.

SMP2 (Simulation Model Portability version 2) is a standard that specifically focuses on the portability of simulation models, with tools and methodologies that might be used in both European and international contexts. It provides a specific methodology for the portability of simulation models, allowing them to be used across various simulation platforms. It is not confined to the space sector and can be applied in different industries that require robust simulation capabilities. With the release of the ECSS-E-ST-40-07 "Simulation Modeling Platform" [5,6], SMP2 was incorporated into the ECSS (European Cooperation for Space Standardization) standards. While the ECSS-E-ST-40-07 extends SMP2, it maintains backward compatibility, allowing the reuse of existing SMP2 models and libraries.

The Simulation Model Portability Version 2 (SMP2) standard was chosen for the exchange of models. One rea-

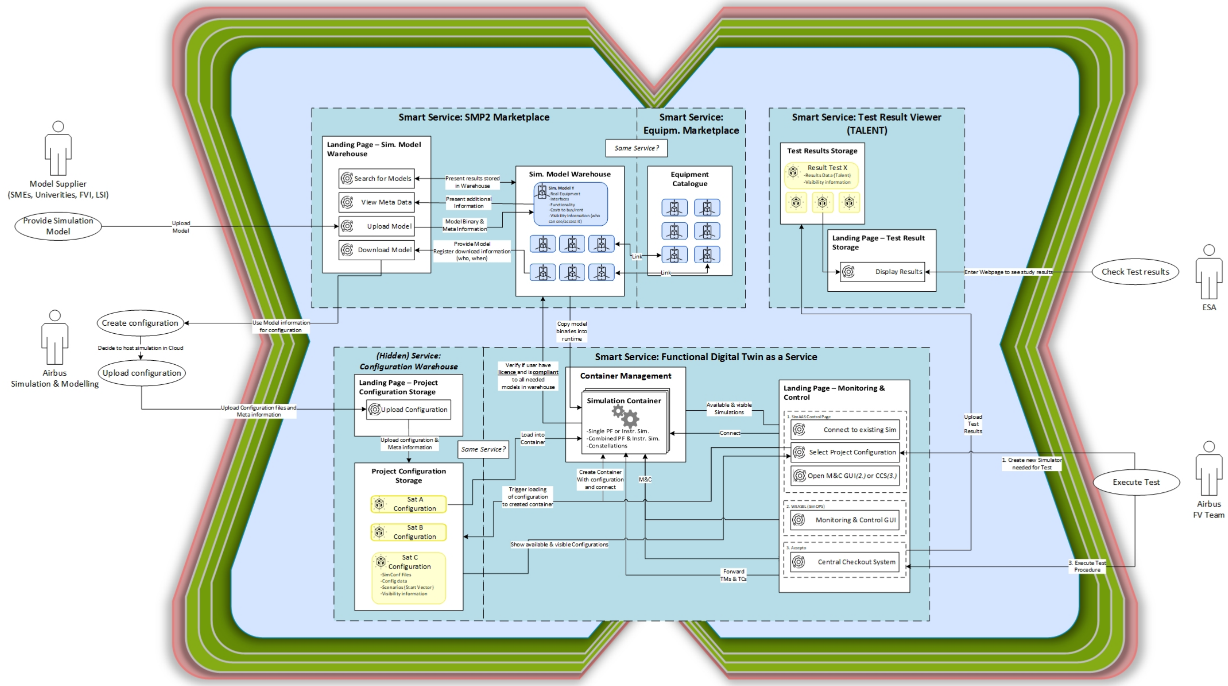

Fig. 3: Smart Services of the AOCS development and verification process and their interaction within the Gaia-X environment.

Table 1: Requirements for the Marketplace

No.	Requirements on Infrastructure and Tooling
1	The Exchange of Data Sheets for the Equipment Information shall be based on a standardized format/template (e.g., EDS [4]).
2	The cloud platform shall provide a web-based artifact library to allow the upload, storage, search, and download of data sheets for equipment information as a single file/artifact.
3	A data governance process shall be established detailing the process, responsibilities, and ownership of the data.
4	The Artifact Library for the EDS Equipment Information shall provide additional meta data for: Equipment Type, Product Designation and Version, Supplier/Manufacturer, a dedicated Version Number, and Release Date for the EDS Files.
5	The data sheets for the Equipment Properties shall at least contain the following information: Connectors & Channel Allocation, Power Consumption & Power Dissipation, and Operational Temperatures (Maximum/Minimum).
6	The EDS for the Equipment Properties shall at least contain the following information (if applicable for the equipment): Command Messages and Format, Command Message Data & Aggregate Parameter, Command Calibration Format & Data, Acquisition Messages and Format, Acquisition Message Data & Aggregate Parameter, Acquisition Calibration Format & Data.
7	The cloud platform shall provide the capability to exchange information on the Functional Behavior of the Equipment Hardware. Note: As a first iteration, it will be sufficient to provide this data in the form of Design Descriptions, User Manuals, and ICD Documents.
8	The cloud platform shall provide the capability to exchange information required to model the operational modes of the equipment based on a finite state machine. This shall cover at least: Operational Modes, Mode Transitions and Triggers, and Timing Information/Transition Delays.

Table 2: Requirements for the Exchange of Equipment Models

No.	Requirements on Infrastructure and Tooling
1	The cloud platform shall provide a web-based artifact library to allow the upload, storage, search, and download of Equipment Models or Model Components as a single artifact.
2	The exchange of the Simulation Model shall be based on a standardized architecture, including at least the SMP2 Standard as the basis for the simulation activities in an ESA context.
3	For Released Models, a minimum set of Quality Rules/Standards/Processes shall be defined and applied.
4	The Model Data Package shall be composed of a standard set of documentation, including: Design Documentation, Interface Description, Test & Validation Spec and Report, and User Manual.
5	The Model Data Package shall include the Binaries pre-built for the target platform (OS).
6	The Model Data Package shall include the Source Code of the Model to enable maintenance, modification, and recompilation of the binaries in the local environment.
7	The Model Data Package shall include a default set of configuration parameters.
8	A data governance process shall be established detailing the process, responsibilities, and ownership of the data.
9	The Artifact Library for the Equipment Models shall provide additional meta data for: Equipment Type, Product Designation and Version, Supplier/Manufacturer, a dedicated Version Number, Release Date, Target Operating System, and Applicable Modeling Standard.
10	The Artifact Library for the Equipment Models shall provide a concept for limited user access and licensing.
11	It shall be possible to link the model library to a local continuous build system.
12	The Artifact Library shall provide the capability to exchange standalone model components to be integrated into the local model development. Components might be built as SMP2 Models, Matlab Models, C/C++ Libraries with standardized interface functions (e.g., init, update).

son is that it is widely used by LSIs and ESA for verification and ground reference models [7–9]. It also ensures compatibility with existing models and infrastructure. Another reason is that a transformation tool from Matlab/Simulink exists. With Matlab/Simulink as the main modeling and simulation tools for GNC engineering, this allows porting existing simulation models on Matlab/Simulink into C/C++ software-based models following the SMP2 standard. This tool, MOSAIC [10, 11], developed by the National Aerospace Laboratory (NLR) of the Netherlands, was procured and implemented on behalf of ESA.

To develop and demonstrate the functionality and the work flow, a pilot SMP2 model of AOCS equipment was generated via modeling in Matlab/Simulink. For that purpose, the SMP2 model for the AMR Magnetometer of ZARM Technik AG was chosen. The process involved several key steps:

1. **Modeling in Matlab/Simulink:** Detailed modeling of the magnetometer in Matlab/Simulink was undertaken to capture essential functionalities and interfaces necessary for accurate simulations.

2. **Conversion to SMP2 using MOSAIC Tool:** The MOSAIC tool was utilized to convert the Matlab/Simulink model to an SMP2-compliant format, ensuring compatibility and functional integrity.

3. **Integration into SMP2 Simulation Environment:** The converted model was integrated into the SMP2 simulation environment to verify its operation and interaction with other system components.

To verify the accuracy and reliability of the converted models, extensive testing and validation activities were carried out. Benchmark data were generated from the original Matlab/Simulink model to serve as a basis for comparison. Furthermore, the outputs and behaviors of the SMP2 model were thoroughly compared against the original Matlab/Simulink model. This comprehensive comparison and analysis ensured that the essential dynamics and functionalities were preserved during the conversion process.

The model's transition to SMP2 was successful, with the SMP2 model closely matching the original in terms of output and functionality. However, challenges were encountered, particularly with the conversion tool's limitations in handling complex structures and achieving full compatibility with SMP2 requirements.

The successful export of the Matlab/Simulink model to SMP2 marks a significant step in facilitating the exchange of equipment models within the aerospace sector. This capability is expected to enhance collaborative ef-

Table 3: Requirements for the Execution of Simulations

No.	Requirements on Infrastructure and Tooling (Cloud)
1	It shall be possible to select a simulation based on data provided by a database via a web-based front-end. Alternatively, it shall be possible to upload a simulator directly to the Cloud node.
2	After the selection of the simulation, a container shall be set up hosting the simulation. Interfaces shall be provided by this container to allow interaction with the simulation.
3	The user shall be able to run tests on the simulator by having either access to a repository or uploading them.
4	It shall be possible to load the binaries of simulation models from different cloud nodes. This facilitates collaborative working by using simulation models from suppliers.
5	The landing page of the service shall allow the user to connect to an already running simulation or to launch a new one. The option to connect to an already existing simulation shall allow one user to take a break or allow several users to work simultaneously on one simulation.
6	A user shall only see and connect to running simulations that are accessible with their user/entity profile.
7	A user shall only see and start launch-able simulations that are accessible with their user/entity profile.
8	One simulation shall be running in a container.
9	The launch-able simulations shall be defined by a configuration artifact, which a user can load and store inside the service. The artifact shall contain XML files defining the used models and how they are configured, and can include binaries or data files necessary for proper execution and simulation.
10	When uploading the configuration, it shall be checked if all models are available either inside the artifact or in a model storage/warehouse.
11	After a simulation is selected/launched, a new docker container shall be started. Several containers are possible and intended for the possibility of constellation simulations.
12	To allow more flexibility regarding the hosted simulations, either the simulation models shall be copied to the container dynamically after launch or, as an alternative, the upload of a simulation configuration will create a new docker image.
13	It shall be possible to connect a Checkout system with a simulation running inside the container allowing the execution of tests.
14	Test results shall be stored separately and can be made accessible to other users/entities.

forts and streamline development and validation processes for on-board software and system integration, reflecting the importance of developing interoperable and standards-compliant modeling tools in aerospace.

4.3 Remote Execution of Simulation Environment

4.3.1 Design

To enable remote execution of simulation environments within a cloud-based system, Tab. 3 summarizes the key infrastructure requirements. These requirements are designed to ensure seamless integration, management, and operation of simulation models and tools through a web-based platform. Each requirement focuses on enhancing the flexibility, accessibility, and efficiency of simulation processes by utilizing modern cloud technologies and containerization. This approach aims to support collaborative simulations, dynamic resource allocation, and secure user interactions, thereby facilitating robust simulation work flows critical in research and development settings.

4.3.2 Implementation and Results

The implementation was carried out on the OVHcloud platform, chosen as the cloud environment for COOPERANTS. The current solution, based on OpenStack, adheres to most software as a service (SaaS) concepts. The Figures 4, 5, and 6 provide an insightful visual representation of the processes and functionalities. Figure 4 illustrates the process of license acquisition and user on-boarding within the Gaia-X Federation. It shows how users are guided through the process, starting with obtaining a license and being directed to an on-boarding page. If a valid license is present, the system automatically generates a new user profile and the corresponding company profile, ensuring that only authorized users gain access to the service. This onboarding process is essential for maintaining security and streamlining user management within the platform. Figure 5 represents the service's landing page, which users access after successfully logging in. This page serves as the main entry point, offering two key options: access-

Fig. 4: License acquisition and user on-boarding within Gaia-X Federation

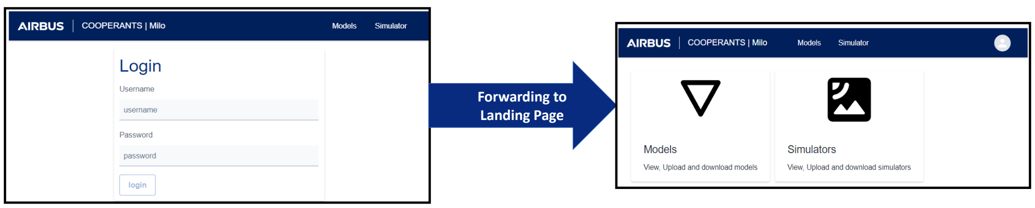

Fig. 5: Login and service landing page with options for accessing models or simulators

ing (view, upload, download) available simulation models or simulators. The layout provides users with a straightforward navigation system, making it easy to engage with various tools and simulators available within the platform, enabling a seamless transition between different functionalities. Figure 6 focuses on the ”Simulations” application, demonstrating how users can upload their simulator configurations and manage access permissions. It highlights the ability to configure simulator visibility, either restricting access to specific users or making it available to others within the company. This functionality is crucial for fostering collaboration, as it allows users to securely share simulation environments and facilitate joint work on engineering processes within the Gaia-X ecosystem. The figure also shows the interaction with simulators through a graphical user interface (GUI). Once a simulation is launched or a user connects to an active instance, the GUI opens, allowing users to monitor and modify various simulation parameters. Through this interface, users can select different scenarios, track real-time data, and receive status updates. This interactive environment provides real-time control and adjustment capabilities, improving the development process by making simulations more adaptable and efficient.

As the COOPERANTS project follows a federated approach, the simulator and its parameters can also be accessed via a REST API, enabling applications such as machine learning to retrieve training data. However, in the short term, the most likely applications utilizing this smart service are Central Checkout Systems (CCS), which are used to execute test scripts for operational flight procedures. Since commonly used CCS do not support REST APIs, an alternative solution will be developed.

Finally, there is an aim to load SMP2 models from the marketplace (see Sect. 4.2) into this SaaS, utilizing the GAIA-X infrastructure to establish contracts between the model providers and the users.

5. Conclusion & Outlook

As the work in COOPERANTS advances, the project continues to break new ground in the digital exchange of equipment models. This work specifically addresses the development and implementation of a systematic framework for generating, exchanging, and validating ”Digital Twins” of aerospace components. These models are crucial for the continuous integration and verification processes that enhance the digital collaboration ecosystem within the aerospace sector.

To date, the achievements within this work package have demonstrated progress in establishing a unified and interoperable platform that supports the seamless exchange of equipment data. The pilot projects carried out have vali-

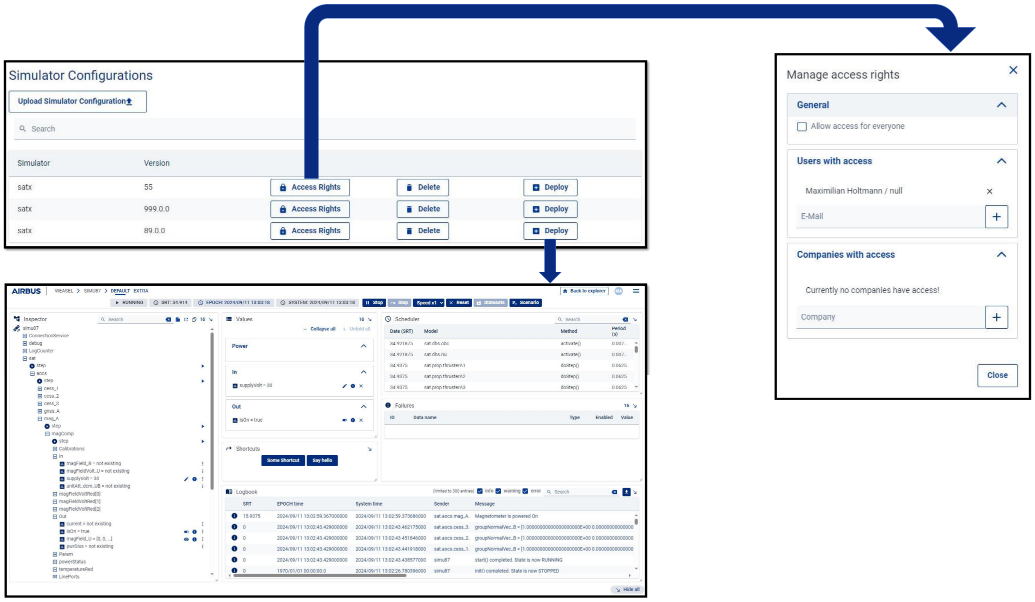

Fig. 6: Simulator configuration management in the "Simulations" application

dated the practicality and feasibility of the digital twins.

Looking forward, the work is set to delve deeper into refining these digital twins and expanding their functionalities. In the short term, a completion and refinement of the building blocks is foreseen. The next phase will focus on deploying these prototypes for enhancing model accuracy, expanding the range of components covered, and increasing the fidelity of simulations.

In conclusion, the journey of COOPERANTS and this work is far from complete, with further enhancements and achievements on the horizon. Stakeholders and participants can look forward to new developments that will not only address the current challenges but also pave the way for next-generation aerospace solutions that leverage digital technologies to their fullest potential.

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