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COOPERANTS: Advancing early-stage project phases by implementing collaborative processes and tools in concurrent engineering studies

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Abstract

The development of efficient collaborative tools and processes is crucial in complex, distributed, knowledge intensive fields such as the aerospace sector. In this regard, a key challenge is to find ways to securely share and link data among various stakeholders. The Gaia-X lighthouse project COOPERANTS (Collaborative Processes and Services for Aeronautics and Space) addresses this challenge within the German aerospace industry. Within this project, DLR and OHB conducted a pilot study to explore the feasibility of linking their Concurrent Engineering Centres (CECs) leveraging some of the smart services provided by COOPERANTS. The study aimed to assess the effectiveness of the process designed for inter-CEC collaboration as well as to evaluate the tools employed. The research utilized APOSSUM, a mission focused on extracting regolith from the Apophis asteroid, as its use case. The outcome from the study revealed that supporting the collaborative design process with the mentioned tools enhanced the synergy and flexibility of the model-based data exchange workflow. In this regard, this paper first outlines the development of the pilot study and the tools used, specifically detailing the smart services involved. Then, it presents the results from the evaluation of these services, providing insights into their effectiveness within the collaborative framework. Overall, this work aims to pave the way for more efficiency and collaboration across entities within the field of concurrent engineering.

Keywords: MBSE, Concurrent Engineering, Collaborative Engineering, COOPERANTS

Acronyms/Abbreviations

API	Application Programming Interface
APOSSUM	APhosphorus SURface saMpler
CEC	Concurrent Engineering Centre
CEF	Concurrent Engineering Facility
COOPERANTS	Collaborative Processes and Services for Aeronautics and Space
COTS	Components Off The Shelf
ESA	European Space Agency
MBSE	Model Based Systems Engineering
PT	Product Tree
RFI	Request for Information
UI	User Interface

1. Introduction

Effective knowledge capture, management, and dissemination is essential in complex, distributed, knowledge-intensive fields such as the space sector. In this domain, projects typically involve collaboration among multiple stakeholders—including customers, prime contractors, subcontractors, and suppliers—rather than being conducted by a single entity. These groups are required to share expertise, competencies, and resources

relevant to the project at hand, linking in some way the effectiveness of information flow to the project success. In this regard, a key challenge remains in establishing secure and efficient mechanisms for sharing and linking data among diverse stakeholders, both within and between organizations. To address this need, the Gaia-X lighthouse project COOPERANTS (Collaborative Processes and Services for Aeronautics and Space) was established. The consortium consisted of twelve partners, including major German aerospace companies, research centres, SMEs, and startups, each contributing with their expertise to the project [1].

Collaborative engineering has been extensively studied since the 1990s. In this regard, Ref. [2] offers a comprehensive overview of the context, concepts and terminology relevant to the collaborative engineering field. Additionally, it defines the typical knowledge representations according to each product phase and explains methods for sharing information both within and across these phases.

Concurrent engineering studies are typically conducted during the initial design phase, focusing on feasibility assessments and preliminary design

development. As noted in Ref. [2], these early stages require the use of various types of representations, including pictorial tools (such as CAD software), linguistic (conferencing platforms), and symbolic and algorithmic tools (e.g., MBSE and mission analysis software).

Another important work is found in Ref. [3], where methods for enhancing the utilization of collaboration technologies are assessed. On the other hand, Ref. [4] addresses the challenges that arose from the implementation of centralized operational models in the architecture and construction sectors. The paper details several experiments conducted in the Netherlands, along with user observations and feedback. Its relevance stems from the industry's highly fragmented nature, similar to the aerospace one, with many specialists focused on specific tasks.

In a nutshell, this paper presents an inter-concurrent engineering study conducted between the *DLR* and *OHB CECs*. The discussion will begin with an introduction to the selected demonstration mission, followed by an overview of the model-based collaborative workflow and an analysis of the results obtained from the testing of the various smart services used during the study. Together, these sections detail the process undertaken and conclude by providing insights into the effectiveness of these tools for our inter-CEC study.

2 Inter CEC design study

A concurrent engineering study was carried out by the DLR and OHB Concurrent Engineering Centres (*DLR-CEF* and *OHB-CEFO*) during the first week of December 2024. The purpose was to assess the collaborative engineering process and tools for linking the two separate facilities, using the DLR mission APOSSUM as a pilot case.

2.1 Pilot mission

The demo mission case study involved flying APOSSUM as a secondary payload on RAMSES, an ESA mission planned for studying the tidal and magnetospheric effects on asteroid Apophis during its close Earth flyby. The spacecraft will be adapted from Hera, ESA's first asteroid mission, which was launched on 7 October 2024. RAMSES is scheduled for an early 2028 launch to observe Apophis during February 2029, two months before its close approach. In July 2024, ESA Member States authorized preparatory work for the Consolidation/Early Implementation phase, awarding the contract to OHB Italy [5].

The APOSSUM probe (APOphiS SURface saMpler) is an in-situ lander designed to collect

samples from the surface of Apophis. By leveraging the asteroid's close pass to Earth, the mission requires only a small delta-v to return samples. APOSSUM aims to gather relatively large, well-preserved regolith pieces within a sample container of at least 1 kg and 1 l in volume. This approach preserves delicate petrological structures that might otherwise be lost during meteorite entry, providing valuable insights into the asteroid's composition and structure [6].

2.2 Integrated mass budget

System-level budgets represent a fundamental result of the concurrent engineering process, capturing and synthesising the work of the various domain and subsystem experts. These budgets provide an initial overview on the system level design and act as reference for future design iterations. Furthermore, they also serve as a checkpoint for the overall mission feasibility.

For the purposes of this study, the mass budget serves as an example to illustrate the process. Other essential budgets such as those for power, dissipation, and data can be developed using a similar methodology.

In contrast to the classical approach where budgets are developed using a central MS Excel file managed by the system engineer, one of the project final outcomes was the creation of a model-based integrated mass budget. This approach integrates the following smart services:

- COTS Database, PartDB
- Semantic Adapter
- Engineering Dashboard

As explained later, during the inter CEC study, the COTS component database, also known as PartDB, and the Semantic Adapter were the smart services evaluated. On the other hand, the Engineering Dashboard was not included as it was unavailable at the time of the study, being however released soon after.

As visualised in Figure 1, the process can be described as follows:

After an initial agreement and booking of the services present in the Marketplace, different actors can collaborate directly via the GAIA-X infrastructure. By doing this, each party can use their preferred MBSE tools. The Semantic Adapter handles the exchange and conversion of

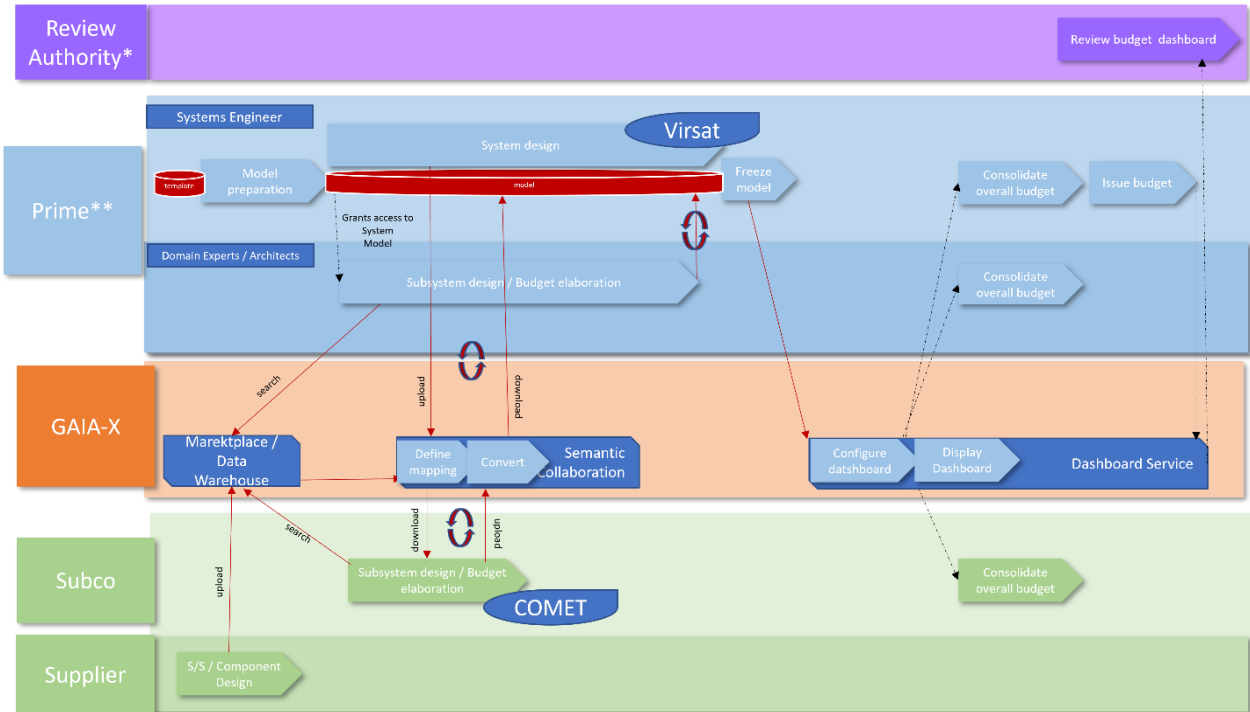


Fig.1. Visualization of model-based Integrated Mass Budget process supported by GAIA-X

information, reducing training efforts and license costs.

Additionally, suppliers can add their design information into the COTS Database, which can be accessed by the prime or subcontractors. This information can be also integrated into different models via the Semantic Adapter. Finally, the Dashboard Service provides a live view of budgets in a pre-configured layout, eliminating the need for static budget files.

2.3 Inter CEC study process definition

In relation to the process definition, three types of domain rounds were identified. These sessions, typically held after a design iteration, involve a structured review aimed at synchronizing the different domains, gathering feedback on the evolving desing, and coordinating the next steps.

1. Status exchange only between the CEC Team Leaders
2. Parallel, unrelated domain round in the different CECs, with a common status presentation

3. Sequential common domain round for both CECs

Regarding the splinter meetings, i.e., breakout sessions held in different rooms, where a specific group of domain experts convenes to address specific issues or advance particular design areas, two different types were identified:

1. Combined splinter meetings: they involve participants from both organisations attending a single splinter session. The meeting is hosted in one of the CECs, with participants from that location relocating to the designated splinter room. Attendees from the other organisation join the conference remotely
2. Independent splinter meetings: they are held in each CEC simultaneously, convening only participants associated to the respective CEC

Finally, a summary of the study schedule is provided in Table 1:

Table 1. Inter CEC study process definition

Day 1	Day 2	Day 3	Day 4
Session 0.1: Valiassistant evaluation	Session 1.1: Domain Round Type 3	Session 2.1: Domain Round Type 2	Session 3.1: Domain Round Type 3
Session 0.2: PartDB and Semantic Adapter introduction and setup	Non-moderated time 1.1: Splinter meeting Type 1	Non-moderated time 2.1-2.2: Splinter meetings Type 2	Session 3.2: Retrospective
	Session 1.2: Domain Round Type 2		Session 3.3: Assessment of processes and services
	Non-moderated time 1.2-1.3: Splinter meetings Type 2		

3 Supportive tools

To support the collaborative process, several tools (or smart services) were developed within the COOPERANTS framework. Furthermore, Valiassistant [7], an artificial intelligence-powered requirement generation tool developed by Valispace (a COOPERANTS partner) and currently in its beta phase, was evaluated during the initial day of the inter-CEC study.

As mentioned earlier, a key aspect of the COOPERANTS approach is that each organisation can maintain its preferred MBSE tool, in this case, DLR's Virtual Satellite and OHB's CDP4-COMET (Starion Group), while the systems are then linked to share an integrated mass budget, in this case, comprising RAMSES and APOSSUM mass breakdowns.

A brief summary of all the tools is presented below:

3.1 Virtual Satellite

Virtual Satellite [8] is a software framework developed by DLR to support system-level design. Serving as a core component of the DLR concurrent engineering environment, Virtual Satellite enables multidisciplinary teams to collaboratively model, analyse, and assess different satellite system architectures. The platform features a modular and extensible data model, and integrates with various domain-specific tools to ensure real-time updates and consistent data exchange across subsystems. It facilitates structured system modelling and rapid design iterations. Additionally, a headless Server version of Virtual Satellite provides a REST API for easy access to the data model.

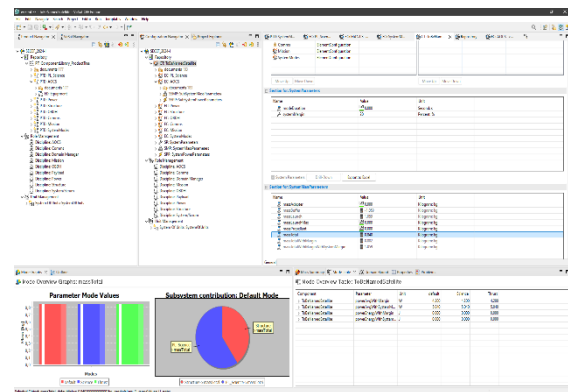


Fig.2. Virtual Satellite UI

3.2 CDP4 COMET

CDP4-COMET is an open-source software designed to support model-based system engineering using the Concurrent Design method. It enables modular system engineering in a collaborative approach, allowing stakeholders to modify design parameters and validate the overall design. The tool serves as a single point of truth for the team, facilitating the automated generation of budgets and ensuring consistency [9].

OHB adopted CDP4-COMET as its standard Concurrent Engineering data model in 2020. Since that time, the OHB Concurrent Engineering Facility (CEFO) team has expanded its use cases and continued to support input from the increasing number of OHB users. The core use case at OHB involves collecting key engineering parameters and producing corresponding viewpoints, such as budgets and reports, from the central data source. OHB has implemented over ten different budget types, including various sub-views and derivations, using the CDP4-COMET report functionality. These reports cover the following key parameters: mass, power consumption, power dissipation, propellant &

delta-v, temperature limits, data volume and cost, and are presented, both, in tabular and graphical formats [10].

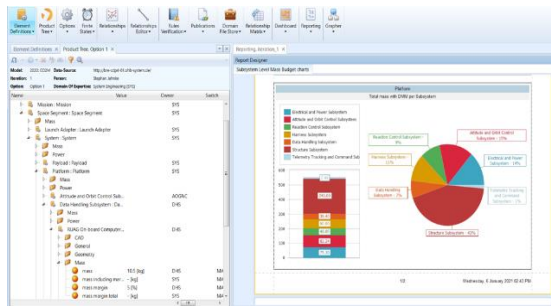


Fig.3: CDP4-COMET UI

3.3 COTS Database, PartDB

PartDB is a database for storing part information and its properties. Each part falls under a category (e.g., solar panel or reaction wheel), which defines its relevant attributes (e.g., length, material, operating temperature). Categories and properties are derived from the spacecraft parts ontology [11], with options for user customization. The ontology supports comprehensive documentation of spacecraft components.

☐	Magnetorquer_MTO_60	Magnetorquer
☐	Magnetorquer_MTO_600	Magnetorquer
☐	Magnetorquer_MTO_900	Magnetorquer
☐	QJ_Solar_Cell_4G32C-Advanced	Solar Panel
☐	Reaction_Wheel_RW1	Reaction Wheel
☐	Reaction_Wheel_RW4	Reaction Wheel
☐	Reaction_Wheel_RW8	Reaction Wheel
☐	Reaction_Wheel_RWp015	Reaction Wheel

Fig.4: List of parts described in the PartDB

Identifier	blue-canyon-rwp015		
Category	Reaction Wheel		
Name	Reaction_Wheel_RWp015		
Description	Our ultra-low disturbance reaction wheels feature an advanced lubrication system for long life and vibration isolation		
depth	19	Unit: mm	
height	42	Unit: mm	
mass	0,13	Unit: kg	
operating temperature range max	60	Unit: °C	

Fig.5: Detail view of a part in PartDB

3.4 Semantic Adapter

The Semantic Adapter connects two RESTful APIs using OpenAPI specifications. It enables, on one hand, interpretation of the specification for interactive exploration (Semantic Matching as per Figure 6) and, on the other, data transfer provided that there is a matching specification. By automating this process, it removes the need for manually writing custom import or export code. Figure 6 illustrates its workflow [12].

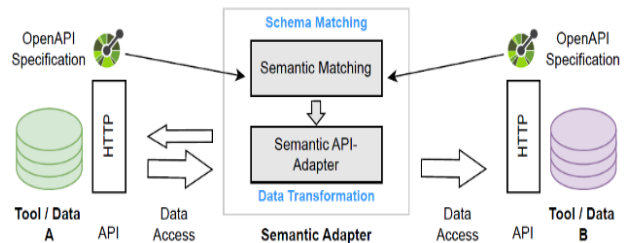


Fig.6: Semantic Adapter conceptual workflow

Both the source and the target tools require an OpenAPI specification, which is used to generate a Semantic Matching file. This file enables the Semantic Adapter to translate data between APIs. The adapter explores each tool's API using its OpenAPI specification. Figure 7 shows a screenshot of the transfer process and an example configuration of the adapter.

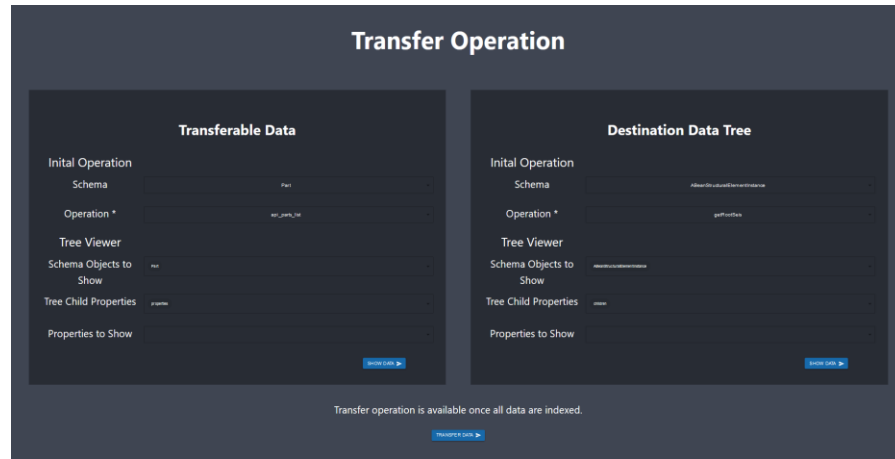


Fig.7: Semantic Adapter transfer process

All the tools were tested locally prior to the study. The Service Offering for the Semantic Adapter was established on the Marketplace, and test purchases were performed [13].

4. Results

The following section provides the results obtained from testing the collaborative tools during the inter-CEC study.

4.1 Valiassistant

Table 2. Valiassistant evaluation results

Aspect	Evaluation
Quality of Requirements	Lower than those created by an expert system engineer during the CE process
Accuracy of values	Often the outputs were focusing on values, which most of the times were not accurate (too precise numbers too early)
Confidentiality level	Low, due to reliance on public sources
Cost budget estimation	Low, likely due to the lack of an overall budget definition
Usefulness	Useful for providing basic inputs to junior or not so experienced system engineers or teams. Helpful in preparatory phases rather than later, in collaborative ones
Error and inconsistency detection	The tool can be useful for searching duplication errors and inconsistencies
Output supervision and verification	Time consuming

Aspect	Evaluation
Prompt selection Potential	Needs to be carefully selected for meaningful requirements High potential, very innovative tool
Reliability	Not reliable enough for direct utilization at this stage of development

Among the suggested improvements are:

Table 3. Valiassistant improvement suggestions

Improvement
- Train AI on specific, relevant data sources - Possibility to upload your own requirements for inconsistency check (the utilization of public AI makes this a challenge though) - Specify sources and references clearly

- Feedback from the inter-CEC study participants**
 The team appreciated the tool's simplicity of use. However, further improvements are necessary before becoming a reliable tool for the direct application in the system engineering process.

4.2 Semantic Adapter

Table 4. Semantic Adapter evaluation results

Aspect	Evaluation
Version control	Important to keep track of the data transferred
MBSE tools PT	Necessary to pay attention to different PTs from different data models for correct transfer

Aspect	Evaluation
Bidirectionality	Currently Semantic Adapter has been only tested for transferring data from Virtual Satellite to COMET
Margin philosophy management	Needs harmonization to avoid conflicts between different margin philosophies in different MBSE software

Among the suggested improvements are:

Table 5. Semantic Adapter improvement suggestions

Improvement
- Impact view implementation to track the potential changes before transferring them - Synchronization among both tools: automatic updates between the MBSE SW - Test bidirectional data transfer - Improve transfer options: option to transfer all or only individual subcomponents

- **Feedback from the inter-CEC study participants**
 While the UI was simple, the process to select and commit the transfer appeared to be rather complex. However, the data was successfully transferred.

4.3 COTS Component Database, PartDB

- **Outputs from its utilization and feedback from the inter-CEC study participants**
 According to the feedback, the functionality and design of the tool were well appreciated. The tool worked without any problems during the demo.

Table 5. PartDB improvement suggestions

Improvement
- Preview of the data for the different components - Add cost category

5. Conclusions

Overall, the study demonstrated the feasibility of remotely connecting two different Concurrent Engineering Centres (CECs). During this study, the possibility of flying the APOSSUM probe as a secondary payload of the RAMSES mission was explored, providing an opportunity to test both the inter-CEC collaborative process and the smart services in a realistic scenario.

The smart services utilized during the study, including the COTS Database (PartDB), Semantic

Adapter, and Valiassistant, are deemed to have great potential. By using the Semantic Adapter, data from CDP4-COMET was successfully transferred and integrated into the APOSSUM model in Virtual Satellite. This allowed for collaborative iterations during the study, resulting in an integrated mass budget for both spacecrafts. However, maintaining consistency in the mass budget proved challenging, highlighting an important aspect to address in the future.

Overall, the functionality and design of the tools were well appreciated, as they provide the required degree of synergy and flexibility to the inter-CEC process. The feedback from participants was positive, indicating that they would use the same services again in future studies. However, a procedure or manual of application needs to be established for future use.

Finally, it should be noted that this paper has primarily focused on the smart tools, maintaining a high-level overview of the collaborative process, as its detailed analysis falls outside the current scope and will be addressed in subsequent publications.

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