Achieving Digital Continuity Across Multiple PLM And SPDM Environments for Automated System-Level Design Optimization

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Abstract

Manufacturing companies face growing product complexity. They need higher levels of simulation in product development. Maintaining simulation results and product data synchronization is essential to shorten design cycles and increase throughput. For many companies, this is still a challenge. There are fragmented design processes across disconnected Product Lifecycle Management (PLM), Simulation Process and Data Management (SPDM) and Multidisciplinary Design Optimization (MDO) environments which run on different applications, leading to siloed datasets. The lack of interoperability between various CAD, CAE and process automation and design optimization authoring tools and data management systems often results in data duplication, loss of traceability and inconsistent user experience. This prevents valuable analysis and simulation information from being maintained and used throughout products' lifecycles. A loss of knowledge and experience in simulation-driven design, amplified by a globally distributed workforce, creates an additional layer of difficulty. This necessitates capturing and transferring knowledge through democratization and automation of engineering workflows. Every stakeholder, from CAD designers to CAE analysts, should participate in the simulation process and seamlessly execute simulation workflows to find trusted designs early in the product development.

In this paper, we present a state-of-the-art federated approach to managing and automating design, simulation and optimization processes through the digital thread, while preserving the relationships between teams, their processes, tools, and data that contribute to improving product performance. This happens by connecting multiple PLM and SPDM systems with an open digital engineering platform. What if this platform can act as a key enabler to orchestrate and automate diverse CAD/CAE authoritative sources of data and models into a ready-to-use simulation workflow to collaboratively perform system-level MDO? We demonstrate this innovative approach by taking the simulation-driven design process of a crankshaft, one of the most important parts of an engine's power transmission system, as a reference. Cross-functional engineering teams such as CAD designers, CAE analysts for structural and

modal analysis, as well as simulation experts and other stakeholders can all benefit from an agnostic web-based framework to convey and automate various CAD/CAE models (stored in different PLM, SPDM and other data management systems) into a single executable simulation workflow. This allows them to seamlessly conduct further design optimization analyses with the goal of finding the best compromise between the crankshaft weight and deformation caused by the load and constrained by its maximum stress.

1. Enabling digital continuity with a PLM/SPDM/MDO federated approach to manage design, simulation and optimization processes

From the initial concept for a product to its design, virtual prototyping, testing and production, the flow of information or digital thread plays a crucial role to enable companies to operate more efficiently and gain reliable results from their product development. Two types of data are particularly important: product data and simulation data. Product data encompasses all the information related to the design and specifications of the product, while simulation data includes the results of virtual tests and analyses. While both are vital, they often exist in silos, making it difficult for teams to access, share and connect the data. This siloed approach can lead to inefficiencies, errors, and missed opportunities for innovation. CAD teams focus on creating the digital models of the product, while CAE teams run simulations to test and analyze them. While dependent on each other, the communication and especially sharing of information between these teams of engineers is often inefficient. This is true for numerical basis, data storage and data management systems.

PLM mainly manages product information from requirements and design to manufacturing and maintenance. PLM and specifically most PLM systems are not designed to support highly dynamic engineering processes or to link to the CAE ecosystem. While PLM is excellent at managing the broad product information, it struggles to keep up with the complex world of engineering simulations. In this context, the common issue is the manual data transfer from CAD to CAE and Multidisciplinary Design Optimization (MDO) environments, which exposes human error and data duplication resulting in a lack of traceability and synchronization. When data is manually transferred between systems, versions can proliferate, and it becomes impossible to track changes and maintain an authoritative source of truth to trace simulation results back to CAE and CAD models used. How do we connect the different systems and their respective teams/users with each other?

In a perfect world, you could just rely on a single SPDM infrastructure that manages the simulation request coming from the CAD stored in a PLM system, orchestrates simulation analysis, stores simulation models and pushes back the simulation results into the PLM. This integrated approach would allow for automatic transfer of models, centralized storage of results, and bidirectional updates between systems.

But, especially due to the proliferation of simulation applications, the reality is quite different. As companies adopt more and more specialized simulation tools, the complexity of orchestrating CAD/CAE automation across systems grows. In this scenario, how can you chain and automate CAD models with multiple CAE analyses (possibly stored in different SPDM repositories) to eventually perform Design of Experiments (DOE) or MDO to evaluate the design space without losing data traceability and interoperability between PLM and SPDM systems? This is the key challenge that we want to address with our state-of-the-art federated approach. Bridging the standardization gap between design optimization, CAD/CAE workflow automation, SPDM and high-level PLM processes. This is enabled by a digital engineering platform equipped with plug-in connectors which can retrieve CAD/CAE models stored in corporate PLM, SPDM or other file storage services according to standard internal procedures. By using its external data source connector, the digital engineering platform can access CAD models stored in a PLM as well as CAE models stored in an SPDM and link them into an automated simulation workflow ready to be executed. This approach minimizes data duplication and ensures traceability. Also, it enables companies to keep their existing data management tools while integrating them into a more cohesive web-based framework which realizes the integration and automation of simulation design processes with MDO studies.

Essentially, our PLM/SPDM/MDO approach aims to address a key challenge in digital engineering. As stated by the Aerospace Industries Association, to achieve a high level of digital engineering maturity, organizations must be able to capture and automate their business, engineering workflows, and processes. And, they must be able to access, connect, and use their data effectively. Specifically, we tackle the absence of comprehensive toolchain agnostic workflow automation that incorporates PLM and SPDM models into the MDO analysis. By bridging this gap, organizations can ensure that optimization results are traceable and aligned with overall product lifecycle objectives, improving the efficiency and effectiveness of engineering processes.

2. Case study: Connecting PLM and SPDM systems to a digital engineering framework for multidisciplinary design optimization (MDO) of a crankshaft

A crankshaft design could have an engineering requirement to find the best compromise between its weight and deformation caused by a load case while also being constrained in its maximum stresses. Starting from an initial design, a group of design engineers creates a detailed 3D CAD model of the crankshaft. This is stored in a PLM system which acts as an authoritative source of truth for all product data from design to manufacturing and maintenance. As a common practice, the CAD model needs to be cleaned to be ready for simulation analysis. In this case, two CAE analysts use the simplified CAD model from the PLM to define the parametric simulation models for the structural and modal analysis. These models can be either stored in a local/shared hard drive or in web-based SPDM systems.

We assume a scenario where a company’s simulation department adopted a commercial SPDM system to collaboratively manage and archive simulation models (Figure 1). As a result, the structural and modal analyses and their results are properly stored in an SPDM system, maintaining version control and a connection of the simulation data to the product digital thread. The key stakeholders can monitor progress and gain access to data quickly, allowing the teams to meet their schedule commitments. However, this is not enough alone to meet the goal of our engineering design project: finding the best crankshaft design without performing time-consuming manual simulation activities. Indeed, the missing piece is the process automation across engineering disciplines with the aim of applying design exploration or optimization strategies. This could allow simulation teams to quickly further investigate the design space and find optimal candidates with the best trade-off between the crankshaft weight and deformation. To accomplish this, an expert in simulation and methods development relies on an agnostic web-based digital engineering platform to convey and automate the CAD crankshaft (stored in a PLM system) as well as the CAE structural and modal analysis models (stored in an SPDM system) into a single simulation workflow to conduct further multidisciplinary analyses.

Figure 1: The PLM/SPDM/MDO federated approach

The digital engineering platform's open architecture and process automation framework (Figure 2), combined with its external data sources connector, allows a methods developer to:

- Create single discipline simulation workflows to automate parametric geometry modification (Appendix, Figure 3), structural simulation (Appendix, Figure 5) and modal analysis (Appendix, Figure 6). Reference the CAD (stored in external PLM system), structural and modal analysis models (stored in the same or an external SPDM system) in the digital engineering platform's data manager. This way all simulation data, with its digital thread, is located on the same platform which is specifically designed to support highly dynamic engineering processes without the duplication of data and while respecting access control.

- Build a multidisciplinary simulation workflow that pulls data and models from the PLM and SPDM systems and links them in an automated process for CAD modification, structural and modal analysis of the crankshaft (see Appendix, Figure 8). The external data source connector enables the management of the entire simulation process automation in a single centralized place that stores automation workflows, simulation results as well as post-processing dashboards.

- Publish the automated multidisciplinary simulation ready to be executed via web with design exploration or optimization strategy.

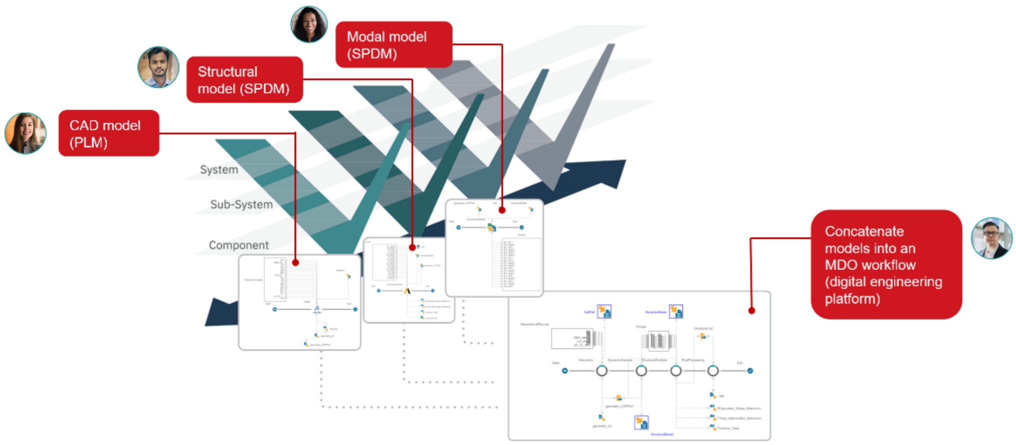

Figure 2: The three single discipline optimization (SDO) component workflows interact in the multidisciplinary optimization (MDO) workflow. Blue nodes indicate CAD (referenced from PLM) and CAE Models (referenced from other SPDMs) using external data source connectors.

The effort of the method developer pays off for the CAD designer and CAE analysts, enabling democratization in the simulation-driven design process. All stakeholders can easily access the digital engineering platform, re-use and execute the multidisciplinary simulation workflow with different evaluation strategies based on their permissions. These strategies include performing a single run or what-if scenario to test a single crankshaft design to see how the model behaves with a specific set of inputs. This framework also enables the application of Design of Experiments (DOE) techniques to gather information on system behavior and to identify sensitivities of the responses of interest to a range of inputs. With a configuration like this, even applying multi-objective optimization algorithms to more deeply explore the design space and to find a set of solutions with the best compromise between the crankshaft deformation and weight becomes possible without significantly increased effort being required. Optimization allows experts to concentrate on value-added engineering—identifying the key desired outcomes of the crankshaft design—and then relying on an algorithm to find the set of inputs that will achieve those optimized results.

The external data source connector streamlines the simulation workflow by automatically updating references to CAD and CAE models. Whenever a new version of these models becomes available, the workflow is automatically updated, ensuring analyses are conducted using the most up-to-date models.

In addition to the seamless execution of complex simulation workflows, democratization is extended to the post-processing of the crankshaft simulation design results. Ideally, all actors involved in the design process can easily access a web dashboard to interpret simulation data with interactive charts, visualizing the entire optimization dataset to select the best crankshaft design or focusing on selected designs to visualize their 3D model and to post-process FEM and modal analysis results.

3. Conclusions

In terms of business operations, the main advantage of the PLM/SPDM/MDO federated approach, implemented with a digital engineering platform, is that simulation becomes an integral part of product development, allowing PLM systems to efficiently use simulation data to shorten design cycles and increase throughput. The platform agnosticism and its ability to address the standardization gap are rooted in its open architecture, integration capabilities, and collaborative features. These aspects enable the platform to standardize engineering processes while accommodating diverse tools and environments. By tightly integrating simulation into the PLM process, companies can leverage the power of simulation to make better, faster design decisions. This should also increase simulation acceptance and usage by designers who normally deal with PLM-related data. The use case shows how a digital engineering platform can make this possible, offering simulation capabilities that are accessible and understandable for a wider audience of engineers. In this context, the role of experts in simulation and method development is going to change. As such, they take on more of a support function aimed at automating existing and developing new, diverse CAD/CAE processes/methodologies into ready-to-use simulation workflows. In this way, CAD designers and CAE analysts can more easily and quickly run simulations, explore design variants with design exploration or optimization techniques, and analyze results, all while preserving the traceability of their CAD and CAE models stored in their respective data storage systems (e.g. PLM and SPDM).

5. References

[1] Aerospace Industries Association (AIA), "Emerging Needs and Considerations for Digital Engineering Software Tools", 2023

Appendix

Simulation workflows

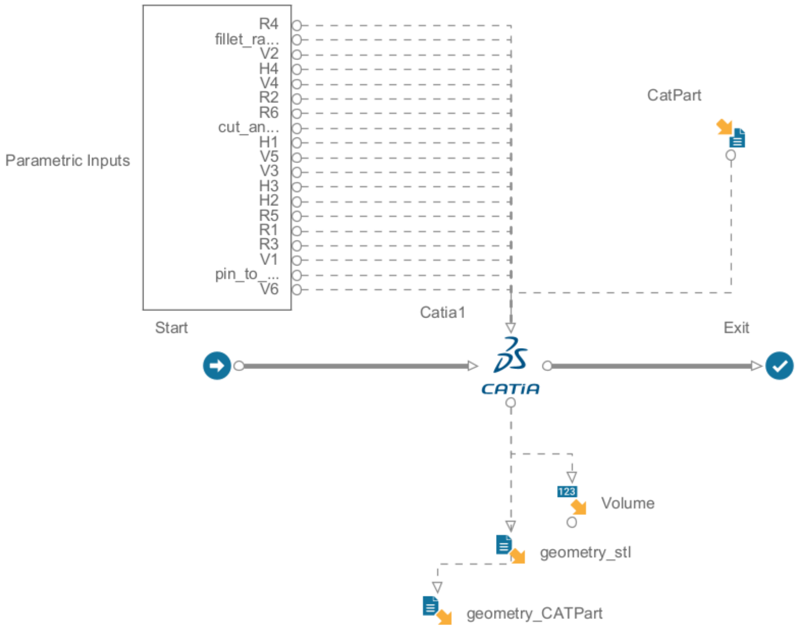

Figure 3: Workflow that modifies the CAD geometry given a set of parametric inputs. The workflow outputs a 3D model which is used in the system level MDO.

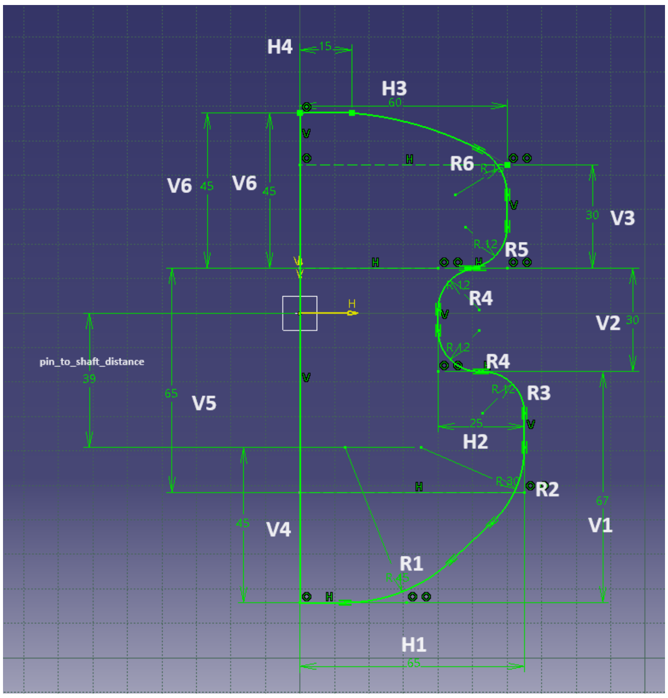

Figure 4: Geometrical parameterization of the CAD model.

Figure 5: Workflow for structural analysis. CAE model is referenced from SPDM using external data source connector.

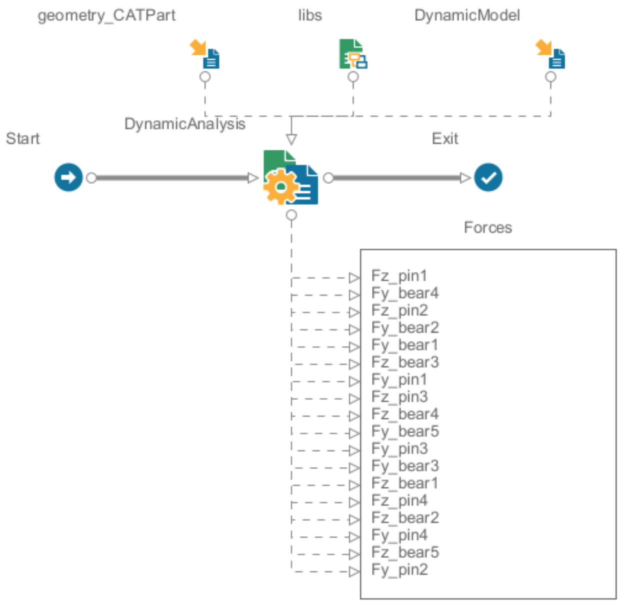

Figure 6: Workflow for dynamic analysis. Dynamic Model is referenced from the SPDM with external data source connector

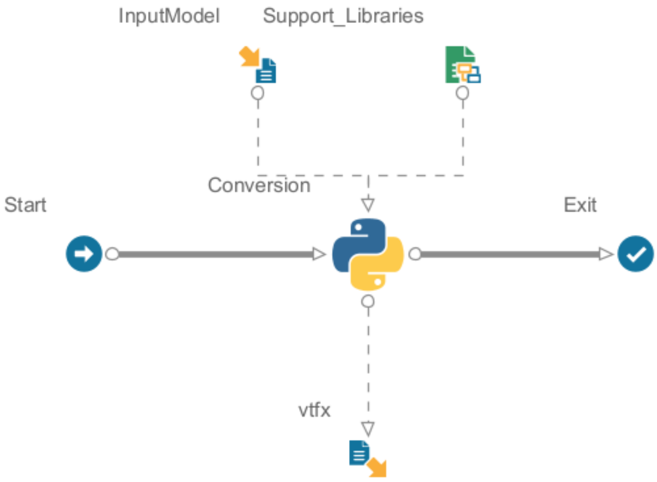

Figure 7: Workflow for the 3D lightweight generation for visualization on the web.

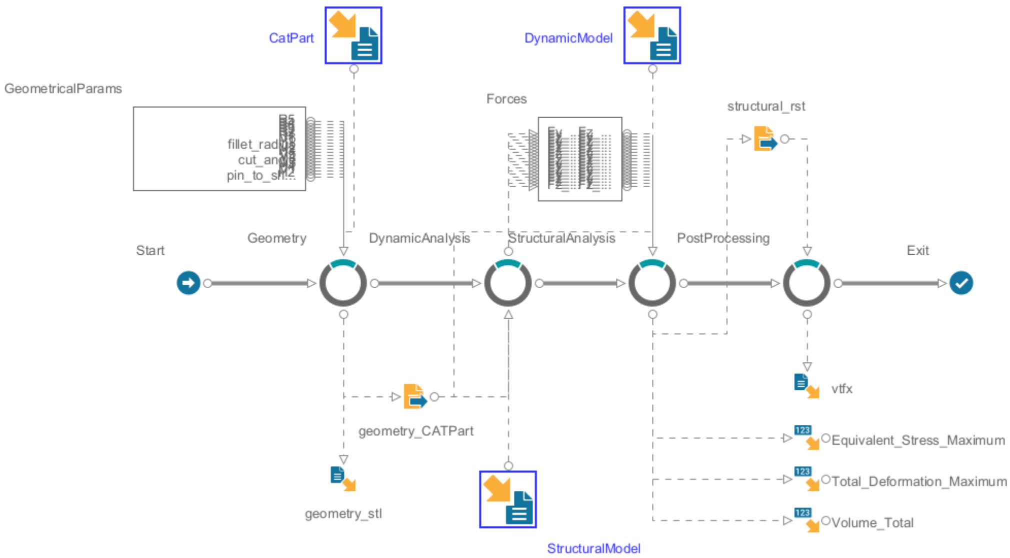

Figure 8: Multidisciplinary optimization workflow that uses the component SDOs and references the CAD and CAE models from PLM and SPDM by means of external data source.