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Interoperability of Simulation Applications for Dynamic Network Enterprises Based on Cloud Computing - Aeronautics Application

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Abstract. The objective of this paper is to propose a solution to the problem of interoperability of simulation applications. Improving simulation data exchange to reduce the development time and cost for design products is one of the major issues of collaborative design environments. Currently, sharing engineering simulation information is still technically challenging due to the complexity and the size of data. Furthermore, in industries including Aeronautics, there are many subcontractors using their own simulation tools with data heterogeneity. In this paper, firstly we analyze the problems of interoperability of simulation applications in the virtual environment of dynamic network enterprises. Then, a novel approach and architecture based on cloud computing technology will be presented. An example of application in the field of Aeronautics will be used to illustrate our research works.

Keywords. Interoperability, Data Exchange, Simulation Software, Cloud Computing, Aeronautic Application

Introduction

In order to face globalization and resulting increasing competition, and focusing on core high added value business activities, enterprises have to establish partnerships with other companies specialized in other complementary domains [1]. As an example, the percentage of targeted subcontracted activities in the Aeronautic industry can reach sixty to eighty percent [2], including not only manufacturing activities but also design activities. An organization with sub-contracting and outsourcing, where enterprises

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must coordinate partner activities and internal resources, is called “Extended Enterprise” [3]. In this collaborative context of efficient exchange, sharing and integration mechanisms are fundamental. One of the objectives of the aviation industry is to improve the exchange and manage their simulation data and process.

Figure 1 shows a generic CAE (Computer-aided engineering) process. Nowadays, one of the most challenging aspects for the CAE process is to ensure that all multi-physics simulations from the different disciplines work on the same product data model.

Generally, the geometrical modeling process (CAD models design) contains meta-information like part number, nomenclature, approval date, name of the designer and other information. This metadata model will be transferred, integrated and managed by the CAE pre-processor.

For a simulation study a pre-processor creates and defines the necessary data, as the mesh, boundary or initial conditions and loads. These data will be available for one or more solvers depending on the type of the physical simulation. The solver creates output files with results. Post-processing is used to gather results and provides the visualization of the computed results.

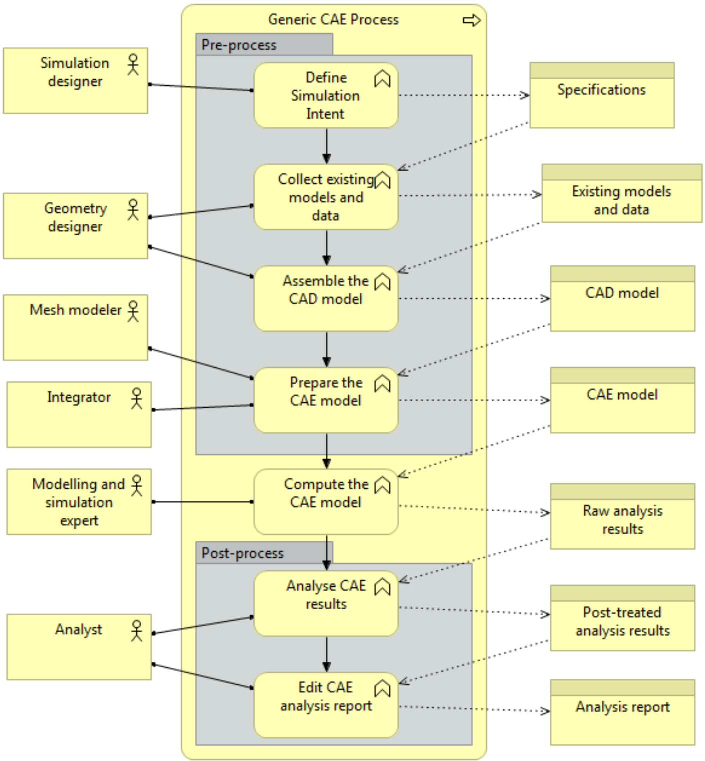

Figure 1. Generic CAE roles and process

Using different software tools and physics, each required pre-processing, modeling, meshing and post-processing stages, necessitates large investment in time, and hence in cost to undertake each of the simulations.

Moreover, different simulation studies require heterogeneous skills, methods and tools, among designers and analysts, who interact with each other. The large number of heterogeneous information handled in different processes, combined to the low level of interconnections between users, result often in large data sets that are scattered and duplicated. In order to facilitate the link and connexion between the different processes, research teams and industries try to find and develop a new collaboration working environment.

We propose a novel collaborative approach and architecture in order to support simulation studies to be distributed between different organizations with heterogeneous skills, methods and tools. The objective of this study is to rationalize simulation and product data exchange all along the simulation chain, involving different physics viewpoints, and allowing to deal with a minimum impact of changes on coupled simulation processes.

1. Collaborative simulation environment

To explain the environment of product development, firstly, we present the definition of the product and the different existing classifications. A product is a physical object that can be realized by manufacturing or natural process (ISO10303, Part 1). The product can be classified by their discipline, by their function and by their structure. For simulation field, we are interested in the product structure model and its relationships with the other models, such as Geometrical and Topological, Finite Elements, Material, Tolerances, etc.

Each of the simulation activities is a complex aggregation of many activities, which uses diverse sources of knowledge, information and data. From the result of the process simulation study, we can deduct that the problems come from the fact that the engineering data is not interconnected and the fact that the interaction between participants are not represented and correlated. To solve this problem two approaches exist:

1. Involving specialists in different domains within the project to join together and give their opinion. Unfortunately the meeting of implied persons of the project is not sufficient to solve completely the problem.
2. Integrating in a computer system all the knowledge related to different expertise and giving the possibility to the persons involved in the simulation collaboration to access to these information and to incorporate them.

In this paper, we focus and propose a solution for the second approach.

In collaborative simulation environment, data analysis is complex and the data file size is too large to be handled in real time, without technical challenges. Furthermore, each simulation system has its own data format increasing the sharing difficulty. Several recent studies and industrial approaches give solutions for the conversion problem between heterogeneous tools in order to manage data in a collaborative environment.

Immersive SIGHT Engineering developed a CAE visualization and sharing tool called Immersive SIGHT [4]. It translates CAE analysis results into a VRML or X3D structure. Commercial formats such as CEI Ensight [5] and GLView VTFx [6] have been also developed. These formats are not standardized and are limited to only some commercial software use.

Song et al. [7] suggested a method to use VR (Virtual Reality) systems for sharing heterogeneous CAE data. They developed the CAE2VR middleware for the translation of CAE data into VRML data based on VTF commercial format [6].

Cho et al. [8] proposed a methodology and a data representation scheme to reduce the FEA data size to increase the exchangeability of information analysis in collaborative environment. However, these research efforts have not provided a generic methodology to hierarchically accommodate the multidisciplinary data analysis within a single lightweight data structure [9].

Park & Kim [9], proposed a FEA lightweight data format for sharing analysis information containing only essential FE information and compressing mesh of FE models. However tested CAE systems were not available for the translation into this format.

These research works try to translate the simulation information in a light format in order to exchange the light visualization of simulation results. This aim is limited because simulation experts don't have the possibility to reuse the simulation data and make multi-physics simulations. In the early development phase, a collaborative approach can help cross-functional engineering organizations and predict system-level performance, it can also improve individual components or subsystems, as well as their interactions with one another, especially with multiple physics.

Analysis information has strong dependency relations with design activities and information. Thus CAD-CAE integration for improving design collaboration is currently an ongoing and important research topic [10][11][12]. STEP ISO 10303-209 provides a means to integrate more closely design and analysis product data by including nominal (CAD) geometry, various idealized CAD geometries, and associated FEM analysis models and results [13].

The figure 2 shows the different analysis viewpoints of a product structure model. This diversity and the links between them create an important complexity for the numerical simulation studies.

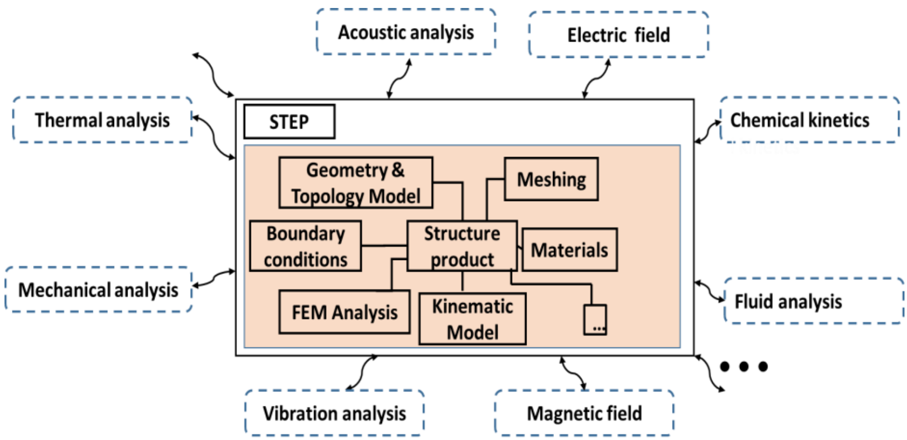

Figure 2. Different analysis viewpoints on the product description

Different disciplines during the simulation process need to collaborate, but they have different views of the design product according to the considered physics. These views are translated into different models of a product, which need to be accommodated in any comprehensive description of a design product. Some models used for product description are given in [14].

Structure is the state of the object, in a given physical environment, and in that environment exhibits certain behaviors. These behaviors affect various physical functions.

To define these concepts, and for the reasons of normalization, we use STEP standard (ISO10303). STEP is an international standard for representation and exchange of product data. We represent the concepts by EXPRESS-G formalism. EXPRESS-G is a graphical language of EXPRESS developed by ISO 10303 STEP (ISO10303-11). The EXPRESS-G basic notations used in figures include entities (rectangles); super-type/subtype relationships (thick solid lines); required attributes (normal lines); relationship for optional attributes (dashed lines). Additionally, the direction of an attribute is symbolized by an open circle, where the circle represents the "many" side of a "one to many" relationship. The structure model is shown in figure 3.

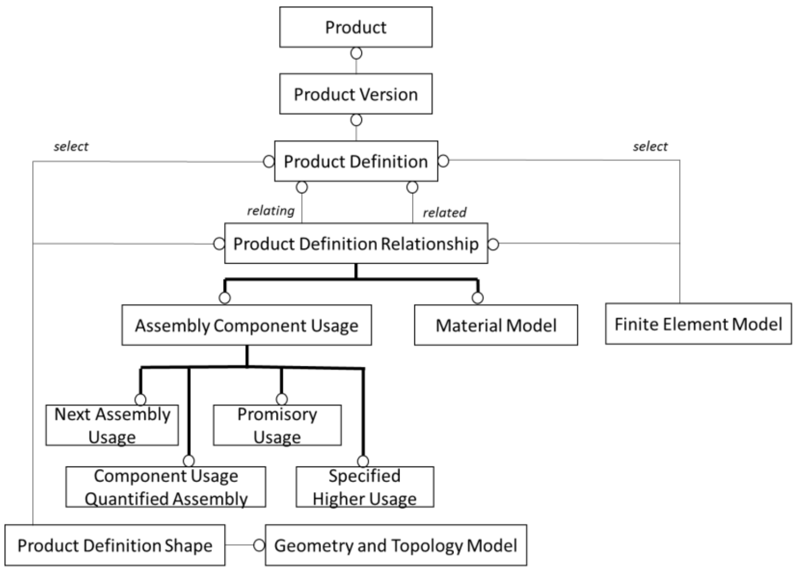

Figure 3. Structure model

Products model are represented with product, product version and product definition entities, which represents the main STEP concept. The other models such as material, geometry, topology and finite element are linked to the product definition. The relation between product definitions is represented by product definition relationship entity, which signifies all kinds of product definition relationships. The example of instantiation of these models is expressed in section 3.

2. Approach

In a collaborative approach for the collaborative simulation process, different participants interact through a product model, according to different viewpoints related to a discipline. For the achievement of this task, it is necessary to represent the participant diversity as well as the different disciplines. The expressed physical question about the product is dispatched though the different disciplines. During the numerical simulation activity, each expert in a given discipline must be able to take into account the other viewpoints, changes and results with respect to his domain of expertise.

The multi-physics analysis based on cloud computing technology is a challenging research area and few approaches have been proposed. We suggest an approach where the different physical viewpoints and the simulation process collaboration requirements are supported. We reuse the collaborative architecture of our team [17] and we adapt it to a collaborative simulation environment. Physics analysis are organized around a blackboard-type system based on cloud technology [15][16]. Each simulation actor publishes his data to the others through a shared blackboard (see figure 4). The blackboard is a common workspace for all simulation actors with several layer of protection. When a simulation actor chooses to publish his activity result (according to application requirements), he chooses also the privacy level of his data. So, only the concerned persons have access to the information: process analysis level, mono-physics level, multi-physics level.

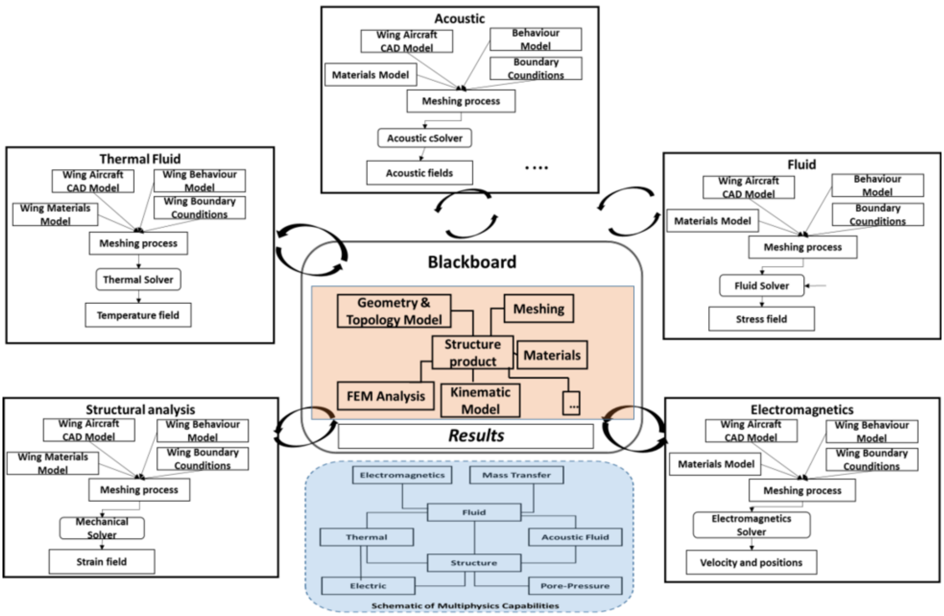

Figure 4. Collaborative simulation environment approach

Each simulation actor uses different types of knowledge: the generic or domain knowledge – related to his specific simulation area – and the specific or experience knowledge, which represents each area of expertise. During a collaborative work, the simulation tasks are performed in parallel and their results should converge to satisfy the simulation objectives. The efficiency of each collaborative work depends on the actor capabilities to collaborate. It is the quality of the exchange knowledge between simulation actors that influence the evolution of the simulation environment. It is necessary to develop an integrated environment while considering human requirements and the efficient tools for collaborative simulation.

The ontologies establish a common vocabulary for community members to interlink, combine, and communicate knowledge shaped through practice and interaction, binding the knowledge processes of creating, importing, capturing, retrieving, and using knowledge. Moreover, it is important to assure the correctness of content. In the proposed architecture, an ontology module exists [17]. It is divided into two parts, the constraint checker and the OWL reasoner. Constrained checking is used as a conflict attenuator. It uses predefined rules/statements to ensure that coherent data will be published. A constraint checking is an automated task, taken to verify the consistency of a given model. The OWL reasoner checks the consistency of the given ontologies/models, expressed in OWL. That is, it verifies whether there are any logical contradictions in two or more ontology axioms. The consistency checking module is activated whenever an ontology publication is done in either collaboration levels.

In our approach, the blackboard is composed of two parts: solution space and collaboration space. The blackboard is present in both the project and the simulation processes workspaces. The collaboration space is where collaboration effectively takes place. It comprises sub-areas: interaction, coordination, pre-defined rules, documentation, conflict, log, and version area. The solution space contains the common data, the merged ontology instances (produced after the collaboration process), and the predefined ontologies (for the generic approach) to be used as "standard models" by the simulation actors. The purpose of the solution space is to provide a centralized access service for the storage and retrieval of simulation process data during the execution of the system. It serves the system not only by storing and retrieving engineering data but also automating data exchange among different design activities. The solution space is accessible to all agents. During the collaborative activity, the simulation actors put CAE models/data into or get CAE models/data from this space, as well as the initial and intermediate results of the reasoning activity.

This architecture is implemented in a cloud platform as a service (blackboard as a service). Allowing various actors to partake it in a multitenant and high available cloud environment. The technology based on cloud computing enables organizations to improve their collaborative process efficiency by reducing the cost and time for exploiting the blackboard services.

3. Application

To validate this architecture, we present an example of collaborative simulation scenario in the aeronautic field. The purpose of this scenario is to study different interactions of physical phenomena on an aircraft wing in order to determine an optimized product structure. High wing vibrations of a flying aircraft may lead to accidents (wing rupture). This collaborative simulation scenario is multi-partner and involves actors from multiple physical domains. A wide variety of analysis software systems are used for virtual product verification. For instance, aircraft wing dimensioning and verification are performed on static strength, fatigue strength, damage tolerance, composite materials analysis, thermal analysis, and other criteria [18].

Figure 5 shows an example of the instantiation of the structure model for an aircraft wing. Wing is a composed of three subsets. For each simulation scenario, the experts are based on a structure model of the airplane wing. This structure model is composed of leading “edge flaps, flaps and spoilers” to vary the lift and the drag of the wing. Ailerons are flight control surfaces, and the wingtip devices are used to reduce the vortex creation at the end of the wing.

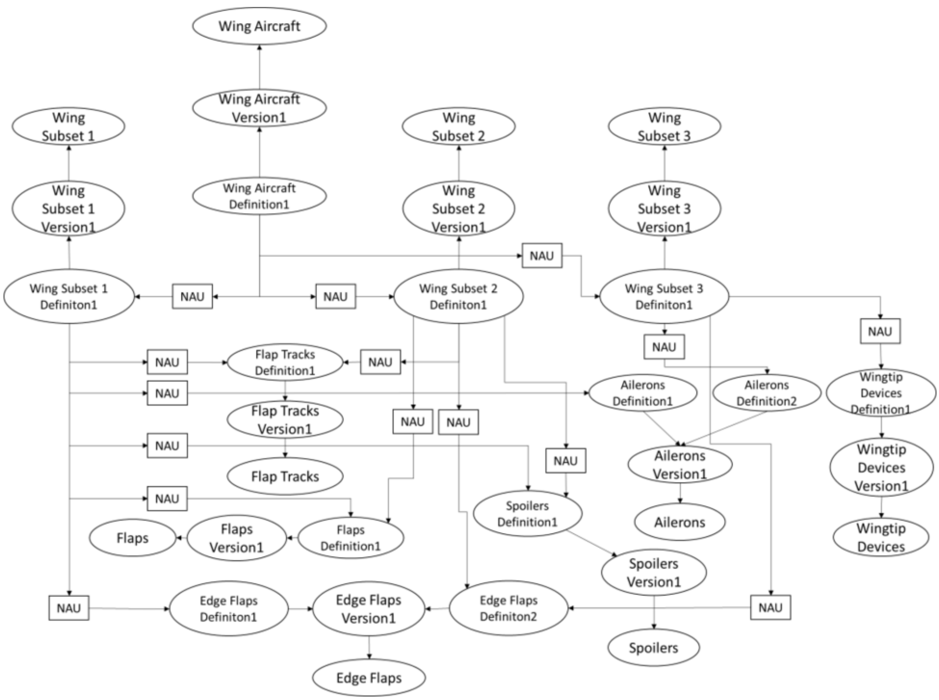

Figure 5. An instance of structure model of wing aircraft

During the design process of an aircraft wing, several simulations are performed involving various physics, in order to modify, verify, validate and optimize the structure of the wing. These physical phenomena are generally coupled. Therefore, there is a need to collaborate throughout the design process.

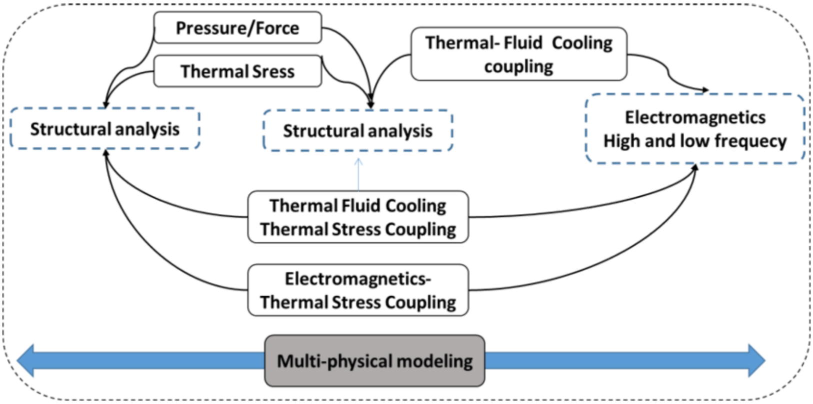

Figure 6. Example of multi-physics modeling applied airplane wing

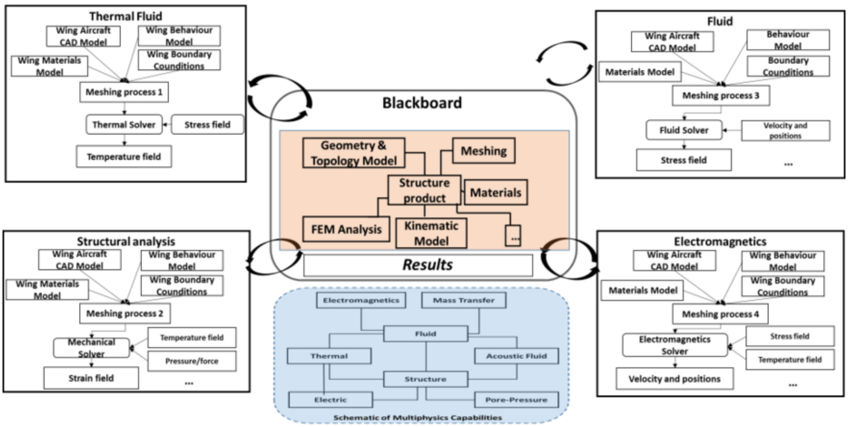

Figure 7. Multi-physics application example through the collaborative architecture

Multi-physics simulation delivers a deeper understanding of the impact of a variety of physical phenomena and gives a comprehensive set of product performances by considering the interaction of multiple engineering disciplines and physics. For our wing example, we can consider to study the fluid flow behavior using a commercial FEM solver (Ansys, Abaqus, CFD…), then to transfer the results to analyze the mechanical structure behavior by the use of the same or another commercial solver for mesh deformation (figure 6). Each expert includes the different results in the blackboard project that integrates all points view. These different points of view are represented in figure 7. When new data is published, other members of the collaborative project are notified by a message. They can then retrieve the results or the modified results. With this architecture, the experts of the simulation can communicate and work on the same product model representation and exchange simulation data (models and results).

4. Conclusion

In this paper, we propose a collaborative approach through an architecture based on cloud computing technology. Due to normalization, we have used the work on the standard product representation and we have represented the structure model by STEP. In our collaborative architecture, we used ontologies to model the different kinds of knowledge and expertise. We consider to use OWL as an efficient approach to represent knowledge in collaborative environments. To validate our architecture, we have studied the case of collaborative aircraft wing simulation. We have represented an example of its structure model instance. Currently, we are working on integrating our architecture in a collaborative workflow in a framework based on cloud computing technology to analyze and solve the problems of interoperability of simulations, providing automated data exchange and optimized solver interactions.

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