SIMULIA Abaqus/ CAE and CATIA Analysis as open & powerful process automation platforms

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Abstract:

The Simulation Automation topics often deal with chaining a wide range of software tools used by organizations to design and simulate their new products. Automatically exploring the design space, this approach is now effective in reducing the companies' design cycle time.

However, the achievement of the automation of each of the bricks of the process that will possibly be chained is the main issue. Included in these automated bricks part of the company's Know-how, it's possible to develop Vertical Applications that will help Engineering Departments deliver more reliable products, while keeping a very high level of innovation. These Vertical Applications are extensive in scope: products' geometry preparation, meshing, preprocessing, setting up boundary conditions & simulation, solver execution, post-processing, and report automation, etc.

This paper presents three robust and complete Simulia-based Vertical Applications and evaluates their contribution to design time cycles.

Keywords:
Automation, Abaqus, Abaqus For CATIA V5, Advanced Meshing Tools, short loops of iterations, Python.

1. Introduction:

In order to confront the increasingly competitive market and actual economic situation, manufacturing industries invest in innovating their products, processes and techniques. Sequential design processes evolve towards concurrent and collaborative processes, considering the use of digital simulation in the upstream phases of the design cycle. However, from a design project to another, the innovative contribution remains flooded by routine designs, thus preventing further shortening and optimization of design cycles.

Some tools bring optimization techniques to industries (such as Isight) in order to build advanced workflows quickly and reviewing results and data. However, these tools are efficient if the models and links chained in the workflow are robust and generative.

Today, SIMULIA software solutions offer more than just simulation tools integrated to CAD software, but also enable industries to embed their routine process in order to reduce considerably the time dedicated on routine operations. This paper describes three Vertical Applications developed in order to quickly process the workflows:

- The first case presents a workbench developed for the design and simulation of a simplified Power Unit. This development is combined with the use of Abaqus For CATIA V5, enabling complex and complete integrations of design and simulation;
- The second case presents a set of tools developed in Abaqus/CAE in order to drive and simulate CAD models purposed to automate the routine processes and operations that incur a waste of time;

- Finally, the last case presents a workbench developed in CATIA V5 using the CATIA Analysis Advanced Meshing Tools. These applications allow users to quickly design the welding and the associated meshes.

2. AFC Cylinder Heads templates:

2.1 Context

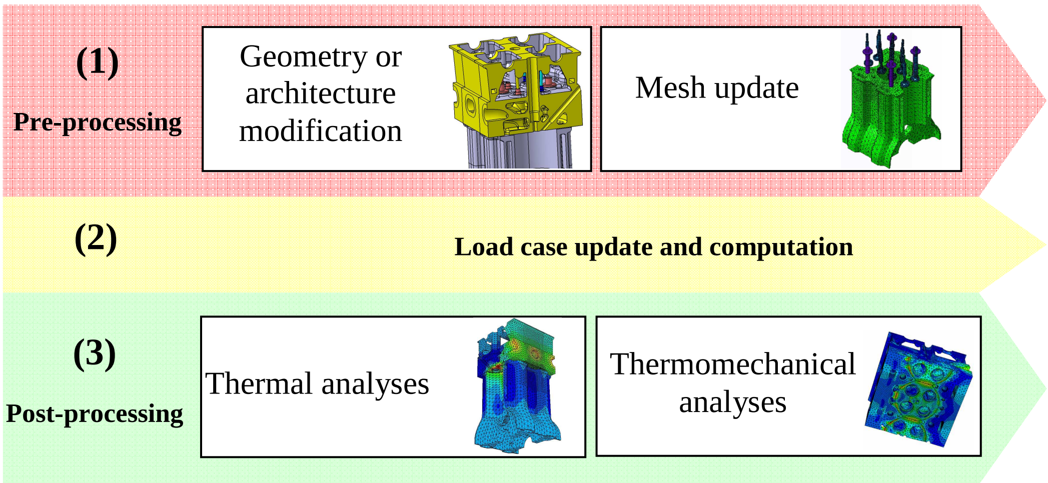
Regarding major manufacturing industries, simulation tends to be used in the upstream phases. It enables them to meet the increasingly restrictive regulations while providing better performances. However, in the upstream phases, many design variants must be simulated in order to make efficient trade-offs, thus generating iteration loops of design and simulation.

With regard to the automotive industry, this section describes how the use of Abaqus For CATIA V5 for the design process of a Head Cylinder greatly reduces the time cycle of iteration loops and enables the integration of design and simulation into a powerful and unique software solution.

2.2 Development

Head Cylinders and crankcases have a major influence on the efficiency of automotive power units. Their designs are of the highest level of complexity and different types of these parts present comparative advantages to the others. Thus, designers and engineers must test different architectures in order to make efficient trade-offs in the upstream phases of a power unit design process. Theses structures are subject to severe temperature and pressure constraints, requiring thermal and thermomechanical analyses.

However, a minor modification on the head cylinder's geometry engenders redefining the mesh and load cases on the updated geometry. Initially, the estimated time for undergoing an iteration loop is estimated about five weeks, and the process can be simplified as follow:



<u>Figure 1</u>: iteration process on a power unit

<u>Modifying the geometry:</u>

Pre-defined models with robust design methods in CATIA V5 enable users to drive different parameterized architecture and combine different features. Figure 2 shows two variants of a head cylinder obtained with the same parameterized model. The parameters are driven by the user and they affect the entire geometry of the structure.

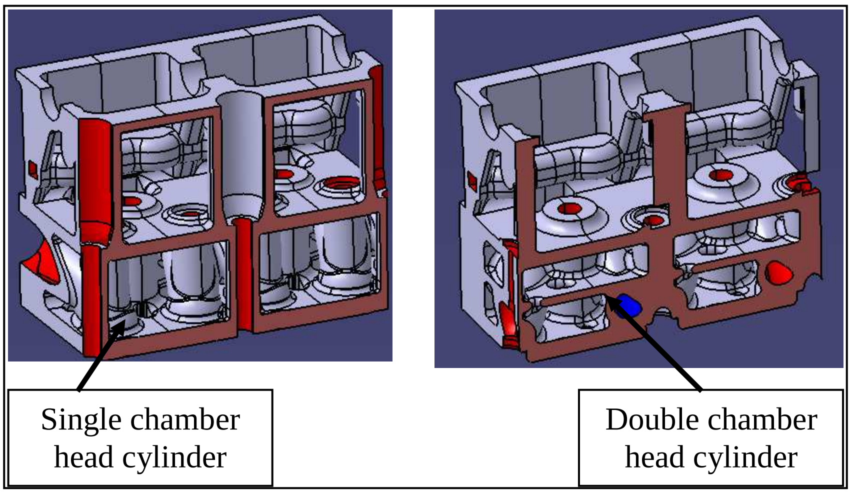


Figure 2: two design alternatives of the head cylinder

Designing structures with CATIA enable the construction of multi-purposed robust parameterized templates, thus reducing considerably the routine design cycles of components.

Updating the mesh:

CATIA V5 provides specific workbenches that enable structure meshing such as the Advanced Meshing Tool. Today, these workbenches cover most of the meshing techniques used by the finite element analyses software. Regarding the power unit case, the element type and dimensions depend on the zone of the structure. Gross mesh is applied to the least constrained zones, whereas fine or structured mesh is applied on the most restrained zones. Although the meshing features are generative and enable automatic update of the mesh after a geometry modification occurs, the geometry must be adapted in a certain way in order to maintain the robustness of the mesh update.

If properly configured, meshing with CATIA is of the utmost advantage as it meets the specifications of industries' standards without requiring any complete remeshing process. Such operations are extremely long and are often subject to mistakes; CATIA V5 integrated meshing features reducing considerably the dedicated time.

Updating load cases and launching computations:

Using directly the mesh issued using CATIA V5, Abaqus For CATIA is a very effective workbench solution that enables all Abaqus/CAE load cases analyses under CATIA V5. Its specificity relies on the associative and generative features: the loads are directly updated as the meshing or geometry is modified, and AFC does not distinguish geometry surface from mesh surfaces, thus rendering it more robust and adaptable to any geometry or mesh modifications. This function is proper to all the CATIA Analysis workbenches as well as the AFC solution whereas importing meshes into finite element analysis software requires redefining load cases and reapplying all the loads on the modified geometry. Such operations are generally unstable and long, whereas AFC embeds directly these inconvenient processes. Besides, AFC uses the Abaqus highly effective solver in order to compute the simulations applied on CATIA V5 meshes and provides outstanding simulation results.

On the power unit presented above, two complex steps are applied to the geometry:

- A thermal step containing the following loads:
  - heat flow generated from the combustion;
  - heat flow generated from friction between the piston and the cylinder;
  - heat flow generated from the boiling water;
  - constant convective exchanges conditions are applied on the water-core, the oil and the air.

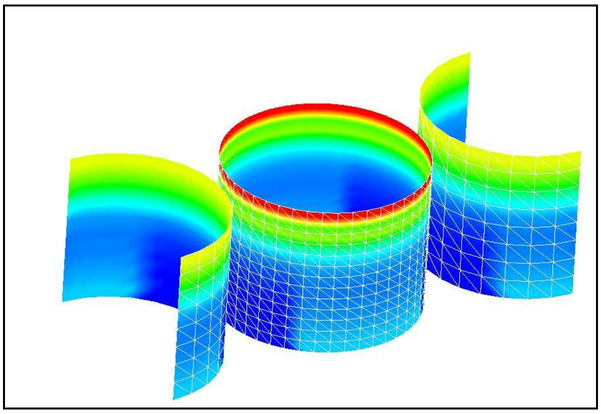


Figure 3: thermal loads applied on the cylinders

- Following the first step from which is extracted the stationary thermal load field at full load, a thermomecanical step simulates:
  - overpressures in the valves;
  - tightening of the head cylinder on the cylinder;
  - pressure peak generated from the combustion.

Post-processing

Once the computation achieved, AFC also enables post-processing features. Regarding that matter, different analyses are conducted on the simulation results:

- Thermal analyses (Figure 4):
  - water-core analysis
  - head cylinder tablature analysis

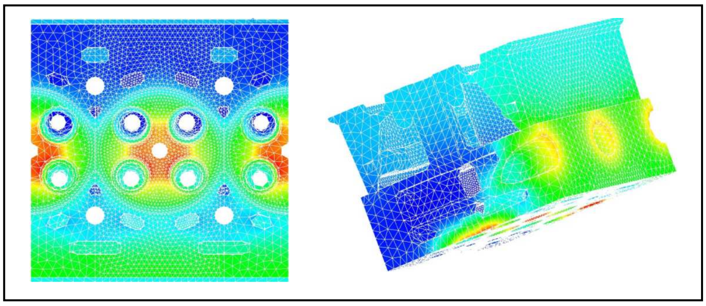


Figure 4: Heat analysis on the head cylinders

- Thermomechanical analyses (Figure5):
  - water-core fatigue analysis
  - head cylinder tablature constraints analysis (Dang Van criteria)

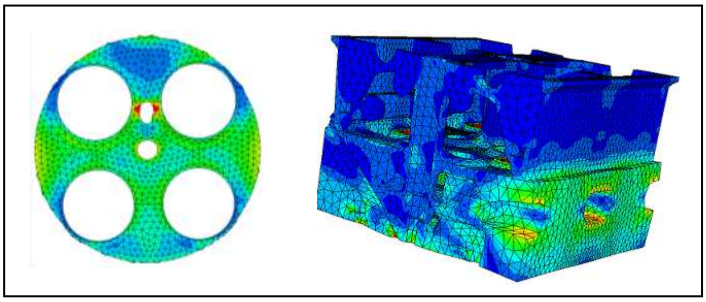


Figure 5: Thermomecanical analyses

2.3 Results

Thanks to the associative and generative integration of Abaqus For CATIA in CATIA V5, the iteration loop on the power unit structure, which initially was estimated about 6 weeks is brought down to 4 days while providing outstandingly realistic simulation results in the upstream phases of the design cycle and orienting designs towards feasible solutions hence the first choice.

3. Abaqus/CAE tools development

3.1 Context

Routine design, computations and generic post-processing incur costs and time for industries. Using Python script for Abaqus, specific tools are developed in order to automate user processes that are long and costly. Regarding this issue, this section presents a vertical application developed for the oil and gas industry, which main objectives are:

- to contribute to higher productivity and reduced analysis time;
- to enable complex Abaqus/CAE models to be easily manipulated by none Abaqus experts;
- to minimize the errors engendered by manual modification of the model;
- to provide model traceability.

3.2 Development

Applications were developed to support the design and simulation of a tee used in sub-sea deep water (Figure 6).

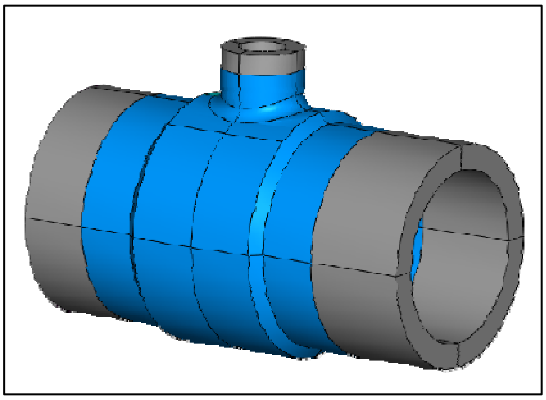


Figure 6: Tee design

The design and simulation workflow implies different iteration loops and can be simplified as follow:

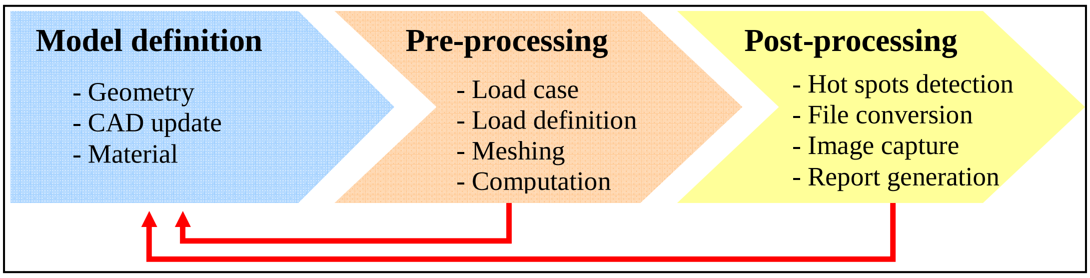


Figure 7: tee design and simulation simplified workflow

This section focuses on how Abaqus solutions contribute, not only in providing the best simulation results, but also in offering a set of programmable features that embeds routine processing and workflows. For each phase defined above, this section describes realizations of high value-added process automation.

Parameter-driven CAD: tee model definition:

Tee dimensions are covered by standards for onshore installation. Designers are often brought to redesign the tee, incurring a waste of time. One day is the estimated time spent on designing the tee under Abaqus/CAE for a complete study. The Abaqus/CAE GUI-based tool developed for the tee design prompts user input for different tee architectures (Figure 8), enabling quicker and safer design as the knowledge laws are embedded in the program.

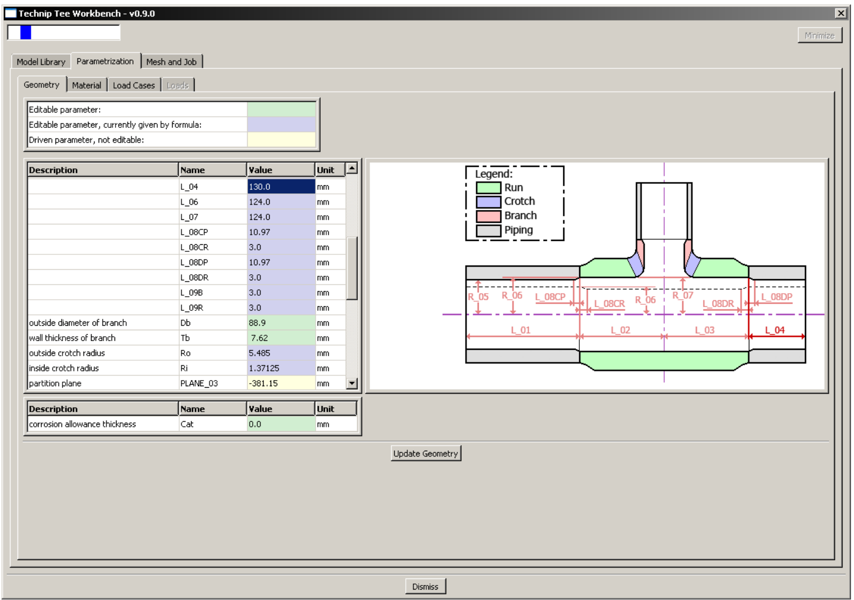


Figure 8: Defining input parameters and visualizing knowledge laws-driven parameter

Figure 9 shows two different design alternatives defined by the same tool. The development is based on Python scripts, Abaqus/CAE models (constituting the design model library) and configuration files (linking Python and the models). This structure enables users to easily add or modify models, and considers different types of parameters (geometrical, material, feature activation, mesh specs).

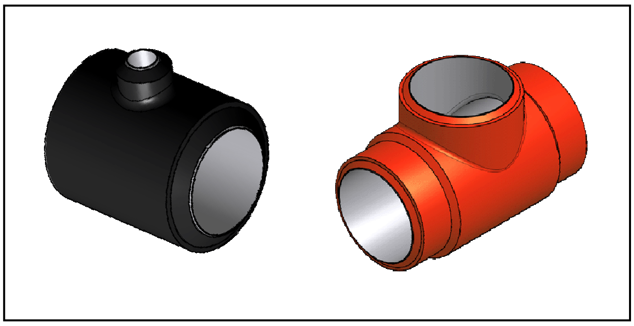


Figure 9: two parameterized tee architecture
(left: reduced outlet tee; right: straight tee)

Pre-processing:

Defining manually common load cases on tee geometries requires a lot of user inputs. This operation must be repeated after each geometry update although it is a routine process. Therefore, it is necessary to consider automating these pre-processing operations that require about half a day of configuration for a complete tee study. Regarding this issue, the developed tools enable automatic configuration of the analyses' parameters. The GUI prompts for user input, defining the loads parameterization (Figure 10).

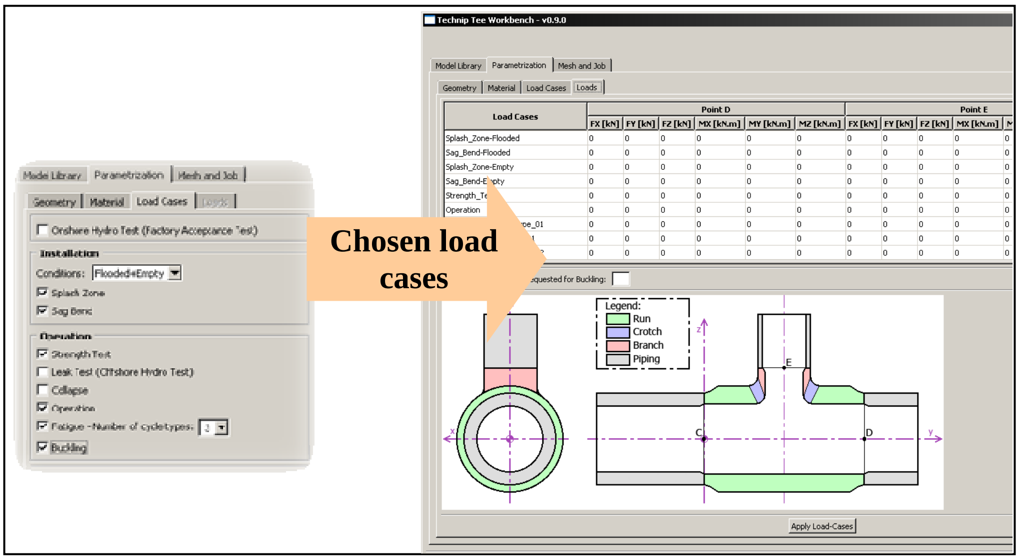


Figure 10: Defining load cases and applied loads

Post-processing:

The post-processing of the tee consists in detecting whether the simulated component verifies certain conditions, such as the maximum admissible Von Mises constraints, or the tolerated displacement, etc. Different analysis cases are performed on the component and post-processed, although the processes are similar, consisting in defining threshold values and checking whether the simulations witness any hot spots. An average of six hours is evaluated for achieving a complete post-processing with a detailed report.

Considering these routine tasks, a complete set of tools is developed to automate hot spots detection, specific view capture, as well as reports generation: the specificity of this tool being its capacity to function whatever component was simulated or whatever analysis case was performed. These tools and GUI were programmed under Abaqus/Viewer using Python scripts.

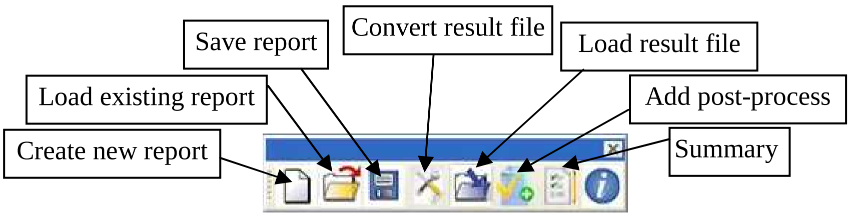


Figure 11: Post-processing tools for Abaqus/Viewer

The following picture is the result of the automatic tee post-processing that detects the hot spots, generates annotations on the concerned elements and captures the picture. Moreover, the tool eases technical documentation writing by generating automatic report information: geometric parameter, material information, loads, mesh, date, model name and image.

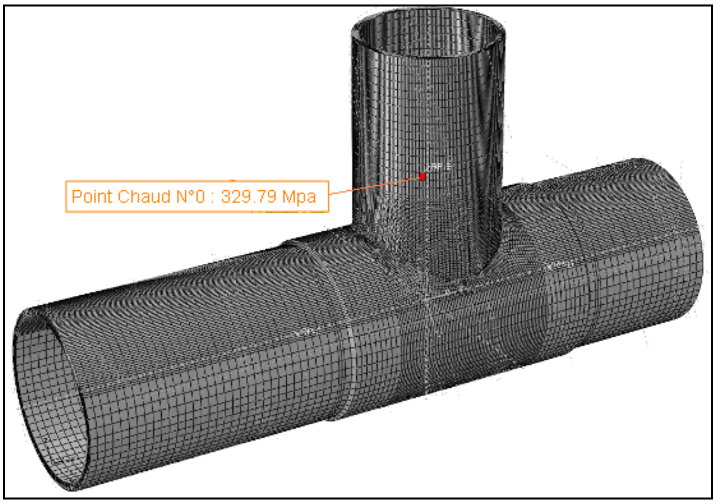


Figure 12: Hot spot detection on Abaqus/Viewer

3.3 Results

42 hours was estimated to configure a complete study on a tee, whereas the described applications enable to fully run the process in less than 3 hours. Hence users save a lot of time in updating the geometry and capitalizing the required knowledge, yet while preventing pre-processing entities from loosing their geometric support.

4. Automotive meshing tools for exhaust system

4.1 Context

As stated in section 2, proper meshing requires geometry preparation. With regard to a tier-one automotive supplier, the design and simulation of the exhaust systems involve a lot of routine welding design and simulation operations. These components are most commonly subject to thermal and thermomechanical analyses. In order to integrate CAD and simulation in CATIA V5, it is necessary for the CAD to be reworked in a certain manner, enabling the generation of a quality mesh that meets the companies' standards and requirements.

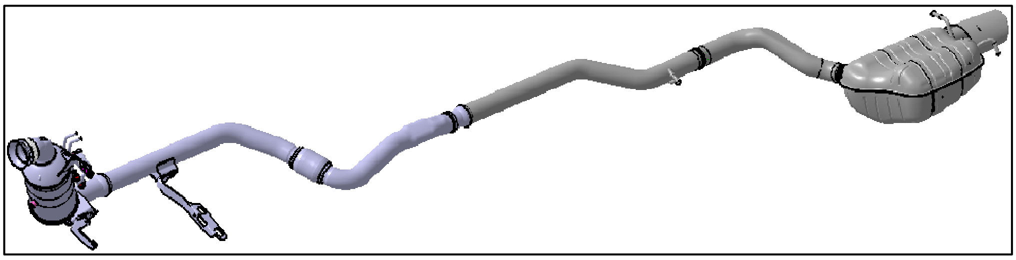


Figure 13: complete exhaust system

4.2 Development

This section presents a tool which objective is to reduce considerably the amount of time spent on reworking the welded geometry sections and on meshing the welding. The tool consists in requiring the least necessary input data in order to generate automatically the welding and its associated mesh. The estimated time without the use of the tools for a complete exhaust system is about 50 hours.

The welding process using the tool can be simplified as follow:

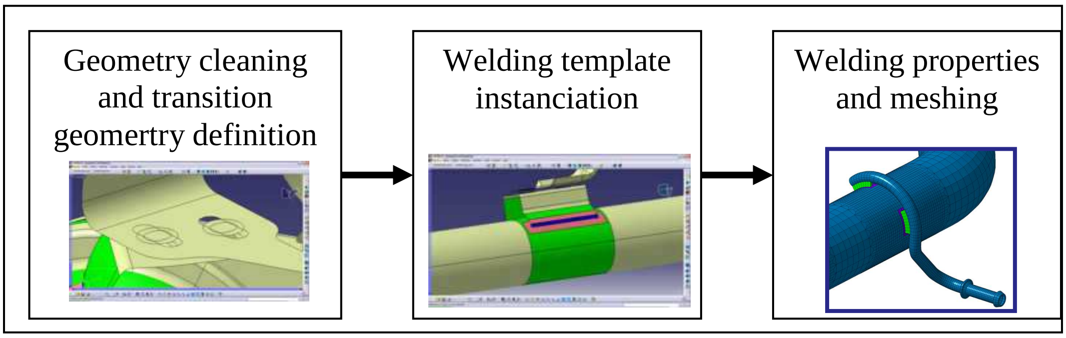


Figure 14: welding workflow

Preparing the CAD for the welding:

Although the tool reduces the number of operations undertaken by the users, users have to prepare the transition areas and guide lines as input data.

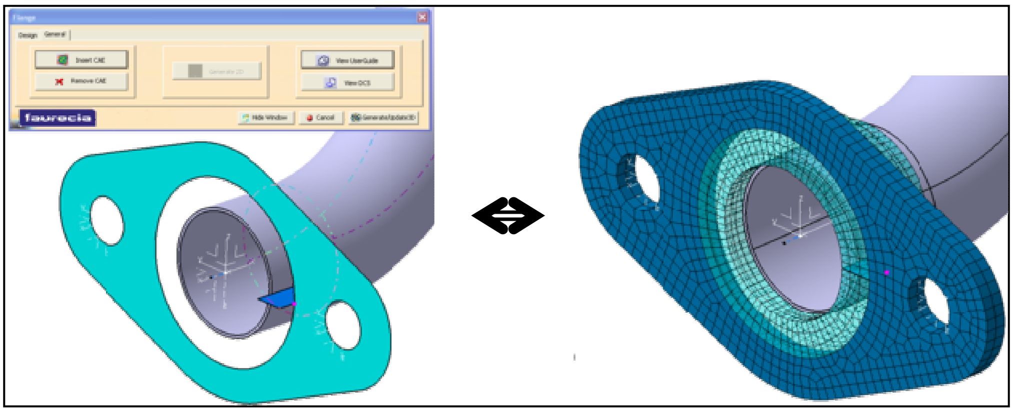


Figure 15: Welding Mesher tool covers all the operations from geometry preparation to meshing.

Instantiating the welding template:

Seven available Power Copies are developed with regard to the tier-one automotive supplier, and cover the different welding types they use for their exhaust system: Lap type welding, Fillet type welding, etc. (Figure 16 shows two types of welding).Each type has several configurations which explains why the time needed to mesh an entire exhaust line is consequent.

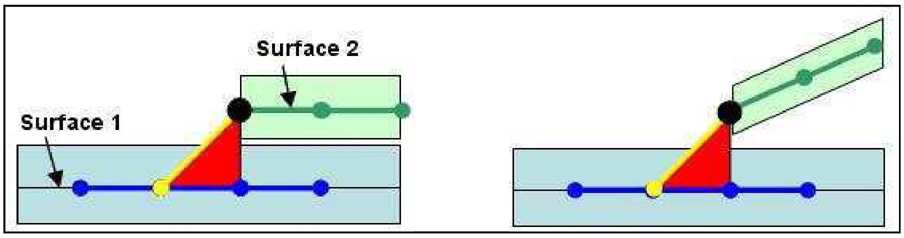


Figure 16: Two types of welding (left: lap type; right: fillet type)

The developed GUI-based tool prompts for user input, as shown in the following figure:

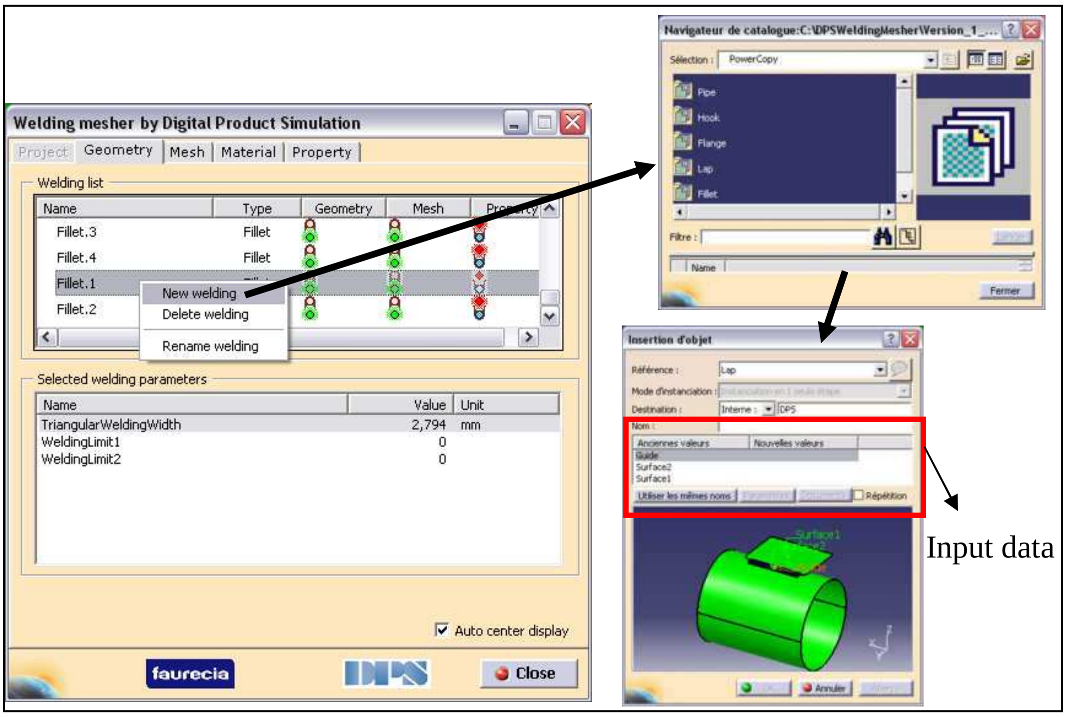


Figure 17: Welding mesher tool – instantiating new welding

All the geometric operations are embedded in the Power Copy and are directly applied on the welded parts with the input data defined by the user. These operations also include the generation of the welding while embedding the expert knowledge of welding techniques and applications.

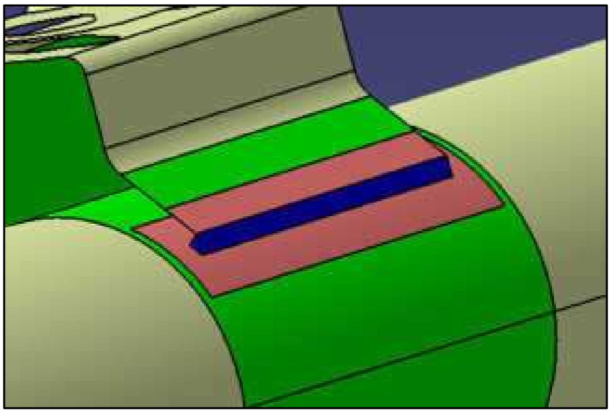


Figure 18: Welding generated by the welding mesher tool

Meshing the welding:

The mesh is also automatically generated by the developed application, which also embeds meshing parameters and material. This tool provides outstanding meshing quality adapted to sensitive areas for a proper computation and analysis.

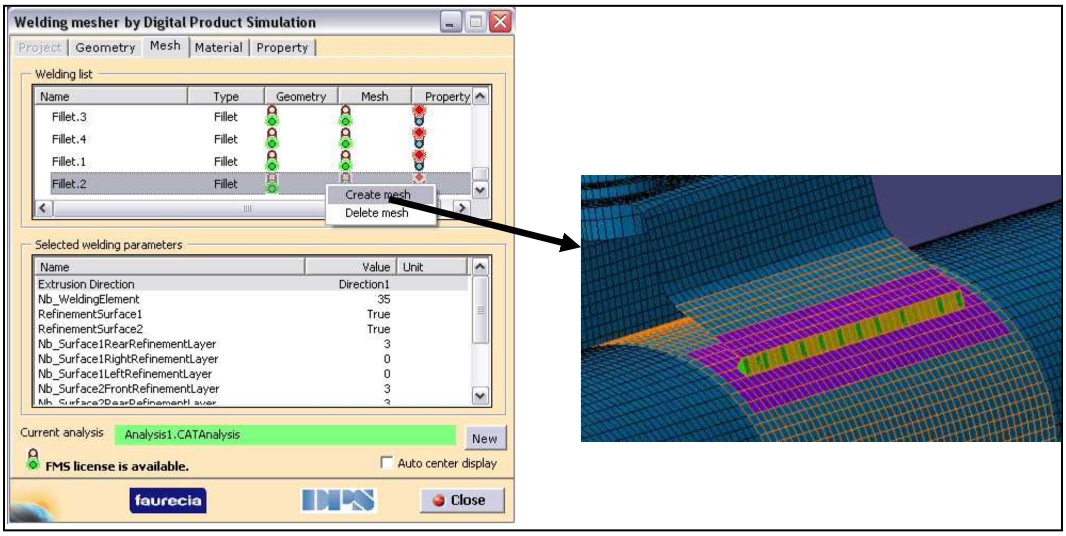


Figure 19: Applying mesh on a welding with the welding mesher tool

4.3 Results

The estimated time of 50 hours to weld the whole exhaust line and mesh the welding and associated areas is reduced to 8 hours while avoiding mistakes and increasing the mesh quality. Moreover, this application, combine with a user friendly GUI, can be operated by none CATIA V5 experts.

5- Investments and returns

We have described in the previous sections several vertical applications that contribute in optimizing the design processes and shortening the time cycles. Although this paper does not focus on the technical nature involved in these developments, this section presents the required investments and the expected returns (ROI).

AFC Cylinder Heads templates:

The simulation methodology was developed for a preliminary design study in order to test different architecture and orient the designers rapidly towards a feasible solution. Six major different variants were to be tested in that matter.

The investment for developing associative and generative robust models depends directly on the complexity of the model and the parameter required to be driven. Regarding this case, an investment of 60 man days was needed to develop the models and run the first loop.

Added value and ROI:

Without the solution methodology, considering 6 weeks per iteration loop, the whole study was expected to last **36 weeks**. Whereas, considering 12 weeks for developing the solution methodology and running the first loop and 4 days for each following iteration loop, this period is brought down to **12 weeks**, and the investment is financially absorbed at the third iteration loop.

It is important to state that without this development, simulating different variants in the upstream phases would have never been considered. Although in this case the 60 man days were conducted by a single person being dual skilled in design and simulation, it is possible to conduct similar activities concurrently (in some cases), thus slightly reducing the dedicated time for building the models.

Abaqus/CAE Tee design and simulation tools:

The vertical application developed with regard to the oil & gas manufacturing industry embeds two different parameterized models and ten different load cases. The development project required approximately 215 man days. However, the development was split in three parallel activities:

- the development of the geometry GUI and the two parameterized models, which required 50 man days of development, extending further more the parametric capability of the CAE model;
- the development of the simulation GUI with the different load cases adaptable to any geometry modification required 80 man days of development;
- finally, the post-processing tools required about 85 man days (in collaboration with the two other activities).

The total time elapsed on developing the complete application was about 6 months with three tri skilled engineers in design, simulation and Python programming working simultaneously.

<u>Added value and ROI:</u>

The tools development investment is absorbed after the 26^{th} tee study. It is important to note that this tool is widely used as tee design projects are very recurrent and as it enables users to drive many iteration loops for optimizing their design choices.

Automotive meshing tools for exhaust system:

The welding mesher tool developed for a tier-one automotive supplier embeds seven different parameterized welding types with their corresponding geometry and comes with user-friendly GUIs. Hence, it enables none experts to issue the welding while guaranteeing the expected quality and results. The development of this tool required 190 man days, in order to embed the seven welding types, adapting the geometry to the required mesh and enabling user to drive all the required parameters.

<u>Added value and ROI:</u>

Considering a gain of 42 man hours for a complete exhaust line, the investment is profitable after approximately 36 complete exhaust lines welding. However, it is important to note that these investments have induced returns:

- In a project, considering redesigning a feasible welding was very risky as it was long and costly: this tool contributes to improving the innovation capabilities by enabling users to test different configurations in order to optimize their design choices;
- In a project, this tool contributes to integrating simulation hence the preliminary design phases;
- It can be operated by none experts, requiring less qualified resources on these tasks.

6- Conclusion

In this paper, we have presented three Vertical Applications that efficiently contribute to design activities:

- by reducing the design time cycles;
- by minimizing mistakes;
- by improving innovation capabilities;
- and by embedding expert knowledge in these applications.

The first solution methodology concerns the intrinsic automation of design and simulation activities by the use of AFC, a simulation workbench integrated to CATIA CAD software.

The second application points out the efficiency of the Abaqus/CAE native customization tools, enabling workflow automation.

Finally, the third application demonstrates how effective the use of VBA for CATIA V5 and CATIA Analysis enables the automation of client processes.

With such robust, automated, high-value added applications, Simulia also provides a software solution, Isight, which enables embedding advanced workflows and optimizing the design choices at the upstream phases of the design process.