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Your Essential Guide to the SIMULIA Community Conference

Gaining Business Value from User Experiences

Hilton Vienna Stadtpark • Vienna, Austria

Conference Dates • May 22 - 24
Advanced Seminars • May 21

www.3ds.com/scc2013

DASSAULT SYSTEMES | IF WE ask the right questions we can change the world.

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Your Personal Invitation

We understand that it is increasingly difficult to justify time out of the office to attend conferences, trade shows and seminars. It used to be the case that events such as these were the only way to find out about a product or subject area however today, with so much information available via the web, this justification is rarely valid, especially in cases requiring international travel.

With this in mind we have assembled this conference information and compiled a User Paper e-Book to convey some of the wider benefits of attending the 2013 SIMULIA Community Conference (SCC) which go above and beyond that of pure product information.

The SCC has been an annual event for the past 26 years allowing SIMULIA users from across the globe to join together to exchange valuable industry knowledge and experiences. During these 26 years we have evolved from HKS to Abaqus to SIMULIA and have visited many different countries along the way. We have seen some exciting conference locations ranging from Barcelona to Boston, heard from over 500 individual presenters and have been joined by more than 2,000 attendees.

The core of the conference is the user experiences presented and this report provides a flavor of this in the form of a few technical papers from past conferences which have been chosen by SIMULIA UK staff. Some of the other features of the conference are also discussed in order to give as full a picture as possible of the benefits attainable from attending this event.

We hope this information and e-Book helps convince you that the benefits of attending the conference more than justify the travel from the UK and time out of the office and we look forward to greeting you in Providence!

Conference Registration Fees: http://www.3ds.com/company/events/scc-2013/registration/

Registration Programs	Dates	Author	Attendee
Early Bird - $100 Off Regular Rate	until February 22, 2013	$795	$895
Regular Rate	February 22 – May 20, 2013	$895	$995
Onsite Registration	May 21 – May 24, 2013	$995	$1095
Advanced Seminar	N/A	$325	$425
Academic Discount	N/A	$695	$695

User Presentations
The centerpiece of the SCC

With invited keynotes from BMW Group and Ethicon Surgical Care, Inc. (a Johnson & Johnson company) and an additional 85 user presentations in 5 parallel sessions it is clear that the sharing of user experiences is the centrepiece of our international conference. These presentations provide first-hand knowledge of deploying SIMULIA solutions and developing workflows for real world realistic simulation. These presentations usually contain additional detail such as videos and animations not available in the published papers. More importantly, the live presentations enrich the paper by providing unique user-specific viewpoints. Attending the conference also provides you with the opportunity to ask questions at the end of each presentation to clarify specific points and to meet the presenters in the networking sessions for more detailed discussion of ideas.

Select user presentations planned for the 2013 SCC include:

Airbus
Tire Debris Impact Modeling on a Composite Wing Structure

Boeing
A User-defined Composite Failure Criteria for XFEM Using UDMGINI

Principia
Concrete Constitutive Model, Calibration and Applications

Tetra Pak
Simulating the Pouch Forming Process Using a Detailed Fluid-structure Interaction

ROKET SAN Missile Ind.
Design and Analysis of a Foldable Wing Mechanism

ABB
GPU-computing with Abaqus: Benchmarking and Scaling for Applications in Mechatronics and Sensor Physics

Rolls Royce Deutschland Gmbh
Collaborative Robust Engine Optimization

Honda R&D
the Extremely Easy External CFD Tool for Designers

TATA Motors Ltd
A study of Vehicle-road Interaction Using Abaqus Co-Simulation Approach

For a complete list of papers visit: http://www.3ds.com/company/events/scc-2013/customer-papers/

Advanced Seminars

Maximize value and enhance knowledge

On Tuesday, May 21, SIMULIA will offer four advanced seminars that will provide in-depth instruction on the theory and application of the latest Abaqus capabilities. These seminars represent new training material covering many new product capabilities.

Advanced seminar topics include:

TECHNIQUES TO RELIABLY SOLVE CHALLENGING CONTACT PROBLEMS WITH ABAQUS

ANALYZING COUPLED MULTIPHYSICS PROBLEMS USING ABAQUS AND PARTNER PRODUCTS

FACILITATING ROBUST DESIGN FOR REAL-WORLD PERFORMANCE AND RISK MITIGATION WITH ISIGHT

MODELING POLYMERS AND PLASTIC WITH ABAQUS

All seminars will be presented by experienced members of the SIMULIA technical staff specialising in the specific subject matter.

For additional details visit: http://www.3ds.com/company/events/scc-2013/seminars/

Networking
Connect to your global community

We expect more than 450 attendees at the 2013 SCC. The attendees will come from all over the world and represent more than 130 unique organizations. The agenda for the 2013 conference has been planned to maximise the opportunities for networking allowing delegates to learn from the experiences of others.

In addition to the usual three breaks per day the 2013 SCC will offer the following networking opportunities:

TUESDAY, MAY 21	**NETWORKING RECEPTION**	**5:30 PM – 7:00 PM**
WEDNESDAY, MAY 22	**PARTNER RECEPTION**	**6:00 PM – 7:30 PM**
THURSDAY, MAY 23	**CONFERENCE BANQUET**	**6:00 PM – 10:30 PM**

In addition to the onsite network, SIMULIA offers a unique SCC event social site only available to attendee which allows you to gain pre-event access to the full conference papers, fellow attendees and SIMULIA employees to allow you to start discussions and relationship building before you arrive in Vienna.

With delegates representing a wide range of industries and academic institutions you are sure to meet somebody working in a similar field to yourself. However, often the breakthroughs in simulation methods come from looking at work on quite different applications, so be sure to speak to a range of delegates.

Attendee Recommendations

"The SCC makes it possible to meet people working on the same problems, with the same tools but in completely different spheres of activity. It is the best place to meet the actors of the digital simulation of tomorrow."
Cyril SAILLEY, **DPS - Digital Product Simulation**

"The conference is a great way to get the inside track on what features are going to be available in future releases of products and to see how people in the real world are using simulation technology."
Daniel Vennetti, **SP – Sweden's Technical Research Institute**

Special Interest Groups
Share your viewpoint

Building on the success of 2012, we will once again host Special Interest Groups (SIGs) at the 2013 SCC, which provide attendees with networking opportunities with other attendees and with SIMULIA staff focused on specific industries or technology.

Each SIG session will be led by an industry expert from SIMULIA who will provide a 15-minute overview of SIMULIA's strategy, capabilities, and new functionalities. Some SIGs will include a presentation from a key customer on an innovative application. The remainder of the time will be spent discussing value, applications (both current and future), and needs. The SIGs will adjourn directly to lunch where individual discussions can continue.

Special Interest Group Topics Planned for SCC 2013 Include:*

- Composites
- Transportation & Mobility
- Energy
- Fracture and Failure
- Life Sciences
- Simulation Lifecycle Management
- Turbomachinery

*Subject to change based on interest.

Partner Sponsors
Discover complementary technology

Partner Sponsors are a significant asset to our conference offering innovative complementary solutions that will help you streamline your overall engineering process. Learn more about select product offerings during the Complementary Solutions sessions taking place each day after lunch.

SIMULIA is pleased to recognize those partners participating in the 2013 SIMULIA Community Conference.

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safe technology

In addition we have 17 Exhibitors and additional conference sponsors, full details may be found here

SIMULIA Technical Representatives

Learn about the newest technology

The 2013 SCC is located a stone's throw from historic and cultural sites as well as entertainment, shopping, cafes and a variety of restaurants appealing to every taste. The conference will be attended many representatives from our Research & Development, Technical Marketing and other technical departments. These people are able to provide a unique perspective on product capabilities and potential applications of our technology.

In addition our technical representatives will be presenting a series of General Lectures throughout the conference. At the SCC 2012 the General Lectures included:

ABAQUS 6.12 MUTIPHYICS: DISCOVER NEW SIMULATION POSSIBILITIES- ERIC WEYBRANT PRODUCT MANAGER, ABAQUS ANALYSIS PRODUCTS, SIMULIA, DHIRAJ NAHAR PRODUCT MANAGER, INTERACTIVE SIMULATION APPS, 3DS SIMULIA

EXPLORE ABAQUS 6.12 AS AN INTEGRAL PART OF AN INDUSTRY WORKFLOW - ERIC WEYBRANT PRODUCT MANAGER, ABAQUS ANALYSIS PRODUCTS, SIMULIA, ASIF KHAN PRODUCT MANAGER, INTERACTIVE SIMULATION APPS 3DS SIMULIA, DHIRAJ NAHAR PRODUCT MANAGER, INTERACTIVE SIMULATION APPS, 3DS SIMULIA

3DS SIMULIA V6 R2013 – A NEW WAY TO DO COLLABORATIVE SIMULATION – FABIEN LETAILLEUR TECHNICAL MARKETING SPECIALIST, 3DS SIMULIA, JON WIENING SIMULATION APPS DESIGNSIGHT PRODUCT MANAGER 3DS SIMULIA; KEN SHORT VP STRATEGY & MARKETING 3DS SIMULIA

ACCELERATING REALISTIC SIMULATION WITH ADVANCES IN HIGH PERFORMANCE COMPUTING – MATT DUNBAR CHIEF ARCHITECT, 3DS SIMULIA

EXPANDING OUR ECOSYSTEM AND TECHNOLOGY FOR ADVANCED COMPOSITES – KYLE INDERMUEHLE TECHNICAL LEAD, AEROSPACE 3DS SIMULIA, JOHN KLINTWORTH 3DS CATIA COMPOSITES, 3DS CATIA

If you would like to meet a member of the technical team for a general discussion or on a particular topic, just let us know and we will arrange an introduction.

SIMULIA Senior Management

Gain insight into SIMULIA's strategy

The SCC is usually attended by all the SIMULIA Senior Management for the duration of the conference. Several strategic presentations are included in the agenda and the Senior Management Representatives will be available during the networking breaks and receptions. Our senior managers can offer a unique perspective on the position and direction of the SIMULIA brand.

Senior Management presentations at the SCC 2012 included:

SIMULIA BUSINESS OUTLOOK: SCOTT BERKEY, CHIEF EXECUTIVE OFFICER, SIMULIA

DASSAULT SYSTÈMES VISION: BERNARD CHARLES, CEO, DASSAULT SYSTÈMES

ISIGHT AS AN ESSENTIAL PART OF REALISTIC SIMULATION: DAVID BARNES, GENERAL MANAGER, AMERICAS, SIMULIA

If you would like to be introduced to one of our senior managers for an informal chat please let us know.

E-Book of Selected User Conference Papers

Click on a review to read a paper

Paper 1 – Advanced Simulation

Predictive Crashworthiness Simulation in Virtual Design Process without Hardware Testing; Jürgen Lescheticky, Hariaokto Hoopurta and Doris Ruckeschel, BMW Group, Munich

"I chose this paper as it provides an excellent illustration of the validation work required to arrive at a reliable simulation methodology for automotive crash simulation. It also highlights the solver capabilities and level of robustness required in order to arrive at a truly predictive workflow that may replace physical prototyping" Chris Smith – Technical Sales Director, SIMULIA BT Sales, Euro North and Nordics

Paper 2 – Advanced Simulation

Bird Strike Simulations on Composite Aircraft Structures; Sebastian Heimbs, EADS, Innovation Works, Munich

"I think this paper is an excellent example of the high quality work presented at the SCC. It combines a number of advanced Abaqus capabilities including Impact Analysis, Fracture and Failure, Fluid-Structure Interaction and Composite Materials. The methodology is clearly described and validated against experimental data. A valuable reference for anybody working in these application areas" Alan Prior Director SIMULIA North-Nordics CSE

Paper 3 – Integration

SIMULIA Abaqus/CAE and CATIA Analysis as Open & Powerful Process Automation Platforms; Patrick Grimberg, Digital Product Simulation

"Integration is increasingly important in increasing the reach and efficiency of simulation processes. This paper provides a number of real world examples of how integration and configuration can rapidly reduce simulation lead times. In addition information is provided on the return on investment from deploying these techniques which clearly quantify the benefits and provides useful information for anybody considering greater integration and automation of their analysis workflows." Jonathan Carter, Senior Technical Manager SIMULIA

Paper 4 – Automation

How Can We Make Best…Better: Using Abaqus and Isight to Optimize Tools for Downhole Expandable Tubulars; Jeff Williams, Baker Hughes Incorporated

"This paper Illustrates how quickly and easily an Abaqus user can deploy Isight to facilitate process automation and design optimisation. It's interesting how the use of this technology leads to unexpected design solutions resulting in similarly surprising improvements in performance and cost savings" Ann-Marie Lambert, Technical Specialist SIMULIA

Paper 5 – Simulation Lifecycle Management

Simulation Life Cycle Management as Tool to Enhance Product Development and its Decision-Making Process for Powertrain Applications; Frank Popielas, Rohit Ramkumar, Jason M. Tyrus, Sealing Products Group, Dana Holding Corporation, Lisle, IL, USA; Brian Kennedy – SIMULIA

"This paper makes an excellent case for SLM showing how this technology may be used to standardise processes leading to increased collaboration by a number of geographically dispersed users, reducing the time it takes to complete an analysis and facilitating a 24x7 approach to Engineering. The improvements in quality and consistency of simulations possible with SLM are also clearly illustrated"; Matthew Hopkins CSE Director UK

Predictive Crashworthiness Simulation in a Virtual Design Process without Hardware Testing

Jürgen Lescheticky, Hariaokto Hooputra, and Doris Ruckdeschel

BMW Group, Munich

In 2006 BMW made a decision to use Abaqus/Explicit for all issues concerning passive safety in the virtual design process. Code quality and reliability of simulation results were identified as the primary reasons to change, and from that decision point forward, all product development teams began migration activities to switch to Abaqus/Explicit.

Meanwhile, the entire vehicle design and development process within BMW began to undergo fundamental changes, from one which previously incorporated key milestones involving physical prototypes, to one which seeks to largely eliminate physical prototypes and associated physical tests. Nowadays, BMW design engineers will get the first feedback from physical tests only after the series production tools have been manufactured. Therefore, design changes at that point will be extremely expensive. Furthermore, no physical test results will be available to calibrate and improve finite element models of virtual crash cars in the earlier phases of the development process. So predictiveness is now the most important criterion for BMW's passive safety simulation.

Because of these fundamental changes to BMW's development process, BMW established a new benchmark for crash solvers in 2009 in order to evaluate in detail the quality of simulation results. This paper intends to demonstrate some of the capabilities of Abaqus/Explicit for crashworthiness and occupant safety, with a strong focus on predictiveness and reliability. These factors are prerequisites for an efficient, cost-effective vehicle development process that relies less and less on physical prototypes and testing. And it explains why BMW has now reconfirmed the earlier decision to use Abaqus/Explicit for its crashworthiness and occupant safety simulation.

1. Introduction

Since 1998, BMW began seeking alternative simulation tools for passive safety design issues. The criteria for selecting a new simulation tool were:

- Algorithms of high quality and overall software robustness
- Competent development team
- Strong commitment to the methods development needs of BMW

After several years of searching and evaluation, BMW made a decision to move to Abaqus/Explicit as its new tool for crashworthiness and occupant safety simulation. Beginning in late 2004, BMW carried out the first car development project using Abaqus/Explicit for passive safety simulation. Successive car projects were also migrated, until all migration was completed by the end of 2006.

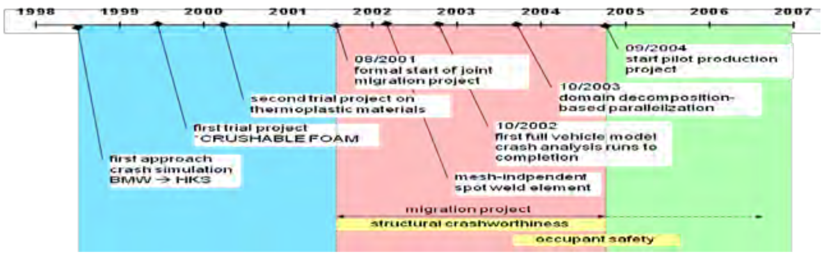


Figure 1: Time frame for software migration

Automotive companies are under constant pressure to develop and produce better cars that meet increasingly stringent legal requirements for crashworthiness and occupant safety, as well as growing consumer demands, and to bring them to market more quickly. To address such pressures, BMW's internal development process is continuously being changed and optimized.

Previously in car development projects, functionalities have been repeatedly refined and confirmed by hardware tests. Nonetheless, the number of hardware tests corresponding to a particular load case is very low, and the predictiveness of a physical test is somewhat limited by the build quality of the prototype, as well as the re-use of vehicle prototypes for multiple load cases.

Time is another unfavorable factor in a development process which relies largely on hardware proofing, because every single part has to be made using prototyping tools, and the vehicle itself is practically assembled by hand. With this conventional approach, the demand for a shortened and more efficient development process cannot be fulfilled, while at the same time being able to optimize functionality, product, and costs.

Therefore, the development process at BMW is in a state of change, from a hardware supported development to a purely virtual development, where the first cars assembled are directly used for homologation. But this requires a change also to the primary aim of virtual development or simulation. Previously, the main focus of virtual development was the global vehicle behavior. Detailed topics, such as the potential failure of connections or material rupture in components, were largely covered by the hardware tests. Because of the goal at BMW to completely eliminate prototype hardware and testing, such issues can only be subsequently evaluated through simulation. This necessarily leads to a complete realignment of virtual design, from "macrocosm" to "microcosm". The earlier simulation focus primarily on global behavior loses its importance, while the detailed behaviors of components and connections, within the context of a complex full vehicle model simulation, become a central part of virtual design for passive safety.

This change in the design and development process means that, besides the original requirements for BMW's crash simulation software to be of high quality and reliable, a new key requirement emerges: predictiveness. Can the crash simulation software accurately predict these detailed behaviors which are known to have important influence on passive safety criteria?

This was the reason for BMW to conduct a new software benchmark in 2009 with the goal of assessing which crash simulation tool can best meet this newer predictiveness requirement. A very detailed list of criteria were compiled and subsequently used to assess the crash simulation tools. In order to ensure a broad range of coverage, a large number of different models and load cases were established:

- Component models for problems typical in car body technology.
- Component models for restraint systems.
- Full vehicle models.

In the following sections, some exemplary results of the benchmark are presented.

2. Predictiveness on Component Models

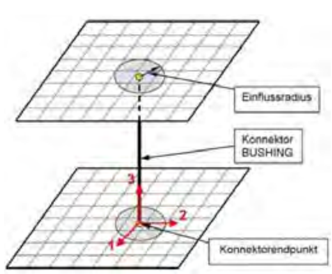
Before using new methods in very complex full vehicle crash models, it is much easier to evaluate the predictiveness on component level tests. With simplified principal tests, simulation results can be assessed more readily and the level of predictiveness can be evaluated.

2.1 Comparison of Spot Weld Failure between Simulation and Test

According to EN ISO 14329 fracture modes of resistance spot welds can be categorized in three large groups: peel, shear, and mixed-mode as illustrated in this order in Figure 2.

Figure 2: Fracture modes for resistance spot welds

In the peel fracture mode, failure occurs in the base material or within the heat affected zone, whereas shear fracture behavior occurs through the weld nugget mostly parallel to the joined surfaces. Often the two modes coexist in the mixed-mode failure behavior. The joint strength and the fracture type of a spot weld are primarily determined by the nugget size, the base material properties and the load case of the weld spot. A shear load case between the spot welded plates results in mostly shear stresses in the nugget, which in turn, leads to shear fracture, whereas peel fracture is more likely to occur with an increasing load angle towards a pulling loading mode. For conventional steels a correlation between fracture mode and energy absorption has been observed for spot welded joints. The energy absorption level is much higher for ductile peel fracture than it is for spot welds with (brittle) shear failure behavior.



Abaqus User's Manual

Figure 3: Spot weld model

For BMW crash calculations, spot welded joints are modeled as fasteners, each consisting of a connector element with six relative degrees of freedom for which a coupled elastic-plastic with damage and failure constitutive bahavior is modeled. The connector end nodes are coupled with the shells of the joined plates via distributed couplings with a specified radius of influence..

The spot weld model was validated through component tests, i.e. T-Joints, where different local stress states were achieved in the spot welds through a variation of the global load case.

Validation results show good correlation between simulation and experiment, illustrated in Figure 4. All experimental curves lie within the scatter band characterized by the standard deviation of the weld spots in series production.

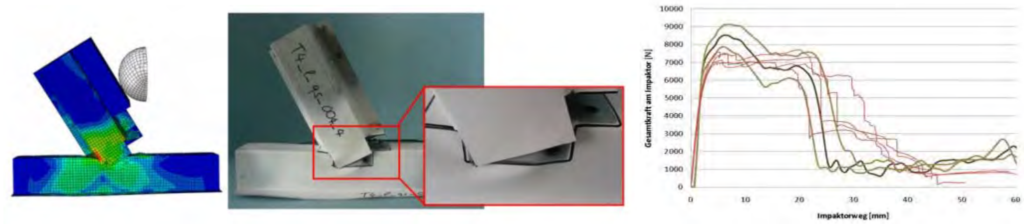


Figure 4: Validation of spot weld model through "T-Joint" component test

2.2 Material Failure Predictions Using the IDS Failure Criteria

Sheets and thin-walled extrusions made from metals generally fail due to one or a combination of the following mechanisms (Figure 5):

- Ductile fracture (based on initiation, growth and coalescence of voids).
- Shear fracture (based on shear band localization).
- Instability with localized necking (followed by ductile or shear fracture inside the neck area).

The failure strains of the different mechanisms depend primarily on strain rate, temperature, anisotropy, state of stress and strain path (deformation history).

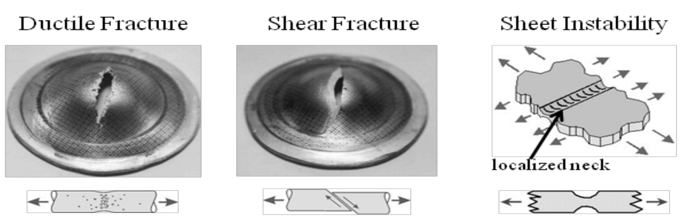


Figure 5: Visualization of ductile fracture, shear fracture and sheet instability

A comprehensive approach for predicting failure of structural components caused by any combination of these mechanisms was proposed in [2] in terms of three phenomenological failure criteria for Instability, Ductile, and Shear fracture (IDS failure criteria). The failure criteria are based on macroscopic stresses and strains and include the effect of anisotropy, state of stress, and strain path. One set of parameters is valid for one temperature and one strain rate regime (quasi-static or dynamic).

The IDS failure criteria have been integrated into Abaqus' general capability (framework) for modeling progressive damage and failure of ductile metals. The capability supports the specification of multiple damage initiation criteria and the corresponding damage evolution laws, including element removal options.

For the characterization of the loading path for all three types of limit curves, the ratio of major to minor principal strain rates, $\alpha = \dot{\varepsilon}_2/\dot{\varepsilon}_1$ is used as a common measure [2]. For the purpose of comparison, all failure limits are combined into a "failure map" in Figure 6 for quasi-static and dynamic cases. The limit curves are plotted for the special case of linear strain paths and membrane deformation. A linear strain path is defined by a constant value of α.

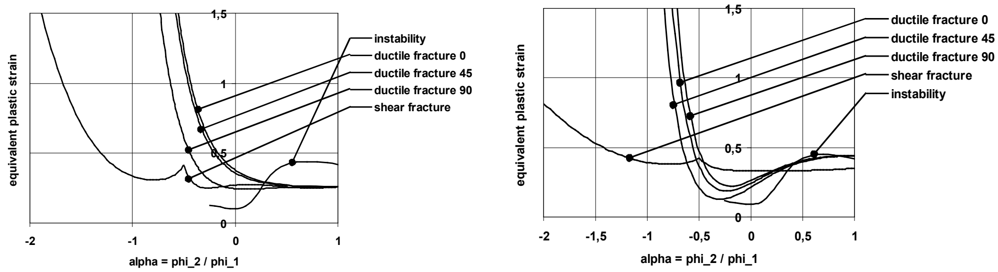


Figure 6: Quasi-static (left) and dynamic (right) failure diagram for extrusion EN AW-7108 T6

In the area of low stress triaxiality (left side of the failure map), shear failure is the dominating failure mechanism for quasi-static as well as for dynamic loading. For higher stress triaxiality, instability, ductile failure as well as shear failure can be the dominating mechanism (dependent on the quasi-static or dynamic loading).

The final validation of the failure model is performed by carrying out a controlled B-pillar instrustion test with a rigid impactor and comparing these test results against a corresponding simulation (Figure 7). In the simulation model, the effects of pre-deformation from the prior forming process for the sheet metal components are taken into consideration in the evaluation of the IDS failure criteria. Moreover, the failure behaviors of the various joining techniques used in the car structure, are also taken into consideration.

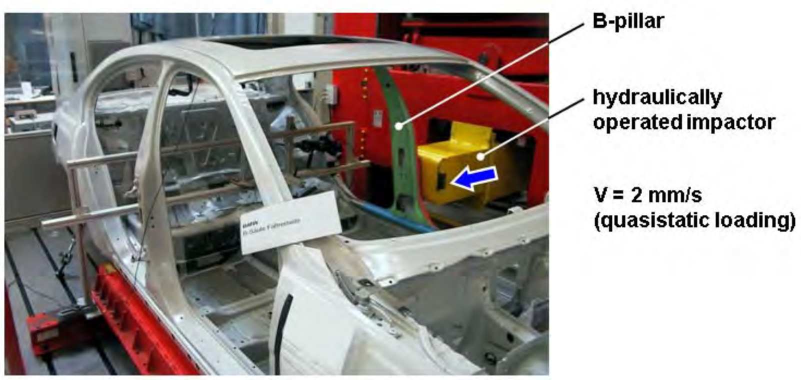


Figure 7: Set-up of the B-pillar intrusion test

The comparison of the fracture pattern between simulation and experiment is shown in Figure 8. The simulations using the IDS failure criteria accurately predict the real fracture pattern which is initiated by instability (localized necking) in the flange area.

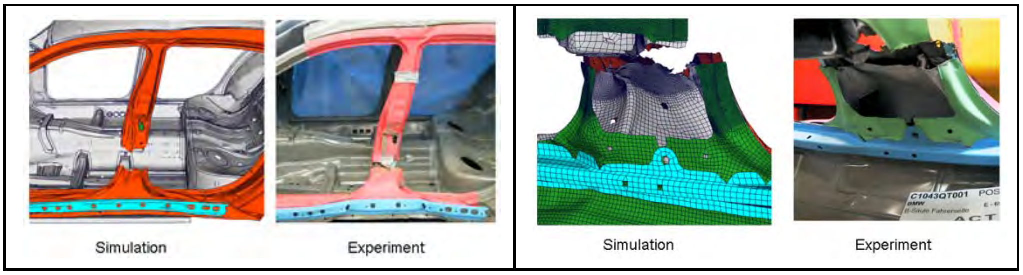


Figure 8: Fracture pattern initiated by instability from test and simulation

Figure 9 shows the force-deflection curve from the contact between the B-pillar and rigid impactor. The drop in force resulting from the crack initiation (instability) and the subsequent elimination of failed elements that initiates in the flange area of the B-pillar correlates extremely well with the experimental test results.

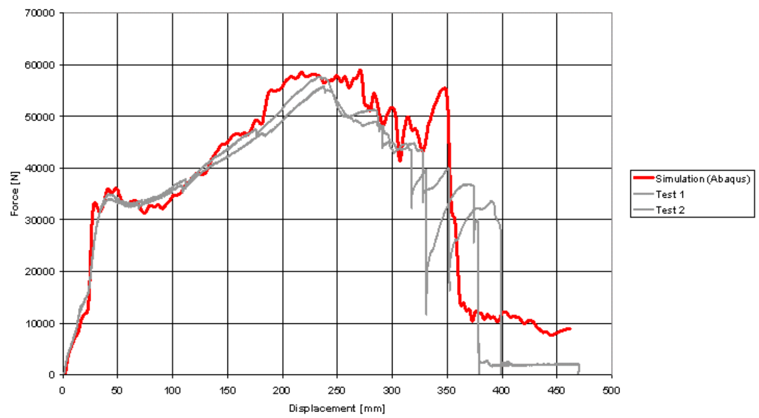


Figure 9: Force-deflection curve from test and simulation

2.3 Airbags

The simulation of airbag restraint systems generally focuses on two working points:

- Airbag in a fully deployed state: In the case of frontal crash, the occupant is protected by fully deployed airbags at the moment of initial contact. It can be assumed that in this state, the gases in the airbag chambers are distributed homogeneously and this simplifies the simulation significantly, since gas flow effects can be neglected and the simplified modeling technique known as the "uniform pressure method" (UPM) can be used.
- Airbag in a partially deployed state: Sometimes, due to trim parts or out-of-position occupants, initial contact between surroundings and airbag can occur before the airbag is fully deployed. During this "airbag unfolding" phase, localized high pressure gradients and high flow velocities have a strong influence on the shape and behavior of the airbag. For this time period, the uniform pressure assumption is not valid and cannot be adopted in studies where the deployment has to be investigated to show the interaction with trim

parts and/or out-of-position occupants. Alternative methods, based on spatial discretization of the airbag volume and consideration of the flow dynamics, are required. Abaqus/Explicit provides the coupled Eulerian-Lagrangian (CEL) capability for this purpose.

In addition to other functionality needed for occupant restraint simulations, the second working point above – description of the flow dynamics in airbags – was considered in detail in the benchmark evaluation. It should be noted that different modeling techniques are available to consider the flow of gas into the deploying airbag. In the following, the software requirements and the results of the current development status of the CEL capability in Abaqus/Explicit are shown, using the example of a curtain deployment in a static test. The intention is the modeling and optimization of the curtain unfolding process as the airbag interacts with trim parts.

In order to be able to consider the flow dynamics in the airbag using the CEL capability, a hexahedron mesh is built over the airbag's volume and the region where the deployment will occur. In each of those elements, the Eulerian equations are solved to describe the gas dynamics. The elements that model the airbag itself follow the Lagrangian equations of motion and intercommunicate with the flow field in the Eulerian elements via momentum exchange.

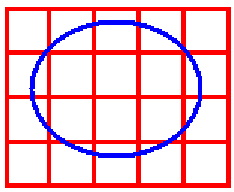
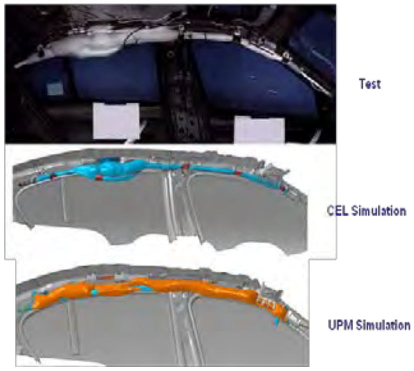
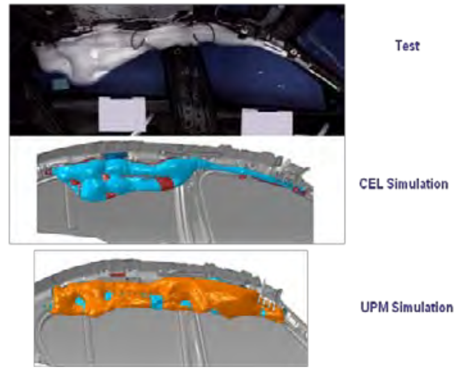


Figure 10: 2D schematic diagram of the mesh formation: Eulerian cells and Lagrangian elements for CEL simulations

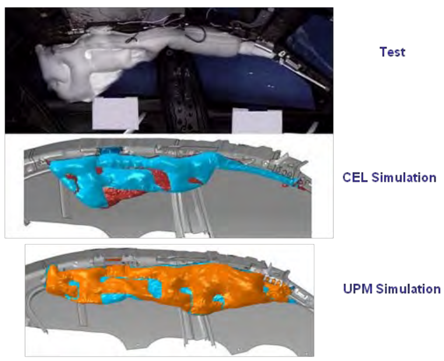
The curtain airbag poses a difficult challenge because of the combination of closely folded fabric layers and long flow channels from the inflator to the far ends of the airbag. While the development of CEL in Abaqus/Explicit is ongoing, the characteristic deployment of the curtain airbag can be modeled in good accordance to the test behavior. Figure 11 shows characteristic airbag shapes in test and simulation, which are investigated in detail. Simulation results shown include both CEL and UPM results in order to contrast the important differences that exist between the two during the deployment.



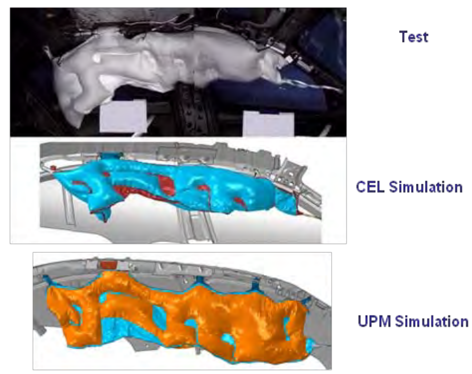
a) Start of airbag filling around the inflator.



b) Funnel shaped tube opening.



c) Gas penetrates close airbag layers.



d) Unrolling before gas reaches the right end.

Figure 11: Characteristic airbag shapes in test (above) and simulation (below)

The airbag filling starts around the inflator (a) and propagates first in the horizontal channel. During these first few milliseconds, the inflowing gas inflates the region of the airbag near the inflator, and begins to produce a funnel-like shape of the airbag in regions further removed from the inflator (b). The unrolling and unfolding of the airbag layers is caused by the combination of two factors:

1. Pressurized inflator gas incrementally penetrates between folded layers, causing them to incrementally separate.
2. Forces that develop in the airbag fabric due to rapid introduction of inflator gas cause overall motions of the airbag that induce further unrolling and unfolding.

As the second factor above begins to become active, it has a loosening effect on the airbag that further facilitates the penetration of inflator gas between fabric layers that are now not so closely folded together as they were in the original configuration.

In a subsequent stage of inflation (c), the region of the airbag nearest the inflator continues to deploy more strongly than regions further removed from the inflator, though inflator gas is beginning to penetrate these regions. In the last stage shown (d), the airbag has unrolled nearly completely at the right end, even though little inflator gas has reached there at this point in time.

In comparing the simulations against these experimental test results, some very distinct differences between UPM and CEL become apparent.

- The simplifying assumptions in the UPM simulation are clearly unable to capture the deployment characteristics, as pressure in the UPM simulation is applied to the entire interior surface of the airbag, regardless of whether inflator gas can physically reach closely folded layers of fabric. In the UPM simulation, the airbag is predicted to open in a generally uniform manner from one end to the other, which clearly is not what happens in the physical test.
- The CEL simulation captures the real deployment characteristics in a much more accurate manner, with early strong inflation and deployment in regions close to the inflator. Reproducing the funnel-like shape of the airbag in the very early stages of deployment is somewhat dependent on the level of mesh refinement for the Eulerian cells. In the latter stages of deployment, the CEL simulation shows a similar unrolling of the right end of airbag with only minimal penetration of inflator gas, as is also indicated in the physical test.

SIMULIA development of the CEL capability continues, and is expected to result in a very powerful tool for the design of airbags and the interaction with their environment during the deployment phase.

3. Predictiveness of Full Car Crash Models

Predictiveness for crash simulation models is best achieved by using proper physical formulations for all phenomena which affect the pertinent functional behavior. For body-in-white structures, the exact formulations of the material behavior, including the failure mechanisms, as well as the failure mechanisms of all joining techniques, are important for the performance of the model. Therefore, following the completion of the migration project in 2006, SIMULIA and BMW continued their strong cooperation in these areas, and as a result, BMW is now able to set up physical crash models with Abaqus/Explicit to meet the BMW internal vision for a design process without physical hardware tests.

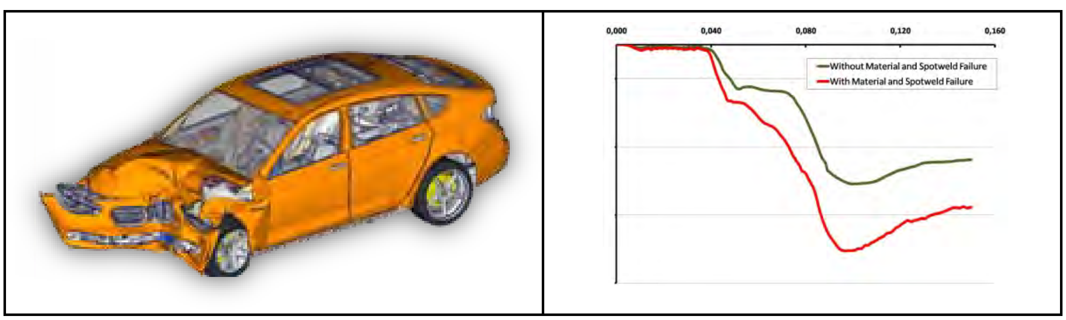
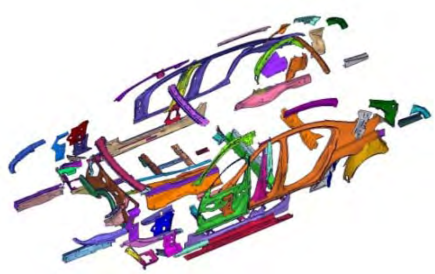


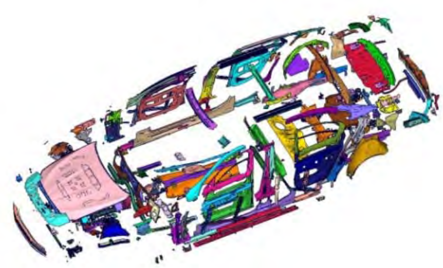
Figure 12: Firewall intrusion result of crash models with old and new modeling

As an example, Figure 12 shows the difference in the firewall intrusion into the passenger compartment for simulation of a frontal offset crash test against a deformable barrier, comparing the old modeling technique (without failure mechanisms) and the new modeling technique (with failure mechanisms). Without any failure mechanisms, the predicted intrusion of the firewall in this full vehicle model shows a response that is 30% stiffer than when compared to a model with all necessary failure mechanisms. In this particular case, as well as in various others, the simulation results obtained when not accounting for potential failure mechanisms to develop are not conservative – they predict less intrusion into the passenger compartment than actually will occur. With fewer and fewer hardware tests to be carried out in the future, there will be little to no experimental information available for validation and tuning of a crash simulation model, and therefore a 30% uncertainty in deformation modes compared to reality is not acceptable. That is the reason why BMW use the new approach for material and spot weld failure now as a standard practice in all crash simulations.

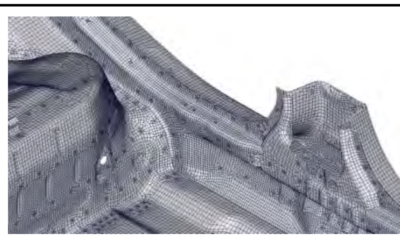
For the benchmark, four different cars have been analyzed and compared to results from real tests. As already mentioned, not only the global deformation has to be calculated exactly but also local effects due to material and joining failure have to be predicted. For that reason a model for an entire car is now built up to include about 3.5 million elements. For a more detailed prediction of the failure, between 100 and 150 parts are mapped with data from deep drawing simulations of these parts. Figure 13 shows the setup of a typical crash model that incorporates effects from deep drawing simulations, material definitions with failure, and spot weld and adhesive definitions with failure mechanisms. In constructing such models, care is taken to ensure that BMW meshing guidelines are followed, and that BMW-released models (including damage and failure) for materials, spot welds, and adhesives are incorporated. These methods have been in standard production usage at BMW for more than a year.



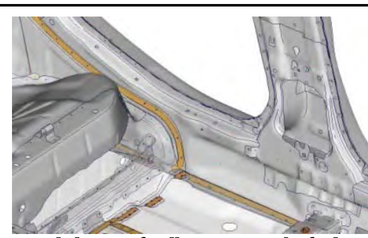
Parts with mapping information



Parts with material failure definitions



Modeling of spotwelds



Modeling of adhesive with failure

Figure 13: Standard features for BIW crash simulation models

3.1 Global Deformation Behavior

The global deformation can be characterized as the global condition of the BIW after the car has been relaxed after the crash. The main issues are global deformations such as dashboard intrusion, pulse, or other geometrical or kinematic results.

In a hardware test, only a few test parameters are recorded; videos from several viewpoints are also recorded to aid in analyzing the hardware test. Only these limited recorded data are then available to help explain and understand the complex deformations that develop throughout the car during the test, as well as the measured injury criteria for the crash dummies. A key advantage of a virtual crash is the wealth of data available throughout the entire model and history of the simulation in order to assist in understanding the detailed deformations, kinematic results, and injury criteria to evolve. To do so requires constructing the full vehicle model with sufficient detail, building it up from the hundreds of different components that are typical in a modern car. Only if the model is constructed with this level of attention to detail will the simulation then be able to accurately predict the hardware test results. For that reason there was done an intensive comparison between simulation and real test for different time steps during the crash.

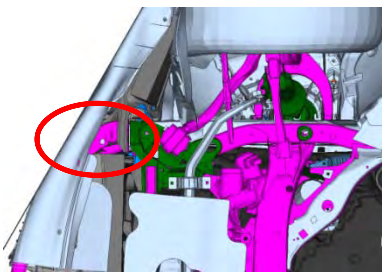
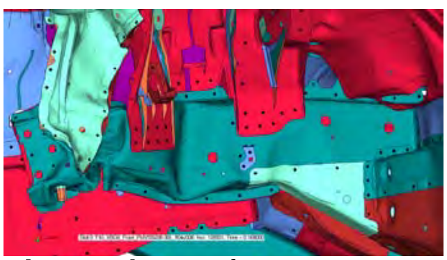
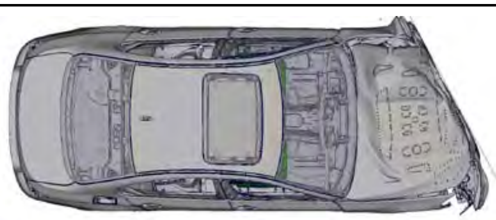
 Simulation after the first ms	 Real crash after the first ms
 Simulation in the area of engine compartement	 Real crash in the area of engine compartement
 Simulation state at the end of the crash	 Real state at the end of the crash

Figure 14: Deformation chain for 30° frontal impact test

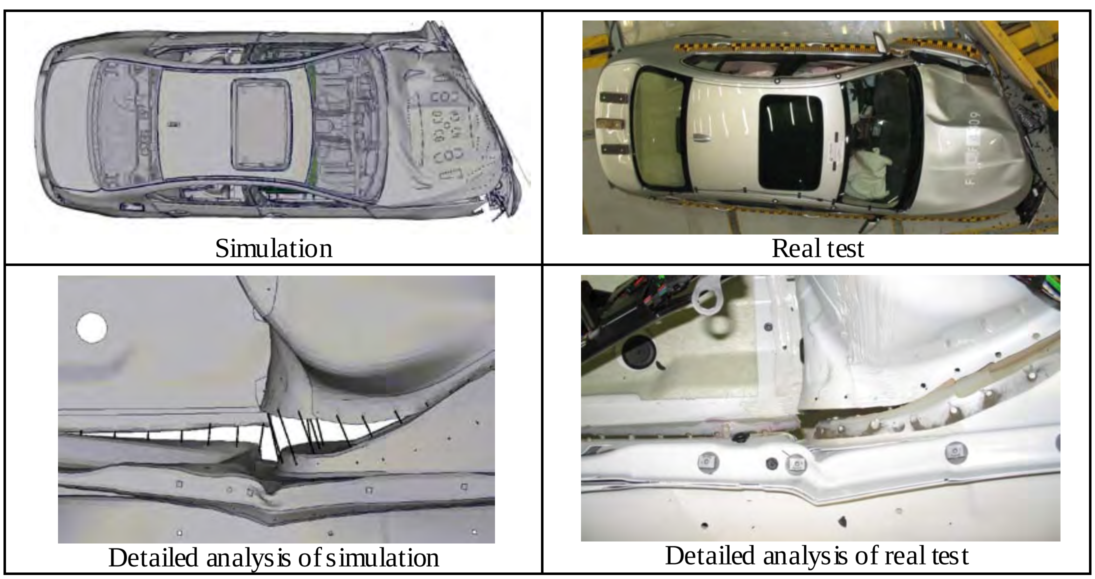
Figure 14 shows the comparison of the deformation between simulation and real test at a few locations and points in time. In order to calculate the final state of the global deformation as precisely as possible, the response and deformation that develop within the first few milliseconds are very important, as that influences subsequent load transfer into the entire car. The top two pairs of images in Figure 14 demonstrate that Abaqus/Explicit correctly predicts the critical sequence or chain of deformations early in the crash event. The last pair of images shows the comparison between test and simulation at the end of the test.

The same level of scrutiny was carried out for all vehicle models included in the benchmark, and in all cases, results from Abaqus/Explicit exhibited the best correlation against physical test.

3.2 Local Deformation Behavior

Because of the significantly reduced hardware testing during a car development program, not only the global deformation characteristics of the car are important, but also very localized behaviors are important to capture, including that of individual spot welds and local sections of components. For that reason, the calculation of such local effects received considerable attention during the benchmark and was also an important factor in BMW's final decision regarding crash simulation software.

Spot weld failure is dependent on the material grades and thickness of the panels being joined. In each car there are typically several hundred different combinations of material grades and panel thickness that are joined by spot welding, and each combination generally requires its own set of failure parameters. It is not feasible to identify the failure parameters for each combination of material grade and thickness by experiment. Therefore, a formula has been developed to calculate the required failure parameters for each combination, based on a limited number of experiments as well as the diameter of the spot weld [3]. The comparison between prediction of spot weld failure from simulation and physical test is shown in Figure 15.



Simulation | Real test
Detailed analysis of simulation | Detailed analysis of real test

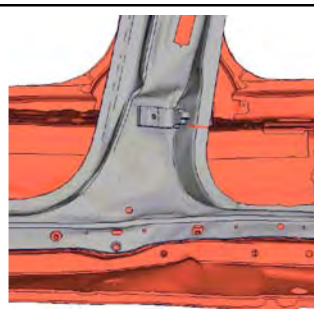
Figure 15: Spot weld failure during crash

It is evident that the simulation with Abaqus/Explicit and the spot weld model from BMW predicts the failure of a spot weld very accurately. An important consideration is that, to obtain such predictions of localized spot weld failure behavior with Abaqus/Explicit, no additional or follow-on simulations are necessary – such results are directly available from the crash simulation involving the entire car. Achieving this level of prediction within the context of the full vehicle simulation is an important factor in being able to most efficiently and effectively carry out the virtual design process.

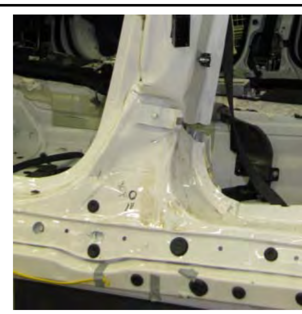
In the early stages of a car development program, it is important to know and understand not only the global deformations that will develop due to various crash load cases, but also the potential for key structural components to rupture or develop cracks. If these can be predicted early in the program, then there is the best opportunity to make design changes that will preclude such behavior. With the previously described method for the calculation of material failure, along with the prescribed meshing guidelines, crack initiation in a part can be predicted very accurately with Abaqus/Explicit. To obtain such predictions, it is not necessary to know a priori where a crack might initiate and subsequently generate a fine mesh in that section. The global element size prescribed in the meshing guidelines is adequate for accurate predictions of where cracks will initiate. Figure 16 shows the comparison of the simulation and hardware test for a side impact load case. As the pictures show, the crack initiation in the B-pillar is predicted very closely to what develops in the hardware test. Differences between simulation and test that do occur are often regarding the length of a crack. However, as cracks are mostly not wanted and sometimes even not allowed, prediction of crack initiation is more important than that of crack length. Nevertheless, the prediction of the exact length of a crack is a subject of pre-development projects within BMW.

Simulation with full crash car model

Real test



Simulation



Real test

Figure 16: Prediction of crack initiation

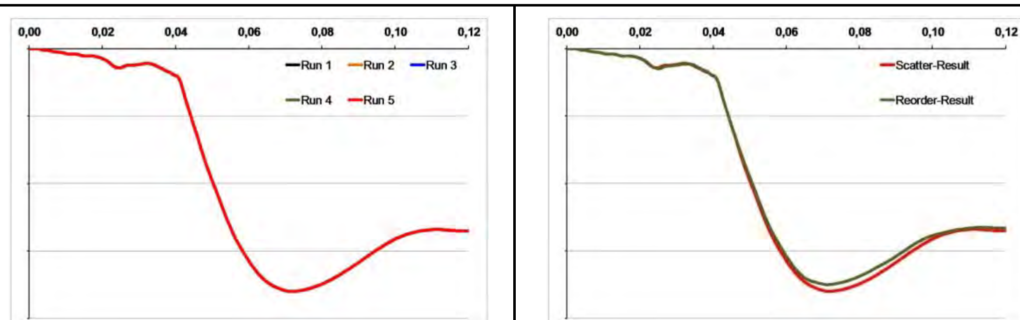
Both above mentioned examples show that it is possible to predict the failure of material as well as of spot welds by Abaqus/Explicit and failure models developed at BMW.

4. Special Investigations

In addition to the topic of predictiveness at the component level as well as for full crash car models, the quality and robustness of the results are essential criteria in the evaluation of crash simulation software. Therefore, additional tests were done during the BMW internal crash software benchmark.

Small perturbations introduced during a crash simulation, such as round-off errors, should not lead to large differences in results. If the crash simulation software uses the proper stable time increment, and the model is adequately discretized and corresponds to a stable and robust vehicle design, results should not change much from one run to another. In the worst case, an unstable model will result in divergence; in other cases it can result in a moderate to severe violation of the energy balance. In addition, since the introduction of stochastic analysis into the study of design robustness, nondeterministic behavior of the crash solver is clearly undesirable because it is unpredictable. Determinism of the solver is a requirement, even if it comes at an additional computational expense. Therefore, BMW investigated numerical sensitivity for one of the benchmark models.

Two basic investigations were performed, and some results are shown in Figure 17. First, a single front impact crash car model was submitted five times on the same hardware with the same number of processors, and all of the results were compared. On the left side of this figure, the firewall intrusions for all five runs are shown. All simulation results are absolutely identical. This is not a standard which can be expected from other crash simulation software.



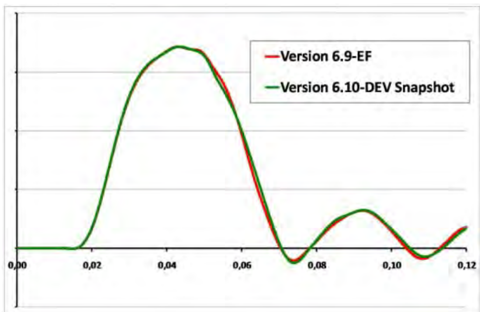
Scatter of 5 identical crash jobs

Scatter between 2 different crash jobs with same physical contents

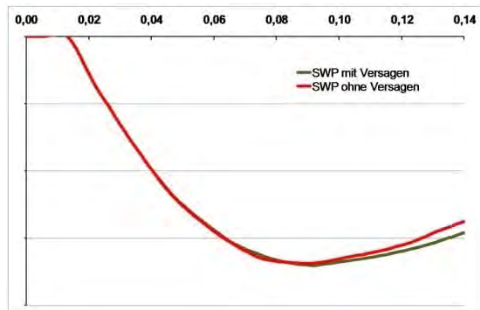
Figure 17: Scatter analysis

Next, stability was examined by increasing the complexity of the investigation. The input file from the same front impact model was assembled in a different way, without changing the physical content. Such a reordered input file is a completely different problem for an explicit solver even if the physical content of the model is exactly the same. The results matched very closely between the original and reordered model. The graph on the right in Figure 17 compares the firewall intrusion between the two simulations, showing a small difference of 3 % in the peak values. This is sufficiently small to allow design engineers to quantify the effects of design changes without having to consider numerical scatter caused by the crash simulation software.

An additional investigation concerning software quality deals with scatter in results caused by changes of the software version. Within our internal benchmark, a comparison between the current general release, Abaqus/Explicit 6.9-EF, and a snapshot of the Abaqus/Explicit 6.10 was performed (this snapshot version 6.10 had not yet been put through the SIMULIA internal release qualification process). The comparison of the driver dummy rib intrusion during a side impact simulation is shown on the left side of Figure 18. The results from both versions are more or less identical.



Results from 2 software versions



Results of 2 different spot weld definitions

Figure 18: Quality of physical formulations with Abaqus/Explicit

One of the primary reasons BMW migrated to Abaqus/Explicit several years ago was due to its strong implementation of physically-motivated models and algorithms. One aspect of the most recent benchmark carried out by BMW sought to confirm this through a particular example – modeling of a spot weld, which can be accomplished in different ways in Abaqus/Explicit if potential damage and failure of the spot weld are not considered:

- Spot weld formulation with rigid connectors (BMW method) without switching damage and failure behavior on.
- Spot weld with the default fastener formulation, where no failure behavior is implemented.

Both spot weld formulations were investigated in a side impact crash model, where the car impacts a rigid pole. Results from both simulations are shown in the plot on the right in Figure 18, comparing the intrusion of the rigid pole into the vehicle. For both definitions of spot welds, the peak intrusion value is identical, and the general shape of the intrusion behavior is nearly the same. Only during the unloading phase do very minor differences between the two simulations become visible.

The quality and robustness of Abaqus/Explicit have been proven by numerous other separate investigations carried out at BMW, each producing consistency of results similar to these four examples. The combination of quality, robustness, and predictiveness are the reasons why Abaqus/Explicit has been confirmed as the best crash solver for BMW needs.

5. Performance

Confidence in results, predictiveness of the simulation, and quality of the software are essential components in the decision process for simulation software in the area of crashworthiness. Additionally, turnaround time for a given simulation is an important factor for effective daily application in product design. Variants should be simulated and evaluated within a very short time. The target turnaround time for a full vehicle simulation, including the new level of predictiveness now available through incorporation of local effects, is approximately 24 hours. And in urgent cases, this target needs to be still lower.

Of course, an increased level of predictiveness would be expected to increase the runtime to some degree, due to greater model refinement and more computationally intensive algorithms. Therefore the change in runtime was investigated between the previous simulation method and the current method, which incorporates the demand for accurate prediction of local effects.

In Figure 19, the green curve displays the dependency of simulation turnaround time on processor count for the old, conventional simulation method. BMW was able to produce results within a very short time. The same figure also displays the increase in turnaround time by a factor of 2.3 due to the application of the new methods which increases the level of predictiveness. At the same time, the number of elements has increased from 1.8M to 3.5M (full vehicle model, including dummy and folded airbags), and significantly more intensive algorithms are activated to simulate failure of spot welds and materials, thereby putting the increase in turnaround time into perspective.

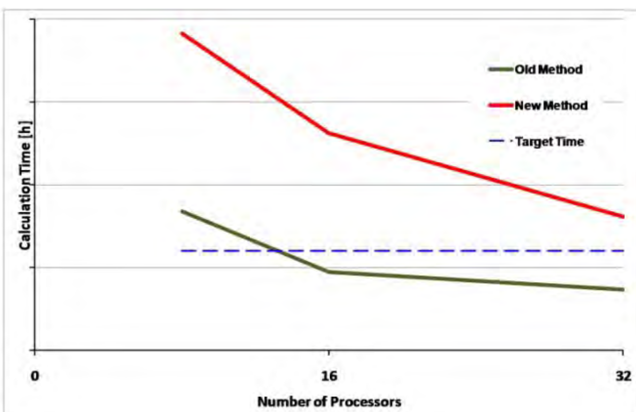


Figure 19: Computation time for a full crash car model (on 2006 hardware)

Since the results using Abaqus/Explicit were so convincing in comparison with the competitors in terms of predictiveness and software quality, additional investigations were made with SIMULIA in the course of the benchmark to get the turnaround time within the target range of 24 hours without sacrificing quality or predictiveness.

Figure 20 displays the jointly identified targets to improve simulation performance. The diagram shows the potential to make adjustments to the BMW internal IT infrastructure that can yield substantial performance gains without a significant incremental investment in hardware. Additionally, performance is a key focus area for ongoing Abaqus/Explicit development, which also positively impacts the overall aim to reduce turnaround times. It is expected that these jointly identified targets regarding hardware and software improvements can be realized within a relatively short timeframe, which should position BMW very well to address its crashworthiness simulation requirements over the coming years.

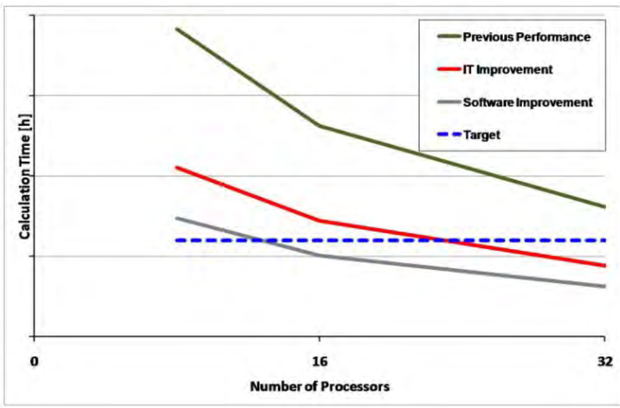


Figure 20: Opportunities for performance increase

6. Conclusion and Outlook

The requirement at BMW to reduce hardware tests by increasing the usage of virtual testing has led to new BMW internal demands for its crash simulation software. The ability to accurately predict local effects like material and connection failure now receives much more attention than has previously been the case. It can be shown that accurately accounting for such behaviors can have a substantial influence on important passive safety criteria – not doing so can lead to incorrect and often non-conservative predictions for these criteria, which are only then realized upon hardware testing.

Therefore a new benchmark of the different vendors of crash simulation software was conducted at BMW in 2009. The focal point of the benchmark was on predictiveness and credibility of simulation results. To be able to reliably evaluate these criteria, the direct comparison of simulation and test was key, both at the component level as well as the full vehicle level. The range of investigations was extensive, and only a small fraction of them have been shown in this paper. In direct comparison with the competitors' products, a significantly higher level of predictiveness can be demonstrated with Abaqus/Explicit – accurate predictions of critical local effects can be obtained for the complete range of relevant models, from components up through full vehicles.

Therefore Abaqus/Explicit continues to be the key design simulation tool for passive safety for BMW cars. Only Abaqus/Explicit enables BMW to fulfill its internal demands for continuing enhancements to simulation functionality and performance, while also meeting the stringent requirements to further compress vehicle development cycles and reduce physical prototypes and associated testing. These benefits can be quantified by cost savings measured in millions of Euros and months of product development time.

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Bird Strike Simulations on Composite Aircraft Structures

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Abstract: Composite materials are increasingly being used for aeronautic primary structures such as wing components or fuselage panels. However, their major drawback is their vulnerability against transversal impact loads, which may lead to internal delaminations or intralaminar fiber/matrix failure. Such loads may arise from numerous impact scenarios, with bird strikes being one of the most relevant load cases. The focus of the current study is on the numerical modeling and simulation of high velocity impact loads from soft body projectiles on composite structures with ABAQUS/explicit. At first, the impact on flat composite plates is studied in experiment and simulation, which allows for the validation of the modeling methods. Some of these plates have been preloaded in tension or compression in order to investigate the influence on the mechanical behavior. It could be shown that the preloading of the plate may have a significant influence on the structural response. As a second example, the bird impact on a composite wing leading edge is treated. Adequate modeling methods for the composite material (stacked shell model), delamination failure (cohesive elements), preloading (implicit-explicit coupling) and soft body impactor modeling (coupled Eulerian-Lagrangian approach) are assessed in this paper. The final simulation results correlate well with experimental test data.

Keywords: Aircraft, Composites, Coupled Analysis, Damage, Delamination, Impact, Bird Strike, Cohesive Elements, Coupled Eulerian-Lagrangian, Preload, Implicit-Explicit Coupling.

1. Introduction

Bird strike is a major threat to aircraft structures, as a collision with a bird during flight can lead to serious structural damage. Although exterior aircraft structures are exposed to various threats of foreign object damage like hail, runway debris or tire rubber impact, about 90% of all incidences today are reported to be caused by bird strike (Meguid et al., 2008). All forward facing components are concerned, i.e. the engine fan blades and inlet, the windshield, window frame, radome and forward fuselage skin as well as the leading edges of the wings and empennage (Figure 1). Consequently, the aviation authorities require that all forward facing components need to prove a certain level of bird strike resistance in certification tests before they are allowed for operational use. For wing leading edges the certification criteria require that even in case of penetration of the leading edge skin no critical damage may be introduced to the front spar elements or the wing tank, so that a continued safe flight and landing after impact are assured. This has to be proven for 4 lb (1.8 kg) birds impacting the wing and 8 lb (3.6 kg) birds impacting the empennage leading edge at operational speed. Nowadays, more and more of such aircraft structures that are exposed to the risk of bird strikes are made of composite materials.

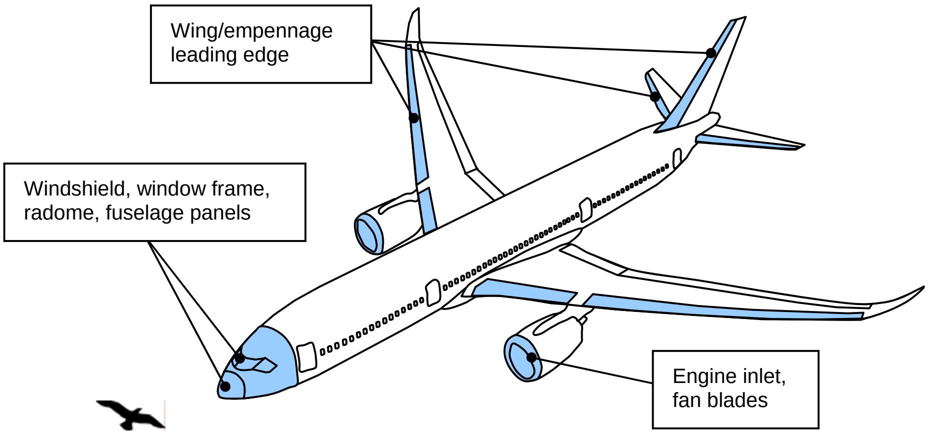


Figure 1. Illustration of aircraft components exposed to the risk of bird strike.

In past years it was common practice for bird-proof design of aircraft components to be built and tested, then redesigned and tested again (Nizampatnam, 2007). One example of this procedure is documented for the development of the bird-proof Dash 8 wing leading edge (John, 1991). Without doubt, this is not only a very time-consuming, but also cost-consuming practice. Therefore, numerical methods were developed and applied since the late 1970s for the purpose of rapid and improved design optimization, ensuring that the very first full-scale bird strike certification test is successful.

The definition of a suitable bird model is often the main problem in the numerical simulation of bird strike incidents. Starting with relatively simple nonlinear calculations and a pressure load applied to the target structure in the 1970s, complex fluid-structure interactions are treated today with explicit simulation codes and high performance computing. Most interestingly, this evolution from simple to complex and accurate methods did not lead to the establishment of one generally accepted bird impactor modeling approach. Instead, there are still at least three techniques today, which are widely used, each having its own advantages and disadvantages (Lagrangian, Eulerian and meshless particle modeling (SPH)). A comprehensive overview of these bird strike modeling methods can be found in (Heimbs, 2011).

The focus of the current paper is on the application of the coupled Eulerian-Lagrangian (CEL) modeling method in Abaqus/Explicit 6.10 for bird strike simulations on composite aircraft structures. After an explanation of the bird impactor and composite material modeling methods, two example load cases are treated. At first, the impact on a flat composite plate is studied numerically and experimentally, which allows for the validation of the modeling methods. Some of these plates have been preloaded in tension or compression in order to investigate the influence on the mechanical behavior. As a second example, the bird impact on a composite wing leading edge is treated.

2. Bird impactor modeling

For bird strike certification tests on aircraft components real birds have to be used. However, real birds with their irregular shape have the disadvantage of large scatter between individual tests. Therefore, artificial birds or substitute birds are typically used for pre-certification impact tests and simulations, leading to advantages in convenience, cost and reproducibility. Typical artificial birds are made from gelatin and have a simplified geometry such as a cylinder with hemispherical ends.

At the velocities of interest, the bird behaves as a soft body and flows in a fluid-like manner over the target structure, with the high deformations of the spreading material being a major challenge for computational simulations. In the current version 6.10 of Abaqus/Explicit, two different soft body impactor modeling methods are available: the Lagrangian and the Eulerian approach. Meshless particle methods like SPH are not yet included in the current version.

The Lagrangian modeling method is the standard approach for most structural finite element analyses with the nodes of the Lagrangian mesh being associated to the material and therefore following the material under motion and deformation (Figure 2a). The major problem of Lagrangian bird impactor models is the severe mesh deformation. Large distortions of the elements may lead to inaccurate results, severe hourglassing, reduced time steps and even error termination, which has to be prevented with adequate element erosion criteria. Although this modeling method is still used today, it is widely accepted that the Lagrangian approach remains an impractical way to model fluid splashing phenomena like bird strikes (Georgiadis at al., 2008).

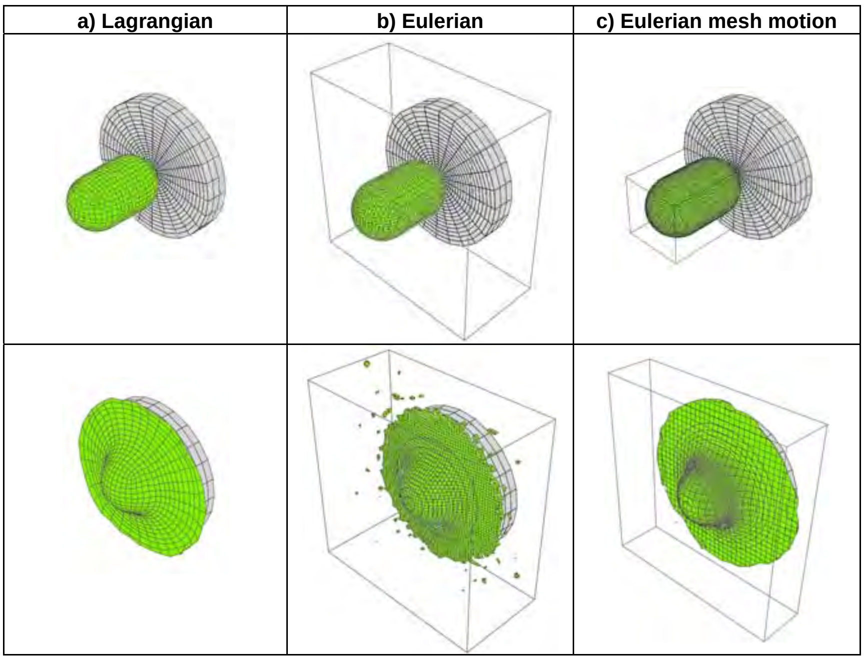


Figure 2. Soft body impactor modeling methods in Abaqus/Explicit 6.10.

A promising alternative is the Eulerian modeling technique, where the mesh remains fixed in space and the material flows through the mesh (Figure 2b). Because the mesh does not move, mesh deformations do not occur and the explicit time step is not influenced. Stability problems due to excessive element deformation do not occur. Since in a bird strike simulation typically only the impactor is modeled as a fluid-like body with Eulerian elements and the target as a solid structure with Lagrangian elements, a coupled Eulerian-Lagrangian approach is used for this fluid-structure interaction problem, which is available in Abaqus/Explicit since version 6.8. Because the mesh in the classical Eulerian technique is fixed in space, the computational domain should cover not only the region where the material currently exists, but also additional void space to represent the region where material may exist at a later time of interest. Thus, the computational domain for structural analyses with the classical Eulerian technique is relatively large, leading to high computational cost due to the high number of elements and the cost-intensive calculation of element volume fractions and interactions. Typically, the element size of the Eulerian mesh has to be defined very small in order to achieve accurate results.

An increase of efficiency is the ‘Eulerian mesh motion’ option in Abaqus/Explicit (Figure 2c). Here, in contrast to the classical Eulerian approach, the surrounding Eulerian box is not fixed in space but can move and stretch if needed. The initial number of elements for the Eulerian domain can significantly be reduced, leading to computational time savings. However, due to the wide spreading of the bird material the lateral expansion of the Eulerian box is significant and the size of the Eulerian elements is increased considerably. As stated before, the accuracy of the results is strongly mesh dependent and requires fine meshes. Therefore, the accuracy of the model with mesh motion may be reduced for severe impactor deformations. For this reason, the classical CEL approach was used in the present study.

The next step in the bird modeling procedure is the definition of an adequate material model for the impactor. Generally speaking, real birds and artificial gelatin birds are mostly composed of water. Therefore, a water-like hydrodynamic response can be considered as a valid approximation for a constitutive model for bird strike analyses. An equation of state (EOS) describes the pressure-volume relationship with parameters of water at room temperature. The Mie-Grüneisen EOS (u_s-u_p approach) in Abaqus/Explicit was adopted for this purpose in the current study.

A common technique to validate the bird impactor model is to use experimental bird strike test data on instrumented plates and to compare the pressure-time history with the numerical results (Figure 3). A large set of publicly accessible experimental bird impact test data was generated in the late 1970’s (Wilbeck, 1978), although the quality of the curves and especially the initial peak pressure is limited due to the limitations of the instrumentation equipment at that time.

Another important aspect for the fluid-structure interaction in the bird impact simulation is the contact algorithm, which prevents penetrations and calculates reaction forces. The contact algorithm has to cope with large deformations and splitting of the projectile, sliding of the bird material over the target surface and the creation of multiple contact interfaces due to possible fracture and penetration of the structure (Lammen and Van Houten, 2008). During the flowing of the bird, significant oscillations in the contact force can occur in a penalty contact algorithm that are often dependent in their frequency and peaks on the penalty stiffness scale factor, which has to be selected with care for this contact pair with highly different stiffnesses (Ryabov et al., 2007). Friction is another aspect, whereas the study in (Shmotin et al., 2009) advises that best results compared to experimental results can be obtained with zero friction.

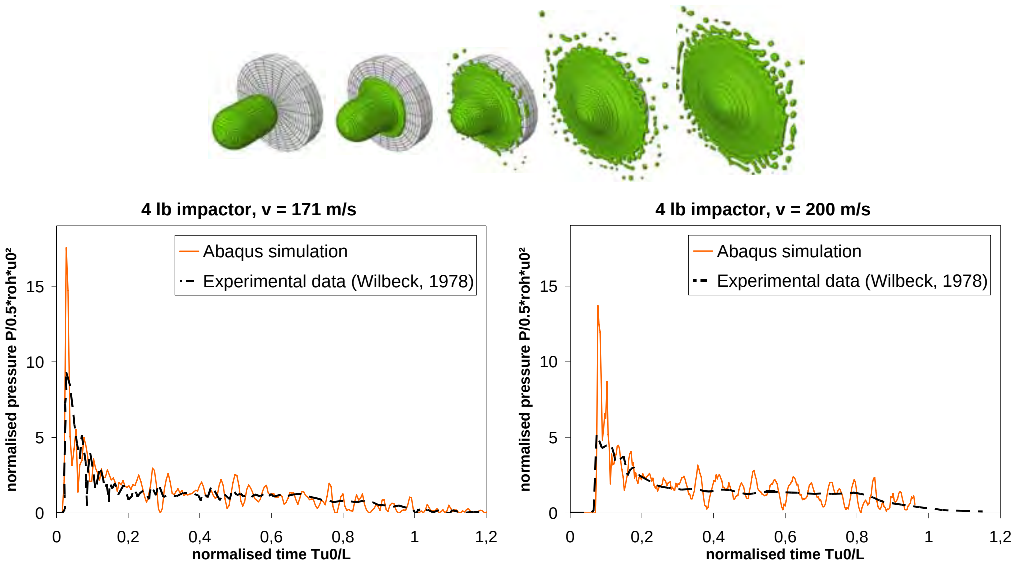


Figure 3. Eulerian bird impactor validation using impact test data on instrumented plates, v = 171 m/s and 200 m/s.

3. Composite material modeling

Since nowadays most aircraft structures subjected to impact loads are made of fiber-reinforced composite materials, the correct constitutive modeling covering all possible impact-induced failure modes is of great importance for reliable simulation results. This involves both intralaminar fiber/matrix damage and interlaminar damage as the separation of individual plies (delaminations).

The standard material model for intralaminar damage in Abaqus/Explicit is based on the Hashin failure criteria for damage initiation and fracture energies for damage evolution. More accurate models, typically implemented as user-defined materials, are often based on continuum damage mechanics and take into account the stiffness degradation and nonlinearities resulting from increasing damage caused by micro cracks under load (Lubineau and Ladeveze, 2008). However, the current study only covers the standard Hashin-based composite material model. Coupon tests have been conducted to obtain the required parameters under different load conditions. For high velocity impact loads the strain rate effect of the target material can also play a significant role, which is to be characterized in dynamic tests. Composite materials are known to show increased stiffness or strength properties under highly dynamic loads (Heimbs et al., 2007). However, as none of the currently available composite material models includes strain rate effects, this phenomenon had to be neglected here.

Delamination damage, which is typically observed under low and high velocity impact loads on laminated composites and which can significantly reduce the global stiffness and residual strength, needs to be included in the model, too. The composite plies are typically modeled with several shell elements across the thickness of the laminate, and the possibility of delaminations is included by cohesive interfaces between these shell elements (stacked shell modeling approach). These interfaces can either be based on a contact definition with cohesive behavior or on cohesive elements. In direct comparison, the cohesive contact has proven to be much more expensive than the cohesive elements. Therefore, in the current study cohesive elements were used. The selection of number of cohesive interfaces needs to be a compromise between accuracy and efficiency. It is often not possible and desired to include a cohesive interface between each individual ply, because the computational cost would be significant and the interfaces may have a negative effect on the global bending stiffness of the composite laminate, which needs to be verified. It is common practice to include one to five cohesive interfaces in a laminate and combine the plies in-between to sub-laminates. The mechanical model of the interface is based on the cohesive zone model with a bilinear traction-separation law. The necessary parameters are typically obtained by double-cantilever beam and end-notched flexure tests, where the critical energy release rates required for the delamination propagation are identified. Simulations of these tests are a good possibility for validation of the delamination model.

4. Bird impact on composite plates with and without preload

As a first generic example load case the bird impact on a flat composite plate is treated. This study, which was performed both experimentally and numerically, was intended to assess the quality of the numerical simulations with a limited amount of complexity. Furthermore, the effect of in-plane compressive or tensile preloads of the plate was investigated.

The 1.625 mm thick target plates were made of T800S/M21 carbon composite material and had a free surface of 300 mm x 200 mm. Both longitudinal ends of the plate were clamped and additional supports on the edges of both free surfaces were introduced that fixate the plate's translational degree of freedom in the plate's thickness direction. The composite plate was modeled with three layers of SC8R shell elements with two layers of COH3D8 cohesive elements in-between. The Hashin failure criteria were used for the ply modeling.

The high velocity impact tests were performed at the DLR gas gun test facility in Stuttgart using hard body (steel sphere and glass sphere) as well as soft body impactors (gelatin bird). This paper focuses on the soft body impact with a 32 g gelatin bird with the geometry of a cylinder with one hemispherical end and a length of 50 mm and a diameter of 30 mm. The impact velocities in this study were selected to be 100 m/s, 150 m/s and 200 m/s. A fixed Eulerian mesh domain was defined with the dimensions 220 mm x 200 mm x 100 mm. A biased mesh size was used with 2 mm elements in the impact centre and 6 mm elements at the outer border. This was useful as small elements are necessary in the impact centre for an accurate calculation but the total number of elements should be as small as possible for computational efficiency reasons. A total number of 364.900 Eulerian elements was used for these simulations.

Since in reality it is rather unlikely that the impacted surface of an aircraft structure during flight is unloaded, the effect of preloads on the impact behavior is of great interest (Garcia-Castillo et al., 2006, Mikkor et al., 2006). Uniaxial tensile and compressive prestrain of 0.1% and 0.25% was applied to the composite plate before impact and the influence on the impact performance was investigated. In the numerical simulation, there are different possibilities how to model the preloading before impact. In most studies in the literature the preloading was also performed within the explicit calculation step (Heimbs et al., 2009, Pickett et al., 2009). If oscillations can be avoided, this approach is working well, but it is relatively expensive. Typically half of the computational cost is ascribed to the preloading, half to the impact simulation. A much more elegant approach, which is straight-forward in Abaqus, is the implicit-explicit coupling. The preloading is performed during an implicit calculation step in Abaqus/Standard, which takes only a few minutes, and then the model and stress state are transferred to a calculation with Abaqus/Explicit for the impact loading.

The bird impact of the 32 g gelatin projectile with velocities up to 200 m/s on the unloaded plate led to no penetration but severe internal damage. While ultrasonic C-scans were used to assess the state of damage in the test plates, the intralaminar and interlaminar damage variables (DAMAGEMT, SDEG) were evaluated in the simulation model (Figure 4).

The tensile preloading for the lower impact velocities of 100 m/s and 150 m/s led to less bending deformation of the plate compared to the unloaded case. Consequently, the delamination damage is slightly smaller. The intralaminar damage is a little higher with an increased number of eroded elements in the top element layer. However, although these results seem to be consistent, the results evaluation of the highest impact velocity of 200 m/s shows a different picture.

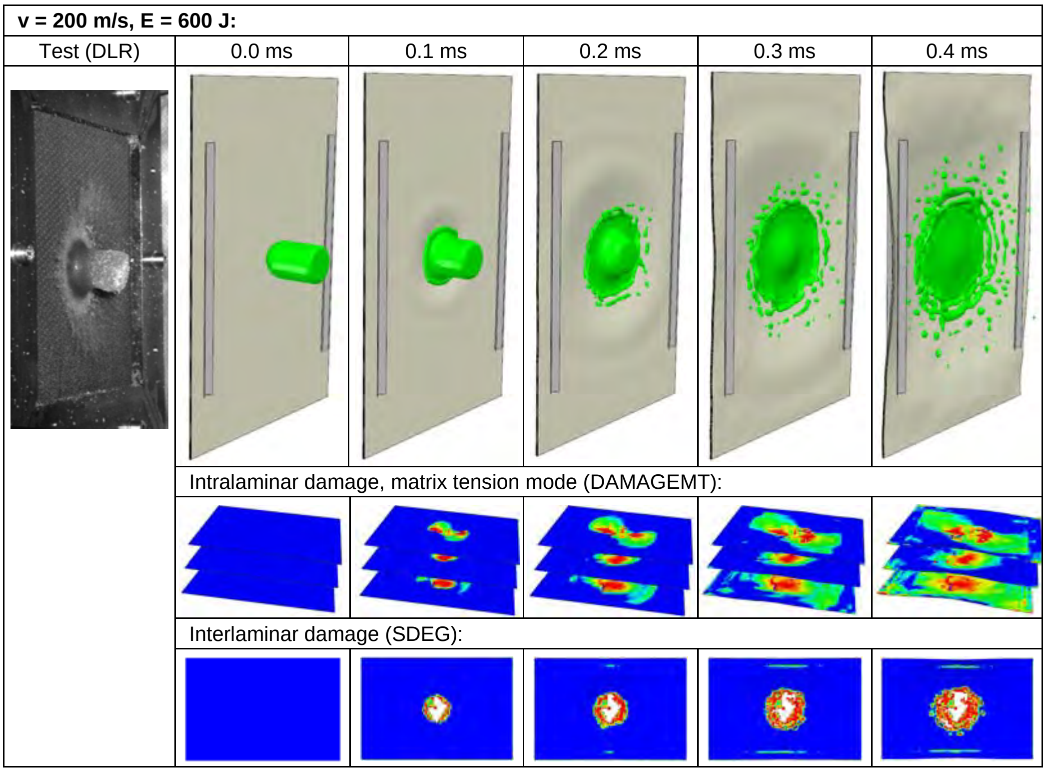


Figure 4. Bird impact simulation results on unloaded composite plate (v = 200 m/s).

In this case, the plate deflection with tensile prestrain is even higher than without preload. Still, it can be seen that the extent of intralaminar damage is higher than in the unloaded case. But also the delamination damage is higher and many more cohesive elements have been eroded (Figure 5). This is because there is so much intralaminar damage resulting from this high impact energy, supported by the tensile prestrain, that the large-scale degradation of the material leads to higher bending deformation and therefore increased delamination damage. A further increase of impact velocity leads to total failure and penetration of the plate. Consequently, the ballistic limit of the plate, defined as the velocity when impactor penetration occurs, is lower for the tensile preloaded plate. At an impact velocity of 225 m/s the tensile preloaded plate fails due to large cracks and global loss of integrity, while the unloaded plate still maintains its structural integrity.

In case of compressive preload, plate buckling becomes an issue due to the small thickness of the composite plate. Different buckling modes occurred depending on the level of compressive prestrain, which can lead to an initial deflection of the plate centre towards or away from the impactor before impact. In this study, the deflection was always selected to be away from the impactor. The assessment of the impact simulation results showed that the global deflection of the preloaded is higher than for the unloaded plate, which is explained both by the initial buckling deformation and the compressive preloading. This higher bending deformation leads to slightly higher delamination damage, which was visible for all impact velocities. The intralaminar damage on the other hand seems to be more localized with higher local damage and more eroded elements compared to the unloaded plate, but a smaller total area of damaged material (Figure 5). The influence of the compressive preload is therefore considerable, leading to more delamination and more localized failure. As a consequence, the ballistic limit of the compressively preloaded plate subjected to bird impact is again reduced. For the impact velocity of 225 m/s the unloaded composite plate can still resist the impact load, while the plate with 0.25% compressive prestrain fails and penetration occurs (Figure 6).

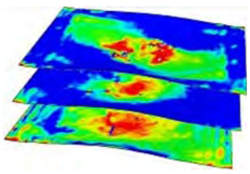
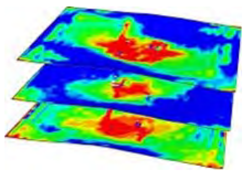
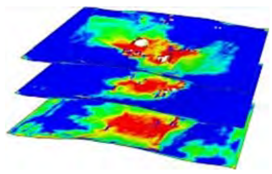
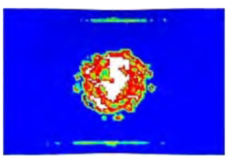
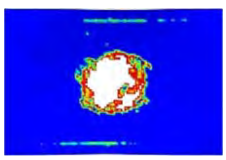
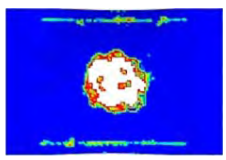
v = 200 m/s, E = 600 J:		
No preload	Tensile preload ε = 0.25 %	Compressive preload ε = -0.25%
Intralaminar damage, matrix tension mode (DAMAGEMT):		
		
Interlaminar damage (SDEG):		
		

Figure 5. Influence of tensile and compressive preload on soft body impact damage (v = 200 m/s, t = 0.4 ms).

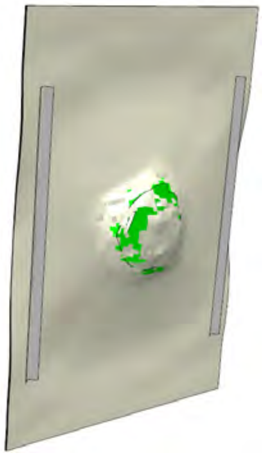
a) unloaded plate	b) compressive preload ε = -0.25%
	
No global failure	Global failure, penetration

Figure 6. Impact simulation results for v=225 m/s (backside view, t = 0.3 ms).

5. Bird impact on composite wing leading edge

As a second example the bird strike simulation on a composite wing leading edge slat with Abaqus/Explicit is presented. The leading edge structure consists of a composite skin, five composite ribs and a metallic back plate, connected by rivets and adhesive bonding. Further details on the design of the wing leading edge can be found in (Roth, 2006) and (Keck et al., 2009).

The artificial bird is a 4 lb gelatin impactor with a cylindrical geometry with two hemispherical ends and the dimensions 208 mm x 118 mm. The impact velocity is 185 m/s with an angle of 34° to the slat surface. These boundary conditions match to the experimental conditions of full-scale bird impact tests on this leading edge that could be used for model validation.

The composite material was modeled with shell elements and the Hashin failure criteria. The metallic parts were modeled as elastic-plastic materials with defined yield curves and fracture strains. For all bonding connections in the model contact definitions with cohesive behavior based on a traction-separation law were used. In this case, damage is controlled by a quadratic traction criterion with defined failure stresses in normal and shear direction for the bonding surfaces. Beam-type connector elements have been used to model the rivet connections with force-based failure criteria.

The bird impactor was modeled as a Eulerian part based on the Mie-Grüneisen EOS with water-like properties. A general contact with a frictionless tangential behavior was defined for the fluid-structure interaction in the CEL model. A Eulerian mesh size of 6 mm was chosen. With this configuration the final model had 735.000 elements, mainly Eulerian elements, and took 22 h CPU time (on 1 CPU) for a simulation time of 10 ms.

The top view of the bird strike simulation on the composite wing leading edge structure is shown in Figure 7, the cross-sectional view in Figure 8. It can be seen that one part of the impactor penetrates through the skin into the structure and damages two ribs, while another part of the impactor splashes away from the outer surface. A correct representation of such impactor splitting phenomena is essential for reliable bird strike simulations to cover realistic loads of the secondary impact of the penetrating impactor material.

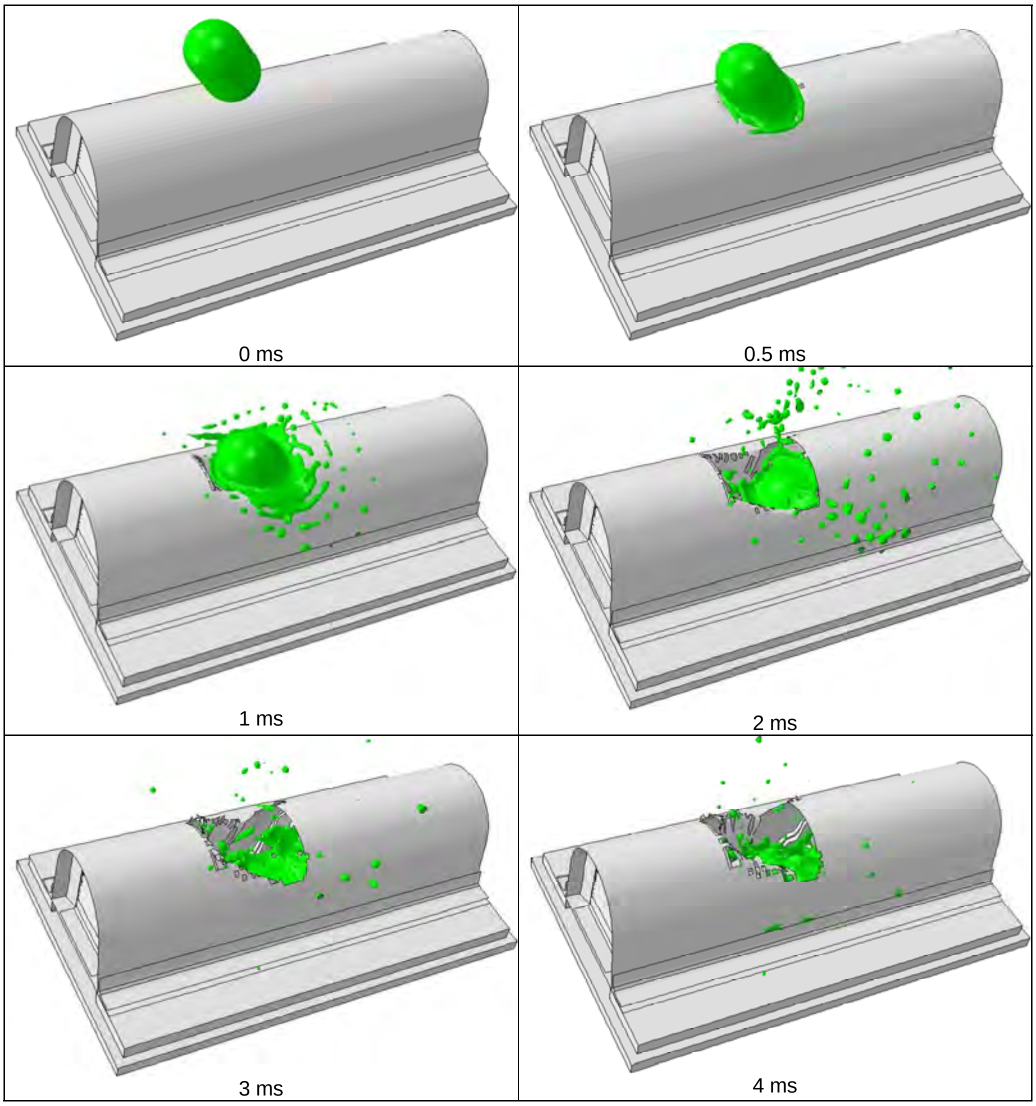


Figure 7. Bird strike simulation on composite wing leading edge (top view).

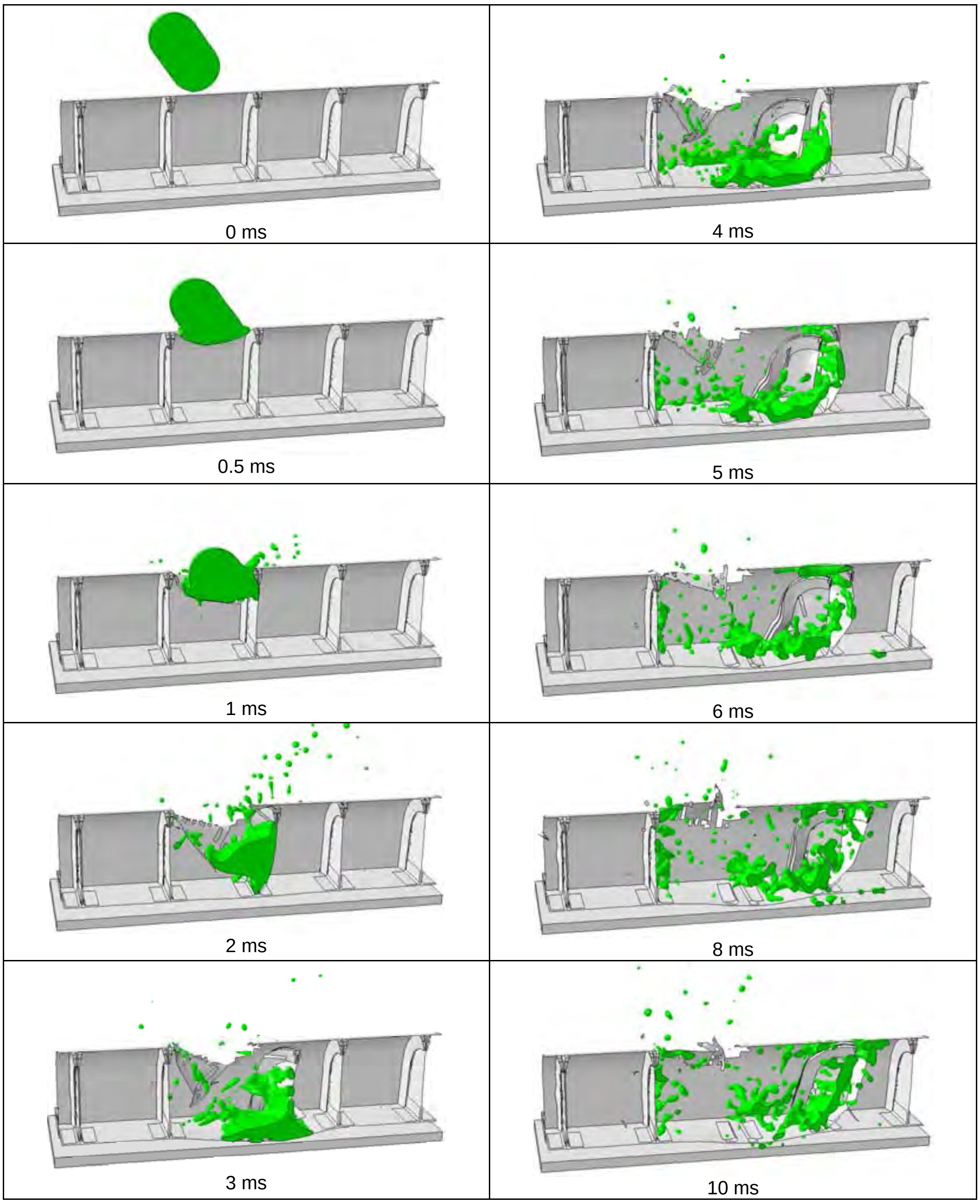


Figure 8. Bird strike simulation on composite wing leading edge (cross-sectional view).

For comparison with experimental impact test data, on the one hand, the qualitative deformations and damage during and after the test were adopted (Figure 9). On the other hand, the residual deformation of the metallic back plate was assessed, which is a good measure of the residual energy of the impactor material after skin penetration. Both comparisons are very satisfying, showing the potential of such bird strike simulations with the CEL modeling option.

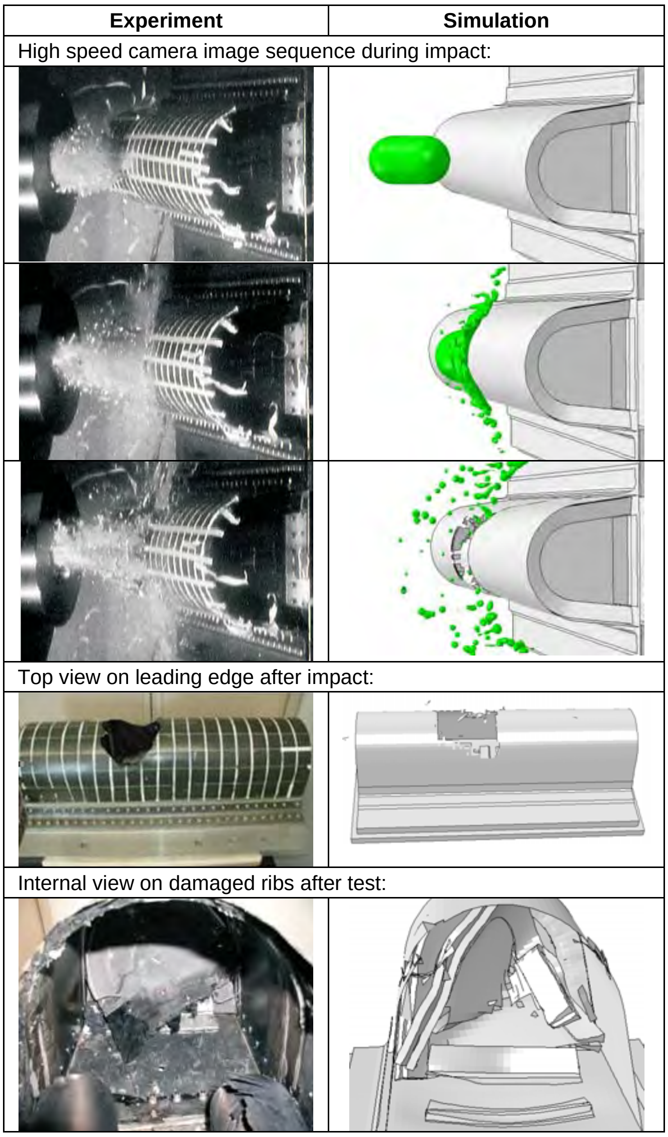


Figure 9. Comparison of test and simulation results.

6. Conclusions

In aircraft engineering there is a strong interest in reliable numerical methods for structural design under vulnerability aspects to reduce testing expenses and development time. One major load case is bird strike on aircraft components that are nowadays typically made of composite materials. This paper assessed the current bird impact simulation methods in Abaqus/Explicit 6.10. The CEL simulation approach is much more appropriate compared to the Lagrangian bird impactor modeling since no problems with excessive element distortion occur. The composite material modeling of the target structure requires the inclusion of intralaminar and interlaminar failure modes. This is typically achieved by a stacked shell modeling technique with cohesive elements for the delamination interfaces. The two example load cases, i.e. bird impact on a flat composite plate and bird impact on a composite wing leading edge, showed promising results that were achieved with these modeling methods and that are close to experimental test data. The influence of preload on the impact behavior of the composite structure could also be assessed, which increased the internal damage and reduced the ballistic limit.

Further ongoing work in order to increase the predictability and reliability of bird impact simulations on composite structures aims at accurate composite damage models for explicit calculations and the standardization of a substitute bird impactor.

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Back

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

Patrick GRIMBERG, Digital Product Simulation, Author

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:

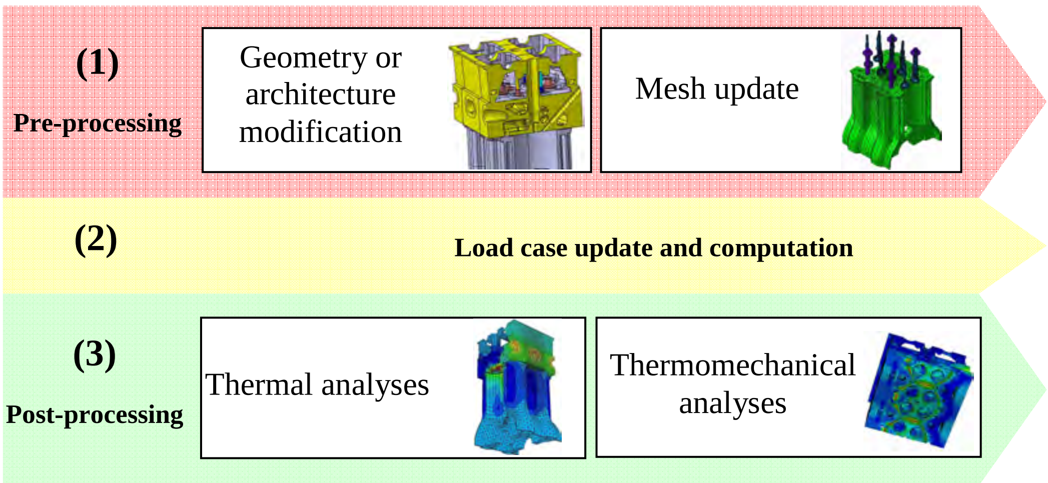

Figure 1: iteration process on a power unit

Modifying the geometry:

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.

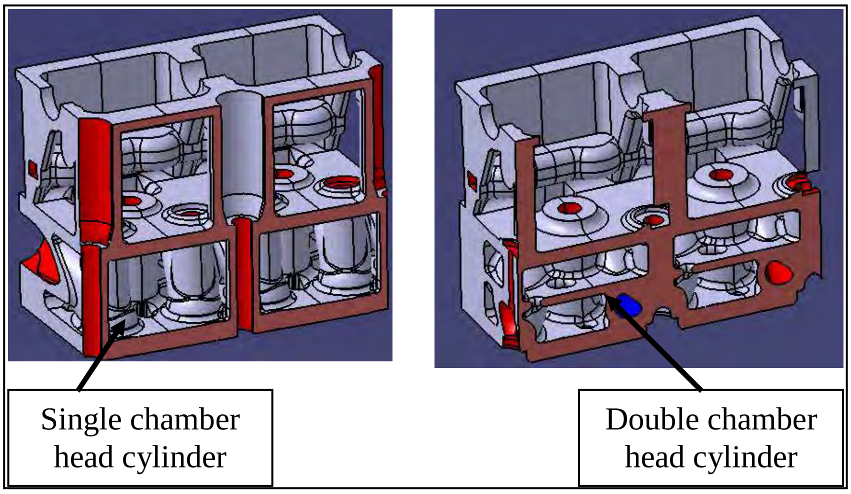

Figure 2: two design alternatives of the head cylinder

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.

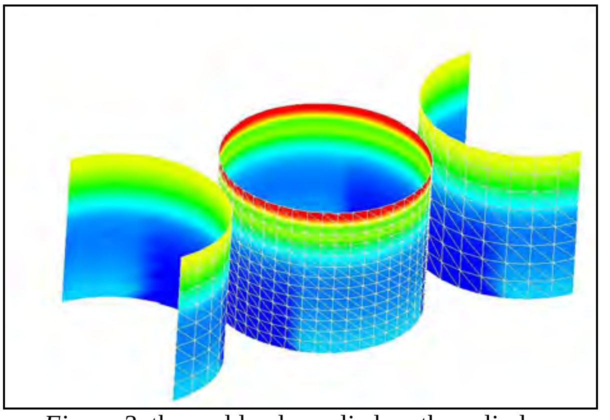

Figure 3: thermal loads applied on the cylinders

- 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

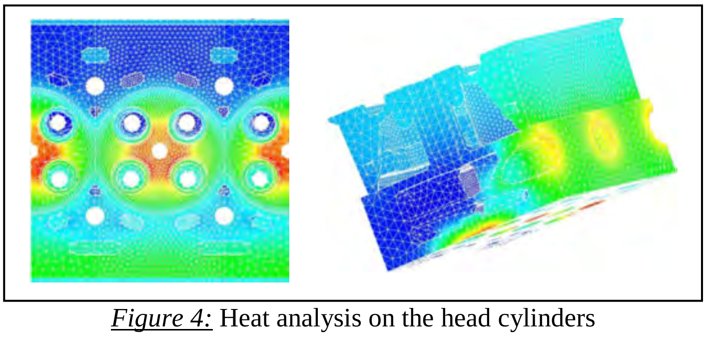

Figure 4: Heat analysis on the head cylinders

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

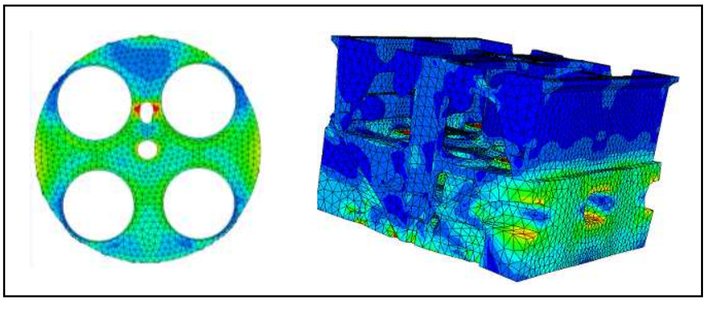

Figure 5: Thermomecanical analyses

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).

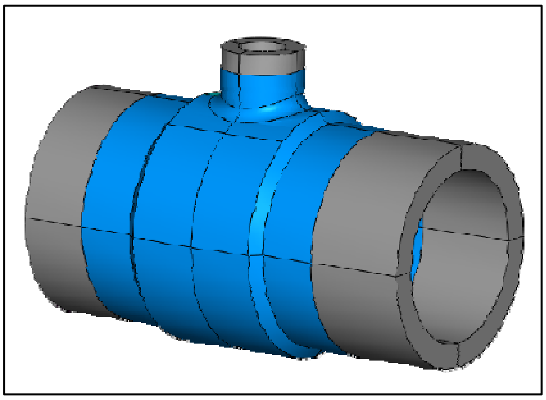

Figure 6: Tee design

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

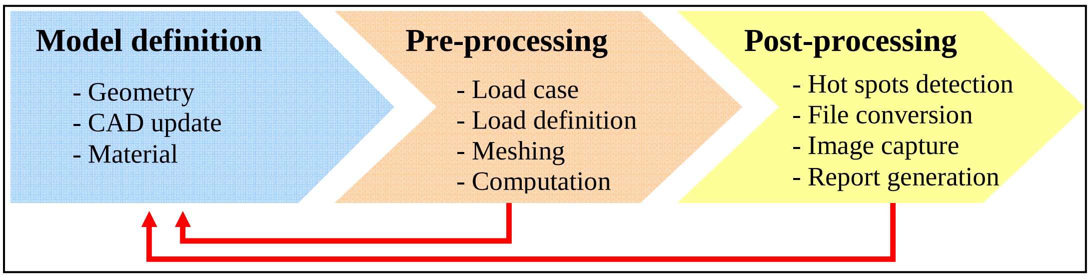

Figure 7: tee design and simulation simplified workflow

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.

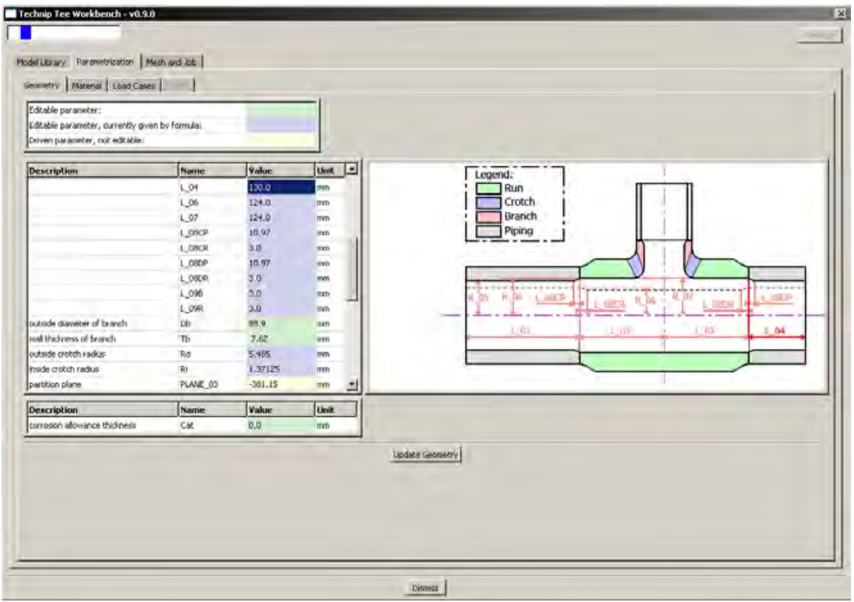

Figure 8: Defining input parameters and visualizing knowledge laws-driven parameter

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).

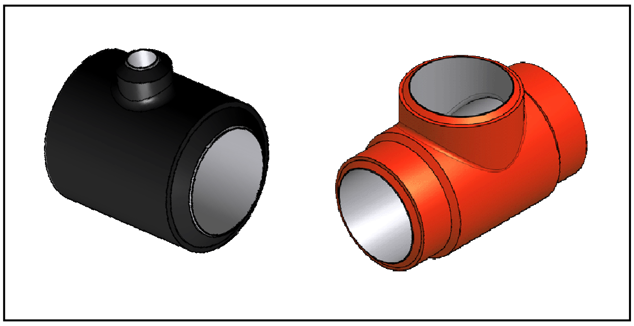

Figure 9: two parameterized tee architecture
(left: reduced outlet tee; right: straight tee)

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).

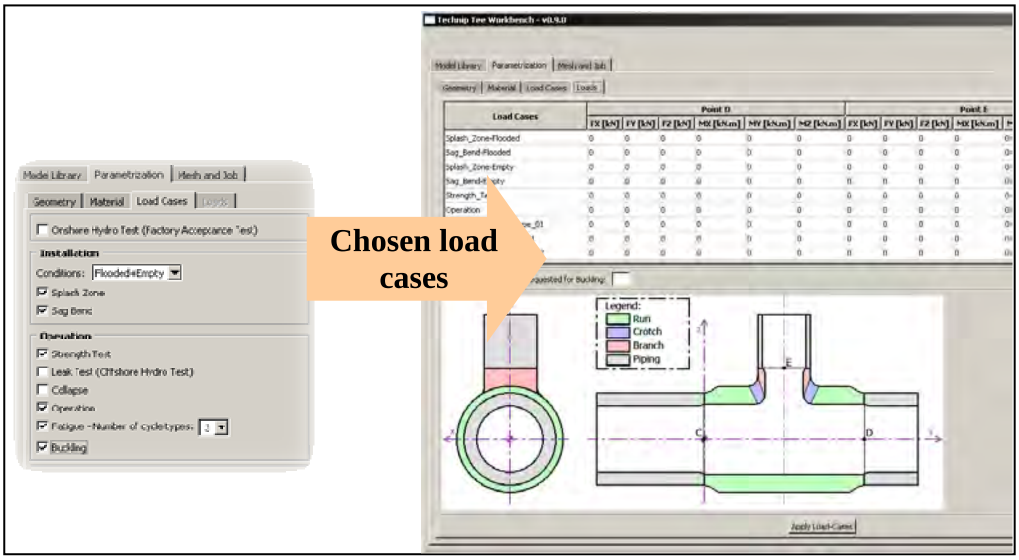

Figure 10: Defining load cases and applied loads

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.

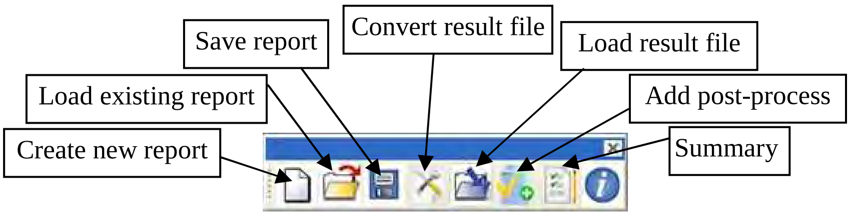

Figure 11: Post-processing tools for Abaqus/Viewer

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.

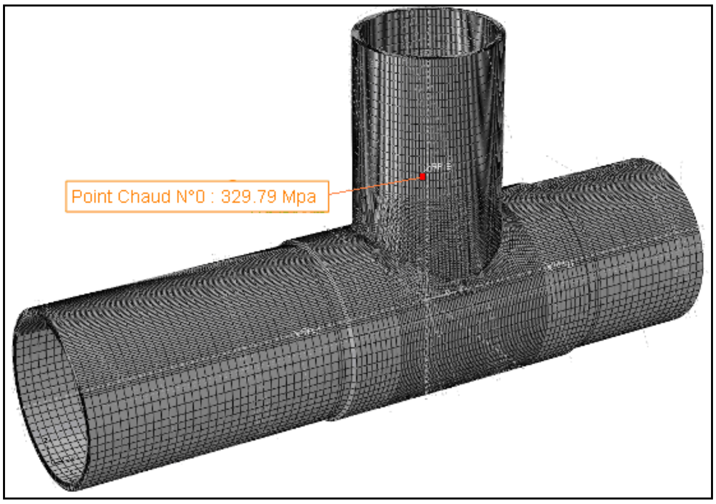

Figure 12: Hot spot detection on Abaqus/Viewer

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.

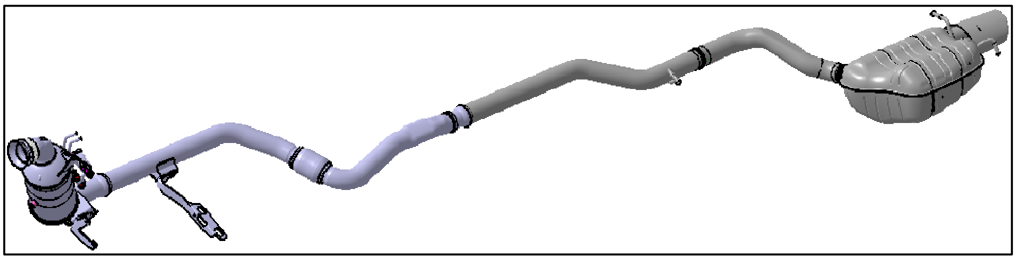

Figure 13: complete exhaust system

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:

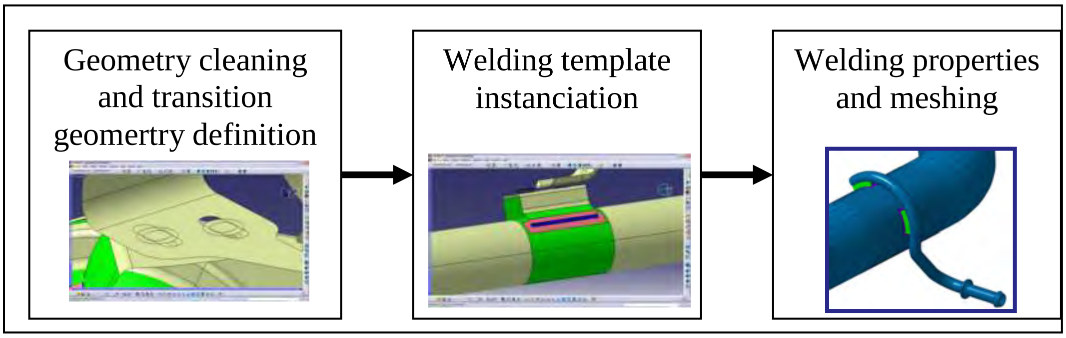

Figure 14: welding workflow

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.

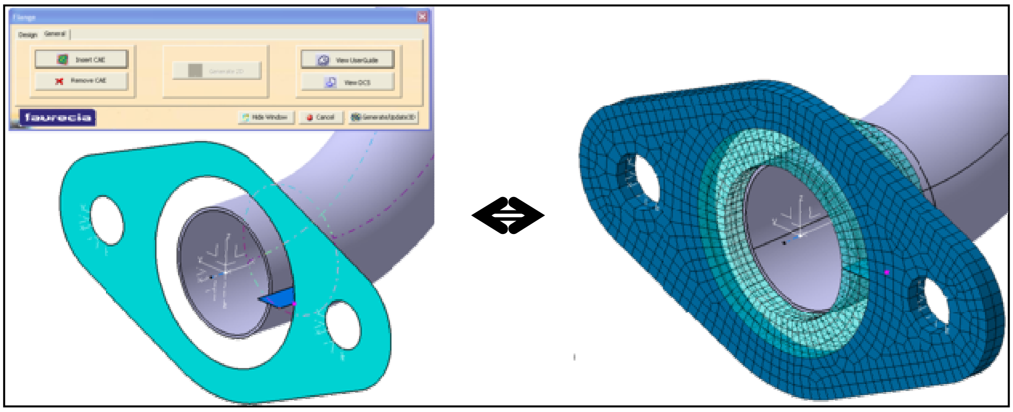

Figure 15: Welding Mesher tool covers all the operations from geometry preparation to meshing.

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.

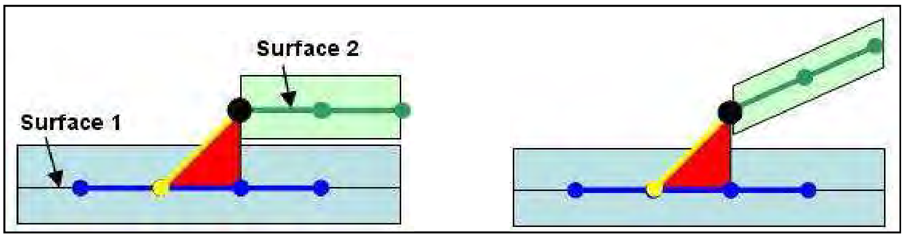

Figure 16: Two types of welding (left: lap type; right: fillet type)

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

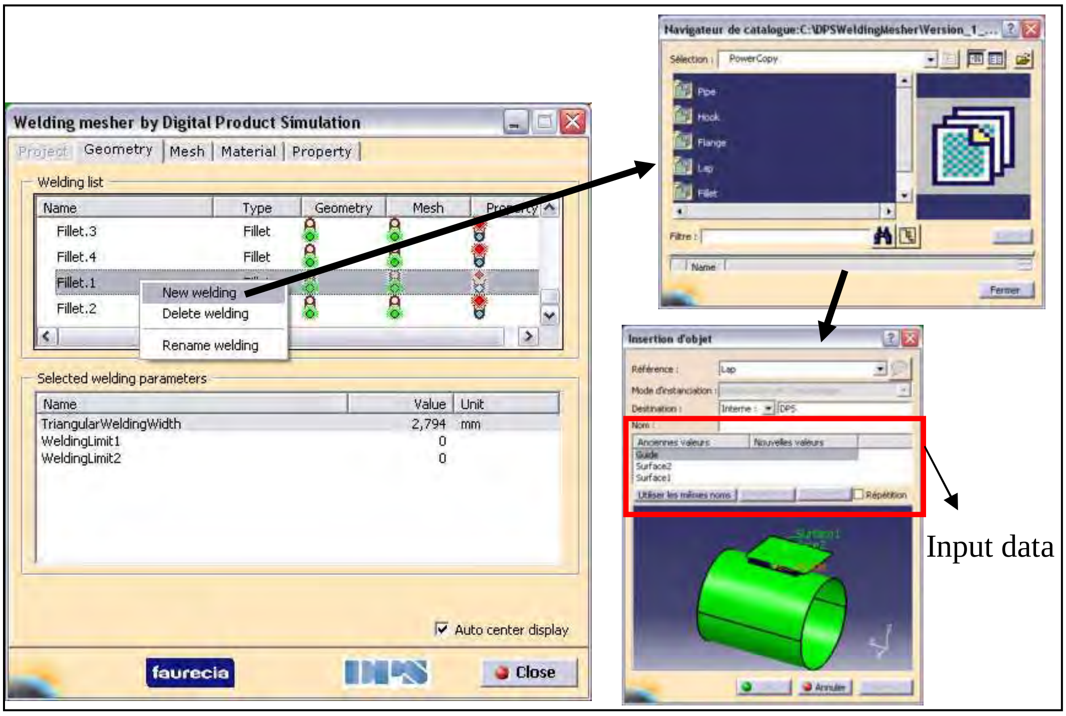

Figure 17: Welding mesher tool – instantiating new welding

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.

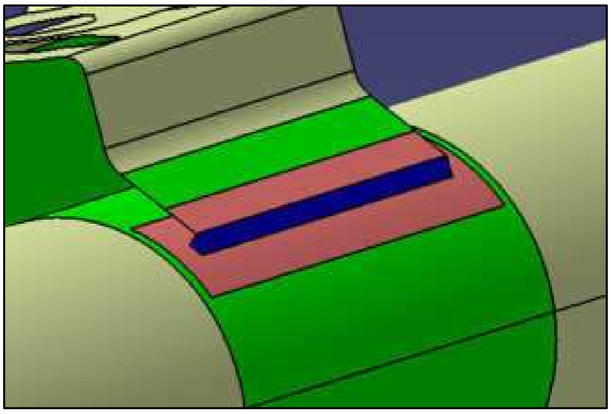

Figure 18: Welding generated by the welding mesher tool

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.

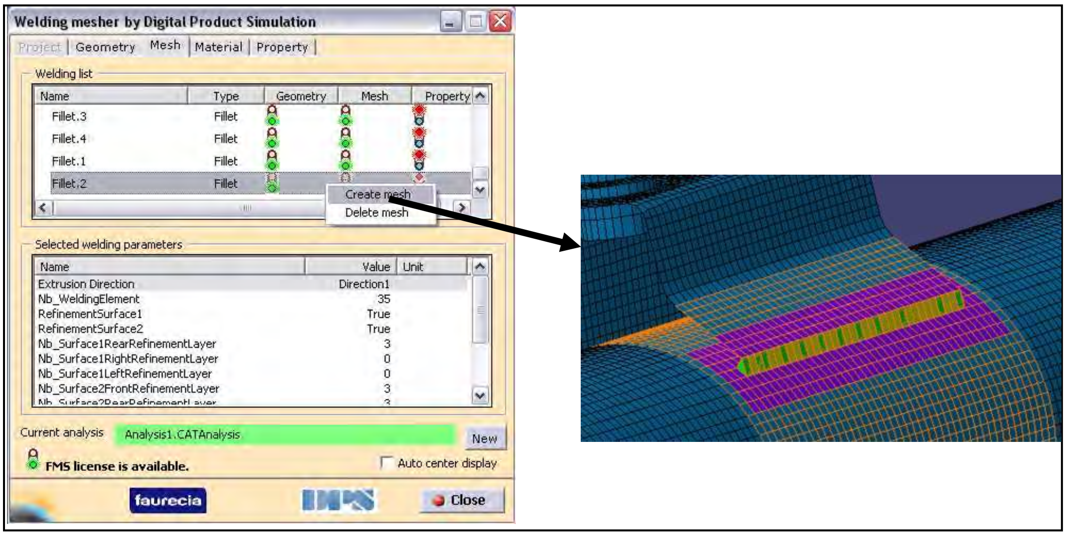

Figure 19: Applying mesh on a welding with the welding mesher tool

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 26th 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.

 Back

How Can We Make Best…Better: Using Abaqus and Isight to Optimize Tools for Downhole Expandable Tubulars

Jeff Williams

Baker Hughes Incorporated

Abstract: The use of expandable tubulars has emerged as a popular technology for drilling and completing wells. While expandable tubulars vary in type depending upon the application and specific well requirements, the most common approach is to actually form the metals downhole, which presents unprecedented challenges for tool designers. The costs and timelines to achieve a "workable" product can be tremendous. The Abaqus and Isight simulators effectively address these impediments and have been proven to be invaluable tools for enhancing understanding of the mechanics and effects of nonlinear/dynamic expansion of metals. In this presentation, the author reviews some of the challenges that had to be overcome in engineering these expandable products. Abaqus has been used to simulate expansion of threaded connections and was instrumental in optimizing the latest expandable thread designs. Meanwhile, Abaqus was used in conjunction with Isight to optimize the geometry of the next generation of expandable cones for the expansion of downhole tubulars. While these applications tested engineering intuition, the two simulation tools cleared the way for the development of an improved approach to downhole expandable tubulars.

Keywords: Optimization, DOE, Expandables, Expandable Tubulars, Oilfield, Expandable Connections

1. The Trial Run

Beginning in December 2008, in-house training on Simulia was followed by a three-month trial of Isight. In February, the Abaqus Isight component was released and first implemented at Baker Hughes. The Abaqus component allows the user to communicate seamlessly with the CAE model behind the scenes. Consequently, it affords the analyst a way to pick the dimensions to change, to either optimize or create a design of experiments (DOE) for the study. If the designer has a SolidWorks model, the analyst can use its associativity in Abaqus and employ Isight to change the model geometry in SolidWorks.

An immediate need arose within the expandables tubular design group to use Isight to optimize tool development. For the past few years, Abaqus has been used in developing expandable products. In the first quarter of 2009, multiple projects simultaneously reached the conceptual stage. With each size of expandable casing, new cone geometries needed to be developed and optimized.

For the trial period, a widely used cone was examined and determined to have the best potential for the latest expandable thread project. Within a week, an Isight study was constructed to monitor various cone geometries and their relation to three distinct outputs (referred to in this report as O1, O2, and O3). A simplified thread expansion was done for Isight with the explicit solver while applying mass scaling to speed up the run times. History outputs were set up to study specific points in the mock threaded connection. Each run would take approximately 5 minutes on a four-CPU machine. Multiple runs were performed to create a design space, and then an optimization study was performed (7 hours total). For Isight (version 3.5), an Optimal Latin Hypercube DOE Technique was used with a 101 sample space. Later, an approximation was created for the response map using the default RBF Model. With this approximation response map, a simple design search can occur in the Runtime Gateway with various constraints and/or ranges. Also, the approximation can be used to run an Optimization Component Model, which is what was used for this study with the Pointer Optimizer Technique. Table 1 summarizes the various iterations of cones on the P2-1 thread iteration with relation to the most significant O1 output.

Table 1: Summary of various expansion cone iterations for the P2-1 thread in a free end expansion state (O1 studied)

Expansion Cone Version	O1 Output (PSI)	Percent Improvement to Original
BR-6 (starting point)	33,844	0
TPV-Cone	40,068	18 %
BR-20 (Best Guess)	83,394	146%
OPTI-Cone (Isight)	102,199	202%

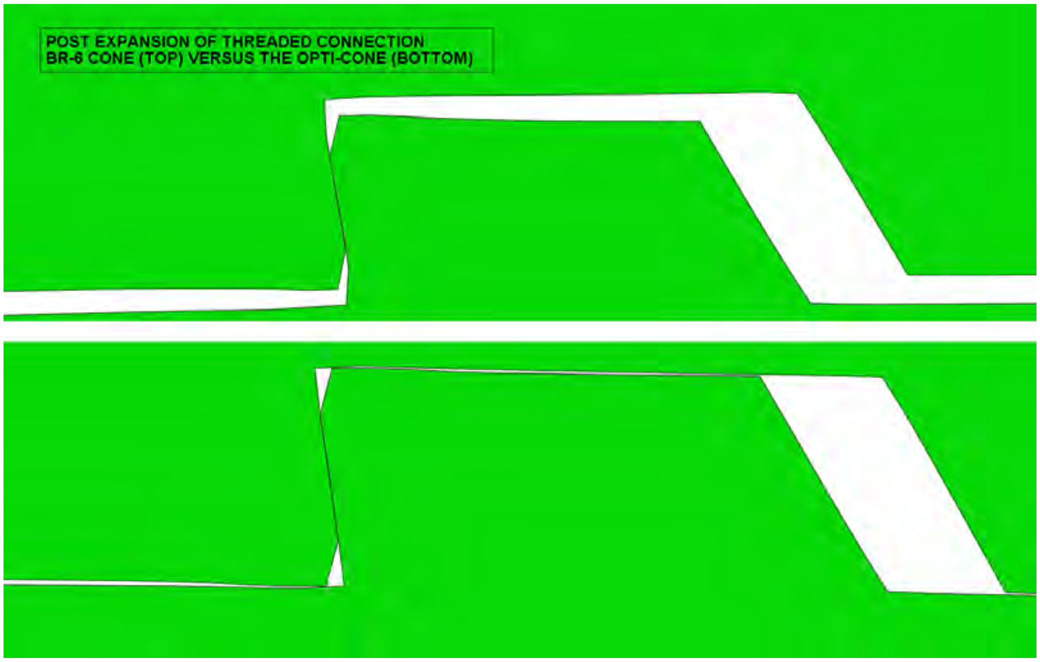

Figure 1: Comparison of original BR-6 Cone versus new OPTI-Cone with a threaded connection

Figure 1 shows the dramatically improved thread engagement of the OPTI-Cone compared with the BR-6 Cone, which had been considered an optimized design. The seal engagement is similarly improved. As shown, the BR-6 cone had about 64% thread engagement post-expansion while the OPTI-Cone achieves 90% thread engagement after expansion. Since the OPTI-Cone uses geometry previously deemed unacceptable, this result conflicted with previous design theories. Those earlier-generation geometries had been considered optimum for all sizes and conditions, while anything out of that paradigm was considered to be damaging to connections. Therefore, if not for Isight, the effective expansion cone geometry would never have been considered.

2. Cost Justification

The development of an expansion cone requires extensive analysis and testing, which combine to make it a cost-intensive exercise. Historically, at least two months of analysis had been required to ascertain an acceptable geometry. With Isight, the development period was reduced to two days. For each cone geometry development, a series of expandable pipe tests are performed. Each series of tests can be very costly, and if repeated for different materials and threads, the costs can accelerate precipitously. For argument's sake, Table 2 assumes only two extra sets of tests per size over the lifetime of the expansion cones. This justification does not take into consideration the schedule impact of determining the correct geometry the first time.

Table 2: Summary of cost estimates and times for development of various expandable projects

Project	Duration/Cost to Build and Test 2 Manual Iterations of Expandable Cones	Cost of One Seat of Isight (With Abaqus CAE Plug-In)
Casing Size 1	2 months/ $50,000	
Casing Size 2	2 months/ $60,000	
Casing Size 3	3 months/ $70,000	
Casing Size 4	3 months/ $80,000	
Total Cost	$260,000	$21,000
Total Duration	20 months	2 weeks

3. Dodging Bullets

Another example of the benefits of Isight is reflected in the study shown in Fig. 2. For connection (A), the "original" cone geometry was optimized manually with testing from five years earlier. The testing had validated the fixed-fixed condition expansion, but the analysis clearly shows it was marginal at best (left of Fig. 2). Continuing with connection (B), the original cone failed the fixed-fixed condition expansion, thus prompting multiple Abaqus simulations to solve the problem. Over a three-month period, the BR-6 Cone was found to be "optimum" for connection (B). Later, interest arose about how the BR-6 cone would perform with connection (A). As illustrated in the middle section of Fig. 2, the earlier perceived “optimum” cone geometry proved to be potentially catastrophic to the older connection (A). The right of Fig. 2 shows the OPTI-Cone expansion results after an Isight DOE. As shown, it is easier on the connection, generating less strain after expansion with improved thread engagement.

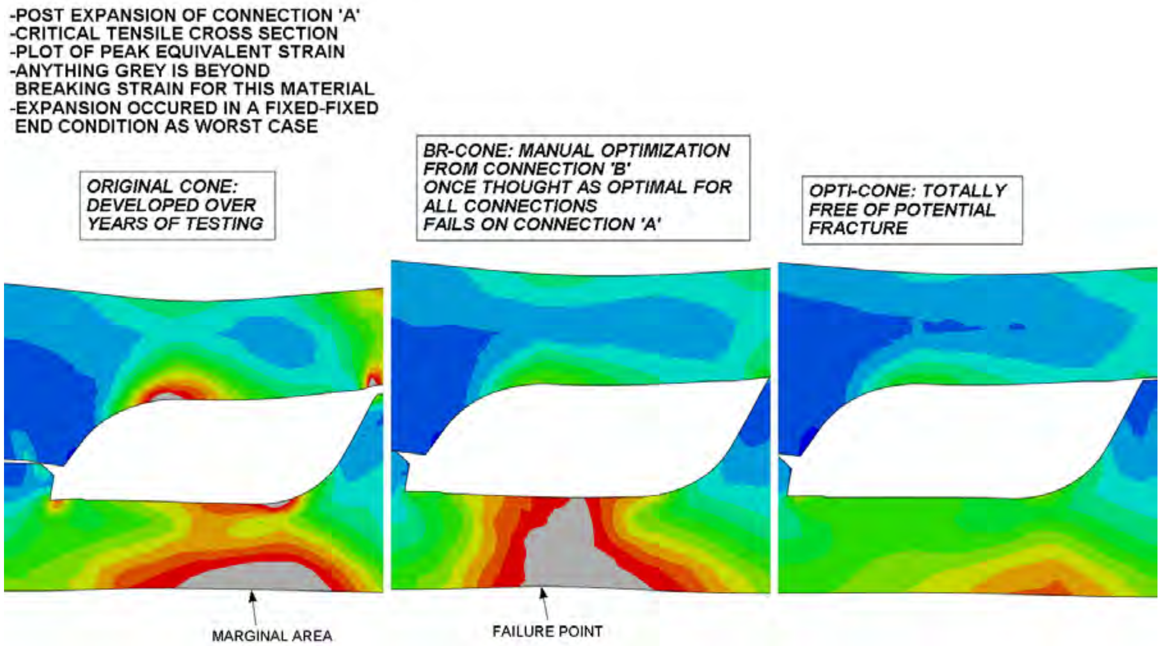

Figure 2: Expansion study of an expandable connection (A) with various expansion cones (fixed-fixed condition). Note: Isight aided in creating the OPTI-Cone, which removes any potential fracture on connection (A) on the right.

4. Summation: Why Isight Has Changed the Expandable Tubular Business

- Isight has a way of taking designers down a path they previously did not foresee
- By having the confidence to revisit pre-existing expansion cone design rules, expandable tubular designers now keep an open mind with new DOE results
- With the OPTI-Cone, new markets previously thought unobtainable can now be pursued
- The ability to run Abaqus CAE from Isight provides a streamlined setup that runs efficiently
- Abaqus creates the potential to incorporate SolidWorks associativity to run bigger models on a High Performance Cluster

 Back

2010 SIMULIA Customer Conference, May 25-27, 2010, Providence, RI

Simulation Life Cycle Management as Tool to Enhance Product Development and its Decision-Making Process for Powertrain Applications

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SIMULIA

Abstract: Product development is becoming more complex. It involves not only system simulation requirements, but also the need to manage and share huge amounts of engineering information that is housed throughout the world. It quickly becomes complex when getting into detailed system simulation for powertrain applications such as sealing products.

Computer Aided Engineering (CAE) has played a major role in development, design, and performance optimization for those applications for a long time. Due to the complexity of the current simulation environment and the need to expand simulation to the whole engineering process, including manufacturing, new analytical tools are required to support development, virtual testing, and decision-making. The sheer complexity requires a new approach to the engineering process. The PLM (Product Life Cycle Management) as we know it will look completely different in the future. We believe that in a simulation-driven engineering business, SLM (Simulation Life Cycle Management) plays a central role.

In this paper we use the processes for cylinder head gaskets (CHG) and material data input management as examples of how SIMULIA SLM provides us with more consistency, accuracy and faster turnaround times through easier, coordinated information flow and access. Using 3D-Live capabilities enables us to provide an easy-to-use environment to make simulation information available to non-CAE users, like engineering management, to support decision-making.

Keywords: SIMULIA SLM, CAE, Sealing, Powertrain, PLM, Virtual Testing, 3D-Live, Engineering Process, CHG, Data Management, HPC

1. Introduction

1.1. Product Development and its Complexity in the Overall Context of Engineering

Product development is a complex thing. Regardless of the type of product, the major steps in product development are:

- Initial idea
- Drawing / concept
- Prototype
- Testing / validation
- Turn over to manufacturing.

Whether the product is automotive, pharmaceutical, industrial, or something else, behind each of the above mentioned steps lay different tasks with additional tasks needed to move between the different steps. In addition to having those steps in common, they all require that data / information between the different tasks be communicated and stored. In this paper we want to focus on engineering products for powertrain applications, with focus on sealing applications. In particular, we will mention the cylinder head gasket (CHG) and how Simulation Life Cycle Management (SLM) can be applied. Figure 1 shows an overview of sealing products for powertrain applications.

Figure 1: Sealing Products for Powertrain Applications

Over the years, the complexity in product development of CHG has increased drastically. What started out as “something” simply having sufficient sealing function placed between the cylinder head and cylinder block to guarantee the engine function, has become a component having a huge influence not only on engine performance, but also emissions, fuel and oil consumption, NVH, and more. In addition, regulatory requirements have become more stringent, which makes sign-off more complicated as well.

While the complexity in CHG development was increasing over the years, a new detailed support structure that was highly engineered and specialized became essential. Many new testing capabilities were developed in order to be able to test and validate the product before providing it to the customer. Some of those tests are:

- Bench tests, such as:
    - Sealability
    - Fatigue
    - Metallurgical examinations
    - Material resistance to the different fluids in a powertrain environment
    - Load / deformation behavior
    - Powertrain component distortion
- Dynamometer testing
- Field testing.

The increase in testing that became required in order to develop a CHG resulted in an increase in the time it took to go from initial idea to final product. At the same time, costs were increasing at an alarming pace. Even though the introduction of more sophisticated bench testing allowed design screening of CHG before dyno testing, to some extent it was not unheard of that there were 10, 20, or even more design iterations during a CHG development. At that point, this after-the-fact development approach was more than ripe for improvement. This was the time when Computer Aided Engineering (CAE) started to find its way into CHG development. Only this technology allows optimization of the CHG before an actual prototype is cut. This is the only way to reduce development time and costs while guaranteeing high performance and quality of the product.

In addition to advanced testing requirements, stronger requirements regarding emission, NVH, and fuel consumption required new technology in exhaust and after-treatment systems as well as injection and control systems. These additional components not only act or function on their own, but also influence and interact with each other. At this point, a simple component-based approach in product development of sealing products started to be insufficient. What was needed in order to satisfy the development needs is a system approach. Figure 2 is an example of how different sealing applications of a powertrain can be put together into a system. This shows not only that the development went into much more detail, but also exponentially increased the amount of data that was generated.

In recent years, additional levels of complexity in product development were introduced with the extreme globalization of our industry:

- The requirement to be present and support our customers in all regions of the world the same way
- The need to be even faster in time-to-market by utilizing a 24x7 approach
- An even larger pressure on keeping costs under control in this complex environment forcing utilization of lower cost alternatives in different regions of the world.

All of the above factors require tremendous effort in effective data management, communication, and decision-making in order to make product development successful.

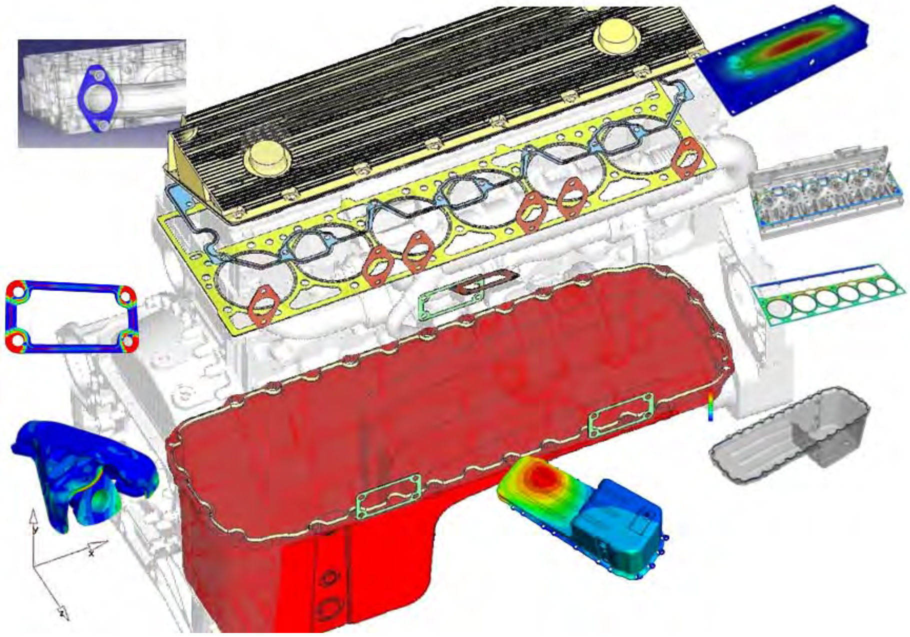

Figure 2: Example of a Sealing System for Powertrain Applications

1.2. Role of CAE in Product Engineering

CAE plays an important role in product engineering now more than ever. With shorter development cycles and time-to-market, CAE is and will be a major contributor to the success of a company. With most companies having “First Time Right” design initiatives, CAE has gone from a “nice-to-have” feature to an essential tool in the product development process. Cost reduction initiatives to cut down on prototype and testing costs have also helped to boost CAE as an essential tool for product development.

With the advances in the computer industry and CAE solver technologies, engineers have been able to conquer more advanced problems in shorter time with a focus more toward system simulation and how one component affects another component. This is all the more important in powertrain analysis due to the presence of thermal and mechanical stresses, components packaged together more closely, as well as a variety of materials being used to reduce weight. Typically for cylinder head gasket analyses, only the cylinder head and block models have been used to analyze the sealing pressure on the gasket. In recent times, more components such as valve seats, injectors, exhaust and intake manifolds, and turbochargers have been included to give a more comprehensive understanding of the system. As the packaging requirements and weight reduction are becoming more and more critical, the effect of heat shields on the thermal stresses has to be considered also. Figure 3 illustrates a rough overview of the CAE approach for multi-layer steel (MLS) CHG covering the main stages from manufacturing to system simulation to correlation and validation.

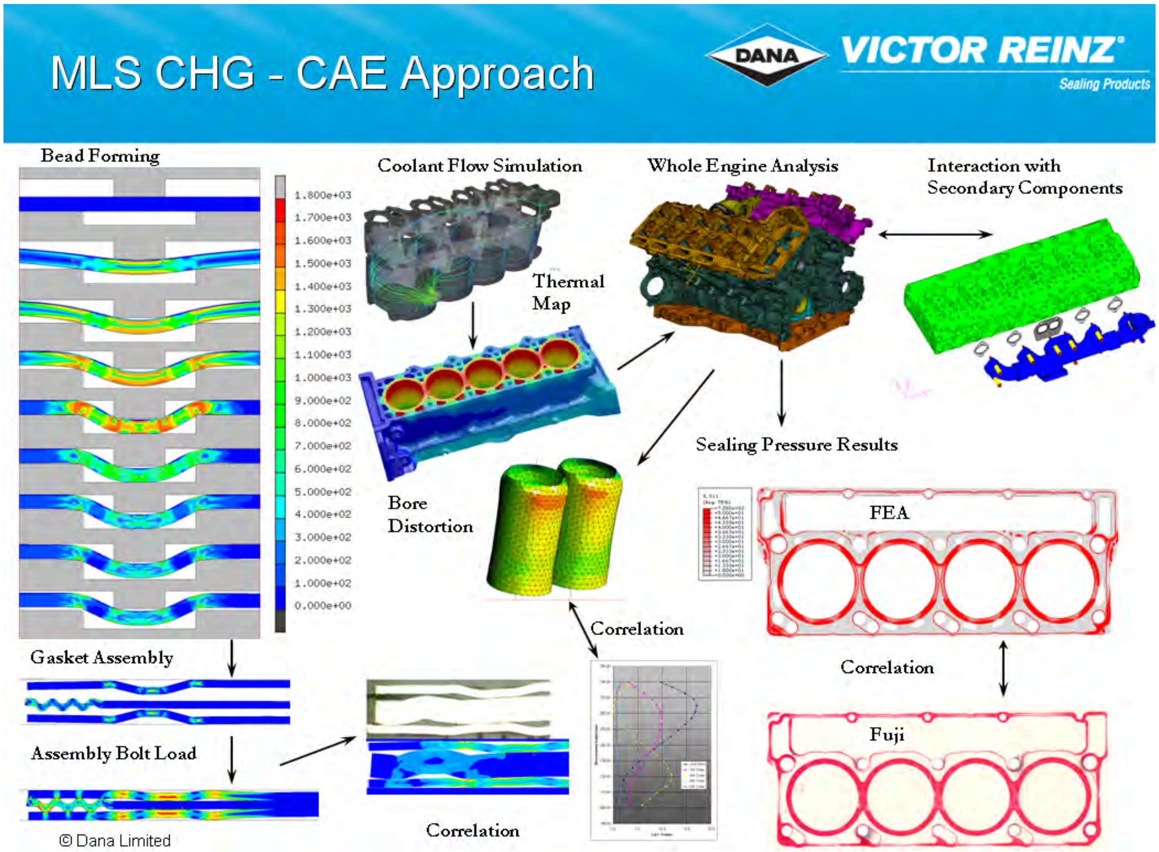

Figure 3: CAE Approach for MLS CHG

Previously, finite element engineers and CFD engineers used to work in separate environments, with certain scripts being used to transfer the results from one code to the other. This was a time consuming process, which quite often resulted in loss of accuracy and increased solution time. With the introduction of fluid-structure interaction (FSI) coupling solution into the mainstream market a few years ago, some of these problems could be solved directly using code coupling, without loss of data due to interpolation. Also, several new varieties of problems which represent more realistic scenarios can now be solved. This process has helped in creating the thermal stress analysis based on exhaust gas flow easier to analyze in a more time effective manner.

Similar advancements in technologies such as iterative solvers and parallel processing have resulted in analyses that used to take weeks to complete finishing in only a few hours. This has allowed the analyst to increase the model complexity and also add more components without sacrificing efficiency or cost.

In the future, these technologies will improve further, and new advancements in the solver technologies will lead to entire system simulation and possibly a "virtual" dynamometer environment which will allow engineers to check the performance of the engine and its different components without having to build any prototype parts. Final validation of the product will always remain.

The cylinder head gasket analysis process encompasses various analysis types ranging from manufacturing processes to thermal profile generation, combustion modeling, sealing functionality, and durability of the part. Because of the comprehensive nature of this process and the various design changes that involve data retention, record keeping is all the more essential for this flow process. Thus, incorporating this process flow into SLM provides standardization, transparency, consistency in simulation, as well as additional efficiency improvement. At the same time, it provides an efficient tool for managing this huge amount of information without any loss or misplacement.

2. Simulation Life Cycle Management as Tool to Enhance Product Development and its Decision-Making Process for Powertrain Applications

2.1. What is SLM?

Management of large amounts of data is never easy especially when talking about the use of CAE as an up-front predicting tool. While simulation technology is constantly evolving to meet the demands of designers and engineers, there remains a wide disparity in the effectiveness of simulations to impact product / process design decisions. This disparity exists at multiple levels: across industry segments, across companies within an industry segment, across simulation disciplines (structural, fluid, chemical, etc.), within a company, and even across individual methodologies within a simulation discipline. The quest to markedly improve the efficiency and effectiveness of simulation remains a challenging but fundamental goal for many companies. [**1**]

The efficiency and effectiveness of simulation within a workgroup or enterprise is driven by several factors, including:

- Competency of the simulation technology and the people utilizing it
- Integration, adoption, and acceptance within standard business processes
- Capture, management, and reuse of the resulting intellectual property.

A well-known data management tool in the industry is Product Lifecycle Management (PLM). PLM systems have evolved rapidly in recent years and now provide collaborative virtual PLM of complex product, process, and resource information - from marketing and design to manufacturing and maintenance. The requirements of simulation technology, methods, data, and processes are in many ways more demanding than those associated with PLM, including:

- Data model
- Performance
- Context.

For example, the data generated through simulation can be divided into 3 main categories [**2**]:

- Data directly supporting product / process IP (intellectual property)
- Data supporting simulation IP
- Un-retained data.

The emerging attention focused on improving simulation effectiveness within PLM and scientific environments is referred to as Simulation Lifecycle Management (SLM) [**1**]. This covers the different disciplines involved in the thermal management / sealing system approach as described above.

The degree of integration across the simulation and product / process worlds will vary with organizational type and structure and is driven by a number of factors, but there are several critical principles that must be followed to achieve the full benefits SLM can deliver. At its core, a SLM solution must have been designed from the outset to possess the appropriate architecture to satisfy the integration, deployment, and maintenance demands of a broad and constantly changing set of information technology (IT) environments. Four functional elements that an effective solution must provide are [**2**]:

- Built-in collaboration
- Simulation data management

- Process automation, integration, and optimization
- Decision support.

The aspects of sealing systems for powertrain applications described above and its detailed complexity epitomizes the need for a SLM system. Collaborating with SIMULIA on developing and implementing SLM and developing specific features for our business needs provides us with the necessary tools to guarantee a functional system approach for the future. This is not only from a simulation perspective, but also from a management perspective. By studying the SLM architecture and the needs of our approach, we can ensure from the outset that all our structural, data, and documentation requirements are met both now and in the future.

2.2. Overview of SLM for Powertrain Applications

The introduction of SLM for the CHG analysis flow process begins with an initial assessment of the process. The goal of such an assessment is to look at the areas in the process which, when implemented through SLM, will provide productivity improvements, reduction in duplication of work, consistency, reuse of data, and also improvement in accountability. All of the parties involved with the design process need to be involved in this assessment process to provide a comprehensive understanding of the design analysis flow from a design concept stage to the prototype stage:

- CAE analysts
- IT
- Development engineering
- Applications engineering
- Sales
- Engineering management.

During the assessment for the CHG analysis process flow, several opportunities for automation to streamline the process tasks were reviewed based on the maturity of the sub-tasks in the process flow and ease of automating those tasks. Studying each task in the process flow in this way results in creating a less complex simulation template and also helps in identifying and defining the different attributes that may be used in data searches to find simulation results for a particular design instance.

Since there are always different instances of product development from the prototype phase to the full production phase, the variability of the gasket properties needs to be monitored, as well as how that variation may cause a change in gasket performance. This process is usually studied in CAE to implement any minor changes that may be needed in the production environment. Therefore, a material data generation flow process based on the part level is tied into the analysis flow process, as it is essential to provide a clear connection to the data that was used for the analysis. Ideally, in the product development cycle, data sets from test coupons are used for the initial simulations. Once prototype samples are made, those samples have to be checked against the test coupons for consistency in the material data. If the data does not match, the simulations must be repeated to show the effect of the change in data. The update in material properties needs to be highlighted to understand which steps in the process need to be updated, or in other words, which results are out-of-date. SLM implementation results in an effective way to manage this entire product development cycle.

2.3. Implementation of SLM for Powertrain Applications

SLM, as used in the product development process described here, is built on top of the V6 PLM platform as illustrated in Figure 4. This environment is one PLM environment for Dassault Systèmes and non-Dassault Systèmes applications that provides the specific capabilities that are needed across all industries to support an integrated environment. At the bottom of the chart is the V6 PLM enterprise foundation, which has an open architecture and embraces the service oriented architecture (SOA) standards. This single foundation provides a unified view and access to all information, whether this information is inside or outside Dassault Systèmes applications. For instance, in the orange databases could be other product management (PM) sources, enterprise resource planning (ERP) tools, or even unstructured data sources. On the SOA foundation is built native CATIA, DELMIA, SIMULIA and ENOVIA applications. This single foundation spans all engineering disciplines and business users to provide a paradigm that is common to all of the applications.

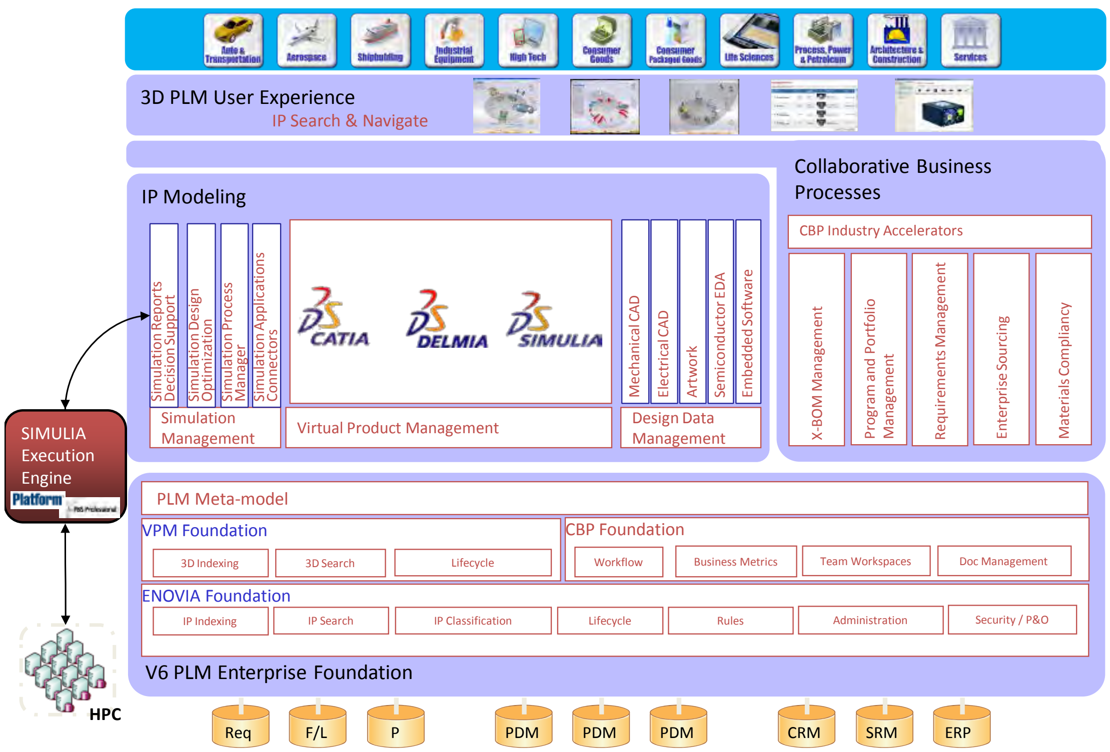

Figure 4: V6 SLM Platform

Next is the collaborative business process layer. It extends from left to right and unifies all engineering disciplines which are on the left hand side and all PLM enterprise processes on the right hand side. The V6 PLM platforms support IP modeling in a single environment for all authoring applications and simulation applications, whether they are Dassault Systèmes applications like CATIA, DELMIA and SIMULIA, or non-Dassault Systèmes applications. The simulation data management needs to manage very heterogonous applications and data, and is optimized so that collaboration and data management can be done from anywhere using only a web connection regardless of the authoring applications. This results in a lightweight and flexible deployment of SLM.

Deploying a SLM system requires different servers each with a specific function that can each be located anywhere around the world. In a SLM system, there are SLM application servers which run the applications being used, file collaboration servers (FCS) which are used for storage, as well as local workstations that run the system and interface with the other servers. The applications and file storage servers take on a modular approach and are separate entities so that the different servers can be housed at any location around the world and all SLM users can have access to all of the components of the system. SLM integrates all of the different sources of information and brings them into a unified structure that can be accessed by users anywhere.

When a user accesses the SLM system on a local workstation, the process flow illustrated in Figure 5 begins. First, an applet starts on the application server. SLM exports the needed files for the activity from the FCS to a scratch directory on the user's local workstation. The user then uses the files for the activity on the local workstation. Upon completion of the SLM activity, the files are then imported from the local workstation back to the FCS. SLM then deletes the scratch directory on the local workstation. Having the system set up in this way allows files to be stored on servers that can be set up in different locations, while also allowing users from anywhere around the world to have complete access to the same information structure. With the increasing globalization of engineering and analysis, it is important for users to have access to the same information regardless of their physical location.

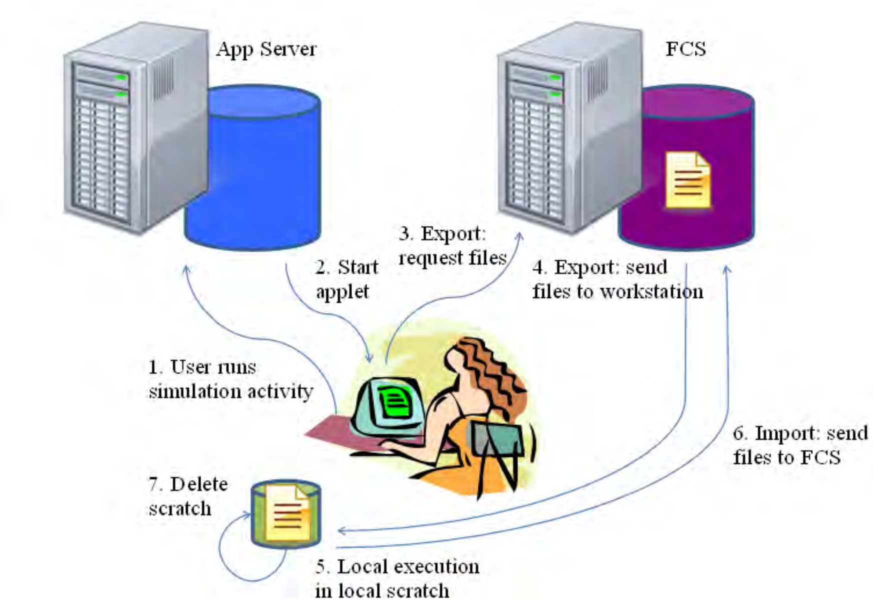

Figure 5**: SLM System Architecture**

Since engineering design and analysis has become a global process, users from different locations all over the world need to have a unified approach to engineering strategy. In a SLM system, workflows are implemented through the use of user-defined standardized templates. Each template is prepared for a specific workflow and the same workflow is used by all users of the template in SLM. In a typical sealing system as illustrated in Figure 2, there are multiple types of sealing products and therefore multiple types of simulations that need to be performed on the components that make up the system. The different steps in each analysis that need to be performed are:

- Meshing of CAD models
- Input file generation
- Material property generation
- Assembly of system
- FEA analysis run
- Post-processing
- Report generation
- Results review and decision-making.

SLM can streamline each of these tasks into templates that standardize the process flow for all users. By using templates to define the simulation process workflow, all users follow the same standardized process.

Users will be less likely to miss steps in the analysis and each analysis can easily be passed to different users at different locations without the need to explain which tasks have been completed, thereby reducing the time it takes to complete an analysis by facilitating a 24x7 approach to engineering. By using SLM to launch each activity in the simulation process, all users are assured to be using the same software and the same standards, so the location of an individual user doesn't matter. Each time there is an update to software or a process flow, the template can be updated in a central location and all users can be automatically upgraded simultaneously to ensure that all users remain consistent with their work.

In addition to standardizing the engineering process flow, using SLM also standardizes file sharing and storage architecture. Defined within the SLM system are import rules and export rules that define which files are saved and which files are deleted after each simulation activity is completed. Often times in an analysis, there are several iterations of files. Additionally, when different users are working on a simulation, duplicate files are often created that can drastically increase the storage space required. With SLM, no duplicate files are created and a standardized naming structure can be used so the large amount of data files that are generated can be easily found for future work regardless of where the file originated.

With the enormous amount of data generated in system simulations, SLM is an effective way to manage the data that is received and generated. One of the reasons so much data is generated is due to the number of design iterations that occur during a typical CHG development process. Typical activities in a CHG development process from a CAE perspective contain the following:

- Import of the different hardware components as CAD files, including:
    - Cylinder Head
    - Cylinder Block
    - Bolts
- Import of the initial CHG model
- Generation of the FEA models
- Import of the material data
- Setup of the input decks
- Simulation (this might include a possible restart analysis)
- Post-processing
- Report generation
- Finalizing simulation project.

To optimize a sealing system effectively, several design changes are often made to each component during the engineering process. Each design change requires a new simulation, thereby generating a new set of data. With so many design revisions, it can become a very complex task to keep track of the different revisions of each component that is used in a particular simulation. SLM uses impact graphs to easily illustrate which version of a particular component is used in a simulation, as well as which simulation activities need to be performed when a design revision to a particular component occurs. The impact graph visually illustrates which versions of the various components of a simulation were used in the analysis and which output database was post-processed to create the final report. When a particular component is updated to a new revision, the impact graph clearly shows which simulation activities that change impacts. The SLM user immediately knows which tasks in the workflow need to be carried out again to accommodate the design change. The impact graph is also useful when tracing a file's origin back to its original CAD geometry. Of course, the CHG development process mentioned above consists of more steps than could be shown here. Those steps contain even more details to ensure consistency, quality, flexibility, and efficiency in the CAE process. For example, Figure 6 illustrates an impact graph for part of the CAD import and meshing activities for the CHG application. These activities can be done simultaneously.

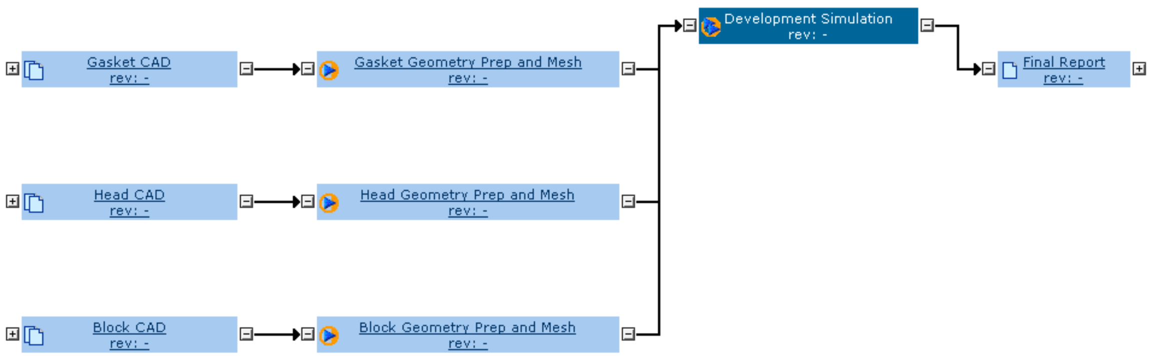

Figure 6: Impact Graph

By using the impact graph, if one user updates a particular file and then passes the analysis to another user, the user immediately knows which activities to carry out. The impact graph visually ensures that all users are working with the latest available information and data, thereby eliminating the possibility of an analysis report containing results for an out-dated component. Additionally, there are no check-out or check-in activities, which can slow down such simulation activities drastically. SLM therefore results in effective management and progression of the entire up-to-date lifecycle of a simulation. Each stage of a simulation process can be tracked by observing the simulation lifecycle, which is illustrated in Figure 7.

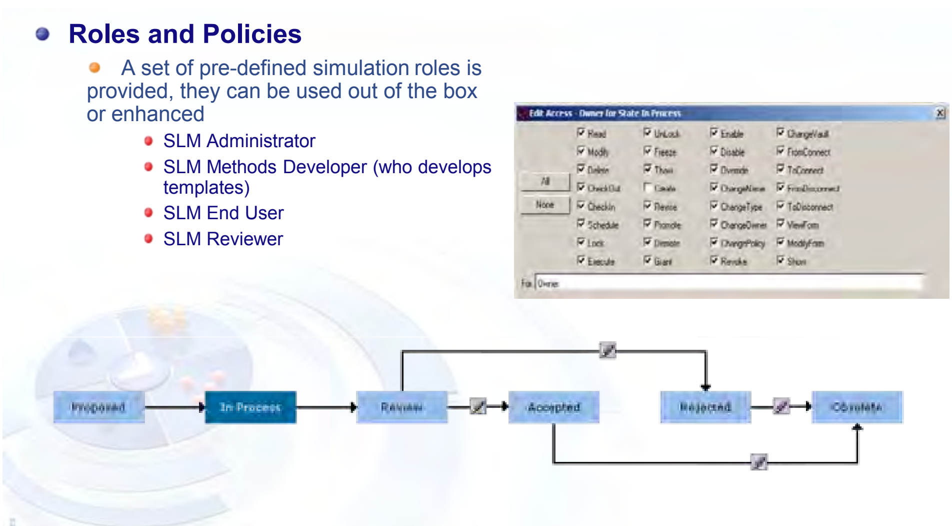

Figure 7: Simulation Lifecycle

The simulation lifecycle involves different user levels depending on the job function of the user. The different user levels can be divided into:

- Method developers
- IT
- General users
- Power users
- Decision makers.

Based on the user's level of SLM usage, each user requires different access rights:

- Admin rights for full control: usually reserved for method developers and IT support
- General read / write access without access to system information of any kind
- Read / viewing access.

SLM provides a standard set of simulation roles that can be assigned to the users. These roles can be adjusted and enhanced as required. SLM uses the combination of roles and lifecycles to track the maturity of a simulation through the analysis process development. At certain stages in the lifecycles, only certain operations are allowed by certain roles. The ability to customize the out of the box roles and lifecycles provides significant flexibility in controlling access to data and allows for only released data to be seen by the final consumers of the simulation data. Other users besides CAE analysts therefore become involved in the decision-making process. Tools such as 3D-Live can display the results in a simplified form so that non-FEA users, such as managers and applications engineers, can review the simulation results quickly and make decisions based on the results.

There clearly exists a wide range of users with different expertise that need access to the highly sophisticated SLM system. In order to be able to deploy such a complex system throughout an organization on a global basis, two things are essential:

- A bottom-up approach for implementation
- Ease-of-use.

A bottom-up approach ensures a full buy-in of the future user community at the same time, while allowing the functionality of the system to be pushed to the limit. The latter is especially important from a cost / performance perspective.

In order to fully utilize the performance of the complex system across a wide range of users in different disciplines, the system needs to be easily learnable, meaning that it must be intuitive. The 3D-Live technology is the key technology to ensure that the system is visual-driven. An example of a 3D-Live environment for powertrain applications is shown in Figure 8.

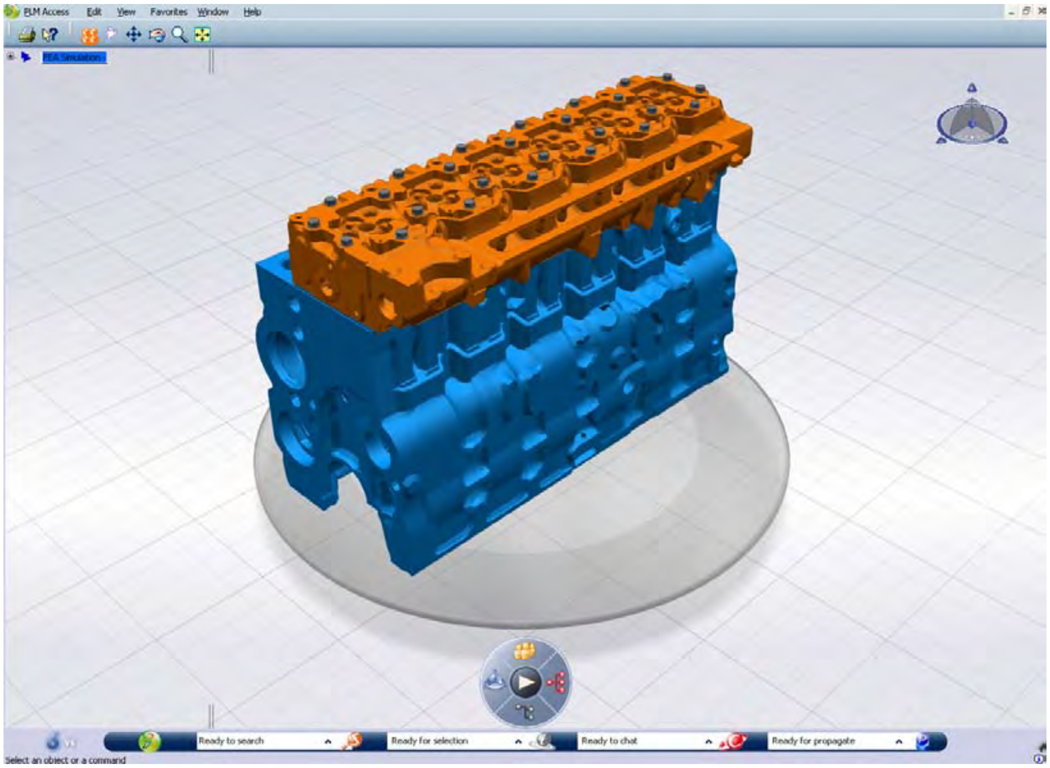

Figure 8: 3D-Live Viewing Environment - Powertrain Application

The 3D-Live environment consists of data and images organized according to each activity in the SLM process workflow. An end-user of 3D-Live searches for a simulation based on search parameters such as part number, customer, simulation name, etc. 3D-Live opens the process from the top level as shown in Figure 8. Expanding the process results in the turntable view illustrated in Figure 9.

The 3D-Live turntable contains results and input data related to each activity in the SLM process workflow. End users of 3D-Live that do not necessarily have FEA experience can easily rotate the display to navigate through the entire simulation process. The user can view simulation input data such as material properties and hardware models used in the analysis as well as the analysis report and other simulation results by expanding any of the activities on the turntable. Figure 10 illustrates the expansion of the assembled model, thereby allowing the user to see each component used in the analysis in a simple way.

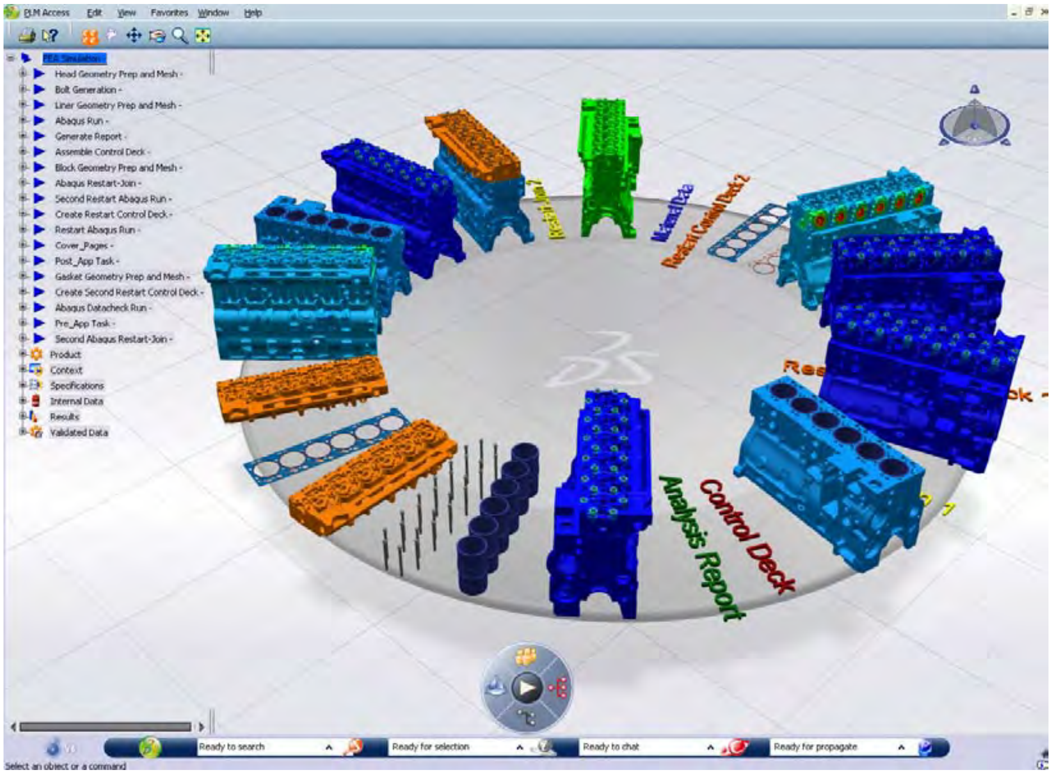

Figure 9: 3D-Live Turntable View - CHG Project

Using SLM tools such as 3D-Live integrates all users such as applications and sales engineers, lab technicians, CAE analysts, and managers into one unified system for data sharing and collaboration as well as results viewing.

In addition to the 3D-Live environment for viewing simulation results, with the globalization of the industry and the increasing use of 24x7 engineering in different regions of the world, there also exists the need to prepare reports and present results to customers all over the world in the same format. SLM allows the automation of several pre-processing and post-processing tasks in order to facilitate a standard procedure for pre-processing and post-processing activities. The integration of scripts within SLM also allows repetitive time-consuming tasks, such as report generation, to be completed very quickly and efficiently. The utilization of common scripts allows standardized result reports to be generated with a few clicks of the mouse. A common analysis report for a CHG is shown in Figure 11.

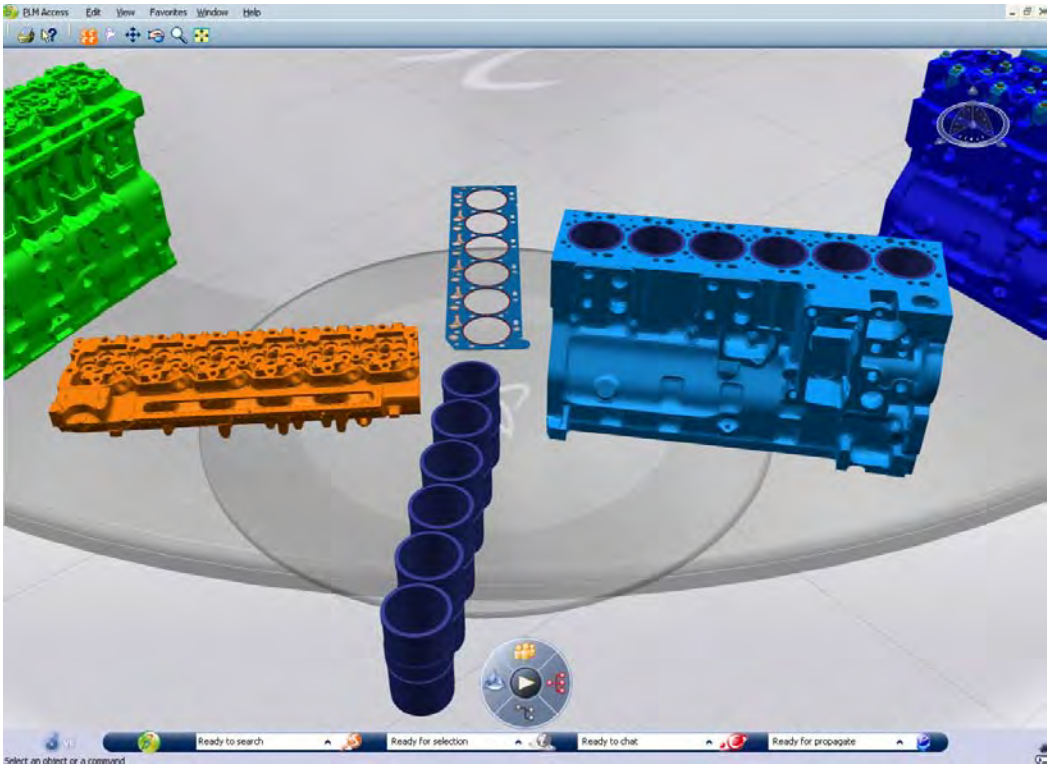

Figure 10: 3D-Live Expanded Activity View - CHG Project

Figure 11: CHG Report

The report contains the simulation steps, contour plots, results charts, as well as data tables. For an analyst to create the complete report from scratch, it may take days to complete. By integrating automated scripts into SLM, the above report can be generated in a few minutes, thereby leaving the analyst more time to analyze the results of the simulation. Because the report can be generated so rapidly, the results of new design iterations can be obtained very quickly, thereby allowing more design iterations to be completed in a shorter amount of time, which can accelerate the time-to-market for a new product design. Another significant advantage to using automation scripts for the report generation is that all of the reports have a uniform standard format no matter where the report is generated. In this way, the automation scripts are also centrally stored and managed, and updates can be pushed to all users at the same time through the SLM templates so that every SLM user is updated at the same time. This ensures that every SLM user is following the same set of standards and is using the latest versions of the software and the scripts. Additionally, every SLM user can understand the report no matter who generated it. Automation is therefore a significant part of a successful SLM implementation.

2.4. Advantages of SLM Implementation

Implementing SLM provides a significant opportunity to capture existing processes and best practice guidelines into managed shared documents within SLM. The shared best practice guidelines can then be promoted and managed as “group” level best practices and made readily available to analysts. By using the SLM system, all users follow the same workflow templates, and therefore perform the same steps in the workflow in the same order. All simulations are constructed and carried out using the same standard procedure. Since all users are following the same architecture and using the same tools for a simulation, the possibility of missing steps in an analysis is greatly reduced. By using standardized templates, quality of simulations is therefore ensured.

The standardized process templates also allow for a majority of the processes to be automated. SLM provides a versionable location to store and track automations, as well as a means to deploy them such that the correct versions are always available and are being used. In addition to simulation data and automation scripts, certain other libraries of files, such as internal data and other design-related data from customers which were loosely managed can be stored in SLM. These files can then be versioned as well.

Once the data is managed within SLM, all users also benefit from a more collaborative environment for data sharing, review, and re-use. When design iterations are made and new simulations are performed with different versions of components, it can quickly become confusing if the data is not managed in an orderly fashion. SLM eliminates the possibility of using out-of-date files by tracking the origin and use of every file entered into the system. When a file is updated, SLM tracks every location where that file is used and which tasks in a simulation need to be performed again because of the change. SLM can also trace which version of a particular component was used in different simulations. By easily keeping track of the latest file versions available, SLM ensures that reports are always prepared with the latest data available. Traceability and knowing where the files are being used also help in situations in which a file is found to have a defect (bug).

With the increasing globalization of engineering and the push to create around-the-clock engineering, traceability also enables different users to work on different tasks in the analysis and clearly see what has been completed. This eliminates the possibility of different users performing the same task and creating duplicate files, thereby reducing storage space needed for an analysis. SLM is also an effective tool when training new employees on specific workflows. In this way, SLM becomes a very useful tool for storing and sharing information.

Moving data into SLM provides search capability as well as more advanced permissions and ownership controls. SLM assigns user-defined attributes to the simulations so that simulation data are easily searchable. By being able to rapidly search simulation results, SLM results in significant time savings. Because SLM utilizes templates which are created with standardized naming processes, all searchable attribute names are uniform, thereby allowing users to find all results, rather than some results being eliminated from searches because attributes are spelled wrong. In this way, SLM becomes a very effective data management tool.

With all analysts using SLM, every user is using the same software versions, the same versions of the automation scripts, and the same format for the report. Data review by decision-makers also provides redundancy to analysis results. In this way, the simulations are all done following a consistent procedure no matter where they are performed and the reports all follow the same format so that all customers see the same results format no matter where they are located around the world.

3. Conclusions

SLM is proven to be an effective tool for managing large amounts of data as used in powertrain applications. At the same time, it drastically improves quality and consistency of simulations by virtually eliminating most common mistakes made by CAE engineers, such as inconsistent naming, using the wrong material data file, etc.

By integrating a much wider range of users into the CAE environment due to ease-of-use, SLM improves efficiency and thus, reduces overall development costs due to the fact that duplication can be avoided and turn-around-time can be increased.

SLM as a technology together with 3D-Live is only in the very infant stages, but the benefits of its implementation are already starting to be seen.

4. References

1. SIMULIA: The Case for Simulation Life Cycle Management; report 1 of 3; White Paper
2. SIMULIA: The Case for Simulation Life Cycle Management; report 2 of 3; White Paper

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