INSIGHTS

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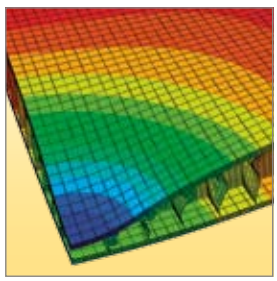
Dassault Systèmes Realistic Simulation Magazine



Alstom Power Improves Steam Turbine Efficiency



Tetra Pak
Innovative Packaging



Abaqus 6.9-EF
Latest Enhancements



MAHLE Powertrain
Engine Downsizing

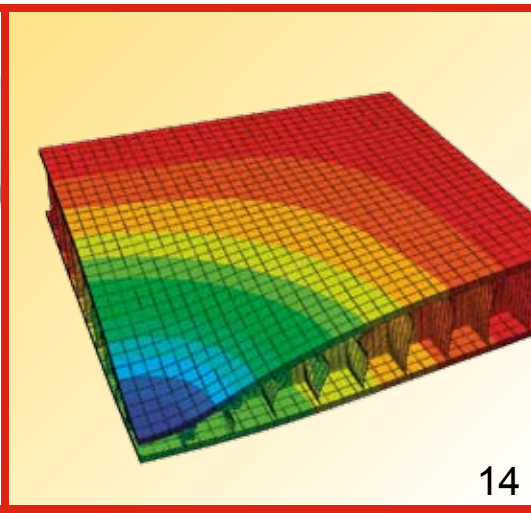
SIMULIA

INSIGHTS

January/February 2010







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Building the Future Together

It was October 2007 when I last wrote this letter for *INSIGHTS* magazine. I wrote about meeting customer expectations by continuing our focus on quality and advanced simulation technology, as well as taking on new responsibilities for making realistic simulation an integral part of Dassault Systèmes' strategy for Product Lifecycle Management (PLM). Now at the beginning of 2010, I am amazed at how much we have accomplished in a relatively short amount of time. Not only did we acquire Engineous Software and release new versions of Isight and the SIMULIA Execution Engine (SEE – formerly known as Fiper), we have also had multiple releases of our Simulation Lifecycle Management (SLM) solution—and made significant inroads in merging the Isight and SEE technology into this growing product suite (see p. 15).

In that earlier issue, I also mentioned that the developers of the CATIA-branded Analysis products were included in our SIMULIA R&D team to focus on making advanced analysis features of Abaqus available in the CATIA design environment. Thanks to their combined efforts, we have released extended analysis capabilities that embed Abaqus technology for nonlinear and thermal analysis within the CATIA V5 environment. We have also launched two releases of our new product family, DesignSight, which allows V6 users to access Abaqus technology within a new and 'guided' user experience that enables robust nonlinear analysis to be a natural part of the design experience. And just recently, the SolidWorks simulation team joined our SIMULIA R&D team to expand our efforts and accelerate our unified and scalable analysis strategy. You can expect to see the results of this continued focus and expansion in the not too distant future.

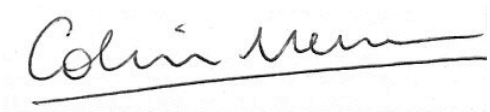
I am proud to say that we have managed the growth of our R&D team and product portfolio while maintaining our commitment to delivering innovative technology, enhancing existing capabilities, and improving the overall usability and quality of our realistic simulation portfolio. Our commitment is exemplified in the release of Abaqus 6.9-EF release (see p. 14) and the upcoming releases of Abaqus 6.10, SIMULIA V6 products, SolidWorks Simulation products, and Isight.

Our customers are also expanding their commitment to leveraging realistic simulation to gain real business benefits. It is rewarding to see customers such as Rolls-Royce (see p. 4) leveraging Isight to capture workflows, automate complex multidisciplinary analyses and apply design of experiments to achieve optimized product performance and overall cost savings. I believe that working closely with customers is essential for our mutual success; this collaboration, whether in special customer forums or simply providing feedback at regional meetings, helps us to develop better engineering software tools so that you can advance the state-of-the art of your product designs. The demands for designers and engineers to improve their designs require software simulation tools which not only have the ability to give accurate results, but also capture simulation modeling knowledge and best practices to provide guidance on using realistic simulation to achieve better designed and engineered products.

We are very pleased that our customers worldwide are embracing our vision of Simulation Lifecycle Management. Several companies are working with us to define new functionality while implementing SLM to manage their simulation processes and improve collaborative decision making based on accurate simulation results.

Our customers' dedication to being part of an international realistic simulation community is displayed each year at our annual SIMULIA Customer Conference (SCC) and Regional Users' Meetings. I invite you to join this growing community by attending the 2010 SCC in Providence, Rhode Island, USA (see p. 23). There will be more than 80 customer papers that cover traditional Abaqus topics, as well as expanded sessions for process automation, design space exploration, and SLM. Close-by to our world headquarters, the event will provide unprecedented access to our senior management and R&D technical staff.

I hope to see you in Providence this spring!



Colin Mercer
Vice President,
Research & Development,
SIMULIA

Assessing Variability to Achieve Robust Design

Alexander Karl, Lead, Robust Design, Rolls-Royce, Indianapolis

One of the most complex mechanical systems relied on everyday is an aircraft engine. The engineers who design the gas turbines that power today's huge commercial jets must master a myriad of details in these highly-integrated, fine-tuned machines. The turbine, the compressor, the combustor, the casing, the rotors and bearings, the inlet and exhaust—all must work in tandem in extreme conditions of temperature, pressure, and stress, not to mention high forces on the rotating components.

Designing an aircraft engine puts many engineering disciplines into conflict: aerodynamics, mechanical stress, noise and vibration, heat transfer, material properties, reliability, life prediction, and more. And the finished product had better be robust; aircraft manufacturers demand efficient operation, long life, and short delivery cycles (it used to take about 10 years to develop a new aircraft engine but the industry now aims for an average of only two).

At the same time, aircraft engine makers are targeting low design, manufacturing and maintenance costs. So it's no surprise that the business of making all this possible can be competitive, demanding—and expensive.

Yet over the past eight years at Rolls-Royce, we have arrived at a roadmap for managing the multidisciplinary complexity of gas turbine design that enables us to work together with maximum efficiency, keep our customers happy and achieve our goals on time. And we've even saved money doing it. The underlying concept for this method is what we call "robust design."

Robust design is a 360-degree assessment of variability in the early design phases. We use this term often because it grabs the attention of designers and engineers by underscoring the pivotal role of design as the entry point into a complete Six Sigma program.

The aim of robust design is to deliver consistent product performance to the customer—so that every engine they buy runs predictably, copes with the extremes in its operating environment and even survives certain unexpected events. Building robustness into our products from the earliest design stages has far-reaching effects down the supply chain: less redesign work, reduced development times, and better control over manufacturing costs.

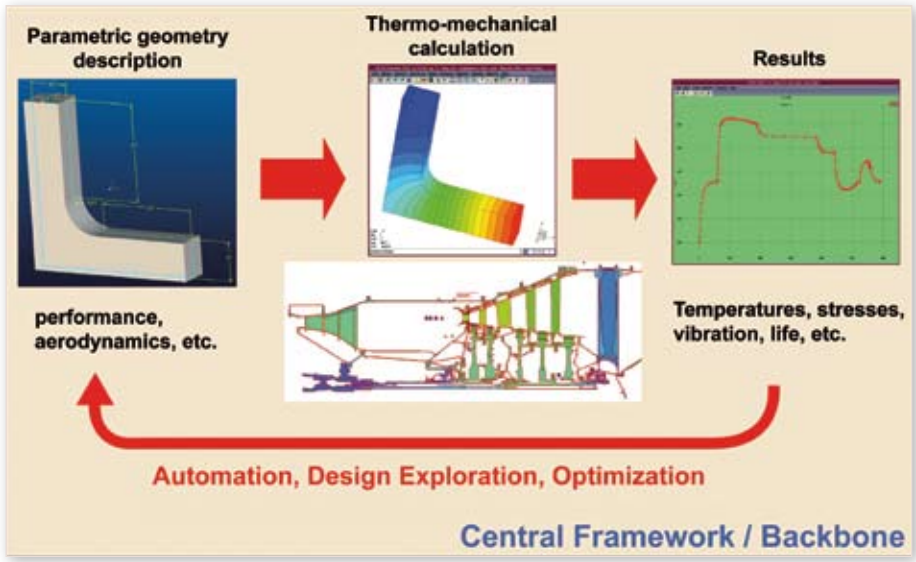


The aircraft turbine is an extremely complex mechanical system. This photograph is reproduced with the permission of Rolls-Royce plc, copyright © Rolls-Royce plc 2009.

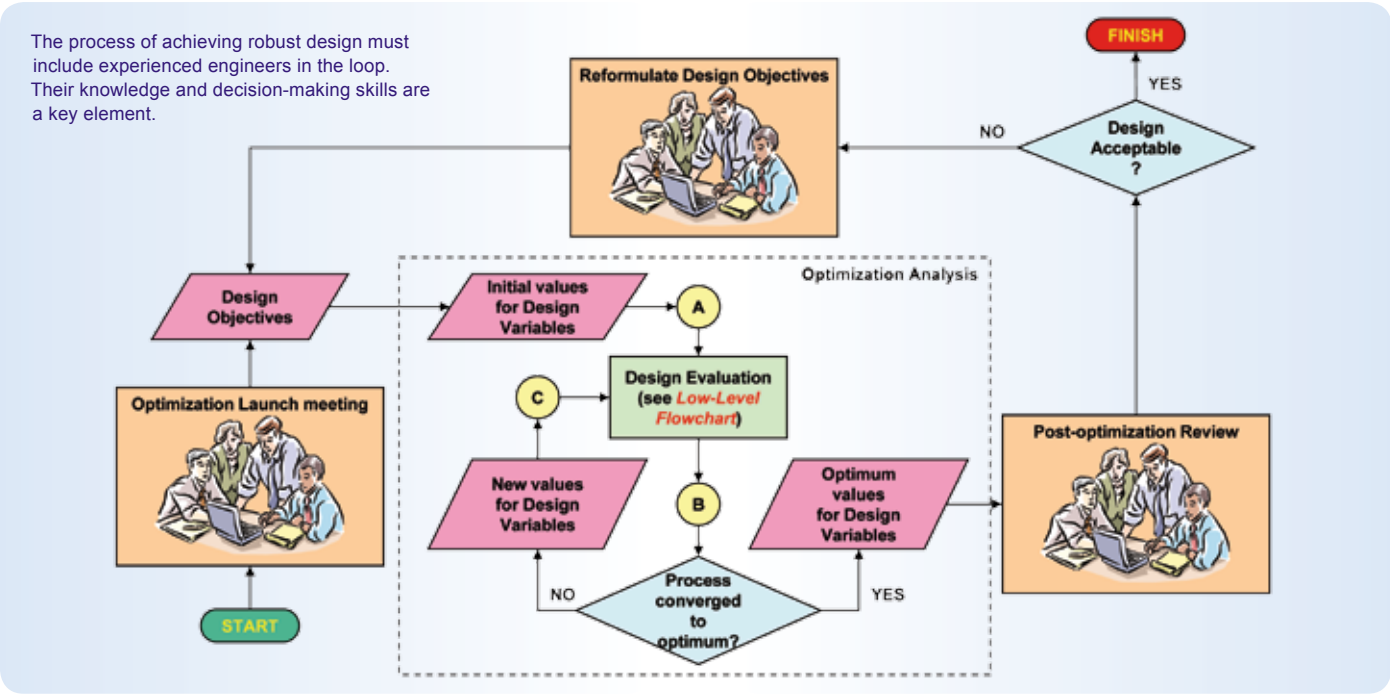
The robust design process enables us to incorporate customer requirements—and even changes—quickly and flexibly, while cost-effectively adhering to the strict quality standards demanded by the aircraft industry.

Why did we implement robust design at Rolls-Royce? Because we realized, early on, that the sheer size and complexity of the aircraft engine design and development "problem" could only be mastered through a combination of simulation, process automation and optimization. We have been using Isight software as our main toolkit for robust design for almost a decade.

At first, our management approached this new technology with caution, but our early successes with it convinced them of the value of standardizing on a single solution



The robust design process assesses variability in the early design phases and uses automation and optimization to deliver consistent performance to the customer.



instead of growing lots of different solutions. Once it was realized that process integration and automation could be a cost driver for manufacturing, everyone was on board. Launching with pilot programs in Germany and the U.K., we now use this software throughout the company.

Our five steps to achieving robust design are:

- Automate the Process – execute design and analysis without human intervention
- Process Integration – build up integrated processes between the various disciplines
- Design Exploration – understand the full design space
- Optimization – achieve the best compromise regarding all requirements
- Achieve Robust Design – ensure that the design performs across variable conditions

We now have the complete toolkit to coordinate these steps. In order to thoroughly assess variability (which is what robust design is all about), we first must automate the design simulation process. The software's easy drag-and-drop capabilities help coordinate this automation through the creation of simulation flows, which enable simulations to be executed 'hands-free.' Next, we integrate the results of our multidisciplinary analyses so that we simultaneously look at aerodynamics and stress and thermal and cost and weight, etc. Then we run any necessary design explorations (with Design of Experiments or Monte Carlo methods, for example), and finally we optimize the entire problem in order to achieve our goals.

Of course, with a highly complex gas turbine engine we are running a vast series of such robust design exercises, starting at the system level (whole engine cycle optimization and turbine preliminary design), through sub-systems (turbine thermo-mechanical analysis, secondary air system analysis, etc.) and finally focusing on components (turbine blade, discs, casings and so forth). Our process automation and integration software is a key part of driving and integrating this entire robust design workflow forward through materials tradeoffs and tolerances all the way to optimum manufacturability.

Because none of this can be accomplished without a great deal of simulation data, we also use integrated frameworks to link our simulation tools and achieve speed-up of simulation tasks, achieve multidisciplinary processes across teams and business units, and lock in standardization of the simulation processes we use over and over again.

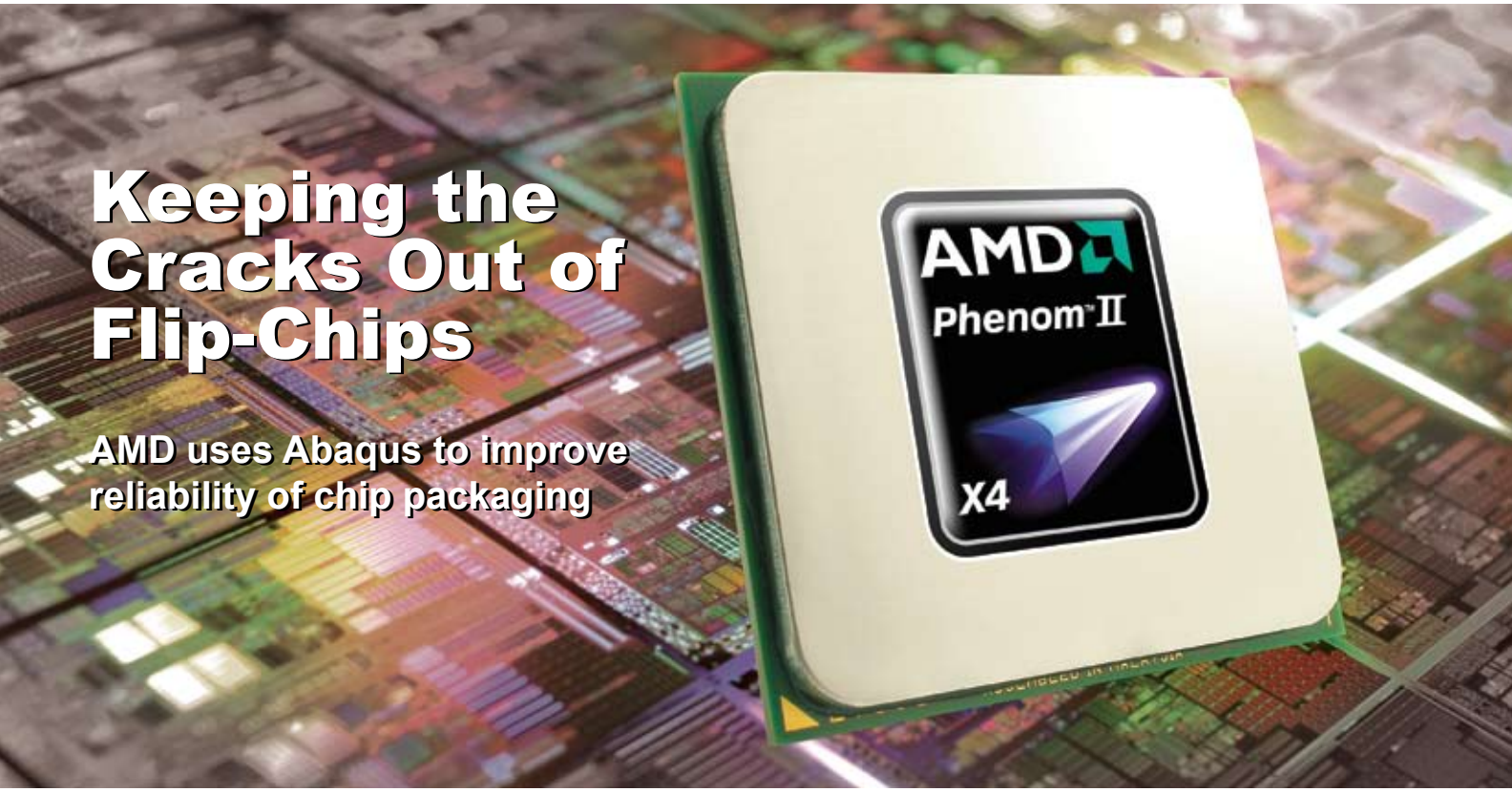
While automating all of these tasks is essential, we cannot achieve robust design without the continued input of a full cadre of highly experienced engineers, which is why I focus so much on training these days. It is critical to keep our people in the loop as their knowledge and decision-making skills remain a key element in the process.

By empowering our people to apply these software tools as broadly—or as narrowly—as needed along the way, we have reduced our development costs and cycle times and reaped a competitive advantage much greater than what we spend on software.

The lessons we have learned, and the techniques we are using, can be applied by other design and development organizations who need to assess a range of variables that impact overall performance and costs. I encourage you to participate in industry groups dedicated to sharing experience and knowledge related to robust design technology and methods. And investigate the use of process integration and automation as part of your design simulation process. It is almost certain that, like Rolls-Royce, you can achieve efficiency gains and cost savings while improving the performance of your product.



Dr. Karl is the lead of Robust Design for Rolls-Royce and is based in Indianapolis, Indiana. He recently chaired the NATO AVT-167 conference in Montreal, Canada, on Strategies for Optimization and Automated Design of Gas Turbine Engines. He holds a Ph.D. in Aerospace Technology from the University of Stuttgart.



Keeping the Cracks Out of Flip-Chips

AMD uses Abaqus to improve reliability of chip packaging

Fifty years after its invention, it is hard to imagine life without the integrated circuit (IC). As the heart—or the brain—of all computers, ICs power the world's most complex systems in communications, manufacturing, and transportation. According to the Semiconductor Industry Association, the overall worldwide market for semiconductors was a healthy $248 billion in 2008. A significant and growing part of this market is the flip-chip.

Developed in the 1960s by IBM and used initially in mainframes, flip-chips are mounted face-down, or flipped, directly onto a substrate, circuit board, or carrier. They make an electrical connection with the surface on which they are mounted through precisely positioned bumps—tiny spheres of conductive material—which also allow heat to dissipate from the chip, act as a spacer between the chip and the board or substrate circuits, and provide mechanical support for the chip (see Figure 1).

Compared to their wire-bonded cousins, flip-chips have a number of significant advantages:

- size – they are small and can reduce circuit board area by up to 95 percent;
- performance – they have improved speed;
- cost – they are less expensive in high volumes;
- reliability – they are more rugged.

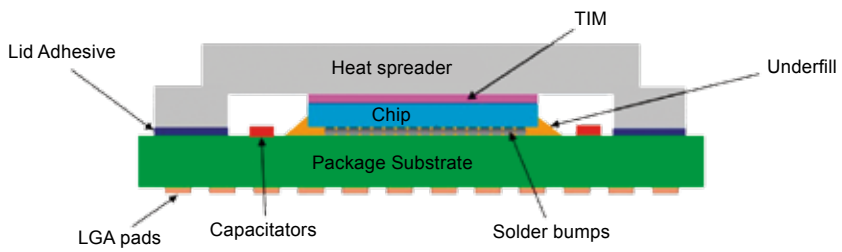


Figure 1. Schematic of generic flip-chip. The flip-chip faces down and is typically attached via solder bumps to the printed package substrate or circuit board. The underfill layer locks the die, or chip, to the substrate layer, protecting the bumps and improving durability.

Because of these advantages, flip-chips have become the chip-of-choice for many portable, cost-conscious applications such as watches, smart cards, RFID tags, cellular telephones, and pagers. And while it's been reported that more than one billion devices a year are manufactured using flip-chips, like any enabling technology, flip-chips still have their design and manufacturing challenges, and reliability improvements are still possible. It's no surprise, therefore, that finite element analysis (FEA) is being used in the ongoing development and improvement of chip design.

Preventing Underfill Failure is Critical

"In flip-chip packages, the mismatch in coefficients of thermal expansion (CTE) of the various layers induces stresses that can result in delamination," says Zhen Zhang, Senior Packaging Engineer at Advanced Micro Devices (AMD), a global supplier of integrated circuits for personal and networked computing and communications, based in Sunnyvale, CA. Especially critical is the underfill, a layer of adhesive between the chip and substrate that locks together the two layers. Once locked, the electrical contact is maintained, the contact bumps are protected from moisture and other environmental hazards, and the assembly has added mechanical strength.

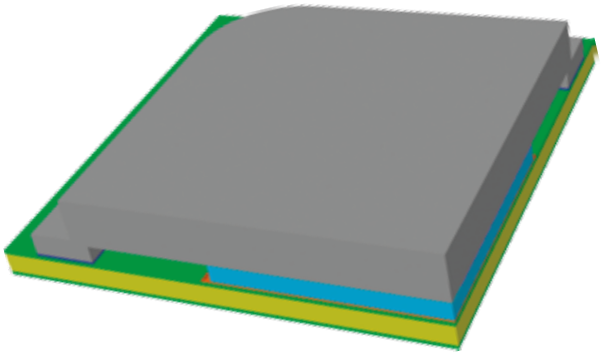


Figure 2. View of a 3D FEA model of a flip-chip. Only a quarter of the flip-chip is modeled because the flip-chip has symmetric geometry, loading conditions, and boundary conditions.

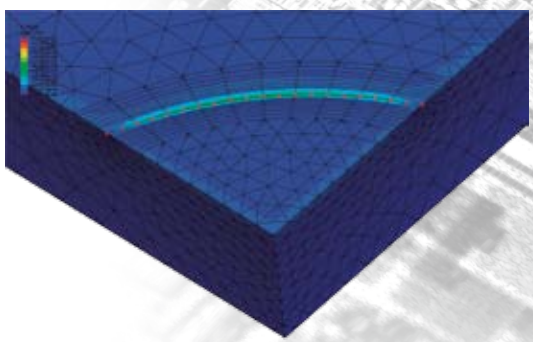


Figure 3. FEA analysis showing the stress field at the crack front.

Typically, a high modulus epoxy is used to underfill this gap and is applied by capillary flow and followed by a heat-curing step. While providing a number of advantages, the underfill layer can also have an impact on package reliability. "For instance, imperfect underfill with voids or microcracks will produce delamination under temperature cycling conditions," Zhang notes.

To help predict and prevent delamination, the engineering team at AMD used Abaqus finite element analysis software. They designed their study to analyze the effect of various underfill design variables that could potentially play a role in crack formation and delamination: the material modulus, CTE, and the dimensions of the underfill layer (fillet height). "We chose Abaqus because of its powerful fracture mechanics capabilities," says Zhang. "In addition, it has other features—such as contact mechanics, global-local submodeling routines, surface-to-surface tie constraints, a variety of partition and meshing tools, and parametric GUI and Python scripting for high productivity—all of which were useful in this study."

FEA Models Help Examine Underfill Behavior

To study delamination, engineers at AMD used Abaqus to create a parametric model of the flip-chip having the capability of automatic crack generation. The model included a base substrate layer (40 mm wide and 1.4 mm thick), a flipped silicon chip (20 mm wide and 0.8 mm thick) on top of the substrate, and an epoxy underfill layer between the substrate and chip (20 mm wide, 0.09 mm thick). In addition, the model included a copper heat-spreader lid that sits on top of the chip itself, gel-like thermal interface materials (TIM) between the chip and lid, and as the very top layer, adhesive for bonding the lid with the package substrate. To save on compute time, and because the geometry and loading conditions are symmetric, the team only modeled a quarter of the flip-chip (see Figure 2).

For the model's material properties, Zhang and his co-workers assumed that all materials were isotropic and had linear elastic behavior. In running analyses, since temperature excursion or cycling is the cause of many failures, the group focused on this variable, using an excursion of 125 to 25 degrees C—from the glass transition temperature of the epoxy underfill to room temperature.

"I used Abaqus/CAE to build the models," says Zhang, who took full advantage of the software's flexibility and automation features. "I modified the journal files into Python scripts and defined the parameters—including geometries, material properties, and loading conditions —for fully parameterized studies. I also used scripting/automation in Abaqus/CAE to post-process the simulation results and output them into Excel files."

The AMD engineering team used both a global model method (26,000 elements) and a global-local method (approximately 19,400 elements in the global model and 18,200 elements in the local model). In both cases they used the C3D20R element, a 20-node quadratic brick. For hardware, Zhang used a Windows XP Pro 32-bit operating system in a workstation powered by an AMD Opteron dual-core processor and visualized using an ATI Radeon HD graphics card.

Simulation Provides 3D Fracture Results and Design Recommendations

For the purposes of this study, Zhang's group inserted a crack at the corner of the interface between the chip and the underfill layer and then examined the effect of a number of variables on crack generation—underfill material properties (modulus and CTE), the height of the underfill fillet, the shape of the crack front, and the size of the crack (see Figure 3). "This complex analysis was made manageable by the parametric capabilities of the Abaqus model," Zhang notes. To optimize reliability and durability, the team analyzed these variables in regards to crack formation and came to the following conclusions about the underfill layer: the material should have a low CTE; the fillet height should be increased, if possible; the glass transition temperature of the material should be as low as possible, but should be higher than the upper bound of temperature range in testing or service condition; and the modulus effect is minimal.

Making Future Flip-Chips Even Better

Zhang, who has been studying flip-chips for two years, has already made significant recommendations and improvements in designs using FEA. "We have optimized solder joints, the contact reliability of the package bottom with the socket, and various package sizes for both single-chip and multi-chip modules—all using Abaqus." In this case, Zhang adds, "The analysis provided reliability data for all flip-chips in which underfill is incorporated—from package to board level, and from assembly to service conditions."

Looking to the future, Zhang notes that such analyses guide material selection and design and assembly optimization as well, and concludes, "The impact on future flip-chip design is positive." In a chip-driven world, this is good news.

For More Information
www.amd.com

SIMULIA Strategy for Turbomachinery Innovation

Realistic Simulation, Design Optimization, and Simulation Lifecycle Management

Jack Cofer, Turbomachinery Industry Lead, SIMULIA Technical Marketing



Image courtesy of Alstom

Turbomachines have been at the heart of human industry for thousands of years—from the early Roman water wheels of the first century B.C. to the modern pumps, turbines, and aircraft engines of today. Turbomachinery engineers continue to strive for the same goals as their Roman ancestors—to improve efficiency and reliability to meet the needs of society within an increasingly challenging marketplace.

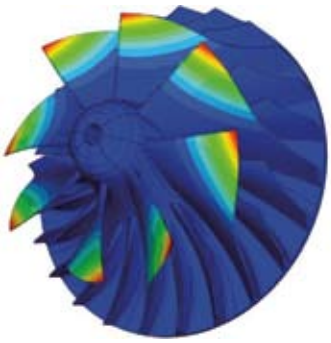
Turbomachines are used in many industries and designed in many shapes and sizes, from the tiny millimeter-scale gas turbines being developed to power cell phones and laptops to the massive steam, gas, and hydro turbines found in power plants all over the world. Whether the purpose of the turbomachine is to pump fluids through pipes, compress gases in industrial processes, or generate thrust for an aircraft, designers share a common need to design the most efficient and reliable product at the lowest cost, in the shortest amount of time.

Realistic Simulation Solutions

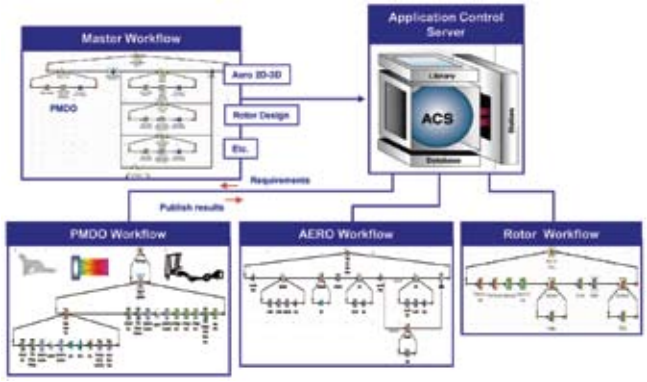
Most turbomachines operate in extreme conditions of temperature, pressure, and stress. Operational forces are extremely high in the rotating components. This environment puts many engineering disciplines in conflict, such as aerodynamics, stress and vibration, and durability. SIMULIA is providing leading-edge simulation, automation, and optimization technologies to enable turbomachinery companies to design competitive machines that achieve the optimum balance between efficiency requirements, mechanical reliability, and manufacturing cost.

Our Abaqus Unified FEA product suite provides a comprehensive set of capabilities including static, dynamic, thermal, acoustic, linear, and nonlinear analyses. These capabilities are well-suited for many common turbomachinery design tasks, including stress and vibration analysis for blading, structural design of rotors, and creep and fracture analysis. The enhanced XFEM capability in Abaqus 6.9 is especially useful for investigating the formation and propagation of cracks in stationary and rotating components.

In this issue's cover story, Alstom Power describes their use of Abaqus to rapidly evaluate and minimize steam turbine start-up time without exceeding stress limits in the rotor. Turbocharger companies are using Abaqus, coupled with CFD codes, to determine centrifugal impeller blade vibration characteristics caused by unsteady flow interactions between the compressor and the vaned diffuser-volute. Aircraft engine companies use it for such applications as analyzing the blade/wheel connections for both compressor and turbine blades, predicting stresses and life for combustor liners, and performing failure analyses in disks. Steam and gas turbine companies use it for applications including stress, vibration, and probabilistic high-cycle fatigue analyses in stationary and rotating blades. Wind turbine companies increasingly rely on Abaqus for composites modeling and simulation to develop lightweight blades with high strength and durability over a wide range of operating conditions.



In this example, calculated mode shapes are shown for a centrifugal compressor impeller. Image courtesy of ABB Turbo Systems Ltd., from ASME paper GT2009-59046.



This is an example of an aircraft engine design process integrated with Isight. With the addition of SLM and an application control server (ACS), multiple processes located on servers at different company sites can be linked together and the process models and simulation data can be managed and shared in a collaborative environment. Image courtesy of Pratt & Whitney.

Automation and Optimization

Turbomachinery design engineers face an inherently multidisciplinary optimization problem with many conflicting design objectives and constraints. To meet this challenge, many turbomachinery companies are using Isight to automate highly complex simulation-based design processes and apply advanced numerical optimization methods to improve performance and reliability. Isight was developed in the 1980s for aircraft engine optimization, and since then has been used by more than 80 companies for many design tasks including cycle optimization, preliminary design and stage layout, and aero/mechanical design of axial airfoils and centrifugal impellers. Isight is used to link together in-house and commercial CAD and simulation codes to automate design and simulation process flows. Expert design rules and constraints are captured in these process flows, enabling various optimization strategies to be applied. Engineers are able to use advanced numerical optimization methods—including DOE, Monte Carlo, and Design for Six Sigma—to explore design envelopes and automatically search the design space to optimize their design for performance goals such as stress, weight, and cost.

Dramatic improvements in performance and reliability can be achieved along with cycle-time reductions of 5 to 10 times compared to traditional manual methods. As exemplified in the article from Rolls-Royce on page 4 of this issue, many companies are now using Isight to achieve robust designs that are insensitive to uncertainties and variability in such things as manufacturing tolerances, material properties, and loading conditions. When combined with SIMULIA SLM and the SIMULIA Execution Engine (formerly called Fiper), extremely large and complex design processes can be captured and managed in a collaborative design environment.

The Value of SLM

The simulation-based processes used to design turbomachines are almost as complex as the machines themselves. These processes produce a tremendous volume of data, and engineering organizations can easily be overwhelmed with process management issues. SIMULIA's Simulation Lifecycle Management (SLM) solution has been developed to bring order to large-scale simulation by combining Product Lifecycle Management (PLM) tools with Isight and the SIMULIA Execution Engine to create a powerful collaborative design environment.

SLM also allows companies to collaborate seamlessly across engineering disciplines, organizations, and suppliers to take advantage of all available global resources in manpower, computing power, and manufacturing capacity. It leverages and secures your simulation intellectual property by facilitating the capture, standardization, and reuse of expert-generated workflows and knowledge, and it enables effective management of data, methods, and processes. It connects individual engineers and design teams to each other and to the enterprise, allowing them to share applications, models, data, and results to ensure that they make the best design decisions. It provides an open platform to manage and deploy in-house and third-party applications, and lowers your computer hardware investment by making effective use of all available computing resources, no matter where they might be located. A number of our major turbomachinery customers have already embraced our SLM technology as the platform for their design environment and are working with us to improve its capabilities to meet their future needs.

Customer-Focused Solutions

SIMULIA's strategy for serving the turbomachinery industry is to engage in an open dialogue with our customers and industry consortiums to address both the technology and business needs of the industry. We are already hard at work making a number of important improvements to Abaqus in the areas of rotordynamics, blade stress and vibration analysis, and cavity radiation. We have introduced a new extension to Isight called Eblade 2.0 that integrates many common airfoil design tools in an easy-to-use GUI for the automated multidisciplinary aero/mechanical optimization of axial turbine blades. We are forging new partnerships with key providers of complementary technology, and are developing an extensive library of components that will allow many common software packages used by turbomachinery designers to be easily integrated with Isight. We are committed to working closely with our customers to determine their future needs for enhancements to SIMULIA products to enable them to design the efficient, reliable, and cost-effective turbomachines that their customers demand.



Jack Cofer
Turbomachinery Industry Lead, SIMULIA

Jack is responsible for developing and directing SIMULIA strategy for the turbomachinery industry. He has over 35 years of experience in turbomachinery design and optimization achieved through various design and management roles at GE Power Generation, Demag Delaval Turbomachinery, and Engineous Software. He has a B.S. from the University of Virginia, a M.S. from the Massachusetts Institute of Technology, and a M.E. from Northeastern University.

For More Information
www.simulia.com/solutions/turbomachinery

Packaged for Freshness with Realistic Simulation



Simulation of material and fluids with Abaqus FEA helps decrease development time while improving quality of innovative aseptic packaging

At the turn of this century, many experts compiled "Top-ten" lists for the greatest record-setting athletic performances, the best all-time songs, the top news stories, and many other social achievements of the previous hundred years. The Number One food science innovation of the twentieth century selected by the Institute of Food Technologists — ahead of even concentrated juices, safe canning, and freeze drying — was aseptic processing and packaging.

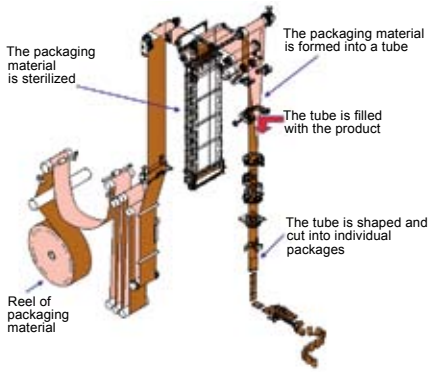
Aseptic processing dates from the early 1960s. It involves ultra-high-temperature (UHT) treatment of milk and other liquid foods for a few seconds in order to remove all harmful micro-organisms while preserving nutrients and flavor compounds better than traditional pasteurization and canning done at lower temperatures for longer times. The result is that UHT food products remain fresh for months during shipping or storage without requiring refrigeration or preservatives. This provides significant cost savings to everyone—from the producer to the consumer—as well as long-life, healthy nourishment in developing countries lacking adequate power grids, cold chains or transportation infrastructure.

Tetra Pak is the world's largest supplier of aseptic packaging. Its founder, Dr. Ruben Rausing, began the company in Lund, Sweden in 1951 with a simple tenet: "A package should save more than it costs." Rausing invented the packaging technology that still forms the basis for much of Tetra Pak's business. Currently the company distributes more than 387 million packages per day in over 150 countries, for a total of more than 141 billion delivered worldwide in 2008.

As the company is committed to providing the lowest-cost packages possible, every new product line presents a challenge: is the thin, lightweight material strong enough to withstand the filling and sealing process? "Complete control over the process is paramount," says Dr. Mattias Olsson, Manager, Virtual Engineering at Tetra Pak. "That requires an in-depth knowledge of the loads and forces involved—both liquid and material."

Cartons, Fluids, and Forces

Both for cost and for control, the packaging process is designed to be as simple as possible. But keeping it simple poses tremendous engineering challenges. A continuous reel of carton-based packing material—a composite of mostly paper, with some ultra thin layers of plastic and aluminum—is fed into the top of a filling machine and sterilized along the way. The flat packaging material is formed into a tube and sealed longitudinally. A pipe from the filling machine enters the top of this packing material tube, filling it with liquid and causing it to expand. A mechanical system folds and transversely seals the package, below the surface of the fluid, keeping it sterile while forming it into the desired shape. The tube is then cut into individual packages.



Schematic of a filling and packaging system for an aseptic liquid container.

Even though the process is simple, the forces it is subject to are not. "Gravity is driving the liquid down," Olsson says, "but the folding and the tube deformation are forcing it backward"—much like the action of putting a kink in a garden hose. A pressure flange (essentially a flat disk with small holes in it) mounted inside the tube, above the folding system, reduces the amount of backflow up the tube. But the packaging tube is subject to deformation under folding and considerable changes in fluid pressure, and it needs to retain its structural integrity without breaking or crimping.

"When designing new package shapes and sizes," Olsson says, "or when modifying the filling machine—for instance by increasing the filling speed—the folding and forming of the package are critical. In the past, these have been difficult to predict." Customarily, the packaging and filling process was verified by physical testing on a nearly finalized machine. But if the test revealed design problems at that stage, it was more expensive to introduce changes than it would have been earlier in product development. "What we needed," Olsson points out, "was a realistic, reliable simulation method that took into account the liquid, the packaging material, and all the major forces acting—and interacting—on them."

So Tetra Pak selected Abaqus finite element analysis software from SIMULIA, the Dassault Systèmes brand for realistic simulation, to evaluate the complexities of its packaging process. The company had previously used Abaqus for structural analyses, but this was the first time that Tetra Pak engineers simulated the dynamics of the fluid-structure interaction during packaging. The resulting analysis generated a greater understanding of the packaging process and provided a means to model it earlier in the design stage. "We anticipate that use of simulation will help save us a significant amount of product development time," says Olsson.

A Model Packaging Process

For their initial trial analysis, the engineers selected the Tetra Fino Aseptic 500 ml, TFA 500s milk package—the mid-range size of an extremely low-cost and high-volume product line. "We already had a strong

knowledge of production parameters for this application," Olsson says, "so it made an excellent choice for our initial analysis." Dr. Anders Magnusson, Technology Specialist at Tetra Pak, worked with Olsson on the simulation.

There were a number of challenges to modeling the process. The packaging material was very thin and flexible, which made for large deformations under pressure changes. The cross-section of the tube rapidly changed from circular cross-section to fully closed when folded. Most important, there was a strong fluid-structure interaction to be modeled that had to take into account the changing pressure waves in the fluid and their effects on the packaging material.

The model for analysis included the following components:

- The composite packaging material (a paper, aluminum and plastic carton tube, modeled as a homogenous material)
- The packaged fluid, including its flow and pressure properties
- The flotation device that rests on top of the fluid surface
- The system that folds the packaging material
- The pressure flange that controls (dampens) pressure waves inside the tube

With the exception of the deformable packaging-material tube and the liquid, the components were modeled as rigid bodies. These structural items were modeled in a Lagrangian framework, which is a commonly used method of simplifying the application of forces to objects and quantifying their reactions.

The flexible packaging material was modeled with shell elements calibrated to represent the laminated material as though it were homogenous, which reduced the computation time for the analysis.

The fluid was modeled using an Eulerian approach that captures the characteristics of non-viscous fluid flow. By coupling this with the Lagrangian approach, Tetra Pak's engineers could now model the interaction of the packaging tube and the fluid in one analysis. "The Coupled Eulerian-Lagrangian capability in Abaqus allowed us to include effects from the packaging dynamics—tube deformation under flow and pressure changes—that we had never simulated in a single model before," Magnusson says. Abaqus' strong contact and nonlinear capabilities were also essential to the analysis.

Because the packaging process is axially symmetric, the engineers were able to model one-half of the system to substantially reduce processing time. The model involved roughly 220,000 elements, with approximately 700,000 variables. The analysis ran on a Linux 86-64 platform with an Intel Xeon Dual core processor, with the runs taking about 24 hours on 8 to16 processors.

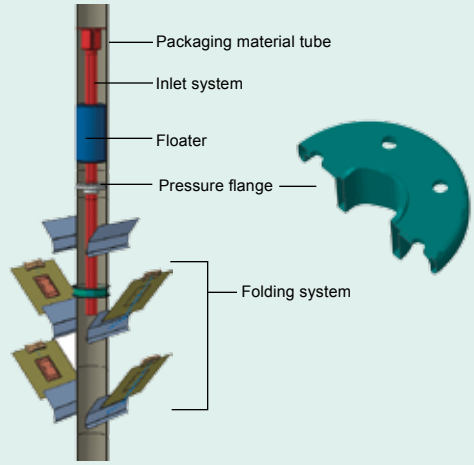
Once the Coupled Eulerian-Lagrangian approach enabled the simulation to capture the deformation of the packaging material, the behavior of the fluid and the interaction between them entirely within a single FEA model, the engineers were able to model and define a variety of design parameters:

- Sequencing the folding system action, including the deformation of the material
- Determining the choice and suitability of the packaging material
- Establishing the correlation between fluid injection rate and formed packaging volume
- Defining the tensile load applied to the material so as to prevent breakage or crimping

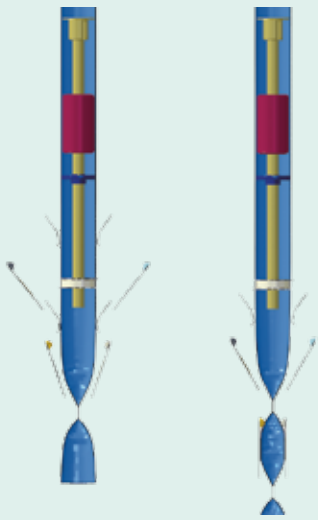
"We were trying to model all the aspects of packaging that we had tested in physical prototyping," Magnusson says. "In the end, we were able to simulate all the important forces of the process, from flow under gravity and pressure changes in the liquid, to deformation in the material."

The Results—Good to Go

The FEA analysis realistically captured the packaging process, right down to arriving at the desired final shape of the filled and sealed package. It also demonstrated that including the interaction of the fluid and the packaging material in the simulation is imperative in order to calculate the degree of package deformation during filling and sealing. The simulation showed the need and effectiveness of the pressure flange device to control the gross bulk motion of the fluid, reducing the dynamic interaction between the fluid and the tube of packaging material. "Originally it was believed that modeling the role of the pressure flange would be difficult using the Coupled Eulerian-Lagrangian method, since physical tests had demonstrated turbulence effects," Olsson observes. "But our analyses, with and without the flange, proved that this method could capture the fluid behavior well." The next step is to verify the results with physical testing.



Half symmetry model of the structural components of packaging system.



Deformation of the packaging tube as the packaging seals.

In the long run, the Abaqus simulation will aid Tetra Pak as it develops new packages and upgrades existing machines. Using simulation early in design is expected to decrease the development time of the packaging processes while increasing package quality—an important goal for a packaging company whose motto is "Protects What's Good," and that strives to provide healthy and nutritious food throughout the world.

"Tetra Pak's vision is that we commit to making food safe and available everywhere," says Olsson. "This FEA analysis is a part of that vision, and it has significantly strengthened our understanding and knowledge of the physics at play in our packaging systems. SIMULIA will be important to our process development method going forward."

For More Information

www.tetrapak.com
www.simulia.com/cust_ref



Fast-Starts Help Squeeze Watts

Alstom Power utilizes Abaqus FEA to improve steam turbine efficiency

Steam turbines go around. Since their invention in 1884, they have made much of the industrial world go around, as well. Sometimes referred to as the perfect engine, steam turbines rapidly replaced the steam engine due to greater efficiency at converting heat into motion and motion into power. Their rotary action also became the primary power source for driving generators to create electricity.

Steam-powered turbines now generate some 80 percent of the world's electricity and are expected to do so well into the future. But given the changing face of energy markets and economic and environmental pressures for greater efficiency and reduced CO_2 emissions, steam turbine performance is being scrutinized under a design and optimization microscope. For manufacturers and power plant operators alike, the goal is to squeeze maximum wattage out of the available energy source.

Winning the Wattage Race

Modern steam turbines are exposed to greater stresses than earlier versions. The faster you can get a turbine up to operating conditions, the more energy you can produce. These rapid start-ups put tremendous thermal stresses on a turbine as the temperature is raised by several hundred degrees in less than an hour. In the past, power providers took their time during start-ups—a typical start-up might have taken over four hours—and as a result, stresses were much lower. Today's power plant operators do not have this luxury, and need to shave start-up time to maximize energy production and efficiency.

Additionally, while power plants in the past ran continuously for long periods of time, modern plants and the steam turbines that drive them need to adapt to varying operating conditions: plants supplying peak power need to ramp up and down on an almost daily basis; Combined Cycle Power Plants (CCPP) have both gas and steam turbines and need to switch regularly between the two power sources; and plants that provide backup for sustainable energy sources need to come online quickly when weather conditions change.

Due to these variable operating conditions, transient events have become common. Unscheduled operations such as double-shifts or load following operation are also the norm. "Steam turbines need to be able to start-up rapidly, react to load changes in a quick and predictable way, and tolerate the stresses inherent in these operating conditions," said Andreas Ehrsam, Project Manager at Alstom Power in Switzerland. "These are key technological challenges for modern power plants and for our engineering team." In the future, the challenges will only increase. According to Ehrsam, "The target for hot start-up of next-generation CCPP steam turbines is well below 30 minutes." With 100 years of experience designing and building steam turbines, and having supplied major equipment for 25 percent of the world's existing electric power generation plants, it's easy to see why Alstom Power is continuously looking for ways to improve turbine performance and maximize power production.

In simplified terms, the rotor in a steam turbine is comprised of rows of rotating

blades that capture the energy from high velocity steam jetted from stationary nozzles in between the rows. During transient events in the operation of a steam turbine, thermal stresses occur causing high fatigue loading—and these stresses are especially prevalent in thick-walled components. At the same time, turbines experience gradual creep loading as a result of general operation at high temperatures. Combining creep and fatigue loading over time puts stresses on the turbine, eventually leading to crack initiation and growth that can limit turbine lifespan.

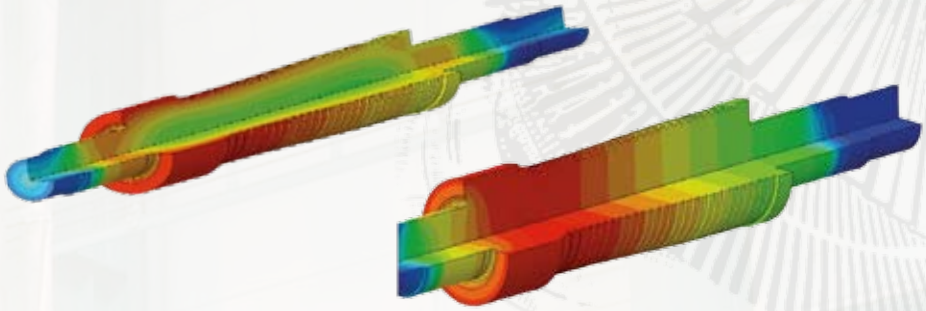


Figure 1 (left). Rotor model non-stationary temperature profile at 60 minutes into start-up. Figure 2 (right). Rotor model with steady-state temperature profile at base load. Images courtesy of Alstom.

Automating a Start-Up Simulation

Alstom Power has been optimizing steam turbine start-up processes for years. They use Abaqus FEA because of its powerful thermo-mechanical simulation capabilities. Prior to this, early optimization analysis at Alstom Power was based on finite difference codes and simplified component models. Moving to FEA, Alstom engineers would first derive the transient thermal boundary conditions for the whole start-up simulation, basing it on a set of predefined process parameters. In a second step, they would perform a finite element analysis to verify these thermal boundary conditions. This sequential approach required numerous iterations—a tedious manual process—to arrive at the optimal process parameters.

With the demand for increased operational flexibility and more accurate modeling, Ehrsam's engineering team looked to the automation capabilities in Abaqus to bypass the time-consuming iterative simulation process. To automate the optimization, the group developed a design tool that interlinked Abaqus with Alstom's in-house thermodynamic code using Python, the programming language of the Abaqus kernel scripting interface. This solution, according to Ehrsam, "allowed direct and easy communication between our proprietary code and Abaqus/CAE." The result was a tool that determined optimal transient thermal boundary conditions based on real-time thermal stresses and automated the search for optimal process parameters through the use of a feedback control algorithm. "Use of this tool eliminated the need for the high number of manual iterations that were previously required," added Ehrsam. "As a result, the process became much more efficient."

The automated simulation happens in the following way: Abaqus calls a subroutine to apply the thermal boundary condition to the model of the turbine rotor. Then it queries the Alstom thermodynamic program for the thermal boundary condition for the first time-step. With this input, Abaqus completes the thermo-mechanical analysis. To calculate the thermal boundary condition for the next time-step, Abaqus extracts the actual stresses at critical locations from its output database, calls the control algorithm to determine the optimal mass flow, queries the Alstom code for the thermal boundary conditions based on this information, and finally performs the thermo-mechanical analysis. This computational loop is repeated for each time-step—from 10 to 60 seconds depending on the application—comparing the computed stresses at critical locations with the material stress limits, while making sure that the mass flow approaches, but does not exceed, the stress limits.

Automation Trumps Iteration

To put the tool to work, Alstom Power chose to simulate a steam turbine rotor during a typical 60-minute start-up. They used Abaqus for a number of steps: for preprocessing; for the creation and meshing of 2D models of simple parts such as axisymmetric rotor models; and for optimization automation using Python scripts. More complex 3D models were created in CATIA V5 and, depending on the application, imported into Abaqus using the CATIA V5 Associative Interface for Abaqus or the CATIA V5 Import feature. The team then used Abaqus to mesh the model and perform the finite element analysis of the rotor. The time step for mass flow control and automation was set to 60 seconds.

To start the simulation, Ehrsam's group modeled the initial temperature profile of the component before start-up. First, the turbine was accelerated to nominal speed for grid synchronization. Then, throughout the 60-minute start-up, the team optimized the loading gradient so the maximum stress in the hottest section of the rotor was kept just below the material stress limit of the rotor materials (see Figure 1), until eventually steady-state temperature profile at base load was reached (see Figure 2). Running on a standard engineering PC, this automated optimization took approximately 16 minutes. Although the earlier manual calculations each took only about a third of this run time, they consumed significantly more set-up time because they were based on estimates that had to be changed manually from run to run.

"As a result of the automated process, we were able to determine the fastest start-up parameters and process without exceeding stress limits," said Ehrsam. This led to a change in the design of the rotor grooves based on global deformation and heat flows. "Comparing the sequential versus automated method," Ehrsam said, "we demonstrated time-savings and improvements in accuracy using the automated tool." A typical time for a start-up optimization using the previous manual method was about 10 man-days. With the new tool, this was reduced to only five. The Alstom Power team validated the automated analysis against the previous process and found good agreement between results data.

Squeezing Maximum Wattage

The advantages of automating this process have since led Alstom Power to begin testing the use of Isight, as it would enable them to conduct an even deeper search of the turbine design space. "In the world of power generation, small changes in efficiency can save millions of dollars a year in fuel cost," said Ehrsam. With savings on this scale, using simulation and optimization together to squeeze maximum wattage out of turbines will become increasingly important to power producers in the future.

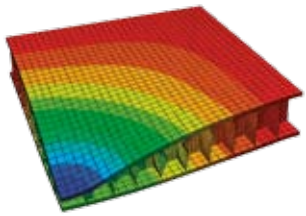
For More Information
www.alstom.com
www.simulia.com/cust_ref

Abaqus 6.9-EF Offers Enhanced Capabilities for Modeling, Advanced Mechanics, and Performance

Designers, engineers, and researchers in a broad range of industries use Abaqus to predict the real-world behavior of products, materials, and manufacturing processes. The latest release, Abaqus Extended Functionality (6.9-EF), delivers key new features and enhancements for modeling, advanced mechanics, and performance. These ongoing improvements are enabling customers to consolidate their simulation software, thereby lowering cost and increasing efficiency in their product development process.

"To meet product performance requirements within ever-shorter product development timelines, it is imperative that we perform physically accurate design simulations as fast as possible," stated Kirk Siefker, Senior Analytical Engineer, Engine Components, Schaeffler Group USA. "With the improved implicit dynamic capabilities in Abaqus 6.9-EF, we are able to simulate the realistic performance of our engine component and system designs 30% faster while enhancing our product's overall performance."

"The extended functionality of Abaqus underscores our ongoing commitment to delivering robust, customer-driven enhancements to our realistic simulation software more quickly," stated Steve Crowley, director of product management, SIMULIA, Dassault Systèmes. "The latest capabilities in 6.9-EF will benefit our users in every industry by helping them accelerate the evaluation of real-world product behavior during the design phase."



Structures subject to air blast loading can be analyzed efficiently in Abaqus 6.9-EF using a new incident wave interaction based on the accepted industry formulation.

New features and enhancements in the Abaqus 6.9-EF release include:

- Interactive support is provided for meshing models using cylindrical elements, which can be useful in the analysis of pipelines by oil and gas companies.
- Discrete orientations provide a convenient method for accurately defining spatially varying material orientations on models with curved geometries such as aircraft panels and car bodies.
- Viscoelastic behavior can be now modeled with orthotropic/anisotropic elasticity in Abaqus/Explicit, which provides more realistic composite damage prediction.
- A new and efficient method is available for analyzing structures subject to air blast loading, which is useful for safety evaluation in the civil engineering and defense industries.
- A new iterative solver in Abaqus/Standard provides performance gains up to 20x or more in comparison to the direct sparse solver. The iterative solver is intended for very large simulation problems typically found in applications such as powertrain, oil reservoir, and material microstructure simulations.

For More Information
www.simulia.com/products/abaqus_fea

Isight 4.0 Increases Efficiency in Component Application Development and Simulation Workflow Creation

Isight provides engineers with an open system for integrating design and simulation models, created with various CAD, CAE and other software applications, together into a simulation process workflow. Isight users can use the workflows to run hundreds or thousands of simulations without manual intervention. Using optimization methods such as Design of Experiments, Approximations, and Design for Six Sigma, engineers are able to explore the complete design space to identify optimal performance parameters.

The newest release, Isight 4.0, provides an Abaqus Unified FEA application component as part of the base Gateway package, greatly enhancing the use of the robust FEA technology from SIMULIA within Isight process workflows. Enhanced support for scripting has been added for customers and partners who use the Isight component software development kit to develop their own custom components. Also, the Dassault Systèmes software developer community is now extended to support third-party simulation component development for Isight with APIs, tools to improve the process of developing robust third-party components that will provide significant efficiency gains to Isight users.



Isight 4.0 users can export approximations to Excel, use Excel features to customize vertical applications, and share Isight approximations with non-Isight users via email.

"The open, component-based technology in Isight simplifies the integration of CAD and CAE applications into a simulation workflow," stated Steve Crowley, director of product management, SIMULIA, Dassault Systèmes. "By leveraging the new features and enhancements in Isight 4.0, our customers will achieve significant efficiency improvements in capturing and automating their simulation workflows. This, in turn, will allow them to dramatically increase the number of simulations they can perform, accelerating their ability to optimize their product's performance earlier in the development cycle."

"Dassault Systèmes' partner program provides our development team with access to software APIs and technical support resources that help us accelerate the development of new components for Isight," stated Jean-Claude Ercolanelli, VP Product Management, CD-adapco. "Integrating STAR-CCM+ into Isight workflows will enhance our customers' ability to perform multidisciplinary design optimization."

For More Information
www.simulia.com/products/isight

Fiper Given a New Name with Release of SIMULIA SLM V62010x

The goal of our Simulation Lifecycle Management is to enable our customers to capture their simulation knowledge, manage simulation applications and data, reuse validated methods, automate multidisciplinary simulations, and collaborate on performance-based decision making. By combining the proven Product Lifecycle Management (PLM) technology from ENOVIA with SIMULIA's simulation process knowledge, we have delivered a breakthrough, economically deployable solution that is gaining significant industry momentum.

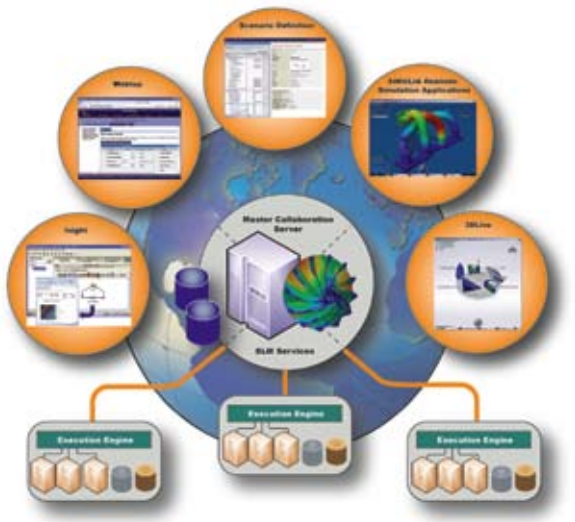
As part of our ongoing strategy to develop and deliver an open and robust SLM solution, we have created two new product names within our SLM portfolio; SIMULIA Scenario Definition and SIMULIA Execution Engine (formerly known as Fiper). The new name for Fiper reflects the improved integration of this leading technology for the execution of simulation process flows, across distributed high-performance computing resources, within a managed simulation environment.

With our newly created Scenario Definition (SCE) product, SLM users are able to access secure workspaces to create and edit simulation scenarios, manage simulation data and results, and collaborate on performance-based decision making. Scenario Definition enables simulation experts to capture their knowledge and approved methods to create process-specific simulation templates. This enables the easy configuration of simulation models with a set of attributes, activities, and applications required to complete the simulation.

Templates can be shared and used by a wide range of users, from designers to engineers. This ensures standard practices are adhered to, improving repeatability and reliability of simulations. The capabilities of Scenario Definition can be extended by leveraging Isight and its related components for integrating simulation process workflows and performing design optimization.

The SIMULIA Execution Engine (SEE) manages the distribution of simulations across existing, distributed computing resources, including high-performance compute clusters. By using the SIMULIA Execution Engine, users, administrators, and IT organizations are able to control where simulations are executed and the process by which they are run, allowing for optimum use of networked computing resources. The software integrates seamlessly with existing enterprise web application servers and databases.

With SIMULIA SLM V62010x, the simulation processes and resulting data are fully searchable and the form-based interface makes it easy to share simulation details—such as simulation properties, parameters, execution status, and history of activities—and launch reviews of simulation results to team members and managers for collaborative, rapid decision making. The complete SIMULIA SLM portfolio improves the efficiency of performing multiple simulations, enhances data quality and traceability, secures simulation intellectual property, and accelerates collaborative decision making.



The SIMULIA Execution Engine enables users to distribute and parallelize the execution of simulation process flows, allowing for optimum use of hardware and computing resources.

For More Information
www.simulia.com/products/slm

Abaqus for CATIA V5R20

Leverage Realistic Simulation Inside CATIA V5

Abaqus for CATIA V5 (AFC) brings Abaqus finite element analysis (FEA) technology into the CATIA V5 user environment. CATIA V5 provides powerful and flexible design capabilities, and Abaqus for CATIA V5 makes the design model and the simulation model one and the same. The result is a complete package for deploying proven FEA-based simulation throughout the design process.

The latest release, Abaqus for CATIA V5R20, offers some exciting new updates. With improved usability and robust design analysis capabilities directly in CATIA V5, the new release enables design and engineering teams to improve collaboration, evaluate design performance through the use of common FEA models, technology, and methods synchronized with their CATIA V5 design, and accelerate the product development process.

Highlights for the Abaqus for CATIA V5R20 release:

- Enhanced catalog of load types, including distributed load and force density
- Local cylindrical and spherical coordinate systems available for load and property definitions
- Probe tool to quickly interrogate results images for detailed information
- Support for optimizations using the CATIA PEO workbench
- Abaqus general contact in nonlinear structural analysis cases
- Bolt pretensioning with solid, 3D bolt geometry
- Data mapping of thermal loads from external data sources
- Support for Abaqus 6.9

For More Information
www.simulia.com/products/afc_V5

The Up Side of Engine Downsizing

MAHLE Powertrain Uses Realistic Simulation to Guide Design of New High-Performance 3-Cylinder Engine



For the last several decades, bigger automotive engines were considered more reliable, powerful, and faster. However, today's emission regulations are more stringent, and future regulations are pushing designers toward ever greater engine efficiency. In 2004, the European Union passed the EU5 standards, which went into effect in 2009 with the lowest CO_2 limits yet (140g/km). Environmental regulations are now providing the impetus for moving toward smaller, more efficient engines—and designers and manufacturers alike are realizing that small can be beautiful.

Green Doesn't Mean Losing Get-Up-and-Go

"Consumers want greener cars, but they want them to have the same performance as their older, larger models," said Mark Stephenson, Chief Engineer of Predictive Analysis at MAHLE Powertrain (MPT), a leading international engine development partner and manufacturer in Northampton, U.K. In the quest for improved operating efficiencies, automotive engineers have tried direct injection, variable valve trains, controlled auto-ignition or homogeneous charge compression ignition, and engine downsizing.

In search of a green, gutsy engine, MPT chose the downsizing strategy and put the company's 50-plus year legacy of engine acumen to work on designing a demonstration model that would decrease engine size by a whopping 50 percent and, as a result, cut fuel consumption by 30 percent—all the while delivering comparable performance.

"There has been a significant increase in the number of downsized engines on the market, with more to be introduced in the near future," said Stephenson. Downsized engines currently available include the Audi 2.0 liter-TFSI, the BMW 3.01 liter Twin-Turbo, the Mazda 2.3 liter Turbo, and the VW 1.4 liter TSI, which are all 25 to 30 percent smaller than the NA (naturally aspirated) engines they replaced. But the MPT team wanted to go even smaller.

To meet the small-yet-powerful goal, the team first chose a 2.4 liter V6 PFI (port fuel-injected) engine as the size and performance standard—typical of a Class C or D European vehicle platform (circa 1600 kg). They then set their sights on replacing it with an aggressively downsized, state-of-the-art, 1.2-liter, three-cylinder, inline engine—the I3. To be comparable with the 2.4 liter V6 configuration, the I3 engine needed to meet the performance targets for torque and power of that engine—286Nm torque at 2500 to 3000 rpm and 144kW maximum power at 6500 rpm.

To minimize size while maximizing performance (high specific power output), the design objectives included the use of a twin turbocharger system combined with state-of-the-art direct injection technology and variable valve timing.

In addition, the MPT team made the decision to manufacture the engine entirely out of precision-cast aluminum, using MAHLE's proprietary Coscast process, a solution that substantially cuts weight while providing superior performance.

Studies have shown that improvements in fuel economy are possible with increased levels of downsizing. "But as specific output increases, so do the technical challenges," said Stephenson. Those challenges include: a robust combustion system that allows a high compression ratio to maintain part-load efficiency; good low-speed torque and transient performance; real-world fuel consumption benefits through a reduction

in full-load fuel enrichment; and engine robustness and durability. "With a long list of technical challenges," said Stephenson, "we rely on finite element analysis to guide, validate, and optimize the design."

Abaqus FEA Drives Successful Downsizing

For about a decade, MPT has been using Abaqus FEA as one of its primary analysis tools. "We originally chose Abaqus because we considered it the best tool for solving the day-to-day nonlinear problems we encounter, such as those involving plasticity and contact, as well as for its ability to perform thermal and NVH simulations" said Stephenson. The broad range of capabilities in Abaqus was also important, as designing an entire engine from the ground up involves many components, a host of separate simulations, and a variety of other specialized software tools (both in-house and commercial).

The big simulation picture for the I3 required the delivery of optimum levels of friction, weight, durability, and robustness to support future requirements as an R&D platform. In addition, the engine design was to be a "blank slate" approach that was not constrained by previous engine designs and manufacturing requirements. "The concept approach was based on the use of technology that would ultimately be available for mass production techniques," Stephenson said.

With all of these factors in play—power output, gas exchange, combustion, friction, durability, manufacturability—the role of unified predictive finite element analysis was paramount. Stephenson's team utilized Abaqus to perform studies of all the main engine components, including structural analysis of the crankshaft, thermo-mechanical analysis of the head and block assembly, and thermo-mechanical analysis of the exhaust manifold.

From Zero to Sixty in Three Simulations

The Crankshaft Analysis: At the heart of the engine is the cranktrain, and at the heart of the cranktrain are the crankshaft and connecting rod. In downsized engines—with very high specific output required and very high combustion pressures resulting—the importance of structural analyses of these two components is accentuated in order to achieve durability while keeping mass and friction to a minimum. Analysis of the connecting rod was relatively simple. But analysis of the crankshaft behavior

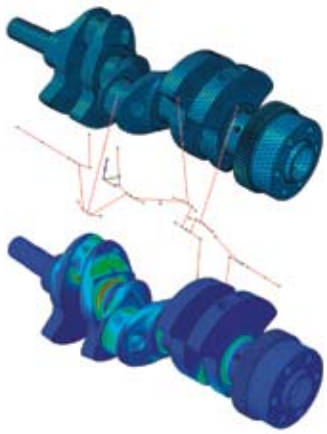


Figure 1. Dynamic simulation of the I3 crankshaft using a condensed (super element) model created using Abaqus. Abaqus FE model (top), Condensed AVL EXCITE model (center) and Abaqus stress results (bottom).

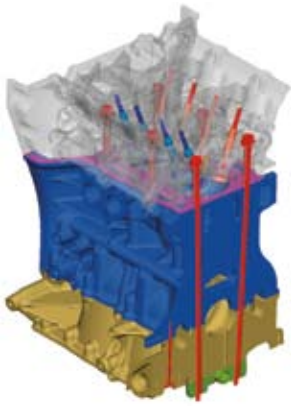


Figure 2. Cut-away view of I3 engine head and block assembly FE model.

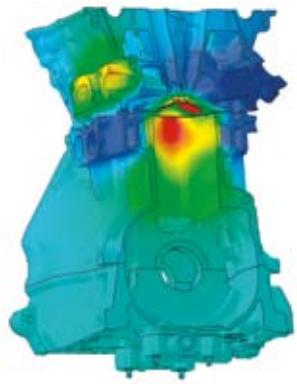


Figure 3. Head and block assembly temperature distribution for I3 engine.

was more complicated, as it included the dynamic loading of the connecting rods, pistons, pulleys, and the fly wheel, and also needed to account for torsional oscillations—all variables that Stephenson's team were able to optimize by using a flexible multi-body model.

For this dynamic analysis, the team created a condensed substructure model of the crankshaft containing 340K elements, 435K nodes, and 1.66M degrees of freedom. They imported the model into AVL EXCITE (a straightforward process due to the partnership between SIMULIA and AVL), ran the dynamic simulation, and then used the deformation results at the retained degrees of freedom to drive the full Abaqus model in order to recover the stresses (Figure 1). With the stresses in hand, Stephenson's group then ran a fatigue analysis for a full 720-degree cycle (two full rotations of the crankshaft), in the end determining the fatigue safety factors for the crankshaft. A submodel of the crankshaft journal fillets was subjected to an additional fatigue analysis to ensure that this critical region met durability requirements. Runtime for this analysis was 24 hours, utilizing a hardware set-up that was used for all analyses: 2 off 4x Dual Core Opteron 8222 3.0GHz Dell Blades, each with 32 GB RAM, running SUSE Linux.

The Head and Block Assembly Analysis: The head and block assembly is comprised of many components, including the latest direct injection technology with both injector and spark plug in the center of the combustion chamber—an arrangement that requires a more complex cooling jacket design. This required both a thermal analysis of the head and block assembly to ensure adequate cooling and a structural analysis to verify durability and head gasket sealing performance. The assembly—including block, bed-plate, nut plate, head bolts, cylinder head, head gasket, valve guides, valve seats, and valves—was extremely large, using 1.01M elements, 1.72M nodes, and 8.8M degrees of freedom (Figure 2).

For the thermal portion of the study, the team mapped htcs (heat transfer coefficients) for the cooling jacket onto the FE model from a CFD analysis. The results were used to assess the cooling around the injector and the effectiveness of the cross-flow cooling configuration (Figure 3).

For the complex structural analysis, the team included: a full nonlinear definition of the cylinder head gasket (modeled using gasket elements and separate gasket properties for each region of the gasket); plasticity for the aluminum head and block; small sliding contact (with friction) between all mating components; interference fits between valve guides, seats, and the head; and head bolt loads applied using pretension sections.

Continued on page 18

The total structural analysis required 10 separate steps (pre-assembly, cold assembly, and hot assembly and firing of each cylinder at hot assembly and cool down). In addition, the team evaluated the pressure of the gasket beads for all firing cases, as well as the durability of the entire assembly, once again performing a fatigue analysis—for high cycle fatigue (hot firing) and for low cycle fatigue (hot assembly to cool down). Runtime for this extremely complex structural analysis was more than 12 days (290 hours) and served to validate the MPT team's downsized engine design decisions. With some small changes to the head design, MPT was able to ensure that temperatures remained within limits and that gasket sealing was good.

The Exhaust Manifold Analysis: With a high-pressure turbo housing integrated into the exhaust manifold, Stephenson's team determined it necessary to conduct a transient thermo-mechanical analysis of the manifold to test the durability of the system. The team used this simulation to mimic an exhaust manifold crack test and structured the heat-up and cool-down test in three steps—seven and a half minutes at maximum power, followed by two and a half minutes at 3000 rpm, followed by a repeat of the first step.

The exhaust model was constructed with 147K elements, 410K nodes, and 1.21M degrees of freedom. From this simulation, the MPT team determined that the maximum stresses to the manifold occurred approximately 30 seconds into the heat-up or cool-down cycles (see Figure 4). They also evaluated manifold durability by comparing the plastic strain amplitude over one cycle to the strain life data for the manifold material. "In the end, our designs were once again validated," Stephenson said, "and only small changes were required in order to improve durability."

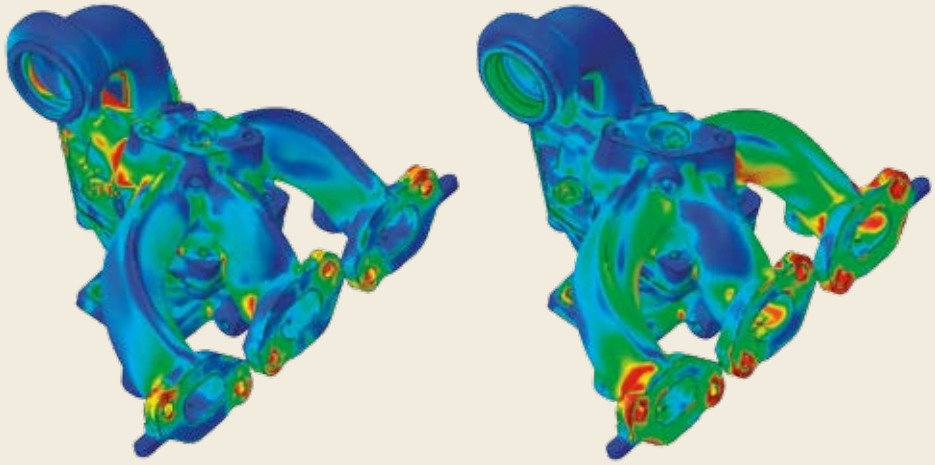


Figure 4. Exhaust manifold von Mises stress distribution 30 seconds into cool-down step (left) and 30 seconds into heat-up step (right).



Figure 5. Inline three cylinder (I3), twin turbocharged downsized engine.

From Test to Track to Thruway

"At MPT we do everything from design concept to manufacture," said Stephenson. "The designers give us their first cut and we analyze it and do two or three design iterations." In this case, analysis ensured that performance targets were met, the engine was durable, and the mass of all components was achieved.

At this stage, the I3 engines are concept level, not final designs. But as demonstration engines, their role is quite important, because they are used to test systems, new component designs, and even new fuels and oils that are in development. What's more, the I3 holds even more promise for MAHLE according to Stephenson. "We sourced as many of the components as possible from the MAHLE Group," he said. "So in the end, this engine is really the showcase of MAHLE's—as well as our R&D group's—capabilities and technologies." (Figure 5)

For now, MPT has built several demonstration I3 engines that are currently racking up hours on indoor test beds at the company's Northampton facility. In the first half of 2010, though, they will find themselves under the hood of a car and accumulating miles on the roads of Northamptonshire. Beyond that, MPT's goals for the new small but lively I3 almost certainly include a public introduction on local thruways—as part of the next generation of environmentally-friendly vehicles—thanks to engineering innovation and realistic simulation.

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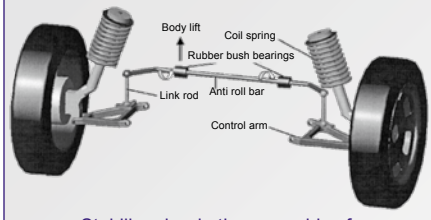
Abaqus FEA and fe-safe™ Used for Automobile Stabilizer Bar Analysis

Safe Technology, Ltd. reseller ProSIM R&D Private Limited of Bangalore, India used Abaqus and fe-safe for design verification and optimization of an automobile stabilizer bar. The study, which also involved automotive OEM Mahindra and Mahindra and tier-1 vendor Tube Products of India, analyzed the effects of bending, shot peening, and induced residual stress.

A stabilizer bar is part of an automobile suspension system. This U-shaped metal bar connects opposite wheels together through short lever arms and is clamped to the vehicle chassis with rubber bushes. Its function is to reduce body roll while cornering, which enhances safety and comfort during driving.

The study first subjected tubular stabilizer bars with varying levels of shot peening-induced residual stress to maximum load during accelerated fatigue testing. Fatigue test life, without considering shot peening effects, was found to be 11,000-20,000 cycles; life with shot peening was 60,000-78,000 cycles. Failure locations were detected in the vicinity of one of the rubber bushes.



Stabilizer bar in the assembly of suspension system.



Configuration of a typical stabilizer bar with rubber bush.

A virtual bench test using Abaqus and fe-safe was then created to analyze the bending process to estimate bending strain and its effect on life. The stress analysis found the effect of rubber bushes (modeled as hyperelastic material) to be critical. An elastic-plastic analysis was also carried out for durability assessment.

For fatigue life assessment, stress and strain history was taken from the FE analysis to fe-safe. Different simulation scenarios were considered for the durability assessment, including the effects of surface roughness and residual and mean stress.

After the fatigue analysis, crack initiation was observed near the rubber bush in the simulation. The number of cycles for crack initiation was noted to be 17,540 without shot peening, and 67,712 with shot peening residual stress. Simulation results matched well to the experimental observations, and based on this work, a design and development protocol was created for the design, analysis, and optimization of stabilizer bars—reducing time for further development activities by over 50 percent and testing effort by over 70 percent.

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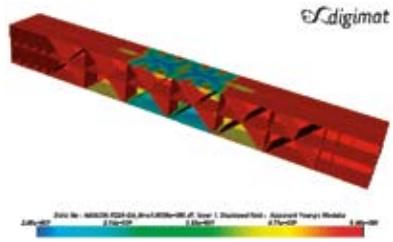
www.safetechnology.com

DIGIMAT® to Abaqus for Predictive Material Modeling

Fiber Reinforced Plastics (FRP) offer a relatively high stiffness-to-weight ratio, making them an attractive lightweight substitute for metals. In the transportation industry, the weight savings is directly translated into a substantial reduction of fuel consumption and CO_2 emissions.

The two main barriers to the use of FRP are the lack of technical familiarity and financial setbacks. These barriers can be greatly reduced with accurate modeling of the material within the structure using nonlinear multi-scale material modeling technology available through DIGIMAT to Abaqus interfaces. DIGIMAT is the nonlinear multi-scale material and structure modeling platform developed by e-Xstream engineering.

"We believe in the incorporation of fiber orientation from flow simulations into a structural simulation package like Abaqus," stated Dr. Ir. Harold van Melick, Global CAE manager DSM Engineering Plastics. "DIGIMAT is the absolute front runner in that. It is not only a trend but an absolute necessity to make simulations of intrinsically anisotropic material like glass fiber reinforced thermoplastics more realistic and to increase their predictive power."



Apparent "isotropic" stiffness of the composite material at the end of the loading. A weakening effect due to the loading (3-point bending) is fairly observable. The apparent stiffness ranges from 2.5 GPa to 5.6 GPa. Model Courtesy of DSM.

This multi-scale modeling solution can be illustrated using an injection-molded beam structure made up of polyamide reinforced with 30% short glass fibers (PAGF30). An injection molding process is used to predict the distribution of fiber orientation on the surface and across the thickness of the part and induces a complex distribution of anisotropic material stiffness that varies along the structure and with time/loading.

The DIGIMAT material is set up via the plug-in available from Abaqus/CAE where the polyamide material is modeled as an isotropic nonlinear and strain-rate dependent material reinforced with 30% short elastic fibers. The fiber orientation is an input to DIGIMAT and is mapped from the injection molding mesh to the optimal Abaqus mesh using Map. The resulting nonlinear micromechanical model is fully embedded into the Abaqus-DIGIMAT simulation.

Accurate modeling of the local anisotropic and nonlinear nature of the material results in 30 to 125% more accurate prediction of local fields such as stresses, strains, or failure indicators and global responses such as force-displacement curves.

For More Information
www.e-Xstream.com

Wright State University Explores New Methods For Damage Detection in Turbomachinery Components

Damage detection in aircraft engines and their subcomponents is an important challenge for cost, performance, and safety of systems. Due to the large amount of kinetic energy stored in the moving parts of the engine, fatigue cracks can cause uncontained engine failures, which may have catastrophic consequences. Debris flying out of the engine may damage vital aircraft systems leading to loss of control and consequent crash, or fatalities on board the aircraft after penetrating the fuselage.

During overhauls, engine components are inspected for presence of damage using one or more of traditional nondestructive evaluation (NDE) techniques such as visual inspections, ultrasonic testing, or fluorescent penetrant method. These techniques are reliant on highly trained personnel to perform the inspection and making a judgment whether the damage is present or not. It is desirable to increase automation in the inspection process and reduce dependence on human judgment when making a decision on the presence or absence of damage. Vibration-based structural health monitoring (SHM) techniques may allow achieving these goals because damage indicators in these techniques are usually obtained with minimal human involvement.

Fatigue cracks result in very little loss of material and do not have a significant effect on the natural frequencies and mode shapes. They do become observable, however, when looking at the characteristic of the crack as it opens and closes during vibration. Opening and closing of the crack result in a very localized nonlinear elastic behavior. Wright State University employed Abaqus FEA software suite to investigate the possibility of utilizing nonlinear vibration phenomena for detection of fatigue damage in turbomachinery components.

A model of a hypothetical integrally bladed compressor disk was created using Abaqus' geometric modeling module. Two cases of damage were considered. In the first case the damage was located in the flange on the downstream side of the disk. In the second case the damage was located near the root of one of the blades.

Contact interaction in Abaqus is described by selecting the surfaces that come into contact and prescribing normal and tangential interaction properties. In this work "hard contact" formulation was utilized for the normal direction. This formulation implies that the surfaces come into contact once the clearance between them reduces to zero, at which point any contact pressure can be transmitted between the surfaces. "Rough contact" interaction was prescribed in the tangential direction. This implies that no slippage occurs between the surfaces while they are in contact. This is equivalent of a friction coefficient of infinity. This choice was driven by the assumption that the crack surfaces are rough and irregular, which will prevent slippage. The baseline undamaged state was modeled by replacing the contact interaction between the surfaces with a mesh tie constraint. The model was meshed using tetrahedral elements, which introduced mistuning in the model due to variations in size and shape of the elements. Abaqus/Explicit solver was utilized to perform the simulations.

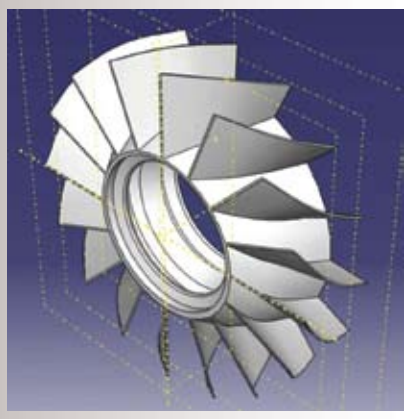


Figure 1: Compressor disk geometry.

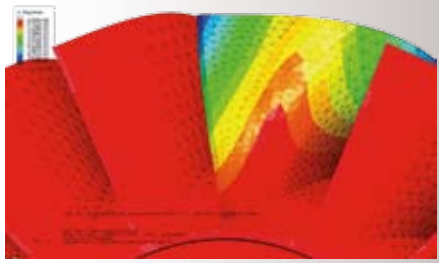


Figure 2: Vibration mode of a damaged blade.

Simulation results indicate that the response spectrum of the cracked disk contains harmonics at multiples of excitation frequency when contact occurs between the surfaces of an opening and closing crack. A super-harmonic resonance was demonstrated on a cracked blade when the excitation frequency is half of the resonant frequency.

The research team at Wright State University carries out additional studies on influences of such factors as the size of the crack and excitation magnitude. Knowledge obtained from this research should help evaluate feasibility of an automated vibration-based damage detection technology.

This article is based on the paper presented at the 50th AIAA/ASME / ASCE/AHS/ASC Structures, Structural Dynamics & Materials Conference, entitled "Investigation of Candidate Features For Crack Detection in Fan and Turbine Blades and Disks," by M. Meier, O. Shiryayev, and J. Slater from Wright State University, Dayton, Ohio, USA.

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University College London Uses Realistic Simulation to Help Develop a New Generation of Heart Valve Implants

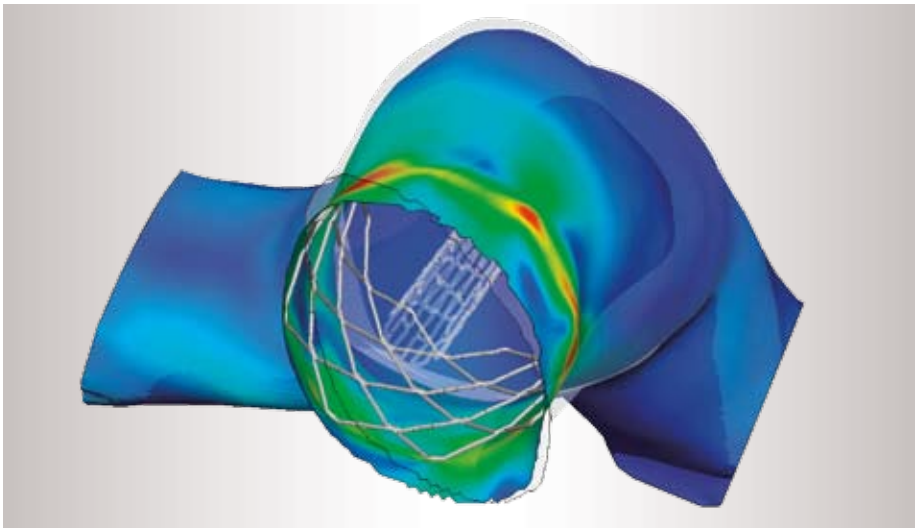
Using the latest advances in cardiac imaging and computer modeling, researchers at University College London (UCL) Institute of Child Health (ICH) and Great Ormond Street Hospital for Children (GOSH), in London, UK are developing a new generation of implants for children with faulty heart valves, potentially removing the need for open-heart surgery for thousands of patients every year.

The procedure is based on an innovative concept developed by Professor Philipp Bonhoeffer in the late 1990s: a valve from a bovine jugular vein is sewn inside an expandable stent and mounted on a balloon catheter for delivery. The catheter is inserted into a vein in the leg and advanced through vascular pathways into the chambers of the heart. Once at the desired implantation site, inflation of the balloon deploys the valved stent and anchors it within the old dysfunctional valve. This technique drastically decreases the risk of death and stroke associated with open-heart surgery and increases patient comfort, reducing the hospital stay to less than 24 hours.

This minimally invasive procedure has formed the basis for a successful clinical program that has treated hundreds of patients. However, the non-surgical procedure is currently available for only a small proportion of cases—less than 15% of patients who need valve replacements. The reason is that everyone's heart is unique. The shape and size differ from patient to patient, especially in children born with cardiac problems who have already undergone multiple surgeries. The current device (Melody™, Medtronic Inc., USA), though life-saving, was never designed to be a one-size-fits-all.

The research team's challenge is to find a way to develop implants for a wider range of patients, while ensuring optimal safety and reliability. Animal experiments in this area are of limited value because they are not representative of human anatomy. Bench tests are also of limited use because of the difficulties in reproducing the in vivo conditions with an experimental apparatus.

The researchers at ICH/GOSH, in collaboration with Medtronic Inc., will use the latest engineering technologies to create a virtual, realistic environment in which to test patient-specific implants without the patient having to enter an operating room.



Computer simulation results after device expansion in a patient specific implantation site.

Magnetic resonance (MR) and computerized tomography (CT) images of the patient's heart are the input data to study cardiac structures because they provide a reliable representation of patient anatomy and dynamics. This information can be translated in computer models (finite element method) that allow for a virtual simulation of the procedure. The results of the analysis give indications on implant performance across a variety of anatomical settings and guide the optimization process toward a robust final device design.

Unlike animal experiments and real life, computer simulations can be repeated many times, relatively quickly and at low cost: the design of the device can be modified and tested using finite element analyses until the optimal implant for the patient is achieved.

For example, a common complication of the current device is fracture, which can lead to major clinical events. Abaqus FEA software was used to understand the mechanical properties of the current device and to compare different outcomes. This led to the development of a "stent-in-stent" concept, where a first stent is placed before the valved stent. This appears to be an effective solution to reduce the device fracture rate and increase the success of the procedure, without compromising its technical ease.

Another engineering technology introduced in the study by the research group at ICH/GOSH is rapid prototyping, commonly used in manufacturing industry. A rapid prototyping system works like a printer in 3D: the machine uses a polymer to build a physical object, layer by layer. Using patients' MR and CT images as input, rapid prototyping creates a detailed 3D photocopy of the heart vessels, providing the cardiologist and/or surgeon with a 3D physical object representative of the patients' anatomy. These models enable them to physically examine the structure of the patient's heart prior to an intervention or surgery, and, if necessary, trial the implantation of a device—testing its correct and safe placement and enabling better treatment decisions.

Engineering methodologies that create both physical and virtual models are instrumental to designing optimal devices and to progress in the field of heart valve implantations. This may lead to significant reductions in manufactured prototypes and animal experiments, shorter learning curves for doctors, and fewer device failures—thus increasing patient safety and avoiding multiple open-heart surgeries.

The ultimate aim of this pioneering work is to develop methods that will enable the rapid translation of device development into safe patient treatment options.

For More Information

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Planatech Reduces Overall Production Time by 30% with CATIA Analysis

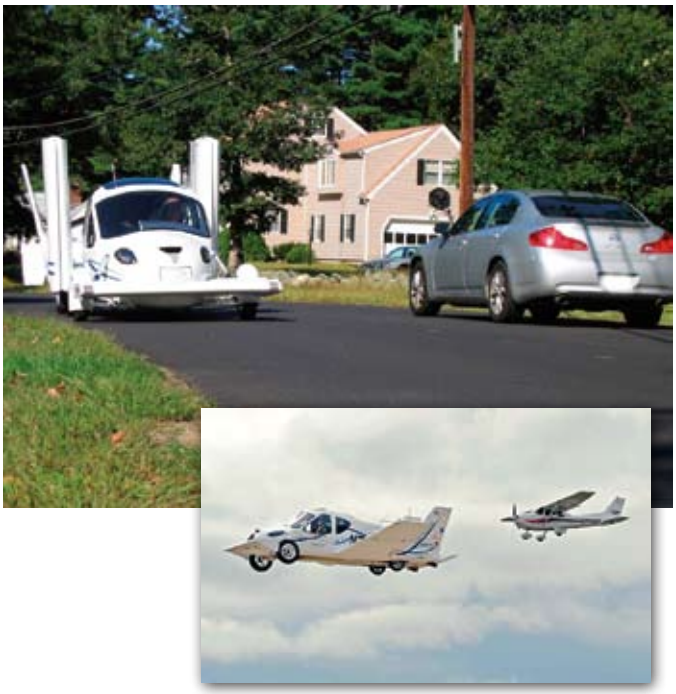


Established in 1989 as a designer of Rigid Inflatable Boats (RIBs), Athens-based Planatech expanded its activities to cover the entire design-to-production process of recreational motorboats, making it the leading manufacturer of RIBs in Greece. The company faced many development challenges starting with the necessity to quickly design new products and the corresponding tooling without compromising quality.

Planatech uses CATIA, CATIA Composites solutions, and CATIA Analysis for its boat and tooling design requirements. CATIA Analysis provides users with realistic design simulation capability within the CATIA design environment. The generative capability of the CATIA Analysis product suite allows design-analysis iterations to be performed rapidly—from simple parts to complex assemblies— and is used during the design phase to give designers a rough view of the stresses a part will endure under real operating conditions. Planatech eliminated the need for physical prototypes thanks to virtual testing with CATIA Analysis products, which helped improve the reliability of designs while promoting innovation and reducing production time significantly.

"Thanks to CATIA Analysis, we no longer need to create detailed prototypes since we can perform accurate stress tests virtually," stated Angelos Protopsaltis, Technical Director, Planatech. "We can implement innovative design ideas faster and have reduced overall production time by 30%."

>> www.planatech.com



Terrafugia Selects CATIA Analysis and CATIA Composites Design

Terrafugia, creators of the revolutionary Transition® Roadable Aircraft, has chosen CATIA Analysis and CATIA Composites Design (CPD) solutions for 3D composites and finite-element modeling to design and develop its beta prototype, with delivery expected in 2011.

The Transition Roadable Aircraft can cruise up to 450 miles at 115+mph, take off and land at local airports, drive at highway speeds on any road and fit in a normal suburban garage space. The two-seat vehicle has front wheel drive on the road and a propeller for flight, transforming from plane to car in thirty seconds.

Impressed by its success with Dassault Systèmes' SolidWorks 3D design suite, Terrafugia enthusiastically adopted CATIA Analysis and CATIA CPD as composite-focused complements to its existing design infrastructure.

For the upcoming second prototype, Terrafugia's design team is using CATIA Analysis to create preliminary design simulations rapidly, easily and within a familiar CAD environment. The solution allows the team to optimize its designs based on product performance specifications and to quickly make updates after real-world testing.

>> www.terrafugia.com



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