HEXAGON

eBook

Breaking Barriers in Engineering: Innovation in Modern Industry

TABLE OF **CONTENTS**

INTRODUCTION

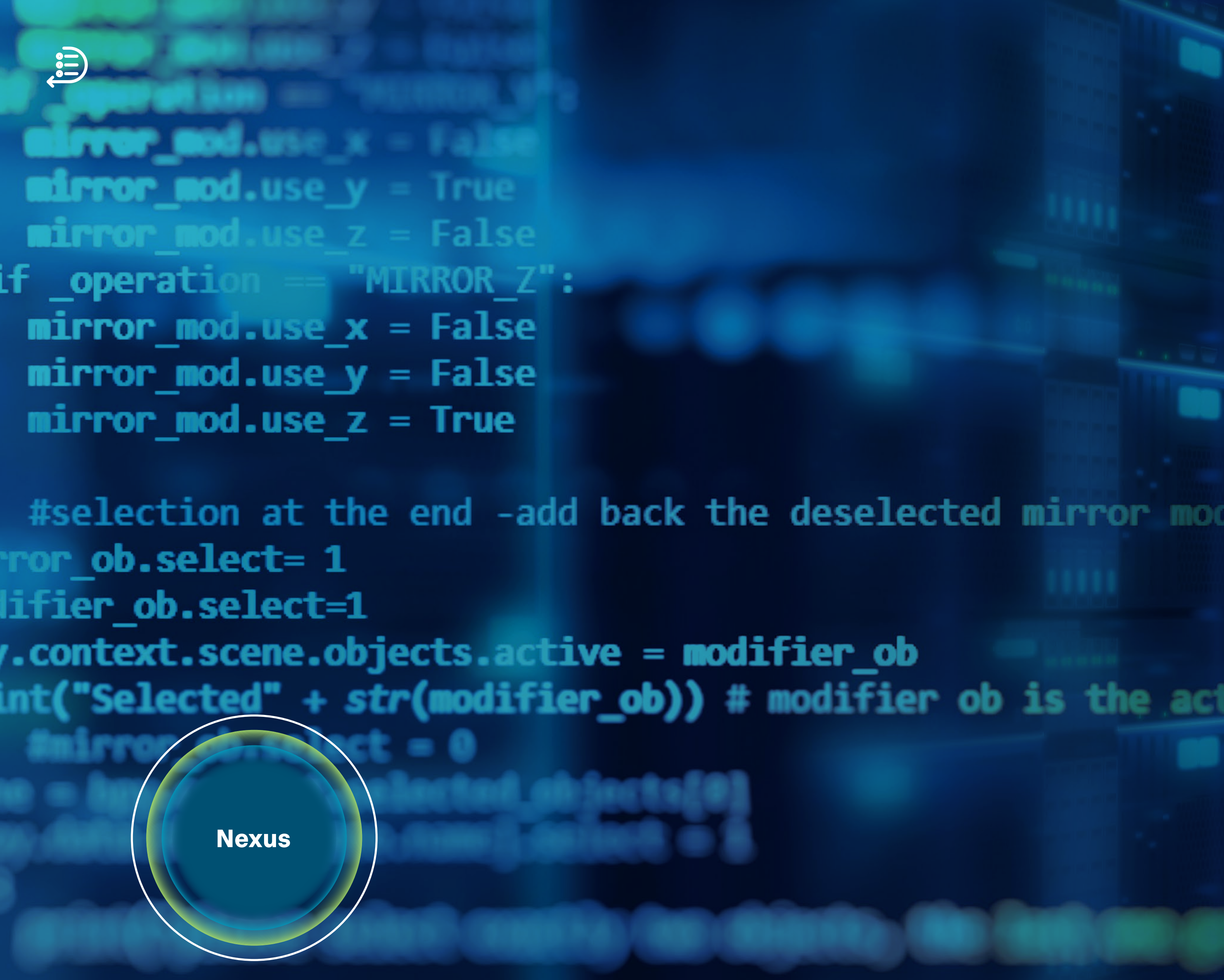
The future of multiphysics simulation is filled with endless possibilities thanks to advances in computing power, numerical methods, and artificial intelligence. It has already revolutionized several fields such as acoustics, automotive, aerospace engineering, medical devices, and environmental science, but we have only begun to scratch the surface of what's possible. The potential for even more groundbreaking applications is immense.

At Hexagon, we are deeply committed to pushing the boundaries of multiphysics simulation. By creating feedback loops with Metrology and Production, we can enhance the accuracy and efficiency of simulations, leading to better products and processes. This integration of different disciplines allows for a comprehensive approach to problem-solving, developing effective solutions that take into account a wide range of factors.

We are excited to showcase the power of multiphysics simulation through real-world case studies as our new Product Suite takes shape. These studies will demonstrate how this technology can solve complex problems and make a significant impact across industries. Multiphysics simulation has the potential to transform entire industries and solve some of the world's most pressing challenges, and we are thrilled to be at the forefront of this evolution.

Our commitment to advancing this technology will lead to even more ground-breaking applications as we continue innovating and collaborating with our partners. Multiphysics simulation will play a crucial role in shaping the future of technology and innovation, solving the world's most complex problems, and transforming industries across the globe.

Bruce Engelmann,
Chief Technology Officer
Design & Engineering business unit,
Hexagon's Manufacturing Intelligence division



The brave new world of CAE software on cloud computing platforms

By **Bruce Engelmann,**
CTO, Hexagon MI, Design & Engineering

The concept of porting CAE simulation software onto cloud computing platforms is not new (1,2). The cloud is a virtual space that combines CPUs, GPUs, software applications, and files that have been around for well over ten years. Companies such as Simscale, Ubercloud, SimulationHub, Onshape, and Rescale have all produced business models based on Computer-Aided Design (CAD) models and Computer-Aided Engineering (CAE) simulations on HPC (high-performance computing) cloud servers. These have commercial CAE software vendor products ported to large cloud-based data centres or open-source CAE software on similar platforms. Over the last 50 years, engineering simulations have progressed from mainframes to desktops and now HPC. The cloud is a natural next-step progression for CAE simulation software because of disciplines such as structural FEA (Finite Element Analysis) and CFD (Computational Fluid Dynamics). These solvers are numerically intensive and heavy users of computer resources and still take days, weeks, and even months to provide valuable data for engineering design. This ability to access increased computational resources on-demand across a product's complete lifecycle is becoming ever more critical after the COVID-19 pandemic of 2020-21 as companies across many industries pivot towards digital transformation in their manufacturing facilities.

Cloud means that CAE users can "rent" whatever they need, including compute cycles on a CPU or graphics processing unit (GPU), file storage, or both. For non-time-sensitive tasks, you can use one CPU until your simulation completes (~24 hours) or twenty four CPUs until your job is accomplished (~1 hour); for time-sensitive tasks, you can employ hundreds of CPUs to execute the task in seconds. External commercial clouds reside in data centres administered and maintained by Amazon Web Services (AWS), Microsoft Azure, or other third parties such as Rescale that bring all their security, fine-tuning, maintenance, and associated expertise to your simulation. These providers host the CAE solver, pre-processing, and post-processing software on their machines. Users interact via a browser, uploading the setup and downloading the results. The significant advantage is that the cloud can deliver HPC capabilities that expand as needed, and you only pay when you are using them – you can consider it HPC on steroids!

Digital transformation for manufacturing implements the most recent technologies to connect devices and systems, empower people with data, expand the intelligence of your enterprise, and become increasingly autonomous (Figure 1). It releases enormous value among workers and industrial assets and forever changes the manufacturing landscape. Smart Manufacturing is the widespread digitization of all manufacturing practices, from the factory floor to all aspects of a business, including product research, design, manufacturing, production, quality assessment, distribution, and service.

Smart manufacturing leverages Industry 4.0, characterized by interconnected physical-digital systems such as inspection machines that can self-diagnose and warn production of quality issues. The increased use of IoT provides connected devices and machinery with smart sensors that upload continuous data streams to the cloud for analysis. Smart manufacturing helps manufacturers become more efficient, stay ahead of the competitive curve, and explore new business models and practices. A cloud-based backbone is foundational for enabling the next generation of autonomous smart manufacturing facilities (Figure 2).

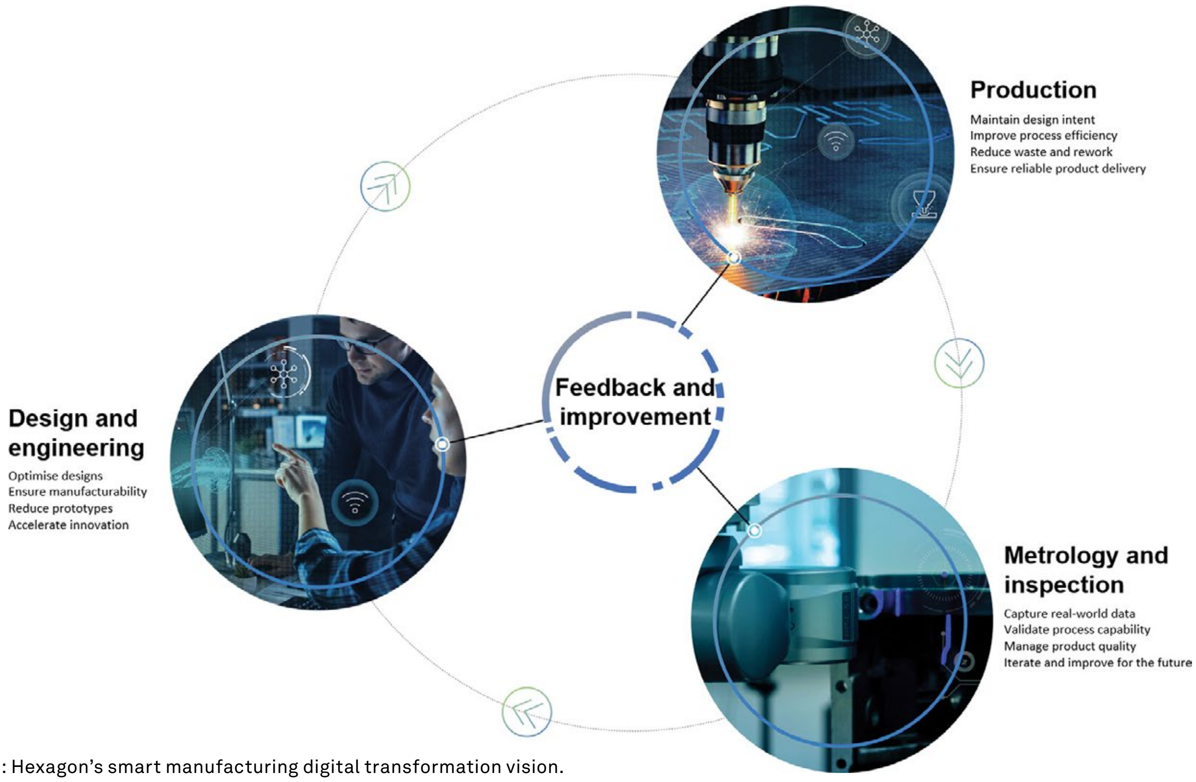


Figure 1: Hexagon's smart manufacturing digital transformation vision.

1. Realistic simulation provides the means to validate product performance and function at both the component and system levels. Connecting the data produced by simulations, test data, and engineering data back into product design can provide the means to continuously improve and optimize product design and give confidence in changes late in the process.

2. When doing design trade studies, physics-based simulations of manufacturing processes can determine the viability of production. Connected data and workflow and compute orchestration on the cloud will enable manufacturing simulations to be performed automatically as standard practice in upfront design.

3. The explosive increase in sensor and IoT data available for advanced products in operations provides us with data that feeds back into both product designs and engineering modelling assumptions. For example, data from after-market assessments on failure modes can update requirements or invoke part re-design to improve the product or warranty performance.

4. The feedback of actual manufacturing performance can inform physics-based manufacturing simulations. This data correlates and improves modelling assumptions, material parameters, loads, and boundary conditions to validate the digital twin.

5. Manufacturing processes use advanced tactile and optical metrology to derive "as-built" part geometry by comparing "as-built" to "as-designed." With the advent of a cloud-based strategy, "as-manufactured" designs can be qualified using standard design validation best practices. State of the art industrial Computer Tomography (CT) scanning measurements can be fed back to modify design engineering assumptions on the material behaviour or correct assumptions.

6. Discrete manufacturing machine data combined with part measurement data provides a rich basis for AI/ML-based models, which can relate the actual process parameters with critical measured data of parts. Physics-based simulation models can produce synthetic data, enhancing the AI/ML models much like model-based control algorithms. Together, these models can be used to provide guidance or automatically adjust machine parameters during production.

7. Earlier adoption of physics-based modelling and simulation improves quality processes in manufacturing. Scaling enabled by cloud computing allows engineers to explore uncertainty and variation of production processes, providing data for what to measure, where to measure, and how often to measure.

8. Cloud computing is a mature and reliable technology, but we have just begun to realize its full potential as an enabler of digital transformation. Cloud computing encourages business innovation with access to core business applications, analytics, and collaboration tools by providing agility to scale and adapt business models to market opportunities and conditions. Cloud computing offers the platform for a flexible innovation infrastructure for growth strategy.

The next generation of smart connected technology built on the cloud is emerging. It will employ the Internet of things (IoT), machine learning, and artificial intelligence. Cloud computing will propel companies into a new era of competitiveness by combining innovative technologies with digital business services. This new implementation of cloud computing creates a next level of customer experience. Companies will apply intelligent technologies in conjunction with the cloud to upgrade their performance and quality for their customers. So now we move to the next phase of cloud transformation - a platform. Here are some of the key elements of this next-level experience:

Fluid interoperability of data and information
The cloud allows us to redefine a single source of truth that is scalable. Gone are the days of a single centralized database managing all critical data. Our approach will connect data and data sources, exposing discoverable relationships and a minimal set of essential and shareable granular data. This connected data approach will form a digital thread that can provide an audit trail connecting data to the actions that transform and create data. It is an incremental approach that will allow our customers to adopt the cloud over time and facilitate a continuous evolution from opaque files to more transparent, open, and standardized data.

Automated workflows to amplify productivity
With scalable and elastic compute, the cloud is an ideal environment to automate processes with sophisticated workflow orchestration that can integrate processes, perform design exploration, and optimize with the simulation of hundreds or even thousands of candidates and variants.
While standardized, robust, and repeatable processes can be orchestrated, many processes are choreographed by humans and machines driven more by events and notification and appear more ad-hoc than prescribed. The digital thread weaves fluid connected data with workflow orchestration and choreography. While workflows of each type are transient, the data footprint and audit trail they leave behind is the record and enables the re-use of data and capture processes. An evolutionary approach on the road to autonomy is possible as more and more data automation is made available.

Connected products and agile end-to-end processes
While people often equate the cloud to web browser apps, the cloud works equally well to connect desktop, web, and mobile applications. Implementing data management, workflow orchestration, choreography, and connections to web services and scalable compute means that your favourite rich modelling applications can be connected to the cloud and exploit the value of a cloud platform. Cloud platform capabilities amplify an essential element of digital transformation in that the technology investments made over many years continue to deliver value.

Real-time collaboration
Real-time collaboration can only occur when desktop applications connect to a cloud platform with fluid data. You can share data and information visually with your team members and collaborate on that data in real-time.

Smart tools, analytics, and insights
Capturing the digital thread with connected, standardized data on the cloud is just the start. Visualization and predictive and prescriptive analytics can use this data to improve products and processes continuously.
In this next generation of cloud computing, we see the need for digital business to go beyond engineering, simulation, manufacturing, quality, support, and maintenance and help companies accelerate their business transformation. Manufacturers are moving towards a circular continuous innovation process, an environment that provides a fluid connected data flow boosted by the cloud. Innovation is evolving to become part of every company's corporate value and culture.
Our world can change in a blink of an eye; it is not enough to tackle current market changes with innovation. Companies need to prepare for the future and transform themselves into intelligent enterprises that can thrive on change. Smart manufacturing enables a business to stay one step ahead of its competition, and it is a vital characteristic of an intelligent enterprise. Early adopters of the next generation of cloud technology and services will be today's and tomorrow's champions.

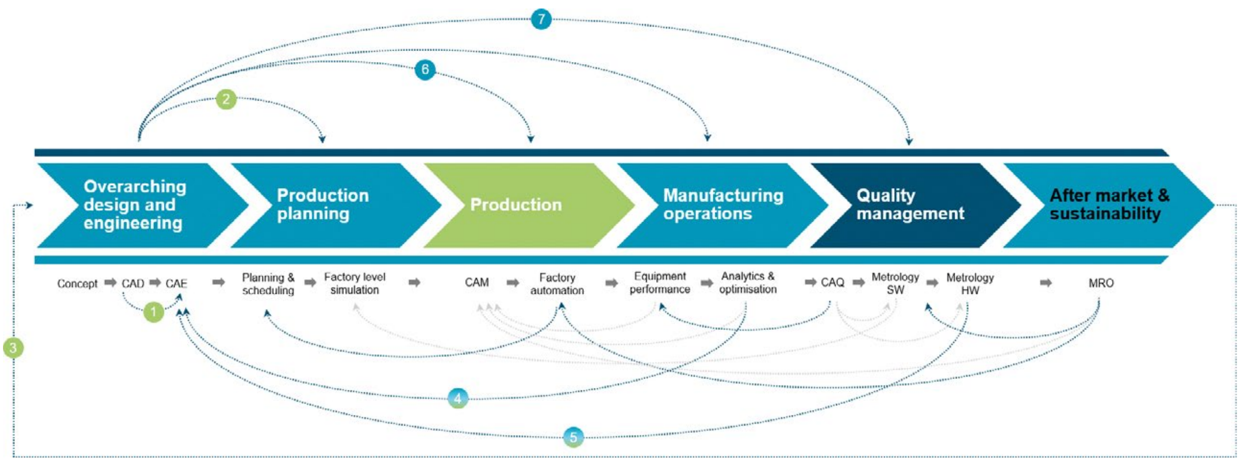


Figure 2. Smarter and more sustainable manufacturing.

Structures

Your HPC autopilot with MSC Nastran

Machine learning based memory management for MSC Nastran's HPC Solutions

By **Mukundan Selvam,** Senior Developer for MSC Nastran's HPC team
Edited by **Sarthak Sheladia,** Structures Marketing, Sarah Palfreyman, Structures Marketing Manager

> “As the need for cloud computing has grown, Rescale has created a platform to allow companies to be software driven rather than hardware driven. With our intelligent computing, everything is available on demand, including recent versions of MSC Nastran, and provided in context so engineers can focus on solving their engineering problems.”

Kevin Cangemi,
Principal, Strategic Partnerships and Alliances at Rescale

In the world of simulation-based engineering, cloud and high-performance computing (HPC) has flourished as essential to addressing the growing sophistication of models and the need to bring simulation at scale to a wider audience. Hexagon’s Design and Engineering HPC team has been innovating and providing solutions to our customers to leverage innovations in computing power for more than a decade. In addition to this, we collaborate with a broad ecosystem of Cloud and Hardware partners such as Amazon Web Services (AWS), Rescale, Microsoft Azure, Intel, Nvidia, AMD and others to accelerate and unlock the full potential of the specific hardware MSC Nastran is executing on.

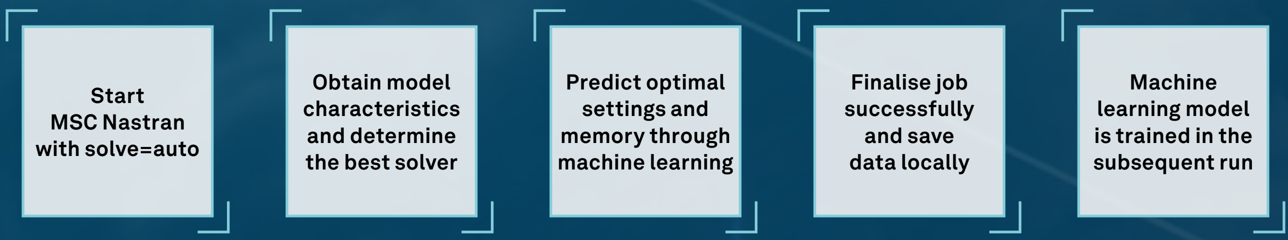
One of the best examples of MSC Nastran’s customer driven investments orientated towards tuning it’s FEA solvers for large DOF models in Cloud and HPC environments is the SOLVE=AUTO feature. This feature is a bit like an Autopilot, or like having an HPC expert at your disposal to ensure optimal performance for every run. The AUTO setting enables logic and algorithms tuned over decades that are designed to maximise compute productivity so that you can focus on the engineering task at hand and not worry about the associated IT including choice of solver, memory management or parallelism.

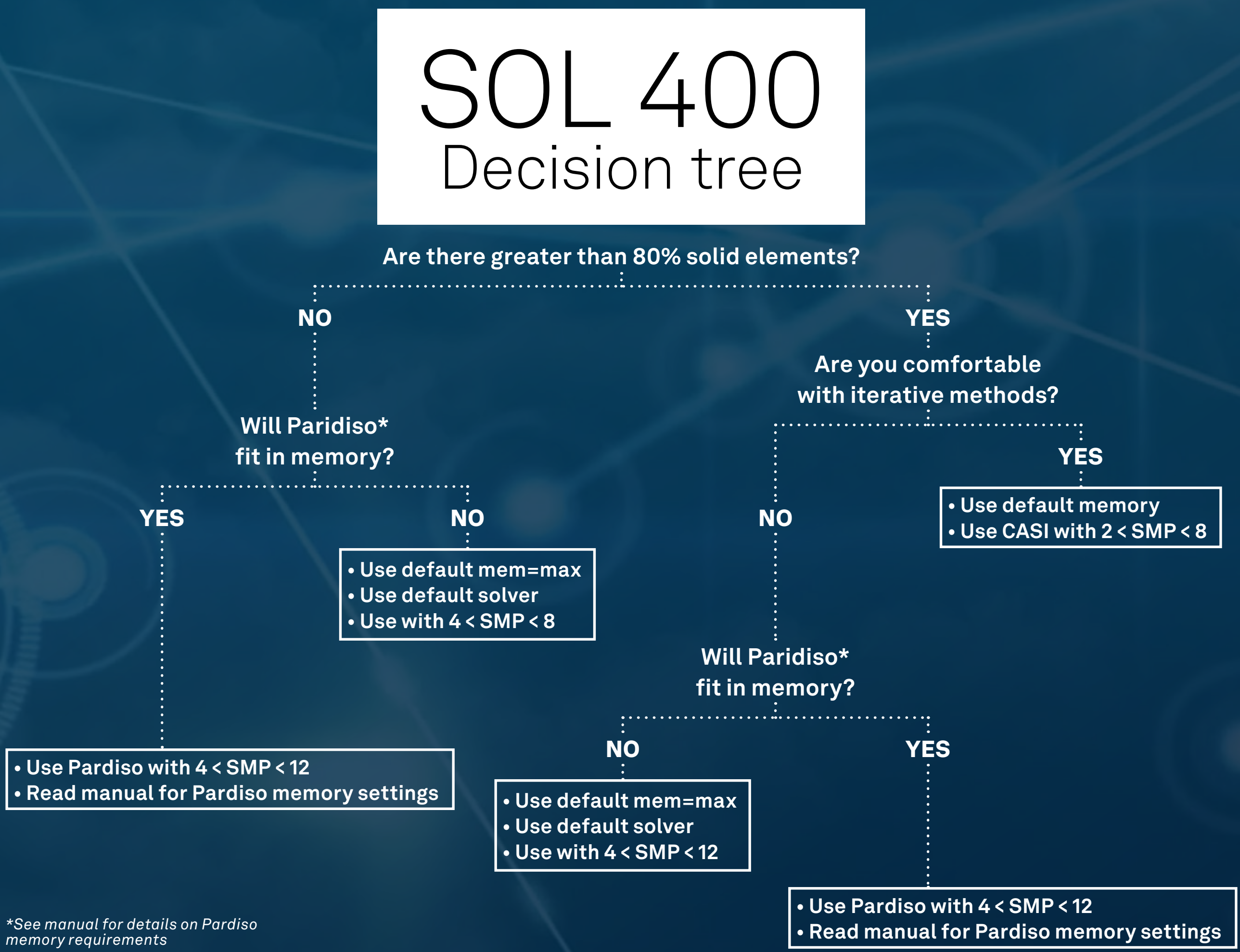
SOLVE=AUTO

As customers want to scale, be it design-of-experiment studies or building up machine learning training data sets, HPC performance really matters. Getting confidence that you have the right selection of specific solvers for your application, memory partitions and parallelism settings can be very challenging. MSC Nastran has positioned itself to maximise value for our customers by automatically determining the optimal configurations using machine learning and curated in-house heuristics.

For example, Aerospace and Automotive OEMs taking advantage of MSC Nastran's implicit nonlinear solution (SOL 400) for composite design can let the SOLVE=AUTO 'autopilot' determine if the FEA model by element count is shell or solid dominant, predict the required memory, choose between the CASI or Pardiso solver and finally set the parallelism settings.

The following diagram describes how SOLVE=AUTO works at a high level.





**See manual for details on Pardiso memory requirements*

- Determine FEA model characteristics.
- Determine the best solver (Sparse direct or iterative or Eigen solver).
- Determine memory requirement.
- Examine available hardware (memory and number of cores).
- Select solver based on the above.
- Select optimal memory and BPOOL.
- Select optimal SMP and DMP values.

To use this feature, users must append SOLVE=AUTO in their input command line.

> **"Leveraging Amazon AWS resources MSC Nastran users can take advantage of virtually unlimited compute, instant access to the latest hardware and technologies with flexible pricing and configurations - and all in a secure fashion."**
>
> **Satish Gandhi,**
> Amazon AWS Business development

Machine learning

Memory management is both challenging and also not where we expect our engineering customers to focus, if you allocate too little memory then MSC Nastran's Pardiso solver takes an efficiency hit for writing temporarily to disk and if you allocate too much memory then you are not being a 'good neighbour' in shared computing resource environments.

Now let's see the machine learning capabilities in action! [In this example,] The wall clock time reduces as the machine learning algorithm and heuristics fine tune the predicted memory required for this model. Thus, with SOLVE=AUTO MSC Nastran gets tuned over time automatically yielding a simpler experience with more optimal run times.

The machine learning models are stored securely and locally in relation to the simulation files, for further information see **MSC Nastran's Installation and Operations guide**.

Run #1 with SOLVE=AUTO
Wall Clock Time: 1796 seconds

```
MEMORY PARAMETERS FOR INTEL MKL PARDISO PARALLEL DECOMPOSITION FOLLOW
                    AVAIL. CORE MEMORY =3250 MB
     APPROX. REQUI. IN-CORE MEMORY =3531 MB
APPROX. REQUI. OUT-OF-CORE MEMORY =1804 MB
```

Run #2 with SOLVE=AUTO
Wall Clock Time: 1750 seconds

```
MEMORY PARAMETERS FOR INTEL MKL PARDISO PARALLEL DECOMPOSITION FOLLOW
                    AVAIL. CORE MEMORY =3384 MB
     APPROX. REQUI. IN-CORE MEMORY =3519 MB
APPROX. REQUI. OUT-OF-CORE MEMORY =1803 MB
```

Run #3 with SOLVE=AUTO
Wall Clock Time: 1241 seconds

```
MEMORY PARAMETERS FOR INTEL MKL PARDISO PARALLEL DECOMPOSITION FOLLOW
                    AVAIL. CORE MEMORY =3539 MB
     APPROX. REQUI. IN-CORE MEMORY =3519 MB
APPROX. REQUI. OUT-OF-CORE MEMORY =1803 MB
```

Getting started today

If you don't have your own on-premise or cloud solution to leverage MSC Nastran's 'autopilot', Hexagon and Rescale have partnered to offer a turnkey solution for our MSCOne solutions. This involves a well-defined support process and available solution architects to help you get started in addition to a promotional offer of $10,000 free HPC cloud services. If your company prefers to run directly on cloud providers like Amazon AWS, we have a well-documented deployment guide to help you and your IT team execute on our software in the Cloud. Hexagon's Structures Centre of Excellence can provide benchmark data and cost guidance to make your decisions easier.

PDF

Download MSC Nastran HPC benchmark timings for vibroacoustics: hexagonmi.com/HPC

MSC Nastran HPC notable achievements

Being one of the world's most heavily and widely used HPC Finite Element Solvers, MSC Nastran developers have constantly optimised the matrix solution times, reducing the cost of input/output and increasing parallelism to achieve the best performance. You can read more about MSC Nastran's HPC performance in a recent set of benchmarks.

Its not just about continual HPC performance improvements, it's about performance in a smart and innovative way. The MSC Nastran HPC team will be investing in the future to use more machine learning in more solution sequences and to leverage AI & collaboration innovations such as reduced order models, super elements, and modules.

For example, soon the team plans to support modules in MSC Nastran implicit nonlinear (SOL 400) to allow users to integrate and exchange different nonlinear FEA models from different departments and suppliers innovating on the way OEMs can improve the performance for models with geometric nonlinearity, material nonlinearity, contact and damage.

Some of the notable achievements over the past few years are, but are not limited to:

2021:

> Mumps distributed sparse direct Solver for linear statics.
> Pardiso parallel performance improvements for Non-linear analyses.

2020:

> Improved scalability of FASTFR, MPYAD utilising Nvidia GPU cards.
> Improved parallel performance for Accelerated ACMS.

2019:

> DMP Implementation of modal participation factor calculations.
> Improved performance of the RANDOM module.

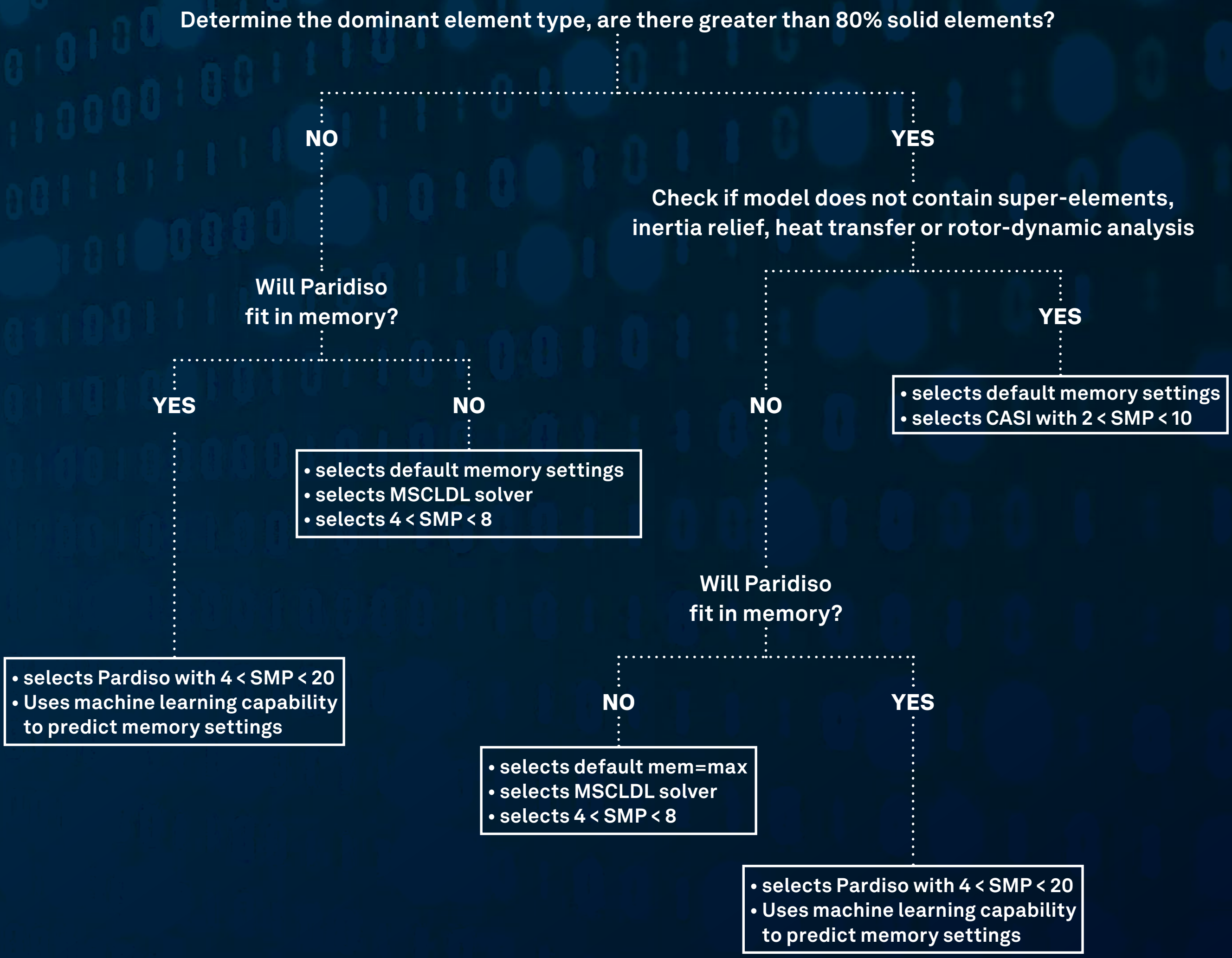
2018:

> Machine learning and automatic solver section option.
> SOLVE=AUTO is available for the following solution sequences.

	Linear Statics SOL 101	Normal Modes SOL 103	Direct Complex Eigenvalues SOL 107	Direct Frequency Response SOL 108	Modal Frequency Response SOL 111	MSC Nastran optimisation SOL 200	Implicit Nonlinear SOL 400
SOLVE = AUTO	Y	Y	Y	Y	Y	Y	Y
Machine learning with Pardiso Solver	Y	N	N	N	N	N	Y

*Current supported solvers as of R2021.4 for MSC Nastran's SOLVE = AUTO are our proprietary solvers MSCLDL, MSCLU and solvers such as Lanczos, ACMS, CASI and Pardiso.

SOL 400
Solve = auto decision tree



Author Profile

Mukundhan Selvam is a Senior HPC Development Engineer at Hexagon. With a background in Aerospace engineering and scientific computing, he has been devising numerical solutions and HPC enhancements for MSC Nastran for more than 5 years. Contributions to MSC Nastran include machine learning and automatic solver selection, Pardiso Sparse Direct Solver, Mumps Distributed Sparse direct solver, and performance enhancements utilising nVidia GPU's. In his free time, he spends his time in developing bots for HF algorithmic trading and racing in his motorcycle.

Automotive

Honda Motor Company engineers cut workflow times by 50%

MSC Apex allows Multibody Dynamics Engineers and Structural Analysts to share a common user experience during their development process, resulting in cutting workflow times by 50%

By **James Pura**, Product Marketing Manager, Hexagon

Today, drivers of modern automobiles take it for granted that their new car prevents them from spilling their drinks as they drive over a speed bump. It's also pretty much guaranteed that your steering wheel won't shake at high speeds when you're on the highway. And probably most important of all, in case of an accident or crash, there's a good probability that you and your family have a high chance of surviving.

These things were not always guaranteed. We have our global automotive engineering community to thank for making these things common amongst the cars we drive today, and at the heart of engineering these designs is an immense amount of mechanical and structural simulation using MSC Nastran and Adams Car - two products that have been at the heart of automotive engineering innovation for decades.

At Honda Motor Company, headquartered in Minato City, Tokyo, Japan, the automotive engineering worlds of "structures" and "mechanics" are incredibly important to the design of a new car. But up until recently, these have been separate groups that historically had very little overlap. Both are heavily involved during the design process, but since each group had different teams of engineers, used different software tools, built different models, and ultimately searched for different answers from those software models, there wasn't an easy way to combine these engineering insights to get a clear high-level picture of how a new car design would behave in the real world.

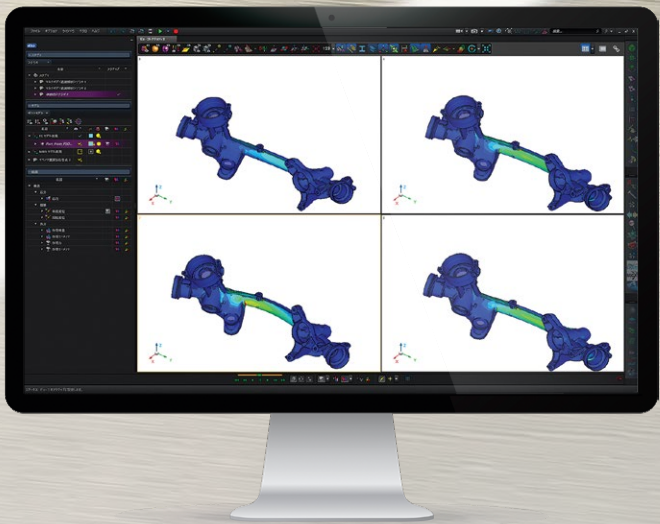
Until recently, multibody dynamics engineers using Adams simulation software were separate from the structural engineers using MSC Nastran finite element software. The engineering leadership team at Honda needed a solution.

Engineers at Honda evaluated MSC Apex as a potential solution to this efficiency issue. Three main driving factors attracted engineers at Honda to MSC Apex – pre/post-processing for the MSC Nastran solver, pre/post-processing for Adams Car (which has the same user experience as MSC Nastran pre/post), and finally the robust Python scripting capabilities allowing them to customise the application to their needs and automate specific tasks to speed up the entire process.

"The engineering team introduced me to MSC Apex and the future plan, and I was very impressed," said Shigeki Nomura, Assistant Chief Engineer at Honda Motor Company. "We knew this was the future of engineering simulation."

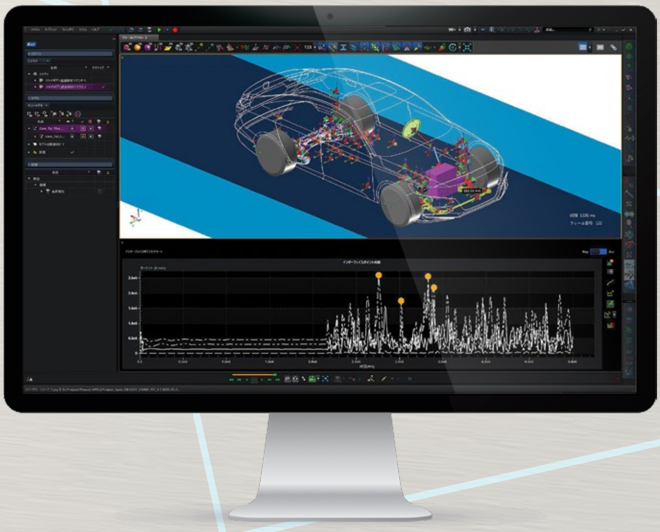
> **"The time required for model creation, analysis preparation and post-processing was shortened by 50%."**
>
> **Shigeki Nomura,**
> Assistant Chief Engineer, Honda Motor Company

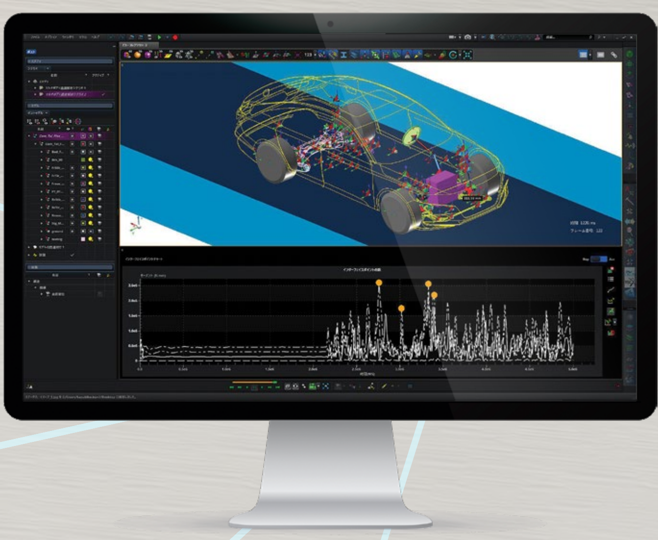
After the initial evaluation, MSC Apex had the possibility to achieve the previously impossible task for Honda – combining mechanical analysis and structural analysis, from two solvers they've trusted for decades – Adams and MSC Nastran. Since MSC Apex can handle both simulation results in the same tool, it had the possibility of increasing the efficiency of its engineers by being able to speak a common software language. In addition to this, MSC Apex's Python scripting enabled additional process automation, which sped things up considerably as well.



In addition to time savings, Designers, Testers, and Analysts were all able to use a common model in MSC Apex, giving a holistic view of the structural and mechanical behaviour of the car.

Due to these inspiring initial evaluation results, engineers at Honda plan to use MSC Apex for mass production model development from now on for their future vehicle designs.





Aerospace

Embraer’s engineers develop aircraft parts and assemblies 3x faster with higher quality

By **Adriano Passini,** Manufacturing Engineer, Tooling Engineering, Embraer S.A. and **Renato Ghiro,** Application Engineer, Hexagon Manufacturing Intelligence

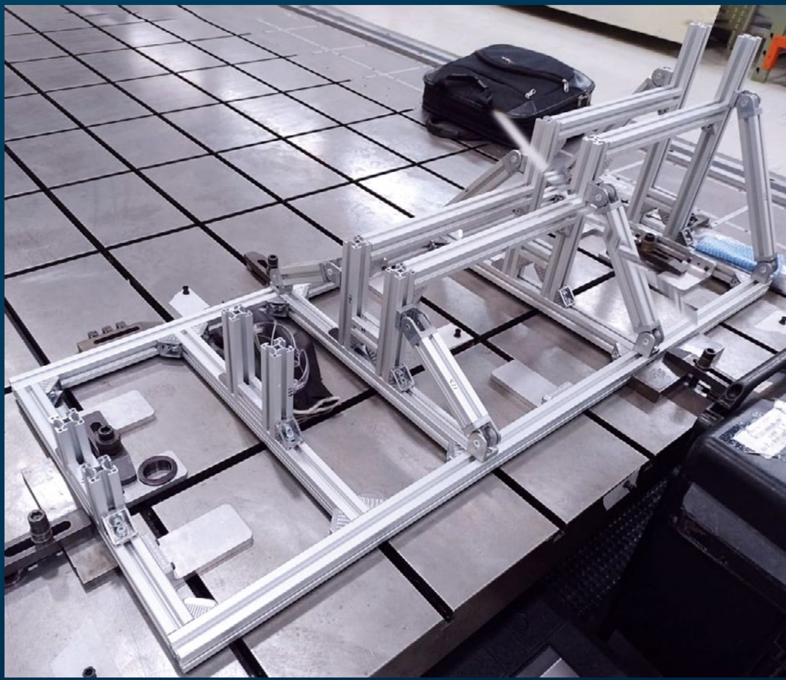
A global aerospace company headquartered in Brazil, Embraer designs, develops, manufactures, and markets aircraft and systems, providing customer after-sales service and support.

Since its founding in 1969, Embraer has delivered more than 8,000 aircraft. On average, every 10 seconds, an aircraft manufactured by Embraer takes off somewhere worldwide, transporting more than 145 million passengers a year. Embraer is the largest manufacturer of commercial jets with up to 150 seats and the leading exporter of high-value-added goods in Brazil.

Overly complex analysis software leads to frustration, lack of design optimisation

Because many aircraft components must be lifted and turned during manufacturing, resulting in potential safety hazards, ergonomics must also be a priority to ensure good work conditions for the workers on the shop floor. And so, aircraft wings, fuselages, vertical and horizontal stabilisers, and flight control components must be designed with the tooling in mind. Safety is paramount, and Tool Engineering is responsible for precisely simulating all parts providing an acceptable safety margin before anything is built. Structural analysis is needed to ensure that the design meets all the requirements before a build can occur and to develop tooling structures that are as ghtweight as possible. This trade-off often requires several iterations.

Embraer's engineering team previously endured an incredibly complicated and time-consuming model-building experience to analyse the tooling structures. This excessive time the team spent modelling and meshing took away from the time they would have spent making design iterations. This led to design decisions with overly conservative safety margins, yielding heavier structures and non-optimal designs.



Aluminium structure for the lifting device.

Embraer saw a boost in efficiency and speed without jeopardising quality

Embraer realized that to address this issue they needed a streamlined solution that met their needs. The new solution had to address cleanup, and enable a modern, more appropriate mixed mesh element types to suit the geometry. For finite element analyses within highly elastic and plastic structural domains, hexahedral meshes have historically offered some benefits over other finite element meshes in terms of reduced error, smaller element counts, and improved reliability. However, hexahedral finite element mesh generation continues to be difficult to perform and automate, with hexahedral mesh generation taking several orders of magnitude longer than current other mesh generators to complete. When evaluating new solutions, they implemented the hexahedral meshing technique in MSC Apex, which effortlessly yielded a much higher-quality mesh. Engineering teams could complete the meshing task three times faster than before.

> **"MSC Apex has improved the quality and decreased the time of all the analyses compared with the previous CAE software. With the same number of engineers, we can deliver more results than before."**
>
> **Adriano Passini,**
> Manufacturing Engineer, Embraer

"The first time I used MSC Apex, I realised it was efficient and useful based on the time I saved. Midsurfacing and surface meshing in MSC Apex gave an excellent result. Some geometry cleanup and corrections were needed, but these tasks were easy due to tools like Defeature and Vertex/ Edge Drag," explained Adriano Passini, Manufacturing Engineer at Embraer.

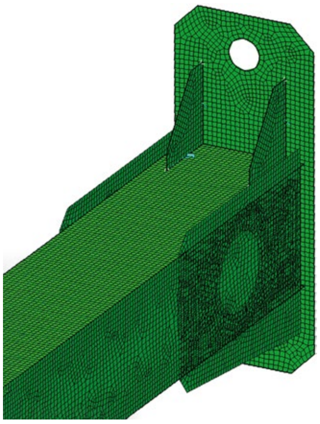
He continues, "The connections MSC Apex automatically created between different surfaces gave me more confidence. The methodology of evaluating the mesh with different kinds of parameters was the confirmation of a good job. The results in post-processing were even better. The animation of the simulation makes it easy to understand the direction and the intensity of displacements, and even helped to explain the results better to the engineers and managers involved in the design."

Most of the shop floors at Embraer facilities are not climatised, and the temperature difference between winter and summer can range from as low as 10 °C to as high as 30 °C (50-90 °F). Depending on some parts' dimensional requirements, simulating the tooling's thermal expansion is critical to ensure manufacturing precision. Further, the aircraft component is placed in an autoclave along with the tooling for manufacturing composite parts. The temperature inside can reach 180 °C of range (356 °F), causing thermal expansion in the tooling.

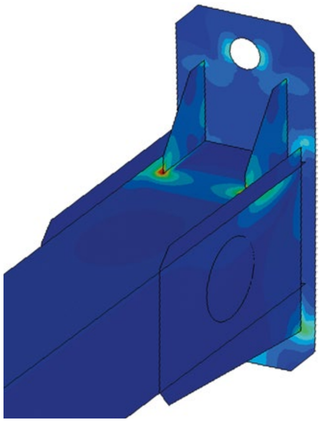
MSC Apex can perform analysis to study the thermal behaviour of a tooling device, allowing the effect of temperature to be predictable for manufacturing engineers. At Embraer, engineers needed to easily apply these two loading conditions to understand the direction of tooling thermal expansion and stresses. Doing so allowed them to choose the best design and material for these structures.

"The first time I used MSC Apex, I realised it was efficient and useful based on the time I saved."

Adriano Passini,
Manufacturing Engineer, Embraer



The surface meshing of the lifting device.



Lifting device von Mises stresses.

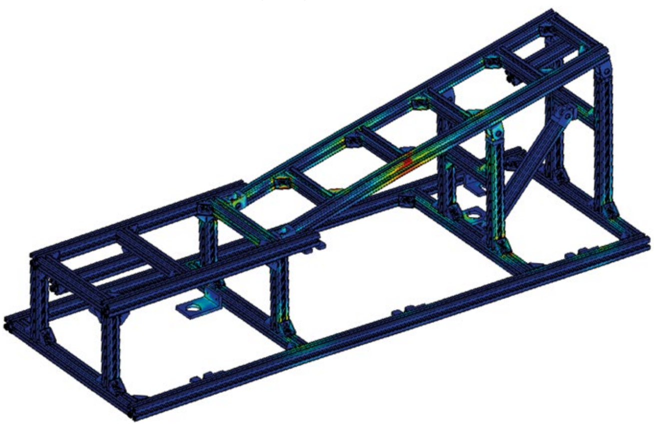
Engineering tasks completed three times faster

After switching to a solution that provided a unified environment for linear, nonlinear, and thermal analysis, Embraer's engineers could complete their work three times faster than previously possible.

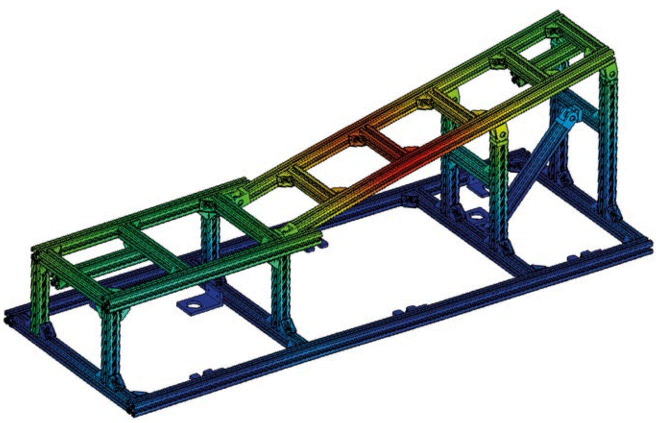
"MSC Apex has improved the quality and decreased the time of all the analyses compared with the previous CAE software. With the same number of engineers, we can deliver more results than before," Passini explains. "Furthermore, the MSC support team added more efficiency because of how fast they gave us answers when we needed them. We plan to expand MSC Apex utilisation for more applications to reduce even more costs and time in engineering simulations."

Faster and more efficient without compromise

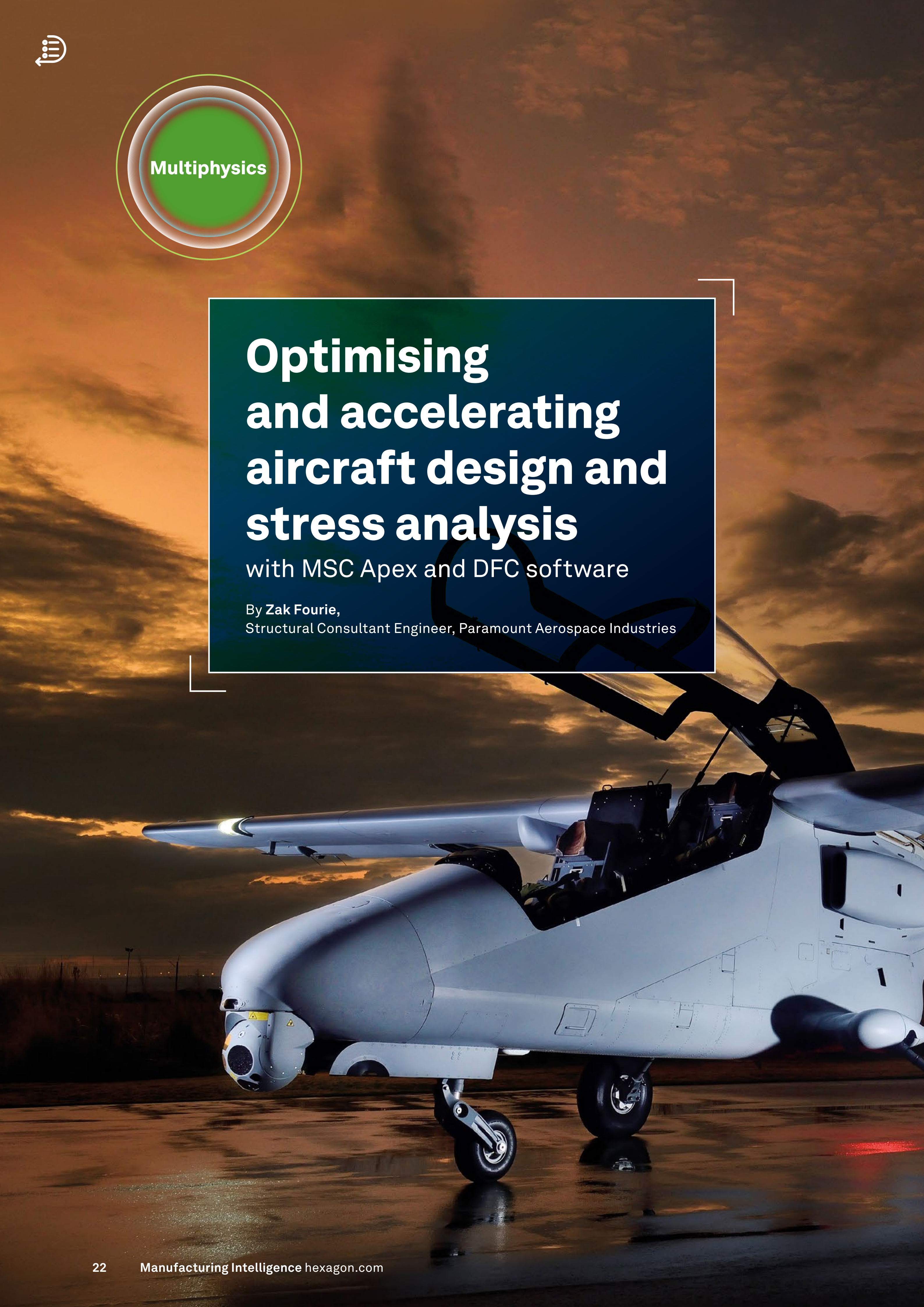
The new modelling environment allows Embraer's engineers to perform tasks three times faster than its previous software package. Its engineers no longer have to approximate structural models, leading to efficient parts, and Embraer can now perform efficient tooling analysis for metallic and composite components. The aeronautics manufacturer has increased speed, accuracy, and efficiency without compromising ergonomics or safety.



Stress in the modular aluminum structure



Displacements in the modular aluminum structure



Multiphysics

Optimising and accelerating aircraft design and stress analysis

with MSC Apex and DFC software

By **Zak Fourie,**
Structural Consultant Engineer, Paramount Aerospace Industries

In 2009, Paramount Aerospace Industries worked with Aerosud, a South African aeronautical design and production company, to create the Advanced High performance Reconnaissance Light Attack (AHRLAC) aircraft. Designed in Africa for low-cost operations, AHRLAC was envisioned as a cost-effective, multi-role surveillance and counter-insurgency aircraft with a modern and sophisticated design and advanced sensor and mission systems.

By coupling MSC Apex with the DFC software from Accentus Aero, engineers were able to build a link between CAD designs and certification-ready stress reports. After the initial testing phase, MSC Apex emerged as the core tool for preparing analysis jobs for MSC Nastran. It provides a GUI to assign structural properties such as joint data and material, and to extract loads. DFC software was then used to generate the calculation files, analyse structures, and interpret results.

"Thanks to MSCOne, we have access to MSC Apex which accelerated the FEA modelling of advanced aerostructures and assemblies. What took months to build models with just a little bit of structural detail, now took weeks for models that had CAD-like representative detail. Structural detail and manufacturing design principles weren't an obstacle anymore."

Zak Fourie,
Structural Consultant Engineer, Paramount Aerospace Industries

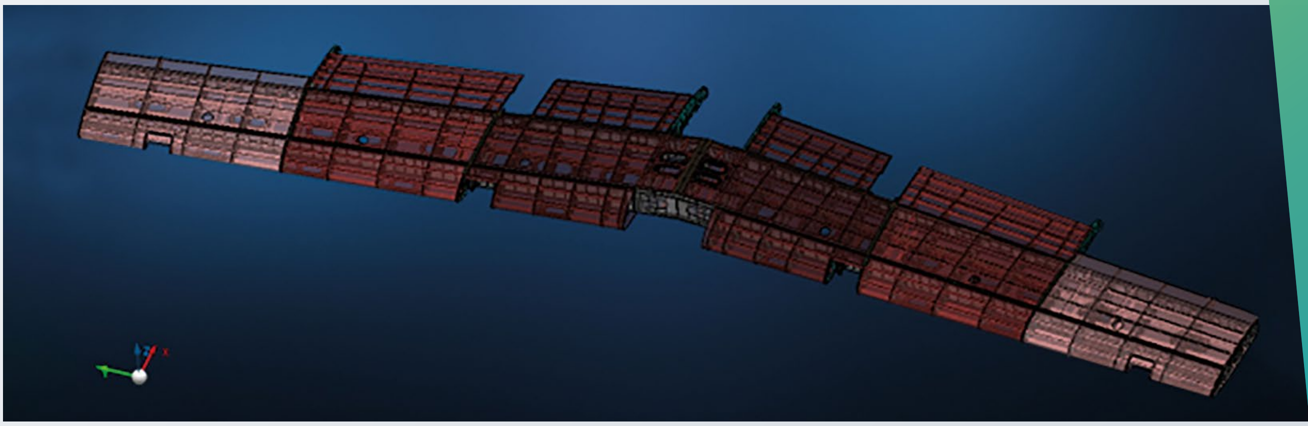


Figure 1: The main AHRLAC wing structure modelled in MSC Apex.

Challenge

Given the advanced geometries and load cases of the AHRLAC aircraft design and its purpose, using traditional calculations for structural analysis was nearly impossible. The CAD geometries needed to be accurately modelled for meshes, connectors, materials, and boundary conditions so that rapid and accurate answers could be achieved by the engineering team to validate aircraft designs.

In addition, Paramount Aerospace was a customer of the MasterKey licensing system, which meant they did not have access to the latest analysis software, including MSC Apex. Building a full finite element analysis (FEA) model using the MasterKey system was going to take longer than the engineering team had available. They needed results, together with a flexible user interface that enabled them to interpret MSC Nastran answers quickly and easily with a minimal amount of training.

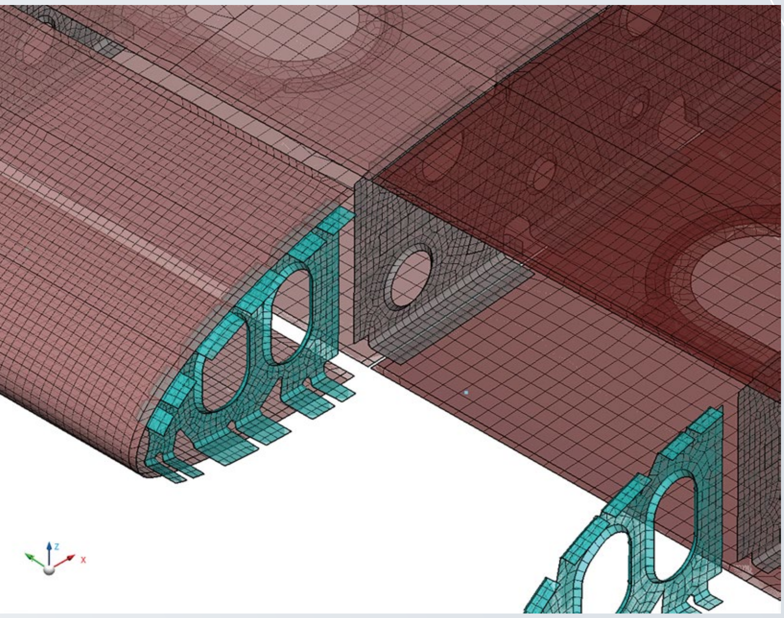


Figure 2: A section of the AHRLAC wing CAD model imported directly into MSC Apex.

Solution

Paramount Aerospace Industries migrated to MSCOne giving its engineering team access to the full set of Hexagon Design and Engineering software portfolio. This accelerated their stress analysis activities and workflows. Paramount's engineers could duplicate the designed assemblies and parts in MSC Apex, and then generate the required meshes, assembly connections, material characteristics, loads and constraints. MSC Apex was the core tool used for preparing analysis jobs for MSC Nastran while providing a nice, user-friendly interface.

Using MSC Apex's parts-and-assemblies approach to a finite element model enabled the Paramount engineers to efficiently model their aircraft. The finite element models for parts and assemblies could be modelled as a complete structure.

Paramount went beyond the MSC Apex-enabled accelerated workflow. It used the new DFC software to generate calculations from the loads it extracts from MSC Nastran. DFC also enabled the engineers to visualize reserve factor (RF) maps of each part.

Aerosud used the open-source customisation capabilities in MSC Apex. Using the built-in Python programming language, it built DFC software, a post-processing and results interpretation toolset. DFC helped the engineers to structure their analyses while applying the correct calculation techniques to the appropriate geometries, meshes and structures.

DFC extracts the internal loads generated by MSC Nastran and organizes the finite element data by part or by section, depending on the engineer's requirement and modelling preferences. It uses the load extraction data in the applicable calculation relevant to the part or structure involved to generate a Reserve Factor (RF). The RF calculation is then published and linked to a stress report and certification-ready documentation. All documentation is traceable and can be reviewed by fellow and independent engineers.

> For one engineer, the entire wing assembly structure modelling task took less than 3 months. Linking it with DFC and creating automatic analyses and calculation files took less than 6 months. This was unprecedented and was a very welcome acceleration in development time."
>
> **Zak Fourie,**
> Structural Consultant Engineer,
> Paramount Aerospace Industries

Results

Using MSC Apex with DFC software for MSCOne emphasised the value of the licensing system for creating CAE models. Paramount's engineers could now focus on model generation to create DFC models. Then, structural engineers could test the stress results. This expedited the engineering stress analysis workflow by removing the need for the stress engineers to generate FEA models. Instead, they could use their time to interpret the stress results, recommending improvements and certifying the new aircraft design.

This combination of Hexagon's Design and Engineering software and DFC software (part of the MSCOne XT licensing system) enabled an aircraft OEM to streamline structural analyses and accelerate development.
With these tools, certification-ready stress analyses can be reduced from years down to months.

About Paramount Aerospace Industries

Paramount Group was formed in South Africa in 1994 with the bold goal of helping African governments better protect their countries. Today, they're a global corporation, leading the way in global defense and aerospace innovation.

Paramount has more than 3000 employees worldwide, working with sovereign governments across five continents and manufacturing in Africa, Asia, and the Middle East.

The AHRLAC aircraft is currently in production and has generated massive interest worldwide.

About DFC Software & Accentus Aero

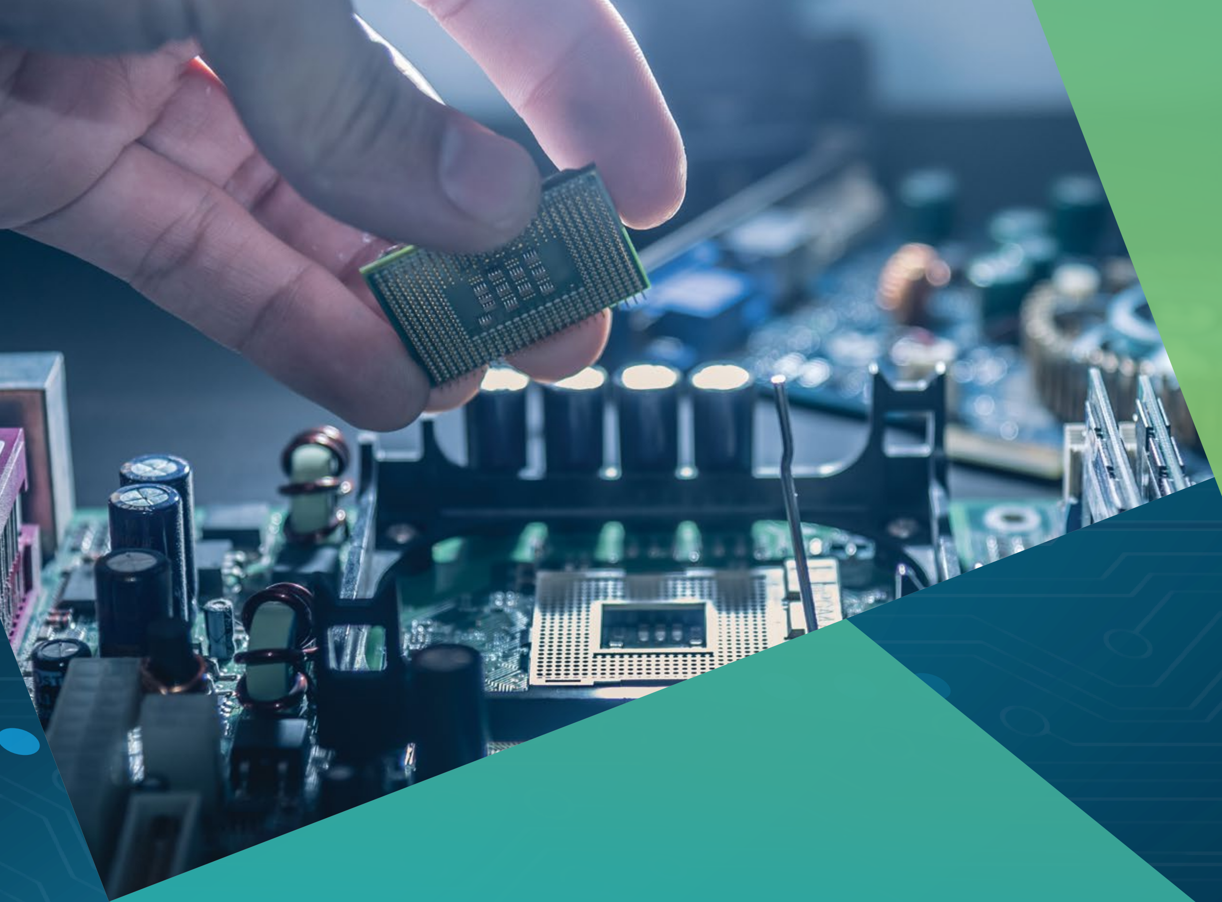
DFC software has been developed and used by Aerosud for more than 20 years in its aerostructure and aircraft interior projects. The commercial version of DFC is now available through Accentus Aero, a company founded by the lead designer of DFC software. The solution is also available within the MSCOne XT partner program.

Optimising aircraft design and stress analysis. Learn more about CAE: hexagon.com

Electronics

Warpage prediction of printed circuit boards

at Western Digital Corporation



Western Digital Corporation in San Jose California is a leading provider of hard drives, solid-state drives, memory cards, and USB flash drives. All products rely on quality printed circuit boards (PCBs). Manufactured from layers of conducting and non-conducting materials, PCBs experience severe thermal cycling and thermomechanical stresses during the manufacturing process. They may warp due to cooling down to room temperature after being subjected to high temperatures during the manufacturing process. Hence, due to differences in the thermal expansion coefficients of materials, residual stresses may lead to unintended deformations illustrated in Figure 1. The resulting warpage can damage soldered connections, which compromises the product performance.

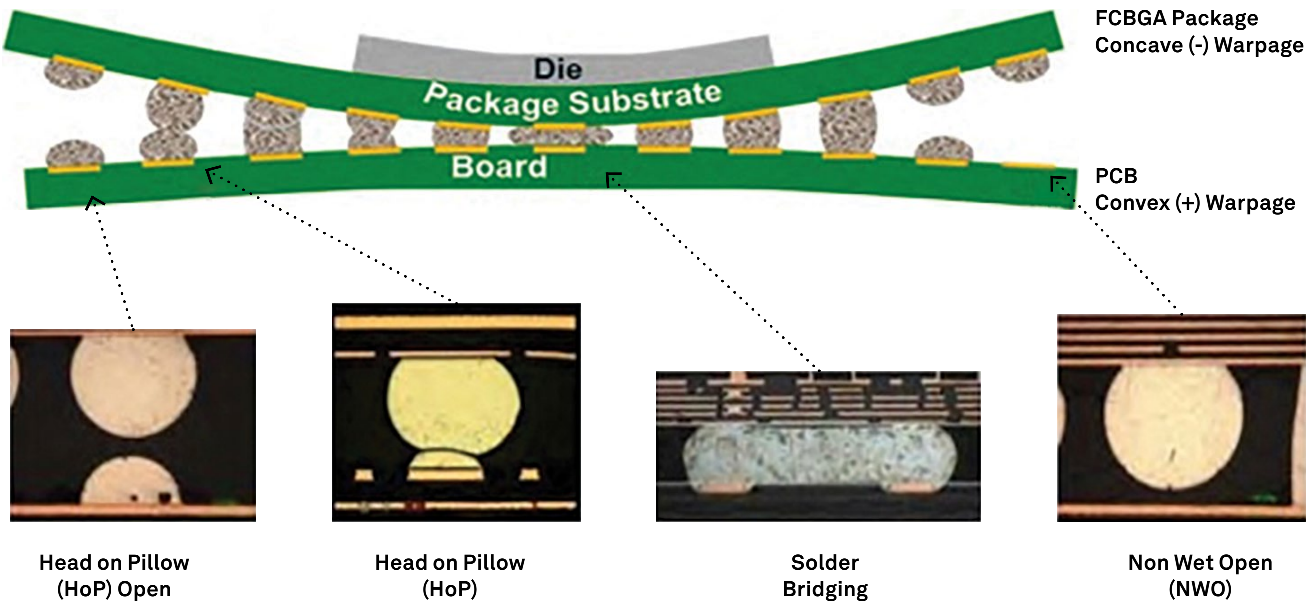


Figure 1: PCB failures due to warpage after the manufacturing process

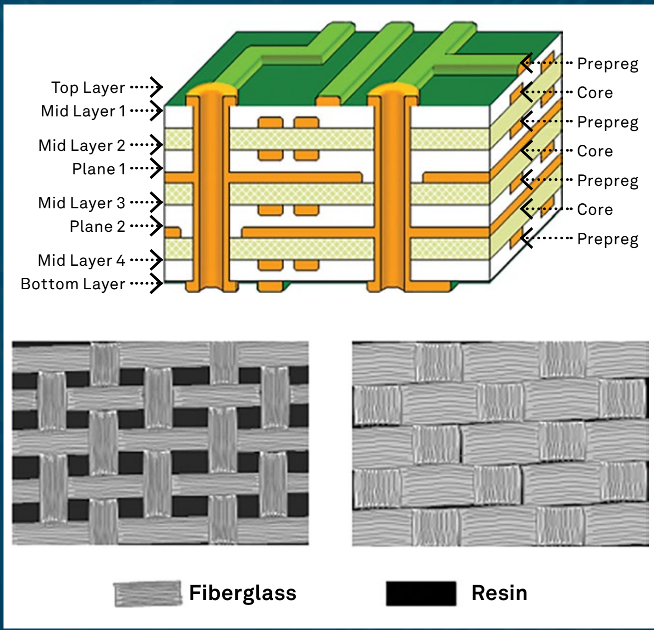


Figure 2: PCB composite materials

As illustrated in Figure 2, a PCB (Printed Circuit Board) is a composite material made of multiple isotropic and anisotropic materials stacked up in layers. These layers mainly consist of copper and prepreg. The copper layers provide the PCB with electrical conductivity, and the prepreg layers provide the PCB with flexibility and mechanical strength. Copper is an isotropic material for which the material properties can easily be found in datasheets. Prepreg, however, is composed of an epoxy resin reinforced with glass fibres. These layers are anisotropic, and their material properties differ in different directions. Furthermore, the different prepreg layers in the PCB can have different thicknesses and densities of epoxy resin and glass fibres. Hence, experimental characterisation of PCB properties is complicated and time-consuming.

To predict PCB warpage using engineering simulation tools requires three steps. First, it is necessary to evaluate the anisotropic material properties of the prepreg layers with different thicknesses and densities of the constituent epoxy resin and glass fibres. Next, the prepreg material properties are used along with the stack up to determine the PCB material properties. Finally, the PCB material properties are used to predict the PCB warpage. Based on the constituent material properties and microstructure parameters, a multi-scale material modelling technology implemented in Digimat-MF from Hexagon helps enable efficient prediction of the anisotropic prepreg material properties for different configurations. In this framework, the prepreg material properties corresponding to a single given thickness and composition of epoxy resin and glass fibre have been characterised experimentally. Because the glass fibre properties are known from datasheets, it is therefore possible to reverse engineer the material properties of the epoxy resin. Thanks to the reverse-engineered epoxy resin properties and known glass fibre properties from datasheets, Digimat-MF can be used to predict the prepreg properties of any thickness and density of epoxy resin and glass fibres, significantly reducing the experimental testing characterisations time and cost. The predicted prepreg properties consist of the anisotropic Young's modulus, Poisson ratio, shear modulus, and thermal expansion coefficients in different directions.

The next step in the PCB simulation process is to determine the PCB material properties with the predicted prepreg material properties. For this purpose, the PCB layers stack up with the thickness and composition of each layer, and they are introduced into Digimat-FE to create the corresponding representative volume element (RVE). A finite element analysis using the Marc solver that underlies Digimat is computed on the RVE to predict the anisotropic PCB material properties. In Figure 3, the PCB layers stack up, and the corresponding finite element model with appropriate mesh and boundary conditions defined in Digimat-FE can be represented.

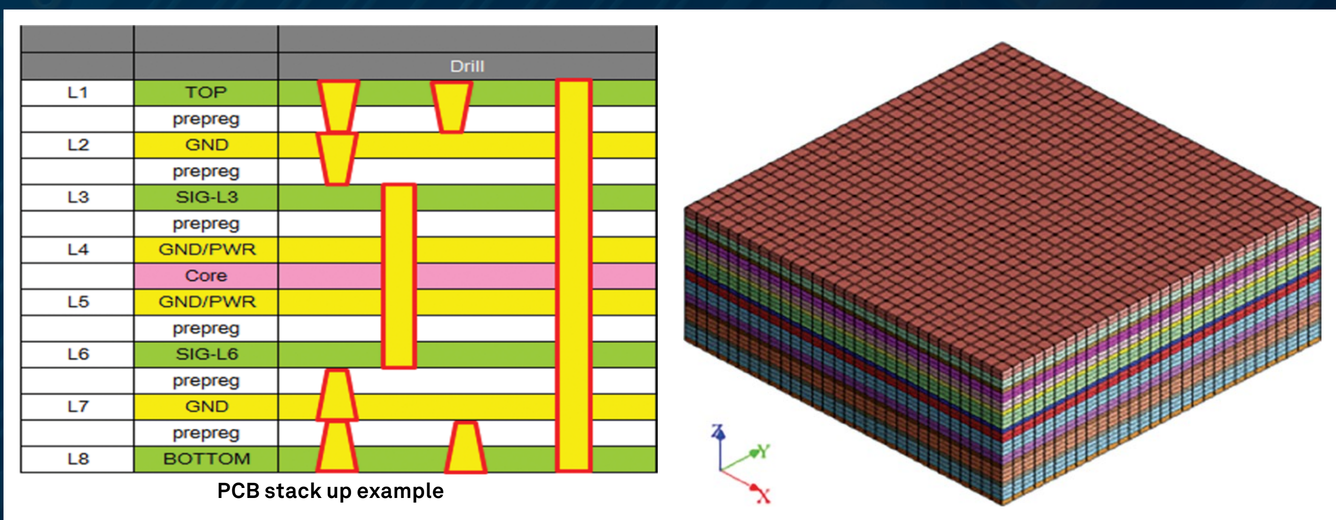


Figure 3: PCB layers stack up (left) and corresponding representative volume element (right)

Finally, the cooling portion of the manufacturing process is simulated in Hexagon's Marc non-linear FEA solver to predict the PCB warpage. To set up the appropriate model, the PCB material properties are used from Digimat, and the thermal loading and boundary conditions are specified in Marc. As a result, Figure 4 shows the predicted PCB deformation because of the temperature change. The simulation helps recommend an appropriate cooling rate to keep the warpage to an acceptable level. Further, the material and manufacturing process parameters can be tuned simultaneously to achieve the desired warpage quality goals.

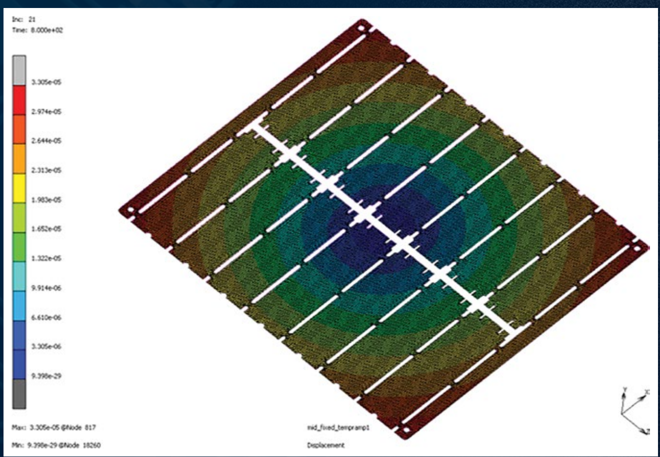


Figure 4: PCB displacement due to thermal cooling

Summary

This engineering simulation study demonstrates how PCB warpage can be predicted and studied before being manufactured. The methodology developed by Western Digital uses Digimat-MF to efficiently evaluate the prepreg material properties for different epoxy resin and glass fibre compositions. These predictions are then used in Digimat-FE to evaluate the PCB material properties required to perform the warpage analysis in Marc. The developed approach described here allows the engineers at Western Digital Corporation to investigate the PCB warpage behaviour at different temperature loadings while significantly reducing the experimental testing time and cost involved.

Hydrogen Energy

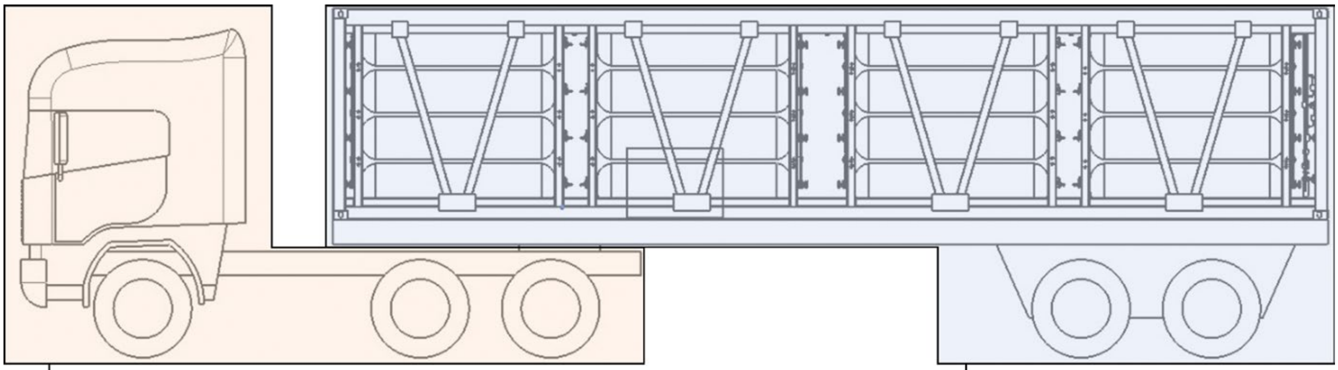
Transient structural analysis of a skid mounted on a hydrogen trailer

By Sungwook Kang[1], Hwanjin Kim[1], Jaewoong Kim[2], Hyoungchan Kim[3], Jinseok Jang[4], Byungmoon Kwak[5], Kiseok Choi[5] and Hong-Lae Jang[6]

Hydrogen has a higher energy density than other alternative sources of energy such as photovoltaic, wind power, hydraulic and geothermal alternative. According to the Hydrogen council, commercialisation of hydrogen will be led in power generation, transportation, building energy and industrial energy. Full scale hydrogen societies will be realised in 2023, starting with the transportation sector.

Hydrogen vehicles account for the largest share of hydrogen consumption. As enabling technologies, Hydrogen charging stations need to be expanded along with technologies to store and transport small and medium quantities of hydrogen safely and efficiently to charging stations. Most of the hydrogen infrastructure on the operations side is site specific. Although hydrogen can be stored and transported in many states, such as gas, liquid, solid, and via LOHC (liquid organic hydrogen carriers), the most common method for supplying hydrogen to charging stations is to use hydrogen tube skid trailers.

The study described in this article conducted a transient structural analysis of the skid structure mounted on the hydrogen tube trailers under shock load induced by road irregularities. The dynamics of the driving trailer according to the unevenness of the road surface were obtained through driving simulations by considering the steering system and damping characteristics of the vehicle's suspension. Four road environments were considered: a flat road and three road irregularities that include pothole, short- and long-wave courses. The transient structural analysis of the tube skid was performed taking the resulting acceleration values into account as constraints. Through the sequential simulations, we evaluated the structural safety of the designed tube skid mounted on the trailer during hydrogen transport.



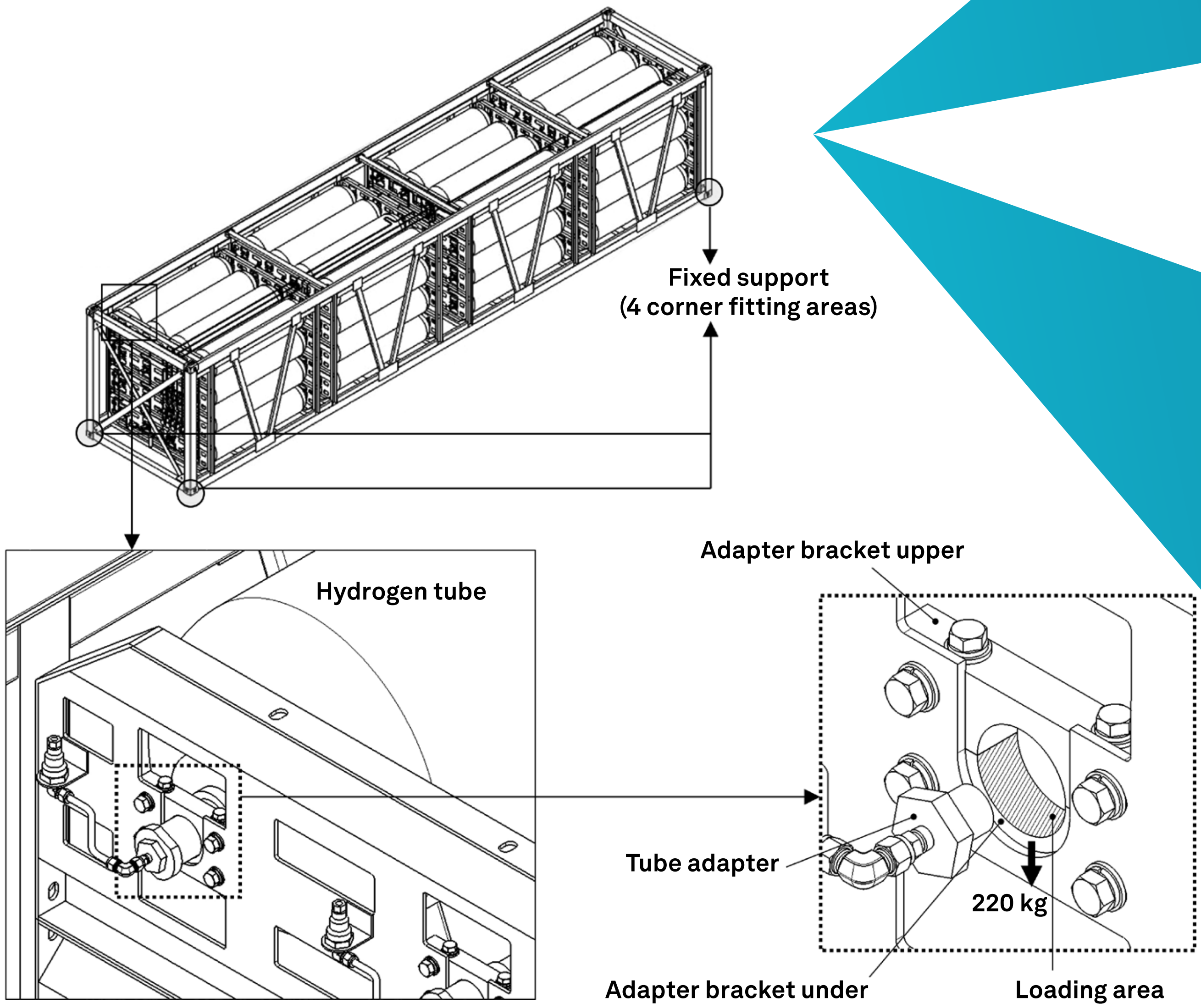
Type 1 and 2 metal hydrogen tanks with capacity of 150-300 bar pressure were used. Type 3 and 4 containers can store 350-700 bar. Previously a Type 1 hydrogen tank with 200 bar pressure was used. In this study a type 4 composite material hydrogen tank with a pressure of 400 bar is utilised to reduce the weight of the entire system and increase the hydrogen transport capacity to significantly increase the efficiency. The container-type skid structure is designed and manufactured to ISO/TC 104 and Convention for Sale Containers.

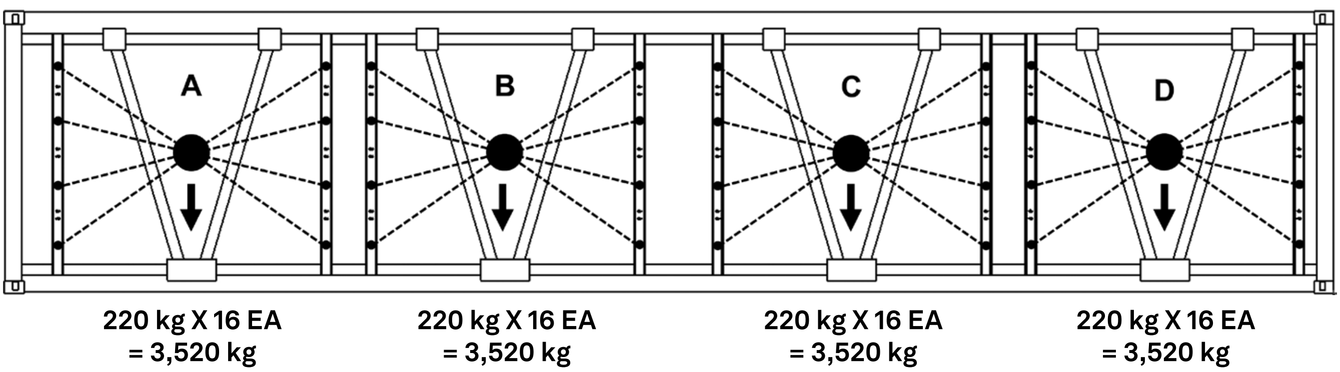
The entire skid structure is made of ASTM A36 steel. Container type skid structure is designed and manufactured by ISO/TC 104 and C.S.C (Convention for Safe Containers) Certification. The container is a box-type structure (length: 12,196 mm, width: 2,436 mm, height: 2,591 mm) with V-shaped reinforcements for each section on the left and right sides of the longitudinal direction and X-shaped reinforcements in the front and back. The base frame is composed of rectangular tube type bottom side rails and cross member which as welded together as sub-assembly and the roof frame is joined by three roof bows, a fixed frame and a corner reinforcement plate. The skid structure is loaded with 64 hydrogen tubes and a pressure control valve and pipeline to transport compressed hydrogen. The partitions that hold the hydrogen tubes are composed of 4 extruded plates assembled with bolts, and two partitions are paired to fix the front and rear adapters of the tubes through a holder.

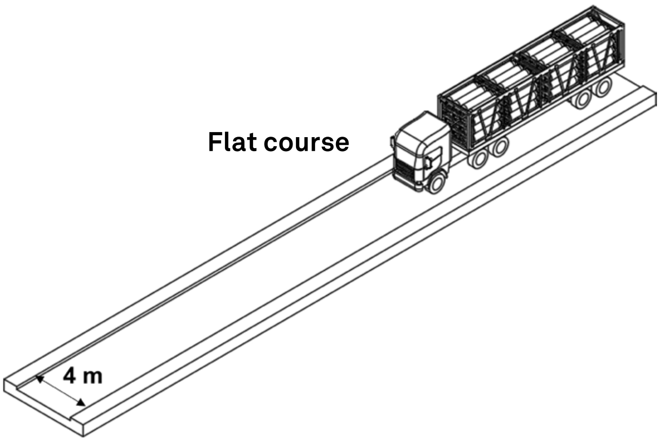
To perform the driving simulation of a hydrogen tube trailer, a full vehicle model was constructed. The truck tractor consists of the front suspension, rear suspension, powertrain and steering. The truck trailer includes a trailer suspension and a trailer body.

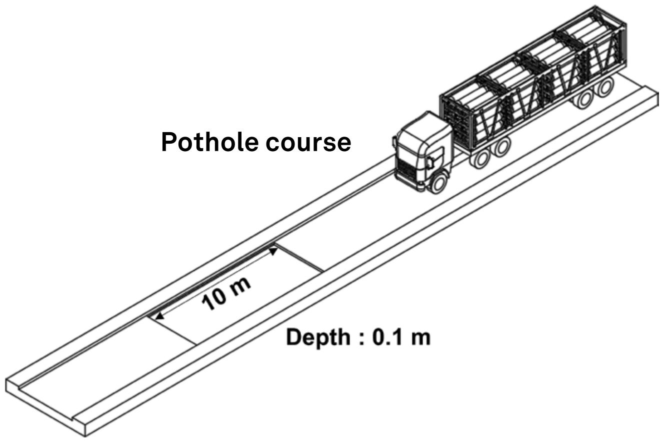
After simplifying the entire system, the hydrogen tube weight was assumed as a distributed mass. As the loading configuration of the skid structure of the trailer is a significant factor in the transport of load vibration and shaft. The figures show where the weight is applied which is in the direction of gravity on a load holder where the front and rear adapters of the hydrogen tube are fixed. To simplify the modelling process this study used the method of applying the weight of 16 hydrogen tubes to the centre of each section.

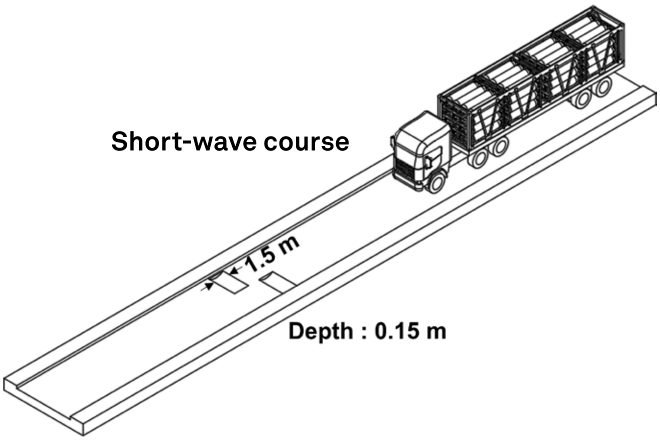
The driving road conditions of the trailer were divided into 4 different courses. The driving courses include a flat course which has a normal flat road surface, a pothole course which has a depression in the road surface, and short/long-wave courses that drastically fluctuate due to different left and right ride heights. The driving simulations were performed on each course at 80 km/h.

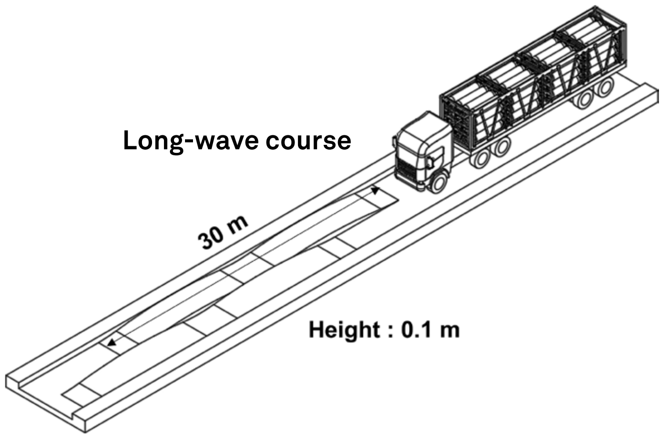






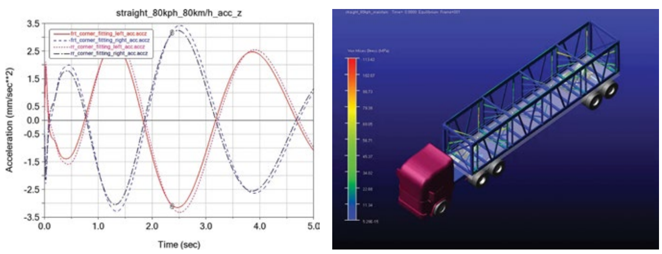




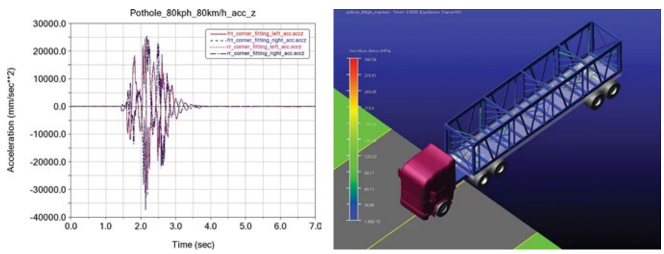


The acceleration was calculated using Adams Car at the corner fitting of the four corners where the vibration of the vehicle body is transmitted to the skid structure.

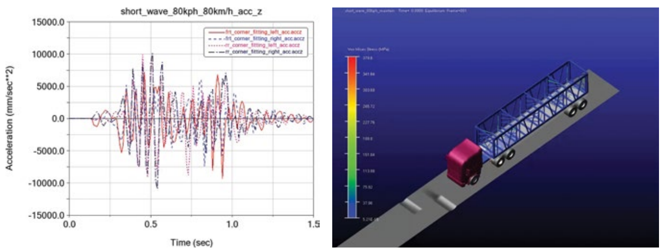
Flat course



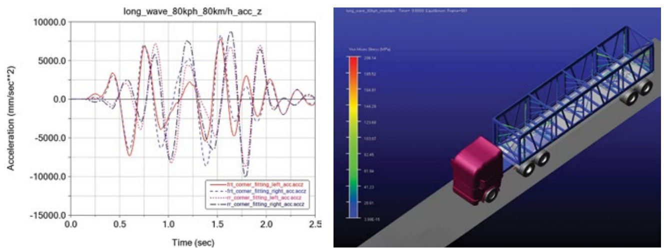
Pothole course

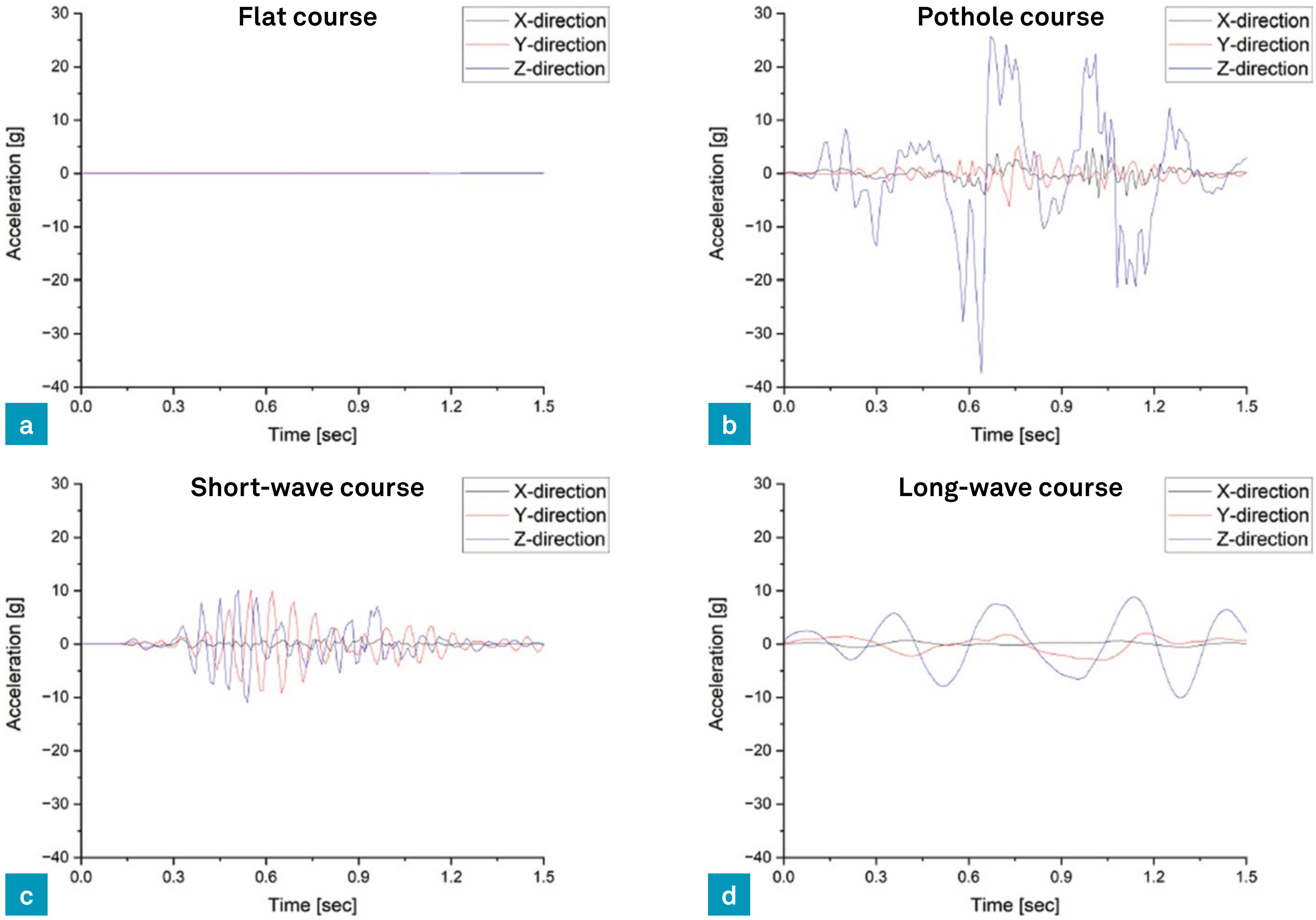


Short-wave course

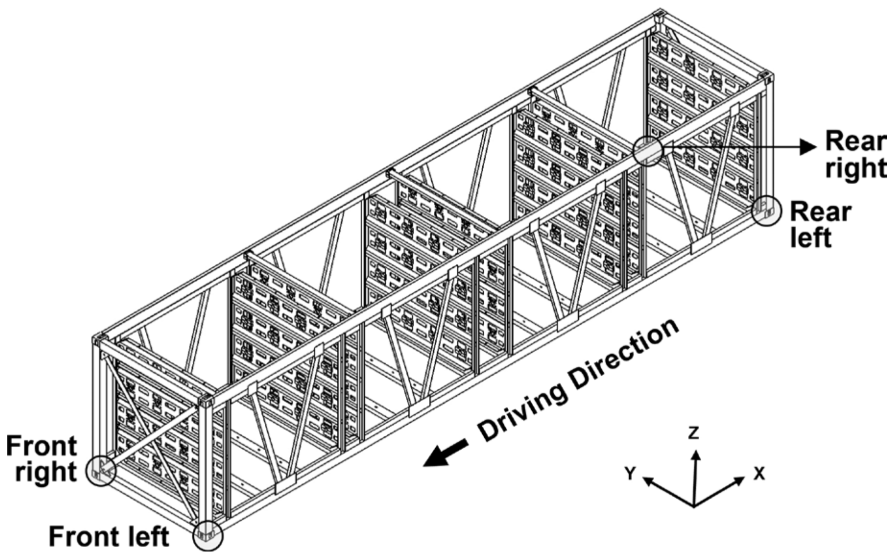


Long-wave course

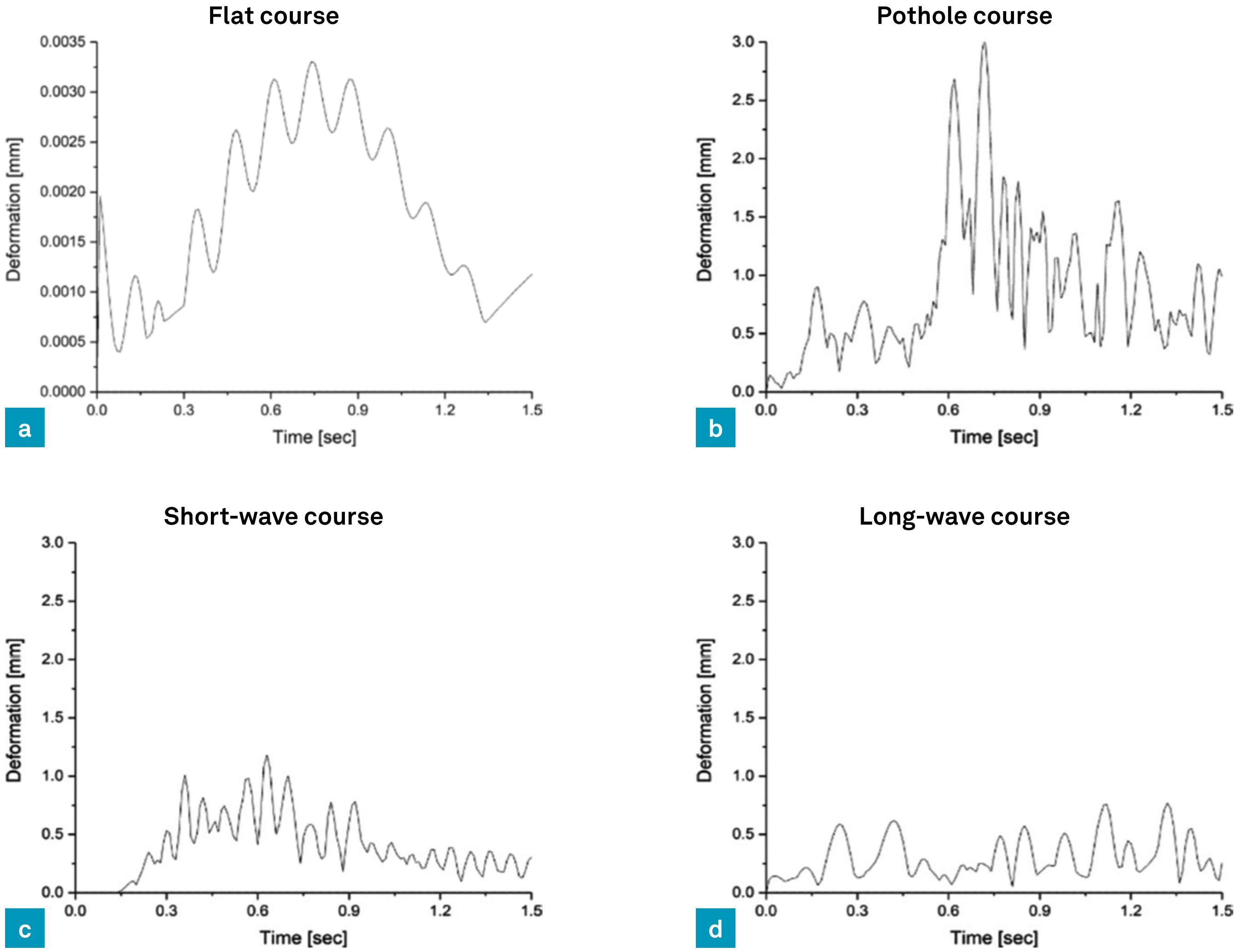




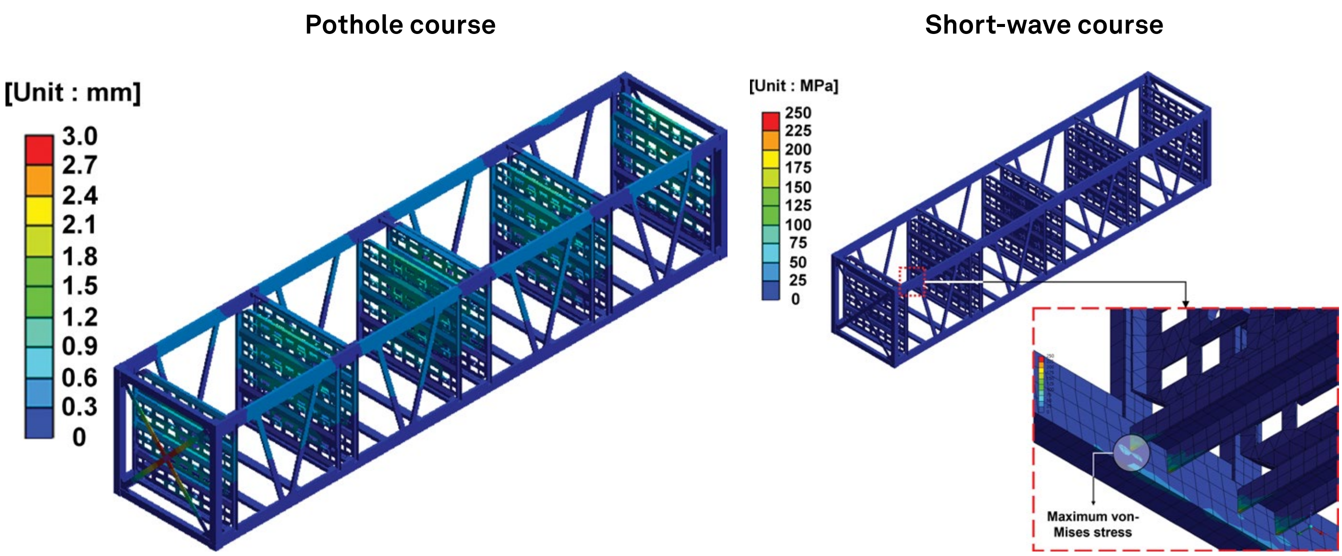
The loading conditions for structural analysis is shown. The difference in the results of each axial acceleration in the corner fitting area (front right, front left, Rear right, Rear left) was within 2 %. The graph below shows the results of the transient acceleration at the rear left position. The pothole course shows the largest acceleration. The acceleration in the Z axis direction was significantly larger than other directions. In the short-wave course the acceleration in the Y direction was significant due to momentary right and left fluctuations in the trailer. In the long wave course, the acceleration in the Y axis was stable and the acceleration in the Z axis was also slow because of constant left and right deflection.



Figures on the next page show the deformation analysis from a structural analysis. A driving simulation was performed to evaluate the safety of a trailer skid structure against shock and vibration loads. The entire vehicle structure was used in the driving simulation and in the structural analysis only the trailer structure was used. In structural analysis the maximum acceleration during driving analysis was input. The maximum Von-Mises stress was related to the maximum acceleration but was influenced more by the acceleration period. In particular for the pothole course a max deformation of 3.05 mm and the location was front reinforcement. For the short wave and the long wave loads, the 1.18 mm and 0.77 mm respectively. The location was the same as the pothole road. In the case of the flat road, the max deformation was almost zero.

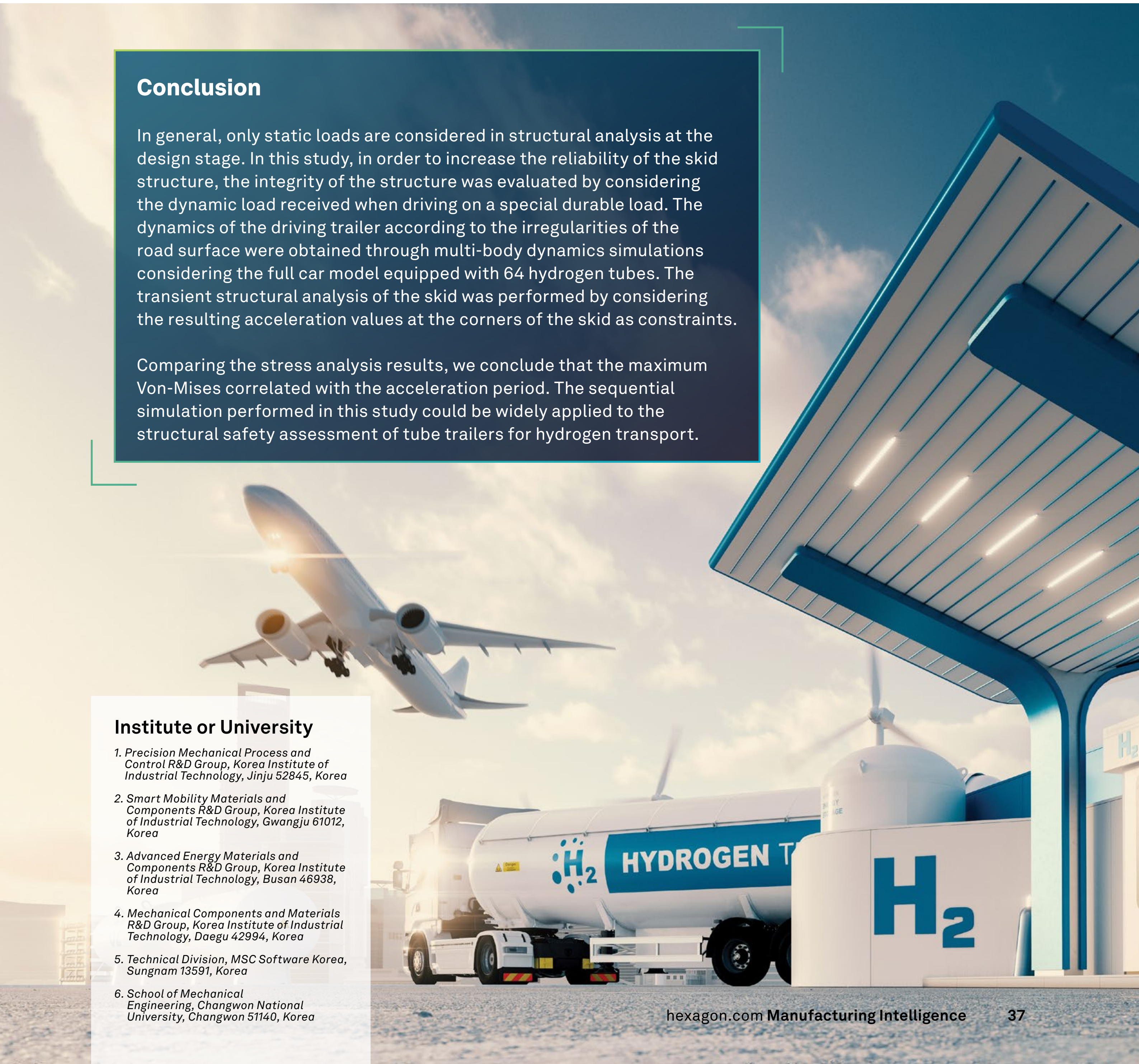


The maximum Von-Mises stress was related to the magnitude of the acceleration and was influenced more by the acceleration period. For the pothole load the maximum acceleration was +/- 30 g and the maximum von misses stress was 160.46 MPa. For the short-wave load the max Von-Mises stress was 210.83 MPa despite the maximum acceleration of +/- 10 g. In the case of the long-wave road with similar accelerations as the short-wave road is 52.1 MPa. This means that the max Von-Mises stress is highly correlated with the acceleration period. The acceleration period in the short-wave road is the shortest. The max Von-Mises stress occurs in the lower reinforcement U-beam. The maximum Von-Mises stress in in the flat road was 0.42 MPa.



Next let's look at the safety factor. The material of the skid was ASTM A36 steel with the yield strength and the ultimate tensile strength of 250 MPa and 400 MPa. All the safety factors compared to the yield strength are higher than 1 for the four driving conditions. In general, only static loads are considered in structural analysis at the design stage. However, there are no rules for the dynamic loads. Thus, the reliability of the structure for further field tests was validated by ensuring that it stays within the elastic region when subject to dynamic loads.

Driving course	Maximum Von Mises stress	Safety factor compared to yield strength	Safety factor compared to ultimate tensile strength
Flat course	0.42 MPa	595.24	952.38
Pothole course	160.46 MPa	1.56	2.49
Short-wave course	210.83 MPa	1.19	1.90
Long-wave course	52.10 MPa	4.80	7.68



Conclusion

In general, only static loads are considered in structural analysis at the design stage. In this study, in order to increase the reliability of the skid structure, the integrity of the structure was evaluated by considering the dynamic load received when driving on a special durable load. The dynamics of the driving trailer according to the irregularities of the road surface were obtained through multi-body dynamics simulations considering the full car model equipped with 64 hydrogen tubes. The transient structural analysis of the skid was performed by considering the resulting acceleration values at the corners of the skid as constraints.

Comparing the stress analysis results, we conclude that the maximum Von-Mises correlated with the acceleration period. The sequential simulation performed in this study could be widely applied to the structural safety assessment of tube trailers for hydrogen transport.

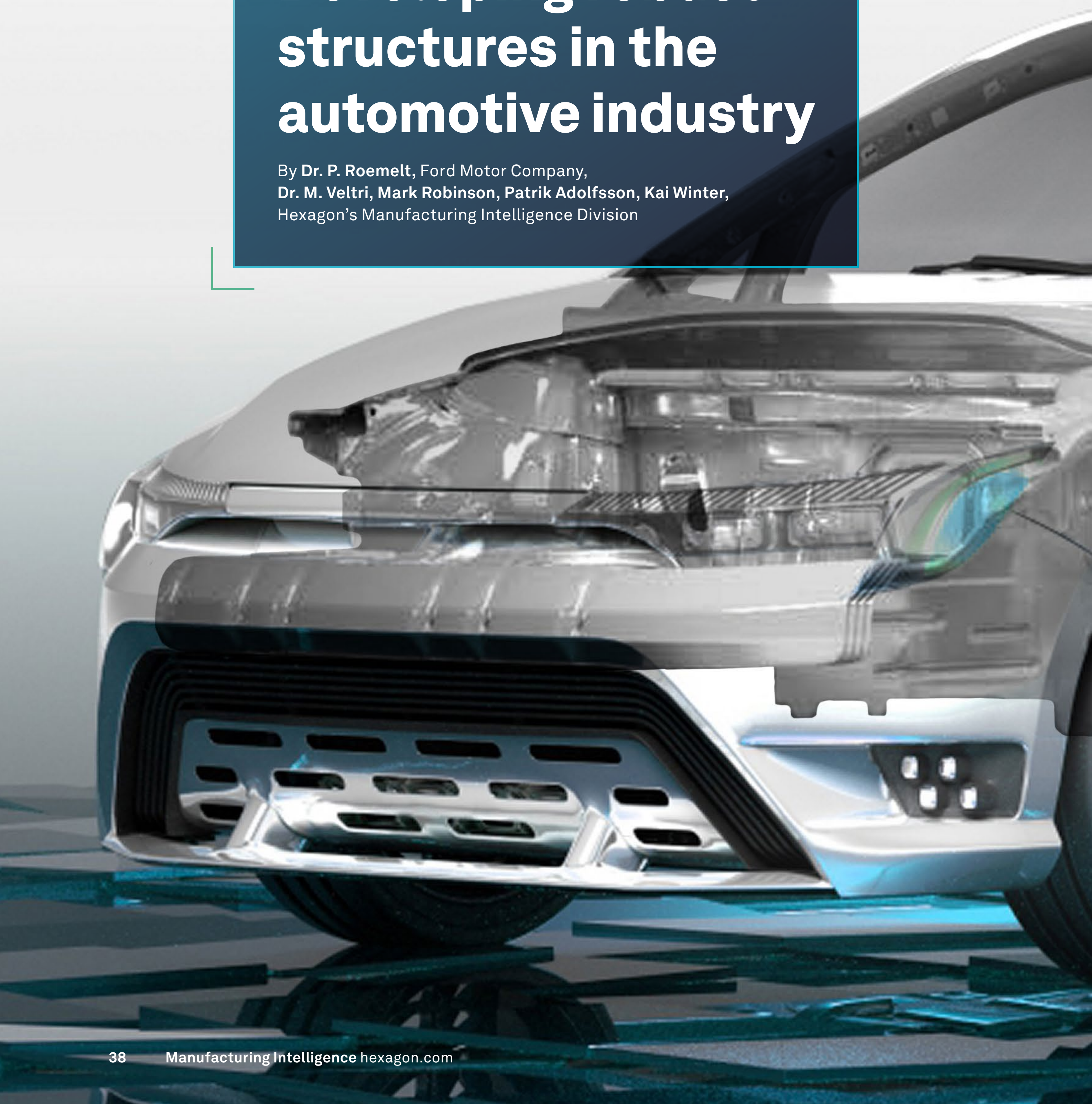
Institute or University

1. *Precision Mechanical Process and Control R&D Group, Korea Institute of Industrial Technology, Jinju 52845, Korea*
2. *Smart Mobility Materials and Components R&D Group, Korea Institute of Industrial Technology, Gwangju 61012, Korea*
3. *Advanced Energy Materials and Components R&D Group, Korea Institute of Industrial Technology, Busan 46938, Korea*
4. *Mechanical Components and Materials R&D Group, Korea Institute of Industrial Technology, Daegu 42994, Korea*
5. *Technical Division, MSC Software Korea, Sungnam 13591, Korea*
6. *School of Mechanical Engineering, Changwon National University, Changwon 51140, Korea*

Automotive

Developing robust structures in the automotive industry

By **Dr. P. Roemelt,** Ford Motor Company,
Dr. M. Veltri, Mark Robinson, Patrik Adolfsson, Kai Winter,
Hexagon's Manufacturing Intelligence Division



More stringent quality and robustness requirements coupled with advances and proliferation of key technologies for high-performance and cloud computing are leading to increased interest in DoE and randomization of input parameters for FE and lifetime analysis to yield more resilient, fit-for-purpose, and robust designs.

Historically, vehicle structures have been overdesigned with large safety factors to ensure proper function and performance under all possible tolerance conditions (material, geometry, assembly, etc.). This meant that car manufacturers put up with unnecessarily high weight. With ever-tightening emission standards and ongoing vehicle electrification, this increased weight is no longer acceptable, forcing automakers to look for other approaches to ensure robust designs.

Therefore, much work has been done recently better to understand variability at the component and system levels. This understanding needs to be translated into the product development process, which is highly dependent on simulation models.

The process begins by defining the tolerances and variances for all input variables used in the FE model ("randomization"). The model is then run many times (typically 50-100 times), randomly changing each input variable within the assigned bounds. This method, based on statistical techniques, is called stochastic simulation.

Subsequent stochastic design improvement cycles support incremental robust design changes to the structure, bringing it closer to one or more goals and achieving improved performance over the nominal FE analysis.

Estimating variability and uncertainty is one of the main difficulties in applying stochastic design methods. Without practical measuring equipment, tolerances and uncertainties are usually carried over from past industrial practice.

Industrial Computed Tomography (CT) or optical scanning devices and software can be effectively deployed to quantify uncertainties and variabilities, thus providing a solid and verifiable input parameter distribution and the key to more credible randomization.

Non-destructive evaluation with Industrial CT and Optical Scanning

Typically, engineers base FE calculations on nominal geometries and the assumption of homogeneous (idealised, defect-free) materials. Many uncertainties and fluctuations can be effectively quantified using physical components, industrial CT or optical scanners, and analysing corresponding data.

Using this information from real components opens new possibilities. The influence of manufacturing technology, production process, real material properties, and defects can be evaluated with selected samples or even in large quantities, with the measurements integrated into production lines (Figure 1).

This approach allows OEMs to create improved and more robust designs and helps identify potential weak points that are susceptible to variability so that appropriate quality controls can be performed in manufacturing facilities.

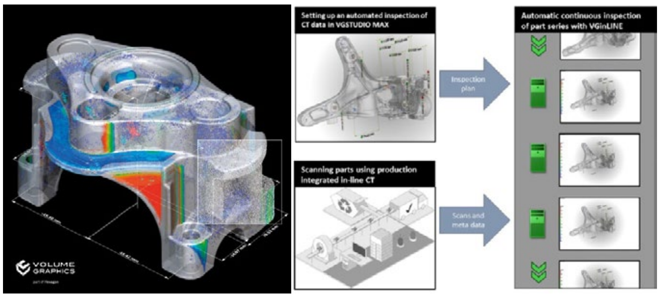


Figure 1: Detailed single-part measurements (left) integrated into the production line (right)

Stochastic simulation and stochastic design improvement cycles

The starting point for the stochastic simulation is FE results that correspond to an assumed nominal reference point that includes customer use, material properties and ideal tolerances and thicknesses.

Uncertainty and variability will primarily affect:

- Duty cycle agenda (varies with customer usage)
- Manufacturing (including pre-stress and defects)
- Load factors
- Material Properties
- Geometrical properties

Uncertainty and variability are employed through a corresponding coefficient of variation and probability distribution. Due to the high number of parameters involved, it is very important that such randomization be executed efficiently, if not automatically.

Typically, the stochastic analysis workflow encompasses the following (Figure 2).

1. Input/output selection: Nominal FE and Fatigue reference input model and output results
2. Parameter Randomization: stochastic variation of all selected input variables
3. Stochastic simulation function study: parallel solution (local or HPC), collecting results in a "meta-model" exhibiting actionable knowledge to support decision making

Key to Robust Design workflow is the capability to build actionable knowledge in multiple ways thus enabling informed decision making about model modifications and enforcing or recommending limits for specific maneuvers and weight.

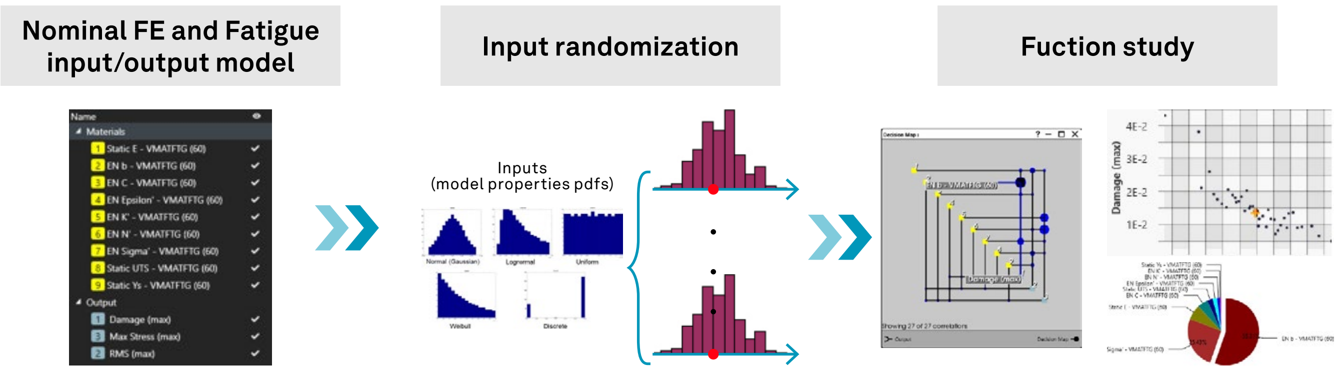


Figure 2: Stochastic Analysis workflow

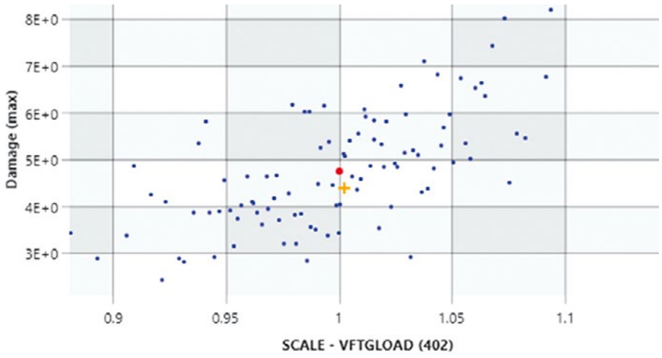


Figure 3: Ant hill plot relating maximum damage to global load factor perturbation

For this purpose, dedicated graphical tools enable quick interpretation of a vast number of results:

Ant hill plots
Visual distribution of input-output pairs, relationships, and correlation shape, for example identifying parameter combinations and values causing unacceptable damage (thresholds or outliers) as in Figure 3.

Decision maps
Visually describing the correlation relationship between input and output, allowing exploration and understanding of how different variables influence the functioning of a product. Higher correlations are shown on the upper right quadrant of the decision map (dot size reflects correlation value) as in Figure 4 left.

Pie charts
Based on correlations ranking, reflects the relative weight and influence of any parameter variation on key outputs such as total mass, stress, mode frequencies or total cumulative damage, Figure 4 right.

Optionally, after the function study has been completed, the workflow continues with stochastic design improvement or a refined optimization strategy such as AI-ML with MOR (model order reduction).

Stochastic design improvement cycles support automated gradual robust design changes to the structure, moving it closer to one or more targets and achieving improved performance over the nominal FE analysis.

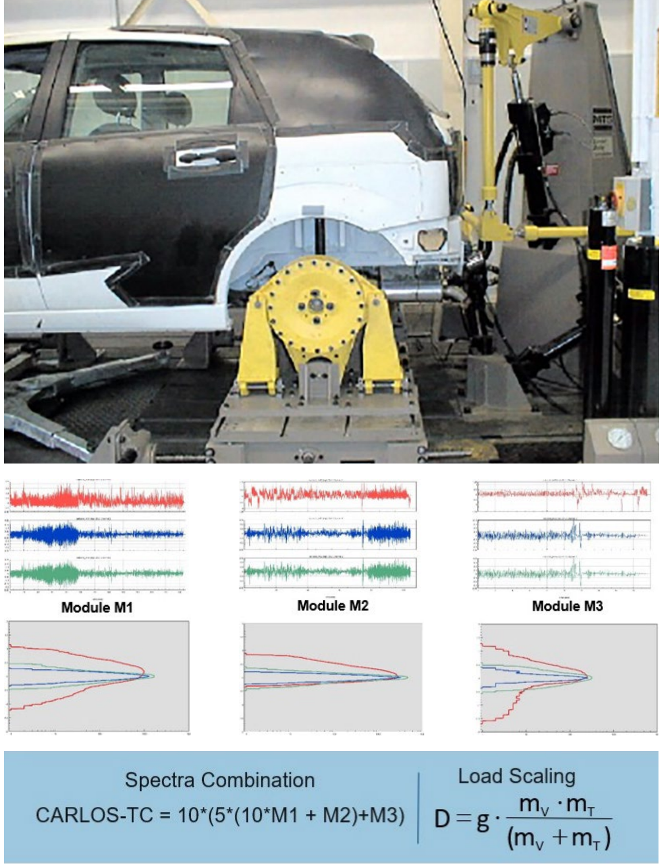


Figure 5: CARLOS test setup and load spectrum

Trailer towing use case: load description

Using a trailer towing attachment as an example, we will demonstrate an approach to ensure robust designs including selected tolerances and material uncertainty. The “ideal” nominal structure is evaluated and the effects of different types of parameters are compared against the nominal performance.

In Europe, trailer towing devices need to fulfill the CARLOS standard spectrum fatigue test[1], which is included in ECE Regulation 94/20[2].

For the physical test a body in white is bolted to a test field at the chassis attachment point. The loading is applied in three directions at the tow ball (figure 5 up). Load amplitudes are scaled using the so-called D factor, which is a function of the full vehicle and trailer masses (figure 5 down).

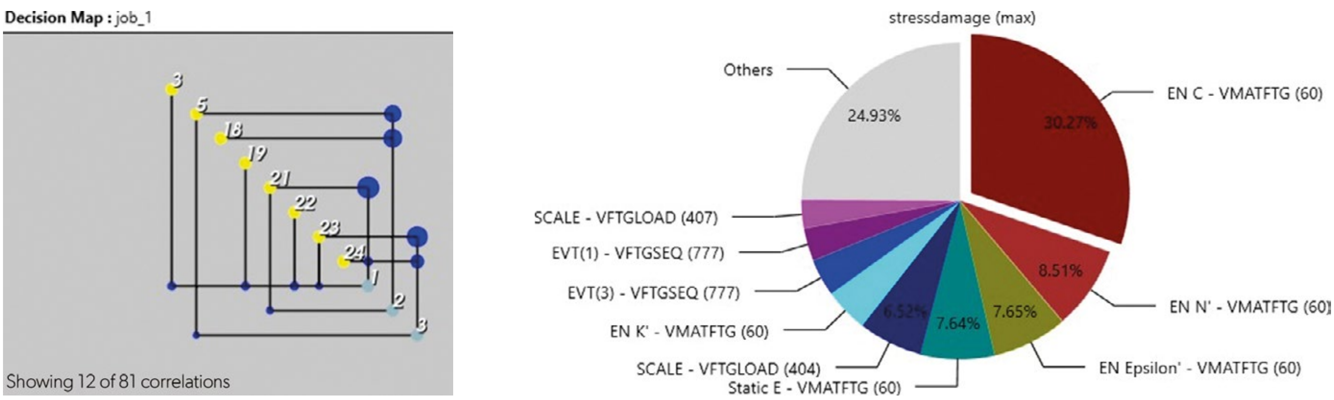


Figure 4: Input-output decision maps (left) and pie chart with relative parameter influence on a given output (right)

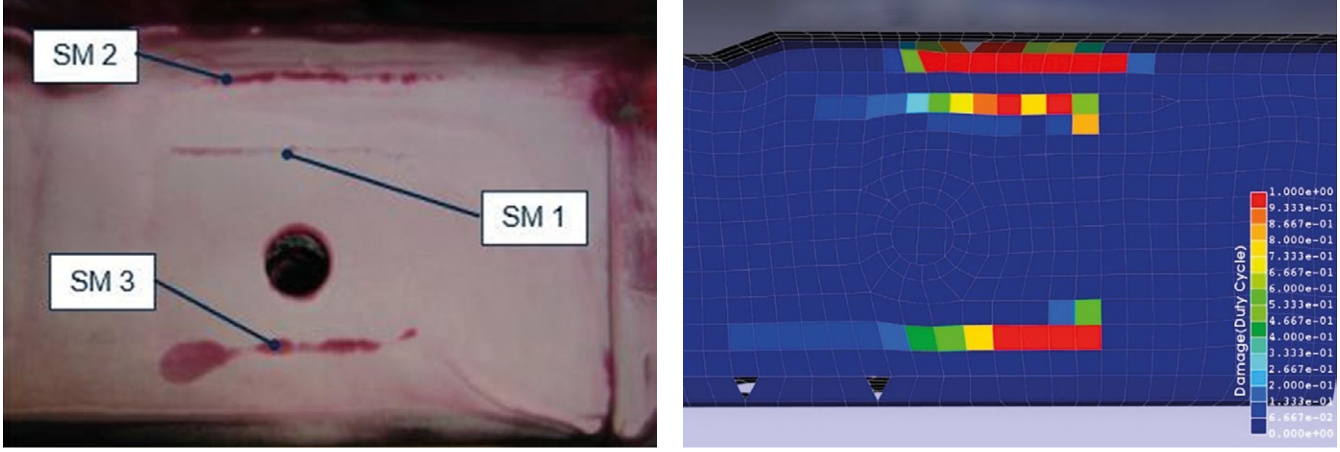


Figure 6: Physical test results (left) vs. simulation (right)

Discrete fatigue cracks developed in the sheet metal during the physical test. These were in the area where the trailer towing device is bolted to the vehicle side rails (figure 6 left).

CAE model and durability analysis

A CAE model is built to model the physical test (figure 7). The attachments to the test fields are defined as boundary conditions.

Local contact conditions play a major role in correlating the fatigue cracks with the CAE model. However, using a nonlinear analysis with contact discontinuities and a load time history means very long analysis times. Therefore, the loading is reduced to a couple of block loads, which create an identical damage distribution to the load time history without contact included as outlined in figure 8[3].

The ensuing fatigue duty cycle analysis is undertaken using the conventional strain-life method. Key elements of the durability process flow are shown in Figure 9.

1. Resources: input FE model and results
2. Materials: library for Strain life modelling.
3. Time Load scheduler: 7 block duty cycle is obtained by linear superposition of up to 14 loading channels.
4. Outputs: various formats, obtained per event as well as per collective “duty cycle” schedule.

As shown in Figure 6 (right), the fatigue analysis using nominal parameters shows good correlation with the critical areas identified in the physical test.

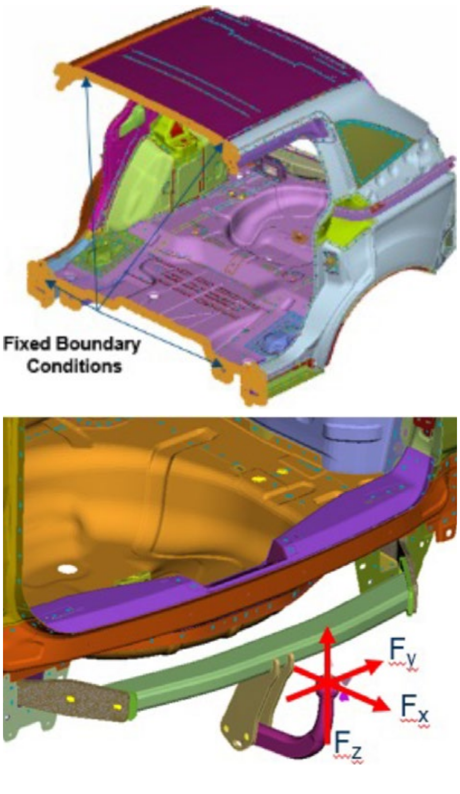


Figure 7: CAE model boundary conditions and load application

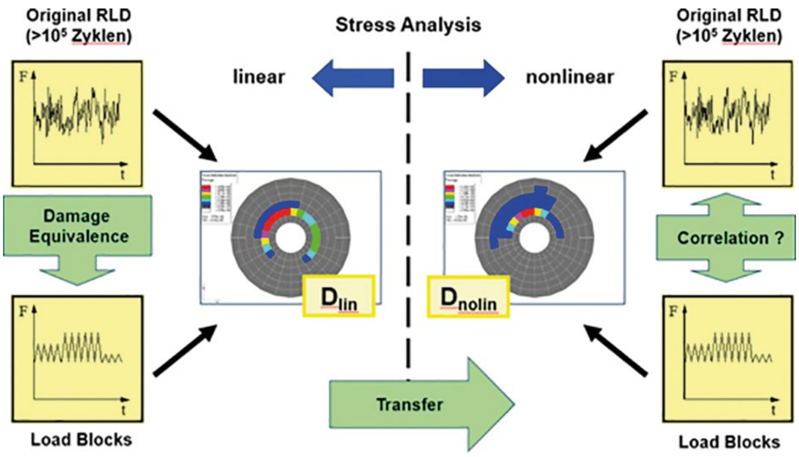


Figure 8: Block load generation

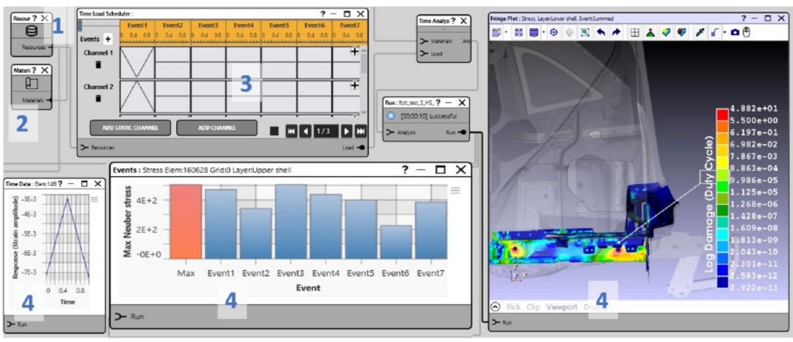


Figure 9: Fatigue process flow with 7 events duty cycle

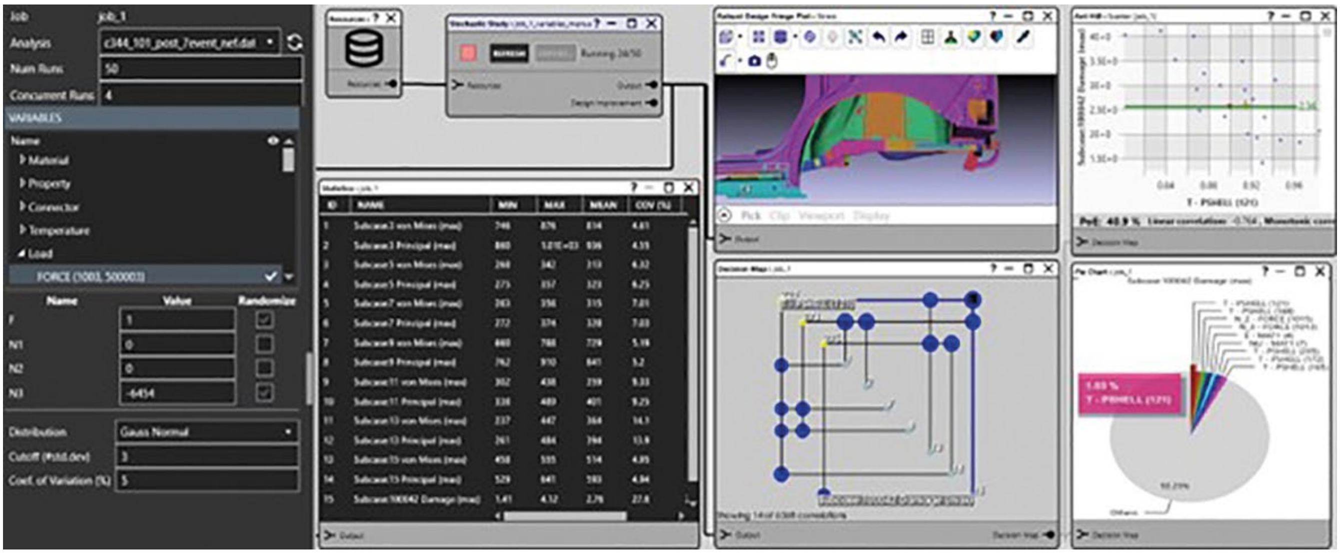


Figure 10: Robust Design workflow[5] for the trailer towing attachment stochastic durability simulation

Stochastic durability simulation workflow

The stochastic function study is a follow-on from the previous nominal stress and fatigue analysis, automatically incorporating uncertainties with the aim of building knowledge about model robustness.

The process flow is driven by a Robust Design interactive template[4], automating the tasks of input parameters randomization, Monte Carlo simulation and output postprocessing (figure 10).

Uncertainty is quantified using the Coefficient of Variation (CoV), the ratio of standard deviation to the mean value times 100. For this exercise a low CoV of 5%[5] and a Gaussian distribution with a range of 3 standard deviations are automatically assigned to all parameters, comprising of material properties, plate thicknesses and boundary conditions.

The deployment of an FE solver with embedded fatigue solution[6] allows for combined non-linear prestress, multiple loading and fatigue calculation all in a single run.

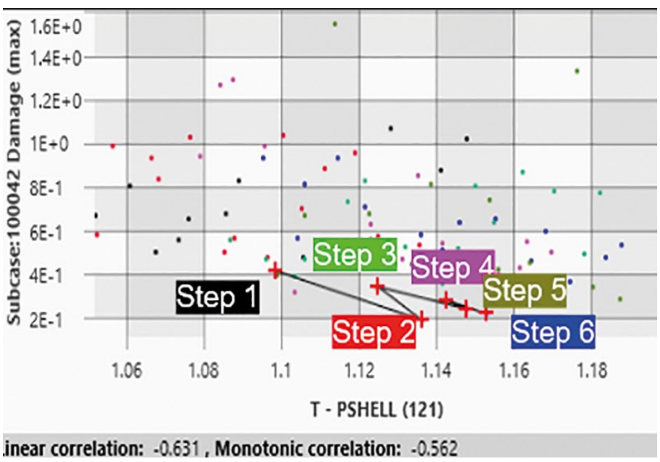


Figure 11: Optimization history

Results summary

In a preliminary result reading, fatigue damage is ranging between 1.41 and 4.12, with a mean value of 2.69, slightly above the nominal value of 2.56 from the deterministic calculation. The probability of survival is only 34.8%.

With the exception of the maximum Damage, most of the output variables show a scatter that is close or slightly above the input tolerances, an indication of a healthy and robust model, at least from a simulation quality viewpoint.

The most damaging events, event 1 and 3, have contained stress CoV, which explains the relatively small scatter of the damage, despite the power law relationship.

As expected, the decision map shows how the side rail thickness parameter (ID=224 labelled "T- PSHELL 121") is negatively correlated with maximum damage. The resulting ant hill plot appears to outline a regular elliptical shape with low risk for outliers or dangerous distribution bifurcations.

Stochastic optimization

After the scatter of the results and the state of the model are established and the critical design parameters are identified, a subsequent stochastic design improvement analysis can be used to mitigate premature crack initiation with a robust stochastic approach.

The identified critical parameters are now considered as design variables and used for optimization. The optimization is performed in six steps, with each step refining the resolution of the design variables. A maximum fatigue damage of 0.2 with a scatter of less than 10% is defined as the goal of the optimization.

After the end of the optimization, a new stochastic analysis is carried out in order to check the optimization result for its robustness. The probability of survival is now 96%.

Summary

A stochastic simulation approach is able to support design and manufacturing in creating improved, more robust designs and identifying potential weak points susceptible to variability. The robustness assessment also supports mitigating risks and liability in misuse.

Industrial CT or optical scanning devices and software can be effectively deployed to quantify uncertainties and variabilities with the goal of ensuring that appropriate quality controls can be implemented in manufacturing plants.

The inclusion of tolerances and scatter in finite element models significantly increases the level of realism, elevating the credibility of the model and reducing the amount of physical testing due to the increased confidence.

Key to Robust Design workflow is the ability to build actionable knowledge in multiple ways. Tools such as ant hill plots and decision maps enable informed decision-making concerning model modifications and enforcing/recommending limits for specific maneuvers or weights.

Automated stochastic design improvement cycles support gradual robust design changes to the structure, moving it closer to one or more targets and achieving improved performance over the nominal FE analysis.

Lastly, manufacturing or supply costs gains could be obtained by identifying components that have little influence on response targets, or present low risk, where associated tolerances may be relaxed.

References

1. *EUR-Lex - 31994L0020 - EN - EUR-Lex, Europa.eu, 2013. https://eur-lex.europa.eu/legal- content/EN/ALL/?uri=celex%3A31994L0020 (accessed Feb. 01, 2023).*
2. *Klätschke, H., Bruder, T.: Standardisierte Lastkollektive und Lastfolgen für PKW- Anhängevorrischtungen als Ergänzung zur EU-Richtlinie 94/20/EG – CARLOS TC; Unveröffentlichter LBF-Bericht Nr. 110833 (d), Fraunhofer Institut für Betriebsfestigkeit LBF, Darmstadt, 2003.*
3. *Weinert, M. & Fels, D. & Wahl, J. & Rottler, A. & Eschenauer, H. (2002). Consideration of nonlinear phenomena in fatigue life estimations by using damage equivalent block loads. 627-640.*
4. *CAEfatigue and Robust Design User's Guide, Version 2023.1, Hexagon Manufacturing Intelligence, 2023.*
5. *Klein, M., Schueller, G.I., et.al.,Probabilistic Approach to Structural Factors of Safety in Aerospace, Proceedings of the CNES Spacecraft Structures and Mechanical Testing Conference, Paris, June 1994, Cepadues Edition, Toulouse, 1994.*
6. *MSC Nastran Embedded fatigue User's Guide, version 2022.4, MSC Software, part of Hexagon Manufacturing Intelligence, 2022.*

Hexagon is a global leader in digital reality solutions, combining sensor, software and autonomous technologies. We are putting data to work to boost efficiency, productivity, quality and safety across industrial, manufacturing, infrastructure, public sector, and mobility applications.

Our technologies are shaping production and people-related ecosystems to become increasingly connected and autonomous – ensuring a scalable, sustainable future.

Hexagon's Manufacturing Intelligence division provides solutions that use data from design and engineering, production and metrology to make manufacturing smarter.

Learn more about Hexagon (Nasdaq Stockholm: HEXA B) at hexagon.com and follow us @HexagonAB.