# BENCH MARK


## Simulation: Home Run

NAFEMS

OCTOBER 2024

THE INTERNATIONAL MAGAZINE FOR ENGINEERING DESIGNERS & ANALYSTS FROM NAFEMS


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Benchmark magazine is delivered free to all NAFEMS members.

You can also subscribe to the magazine for either 1 or 3 years.

1 Year Subscription (4 issues): £40
3 Year Subscription (12 issues): £100

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NAFEMS

ISSN 0951 6859

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# BENCHED

## A VIEW FROM YOUR EDITORIAL TEAM

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As soon as the idea of an article on baseball bats was pitched to me out of left field, I knew it would be a home run in terms of puns. And as if getting three of them into one sentence wasn't enough of a result, this issue of benchmark steps up to home plate and hits it out of the park with a world series of articles for your reading pleasure.

Our cover feature on how simulation is increasingly involved in the design of Louisville Slugger baseball bats is another fascinating insight into how modelling & simulation is making its way into every aspect of life, including sports. Following on from the July 2024 issue, which had a look at the football used in UEFA Euro 2024, we've spun right back stateside to look at a sport in which the US is firmly a world leader. The article is based on Matt Bynum's presentation from the NAFEMS Americas Regional Conference in Louisville this summer and leads this issue in fine style.

As well as sport, we've got an excellent piece on how FEA is vital in modelling the older person's brain. There was much back and forth in the Benchmark team about how to talk about people's ages in a sensitive fashion, and it made us realise exactly how much words can matter when discussing subjects such as age. The article itself gives great insight into how older brains need to be looked at in a different way when examining the effects of brain injuries, and we're sure you'll enjoy it.

Our "Speaking of Simulation" series, continues with a discussion on probabilistic analysis, and we've also got a brand-new columnist on board this issue; Laurence Marks gives his take on whether the industry is promoting integration of software tools over what he terms 'heavyweight simulation prowess'. Monica Schnitger is back with her regular column on the business of simulation, urging us all to broaden our thinking and use technologies that allow us to explore new ideas while still meeting requirements. We also have contributions from the ASSESS initiative and the NAFEMS Metallic Additive Manufacturing Focus Team.

As if that wasn't enough, this is the last benchmark opportunity I get to remind you to get your abstract in for the NAFEMS World Congress 2025. The deadline is November 22nd, and we'd love to see you in Salzburg. So, get submitting at **nafems.org/congress.**

Enjoy this issue of benchmark. ■

**David Quinn - Editor**

# Particle Methods Technical Group

NAFEMS is launching a Particle Methods Technical Group and is looking for members. If you think you would be a great fit, fill out the form at **nafe.ms/particle.**

Recognising the growing importance of these methods, this group will be dedicated to: Promoting Best Practices. We aim to develop resources that promote the best use of particle methods in engineering applications by leveraging our members' collective expertise.

Supporting Education and Knowledge Transfer. We will work to disseminate knowledge to equip the next generation of engineers and researchers with the skills needed to utilise particle methods effectively.

Facilitating Collaboration. We are a platform for open dialogue and exchange of ideas among professionals from industry, academia, and software development.

The first meeting will be in November 2024. For further information, please contact **marton.groza@nafems.org**

**nafe.ms/particle**

# New Latin America Webinar Series

The 2nd NAFEMS Latin America webinar "Dos dados à inovação: O poder da simulação e da integração PLM" (From Data to Innovation: The Power of Simulation and PLM Integration) will take place on December 5th 2024.

Join us to discover how integrating simulation data with PLM systems accelerates product development, improves decision-making, and addresses workforce challenges in today's fast-paced market. Our speaker, Rodrigo Britto Maria, will share real-world case studies and practical strategies for success.

*Portuguese language event.*

**nafe.ms/la-24**

# Eastern Europe Student Award

We are delighted to launch the 2024 – 2025 NAFEMS Eastern Europe Student Award, sponsored by ANSYS and Knorr-Bremse, for outstanding student work in engineering simulation.

The NAFEMS Eastern Europe Student Award recognises exceptional achievements in engineering simulation among mechanical engineering students in the Eastern Europe region.

This prestigious award invites mechanical engineering students to showcase their innovative use of simulation technologies such as Finite Element Analysis, Computational Fluid Dynamics, Computational Electromagnetics, System Simulation and other numerical techniques used in mechanical engineering applications. By participating, students gain the opportunity to have their work evaluated by experts, receive valuable feedback, and compete for recognition at an international level.

**Submissions deadline: 30th of September 2025.**

**Find out more: nafe.ms/ee-student**

# Invitations to Tender

We are pleased to announce one of our most significant tender processes to date. Eight publications and four on-demand training courses are now open to tender, with proposals due by January 1st 2025. The publications and courses out for tender are:

**Publications**

- Why do Surrogate Modelling?
- Why do System Simulation?
- How to Model Delamination and Failure of Composites
- Why use Particle Methods? and How to use Particle Methods
- Update – How to Manage Engineering Analysis
- Update – How to Undertake a Contact and Friction Analysis
- How to Analyse Rotating Machinery

**On-demand Courses**

- Getting Started with System Simulation
- Worked Examples for Cyclic Plasticity and Low-cycle Fatigue Strength Assessment
- Worked Examples for High-cycle Fatigue Strength Assessment
- An Introduction to Thermal Analysis in Solid Structures

Full details can be found on page 46 of this issue, and at **nafems.org/tenders**

## A Lifetime Journey with Product Development Analysis and Simulation

Join us for the latest NAFEMS Americas WISE Subcommittee webinar, featuring Alice Popescu-Gatlan, ex-John Deere, on Thursday, 21 November.

Alice will take us on a journey through the past thirty years on how data has driven product development and where this journey will take us, as product developers, in the Industry 4.0 and 5.0 era. **nafems.org/events**

# September Issue of NAFEMS Magazin

September Issue of  NAFEMS Magazin, the online publication in the German language specifically aimed at the analysis community in the DACH region, is now available to download.

The magazine is published four times a year and is aimed at users of numerical simulation methods and related areas: FEM, CFD, MKS, VR, process simulation, and SDM.

The 71st edition covers technical reports, information on upcoming events, training, etc. The articles cover lifetime prediction, improved algorithms for reliability and sensitivity analysis, topology optimization in crash-loaded structures, elastic multibody simulation of rolling bearings, and the use of AI expert systems for preserving valuable expertise and promoting sustainable resource planning in product development.

**nafems.org/magazin**


# The Next Volume of EMAS is in the Works

***Engineering Modelling, Analysis & Simulation*** **(EMAS)** is the NAFEMS Journal, an open-access publication that showcases the latest advancements, research, and novel applications of engineering simulation and related technologies.

Volume 2, Issue 1 (2025) of Engineering Modelling, Analysis & Simulation is now being populated with articles, many of which are extended versions of papers originally presented at NAFEMS regional conferences in 2024. The first three open-access articles are already available and more content will be added soon!

**emas.nafems.org**

# DACH Student Award

Congratulations to the winners of the NAFEMS DACH Student Award for academic session 2022/23!

- Carolin Schliephake, RWTH Aachen
- Evelyn Sabella Rugerri, Karlsruher Institut für Technologie KIT
- Magdalena Lang, Ostbayerische Technische Hochschule Amberg-Weiden

The award for the 2023/24 session is now open. Submissions are due by March 31st, 2025.

The award is aimed at students who have completed a degree in the areas of computation and simulation (e.g., structural strength and dynamics, fluid flow, optimization, electromagnetism, etc.) within an engineering discipline.

**nafe.ms/dach-student**

# Latest Italian Webinar

Join us on 29 October for an exciting new webinar in the Caffè e Simulazione Webinar Series: "Quantum Computing & CAE: buone prassi ed esempi applicativi!"

Caffè e Simulazione with NAFEMS Italia is a digital forum for the discussion and sharing of CAE methods and tools. In our forum, simulation experts come together to exchange experiences and best practices with the goal of promoting and encouraging the use of simulation.

Don't miss this opportunity to explore the basics and real-world applications of quantum computing for engineering simulation with industry experts!

*Italian language event.*

**nafe.ms/italy-24**

# New Member Downloads Now Available

**Expert Perspectives on Modelling and Simulation in Engineering – A Cross-Industry Study**
This paper summarises work that was undertaken to determine the current attitude within the industry to the use of simulation to support engineering activity. The project was progressed using a series of interviews with subject matter experts, supported by literature reviews and other evidence and experience gained by the project team.

**nafe.ms/r0137**

**Evolution of Simulation to Support Automotive Crash**
The report includes a history of crash simulation through a 50-year period, with highlights of the business drivers for each decade of progress. This is described in relation to the important stakeholders—the automotive OEMs, academia, the supply chain, and the supporting ecosystem of consultants and software providers. The progress is reviewed through the lens of 'value streams', such as cost, time, quality, innovation, and market leadership, with additional discussion on how those value streams have evolved and might be prioritised today.

**nafe.ms/r0138**

**Getting Started with Engineering Data Science**
This paper emphasises the important role that data science is now playing in engineering fields before going on to describe the data science process and discussing the distinctive qualities of engineering data. Examples of value propositions and applications of data science across the lifecycle are provided. It concludes by providing guidance on how to get started with engineering data science and machine learning.

**nafe.ms/ht56**

# Biomed In Silico France

The three members of the "Biomed in Silico France" initiative, Micado, The Avicenna Alliance, and NAFEMS, represented by Didier Large, organized a seminar on Monday, September 30th, with the support of CETIM (a major French institute for mechanical research and NAFEMS member) and the "Digital Health" team of CETIM St-Etienne. Philippe Poncet, CETIM's General Manager, introduced the seminar.

Nearly forty participants (R&D engineers from SME and academics) attended live, and additional participants attended online. Five highly interesting presentations of real-world case studies and advanced research confirmed, if proof were still needed, the significant contribution of high-performance modelling and simulation to the entire biomedical sector.

Several speakers highlighted the value of applying ASME V&V40 concepts to improve the credibility of simulations and thus provide acceptable digital evidence to regulatory bodies.

During the round table, the SME representatives stressed the necessary help they would like to receive in implementing these new methodologies and tools.
The program included the following presentations:

- Accelerate the qualification process, by M. Chollet – P. Amuzuga, CETIM
- Emergence of In Silico for oncology, by Thierry Marchal, Avicenna Alliance & ANSYS
- Personalized Medicine: Digital tools to help with surgical planning, by Pr. Bou Said, Lamcos INSA Lyon
- Clinical and industrial applications of numerical simulation in the cardiovascular field, by D. Perrin, PrediSurge
- Biomechanical digital twins in surgery and vascular medicine, by Stéphane AVRIL, Professor at Mines Saint-Etienne

In the afternoon, CETIM organized a tour of their Biomechanics and Additive Manufacturing Platform test laboratories. The day ended with a round table discussion, inviting participants to take part in the activities of the Steering Committee set-up in 2024. The audience recognized the need to embrace in silico methods quickly but emphasized the need to demonstrate ROI when deploying computational modelling and simulation in their organization. PDFs of the presentations will be available soon in the NAFEMS Resource Centre.

For further details, contact **didier.large@nafems.org**

# NAFEMS Americas Membership Subcommittee - Get Involved

As a member, you will participate in an ongoing feedback loop, providing valuable insightsfor our  members in the Americas region.

Your participation will have a direct impact on how we serve our community, as tasks evolve on a regular basis. We are committed to representing our members' interests. Together, let us ensure that NAFEMS remains responsive, relevant, and continues to meet the needs of all of our members.

Join us today to make your voice heard – contact **kathy.elliott@nafems.org** for more information

# UPCOMING EVENTS

### Simulation Governance: Challenges in the Age of Data and Digitalization
**November 6th 2024**
Webinar

### How Engineering Simulation is Bringing a Revolution for Product Development
**November 7th 2024**
Webinar

### Engineering Excellence: Simulation for Fatigue Strength and Durability
**November 13th 2024**
Online Seminar

### NAFEMS Iberia Conference
**November 14th 2024**
Conference | Madrid, Spain

### NAFEMS France Conference 2024
**November 19th 2024**
Conference | Senlis, France

### AI and ML in Simulation Driven Design
**November 20th 2024**
Seminar | Lund, Sweden

### Dos dados à inovação: O poder da simulação e da integração PLM
**December 5th 2024**
Webinar

### Engineering Simulation in Electronics Conference
**December 9th 2024**
Online Conference

### Solving Structural Integrity Challenges with Engineering Simulation
**February 20th 2025**
Seminar | Madrid, Spain

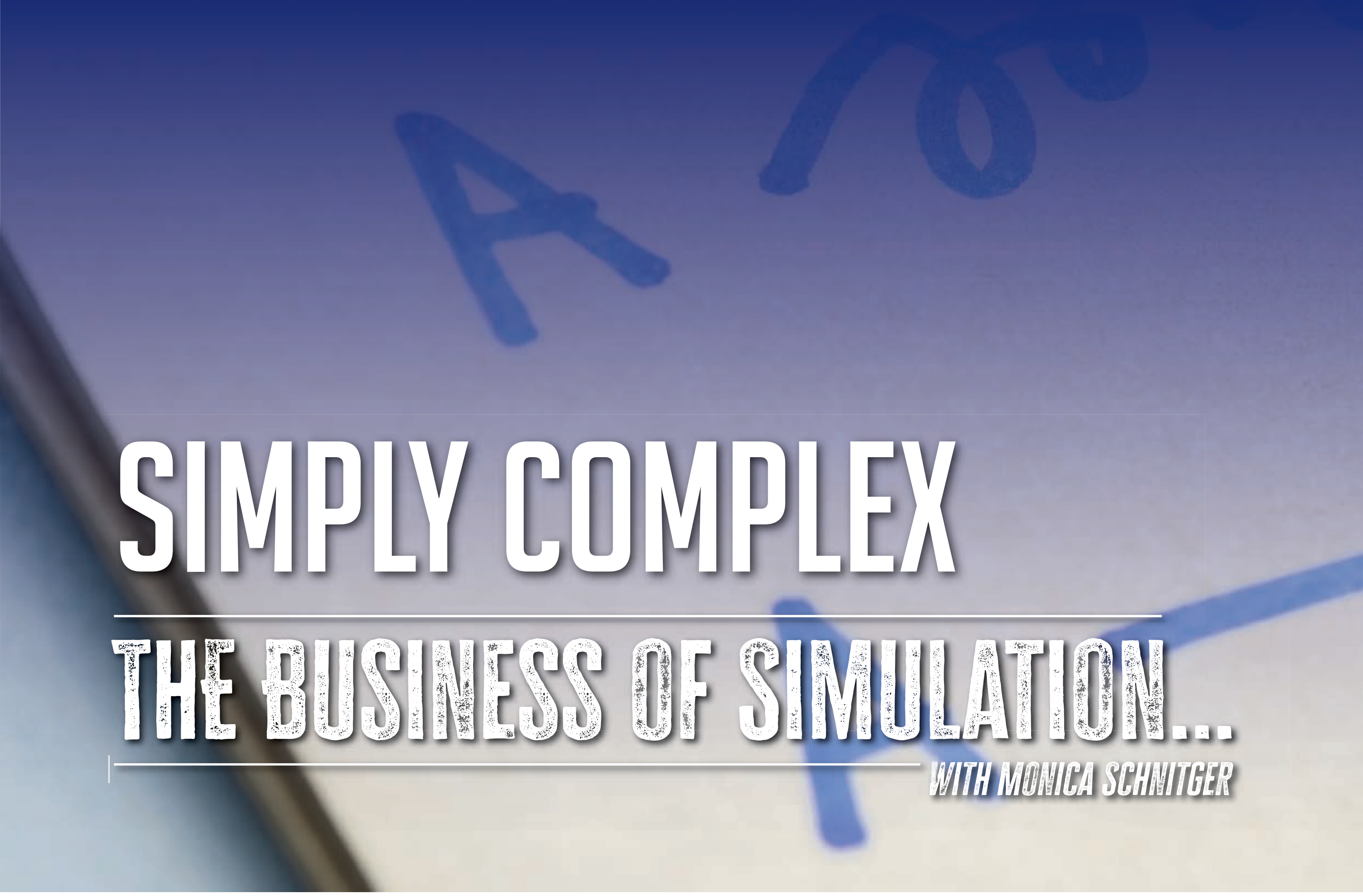
### ASSESS Summit 2025
**March 10th 2025**
Summit | Atlanta, GA, USA

### NAFEMS World Congress 2025
**May 10th 2025**
World Congress | Salzburg, Austria

### NAFEMS India Conference
**September 2025**
Conference | Bengaluru, India

### Engineering Simulation in the Automotive Industry
**November 6th 2025**
Seminar | Troy, MI, USA

**nafems.org/events**



# SIMPLY COMPLEX

## THE BUSINESS OF SIMULATION...

*WITH MONICA SCHNITGER*

**Let's face it: the world is speeding up. Consumers demand an ever-increasing refresh rate, whether we're talking cars, cell phones, toys, or industrial equipment. They want the newest features and fanciest finishes, which may require a more complex manufacturing or assembly process. These same buyers won't skimp on quality and are usually unwilling to pay more. And the kicker: they won't stay loyal to a brand they feel no longer meets their needs. Producers need to ramp up their innovation processes while ensuring the products they create meet real market needs – or get left behind.**

Since you're reading Benchmark, you already know that part of the solution to meeting these challenges is to simulate earlier in the design cycle to understand your product and its behavior under typical use cases. You shorten a design cycle by weeks or months using ideation-stage simulation to identify concepts likely to meet these market requirements; rejecting no-gos early on saves cycle time you can better devote to honing in on what matters to your buyers. And you're likely to put out a product that is easier to manufacture and maintain and minimizes the use of valuable materials and energy.

But is that enough? Unfortunately, perhaps not any longer. No matter how good a designer or engineer you are, your thought process is likely limited by the designs you have made before and how you think about the challenges your products face in the market. Of course, you can start exploring design optimization tools to identify new shapes, materials, assemblies, and other concepts you might not natively have considered. However, as you continue to get creative with your design, you also have to keep your end buyer in mind. And as you continue building your simulation prowess and modeling more complex assemblies and use cases, you also have to consider using artificial intelligence to help ensure that you're checking (ticking?) as many boxes as possible in your requirements specification.

We all hear about generative artificial intelligence, which creates whatever we ask it to from prior data. If you've tried it, you know that much of what's available right now is, at best, more right than wrong and needs rigorous fact-checking. What if we step back from that more advanced use case to a more practical and accessible use, like requirements management?

Depending on its particulars, a new product may have hundreds to thousands of requirements, including size and color, physical performance, energy usage, and material provenance. Regulatory and legal compliance may also be necessary in many industries, adding an external set of requirements that often shift with little warning.

Keeping track of each of these details is a real challenge. There are great tools on the market to collect, trace, and analyze existing requirements and manage the inevitable changes during any design program. But what manages external requirements? What keeps track of legal or regulatory changes? Predicts how customer demand might shift during that design phase? Tracks supplier changes to ensure that sourcing decisions are still valid?

Enter AI. Requirements are typically textual, which is easy for most algorithms to process. AI can analyze test results and compare them to regulations to identify when a design might deviate from the latest requirements. Let's say we're developing a refreshed infant car seat; our latest impact analysis shows results X. X was compliant with the regs in the region we intended for this design when we began the project. Then the rules changed, and we're now out of compliance. We have options: don't sell in that region and keep design X or redesign to return to compliance. Knowing this as early as possible gives us those options; waiting too long to do a compliance check removes those choices.

Lastly, why are we still simplifying models? In the past, we simulated an abstracted, simplified version of a complex design because we lacked the compute power (and, let's face it, algorithms were often less efficient) to model the entire assembly. We simplified models to solve them faster and fit simulation processes into a design timetable. Today, with GPU, HPC, and cloud resources readily available, such simplification may no longer be necessary. How many simplifications are legacy artifacts, because that's how we've always done things?

All of these suggestions are, at their heart, not technological solutions to the challenges of changing market expectations. They're business process and people-based solutions. Simulate early and quickly reject unsuitable design concepts but broaden your thinking using technologies that allow you to explore new ideas while still meeting requirements. Today's producers must rethink everything they do to compete with the best in their industry. That's the way to win and keep customers. ■

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**Monica Schnitger** is passionate about engineering IT: CAD/CAM, CAE, PLM, AEC, IoT and the other technologies used to create the world around us. She tries to explain what these are, how they affect product or asset creation and operations, and how businesses can best implement these tools, to technology buyers, investors and developers. She holds a B.S. in Naval Architecture and Marine Engineering from MIT and an honors MBA from the F.W. Olin School of Management at Babson College.

# We're celebrating the 20th NAFEMS World Congress by bringing you the best experience yet.

**Four days of cutting-edge simulation, including**

- Over 300 technical presentations in 80 dedicated presentation sessions
- A range of enlightening training courses and workshops
- The largest and most comprehensive hardware and software exhibition dedicated to simulation
- Panel discussions with NAFEMS Technical Groups, giving you an opportunity to get more involved with the community.
- Exclusive software vendor 'inside track' sessions, where you can get the latest news from your favourite piece of software before anyone else.
- Q&A panel discussions.
- And of course there's the now legendary not-to-be-missed World Congress Gala Dinner, our excellent networking reception, and an optional social programme to help you make the most of your time in Salzburg.

**The excitement is building towards the 20th NAFEMS World Congress in May 2025. Have you saved the date yet?**

## NWC25 Topic Guide

If your abstract is related to engineering simulation, modelling, and analysis, we'll consider it. In fact, if you've found your way to the NAFEMS website, the chance are your topic will be relevant.

**The headline areas we'll be looking at this time include:**

- Upfront Simulation
- System-level Simulation
- Physics-based Simulation
- Model Credibility
- Engineering Data Science
- AI & Machine Learning in Simulation
- Simulation Supporting Certification
- Simulation Data Management
- CAE in the design process
- The Role of Simulation in Sustainability
- Integration of Simulation and Test
- Emerging Methods

We'll cover all industries, research, and education areas, all methods (e.g. optimisation, stochastics, fatigue etc), all strategies (e.g. digital twins, standards, simulation governance), and much much more.

Early-access sponsorship opportunities available - contact **roger.oswald@nafems.org** for more details

nafems.org/congress

# In Praise of the Point Solution...

OPINION

Laurence Marks

I have an uneasy relationship with CAD sales. At a tradeshow in the early 90's I was on my then company's stand and a salesman from the OEM whose CAD products we sold introduced himself and asked what I did. Before I'd finished explaining that I worked with finite element code he started walking off, muttering "point solution..." under his breath. If we ignore the stupendous rudeness, which still rankles, the idea of "point solution" as an insult tells a lot about how the PLM world views us, even 30 years later.

Nobody with any interest in our part of the technical world can have failed to notice how the big 4 or 5 PLM megacorps have been hoovering up simulation operations to add to their portfolios, building their predominantly white coloured visions of the CAE future, where using whatever comes with the CAD system somebody else chose is your simulation tool of "choice". Your company chooses one CAD system and the expectation, from the CAE vendor at the very least, is that you'll use their FEA or CFD system, whether it's the last word in linear analysis for airframes or the world's most capable non-linear solver.

Accompanying that expectation has been an across the board "streamlining" of support services. Once upon a time the user/support engineer relationship was pretty much in the "Luke/Yoda" mould; I remember my Friday afternoon audiences with Alex Ramsay at MARC in Milton Keynes with huge affection. Now, it's fair to say simulation support is, well, more corporate. While this may simply be a reflection of the increased scale of the organisations supplying our code, it isn't great for the whole personal development thing. Don't get me wrong, there's no greater enthusiast for widening and disseminating simulation across the enterprise through close technology integration and efficient interaction than me, I just don't think that one impersonal size fits all.

I didn't get into simulation because I wanted to follow the herd. I wanted to work with interesting, possibly even exciting technologies that would change the way machines were created, and maybe even unlock some of the complexities of the human body along the way. And that's about creative thinking and looking at possibilities. All of the possibilities. Not just the tick list in the "add ins" menu of a CAD system. At this point, you could be forgiven for getting depressed at the direction of travel in our industry. A year or two ago I'd have said the situation looked quite bleak.

But maybe there's some light at the end of our specialist tunnel. Like all social media, LinkedIn is something of a "curate's egg". For every 100 animations of terrible models using compromised FSI approaches with non-existent validation, or wannabe tech influencers pretending a tutorial I wrote ten years ago is something their company does, there's a posting about a new simulation startup. And there seem to be quite a few; it truly gladdens the jaded heart. If we power rapidly through any negative thoughts which dwell on whether the world actually needs another SPH or LBM solver, and if the cloud actually does unlock any potential –we'll possibly return to these heretical topics another time– we pretty soon reach the conclusion that the simulation world is developing lots of new "point solutions", and that this is being done in a market where the major players are generally promoting integration rather than heavyweight simulation prowess.

As I mentioned before, we are here to develop innovative solutions to design problems through simulation. Well, I am. And these newly minted software programs, projects and, above all, organisations, give me real hope for the future. A future where the ability to integrate disparate solvers and technologies, both paid for and public domain, will be the "modus operandi" of the simulation engineer. Almost certainly enabled by Python. A future where we work where the physics is challenging and the simulation is complicated. And a future where simulation really drives product development further and more creatively than optimising the last 5% of performance out of ever more welded and bolted steel fabrications. Maybe the point solution will show us the way. ■

**Laurence Marks** has been building and writing about finite element models since spending a relaxed summer in the mid-1980s running PAFEC at the Ministry of Defence. The intervening years have been spent in numerous simulation roles covering consulting, support, training and even software sales, and haven't done anything to dull his enthusiasm for the subject. Recently he was the founder and CEO of SSA, until it became part of Technia, has worked in academia at his local universities and continues to undertake consulting and training engagements. In his sparse spare time he is a not particularly rapid Formula Ford driver.

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## NOVEMBER **24**

| | |
|---|---|
| 6th | Advanced Dynamic FEA |
| 7th | Fatigue & Fracture Mechanics in FEA |
| 13th | Next Steps with Multibody Dynamics Simulation |
| 18th | Simulation of Lubricated Contacts |
| 21st | 10 Steps to Successful Explicit Dynamic Analysis |

## DECEMBER **24**

| | |
|---|---|
| 4th | Metals Material Modelling: Plasticity |
| 6th | Elements of Turbulence Modeling |
| 11th | Non-Linear FEA |

## JANUARY **25**

| | |
|---|---|
| 8th | Metals Material Modelling: Creep |
| 10th | Introduction to Practical CFD |
| 16th | Practical Modelling of Joints and Connections |

## FEBRUARY **25**

| | |
|---|---|
| 12th | Introduction to Dynamics using FEA |
| 13th | Basic Finite Element Analysis |


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# The Growing Use of Design Simulation in the Manufacture of Professional Wood Baseball Bats

Matt Bynum | Hillerich & Bradsby Co.

**Major League Baseball (MLB) has historically been, and will always be, a game of statistics. Hundreds of different data points, both offensive and defensive, are tracked, analyzed, and strategized by organizations to try and gain an edge over opponents. In recent years, technology has come online that allows for the study of how well a baseball player pairs with their bat using high-speed cameras and software that creates and presents real-time analytics.**

## MLB Rules Regarding Bats

Major League Baseball (MLB) has a very extensive list of rules and regulations. This includes requirements for all equipment and apparel used and worn on the field by the athletes during games, as well as a long list of rules and regulations just for the manufacture of baseball bats. The six most important rules regarding baseball bats are as follows:

1. Bats used in MLB games must be made of a solid piece of wood. No composite or metal materials are allowed.
2. The length of the bat cannot exceed 42 inches.
3. The diameter of the bat cannot exceed 2.61 inches at its thickest part.
4. The overall shape of the bat must be smooth. No foreign substances or alterations that would affect the performance of the bat. For example, a bat cannot be altered to have a "trampoline effect".
5. There is no specific minimum or maximum weight limit. There are, however, rules about the distribution of weight. For instance, a certain percentage of weight needs to be near the barrel – this is never a problem due to the typical shapes of bats.
6. All bat manufacturers must be certified by MLB and each bat must have a certification mark.

## MLB Bat Market

During the regular season, there are 780 active MLB players across the 30 teams (26-player roster per team). Teams are allowed to increase their roster to 28 players on September 1st so long as the roster has no more than 14 pitchers. Of these 780 active players, approximately 405 are regular hitters due to pitchers usually not hitting.

Currently, there are 30 MLB-approved bat manufacturers vying for each of these 405 players. This makes for an extremely competitive marketplace where even gaining two or three new players is a big deal. With such a small customer pool approved wood bat manufacturers go to extraordinary lengths to get their product in the hands of players in the hopes that the bats will make it onto television. Essentially, MLB is the marketing tool for bat manufacturers.

## What Do Baseball Players Want in Their Bats?

One of the biggest hopes a baseball player has is to get a hit every time they have a turn at bat. During a typical game, a player can expect to have four at-bats on average.162 regular season games comprise a season, giving a player approximately 648 at-bats. Another objective for players is to hit the ball as hard and as far as possible.

Hitting a pitched baseball is widely considered one of the hardest things to do in sports. A professional who can get a hit four out of every ten at-bats would be considered one of the best hitters in the game. In fact, the last time a player achieved this in one season was Ted Williams (Boston Red Sox) in 1941.

Players are currently given the opportunity to select the bat they use through a series of product choices.

- Bat Model
- Wood Species (Maple, Birch)
- Finish Color(s)
- Bat Length
- Bat Weight
- Cupped or Un-Cupped
- Graphics Color(s)

These selection choices are of a general nature and many players end up using similar products. The MLB rules regarding how bats must be manufactured limit the engineering modifications that can be made to tailor each individual bat's performance characteristics to a specific player's needs.

## Raw Materials

The finished weight of the bat is one of the most important aspects for the players. Due to this, the billet (the stock piece of wood that a bat is turned from) can only be selected from an extremely small weight range, which adds additional restrictions on the manufacturing process. Figure 1 attempts to provide a visual reference to the typical distribution.

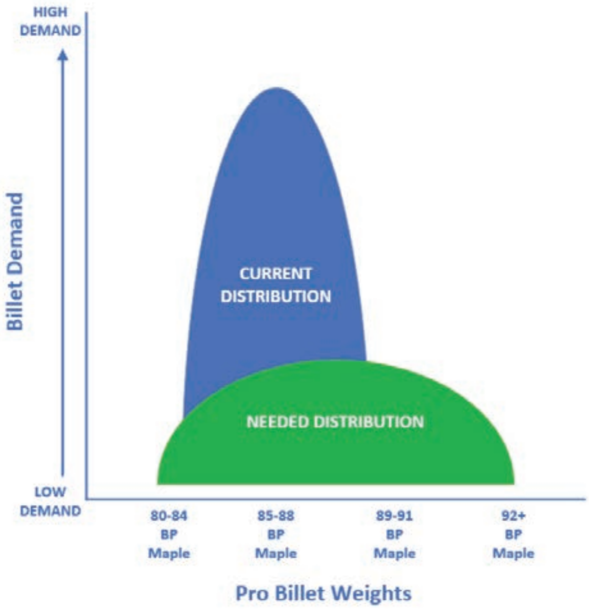



Figure 1: Billet distribution.


Kyle Schwarber #12 of the Philadelphia Phillies in action against the Milwaukee Brewers during a game at Citizens Bank Park on July 20, 2023 in Philadelphia, Pennsylvania.

(Photo by Rich Schultz/Getty Images)

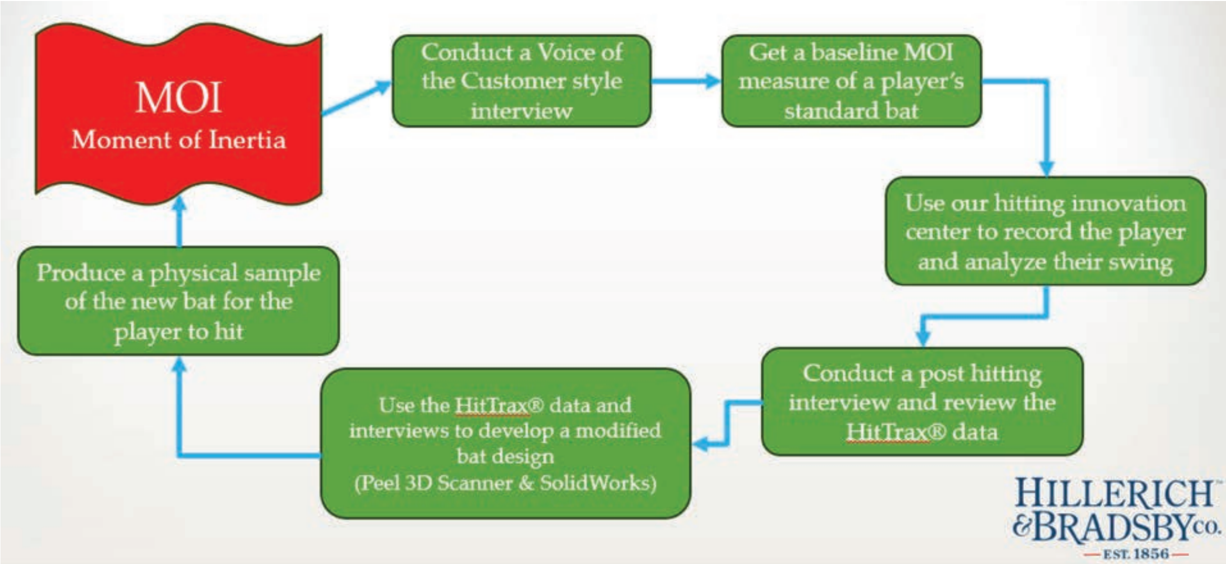
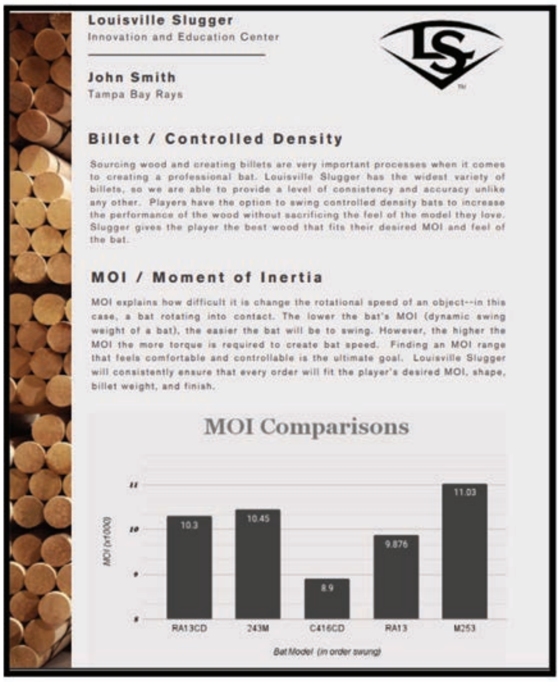



Figure 2: MOI Modification workflow.

## Manufacturing Goals

Over the last several years, technology, in the form of high-speed camera systems paired with analytics software, inexpensive 3D scanners, and modeling software have become available for use. These tools allow us to begin to challenge the notion that wood bats cannot be designed with theoretical performance outcomes. Meshing these tools together enables manufacturers to achieve several of their goals, namely:

1. Help educate young professional baseball players on what Moment of Inertia (MOI) is, how it can affect their swing, and how manipulating the MOI of their bat can give them an entirely new bat individually fitted to them.
2. Use technology to show these players that their fitted bat improves performance during an at-bat (i.e. hitting the bat harder and farther).
3. Modify the bell curve of available billets for professional bats to help use heavier billets.



Louisville Slugger
Innovation and Education Center

John Smith
Tampa Bay Rays

**Billet / Controlled Density**

Sourcing wood and creating billets are very important processes when it comes to creating a professional bat. Louisville Slugger has the widest variety of billets, so we are able to provide a level of consistency and accuracy unlike any other. Players have the option to swing controlled density bats to increase the performance of the wood without sacrificing the feel of the model they love. Slugger gives the player the best wood that fits their desired MOI and feel of the bat.

**MOI / Moment of Inertia**

MOI explains how difficult it is change the rotational speed of an object--in this case, a bat rotating into contact. The lower the bat's MOI (dynamic swing weight of a bat), the easier the bat will be to swing. However, the higher the MOI the more torque is required to create bat speed. Finding an MOI range that feels comfortable and controllable is the ultimate goal. Louisville Slugger will consistently ensure that every order will fit the player's desired MOI, shape, billet weight, and finish.



## Path to Success

**Step 1.** Everything begins with developing strong interpersonal relationships with professional baseball players. These relationships build the trust necessary to have the in depth conversations that lead to the manufacture of a better bat for the player. The relationship building allows us to educate the ball players on what MOI is, how we can pair that with swing analysis technology and what we can do with the data we gather.

**Step 2.** Conduct a Voice of the Customer style interview with the ball player. These interviews allow for a deeper dive into how the individual player feels their bat can be improved to help guide them toward the performance they want for themselves on the playing field. Data points and informational nuggets are gathered for use after the swing analysis to see if the collected scientific data matches what was captured during the interview.

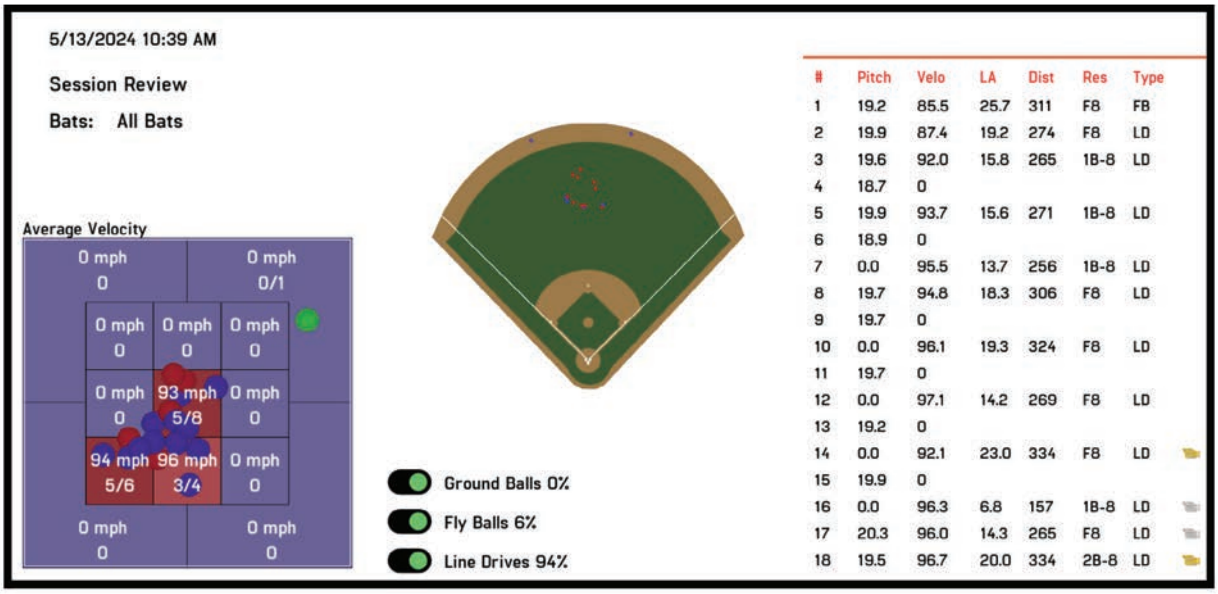
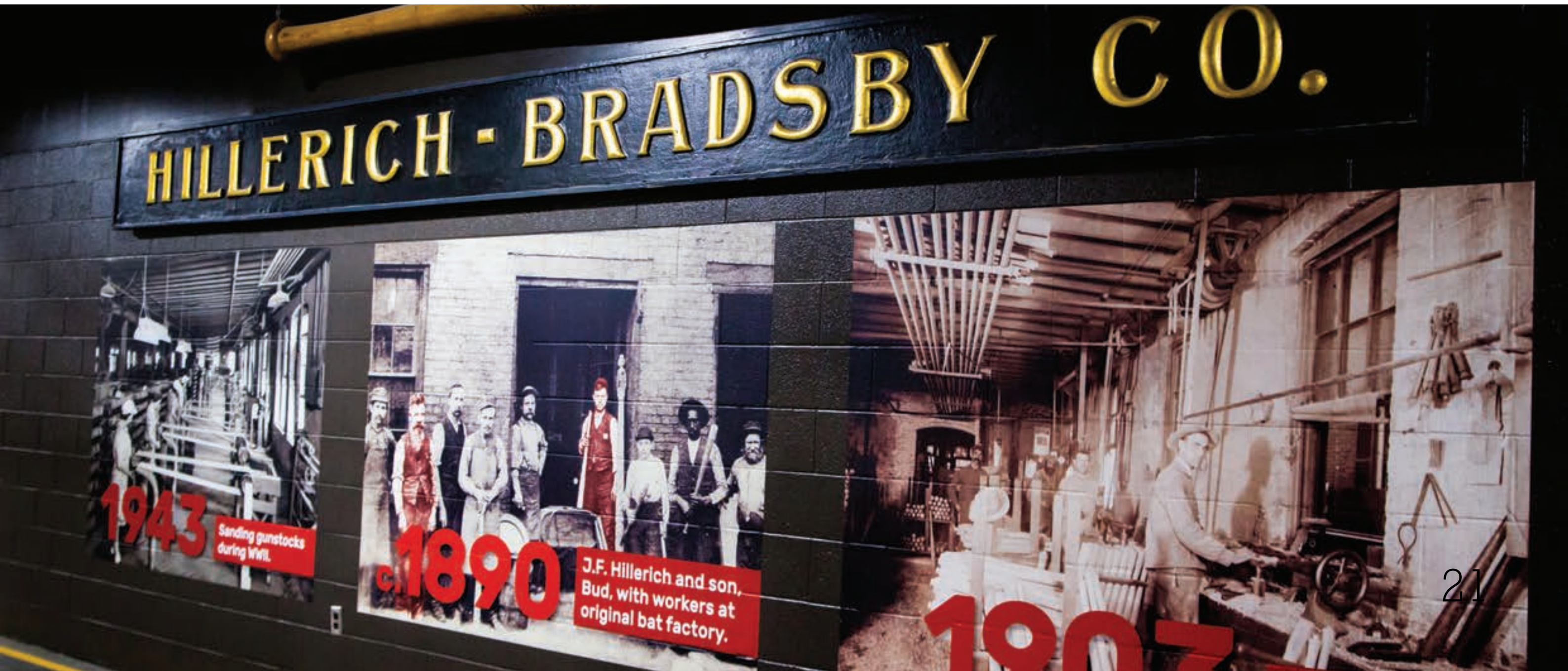



Figure 4: HitTrax analytics summary.

**Step 3.** Measure the MOI of the ball player's current bat. The MOI is calculated by utilizing a MOI measurement rig built specifically for baseball bats by an outside engineering firm. Along with MOI, the software also calculates the Center of Percussion and Balance Point for the bat. All these data points are used to provide the ball player with a baseline measure to work with once we begin the design phase of their new bat.

**Step 4.** The live hitting portion of the process is most important for understanding the ball player's approach to hitting a baseball. The ball player is asked to hit pitched baseballs, using the bat we just measured on the MOI rig, inside a batting cage linked to a HitTrax® system. High-speed cameras film the player during their time in the cage. After the hitting session, which is usually 12 to 24 swings, the HitTrax® system provides analytics including but not limited to the following:

- Exit Velocity of the baseball on impact
- Launch Angle of the baseball
- Estimated travel distance of the baseball
- Type of hit
    - Flyball
    - Linedrive
    - Groundball
- Spray chart of where the baseball would have landed on a baseball field




Louisville Slugger Museum & Factory, Louisville, Kentucky, USA

**Step 5.** Conduct a post hitting interview using the data analysis from both the MOI rig and the HitTrax® live hitting session to lead the discussion. The discussion is centered on the following topics:

- Making sure that the player understands what the MOI measurement means and how it plays into the metrics calculated with HitTrax®.
- Educating them on how we can slightly modify the design of their bat and maintain the same MOI score measured on their original bat and that this slight modification would not change how their bat feels to them.
- Getting the player to feel confident and agree to try out a modified bat design.

**Step 6.** Modify the shape of the ball player's bat using SolidWorks® software to reshape the original design in a manner that maintains the original MOI and overall shape of the player's bat. If the bat model the player uses exists in the CNC file library, it is imported into SolidWorks and rendered into a 3D image that can be modified. If the bat model happens not to exist then a 3D scanner is utilized to model the bat and transfer it into SolidWorks. Using the Mass Properties feature in SolidWorks, the render is used to calculate the MOI and confirm that it matches the MOI measured using the Physical MOI rig. If these two MOI measurements don't match, the 3D render is checked for accuracy and adjusted if any discrepancies are found. The MOIs must match for the model manipulation to yield positive results for the player.

Keeping in mind that the new design must maintain the same overall shape of the original bat, feel the same to the player when used, and not contain foreign substances, the focus during the redesign is moving the Center of Mass closer to the handle by shrinking the overall barrel diameter and trimming down the length of the bat in quarter inch steps where needed. These changes are performed incrementally so that the MOI can be checked periodically using the Mass Properties feature. A new CNC file can be created once a suitable design has been developed.

**Step 7.** Create a prototype of the modified bat using the new design. Again, this is accomplished starting with SolidWorks software. First, a 2D profile is generated, this is necessary for building the tool path to create the CNC program for the new design. The new bat model is then turned and presented to the ball player for a second hitting session. The process, from model modification to CNC program and, finally, prototype bat creation, is accomplished in a short amount of time. The prototyping process can and does happen with the ball player present, providing a huge boost to the player's confidence.

- Analyze the player's swing using the prototype bat and compare the results against the original analytics presented during the first hitting session focusing on the following metrics.
- Exit Velocity
- Estimated travel distance of the baseball (in feet)
- Launch Angle

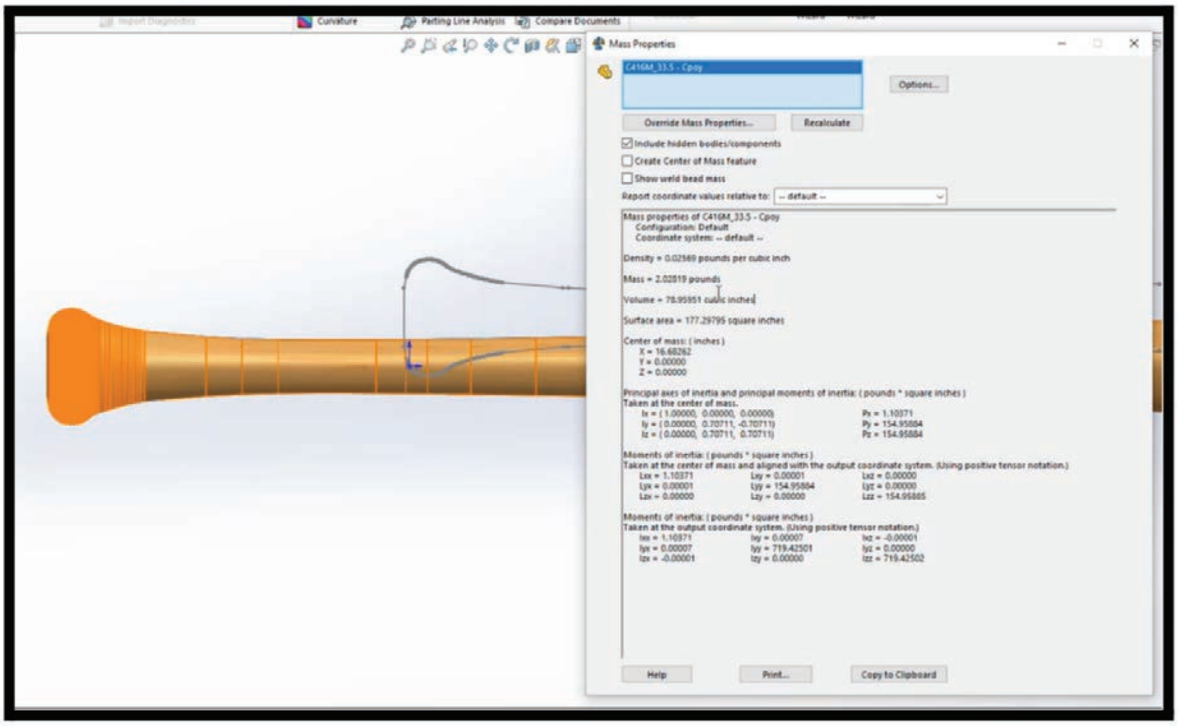



Figure 5: SolidWorks mass properties summary.

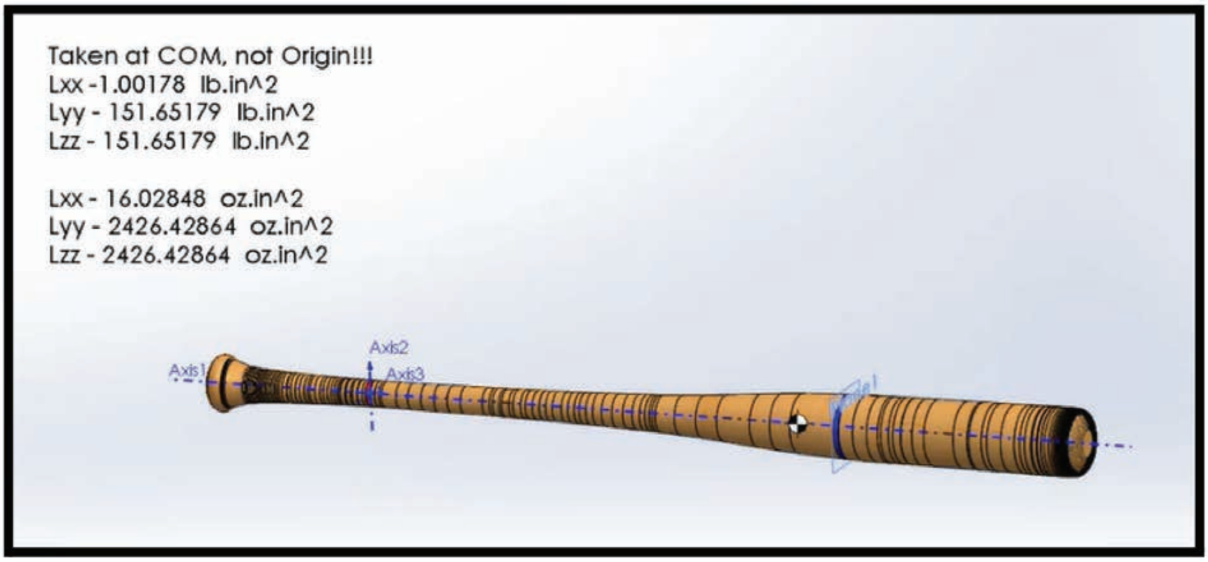



Figure 6: SolidWorks rendering showing Center of Mass.

**Step 8.** Analyze the player’s swing using the prototype bat and compare the results against the original analytics presented during the first hitting session focusing on the following metrics:

- Exit Velocity
- Estimated travel distance of the baseball (in feet)
- Launch Angle

**Step 9.** Conduct a second post hitting interview using the new hitting data and compare it to the first hitting session. This interview is used to work with the player to confirm several things:

- They truly understand the concepts around MOI.
- The modified bat feels identical or close to identical to their original bat.
- The HitTrax® analytics showed that the modified bat provided improved results over the original hitting session.
- Whether the player would be open to moving their bat selection to the modified version.

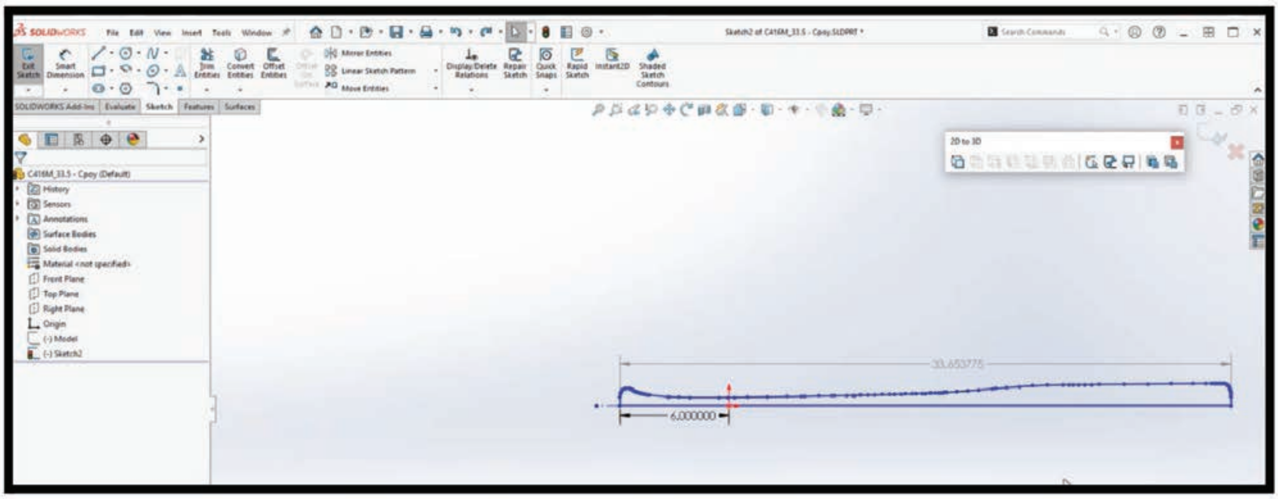


Figure 7: 2D render for CNC lathe program.

## Conclusion

The early findings with professional baseball players in the redesigning of bats has extremely positive results. Engaging with the players in a process that lets them hit baseballs while using technology to analyze their swing in real-time gains their trust in the theory of MOI. This trust increases the likelihood that more baseball players will engage with manufacturers that use this style and method in their bat manufacturing process.

Along with better engagement with the professional player, the reduction of stress in the billet supply chain is a huge benefit. Current data shows that modifying a bat by just 5% allows for the use of a billet that can weigh as much as 3 ounces more than the original bat required. This results in a bat that, for the player, feels identical to the original they are familiar with but has the added benefit of offering improved on-field performance. ■

**Matt Bynum** is the wood bat factory lead engineer for the Hillerich & Bradsby Co. Since 2014, Matt has also held the position of Product Development Liaison between Wilson Sporting Goods and Hillerich & Bradsby Co. He is a two-time graduate of the J.B. Speed School of Engineering at the University of Louisville, with both a bachelor's and master's degree in industrial engineering. His 25-year career with Hillerich & Bradsby has provided him with the rare opportunity to watch the sport of baseball evolve into a business that relies heavily on scientific study, data collection, testing, and the use of software to craft baseball bats into tools that players can use to be more successful.

Kyle Schwarber of the Washington Nationals, pictured in 2021.

SMiRT 28

## Themed "Harnessing Nuclear Technologies & Innovation as a Path to Net Zero by 2050", the 28th Structural Mechanics in Reactor Technology (SMiRT28) conference is scheduled for August 10 -15, 2025, in Toronto, Canada.

The SMiRT conference, a prestigious platform for discussing structural mechanics in reactor technology and innovation, eagerly anticipates your contribution to nuclear structural mechanics in several topical technical areas. Your expertise, particularly in the growing area of Small Modular Reactor design and development, is highly relevant and will greatly enrich our discussions. Your participation will not only contribute to our conference's success but also provide you with an exciting opportunity to network with other experts, gain insights into the latest developments in the field, and enhance your professional reputation.

Your abstract submission will be an invaluable contribution to our collective understanding of structural mechanics in reactor technology, and we look forward to receiving it by November 1, 2024.

### The technical areas for your abstracts are:

- Mechanics of Materials
- Fracture Mechanics & Component Structural Integrity
- Computation, Simulation and Visualization of Components and Structures
- Hazards & Load Characterization: Internal & External
- Response Characterization Using Testing and Analysis Techniques
- Design Codes, Standards, and Issues
- Reliability, Risk, and Safety Margins
- Ageing and Plant Life Management (PLiM), Monitoring, Inspection & Maintenance
- Fuel Cycles, Facilities, Waste Management and Decommissioning
- Constructability and Construction Management
- New Technologies (Additive Manufacturing, AI, Digital Twin)

The abstract template, deadlines and more information are available at www.smirt28.com. The website also provides the full paper template, exhibition manual, and details for organizations wishing to sponsor the conference, which will be made available as the planning process advances.

The city of Toronto and the Greater Toronto Area (GTA) is a nuclear industry hub and the most populous area of Canada, making it an economic growth powerhouse. The region is home to two large multi-unit stations, Pickering and Darlington, as well as the Bruce Nuclear Generating Station, the largest in the world, located within 200 km of the city. The province of Ontario has invested CAD 26 billion in a 15-year program into what is one of North America's most significant clean energy projects. The work continues at a national level, with Canada currently embarked on several other initiatives, such as isotope production in power reactors, decommissioning projects, and innovative technologies in the nuclear industry.

### The Venue

The SMiRT28 venue, the Westin Harbour Castle hotel, Toronto, offers well-appointed, luxurious accommodations. Select rooms boast views of Lake Ontario and Toronto's spectacular city skyline. The hotel is within walking distance of the Harbourfront Centre, Scotiabank Arena, and the Toronto Eaton Centre. With excellent air transport connections and convenient public transport, the GTA is easy to get to and navigate. It offers many visitor attractions, including the CN Tower, St. Lawrence Market, the Royal Ontario Museum, and Niagara Falls, a short day-trip away from the conference venue. The pleasant August weather will offer an excellent opportunity for visitors to explore the area.

Join us at SMiRT28 and connect with other experts in the field, share your research and experiences, and learn from their insights. We look forward to receiving your abstract submission and seeing you in Toronto.

# Speaking of Simulation...

# Part 2 - Probabilistic Analysis

Márton Gróza & Ian Symington | NAFEMS

**This exclusive series explores how leading organisations in the engineering simulation community utilise different simulation techniques. For each article in the series, we have interviewed key members of the NAFEMS community. This article focusses on probabilistic analysis.**

**In engineering simulation, managing uncertainties is a key challenge. When answering our questions, experts shared various approaches to address this, aiming to ensure reliability despite inherent variability.**

**The discussion starts with capturing uncertainty in the simulation input data. Ideally, a company would conduct measurements first-hand to ascertain the distribution of the parameters influencing the behaviour of their products. Due to the sheer number of influencing factors (e.g. material variability, uncertainty in loading conditions), one needs to make some simplifying considerations or employ certain techniques to tackle this. A recurring point from the different experts has been that the use of sensitivity analysis can reduce the size of this task b y identifying the key parameters to focus on. To address the issue of uncertain simulation input data from a different angle, one can also employ Bayesian statistics to infer the distribution of the input parameters knowing the physical model and the distribution of experimental measurements of the investigated behaviour.**

**Both analytical and sampling-based methods are commonly used to propagate uncertainties through the calculation models. When it comes to ensuring reliability despite the uncertainties present, several experts highlight the application of well-documented processes (e.g. Six Sigma) designed to handle variability and the use of direct statistical simulation.**

**Having the proper results and clearly communicating the uncertainties to the decision makers is an important part of the engineer’s job. Our interviewees emphasized the usefulness of statistical metrics, figures, or analogies linking the uncertainty in the present to previously successfully tackled problems.**

**Although most of the methods have been around for some time, developments in computing power and the rise of data-based modelling are expected to lead to significantly wider industrial adoption of direct probabilistic modelling.**

**The experts we have interviewed for the series each bring a wealth of experience and expertise in various aspects of engineering simulation. Their insights provide us with a deeper understanding of both the current capabilities and future potential.**

- **Gene Allen,** Founder at Decision Incite LLC, Member of the NAFEMS Stochastics Working Group
- **Dr. Frank Günther,** Director of Analysis & Simulations at Knorr-Bremse Rail Systems, Member of the NAFEMS Stochastics Working Group and NAFEMS Simulation Governance and Management Working Group
- **Dr. Steve Howell,** Technical Director at Abercus, Chair of the NAFEMS Computational Fluid Dynamics Working Group and member of the NAFEMS Simulation Governance and Management Working Group
- **Dr. Nadir Ince,** Director, Analytics & Digital Engineering Power Digital Solution GE Power, Chair of the NAFEMS Optimisation Working Group and member of the NAFEMS UK Steering Committee
- **Dr. William Oberkampf,** Engineering Consultant, Member of the Simulation Governance Working Group
- **Dr. Javier Rodriguez,** Technical Director at Principia Ingenieros Consultores, Member of the NAFEMS Impact, Shock and Crash Working Group
- **Dr. Fabio Santandrea,** Researcher at RISE Research Institutes of Sweden, member of the NAFEMS Stochastics Working Group and the NAFEMS Nordic Steering Committee
- **Dr. Dietmar Vogt,** Enterprise IT-Architect for the Physical Aircraft PLM at Airbus, Member of the NAFEMS Stochastics Working Group
- **Louise Wright,** Head of Science for Data Science and Head of Digital Metrology at the National Physical Laboratory (UK), Chair of the NAFEMS Computational Mechanics Working Group, member of NAFEMS Stochastics Working Group and member of the NAFEMS UK Steering Committee

## How does your organisation capture the uncertainty linked to the input data for engineering simulation?

**Dr. Nadir Ince | GE Power –** We are currently developing a process for uncertainty quantification in which input uncertainty is characterised by its "shape" and "level." For a long time, we have focused on sensitivities to identify the most significant parameters with the largest effect, as reducing tolerances can be costly. It is essential to ensure that nominal performance is achieved under all operational conditions, highlighting the importance of a robust design.

**Dr. Fabio Santandrea | RISE –** In most cases, the uncertainty in the Quantity of Interest (QoI) and its sensitivity to the input factors are evaluated analytically by mapping the problem under consideration to a linear model and computing mean, variance, and partial derivatives of the QoI from the data known about the input factors (which might be measured or estimated). This linear model is generally an approximate representation of the original problem that might still be relatively accurate locally in the neighbourhood of the nominal values of the input factors. In some cases (e.g. fatigue models), a transformation can be applied to linearise the original, nonlinear problem, and the analytical treatment will be exact. Depending on the budget available and the role of the uncertainty quantification within the project, the preliminary analytical procedure is sometimes followed by a sampling-based approach where both the uncertainty and sensitivity of the QoI are evaluated.

**Dr. Javier Rodriguez | Principia –** We often account for input uncertainty using safety factors, by following various standards and guidelines. We utilise what is known as characteristic strength, which incorporates assumptions about its expected distribution. Similarly, safety factors can reflect the probabilistic nature of loading conditions. We sometimes apply methods that incorporate probabilistic aspects more directly. Typically, the simulations we conduct are deterministic, although the conditions considered do reflect probabilistic elements. However, exceptions exist, such as Power Spectral Density (PSD) analyses for random vibration response.

**Dr. Frank Günther | Knorr Bremse –** Employing Bayesian statistics proves particularly effective in synthesising information from various sources and integrating them into a coherent understanding, even when data is limited. The first step in applying Bayesian methods is to describe the information already available accurately. This may include data from previous tests, expert knowledge, or established physical laws. Even with a relatively small dataset, meaningful results can still be derived.

*In engineering simulations, we often possess a solid understanding of the relationship between input and output. When the output is known or can be measured, Bayesian methods enable us to work backwards – from output to input – to make informed conclusions about the input data.*

This approach is invaluable in situations where direct measurement of input data is difficult or impossible. It is important to acknowledge that the initial stages of working with Bayesian statistics can be more complex than traditional methods. However, this initial complexity is outweighed by the advantages it offers. Once implemented, Bayesian methods can simplify many aspects of data analysis and simulation.

**Dr. Steve Howell | Abercus –** Abercus undertakes CFD-based explosion risk assessments, primarily for offshore assets, in line with the probabilistic methodology set out in Norwegian Standard NORSOK Z 013. The uncertainties linked to the input parameters need to be considered as part of this process. The main parameters with uncertainty are the wind (speed and direction), the nature of the flammable release (location, direction and release rate) and the ignition (location and timing). The process involves the simulation of hundreds of dispersion and explosion scenarios to explore the parameter space, and then the peak overpressures are evaluated at locations of interest in relation to their probability of occurrence. The output information is a set of exceedance curves for the locations of interest, which is a plot of the frequency of occurrence versus the explosion consequence. Since the NORSOK Z-013 is not prescriptive, the results of this type of analysis depends heavily on the assumptions one takes during the solution of this problem. An additional layer of numerical uncertainty is added by the application-specific CFD codes which are necessarily used – small-scale congestion is an important factor for the strength of a vapour cloud explosion, and application-specific CFD codes capture congestion using a distributed porosity concept, which enables the solution of these large scale, yet meticulously detailed problems. As a consequence, if different parties undertaken a nominally identical analysis, the output exceedance curves are likely to be different. This is clearly not ideal, and Abercus has highlighted this in the public domain and has tried to initiate a blind benchmarking activity to better quantify the level of this variation. In some jurisdictions, this has led to a move away from the CFD-based probabilistic explosion approach altogether, and this is an important lesson for other industries when considering certification by simulation. The many uncertainties include:

- Uncertainties in the input data
- Uncertainties in the CFD predictions – more so with the application-specific CFD codes that are necessarily used for explosion analysis than with traditional general-purpose codes because with the explosion CFD codes, the predictions do not generally converge with reducing mesh
- Uncertainties in how the CFD predictions are post-processed – for example, the order in which averages are undertaken

At least with standard automated SDM-driven workflows, Abercus can minimise some of the variation between users within the company, but there will inevitably be differences between the workflows developed by Abercus and other companies in this sector.

## How can one assume realistic input distributions without sufficient data?

**Dr. Javier Rodriguez | Principia –** As a first step, it is essential to determine the sensitivity of the output with respect to the input parameters, and then focus more detailed investigations on those deemed most significant. We acknowledge the uncertainty in our input data and consider this in our conclusions, designs, and communications with our customers. The use of big data analytics and cloud platforms plays a crucial role in processing and analysing vast amounts of data from in-service performance and manufacturing processes. This capability enables us to gain deeper insights and make more informed decisions.

**Dr. Dietmar Vogt | Airbus –** Initial material properties are often sourced from supplier data sheets. However, these data sheets are generally generic and may not accurately reflect the specific characteristics of the materials used in production. To address this, our organisation conducts its own material qualification process. This process involves internal laboratories and teams that test and analyse the materials to determine their actual properties. By doing so, we gain a better understanding of the variability and potential deviations in material properties.

*It is crucial to recognise that there can be significant differences between suppliers, and even between different batches from the same supplier.*

This variability may arise from factors such as differences in production sites or processes. In addition to material properties, manufacturing quality and tolerances are also critical. These factors are closely monitored, and the statistics derived from them are integrated into our engineering tools. This data, which includes information about the quality of the manufactured components, is essential for conducting realistic simulations.

**Dr. Fabio Santandrea | RISE –** It is important to clarify what is intended by “realistic”. We often deal with input data that result from the subjective judgement of (one or a few) designers or technical experts, rather than from a (possibly) set of measurements done under controlled conditions. The type of input distributions does not emerge from a direct interrogation of nature, but it incorporates a significant element of subjectivity: how to measure the degree of reality? However, if by “realistic” we mean “adequately reflecting our state of current knowledge and its limitations”, it is possible to define systematic (albeit not unique) procedures to characterize uncertainty in input factors. One approach that we used on several occasions is based on Pedigree Matrices: a set of quality attributes are defined (depending on the problem at hand) and a corresponding rating system. That covers aspects such as the quantity and accuracy of experimental or computational data, the validity of adopted methodologies, nature of the parameters, etc. The higher the score one factor gets, the sharper the probability distribution used to quantify its uncertainty. Of course, several options are possible for the distribution, but in practice, we often resorted to a 4-parameter Beta distribution due to its flexibility to represent different uncertainty scenarios (that is, from wide ignorance to almost certainty).

## Which areas of engineering analysis could the combination of data- and physics-based techniques lead to the biggest improvement?

**Dr. Nadir Ince | GE Power –** We run Design of Experiments (DoE) studies and use surrogate models for uncertainty propagation.

**Dr. Fabio Santandrea | RISE –** Both analytical (e.g., Taylor-series expansions or nonlinear transformations) and sampling methods are used (crude Monte Carlo and Quasi-Random Monte Carlo, the latter particularly to evaluate sensitivity coefficients).

**Dr. Steve Howell | Abercus –** Rather than providing a single set of results, we also present sensitivities to demonstrate to our clients that the results are not definitive answers but are instead influenced by inputs and assumptions.

## How does your organisation handle the uncertainty linked to the simulation results?

**Dr. Fabio Santandrea | RISE –** Uncertainty quantification is usually performed in the context of research projects with industrial stakeholders to whom we communicate the results. Then, it is up to them to consider possible actions to reduce uncertainty and the likelihood of unwanted consequences; we just help them identify the most critical sources of uncertainty.

**Dr. Javier Rodriguez | Principia –** We use sensitivity analyses to identify key parameters, drawing on practical experience from past projects. We transparently communicate the degree of uncertainty to the customer, who ultimately makes the final decision.

*"Risk" is not solely the responsibility of the consultant; it must be shared among the various parties involved.*

We also often adopt conservative assumptions in both our modelling approach and the input properties. However, caution is required, as determining what constitutes "conservative" in a specific context is not always straightforward.

**Dr. Nadir Ince | GE Power –** A well-established method involves testing under conditions more severe than those encountered in actual use cases. While certification continues to rely on physical testing, simulation is essential for reducing the number of prototypes required.

## How does your organisation harmonise the concept of reliability and safety with uncertain information?

**Dr. Frank Günther | Knorr Bremse –** In our organisation, this is accomplished through probabilistic modelling techniques, which act as the "glue" that binds these concepts together, thereby enhancing our understanding and approach to uncertainty in engineering processes. Traditionally, our assurance of reliability and safety has been rooted in experience. We have relied on tried-and-tested methods, confident in their effectiveness because of their past success. However, in recent years, we have shifted towards a more principled approach, employing probabilistic models to express probabilities and quantify uncertainties. This shift represents a significant evolution in our methodology, providing a more scientific and quantifiable foundation for our decisions.

*We recognise that the most effective approach combines both traditional experience-based methods and modern probabilistic techniques.*

Our organisation employs various testing and simulation processes to ensure a high level of reliability and safety, even though the exact degree of this reliability may not always be precisely known. This is where probabilistic models play a crucial role, helping to articulate and quantify the level of reliability we achieve. A prime example of this approach can be seen in the standards for braking distance testing of trains. Traditionally, these standards were developed based on empirical data and repeated tests under various parameters, in order to satisfy a safety requirement that the target braking distance should only be exceeded in extremely rare cases. By employing statistical simulation, we can analyse this testing procedure in greater depth to understand and even quantify exactly how it contributes to the extremely high level of safety of traveling by train. Furthermore, this analysis enables us to explore alternative, potentially more efficient methods that achieve the same level of reliability while being less time-consuming.

**Dr. Dietmar Vogt | Airbus –** Following established procedures ensures consistency and reliability in managing and propagating uncertainties within simulations. LEAN and Six Sigma methodologies, which focus on minimising waste and reducing variability in manufacturing processes, are instrumental in our organisation's efforts to achieve high quality and consistency in production, thereby reducing uncertainty. Root Cause Analysis (RCA) and Failure Mode and Effects Analysis (FMEA) are critical tools for identifying potential failure modes and their causes. By understanding the root causes of failures, simulations can be designed to better account for these factors, effectively incorporating potential uncertainties. Model-Based Systems Engineering (MBSE) offers a comprehensive approach to systems engineering, integrating all aspects of a system's lifecycle. This approach is complemented by the "V" model, which emphasises verification and validation at each stage of development. Together, these approaches ensure that uncertainties are identified and addressed throughout the system's development lifecycle. A strong focus on verification and validation is inherent to the MBSE approach, ensuring that all models and simulations accurately reflect real-world conditions and that uncertainties are appropriately accounted for and tested against real-world scenarios. By prioritising safety and security as non-negotiable aspects, our organisation ensures that all simulations consider worst-case scenarios and include safety margins to address uncertainties. Using multiple redundancies in systems, such as having multiple engines and auxiliary power units, is a practical method for managing uncertainty. These redundancies help ensure systems remain operational despite unexpected failures or conditions. While simulation is not yet officially part of the airworthiness certification process, the main emphasis continues to be on rigorous testing. The thoroughness of this testing phase, as demonstrated by the A350's 14-month test campaign comprising a five-aircraft fleet that performed over 2600 flight hours in total, ensures that all potential issues are identified and resolved before the aircraft enters service. This comprehensive testing is essential both for proving the safety of the aircraft and for meeting regulatory requirements.

**Dr. Javier Rodriguez | Principia –** We frequently perform the same task using different modelling approaches, which helps build trust in the simulations and allows us to establish more general conclusions. For instance, we often carry out deterministic calculations both to obtain the best estimate and to determine the characteristic response.

**Dr. Steve Howell | Abercus –** As mentioned, we currently present sensitivity curves without incorporating confidence levels. Consequently, our curves are essentially a direct comparison between the best estimate curve and an acceptability criterion. Quantifying confidence levels would allow us to capture uncertainty better when assessing these criteria. However, none of our clients, nor anyone in our industry to my knowledge, are requesting this level of detail at present. Although Abercus has discussed the potential for this approach with leading industry figures at conference events, there has yet to be a clear consensus on the way forward.

**Dr. Fabio Santandrea | RISE –** We try to translate the outcomes of uncertainty quantification into safety factors that can be readily used in the design process. This logic also underpins Eurocode, the standardized design code for building and civil engineering in Europe.

## How can traditional safety factor-based and probabilistic techniques coexist?

**Dr. Frank Günther | Knorr Bremse –** Traditional safety factor-based methods and probabilistic techniques can coexist effectively by harnessing the strengths of each approach. Safety factors are grounded in long-standing experience, often accumulated over centuries, and offer a proven method for ensuring safety. In contrast, probabilistic methods begin with fundamental principles and utilise statistical analysis to derive solutions. By applying probabilistic methods, engineers can quantify the underlying risks and confirm the adequacy of safety factors. When there is clear evidence that certain safety factors are effective, they should be utilised. Probabilistic methods can then enhance our understanding of these safety factors, providing a scientific explanation for their effectiveness. This approach helps bridge the gap between empirical practices and theoretical understanding, leading to more robust and scientifically grounded engineering solutions.

**Dr. Javier Rodriguez | Principia –** They are not mutually exclusive and, in fact, coexist naturally to some extent. For instance, determining characteristic values in the Eurocodes involves assumptions about probability distributions. This integration of probabilistic concepts within traditional safety factor-based methods exemplifies how these approaches can complement each other effectively.

**Dr. Nadir Ince | GE Power –** Probabilistic techniques are refining the safety factor-based approach by providing a deeper understanding of these factors. They can explain the rationale behind safety factors and, when necessary, can be used to define them more precisely.

**Dr. Fabio Santandrea | RISE –** It is possible to derive safety factors from the results of uncertainty quantifications, for example by defining them in terms of given percentiles of the probability distribution of the Quantity of Interest, or associating ranges for input factors to a given probability of failure.

## How can one effectively communicate the uncertainties related to engineering simulation results?

**Dr. Frank Günther | Knorr Bremse –** Effectively communicating the uncertainties associated with engineering simulation results can be challenging, particularly when decision-makers prefer certainty. Despite the natural tendency to avoid uncertainty in decision-making, it is crucial to convey this aspect responsibly and transparently. One effective method is to use statistics to provide technical insights. However, it is important to acknowledge that even with statistical support, people may still be hesitant to confront uncertainty. To address this reluctance, it can be helpful to connect statistical findings to familiar experiences. By using analogies and drawing parallels to past events, we can make the concept of uncertainty more relatable and easier to understand. For example, comparing the uncertainty in a current project to similar uncertainties that were successfully managed in previous projects can make the idea more tangible for stakeholders. Additionally, emphasising the robust processes in place can be reassuring. Highlighting the organisation's established procedures for managing and mitigating uncertainty can build stakeholder confidence. This approach assures them that, despite the inherent uncertainties, every possible measure has been taken to understand and effectively manage these factors.

**Dr. Steve Howell | Abercus –** As mentioned earlier, we present sensitivity curves to demonstrate to our clients that exceedance curves are not exact answers but are instead sensitive to the inputs and assumptions. In our experience, this level of reporting sensitivities is uncommon, so we make an effort to educate our clients on its importance. Abercus acknowledges that these are basic sensitivity curves without associated confidence levels—an area we aim to improve and incorporate in the future.
Dr. Javier Rodriguez | Principia – We can effectively illustrate how sensitive the outcomes are to various plausible and reasonable engineering assumptions by presenting results derived from different hypotheses. It is crucial to explain the sources of uncertainty and their impact on the results. Where feasible within the framework of a given project, presenting test results can also be beneficial. The most effective approach will depend on the specific industry and the audience's background, whether they are engineers or non-technical individuals. Tailoring the communication to suit the expertise and expectations of the recipients is essential for ensuring that the information is understood and appreciated.

**Dr. Nadir Ince | GE Power –** In my experience, statistical metrics offer a clearer and more precise description than text alone. Visualising these metrics with figures can further enhance understanding, as they allow complex data to be presented in an accessible and intuitive way. This combination of statistical data and visual representation is often the most effective method for conveying detailed information clearly and efficiently.

**Dr. William Oberkampf –** Firstly, the analyst preparing and presenting the probabilistic results should not assume that the audience is familiar with this type of analysis. The presentation should clearly explain what the results signify and how to interpret them, and include a well-understood analogy, such as throwing dice, to aid comprehension. Secondly, the presentation should carefully and explicitly outline all assumptions and approximations made in deriving the probabilistic results. Additionally, it should discuss the limitations and restrictions on interpreting the results, emphasising how they should not be used in decision-making. Developing an organisational understanding of probabilistic results, whether from simulations or experiments, should be regarded as cultivating a strategic capability. This endeavour demands a determined and persistent commitment from all management levels, especially top-tier leadership. For staff and managers untrained or inexperienced in probabilistic analyses, the transition from deterministic to non-deterministic thinking represents a profound shift. Instead of envisaging a single outcome from a process or analysis, one must accept the existence of multiple possible results. The most favourable scenario with a probabilistic outcome is merely a likelihood of a set of occurrences. To effect this cultural transformation within the organisation, two approaches should be employed. Firstly, time and resources should be allocated to training staff and management in understanding probabilistic results. Secondly, place greater emphasis on hiring staff and managers, who possess knowledge in probabilistic analyses.

**Gene Allen | Decision Incite –** It's important to emphasise that reality is inherently variable, and relying on single-value results will inevitably lead to inaccuracies. We need to make our messaging clear and accessible. There's often a tendency to use complex terminology in an attempt to appear knowledgeable, but this can hinder understanding. Instead, we should focus on communicating in straightforward terms that make the concepts easier for everyone to grasp.

**Dr. Fabio Santandrea | RISE –** An effective approach might be to focus on the consequences of uncertainty for the problem or application under consideration. Even in applications without a formal risk-oriented setting, it is always possible to define possible losses in terms of additional costs or time needed to complete some tasks. Uncertainty quantification provides a common and transparent language to inform the judgement about if we should practically worry about such losses or not. That is a natural connection to the way decision-makers are used to thinking in their daily work, and it can be applied at several levels (that is, from a single component or full system/product).

## Which recent advancements are making their way into everyday engineering practice just now or will make their way into it shortly?

**Dr. Javier Rodriguez | Principia –** Probabilistic modelling techniques are gradually gaining popularity. The methods themselves are well established, and the continuous increase in computing power is enabling us to use them more effectively. For instance, whereas in the past we typically conducted analyses for the maximum credible earthquake load, we now employ a probabilistic modelling procedure.

**Dr. Steve Howell | Abercus –** In Norway, a shift is underway from the CFD-based probabilistic explosion approach towards a much simpler black box online tool. This tool requires only a few input parameters and then retrieves the necessary information from a fixed historical database of previous CFD predictions. While it has not yet been labelled as machine learning, this lookup approach is essentially a primitive form of ML. The major advantage of this method is that it ensures consistency – regardless of who enters the parameters, the retrieved information will be the same.

**Dr. Fabio Santandrea | RISE –** I think the major hindrance to a broader application of uncertainty quantification is more on the cultural/educational side than technological. The computing power required to run large batches of simulations is relatively available nowadays, as well as techniques to reduce that burden by means of, for example, surrogate modelling. Perhaps the current trend of combining data-driven methods such as Machine Learning with physics-based engineering simulations will also boost somehow the interest towards uncertainty quantification due to the intrinsic statistical nature of these procedures.
Within the NAFEMS Community, the Stochastics Working Group is responsible for fostering collaboration within industrial and academic experts and for the development of technical resources related to probabilistic modelling techniques. ■

Within the NAFEMS Community, the Stochastics Working Group is responsible for fostering collaboration within industrial and academic experts and for the development of technical resources related to probabilistic modelling techniques.

Visit **nafems.org/community/working-groups/stochastics** to learn about the activities of the group.

# Finite Element Head Models for Older People

## *Why we need traumatic brain injury metrics specific to older people*

Samuel Swift | TECHNIA and University of Nottingham

**The term traumatic brain injury (TBI) is very descriptive, so most people understand that it relates to an injury to the brain as a result of some trauma to the head, such as an object striking the head (like an assault with a weapon) or the head striking an object (such as a fall). It's also generally safe to assume that everyone understands the importance of the brain and can appreciate that a brain injury has serious life-altering potential or even life-threatening consequences.**

**What tends to shock people is how prevalent traumatic brain injuries are. A commonly quoted statistic in the literature suggests that annual visits to the emergency department (ED) relating to head injuries are approximately 1.4 million in the UK and 2.5 million in the US, and of those ED visits approximately 10% are serious enough to require hospitalization. This data is supported by Headway, a UK-based charity for people with brain injury, whose website states that there are approximately 433 hospital admissions per day relating to head injuries (compared to 376 stroke related admissions), and that this number has been steadily rising since 2005 [1].**

**The real shock for me comes when these statistics are put into the context of other injuries. The National Safety Council ranked falls as the second highest means of preventable death in the US in 2022, greater than all deaths caused by motor vehicle related deaths and accounting for 21% of all preventable deaths that year [2]. This statistic gets more alarming when the data is broken down by age. The graph below reports the top three causes of preventable death in the US for 2022, showing total number of deaths against age (Figure 1). It shows a sharp increase in deaths due to falls at the age of 67, surpassing all other modes of preventable death from the age of 69 and peaking around the age of 87 before dropping off. What isn't captured in this graph is that the decrease in number of deaths beyond the age of 87 is simply due to the reduced population at this age. If we were to plot the mode of death against death rate, rather than total deaths, the data would show that the rate of death continues to increase with age from the age of 50 to 99.**

**This isn't limited to the US either. According to the Office for National Statistics, UK accidental death data shows exactly the same results, with fall related deaths ranking in the top three modes of death. UK data also indicates that deaths due to falls surpasses all other modes from ages 70+, including diabetes related deaths.**

**With an issue this prevalent, it's natural to start asking; what's being done about this?**

## What we Currently do About Head Injuries

A key part of the data reported by the National Safety Council is the wording – preventable. The implication here is that something can be done about it, so, is it?

Head injury is a well-studied subject and safety tests are readily performed to ensure that the probability of TBI is limited in high-risk situations. Cars go through rigorous impact testing to measure head accelerations of test dummies, cycle helmets are tested for energy dissipation, and protective military equipment is tested for user safety. Tests are performed using both FEA and more traditional physical models to ensure they meet the industry specific safety standards that each of these applications must adhere to. Beyond safety standards, more recently there has even been a drive to study the effects of repeated impacts in contact related sports like rugby, American football and boxing. So, clearly, something is being done.

However, there's one common theme in these tests, which is that they're all designed for applications which are dominated by the general adult population and are not specific to older people. There's no equivalent testing procedure for older subjects, no injury metrics, and no adjustable parameters for existing test criteria to account for the age of the subject.

This leads to the question – is this a limitation of the existing standards, or do they not exist because the differences are trivial?

## What's so Different About the Brains of Older People when Compared to Younger Adults?

There are two main differences when considering TBI in an older person compared to that in a younger adult. The first is how older people typically acquire TBI and the second is the anatomy of an older subject.
As indicated in the data above, the overwhelming majority of TBI cases in older people are due to fall related incidents. The likely situation is that an older person may lose balance, fail to protect themselves during a fall, and end up hitting their head against the floor. In a scenario like this any carpet covering the rigid floor offers little protection and the head sees a full reversal of load over a duration of two to four milliseconds. Compare this to a collision in a car where impact durations measure tens to hundreds of milliseconds thanks to all the safety features which serve to dissipate the energy.

The differences in anatomy due to ageing can be seen when comparing brain scans of a 20 year old subject to a subject in their 80s (Figure 3). A totally normal part of the ageing process is the atrophying of brain tissue with averages reported in the range of 30-35% tissue loss between the ages of 21 and 80. This has been shown in a meta study performed by Coupé and Manjón where tissue loss was indicated by an increase in cerebrospinal fluid (CSF) [3].

Now that we've established that the brains of older people are structurally different to their younger adult counterparts, the question becomes 'do they also respond differently to an impact load?'.

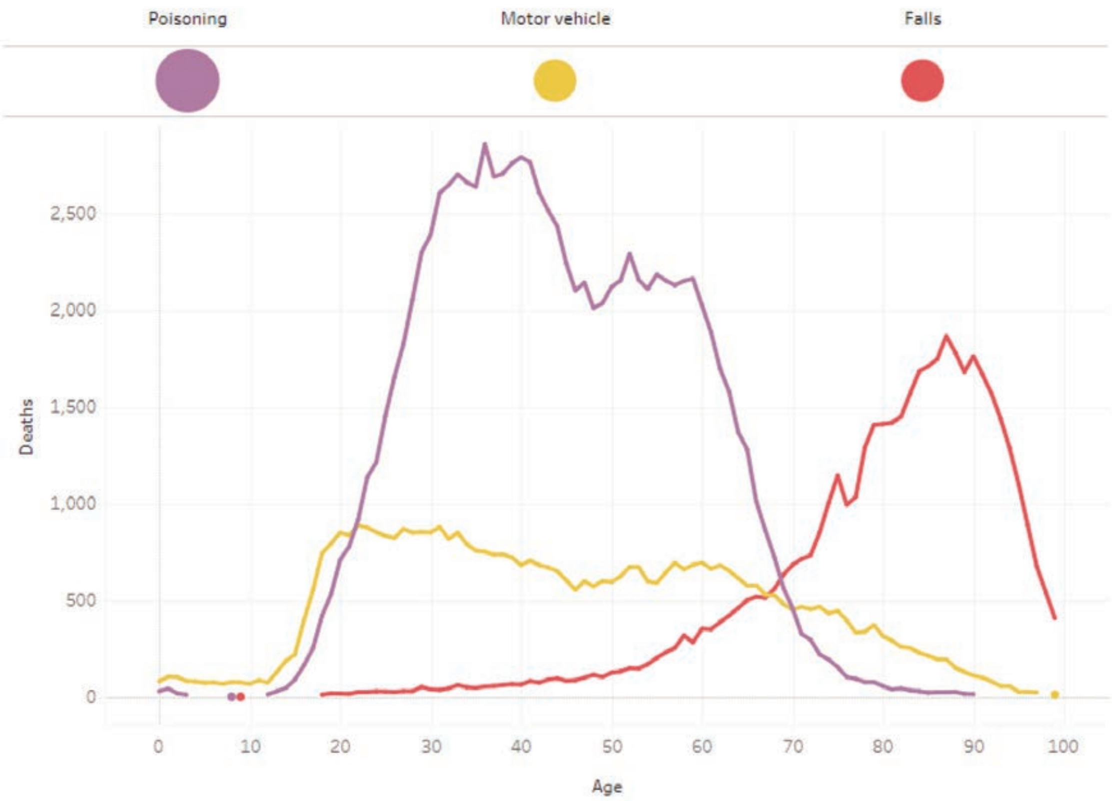



Figure 1: Method of preventable death by age in America in 2022 [2]. (© National Safety Council, 2024).

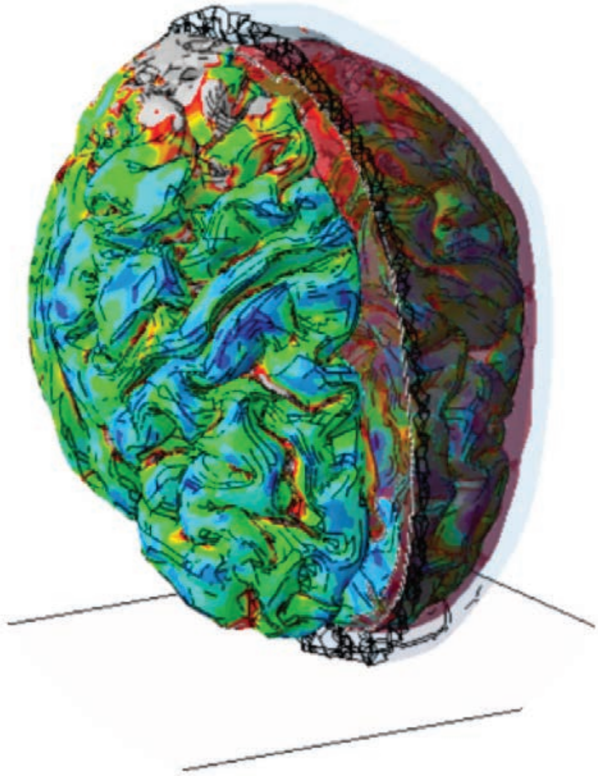


Figure 2: Strain plot of an older person's head during a head impact to the floor.

## A First Look at Tools for Simulating TBI

The majority of head injury risk assessments are performed through physical tests and evaluating the motion of the head against acceleration-based injury criteria or other similar safety standards. However, in some cases, a more comprehensive assessment is conducted through the use of finite element head modelling (FEHM).

FEHMs are a great tool for understanding injury mechanisms and assessing the response of the brain under load. As with any FE analysis, a well-defined model can offer a much more detailed view of the problem than any physical tests can. This becomes even more critical when simulating head injuries as an FE model is not restricted by the ethical limitations associated with testing cadavers or live subjects. FEHMs do, however, have their own limitations. In this case, the main issue with existing FEHMs is that the majority are based on subjects in their 20s, and as already demonstrated, there are significant differences in the brains of these two population groups.

Currently, there are a limited number of FEHMs which are geared towards older members of the population. However, these models are typically adapted from younger-adult FEHMs and the 30-35% age-related tissue loss is typically represented by scaling down the volume of the brain. The issue with this is that the change in structure of an atrophied brain cannot be represented by simply shrinking a non-atrophied brain.

The difference in structure between the brain of an older person and that of a younger adult can be seen in an MRI scan where the older brain will show clear separation between the gyri (folds), and the younger brain will, typically, be more tightly packed and separation of the gyri is not as clearly visible. The difficulty in identifying individual gyri in younger adult brain scans is the reason existing FEHMs represent the brain with a smooth or textured surface. A model of an older person's brain created by scaling down the volume of a younger adult brain will therefore also be represented by a smooth or textured surface.

Therefore, to answer the question of whether the brain of an older person responds differently to an impact load compared to a younger adult brain, it is necessary to build a new age-specific FEHM.

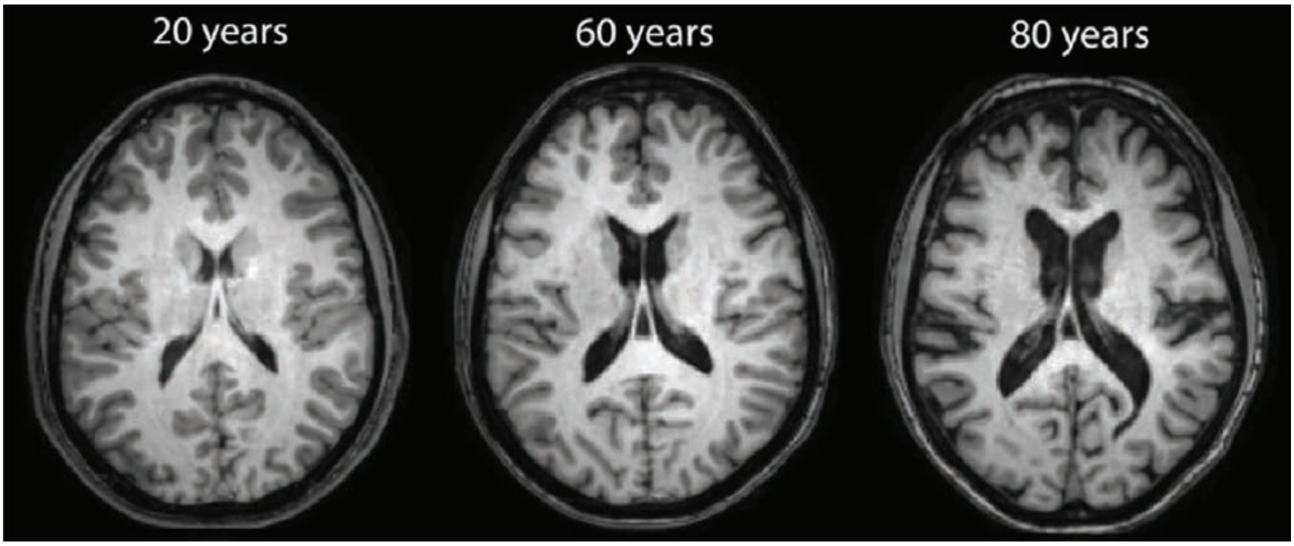



Figure 3: Comparison of MRI brain scans for ages 20, 60, and 80 years old.

## Creating the Model

To test the theory that the brains of older people do indeed respond differently to their younger adult counterparts we built a subject-specific FEHM of an older person's brain showing normal tissue loss. The different structures of our subject's head were separated by labelling a series of 2D MRI scans of the whole head, a process referred to as segmentation. This process was completed using a combination of the automated segmentation software volBrain [3] and the semi-automated ITK-Snap [4]. The segmentation process separated the head into the following structures; the skull, the fluid (CSF), and the three main parts of the brain (cerebrum, cerebellum and brainstem). The separate structures were then exported as 3D models in *.stl format and converted into CAD geometry using the reverse engineering tools within CATIA® v5.

The structures were separated into two categories; the solid regions and the fluid regions. The solid regions were then further subdivided into two categories, soft tissue (the brain) and hard tissue (the skull). For this assessment we ignored any injury to the skull since our focus was trauma to the brain. The inclusion of the skull was simply to serve as a load path and to keep all the fluid in place. For this reason, the skull was modelled with simple linear-elastic properties. The brain however is more critical, and testing for brain tissue properties is notoriously difficult.

Brain tissue is highly compliant and highly fragile, which makes the physical process of testing difficult to perform and difficult to reproduce. There are also the ethical implications of obtaining tissue samples and the fact that the properties change depending on time post-mortem. Plus, the response of brain tissue varies with loading rate, tension/compression loading, preconditioning, and exhibits an asymmetric loading/unloading response. For these reasons, obtaining accurate brain tissue properties for a range of applications remains one of the biggest challenges within the field.

For this assessment, the brain tissue was modelled with a first-order Ogden hyperelastic material model. This is generally accepted as the most appropriate material model in literature published in the past 20-ish years. As has already been indicated, the impact duration for this application is much shorter than typical applications, and this is reflected in the strain rates of the published test data. Due to limited data availability, the strain rate which most closely matched a fall-like scenario was used.
As we established previously, the scenario in which an older person suffers an injury typically differs from what a younger adult is likely to experience. This means that standardized testing procedures and published acceleration data is not relevant to this application. Therefore, to model a realistic fall scenario, velocity data was taken from tests conducted by dropping anthropomorphic test dummies from various standing positions. The testing procedure included falling forwards, backwards and sideways, and included scenarios where the knees and hips were/weren't allowed to bend. The data was then reviewed to determine the most onerous load case, which was a forward fall from standing, with no knee bend. The velocity at the point of impact for the forward fall case was used as the initial velocity for the simulation.
The FEA software of choice for this simulation was Abaqus, owing simply to the significant experience the author has in this software compared to other viable products.

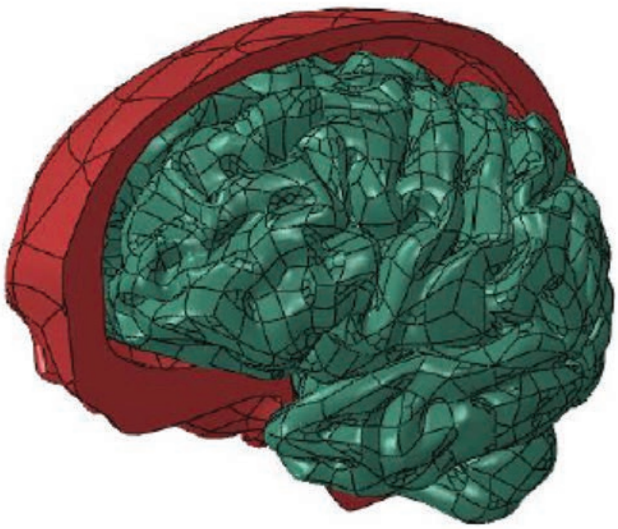


Figure 4: CAD model of an older person’s head.

## What is the best way to represent the fluid layer in the brain?

The volume between the skull and the brain is filled with cerebrospinal fluid (CSF). This fluid layer serves to dampen the motion of the brain and protect it from injury. It is therefore critical to accurately represent the behaviour of the fluid when simulating head impact scenarios.

To model the behaviour of the fluid layer, there are several options proposed in the literature. These range from early models representing the fluid with Lagrangian elements and a hyperelastic material definition, to the various new fluid structure interaction (FSI) techniques. Thanks to the increased availability of FSI techniques, and the limitations of Lagrangian methods for modelling extreme deformation, using FSI to model the fluid is becoming more common.

A preliminary investigation was performed to determine which method is most appropriate for modelling the CSF in an advanced age specific FEHM when simulating a fall scenario. The comparative study assessed the four primary techniques available within Abaqus for modelling the effect of the fluid on the brain. These were as follows:

- Arbitrary Lagrangian Eulerian Remeshing (ALE) – where the CSF is modelled with Lagrangian elements, which have fluid properties, and are restructured during the analysis to maintain uniformity
- Coupled Eulerian Lagrangian (CEL) – where the CSF is modelled as a volume of material flowing through a fixed Eulerian grid (this method was repeated with various contact options enabled)
- Smooth Particle Hydrodynamics (SPH) – where the CSF is modelled as a volume of particles acting as a continuum of material
- Fluid Cavity – where the CSF is not explicitly modelled, but a representative volume and pressure for the fluid is maintained

The results indicated that the fluid cavity model and the CEL model with soft exponential contact were not appropriate methods as both resulted in non-physical deformations of the brain.

The CEL model with default hard contact was also omitted due to the tendency for the fluid region to penetrate into the brain region when the contact failed. This was likely due to incompressibility of the fluid, incompressibility of the brain, and pressure waves of the impact.

The ALE model indicated promising results; however, this assessment was performed on simplified geometry which did not account for the folds in the brain. The ALE model was therefore omitted from selection due to the limitation in its ability to represent complex geometry.

It was therefore concluded from this assessment that the most appropriate methods for modelling CSF in advanced age specific FEHMs simulating fall scenarios was either SPH, or CEL when using the enhanced contact definition.

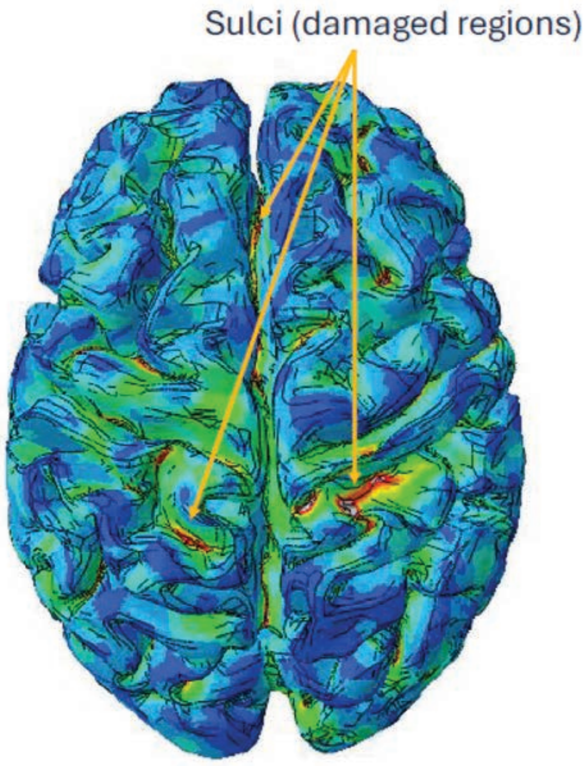



Figure 5: Strain plot of an older person's head during a head impact to the floor, highlighting damaged regions.

## Did the Older Brain Respond Differently?

Finally, the model for the advanced age specific brain was built in Abaqus and a fall from standing with no knee bend scenario was simulated. Based on the findings for the FSI assessment, the CEL with enhanced contact option was selected for this analysis.

The duration of the simulation is 5ms, however it can be seen from analysing the global energies in the model that the peak impact occurs much quicker. From the start of the analysis there is a reduction in kinetic energy and an increase in strain energy. The strain energy peaks after 1ms before decreasing, indicating an almost full reversal of energy after 2ms total duration.

What is immediately obvious from the results is that the highest strains occur in the sulci (grooves). The cause for these damaging strains becomes clear when animating the result frames. As the brain impacts the rigid surface, a pressure wave propagates through the brain causing the gyri to resonate. What is critical about this is that the gyri move independently causing the sulci to open and close, which results in the localized strain.

These results highlight a mechanism for injury which existing FEHMs specific to older people are unable to replicate as they lack the necessary anatomical detail to show high strains in the gyri region. The next step in this research is to compare this model with these existing pseudo specific models under comparable loading scenarios, however initial tests have proven to be positive! ■

## References

[1] Headway, "Statistics". [Online]. Available: https://www.headway.org.uk/about-brain-injury/further-information/statistics/ (Accessed: 16 October 2024).

[2] National Safety Council, "Deaths by Demographics: Age and Cause". [Online]. Available: https://injuryfacts.nsc.org/all-injuries/deaths-by-demographics/deaths-by-age/data-details/ (Accessed: 16 October 2024).

[3] J. V. Manjon and P. Coupe, volBrain, "An Online MRI Brain Volumetry System," *Frontiers in Neuroinformatics*, vol.10, Jul. 2016.

[4] P. A. Yushkevich, J. Piven, H. C. Hazlett, R. G. Smith, S. Ho, J. C. Gee and G. Gerig, "User-guided 3d Active Contour Segmentation of Anatomical Structures: Significantly Improved Efficiency and Reliability," *NeuroImage*, vol. 31, issue 3, Jul. 2006.

**Samuel Swift** splits his time between commercial FEA work as a senior simulation engineer for TECHNIA, where he works as a simulation consultant over various industries from medical devices to offshore power generation, and academic research with the University of Nottingham in the Bioengineering department, where his focus is simulating head injury.

He has recently been described as "someone who somehow balances commercial work, academic research, a busy home life and running galactic distances".

# ASSESS SUMMIT

ATLANTA
MARCH 10-12
2025

**The NAFEMS ASSESS Initiative has one vision - to lead every aspect of engineering simulation toward a more valuable and accessible future in the medium to long term, leveraging the expertise and knowledge of top-level figures in industry, government, and academia.**

To continue that journey, the 2025 ASSESS Summit will be held in Atlanta, Georgia, between March 10th and 12th. This won't be a traditional conference. It will be an opportunity for thought leaders to work as one to map out the future of engineering simulation and lead the way toward it.

The 2025 ASSESS Summit will bring together key leadership participants, including experts, industry analysts, software providers, researchers, simulation users, and others in the community of model-based analysis, simulation, and systems engineering.

The conference will be highly interactive, splitting into several theme workshops where participants will meet, discuss, and report to the main plenary.

## Keynote Speaker

**Dr. Carmen Torres-Sanchez**
*Multifunctional Materials Manufacturing Lab | Loughborough University*

Carmen Torres-Sanchez PhD CEng FHEA MIMechE leads the Multifunctional Materials Manufacturing Lab at Loughborough University, England (UK). Her work sits at the interface of mechanical, chemical, bio-engineering, materials science and embedded intelligence. Her multidisciplinary lab works in the design, manufacture and validation (both in- and ex-silico) of structures and materials with coupled functionalities (e.g., structural and biological; acoustic and lightweight). Close collaboration with industry has seen her innovations applied in sectors such as Automotive, Food Technology and Medical devices.

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## Program

Attire for the duration of the ASSESS Summit 2025 is casual.

### Monday | March 10

| | |
|---|---|
| 18:00 PM | Registration and Badge Pick-up Opens |
| 6-9 PM | **Welcome Reception & Cocktails** |
| | *Please join us for food, drinks, and networking opportunities. You'll have a chance to meet and talk with the other NAFEMS ASSESS Congress participants. We ask that all participants try their best to attend this reception.* |

# Tuesday | March 11

7:45-8:30 AM — Breakfast - *Join us for breakfast prior to starting the day's activities.*

8:30 AM — Kickoff: Opening Remarks and Call to Order
Joe Walsh will set the stage for the day's activities

9:00 AM — Keynote Presentation:

**Multifunctional structures: A journey from Physics-based simulations to Data-driven approaches**
Carmen Torres, University of Loughborough

9:45 AM — Break

10:15 AM — Platinum Sponsor highlight 1

10:30 AM — Notes from the Front Presentations 1

**SLB journey to SDPM**
Amandine Battentier, SLB

**Digital Engineering Methods for Architecting Cislunar Ecosystems**
Michale Balchanos, ASDL

**The Business Benefits of Early-stage Digital Twins for RFIs/RFQs in the Automotive Industry**
Alfred Svobodnik, MVoid Group

11:15 AM — Invited Presentation: McKinsey Consulting

12:00 noon — Lunch, Networking, & Discussion

1:15 PM — Working Session Breakout 1

*We will be breaking out into a set of working groups to discuss focused questions for each ASSESS Theme:*

**Business:** What are the current items that are limiting broader business benefits enabled by Engineering Simulation including organizational limitations of Engineering Simulation driven business benefits and how can we address them?

**Certification:** What makes Certification by Engineering Simulation different from Credibility & confidence?

**Credibility:** How can we address the organizational, social and cultural challenges with establishing confidence (internal) and credibility (external)?

**Democratization:** What are the technological and organizational barriers to democratization?

**Integration:** What are the concerns and possibilities of integrating multi-fidelity models to drive Physics Informed AI?

**Twins:** Which scenarios/activities can benefit from an Engineering Simulation Digital Twin?

2:30 PM — Break & Transition to Notes from the Front Presentations 2

2:45 PM — Platinum Sponsor highlight 2

3:00 PM — Notes from the Front Presentations 2

**Automating the extraction of engineering simulation metadata**
Olivia Fischer, ASDL

**Enabling the Next Big Leap in CAE**
Jared Cox, Honda Development & Manufacturing of America

**Certification by Analysis**
Trevor Robinson, School of Mechanical and Aerospace Engineering in Queen's University Belfast, Northern Ireland

3:45 PM — Break & transition to Working Session Breakout 2

4:00 PM — Working Session Breakout 2

*We will be breaking out into the second set of working groups to discuss focused questions for each ASSESS Theme:*

**Business:** How can we broaden the audience (executive, government, …) regarding Engineering Simulation driven business benefits (e.g. ongoing collaboration with McKinsey)?

**Certification:** How can the Certification by Simulation procedures used, for instance, in the Aerospace and Nuclear fields be exploited in other sectors?

**Credibility:** Can organizations make design decisions based on simulation alone, if not why and how can we move here?

**Democratization:** How do we foster broader use of Advanced Technologies (e.g., accuracy driven adaptivity, AI, Quantum Computing, meshless) to support democratization?

**Integration:** How can we leverage an understanding of model "appropriateness" to improve integration of multi-fidelity models and associated information?

**Twins:** How to integrate across multi-fidelity ES Digital Twins?

5:15 PM — Close-up sessions

6:00 PM — Reception

7–9 PM — Dinner

*Join us for a night of good wine, good food, and good company*

# Wednesday | March 12

7:45-8:30 AM — Breakfast
Join us for breakfast prior to starting the day's activities.

8:30 AM — Kickoff: Opening Remarks

8:35 AM — Keynote Presentation:
**Driving Digital/MBE Realization in the Airframe Loads and Dynamics Value Stream with a North Star Strategy**
Jack Castro, The Boeing Company

9:20 AM — Break

9:45 AM — Platinum Sponsor highlight

10:00 AM — ASSESS Presentation:

**Understanding the Different Forms of Democratization of Engineering Simulation**
Joe Walsh

10:45 AM — Break

11:00 AM — Plenary Session – Open Discussion General discussion of the ASSESS Initiative

12:00 noon — Close of NAFEMS ASSESS Congress 2025 & Lunch

# invitation 2 TENDER

NAFEMS

A core part of the NAFEMS mission is to develop and produce application-ready, software-independent, best-practice guidance for the modelling and simulation community. We are focused on finding ways to best serve the industry and ensure that the community is well-equipped to use simulation in the most efficient, effective, and responsible manner. Thanks to the depth of knowledge and expertise of our Technical Working Groups, NAFEMS is in a position to identify areas where guidance and training opportunities are required.

As part of that process, we produce invitations to tender on selected topics to ensure that our publications and training courses are developed, written, and scrutinized by leading experts in each particular field.

We are pleased to launch one of our most significant tender processes to date.

**Eight publications and four on-demand training courses are now open to tender.**

NAFEMS publications uniquely combine theoretical and practical aspects, distinguishing them from purely academic works. Thanks to our membership model, these books are widely accessible to practising engineers in print and digital formats.

Our on-demand courses, available through the newly redeveloped Learning Hub, bridge the gap between academic study and software-specific training, catering exclusively to our members.

You can submit a proposal, ask a question, or put forward a new suggestion by emailing technical@nafems.org, where our technical staff are on hand to assist. Please also forward these opportunities to any colleagues you think may be interested, or promote them within your own organization or networks.

The closing date for all completed proposals is January 1st, 2025, and you are welcome to contact us to discuss any submissions before this deadline.

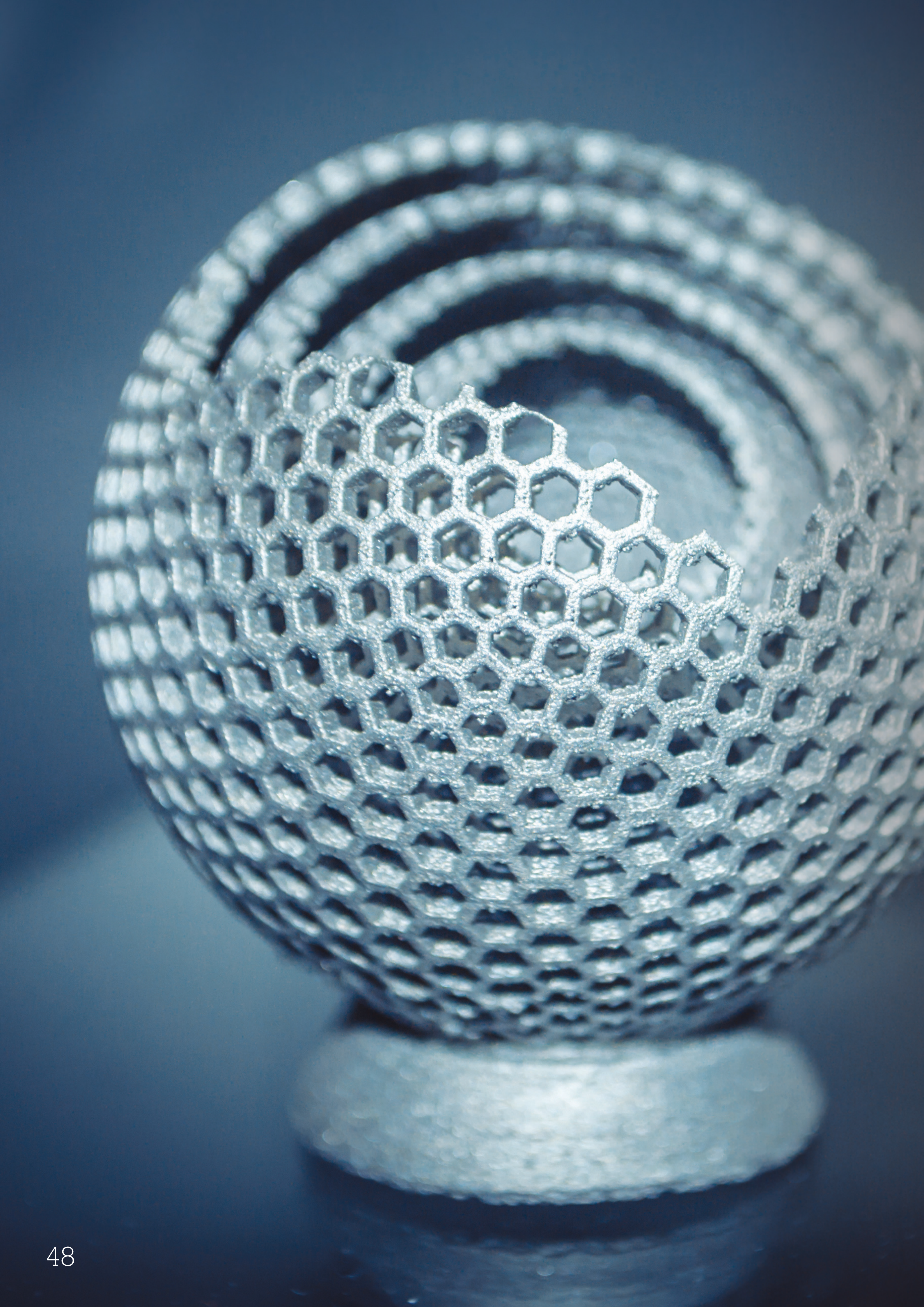
## Publications

- Why do Surrogate Modelling?
- Why do System Simulation?
- How to Model Delamination and Failure of Composites
- Why use Particle Methods? and How to use Particle Methods
- Update – How to Manage Engineering Analysis
- Update – How to Undertake a Contact and Friction Analysis
- How to Analyse Rotating Machinery

## On-demand Courses

- Getting Started with System Simulation
- Worked Examples for Cyclic Plasticity and Low-Cycle Fatigue Strength Assessment
- Worked Examples for High-Cycle Fatigue Strength Assessment
- An Introduction to Thermal Analysis in Solid Structures

For full details visit **nafems.org/tenders**



# Predicting Buckling due to Thermal Distortion

## *An Example Problem for Additive Manufacturing (AM) Process Simulation*

**Sjoerd Van-Der-Veen** | Airbus
**Anas Yaghi** | TWI
**Shukri Afazov** | Nottingham Trent University
**Tyler London** | Reckitt
**Yongle Sun** | Cranfield University
**Guglielmo Vastola** | Institute of High Performance Computing
**Mustafa Megahed** | ESI
**Marton Groza** | NAFEMS

*Reviewed and endorsed by the NAFEMS Metallic Additive Manufacturing Focus Team*

**The recently published book *How to – Model the Additive Manufacturing Process* [1] by the NAFEMS Metallic Additive Manufacturing Focus Team [2], a part of the Manufacturing Process Simulation Working Group [3], offers practical advice on modelling the additive manufacturing process. The team has now gone further and devoted considerable effort to developing a suite of example problems that encapsulate the complexities of simulating the Additive Manufacturing (AM) process.**

*The first problem revolves around the buckling phenomenon observed when printing thin-walled structures. The reader is encouraged to simulate the phenomenon based on the included and referenced information, and then share their experience with the community.*

**The current problem highlights the buckling susceptibility of thin-walled structures due to the AM process. This buckling phenomenon is evident in the tube-like components shown in Figure 1, where the walls demonstrate an outward distortion after the tube is separated from the substrate post-printing. G. Vastola et al. [4] have investigated this effect in similar geometries and found that the buckling analysis results align with the observed distortions, strongly supporting the identification of this distortion as buckling.**

**Further details on this phenomenon can be found in the "Methodology and Validation of Rapid Prediction of Distortion for Powder-Bed Additive Layer Manufacture" [5] conference paper and in the "Distortion Prediction and Compensation in Selective Laser Melting" [6] article for Ti6Al4V.**

The team has confirmed that the proposed geometry exhibits buckling across a broad range of materials and process settings. In all experimental and numerical settings evaluated, buckling has occurred. For companies and institutions engaged in thin-walled metal additive manufacturing, the ability to predict this buckling phenomenon is crucial when selecting simulation software and methodologies.

To capture the buckling effect in the manufacturing process simulation, various methods may be employed. Sequentially coupled thermal-mechanical simulation is the general solution for this type of problem. The group has replicated the experimental results in a qualitative manner with the inherent strain approach [1], the shrinkage model [7], and with an approach that utilises a calibrated analytical thermal model integrated within the structural Finite Element Analysis [5], [6].

Buckling manifests progressively during the additive manufacturing building process, leading to the component being in a permanent post-buckling state. Consequently, it is advisable to conduct the process simulation with geometric non-linearity (large displacement) enabled.

From the team's experience, the resolution of the mesh and the selection of the appropriate element type significantly influences the simulation outcomes. Shell elements or continuum shell elements are recommended; however, it has also been demonstrated that hexahedral solid elements, when appropriately chosen, can effectively predict buckling. Software packages that conceal the meshing step might struggle with accurate buckling prediction.

Correctly setting the boundary conditions is crucial for accurately simulating the separation of the specimen from the substrate. The simulation should ideally include two phases: the building process, where the part is affixed to the baseplate of the laser powder bed machine, followed by a step to sever it from the substrate. Additionally, achieving an effective simulation also depends on maintaining a balanced ratio between the actual and simulated layer heights.

The following two sections introduce the details of the observed buckling phenomenon for both 316L stainless steel and Ti6Al4V. The two main aspects connecting these observations are that they share the same tube type test specimen geometry and the observed results are also analogous in nature, with AM Ti6Al4V exhibiting the effect in a more pronounced way.

## The Buckling Phenomenon for 316L Stainless Steel

To provide experimental grounds for posing the benchmark, twelve stainless steel (316L) specimens have been built with an EOS M290 (400W) machine (Figure 1).

The overall dimensions of the tube type test specimen are: 140 mm height and 10 mm base plate thickness, 46 mm x 34 mm bounding dimensions for the cross section, and 1 mm wall thickness. Figure 2 displays a sketch of the tube type test specimen. The test specimen represents a simplified section of an additively manufactured bicycle frame.

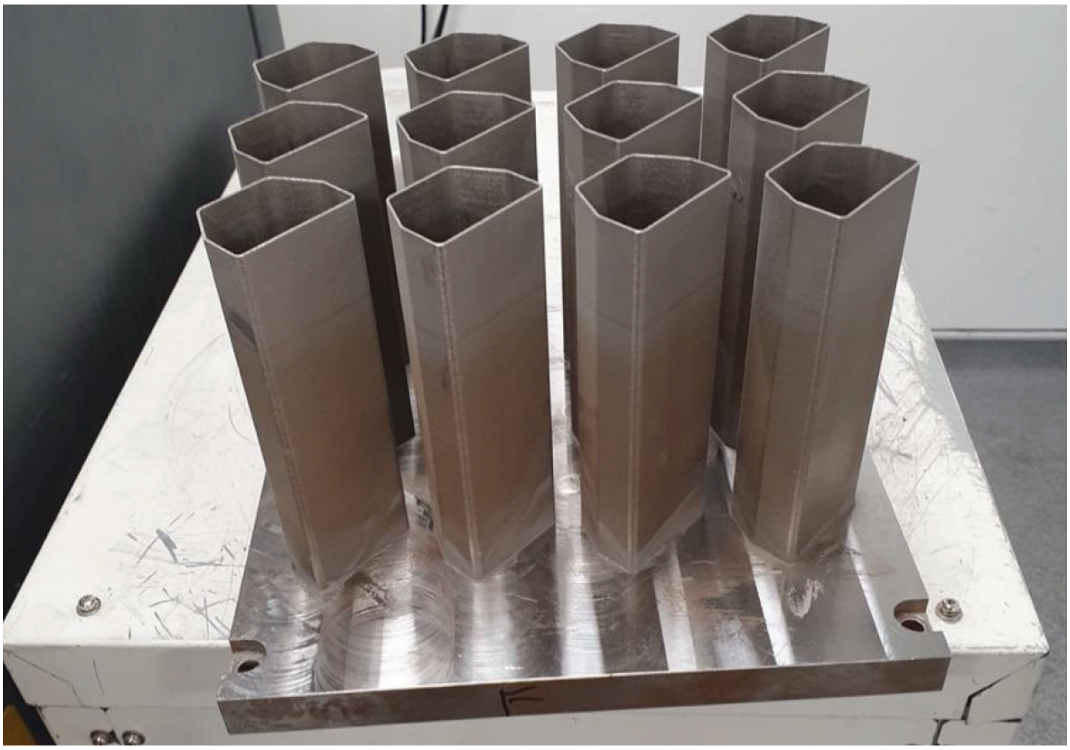


Figure 1: Twelve steel specimens that have been built at TWI with an EOS M290 (400W) machine.

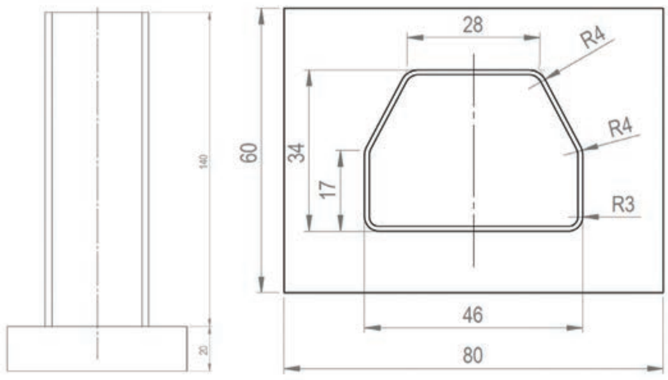



Figure 2: Dimensions for the tube type 316L stainless steel test specimens.

The stainless-steel powder “EOS StainlessSteel 316L” has some of its material properties included in the material data sheet [8]. The following printing parameters have been set when printing the twelve tube-type test specimens (further details can be found in the Appendix):

- Total printing time: 39 hours and 27 minutes,
- Start Z: 0.04 mm, End Z: 144 mm, height: 143.96 mm (3599 layers),
- Layer thickness: 0.04 mm,
- Beam offset: 0.08 mm, platform temperature: 20°C,
- Laser Temp.: Max. Temp. 26.4°C / Min. Temp. 25.2°C,
- Exposure duration per layer: 30 seconds,
- Substrate was 316L dimensions as shown with thickness 20 mm.

Figure 3 presents the optically measured distortion magnitude of 316L stainless steel specimens, assessed via laser scanning. The figure shows the backside of the specimens. The distortion was evaluated using STL files from the reference geometry intended for the printing process and from individual scans of the twelve specimens post-removal from the substrate. The average outward distortion at the middle of the backside is approximately 0.12 mm, derived from an approximate evaluation of the displayed measurements. Although all twelve specimens demonstrated the buckling phenomenon, the authors have chosen to disclose only six plots. This selection was due to the challenges in aligning the reference and distorted STL scans, which often complicated the derivation of reliable results.

## The Buckling Phenomenon for Ti6Al4V

The buckling-like thermal distortion effect has also been observed in AM Ti6Al4V. The extent of distortion can be quantitatively estimated by the ratio of yield strength to Young's modulus, which is notably high for Ti6Al4V. This leads to the max. outward distortion of the tube being in the range of 0.2 mm, which is notably higher than the app. 0.12 mm observed for the steel specimens. According to the team's experience, variations in printing process parameters do not fundamentally alter the observed buckling behaviour.

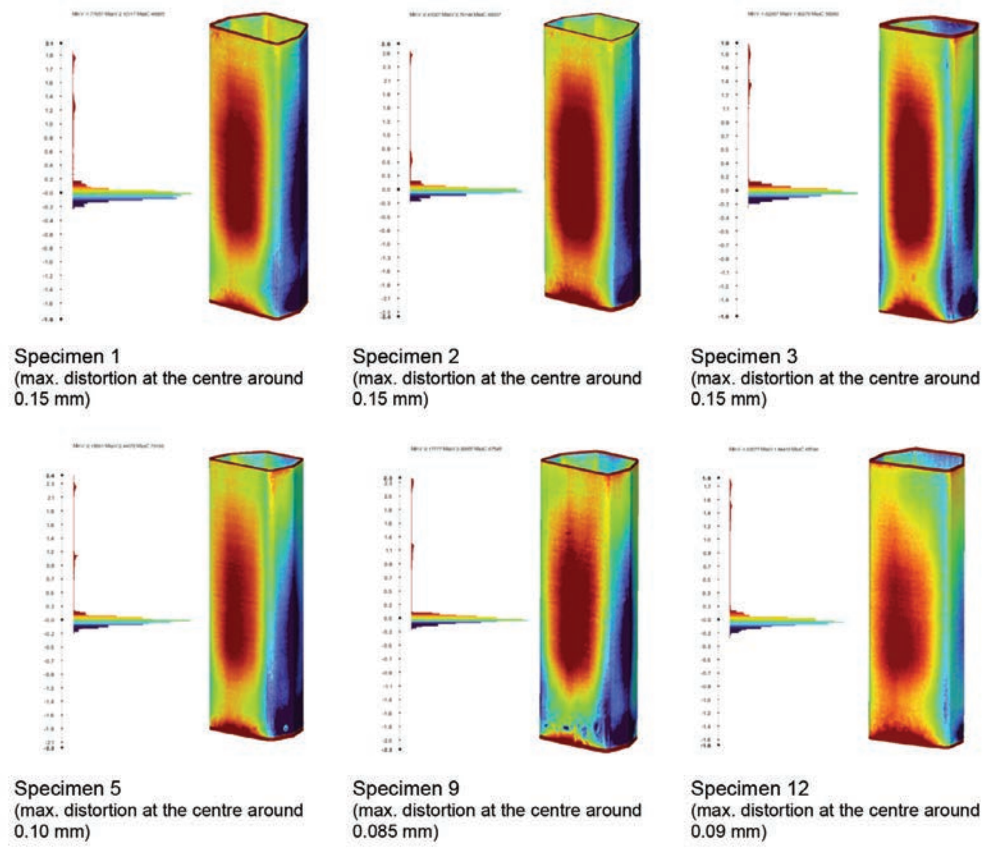



Figure 3: Distortion magnitude for the 316L stainless steel specimens (backside visible, positive numbers and warmer colours signal outward deflection).

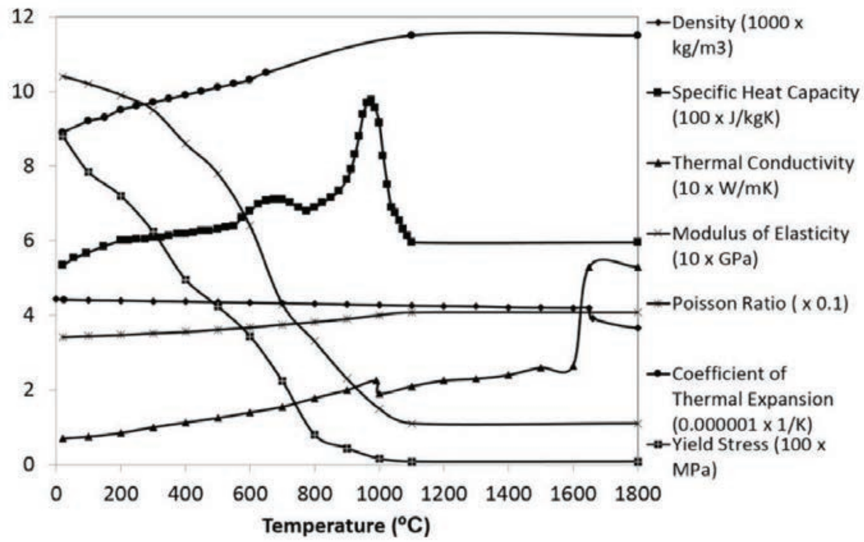



Figure 4: Temperature dependent material properties for additively manufactured Ti6Al4V [5].

The titanium specimens were fabricated using a Renishaw AM250 SLM (200 W) machine, adhering to the default process parameters established for Ti6Al4V [9].

Figure 4 illustrates the temperature-dependent material properties of Ti6Al4V, with additional details included in the powder's data sheet [9]. These properties in Figure 4 are provided for further reference. The authors have effectively predicted the buckling using the inherent strain approach [1], which does not require temperature-dependent material properties.

Figure 5 displays the measured (scanned using optical 3D scanning technology) and simulated distortion of the tube, after it has been cut from the substrate. The measured outward distortion at the middle of the backside is approximately 0.20 mm. ■

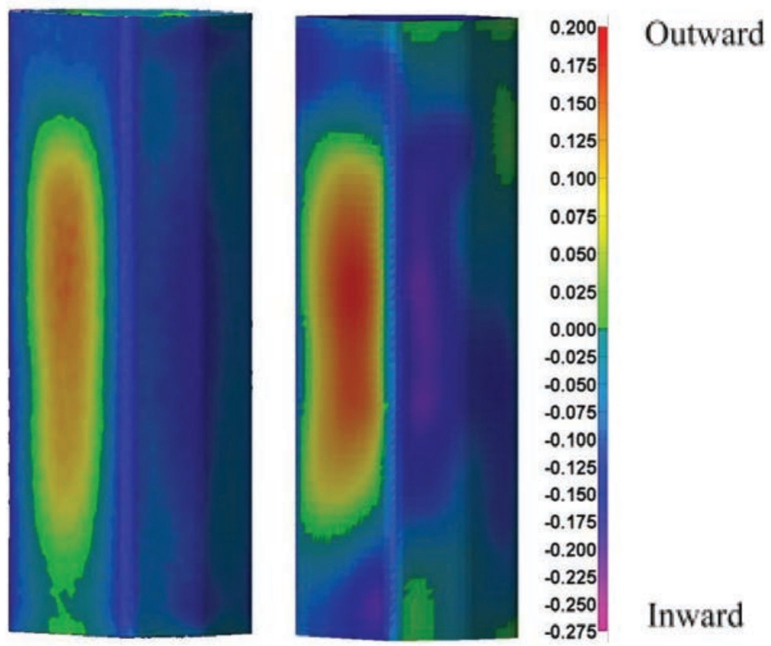



Figure 5: Measured distortion magnitude on the left (the scans were made after the part had been cut from the baseplate), simulation results on the right (in mm) for Ti6Al4V (showing the face that is 46mm wide) [5].

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## Acknowledgement

The authors wish to take this opportunity to thank the NAFEMS Metallic Additive Manufacturing Focus Team members for their help and support in the preparation of this article.

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Get the 3D geometry in STEP format from the example problem at **nafe.ms/buckling**. We invite you to join the community discussion forum at **nafe.ms/am-discussion** to share your experiences related to the buckling example.

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Within the NAFEMS Community, the Metallic Additive Manufacturing Focus Team, part of the Manufacturing Process Simulation Working Group, is dedicated to fostering collaboration between industry and academic experts and developing technical resources in this field. To learn more about the group's activities, visit **nafe.ms/manwg**

# Understanding the Different Forms of Democratization of Engineering Simulation

Joe Walsh | ASSESS

**The ASSESS Initiative has published a Strategic Insight Paper to provide information, insights, and clarity on the different forms of democratization of engineering simulation including different purposes, requirements, valid approaches and issues. This article is a summary of the paper, NAFEMS members can download it in full at nafe.ms/assess-democratization**

*“**Democratization of Engineering Simulation** means a significant expansion in the use of Engineering Simulation by all users in a reliable way, for whom access to the power of Engineering Simulation would be beneficial.”*

**Initial democratization efforts were driven by engineering simulation vendors seeking to expand their potential market. Over the past few decades, there has been a growing awareness that the effective application of engineering simulation can significantly reduce the time it takes to make more informed decisions with confidence while also enabling the evaluation of more design options. This has led to a shift from vendors being the drivers of engineering simulation democratization to customers being at the forefront of growth in this area.**

In 2023, the ASSESS Initiative published the Strategic Insight Paper “Understanding the Path to Realizable Business Benefits through Engineering Simulation [1]”. This paper outlines how engineering simulation can lead to a broad range of business value benefits.

1. Time reduction
    a. Reduced time to market
    b. Increased speed of learning, understanding, and knowledge creation
2. Cost reduction
    a. Part, product, and process cost reduction
    b. Product design and development process cost reduction
    c. Warranty risk and cost reduction
    d. Manufacturing work-in-progress cost reduction
3. Increased innovation
4. Improved safety

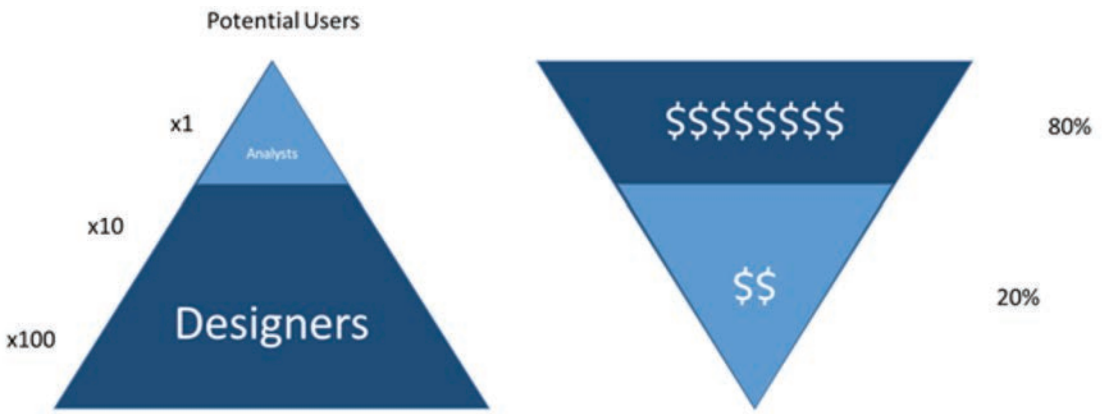
As the capability of the software and the experience of the users have increased, the role of engineering simulation has evolved from being a “supporting act” supplemental to the mainstream design process to being in a “leadership” role during the product design creation, integrating complex systems, optimizing product performance, reducing cycle times, improving robustness, and supporting operational and maintenance issues. Consequently, engineering simulation in today’s organizations takes on a very broad responsibility for product/process lifecycle performance and achieving business goals.

The importance of broader usage of engineering simulation has begun to permeate beyond individual vendors and customer organizations as industry focused initiatives have come into play that significantly reduce the time, cost, and risk associated with advancing each industry.  One such initiative is focused on product and process certification supported by simulation as a key objective for many industries including biomedical, aerospace, and automotive.

At the 2023 NAFEMS World Congress, McKinsey Consulting’s presentation “Unveiling the next frontier of Engineering Simulation” [2] indicated that as a boardroom topic, the business case for simulation is shifting from a digital product development tool toward that of a key support for digital transformation; significantly broader use of engineering simulation is now required by most companies to enable digital transformation.

The three different forms of drivers for implementing democratization of engineering simulation have resulted in their own different objectives, issues, opportunities, and obstacles.

- **Provider Driven** democratization of engineering simulation implementations are related to efforts by software and solution providers to reshape their core technologies by broadening their applicability and significantly increasing their market potential.
- **Customer Driven** democratization of engineering simulation implementation is related to efforts by an organization that aim to significantly broaden the usage and benefit of engineering simulation within the organization. The business goals & benefits are the strategic impetuses, with the broader use of engineering simulation being an integral component of the tools & processes to achieve those goals. The potential business benefits and associated risks increase as the level of democratization of engineering simulation increases from product/project to enterprise-wide implementation.
- **Industry Driven** democratization of engineering simulation implementation efforts are related to government and industry consortiums coming together to more effectively leverage engineering simulation throughout their industrial domain.




The initial efforts at democratization of engineering simulation focused on the first objective were driven by engineering simulation vendors to expand their potential market.  The drive began to enable "simulation for designers." The emphasis of provider driven democratization of engineering simulation has been to provide technological enhancements to enable significantly broader use of engineering simulation.

The broader usage of engineering simulation has resulted in sustained growth; however, large scale democratization of engineering simulation has rarely been achieved. The shifts in thinking and practice required for successful large-scale democratization of engineering simulation are becoming clearer. Successful large-scale democratization of engineering simulation requires a combination of multiple shifts from current practice as noted below.

- A goal shift to business benefits
- An expertise shift
- A culture and organizational shift
- A shift to include variability, uncertainty, and robust design
- A shift to appropriateness to establish credibility
- A shift to near "real-time" results via Artificial Intelligence / Machine Learning (AI/ML)
- A shift to common metadata for interoperability & context
- A shift to formalized Simulation Governance
- A shift to a formalized Engineering Simulation Infrastructure

There are several potential levels of democratization of engineering simulation an organization could adopt that are appropriate to achieve their business goals while accounting for the way engineers design products and processes. These levels are as follows:

- **Product/Project Level** democratization of engineering simulation is focused on supporting a specific product or project activity and applies to both large enterprises and small to medium-sized businesses.
- **Product Development Process Level** democratization of engineering simulation is focused within a company, at a product level that crosses various departments involved in the development of a product, and typically applies to large enterprises.
- **Enterprise-Wide Level** democratization of engineering simulation is focused on standard practice across an entire enterprise; the large enterprise has standardized simulation practices, wishes to enforce them globally, and has committed to putting simulation in the hands of everyone who needs it.

Democratization of engineering simulation is not a "one size fits all" approach.  The objectives, issues, opportunities, obstacles, and applicable approaches of democratization of engineering simulation are influenced by the size of the organization involved.

- Small companies are more focused on nimbleness and ad-hoc adjustments that are typically limited to product/project level democratization.
  - Product/Project Level
  - Enterprise-Wide Level (rare but strategic)
- Medium-sized companies are focused on effectiveness, efficiency, competitiveness, and are typically limited to the product/project level and product development process level of democratization of engineering simulation.
  - Product/Project Level
  - Product Development Process
  - Enterprise-Wide Level (rare but strategic)
- Large Enterprises are also typically limited to product/project level and product development process level of democratization of engineering simulation. However, the rapid growth of Digital Twins and increased focus on digital transformation are creating a growing demand for implementing enterprise-wide level democratization of engineering simulation.
  - Product/Project Level
  - Product Development Process
  - Enterprise-Wide Level (rare but required for digital transformation)

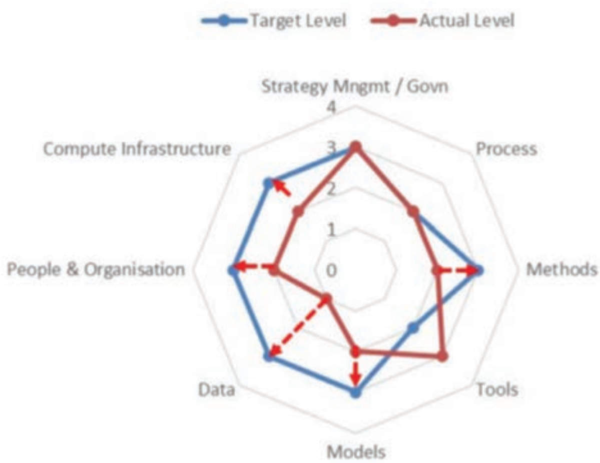
The importance and depth of each required shift is a function of both the level of democratization and the associated business goals.

| Importance of Necessary Shifts by Levels of Democratization | | | |
|---|---|---|---|
| Shifts | Product/Project Level | Product Development Process Level | Enterprise-Wide Level |
| Goal shift to business benefits | Highly Recommended | **Required** | **Required** |
| Expertise shift | Highly Recommended | **Required** | **Required** |
| Culture and organizational shift | Optional | **Highly Recommended** | **Required** |
| Shift to include variability and uncertainty | Recommended | **Highly Recommended** | **Required** |
| Shift to appropriateness | Highly Recommended | **Required** | **Required** |
| Shift to near "real-time" results | Optional | **Recommended** | **Required** |
| Shift to common metadata | Highly Recommended | **Required** | **Required** |
| Shift to Simulation Governance | Highly Recommended | **Required** | **Required** |
| Shift to an Engineering Simulation Infrastructure | Highly Recommended | **Required** | **Required** |

Successful implementation of customer driven democratization of engineering simulation requires a holistic plan. The key steps to a successful democratization of engineering simulation implementation plan are:

- Start with clearly defined business goals
- Determine the appropriate level of democratization of engineering simulation to achieve the defined business goals
- Determine the "shifts" needed to achieve the defined business goals
- Determine the appropriate tools & techniques to implement
- Develop the engineering simulation infrastructure required
- Standardize on metadata, "appropriateness", and engineering simulation governance
- Plan and implement changes to enable shifts and achieve required maturity levels

NAFEMS members can download the full paper at **nafe.ms/assess-democratization**

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# Simulation Maturity Assessment Service

## Unlock the Potential of your Modelling & Simulation Capability to Achieve your Business Goals

## What is a Simulation Maturity Assessment?

- An **independent assessment** of ALL aspects of your Modelling and Simulation capability
- Aligned to your product and business **goals**
- Uses an established **framework** to assess the strength and weaknesses of each of the core elements of an effective and efficient M&S capability
- Provides a **standardised** score reflecting the level of maturity of each of the core elements of your M&S capability compared with best practice
- Identifies areas the organisation should **target and prioritise** improvement action to achieve goals
- Provides a summary of potential **improvement** approaches and options

| **Benefits of a Maturity Assessment** | Impact | | | | | | | | Criteria | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Product | Process | Methods | Tools | Models | Data | Org | Compute | Effectiveness | Efficiency | Cost |
| Optimise engineering simulation capability to deliver more great products faster | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | | | ✓ | ✓ | ✓ |
| Provide a metric to quantify current status for the core M&S elements | | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | |
| Benchmark your organisation against best practice criteria | | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | |
| Identify strengths, constraints, weaknesses, and opportunities affecting your M&S | | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | |
| Build confidence in, and expand, your M&S capability | ✓ | ✓ | ✓ | ✓ | ✓ | | ✓ | | ✓ | | ✓ |

## Want to know more?

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