Riding the Digital Wave
Page 4

Digital viruses and digital vaccines
Page 18

Flying High with Team INEOS
Page 46

Engineer INNOVATION

Issue 7

Surfing, skiing, snowboarding and sailing…

and this is work?

2021 is a year of firsts for me, the first time writing the introduction to our magazine, Engineer Innovation, the first time it is in the exciting new fully-digital format and the first time I have heard of a 'Flip-flop engineering symposium'. Our lead article transports you to Hawaii and the Surf Engineering Association (SEA), the methodologies presented at that 'flip-flop symposium' are some of the most disruptive and exciting engineering technologies of our time.

But the excitement isn't confined to that beach in Hawaii, our writers take you on a tour of some of the most interesting challenges our profession faces, challenges that I have faced in my career and remain committed to being part of the solution.

The first of those challenges is data…from the miniscule 7.5kb of data wrapped inside the SARS-CoV-2 virus to the almost limitless data collected from ADAS systems in the vehicles of tomorrow, we need to interrogate, understand and use it to provide better solutions. Artificial Intelligence offers many possibilities here and if the data we collect holds golden nuggets then AI is the key to finding them and using them. Our partner Maya HTT shines a light on the possibilities.

If we are going to avoid the most devastating consequences of the climate emergency, we have to act immediately. One of the biggest challenges that we need to overcome is alternative fuel sources to replace CO2 belching hydrocarbons. Our customer B&B-AGEMA has been pioneering the use of hydrogen powered gas turbines to backfill for solar and wind-power gaps, helping that transition to seamless green energy production.

The recent America's Cup, the world's oldest sailing competition, was mesmerizing and the lines between marine and aerospace were truly blurred, without putting anything on the water the engineers had to be confident that their designs were feasible. The key is constant improvement through simulation, the same challenge faced by those revolutionizing air travel. Cleaner propulsion, with lower emissions, comes at the cost of reduced range, and urban-aircraft manufacturers will have to work hard to gain passenger confidence in the reliability of battery powered aircraft. Simulation again offering invaluable insight, early.

Finally, 2021 marks the 35th anniversary of the devastating Chernobyl disaster. The safety of nuclear energy is undeniably entwined with this incident, where many tragically lost their lives. Our Brownian Motion author tackles the 'radioactive elephant in the room' with some challenging questions.

À bientôt,
Jean-Claude

Contents

Explore the Possibilities

4 Riding the Digital Wave

60 10 Secrets to a stunningly fun CFD simulation

68 Adopt a people-centric approach to electric vehicle sound engineering

Go Faster

18 Digital viruses and digital vaccines

36 How end-of-line testing can automate product fault detection

46 Flying high at the America's Cup

53 The Vendée Globe with a digital twist

Stay Integrated

24 How data collection will save your life

30 Why your AI strategy needs more than data

64 The next generation aircraft

Model the Complexity

32 The new science of digital materials

40 B&B-AGEMA meets future energy needs

54 The fatigue challenge of additive manufacturing

Regular Features

14 Interview: Jean-Claude Ercolanelli

74 Blog all about it

76 Geek hub

80 Brownian Motion

NablaFlow

Riding the Digital Wave

By Simon Fischer

The flip-flop engineering symposium

Monday, December 9, 2019, 7 pm. Sunset Beach Elementary School Cafeteria, Oahu's North Shore, Hawaii. Two laptops and a projector, the child-sized chairs arranged in auditorium style seating, and a paper Christmas tree, presumably made by the children that would normally occupy the tiny chairs, is pinned to the wall. The venue offers no obvious clues as to what the next two hours will bring. And while the room is packed with people ranging from industry leaders to high-performing athletes their attire of shorts and t-shirts make it impossible to grasp the objective of this meeting. And even when Marc in het Panhius, Luca Oggiano, David Shormann, and Eric Arakawa walk on stage one after the other, with their flip-flops still shedding sand from the beach across the street, I still had no idea that I was about to witness an outstanding engineering achievement.

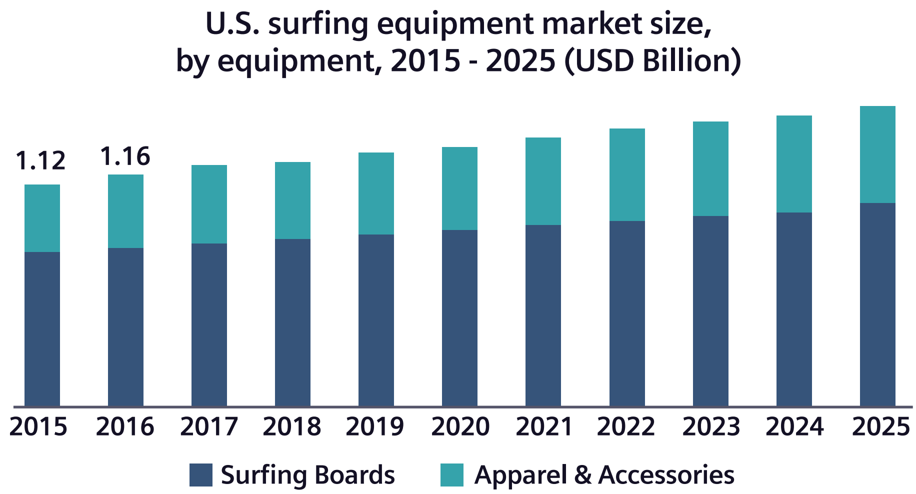
Across the street from the 2019 Billabong Pipemasters contest, the Surf Engineering Association (SEA), hosted the first ever Annual Surf Science Symposium. The presentation on additive manufacturing, big data in the cloud, biomimicry, computer aided structural analysis, and computational fluid dynamics that followed was a sharp contradiction to the sunny beach and laid-back flip-flop and boardshort uniformed panel. The methodologies presented by the four panelists read like a cookbook of disruptive engineering technologies. Technologies applied for only one goal: design superior surfboards.

The soul and the surf industry

But why, you might ask, is all this technology really required? Surfing has existed for hundreds of years. For those that get close to the “soul of surfing”, riding the wave is an art, just like shaping a surfboard. Hardcore surfers base their entire lifestyle around the sport, and the spirit of surfing has become a cliché in a dimension yet unseen for any other sport.

Surfing has become a huge industry, with established brands and continuous technology improvements. The sport is due to become an Olympic sport, but like many things this past year, COVID-19 has delayed this. All over the world artificial wave pools are being built to make the sport accessible to the masses. Recent figures indicate that the surfing industry is worth several billion USD and one of the fastest-growing action sports industries in the world. In short, the sport is being taken seriously and has outgrown its niche market.

There is a big “However!” Marc in het Panhius, researcher, engineer and surfer explains: “Most companies in the surfing industry use the emotion of a surfer to get the consumer to identify with their products



Second right:
Source: https://www.grandviewresearch.com/industry-analysis/surfing-equipment-market

and brand. This combined with the ability to use high profile surfers from all around the world is what drives marketing campaigns and business for the bigger companies. However, has anyone ever thought about taking a scientific engineering approach to designing and testing a range of different surfboards and or fins?" Marc continues. The answer even in 2020 is indeed quite surprising. "Not really", Marc answers his own question.

The systematic disruption of the surfboard industry

Based on this assumption Marc in het Panhius, Luca Oggiano, David Shormann, and Jimmy Freese formed the Surfboard Engineering Association (SEA). Their ambitious goal is simple: To disrupt the surfboard industry with a systematic scientific engineering approach. But not in a conventional manner: "It's all about mixing two worlds focusing on the same problem but from two very different perspectives." Luca explains.

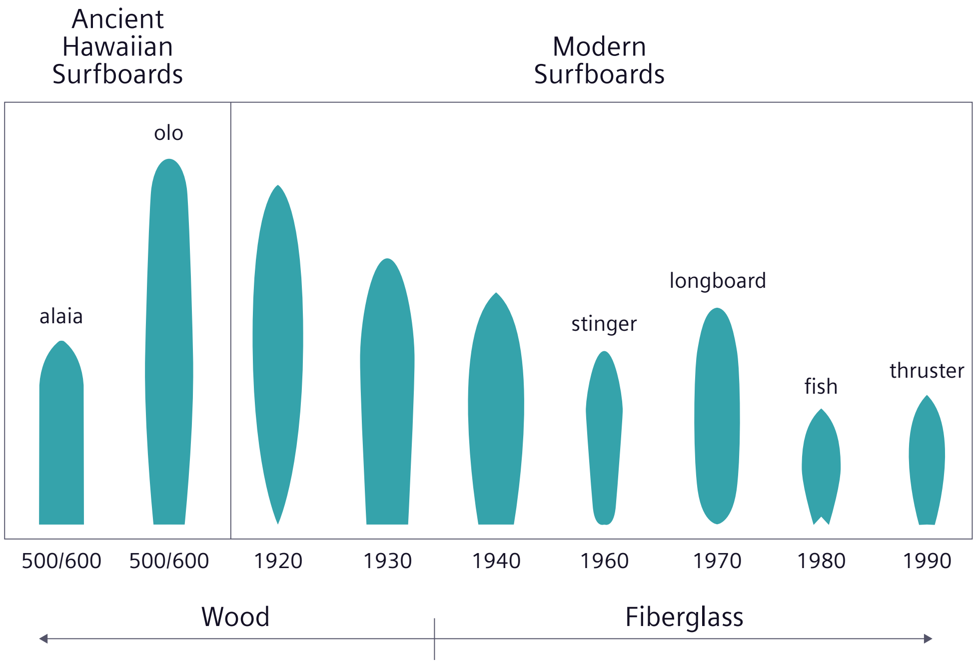
And like his colleagues, Luca a sports aerodynamicist; CFD expert; associate professor at Norwegian University of Science and Technology, and a passionate surfer, takes the mission very seriously. Computational Fluid Dynamics Simulation (CFD) of Surfboards has become one of his research focus areas and is now even an intrinsic part of his offerings at NablaFlow, Luca's startup, that aims to bring to the average user a wide range of fluid flow analysis, such as wind engineering, aerodynamics and multiphase flow.

"We are trying to blend the traditional soul shaping approach with a rigid engineering approach to come up with superior surfboard designs." Luca summarizes the ultimate goal.

What makes a superior surfboard?

For an engineer that is not into surfing the first question to ask is probably this "What exactly is it that makes a surfboard superior over another?"

The first thing to understand is what defines an outstanding ride for a surfer. Clearly speed, agility, control and therefore safety, are on the list, but there are trade-offs between those attributes. As well as this, finding the right balance between these attributes is a very individual and personal thing, that depends on a surfer's style,



skillset, preferences and where they surf taking wave energy, size and shape into consideration.

Even if the target specifications are defined, the engineer will ask what are the quantifiable, engineering metrics of the board that then translate into that outstanding ride experience for a surfer. And finally, even if you quantified those metrics that classify a board, how do you design a board to meet those?

"Professional surfers in the future will no longer pick their boards based on their feelings, but on the conditions and results that are available". Luca says. "Therefore, as engineers our major goal is no longer simply to define a board in terms of its shape or its geometrical quantities. Instead what we would like to do is define a board in terms of its performance attributes."

Gone are the days when surfboards could solely be specified by their shape and length. To meet customer expectations surfboards in the 21st century must be engineered in terms of targeted performance attributes.

As a consequence, surfboards designed for modern surfers come with an explosion of complexity in their development. This will require a disruptive yet systematic engineering approach, an approach that already adopted in many other sports.

The digital twin of surfboards
The good news is that today, engineers and surfboard designers already have the relevant tools to make this shift happen. With today's technology a comprehensive digital twin of a surfboard is within reach. Boards can be designed and their performance tested using computer aided design (CAE) tools before any real shaping is takes place. The boards can then be optimized based on the insights their digital twin delivers and even the wildest shapes could be realized thanks to advanced manufacturing processes such as additive manufacturing. Finally, in-situ real world data acquisition can be used to feedback experiences from the field into the design process and result in a continuous improvement loop.

Riding the digital wave with CAE
Surfing is a watersport, so it is no surprise that among the tools that are of paramount importance to deliver insight into a surfboard's performance is CFD. "To me CFD is a design tool that should become an intrinsic part of the design process." Luca says. "A knowledge gaining tool, indicating what is really happening, what are the physics that are making a good or a bad shape, fin, board."

Now the question remains, what are the engineering attributes gained from CFD that translate into speed, agility, control (safety) and stability? In cycling, applying CFD is a little easier because all you want to do is

reduce drag. In surfing using CFD will be about defining multiple properties of a board: “In the first place, this can be the forces and moments, lift and drag, ultimately also lift and drag distributions.” Luca explains.

Despite these challenges and opportunities, the state of CFD in the surfboard industry is lagging: “At best you will find a limited use of CFD looking at a fixed board or a single fin under steady state flow conditions.” Luca explains. And while this type of simulation already delivers the initial guidance on a design’s performance, it will only have limited value to achieve the complex goal of virtually designing customized attributed boards. Therefore, an important first step towards more relevant predictions is further increasing realism in the CFD simulations.

Considering transient maneuvers on the surface of a flat ocean with a moving board that undertakes a prescribed motion is a significant first step. This includes events such as turns or stalling. “Using these types of simulations in conjunction with real surfing experiences you already can get a valuable engineering understanding of what a surfer feels during these maneuvers.” says David “and compare different board and fin designs and gain detailed insights, how

differentiators in the design are affecting core performance indicators" Luca adds.

Learning from humpback whales
To assess the value of CFD for surfboard engineering Luca, David and Marc started a joint project exploring non-standard fin designs to provide improved performance and safety. The goal was to compare standard surfboard fins with those inspired by the fins of humpback whales, resulting from a classical biomimicry approach.

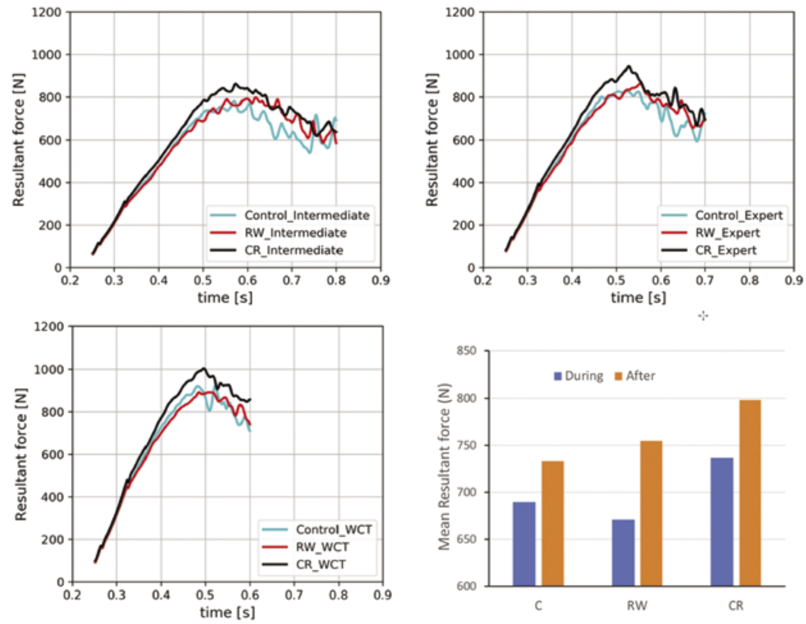
Why humpback whales you might ask? It is well known in maritime biology and the marine industry, that unique flipper designs give the humpback whale extreme maneuverability. Leading edge bumps, also known as tubercles, improve stability of the whale's movement through the water by two major mechanisms: First, they foster a delayed stall, meaning the whale can increase the fin's angle of attack further before flow detachment separation occurs, leading to a loss of control. Second, even under stalling conditions the drop of lift over drag does not happen suddenly, as the angle of attack increases but more gradually. Finally, humpback whale fins are known to be more efficient, meaning less energy is required for the whale to move at a given speed.

All that said, the hypothesis for surfboards was considered. Humpback type fins featuring tubercles, should provide enhanced control during a cutback, when a surfer rapidly changes direction.

CFD predictions and validation
To really assess the value of CFD, the engineers at NablaFlow analyzed this hypothesis with simulation and compared them to the experiences gathered in the field or - to be precise - the ocean. In a first step, GPS sensors with 9-axis motion sensors were used to collect data on nearly 2,000 surfed waves. Data was collected from four surfers of differing skill levels, ranging from intermediate, advanced through to top-ranked professional. On their shortboards with a three-fin configuration some surfers used one of three different fin types: a standard commercial fin; grooved fins; and the 3D-printed, humpback whale-inspired fin with typical tubercles.

The first, unsurprising, experimental result the engineers observed was a positive correlation between surfer skill level and the roll, pitch and yaw rates during a cutback. That is, a more skilled surfer will be able to push a more aggressive, faster turn. Those averaged turn rates for each respective surfer level and fin type from the field

First left:
Image sequence showing a surfer (Dylan Perese) transitioning from a bottom turn to a cutback (also known as top turn). A) bottom turn, B) climbing the wave, C) setting up the cutback, D)-E) performing the cutback, and F) descending the wave. Photo credit: David "IndoEye" Biner



First right:
Time series of rider direction resultant forces for all fins during cutback maneuvers at intermediate, expert and WCT level. All turns start at 0.25 s, with A) intermediate ending at 0.8 s, B) Expert ending at 0.7 s, and C) WCT ending at 0.6 s. See Table S3 for detailed resultant forces and direction means. D) Mean resultant force during (0.3 to 0.5 s) and after a WCT level cutback maneuver. C, RW and CR indicate control fins, fins with tubercles, and grooved fins, respectively.

research then went into simulation to define the prescribed motion of the respective board and fins.

Transient CFD simulations on a flatwater surface were conducted and the sustained resultant forces relative to the rider direction were monitored over time during the respective turns. In a nutshell these forces represent how much the surfer must push to realize a given turn rate. And while the flatwater surface clearly still is an approximation compared to the real ride on a breaking wave, it offers relevant engineering insights, that are impossible to gain from steady state simulations and rather expensive to obtain experimentally on a regular basis.

The CFD simulations predicted lower forces for the whale-inspired fins (RW) during the turn suggesting a less-skilled surfer could generate faster and more powerful turns using those fins. Likewise, in the field statistically significant cutback performance improvements were seen when surfers used the whale-inspired fin. In line with field results, the CFD predicted that an expert surfer performed closer to a world class surfer when using the whale inspired fins, but not when using control fins. The lower resultant forces acting on whale-inspired fin designs during cutbacks suggests that fins with tubercles are more maneuverable compared to the fin designs with grooves and a smooth surface. In surfing parlance this would translate to improved ability to "pivot" more easily. In contrast, the study also reveals that fins with a grooved surface always exhibited the highest mean resultant forces at the most negative angle. In other words, the greatest overall force in opposition to the rider, usually described by surfers as the "hold" to the wave.

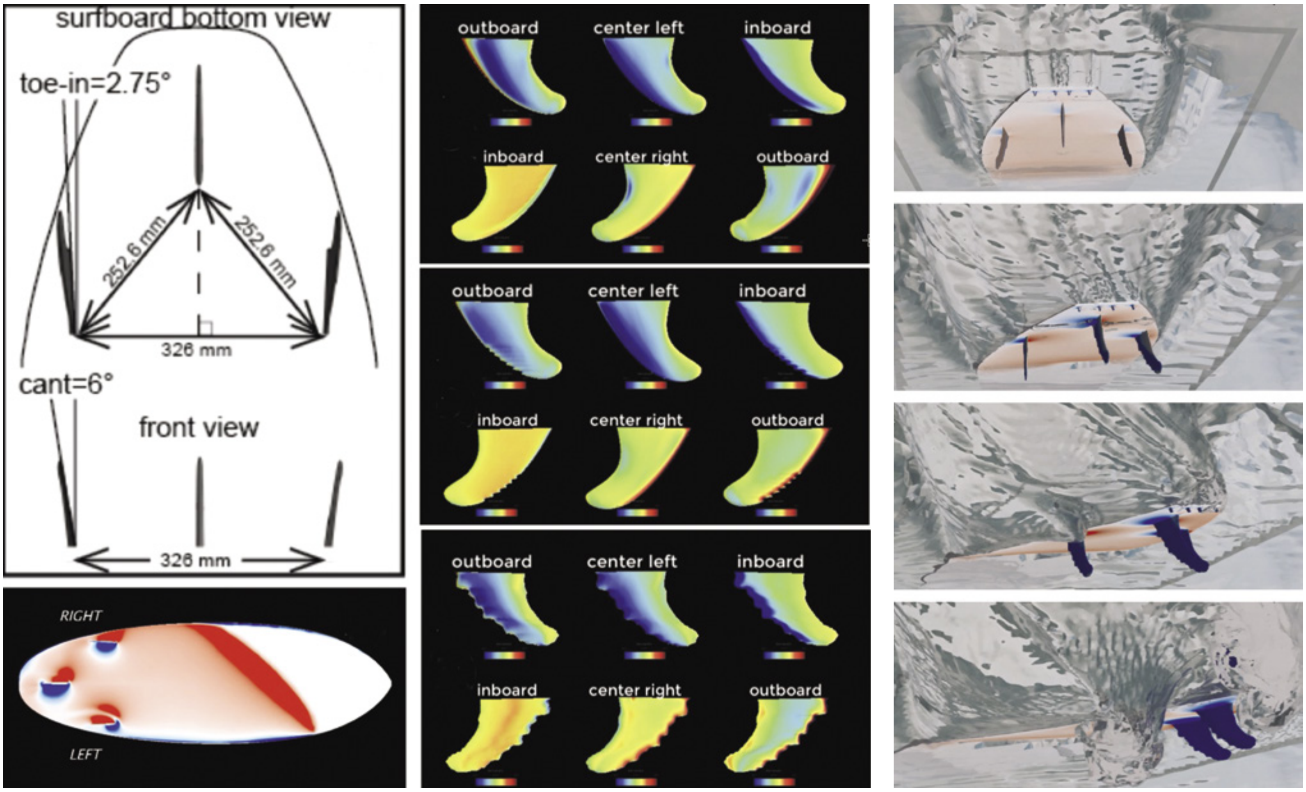
It's not only the absolute values of forces that reveal insights on the surfboard performance. Looking at the temporal fluctuations of forces reveals clear indications of the stability of the board during the maneuver. A steadier force for the surfer to respond to during the cutback and recovery means a more stable, hence easier to control, board. As the fluctuations in force especially towards the end of the turn reveal, the CFD simulations suggest that the whale-inspired fins should give the best control – in line with the measurements. Further beneficial to a steadier ride is the tubercles' tendency to a delayed more gradual stall, both observed in CFD and experiment.

While the whale-inspired fin offers more maneuverability and stability, the study also showed that conventionally grooved fins could be more suitable for speed generation or "drive" in surfing parlance. This could suggest that they perform best in wave conditions where speed generation and increased hold on the wave are required.

Surfers could therefore enhance their surfing experience depending on the type of surfing they want to achieve. Fins with tubercles would lead to more maneuverability, whereas fins with grooves would result in increased ability to generate speed and hold compared to fin designs with smooth surfaces.

The insights coming from CFD do not stop at those integral numbers. The big insights come from the simulation where all relevant data is always accessible at all locations of the board at all times of a maneuver. That said, the engineer and surfboard designer will not only be able to digitally predict a surfboard's performance, but they will be able to truly understand and correlate integrated performance numbers with local flow conditions and ultimately take targeted corrective actions for performance improvements.

In the whale-fin project a detailed analysis of the CFD results showed the importance of the respective fin-fin and fin-board



interaction of the three-fin design depending on their particular shape. The increasing variability of control forces in all designs towards the end of each turn is resulting from turbulence from both the board and fins. Towards the end of a turn, the center fin receives heavy turbulence coming off the right fin and the right rail. Yet, the right fin in the control set always had a significantly lower mean resultant force and least negative direction, suggesting degraded performance due to interactions with turbulence from the surfboard's side, or rail. Ultimately the detailed flow analysis also reveals that the whale-inspired fins provide a "damping effect" to the turbulent flow meaning less turbulence is affecting the maneuver.

In addition to the turbulent perturbation of the water, the CFD proves how ventilation i.e., air mixing with water also appears to occur along the right rail, impacting the fins towards the end of each turn. Ventilated flow is turbulent, but more importantly its density is highly variable, which can further significantly impact a fin's lift characteristics.

Understanding those fluid mechanics finally allows the designer to understand how the whale-inspired fins are able to produce the lowest force variability, up to 27 percent less than the control fin.

The ultimate validation came from a skill level eight surfer, during the field testing. Right after he did a turn on his board equipped with the standard fin, the wave caught up to him and he fell off. "After he didn't make that heat", David explains, the guy came over to me and said "Man, if I had that whale fin I could have kept going!".

In conclusion, even though a perfectly flat water surface does not represent real wave breaking conditions, CFD results matched well with field research to predict relevant trends. In a first pilot project the engineers proved how simulation truly helps to confirm what surfers feel – and even understand why they feel it from an engineering perspective. "This is the first time ever validation of surfboard CFD riding the wave." David concludes "and CFD matched field results" Luca adds with a smile.

The digital Teahupo'o

But Luca and his team at NablaFlow want more for their CFD models, they want a wave and they want the board moving on that wave. "Ten years ago, this was not even thinkable. But these things are possible today." So, Luca took his Laptop and started to replicate none other than Teahupo'o, the legendary wave on the southwestern coast of the island of Tahiti, and one of the most famous yet most dangerous surf spots on

Third left:
CFD simulation of ventilation (air entrained into water) affecting surfboard turn performance

this planet. The goal is clear: Even more realistic CFD models and conditions for board and fin testing delivering even more realistic insights. Detailed insights that not only qualitatively match the experimental data but truly predict the ride of the wave and reveal the details of board-wave interaction in various realistic maneuvers.

And while his first attempts are still limited to a linear prescribed motion of the surfboard, the ride of the digital twin of Theaupo'o already delivered some initial unexpected insights. Looking at the three fins - central, crest side and thrust side fin it turns out that in the tunnel "it is the thrust side fin that is taking all the beating". Luca explains "This is something I would not have expected. In all honesty I would have expected the wave side."

Riding the digital wave

Asked about the future, Luca says "I see a very bright future for the sports of surfing. In this specific moment there is a synchrony of events. Everything is at the right place." Surfing is getting into the Olympics, wave pools are popping up all over the world, there is technology available like additive manufacturing and advance in-situ data mining. And of course, CFD but also Finite Element Methods to simulate fluid dynamics, stiffness, damping and fluid structure interaction of the surfboard will be a continuously important game changer.

"And CFD will not stop at the board, digital wave pool design and tuning will be a completely new application area. And finally, when it comes to equipment and you compare to other sports like cycling, surfing is a complete virgin field." Luca adds.

So, clearly, it's time for surfboard industry to ride the digital wave! ■

More info on NablaFlow

Q&A

We sat down with Jean-Claude Ercolanelli, Siemens' new Senior Vice President of Simulation and Test Solutions to find out more about him, and his views on the future of Computer Aided Engineering.

Let's start with the most obvious questions who are you, and how did you get here?
Ok, then let's start. I'm 55 years old, I've been married for 29 years, and I have two grown-up children. My background is in mechanical engineering and non-linear mechanics, I'm also a graduate of the INSEAD business school.

I've been actively involved in CAE business for more than 30 years, most of that time working at various independent software vendors - starting at Framasoft, ESI Group, Ansys and then CD-adapco, who were eventually acquired by Siemens. Which is how I got here; it may seem as if I got here by accident

When I first started in CAE, I worked in a technical support role, and I really enjoyed helping other engineers solve difficult engineering problems using the tools that I was supporting. I carried that through a spell in pre-sales, in which I helped inspire engineers to take the next steps on their simulation journey. And I've carried it on ever since, I'm still inspired by helping engineers use engineering tools in the best way possible to solve problems, and enable innovation that matters in their products, in their own industries. It sounds like a cliché, but I like helping other people. After all, engineering is a vocation, and I think that most people get into it because they genuinely want to contribute towards making the world a better place.

What keeps you interested and inspired?
I have a burning desire to see simulation solutions being used by every engineer, installed on every piece of hardware equipment. Because I strongly believe in the value of simulation and analysis in engineering, whether that's software, hardware or services, I think it's the lifeblood of innovation. Since the 1970s CAE has had a massive impact on how we live, how we travel, how we communicate and connect with one another, and increasingly how we can be cured. If you look carefully you will see the impact of simulation in every facet of our lives.

That goes beyond improving, the performance and durability of the products we use every day. Simulation and test solutions occupy a prominent position in the fight against climate change, contributing to the reduction of greenhouse gas emissions, reducing total material use and waste and increasing energy efficiency and operational performance of the product. Simulation and test solutions are also key in improving and accelerating the safety in all types of industries, whether in transportation with more reliable vehicles and continuous advances in autonomous and driving assistance systems, or in the medical and pharma field with more precise devices and faster drug development and their production processes. So, in the end, it helps to make the world a better place to live in.

The climate change question is a huge one, isn't it?
One of the things that I am most proud of is the way in which we have helped many industries to reduce their carbon footprint. I realize that we still have a long way to go,

but if global economies are going to meet their 2030 and eventually 2050 decarbonization targets, they can only do that through the increased use of simulation and analysis solutions.

That includes the obvious things, such as energy savings through enabling better aerodynamic, and hydrodynamic performances, drag reduction that decreases the consumption of fossil fuels, but also through transformative technologies such as electrification and carbon-capture units. This is a complex multi-faceted problem that represents the greatest engineering challenge that our species have ever faced. If we are going to avoid the catastrophic consequences of climate change, we need to rapidly increase our rate of innovation, that's only going to be possible through the extensive use of engineering simulation and tests.

You said earlier that you have a burning ambition to see "CAE simulation being used by every engineer, installed on every piece of hardware equipment." Is that something we can realize during your tenure at Siemens?
Absolutely yes! I think it's essential, and it will be enabled by the rapid evolution of technology. The mobile phone that I am carrying in my pocket is millions of times more powerful than the guidance computer for the Apollo missions. In terms of processing power, the latest smartphone generation has more processing power than the largest supercomputer in the world when I first started working in engineering simulation in the 1990s. So, the technology already exists that will allow us to embed engineering simulation into products and devices. I recommend everyone keeps a close eye on how executable digital twins are progressing and spreading within the products.

I think that we're also at a stage where AI and machine learning are beginning to change the way that we think about simulation and analysis. So, rather than just performing a handful of physics-based simulations we are also complementing this information with test and operating data, navigating them using artificial intelligence machine learning and physics informed neural networks. This means that we will be able to accelerate design performance predictions and deliver them faster than ever before, lowering the barriers to make more informed design decisions with confidence earlier, and at the same time democratizing the use of CAE.

You've worked for a lot of CAE companies, what is different about Siemens?
What I like most about working for Siemens is that they do not have an attitude of "racing for profitability". Instead, we have a culture of professional excellence, in which we put the success of our customers first in everything that we do. I'm sure that some of our competitors would say that they do the same thing, but my impression is that it is more explicit here because it's in our core values. And I think that we have demonstrated that if you focus on customers first, then commercial success almost always follows. Because we have always put them first, our customers know they can count on us to deliver what they need in order to do their work more effectively. Many of our customers are very loyal to us, which means that we can work together over long periods of time to help them realize their own engineering ambitions.

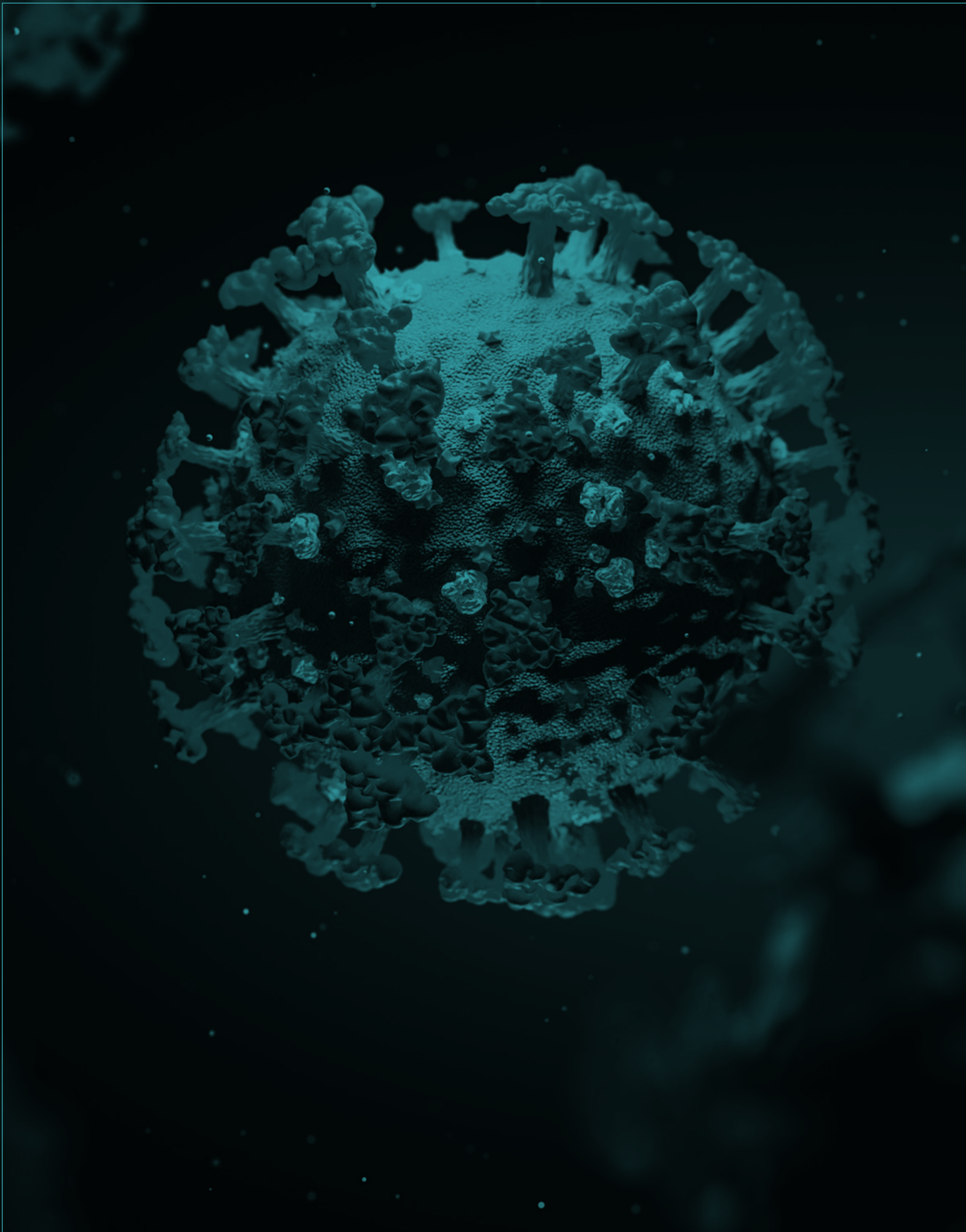
So finally, enough about work, what do you do to relax?
I read a lot; you might say that I'm an obsessive reader. I don't really listen to podcasts or audiobooks; I need the information to enter through my eyes rather than my ears. I'm a big fan of economic journals, as well as business management books. I also try to keep on top of the new developments and trends in industry, and so I read a lot of industry-specific publications, especially those to do with circular economy, energy, transportation and electrification. I've just finished two books about AI and I'm currently feeling very inspired by a book called "Dreams and Details" which is about reinventing yourself when in a position of strength by empowering the members of your team.

My guilty secret is that I love comic books, American, French and Belgian ones mainly, but also Japanese manga. I got into those through my children, but I travel a lot to Japan and it's really helped me to understand the culture and engage with Japanese colleagues and customers, talking about something that we both really enjoy.

I'm also a recent convert to running, during lockdown I've been running 60km a week, which is good thinking and relaxation time - I highly recommend it. ■

“I have a burning desire to see simulation solutions being used by every engineer, installed on every piece of hardware equipment.”

Jean-Claude Ercolanelli, Senior Vice President of Simulation and Test Solutions, Siemens



Digital viruses and digital vaccines

How 7.5kb of data brought the world to its knees, and how only the digital twin can save it.

By Stephen Ferguson

The late Nobel Laureate Sir Peter Medawar once described viruses as "bad news wrapped in protein". In the case of the SARS-CoV-2 virus, that "bad news" has prematurely ended millions of lives and continues to cause billions of dollars' worth of economic damage that will haunt us for many years into the future.

First left:
The SARS-CoV-2 virus contains just 7.5kb of data wrapped up in 29 proteins. This simple package of data has managed to kill over a million people and caused immense economic damage.

The virus itself is surprisingly simple - just 29 proteins wrapped around a single strand of RNA. The entire genome for the SARS-CoV-2 virus is just 30,000 letters long. You can type the whole thing on about 13 sheets of paper. In total it contains just 7.5 kilobytes of data. By comparison, the human genome is more than 3 billion letters long - which is about the same as a stack of 1000 King James Bibles or about 725 Mb of data.

It turns out that this idea of considering a virus as a unit of data storage is more than just a metaphor; the solution to this crisis depends on a whole generation of "digital vaccines", some of which were designed in silico (on a computer) rather than in vivo (in a lab), and approved in less than a year - something that would have been unheard of even a few years ago.

However, the challenge does not end with the discovery of vaccines. The world has never before needed to implement mass immunization of its entire adult population. That amounts to over 10 billion doses, at two doses per adult, even neglecting the enormous potential for spoiling and wastage of temperature-sensitive vaccines. This represents the biggest manufacturing and logistics effort since the end of the Second World War: scaling up production from a small quantity of "working vaccine" in a lab to billions of doses and eventually successfully inoculated patients.

This article is the story of the virus, the vaccines, and the digital twin technology behind the effort to vaccinate the whole world.

Anatomy of a virus

So how did less than 10 kilobytes of data manage to bring the whole world to its knees? Partly because this apparent simplicity is deceptive. Designed by the forces of evolutionary selection - which work rapidly in a virus that is copying itself billions of times a second in host organisms around the world - the SARS-CoV-2 virus is a carefully engineered invasion and replication machine.

Each of its 29 proteins has a finely tuned role to play in fulfilling the objective of invading the cells of a host organism and injecting 7.5kb bytes of deadly data (a single strand of RNA) into its nucleus, hijacking the cell's protein production machinery to produce multiple copies of the virus (which in turn can then infect other cells, and eventually other hosts, transported in mucus particles in virus-induced coughing and sneezing fits).

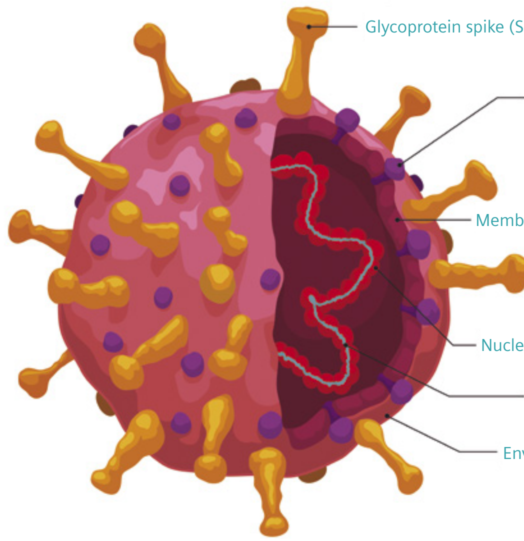
There are saboteur proteins that disrupt the natural production of proteins by the infected cell, forcing it to make virus proteins instead. Copying proteins (NSP12), which help to make new copies of the RNA genome that will end up inside new copies of the virus. Camouflage proteins (NSP10, NSP16) that disguise the virus from the body's immune system. There are even proofreading proteins (NSP14) that check for replication errors in copies of the genome and escape proteins that drill holes in the cell membrane (ORFra) and evade the cell's anti-escape mechanisms (ORF7a).

However, of all these proteins, the most prominent is the so-called spike proteins which form a "crown" of extensible bulbous protrusions from the virus surface (each about 20 nm long), and for which the "coronavirus" is named. These spike proteins are the principal means by which the SARS-CoV-2 virus invades host cells in the human respiratory system. Firstly, they latch onto a host cell, binding with ACE2 enzymes that are found on cells in the upper airway, before penetrating the host cell's membrane.

Without these spike proteins, the SARS-CoV-2 virus would be unable to enter the cells of the host organism and would therefore be rendered harmless - viruses can only replicate inside a host cell. Because of this, spike proteins are the target of vaccination efforts.

Vaccines

Vaccines work by tricking the immune system into "recognizing" a virus that it has never been exposed to. By providing it with a "preview" of the virus structure, vaccines allow the immune system of the patient to design powerful antibodies that can be deployed to neutralize the real virus if the individual is ever infected. The World Health Organization estimates that 2-3 million lives a year are saved as a result of vaccination.



Coronavirus Structure

There are currently about 70 vaccines in various stages of clinical trials, with many more in preclinical trials. While the ultimate aim of each is the same, there are four different approaches to vaccination

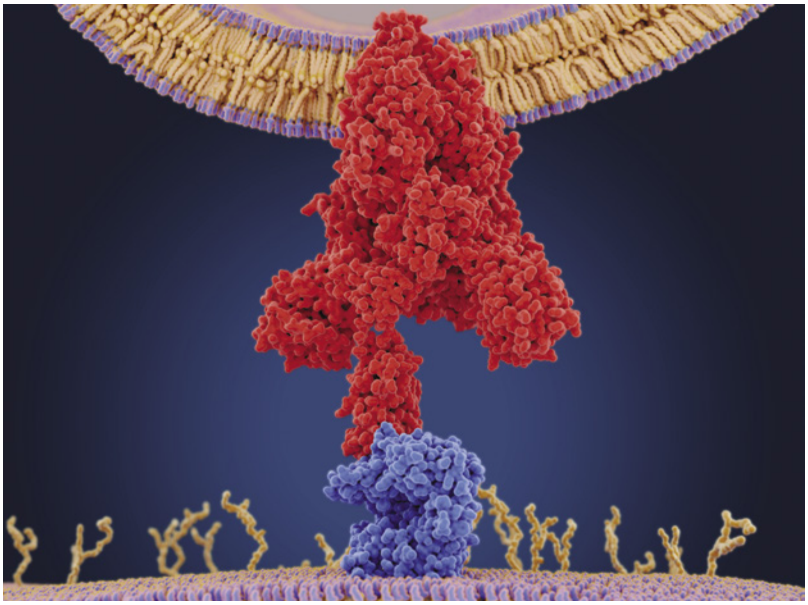
Inactivated or Attenuated Coronavirus Vaccines: traditional vaccines, in which the patient is inoculated with a strain of the SARS-CoV-2 virus that has been weakened through genetic engineering, or has been inactivated through exposure to chemicals, and is, therefore, unable to replicate.

Protein-Based Vaccines: rather than inoculating the patient with the complete virus, these "sub-unit" vaccines contain copies of some of the signature proteins. In the case of SARS-CoV-2, the candidate vaccines use the spike protein, sometimes connected to the shell of a nanoparticle. Since no genetic material is included (RNA or DNA) these proteins cannot replicate.

Genetic Vaccines: these work by injecting a portion of the SARS-CoV-2 genome, encoded in either RNA or DNA, surrounded by a protective lipid bubble. Once absorbed by host cells, these genetic instructions tell the cell to manufacture multiple copies of certain SARS-CoV-2 proteins (usually spike proteins) for several days. The synthetic genetic material is only a partial copy of the genome and cannot replicate.

Viral Vector Vaccines: are similar to the Genetic Vaccines described above, but instead of using a bubble of lipids to host the genetic material (which is usually DNA), it uses a

First Left:
Some of the 29 proteins that make up the SARS-CoV-2 virus



First right:
The coronavirus spike protein (red) mediates the virus entry into host cells. It binds to the angiotensin-converting enzyme 2 (blue) and fuses viral and host membranes.

deactivated or weakened host-virus (for example adenoviruses or influenza viruses). Once absorbed by host cells, the RNA or DNA instructs the cell to manufacture multiple copies of certain SARS-CoV-2 proteins (usually spike proteins) for a number of days. The synthetic genetic material is only a partial copy of the genome and cannot replicate.

At the time of writing, only two vaccines have received widespread emergency approval and are being deployed in large scale inoculation programs around the world. Both are mRNA genetic vaccines, one from Pfizer-BioNTech that had an efficacy of 95 percent in stage three trials, and another from Moderna which demonstrated efficacy of 94.5 percent in trials. These vaccines are the first genetic vaccines ever to reach wide-scale approval. Genetic vaccines have the advantage of being entirely synthetic, and so do not require the cultivation of large numbers of host cells and viruses.

Designed in-silico, genetic vaccines also have the advantage of being relatively easy to "update" should mutations in the virus reduce their efficacy. The major disadvantage of the two approved vaccines is that mRNA is fragile which means that the vaccines must be stored and transported at very low temperatures, which presents a significant logistical challenge.

The viral vector vaccine from Oxford-AstraZeneca has also reached emergency approval in over 100 countries.. It shares many of the advantages of the existing genetic viruses, in that genetic instructions that it carries are designed in-silico and are relatively easy to update. However, because it uses a genetically engineered adenovirus (a common cold-like virus) to carry DNA into host cells, it is significantly more robust than the mRNA vaccines. This means that the Oxford-AstraZeneca vaccine can be transported and stored using conventional refrigeration facilities.

From a manufacturing perspective, all of the vaccines described above can be broadly split into two groups, the genetic mRNA vaccines, which are entirely synthetic, and all of the others, which are biological in nature, and require the cultivation enormous quantities of host cells in which viruses can replicate.

Virus farming for vaccine production

Except for entirely synthetic (and still rather novel) mRNA genetic vaccines, the production of vaccines begins with the selection of a "seed strain" of a virus. That might be SARS-CoV-2 that is either weakened through genetic engineering, or a standard strain that will eventually be inactivated through exposure to chemicals as part of a downstream process. Or, in the case of a viral vector vaccine, it might be an adenovirus that has been genetically engineered to contain some of the SARS-CoV-2 genome.

In either case, the aim is to generate enough of the virus, initially to supply animal trials, and then in increasing amounts to support the various stages of clinical trials, each requiring progressively larger population sizes. Eventually, for a successful vaccine, production needs to be scaled to provide enough virus for billions of doses.

Because viruses only replicate inside the cells of a suitable host organism, non-synthetic vaccine production relies on identifying, and cultivating, a suitable living medium in which large numbers of viruses can be produced. For many viruses that "host cell platform" for vaccine production is embryo containing chicken eggs, however, SARS-CoV-2 vaccines typically use cultures of human kidney cells. For viral vector vaccines these cells are genetically engineered to allow the adenoviruses to replicate in a way that they do not in regular human cells.

These "virus infected" cells are grown inside bioreactors, carefully controlled nutrient enriched mixing environments in which the temperature, oxygen and pH are precisely controlled to maximize the yield of both the cells and viruses (or in the case of sub-unit is used earlier in the article vaccines, proteins manufactured by the virus infected cells).

However, producing enough virus in a lab to produce a small number of vaccines is only a small part of the challenge. In order to produce billions of doses, vaccine manufacturers need to scale up those processes to an industrial scale in multiple production facilities spread around the world. Therein lies the challenge – biological processes do not scale linearly with the geometric size of the bioreactor. Maintaining the ideal cultivation conditions developed in a 10-liter bench experiment in a 4000-liter industrial bioreactor is a difficult engineering problem, and one of the main reasons behind the production delays that have been extensively reported in the press, and are the cause of considerable international political tension.

Of all the vaccine production facilities in the world, the largest by volume is the Serum Institute of India, who are licensed to produce the Oxford-AstraZeneca vector vaccine and the (as yet unapproved) Novax sub-unit vaccine. They aim to produce billions of low-cost vaccine doses to supply India and low and middle-income countries. The Serum Institute recently purchased six 4000-liter single-use bioreactors from ABEC, the American manufacturer of the world's largest bioreactors, allowing them to double the production of vaccine per unit floor space - to achieve the lowest possible cost per dose.

The challenge is that biological processes scale at different rates as the geometric size of the bioreactor is increased; the design of an industrial scale bioreactor will be significantly different from that of the laboratory scale bioreactors in which the original process was designed.

Paul Kubera, vice president of process technology at ABEC, told us "A typical scenario might involve a project that has moved from the laboratory bench at the tens-of-liters scale to process development, which may be operating on a few hundreds-of-liters scales. And then into production where they need to ramp up by thousands of liters in multiple units."

The challenge with bioreactors is keeping the host-cell-platform alive. According to Kubera, "The growth of the organism must be supported – it needs food, a carbon source and to take in oxygen and give off carbon dioxide.

It is critical to be able to deliver a known amount of oxygen in a given timeframe and remove carbon dioxide for all the organisms in the vessel."

In the traditional vaccine development process, which took many years, the scale up process was often lengthy and expensive, and based mostly around trial and error. However, ABEC, like most of the industry. now uses extensive computational fluid dynamics simulations to perfect scaling processes.

"With Simcenter, we can run a computational simulation of the laboratory configuration and confirm the same results. We can then run a large-scale simulation and be confident that the measured performance of the delivered equipment will track with expectations. As an example, we demonstrated that we can cut blend time 50 percent by using laboratory tests to screen options and Simcenter simulation to extend the results."

Platform incompatibilities present another potential obstacle. No single facility can produce billions of doses and so industrial scale production means ensuring similar production standards across multiple facilities. ABEC assists biopharmaceutical customers in bridging different platforms, from small to large, to ensure the same results are achieved at different facilities. The challenge is to create a uniform environment that is consistent for each organism in a vessel at each of those scales across platforms.

Purely synthetic vaccine manufacture

The first two vaccines to reach wide scale approval were both mRNA genetic vaccines,

First left:
A small lab scale bioreactor used to breed viruses in the early stages of vaccine production

which are entirely synthetic and do not require the cultivation of viruses or host-cells. This is an enormous advantage for manufacturing point of view because synthetic processes are easier to scale than biological ones.

Rather than use an actual virus to inject DNA into the cells of the patient, mRNA vaccines (and potentially DNA genetic vaccines) carry the genetic information inside a bubble of lipid nanoparticles – the diameter of each is measured in tens of nanometers (there are a million nanometers in a single millimeter). In order to manufacture this type of vaccine, the thread of genetic material must be combined with the lipid nanoparticles in a carefully controlled mixing process. Because of the scale of the particles involved, and the fragility of the RNA, macroscale bulk mixing is not effective.

Instead the manufacture of synthetic genetic vaccines relies on the emerging discipline of "microfluidics" in which individual streams of RNA (or possibly DNA) and lipid-particles at a nanoscale. Mixing is achieved using "chaotic mixers" which employ complicated three-dimensional grooves as mixing structures. Care must be taken to ensure that individual lipid nanoparticles do not clog up these grooves and stagnate the mixing process.

First right:
For manufacturing of the vaccine, large scale bioreactors are used, often measured in thousands of liters

The whole field of microfluidics depends entirely on multiphase computational fluid dynamics simulations to design and validate the devices, and synthetic vaccine production would not be impossible without digital simulation.

Unsurprisingly, these human-made "virus like particles" are less robust than actual viruses that are designed over millions of years of evolution. A consequence of this is that viral vaccines need to be stored at much lower temperatures than more traditional vaccines (which only require standard refrigeration). Simulation has been extensively used in designing the cold chain logistics processes that ensure that these vaccines reach the patient in good condition.

The future

In this article I have highlighted a few of the ways that simulation is helping to scale up the global vaccination effort. There are many more.

When they come to tell the story of the Covid-19, and all of the terrible devastation that it caused, I hope enough attention is given to the monumental scientific and engineering effort evolved in developing many vaccines used to combat it, in months rather than years. To me it is one of the greatest illustrations of engineering innovation. And an illustration of how much we can achieve as a species if we all work together. ■

How data collection will save your life

Examining advanced driver assistance system data collection for the future of vehicle engineering

By Joelle Beuzit

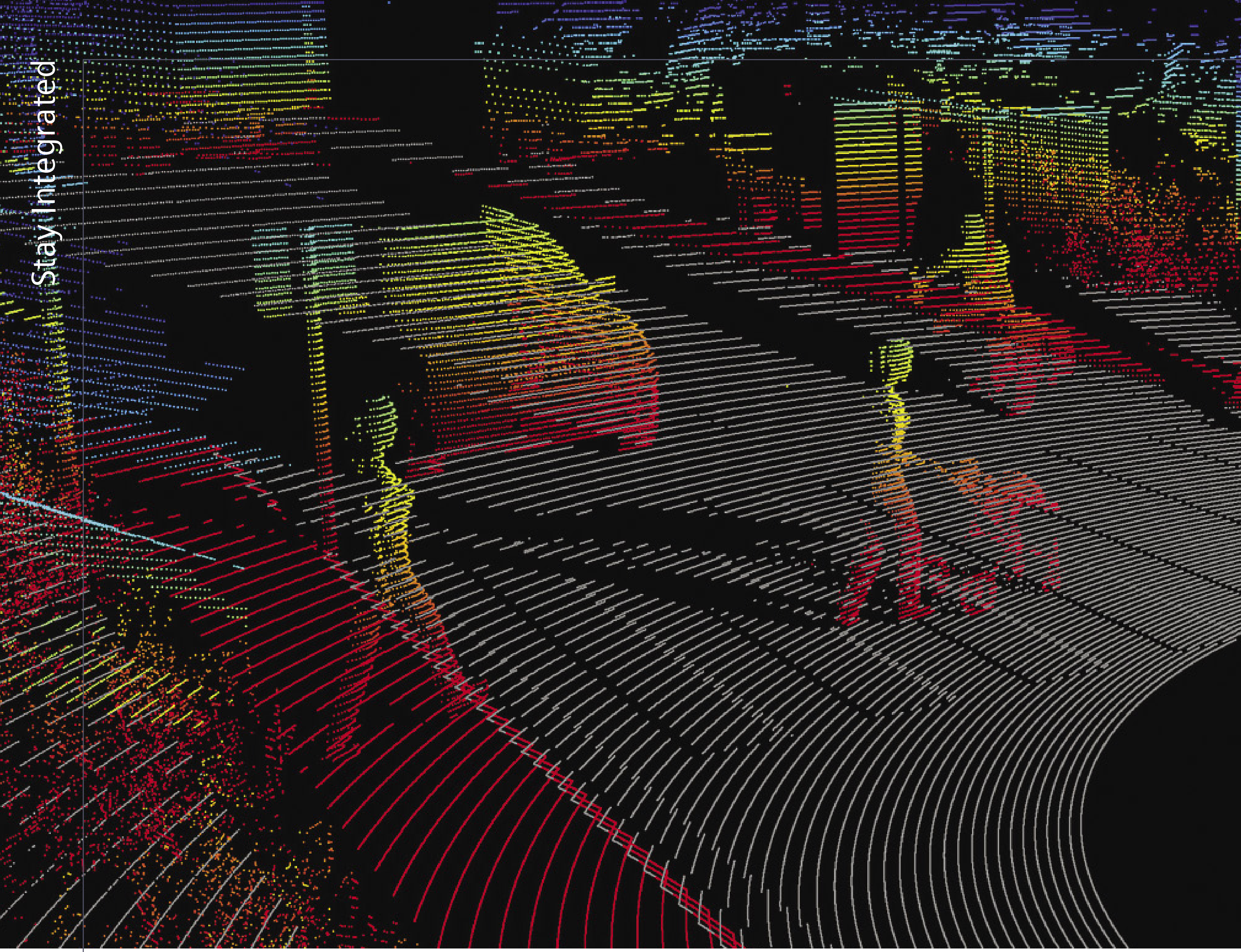
What is ADAS? What does the acronym stand for? ADAS means advanced driver assistance systems. It is a generic denomination to designate all past, current, and future electronically controlled, advanced safety systems in a car. It includes, but is not limited to, automated emergency braking systems (AEBS), lane-keeping assistance systems (LKA), adaptive cruise control (ACC), blind-spot monitoring (BSM), etc.

Behind the acronyms hides essential technology that saves lives. Human error causes most road accidents, so driver assistance systems were developed to enhance vehicle systems for safe and comfortable driving. Based on the information captured by the sensors around the car, the assistance system will warn the driver of a critical driving condition. The lane-keeping assistance system, for example, uses front cameras to detect the presence and trajectory of the driving lanes. If the driver veers unexpectedly off the lane, the system issues sensory warnings to the driver, with a short beep, a warning light, and a sensation of resistance in the steering wheel. Based on the level of automation of the car, the assistance system might even initiate the braking or escaping maneuver, for driver and vehicle protection.

How assistance systems work

Vehicles that feature advanced driver assistance systems are fitted with many sensors. These various sensors, short and long-range radars, low or high-resolution cameras, or 3-D laser scanning sensors (lidars), gather the information on its operational environment. The vehicle's electronic control unit (ECU) uses this information to meet an appropriate driving decision, such as issuing a warning, slowing down, or applying the brakes.

However, real-life driving conditions are rarely simple. Take, for example, pedestrian detection systems which are designed to avoid a potentially fatal collision between cars and pedestrians on the roads. The American Automotive Association performed a study in October 2019 which warned vehicle owners to not completely rely on their collision avoidance systems, and to be an engaged and alert driver regardless of these



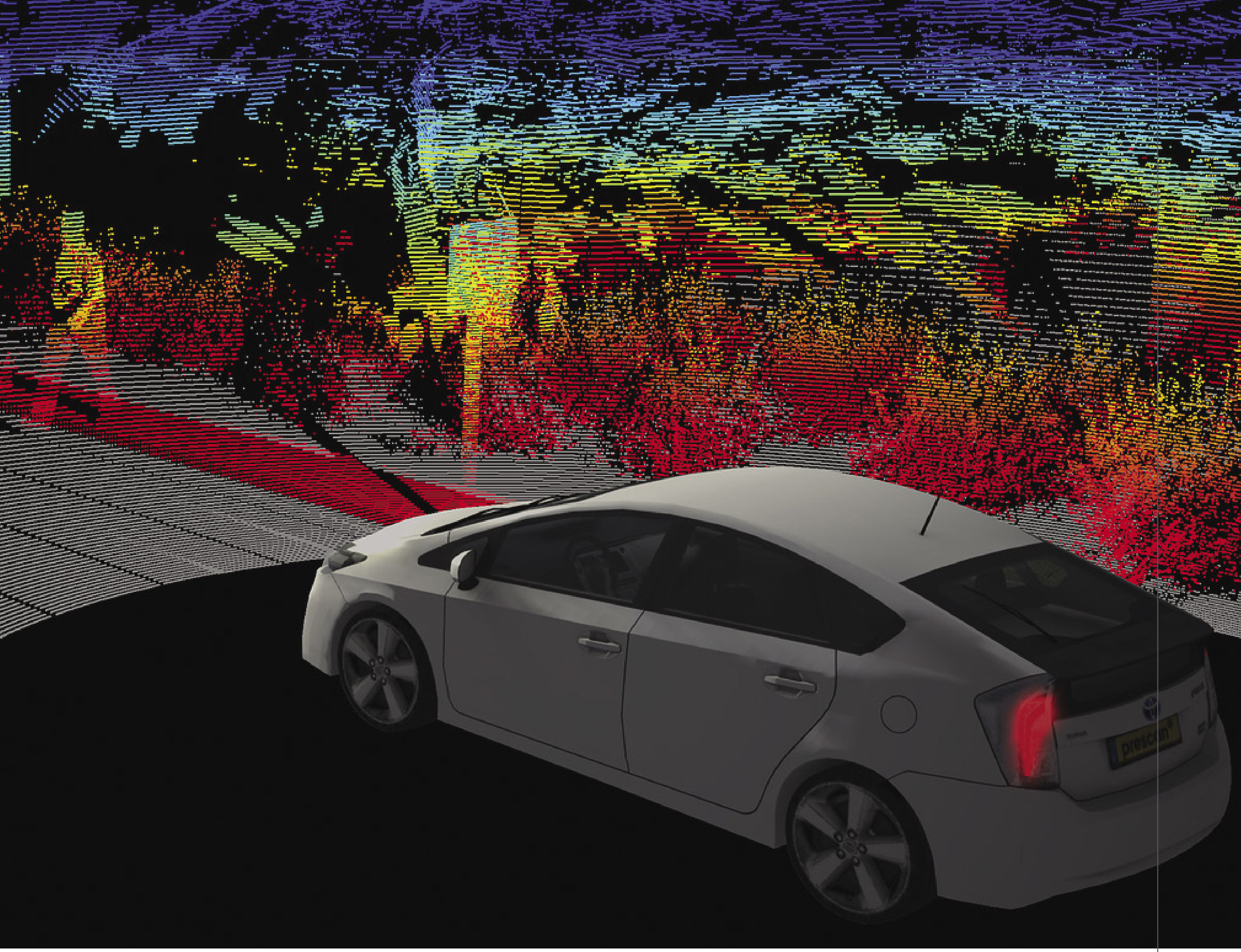
safety features. While most systems detected the presence of an adult crossing the streets, the vast majority failed to avoid a collision with a child darting out. Worse, all systems failed to properly detect pedestrians at night.

So, why do these systems fail so easily? From the perspective of a computer, determining what a pedestrian looks like can be a challenging task. Human beings present a wide variety of features. An anti-collision system must be able to identify any pedestrian crossing the road, adults and children alike, even a person in a wheelchair. Equally, the system should not apply the brakes when spotting the image of a running child featured on a digital billboard. It must be smart enough to identify real driving hazards and be able to isolate them from non-threatening situations.

Using real-life data to validate the systems and train the algorithms

Beyond the major accidents that hit the newspapers headlines, users of partially autonomous vehicles often report minor systems failure on the internet. The more advanced the system, the more they are prone to fail, often for lack of properly understanding the signals collected by the sensors. Recently, a Tesla driver shared a short video, in which the car's autopilot misunderstands the red letters of a vertical banner display, a supermarket's brand logo, and interprets the red letter "O" as a red light. The car was already parked and didn't stop unexpectedly, but this small error could have resulted in an accident in regular traffic.

Of course, the human brain wouldn't make this error. But how can engineers prevent the artificial intelligence of a computer from misinterpreting the signs it comes across? The increasing levels of automation require increasing amounts of data to train the AI algorithms and to identify critical scenarios that happen on the road for systems safety



performance testing. The data can be generated synthetically, through simulation environments in Simcenter , or using real-life recorded data.

Testing and validating the systems using real-life data is essential. To validate the system and to train the algorithms, ADAS data collection is an essential step for the development of self-driving cars.

By driving millions of miles and coming across a myriad of different complex driving scenarios, vehicles equipped with ADAS sensors collect the terabytes of data that will be used to train the driving automation algorithms. This data feed the algorithms with real-world information. And helps them understand how a red O differs from a red light. Additionally, the collected ADAS data is an indispensable element for the testing and validation of the vehicle's ADAS systems.

But collecting ADAS sensor data isn’t a straightforward task. What would be the consequences of feeding the algorithms with incorrect, incomplete, or corrupt data? Worse, would you trust a system that’s validated by flawed data?

The complexity of collecting ADAS sensor data

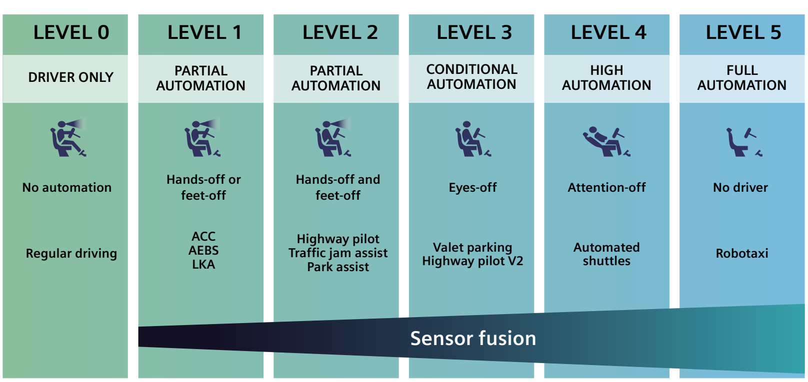
Data acquisition and processing have already been part of a vehicle development process for many years, so why is it different with ADAS sensor data? Firstly, this data needs to be raw. Only authentic, uncompressed data will render a genuine vision of a complex driving situation. This raw data is essential to the training of the algorithms.

Secondly, as the driver assistance systems evolve towards a higher degree of automation, the number of car sensors and of corresponding data increases exponentially. The society of automotive engineers (SAE)

defines 6 levels of driving automation, ranging from 0 (fully manual) to 5 (fully autonomous). The chart below illustrates these levels. Many vehicles driving on the road today feature level 2 partial driving automation, but car manufacturers plan to introduce higher levels of driving automation in near future. These systems will require more sensors, and more data to operate.

Thirdly, all this raw data streaming from various sensors must be perfectly synchronized. The slightest delay could result in delivering the wrong information about a driving situation, which could lead to a fatal collision. To prevent this incident, engineers need to quickly and accurately timestamp the data, as close as possible to the sensors themselves.

So, how is this achieved? To accelerate the development of multi-sensor autonomous driving and advanced driver assistance



systems, automotive need to rely on a trusted ADAS data collection solution. A complete system that records, stores, analyzes and replays vast amounts of raw data.

Capture raw ADAS data at ultra-high speed with Simcenter SCAPTOR

With the introduction of Simcenter SCAPTOR, Siemens is the first company in the world that combines a physics-based sensor simulation platform with a raw sensor data acquisition solution in a single portfolio, leveraging simulation to enrich recorded data sets.

Simcenter makes it possible to record these massive data streams, store them and upload them onto a cloud or local cluster storage solution. It allows the replay of recorded sensor data in a time-synchronized way, to enable Hardware-in-the-Loop and Software-in-the-Loop testing. This makes it possible to run tests in a laboratory environment. The tests are repeatable, efficient, and less costly than testing on real roads. A thorough and well-documented development process is also critical. It ensures the required levels of safety and to demonstrate the work done in case of liability claims. A model-based system engineering workflow and toolchain support that. For autonomous vehicles and ADAS, a major part of the process is validation and verification data, which is drastically increasing. Most important is the traceability between requirements, test cases, test execution and test results supported by documentation. Siemens' Xcelerator portfolio of integrated technologies is now further extended with traceability towards recorded data for automated driving technology. ■

Why your AI strategy needs more than data

By Remi Duquette, Vice President Innovation and Industrial AI at Maya HTT

The artificial intelligence (AI) revolution has been underway since about 2016. As a result of great increases in computational power, AI no longer belongs to the realm of media hype and science fiction. Today, AI offers concrete benefits in all areas of engineering, manufacturing, and operations. From deep neural networks and long short-term memory (LSTM) algorithms to reinforcement and physics informed neural networks (PINN), the possibilities are endless, and the real-world applications are only just beginning to truly be exploited. Industry data holds gold nuggets; AI is the key to finding and using them.

As companies seek to take advantage of AI, one of the first challenges is how and where to start.

Simcenter partner, Maya HTT have collated insights and advice from leading experts in applied industrial AI to deliver a no-fluff rundown of what you need to know and do to prepare the right way.

By some accounts, as many as 85% of AI projects fail. Many more companies run into problems with their data. Data quantity is important, but so is quality. Having an AI goal is not enough to succeed. Strategy and preparation are key.

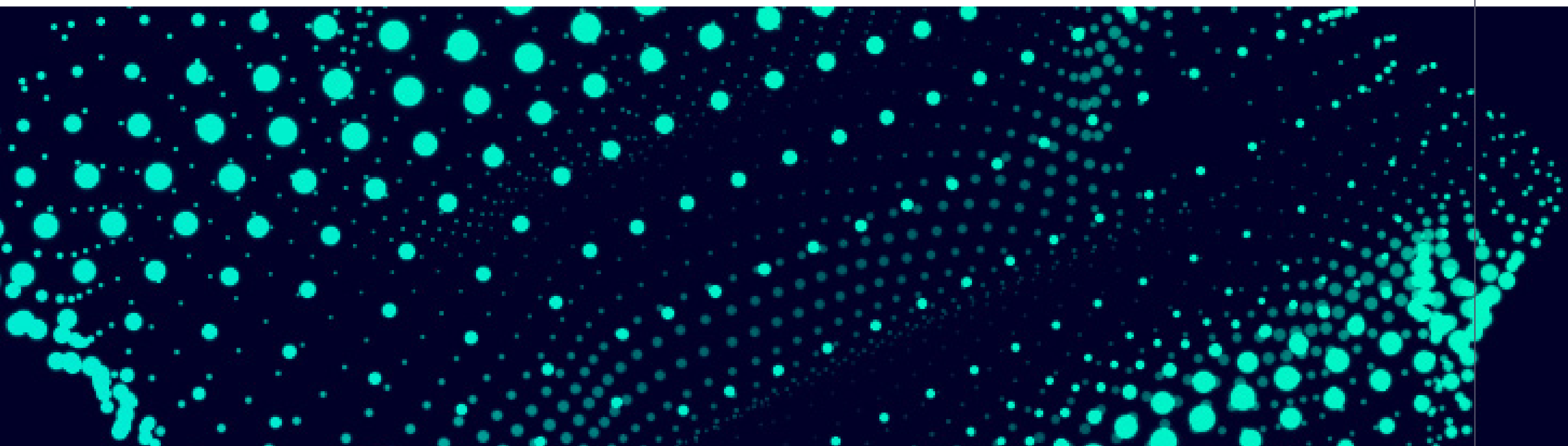
Identify goals & establish a strategy
Business goals, not AI technologies, must drive the AI roadmap. Leverage only those AI technologies that align with and serve the business goals throughout the company to increase overall efficiency. Strategy helps AI become a cellular reality across the enterprise. Without strategy, AI remains, at best, a set of more-or-less successful projects.

Start Small: Early Results Are Important
Plan first to apply AI in small ways. Find early business challenges for which an AI approach makes sense and where existing data is good and has few gaps. The end goal is enhanced accuracy, reliability and efficiency, and naturally, innovation.

Choose the Right AI Partner
A great deal of the hesitation organizations have about adopting AI stems from not knowing how to proceed. With the rapid pace of technological advancement, both in AI and IoT/IIoT, it is difficult for organizations to keep up. Understanding the challenges, pitfalls, and change management preparation required is critical.

The right partner should:
- Provide knowledgeable support,
- Be the right fit, and
- Identify any blind spots.

It's all about data
As many organizations understand that data plays a key role in AI, the primary concern when planning to implement an AI strategy is often to gather enough data and high quality data. Although it's true that the IoT and IIoT produce a staggering amount of data, that alone is not enough to get started. Successfully launching AI,



automation, and machine learning requires the right data, and clean data.

Plan for Change Management
Corporate leaders who want to help their organization reap the benefits of AI should incorporate change management considerations in their AI strategy and solution. The assistance of a knowledgeable support partner early in the process can help leaders proactively manage employee expectations about their changing realities and ensure a smooth implementation of their AI strategy.

AI - Now & For the Future
AI, machine learning, and deep learning will have a major impact on all companies in the near future. Successful implementation of this new technology cannot happen with a start-and-stop or piecemeal approach.

AI is a powerful and accessible set of new technologies that organizations of all sizes can use to remain competitive that begins with setting business goals, strategy, and small wins. Don't underestimate the need for change management. With a strategic approach, you can benefit from AI now and in the future Discover the potential AI holds for manufacturing, and find out how you can maximize AI success and ROI.

Take the first step into your AI future. ■

Download the white paper today.

The new science of digital materials

By Stephen Ferguson

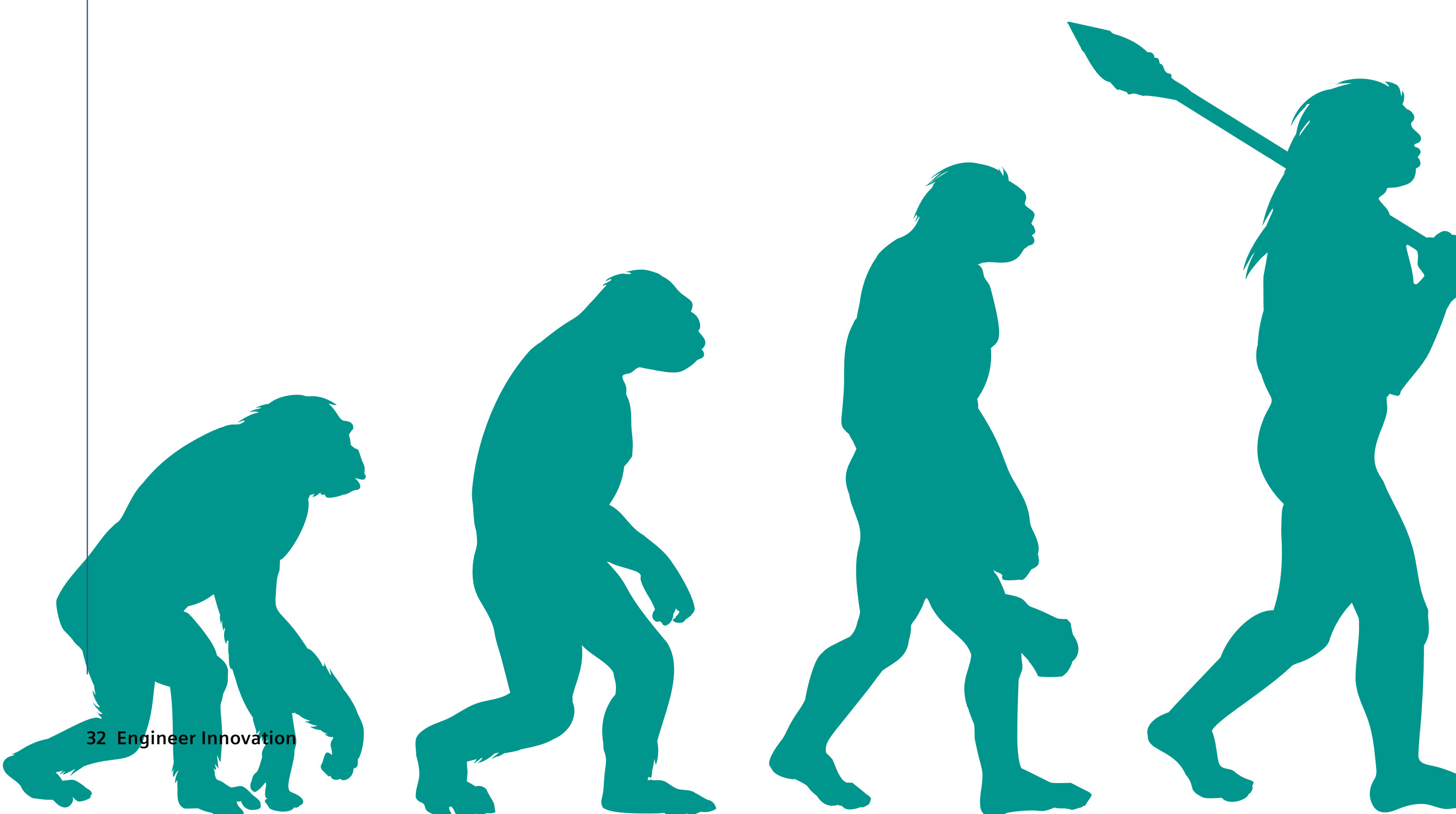
As engineers, we tend to take materials for granted. In most engineering projects materials are "a given", defined at the start of the design process, and rarely changed throughout it. We are prepared to tweak every single geometric parameter in the search for optimal engineering solutions, but materials are treated as a constraint rather than a degree of freedom. The recent development of "digital materials" that can be designed, analyzed and optimized via simulation changes this paradigm forever and unlocks endless possibilities for technological and cultural development.

Every significant advance in human civilization has been driven by revolutionary (rather than evolutionary) developments in material science: from the Bronze Age to the Stone Age to the Industrial Revolution, to the current "Silicon Age", developments in materials technology have heralded new eras of technological and cultural progress.

However, until recently, the pace of development in materials science has lagged behind the rate of product development innovation, because of the time and expense required to develop and test novel materials which often requires the experimental investigation of hundreds (if not thousands) of possible variants of microstructural configurations and chemical recipes.

Engineering and materials science

Large technological advancements are almost always dependent on the creation (or discovery) of novel materials. Revolutionary developments in materials science enable the



next generation of technological advancement. The full exploitation of those technologies (by engineers) will often require further investment into the evolutionary development of those materials.

Innovations in shapes at both the macro and micro scales are driving increased product complexity and are challenging mainstream simulation tools to keep pace

So, although engineers and material scientists inspire each other to new levels of innovation via a sort of "virtuous arms race," engineering and materials science have largely been separate disciplines. Co-operation has always been limited by the fact that, although the bulk of engineering design has moved towards CAE simulation, developing novel materials is usually done in the lab rather than a computer. This makes it time-consuming, difficult and expensive.

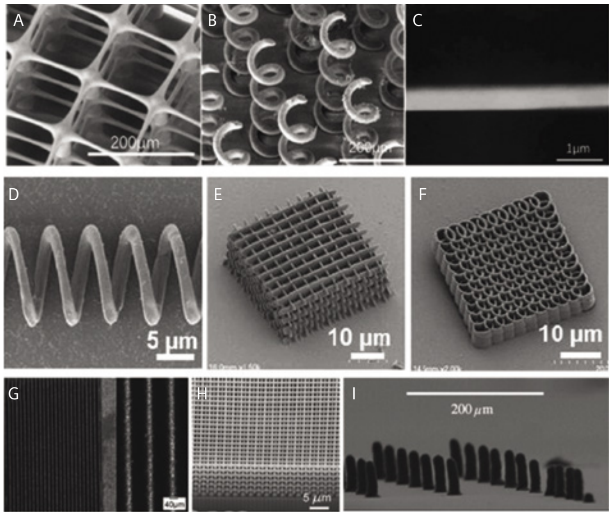
A material's behaviour is determined by its microstructure. Including any defects introduced during the manufacturing process. Failure starts at the microscale level and propagates to larger scales

The job of engineers is to progressively improve the performance of a product with regard to objectives such as stress, temperature, fatigue, sound, cost or sustainability, by making incremental design changes. Sometimes those are manually driven, but increasingly through a process of automated design exploration where AI determines the next improvement from the results of previous simulations. While there are obviously constraints, engineering progress depends on the exploitation of every possible degree of freedom, tweaking every geometrical and mechanical parameter until an optimal solution is found.

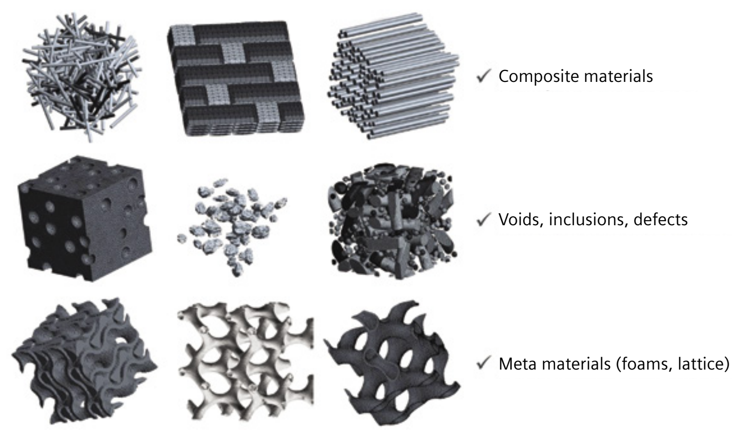
However, this process typically starts with the selection of a commercially available material (from an online database or pdf catalogue) and the design process will optimize performance based on the material already chosen. So, while the design process might alter any number of geometrical parameters, the materials remain fixed throughout. In other words, the material is a constraint, rather than a degree of freedom.

Which is a pity, because constraints can often turn into compromise, as engineers are forced into a trade-off between fulfilling some objectives at the expense of others. By treating materials as a constraint, we are leaving potential revolutionary developments "on the table" (or more accurately back at the material lab).

It doesn't have to be that way.



Digital materials: a new paradigm
The recent acquisition of MultiMechanics Inc by Siemens changes that forever by giving Simcenter users (and the wider engineering community) the ability to test and optimize novel materials from the comfort of their computer. And more importantly, offers the opportunity to make material design part of the design exploration process. Put simply, MultiMech allows you to predict (and therefore perfect) how the microstructural properties of an advanced material affect its engineering properties and performance.



However, this is only half the story. With millions of potential variants, the potential design space is huge. To include materials in our automated process, the design exploration algorithm needs to make intelligent choices about which variants to test next. Materials data is complicated and difficult to share and organize. What is missing is materials-aware Artificial Intelligence, to help engineers (and automated design exploration algorithms) navigate the materials design space. Of course, that is never an absolutely free choice. It doesn't make any sense to design a tailored material that is un-manufacturable, or only at a prohibitively high cost.

Macroscale finite element simulations of a composite can now directly use macroscale simulations of material properties that account for fibre and grain alignment, and voids and imperfections.

To solve that problem, Siemens have partnered with Citrine Informatics, who are the industry leaders in materials informatics, which combines data science, materials science, and materials-specific machine learning that assists in the design and exploration of advanced materials.

Citrine has built the first enterprise materials informatics platform for data-driven materials and chemicals development. Their platform combines smart materials data infrastructure and AI, which accelerates development of cutting-edge materials. By combining this capability with product design simulation, it unlocks materials design as a degree of freedom for design engineers.

Of course, not all engineering materials are rigid. Siemens also recently acquired computational chemistry company Culgi. This technology allows engineers to predict the chemical and thermodynamic properties of fluids, and so called "soft-materials", whose macroscopic behavior depends on interactions at a microscopic, and even quantum scale.

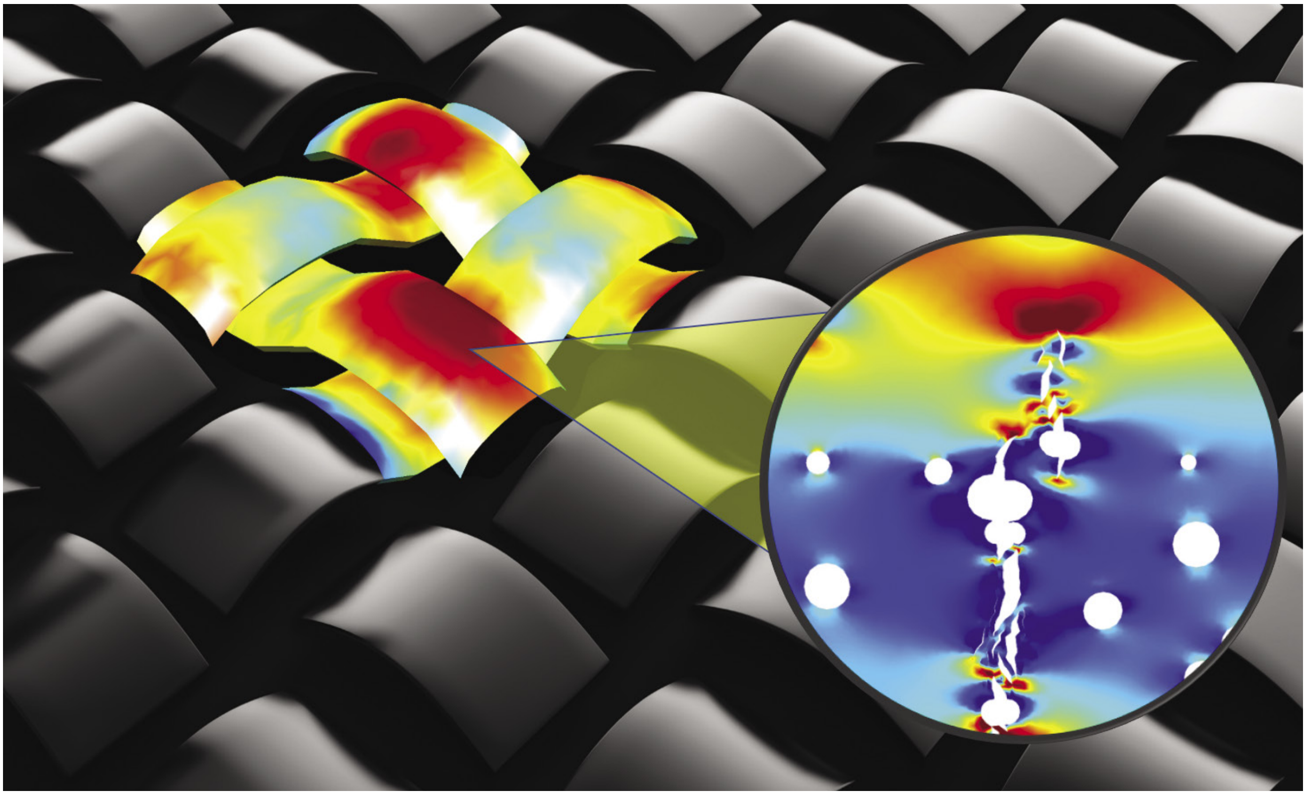
This is nothing short of a paradigm shift: for the first time in the history of our species,

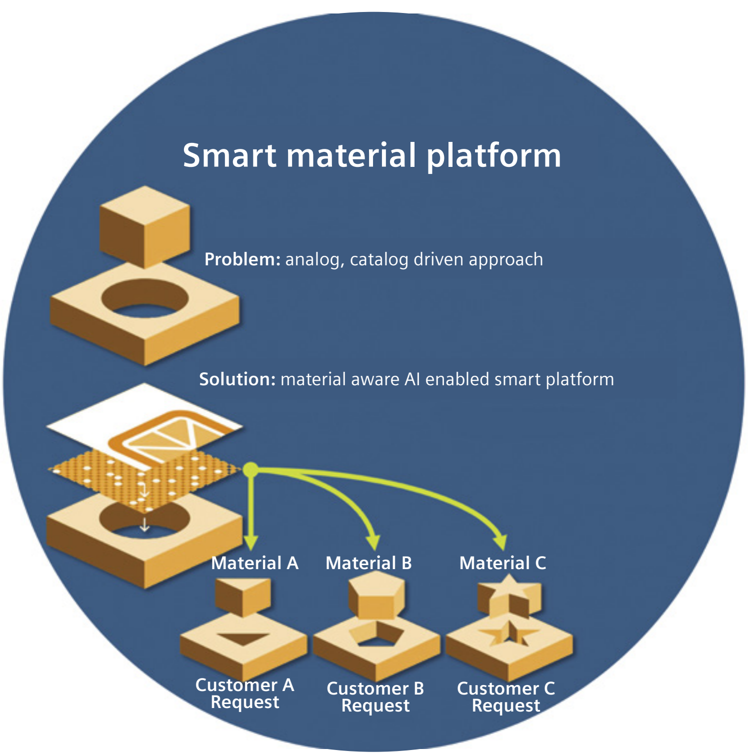
First left:
Innovations in shapes at both the macro and micro scales are driving increased product complexity and are challenging mainstream simulation tools to keep pace

Second left:
A material's behaviour is determined by its microstructure, including any defects introduced during the manufacturing process. Failure starts at the microscale level and propagates to larger scales

Third Left:
MultiMech allows engineers to predict (and therefore perfect) how the microstructural properties of an advanced material affect its engineering properties and performance.

First right:
Macro scale finite element simulations of a composite can now directly use macroscale simulations of material properties that account for fibre and grain alignment, and voids and imperfections.





Second right: Citrine Informatics' materials-aware AI platform helps engineers to choose the materials that best fulfil their objectives, reducing compromise.

materials development can progress at the same pace as engineering innovation. This has the potential to unlock unprecedented collaboration between materials scientists and product design engineers, and to develop the right material for the right application, every time.

Citrine Informatics" materials-aware AI platform helps engineers to choose the materials that best fulfil their objectives, reducing compromise.

Materials of the future

I started by talking about how material science has been at the heart of every major cultural, technological and economic benefit that our species has experienced over the last 6000 years. In lots of ways, the cadence of that development has been driven by the pace of development of novel materials that allow engineers to solve the challenges that we face as a species.

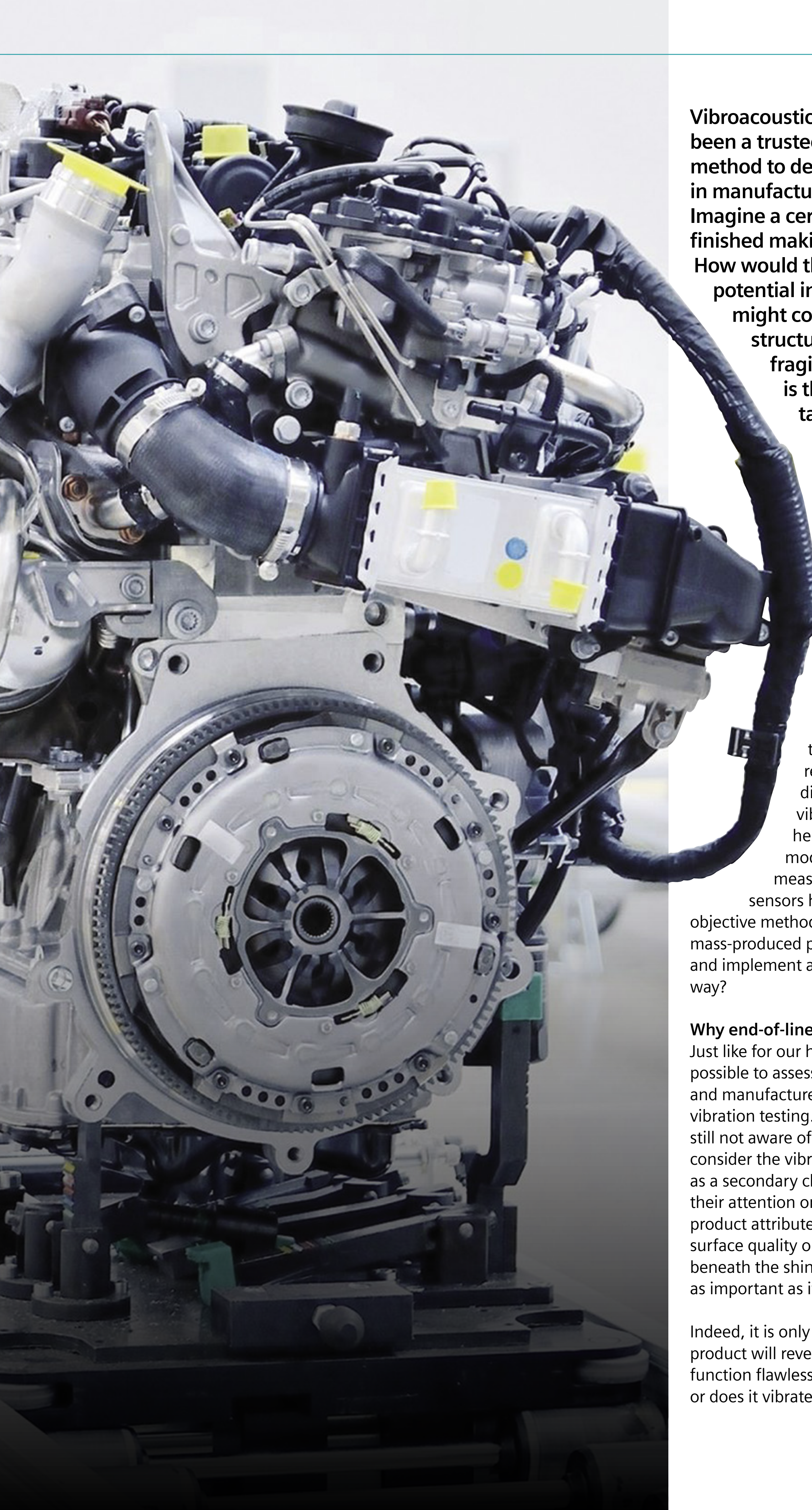
I think that it's fair to say that as we try to avoid the catastrophic consequences of climate change in the next 20 years, it will require a much tighter coupling between the materials science and engineering. As we strive to build a clean energy future, we will need less-polluting methods of transportation, lighter weight alloys, biodegradable plastics, better batteries, more efficient wind turbines, solar panels and nuclear reactors. We will also have to find alternatives for many of the rare earth elements that have been depleted by industrialization and globalization.

It's time to exploit materials as a degree of freedom, and to stop treating them as a constraint. ■

How end-of-line testing can automate product fault detection

By Joelle Beuzit

In the automotive sector, end-of-line testing uses vibroacoustic measurements to automatically and objectively detect faulty parts in the production line. Learn how automated measurements can help you minimize quality issues. And understand also how to optimize this process.
Register for the webinar: End-of-line testing for automotive



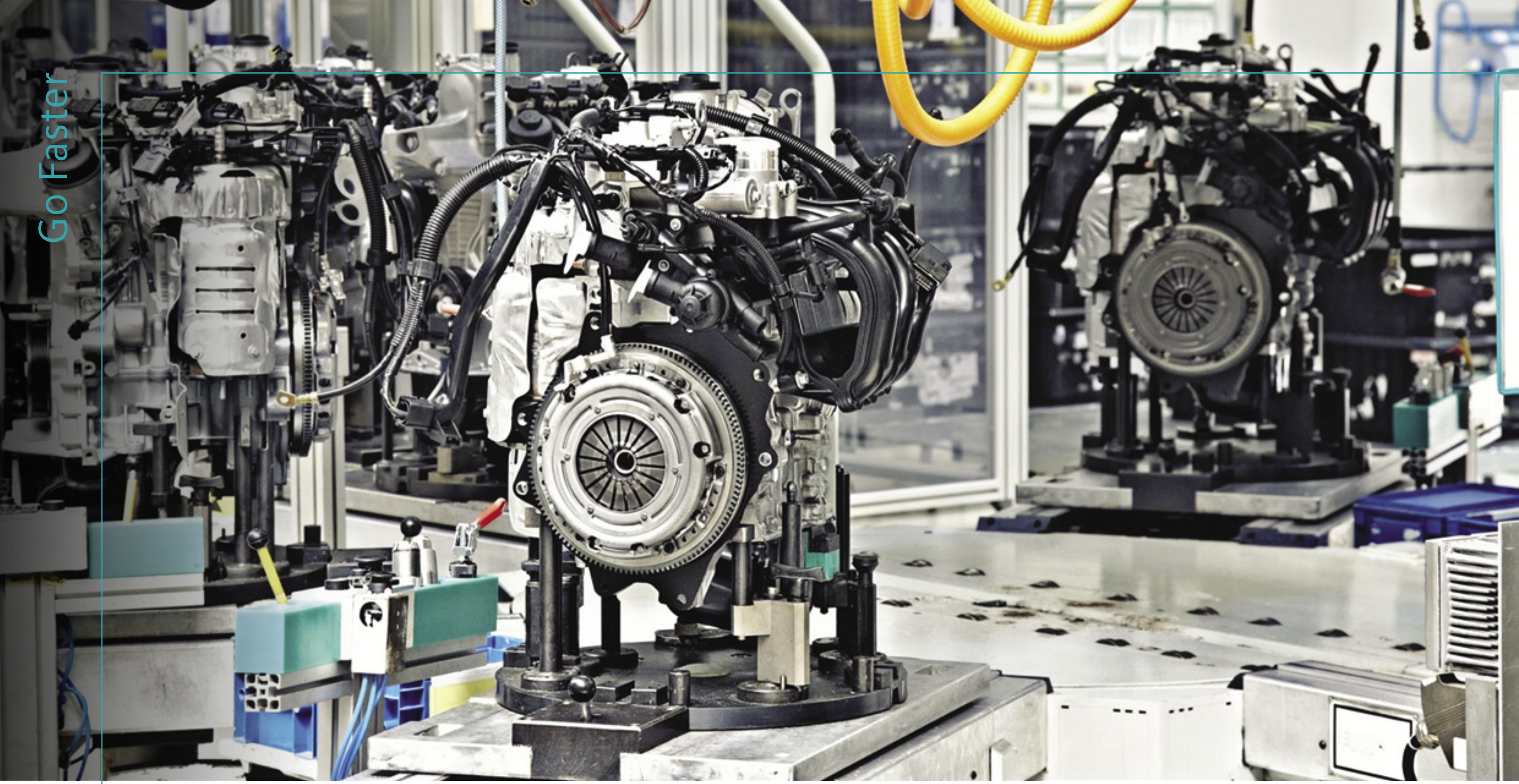
Vibroacoustic measurement has been a trusted end-of-line testing method to detect faults and defects in manufacturing for centuries. Imagine a ceramist who had just finished making a fine pottery vase. How would they go about detecting potential invisible flaws that might compromise the structural integrity of the fragile object? The answer is that they would gently tap the vase and listen carefully for the acoustic response. Does the structure sound healthy and whole? Or does it produce a dull tone, hinting at the presence of small air bubbles or tiny cracks under the flawless surface?

Indeed, from the ancient times, over the industrial revolution, to the modern digital age, noise and vibrations measurements have helped reveal many defects. In modern times, vibroacoustic measurements using calibrated sensors have become an automated, objective method to test high volumes of mass-produced parts. But, how do you apply and implement automated testing the right way?

Why end-of-line testing is important

Just like for our handcrafted vase, it is possible to assess the quality of many parts and manufactured products using noise and vibration testing. Yet, many companies are still not aware of this opportunity. Some consider the vibration behavior of a product as a secondary characteristic. They focus their attention on other, more tangible, product attributes such as its design, its surface quality or its color. But what lies beneath the shiny surface of the item is just as important as its appearance.

Indeed, it is only during operation that a product will reveal its true quality. Does it function flawlessly according to expectations or does it vibrate abnormally? Excessive noise



and vibrations are often a sign of a production defect that so far went unnoticed. From the imperfections in the finish of a gear tooth to the imbalances of a bearing part, you can hear and feel the defects, even without seeing them.

How can you use noise and vibration testing to your advantage and unveil defaults in the parts, early in the manufacturing process?

Automated vibroacoustic measurements offer a fool-proof method to rapidly test every single part that comes off the production line for its quality.

What should you test?
In fact, every moving part and piece of a mechanical machine can, and should, be tested for its vibroacoustic behavior. This includes:

- Parts of and whole internal combustion engines, of all sizes and for all applications;
- Parts of and whole electric motors, of all sizes and for all applications, from the powerful; traction motors down to the tiny windscreen wiper motor or the seat adjustment motor;
- The extremely fast turning parts of turbochargers; and
- All types of compressors for air-conditioning units or for refrigerators.

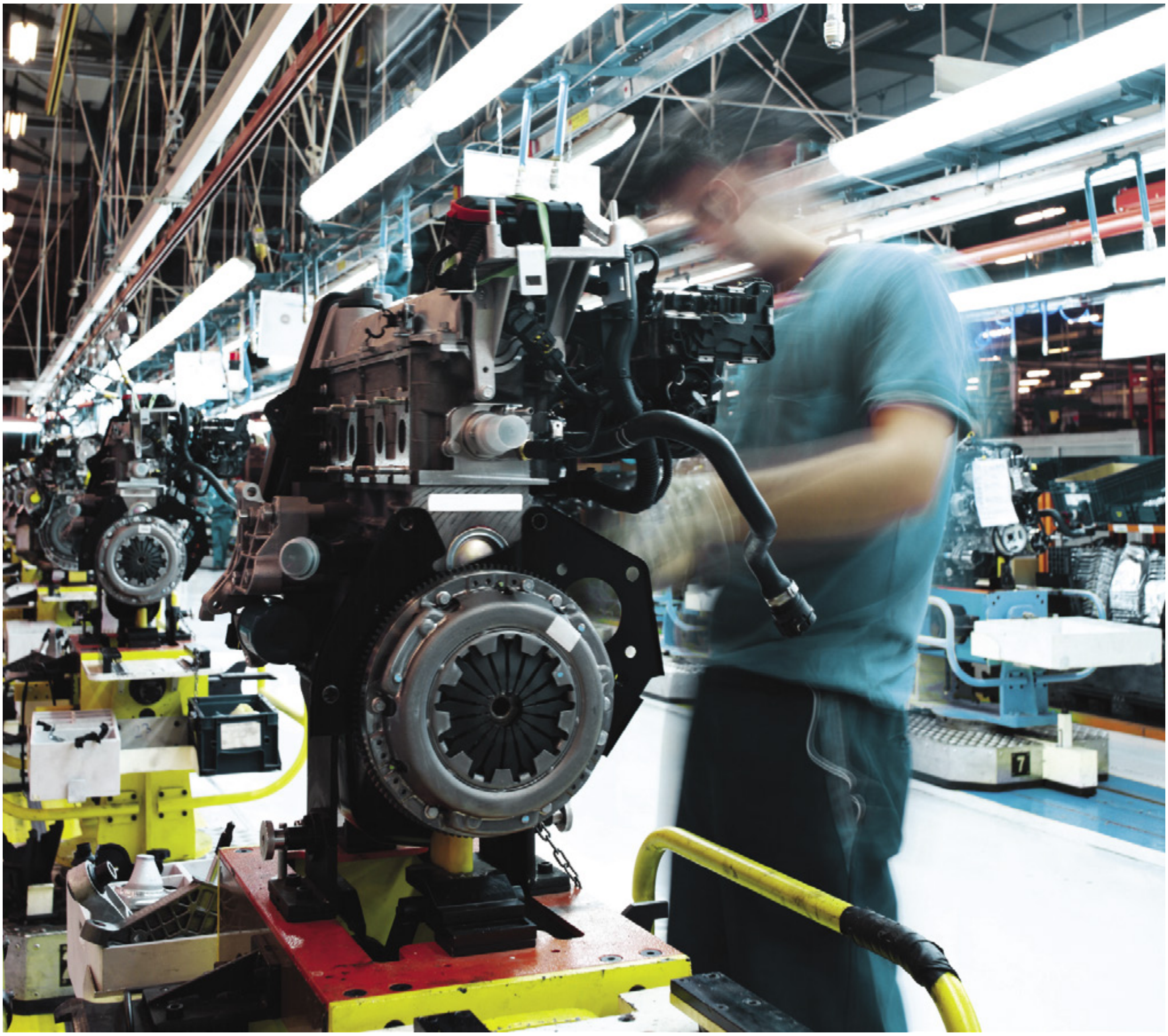
The applications of systematic end-of-line testing are not limited to parts produced for

the automotive industry. Other industries can also benefit from this trusted method.

Even single component and non-moving part are suitable test subjects. The method called acoustic resonance testing consists in exciting the part, for example, by hitting it with a small impact device and listening to its acoustic and vibration response. This method helps identify imperfections like cracks, cavities, improper heat treatment, wrong or missing material, and much more.

How to implement vibroacoustic end-of-line testing
So, now you understand why you should implement end-of-line testing. But how should you do it?

First left:
Manufacturing car engine parts.



As with many other defect detection methods, it is best to rely on the knowledge and experience of a trusted partner. If you want to meet the demands of industrial quality testing, you should ask them questions such as:

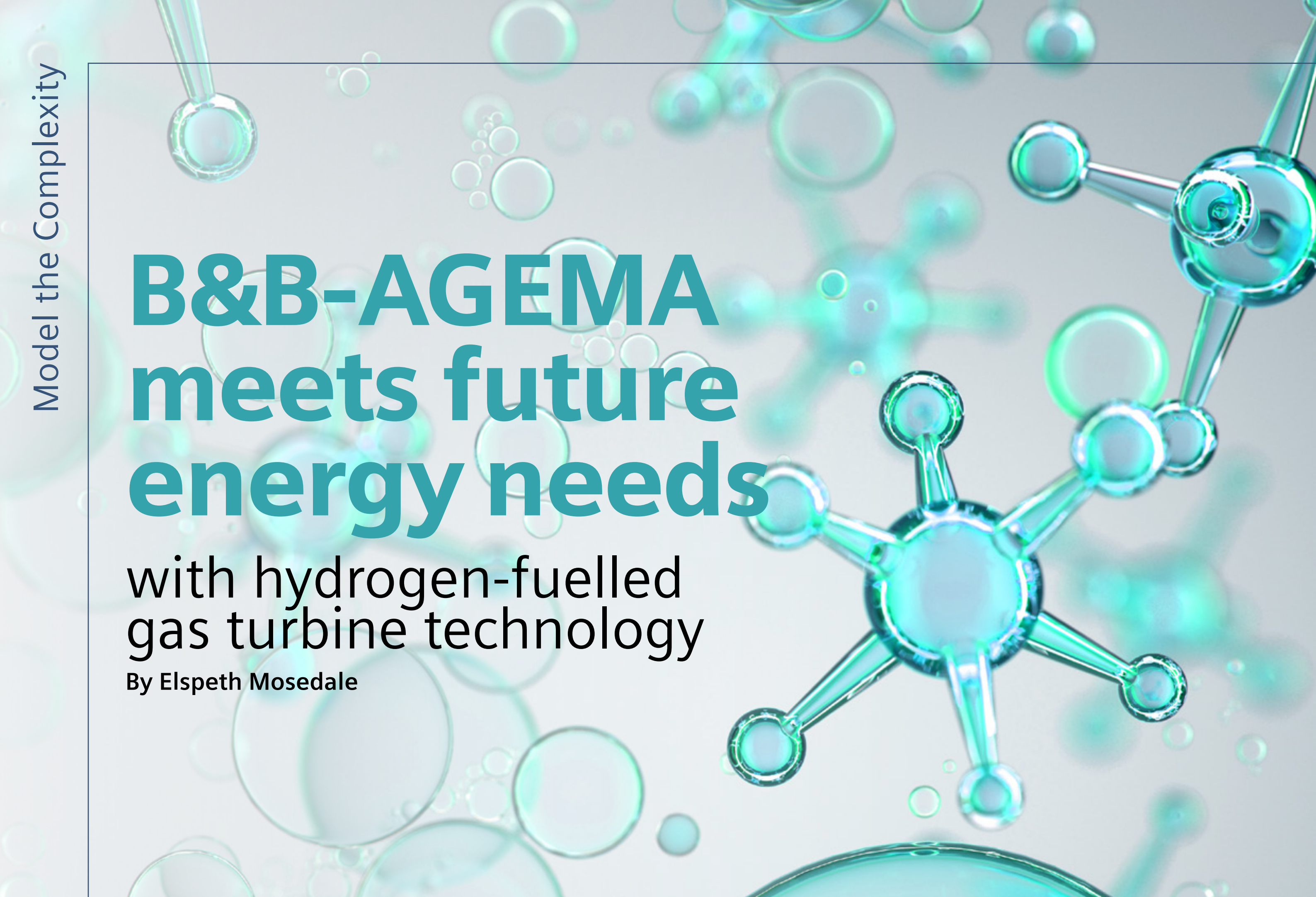
- Which sensors should I use and where should I position them?
- How can I catch the signal of interest using highly sophisticated trigger mechanisms?
- Which analysis functions and evaluation algorithms should I apply?
- How can I build a test bench?
- How should I design the test cycle?

Introducing Simcenter Anovis

The questions above are the ones that Siemens experts can help you with when you implement the Simcenter Anovis solution.

Simcenter offers a robust and reliable industrial quality testing system. It is easy to integrate into end-of-line test benches and production lines. It helps to deliver product quality at lower production costs while preventing production line outages and reliably identifying defects.

Beyond simple fault detection, Simcenter Anovis also provides deeper, valuable insights into the product's characteristics. These insights foster product enhancements or innovations. Indeed, they clearly point at the possible root cause of the identified problem. This information is not only valuable for the manufacturing team, which consequently implements improvements along the production line. It is also useful for the research and development teams, as a reliable, real-life input into future product enhancements. ■



B&B-AGEMA meets future energy needs

with hydrogen-fuelled gas turbine technology

By Elspeth Mosedale

The challenge of energy for the future (why hydrogen?)
The global demand for energy continues to increase, with the impetus now behind ensuring as much energy production as possible is from clean sources. Whilst low NOx renewable sources have seen a dramatic increase (from 5451TWh in 2000 to 9824TWh in 2019), large-scale energy storage is still a challenge. There is still a need for energy production to backfill when solar and wind-power are off-line. Using hydrogen as a gas turbine fuel offers the possibility of clean production that can be brought on-line to produce energy in renewable downtime.

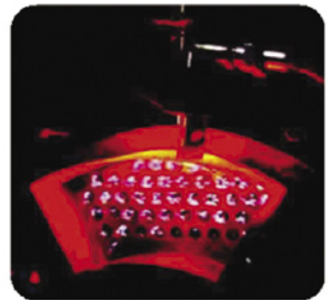
Hydrogen combustion is not entirely straightforward. Because of its extreme flammability range and flame speed it easily leads to flashbacks and needs the right combustion technique to keep NOx production low. Wet NOx combustion is the current method used, where water or steam is injected into the combustion chamber to reduce the combustion temperature. The water/steam must be free from impurities, while reducing the NOx emissions this method is still not environmentally sound or efficient. "Dry low NOx" (DLE) offers an alternative, but the combustion process handling requires that engineers think outside the typical "lean combustion – low NOx" box and develop new techniques.

Micromix technology

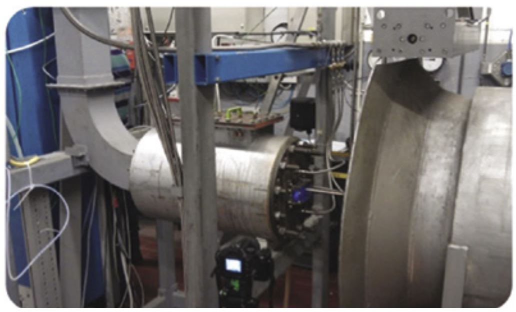
The most promising and flash-back safe combustion technique relies on Micromix combustion technology. This is achieving lower NOx emissions without large water usage and delivering dry low emissions (DLE) technology. Micromix technology has been in research and development since the late 1980s by Aachen University of Applied Sciences (AcUAS, FH Aachen), and subject of many collaborative projects – mainly together with B&B-AGEMA and Kawasaki

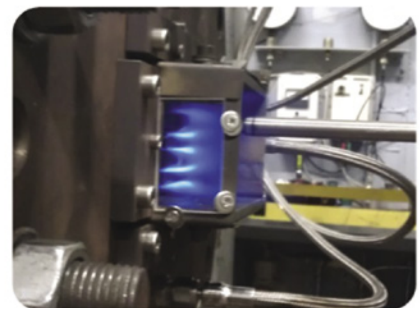
Generation 1

Generation 2



Generation 3





First right:
Early versions of the Micromix Combustion Chamber

Second right:
2 Micromix 2D liner burner test rig (Methane-Hydrogen Combustion)

Heavy Industries Ltd., Japan (KHI). The two basic ideas behind the concept are explained by Jens Dickhoff from B&B-AGEMA:

1. In order to suppress NOx formation, one can either lower the flame temperature or reduce the residence time of fuel/air inside the high temperature zone of the flame. NOx molecules can only form under certain fuel/air conditions and high temperatures. If the N and O molecules reach colder zones behind the flame before they undergo a chemical bond, they literally "missed their chance".

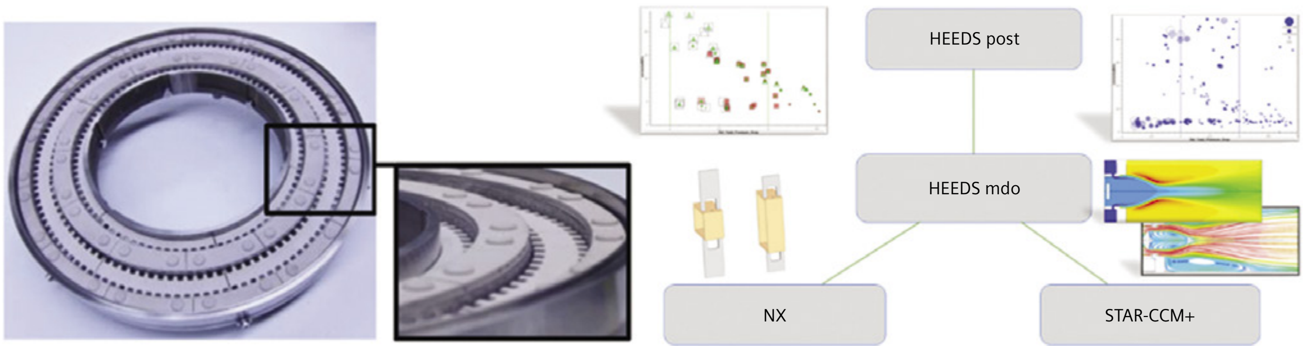
2. Pure hydrogen cannot burn. A diffusion flame is consequently flash-back safe whilst pre-mixed flames will always bear a very destructive risk.

   This led to the concept of multiple miniaturized diffusion flames, which simultaneously prevents flashbacks and suppresses NOx production.

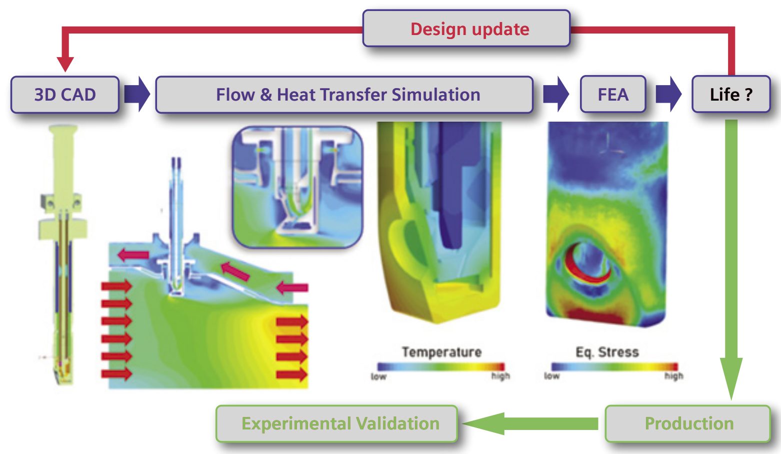
Early designs used cold flow mixing: a hollow perforated plate filled with hydrogen, which allowed air to transition through the holes. This technology was not easy to manufacture at a large scale and also led to some hotspots at the hydrogen injection ports. The next generation incorporated tubes on the hot side of the plate to control where the air mixed with hydrogen, aiming to ensure rich and lean zones that lower NOx emissions. However this hydrogen layer was quite irregular and so proved impractical and costly. Building on this, the improved design kept the perforated plate but with bigger holes and an air jet. The hydrogen is then injected perpendicularly to the air jet. This design gave lower NOx values but also had some problems with thermal stress, and the overall assembly was complex to manufacture.

Overall, these projects had proved the viability of the Micromix technology. While earlier combustion methods had proved less safe due to the possibility of flashback, this newer method was inherently safe, and the mixing and burning occurs simultaneously after injection. However, it was still possible to refine the micro-mix combustor further, to ensure optimal fuel delivery, enhance the fuel flexibility, part load stability and thermal load, and optimize the design for ease of manufacture – all substantial steps for real engine application.

Prototyping and optimization
B&B-AGEMA have been involved in the development of Micromix technology together with its partners from KHI and FH Aachen since 2010. To improve on the fourth generation, B&B-AGEMA used CFD simulation to both understand the combustion characteristics and optimize the design. The ultimate goal was to have low NOx emissions from combustion, while maintaining an acceptable pressure drop in the combustion chamber. Advanced CFD methods proved to be a game-changer in developing this technology.



First left:
Left: Micromix Combustor for APU application; Right: Automated Design space exploration for the Micromix geometry governed by Heeds mdo.



Second Left:
Engineering workflow of the air-cooled borescope development for Micromix flame visualization (white light and infrared) inside the gas turbine combustor end for real engine application

Using Simcenter STAR-CCM+ they performed intensive CFD investigations of the combustor, looking at the aerodynamic flow parameters and the combustion structures (flame shapes). The aim was to find the optimal design and length of the flame to ensure low NOx combustion and at the same time simplify the design by reducing the number of injectors. The CFD simulations included reactive chemistry to predict the flame shape, size and temperature signature. This was the first time that B&B-AGEMA used this approach. The results from the simulations compared very well with experimental observations from the combustor test bench.

As a result of this research, AcUAS and B&B-AGEMA developed the fifth generation Micromix combustor. With this generation simulation and design exploration became a substantial part of the design loop. Jens explains “We used NX for CAD modeling and Simcenter STAR-CCM+ for reactive CFD simulations. The optimization loop was controlled by HEEDS, so the geometry variation was done automatically. We investigated the response of the flame shape and temperature distribution in the volume behind the combustion chamber, based on the geometry changes”. This approach enabled the team to run many more cases than would be possible on a test bed. As Jens describes, “Design optimization allowed us to accelerate the design, and especially to find new setups and new flame shapes. The CFD simulations have shown a new flame shape with very low NOx properties, which was never considered before”. Having found this design variant, the team manufactured and tested a prototype burner, which proved the flames exist and are beneficial for combustor designs.

Fuel flexibility

The fuel flexibility of a typical power plant turbine will change in the future, with the shift toward ‘green hydrogen’ and hydrogen-methane fuel mixes. By running conjugate heat transfer (CHT) simulations, B&B-AGEMA was able to assess the impact of different fuel types on the thermal load of the burner. The simulations included detailed chemistry for combustion and both solid and fluid domains. Jens explains “there is a transfer of heat from the fluid domain to the hydrogen bar. If you warm the bar, this energy is fed to the hydrogen gas, which in turn increases the injection depth of the hydrogen into the cross flow. This leads to different NOx results.” This CHT approach improved the agreement between simulation and experimental results, and proved the suitability of the Micromix design for a range of fuel types.

Large eddy simulation of combustion

B&B-AGEMA have collaborated with KHI and AcUAS on a succession of projects aimed at developing a hydrogen combustion gas turbine for practical use. During this cooperation, B&B-AGEMA ran intensive numerical simulation projects on the Micromix burner, both for verification and design optimization, building on the work described above. One thing the team investigated was the potential use of Large Eddy Simulation (LES) in the combustion simulations. LES is a transient technique where the large scales of the turbulence are solved explicitly, and the small-scale motions are modelled. In comparison, steady RANS methods model rather than resolve turbulence. Whether a turbulent eddy is resolved or modelled by the LES scheme depends on the local grid resolution, which means that LES calculations require fine computational meshes and small timesteps. This can make this approach computationally expensive, but in this case the results were clear. Jens explains: "RANS simulations tend to show a very stretched, long flame, but this is not the case for LES. The flame shape matches much, much better with the real flame impression. We could predict NOx values which are very close to the experiment. We have never seen such good results before. They even provided an explanation for a transient phenomenon about which we have speculated and discussed many times based on experimental and steady RANS results. With RANS results we just had tendencies correct. Now we have the quantitative values and transient behaviour also correct."

Optimizing monitoring tools

Throughout the Micromix design process, B&B-AGEMA also developed monitoring tools. One example is the air cooled borescope: this is an optical monitoring device equipped with an infra red or white light endoscope which is inserted into the combustor to monitor the flames. The Borescope has to be able to withstand the high temperatures within the combustor which can reach up to more than 1450°C. B&B-AGEMA combined CHT simulations and FEA analysis on the borescope geometry to predict stress curves and lifetime for the component. They simulated a range of alternative designs, aiming to optimize the internal cooling pathways and ensure structural integrity. The final design was then manufactured: in tests this prototype was successfully operated in both high and low pressure combustion tests of the brand new hydrogen combustor from KHI applied with the MMX combustion technology.

From theory to reality: the world's first DLE turbine

The overall aim of this project was to lower the NOx values for hydrogen-driven combustors, while ensuring acceptable pressure drop in the combustor. The target was to have less than 35 PPM NOx at 100% hydrogen from 50% to 100% load, with low NOx values at part-load operation as well. Additional requirements were a stable ignition all the time, no flashback risks and an acceptable pressure drop of 3.5%. With their intensive program of CFD simulation, design optimization and benchmark validation, B&B-AGEMA, KHI and the AcUAS created a Micromix burner design which successfully met all these targets. Simulation was key to their success. Jens comments: "For B&B-AGEMA the Siemens software portfolio is the clear market leader for turbine and combustor flow, chemistry and heat transfer analysis."

The Micromix design was patented by B&B-AGEMA and KHI in 2016. Thereafter the focus was on implementing this new technology into industrial turbines. On 21st July 2020, after a few years "under the radar" to protect the technology, the Japanese New Energy and Industrial Technology Development Organization (NEDO) and B&B AGEMA's partner KHI, announced the successful demonstration of the first DLE 100%-Hydrogen-fuelled gas turbine under commercial operating conditions in the port of Kobe, Japan. Jens sums up their thoughts: "We are very excited to see this, and we are also very proud to be part of the Hydrogen Road of Kawasaki. This is a great achievement on the way into the Carbon-free future for electricity production based on the Hydrogen technology" ■

How to keep pace with tomorrow's digital industrial transformation

For companies of all sizes and in all industries, the pace of innovation and change is faster than ever as the world becomes more digital and connected. Paradoxically, another hallmark of industry today is a persistent growth in the complexity of developing, manufacturing and deploying products to market. Whether its consumer electronics, connected machinery, or next-generation vehicle platforms, product design increasingly is characterized by the integration of electronics, software and mechanical systems.

Meanwhile, how we manufacture products is also rapidly evolving. Companies are connecting product design with manufacturing to enable product optimizations through design for manufacturing techniques. This also allows companies to prepare for new industrial technologies such as 3D printing (also known as additive manufacturing). Then, as products move into the field, they are being connected to the cloud through the IoT to analyze product performance data with real and virtual sensors, creating a closed-loop feedback cycle with design and manufacturing.

All of this is changing the way design and manufacturing work together, adding another dimension to complexity. Many different elements of industrial and technology organizations are being brought into closer collaboration to produce and deploy today's products. These elements are inherently different, and face unique challenges driven by their capabilities, differentiating IP and strategy.

Digitalization makes the concurrent rise of speed and complexity possible, and manageable. Through digitalization and digital business transformation, we have seen that the previously hard limits to scaling and coordinating across vast organizations and value chains are falling away. Likewise, the rigid boundaries between engineering domains and vertical specializations are blurring as the power of leveraging data and analytics horizontally across previously siloed categories becomes better understood.

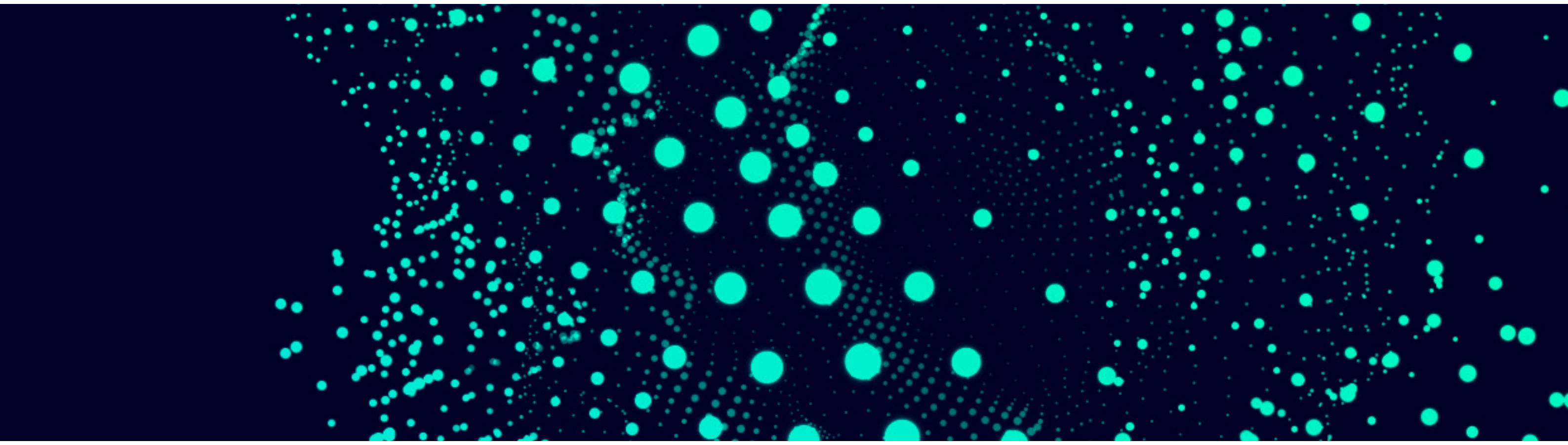
Digital transformation is the focus of Siemens Digital Industries Software and the Xcelerator portfolio, both of which were announced last fall in New York. The name Xcelerator is a nod to the reality of the digital age – the accelerating cadence of nearly every aspect of the design-manufacturing-utilization flows in the industrial economy today.

A catalyst for enterprise digital transformation

Driving enterprise-level digital transformation through market leading software, services and impactful collaboration among peers, Siemens provides the catalyst to not only enable, but also accelerate digital transformation for companies of all sizes and in all industries. The Xcelerator portfolio encompasses Siemens' capabilities for digital transformation and supports three key facets of the digital enterprise:

The Xcelerator portfolio supports digital transformation through software, services, the IoT and an application development platform.

Comprehensive digital twin. The comprehensive digital twin is at the center of digital transformation. It is made of many



First right: The Xcelerator portfolio supports digital transformation through software, services, the IoT and an application development platform.

digital threads at varying levels of abstraction from product design, manufacturing and in-field utilization data gathered through the IoT. By combining these digital threads, the comprehensive digital twin enables cross-domain engineering, virtual validation and continuous product and process improvement through a closed feedback loop supported by cloud-based analytics.

Personalized, adaptable solutions. Every organization faces unique challenges and, therefore, demands tailored solutions and a customized point-of-entry to digital transformation. These solutions must adapt to each company's digital roadmap and unique characteristics, such as geographical distribution and organizational experience with specific tools.

New low-code and no-code application development platforms are a critical component. These platforms open up the ability to drive digital business transformation through custom software application development. Now, employees of all experience levels can create applications to fit their needs. This fosters a network of internal citizen developers, deriving insight and speeding digitalization by connecting new and legacy systems, automating processes and facilitating data analytics.

Open, modern ecosystem. As products become more complex, companies will need to create new connections both within and beyond their organization to leverage technology and experience from around the industry. This industrial network effect brings buyers, developers, designers, production houses, sub-contractors, suppliers and more together in a global ecosystem with hubs of innovation and collaboration. Tight integrations with this industrial network will be a key characteristic of thriving future companies.

Tomorrow, companies will need more than advanced engineering and IT solutions to thrive in the new industrial landscape. They will need to undertake organizational transformation, build a digital platform, and engage in peer-to-peer collaboration to drive success in the future. With the Xcelerator portfolio and a breadth of industrial experience, Siemens Digital Industries Software is unique in its ability to drive digital transformation and foster collaboration in all industries and companies, regardless of size. This is where today meets tomorrow. ■


BELSTAFF
ENGLAND 1924
INEOS | BRITANNIA

FLYING HIGH

CFD simulation accelerates development of America's Cup racing boat

By Patrick Farrell

> "The one commodity you cannot buy is time – it is in a way our most important currency – but running with Simcenter STAR-CCM+ in the cloud allows us to do just that"
>
> Max Starr, CFD Engineer, INEOS TEAM UK

A new paradigm in high-performance sailing
The America's Cup represents the forefront of technological development in the sport of sailing. Today, that means racing in boats that not only float in the water but are also capable of flying above it on foils, allowing them to reach previously unimaginable speeds. As well as being an exciting and demanding challenge for the sailors, it is also a challenge for the design teams, with the 36th America's Cup introducing a significant rule change with the introduction AC75 foiling monohull class.

Crucial insight
Computational fluid dynamics (CFD) simulation has played an important role in previous editions of the America's Cup, however the rules have changed substantially for the 2021 event. Under the AC75 class rule, physical testing in wind tunnels or towing tanks is not permitted. In addition, teams are limited to building only two race boats with a maximum of three rigs, four rudders and three pairs of foils, so there is very little room for error.

Max Starr, CFD engineer at INEOS TEAM UK, explains: "At the start of the campaign, the AC75 class was completely novel, so CFD was crucial for us to validate our design choices early on and be confident that the design would be physically feasible." As the team worked to navigate the vast design space, simulation was an invaluable tool to help them to understand how their designs would behave on the water in all situations.

"In CFD you can put the boat through many different scenarios which wouldn't be easy to do with a model test or a full-scale boat test, like measuring slamming loads if the boat comes off the foils suddenly and the hull is thrown into the water," Starr says.

In a competition where no physical testing can be done, data from CFD simulations becomes the lifeblood of the virtual design and testing

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>
> Max Starr, CFD Engineer, INEOS TEAM UK

process. By simulating many different boat states (unique configurations of the boat including hull position, sail trim and rudder and foil angles), CFD data is used to feed the team's Velocity Prediction Program (VPP) which predicts the boat speed under different conditions, crucially enabling designers to understand the relative merits of different designs. The VPP data is also fed into the team's motion platform simulator, meaning that the sailing team can 'sail' different designs around a race course. As well as providing valuable feedback to the design team, this is a vital tool for the sailors to learn this completely novel class of yacht and make the most of their time on the water once it is built.

Following a successful technical partnership with Siemens during its previous America's Cup campaign, INEOS TEAM UK selected Simcenter™ software to aid them in their quest to win the 36th America's Cup. Simcenter is part of the Xcelerator portfolio of solutions and services from Siemens Digital Industries Software.

INEOS TEAM UK uses Simcenter STAR-CCM+™ software for the company's CFD simulations and Simcenter 3D software for structural analysis. Recognizing the value of the digital twin in such a fast-paced design environment, the team also relies heavily on Siemens NX™ software for computer-aided design and Teamcenter® software for product lifecycle management to build a complete digital model that can be leveraged by the whole team – from designers to boatbuilders as well as by the sailors, throughout the boat's design and lifecycle.

Beating the clock

While the America's Cup rules do not place any limits on team budget, headcount or other resources, the design cycle is very short. "With only two physical boats, you have to go through as many design iterations as you possibly can in simulation," says Starr. "But to account for all the possible wind speeds, sail choices and boat states, we need to run thousands of simulations to understand how well each design will perform on the water," and that means that the CFD team has to work as efficiently as possible.

One way the team can save time is by building advanced automation into their CFD workflows. The Design Manager capability of Simcenter enables multiple designs to be executed automatically from a single template simulation. "The high degree of scriptability lets us automate repetitive tasks, and when combined with Design Manager it allows us to easily push through large batches of simulations at a time," explains Starr. The CFD team has also taken advantage of the deep automation via Java macros to set up part-specific workflows enabling design team members to submit designs to be run over a matrix of boat states automatically and without any CFD expertise. Democratizing simulation work in this way frees up time for the more experienced analysts to focus on more challenging simulations including cavitation and ventilation of the foils and rudder.

> "Pay-as-you-go licensing makes it a bit easier to budget for simulation, and it also means that you never have licenses going to waste."
>
> Max Starr, CFD Engineer, INEOS TEAM UK

To ensure competitiveness, the team must regularly re-evaluate its choice of toolsets. "Because time is our biggest enemy, we need to make sure we have the right tool for the job, and Simcenter has the ability to span all of our needs and requirements in a single package," Starr says. "It ticks a lot of boxes for us, and is a very strong tool technically."

Moving to the cloud

As the boat design progressed, INEOS TEAM UK ran more and more designs and boat states through CFD, using more complex models and quickly reaching the limits of the computing cluster at their base in Portsmouth, UK. "Sometimes, if you have to wait for results then that's okay, but in other

cases you really needed the answer yesterday," Starr explains. "And in those cases, the solution is to go somewhere where you can scale up."

"That was the biggest driver for us to move to the cloud – simply the fact that we could run on as many cores as we could afford," Starr continues. "The ability to then scale up becomes a massive advantage." The team also benefits from the flexibility of being able to tap into extra compute capacity during busy periods in the design cycle in a cost-efficient manner.

Having formed a partnership with Amazon Web Services (AWS), INEOS TEAM UK set to work to configure a virtual cluster in the cloud for running larger simulations and more extensive performance maps. By using the discounted spare computing capacity of Amazon EC2 Spot instances, the team was able to increase maximum simulation throughput by around 20 times, while reducing run time from months to days for large simulations.

Since INEOS TEAM UK was paying for compute resources on AWS by the hour, the power on demand (POD) license scheme for Simcenter was a great fit. "Pay-as-you-go licensing makes it a lot easier easier to budget for simulation, and it also means that you never have licenses going to waste," says Starr.

Better together

On the highly competitive battleground of the America's Cup, it is especially important to be getting the most out of simulation and high-performance computing (HPC) resources. The team's partnerships are crucial to maintaining that competitive edge. "having my Siemens support engineer guide me to new features that they know will be relevant and helpful, and advise when something isn't going to be a good use of my time has been invaluable," Starr explains. "Support engineers have also helped us to get a deeper understanding of some of the models with help from the developers, which has been fantastic, making sure we are getting the most out of the tool."

The team was also able to rely on HPC experts at AWS to assist with the selection and configuration of virtual cluster components to create an optimal setup for CFD simulation on the AWS platform. "Having access to solution architects for advice on fine-tuning has been invaluable to us," Starr says. "They've been there whenever we had questions, and having that help readily available has allowed us to save a lot of time in the setup process."

Buying back time

In October 2020, INEOS TEAM UK launched their second race boat, Britannia, in Auckland, New Zealand – the culmination of three years of intensive design, analysis and training in the simulator and on the water. But the CFD simulation work never stops. "Even though we are now so close to the Cup, I'm still developing the analysis further, as we are learning things about the boat all the time. CFD is very helpful to develop that understanding, and to prove or disprove theories about the boat's behavior on the water."

When asked if simulation in the cloud is likely to become a long-term strategy for the team, Starr summarizes: "As time goes by, the case for running simulations in the cloud gets stronger and stronger." What are the downsides? "There will always be pitfalls, much like there will always be for on-premise clusters. Sometimes it just takes a change of mindset – for example, plugging additional storage into an on-premise cluster is cheap to do, but on the cloud it may be more cost-effective to simply re-run calculations if we need access to those files later on."

America's Cup cycles are very short but intensive periods of engineering work. "The one commodity you cannot buy is time – it is in a way our most important currency – but running with Simcenter in the cloud allows us to do just that," Starr says, summarizing the importance of making the most of the technology available. By gaining efficiencies in its CFD workflow and scaling up on the AWS cloud, the team is able to, in effect, gain back more time to spend making better-informed design decisions and discovering innovative solutions. ■

Customer's primary business

INEOS TEAM UK is a commercial sporting team led by four-time Olympic gold medalist and 34th America's Cup winner, Sir Ben Ainslie. The team's long-term aim is to bring the prestigious America's Cup back to Britain, where the first challenge was held in 1851 off the Isle of Wight.

Customer location

Portsmouth
England
https://ineosteamuk.com

> "Having the Siemens support engineer guide me to new features that they know will be relevant and helpful and advise when something isn't going to be a good use of my time has been invaluable."
>
> Max Starr, CFD Engineer, INEOS TEAM UK

The Vendée Globe with a digital twist

Around the world in 80 days

The Vendée Globe is one of the toughest endurance sailing races literally around the planet. Every 4 years, famous and soon-to-be-famous sailors single-handedly sail IMOCA 60 class monohull yachts around the world. The current record is held by Armel Le Cléac'h. He won the 2017 edition with a stellar 74-day around the world nautical sprint. This year the finish wasn't a record-breaker, but rather a tale of heroic proportions. On January 27th, 2021 at 8:30 at night, Charlie Dalin became the first to cross the finish line in Les Sables d'Olonne, France. He clocked in an impressive 80-day jaunt around the world.

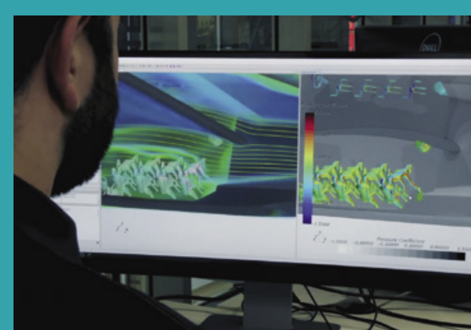
Dalin wouldn't be crowned the winner, though. Turn the clock back to the early race days on November 30th, 2020, about 840 nautical miles west of Cape Town, South Africa. Experienced St. Malo skipper, Kevin Escoffier, witnessed his high-flyer, the PRB, literally split into two within minutes. After a nerve-racking eleven-plus hours in his life raft, bobbing amongst high winds and huge swells, he was heroically rescued by Jean Le Cam, a Vendée Globe icon.

Le Cam and two other sailors who were rerouted for the rescue received time credit. In the end, Yannick Bestaven was declared the winner even though he finished third. The characteristic Le Cam, after time credit, was ranked fourth.

Like America's Cup racing yachts, Vendée Globe monohulls are high-tech, carbon-fiber speed machines. Designers and naval architects have to follow IMOCA class restrictions when it comes to size (60 feet or 18.28 m), the gauge and the keel. That being said, there is room for design differentiation: a choice of two masts, limited sailing ballasts and foils. As expected, the big news this year was the foils: those "little feet" or "fins" that lift the boat off the water, so that it flies at top speeds. Compared to 2016, where there were only 6 boats with foils, this race featured 19 boats equipped with various foils.

Even better than the real thing

To the delight of many landlocked sailors this year, there was also the Virtual Vendée Globe, a hybrid sailing race simulator that dropped virtual racers right into the action with the real sailors. With the pandemic, the Virtual Vendee Globe took off like wild fire -- over one million



people raced along. Virtual racers could build and modify a digital twin of an IMOCA 60 sailboat, adding foils and ballasts just like a naval architect. Virtual Vendée Globe sailors raced using real-time data (or as close as possible in some areas of the world). This included weather conditions, winds, currents, waves and positions of ice, land and other obstacles including real and virtual competitors. Like the solo navigators in the real thing, virtual sailors had to master the control of foils and sails, read and predict the weather conditions, and use their navigational moxie twenty-four hours a day to get around the globe in one virtual piece.

More about the Vendée Globe and digitals twins

The fatigue challenge of additive manufacturing:

A SIMULATION-BASED APPROACH

Additive Manufacturing (AM), also known as 3D-printing, allows the production of complex components layer by layer, using only the material you need. This is a contrary method to subtractive manufacturing, for which unneeded material is cut away from larger material volumes. AM has proven to be advantageous through its large design freedom, less material waste and shorter lead time after designing a 3D structure, since it can directly be 3D-printed. It works for metals and polymers, which use a range of processes. In this article, we will focus on addressing the fatigue challenge of additive manufacturing of metal alloys.

The metal AM processes can lead to local artifacts in the printed structure like variable surface roughness, porosities and microstructure. The control of the occurrence and the cause for these local artifacts is not yet well understood and depends on the type of process. Additionally, there is a lack of CAE tools with predictive quality of complex dynamic performance that can account for the effect of such local artifacts induced by the AM process; therefore, industry (automotive, aerospace, machinery, …) must often rely on expensive prototype tests, for which the results become available very late in the product development process.

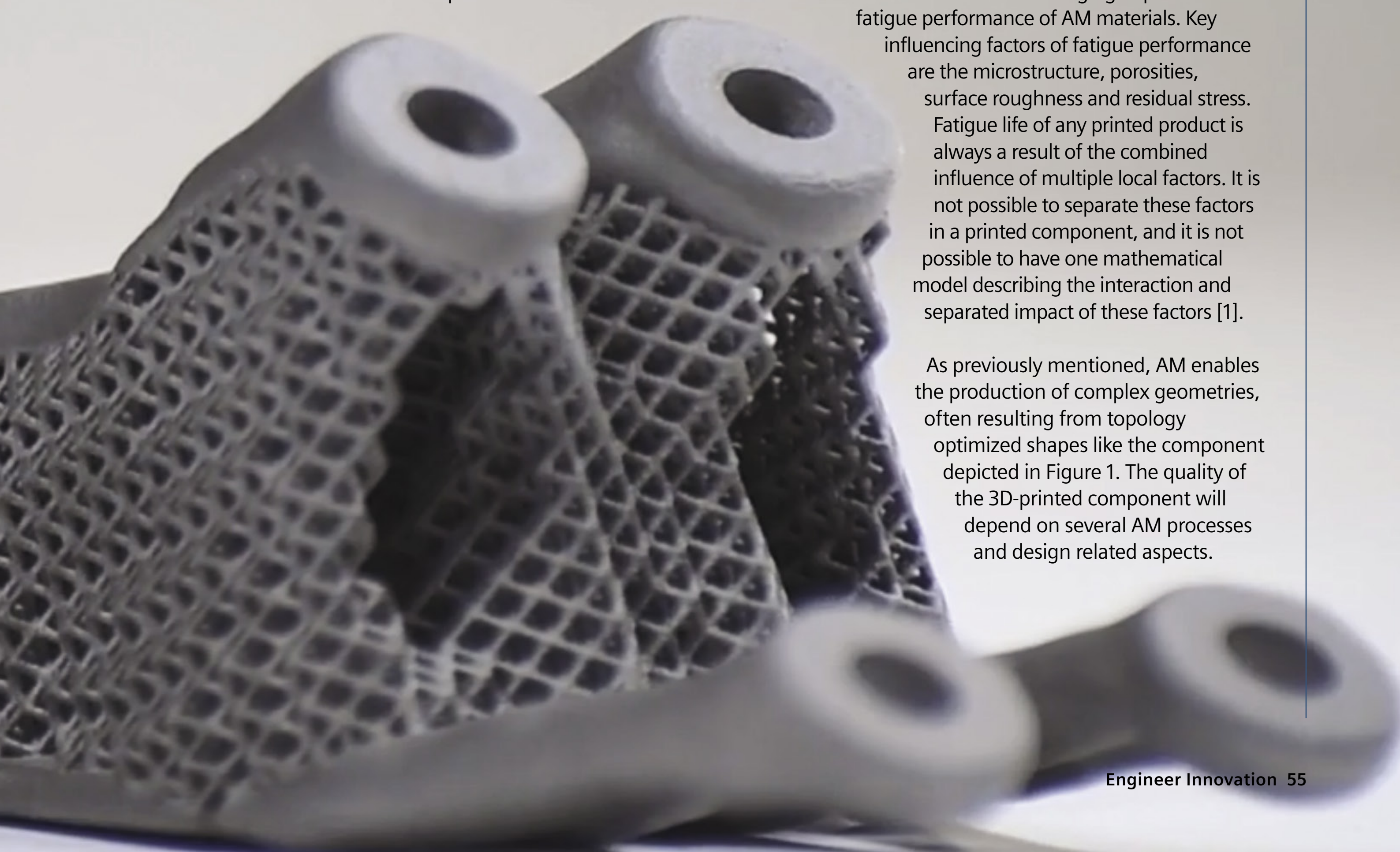
Siemens Digital Industries Software is delivering simulation-based solutions to improve the understanding of the material structure, as well as to predict and optimize the performance of the printed product. This becomes increasingly important, since AM shifts from conceptual design studies to the printing of functional components, for which the performance (durability, structural integrity, …) is crucial. This article looks at the durability performance attribute. You can also reference our automotive durability website.

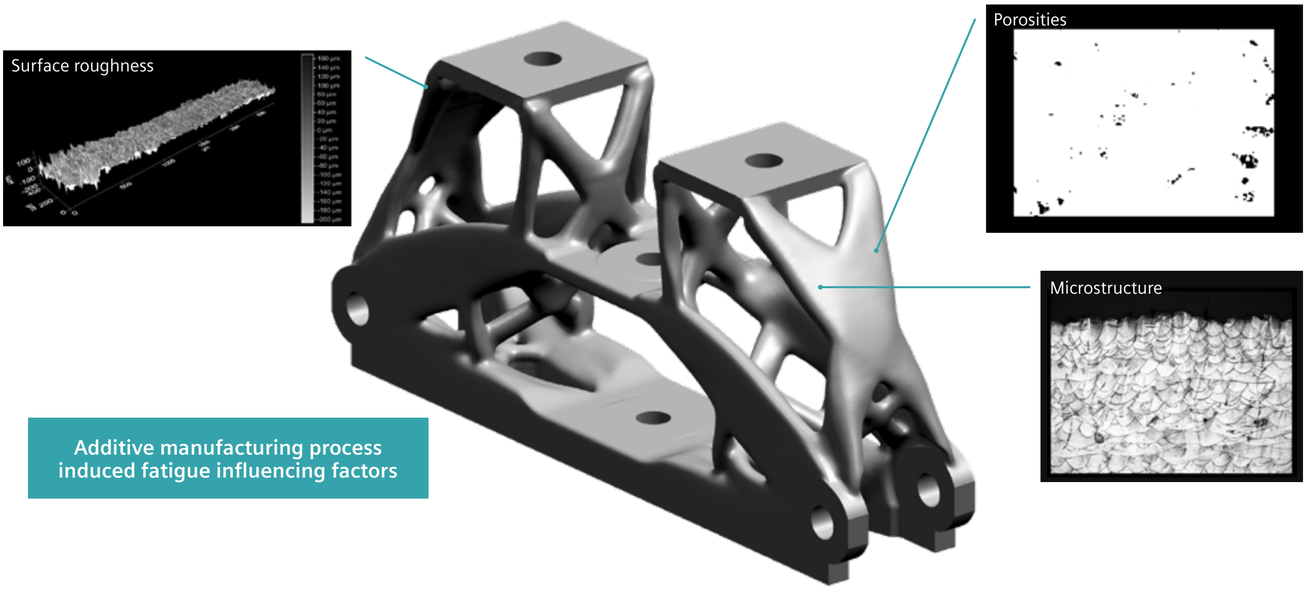
The fatigue challenge of additive manufacturing

Several AM process factors have an influence on the induced fatigue performance. The AM process is less controlled than the conventional manufacturing process and leads to process-induced fatigue-influencing artifacts. These fatigue-influencing artifacts are highly dependent on the geometry, and therefore exhibit a local nature.

All of this makes it challenging to predict the fatigue performance of AM materials. Key influencing factors of fatigue performance are the microstructure, porosities, surface roughness and residual stress. Fatigue life of any printed product is always a result of the combined influence of multiple local factors. It is not possible to separate these factors in a printed component, and it is not possible to have one mathematical model describing the interaction and separated impact of these factors [1].

As previously mentioned, AM enables the production of complex geometries, often resulting from topology optimized shapes like the component depicted in Figure 1. The quality of the 3D-printed component will depend on several AM processes and design related aspects.





Surface roughness of a 3D-printed component

For example, the build direction will implicitly impact the orientation of the different surfaces of the printed geometry. Since the surface roughness of a 3D-printed component also depends on the overhang angle (the angle between the build plate plane (x-y) and the overhanging surface tangent in the x-z (or y-z) plane), a different orientation of the component in the build tray will lead to a different distribution of the surface roughness. One may want to optimize the use of build space and stack several instances of the same component with different orientations in the build to produce as many as possible components in one shot.

Having oriented several components in a different manner will lead to components with different distribution of surface roughness, porosity distribution and local microstructure.

3D printing of safety-critical, load-bearing components

Since surface roughness is a major influencing factor for fatigue, the different components will exhibit different fatigue behavior, even though they have the same geometry and they have been produced with the same machine and from the same material.

Furthermore, the residual stress in the part during the additive manufacturing process and the different heat treatments applied after the manufacturing process also influence the fatigue performance of the component.

To enable the 3D printing of safety-critical, load-bearing components, it is vital to be able to predict the effect of additive manufactured induced local artifacts on the fatigue life of the produced part. To achieve this, predicting the local artifacts is only one piece of the puzzle. One must also have the means to directly assess the impact of AM-induced local artifacts on the fatigue behavior of the 3D-printed material. Furthermore, a durability solver is needed that can handle local fatigue-influencing artifacts in an efficient manner. The following paragraphs will detail these aspects.

Using machine learning to accurately predict the fatigue performance of additive manufacture structures

The fatigue performance of the 3D-printed material depends on several aspects such as the manufacturing process and material used, geometry and loading conditions, microstructure, residual stress, surface roughness, porosities and post treatments (surface and volume treatments). When characterizing the fatigue performance of a material, typically the sample geometry, manufacturing process and loading related aspects are all fixed. The effects of the remaining parameters are then assessed. However, in the case of AM, many of the conditions are tightly linked to each other. For example, the build orientation will implicitly impact the surface roughness of the sample and the microstructure (since the layer-by-layer deposition will favor certain growth paths of the metal grains).

As mentioned in the previous paragraph, in a complex 3D-printed component, many combinations of these factors are present, and one should have data on all encountered combinations of fatigue-influencing factors, in order to assess the fatigue performance accurately. This means that characterizing the fatigue performance of a 3D-printed material inevitably leads to a huge test campaign to cover as many combinations of factors as possible. It also leads to a significant challenge to derive models which can fit and enable the assessment of un-tested combinations.

New approach to assess the fatigue performance
Siemens Digital Industries Software (DI SW) has developed a new approach to assess the fatigue performance of 3D-printed components by leveraging on the power of machine learning [2][3].

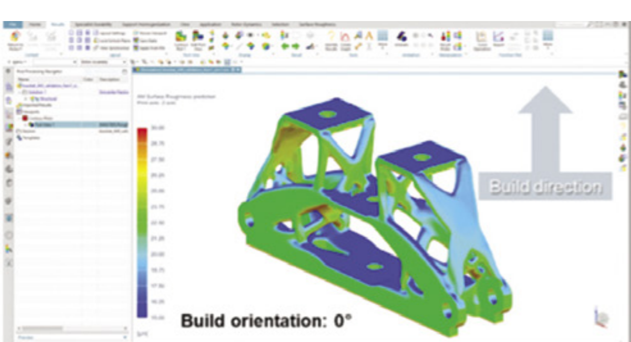
Going back to the example mentioned above, to be able to accurately predict the fatigue performance of this 3D-printed part, a material model is needed that can predict the effect the AM-induced local artifacts have on the fatigue property of the material. A machine learning (ML) based material model has been developed that relies on a limited set of training data. This ML model can fit the multi-attribute space of SN curves (Wöhler curves) experimentally determined for a set of different conditions (orientation in the build, different surface treatments, heat treatments, etc.) and can predict the SN curve for untested combinations of conditions. The ML material model has been integrated as an AM enhancement module in our open durability solver environment to account for the effect of the AM-induced local fatigue-influencing factors [4].

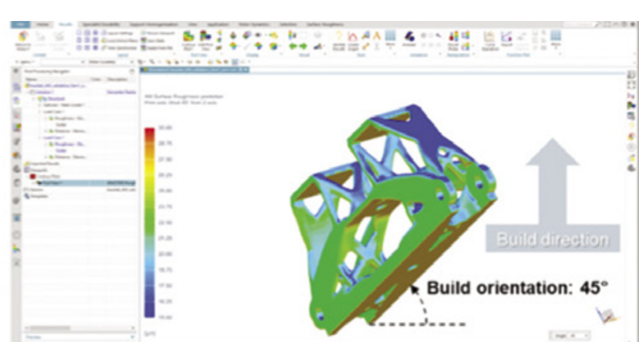
Experimental data needed for training the ML algorithm has been produced using the experimental setup and test procedure as described in source [2]. This includes specimens printed by 3D Systems according to a fixed set of processing parameters, for which the fatigue testing was performed by the Manufacturing Processes and Systems (MAPS) department of KU Leuven, using an Instron ElectroPuls E10000 while considering a variety of surface and heat treatments [5]. Bearing in mind the cost of fatigue testing on additively manufactured components, it is unrealistic to test all possible parameter combinations.

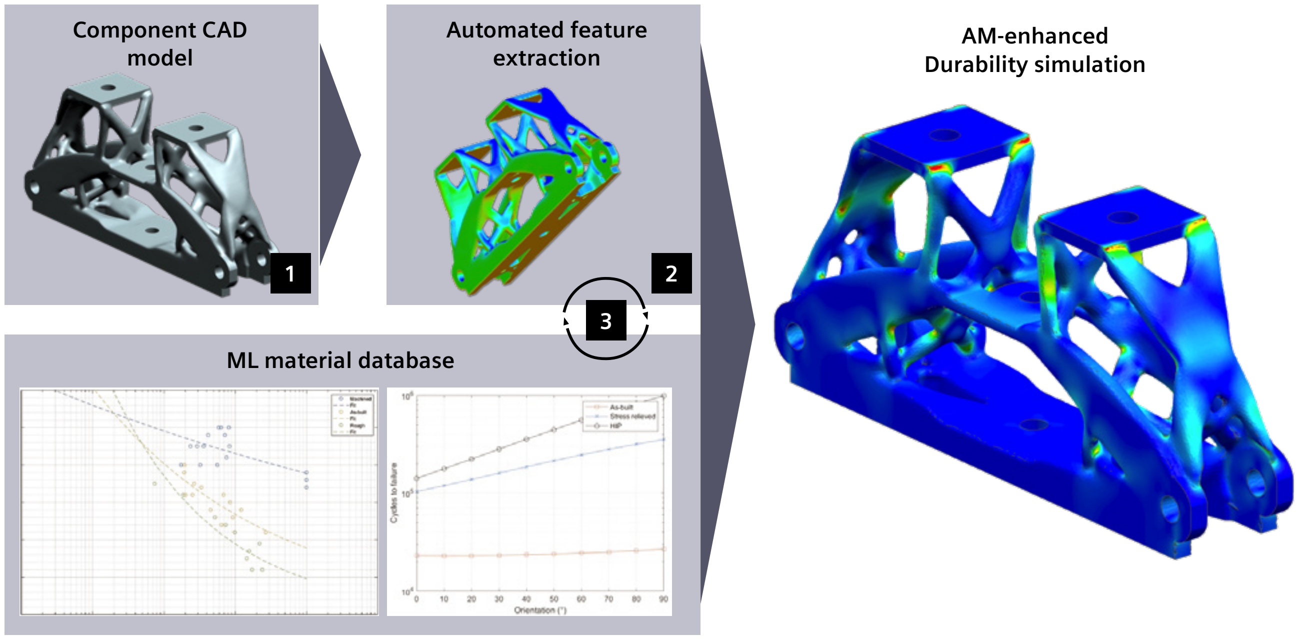
Gaussian process regression approach
Also, coupon level testing may not allow the replication of all possible conditions, that, for example, could be encountered in thin-walled sections or near internal cavities. Therefore, a methodology is required that is capable of extrapolating fatigue properties for a multitude of artifacts based on a minimal set of test results. Machine Learning (ML) is employed for that purpose, using a so-called Gaussian Process Regression. The benefit of this approach over more classical interpolation/extrapolation approaches is that it makes minimal assumptions on allowable mathematical models to approximate the test data. This is important, given the complex interactions between different parameters and the limited data available for calibration.

The ML approach was implemented, extending the existing durability solver in Simcenter 3D Specialist Durability. The inputs that influence the fatigue properties can be defined per region or per element. In addition, they can be entered by the user, via a file or with an automatic tool that assigns fatigue-relevant parameters to each element.

Workflow
The schematic representation of the workflow efficiently links together the AM-induced fatigue-influencing factors with the effect they have on the local fatigue property of the 3D-printed material to enable an AM-enhanced durability solution. On the left-hand side, the ML approach is depicted, which takes the predicted local artifacts as inputs and returns the estimated corresponding local SN curves to the durability solver. On the right-hand side, the CAD model (1) is illustrated, which is required for the FE analysis (for which







the results are not shown) and the automated feature extraction tool (2) that will predict the local AM-induced fatigue-influencing factors needed as input for the ML model (3). Subsequently, the AM-enhanced durability simulation can be performed. The user-defined loads are not included in the illustration.

The workflow presented above enables the user to, for example, assess the impact that orientation of the component in the build tray has on the fatigue performance. In the above described case with several instances of the same component with different orientations in the build tray, using the approach shown above, the user can predict the local surface roughness for a selected build orientation of the component. The surface roughness is available per element in the model, which is passed to the ML material model along with other relevant parameters such as the heat treatment of the selected material.

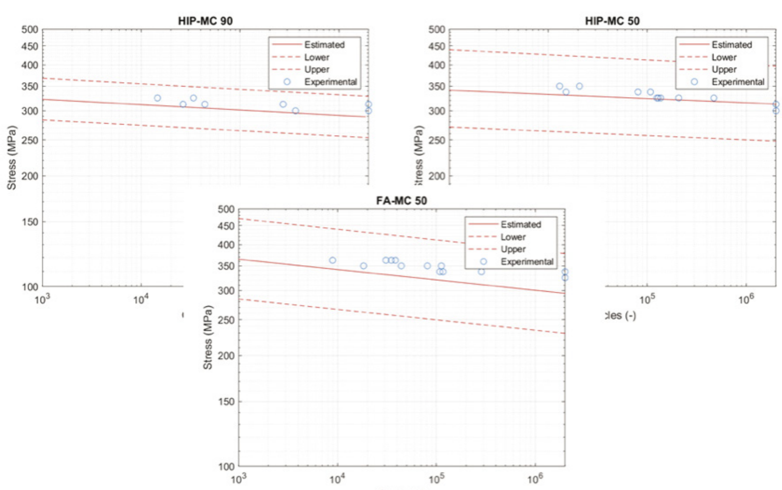
The machine learning material model will be used to derive the local SN curves at each surface element of the structural mesh that corresponds with the CAD geometry model according to the local fatigue-influencing factors. To calculate the durability performance of the entire printed component, a durability calculation is then conducted using the AM-enhanced Simcenter 3D Specialist Durability solution. This performs the damage accumulation for the entire structure according to the local conditions, including two new and highly important features: the efficient handling of local material properties, and the mapping of local SN curves on the model. This virtual approach avoids potentially hundreds, if not thousands of tests, by using machine learning together with a limited test set, resulting in a model that can interpolate/extrapolate for untested conditions.

Results and outlook

Applying machine learning to more accurately model fatigue life performance of additive manufactured components has several benefits. First, no inferences are needed on how the combination of different artifacts affect fatigue life. Furthermore, the approach is flexible, accounts for local phenomena, requires limited testing, enables accurate extrapolation and enables the study of the impact of different factors in an uncoupled manner (which is often impossible to achieve based on experimental data).

The figure opposite shows the results for a blind test to validate the model. The ML algorithm has been trained with a subset of experimentally obtained SN curves corresponding to different combinations of factors. Some combinations have been withheld from the training set, more specifically the cases of 90 degree oriented samples that have been machined and submitted to hot isostatic pressing treatment (HIP) and the cases of machined, 50 degree oriented fully annealed (FA) and HIP-ed samples. The red solid lines represent the predicted SN curves for the aforementioned unseen cases, also giving a corresponding confidence interval for them (dashed lines). The actual test results have been then plotted on top of the predictions, shown with blue circles in the picture. This shows the good correlation of the predictions with the actual measurements.

The AM-enhanced durability simulation in Simcenter 3D Specialist Durability, combines the best of both worlds of experimental data and physics-based modelling. It is also possible to purely rely on experimental and/or simulation data. A customized durability analysis can be performed, leveraging Open Solver technology (of the Simcenter 3D Specialist Durability Solver) to calculate the durability performance of a structure, accounting for the key fatigue-influencing factors: the surface roughness, as shown in this blogpost, and other localized phenomena (void-rich areas, residual stress, etc.). One ongoing work is the prediction of the fatigue performance/SN curves relying on multi-scale modelling, based on a method developed by Ghent University [6].



This article puts a spotlight on the new solution for fatigue Challenge of Additive Manufacturing parts. In a broader view, Siemens Digital Industries Software is working on predictive simulation capability for AM materials across different performance attributes (strength, stiffness, fatigue life, …), aiming to bring in place a predictive CAE toolchain for AM. You can find more information at this link. New simulation methodologies to predict the fatigue performance of additive manufacturing materials are developed in the context of the R&D project FATAM. You can read more about FATAM in our previous blogpost.

Acknowledgements
The authors gratefully acknowledge the IBO project FATAM ("Fatigue of Additive Manufactured components – Relating AM process conditions to long-term dynamic performance of metallic AM parts", 2017-2020), which fits in the MacroModelMat (M3) research program, coordinated by Siemens (Siemens Digital Industries Software, Belgium) and funded by SIM (Strategic Initiative Materials in Flanders, see here) and VLAIO (Flemish government agency Flanders Innovation & Entrepreneurship, see here). ■

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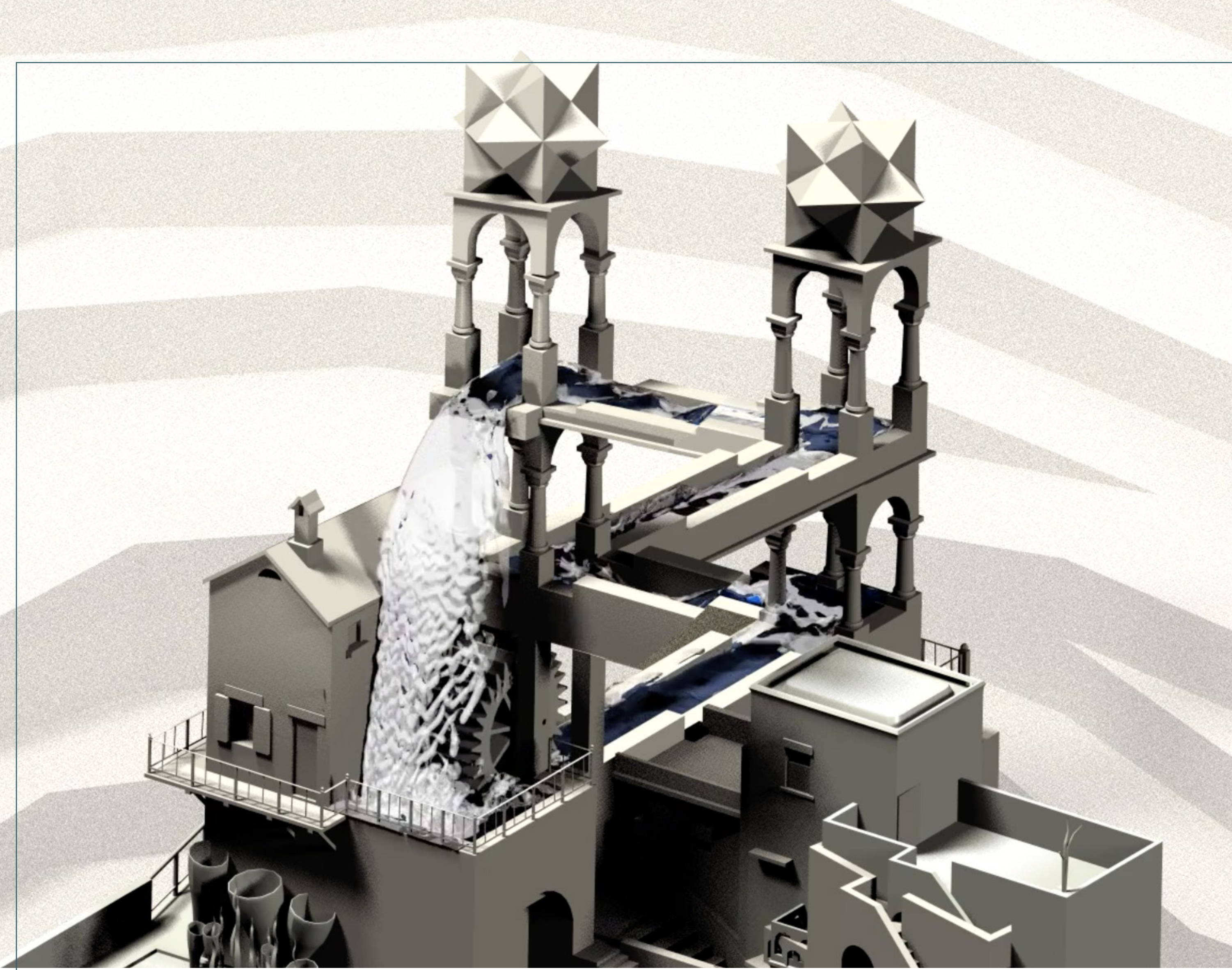


10 SECRETS TO A STUNNINGLY FUN CFD SIMULATION

By Simon Fischer

Another Friday afternoon, another chance for a fun CFD simulation! Those tiny little projects we do out of pure curiosity. The ones we sometimes do just because we can. The ones we do because we all like those five minutes of fame when our engineering mates give us their kudos. But most importantly, the ones we do because we love fluid mechanics.

We all know it's true.
But, all that motivation aside, what sets the brilliant, outstanding, engaging fun CFD simulation apart from the vast majority of attempts. What is the secret of those masterpieces of fun CFD simulations that inspire the masses?

The honest answer is "I have no idea". But I have some educated guesses.

Here are my top-ten tips to make your fun CFD simulation project inspire the masses

1

Do it for the sake of itself

Whatever you choose to simulate, in first place do it because you want to do it. Because you really want to see that thing running and get some engineering insights.

One fun CFD simulation project I did just because I always wanted to is E.C. Escher's waterfall. Funnily it quite nicely represents the concept of doing something just for the sake of itself.

Do fun CFD simulation projects for the sake of themselves.

2

Do something creative

After Elon Musk lifted the secret, how many times have you seen the aerodynamics simulation of the Tesla cybertruck? Frankly, after the fifth one done quick and dirty in two days, I was so bored by it that I could barely stand it.

CFD can be used for so many things. With the right tool CFD is capable of far more than single phase flow of a car (no doubt even the latter can have a great appeal, see #6). When you want to do something that catches peoples' interest, be creative in your choices. Take this great example by my former colleague Nipun:

Cheers! Applied fluid dynamics simulation. Don't drink too fast!

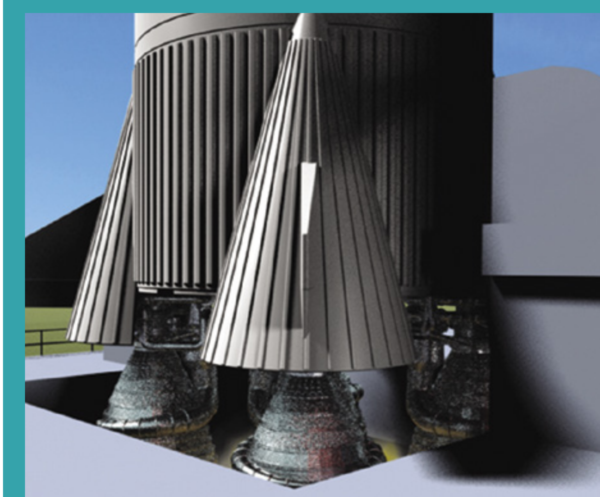
3

Take care of the details

As simulation engineers it has taken us decades to build up credibility of CFD in serious engineering processes. Thousands of CFD engineers before you have spend millions of hours to achieve the standing CFD today has. However meanwhile, thanks to commercial tools, with all their automation, ease-of-use, stability, performance and postprocessing capabilities, CFD simulation has become accessible to many. Gone are the times when only the hardcore numericists could handle the codes.

That brings us to a serious word of caution for any fun CFD simulation: even if it's just for fun, even if the programs are easily to handle, the devil is ALWAYS in the details. And only if you are willing to take care of the details, will you make a high quality CFD simulation. Mesh matters, boundary conditions matter, model choices matter! A high quality CFD simulation requires research. Guaranteed, your fellow engineers will distinguish the quality ones from the quick and dirty ones.

Don't destroy the credibility of CFD, now no longer being flagged colorful fluid dynamics or color for directors! It's your responsibility with each and every CFD simulation, and fun CFD simulations are no different.



4

Be prepared to invest more than you thought

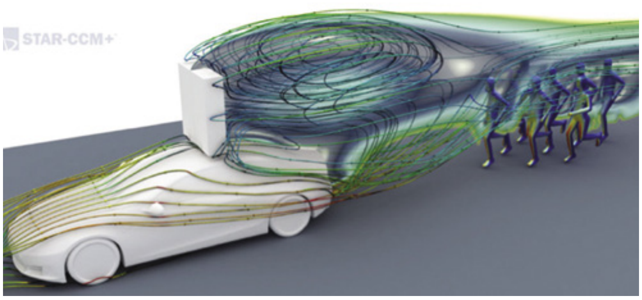
If you take #3 seriously, I can tell you you will always run into #4. The nature of #2 implies that you will probably explore something, you have not done before, that implies you will run into traps you did not see coming, you need to find solutions to problems you did not expect, you will understand the problem requires way more complex physics and a way finer mesh and time step than you would have ever thought.

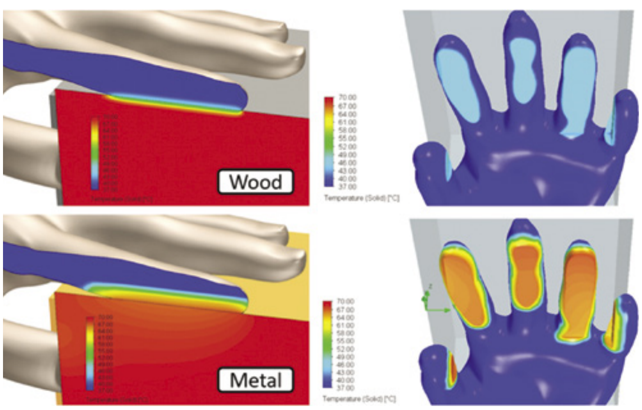
In short, you will engineer innovation.

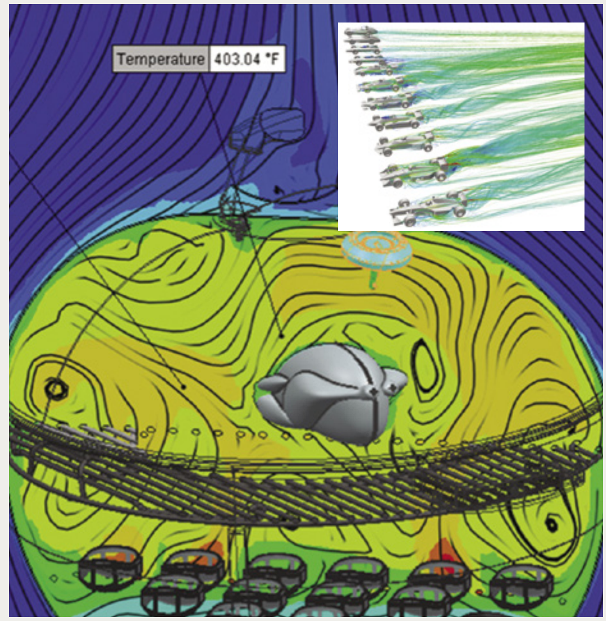
5

Raise curiosity and then deliver insight

This is the key of every well-told story. And well made fun CFD simulations are nothing but a story told in the format of computer aided engineering. At the core of storytelling is the idea of bonding the audience to the story, create suspense to keep the bonding, raise the question “How is this going to turn out?” and then at the moment of maximum tension, at the ultimate crisis choice of the hero, deliver an insight the audience has not had before.







6

Make the simulation relatable to the masses

Engineers are one bunch, “common people” are a huge audience. If you really want to help with the democratization of CFD the latter should be your target just like the former. If you are able to make that stretch with your simulation, success of your fun CFD simulation project will follow. Now I understand this is not an easy one, serving the longtime CFD engineer, who is into turbulence model details and the dude from next door at the same time is pretty tricky. But after all we are all human!

7

Make postprocessing a visual firework

I love that one. Because it is always an invitation to the old school CFD folks to jump onto the good old “color for directors/colorful fluid dynamics” train!

Here’s my response to them all the time, inspired by one of my personal legends of science, Richard Feynman:

Feynman: “I have a friend who’s an artist [..]. He’ll hold up a flower and say ‘I as an artist can see how beautiful this is but you as a scientist take this all apart and it becomes a dull thing,’ Feynman: ‘I can appreciate the beauty of a flower. At the same time [..] I could imagine the cells in there, the complicated actions inside, which also have a beauty. [..] there’s also beauty at smaller dimensions [..] The fact that the colors in the flower evolved in order to attract insects to pollinate […] adds a question: does this aesthetic sense also exist in the lower forms? Why is it aesthetic?

All kinds of interesting questions which the science knowledge only adds to the excitement, the mystery and the awe of a flower. It only adds. I don’t understand how it subtracts. ”

8

Make sure your fun CFD simulation is relevant

Christmas, soccer world championships, Halloween, St. Patricks day, Superbowl,... it's the 101 of marketers to have those on the schedule and then, right on spot, have some fun CFD simulation go out the door (see my project for the 50th Apollo 11 anniversary).

If done right and delivered on time, #8 will be a massive – if not the – booster to make your fun CFD simulation travel the world: two great examples stem from my colleague Prashanth who participated in the FIFA World Cup AND the Superbowl. The simulations were done with care, insightful, relevant to a huge audience and... delivered spot on. Results on social media followed.

More than just fun: CFD delivers insight into CR7's legendary free-kick

Superbowl!

9

Take your fun CFD simulation project seriously

They are called fun CFD simulation projects, but the secret to make something that matters to the world is, tackle it as seriously from a technical perspective as any real engineering challenge! Follow tips 1 to 10 with care and chances are high you will succeed.

Why so serious? When CFD simulation can be so much fun.

10

Choose a fun-to-work-with tool

And even though #9 sounds like hard work (because it is), my #10 is the ultimate key to success: A fun CFD simulation project has to be conducted with joy. And while we probably all love doing CFD, there is one thing that will further raise the joy – and that's using the right toolset: ■

Read Simon's full blog here

The next-generation aircraft

Designed with Simcenter comprehensive digital twins

By Jennifer Schlegel

A short 50 or 60 years ago, air travel was for an exclusive club of jetsetters – international high flyers, diplomats, time-is-money business executives, movie stars and the rich. Today, flying has become everyday. No longer for the happy few, the airline industry fulfills the crucial role of connecting people, goods and businesses.

Although the pandemic has thrown a wrench in the curve, so to speak, passenger travel volume should continue to grow steadily. Prior to the pandemic, experts predicted that the number of passengers traveling by air could be expected to double between 2017 and 2032. This may continue to slow down the next year or so, but it is likely that the current major dip will just be a temporary glitch. Air travel is here to stay. It has become a globalization cornerstone for more than 50 years and it will continue to play this role in the future.

A better flying machine?

Everyone knows that the aviation industry needs to change. We've come to a point where there is a scientific consensus that if no action is taken promptly, the global warming damage will be irreparable. The problem of global warming has led to international agreements on man-made CO_2 emissions.

This has resulted in legislation concerning all transportation industries. Combined, transportation is responsible for about 15 percent of the total greenhouse gas emissions worldwide. And even though aviation's share in this is relatively small (around 2 percent of the total, or 12 percent of transportation), the industry suffers from a negative perception.

Radical new technologies will be required to reach the targeted reduction of 50 percent by 2050. In addition to biofuels and hydrogen fuel types, alternative airframe configurations and structural and material technologies, such as morphing wing technology, and electric and hybrid-electric aircraft propulsion systems show potential. Next to these environmental concerns, it's important to mention the aviation industry has an additional incentive to improve energy efficiency and decrease its dependency on fossil fuels, especially for the commercial aircraft sector.

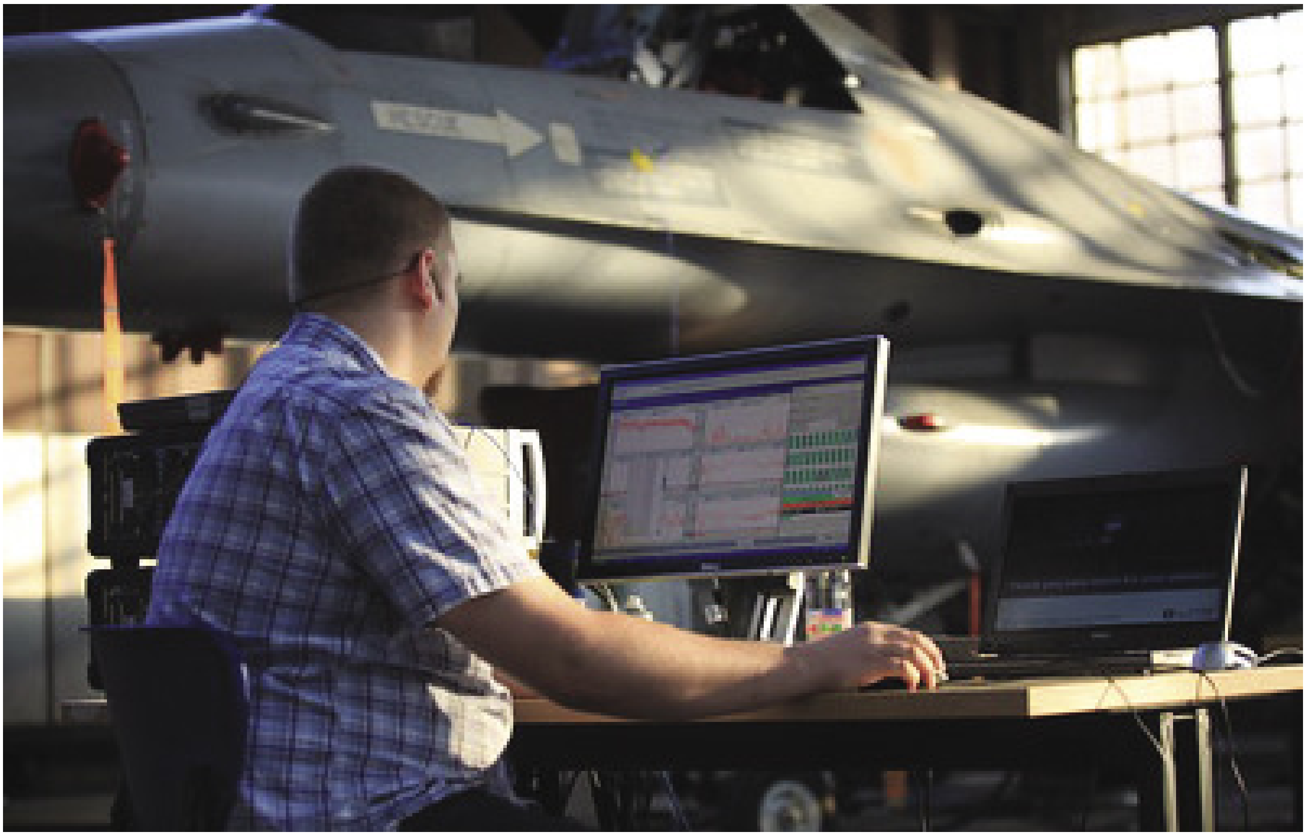
If you take the total cost of ownership of a typical Boeing model 737-800, over 50 percent is directly related to fuel. For aircraft operators, this is a huge financial burden and even a risk because fossil fuel prices can be volatile.

In addition to fuel consumption and emissions, noise and local air quality are part of the overall environmental impact of aviation. Electrification presents numerous advantages here. Electrical drives could reduce the rotational speed of propellers and fans, while maintaining propulsion power. Further, they could enable the application of distributed propulsion. This will allow engineers to experiment with the aircraft architecture and design fans that are shielded by the aircraft structure to avoid direct noise propagation toward the environment.

Finally, one cannot talk about aviation without a word about safety, still the number one design criterion in the industry. Even though flying is becoming increasingly safer, it can be better. Even the smallest incident can lead to a perception problem that affects the entire sector, especially today, with news spreading around the world at the speed of light.

Complex, electric, flying super-computers

According to the IATA Aircraft Technology Roadmap to 2050, we are currently in a period of evolutionary developments regarding aircraft as we know them: classic tube-and-wing-and-jet-engine configurations. Although experts predict that we could reach a new, more radical innovation wave by 2035, providing the economic framework is favorable. Today, we are still taking baby steps when it comes to aircraft electrification and design evolution, including innovative structural and material technologies. To be fair, there is still a lot of work to do before we can speak of a real industry transformation.



Besides radical changes in design, materials and propulsion, the next-generation aircraft will contain lots of automated systems that are man-made and therefore not immune to malfunction. Altogether, this can lead to a totally new dimension of complexity in the aircraft itself and the overall development process. Specifically, electrification in aircraft will lead to an enormous number of new systems, which often combine diverse technologies. That will undoubtedly challenge the aircraft integration problem even more, especially when working with various stakeholders in a global organization.

Designing the next-generation of electrified aircraft successfully will require innovative technologies and new development processes. A model-based engineering approach can help aircraft manufacturers and their suppliers deploy a comprehensive digital twin for performance engineering. This methodology facilitates behavioral verification and validation by using realistic simulation to more effectively tackle design complexities by removing silos between disciplines and applications, resulting in shorter development time and reduced risk. Together with the deployment of a digital thread, this leads to program execution excellence.

Work in progress

All this being said, there is already quite a lot of positive progress in regards to electrification and the next generation of aircraft. Power density, development process adjustments and digital twin adaptation are well underway.

Power density

Every kilogram counts on an aircraft. Today's industrial electrical motors typically reach power densities of about 1 kilowatt per kilogram (kW/kg). That is simply insufficient. To successfully implement electric propulsion units (EPUs), this value would need to increase to at least 10 to 15 kW/kg. Apart from the motor, the same holds for subsystems, such as inverters.

Too many silos

A major issue in current aircraft development is that scale and complexity have led to programs being split up between various partners around the world. The division of work mostly happens as if an aircraft is an assembly of separable systems that can be integrated at a later stage. There is obviously a constant flow of communication between the various stakeholders, but often this is based on dead digital data, or other words flat documents that are shared throughout the organization. A good example could be the cooling budgets between electrical and ECS departments, which are usually described as flat numbers. Other examples can be found in thermal management and electrical system integration, amongst others.

Unfortunately, document-based engineering isn't effective enough to get the results needed for successful electric propulsion systems. The power density this requires will generate thermal concerns, electrical system integration challenges and intensify the interaction between various physics. To handle these complexities, aircraft integrators will need to upgrade their development processes. This means changing from a siloed, static, document-based engineering approach to a dynamic model based engineering approach. The portfolio of Simcenter™ solutions offers a comprehensive set of scalable and collaborative tools for dynamic model-based performance engineering, from concept design to certification, all on one platform and traceable. This will enable consistent and accurate behavioral verification and validation throughout the design cycle.

A wide range of in-depth applications

The technological challenges in future aircraft development for aspects such as power density and thermal management will not be minor. To be a successful innovation partner, one cannot be a master of all disciplines. Quite the contrary, especially when the focus is on removing silos and creating comprehensive solutions, it is crucial to make sure state-of-the-art tools are available for every individual discipline.

To help this process along, Siemens has been investing in technology companies and their associated tools that have all the necessary pre- and postprocessing capabilities as well as robust and high-performance solvers, for a wide range of applications, and bundled them in the Simcenter platform to accelerate performance-driven engineering based on comprehensive simulation and testing.

Testing and the digital twin

During the earlier development stages, the value of the comprehensive digital twin approach is to a large extent defined by the degree of modeling realism that can be achieved. During this time, real measured data is vital to endorse modeling accuracy. Realistic simulation demands continuous testing work on components, materials, boundary conditions and more. This goes way beyond measuring accurate data for standard structural correlation analysis and model updating. Testing allows aviation engineers to explore uncharted design territories and build knowledge about new materials and all the additional parameters that come with mechatronic components. This often involves multiple physics and requires innovative testing methodologies.

At the end of the development cycle, especially during certification, the situation is different, as typically testing is then at the center of events. At this time, the pressure is on. Prototypes and testing infrastructure are costly to use, and late discovery of defects can directly impact the aircraft's market entry. And with increasing aircraft complexity, including after-delivery updates, the share of work in this area can be expected to grow due to many more product variations, parameters, operating points, etc. At this stage, simulation can be a great addition and help to classic testing processes.

Indeed, virtual testing takes an increasingly prominent place in the certification process. But there are limits regarding airworthiness certificates. Authorities will always require evidence from integrators to prove modeling assumptions in simulations were correct. Therefore, Siemens strongly believes that it is best to investigate approaches where physical and virtual testing go hand-in-hand, and where cheaper and better verification and certification processes can be achieved. For example, simulation could help define the best test configuration. There are often huge opportunities to simplify physical test benches and complement physical testing aspects with simulated elements. This can lead to cheaper test setups or reduced testing risks.

In this sense, Simcenter is quite a unique environment as it is the only portfolio on the market that directly connects physical testing with system simulation, 3D computer-aided engineering (CAE) and 3D computational fluid dynamics (CFD). The Simcenter solutions portfolio, which is part of Xcelerator, offers aviation engineers a comprehensive set of scalable and collaborative tools for model-based performance engineering during aircraft development, from concept design to certification, all traceable and on one platform. ■

Learn more here

Adopt a people-centric approach to electric vehicle sound engineering

How does your electric vehicle sound? Discover why Simcenter adopts a people-centric approach to the NVH performance engineering of electric cars.

By Joelle Beuzit

There's no doubt about the future of transportation: it is electric. In many regards, electric vehicles answer the need for smart mobility. They allow for modular vehicle architectures, adapt better to the requirements of urban mobility, suppress harmful particle emission, and reduce noise pollution and nuisances in densely populated areas.

How does an electric vehicle sound?

Electric vehicles are often praised for being silent. While this is partially true, considering that they are quieter than regular combustion engine vehicles, they are still anything but soundless. They whizz, they whine, they hiss, they buzz. They tick, they click, they snap, they pop.

All the parts and pieces that compose the car make audible sounds when operating. Surely the decibel levels will not damage your hearing capabilities. But are the sounds pleasant? Think of the subtle whizz of a mosquito in a calm, tepid, summer night. Barely audible but unsettling enough to keep you awake most of the night.

I recently chatted with Steven Dom, Simcenter Automotive Expert, about the sound of electric vehicles. Steven has many years of experience in the NVH engineering of traditional combustion engines, modern electric vehicles, and more. So, I asked him: how do electric vehicles sound? And, most importantly, how should they sound?

A passenger-centric approach to electric vehicle sound engineering

To begin with, Steven Dom didn't want to talk much about technology: "Over the years, we have gained tremendous experience in acting on the various noise sources that you find in an electric vehicle. We have expertise in almost all domains of NVH performance engineering. We've helped many companies, OEMs and suppliers, lower the noise levels of their vehicles and parts. But as engineers, when we tackle a noise issue, we run the risk of focusing on the technology and losing sight of the most important aspect of acoustic optimization: the comfort and well-being of the vehicle's occupants".

Indeed, Simcenter engineers are experts in strategies to reduce the noise levels of vehicles. From locating the origins of sound to applying proper insulating tactics, they master the know-how required to optimize the NVH performance of electric vehicles. For example, they helped the start-up Karma Automotive resurrect an iconic electric vehicle that meets the highest standards of comfort.

From hushing the noise to crafting the sound

To tackle the issue of perfecting NVH, Steven Dom still relies on the proven source-transfer-receiver. For over 30 years, the Simcenter engineers have employed the model to systematically address NVH issues. They scout for the problem's root cause and analyze the transfer paths of sounds and vibrations to accurately resolve problems. But Steven Dom also takes a step back and reverts the model: the spotlight should not fall on the problem's root cause, the source, but rather on the receiver, the human being who is experiencing the problem.

In fact, electric vehicles are not as quiet as we like them to be. Firstly, the electric and electro-magnetic parts in the machine often emit unpleasant high-frequency whizzes. Secondly, and that it is sometimes even more annoying, the comforting humming sound of the engine is gone and replaced by a range of unsettling noises: the rolling of the tires on the bitumen, the whoosh of the wind, the buzz of the wipers' motor. A cacophony of trivial noises that our human brain, used to the sound of combustion engines, misinterprets as warning signals. Something isn't functioning properly, is it? It shouldn't sound that way, should it?

Shaping the external noise

The question of how humans perceive the sound of an electric vehicle pops up even before a person sits behind the steering wheel. There's no denying that electric mobility contributes to reducing noise pollution in urban areas. Nissan conducted an experiment in bustling Bangkok to prove its point: by diminishing acoustic nuisances, electric vehicles help combat mild to severe health issues.

Silent vehicles are great, but how silent are they allowed to become? Newer vehicles introduced in Europe and the US need to feature an acoustic vehicle alert system, in short AVAS. Pedestrian safety should not be compromised by vehicles that are too well-engineered. Early on, as part of the eVADER project, Siemens has been working on simulating and studying the detectability, annoyance, and branding of sound systems that harmoniously balance all the acoustic elements. Today, the active sound design technology permits an approach to sound engineering that does not only take pedestrian safety into account. It also considers their comfort while safeguarding the carmaker's brand integrity.

A vehicle sound: more than just noise, the expression of a brand personality

In every challenge lies an opportunity. By forcing manufacturers to shape the sound of their electric models, governmental institutions have given them an excuse to invest more engineering efforts into the design of their acoustic signature.

From Audi to Mercedes, over the appealing Nissan's Canto, car manufacturers take the sound design issue very, very seriously. The focus is not only on the high-end luxury models or the comfortable limousines. All brands, models and makes aim at authoring their acoustic signature, from the small urban Renault Zoe to the sporty Jaguar iPACE.

From engineer to psychologist: a fascinating perspective into the human mind

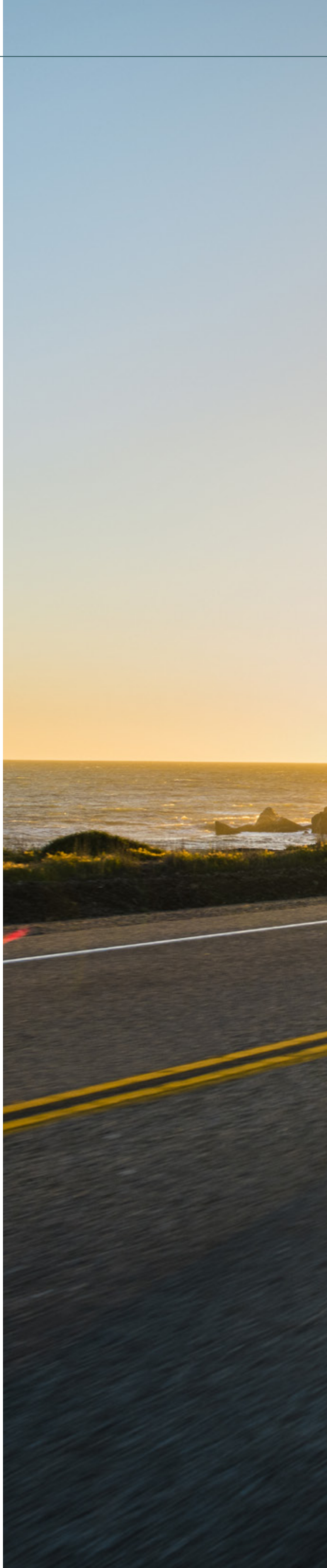
How do you let your inner artist express himself? Luckily for the engineer, some objective metrics aid in qualifying the depth, the tone, the fluidity, or the texture of a sound. Psychoacoustics is the science of sound perception. It studies the psychological and physiological responses associated with sound. It combines an objective assessment that analyzes the sound with quantifiable metrics and a subjective assessment that studies the perception of the sound, unveiling the positive and negative contributors to an agreeable or unpleasant sound.

Listen now to the sound of the SimRod, a fun all-electric sports car that serves as a test object for many Simcenter engineers.

So, does it sound nice? Not really: the SimRod is designed to satisfy your other senses and satiate your need for speed. Yet our engineers have nearly as much fun scrutinizing the sounds of the SimRod as they have driving it. And when it comes to creating the car's digital twin, no aspect is negligible.

Designing the interior sound

As said, AVAS has become a reason to invest in perfecting the vehicle's exterior noise. But more care goes into designing the interior sound. The task is not a simple one.



“A vehicle sound: more than just noise, the expression of a brand personality”

Looking at the source-transfer-receiver model, Steven Dom admits that it is not enough to emphasize the role of the receiver (the occupant). The transfer path also deserves special attention. In a car, the vehicle body is the transfer path. All conventional combustion engines feature a relatively similar build, with the variants of traction or propulsion.

Meanwhile, there are no set rules for building the architecture of an electric vehicle. Where should the motor(s) lie? Or the battery pack(s)? The outcome might be a car that looks and feels entirely different: a blank sheet of paper for the NVH engineer. Established car manufacturers are facing rude competition from start-ups that are thinking fully out-of-the-box and daring revolutionary designs. Project Vector demonstrates that well-known companies also take up the challenge and rethink their principles.

Cascading sound design down to suppliers

Imagine that you've achieved the interior sound that you were targeting. From predicting e-motor noise and identifying system sensitivities in the concept phase to defining the optimal inverter control strategy that balances the switching noise with the vehicle's driving performance, you've estimated the NVH performance in the earliest stage of conception. The vibroacoustic simulation models based on electro-magnetic loads calculation have validated the estimation. The final testing phase delivered the full vehicle diagnostic most completely and accurately. And despite the fact that the electrification heavily impacts the NVH balance, you've successfully deployed simulation and testing solutions to tame the aerodynamic noise.

It all sounds perfect until suddenly, like a mosquito in the night, you hear the annoying

buzz of the window-opening motor. Noise emitted by ancillary systems accounts for 15% of the total noise contribution perceived in the car's interior. Suppliers have been quick to realize that their components play an important part in the overall sound perception and design. NVH target setting evolves from defining a maximum acceptable noise level to detailing the characteristics of the component's sound, as a contributor to the overall sound design.

The video "Simcenter Solutions for the NVH of Electrified Vehicles: Designing sound that adheres to the vehicle brand image" also reveals how Simcenter solutions help adopt a holistic approach to the engineering of hybrid and electric vehicles.

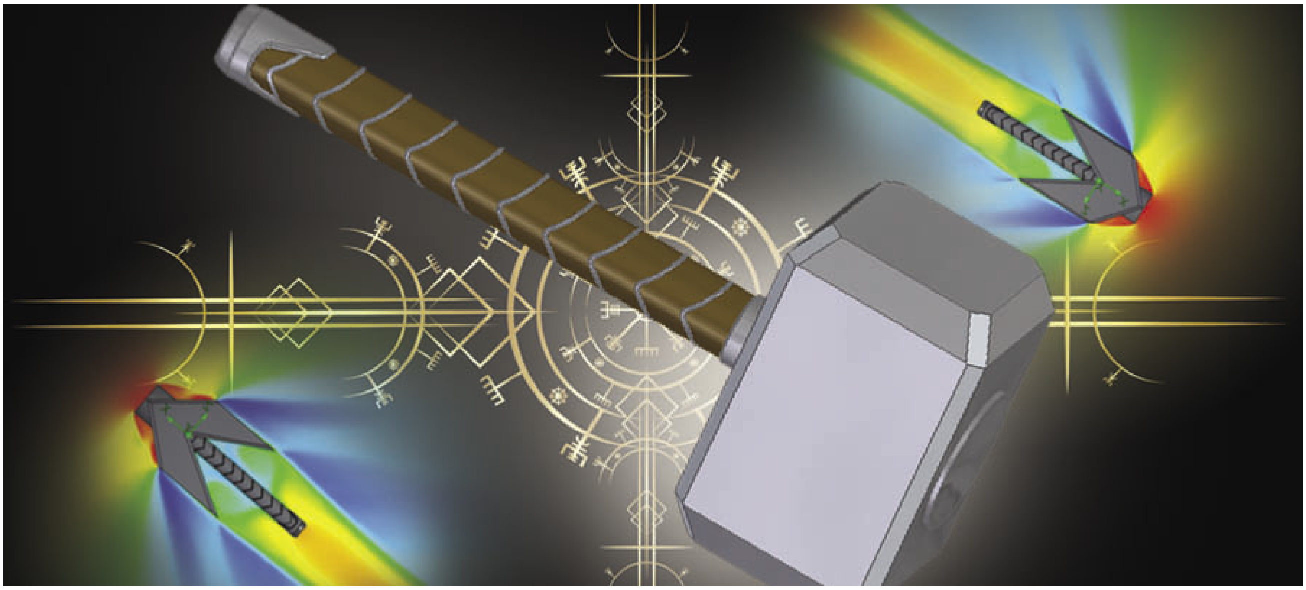
What's the future of electric vehicle sound engineering?
Despite his extensive NVH experience, Steven Dom is thrilled to say that he doesn't know what the future looks like. Ultimately, autonomous electric vehicles increase the challenge for NVH engineers: acoustic comfort becomes the number one performance attribute. What will millennials expect compared to generation X passengers? How will an aging population alter the perception of comfort?

"There are so many angles to the question that we don't know what the future will be made of. The car's interior becomes a space that is not purely functional anymore. Of course, we can imagine many ways to enhance the sensory environment of the cabin, to meet and exceed passengers' expectations. It will not be an easy challenge, which is why it's such an exciting one!" ■

Learn more about Simcenter solutions by visiting the website NVH & Acoustics for Hybrid & Electric Vehicles

About Steven Dom
Steven Dom has been with Siemens Digital Industries Software (and former LMS International) for over 20 years, working in various areas of engineering, engineering management, product management, and sales.

He is currently Director Automotive Industry Solutions, responsible for developing Siemens Industry Software business in the automotive industry.



BLOG ALL ABOUT IT

Did you know you don't have to wait for the next edition of Engineer Innovation to find out about the latest exciting developments with Simcenter? Not to mention some of the more unusual projects our team have been working on.

Our blog is regularly updated with all this and more. And whilst it's only a click away, we thought we'd give you a taster of what we've been talking about in recent months.

Aerodynamics to Marvel at

Let's start with Thor's Hammer, or Mjölnir, to give it its proper name. Marvel fans will know it was created by the dwarfs Brokk and Sindre, but is it as powerful and effective as it could be? They used years of experience and dwarven magic to make the hammer behave more like a boomerang than a brick, but they didn't have Simcenter. Boris Marovic took a deep dive into the aerodynamics of the hammer to see if he could improve its design with all the tools at his disposal.

He used Simcenter FLOEFD and Simcenter HEEDS to model and simulate different parameters of the hammer and after two days of automated processing the software delivered some very interesting results. Could Thor's Hammer be better? Should it be better? Head over to the blog and see for yourself.

Are flying cars for real?

Even if you haven't seen the movie, you've probably heard of Back to the Future as it's one of the most popular time travel stories ever told. Prashanth Shankara has never watched it, but that didn't stop him from using Simcenter STAR CCM+ to analyse how Doc made his DeLorean fly and how realistic that might be.

Prasanth's initial calculations found that the Doc's car had the same drag coefficient as the 1979 Mercedes Benz G class. Given this is an off-road vehicle which listed No.4 on the top 10 least aerodynamic cars ever made, it seemed a pretty tall order to prove that a similar car could fly. But that didn't stop him doing his best, and he also did an impressive job of shoehorning in quotes from a movie he's never seen. And be sure to read to the end to find out how a Simcenter customer is making the dream of electrical flight in metropolitan areas a reality.

SimSailing the Seven Seas

Any budding sailors out there? Or have you ever wondered if, had Jack Sparrow had access to the latest technology, would his trips across the high seas have run smoother?

Wonder no more, because Romain Nicolas has shown how the new marine-related features in Simcenter Amesim 2020.2 could have got Captain Jack to his buried treasure in double quick time.

Gaming the system

If you've got your own gaming PC, you'll know that cooling is one of the most crucial aspects of its design. You can splash as much cash as you like on high end processors and graphics cards, but if they're constantly overheating it will be money poorly spent.

Baptista De Noronha simulated his own PC using Simcenter Flotherm XT in order to understand how the cooling system works, why it's so effective, and if virtual engineering tools could help design something even more efficient.

Got your own ideas?

Feeling inspired to setup your own fun simulation? Great! We love to see all the new and inventive ways you use our software and hardware to experiment, prove theories, and expand your knowledge. And it's a fantastic way to improve your skills when you're between projects.

But the hardest part is often getting started. How do you settle on a project and ensure it will be both fun and worthwhile? The answer will probably be slightly different for everyone, for anyone considering taking on such a task. Have a look and see if it sparks any ideas – who knows, maybe your project could be featured in Engineer Innovation one day.

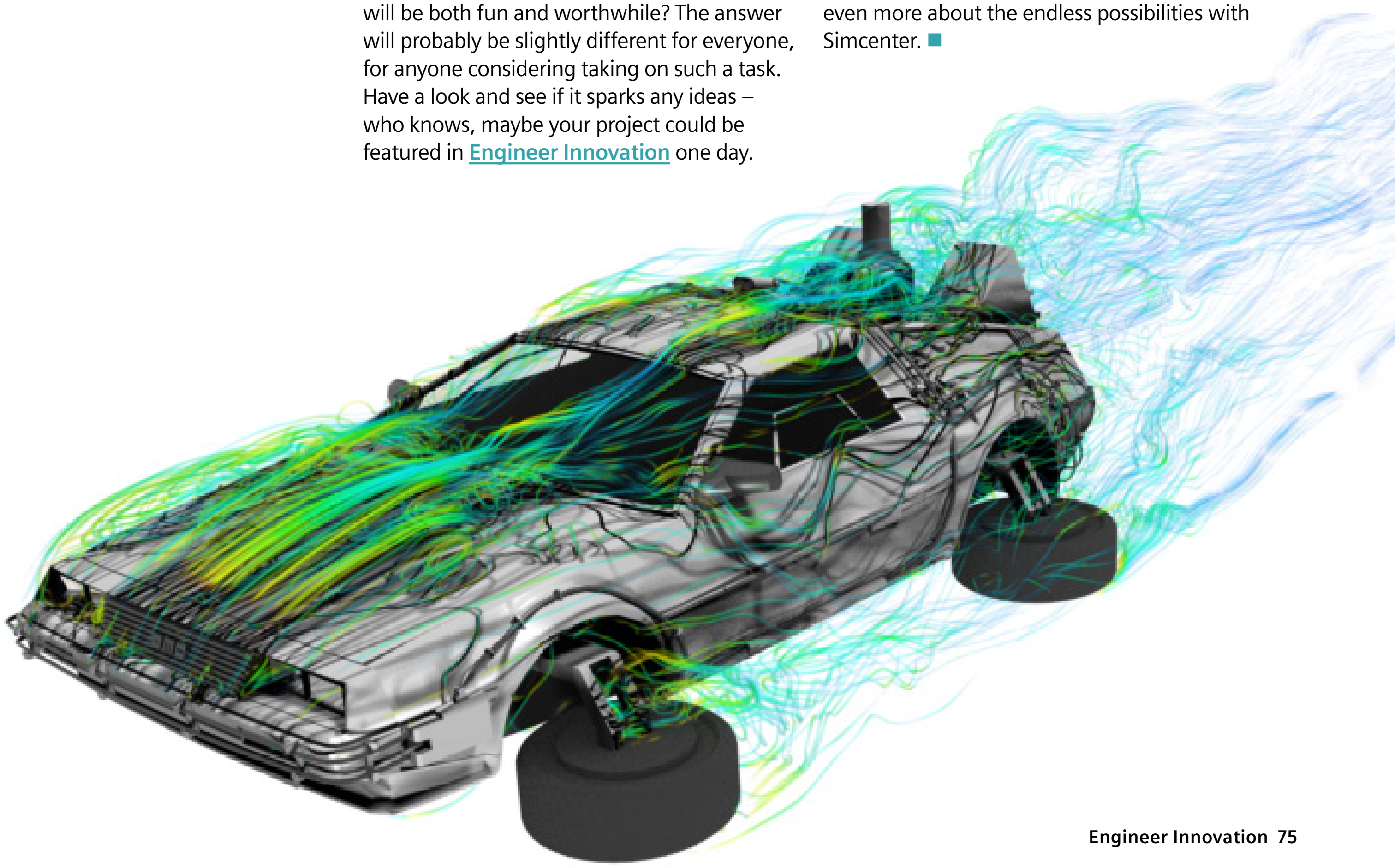
The history of the Digital Twin

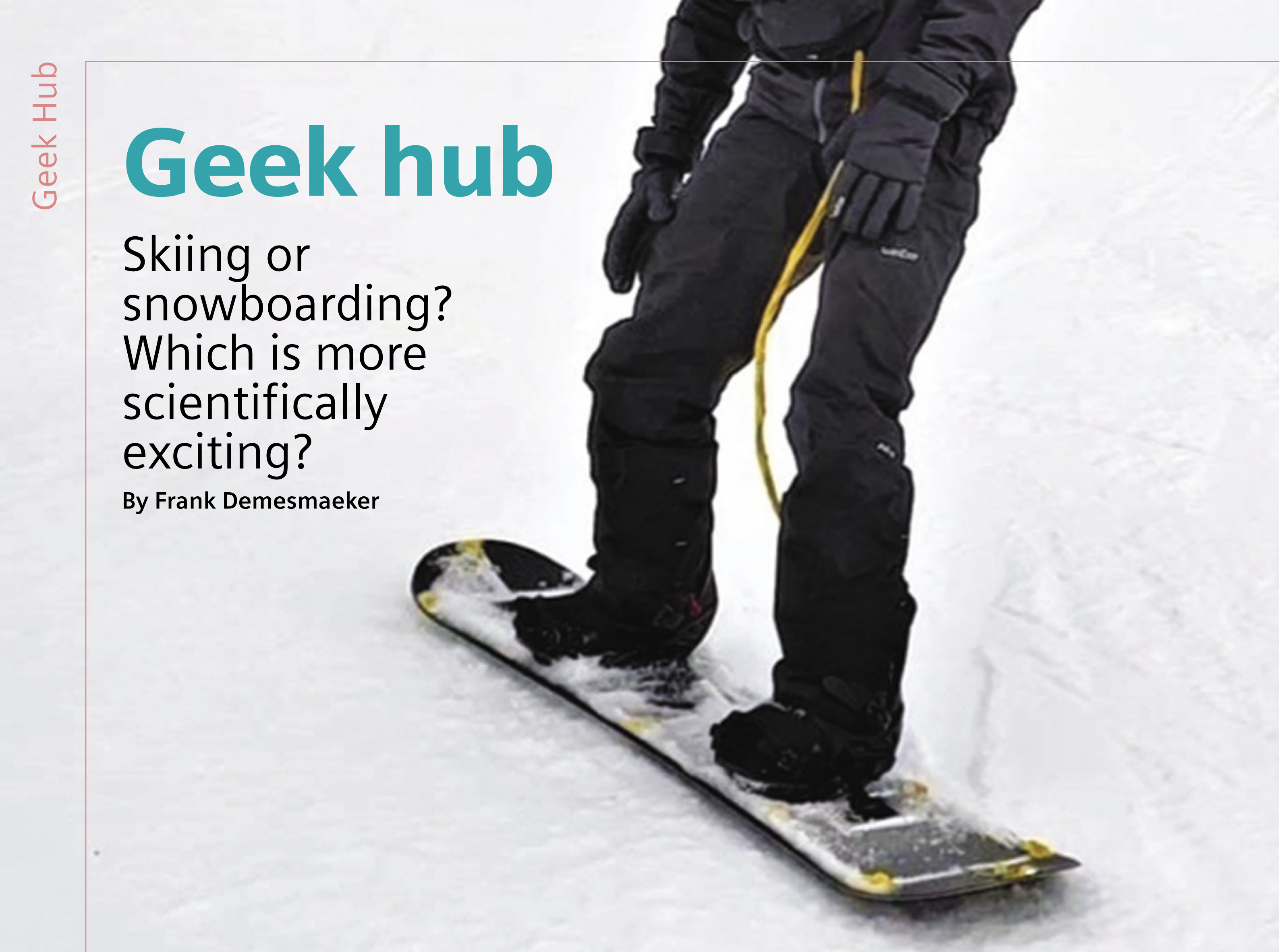
Our team don't just blog about their own work. It can be just as interesting to analyse what others have achieved or, as Stephen Ferguson did last year, investigate the history of CFD simulations.

Until Tom Hanks starred in Apollo 13 in 1995, most people were unaware of the significance of the space mission and how close it was to disaster. But now we know that the crew were all saved thanks to remarkable work and calculations carried out by the astronauts and engineers on simulators back at Mission Control.

Stephen took an in-depth look at how this was done, and questioned if, whilst this mission wasn't the first to have a simulator on the ground, was it the first true Digital Twin? He also explained how Siemens contributed to saving electricity on the spacecraft, which ultimately was the difference between life and death.

With new posts being published every day, the blog will always have something to satisfy every curious mind. Whether it's the new features in the latest version of a particular toolset, or expert analysis on ground-breaking work being undertaken around the world. So don't miss out, it's the best way to discover even more about the endless possibilities with Simcenter.





Geek hub

Skiing or snowboarding? Which is more scientifically exciting?

By Frank Demesmaeker

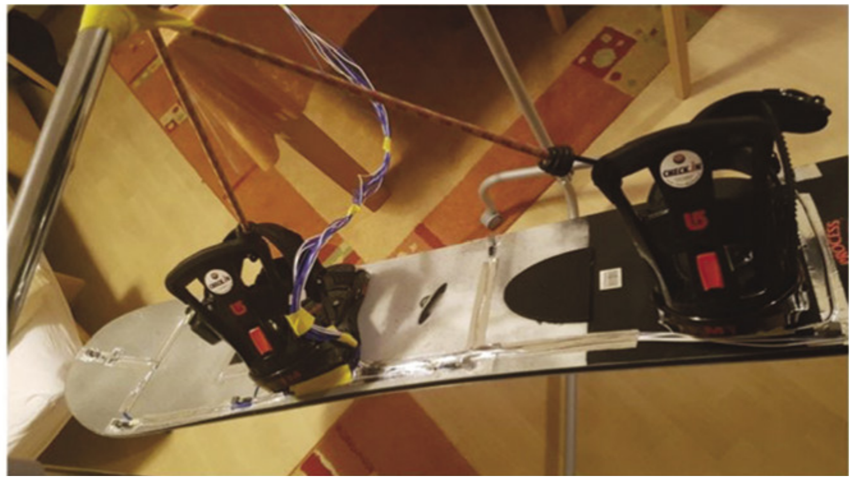
Whether you like to ski or to snowboard is, of course, your personal preference. Trying to determine which sport is more exciting risks resulting in endless debates between both parties, which is not the purpose of this article. So, let us try to objectively answer the question through science!

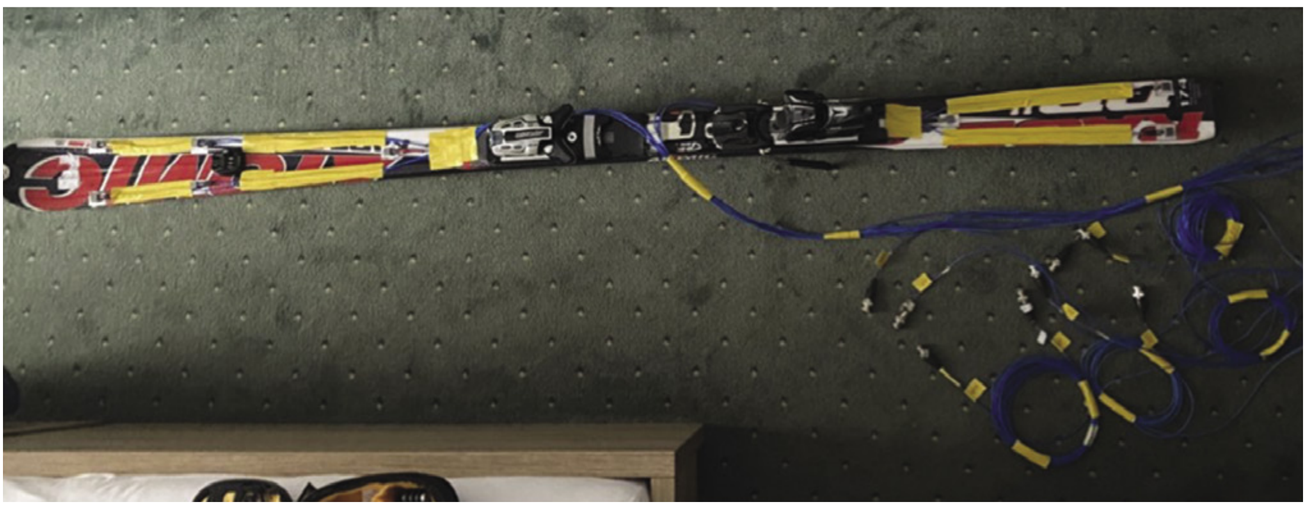
A more relevant and scientific question would be: "how much is your ski or snowboard excited (literally) when going down the slopes?" To answer this, we must look at the physical behavior of their structures.

The operational vibration response of skis and snowboards is an important design parameter for manufacturers; they want a lightweight product with good stiffness, while also damping its operational vibrations. Depending on the specific goal (cross-country, high speed, slalom, freestyle, etc.), different parameters need to be chosen and tuned for optimal performance.

So how do you test all these conditions in a realistic way? A ski or snowboard behaves completely different in free-free conditions, compared to going down the slopes. Think, for instance, about the weight of the boarder standing with both feet on the board, the interaction with different surfaces such as snow, ice and deep snow, and their influence on the vibration response.

To give an answer to the challenge mentioned above, we must get real-life data from operational experimental tests. And as this is 'reality' we are dealing with, actually measuring during use will tell us how the snowboard reacts to real operational vibrations. So, during the last winter holidays, we decided to take some test equipment with us and measure on both snowboard and skis!





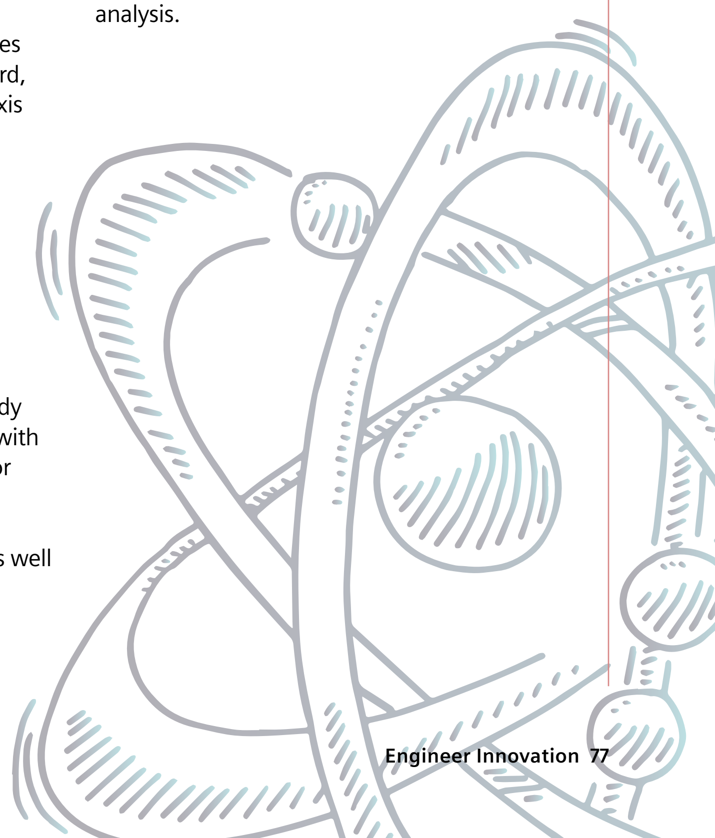
First right:
Impact setup with 12 accelerometers using Simcenter SCADAS XS and Simcenter Testlab

Second right:
Sensors attached to the skis, connected to the Simcenter SCADAS XS

How we did it
In order to experimentally test the operational vibration behavior, we did a hammer impact test in our hotel rooms, as a first step to identify the natural resonance frequencies and their damping values. The snowboard, then, was instrumented with 12 single axis accelerometers and excited using an impact hammer. All signals were connected to the Simcenter SCADAS XS system and a laptop running Simcenter Testlab Impact testing. For the testing of the skies we've focused on one of them and instrumented with 8 accelerometers.

There, in the hotel room, we could already instrument the boards and play around with our computer using Simcenter Testlab for analysis.

The first bending and torsional modes as well as their damping values could be easily identified with Simcenter testing solutions, using the predefined templates for measurement and modal analysis. Both the PolyMAX algorithm and the automatic pole selection allow even novice users to perform an accurate modal analysis.



Watch now
Experimental Modal Analysis based on Impact Testing – first bending and torsional modes

However, by measuring in free-free conditions in the hotel room, we miss the realistic boundary conditions of the snow interaction and the weight of the person on top of the snowboard or the skies.

So… the next step was to take the instrumented gear on the slope and measure the operational vibrations in action. This required a measurement system that was small enough to fit in your pocket, with enough battery autonomy, sufficient local data storage for all the data, and the ability to measure without a laptop.

Taking it to the slopes
Luckily, the same Simcenter SCADAS XS that was used for the PC-based impact test could also be used as a standalone time data recorder. Once it was safely packed in our backpack, the measurement automatically started, based on a trigger set on the g-level of the front accelerometer. This meant that simply "slapping" the ski or the board did the job—there was no need to manually push any buttons.

Watch now
Pocket-sized Simcenter SCADAS XS used for the measurements on the slope

The only extra precaution was protecting the sensors from the humidity of the snow; covering them with duct tape prevented them from coming loose. In addition, fixing and bundling of the cables needed some extra attention: you do not want the sensor cables to get stuck on the ski lift bars when you try to get off it. But apart from those instrumentation challenges, the actual measurement went very easy and smooth.

Next to the accelerometers, we also connected the GPS sensor, which supplied information on the position, speed, altitude, etc. Also the heart rate was measured (with a strong relation to speed) and a GoPro was used to record the test. All this data was synchronized and replayed afterwards using Simcenter Testlab Neo. It showed the acceleration data, the time animated deformation of the snowboard, altitude and heart rate, a Google Maps display that showed the trajectory, the synchronized video, and all sorts of other measurements.

Watch now
Simcenter Testlab Neo Desktop combining different data including GPS, video, animation …
(In case you want to join me for the full descent, click here).

The "dashboard" visualization in the desktop of Simcenter Testlab Neo already gave us a lot of interesting information. However, the final step was to use the operational vibrations to get more realistic resonance frequencies, damping values and mode shapes. This could be done using operational modal analysis.

Watch now
Operational Modal Analysis results showing bending and torsional modes of the snowboard

Watch now
Operational Modal Analysis results showing bending and torsional modes of the ski

First left:
Fully instrumented snowboard with duct tape protection against snow humidity

Looking at the results from the operational modal analysis shows different mode shapes when comparing to the impact based experimental modal analysis (which was taken in free-free conditions). As expected, the central part hardly moves, while the front and back ends behave like a clamped beam.

Watch now
Comparison of mode shapes from Operational (left) and Experimental (right) modal analysis

Similarly, different types of slopes, boards and conditions could be compared, such as taking the ski lift:

Watch now
Measurements on the ski lift

The Results
So, back to our main question: which one is more exciting? Skiing or snowboarding?

In order to be more objective, we came up with the unbiased comparison below, rating both winter sports in 5 categories:

All jokes aside, whether you prefer skiing or snowboarding does not matter, as long as you keep it safe and enjoy your winter holidays (keeping the time spent on gluing accelerometers in your hotel room to the minimum).

And who knows? One day you might also experience the joy of using our Simcenter SCADAS XS and Simcenter Testlab solutions to find out even more exciting things. ■

For more details on the different steps to be taken for an operational modal analysis, click here.

	How snowboarders see skiing	How skiers see snowboarding	How they both see Simcenter SCADAS XS
Compact	Why do you need TWO skis and an additional 2 sticks when you can go down the slopes on a single board?	And how many skis can you fit on a car roof rack versus snowboards	No need of any accessories, pocket sized Simcenter SCANDAS XS with battery and internal storage
Easy to use	With snowboarding boots so comfortable and easy to slip into - why do you want to stumble around in hard ski boots that always seem 2 sizes too small and cut off your blood circulation?	Taking the ski lift is so much more convenient with skis, just watch those boarders when trying to catch the seat- or worse - the anchor lift	Predifined setup with automatic triggering and safe storage of the data on a single device - how easy can it get?
Flexible	Do you know why snowboarders are the first at the aprés-ski party? Because the skiers are still trying to get out of their bindings.	Since I can move both skis independently, it gives me many more degrees of freedom, AND I always have to pull snowboarders with my sticks on long flat runouts	The Simcenter SCANDAS XS can be used connected to a PC, to other SCANDAS systems, to a tablet or used as a standalone recorder
Fit or all needs	Snowboarding can be done on snow, ice, deep snow,...	I can ski on exactly the same places in exactly the same snow types as snowboarders	The Simcenter SCANDASXS allows to measures different types of signals (mics and accelerometer, CPS, RPM, binaural headset, CAN-bus,...).
Full day operation	Full day fun on the snowboard guaranteed.	Full day fun on skis - check!	With it's internal battery, the Simcenter SCANDAS XS guarantees a full day of testing fun.

Brownian Motion...

The random musings of a Fluid Dynamicist

The Radioactive Elephant in the Room

In last month's Brownian Motion I talked about our energy consumption as a species and, on the back of an envelope, calculated that every person in the world uses sixty times more energy than we could possibly generate through manual work alone.

If for just a minute, we forget coronavirus, the biggest challenge facing our energy-hungry species is how to secure a future supply of energy that does not also destroy the planet through global warming.

In the 1960s, 70s and 80s we imagined that "Atomic Power" would provide an almost limitless supply of cheap, clean, energy that would power the future advancement of our civilization. And then, 35 years ago, in the early hours of April 26, 1986, a botched test at the nuclear plant in then-Soviet Ukraine triggered a meltdown that spewed deadly clouds of atomic material into the atmosphere, forcing tens of thousands of people from their homes, and ultimately leading to the premature death of thousands more.

It's impossible to have a rational discussion about the future of nuclear power, without someone mentioning Chernobyl and Fukushima (which is approaching its 10th Anniversary), the two most serious incidents in the history of the nuclear industry.

In this article, I want to examine, in the starkest possible terms, the question of nuclear safety. In order to do that, we have to acknowledge that no mode of energy production is absolutely safe and that some people will die prematurely either in the production process or as a downstream consequence of the pollution caused by that production.

For example, most of us will happily fill our vehicles with gasoline or petrol, without much thought for the lives of people working on the offshore oil rigs that produce that oil. The fatality rate for offshore workers is several times higher than for the population as a whole. The same is true for coal, most of us would acknowledge that, despite the best efforts of the industry, working in a coal mine is a much more dangerous pursuit than engineering simulation work (or writing magazine articles).

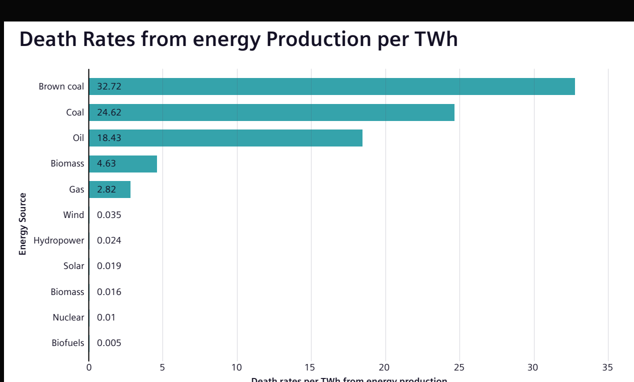
Let's try a thought experiment. Imagine two small towns, one in the USA with a population of 11,000, one in the EU with a population of 27,000. Each of those towns would consume about 1 TWh of energy to meet all of their needs over the course of a single year. The American town is smaller because Americans on average consume much more energy than Europeans (70MWh per year compared with 37MWh in 2015).

Now let's imagine that each of those towns gets all their energy from a single local source. To provide 1TWh of energy, how many people in each town would die due to the production of that energy?

Staggeringly, if they got all their energy from coal, by the end of the year, 25-30 residents in each town would have died prematurely, some as a result of production accidents, but mostly as a consequence of air pollution from burning the coal. If the energy was from oil, then on average 18 residents would die prematurely during the year. Five people in the town would die if all of the energy came from the combustion of biomass, and three if the energy came from gas.

And what about nuclear? Well if the towns got their energy from a nuclear power plant, probably none of them would die in a single year. In fact, it would take 14 years of nuclear production and consumption before we'd expect to lose a single resident to premature death in either town. The 0.07 deaths/TWh fatality rate that we have used for nuclear includes a conservative estimate of the deaths that resulted from Chernobyl. It is taken from a 2007 study that obviously did not include Fukushima casualties, however, a more recent 2016 study that does include the Japanese disaster estimates 0.01 deaths/TWh from nuclear energy.

Even if you do not agree with the nuclear casualty numbers used to produce these estimates (and by most accounts, they are very conservative) since nuclear power contributes 2500 TWh of baseload electricity generation across the world every year, the casualties would have to be orders of magnitudes



higher to be comparable with deaths caused by coal or oil.

Of course, no-one gets all their energy from a single source like in the thought experiment towns. If you take into account the current mix of energy sources in the EU and the US, then you'd expect about 11 deaths in each village (remembering that the American town is much smaller than the European one).

"But what about renewable sources of energy?", I hear you ask, well even then, nuclear compares favorably. If you accept the 2016 estimate of 0.01 TWh per nuclear fatality, then nuclear is approximately three times safer than even wind energy.

We started off by talking about Chernobyl, I don't want to minimize the suffering of the victims of that terrible incident. Lots of them died painful, horrible deaths, many as a result of selflessly sacrificing their own health in order to save others. As a child, I was haunted by the images of the liquidators, the so-called bio-robots, men who were charged with cleaning large chunks of radioactive graphite from the roof of the reactor. I visited the Chernobyl power plant, and the abandoned city of Prypiat last year, and I was taken by the monument to the victims that stands outside the reactor compound and reads "To the heroes, professionals, to those who protected the world from nuclear disaster". They are heroes in every sense of the word.

However, replacing nuclear energy with fossil fuels kills people every single day. If you consider all of the lives that have been lost as a consequence of the additional reliance on coal, oil, and gas as a result of largely unfounded public fear (and hysteria) about nuclear, the tragedy of Chernobyl and Fukushima seem small by comparison. ■

SIEMENS

Director of publication: Peter De Clerck

Editor-in-chief: Natasha Antunes

83663 04/21